Atmel AVR2025: IEEE 802.15.4 MAC Software Package - User Guide

8-bit Atmel Microcontrollers

Application Note

Features

- **Portable and highly configurable MAC stack based on IEEE® 802.15.4**
- **Atmel® MAC architecture and implementation introduction**
- **Support of several microcontroller families**
- **Support of all Atmel IEEE 802.15.4 transceivers and single chips, that is, Atmel ATmega128RFA1, Atmel ATmega256RFR2, Atmel AT86RF212, Atmel AT86RF230 ,Atmel AT86RF231, Atmel AT86RF232 and Atmel AT86RF233**
- **Example application description**

1 Introduction

This document is the user guide for the Atmel MAC software for IEEE 802.15.4 transceivers. The mechanisms and functionality of the IEEE 802.15.4 standard is the basis for the entire MAC software stack implementation. Therefore it is highly recommended to use it as a reference. Basic concepts that are introduced by the IEEE standard are assumed to be known within this document.

The user guide describes the Atmel AVR®2025 MAC software package release 2.8.0.

The software contains the 2nd generation MAC, which:

- Allows a highly flexible firmware configuration to adapt to the application requirements
- Supports different microcontrollers and platforms/boards
- Supports different IEEE 802.15.4 based transceivers and single chips
- Allows easy and quick platform porting
- Provides project files for two supported IDEs (IAR Embedded Workbench®, Atmel AVR Studio® / WinAVR)
- Supports star networks and peer-to-peer communication
- Supports non-beacon and beacon-enabled networks

The MAC software package is a reference implementation demonstrating the use of the Atmel IEEE 802.15.4 transceivers. It follows a generic approach and is not optimized to any specific application requirement. The user needs can be adapted to its specific application requirements.

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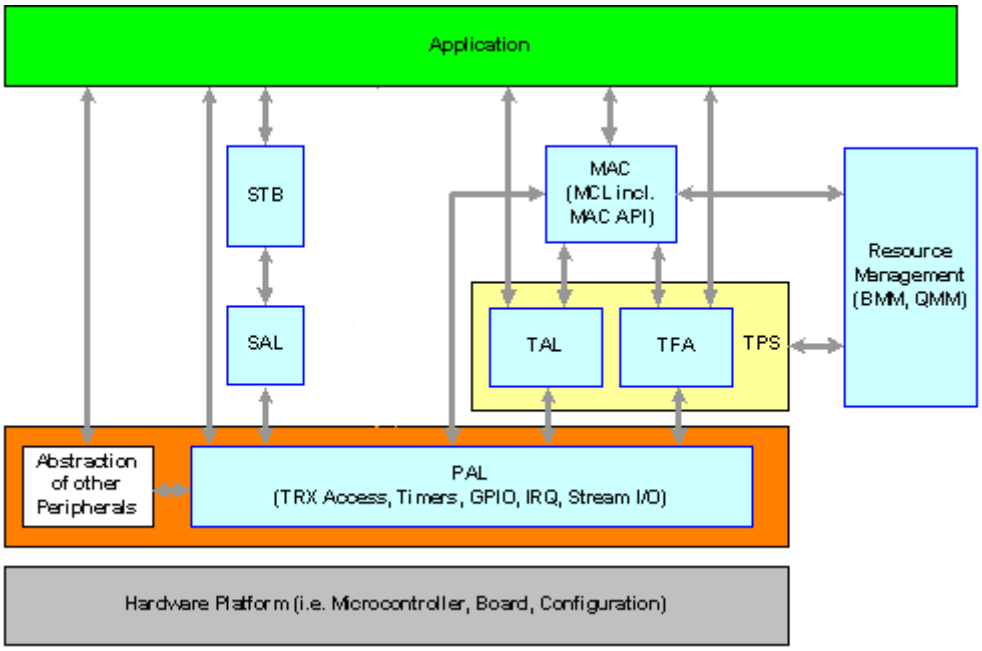
2 General architecture

The MAC software package follows a layered approach based on several stack modules and applications. Figure 2-1 shows the stack's architecture. The stack modules are from the bottom up:

- Platform Abstraction Layer (PAL) (see Section 2.1.1)
- Transceiver Abstraction Layer (TAL) (see Section 2.1.2) and Transceiver Feature Access (TFA) (see Section 2.2.4)
- MAC including MAC Core Layer and MAC-API (see Section 2.1.3)
- Security Abstraction Layer (SAL) and Security Toolbox (STB) (see Sections 2.2.2 and 2.2.3)
- Resource Management including Buffer and Queue Management (BMM and QMM) (see Section 2.2.1)

Figure 2-1. MAC architecture.



For a complete description of the API of each layer and component please refer to the "AVR2025 IEEE 802.15.4 MAC Reference Manual" (MAC_readme.html) located in the AVR2025 top directory.

2.1 Main stack layers

The main MAC stack software consists of three layers starting from the bottom up:

- Platform Abstraction Layer - PAL
- Transceiver Abstraction Layer - TAL
- MAC Core layer – MCL

For other stack layers please refer to Section 2.2.

2.1.1 Platform abstraction layer (PAL)

The Platform Abstraction Layer (PAL) contains all platform (that is, MCU and board) specific functionality (required by the MAC software packages) and provides interfaces to the upper modules. Therefore, all upper modules are independent from the underlying platform. Since some components of the PAL maybe dependent on the actual platform/board, certain functionality within the PAL has to be implemented for each setup, like LEDs and buttons.

For each microcontroller a separate implementation exists within the PAL layers. The board and application needs are adapted via a board configuration file (pal_config.h). This board configuration file exists exactly once for each supported hardware platform.

The PAL provides interfaces to the following components:

- Transceiver access functionality, that is, via SPI or direct memory access
- GPIO control (access from microcontroller to the GPIO pins connected to the transceiver)
- Low-level interrupt handling
- Timers (high-priority and software timers)
- Serial stream I/O support (via USB or UART)
- Access to persistent storage (for example, EEPROM)
- LED control or button access support

These components are implemented as software blocks and are ported based on the target microcontroller. The transceiver access module provides interface to the registers and frame buffer of the transceiver. The timer module implements software timer functionality used by the MAC, TAL, and application layer. The serial stream I/O module provides communication services for transmission and reception of serial data, for example, UART/USB communication. The GPIO module controls the general purpose I/O pins of the microcontroller. The interrupt module handles the transceiver interrupt(s). Hardware timer interrupts and other interrupts are handled internally by the PAL.

The function prototypes for all PAL API functions are included in file PAL/Inc/pal.h.

2.1.2 Transceiver abstraction layer (TAL)

The Transceiver Abstraction Layer (TAL) contains the transceiver specific functionality used for the 802.15.4 MAC support and provides interfaces to the MAC Core Layer which is independent from the underlying transceiver. Besides that, the TAL API can be used to interface from a basic application. There exists exactly one implementation for each transceiver using transceiver-embedded hardware acceleration features. The TAL (on top of PAL) can be used for basic applications without adding the MCL.

The following components are implemented inside the TAL:

- Frame transmission unit (including automatic frame retries)
- Frame reception unit (including automatic acknowledgement handling)
- State machine
- TAL PIB storage
- CSMA module
- Energy detect scan

- Power management
- Interrupt handling
- Initialization and reset

The Transceiver Abstraction Layer uses the services of the Platform Abstraction Layer for its operation. The Frame Transmission Unit generates and transmits the frames using PAL functionality. The Frame Reception Unit reads/uploads the incoming frames and pushes them into the TAL-Incoming-Frame-Queue. The TAL handles the Incoming-Frame-Queue and invokes the receive callback function of the MCL. The operation of the TAL is controlled by the TAL state machine. The CSMA-CA module is used for channel access. The PIB attributes related to the TAL are stored in the TAL PIB storage.

The function prototypes for the TAL features are provided in file TAL/Inc/tal.h. The implementation of a TAL is located in a separate subdirectory for each transceiver.

2.1.3 MAC core layer (MCL)

The MAC Core Layer (MCL) abstracts and implements IEEE 802.15.4-2006 compliant behavior for non-beacon enabled and beacon-enabled network support. The implemented building blocks are:

- MAC Dispatcher
- MAC Data Service
- MAC Management Service (like start, association, scan, poll, etc.)
- MAC Beacon Manager
- MAC Incoming Frame Processor
- MAC PIB Module
- MAC-API
- MAC stack task functions

The MAC Core layer provides an API that reflects the IEEE 802.15.4 standard ([4]).

2.1.3.1 Stack task functionality

The stack (consisting of PAL, TAL, and MCL) task functionality consists of the following API:

- Initialization
  The function wpan_init() initializes all stack resources including the microcontroller and transceiver using functions provided by the TAL and the PAL.
- Task handling
  The function wpan_task() is the stack task function and is called by the application. It invokes the corresponding task functions of the MCL, TAL, and PAL. Using the MAC software package it is required to call this function frequently supporting a round robin approach. This ensures that the different layers' state machines are served and their queues are processed.

2.1.3.2 MAC-API

The application interfaces the MAC stack via the MAC-API (see file mac_api.h in directory MAC/Inc).

It sends requests and responses to the stack by calling the functions provided by the MAC-API. The MAC-API places these requests and responses in the NHLE-MAC-

Queue. It also invokes the confirmation and indication callback functions implemented by the user.

2.1.3.3 MAC core layer functionality

The MAC Dispatcher reads the NHLE-MAC-Queue and passes the requests or responses to the MAC Data Service or the MAC Management Service. The MAC Dispatcher also reads the internal event queue (TAL-MAC-Queue) and calls the corresponding event handler.

The MAC Data Service transmits data using the frame transmission services of the Transceiver Abstraction Layer and invokes the confirmation function mcps_data_conf(), which is implemented in the MAC-API. This function in turn calls the usr_mcps_data_conf() callback function implemented by the application. The indirect data requests are queued into the Indirect-Data-Queue, where the frames are re-fetched from when a corresponding data request (poll request) is received from a device.

Receiving a data frame from the TAL through MAC Incoming Frame Processor, the MAC Data Service invokes the indication function mcps_data_ind(), which is implemented by the MAC-API. This function calls the usr_mcps_data_ind() callback function implemented by the application.

The MAC Management Service processes the management requests and responses through TAL and PAL and if applicable invokes the respective confirm function implemented by the MAC-API. This function in turn calls the usr_mlme_xyz_conf() callback function implemented by the application.

Receiving a command frame from the TAL through the MAC incoming frame processor, the MAC Management Service invokes the indication function mlme_xyz_ind(), which is implemented by the MAC-API if required. The mlme_xyz_ind() function calls the usr_mlme_xyz_ind() callback function implemented by the application.

The MAC Incoming Frame Processor receives frames from the TAL and depending on the type of the frame, passes it to the MAC Data Service or the MAC Management Service for further processing.

The MAC PIB attributes are stored in the MAC PIB and are accessed by the MAC Data Service, the MAC Management Service and the Beacon Manager. PIB attributes that are used by the TAL module are stored within the TAL.

The Beacon Manager generates the beacon frames which are transmitted using the TAL. The beacon manager is also responsible for beacon reception at the start of a superframe and its synchronization. The received beacons are processed based on the current state of the MAC and if required indications or notifications are given to the MAC-API.

2.1.4 Usage of the stack

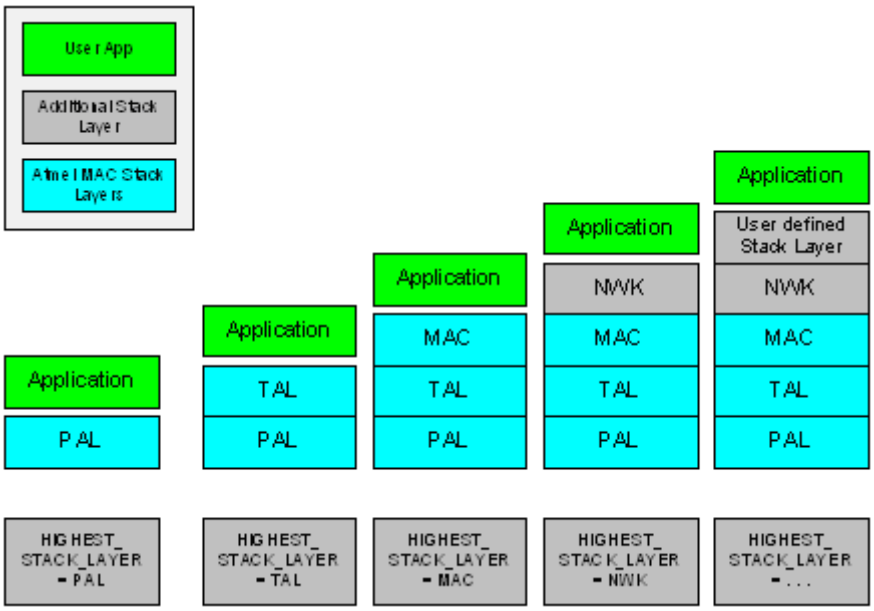
An application can use any layer as desired depending on the required functionality. An application that is based on a standard IEEE 802.15.4 MAC uses the MAC-API based on the stack built by PAL, TAL, and MCL. Another application (for example, a simple data pump) may want to use only the basic channel access mechanism, automatic handling of Acknowledgments, etc. In this case potentially only the TAL API based on a stack consisting of PAL and TAL will be used. A very simple application may even only use the PAL API based on the PAL layer. What kind of stack is

actually being used by the application is always depending on the end user needs and the available resources.

In order to specify which layer of the stack the application is actually based on (that is, which API it is using), the build switch HIGHEST_STACK_LAYER needs to be set properly. Depending on this switch only the required resources from the stack are used for the entire application. For further information about the usage of HIGHEST_STACK_LAYER please see Section 6.1.1.1 HIGHEST_STACK_LAYER.

The following picture shows which layers of the stack are available for the application depending on the build switch HIGHEST_STACK_LAYER. Obviously a trade-off needs to be found between required functionality on one hand and the footprint on the other hand.

Figure 2-2. Stack usage.



2.2 Other stack components

2.2.1 Resource management

The Resource Management provides access to resources to the stack or the application. These resources are:

1. Buffer Management (large and small buffers): provides services for dynamically allocating and freeing memory buffers.
2. Queue Management: provides services for creating and maintaining the queues.

The following queues are used by the software:

3. Queue used by MAC Core Layer:
    a. NHLE-MAC-Queue
    b. TAL-MAC-Queue
    c. Indirect-Data-Queue
    d. Broadcast-Queue
4. Queue used by TAL:
    a. TAL-Incoming-Frame-Queue

5. Additional queues and buffers can be used by higher layers, like application such as the MAC-NHLE-Queue.

2.2.2 Security abstraction layer

The SAL (Security Abstraction Layer) provides an API that allows access to low level AES engine functions abstraction to encrypt and decrypt frames. These functions are actually implemented dependent on the underlying hardware, for example, the AES engine of the transceiver. The API provides functions to set up the proper security key, security scheme (ECB or CBC), and direction (encryption or decryption).

For more information about the SAL-API see file SAL/Inc/sal.h.

For information about the usage of the SAL for application security see Section 4.6.

2.2.3 Security toolbox

The STB (Security Toolbox) is a high level security abstraction layer providing an easy-to-use crypto API for direct application access. It is placed on top of the SAL and abstracts and implements transceiver or MCU independent security functionality that encrypts or decrypts frames using CCM* according to 802.15.4 / ZigBee®.

For more information about the STB-API see file STB/Inc/stb.h.

For information about the usage of the SAL for application security see Section 4.6.

2.2.4 Transceiver feature access

2.2.4.1 Introduction

The current 802.15.4 stack is designed to be fully standard compliant. On the other hand Atmel transceivers provide a variety of additional hardware features that are not reflected in the standard. In order to have a clear design separation between the standard features and additional features, a new software block has been introduced – TFA (Transceiver Feature Access).

If the TFA shall be used within the application a special build switch needs to be set in order to get access to these specific features (see Section 6.1.4.2).

2.2.4.2 Features

The following features have been implemented within the TFA:

- Additional PIB attribute handling
  - Function for reading or writing special PIB attributes (not defined within [4]) are provided
  - Example: Transceiver Rx Sensitivity (see the Data Sheets of the transceivers for more information about the Transceiver Rx Sensitivity)
- Single CCA
  - Based on [4] a function is implemented to initiate a CCA request to check for the current state of the channel
  - The result is either PHY_IDLE or PHY_BUSY
  - Allows for CCA measurements independent from the MAC-based CSMA-CA algorithm

- Single ED measurement
    - Based on [4] a function is implemented to initiate a single ED measurement separate from the cycle of a full ED scanning
- Reading transceiver's supply voltage
    - The battery or supply voltage reading can be enabled separately without enabling the entire TFA. If only the reading (function tfa_get_batmon_voltage()) of the supply voltage is needed, the build switch TFA_BAT_MON needs to be set. See also Section 6.1.4.2 for further information about build switches for the TFA
- Continuous transmission
    - For specific measurements a continuous transmission on a specific is required
    - In order to support this feature functions are implemented to initiate or stop a continuous transmission
- Temperature Measurement (Single Chip transceivers only)
    - A function is implemented to read the temperature value from the integrated temperature sensor in degree Celsius

For more information about the TFA implementation see file TFA/Inc/tfa.h and the source code for the various transceivers (TFA/tal_type/Src/tfa.c).

For further explanation of applications and the included example applications please refer Chapter 9.

3 Understanding the software package

The following chapter describes the content of the MAC software package and explains some general guidelines how the various software layers are structured.

3.1 MAC package directory structure

Once the MAC package has been extracted into the proper place the directory structure looks as follows:

```
MAC_v_2_8_0
├──Applications
│   ├──Helper_Files
│   │   ├──SIO_Support
│   ├──MAC_Examples
│   │   ├──Nobeacon_Application
│   │   │   ├──Coordinator
│   │   │   │   ├──AT86RF212_AT32UC3A3256S_RZ600
│   │   │   │   ├──. . .
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   └──Device
│   │   │       ├──AT86RF212_AT32UC3A3256S_RZ600
│   │   │       ├──. . .
│   │   │       ├──Inc
│   │   │       └──Src
│   │   ├──Beacon_Application
│   │   │   ├──Coordinator
│   │   │   │   ├──. . .
│   │   │   │   ├──AT86RF231_AT32UC3A3256S_RZ600
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   ├──Device
│   │   │   │   ├──. . .
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Basic_Sensor_Network
│   │   │   ├──. . .
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Promiscuous_Mode_Demo
│   │   │   ├──AT86RF230B_ATMEGA1281_ATZB_24_MN2
│   │   │   ├──. . .
│   │   │   ├──Inc
│   │   │   └──Src
```

```
│   │   └──Star_Nobeacon
│   │       ├──. . .
│   │       ├──Inc
│   │       └──Src
│   ├──STB_Examples
│   │   ├──Secure_Remote_Control
│   │   │   ├──. . .
│   │   │   ├──ATMEGA128RFA1_RCB_6_3_PLAIN
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Secure_Sensor
│   │   │   ├──Data_Sink
│   │   │   │   ├──. . .
│   │   │   │   ├──ATMEGA128RFA1_RCB_6_3_SENS_TERM_BOARD
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   ├──Inc
│   │   │   ├──Sensor
│   │   │   │   ├──. . .
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   └──Src
│   │   └──Secure_Star_Network
│   │       ├──Coordinator
│   │       │   ├──. . .
│   │       │   ├──AT86RF231_AT91SAM7X256_REB_4_0_2_REX_ARM_REV_3
│   │       │   ├──Inc
│   │       │   └──Src
│   │       └──Device
│   │           ├──. . .
│   │           ├──Inc
│   │           └──Src
│   ├──TAL_Examples
│   │   ├──Performance_EVK
│   │       ├──. . .
│   │       ├──Inc
│   │       └──Src
├──Build
│   └──Build_MAC
│       ├──GCC
│       │   └──AVR
│           └──AVR32
│       └──IAR
│           ├──ARM
│           └──AVR
│           └──AVR32
```

```
├───Doc
│   ├───Application_Guide
│   ├───Reference_Manual
│   │   ├───MAC
│   │   ├───. . .
│   │   └───PAL_ATMEGA128RFA1_RCB_6_3_PLAIN
│   └───User_Guide
├───Include
├───MAC
│   ├───Inc
│   └───Src
├───PAL
│   ├───ARM7
│   │   ├───AT91SAM7X256
│   │   │   ├───Boards
│   │   │   │   └───REB_5_0_REX_ARM_REV_3
│   │   │   │   └───REB_2_3_REX_ARM_REV_2
│   │   │   │   └───REB_4_0_2_REX_ARM_REV_3
│   │   │   ├───Inc
│   │   │   ├───Src
│   │   │   └───Startup
│   │   ├───Generic
│   │   │   ├───Inc
│   │   │   └───Src
│   ├───SAM3
│   │   ├───AT91SAM3S4B
│   │   │   ├───Boards
│   │   │   │   └───SAM3_RFEK01
│   │   │   │   └───SAM3_RFEK02
│   │   │   ├───Inc
│   │   │   ├───Src
│   │   ├─── AT91SAM3S4C
│   │   │   ├───Boards
│   │   │   │   └───RZ600_212_SAM3SEK
│   │   │   │   └───RZ600_230_SAM3SEK
│   │   │   │   └───RZ600_231_SAM3SEK
│   │   │   ├───Inc
│   │   │   ├───Src
│   │   ├───Generic
│   │   │   ├───Inc
│   │   │   └───Src
│   │   ├───Libraries
│   │   │   ├───usb
│   │   │   │   └───common
│   │   │   │   │   └───cdc
│   │   │   │   │   └───core
```

```
│   │   │   │   └──device
│   │   │   │   │   └──cdc-serial
│   │   │   │   │   └──core
│   │   │   │   └──usbd
│   ├──AVR32
│   │   ├──AT32UC3A3256
│   │   │   ├──Boards
│   │   │   │   └──RZ600_212
│   │   │   │   └──RZ600_230
│   │   │   │   └──RZ600_231
│   │   │   ├──Inc
│   │   │   ├──Src
│   │   ├──AT32UC3L064
│   │   │   ├──Boards
│   │   │   │   └──RZ600_212_UC3LEK
│   │   │   │   └──RZ600_230_UC3LEK
│   │   │   │   └──RZ600_231_UC3LEK
│   │   │   ├──Inc
│   │   │   ├──Src
│   │   ├──AT32UC3B1128
│   │   │   ├──Boards
│   │   │   │   └──REB_2_3_STK600
│   │   │   │   └──REB_4_0_STK600
│   │   │   │   └──REB_5_0_STK600
│   │   │   │   └──REB_7_0_STK600
│   │   │   ├──Inc
│   │   │   ├──Src
│   │   ├──Generic
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Libraries
│   │   │   ├──USB
│   │   │   │   └──cdc-serial
│   │   │   │   │   └──Inc
│   │   │   │   │   └──Src
│   ├──AVR
│   │   ├──ATMEGA1281
│   │   │   ├──Boards
│   │   │   │   ├──RCB_3_2_PLAIN
│   │   │   │   ├──RCB_3_2_SENS_TERM_BOARD
│   │   │   │   ├──RCB_4_0_PLAIN
│   │   │   │   ├──RCB_4_0_SENS_TERM_BOARD
│   │   │   │   ├──RCB_4_1_PLAIN
│   │   │   │   ├──RCB_4_1_SENS_TERM_BOARD
│   │   │   │   ├──RCB_5_3_PLAIN
```

```
│   │   │   │   ├──RCB_5_3_SENS_TERM_BOARD
│   │   │   ├──Inc
│   │   │   └──Src
│   │   └──Generic
│   │       ├──Inc
│   │       └──Src
│   ├──Inc
│   ├──MEGA_RF
│   │   ├──ATMEGA128RFA1
│   │   │   ├──Boards
│   │   │   │   ├──EK1
│   │   │   │   ├──RCB_6_3_PLAIN
│   │   │   │   ├──RCB_6_3_PLAIN_OR_STB
│   │   │   │   └──RCB_6_3_SENS_TERM_BOARD
│   │   │   ├──Inc
│   │   │   └──Src
│   │   └──Generic
│   │       ├──Inc
│   │       └──Src
│   └──XMEGA
│       ├──ATXMEGA256A3
│       │   ├──Boards
│       │   │   ├──REB_2_3_CBB
│       │   │   ├──REB_4_0_CBB
│       │   │   ├──REB_4_1_CBB
│       │   │   ├──REB_5_0_CBB
│       │   │   ├──REB_7_0_CBB
│       │   ├──Inc
│       │   └──Src
├──Resources
│   ├──Buffer_Management
│   │   ├──Inc
│   │   └──Src
│   └──Queue_Management
│       ├──Inc
│       └──Src
├──SAL
│   ├──AT86RF2xx
│   │   └──Src
│   ├──ATMEGARF_SAL
│   │   └──Src
│   ├──ATXMEGA_SAL
│   │   └──Src
│   ├──Inc
├──STB
│   ├──Inc
```

```
│   └──Src
├──TAL
│   ├──AT86RF212
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF230B
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF231
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF232
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF233
│   │   ├──Inc
│   │   └──Src
│   ├──ATMEGARFA1
│   │   ├──Inc
│   │   └──Src
│   ├──Inc
│   └──Src
├──TFA
│   ├──AT86RF212
│   │   └──Src
│   ├──AT86RF230B
│   │   └──Src
│   ├──AT86RF231
│   │   └──Src
│   ├──AT86RF232
│   │   └──Src
│   ├──AT86RF233
│   │   └──Src
│   ├──ATMEGARFA1
│   │   └──Src
│   └──Inc
```

These directories contain the following items (in alphabetical order):

- Applications:
    - The MAC package comes with a variety of applications which comprise MAC applications (using the MAC-API on top of the MAC Core Layer), TAL applications (using the TAL API), and STB Applications (Secure Remote Control using the TAL API, Secure Sensor using the MAC-API on top of the MAC Core Layer)
    - Makefiles, Atmel AVR Studio 4, Atmel AVR Studio 5 and IAR™ Embedded Workbench project files are available for every supported

microcontroller / transceiver / board configuration and can be used as quick start

  - Hex/elf/bin files for AVR , AVR32 and ARM microcontrollers respectively to be downloaded onto available hardware are provided

- Build:
  This directory contain Windows® batch files, that can be easily used to rebuilt any desired (MAC, TAL, or STB) application or all applications at once
- Doc:
  - This directory contains the MAC reference manual in html format, which can be started by double clicking file MAC_readme.html in the root directory of the MAC package
- Include:
  This directory contains header files that are of general interest both for applications and for all layers of the stack, such as IEEE constants, data types, return values, etc.
- MAC:
  This directory contains the MAC Core Layer (MCL) and the MAC-API
- PAL:
  This directory contains the Platform Abstraction Layer with subdirectories for each microcontroller family. It provides all required source and header files for each microcontroller and the supported board configurations
- Resources:
  This directory contains the buffer and queue management implementation used internally inside MCL and TAL. Also hooks for application usage are provided
- SAL:
  This directory contains the Security Abstraction Layer providing specific security implementations based on available hardware support
- STB:
  This directory contains the Security Toolbox implementing an independent crypto API
- TAL: This directory contains the Transceiver Abstraction Layer with subdirectories for each supported transceiver providing specific implementations addressing the specific needs of each transceiver
- TFA:
  This directory contains the Transceiver Feature Access with subdirectories for each supported transceiver providing access to unique transceiver features, like receiver sensitivity configuration, etc.

3.2 Header file naming convention

The different modules or building blocks of the stack are structured very similar. Once the reader is familiar with the provided file structure, it becomes very easy to find any required information.

Each stack layer directory or building block has a directory named Inc:

- MAC/Inc
- PAL/Inc
- SAL/Inc
- STB/Inc
- TAL/Inc

- TFA/Inc

These directories contain basic header files that are generic for the entire block (independent from the specific implementation) or required for the upper layer.

Additionally there are further Inc subdirectories designated to specific implementations. Each transceiver implementation inside the TAL has its own Inc directories (for example, TAL/AT86RF231/Inc) or each microcontroller family and each single microcontroller have their own Inc directories (for example, PAL/XMEGA®/Generic/Inc or PAL/AVR/ATMEGA1281/Inc).

Generally the following header file naming conventions are followed:

6. layer.h:
    - This file contains global information that forms the layer or building block API such as function prototypes, global variables, global macros, defines, type definitions, etc.
    - Each upper layer that wants to use services from a lower layer needs to include this file
    - Examples: mac.h, tal,h, pal,h, stb.h, sal.h, tfa.h
7. layer_internal.h:
    - This file contains stack internal information only. No other layer or building block shall include such a file
    - Examples: MAC/Inc/mac_internal.h, TAL/AT86RF212/Inc/tal_internal.h, PAL/AVR/Generic/Inc/pal_internal.h
8. layer_types.h:
    - This file contains the definitions for the supported types of each category that can be used with Makefiles or project files to differentiate between the various implementations and make sure that the proper code is included
    - Whenever a new type of this category is introduced (for example a new hardware board type), the corresponding file needs to be updated
    - Examples: tal_types.h, pal_types.h, sal_types.h, pal_boardtypes.h, vendor_boardtypes.h
9. layer_config.h:
    - This file contains definitions of layer specific stack resources such as timers or buffers.
    - For further information see Section 4.3
    - Examples: mac_config.h, tal_config.h, pal_config.h

4 Understanding the stack

The following chapter explains how an end user application is configured. Generally the stack is formed by every software portion logically below the application.

The stack can comprise:

- Only the PAL, or
- The TAL based on PAL, or
- The MAC based on TAL and PAL, or
- A network layer (NWK) based on MAC, TAL, and PAL
- Any other layer residing below the application

For configuring the stack appropriately please refer to Chapter 6.

4.1 Frame handling procedures

4.1.1 Frame transmission procedure

This section shall explain the stack layer interworking for the transmission of a MAC data frame. The payload of such a frame requires special treatment, since it is handed over from the higher layer or application, whereas other MAC frames are generated inside the MAC layer itself.

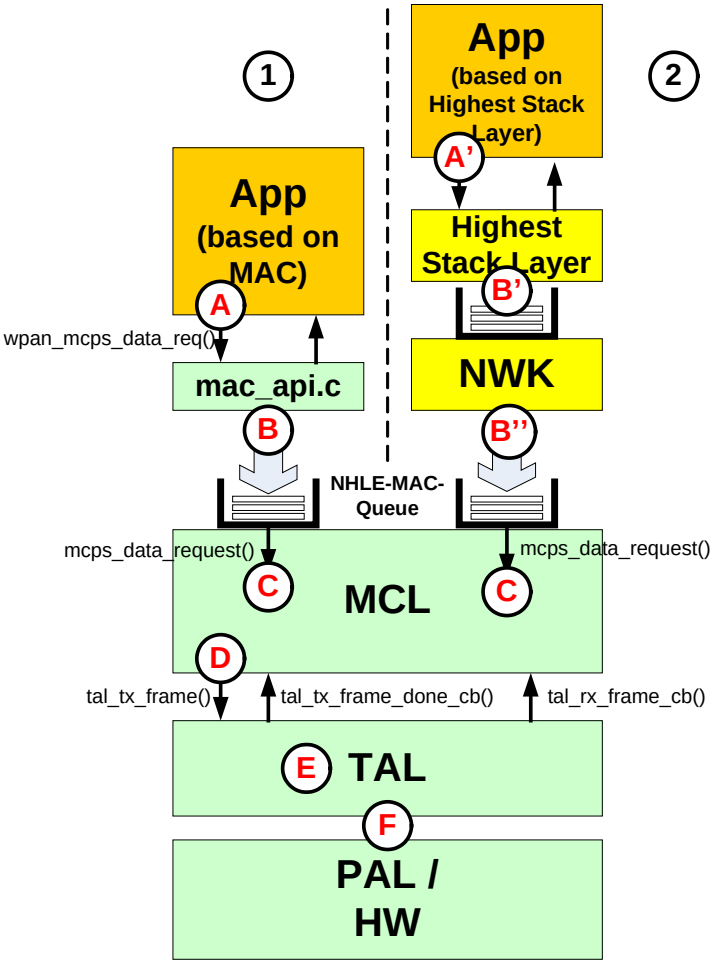
The stack is always separated into a stack domain and an application domain. The application resides on the stack layer called Highest Stack Layer (see Section 2.1.4). The AVR2025 software package can be utilized in the following two different architectures:

(**1**) An Application residing on top of the MAC layer: The application interacts with the MAC Layer by means of functions call (residing in file mac_api.c) and callbacks (residing in files usr_*.c). The MAC-API in return interacts with the MAC Core Layer (MCL) by means of messages handled with an internal queue.

(**2**) An application residing on top of another layer (above the MAC layer): The application interacts with the “Highest Stack Layer” by means of function calls and callback to be implemented within the highest stack layer and/or the application. The stack layer above the MAC (that is, the Network Layer – NWK) interacts with the MAC by means of messages handled with an internal queue (similar to (**1**)).

4.1.1.1 Part 1 – Data frame creation and transmission

Figure 4-1. Data frame transmission procedure – Part 1.



How is the procedure for a MAC Data frame which shall be transmitted?

(**A**) In case the MAC application wants to initiate a frame transmission, it call the MAC-API function wpan_mcps_data_req() function with the corresponding parameters (see file *MAC/Inc/mac_api.h*). As part of the parameter list the application needs to specify the proper MAC addressing information and the actual application payload.

In case the application resides on another higher layer than the MAC, the Highest Stack Layer needs to provide a similar API than the MAC and should handle the request of the application for a frame transmission similarly (**A'**).

(**B**) Within file mac_api.c the corresponding MAC message is generated and queued into the NHLE-MAC-Queue (which handles all MAC layer request and response messages). During this process the actual application payload is copied once into the proper position of the MCPS message. This is actually the only the data payload is copied during the entire frame transmission process. During the further processing of the frame, the payload is not copied further (except for the utilization of MAC security).

In case the application resides on another higher layer than the MAC, the Highest Stack Layer needs to generate the corresponding message accordingly and queued this into the proper queue. Here the application payload is also copied only once at the interface of the Highest Stack Layer (**B'**). If the application is already at the right position, is it not necessary to copy the application payload again during the further process of the frame in all lower layers down to the MAC layer (**B''**).

The subsequent handling of the frame transmission attempt is identical independent from the stack layer the application is actually residing on.

(**C**) Within the MAC Core Layer (MCL) the dispatcher reads the message form the NHLE-MAC-Queue and call the corresponding function mcps_data_request() (see file *MAC/Src/mac_mcps_data.c*). The following functions are performed:

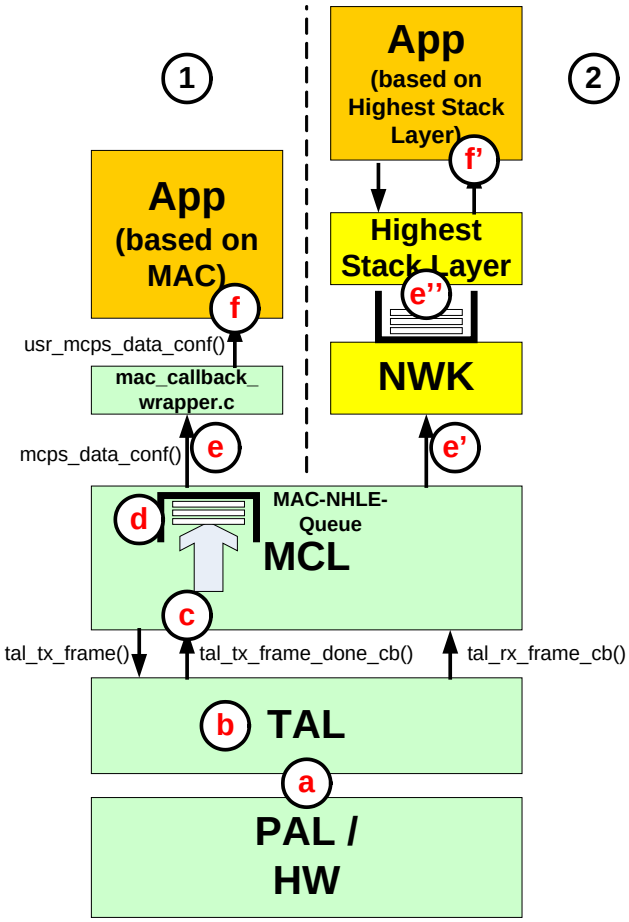
- Parsing of MAC address information
- Creation of the actual MAC frame by filling the information structure (structure ***frame_info_t*** – see file *TAL/Inc/tal.h*)
- The frame_info_t structure for the data frame contains a fully formatted MAC frame including the MAC Header information and the MSDU (that is, the MAC payload of the frame); the MSDU is not copied again during this process of the MAC frame creation

(**D**) Once the MAC frame is properly formatted, the corresponding TAL-API function is called in order to initiate the actual frame transmission (see function tal_tx_frame(); declaration in *TAL/Inc/tal.h*). The TAL functions required the frame_info_t structure as input.

(**E**) Inside the TAL no further formatting of the MAC frame is done. The frame is transmitted using the requested CSMA-CA scheme and retry mechanism. This is done by means of using PAL functions and the provided hardware (**F**). For further information, check function tal_tx_frame() in file *TAL/tal_type/tal_tx.c*.

4.1.1.2 Part 2 – Data frame clean-up and confirmation

Figure 4-2. Data frame transmission procedure – Part 2.



(a)(b) Once the MAC frame has been transmitted (either successfully or unsuccessfully) by means of using PAL functions and the provided hardware, the TAL calls the frame transmission callback function tal_tx_frame_done_cb() residing inside the MAC (see *MAC/Src/mac_process_tal_tx_frame_status.c*) (c).

(d) Inside the MCL the corresponding callback message is generated including the frame transmission status code for the MAC DATA frame and queued into the MAC-NHLE-Queue (which handles all MAC layer confirmation and indication messages).

(e) The dispatcher extracts the confirmation message and calls the corresponding callback function (mcps_data_conf() in file *MAC/Src/mac_callback_wrapper.c*) if the application is residing on top of the MAC layer.

In case the stack utilizes another stack on top of the MAC layer, the callback functions are implemented inside the higher stack layers (e')(e'').

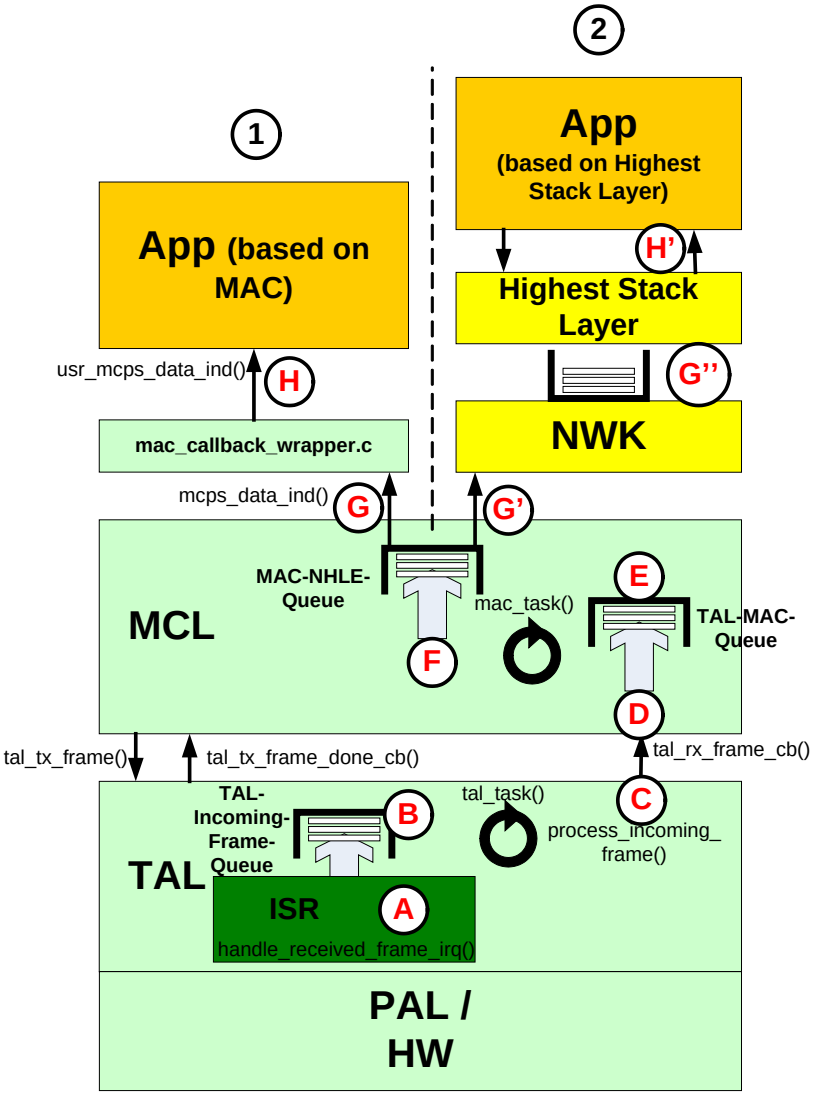
(f)(f') Finally the application is notified about the status of the attempt to transmit a data frame by means of the callback function (usr_mcps_data_conf() if the application resides on top of the MAC layer) to be implemented inside the application itself.

4.1.2 Frame reception procedure

This section shall explain the stack layer interworking by for the reception of a MAC data frame.

As already explained in Section 4.1.1 the stack is always separated into a stack domain and an application domain.

Figure 4-3. Data frame reception procedure.



How is the procedure for a MAC Data frame which is received?

(A) Once the frame has been received by the hardware the ISR is invoked and function handle_received_frame_irq() (located in file *TAL/tal_type/Src/tal_rx.c*) is called within the ISR contect. In this function the following tasks are performed:

- Reading of the ED value of the current frame
- Reading of the frame length
- Uploading of the actual frame including the LQI octet appended at the end of the frame

- Constructing the “mdpu” array of the frame_info_t structure for the received frame by additionally appending the ED value after the LQI value (for more information about the structure of the received frame see Section 4.2.1.2)
- Reading of the timestamp of received frame if required
- Queuing the received frame into the TAL-Incoming-Frame-Queue for further processing in the main context

(**B**) During the subsequent call to tal_task() (see file *TAL/tal_type/Src/tal.c*) the frame is extracted from the TAL-Incoming-Frame-Queue and function process_incoming_frame() (see file *TAL/tal_type/Src/tal_rx.c*) is called

(**C**) Within function process_incoming_frame() further handling of the frame is performed (such as calculation of the normalized LQI value based on the selected algorithm for LQI handling) and the callback function tal_rx_frame_cb() residing inside the MAC (see file *MAC/Src/mac_data_ind.c*) is called

(**D**) The callback function tal_rx_frame_cb() pushes the TAL frame indication message into the TAL-MAC-Queue for further processing inside the MCL

(**E**) During the subsequent call to mac_task() (see file *MAC/Src/mac.c*) the TAL indication message is extracted from the TAL-MAC-Queue and function mac_process_tal_data_ind() (see file *MAC/Src/mac_data_ind.c*) is called

(**F**) Within MCL the following task are performed once function mac_process_tal_data_ind() is executed

- Depending on the current state of the MCL the frame type is derived and the function handling the specific frame type is invoked
- In case of a received MAC Data Frame received during regular state of operation (that is, no scanning is ongoing, etc.) the corresponding function is mac_process_data_frame() residing in *MAC/Src/mac_mcps_data.c*
- Within function mac_process_data_frame() the MAC Header information is extracted from the received frame and the corresponding MCPS-DATA.indication primitive message is assembled
- The formatted MCPS-DATA.indication message is pushed into the MAC-NHLE-Queue

(**G**) The dispatcher extracts the indication message and calls the corresponding callback function (mcps_data_conf() in file *MAC/Src/mac_callback_wrapper.c*) if the application is residing on top of the MAC layer.

In case the stack utilizes another stack on top of the MAC layer, the callback functions are implemented inside the higher stack layers (**G’**)(**G’’**).

(**H**)(**H’**) Finally the application is notified about the reception of a Data frame data by means of the callback function (usr_mcps_data_ind() if the application resides on top of the MAC layer) to be implemented inside the application itself.

Once the received frame content is uploaded from the hardware into software, during the further process of the reception of a MAC Data frame, the actual payload of the Data frame only needs to be copied once within the receiving application on top of the MAC layer (or on top of another Highest Stack Layer). Within the stack itself the payload handling is very efficient and the content never needs to be copied.

4.2 Frame buffer handling

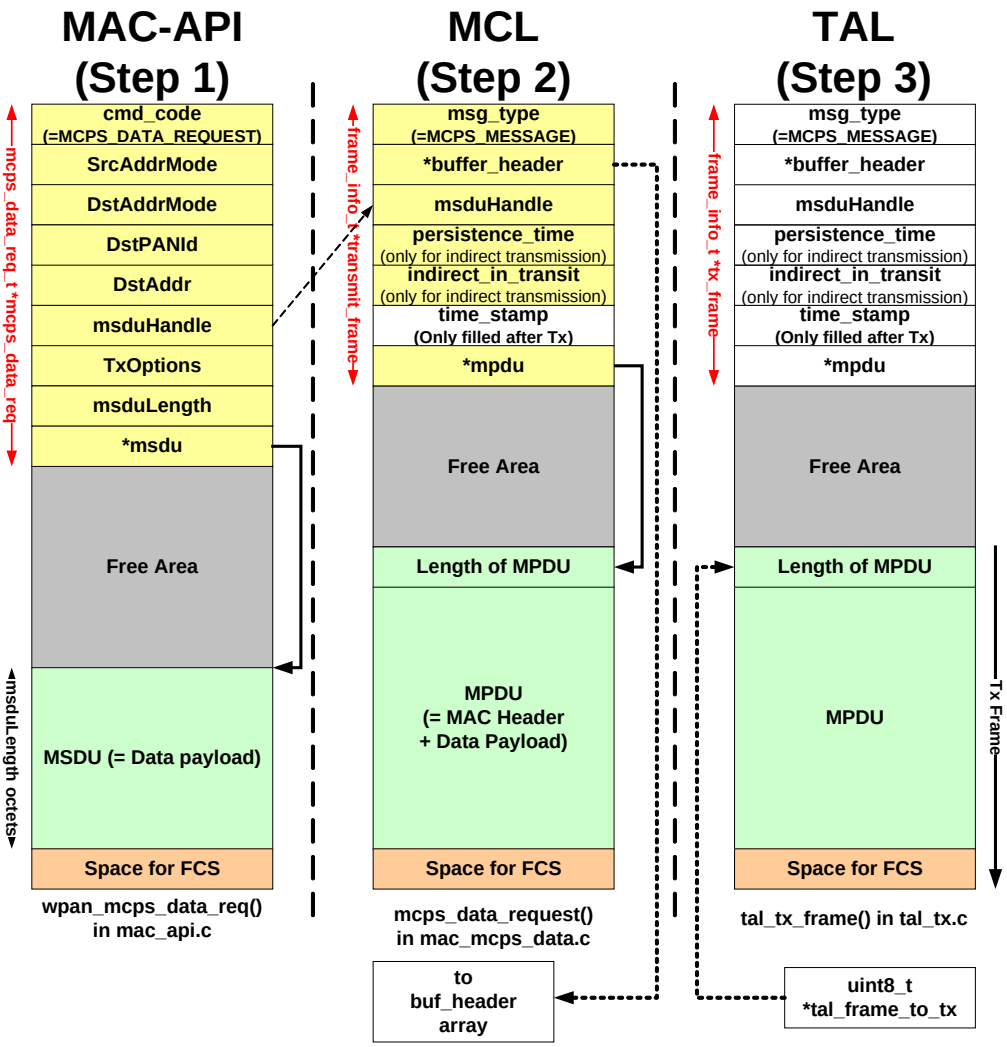
4.2.1 Application on top of MAC-API

This section explains the buffer handling for applications residing on top of the MAC-API (HIGHEST_STACK_LAYER = MAC).

4.2.1.1 Frame transmission buffer handling

The following section describes how the buffers are used inside the stack during the procedure of the transmission of a MAC Data Frame.

Figure 4-4. Frame buffer handling during data frame transmission – part 1.



Step 1:
If an application based on the MAC layer as Highest Stack Layer shall transmit a frame to another node, the MAC needs to generate a MAC Data frame. Initially the application calls function wpan_mcps_data_req() (located in file mac_apic.). In this function a new (large) buffer is requested from the Buffer Management Module (BMM) by means of the function bmm_buffer_alloc(). After the successful allocation of

the buffer the structure of type *mcps_data_req_t* is overlaid over the actual buffer body:

```
mcps_data_req =
   (mcps_data_req_t *)BMM_BUFFER_POINTER(buffer_header);
```

For more information about the *mcps_data_req_t* structure see file *MAC/Inc/mac_msg_types.h*.

The mcps_data_req_t structure is filled according to the parameters passed to function wpan_mcps_data_req() and the Data frame payload (MSDU) is copied to the proper place within this buffer. This is the only time the actual payload is copied during frame transmission inside the entire stack. The MSDU will reside right at the end of the buffer (with additional space for the FCS). The size of such a buffer fits the maximum possible payload (according to [4]). Also the parameter *msdu* is updated to point right at the beginning of the MSDU content.

The entire frame buffer is then queued as an MCPS_DATA_REQUEST message into the NHLE-MAC-Queue.

Step 2:
Once the MCPS_DATA_REQUEST message has been de-queued and the dispatcher has called the corresponding function mcps_data_request() (see file *MAC/Src/mac_mcps_data.c*), the structure of type *frame_info_t* is overlaid over the actual buffer body:

```
frame_info_t *transmit_frame =
    (frame_info_t *)BMM_BUFFER_POINTER((buffer_t *)msg);
```

For more information about the *frame_info_t* structure see file *MAC/Inc/mac_msg_types.h*.

Afterwards the corresponding elements of the *frame_info_t* structure are filled accordingly:

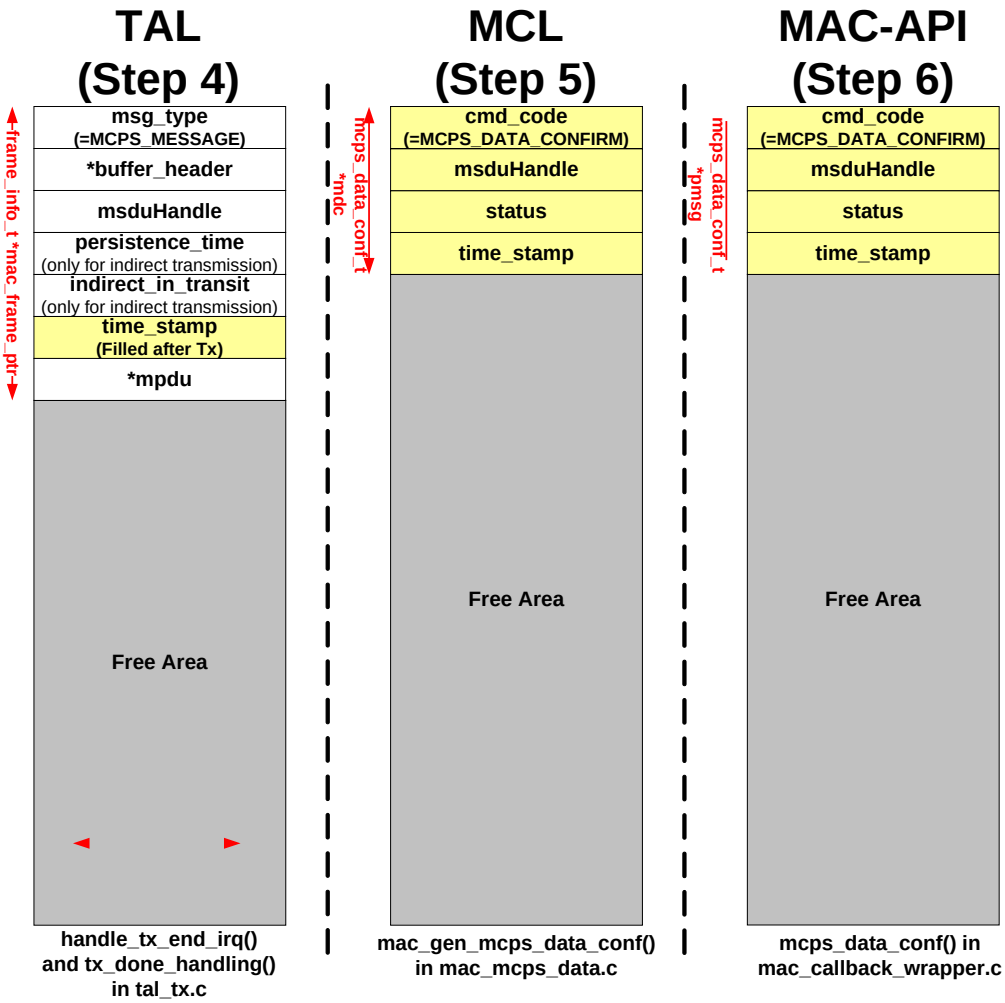
- The message_type parameter is set to MCPS_MESSAGE
- The MSDU handle is copied to the proper place
- The parameter in_transit (only utilized during indirect transmission) is set to the default value
- The buffer_header parameter is set to point to the actual buffer header; this is required once the transmission has finished to free the buffer properly

As the last step the complete frame (that is, the MPDU) is formatted. This is done by simply adding the required MAC Header information fields at the correct location in front of the MSDU (that is, the Data payload). The first element of the MPDU fill then contain the length of the entire MPDU to be transmitted, and the *mpdu* pointer within the *frame_info_t* structure is updated to point to the beginning of the frame.

This step within the MCL is finalized by initiating the actual frame transmission by calling the TAL function tal_tx_frame().

Step 3:
Within the TAL in function tal_tx_frame() (see file *TAL/tal_type/Src/tal_tx.c*) a pointer is set to the location of the actual MPDU inside the frame buffer (member *mpdu* of structure *frame_info_t*). This pointer is used for initiating the frame transmission (by means of function send_frame() with the appropriate parameters for CSMA-CA and frame retry.

Figure 4-5. Frame buffer handling during data frame transmission – part 2.



Step 4:
Once the transmission of the frame has been finished (either successfully or unsuccessfully), the transceiver generates an interrupt indicating the end of the transmission. This interrupt is handled in function handle_tx_end_irq() located in file *TAL/tal_type/Src/tal_tx.c*. In case timestamping is enabled, the time_stamp parameter is written into the proper location of the frame_into_f structure of the frame buffer. This happens in the context of the Interrupt Service Routine.

Afterwards function tx_done_handling() (located in *TAL/tal_type/Src/tal_tx.c*) is called in the main execution context. Here the timestamp is updated and the corresponding callback function tal_tx_frame_done_cb() inside the MCL is called.

Step 5:
Function tal_tx_frame_done_cb() (residing in file *MAC/Src/mac_process_tal_tx_frame_status.c*) calls a number of other functions inside the MCL, which (in the case of a processed Data frame) finally will end up in function mac_gen_mcps_data_conf() in file *mac_mcps_data.c*.

Here the structure of type *mcps_data_conf_t* is overlaid over the actual buffer body:

```
mcps_data_conf_t *mdc =
    (mcps_data_conf_t *)BMM_BUFFER_POINTER(buf);
```

For more information about the *mcps_data_conf_t* structure see file *MAC/Inc/mac_msg_types.h*.

The mcps_data_conf_t structure is filled accordingly and the entire buffer is then queued as an MCPS_DATA_CONFIRM message into the MAC-NHLE-Queue.

Step 6:
Once the MCPS_DATA_ CONFIRM message has been de-queued and the dispatcher has called the corresponding function mcps_data_conf() (see file *MAC/Src/mac_callbcak_wrapper.c*), the structure of type *mcps_data_conf_t* is again overlaid over the message (which is the actual buffer body):

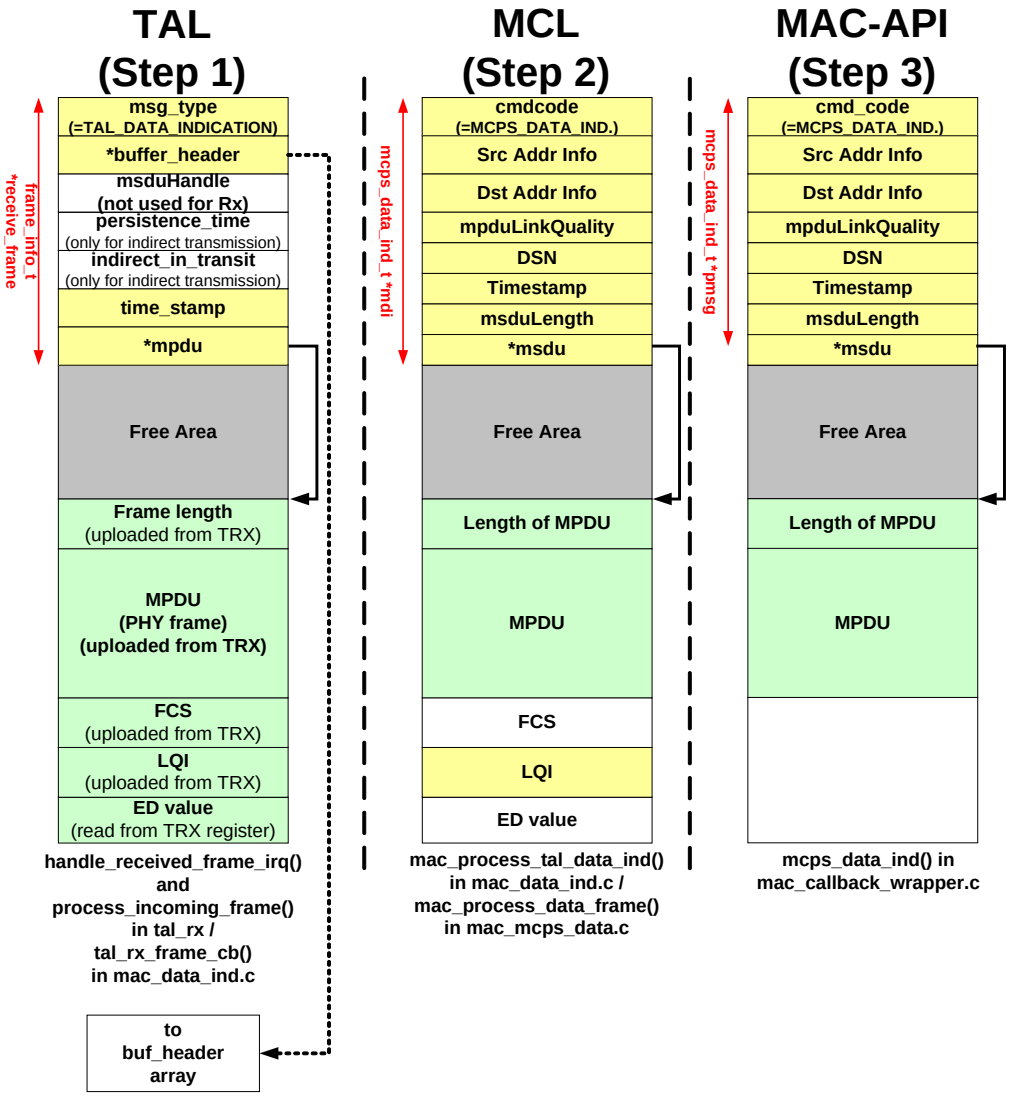
```
pmsg =
    (mcps_data_conf_t *)BMM_BUFFER_POINTER(((buffer_t
*)m));
```

Finally the corresponding parameters of the callback function inside the application (function usr_mcps_data_conf()) are filled by the corresponding members of the *mcps_data_conf_t* structure and the buffer is freed again by calling function bmm_buffer_free(). The buffer is now free for further usage.

Through all steps from (1) to (6) the same buffer is used.

4.2.1.2 Frame reception buffer handling

Figure 4-6. Frame buffer handling during data frame reception.



Step 1:
Once the transceivers raises an interrupt indicating the reception of a frame, function handle_received_frame_irq() (located in file *TAL/tyl_type/Src/tal_rx.c*) is called in the context of an ISR. Here a structure of type *frame_info_t* is overlaid over the current receive buffer body:

```
frame_info_t *receive_frame;
…
receive_frame =
    (frame_info_t*)BMM_BUFFER_POINTER(tal_rx_buffer);
```

After reading the ED value of the current frame and the frame length, the entire frame is uploaded from the transceiver and the ED value is stored at the location after the LQI (which automatically was uploaded from the transceiver). The mpdu pointer of the frame_info_t structure points to the proper location where the actual frame starts

within the buffer. Afterwards the entire buffer is pushed into the TAL-Incoming_Frame-Queue for further processing outside the ISR context.

After removing the buffer from the TAL-Incoming-Frame-Queue function process_incoming_frame() (also located in file *TAL/tal_type/Srctal_rx.c*) is called. Here again a structure of type *frame_info_t* is overlaid over the receive buffer body:

```
frame_info_t *receive_frame =
    (frame_info_t*)BMM_BUFFER_POINTER(buf_ptr);
```

Before the callback function inside the MAC is called, the proper buffer header is stored inside the buffer_header element of structure *frame_info_t*:

```
receive_frame->buffer_header = buf_ptr;
```

The processing inside the TAL is done once tal_rx_frame_cb() is called. Although this function resides inside the MCL (see file *MAC/Src/mac_data_ind.c*), the functionality is considered here being logically part of the TAL. Here the msg_type of the frame residing in the current buffer is specified as TAL_DATA_INDICATION and the buffer is pushed into the TAL-MAC-Queue.

Step 2:
Once the TAL_DATA_INDICATION message has been de-queued from the queue the dispatcher calls the corresponding function mac_process_tal_data_ind() (see file *MAC/Src/mac_data_ind.c*). In this function the received frame is parsed and eventually the dedicated function handling the particular frame type is invoked, which is mac_process_data_frame() in file *MAC/Srcmac_mcps_data.c*.

Here a structure of type *mcps_data_ind_t* is overlaid over the receive buffer body:

```
mcps_data_ind_t *mdi =
    (mcps_data_ind_t *)BMM_BUFFER_POINTER(buf_ptr);
```

For more information about the *mcps_data_ind_t* structure see file *MAC/Inc/mac_msg_types.h*.

The members of the mcps_data_ind_t structure are filled based on the information within the received MAC Data frame. The message is identified as a MCPS_DATA_INDICATION message and is queued into the MAC-NHLE-Queue.

Step 3:
Once the dispatcher removes the MCPS_DATA_INDICATION from the queue, the corresponding function for handling this message is called - mcps_data_ind() in file *MAC/Src/mac_callback_wrapper.c*. Here the structure of type *mcps_data_ind_t* is overlaid again over the actual buffer body:

```
pmsg =
    (mcps_data_ind_t *)BMM_BUFFER_POINTER(((buffer_t *)m));
```

Finally the corresponding parameters of the callback function inside the application (function usr_mcps_data_ind()) are filled by the corresponding members of the *mcps_data_ind_t* structure and the buffer is freed again by calling function bmm_buffer_free(). The buffer is now free for further usage.

Through all steps from (1) to (3) the same buffer is used.

4.2.2 Application on top of TAL

While an application on top of the MAC-API is logically decoupled from the actual buffer handling inside the entire stack (such an application does neither need to allocate nor free a buffer), an application on top of the TAL requires more interworking

with the stack in regards of buffer handling and internal frame handling structures. This is explained in the subsequent section.

As an example for an application residing on top of the TAL (HIGHEST_STACK_LAYER = TAL) is described in Section 9.2.2.1.

4.2.2.1 Frame transmission buffer handling using TAL-API

The following section describes how buffers are used inside the stack during the procedure of the transmission of a Frame using the TAL-API.

While the application on top of the TAL needs to free buffers received by the frame reception callback function (since these buffers are always allocated inside the TAL automatically), for frame transmission two different approaches are available:

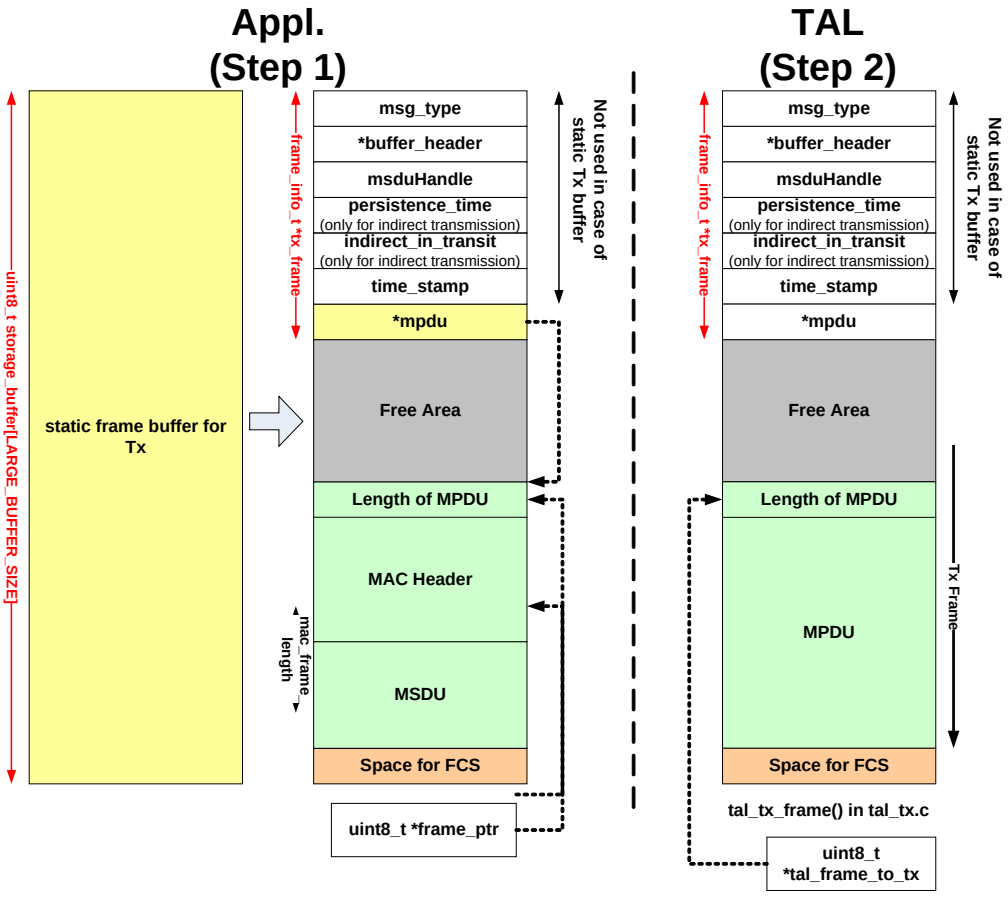
10. Application uses buffer management module provided by stack including allocation and freeing of buffers for frame transmission, or
11. Application uses static frame transmission buffer without the need for allocating or freeing buffers dynamically.

Approach (2) will be used subsequently (similar to the source code based on example application in Section 9.2.2.1).

IMPORTANT

Independent from the selected approach regarding the buffer management, it is important that the frame finally presented to the TAL for transmission follows the scheme in Figure 4-7. The frame needs to be stored at the end of the buffer (right in front of the space for the FCS). This is required in order to fit a frame using the maximum frame length according to [4] into a buffer of size LARGE_BUFFER_SIZE. If this scheme is not proper applied, memory corruption may occur.

Figure 4-7. Frame buffer handling during frame transmission using TAL-API.



Step 1:

The application (not using dynamic buffer management for frame transmission) requires a static buffer for frame to be transmitted, such as:

```
static uint8_t storage_buffer[LARGE_BUFFER_SIZE];
```

A large buffer is big enough to incorporate the longest potential frame to be transmitted based on [4].

Later a structure of type *frame_info_t* is overlaid over the static transmit buffer:

```
tx_frame_info = (frame_info_t *)storage_buffer;
```

For more information about the *frame_info_t* structure see file T*AL/Inc/tal.h*.

The static frame buffer is filled with the MSDU (that is, the actual application payload) and the MAC Header information as required by this frame. Note that also a free format frame not compliant with [4] can be created within the application. The octet in front of the MAC header needs to store the actual length of the frame.

Afterwards the *mpdu* pointer (member of the *frame_info_t* structure) is updated to point at the start of the MPDU (that is, the octet containing the length of the actual frame). Since dynamic buffer management is not used for frame transmission, the other members of the *frame_info_t* structure are not used in this frame transmission approach.

Once the frame formatting is completed, the frame is handed over to the TAL for transmission by calling function tal_tx_frame().

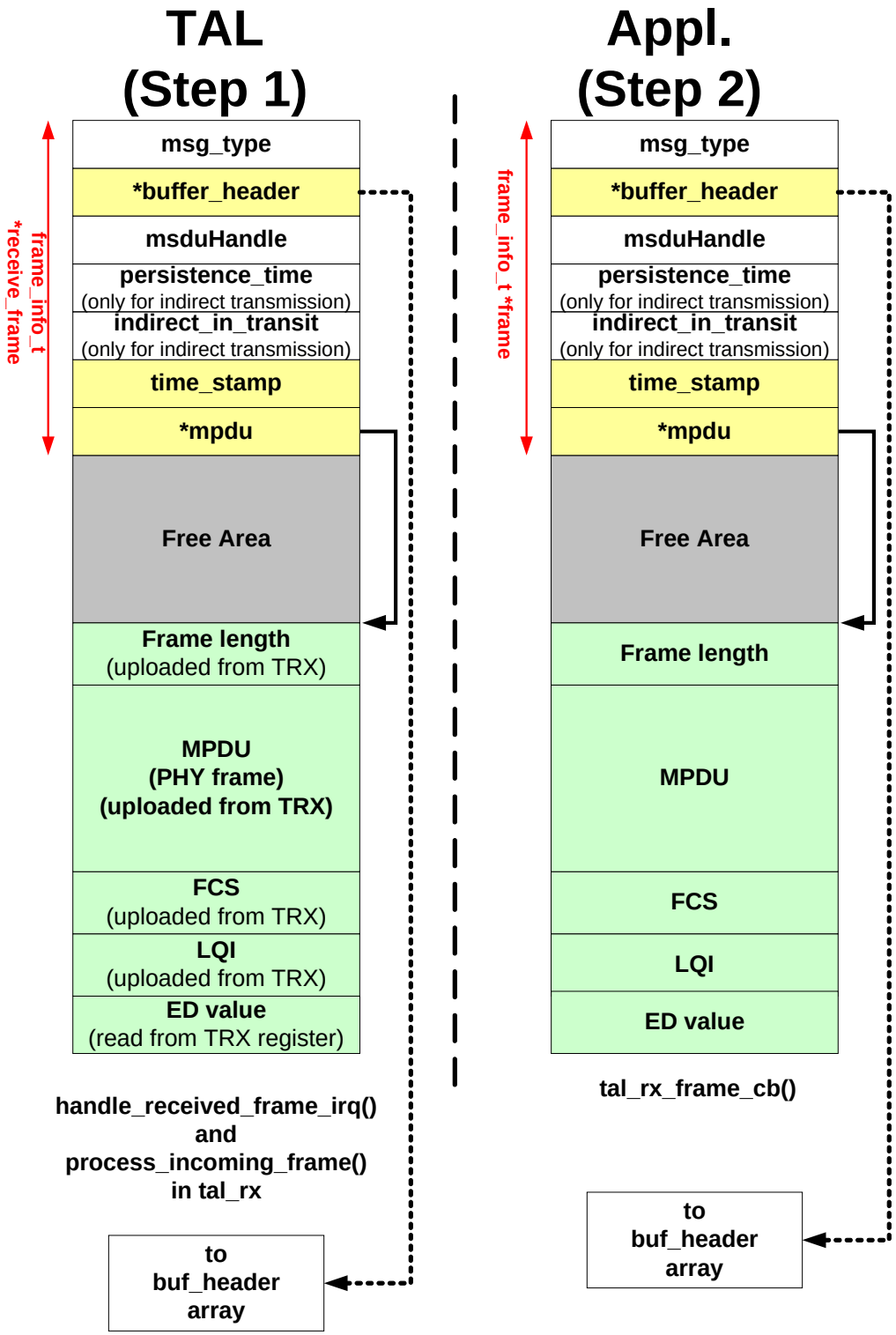
Step 2:
Within the TAL in function tal_tx_frame() (see file *TAL/tal_type/Src/tal_tx.c*) a pointer is set to the location of the actual MPDU inside the frame buffer (member *mpdu* of structure *frame_info_t*). This pointer is used for initiating the frame transmission (by means of function send_frame() with the appropriate parameters for CSMA-CA and frame retry.

Step 3 (not included in Figure 4-7):
After the frame has been transmitted the TAL acts as similar at described in Section 4.2.1.1. Once the TAL frame transmission callback function tal_tx_frame_done_cb() (residing inside the application) is called, no further handling is required in case of the usage of a static frame transmission approach. The static frame buffer can immediately be re-used for further transmission attempts. In case of dynamic buffer handling the Tx frame buffer needed to be freed additionally by calling function bmm_buffer_free().

4.2.2.2 Frame reception buffer handling using TAL-API

The following section describes how buffers are used inside the stack during the procedure of the reception of a Frame using the TAL-API.

Figure 4-8. Frame buffer handling during frame reception using TAL-API.



Step 1:
The processing of a received frame in side the TAL is independent from the layer residing on top of the TAL. The same mechanisms as described in Section 4.2.1.2 apply within in the TAL layer.

Step 2:
Once the TAL frame reception callback function tal_rx_frame_cb() (implemented inside the application) is called, the application can access the frame buffer via a *frame_inof_t* structure. At the end it is necessary to free the receive buffer by calling the function bmm_buffer_free(). A new buffer for frame reception is automatically allocated inside the TAL itself, so the application does not need to take for Rx buffer allocation.

4.3 Configuration files

The stack contains a variety of configuration files, which allow:

- The stack to configure the required stack resources according to the application needs based on the required functionality, and
- The application to configure its own resources

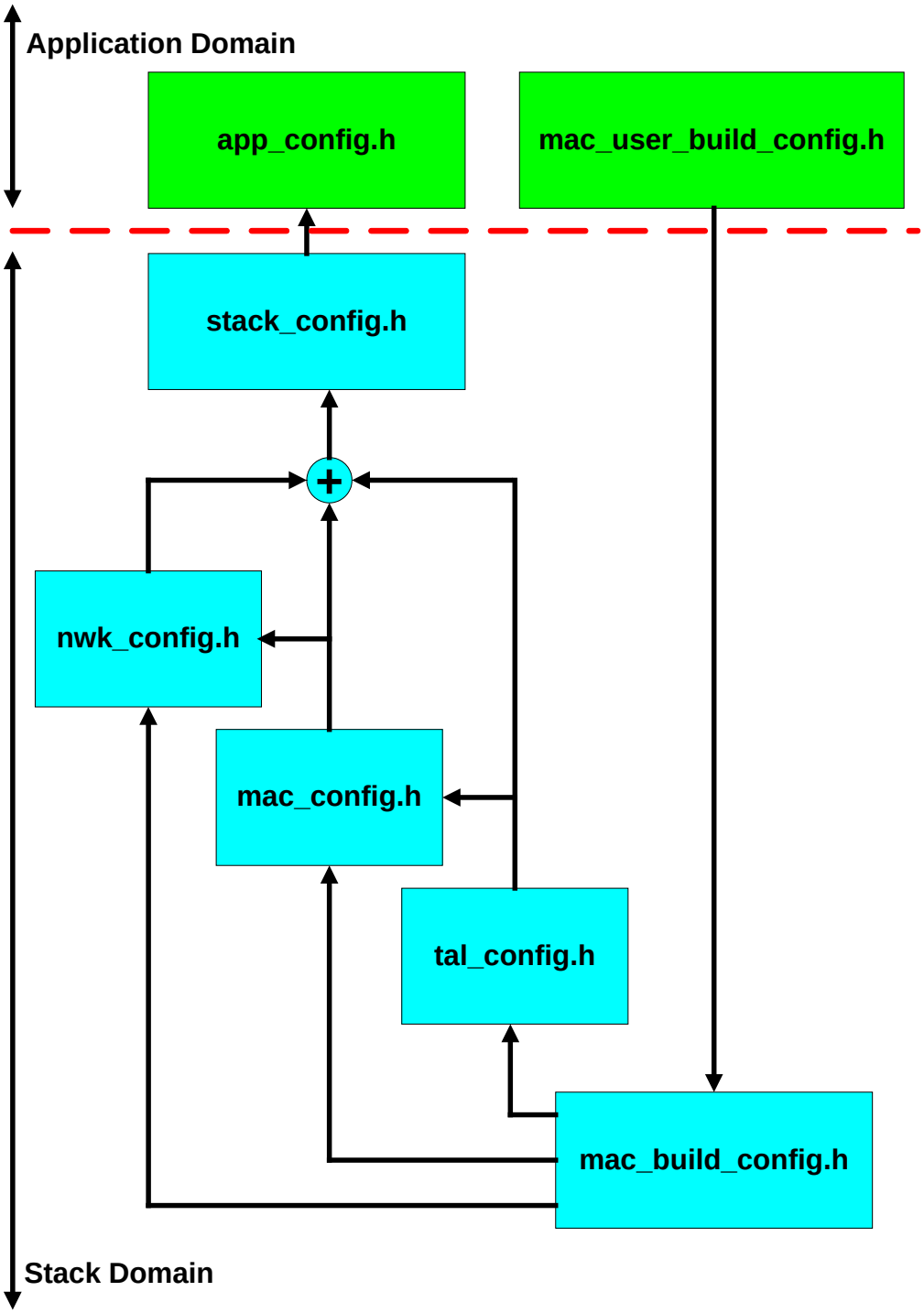
Throughout the various layers and thus directories within the software package the following configuration files are available:

- app_config.h
- stack_config.h
- pal_config.h
- tal_config.h
- mac_config.h
- mac_build_config.h
- mac_user_build_config.h

The meaning of these configuration files are described in more detail in the following sections.

The following picture shows the “#include”-hierarchy (`#include “file_name.h”`) for these configuration files.

Figure 4-9. Configuration file #include-hierarchy.



4.3.1 Application resource configuration – app_config.h

Each application is required to provide its own configuration file *app_config.h* usually located in *Inc* directory of the application.

This configuration file defines the following items:

- Timers required only within the application domain (independent from the timers used within the stack): Here the number of application timers and their timer IDs are defined
- Large and small buffers required only within the application domain (independent from the buffers used within the stack)
- Additional settings regarding the buffer size of USB or UART buffers
- Any other resources as required

In order to allow for proper resource configuration (for example, to calculate the overall number of timers) app_config.h includes the file stack_config.h which contains resource definitions from the stack domain (without the application).

This file can be adjusted by the end user according to its own needs.

4.3.2 Stack resources configuration – stack_config.h

The stack uses its own configuration file *stack_config.h* located in directory Include.

This configuration file defines the following items:

- IDs of the currently known stack layers (PAL up to NWK)
- Size of large and small buffers
- Total number of buffers and timers

Depending on the setting of the build switch HIGHEST_STACK_LAYER the configuration file of the highest layer of the stack (tal_config.h, mac_config.h, etc.) is included in order to calculate the resource requirements at compile time.

IMPORTANT This file must not be changed by the end user.

4.3.3 PAL resource configuration – pal_config.h

The PAL layer does not require own resources such as timer or buffers, so this does not need to be taken into consideration in the resource calculation for the application. Nevertheless there exists a unique *pal_config.h* file for each platform type (for example, for each board) which can be found in the directories PAL/*pal_generic_type_name/pal_type_name/Boards/board_type_name*, for example PAL/AVR/ATMEGA1281/Boards/REB_4_0_231. These pal_config.h files define all platform specific hardware components.

4.3.4 TAL resource configuration – tal_config.h

The TAL layer uses its own configuration file *tal_config.h* located in directory TAL/*trx_name*/Inc, that is, each transceiver (and thus each TAL implementing code for a specific transceiver) has its own TAL configuration file:

- TAL/ ATMEGARF_TAL_1/Inc (for ATmega128RFA1)
- TAL/AT86RF212/Inc
- TAL/AT86RF230B/Inc
- TAL/AT86RF231/Inc
- TAL/AT86RF232/Inc

- Etc.

These configuration files define the following items:

- Transceiver dependent values required by any upper layer (radio wake-up time)
- Timers and their IDs used within this particular TAL implementation
- The capacity of the TAL-Incoming-Frame-Queue

If the build switch HIGHEST_STACK_LAYER is set to TAL, the proper tal_config.h file (depending on build switch TAL_TYPE) is directly included into file stack_config.h since there are no further stack layers defined.

IMPORTANT These files must not be changed by the end user.

4.3.5 MAC resource configuration – mac_config.h

The MAC layer uses its own configuration file mac*_config.h* located in directory MAC/Inc.

This configuration file defines the following items:

- Timers and their IDs used within the MAC layer based on the current build configuration
- The capacity of certain MAC specific queues

If the build switch HIGHEST_STACK_LAYER is set to MAC, mac_config.h is directly included into file stack_config.h since there is no upper stack layer defined.

IMPORTANT This file must not be changed by the end user.

4.3.6 NWK resource configuration – nwk_config.h

Once a network layer (NWK) is provided as part of the stack on top to the MAC, the network layer uses its own configuration file *nwk_config.h* located in directory NWK/Inc.

If the build switch HIGHEST_STACK_LAYER is set to NWK, nwk_config.h is directly included into file stack_config.h since there is no upper stack layer defined.

IMPORTANT This file must not be changed by the end user.

4.3.7 Build configuration file – mac_build_config.h

File mac_build_config.h located in directory */Include* defines the MAC features required for specific build configurations. See Section 6.2.1 for more information about mac_build_config.h.

IMPORTANT This file must not be changed by the end user.

4.3.8 User build configuration file – mac_user_build_config.h

Each application may provide its own user build configuration file mac_user_build*_config.h* usually located in Inc directory of the application, although this is not required. This configuration file defines the actual MAC components used for the end user application and can actually reduce resource requirements drastically.

If the application wants to use its own user build configuration the build switch MAC_USER_BUILD_CONFIG needs to be set. See Section 6.2.2 for more information about mac_user_build_config.h.

This file can be adjusted by the end user according to its own needs.

For more information about user build configurations and its utilization please refer to Section 4.4 and Section 6.2.2.

An example for an application using the configuration file *mac_user_build_config.h* to create an application defined stack can be found in Section 9.2.1.3.

4.4 MAC components

The MAC is implemented to be fully compliant to the IEEE 802.15.4-2006 standard.

The MAC components are clustered in essential components and supplementary components.

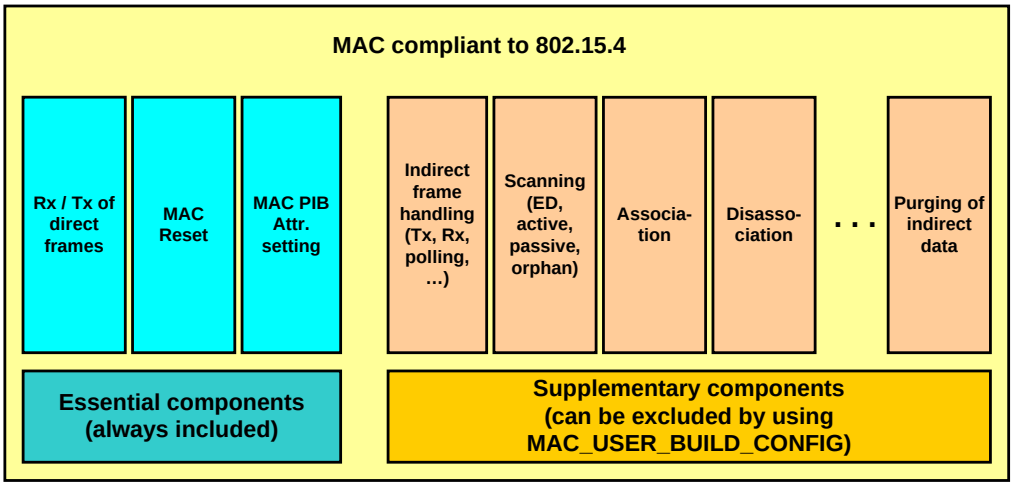
Essential components are required for a minimum reasonable application based on the MAC and are thus always included in a build. These components are:

- MAC reset
- Direct data transmission and reception
- Writing MAC PIB attributes

Supplementary components are components that provide standard MAC functionality that might not be required for some applications. This is example association, indirect data transmission, scanning, etc. These components are also included in the standard build and can be used by any applications, so the end application does not have to worry about the inclusion of any functionality.

On the other hand all supplementary components can be removed from the build in order to drastically reduce footprint. For more information about how to add or remove components from the build please see Section 6.2 (using build switch MAC_USER_BUILD_CONFIG).

Figure 4-10. Essential and supplementary MAC components.



The following sections describe some of these supplementary components (especially the more complex ones) in more detail.

4.4.1 MAC_INDIRECT_DATA_BASIC

This feature is usually required for any node (both RFD and FFD) that wants to receive indirect data. This is for instance helpful, if a node is usually in power save mode and thus cannot receive direct frames from its parent. The node could then periodically wake-up and poll its parent for pending data.

This feature includes the following functionality:

- Initiation of explicit polling for pending of indirect data (usage of wpan_mlme_poll_req() / usr_mlme_poll_conf())
- Transmission of data request frames to its parent
- Reception of indirect data frames
- Initiation of implicit polling for indirect data (that is, transmission of data request frame without an explicit call of function wpan_mlme_poll_req()):
    - Polling for an association response frame during the association procedure
    - Polling for more pending data once a received frame from its parent has indicated more pending data at the parent
    - Polling for pending data in case a received beacon frame from its parent has indicated pending data at the parent

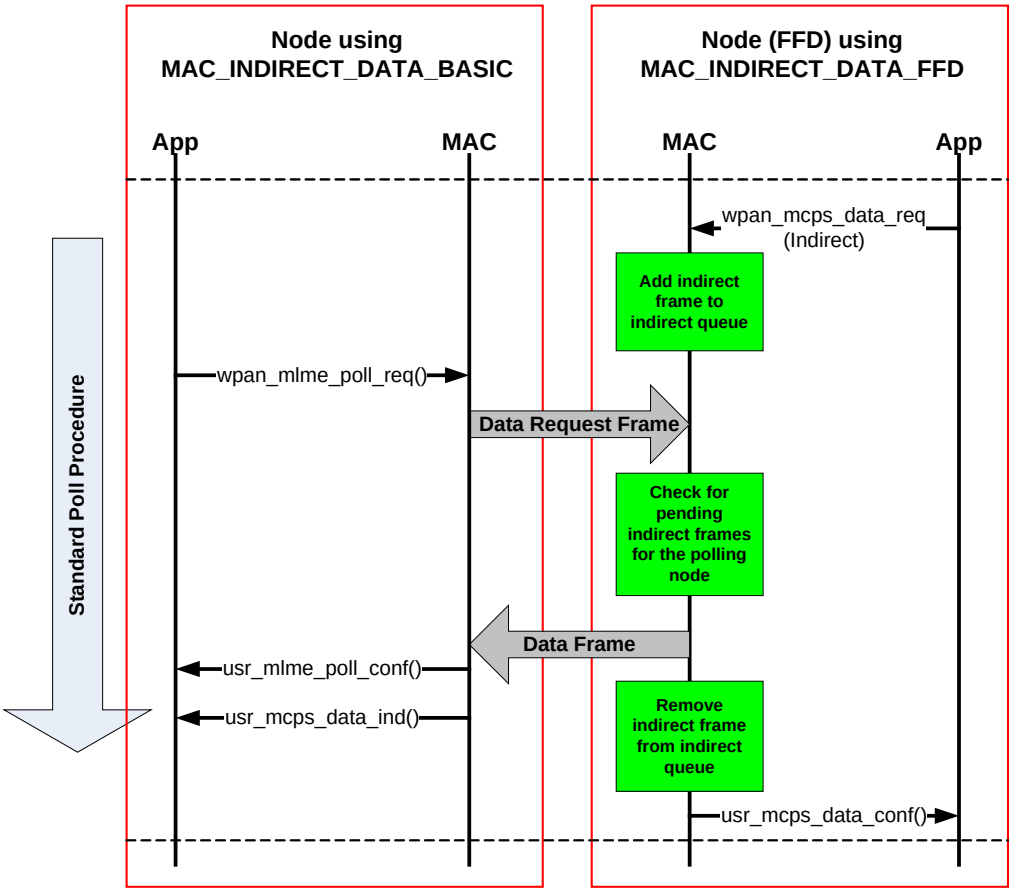
4.4.2 MAC_INDIRECT_DATA_FFD

This feature is a further extension of the feature MAC_INDIRECT_DATA_BASIC (that is, in order to use MAC_INDIRECT_DATA_FFD also MAC_INDIRECT_DATA_BASIC is required). It is designed for FFDs (PAN Coordinators or Coordinators) to allow the handling of transmitting indirect data frames.

This feature includes the following functionality:

- Initiation of indirect data transmission (usage of wpan_mcps_data_req() with TxOption = Indirect Transmission)
- Handling of the Indirect-Data-Queue
    - Adding and removing of indirect frames
    - Handling of a persistence timer in order to check for expired transactions
- Transmission of association response frame or indirect disassociation notification frames
- Handling of received data request frames and the proper responses (either with pending frames or a data frame with zero length payload)
- Setting of Frame Pending bit in the Frame Control field
- Adding of address of nodes with pending frames in the beacon frame payload

Figure 4-11. Example of provided functionality for MAC_INDIRECT_DATA_BASIC and MAC_INDIRECT_DATA_FFD.



4.4.3 MAC_PURGE_REQUEST_CONFIRM

This feature is a typical FFD feature allows a node to purge pending indirect frames from its Indirect_Data_queue by means of using functions wpan_mcps_purge_req() / usr_mcps_purge_conf().

Since purging of pending data requires handling of transmitting indirect frames, the feature MAC_INDIRECT_DATA_FFD is also required.

4.4.4 MAC_ASSOCIATION_INDICATION_RESPONSE

This feature is a typical FFD feature that allows a node to receive and process association request frames and handle them properly. In case the network uses short addresses, a short address may be selected and returned to the initiating device by means of association response frame.

Since the association procedure is perform using indirect traffic and the node using MAC_ASSOCIATION_INDICATION_RESPONSE has to transmit the association response frame indirectly also the components MAC_INDIRECT_DATA_BASIC and MAC_INDIRECT_DATA_FFD are required.

4.4.5 MAC_ASSOCIATION_REQUEST_CONFIRM

This feature allows a node (both RFD and FFD) to associate to a parent (PAN Coordinator or Coordinator) to initiate an association procedure (by transmitting an

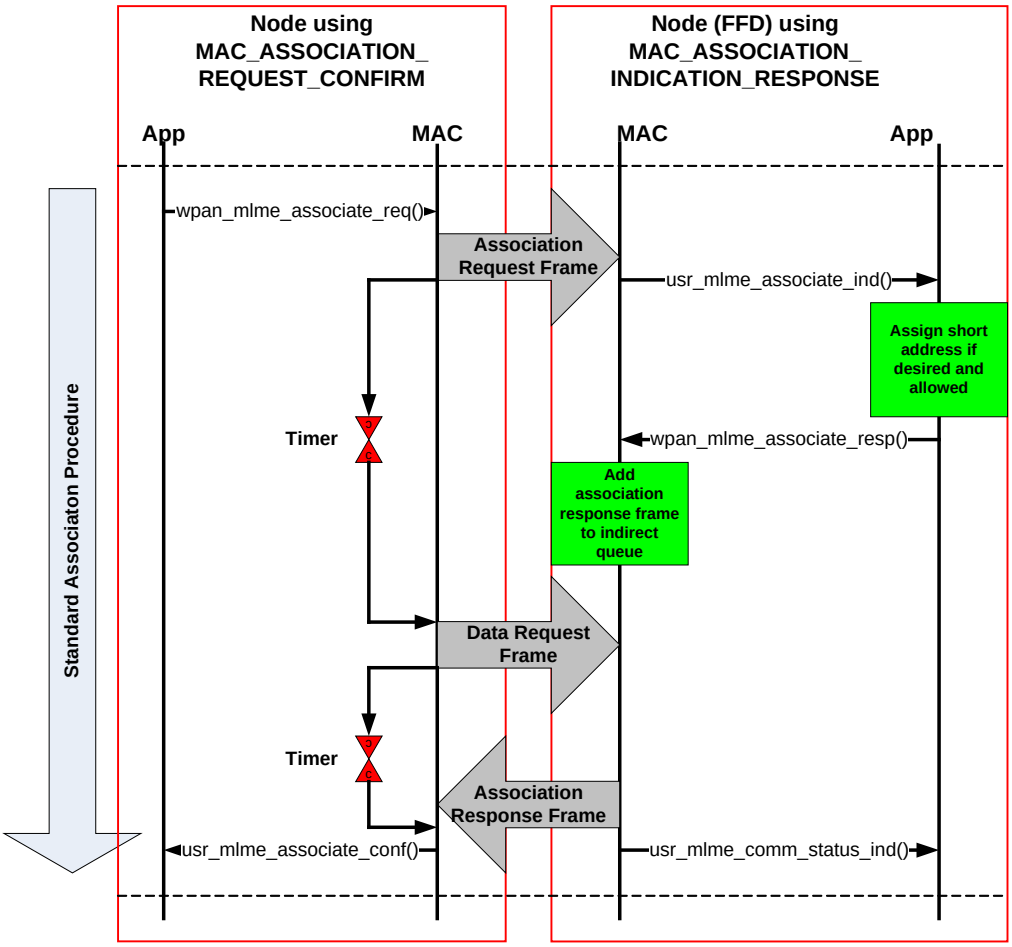
association request frame) and handle the reception of an association response frame.

In case a short address is desired this will be requested by the parent if allowed. All required timer for the association process are handled as well.

Since the association response frame is received indirectly, also the feature MAC_INDIRECT_DATA_BASIC is required.

The node is able accept and process a request from its upper layer (for example, the network layer) to associate itself to another node (that is, its parent).

Figure 4-12. Provided functionality for MAC_ASSOCIATION_INDICATION_RESPONSE and MAC_ASSOCIATION_REQUEST_CONFIRM.



4.4.6 MAC_DISASSOCIATION_BASIC_SUPPORT

This components allows

- A node (both RFD and FFD) to initiate a disassociation procedure from its parent (PAN Coordinator or Coordinator),
- a node (both RFD and FFD) to handle a received disassociation notification frame from its parent,
- a node (both RFD and FFD) to poll for a pending indirect disassociation notification frame,

- a node (FFD only) to initiate a disassociation procedure to its child

Since the disassociation notification frame may be received indirectly, also the feature MAC_INDIRECT_DATA_BASIC is required.

4.4.7 MAC_DISASSOCIATION_FFD_SUPPORT

This feature is a typical FFD feature that allows a node to transmit an indirect disassociation notification frame to one of its children.

The following components are required as well:

- MAC_DISASSOCIATION_BASIC_SUPPORT
- MAC_INDIRECT_DATA_BASIC
- MAC_INDIRECT_DATA_FFD

4.4.8 MAC scan components

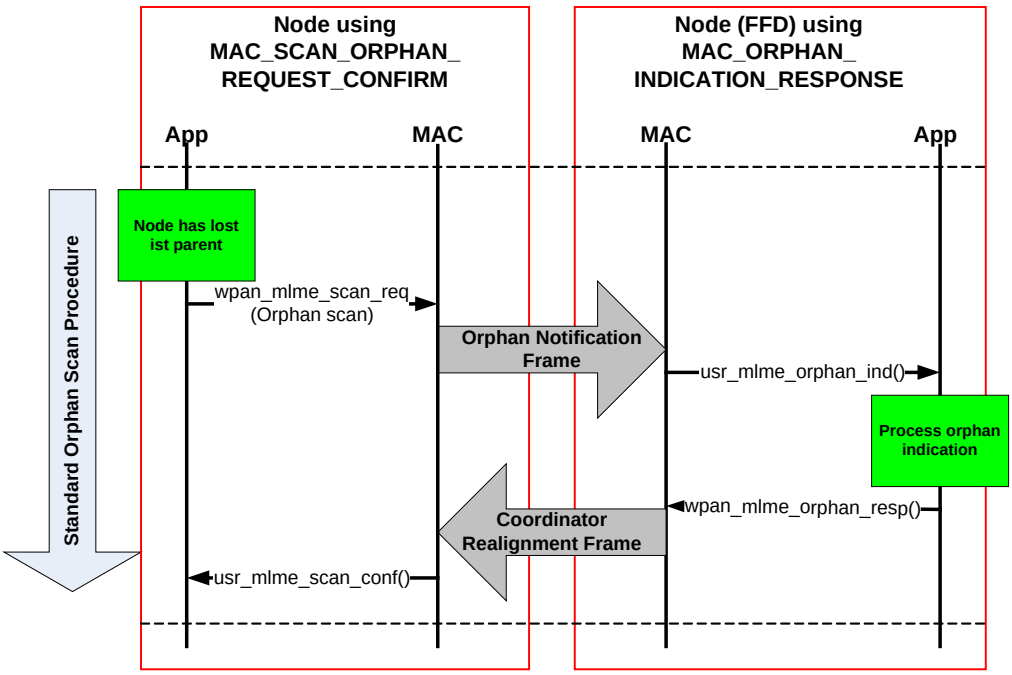
These components allow a node to perform a specific type of scanning.

- MAC_SCAN_ACTIVE_REQUEST_CONFIRM
  The node is able to perform an active scan to search for existing networks
- MAC_SCAN_ED_REQUEST_CONFIRM
  The node is able to perform an energy detect scan
- MAC_SCAN_ORPHAN_REQUEST_CONFIRM
  The node is able to perform an orphan scan in case it has lost its parent
- MAC_SCAN_PASSIVE_REQUEST_CONFIRM
  The node is able to perform a passive scan to search for existing networks. This feature is only available if beacon-enabled networks are supported

4.4.9 MAC_ORPHAN_INDICATION_RESPONSE

This feature is a typical FFD feature that allows a node to process a received orphan notification frame from any of its children (initiated via an orphan scan request at the children) and process them properly. In response a realignment frame may be returned.

Figure 4-13. Provided functionality for MAC_ORPHAN_INDICATION_RESPONSE and MAC_SCAN_ORPHAN_REQUEST_CONFIRM (orphan scan procedure).



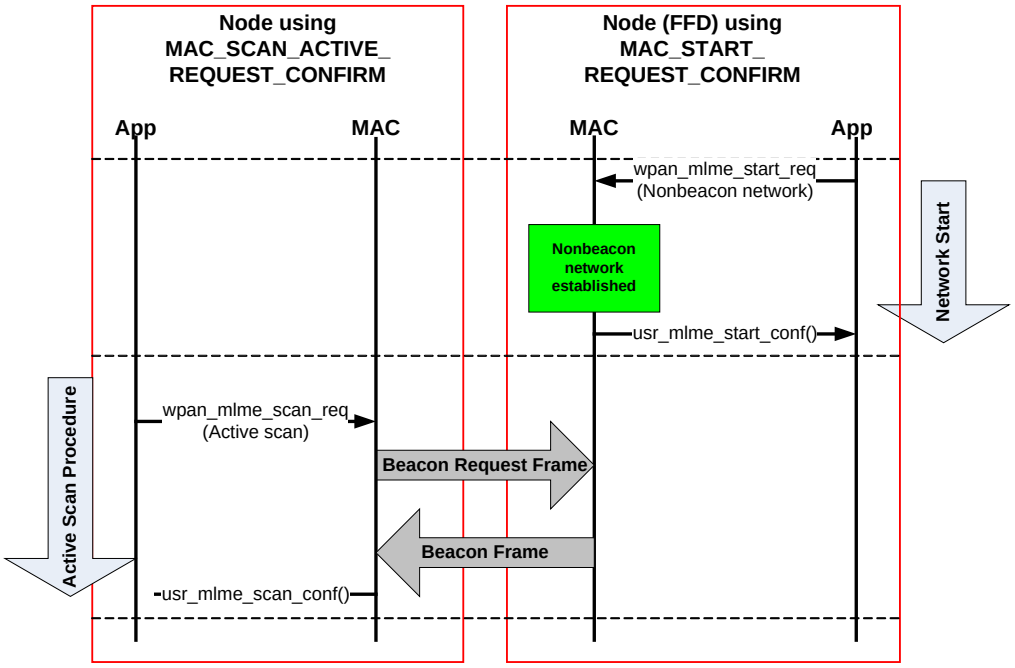
4.4.10 MAC_START_REQUEST_CONFIRM

This feature is a typical FFD feature that allows a node to start a new PAN (network) by means of using functions wpan_mlme_start_req() / usr_mlme_start_conf(). Depending on the setting of BEACON_SUPPORT this can be either only a non-beacon enabled network or also a beacon-enabled network.

Consequently this also enables the ability of the node to:

- Transmitting beacon frames (in case beacon-enabled networks are supported)
- Respond to beacon request frames (active scan by another node) with proper beacon frames
- Perform network realignment and transmit coordinator realignment frames (initiated by calling function wpan_mlme_start_req() with parameter CoordinatorRealignment = true)

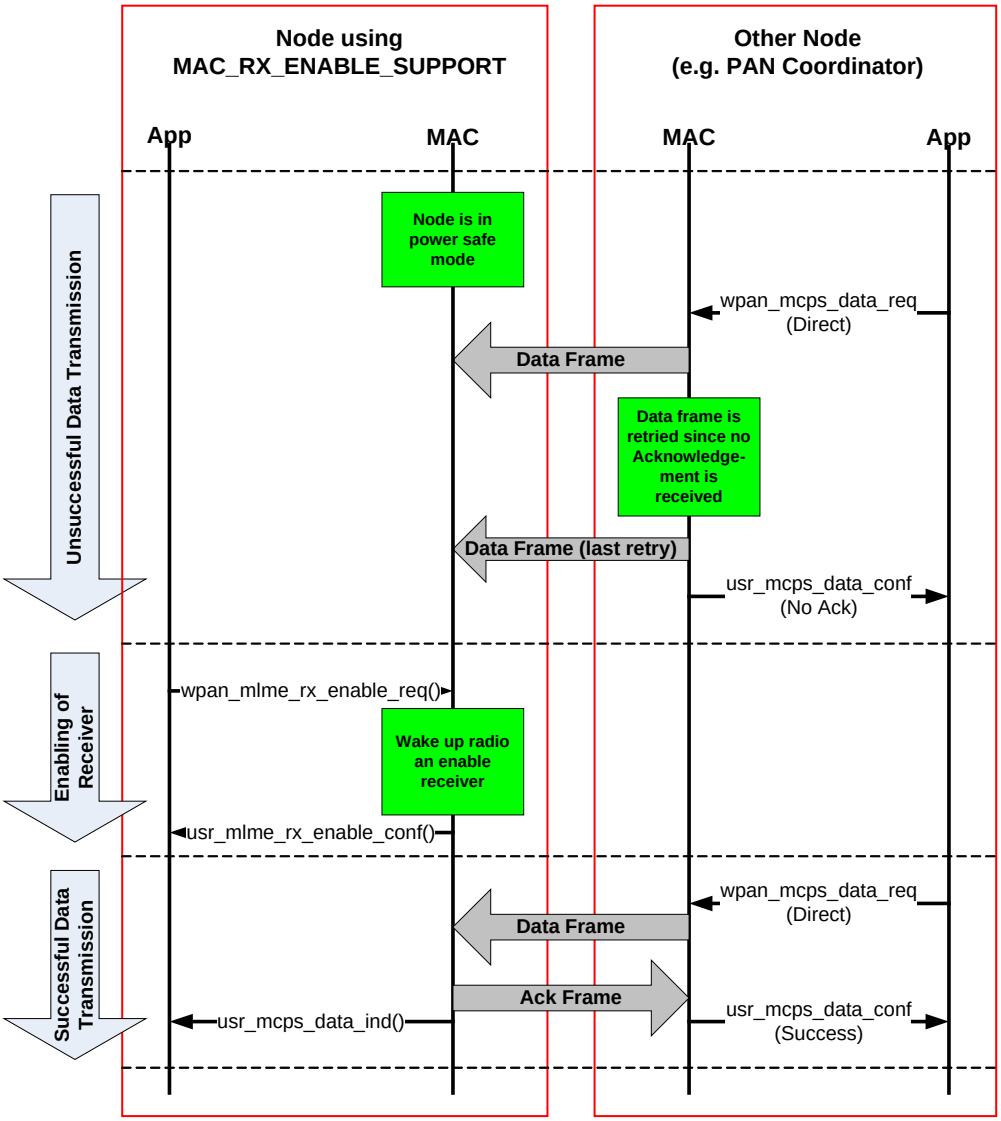
Figure 4-14. Start of non-beacon network and active scan.



4.4.11 MAC_RX_ENABLE_SUPPORT

This feature is usually required for any node (both RFD and FFD) that wants to enable its receiver for a certain amount of time or disable its receiver. Most commonly it is utilized at an RFD that goes to sleep mode during idle periods to save as much power as possible. In order to periodically listen to the channel or frames to be received, the application can initiate a wpan_mlme_rx_enable_req() with proper parameters (see MAC Example Basic_Sensor_Network in Section 9.2.1.1).

Figure 4-15. Enabling of receiver and proper data reception.



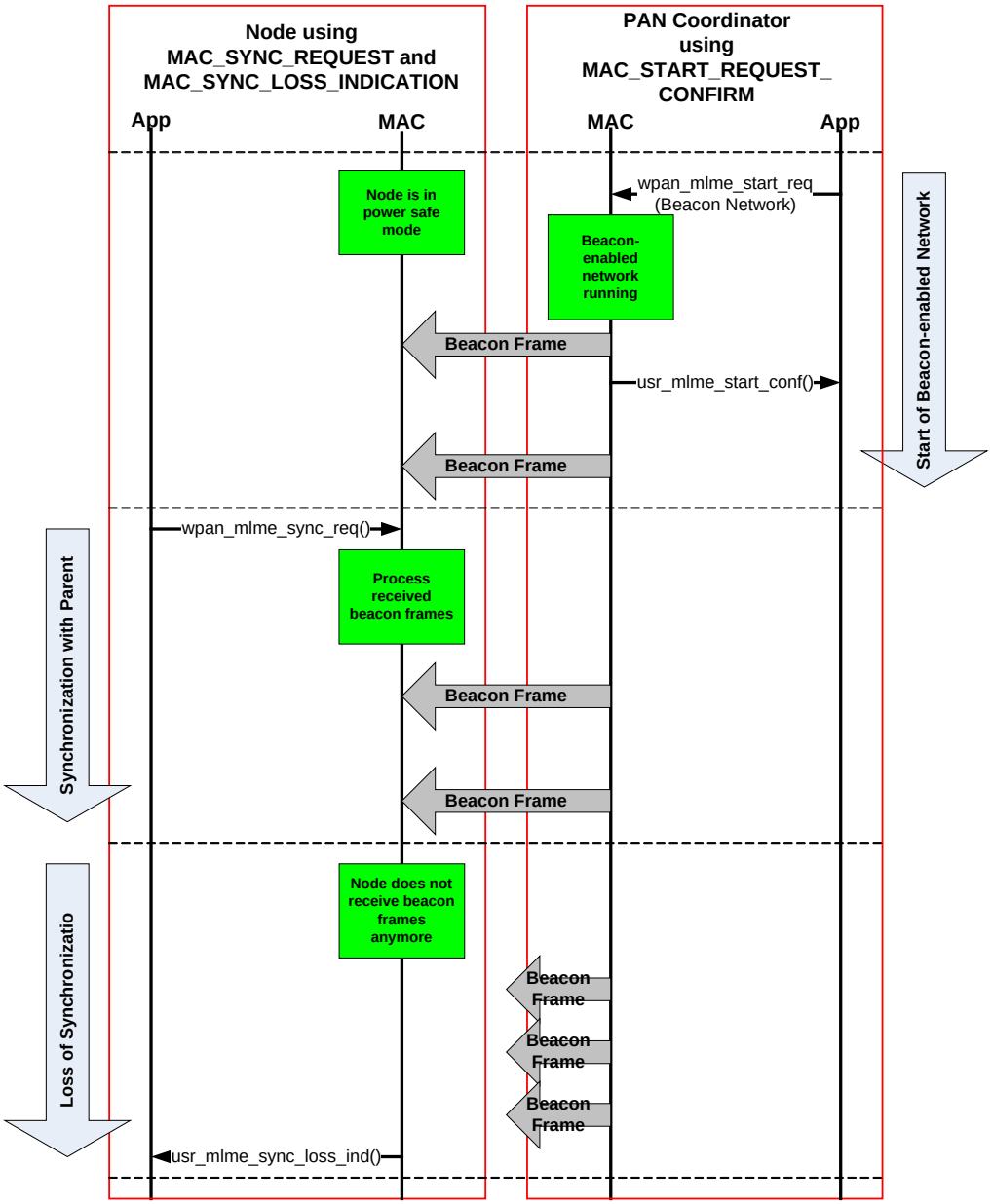
4.4.12 MAC_SYNC_REQUEST

This feature is usually required for any node (both RFD and FFD) that wants to synchronize with its beacon-enabled network tracking beacon frames from its parent by means of using function wpan_mlme_sync_req().

4.4.13 MAC_SYNC_LOSS_INDICATION

This feature is usually required for any node (both RFD and FFD) that needs to be able to report a sync loss condition to its upper layer. This can be either the reception of a coordinator realignment frame from its parent, or caused by the fact that a synchronized node has not received beacon frames from its parent for a certain amount of time.

Figure 4-16. Synchronization and loss of synchronization.



4.4.14 MAC_BEACON_NOTIFY_INDICATION

This feature is usually required for any node (both RFD and FFD) that may need to present received beacon frame to its upper layer. This could be caused by the fact that the received beacon frame contains a beacon payload or the MAC PIB attribute macAutoRequest within the node is set to false.

4.4.15 MAC_GET_SUPPORT

This feature allows reading the current values of MAC PIB attributes by means of using function wpan_mlme_get_req().

4.4.16 MAC_PAN_ID_CONFLICT_AS_PC

This feature is a typical FFD feature that allows a PAN Coordinator node to detect a PAN-Id conflict situation and report this to its higher layer, allowing the higher layer or application to initiate the proper PAN-Id conflict resolution. The node is able to detect a PAN-Id conflict situation while acting as a PAN Coordinator by checking received beacon frames from other PAN Coordinators and being able to act upon the reception of PAN-Id Conflict Notification Command frames from its children.

The following components are required as well:

- MAC_START_REQUEST_CONFIRM
- MAC_SYNC_LOSS_INDICATION

4.4.17 MAC_PAN_ID_CONFLICT_NON_PC

This feature is usually required for any node (both RFD and FFD) that may need to detect a PAN-Id conflict situation while acting not as a PAN Coordinator node. The node is able to detect a PAN-Id conflict situation while NOT acting as a PAN Coordinator by checking received beacon frames from other PAN Coordinators and being able to initiate the transmission of PAN-Id Conflict Notification Command frames from its parents if required.

The following components are required as well:

- MAC_SYNC_LOSS_INDICATION
- Either MAC_ASSOCIATION_REQUEST_CONFIRM or MAC_SYNC_REQUEST

4.5 Support of AVR platforms larger than 128Kbyte program memory

4.5.1 General

In order to support applications larger than 128KByte program memory that are using function pointers (such as callbacks in the stack), special implementation support both by the stack and the application is required.

Function pointers are usually 16-bit pointers, which can address only 64Kbyte of program memory. Functions located in the memory between 64Kbyte and 128Kbyte can still be addressed by 16-bit function pointers, since all addresses start on an even address in program memory, which increases the addressable space of a 16-bit pointer to 127Kbyte. So no special care is required for code up to 128Kbyte.

In case function pointers shall be used for builds which are larger than 128Kbyte (when using for instance the Atmel ATxmega256A3 MCU), the function pointers need to be declared as large pointers, that is, pointers which are 24-bit. The Section 4.5.2 describes the current implementation used for IAR compilers.

NOTE Currently AVR-GCC does not provide a clean method to support such constructs. Therefore program code larger than 128Kbyte is not supported by this software package. Nevertheless there are a number of workarounds to overcome this issue by forcing all functions which shall be accessed via function pointers into the lower 128Kbyte of memory. Such a workaround implementation for AVR-GCC is not provided by this software package.

4.5.2 Stack implementation

The stack has been modified in order to support function pointers which can address functions residing in the program memory larger than 128Kbyte.

4.5.2.1 File avrtypes.h

The header file *avrtypes.h* residing in directory *PAL/Inc* contains the following construct in the section dedicated to IAR based builds:

```
#if (FLASHEND > 0x1FFFF)
    // Required for program code larger than 128K
    #define FUNC_PTR void __farflash *
#else
    #define FUNC_PTR void *
#endif  /* ENABLE_FAR_FLASH */
```

In case the utilized AVR MCU provides more than 128Kbyte of flash memory, all function pointers defined by FUNC_FAR are defined as 24-bit pointers.

4.5.2.2 Function pointers as function parameters

Function parameters which are actually function pointers need to be defined as FUNC_PTR in order to allow for 24-bit support. This is implemented in the following two PAL API functions:

- pal_trx_irq_init:

```
void pal_trx_irq_init(trx_irq_hdlr_idx_t trx_irq_num,
                      FUNC_PTR trx_irq_cb)
```

- pal_timer_start

```
retval_t pal_timer_start(uint8_t timer_id,
                         uint32_t timer_count,
                         timeout_type_t timeout_type,
                         FUNC_PTR timer_cb,
                         void *param_cb)
```

4.5.2.3 Usage of function pointers as function parameters

These functions containing function pointers need to be called with the corresponding FUNC_PTR type. Examples are:

- File *mac_mcps_data.c* in directory *MAC/Src*

```
/* Start the indirect data persistence timer now. */
status = pal_timer_start(T_Data_Persistence,
                         persistence_int_us,
                         TIMEOUT_RELATIVE,
                         (FUNC_PTR)mac_t_persistence_cb,
                         NULL);
```

- File *tal_init.c* in directory *TAL/AT86RF231/Src*

```
/*
 * Configure interrupt handling.
 * Install a handler for the transceiver interrupt.
 */
pal_trx_irq_init(TRX_MAIN_IRQ_HDLR_IDX,
                 (FUNC_PTR)trx_irq_handler_cb);
```

4.5.3 Application support

Applications that are built for Atmel AVR MCUs with more than 128Kbyte flash (and thus potentially need large function pointers) shall use the same way of calling these specific PAL API functions containing functions pointers. Therefore all applications are updated within this software package as described in Section 4.5.2.3.

As an example, see file main.c of the MAC example application Star_Nobeacon (in directory Applications/MAC_Examples/Star_Nobeacon/Src):

```
pal_timer_start(TIMER_TX_DATA,
                DATA_TX_PERIOD,
                TIMEOUT_RELATIVE,
                (FUNC_PTR)app_timer_cb,
                NULL);
```

NOTE It is strongly recommended to follow this scheme in all components of the application.

4.6 Application security support

The MAC stack supports application security features (such as the CCM* algorithm or plain AES encryption support) by means of two different layers:

- SAL: Security Abstraction Layer (see Section 2.2.2)
- STB: Security Toolbox (see Section 2.2.3)

The SAL as low level AES functionality API is supported for various hardware AES engines (in MCUs and transceivers).

The STB as high level security abstraction API is

- Supported for SAL based systems (the STB requires either one of the SAL implementations, see Sections 6.1.5.2 and 6.1.5.1), or
- Used stand-alone (without using any SAL implementation) for ARM systems with incorporated hardware crypto engine (see Section 6.1.5.3) such as the Atmel AT91SAM7XC256

Figure 4-17. Usage of the security layers by an application.

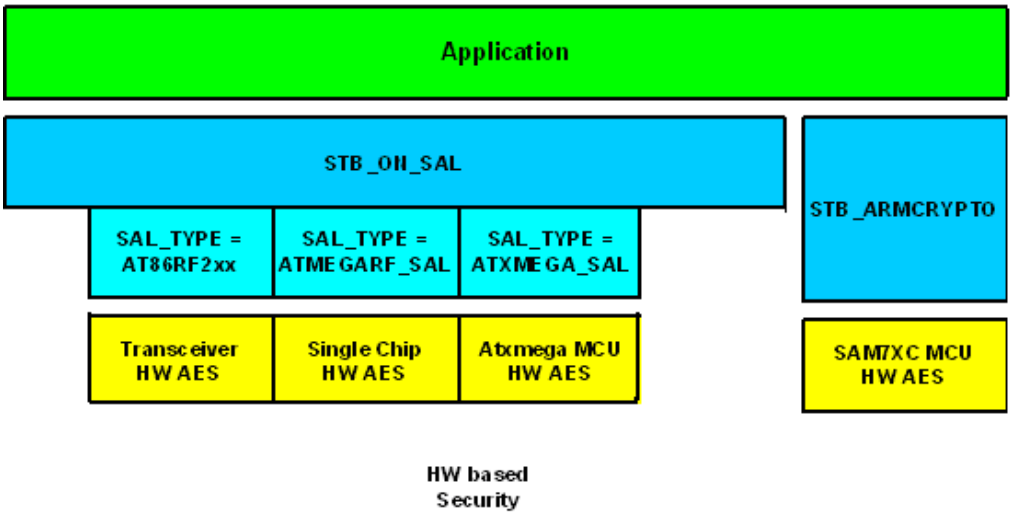


Figure 4-17 gives an overview which combinations of the two security layers are meaningful. It can be seen that the following security combinations are supported:

12. Utilization of hardware AES in transceivers, such as Atmel AT86RF212, Atmel AT86RF231 and Atmel AT86RF232, by using the STB on top of the SAL (SAL_TYPE = AT86RF2xx);
    This combinations can be used in conjunction with any MCU.
13. Utilization of hardware AES in single chip transceivers, such as Atmel ATmega128RFA1, by using the STB on top of the SAL (SAL_TYPE = ATMEGARF_SAL).
14. Utilization of hardware AES in ATxmega MCUs, such as Atmel ATxmega128A1, by using the STB on top of the SAL (SAL_TYPE = ATXMEGA_SAL);
    This combination can be used in conjunction with any transceiver, even with Atmel AT86RF230.
15. Unitization of the ARM hardware crypto engine by using STB_ARMCRYPTO without any SAL;
    This combination is supported for Atmel SAM7XC MCUs and can be used in conjunction with any transceiver, even with AT86RF230.

4.7 High-density network configuration

The IEEE standard [4] provides knobs to adjust the MAC layer to the application needs. These knobs are the PIB attributes that allow configuring the behavior of the MAC. In particular, in high-density networks where many nodes access the network at the same time it might be necessary to tweak the MAC to achieve better performance. This applies to non-beacon enabled and beacon-enabled networks. The following PIB attributes can be used to tweak the MAC in this regard:

- Back off exponent: The PIB attributes *macMinBE* and *macMaxBE* determine the potential length of the back off exponent used for the CSMA algorithm. By default macMinBE = 3 and macMaxBE = 5. In order to reduce the probability that different nodes use the same back off period, it is recommend changing the PIB attribute values from the default values. Example: macMinBE = 6 and macMaxBE = 8. The macMaxBE value needs to be increased before the macMinBE is increase.
- Frame retries: The PIB attribute *macMaxFrameRetries* defines the maximum number of re-transmissions if a requested ACK is not received. The default value (defined by the IEEE standard and used by the MAC implementation) is three. The IEEE standard allows increasing the number of retries up to seven.
- Maximum CSMA back offs: The PIB attribute *macMaxCSMABackoffs* defines the number of back offs that are allowed before the channel is finally determined as busy and no transmission happens. The MAC implementation uses the default value of four. Increasing the value to five also increases the probability of successful transmission of a big number of nodes trying to access the channel at the same time.

4.8 High data rate support

The Atmel transceivers (except for the AT86RF230) are capable of transmitting frames at higher data rates than the standard data rates within the given band. The supported data rates are currently up to 2Mbit/s. These higher data rates are rates not defined within the IEEE standard (see [4]). For more information about high data rate support please refer to the data sheet for the corresponding transceiver.

In order to enable higher data rates than the standard rates, the following two items needs to be done:

16. Enable the build switch HIGH_DATA_RATE_SUPPORT within the corresponding Makefile or project file (see Section 6.1.4.3).
17. Set the PIB attribute phyCurrentPage to the corresponding value (for example, phyCurrentPage = 17 for 2Mbit/s support); after setting the correct channel page all frames will be transmitted using the corresponding data rate belonging to this channel page.

Table 4-1 shows which data rate can be selected (by setting a specific channel page) using a particular transceiver. The table entries with yellow background refer to Atmel proprietary channel pages for non-standard high rates. Please note that the standard channel page is always channel page 0.

Table 4-1. Channel pages vs. data rates.

Frequency band/ transceiver	**MAC-2003 compliant channel page 0**	**MAC-2006 compliant**	**High data rate mode 1**	**High data rate mode 2**
Sub-1 GHz **Channel 0** **Channel 1-10** **AT86RF212**	20kb/s @ -110dBm 40kb/s @ -108dBm (2)	Channel Page 2 100kb/s 250kb/s	Channel Page 16 200kb/s 500kb/s (1)(3)(4)(5)(6)	Channel Page 17 400kb/s 1000kb/s (1)(3)(4)(5)(6)
Chinese Band **Channel 0-3** **AT86RF212**	N/A	Channel Page 5 250kb/s	Channel Page 18 500kb/s (1)(3)(4)(5)(6)	Channel Page 19 1000kb/s (1)(3)(4)(5)(6)
2.4GHz **Channel 11-26** **AT86RF231, ATmega128RFA1, …**	250kb/s @ -101dBm	Channel Page 2 500kb/s (1)(3)(5)	Channel Page 16 1000kb/s (1)(3)(5)	Channel Page 17 2000kb/s (1)(3)(5)

Notes:
1. PSDU data rate.
2. BPSK.
3. Reserved channel pages are used to address the appropriate mode (non-compliant).
   Marked w/ yellow background color. The Atmel AT86RF212's sensitivity values for the proprietary modes are based on PSDU length of 127 bytes.
4. Scrambler enabled.
5. Reduced ACK timing. Proprietary channel pages can be enabled using build configuration switch HIGH_DATA_RATE_SUPPORT.
6. Proprietary channel pages 18 and 19 used for Chinese frequency band. Pages 18 and 19 support channels 0-3.

For a MAC example using a high data rate of 2Mbit/s please refer to Section 9.2.1.4.

5 MAC power management

The MAC stack provide built-in power management that allows to put the transceiver into power save state as often as possible in order to save as much energy as possible. This allows for example End Devices, which are usually battery powered, to use a sleeping state of the transceiver as default state. The entire power management is inherent in the MAC itself and works without any required interaction from the application. On the other hand there exist means for the application to control the power management scheme in general as desired.

5.1 Understanding MAC power management

The following section is only valid for MAC applications (or applications on higher layers), but not for TAL applications. For TAL applications please refer to Section 5.4.

Once a node (running an application on top of the MAC stack) has finished its initialization procedure, the MAC layer decides whether the node stays awake or enters SLEEP state. This is controlled by the MAC PIB attribute macRxOnWhenIdle.

Whenever this PIB attribute is set to True, the MAC keeps the radio always in a state where the default state of the receiver is on, that is, the transceiver is able to receive incoming frames whenever there is nothing else to do for the stack. Since this is a non-sleeping state for the transceiver and requires much more energy than a power safe state, this behavior is usually applied for all mains powered nodes, such as PAN Coordinators or Coordinators/Routers (nodes built using build switch FFD, see Section 6.2.1.1).

As mentioned MAC power management works automatically within the stack. Once a node is started, it is automatically in power save mode. This is handled by the MAC PIB attribute macRxOnWhenIdle. The default value for macRxOnWhenIdle is False, that is, the radio shall be off in case the node is idle, meaning that the radio will be in sleep mode. This is valid for all nodes including End Devices, Coordinators and PAN Coordinators.

Any node that shall not be in sleep as the default mode of operation needs to be put in listening mode by setting the PIB attribute macRxOnWhenIdle to True. Usually this is only done for mains powered nodes, such as Coordinator or PAN Coordinators. This will be explained in more detail in the subsequent sections.

For battery powered nodes (usually End Devices) the default state shall be sleeping, since otherwise the battery would be emptied too fast. Since the PIB attribute macRxOnWhenIdle is per default set to False, such nodes will automatically enter SLEEP state when there is nothing to be done for the transceivers.

The transceiver of such nodes will be woken up automatically whenever a new request from the upper layer (for example, the application on top of the MAC or the Network layer), which requires the cooperation of the transceiver, is received. This could be the request to transmit a new frame (wpan_mcps_data_req()), the request to set a PIB attribute that is mirrored in transceiver registers, the request to poll for pending data at the node's parent, etc.

Once such a request has been received at the MAC-API, the MAC performs a check whether the radio is currently in SLEEP state and wakes up the transceiver if required. Afterwards the MAC can us the transceiver to perform whichever action is required. After the ongoing transaction is finished, the MAC will put the transceiver back to SLEEP if allowed.

This complete MAC controlled power management implies that a node being in idle periods in SLEEP is not able to receive any frame during these time periods, that is, a PAN Coordinator would not be able to send a direct frame to its sleeping child being and End Device. This can be reproduced using the provided MAC example applications Nobeacon_Application (see Section 9.2.1.1) and Star_Nobeacon (see Section 9.2.1.5). In both of these applications all directed traffic goes from the End Device to the PAN Coordinator. If these applications where changed so that the PAN Coordinator sent traffic to the End Device, the End Device would not accept these frames, since it is in SLEEP most of the time.

Of course there is variety of means defined within IEEE 802.15.4 to allow a reasonable communication between mains powered nodes and battery powered nodes (applying power management) in both directions. This is explained in more detail in the following section. One way to allow communication from the PAN Coordinator to the End Device is to use a timer which wakes up the End Device periodically, allowing this device to receive frames during this time period from other nodes. This is implemented in MAC example Basic_Sensor_Network (see Section 9.2.1.1).

5.2 Reception of data at nodes applying power management

When data shall be received by an End Device (that is, a node applying MAC power management as default), we have several options as described in the subsequent sections.

5.2.1 Setting of macRxOnWhenIdle to true

One option is to leave the receiver of the node always on, so the device is able to always receive frames. This can be done be setting the MAC PIB Attribute macRxOnWhenIdle to True (1) (by using the API function wpan_mlme_set_req()) at any time. This will immediately wake up the radio and enable the receiver of the node.

If this scheme is applied, the node will not enter SLEEP state anymore and thus use is battery power very extensively. So for battery powered End Devices this is not recommended, although it might be an easy solution for mains powered End Devices.

5.2.2 Enabling the receiver

If a PAN Coordinator wants to send data to an End Device periodically, the application of the Device can be implemented as such, that the Device maintains a timer with the same time interval that the Coordinator wants to transmit its data to the Device.

Upon expiration of this timer the application of the Device can then enable its receiver for a certain amount of time or until it receives data from the Coordinator, and turn off the receiver again. The receiver can be enabled or disabled by using the MAC-API function “wpan_mlme_rx_enable_req”.

The parameter RxOnDuration contains the value (number of symbols, for example, one symbols is 16µs for 2.4GHz networks) that the receiver shall be enabled. If this parameter is zero (0), the receiver of the node will be disabled.

The parameters DeferPermit and RxOnTime shall be set to 0 for a nonbeacon-enabled network, since these parameters are obsolete for nonbeacon-enabled networks.

If this scheme is used, handling of power management is done by the device itself. When the RxEnable timer expires, or if parameter RxOnDuration is zero, the MAC will

initiate its standard power management scheme and put the transceiver again into SLEEP if allowed (that is, in case macRxOnWhenIdle is False).

5.2.3 Handshake between end device and coordinator

Another scheme is based on a combination of enabling the receiver in conjunction with a handshake scheme between End Device and the Pan Coordinator.

The End Device enables its receiver periodically (as in Section 5.2.2), and sends a data frame to the Coordinator indicating it is alive for a certain amount of time. The Coordinator in return either answers with direct data to the Device directly (in case it has something to deliver) to the Device, or simply does nothing.

After the device has received a frame from the PAN Coordinator the End Device disables its receiver again. This can be done by simply letting the RxEnable timer expire (depending on the original value of RxOnDuration" at the first call of wpan_mlme_rx_enable_req") by directly calling by calling wpan_mlme_rx_enable_req" with parameter RxOnDuration" set to zero.

If the End Device does not receive a frame from its Coordinator, the device automatically goes to sleep depending on the original value of RxOnDuration" at the first call of wpan_mlme_rx_enable_req".

If this scheme is used, handling of power management is done by the device itself. When the RxEnable timer expires, or if parameter RxOnDuration is zero, the MAC will initiate its standard power management scheme and put the transceiver again into SLEEP if allowed (that is, in case macRxOnWhenIdle is False).

5.2.4 Indirect transmission from coordinator to end device

Another option is to use indirect data transmission from the Coordinator to the End Device and let the Device poll the Coordinator periodically for pending data. When this scheme is applied the Coordinator sets the parameter TxOptions of the API function:

```
bool wpan_mcps_data_req(uint8_t SrcAddrMode,
                        wpan_addr_spec_t *DstAddrSpec,
                        uint8_t msduLength,
                        uint8_t *msdu,
                        uint8_t msduHandle,
                        uint8_t TxOptions)
```

to WPAN_TXOPT_INIDIRECT_ACK (indirect, but acknowledged Transmission; value 5), instead of WPAN_TXOPT_ACK (direct, acknowledged Transmission value 1) as it is currently (see file mac_api.h in directory MAC/Inc).

NOTE This requires an additional check which device type the node is currently, since data from the Device to the Coordinator is still only transmitted directly.

Additionally the Device needs to implement a polling scheme in its application, during which it periodically calls function wpan_mlme_poll_req(). This will initiate a data request frame to the Coordinator. In case the Coordinator does have pending data for the Device, it initiates the direct transmission of those frames. Otherwise Coordinator sends a null data frame (data frame with empty payload). The Device both receives the response from the Coordinator and, if there is no further action to be done, returns to standard power management procedures. For more information see Sections 4.4.1 and 4.4.2.

If this scheme is used, handling of power management is done by the device itself.

5.3 Application control of MAC power management

As indicated throughout the previous sections there are several means for the application to control the general power management scheme applied by the MAC.

These are setting the MAC PIB attribute macRxOnWhenIdle and the MAC primitive MLME_RX_ENABLE.request.

5.3.1 MAC PIB attribute macRxOnWhenIdle

Setting the MAC PIB attribute to a specific value controls the handling of MAC power management. Whenever a transaction within the MAC has finished (for example, transmitting a frame, setting of PIB attributes residing within the transceiver, etc.) the MAC checks this PIB attribute. If the corresponding value is False, the radio enters SLEEP mode again, otherwise the transceiver stays awake.

Any node will always enter SLEEP mode after each finished transition, since the PIB attribute macRxOnWhenIdle is False as default.

If this behavior shall be altered (especially for Coordinators or PAN Coordinators), the application needs to change the value of macRxOnWhenIdle to True after whenever this shall be applied.

The current value of the MAC PIB attribute macRxOnWhenIdle can be altered by calling function wpan_mlme_set_req() with the appropriate value (see file *main.c* of example in Section 9.2.1.2):

```
/* Switch receiver on to receive frame. */
wpan_mlme_set_req(macRxOnWhenIdle, true);
```

or

```
/* Switch receiver off. */
wpan_mlme_set_req(macRxOnWhenIdle, false);
```

Please note that the transceiver will be immediately enabled or disabled.

5.3.2 Handling the receiver with wpan_rx_enable_req()

While setting of the PIB attribute macRxOnWhenIdle is a more “globally” or “statically” applied means to change the standard MAC power management scheme, the MAC primitive MLME_RX_ENABLE.request can be used to change the behavior more temporarily.

The receiver can be enabled by calling function wpan_mlme_rx_enable_req() with (the 3rd parameter) RxOnDuration larger than zero:

```
/* Switch receiver on for 10000 symbols. */
wpan_mlme_rx_enable_req(false, 0, 10000);
```

This wakes up the transceiver (independent from the current value of the PIB attribute macRxOnWhenIdle) if required and switches the receiver on.

After the timer with the specified time (RxOnDuration symbols) expires, the receiver is disabled automatically if the current value of macRxOnWhenIdle is false, or remains in receive mode if macRxOnWhenIdle is true.

The receiver can be disabled explicitly by calling wpan_mlme_rx_enable_req() with (the 3rd parameter) RxOnDuration equal to zero:

```
/* Disable receiver now. */
wpan_mlme_rx_enable_req(false, 0, 0);
```

This disables the receiver if the current value of the PIB attribute macRxOnWhenIdle is false and puts the transceiver to SLEEP mode.

For more information about function wpan_mlme_rx_enable_req() see files *mac_api.c* and *mac_rx_enable.c* in directory MAC/Src.

For more information about the interaction of MLME_RX_ENABLE and macRxOnWhenIdle see file *mac_misc.c* in directory MAC/Src and check the following function mac_sleep_trans().

For an example implementation of this features see MAC example application Basic_Sensor_Network in Section 9.2.1.1.

5.4 TAL power management API

The MAC power management mechanisms as described in the within this chapter are only valid if the application is residing on top of the MAC layer (or a higher layer on top of the MAC). In case the application is only residing on top the TAL layer, the application needs to take care for transceiver power management itself.

Therefore the TAL provides a Power Management API which is generally used by the MAC layer but can also be used by an application residing on top of the TAL. Nevertheless an application residing on top of any higher layer than the TAL must not use this TAL API explicitly, otherwise this may lead to undefined behavior.

The TAL Power Management API consists of two functions:

- tal_trx_sleep()
- tal_trx_wakeup()

For more information see file *tal.h* in directory TAL/Inc and the various implementations for each transceiver in file *tal_pwr_mgmt.c* in directories TAL/*TAL_TYPE_NAME*/Src.

6 Application and stack configuration

The MAC and its modules are highly configurable to adapt to the application requirements. The utilized resources can be configured and adjusted according to the application needs. This allows a drastic footprint reduction.

During build process the required features are included depending on the used build switches and basic configuration type.

Qualitative configuration includes:

- Features or modules can be included to or excluded from the firmware using build switches
- The build configuration is controlled by switches within Makefiles or IAR project files
- Several Makefile or IAR project file templates are provided for getting started (see directory Applications)
- Primitives as defined within IEEE 802.15.4 (and thus features within the MAC) can be included or excluded depending on the required degree of standard compliance or application needs
- Two generic profiles are provided: RFD and FFD primitive configuration

Quantitative configuration includes:

- Resources can be adjusted to the application needs
- The file app_config.h (usually located in the Inc path of the applications) provides hooks for the application configuration to configure its own resources
- Each demonstration application comes with its own configuration file (app_config.h) that can be re-used for own application design

6.1 Build switches

The stack and application based on the stack can be highly configured according to the end user application needs. This requires a variety of build switches to be set appropriately. The following section describes that build switches may be used during the build process.

The switches may be categorized as follows:

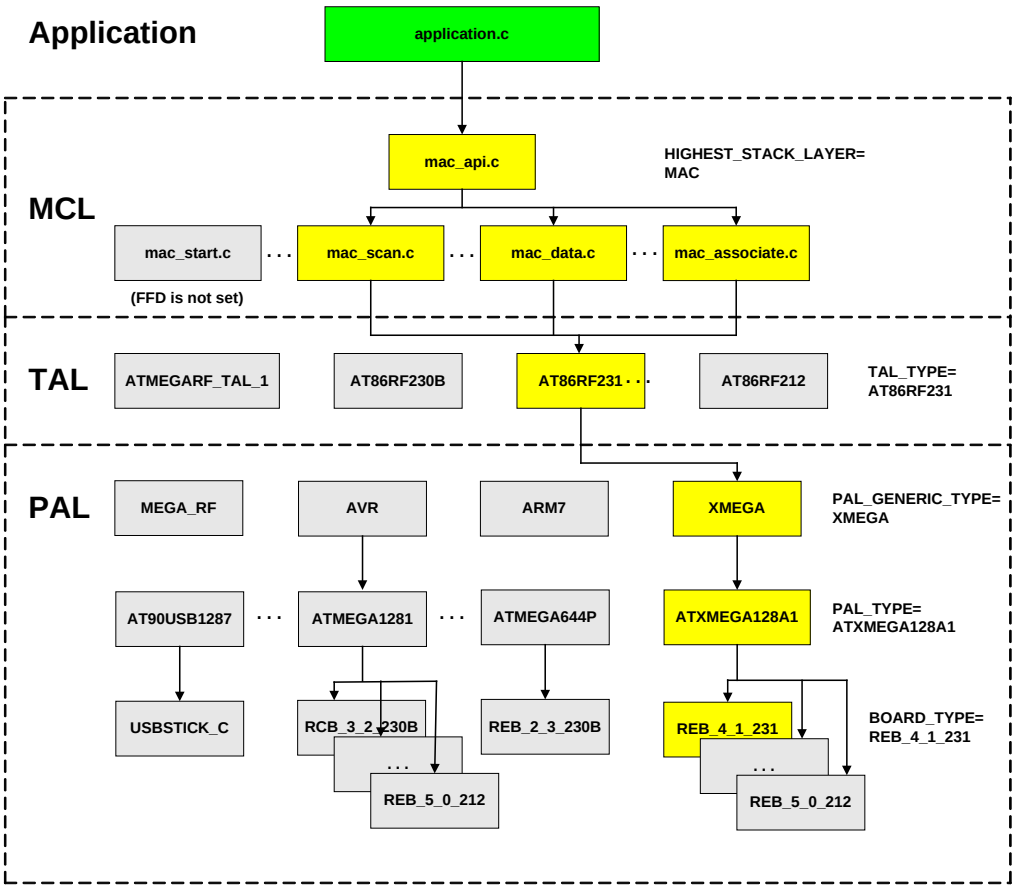
18. Global stack switches
    - HIGHEST_STACK_LAYER
    - REDUCED_PARAM_CHECK
    - PROMISCUOUS_MODE
    - ENABLE_TSTAMP
19. Standard or user build configuration switches
    - BEACON_SUPPORT
    - FFD
    - MAC_USER_BUILD_CONFIG
    - MAC_SECURITY_ZIP
20. Platform switches
    - PAL_TYPE
    - PAL_GENERIC_TYPE

- BOARD_TYPE
- SIO_HUB;UART0,UART1,USB0
- ENABLE_TRX_SRAM
- ENABLE_HIGH_PRIO_TMR
- EXTERN_EEPROM_AVAILABLE
- NON_BLOCKING_SPI
- F_CPU (formerly SYSTEM_CLOCK_MHZ)
- BAUD_RATE
- VENDOR_BOARDTYPES
- VENDOR_STACK_CONFIG
- ENABLE_ALL_TRX_IRQS (MEGA_RF only)
- ENABLE_RC_OSC_CALIBRATION (MEGA_RF only)
- WATCHDOG
- SLEEPING_TIMER

21. Transceiver specific switches
    - TAL_TYPE
    - ENABLE_TFA
    - TFA_BAT_MON
    - HIGH_DATA_RATE_SUPPORT
    - CHINESE_BAND
    - RSSI_TO_LQI_MAPPING
    - ENABLE_FTN_PLL_CALIBRATION
    - DISABLE_IEEE_ADDR_CHECK
22. Security switches
    - SAL_TYPE
    - STB_ON_SAL (formerly ENABLE_STB)
    - STB_ARMCRYPTO
23. Test and Debug switches
    - DEBUG
    - TEST_HARNESS

The following picture shows an example how the various build switches lead to a particular configuration. For simplicity reasons only the basic building blocks are included. More advance blocks (for example, TFA or STB have been omitted). The used build switches are explained in the subsequent sections.

Figure 6-1. Build configuration example.



6.1.1 Global stack switches

6.1.1.1 HIGHEST_STACK_LAYER

This build switch defines the layer that the end user application is actually based on. The MAC software package comprises of three real layers (from bottom: PAL, TAL, and MAC Core Layer). All these layer are forming the stack, although not necessarily all layers are always part of the actual binary. Depending upon the required functionality (full blown MAC versus simple data pump), the user application needs to define which layer it shall be based on (that is, which API it is using). If an application for instance only uses the PAL and TAL layers (that is, MAC is not used), all resources required for MAC are not part of the final application. This reduces code size and SRAM utilization drastically.

Also, if a Network Layer (NWK) will be part of the stack and residing on top of the MAC layer, a number of resources are used differently compared to an application on top of the MAC.

Example: Reading of PIB attributes residing in TAL layer.

If the HIGHEST_STACK_LAYER is MAC (HIGHEST_STACK_LAYER = MAC), the function tal_pib_get() in file tal_pib.c is not included in the binary, because the MAC reads all PIB attributes residing in TAL directly by accessing the global variables. On the other hand, if the HIGHEST_STACK_LAYER is TAL (HIGHEST_STACK_LAYER

= TAL) this function is available, because an application (being not part of the stack) shall not access global variables of the stack directly.

Conclusion:

If the application sits on top of the MAC layer, this build switch shall be set to „HIGHEST_STACK_LAYER = MAC“.

If the application sits on top of the TAL layer, this build switch shall be set to „HIGHEST_STACK_LAYER = TAL“.

If the application sits on top of the PAL layer, this build switch shall be set to „HIGHEST_STACK_LAYER = PAL“.

Usage in Makefiles:

```
CFLAGS += -DHIGHEST_STACK_LAYER=MAC
```

or

```
CFLAGS += -DHIGHEST_STACK_LAYER=TAL
```

Usage in IAR ewp-files:

```
HIGHEST_STACK_LAYER=MAC
```

or

```
HIGHEST_STACK_LAYER=TAL
```

For more information check file Include/*stack_config.h*. This shows how the timer resources are used and included in the end application depending upon the highest stack used.

6.1.1.2 REDUCED_PARAM_CHECK

Whenever an application or a higher layer accesses an API function of a lower layer usually a variety of parameter checks are done in order to ensure proper usage of the desired functionality. This leads to a more robust application. On the other hand, if the higher layer is designed to always call an API function with reasonable parameter values, this build switch might be omitted. This will reduce the code size.

As an example what this build switch causes, please check file MAC\Src\MAC\mac_mcps_data.c. In function mcps_data_request() a number of additional checks are performed if this switch is not set.

It is strongly recommended to disable this build switch at least during the development cycle of the application.

Usage in Makefiles:

```
CFLAGS += -DREDUCED_PARAM_CHECK
```

disables the additional parameter checking.

Usage in IAR ewp-files:

```
REDUCED_PARAM_CHECK
```

reduces the additional parameter checking.

6.1.1.3 PROMISCUOUS_MODE

This build switch allows for the creation of a special node that can be put into promiscuous mode thus allowing it acting as a very simple frame sniffer on a specific sniffer. It can be used a very simple network diagnostic tool.

When this switch is enabled the node is not supposed to act as a standard node being part of network, that is, the node will never acknowledge any received frame, etc. Instead the node will be able receive any proper IEEE 802.15.4 frame on its channel within range and present it to the application. The application can reside on top of the MAC layer (using MAC-API callback function *usr_mcps_data_ind()*) or on top of the TAL layer (using TAL callbacks).

Switching promiscuous mode on or off is controlled by the standard MAC PIB macPromiscuousMode (see IEEE 802.15.4-2006, Section 7.5.6.5 Promiscuous Mode). The payload contained in the usr_mcps_data_ind() callback function is the MAC Header (MHR) of the received frame concatenated with the original payload of the received frame.

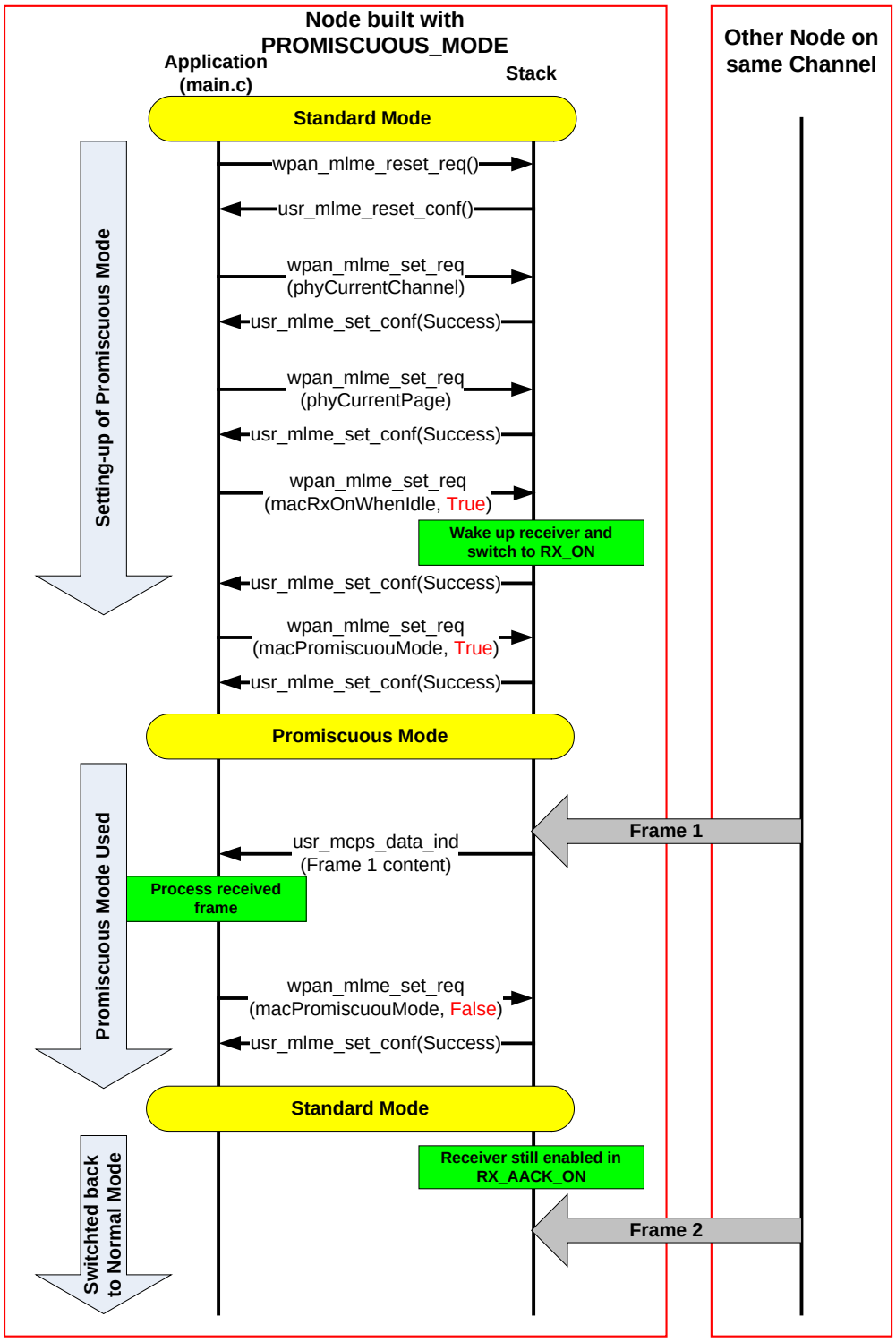
An example application presenting all received frames on a serial terminal can be found in the directory Applications/MAC_Examples/Promiscuous_Mode_Demo (see Section 9.2.1.4).

Promiscuous mode can be switched on or off by setting or resetting the PIB attribute macPromiscuousMode. If the radio is awake and in receive mode on the current channel, the node will present all received frames to the upper layer. In order to work properly, the receiver needs to be enabled. This can be done, for example, by setting MAC PIB attribute macRxOnWhenIdle to 1 before turning promiscuous mode on. Generally the transceiver state can be controlled similar to normal operation (see Chapter 5).

Once the PIB attribute macPromiscuousMode is reset, the node switches back to normal operation. It will be in the same state as before switching to promiscuous mode, for example, a node that was associated will still be connected to the same network.

The following picture indicates the proper handling of promiscuous mode.

Figure 6-2. Handling of promiscuous mode.



6.1.1.4 ENABLE_TSTAMP

This build switch allows creation of timestamping information throughout the entire MAC stack. This includes two different angles:

- Generation of timestamping information within the TAL
- Inclusion of timestamp information in the MAC-API primitives (see function usr_mcps_data_conf() and usr_mcps_data_ind() in file *MAC/Inc/mac_api.h*)

In case timestamping information shall be generated and included in the MAC-API for further utilization within the application, the compile switch needs to be set.

Usage in Makefiles:

```
CFLAGS += -DENABLE_TSTAMP
```

enables the timestamping.

Usage in IAR ewp-files:

```
ENABLE_TSTAMP
```

enables the timestamping.

6.1.2 Standard and user build configuration switches

The standard and user build configuration switches are described in detail in Sections 6.2.1 and 6.2.2.

6.1.3 Platform switches

The PAL (Platform Abstraction Layer) contains all platforms (that is, MCU and board) based functionality and provide an API to the TAL, which is independent from the underlying platform.

6.1.3.1 PAL_GENERIC_TYPE

Certain portions of the PAL are generic to a specific microcontroller family. Examples for such generic code are transceiver access via SPI for 8-bit AVR controller (see file AVR\Generic\Src\pal_trx_access.c), or using Event System of the Atmel AVR XMEGA controller. This code is separated from the non-generic code in special directories.

In order to make sure that the correct code belonging to the proper microcontroller family is used for the application, the build switch PAL_GENERIC_TYPE needs to be set accordingly.

The currently defined microcontroller families are:

- Atmel AVR
- Atmel AVR32
- Atmel SAM3
- Atmel XMEGA
- Atmel ARM7

For more information check file PAL\Inc*pal_types.h*.

Usage in Makefiles:

```
CFLAGS += -DPAL_GENERIC_TYPE=XMEGA
```

selects the AVR XMEGA microcontroller family.

Usage in IAR ewp-files:

```
PAL_GENERIC_TYPE=AVR
```

selects the Atmel 8-bit AVR ATmega microcontroller family.

6.1.3.2 PAL_TYPE

To build the proper code the compiler needs to know which microcontroller is used. Also depending on the microcontroller specific code portions needs to be used within the build (since for example some microcontrollers do not support USB while others do). The type of microcontroller is specified by the build switch PAL_TYPE.

Examples of currently supported microcontrollers are:

- Atmel ATmega1281
- Atmel ATxmega128A1
- Atmel ATxmega256A3
- Atmel AT91SAM3S4C
- Atmel AT32UC3A3256S
- Atmel AT32UC3L064

For more information check file PAL\Inc\ *pal_types.h*.

Usage in Makefiles:

```
CFLAGS += -DPAL_TYPE=ATXMEGA256A3
```

selects the ATxmega256A3 microcontroller.

Usage in IAR ewp-files:

```
PAL_TYPE=ATXMEGA256A3
```

selects the ATxmega256A3 microcontroller.

6.1.3.3 BOARD_TYPE

Since the platform may vary between different boards even for one specific microcontroller, certain functionality within a specific PAL has to be implemented depending on the type of board used.

The supported board types for one microcontroller can be found in file pal_boardtypes.h for each MCU, for example, for Atmel ATmega1281 this file is located in directory PAL\AVR\ATMEGA1281\Boards.

If a new board is designed which requires specific software changes, a new board has to be added to the PAL and the board type has to be added to file pal_boardtypes.h, or, preferably, added to a customer specific file vendor_boardtypes.h (being enabled by setting compile switch VENDOR_BOARDTYPES; see Section 6.1.3.11 or 11.3.1.1).

Usage in Makefiles:

```
CFLAGS += -DBOARD_TYPE=USBSTICK_C
```

selects the Raven USB stick revision C.

Usage in IAR ewp-files:

```
BOARD_TYPE=RCB_4_1_SENS_TERM_BOARD
```

selects the Radio Controller Board Revision 4.1 using antenna diversity for the Atmel AT86RF231 microcontroller.

6.1.3.4 SIO_HUB, UART0, UART1, USB0

Certain applications (for example, TAL example Performance_Test_EVK) require Serial I/O support (SIO) in order to print characters on a serial terminal or get input from the user. For easy SIO configuration the concept of a SIO-Hub was introduced. This implements a simple software multiplexer/de-multiplexer, which allows the application or stack to access SIO hardware resources without actually knowing which kind of SIO hardware support is provided. The actually supported hardware is currently UART or USB.

In order to enable SIO functionality the build switch SIO_HUB has to be set. Also the proper USB or UART channel needs to be set.

Usage in Makefiles:

```
CFLAGS += -DSIO_HUB -DUSB0
```

enables the SIO-Hub and uses USB channel 0.

Usage in IAR ewp-files:

```
SIO_HUB
UART1
```

enables the SIO-Hub and uses UART Channel 1.

6.1.3.5 ENABLE_TRX_SRAM

In general there are two different ways of accessing the memory of the transceiver, either by frame buffer access (1) or by direct SRAM access (2). Please check the data sheet for more information. When a frame needs to be uploaded or downloaded into or from the transceiver, this can be done by using the corresponding frame buffer functions or transceiver SRAM access functions. It is always recommended to use the frame buffer functions.

For more information please see file PAL\Inc\pal.h or file PAL\AVR\Generic\Src\pal_trx_access.c.

24. Functions for frame buffer access (always enabled):
    ```
    void pal_trx_frame_read(uint8_t* data, uint8_t length);
    void pal_trx_frame_write(uint8_t* data, uint8_t length);
    ```
25. Functions for direct transceiver SRAM access (only enabled if ENABLE_TRX_SRAM is set):
    ```
    void pal_trx_sram_read(uint8_t addr, uint8_t *data, uint8_t
    length);
    void pal_trx_sram_write(uint8_t addr, uint8_t *data, uint8_t
    length);
    ```

For transceivers providing AES security the SRAM functions are required if transceiver security is used.

For Atmel AT86RF230 it is recommended not using this switch in order to save code space.

6.1.3.6 ENABLE_HIGH_PRIO_TMR

AT86RF230 transceivers need to have an ED sampling timer running in case Energy Detect scanning is used. This timer is implemented by means of a unique and very accurate hardware timer (High priority timer). In other transceivers (Atmel

AT86RF231 or Atmel AT86RF212) this hardware timer is not required for Energy Detect scanning, since additional hardware support is provided.

On the other hand the provided standard software timers have limited accuracy, since several software timers share one hardware resource. An application may want to use this timer if desired for their own purpose. In this case this build switch has to be set. But the application has to make sure that it is not using this hardware timer concurrently with the stack.

All provided example applications within the MAC package do not use this feature, so in order to save code space this timer is not enabled.

Usage in Makefiles:

```
CFLAGS += -DENABLE_HIGH_PRIO_TMR
```

enables the code for the high priority timer.

Usage in IAR ewp-files:

```
ENABLE_HIGH_PRIO_TMR
```

enables the code for the high priority timer.

6.1.3.7 EXTERN_EEPROM_AVAILABLE

Each node needs to have a unique 64-bit IEEE address (extended address) to identify itself within the network. All example applications delivered within the MAC software package are only working if the node has such an IEEE address.

This address is usually stored in an EEPROM, either in the internal EEPROM of the MCU or in an external chip on the board. If the hardware board has such an external EEPROM where the IEEE address is stored, this build switch has to be enabled. The actual implementation of the code for reading the address from an external EEPROM is board dependent and might be adapted by the end user depending on their hardware.

If the IEEE address is stored within the internal EEPROM of the MCU (located in the first eight octets of the internal EEPROM), this build switch should to be omitted.

Usage in Makefiles:

```
CFLAGS += -DEXTERN_EEPROM_AVAILABLE
```

enables reading the IEEE address from the external EEPROM.

Usage in IAR ewp-files:

```
EXTERN_EEPROM_AVAILABLE
```

enables reading the IEEE address from the external EEPROM.

6.1.3.8 NON_BLOCKING_SPI

Currently, for all transceivers connected to the microcontroller via SPI, the SPI frame download or upload is done blocking, that is, while the controller is access the transceiver no other action can be on the microcontroller.

Since more powerful microcontroller may require performing other application or stack tasks while accessing the transceiver via SPI, an option to perform non-blocking SPI access has been implemented. This access makes use of interrupt driven SPI access for downloading frames. In between the microcontroller is able to do other tasks as required.

The non-blocking SPI can be controlled via the build switch NON_BLOCKING_SPI.

Usage in Makefiles:

```
CFLAGS += -DNON_BLOCKING_SPI
```

enables non-blocking SPI frame download.

Usage in IAR ewp-files:

```
NON_BLOCKING_SPI
```

enables non-blocking SPI frame download.

6.1.3.9 F_CPU (formerly SYSTEM_CLOCK_MHZ)

Currently each supported platform (that is, each supported board) has a specific clock speed set for the system clock. This clock speed might need to be changed for certain applications.

For the platform Atmel ATxmega128A1 with Atmel AT86RF231 on REB_4_1_600 the clock speed can be changed at compile time (4…32MHz).

The current system clock speed can be controlled via the build switch F_CPU. If the build switch is omitted, the standard system clock speed is used.

Usage in Makefiles:

```
CFLAGS += -DF_CPU=4/8/32
```

configures the system clock to 4/8/32MHz.

Usage in IAR ewp-files:

```
F_CPU=4/8/32I
```

configures the system clock to 4/8/32MHz.

Example Makefiles and IAR project files are provided for the MAC example application Star_Nobeacon.

For more information please see Section 11.1.

6.1.3.10 BAUD_RATE

This build switch allows for changing the used UART baud rate. The default UART baud rate is 9600 bps. This may be changed by setting this build switch to a different meaningful value.

Usage in Makefiles:

```
CFLAGS += -DBAUD_RATE=38400
```

configures the UART baud rate to 38400 bps.

Usage in IAR ewp-files:

```
BAUD_RATE=38400
```

configures the UART baud rate to 38400 bps.

Omitting this build switch sets the default baud rate of 9600 bps. For USB this build switch has no meaning.

Pease note that the proper working of the UART with certain baud rates is depending on the current system clock speed (see build switch F_CPU) and the error in the used

oscillator frequency. As a rule of thumb the error of the oscillator frequency shall not be more than 2%.

For example, in case the Atmel ATmega1281 is used with F_CPU = 8MHz, the error for 38400 bps is 0.2%, which is perfectly fine, but for 115200 bps the error is -3.5% which may lead to improper functioning of the UART. For more information about the UART oscillator frequency error please check the data sheet of the utilized MCU type.

6.1.3.11 VENDOR_BOARDTYPES

This build switch allows for the support of customer specific hardware boards which are directly supported within this software package without the need to change any single file.

If this switch is set in the application, the known boards defined in the corresponding files *pal_boardtypes.h* are ignored. Instead a file *vendor_boardtypes.h* searched in the current include path. If such a file is found, the boards defined in *vendor_boardtypes.h* are used during the build process. For example, see file *PAL/AVR/ATMEGA1281/Boards/pal_boardtypes.h*, where the following code is included:

```
#if defined(VENDOR_BOARDTYPES) && (VENDOR_BOARDTYPES != 0)
#include "vendor_boardtypes.h"
#else   /* Use standard board types as defined below. */
```

In order to enable the utilization for customer specific board types, the compile switch must be set in the corresponding project files. If this

Usage in Makefiles:

```
CFLAGS += -DVENDOR_BOARDTYPES
```

or

```
CFLAGS += -DVENDOR_BOARDTYPES=1
```

enables the utilization of customer specific board types.

Usage in IAR ewp-files:

```
VENDOR_BOARDTYPES
```

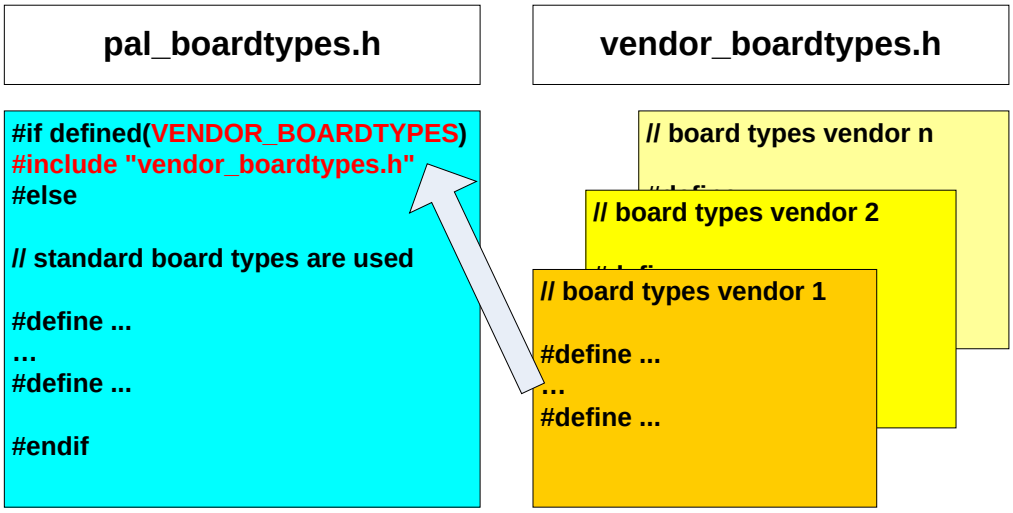
or

```
VENDOR_BOARDTYPES=1
```

enables the utilization of customer specific board types.

If this build switch is omitted or set to zero in the corresponding project files, the board definitions from the current file *pal_boardtypes.h* are used as usual.

Figure 6-3. Inclusion of vendor_boardtypes.h.



For more information about how to use this switch and how to enable customer specific boards, please refer to Section 11.3.1.1.

6.1.3.12 VENDOR_STACK_CONFIG

This advanced build switch can be used by customer that want to add another stack layer on top of the MAC layer, which shall not access the MAC layer via the MAC-API, but rather via the queuing mechanism (similar to other network layers such as RF4CE). By this the stack layer can utilize the provided buffers and queues.

In order to enable a customer specific stack on top of the MAC, the build switch VENDOR_STACK_CONFIG needs to be added to the project files. In this case a file called vendor_stack_config.h is included while parsing the common stack configuration file stack_config.h.

Usage in Makefiles:

```
CFLAGS += -DVENDOR_STACKCONFIG
```

enables the utilization of customer defined stacks.

Usage in IAR ewp-files:

```
VENDOR_STACKCONFIG
```

enables the utilization of customer defined stacks.

6.1.3.13 ENABLE_ALL_TRX_IRQS (MEGA_RF only)

Each transceiver has a variety of transceiver interrupts connected to the MCU depending on the used transceiver and board type. Depending on the type of application and the footprint requirements, not all transceiver interrupts may be used within a specific application. Single chip transceivers (PAL_GENERIC_TYPE = MEGA_RF) have a large number of available transceiver interrupts. For example, the Atmel Atmega128RFA1 provides up to usable 10 transceiver interrupts.

The provided software package only requires three transceiver interrupts being support mandatorily:

26. TX END IRQ (that is, the main transceiver interrupt),

27. RX END IRQ, and
28. CCA ED IRQ,

whereas the other transceiver interrupts may be utilized within specific applications if desired. The timestamp interrupt can be enabled by using the build switch ENABLE_TSTAMP (see Section 6.1.1.4).

The other enhanced transceiver interrupts of MEGA_RF platforms:

29. AMI IRQ
30. Batmon IRQ
31. Awake IRQ
32. PLL Lock IRQ
33. PLL Unlock IRQ
34. AES Ready IRQ

are not used within the Atmel AVR2025 software package, but may nevertheless be required by any application of customer specific enhancement. These transceiver interrupts can be enable by setting the build switch ENABLE_ALL_TRX_IRQS.

Usage in Makefiles:

```
CFLAGS += -DENABLE_ALL_TRX_IRQ
```

enables the utilization of all enhanced transceiver interrupts.

Usage in IAR ewp-files:

```
ENABLE_ALL_TRX_IRQ
```

enables the utilization of all enhanced transceiver interrupts.

6.1.3.14 ENABLE_RC_OSC_CALIBRATION (MEGA_RF only)

On most AVR based systems, the internal RC oscillator is not only used for UART clocking, but also as timer clock source. In contrary on Mega-RF based systems the internal RC oscillator is not used as timer clock source. Only megaRF boards using UART (instead of USB) require an accurate internal RC oscillator.

In order to enable RC oscillator calibration, this feature needs to be enabled explicitly by setting this build switch during compilation.

Usage in Makefiles:

```
CFLAGS += -DENABLE_RC_OSC_CALIBRATION
```

enables the calibration of the internal RC oscillator.

Usage in IAR ewp-files:

```
ENABLE_RC_OSC_CALIBRATION
```

enables the calibration of the internal RC oscillator.

6.1.3.15 WATCHDOG

Each microcontroller has a Watchdog module whose basic purpose is to trigger a system reset and start executing from the boot vector in case the program hangs due to same fault condition. When the system is running fine it regularly services the Watchdog timer by clearing it periodically.

In order to enable the usage of Watchdog, this feature needs to be enabled explicitly by setting this build switch during compilation.

Usage in Makefiles:

```
CFLAGS += -DWATCHDOG
```

enables the Watchdog module.

Usage in IAR ewp-files:

```
WATCHDOG
```

enables the Watchdog module.

6.1.3.16 SLEEPING_TIMER

In cases where it is needed a timer to be running while the microcontroller unit is in sleep either to count system time or to fire an interrupt to wake up the microcontroller this feature needs to be enabled explicitly by setting this build switch during compilation.

Usage in Makefiles:

```
CFLAGS += -DSLEEPING_TIMER
```

enables the Sleeping Timer.

Usage in Makefiles:

```
SLEEPING_TIMER
```

enables the Sleeping Timer.

6.1.4 Transceiver specific switches

6.1.4.1 TAL_TYPE

The TAL (Transceiver Abstraction Layer) contains all transceiver based functionality and provides an API to the MAC which is independent from the underlying transceiver. Certain functionality that for instance the MAC or an application may require is dependent from the actual used transceiver chip. Examples are the utilization of antenna diversity, time stamping mechanisms, or the automatic CRC calculation in hardware.

Examples of currently supported transceivers are:

- Atmel ATmega128RFA1 (TAL directory ATMEGARF_TAL_1)
- Atmel AT86RF230B (AT86RF230 Revision B)
- Atmel AT86RF231
- Atmel AT86RF232
- Atmel AT86RF212

For more information please check the TAL\Inc*tal_types.h* file.

Usage in Makefiles:

```
CFLAGS += -DTAL_TYPE=AT86RF212
```

selects the AT86RF212 transceiver.

Usage in IAR ewp-files:

```
TAL_TYPE=AT86RF231
```

selects the AT86RF231 transceiver.

6.1.4.2 ENABLE_TFA

This build switch enables the usage of non-standard compliant features of the transceiver based on the block Transceiver Feature Access (TFA).

Currently the following features are implemented in the TFA:

- Changing of Receiver Sensitivity
- Perform CCA
- Perform ED (Energy Detect) measurement
- Reading the current transceiver supply voltage (transceiver battery monitor). Reading the current transceiver supply voltage (transceiver battery monitor). The reading of the supply voltage can also be enabled separately by setting the build switch TFA_BAT_MON
- Reading of current temperature (only Atmel ATmega128RFA1 only)

CCA and ED measurement are an inherent part of the MAC/TAL, so there is no need for a standard application to use this. On the other hand there could be special test applications which might use such functionality.

If only standard defined behavior is required or code size is important this switch should not be set.

Usage in Makefiles:

```
CFLAGS += -DENABLE_TFA
```

enables the usage of the TFA.

Usage in IAR ew-files:

```
ENABLE_TFA
```

enables the usage of the TFA.

6.1.4.3 HIGH_DATA_RATE_SUPPORT

All 802.15.4 Atmel transceivers supported with this software package beyond AT86RF230 provide high data modes not defined within the IEEE 802.15.4 standard. In order to enable these high speed transmission modes, the build switch HIGH_DATA_RATE_SUPPORT needs to be set. An example application where this switch is used to gain a significantly higher data throughput is the Performance Test Application (see Applications\TAL_Examples\Performance_Test). If only standard rates are used or code size is important this switch should not be set.

Usage in Makefiles:

```
CFLAGS += -DHIGH_DATA_RATE_SUPPORT
```

enables support of high speed data rates.

Usage in IAR ewp-files:

```
HIGH_DATA_RATE_SUPPORT
```

enables support of high speed data rates.

6.1.4.4 CHINESE_BAND

This build switch is used in conjunction with a Sub-GHz transceiver chip that is capable of working properly within the Chinese 780MHz radio band (for example, the

Atmel AT86RF212). Within the stack this switch is solely used to set the proper default value for the channel page. So any application that per default is required to operate within this particular band (and uses the proper TAL type) may use this build switch to set the channel page to a proper default value.

Usage in Makefiles:

```
CFLAGS += -DCHINESE_BAND
```

enables the channel page for the Chinese band as default.

Usage in IAR ewp-files:

```
CHINESE_BAND
```

enables the channel page for the Chinese band as default.

For more information please check file *tal_constants.h* in directory TAL/AT86RF212/Inc.

Example applications using this build switch in Makefiles or IAR project files can be found in directory

```
Applications/TAL_Examples/Wireless_UART/AT86RF212_780_MHZ_ATMEGA128
1_RCB_5_3_SENS_TERM_BOARD.
```

6.1.4.5 RSSI_TO_LQI_MAPPING

This build switch is used to control the mechanism for calculation of the normalized LQI value of received frames. The normalized LQI value (that is provided to the higher layer of the MAC as parameter *ppduLinkQuality*) is

- based on the RSSI/ED value (switch RSSI_TO_LQI_MAPPING is used) where only the ED value (signal strength) is mapped to a LQI value, or is
- based on the ED (signal strength) and the measured LQI value (quality of received packet) (switch RSSI_TO_LQI_MAPPING is not used)

For further information about the LQI value, see IEEE 802.15.4-2006 Section 6.9.8. The build switch RSSI_TO_LQI_MAPPING reflects the “and/or” relation described in the first paragraph of the mentioned section. If RSSI_TO_LQI_MAPPING is set, signal strength is only used for LQI measurement.

Usage in Makefiles:

```
CFLAGS += -DRSSI_TO_LQI_MAPPING
```

enables the calculation of the normalized LQI value based on RSSI/ED value.

Usage in IAR ewp-files:

```
RSSI_TO_LQI_MAPPING
```

enables the calculation of the normalized LQI value based on RSSI/ED value.

For more information please check the implementation in the files TAL/*tal_type*/Src/*tal_rx.c.*

6.1.4.6 ENABLE_FTN_PLL_CALIBRATION

This build switch is used to enable the filter tuning and PLL calibration for the transceiver. Once this feature is enabled in an application, a period timer is started, which ensures that the proper filter tuning and PLL calibration is executed after a certain amount of time.

This feature might be required in case the environment conditions (that is, temperature) vary over time.

The filter tuning and PLL calibration is done automatically when a node periodically enters sleep state, or when other specific state changes are performed within the transceiver periodically. For more information please check the corresponding transceiver data sheets.

The current timer interval is five minutes, that is, whenever the node does not enter sleep state within this timer interval, the filter tuning and PLL calibration mechanism will be invoked.

This switch is currently not enabled in any example application.

6.1.4.7 DISABLE_IEEE_ADDR_CHECK

This build switch is used to disable the check whether the node has a valid IEEE address (that is, the IEEE address is different from 0 or 0xFFFFFFFFFFFFFFFF).

Currently all TAL and MAC based applications require a valid and unique IEEE address being present on each node. Since some board may not necessarily have a valid IEEE address stored in (either internal or external) EEPROM (for example Atmel AT91SAM7X-EK boards), the applications cannot run properly. For the purpose of proper example demonstration a check for this IEEE address is implemented. If the IEEE address is not correct (that is, it is 0 or 0xFFFFFFFFFFFFFFFF), a random IEEE address is assigned to this node.

Some applications do not require this specific IEEE check. In this case the code can be significantly smaller by setting the build switch DISABLE_IEEE_ADDR_CHECK.

Also this build switch gives a very good indication which portions or the TAL need to be changed or removed for smaller code size by simply searching for build switch DISABLE_IEEE_ADDR_CHECK.

This switch is currently not enabled in any example application, since all example applications require a valid IEEE address.

Boards providing a valid IEEE address always use their original unique IEEE address during operation.

6.1.4.8 DISABLE_TSTAMP_IRQ

This build switch is used to disable the Timestamp interrupt (that is, the second transceiver interrupt for Atmel AT86RF231, Atmel AT86RF232 and Atmel AT86RF212) on systems which do not utilize this transceiver interrupt. This is for example valid for boards based on Atmel ARM AT91SAM7X256 MCUs in conjunction with AT86RF231.

The TAL for AT86RF231, AT86RF232 and AT86RF212 is designed to utilize the Timestamp interrupt as default for generating timestamp information. If this build switch is explicitly set in the project files or Makefiles for an application, the timestamp information is generated similar as for Atmel AT86RF230 based systems.

6.1.4.9 TRX_REG_RAW_VALUE

This build switch is used to disable the scaling of ED value.By default ED value read from the RG_PHY_ED_LEVEL register shall be scaled using CLIP_VALUE REG value.By using this buid switch, this can be avoided and raw value of ED sall be used.

6.1.4.10 SW_CONTROLLED_CSMA

This build switch SW_CONTROLLED_CSMA includes functions to the build process that control the CSMA-CA algorithm by software. CCA, backoffs and re-transmissions are controlled by software while the transceiver handles frame validation (e.g. CRC and frame filtering) and ACK transmission using its automatic (extended) modes.

6.1.4.11 TX_OCTET_COUNTER

This build switch TX_OCTET_COUNTER includes functions to the build process that count the number of actually sent bytes over-the-air. The number of bytes are accumulated in the variable tal_tx_octet_cnt. This includes data frames that are sent "actively" and ACK frames that are sent due to received frames including preamble, SFD and length field.
The application can reset and read the tal_tx_octect_cnt variable. It can be used to calculate an actual duty-cycle. In order to use the TX_OCTET_COUNTER switch the build switch SW_CONTROLLED_CSMA needs to be set as well

6.1.4.12 TX RX_WHILE_BACKOFF

The build switch RX_WHILE_BACKOFF enables switching the receiver on during backoff periods of the CSMA algorithm. If the build switch RX_WHILE_BACKOFF is not defined for the build, the receiver remains off during backoff periods. In order to use the RX_WHILE_BACKOFF switch the build switch SW_CONTROLLED_CSMA needs to be set as well.

If the receiver is switched on during backoff periods and a frame is received (including automatic ACK transmission), the received frames get queue into the receive frame queue. After frame reception the CSMA algorithm is continued with the next CSMA attempt.

Impacts with RX_WHILE_BACKOFF

- In a "normal" scenario (low traffic) the maximum data throughput is reduced by about 2 percent (at 250kb/s and about 1 percent at 100kb/s) due to the software-controlled CSMA using a SPI-based transceiver.
- In high density networks the outgoing data throughput highly varies based on the number of received frames during the backoff periods.
- The implementation of the software-controlled CSMA algorithm requires about 0.5 kB (Xmega; 0.8kB ARM7) program code.
- An additional (software) timer is required and the MCU utilization is higher during the actual CSMA procedure.

6.1.5 Security switches

In order to provide security support to the application a number of switches controlling the incorporation of code for security is defined.

For examples on how to use security within an application based on MAC or based on the TAL please check the applications in directory Applications\STB_Examples.

6.1.5.1 SAL_TYPE

Security support is implemented in two different layers. The lower layer (SAL – Security Abstraction Layer) implements all portions of security that are dependent of

the used platform (for example, AES engine implemented in transceiver or microcontroller, etc.). The upper layer (STB – Security Toolbox) implements functionality that is independent from the used platform and provides a generic API to the application (for instance securing a frame with CCM* security).

In order to provide the proper code or hardware support for basic security functions the type of the used Security Abstraction Layer needs to be specified as build switch.

The currently supported SAL types are:

- AT86RF2xx – SAL with transceiver based AES via SPI
- ATMEGARF_SAL – SAL with single chip transceiver based AES
- ATXMEGA_SAL – SAL with ATxmega family based AES

For more information please check the SAL/Inc/*sal_types.h* file, and see Section 4.6.

Usage in Makefiles:

```
CFLAGS += -DSAL_TYPE=AT86RF2xx
```

enables transceiver based AES security via SPI.

Usage in IAR ewp-files:

```
SAL_TYPE=AT86RF2xx
```

enables transceiver based AES security via SPI.

6.1.5.2 STB_ON_SAL (formerly ENABLE_STB)

While the SAL only provides a basic security API, most applications do require more advance security features, for example, securing a complete frame with a specific key. Such functionality is implemented in the Security Toolbox.

To incorporate the Security Toolbox features for system requiring the STB layer on top of an SAL implementation (see Section 4.6) during the build process the switch STB_ON_SAL needs to be set.

Usage in Makefiles:

```
CFLAGS += -DSTB_ON_SAL
```

enables the Security Toolbox features.

Usage in IAR ewp-files:

```
STB_ON_SAL
```

enables the Security Toolbox features.

6.1.5.3 STB_ARMCRYPTO

The ARM hardware crypto engine residing in the Atmel SAM7XC is very powerful and thus does not require the implementation of an additional SAL layer for such systems. Therefore the utilization of security for SAM7XC systems allows for the easy handling of security features by only relying on a special STB implementation called STB_ARMCRYPTO.

To incorporate the Security Toolbox features using the ARM crypto engine during the build process the switch STB_ARMCRYPTO needs to be set (see Section 4.6).

Usage in IAR ewp-files:

`STB_ARMCRYPTO`

enables the Security Toolbox features for SAM7XC systems.

6.1.6 Test and debug switches

6.1.6.1 DEBUG

This build switch enables further debug functionality and additional sanity checks within the software package, but also increased code size or changes run time behavior since the optimization level is changed.

If the GCC compiler is used, this switch also enables printout functionality for debug purposes (ASSERT).

6.1.6.2 TEST_HARNESS

This build switch is solely present for Atmel internal regression testing and not to be used by an application.

NOTE Although the code in file mac_pib.c may lead to the conclusion, that this switch needs to be set in order to be allowed to set the IEEE address of this node via software, this is not supposed to be used this way.

Each device has its own IEEE address that is fixed for this device and usually it is located in any type of persistent storage. This is actually not a PIB attribute but rather a MAC constant (see IEEE 802.15.4-2006 Section 7.4.1, Table 85 (aExtendedAddress)). So the value is only READ_ONLY and in normal mode not supposed to be written by the application or stack. Therefore this attribute can be read using API functions (wpan_mlme_get_req()) but not written (wpan_mlme_set_req()).

6.2 Build configurations

6.2.1 Standard build configurations

Based on the IEEE 802.15.4 standard there are four basic standard configurations available which provide different functionality to the user application. This implies different APIs for each of these configurations and also different footprints (codes size, SRAM utilization).

These standard configurations can be classified in two categories:

- Support of beacon enabled networks
- Reduced Functional Devices - RFD (for example, End Devices) vs. Full Functional Devices – FFD (PAN Coordinators, Coordinators)

The Atmel MAC provides two build switches that can be used in Makefiles or IAR Embedded Workbench project files to enable or disable these configurations. Depending on the usage of these switches in the project, the MAC provides certain functionality to the user application.

I. FFD

- Omitting of this build switch only enables functionality required for a simple RFD node
- Setting of this build switch additionally enables functionality required for a FFD node

II. BEACON_SUPPORT

- Omitting of this build switch only enables functionality required for a networks without using a superframe structure, that is, non-beacon enabled networks
- Setting of this build switch additionally enables functionality required for a network using a superframe structure, that is, beacon-enabled networks

III. MAC_SECURITY_ZIP

- Omitting of this build switch only enables functionality required for a networks without security features
- Setting of this build switch additionally enables functionality required for a network using security features

Example 1: A node that shall start its own network always has to be an FFD, because starting of networks is only supported for an FFD configuration.

Example 2: A node that shall be able to join both non-beacon and beacon-enabled networks has to use an application built with BEACON_SUPPORT.

Example 3: A node that shall be able to tranmit secured data frames has to use an application built with MAC_SECURITY_ZIP.

Please refer to file "/Include/mac_build_config.h" for more information about the supported functionality.

6.2.1.1 FFD feature set

The following features are enabled if FFD is set during the build process:

- MAC_ASSOCIATION_INDICATION_RESPONSE
  The node is able to accept and process association attempts from other nodes. Also this node can provide Short Addresses to other nodes if desired
- MAC_ASSOCIATION_REQUEST_CONFIRM
  The node is able accept and process a request from its upper layer (for example, the network layer) to associate itself to another node (that is, its parent)
- MAC_BEACON_NOTIFY_INDICATION
  The node is able to present received beacon frame to its upper layer in case the beacon frame contains a beacon payload or the MAC PIB attribute macAutoRequest is set to false
- MAC_DISASSOCIATION_BASIC_SUPPORT
  The node is able to accept and process a request from its upper layer to disassociate itself from its network or disassociate one of its children, or to process a received disassociation frame from another node
- MAC_DISASSOCIATION_FFD_SUPPORT
  The node is able to transmit an indirect disassociation notification frame. This requires that the switch MAC_DISASSOCIATION_BASIC_SUPPORT is also set
- MAC_INDIRECT_DATA_BASIC
  The node is able to poll its own parent for indirect data
- MAC_INDIRECT_DATA_FFD
  The node is able to handle requests to transmit data frames to its children indirectly once being polled by those nodes. This requires that the switch MAC_INDIRECT_DATA_BASIC is also set
- MAC_ORPHAN_INDICATION_RESPONSE
  The node is able to accept and process a received orphan indication frame by one of its children and respond appropriately
- MAC_PAN_ID_CONFLICT_AS_PC
  The node is able to detect a PAN-Id conflict situation while acting as a PAN

Coordinator by checking received beacon frames from other PAN Coordinators and being able to act upon the reception of PAN-Id Conflict Notification Command frames from its children

- MAC_PAN_ID_CONFLICT_NON_PC
  The node is able to detect a PAN-Id conflict situation while NOT acting as a PAN Coordinator by checking received beacon frames from other PAN Coordinators and being able to initiate the transmission of PAN-Id Conflict Notification Command frames from its parents if required
- MAC_PURGE_REQUEST_CONFIRM
  The node is able to purge indirect data frames from its Indirect-Data-Queue upon request by its upper layer
- MAC_RX_ENABLE_SUPPORT
  The node is able to switch on or off its receiver for a certain amount of time upon request by its upper layer. This is required in order to allow for the upper layer to receive frames in case the node is generally in a power safe state
- MAC_SCAN_ACTIVE_REQUEST_CONFIRM
  The node is able to perform an active scan to search for existing networks
- MAC_SCAN_ED_REQUEST_CONFIRM
  The node is able to perform an energy detect scan
- MAC_SCAN_ORPHAN_REQUEST_CONFIRM
  The node is able to perform an orphan scan in case it has lost its parent
- MAC_SCAN_PASSIVE_REQUEST_CONFIRM
  The node is able to perform a passive scan to search for existing networks. This feature is only enabled if also BEACON_SUPPORT is enabled
- MAC_START_REQUEST_CONFIRM
  The node is able to start its own network. Depending on the setting of BEACON_SUPPORT this can be either only a non-beacon enabled network or also a beacon-enabled network
- MAC_SYNC_LOSS_INDICATION
  The node is able to report a sync loss condition to its upper layer. This can be either the reception of a coordinator realignment frame from its parent, or (if BEACON_SUPPORT is enabled and the node is synchronized with its parent) caused by the fact that the node has not received beacon frames from its parent for a certain amount of time

Please check IEEE 802.15.4-2006 for further information about the MAC primitives and the implementation of their corresponding features in the MAC.

6.2.1.2 RFD feature set

The following features are enabled if FFD is NOT set during the build process:

- MAC_ASSOCIATION_REQUEST_CONFIRM
  The node is able accept and process a request from its upper layer (for example, the network layer) to associate itself to another node (that is, its parent)
- MAC_BEACON_NOTIFY_INDICATION
  The node is able to present received beacon frame to its upper layer in case the beacon frame contains a beacon payload or the MAC PIB attribute macAutoRequest is set to false
- MAC_DISASSOCIATION_BASIC_SUPPORT
  The node is able to accept and process a request from its upper layer to

disassociate itself from its network, or to process a received disassociation frame from its parent

- MAC_INDIRECT_DATA_BASIC
  The node is able to poll its own parent for indirect data
- MAC_PAN_ID_CONFLICT_NON_PC
  The node is able to detect a PAN-Id conflict situation while NOT acting as a PAN Coordinator by checking received beacon frames from other PAN Coordinators and being able to initiate the transmission of PAN-Id Conflict Notification Command frames from its parents if required
- MAC_RX_ENABLE_SUPPORT
  The node is able to switch on or off its receiver for a certain amount of time upon request by its upper layer. This is required in order to allow for the upper layer to receive frames in case the node is generally in a power safe state
- MAC_SCAN_ACTIVE_REQUEST_CONFIRM
  The node is able to perform an active scan to search for existing networks
- MAC_SCAN_ORPHAN_REQUEST_CONFIRM
  The node is able to perform an orphan scan in case it has lost its parent
- MAC_SYNC_LOSS_INDICATION
  The node is able to report a sync loss condition to its upper layer. This can be either the reception of a coordinator realignment frame from its parent, or (if BEACON_SUPPORT is enabled and the node is synchronized with its parent) caused by the fact that the node has not received beacon frames from its parent for a certain amount of time

The following features are disabled if FFD is NOT set during the build process:

- MAC_ASSOCIATION_INDICATION_RESPONSE
  The node is not able to handle association attempts from other nodes
- MAC_DISASSOCIATION_FFD_SUPPORT
  The node is not able to transmit an indirect disassociation notification frame
- MAC_INDIRECT_DATA_FFD
  The node is not able to handle requests to transmit data frames indirectly
- MAC_ORPHAN_INDICATION_RESPONSE
  The node is not able to handle orphan indication frames by other nodes
- MAC_PAN_ID_CONFLICT_AS_PC
  The node is not able to act upon the reception of PAN-Id Conflict Notification Command frames
- MAC_PURGE_REQUEST_CONFIRM
  The node is not able to purge indirect data
- MAC_SCAN_ED_REQUEST_CONFIRM
  The node is not able to perform an energy detect scan
- MAC_SCAN_PASSIVE_REQUEST_CONFIRM
  The node is not able to perform a passive scan
- MAC_START_REQUEST_CONFIRM
  The node is not able to start its own network

Please check IEEE 802.15.4-2006 for further information about the MAC primitives and the implementation of their corresponding features in the MAC.

6.2.1.3 BEACON_SUPPORT feature set

If BEACON_SUPPORT is set during the build process all functionality required to support beacon-enabled networks are enabled. The actually enabled functionality differs depending on the internal requirements for FFDs or RFDs.

Additionally the following feature is enabled:

- MAC_SYNC_REQUEST
  The node is able to sync itself with its parent by tracking the corresponding beacon frames

Please check IEEE 802.15.4-2006 for further information about the MAC primitives and the implementation of their corresponding features in the MAC.

6.2.1.4 MAC_SECURITY_ZIP

If MAC_SECURITY_ZIP is set during the build process, all functionality required to support security are enabled.

Additionally, the following feature is enabled:

- STB_ON_SAL
- SAL_TYPE

Please check IEEE 802.15.4-2006 for further information about the MAC primitives and the implementation of their corresponding features in the MAC.

6.2.2 User build configurations – MAC_USER_BUILD_CONFIG

6.2.2.1 Introduction

Since a number of applications do not necessarily need the functionality provided by any of the standard build configurations, or may even have more rigid requirements concerning FLASH or RAM utilization, the concept of user build configuration has been introduced. The usage of the build MAC_USER_BUILD_CONFIG in the Makefiles or IAR Embedded Workbench project files allows the end user to tailor its MAC completely according to its own needs.

The following MAC features can be separately selected or removed from the build:

- Association
- Disassociation
- Support of scanning (energy detect, active, passive, or/and orphan scanning)
- Starting of networks
- Support of transmitting or receiving indirect data including polling of data
- Purging of indirect data
- Enabling of the receiver
- Synchronization in beacon-enabled networks
- Presentation of loss of synchronization
- Handling of orphan notifications
- Handling of beacon notifications

Each feature can be used independently from each other. It is also possible to deselect all of the above features, which leads to a minimum application in terms of resource utilization. In this case only the following basic MAC features are available:

- Direct data transmission and reception
- Initiation of a MAC reset
- Reading and writing of PIB attributes

An example application implementing the proper utilization of this feature can be found in Applications/MAC_Examples/Basic_Sensor_Network. In this example only RX-ENBALE is used in addition to the standard features. For more information about this example application please refer to Section 9.2.1.1.

6.2.2.2 File mac_user_build_config.h

If the switch MAC_USER_BUILD_CONFIG is activated, the C-pre-processor looks for a file mac_user_build_config.h in the current include path (usually in the Inc directory of the application). See file /Include/mac_build_config.h:

```
#ifdef MAC_USER_BUILD_CONFIG
#include "mac_user_build_config.h"
#else
...
```

The standard feature definitions for an FFD or RFD configuration are by-passed, and instead the user defined feature set from mac_user_build_config.h is used. This features set needs to be defined entirely, that is, each feature needs to be either enabled or disabled.

An example for a basic MAC application that only needs minimum features, and thus only requires minimum resources, can be found at Applications/MAC_Examples/Basic_Sensor_Network.

6.2.2.2.1 Examples

Example 1: An end device that does neither use association nor disassociation functionality, but still wants to poll indirect data from its parent, may set the following the build switches in file mac_user_build_config.h:

```
#define MAC_ASSOCIATION_INDICATION_RESPONSE     (0)
#define MAC_ASSOCIATION_REQUEST_CONFIRM         (0)
#define MAC_DISASSOCIATION_BASIC_SUPPORT        (0)
#define MAC_DISASSOCIATION_FFD_SUPPORT          (0)
#define MAC_INDIRECT_DATA_BASIC                 (1)
#define MAC_INDIRECT_DATA_FFD                   (0)
```

Example 2: A network whose nodes read their fixed network parameters from a persistent store, and thus never perform scanning or start a network, may set the following build switches in file mac_user_build_config.h:

```
#define MAC_SCAN_ACTIVE_REQUEST_CONFIRM         (0)
#define MAC_SCAN_ED_REQUEST_CONFIRM             (0)
#define MAC_SCAN_ORPHAN_REQUEST_CONFIRM         (0)
#define MAC_SCAN_PASSIVE_REQUEST_CONFIRM        (0)
#define MAC_START_REQUEST_CONFIRM               (0)
```

The other features are omitted in the examples, but have to be set according to the application need.

6.2.2.3 Implications and Internal Checks

There are a number of dependencies between several of the features mentioned above. In order to keep the burden for the end user low, certain required internal checks or further implicit settings are done while configuring the build. These checks and implications can be seen in file /Include/mac_build_config.h.

6.2.2.3.1 MAC_COMM_STATUS_INDICATION

Communication systems usually follow the approach to implement primitives in pairs. This is (1) Request / Confirm (for example, MLME_ASSOCIATE-request and MLME_ASSOCIATE.confirm, or (2) Indication / Response (for example, MLME_ASSOCIATE.indication and MLME_ASSOCIATE.response). Whenever such an Indication / Response scheme is applied, the corresponding node needs a confirmation that its last transaction has finished successfully (for example, the last transmitted frame has been acknowledged by its receiver). This confirmation is done within IEEE 802.15.4 by creating an MLME_COMMUNICATION_STATUS.indication message to the upper layer.

This implies that whenever MAC_ASSOCIATION_INDICATION_RESPONSE or MAC_ORPHAN_INDICATION_RESPONSE is used (both is valid for an FFD only), the feature MAC_COMM_STATUS_INDICATION is enabled automatically.

6.2.2.3.2 MAC_SYNC_REQUEST vs. MAC_SYNC_LOSS_INDICATION

Whenever the feature MAC_SYNC_REQUEST is used, also the feature MAC_SYNC_LOSS_INDICATION is required to be included in the build. If the requirement is not met, the C-pre-processor will indicate an error.

6.2.2.3.3 Dependency from MAC_INDIRECT_DATA_BASIC

Whenever one of the subsequently listed features is used, also the feature MAC_INDIRECT_DATA_BASIC is required to be included in the build:

- MAC_ASSOCIATION_INDICATION_RESPONSE
- MAC_ASSOCIATION_REQUEST_CONFIRM
- MAC_DISASSOCIATION_BASIC_SUPPORT
- MAC_DISASSOCIATION_FFD_SUPPORT
- MAC_INDIRECT_DATA_FFD
- MAC_PURGE_REQUEST_CONFIRM

If this requirement is not met, the C-pre-processor will indicate an error.

6.2.2.3.4 Dependency from MAC_INDIRECT_DATA_FFD

Whenever one of the subsequently listed features is used, also the switch MAC_INDIRECT_DATA_FFD is required to be included in the build:

- MAC_ASSOCIATION_INDICATION_RESPONSE
- MAC_DISASSOCIATION_FFD_SUPPORT
- MAC_PURGE_REQUEST_CONFIRM

6.2.2.3.5 MAC_PAN_ID_CONFLICT_AS_PC

Whenever the feature MAC_PAN_ID_CONFLICT_AS_PC is used, also the following features are required to be included in the build:

- MAC_START_REQUEST_CONFIRM
- MAC_SYNC_LOSS_INDICATION

6.2.2.3.6 MAC_PAN_ID_CONFLICT_NON_PC

Whenever the feature MAC_PAN_ID_CONFLICT_ NON _PC is used, also the following features are required to be included in the build:

- MAC_SYNC_LOSS_INDICATION
- MAC_ASSOCIATION_REQUEST_CONFIRM or MAC_SYNC_REQUEST

6.2.2.3.7 Dependency from BEACON_SUPPORT

Whenever the feature MAC_SYNC_REQUEST is used, also the switch BEACON_SUPPRT is required to be included in the build. If the requirement is not met, the C-pre-processor will indicate an error.

7 Migration History

7.1 Guide from version 2.6.x to 2.7.x

Atmel AVR2025 version 2.7.x contains mac security and example applications to demonstrate the mac security feature. AVR Studio 5® support got added for all the Atmel AVR 8bit and 32bit families. Two new MAC applications got added which covers most of the features of Beacon and No-beacon MAC.

1.1 Guide from version 2.5.x to 2.6.x

With the release of Atmel AVR2025 version 2.6.x a number of significant hardware platforms added. Different families of MCUs are added to the current release and naming few of them are Atmel AVR32, Atmel SAM3S, and CBB kit. The kits supported on AVR32 Family are Atmel RZ600 (Atmel AT32UC3A3256), Atmel AT32UC3L-EK (Atmel AT32UC3L04) and Atmel STK®600 (Atmel AT32UC3B1128). The kits supported on SAM3S family are Atmel SAM3S-EK (Atmel AT91SAM3S4C) and DERF_USB_13E00, DERF_USB_23E00 USB Kits (Atmel AT91SAM3S4B).

7.2 Guide from version 2.4.x to 2.5.x

With the release of Atmel AVR2025 version 2.5.x a number of significant improvements have been achieved by introducing design changes throughout the PAL, TAL and MCL layer and by introducing the Tiny_TAL layer.

Although these design changes do not significantly change the MAC-API, both the TAL-API and partially the PAL-API have been changed. This is based on the fact that large portions of the code formerly residing inside the TAL layer have been shifted up to the MCL layer. This leads to an overall code size reduction, as well as to the much simpler TAL-API, which can be used more easily for simple applications.

The PAL-API was changed mostly for handling transceiver related interrupts with the focus of reducing the overall code size and excluding functionality not used per default.

In order to better understand the impact of these design improvements on the end user applications or stack layers the following sections will describe the most important changes in detail.

7.2.1 MAC-API changes

The API changes within the MAC-API can be classified into the following groups:

- Handling of Timestamp parameter in MCPS-DATA primitives
- Type of AddrList parameter in MLME-BEACON-NOTIFY.indication primitive

7.2.1.1 Handling of timestamp parameter in MCPS-DATA primitives

According to [4] both the MCPS-DATA.confirm and the MCPS-DATA.indication primitive contain a Timestamp parameter. This is implemented in the MAC callback functions usr_mcps_data_conf() and usr_mcps_data_ind().

In many cases the timestamping functionality is not used within the entire application. In order to save code size, and simply the application (if the Timestamp parameter is not required), the Timestamp parameter as well as the complete handling to timestamping in the entire stack can be omitted. This can be controlled via the build

switch ENABLE_TSTAMP. For more information about this build switch see Section 6.1.

Starting with release 2.5.x timestamping is excluded as default, i.e. the Timestamp parameter is not included into the mentioned callback functions. If an application utilizes the build switch in its Makefile or project files, timestamping is performing within the stack, and thus the Timestamp parameter is included in the callback functions. An example of a MAC application using timestamping can be found in App3_Beacon_Payload.

The updated API for the corresponding callback functions is defined as:

```
#if defined(ENABLE_TSTAMP)
void usr_mcps_data_conf(uint8_t msduHandle,
                        uint8_t status,
                        uint32_t Timestamp);
#else
void usr_mcps_data_conf(uint8_t msduHandle,
                        uint8_t status);
#endif  /* ENABLE_TSTAMP */
```

and

```
void usr_mcps_data_ind(wpan_addr_spec_t *SrcAddrSpec,
                       wpan_addr_spec_t *DstAddrSpec,
                       uint8_t msduLength,
                       uint8_t *msdu,
                       uint8_t mpduLinkQuality,
    #ifdef ENABLE_TSTAMP
                       uint8_t DSN,
                       uint32_t Timestamp);
    #else
                       uint8_t DSN);
    #endif  /* ENABLE_TSTAMP */
```

The function prototypes can be found in MAC/Inc/mac_api.h file.

If the build switch ENABLE_TSTAMP is not used within an application, the corresponding implementation in the application needs to be adjusted accordingly. An example of this can be found in file *main.c* in the directory *Applications\MAC_Examples\Star_Nobeacon\Src*.

7.2.1.2 *AddrList parameter in MLME-BEACON-NOTIFY.indication primitive*

The MLME-BEACON-NOTIFY.indication primitive implemented in the MAC callback function usr_mlme_beacon_notify_ind() function has an updated type of the included parameter AddrList:

The callback function definition has been changed from

```
void usr_mlme_beacon_notify_ind(uint8_t BSN,
                                wpan_pandescriptor_t
*PANDescriptor,
                                uint8_t PendAddrSpec,
                                void *AddrList,
                                uint8_t sduLength,
```

```
                                    uint8_t *sdu);
```

to

```
void usr_mlme_beacon_notify_ind(uint8_t BSN,
                                    wpan_pandescriptor_t
*PANDescriptor,
                                    uint8_t PendAddrSpec,
                                    uint8_t *AddrList,
                                    uint8_t sduLength,
                                    uint8_t *sdu);
```

The function prototype can be found at /MAC/Inc/mac_api.h.

7.2.2 TAL-API Changes

In order to reduce code size and complexity of the entire stack, and to allow the development of TAL based applications, the design and the API of the TAL have been simplified significantly. The API changes within the TAL-API can be classified into the following groups:

- Simplification of structure frame_info_t used within the TAL frame handling functions
- Simplification of frame indication callback function tal_rx_frame_cb()
- Simplification of Beacon handling API

7.2.2.1 Simplification of structure frame_info_t

Frames being exchanged between the MCL and the TAL layer (that is, frames to be transmitted and frames being received), are handled at the TAL-API by means of a specific frame structure containing all relevant frame information. This structure has the type frame_info_t and is defined in file *tal.h* in directory *TAL\Inc*. It is used in the following functions:

- tal_rx_frame_cb()
- tal_tx_frame()
- tal_tx_beacon() (new since 2.5.x)

Figure 7-1. Content of frame_info_t structure

Release 2.4.x (obsolete):

```
typedef struct frame_info_tag
{
    frame_msgtype_t msg_type;
    buffer_t *buffer_header;
    uint16_t frame_ctrl;
    uint8_t seq_num;
    uint16_t dest_panid;
    uint64_t dest_address;
    uint16_t src_panid;
    uint64_t src_address;
    uint8_t payload_length;
    uint32_t time_stamp;
    uint8_t *payload;
    } frame_info_t;
```

Contains only MSDU (MAC payload)

MAC Header Fields

Release 2.5.x:

```
typedef struct frame_info_tag
{
    frame_msgtype_t msg_type;
    buffer_t *buffer_header;
    uint8_t msduHandle;
    bool in_transit;
    uint32_t time_stamp;
    uint8_t *mpdu;
} frame_info_t;
```

Contains both MAC Header and MSDU

Address info now removed from frame header, since already included in assembled/received frame

The MAC header information previously included by means of several structure elements has been migrated into the new element “mdpu”, which contains the complete MPDU (both the MAC Header and the MSDU = Data Payload). This implies that starting with release 2.5.x the MAC header information is only parsed and formatted inside the MAC layer and is fully transparent for the TAL layer.

7.2.2.2 *Simplification of Function tal_rx_frame_cb()*

The TAL callback function for a frame indication (once a valid has been received and needs to be forwared to the MCL) has been simplified. The function tal_rx_frame_cb() has changed from

```
void tal_rx_frame_cb(frame_info_t *mac_frame_info, uint8_t lqi)
```

to

```
void tal_rx_frame_cb(frame_info_t *rx_frame)
```

The parameter LQI has been removed, since the LQI value of the current frame is now part of the element “mpdu” of the frame_info_t structure variable “rx_frame”. For more information check function tal_rx_frame_cb() in file *TAL/Src/tal_rx_frame_cb.c*. For more information how to extract and use the LQI value of the received frame see Section 4.2.1.2.

7.2.2.3 *Simplification of Beacon Handling API*

The API handling (periodic) Beacon frames (within a beacon-enabeld network) has been simplified by removing function tal_prepare_beacon() and updating function tal_tx_beacon().

Originally (release 2.4.x) the periodic Beacon transmission was performed by obeying the following steps:

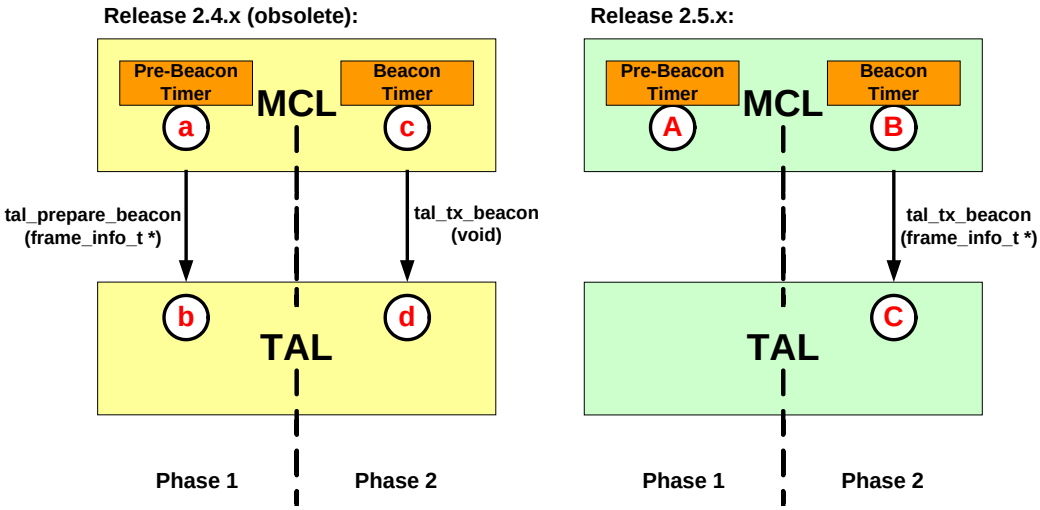
(a) Expiration of Pre-Beacon timer in MCL - Preparation of next Beacon frame within MCL

(b) Calling of TAL-API function tal_prepare_beacon() including the frame information structure to initiate formatting of frame in TAL; Beacon frame is stored inside TAL until transmission time

(c) Expiration of Beacon time in MCL – Calling of TAL-API function tal_tx_beacon to trigger immediate Beacon frame transmission

(d) TAL used stored frame and initiates Beacon frame transmission

Figure 7-2. Transmission of periodic Beacon Frames



Starting with release 2.5.x this has been simplified:

(A) Expiration of Pre-Beacon timer in MCL – Complete formatting of next Beacon frame within MCL; not further interaction with TAL; function tal_prepare_beacon() does not exist anymore

(B) Expiration of Beacon time in MCL – Calling of TAL-API function tal_tx_beacon() to trigger immediate Beacon frame transmission; function tal_tx_beacon contains complete Beacon frame already formatted

(C) TAL uses parameter of type frame_info_t in function tal_tx_frame() to initate Beacon frame transmission

7.2.3 PAL-API Changes

In order to reduce code size and to taylor the actually included functionality of the PAL according to the user application needs, the PAL-API has been updated. The API changes within the PAL-API mainly affect the functions handling transceiver interrupts.

7.2.3.1 TRX IRQ Initialization

7.2.3.1.1 Releaes 2.4.x

The initialization of transceiver interrupts has been changed from release 2.4.x:

```
void pal_trx_irq_init(trx_irq_hdlr_idx_t trx_irq_num,
                      FUNC_PTR trx_irq_cb)
```

The implementation comprised of exactly one function for interrupt initialization, which required an ID for the actual interrupt number.

7.2.3.1.2 Releaes 2.5.x

Since most applications do not require all transceiver interrupts, this approach has been changed starting from release 2.5.x. The focus here is clearly on reduced footprint. Each single transceiver interrupt is initialized with a dedicated initializiation function. The original parameter specifying the dedicated transceiver interrupt is not used anymore. Furthermore only required transceiver interrupts are included into the code based on additional build switches that can be used.

The following functions are provided starting from release 2.5.x:

Initialization of main transceiver interrupt:

```
void pal_trx_irq_init(FUNC_PTR trx_irq_cb)
```

Initialization of transceiver timestamp interrupt (only available if ENABLE_TSTAMP is used):

```
void pal_trx_irq_init_tstamp(FUNC_PTR trx_irq_cb)
```

Initialization of additionally required transceiver interrupts for MEGA-RF single chips:

```
void pal_trx_irq_init_rx_end(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_tx_end(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_cca_ed(FUNC_PTR trx_irq_cb)
```

Initialization of further optional transceiver interrupts for MEGA-RF single chips (only available if ENABLE_ALL_TRX_IRQS is used):

```
void pal_trx_irq_init_ami(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_batmon(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_awake(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_pll_lock(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_pll_unlock(FUNC_PTR trx_irq_cb)
void pal_trx_irq_init_aes_ready(FUNC_PTR trx_irq_cb)
```

For more information see file *PAL/Inc/pal.h* and the corresponding *pal_irq.c* file for each platform implementation.

7.2.3.2 TRX IRQ Enabling and Disabling

7.2.3.2.1 Releaes 2.4.x

Enabling and disabling of transceiver interrupts has been changed from release 2.4.x:

```
inline void pal_trx_irq_enable(trx_irq_hdlr_idx_t trx_irq_num)
inline void pal_trx_irq_disable(trx_irq_hdlr_idx_t trx_irq_num)
```

The implementation comprised of exactly one inline function for enabling or disabling transceiver interrupts, which required an ID for the actual interrupt number.

7.2.3.2.2 Releaes 2.5.x

Since most applications do not require all transceiver interrupts, this approach has been changed starting from release 2.5.x. Both the main transceiver interrupt and the timestamp interrupt are now enabled or disable by using a macro. The original parameter specifying the dedicated transceiver interrupt is not used anymore.

The following macros are provided starting from release 2.5.x:

Enabling and disabling of the main transceiver interrupt:

```
#define pal_trx_irq_en()            (ENABLE_TRX_IRQ())
#define pal_trx_irq_dis()           (DISABLE_TRX_IRQ())
```

Enabling and disabling of the transceiver timestamp interrupt (only available if ENABLE_TSTAMP is used):

```
#define pal_trx_irq_en_tstamp()     (ENABLE_TRX_IRQ_TSTAMP())
#define pal_trx_irq_dis_tstamp()    (DISABLE_TRX_IRQ_TSTAMP())
```

Please note that the macro above are only available for non-single chip transceivers, since in single chip transceivers (MEGA_RF platforms) there is no separation between enabling/disabling transceiver interrupts at the transceiver, and setting/clearing the IRQ mask at the MCU. Therefore the transceiver interrupts in single chips are enabled/disabled by setting the MCU IRQ mask.

For more information see file *PAL/Inc/pal.h* and the corresponding *pal_config.h* file for each platform implementation.

7.2.3.3 TRX IRQ Flag Clearing

7.2.3.3.1 Releaes 2.4.x

Clearing the interrupt flag of transceiver interrupts has been changed from release 2.4.x:

```
inline void pal_trx_irq_flag_clr(trx_irq_hdlr_idx_t trx_irq_num)
```

The implementation comprised of exactly one inline function for clearing the transceiver interrupt flag, which required an ID for the actual interrupt number.

7.2.3.3.2 Releaes 2.5.x

Since most applications do not require all transceiver interrupts, this approach has been changed starting from release 2.5.x. Each single transceiver interrupt flag is cleared using a macro. The original parameter specifying the dedicated transceiver interrupt is not used anymore. Furthermore only required transceiver interrupts are included into the code based on additional build switches that can be used.

The following macros are provided starting from release 2.5.x:

Clearing the main transceiver interrupt flag:

```
#define pal_trx_irq_flag_clr()          (CLEAR_TRX_IRQ())
```

Clearing the transceiver timestamp interrupt flag (only available if ENABLE_TSTAMP is used):

```
#define pal_trx_irq_flag_clr_tstamp()   (CLEAR_TRX_IRQ_TSTAMP())
```

Clearing of additionally required transceiver interrupt flags for MEGA-RF single chips:

```
#define pal_trx_irq_flag_clr_rx_end()   (CLEAR_TRX_IRQ_RX_END())
#define pal_trx_irq_flag_clr_tx_end()   (CLEAR_TRX_IRQ_TX_END())
#define pal_trx_irq_flag_clr_cca_ed()   (CLEAR_TRX_IRQ_CCA_ED())
```

Clearing of further optional transceiver interrupt flags for MEGA-RF single chips (only available if ENABLE_ALL_TRX_IRQS is used):

```
#define pal_trx_irq_flag_clr_ami()      (CLEAR_TRX_IRQ_AMI())
#define pal_trx_irq_flag_clr_batmon()   (CLEAR_TRX_IRQ_BATMON())
#define pal_trx_irq_flag_clr_awake()    (CLEAR_TRX_IRQ_AWAKE()
#define pal_trx_irq_flag_clr_pll_lock() (CLEAR_TRX_IRQ_PLL_LOCK())
#define pal_trx_irq_flag_clr_pll_unlock()
CLEAR_TRX_IRQ_PLL_UNLOCK())
```

For more information see *PAL/Inc/pal.h* file and the corresponding *pal_config.h* file for each platform implementation

8 Toolchain

The following sections describe the used toolchain for the development and build process and how the provided example applications can be built.

8.1 General prerequisites

The following tool chain is used for building the applications from this MAC package:

- Atmel AVR Studio 4.18
  (see http://www.atmel.com/dyn/products/tools_card.asp?tool_id=2725)
- AVR Studio 5
  (see http://www.atmel.com/dyn/products/tools_card.asp?tool_id=17212)
- WinAVR 20100110 including AVR-GCC for Windows
  (see http://sourceforge.net/projects/winavr)
- Atmel AVR32 GNU Toolchain for Windows
  (see http:http://www.atmel.com/dyn/products/tools_card.asp?tool_id=4118)
- ARM Code Sorcery GCC Toolchain for Windows(IA32 Windows Installer)
  (see http://www.codesourcery.com/sgpp/lite/arm/portal/release642)
- IAR Embedded Workbench for Atmel AVR V5.51.0
  (see http://www.iar.com/)
- IAR Embedded Workbench for Atmel AVR32 V3.31.0
  (see http://www.iar.com/)
- IAR Embedded Workbench for Atmel ARM V6.20.0
  (see http://www.iar.com/)

8.2 Building the applications

All example applications contain precompiled hex-files that can be downloaded and run out-of-the-box.

In order to rebuild any of the applications for any desired hardware platform one of the following three ways described in the subsequent sections can be chosen generally.

8.2.1 Using GCC makefiles

Each application can be rebuilt using the provided Makefiles. Please follow the procedure as described:

- Change to the directory where the Makefile for the desired platform of the corresponding application is located, for example:

  ```
  cd Applications\MAC_Examples\Promiscuous_Mode_Demo
  cd AT86RF212_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD
  cd GCC
  ```

- Run the desired Makefile, for example:

  ```
  make –f Makefile
  ```

  or

  ```
  make –f Makefile_Debug
  ```

NOTE Makefile builds a binary optimized for code size without Serial I/O support, whereas Makefile_Debug builds a version for better debug support without optimization but with additional Serial I/O support

- After running one of the Makefiles the same directory contains both a hex-file and an elf-file which can be downloaded onto the hardware (see Section 8.3)
- The above procedure for building the Makefiles is common for Atmel AVR8, Atmel AVR32, and ARM Platforms

8.2.2 Using AVR Studio 4

Each application can be rebuilt using the Atmel AVR Studio directly. Please follow the procedure as described:

- Change to the directory where the AVR Studio project file (aps-file) for the desired platform of the corresponding application is located, for example:

```
cd Applications\MAC_Examples\Promiscuous_Mode_Demo
cd AT86RF212_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD
```

- Double click on the corresponding AVR Studio 4 Project file (aps-file), for example *Promiscuous_Mode_Demo.aps*
- Select the desired configuration (Release or Debug). Depending on the selected configuration the corresponding external Makefile is chosen during the build process. These Makefiles are exactly those Makefiles (located in subdirectory GCC) that are used to build the application from command line (see Section 8.2.1)
- Rebuild the entire application in AVR Studio 4
- After building the application the subdirectory GCC contains both a hex-file and an elf-file which can be downloaded onto the hardware (see Section 8.3)

8.2.3 Using AVR Studio 5

Each application can be rebuilt using the Atmel AVR Studio 5 directly. Please follow the procedure as described:

- Change to the directory where the AVR Studio 5 project file (avrsln-file) for the desired platform of the corresponding application is located, for example:

```
cd Applications\MAC_Examples\Promiscuous_Mode_Demo
cd AT86RF212_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD
```

- Double click on the corresponding AVR Studio 5 solution file (avrsln-file), for example *Promiscuous_Mode_Demo.avrsln*
- Select the desired configuration (Release or Debug). Depending on the selected configuration the corresponding external Makefile is chosen during the build process. These Makefiles are exactly those Makefiles (located in subdirectory GCC) that are used to build the application from command line (see section 8.2.1).
- Rebuild the entire application in AVR Studio 5
- After building the application the subdirectory GCC contains executable files and hex-file which can be downloaded onto the hardware (see section 8.3)

8.2.4 Using IAR Embedded Workbench

Each application can be rebuilt using the IAR Embedded Workbench directly. Please follow the procedure as described:

- Change to the directory where the IAR Embedded Workbench workspace file (eww-file) for the desired platform of the corresponding application is located, for example:

  ```
  cd Applications\MAC_Examples\Promiscuous_Mode_Demo
  cd AT86RF212_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD
  ```

- Double click on the corresponding IAR Embedded Workbench file (eww-file), for example *Promiscuous_Mode_Demo.eww*
- Select the desired workspace (Release or Debug) and Rebuild the entire application in IAR Embedded Workbench
- After building the application the subdirectory IAR/Exe contains either an a90-file (in case the Release configuration was selected) or a d90-file (in case a Debug configuration was selected). Both binaries can be downloaded onto the hardware (see Section 8.3)
- The Release configuration binary (a90-file) can both be downloaded using IAR Embedded Workbench directly or AVR Studio
- The Debug configuration binary (d90-file) can only be downloaded using IAR Workbench and can be debugged using IAR C-Spy®
- In case is it desired to create a binary with IAR Embedded Workbench, which contains AVR Studio Debug information and can thus directly be downloaded and debugged using AVR Studio, the following changes need to be done with IAR Embedded Workbench:
  - Select the Debug configuration
  - Open the “Options” dialog
  - Select “Category” “Linker”
  - Select tab “Output”
  - Change “Format” from “Debug information for C-Spy” to “Other”
  - Select “ubrof 8 (forced)” as “Output format”
  - Select “None” as “Format variant”
  - Rebuild the application
  - The generated binary can now contains debug information that can be used directly within AVR Studio

8.2.5 Using IAR AVR32 Embedded Workbench

Each application can be rebuilt using the IAR AVR32 Embedded Workbench directly. Please follow the procedure as described:

- Change to the directory where the IAR Embedded Workbench workspace file (eww-file) for the desired platform of the corresponding application is located, for example:

  ```
  cd Applications\MAC_Examples\Promiscuous_Mode_Demo
  cd AT86RF212_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD
  ```

- Double click on the corresponding IAR Embedded Workbench file (eww-file), for example *Promiscuous_Mode_Demo.eww*
- Select the desired workspace (Release or Debug) and Rebuild the entire application in IAR Embedded Workbench
- After building the application the subdirectory IAR/Exe contains either an elf-file (in case the Release or Debug configuration was selected).The binaries can be downloaded onto the hardware (see Section 8.3)

- The Release configuration binary (elf-file) can both be downloaded using IAR AVR32 Embedded Workbench directly or AVR Studio
- The Debug configuration binary (elf-file) can only be downloaded using IAR AVR32 Workbench and can be debugged using IAR AVR32 C-Spy®

8.2.6 Using IAR ARM Embedded Workbench

Each application can be rebuilt using the IAR ARM Embedded Workbench directly. Please follow the procedure as describe:

- Change to the directory where the IAR Embedded Workbench workspace file (eww-file) for the desired platform of the corresponding application is located, for example:

```
cd Applications\MAC_Examples\Promiscuous_Mode_Demo
cd AT86RF231_AT91SAM3S4C_SAM3SEK
```

- Double click on the corresponding IAR Embedded Workbench file (eww-file), for example *Promiscuous_Mode_Demo.eww*
- Select the desired workspace (Release or Debug) and Rebuild the entire application in IAR Embedded Workbench
- After building the application the subdirectory IAR/Exe contains either a binary file or an elf-file (in case the Release or Debug configuration was selected). The binaries can be downloaded onto the hardware (see Section 8.3)
- The Release and Debug configuration binary or elf-file can both be downloaded using IAR ARM Embedded Workbench directly

8.2.7 Batch build

If several applications shall be built or all applications need to be re-built, bat-files are provided to initiate an automatic batch build. Please check directory Build and run the corresponding bat-file as desired.

8.3 Downloading an application

This section describes how the binaries of the applications can be downloaded onto the hardware.

Please note that in case the board stores its IEEE address in the internal EEPROM of the microcontroller, it is important to ensure, that this IEEE address is not overwritten by the tool, that is, the content of the internal EEPROM needs to be preserved. If this rule is not followed properly, the EEPROM content might be overwritten, and the example applications will not run, since all example application are required to have a unique IEEE available for each node being detected during runtime.

In the subsequent section this is indicated both for AVR Studio and IAR Embedded Workbench.

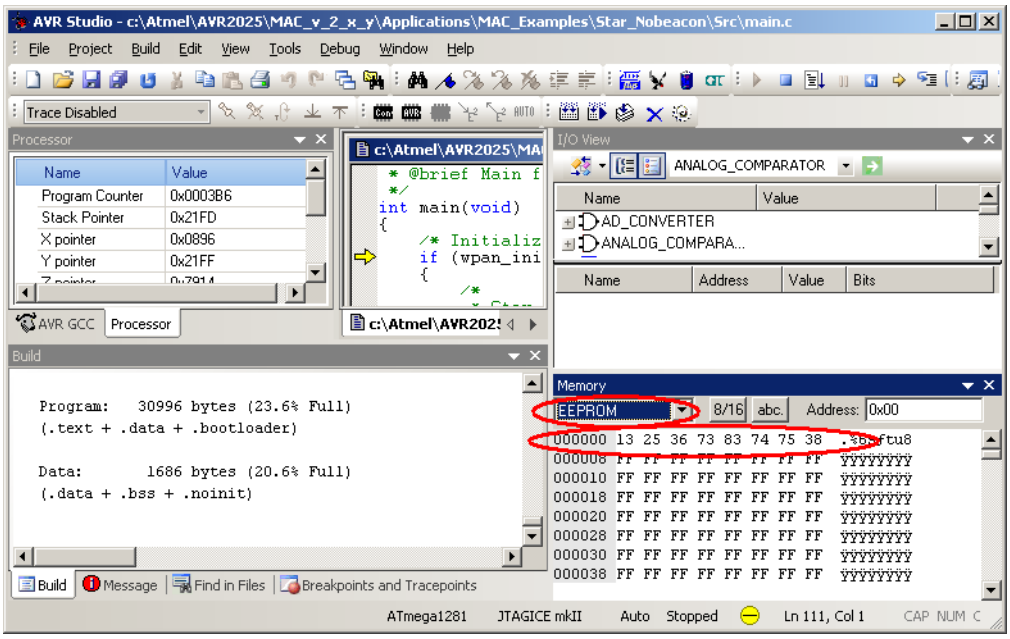
8.3.1 Using AVR Studio 4 directly

When the application has been built using AVR Studio 4 directly by double clicking the corresponding aps-file, the EEPROM settings are handled properly without any user interaction. The provided aps-files contain an entry that requires the system to preserve the current EEPROM settings (`<PRESERVER_EEPROM>1</PRESERVE_EEPROM>`).

In order to re-build the application and download it onto the desired hardware platform, follow the steps below:

- Select menu “Build” item “Build and Run”.
- Once the application has been built successfully, (and in case there has been more than one Atmel AVR JTAGICE mkII detected) a window pops up, asking to select the proper JTAGICE mkII to be used.
- In case the IEEE address of the node is stored in the internal EEPROM of the microcontroller perform as follows:
    - After successful download of the application check whether a valid IEEE address (different from 0xFFFFFFFF) is stored in the internal EEPROM. Select menu “View” item “Memory”
    - If the IEEE address is not set properly, write the correct IEEE to the first eight octets of the EEPROM (see Figure 8-1)
- Start the application by pressing “F5” or clicking the “Run” button

Figure 8-1. Atmel AVR Studio – verifying and setting of IEEE address.



8.3.2 Using AVR Studio 4 after command line build of application

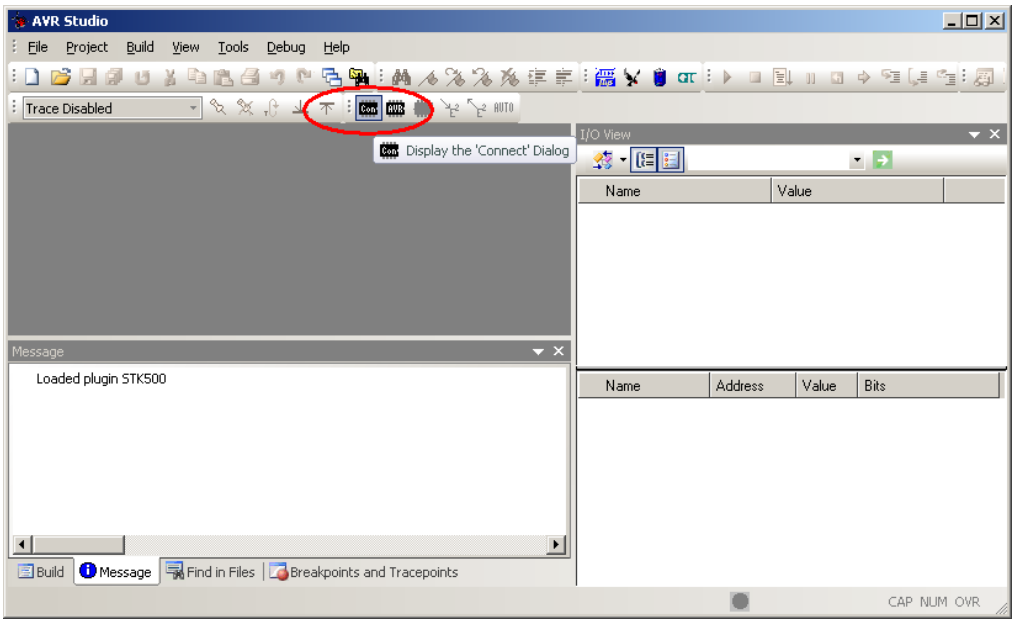
When the application has been built using external Makefiles from the command line, the application can be started following the steps described below.

8.3.2.1 Starting the release build

The release build can simply be started as follows:

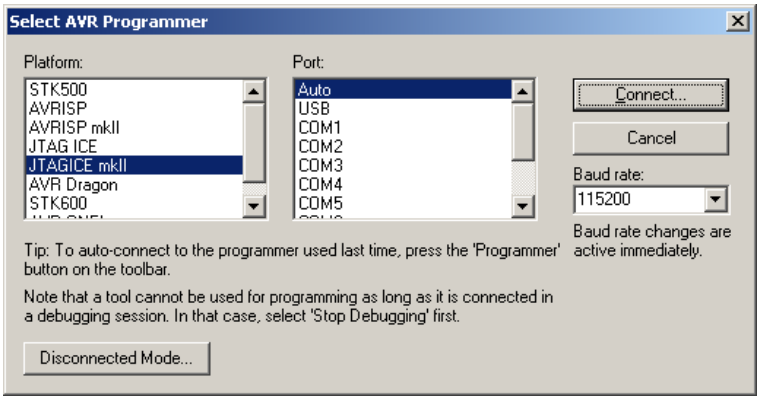
- Start AVR Studio 4
- Display the “Connect” dialog

Figure 8-2. AVR Studio 4 “Connect” dialog.



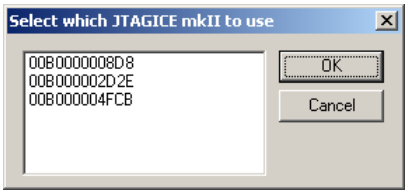
- Select the proper Atmel AVR Programmer (for example, Atmel AVR JTAGICE mkII) and press “Connect”

Figure 8-3. Atmel AVR Studio 4 “Select AVR Programmer” dialog.



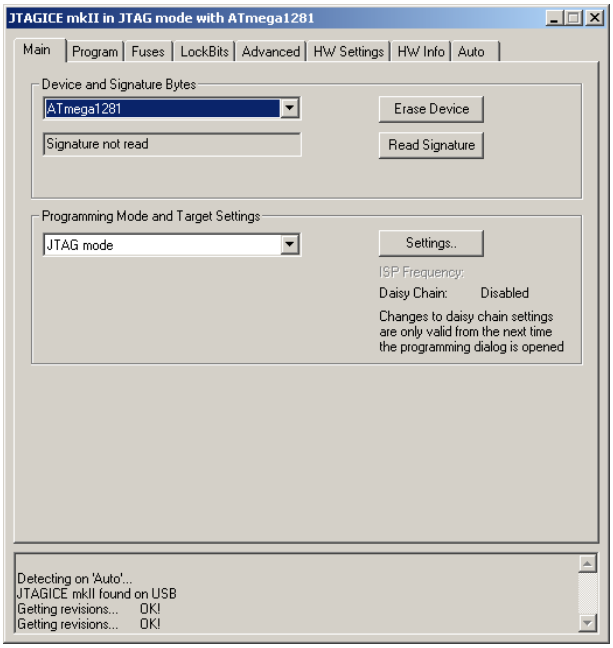
- In case more than one JTAGICE mkII are detected by AVR Studio select the proper Id

Figure 8-4. AVR Studio 4 “Select JTAGICE mkII” dialog.



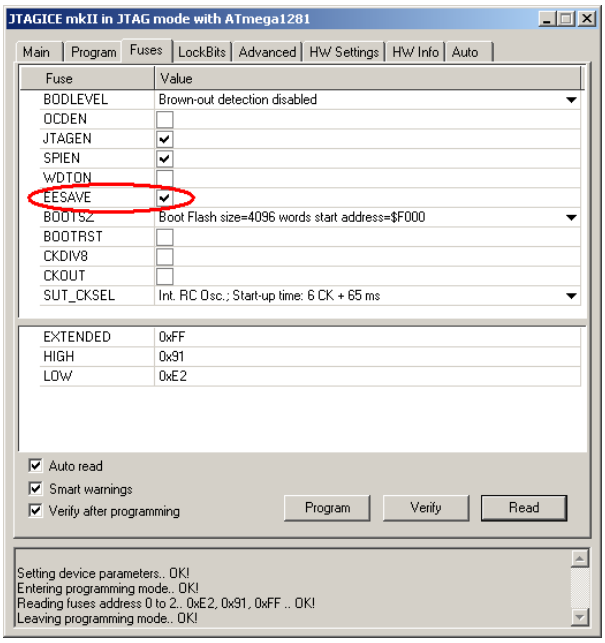
- After the JTAGICE selection the “JTAGICE mkII” dialog opens. Select the “Main” tab. Within this tab select the proper “Device and Signature Bytes” (for example Atmel “ATmega1281”) and the proper “Programming Mode and Target Settings” (for example, “JTAG mode”)

Figure 8-5. Atmel AVR Studio 4 “JTAGICE mkII” dialog with “Main” tab.



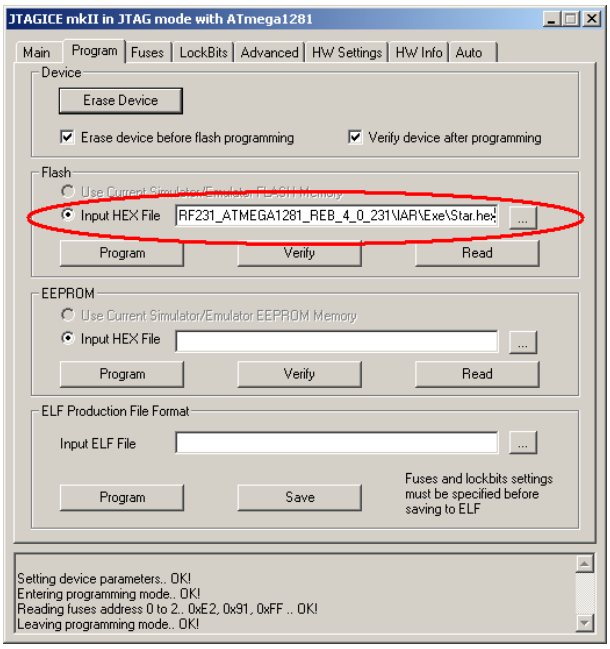
- Select the “Fuses” tab. Within this tab make sure that the EESAVE fuse is selected. This preserves the EEPROM through the Chip Erase cycle

Figure 8-6. AVR Studio 4 “JTAGICE mkII” dialog with “Fuses” tab.



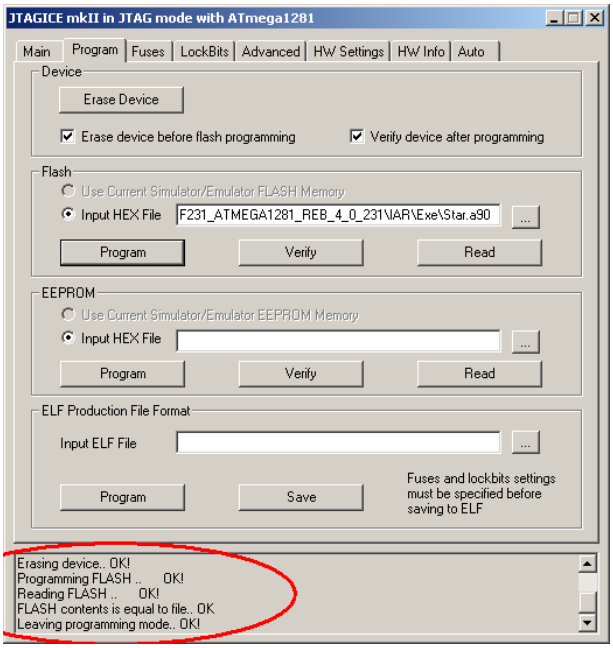
- Select the “Program” tab. Within this tab select the “Flash” section selection the proper Intel Hex File in either hex- or a90-format. Afterwards press button “Program”

Figure 8-7. Atmel AVR Studio 4 “JTAGICE mkII” dialog with “Program” tab.



- The image will be downloaded onto the target and the status will be indicated

Figure 8-8. AVR Studio “JTAGICE mkII” dialog with “Program” tab download status.



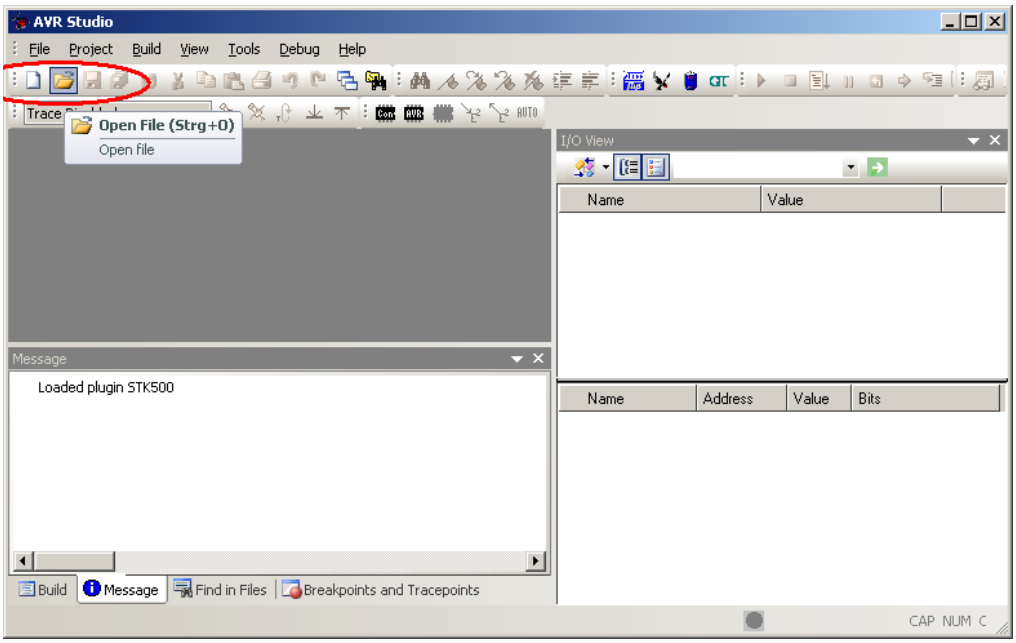
- Close the “JTAGICE mkII” dialog. This starts the application. No further feedback within AVR Studio can be seen. In order to verify the proper functioning of the application check the corresponding outputs (LED status, Sniffer output, Terminal Window output, etc.)
- In case the application does not work as desired (and especially if the three standard LEDs are blinking fast) check first the proper IEEE address setting (see Section 8.3.1 or Section 8.3.2.2), or whether the proper binary has been selected (selection of transceiver type, microcontroller type, and board type)

8.3.2.2 Starting the debug build

The debug build can simply be started as follows:

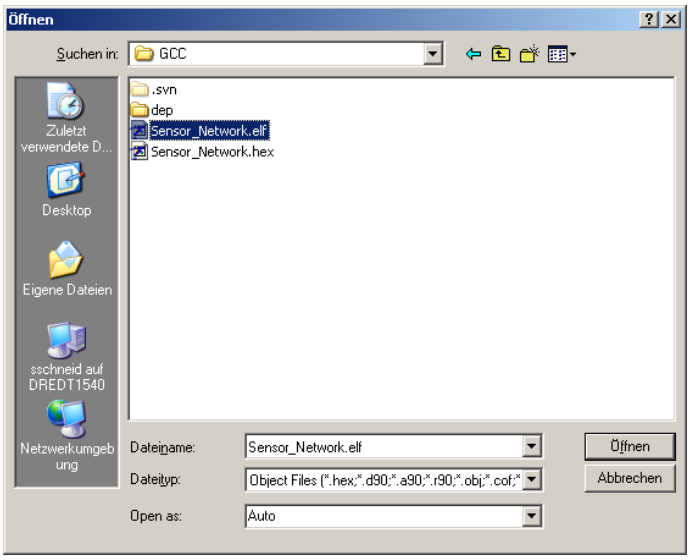
- Start Atmel AVR Studio 4
- Display the “Open File” dialog

Figure 8-9. AVR Studio “Open File” dialog.



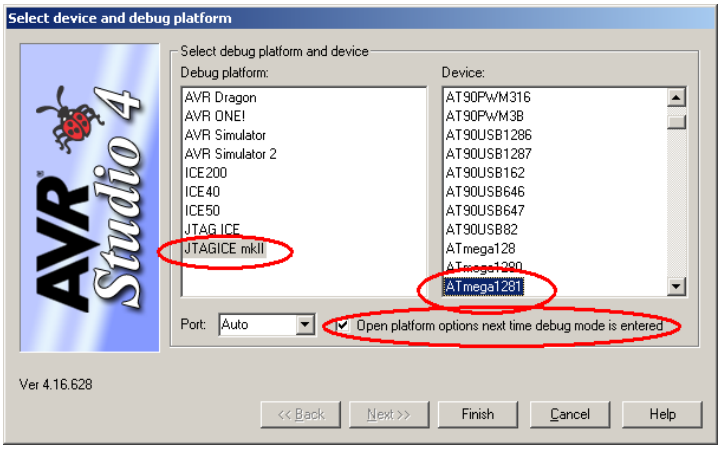
- Select the proper elf-file

Figure 8-10. AVR Studio 4 – select .elf-file.



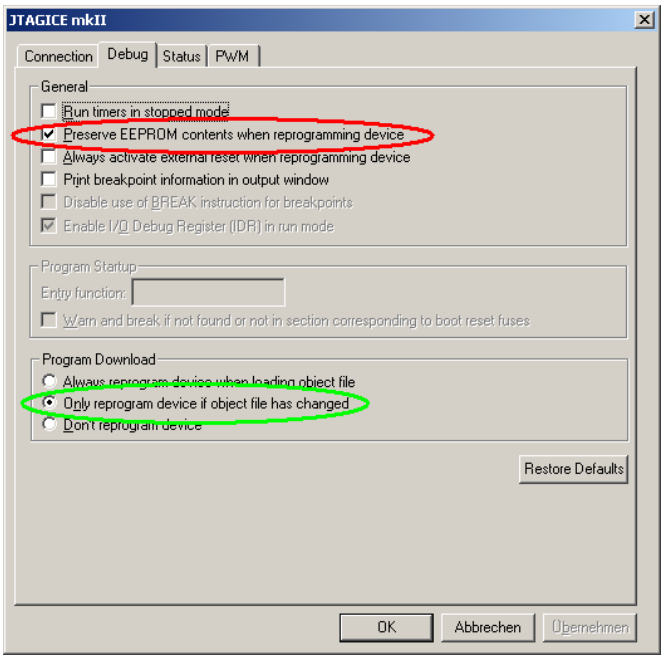
- In case a window pops up asking whether to save changes to a specific project press “Yes” and select the proper place to store the existing project file.
- The “Select device and debug platform” window opens. Select the proper “Debug platform” (for example, Atmel AVR JTAGICE mkII) and “Device” (for example Atmel ATmega1281). Make sure that “Open platform options next time debug mode is entered” is selected

Figure 8-11. Atmel AVR Studio “Select debug platform and device” window.



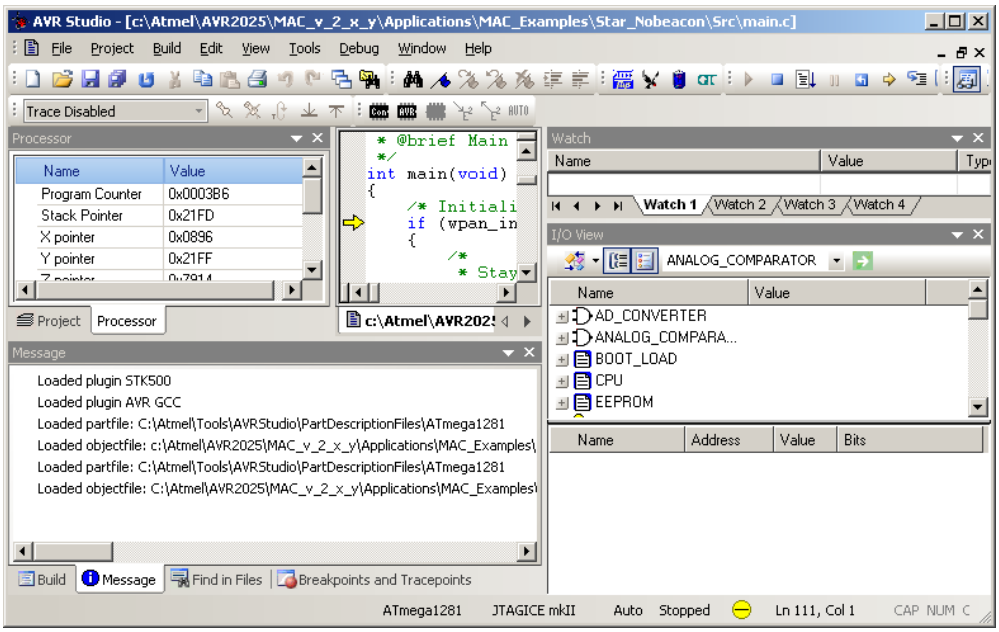
- Press “Finish”
- In case there has been more than one JTAGICE mkII detected a window pops up asking to select the proper JTAGICE mkII to be used
- The JTAGICE mkII Dialog opens. Select the “Debug” tab. Within the “Debug” tab make sure that “Preserve EEPROM contents when reprogramming device” is selected

Figure 8-12. AVR Studio “JTAGICE mkII” dialog with “Debug” tab.



- Press “OK”. The image will be downloaded and the download status is indicated within Atmel AVR Studio 4
- Now Atmel AVR Studio 4 looks like Figure 8-13

Figure 8-13. AVR Studio after successful debug build download.



- In case the IEEE address of the node is stored in the internal EEPROM of the microcontroller perform as follows:

- o Check whether a valid IEEE address (different from 0xFFFFFFFFFFFFFFFFand 0x0000000000000000) is stored in the internal EEPROM. Select menu “View” item “Memory”
- o If the IEEE address is not set properly, add the correct IEEE to the first eight octets of the EEPROM (see Section 8.3.1)

- Start the application by pressing “F5” or clicking the “Run” button

8.3.3 Using AVR Studio 5

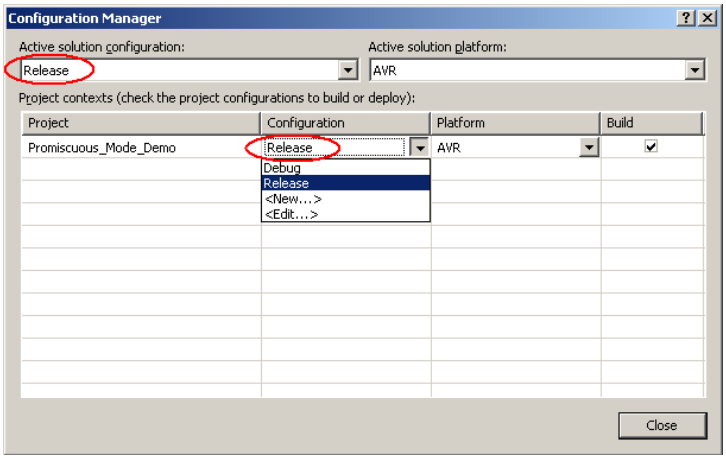
When the application has been built in Atmel AVR Studio 5 (see Section 8.2.3), the application can be started following the steps described below.

8.3.3.1 Starting the Release Build

The release build can simply be started as follows:

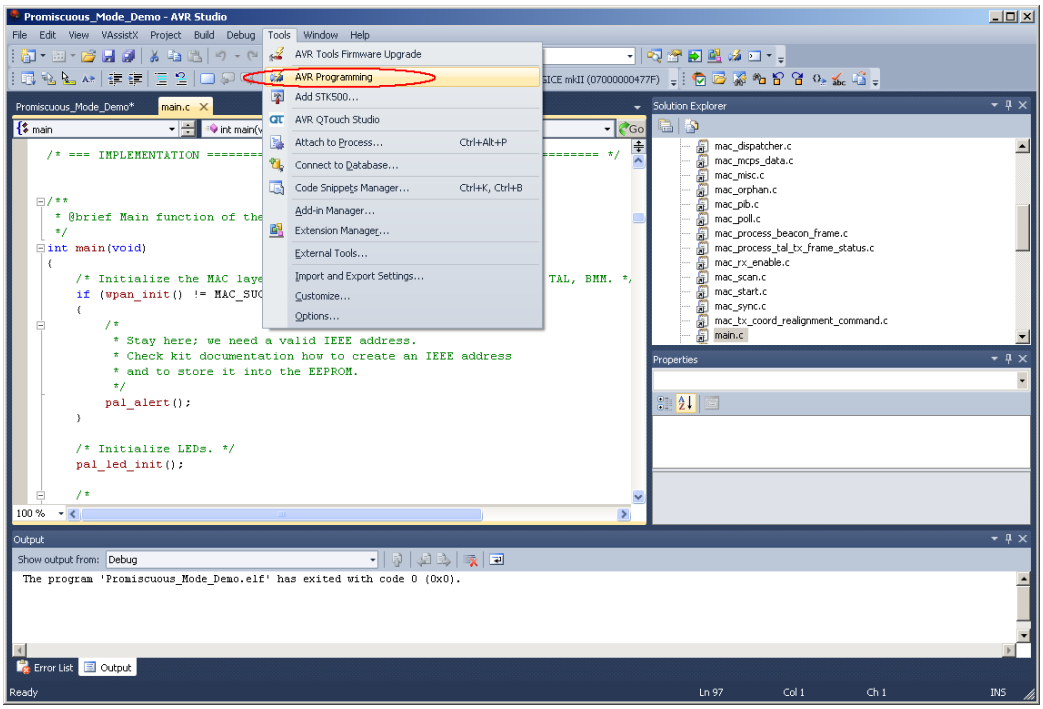
- Open AVR Studio 5 by double clicking on the corresponding AVR Studio 5 solution file (avrsln-file)
- Select “Release” configuration from the “Configuration Manager”

Figure 8-14. AVR Studio 5 - “Build” -> “Configuration Manager” ->”Release”.



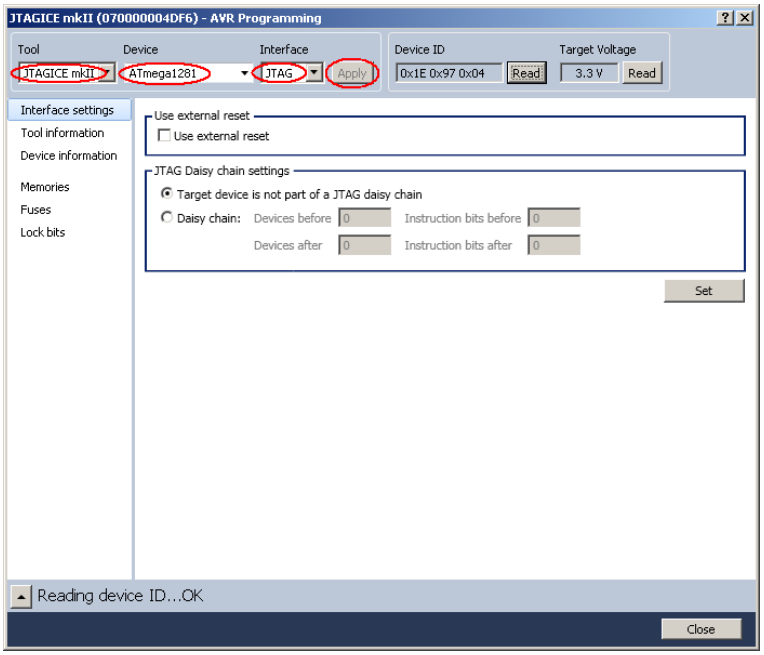
- Rebuild the application in AVR Studio 5
- Open the “AVR Programming” Dialog from the “Tools” menu bar

Figure 8-15. AVR Studio 5 - “Tools” -> “AVR Programming”.



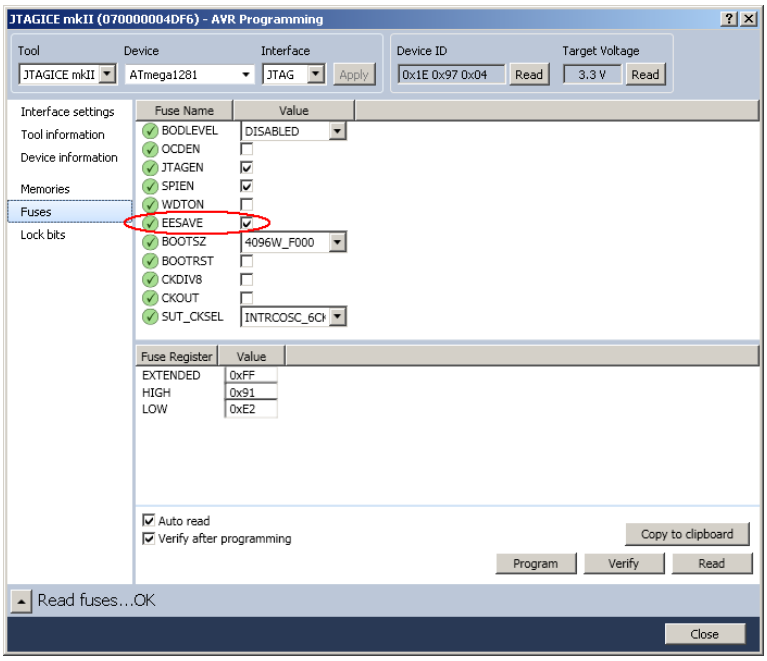
- After selecting proper Tool, Device and Interface; press “Apply” button

Figure 8-16. AVR Studio 5 – “AVR Programming” dialog.



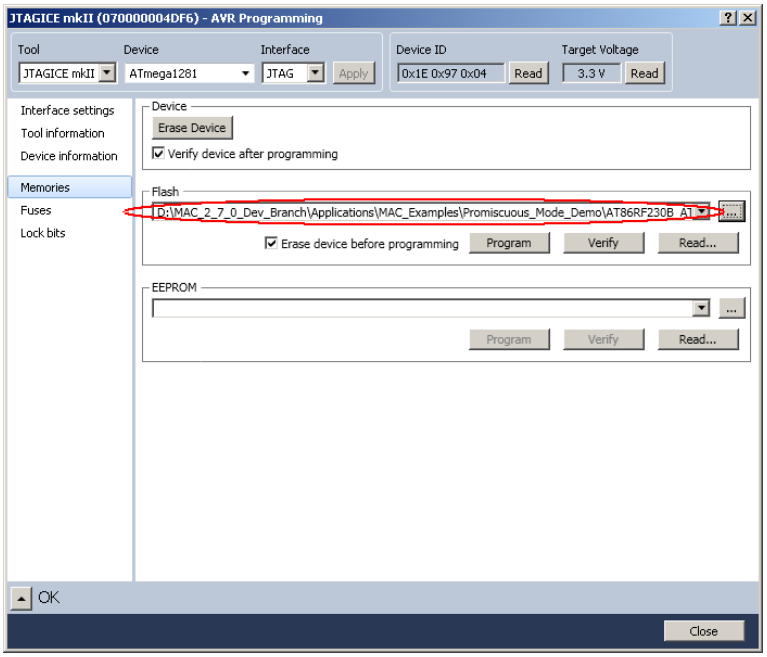
- Select the “Fuses” tab. Within this tab, make sure that the EESAVE fuse is selected. This preserves the EEPROM through the chip erase cycle

Figure 8-17. AVR Studio 5 - “AVR Programming” dialog with “Fuses” tab.



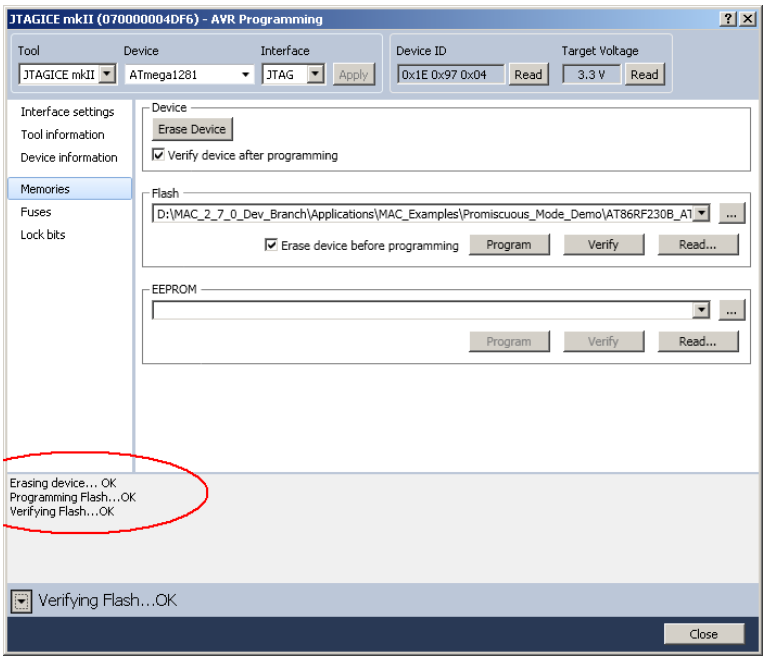
- Select the “Memories” tab. Within this tab select the “Flash” section selection the proper Intel Hex File. Afterwards press button “Program”

Figure 8-18. AVR Studio 5 - “AVR Programming” dialog with “Memories” tab.



- The image will be downloaded onto the target and the status will be indicated

Figure 8-19. AVR Studio 5 - “AVR Programming” dialog with “Memories” tab.



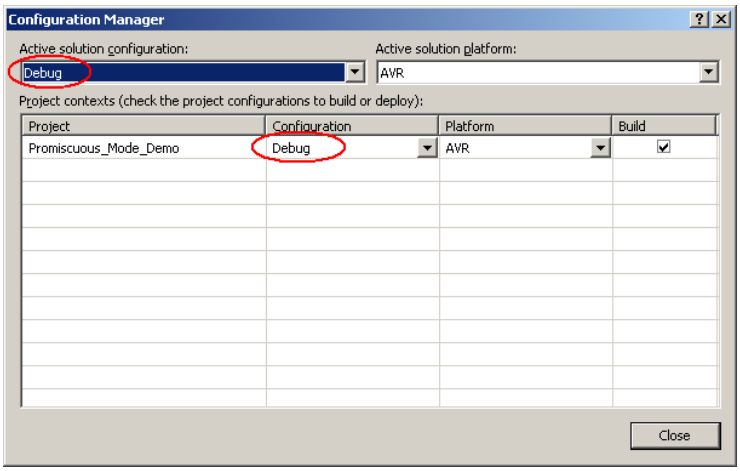
- Close the “AVR Programming” dialog. This starts the application. No further feedback within AVR Studio 5 can be seen. In order to verify the proper functioning of the application check the corresponding outputs (LED status, Sniffer output, Terminal Window output, etc.)
- In case the application does not work as desired (and especially if the three standard LEDs are blinking fast) check first the proper IEEE address setting (see Section 8.3.1 or Section 8.3.2.2), or whether the proper binary has been selected (selection of transceiver type, microcontroller type, and board type)

8.3.3.2 *Starting the Debug Build*

The debug build can simply be started as follows:

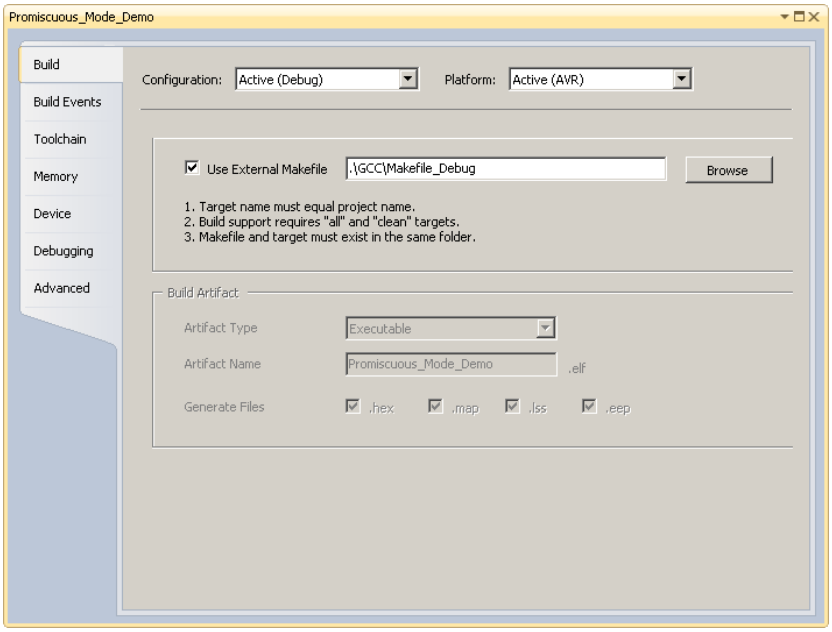
- Open AVR Studio 5 by double clicking on the corresponding AVR Studio 5 Solution file (avrsln-file)
- Select “Debug” configuration from the “Configuration Manager”

Figure 8-20 AVR Studio 5 - “Build” -> “Configuratoin Manager” -> ”Debug”.



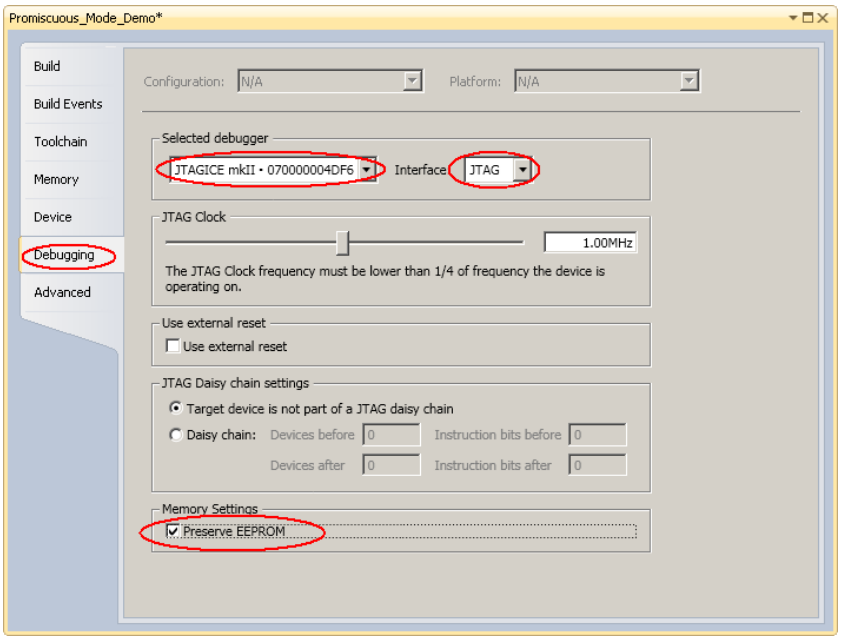
- Rebuild the application in AVR Studio 5
- Open Project Properties

Figure 8-21. AVR Studio 5 – “Project” -> “Properties”.



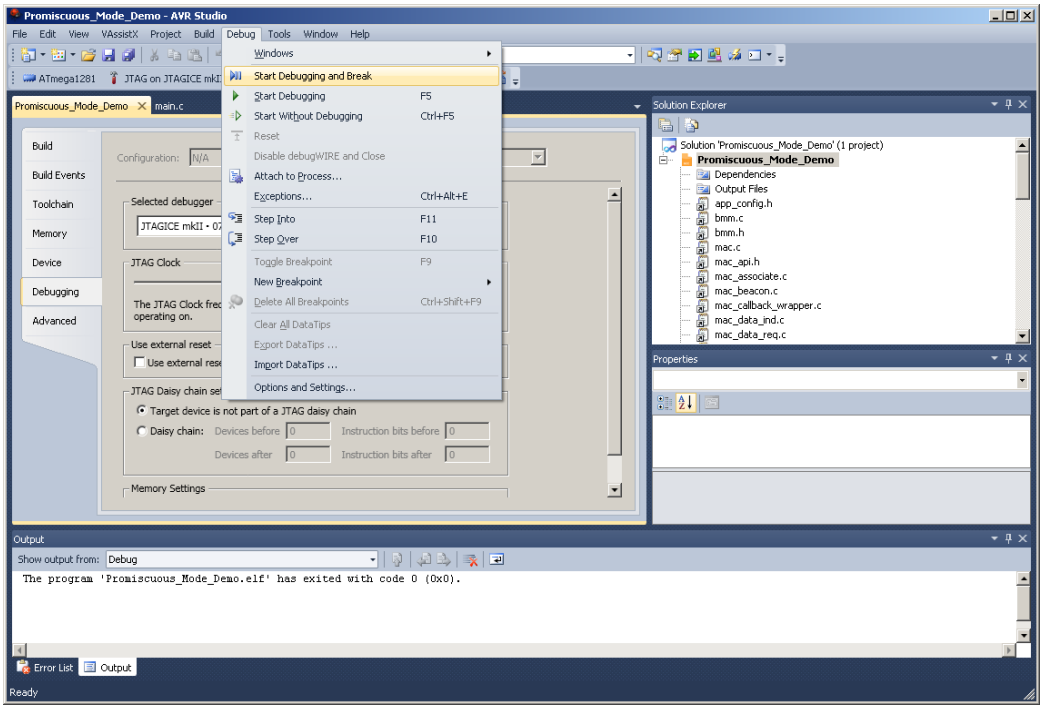
- On the project property window, select “Debugging” tab. Here, select the debugger and interface. Make sure that “Preserve EEPROM” is selected.

Figure 8-22. AVR Studio 5 - “Project Properties” dialog with “Debug” tab.



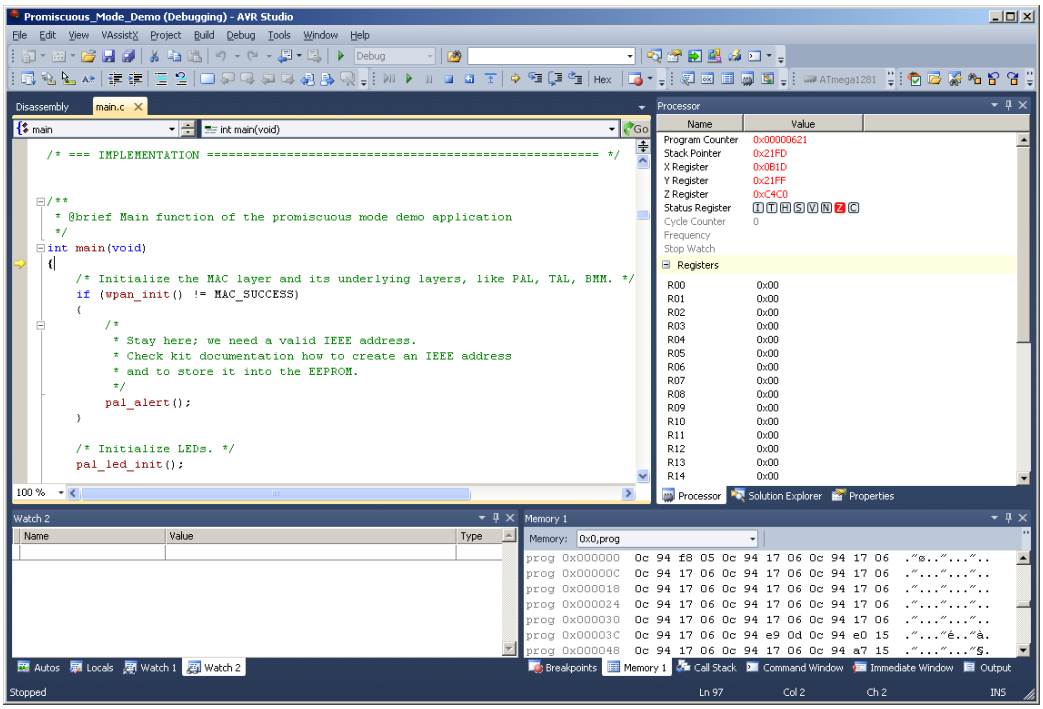
- Start Debug session

Figure 8-23. AVR Studio 5 - “Start Debugging and Break”.



- The image will be downloaded and the download status is indicated within AVR Studio 5
- Now AVR Studio 5 looks like below

Figure 8-24. AVR Studio 5 after successful debug build download.



- In case the IEEE address of the node is stored in the internal EEPROM of the microcontroller, please perform the following steps:
    - Check whether a valid IEEE address (different from 0xFFFFFFFFFFFFFFFFand 0x0000000000000000) is stored in the internal EEPROM. From the “Debug” menu, go to “Windows” item and sub item “Memory”.
    - If the IEEE address is not set properly, add the correct IEEE address to the first 8 octets of the EEPROM (see section 8.3.1).
- Start the application debug session by pressing “F5” or clicking the “Run” button

8.3.4 Using IAR Embedded Workbench

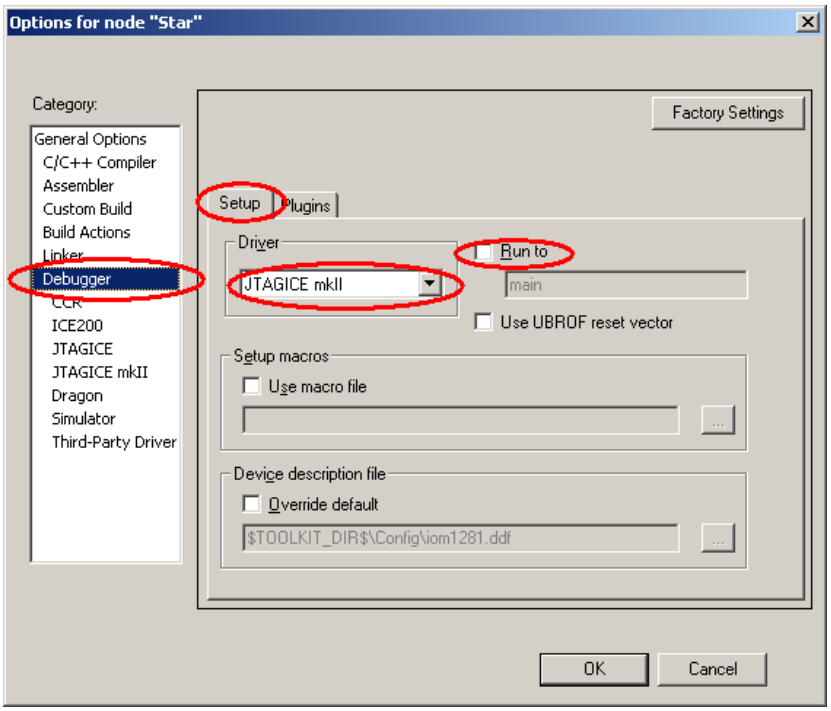
When using IAR Embedded Workbench directly by double clicking the corresponding eww-file, the application can be downloaded onto the desired hardware platform as described below.

8.3.4.1 Starting the release build

The release build can simply be started as follows:

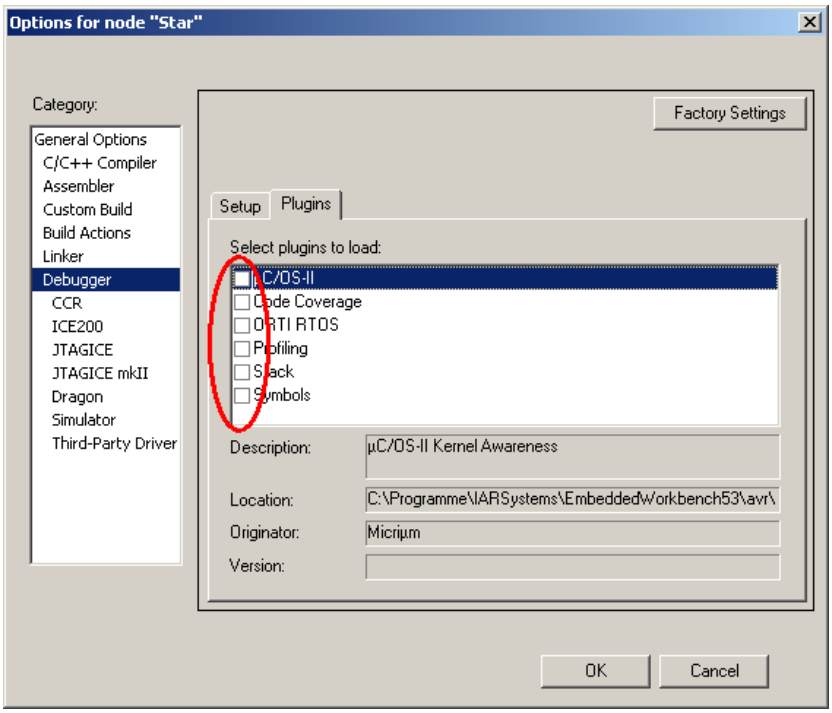
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Embedded Workbench by double clicking the desired eww-file
- Select the “Release” Workspace
- Open the “Options” window for the “Release” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-25. IAR Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



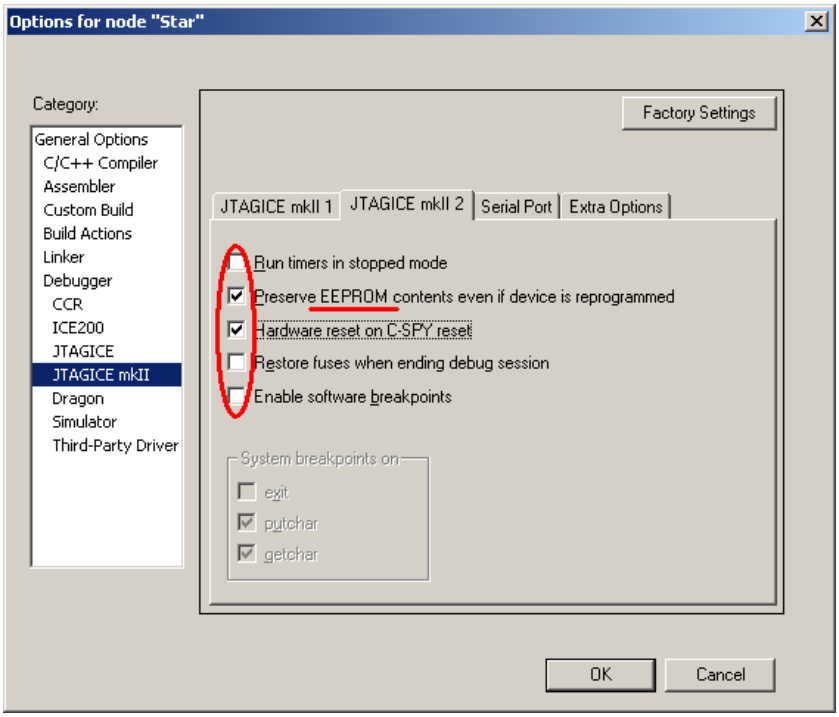
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and deselect “Run to (main)”
- Change to the “Plugins” tab and deselect all entries

Figure 8-26. IAR Embedded Workbench – “Options” -> “Debugger” -> “Plugins”.



- Within the “Options” window for the “Release” Workspace select now the “JTAGICE mkII” window and within this window select the “JTAGICE mkII 2” tab

Figure 8-27. IAR Embedded Workbench – “Options” -> “JTAGICE mkII” -> “JTAGICE mkII 2”.



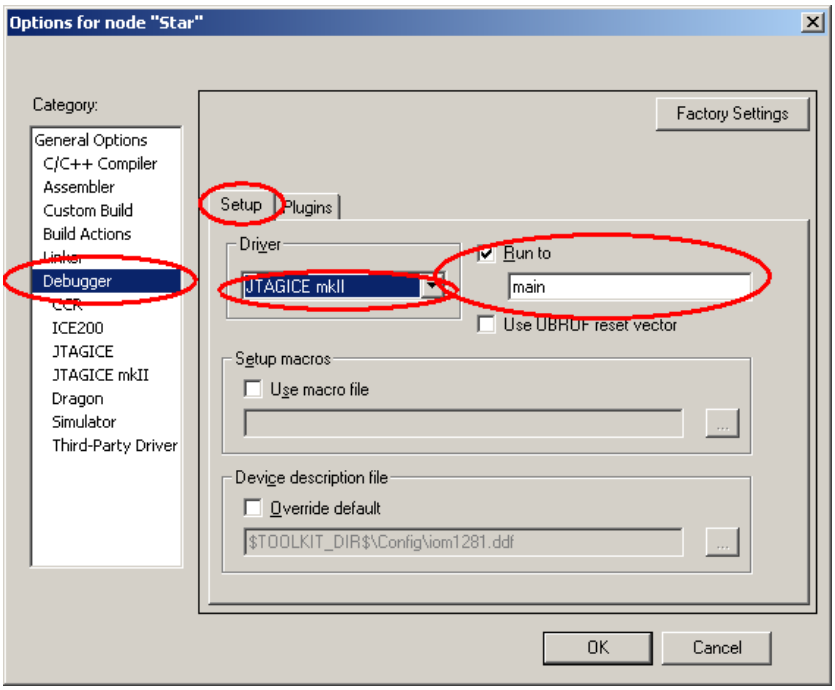
- Within the “JTAGICE mkII 2” tab check the items as shown above. Especially make sure that the EEPROM will be preserved if the device is reprogrammed
- Press “OK”
- Press the button “Download and Debug”
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and deselect “Run to (main)”
- Change to the “Plugins” tab and deselect all entries

8.3.4.2 Starting the debug build

The debug build can simply be started as follows:

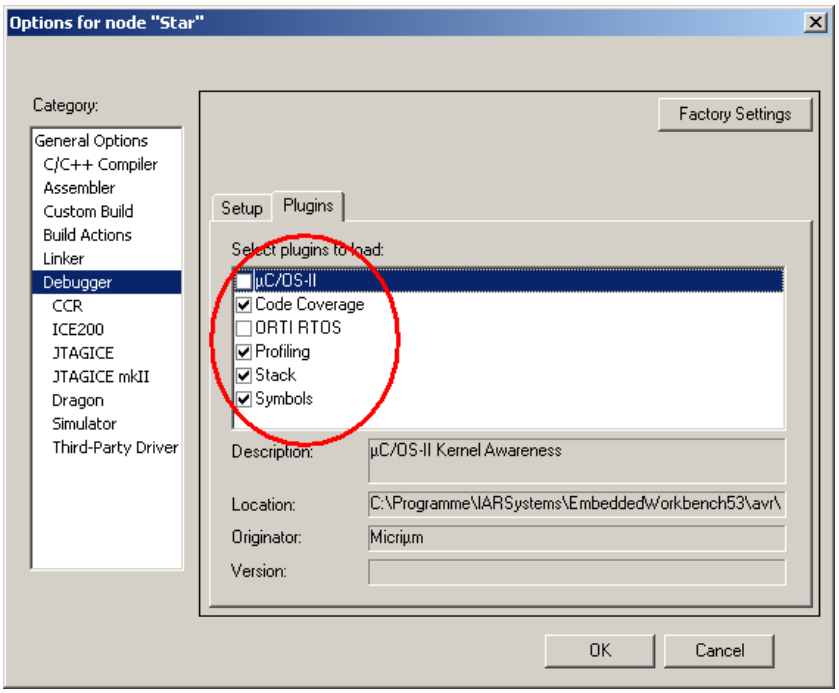
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Workbench by double clicking the desired eww-file
- Select the “Debug” Workspace
- Open the “Options” window for the “Debug” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-28. IAR Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



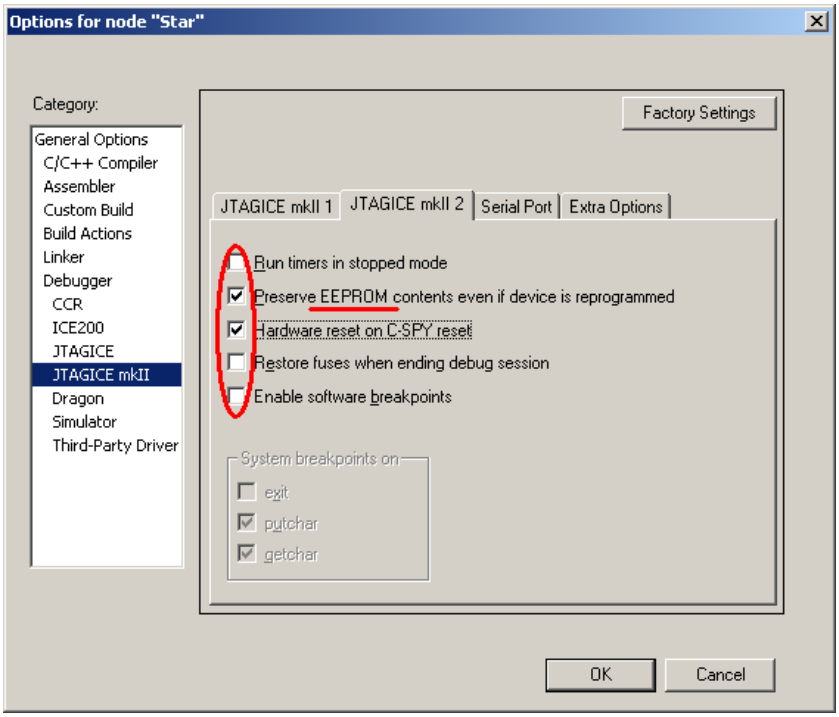
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and select “Run to (main)” (this is different to “Release” build)
- Change to the “Plugins” tab and select the entries as shown in Figure 8-

Figure 8-29. IAR Embedded Workbench – “Options” -> “Debugger” -> “Plugins”.



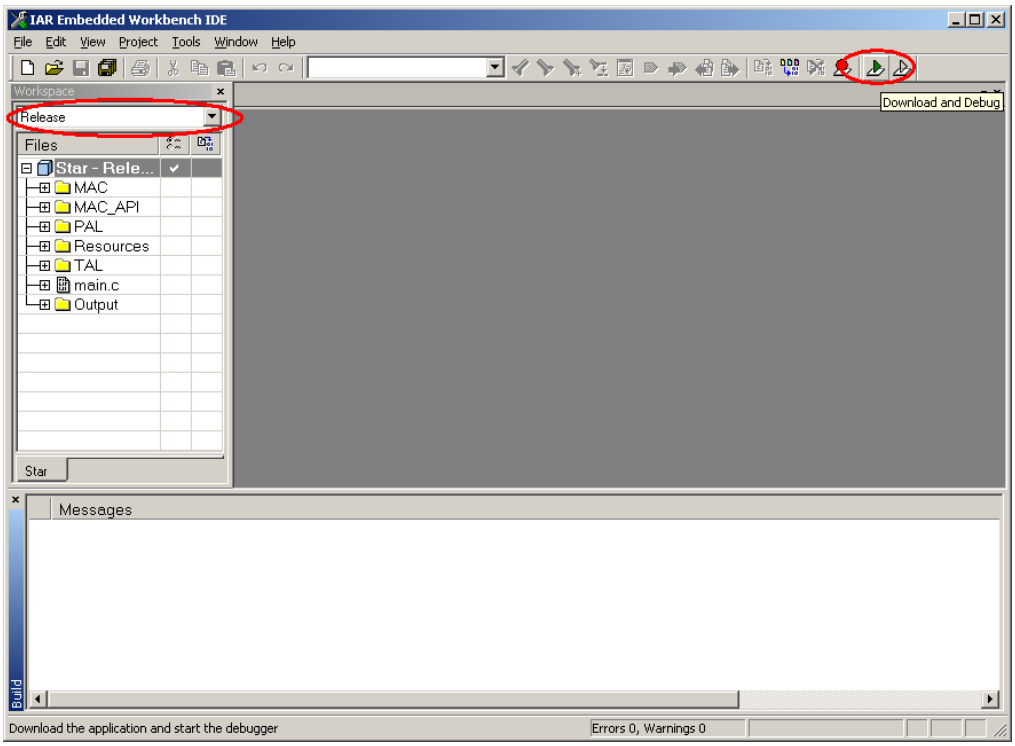
- Within the “Options” window for the “Release” Workspace select now the “JTAGICE mkII” window and within this window select the “JTAGICE mkII 2” tab

Figure 8-30. IAR Embedded Workbench – “Options” -> “JTAGICE mkII” -> “JTAGICE mkII 2”.



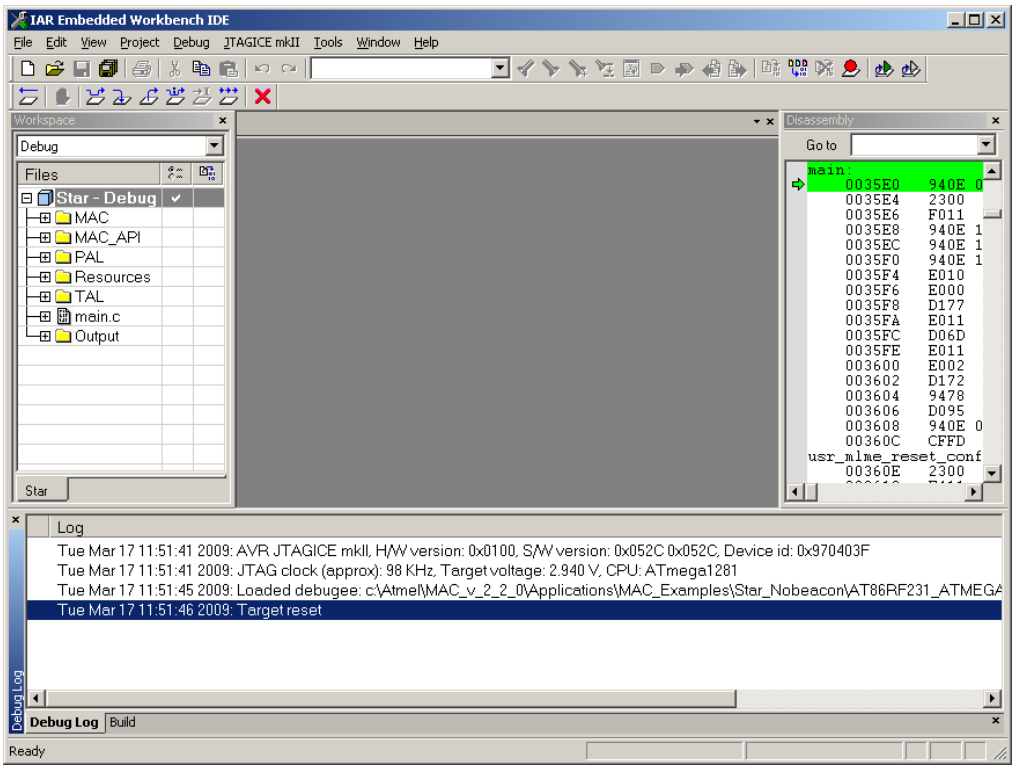
- Within the “JTAGICE mkII 2” tab check the items as shown in Figure 8-. Especially make sure that the EEPROM will be preserved if the device is reprogrammed
- Press “OK”
- Press the button “Download and Debug”

Figure 8-31. IAR Embedded Workbench – start “Download and Debug”.



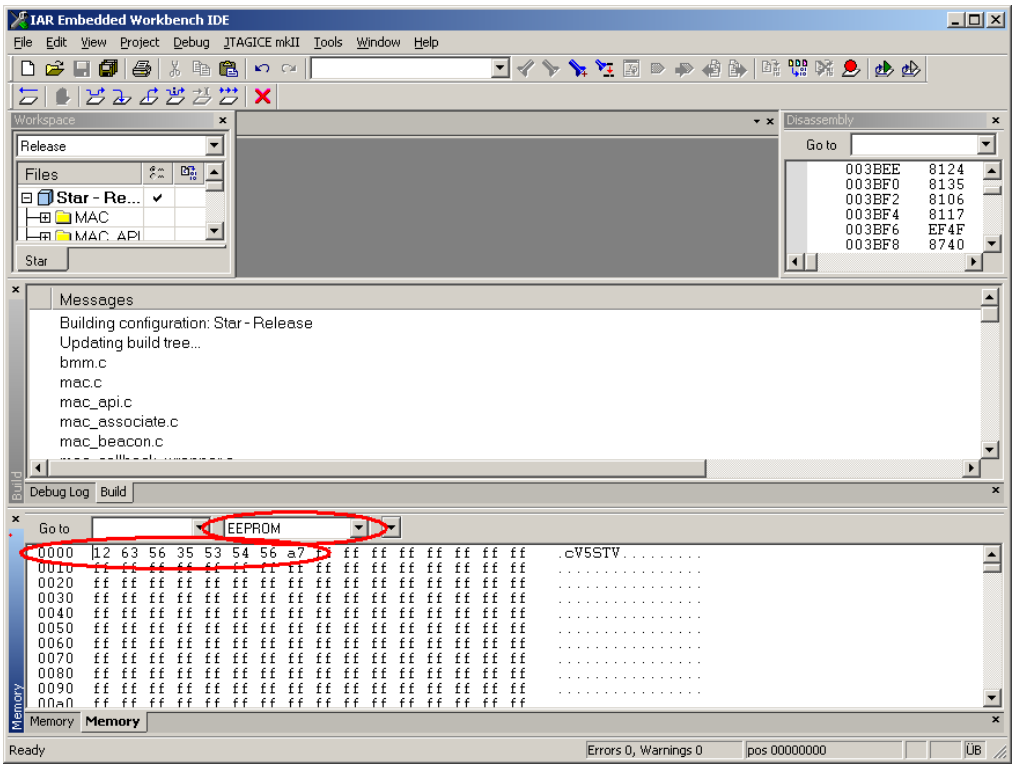
- A Window will pop-up indicating the status of the download of the binary
- After successful download the IAR Workbench will looks as shown in Figure 8-. After the download of the debug build the main function is displayed since all debug and source code information is included in the build

Figure 8-32. IAR Embedded Workbench – successful download of debug build.



- In case the IEEE address of the node is stored in the internal EEPROM of the microcontroller perform as follows (only for 8-bit IAR):
    - Check whether a valid IEEE address (different from 0xFFFFFFFFFFFFFFFF and 0x0000000000000000) is stored in the internal EEPROM. Select menu “View” item “Memory”. In this window select “EEPROM”
    - If the IEEE address is not set properly, add the correct IEEE to the first eight octets of the EEPROM

Figure 8-33. IAR Embedded Workbench – verifying and setting of IEEE address.



- Start the application by pressing the “F5” or the “Go” button

8.3.5 Using IAR AVR 32 Embedded Workbench

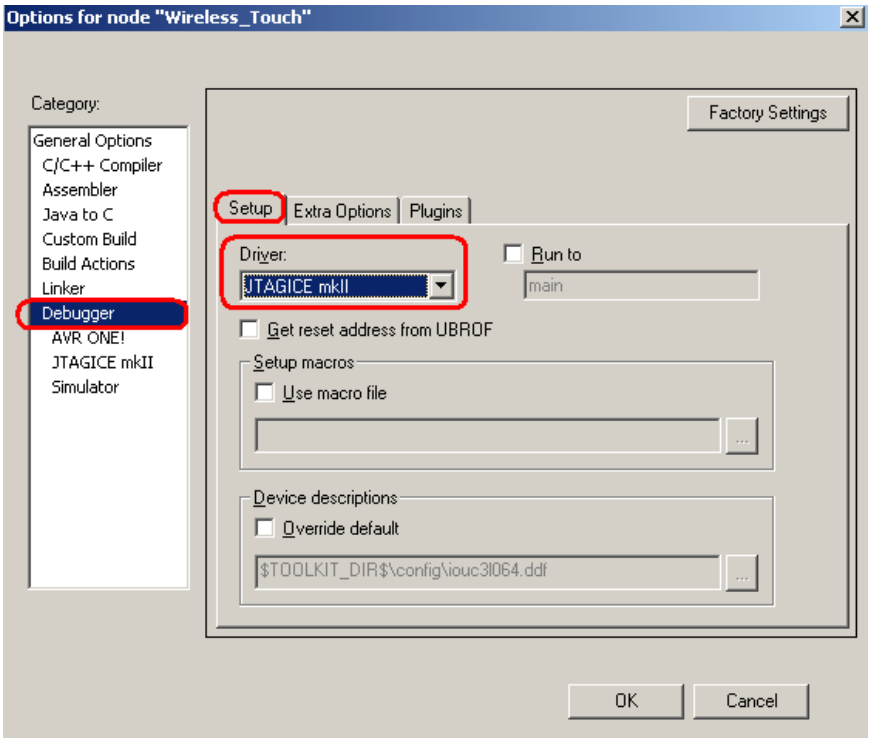
When using IAR AVR32 Embedded Workbench directly by double clicking the corresponding eww-file, the application can be downloaded onto the desired hardware platform as described below.

8.3.5.1 Starting the release build

The release build can simply be started as follows:

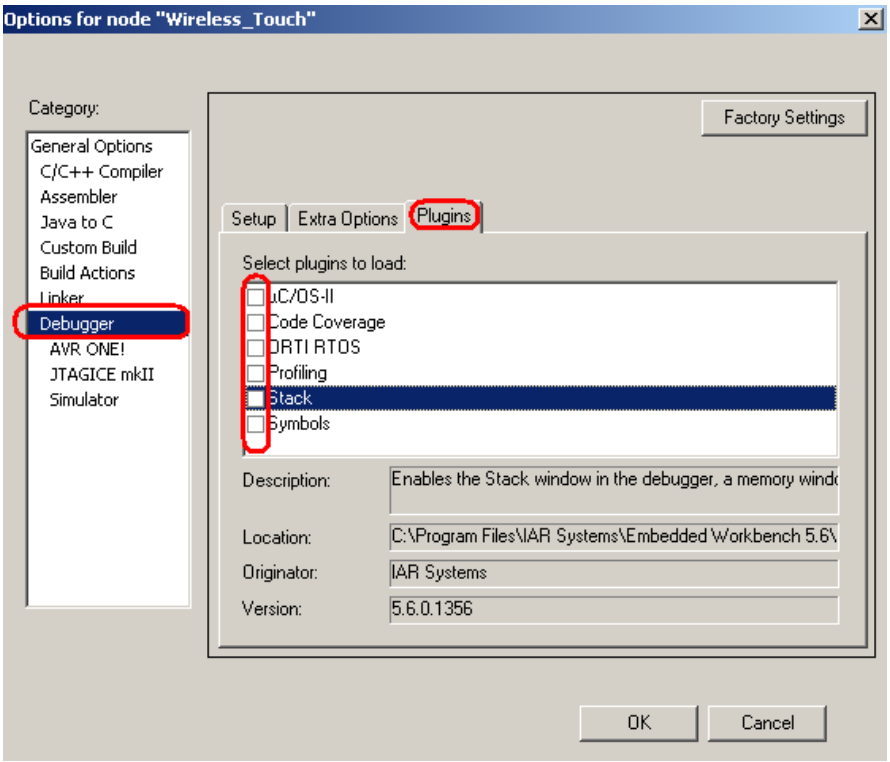
- Make sure that only the Atmel AVR JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Embedded Workbench by double clicking the desired eww-file
- Select the “Release” Workspace
- Open the “Options” window for the “Release” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-34. IAR AVR32 Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and deselect “Run to (main)”
- Change to the “Plugins” tab and deselect all entries

Figure 8-35. IAR AVR32 Embedded Workbench – “Options” -> “Debugger” -> Plugins”.



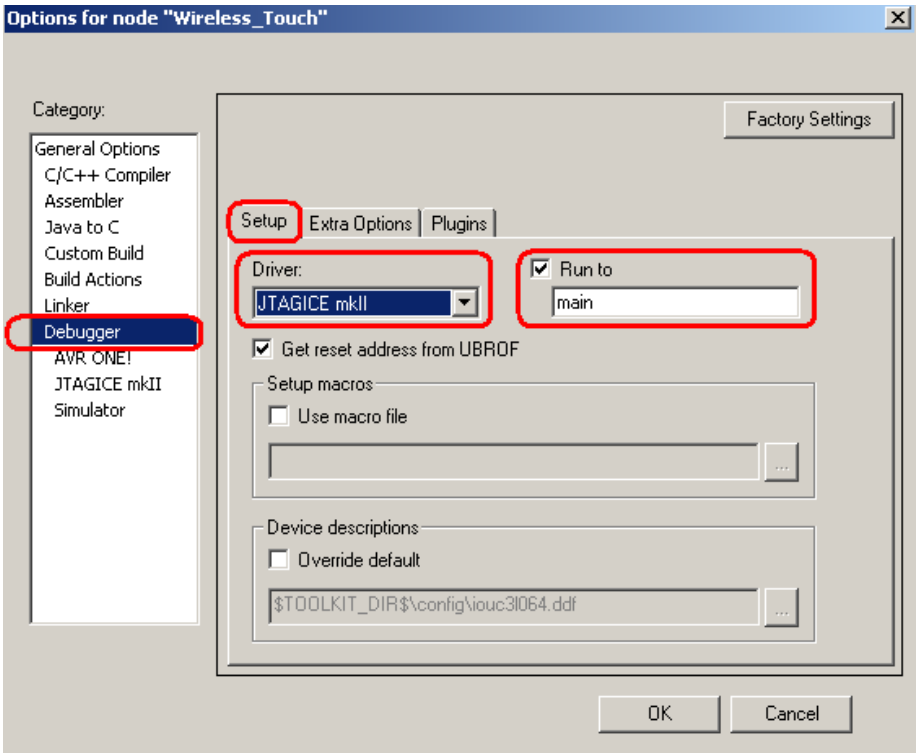
- Press “OK”
- Press the button “Download and Debug”

8.3.5.2 Starting the debug build

The debug build can simply be started as follows:

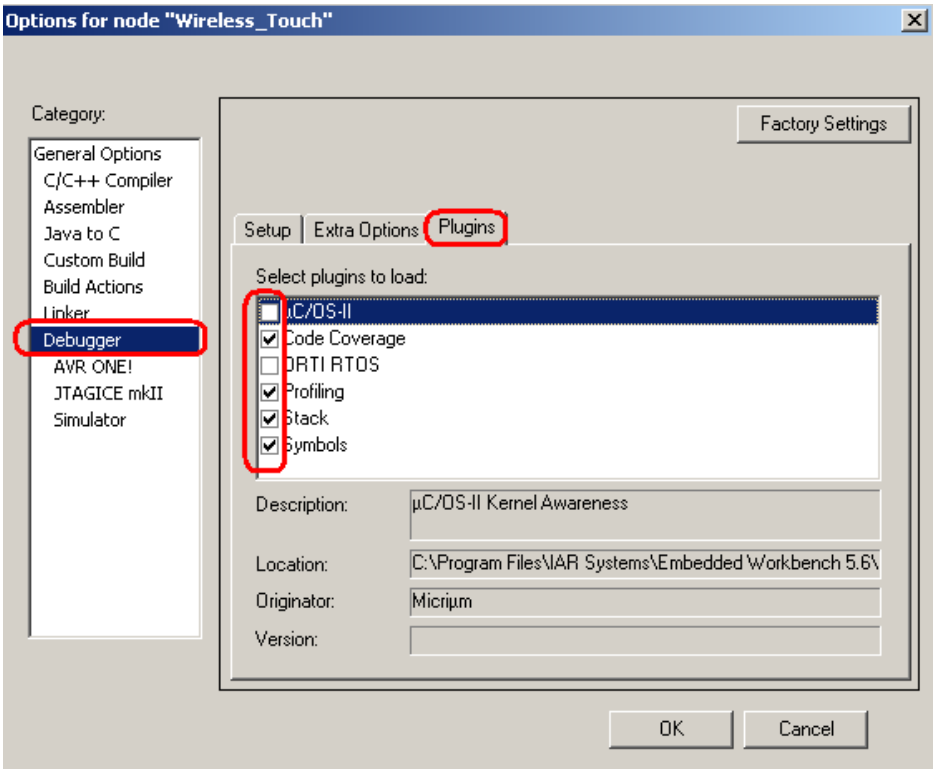
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Embedded Workbench by double clicking the desired eww-file
- Select the “Debug” Workspace
- Open the “Options” window for the “Debug” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-36. IAR AVR32 Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



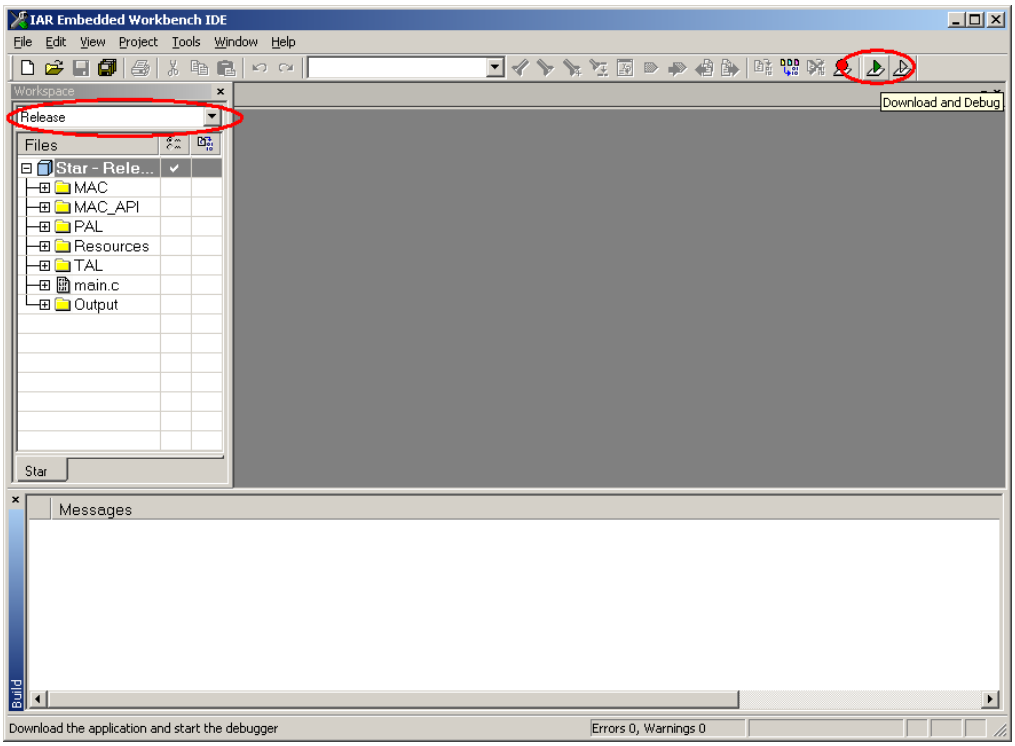
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and select “Run to (main)” (this is different to “Release” build)
- Change to the “Plugins” tab and select the entries as shown in Figure 8-

Figure 8-37. IAR AVR32 Embedded Workbench – “Options” -> “Debugger” -> “Plugins”.



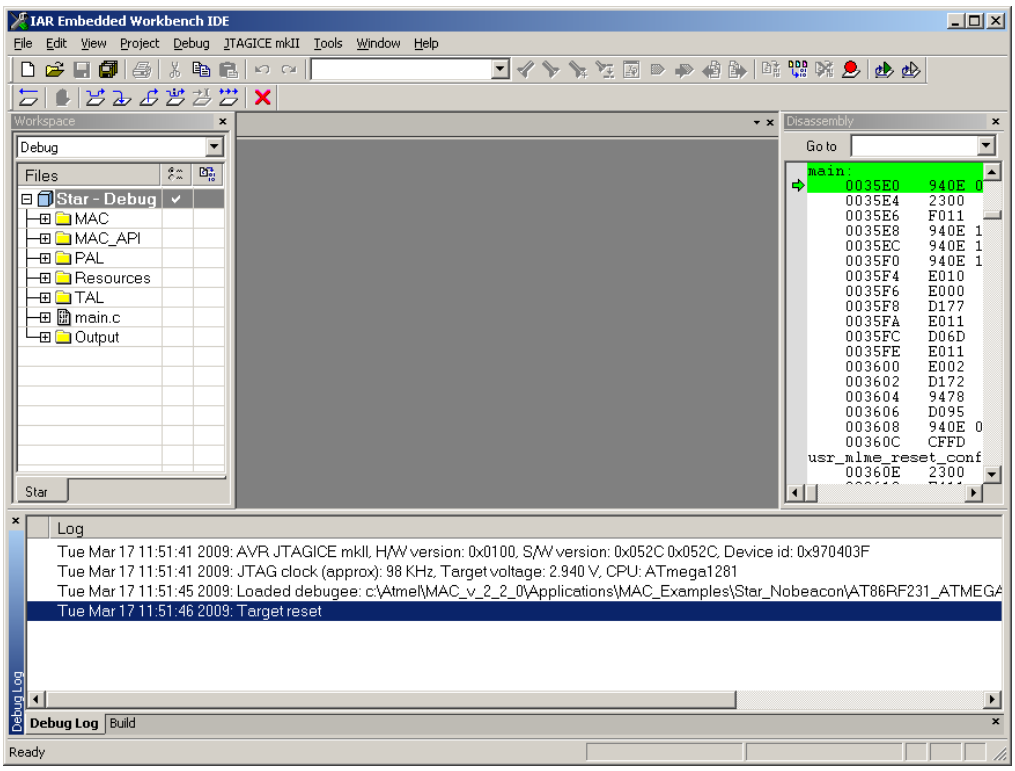
- Press “OK”
- Press the button “Download and Debug”

Figure 8-38. IAR AVR32 Embedded Workbench – start “Download and Debug”.



- A Window will pop up indicating the status of the download of the binary
- After successful download the IAR AVR32 Workbench will looks as shown in Figure 8-. After the download of the debug build the main function is displayed since all debug and source code information is included in the build

Figure 8-39. IAR AVR32 Embedded Workbench – successful download of debug build.



- Start the application by pressing the “F5” or the “Go” button

8.3.6 Using AVR32 GCC commandline programming

The application can be downloaded using GNU utility avr32program.Change to the directory where the Makefile for the application is located, for example:

cd Applications\TAL_Examples\Performance_Test_EVK

cd AT86RF212_AT32UC3L064_RZ600_UC3LEK

cd GCC

Download the project using the following command

- For AT32UC3L064:

avr32program.exe -p jtagicemkii --part UC3L064 program -finternal@0x80000000 -eu --run -R -cint *.elf

- For AT32UC3A3256S:

avr32program.exe -p jtagicemkii --part UC3A3256S program -finternal@0x80000000 -e -r -v -R *.elf

- For AT32UC3B1128:

avr32program.exe -p jtagicemkii --part UC3B1128 program -finternal@0x80000000 -eu --run -R -cint *.elf

8.3.7 Using IAR ARM Embedded Workbench

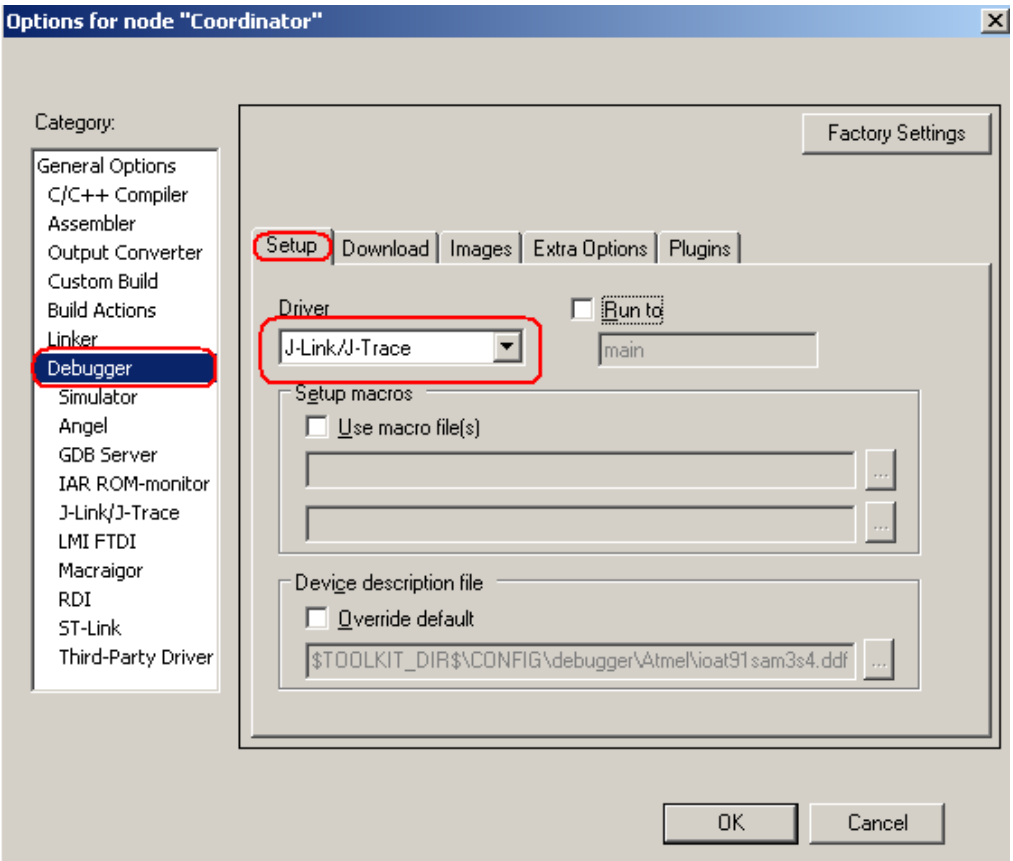
When using IAR ARM Embedded Workbench directly by double clicking the corresponding eww-file, the application can be downloaded onto the desired hardware platform as described below.

8.3.7.1 Starting the release build

The release build can simply be started as follows:

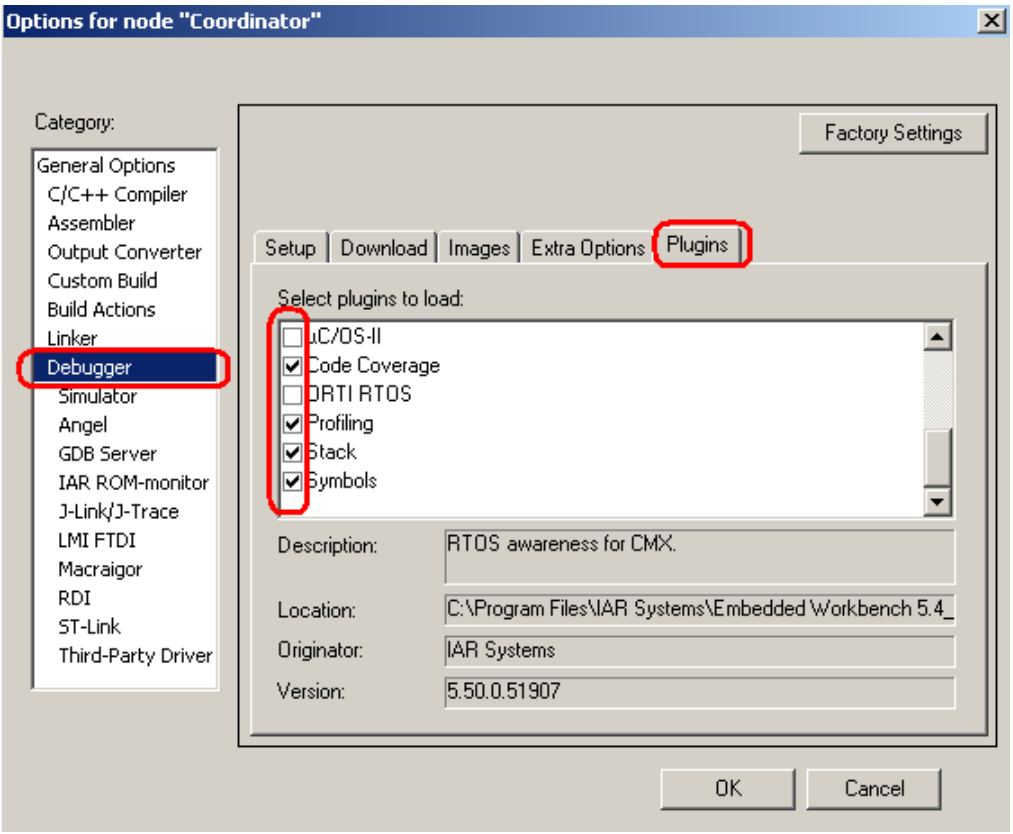
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Embedded Workbench by double clicking the desired eww-file
- Select the “Release” Workspace
- Open the “Options” window for the “Release” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-40. IAR ARM Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



- Within the “Setup” tab select the “Driver” “J-Link/J-Trace” and deselect “Run to (main)”
- Change to the “Plugins” tab and deselect all entries

Figure 8-41. IAR ARM Embedded Workbench – “Options” -> “Debugger” -> “Plugins”.



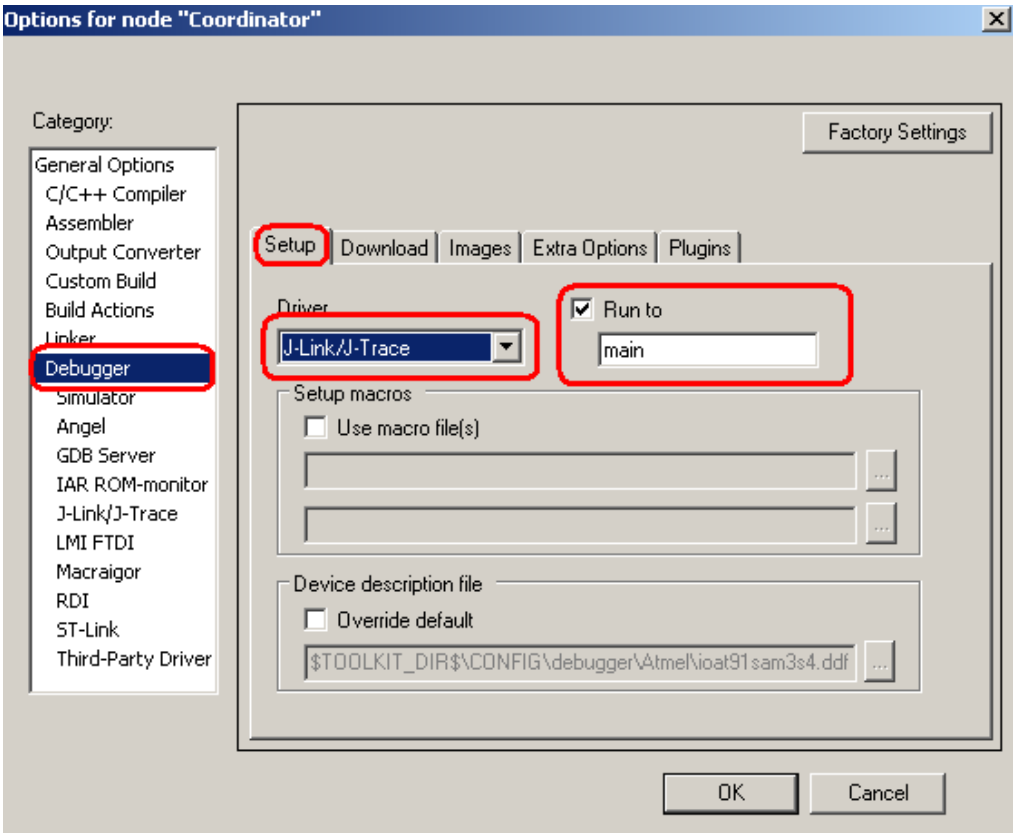
- Press “OK”
- Press the button “Download and Debug”

8.3.7.2 Starting the debug build

The debug build can simply be started as follows:

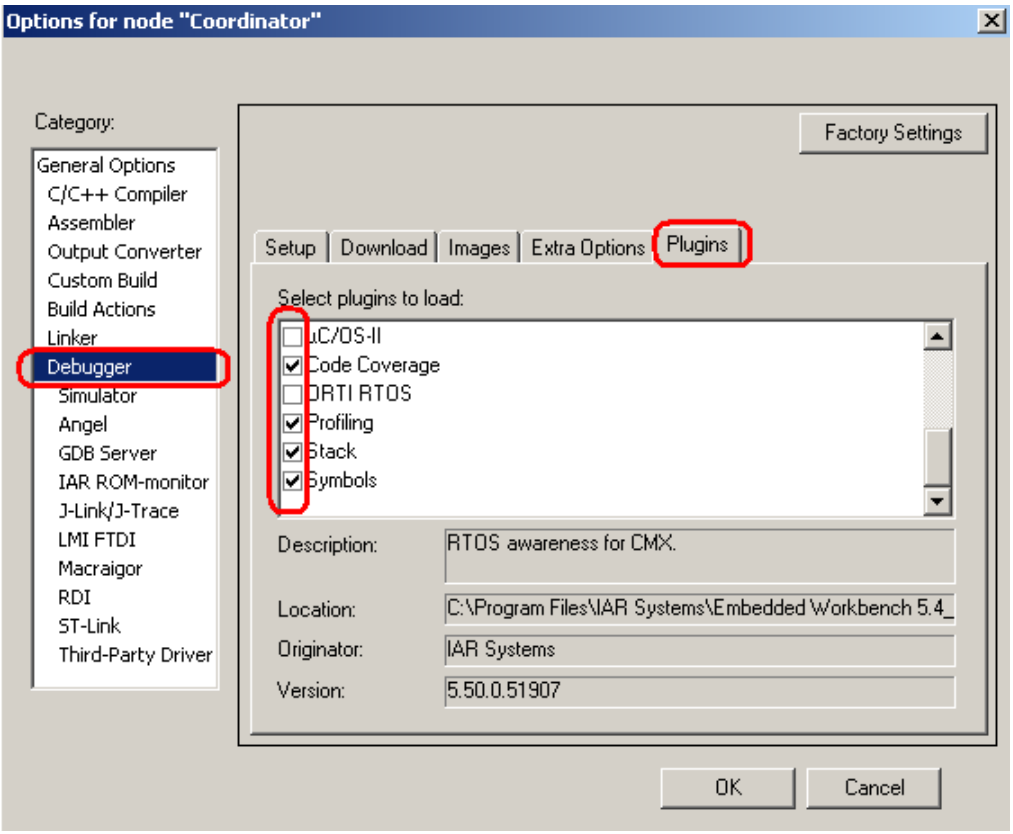
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE
- Open IAR Embedded Workbench by double clicking the desired eww-file
- Select the “Debug” Workspace
- Open the “Options” window for the “Debug” Workspace. Select the “Debugger” window and within this window select the “Setup” tab

Figure 8-42. IAR ARM Embedded Workbench – “Options” -> “Debugger” -> “Setup”.



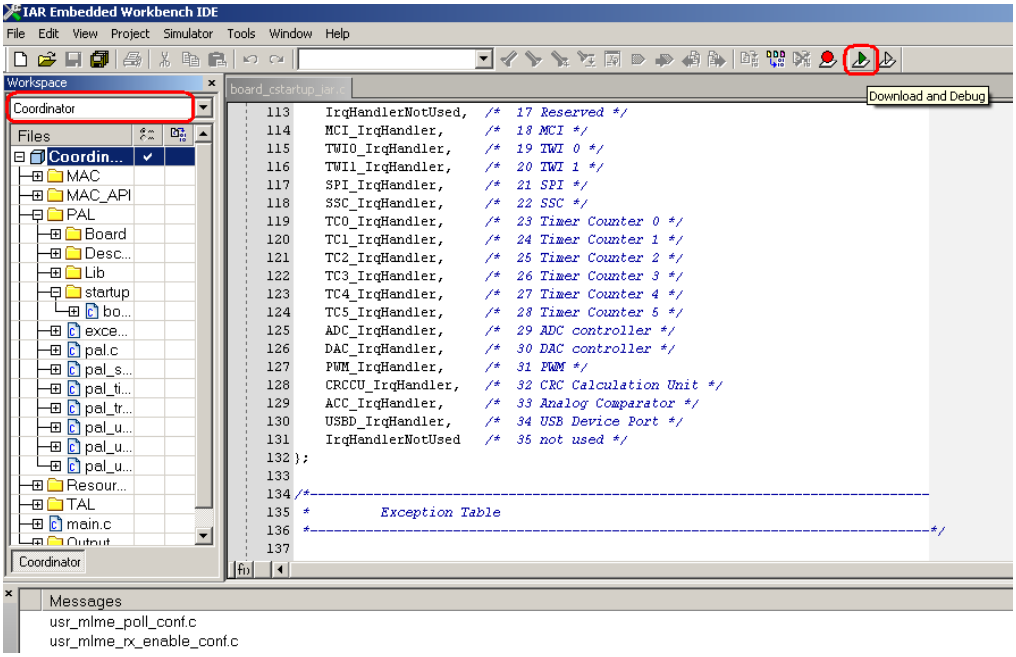
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and select “Run to (main)” (this is different to “Release” build)
- Change to the “Plugins” tab and select the entries as shown in Figure 8-

Figure 8-43. IAR ARM Embedded Workbench – “Options” -> “Debugger” -> “Plugins”.



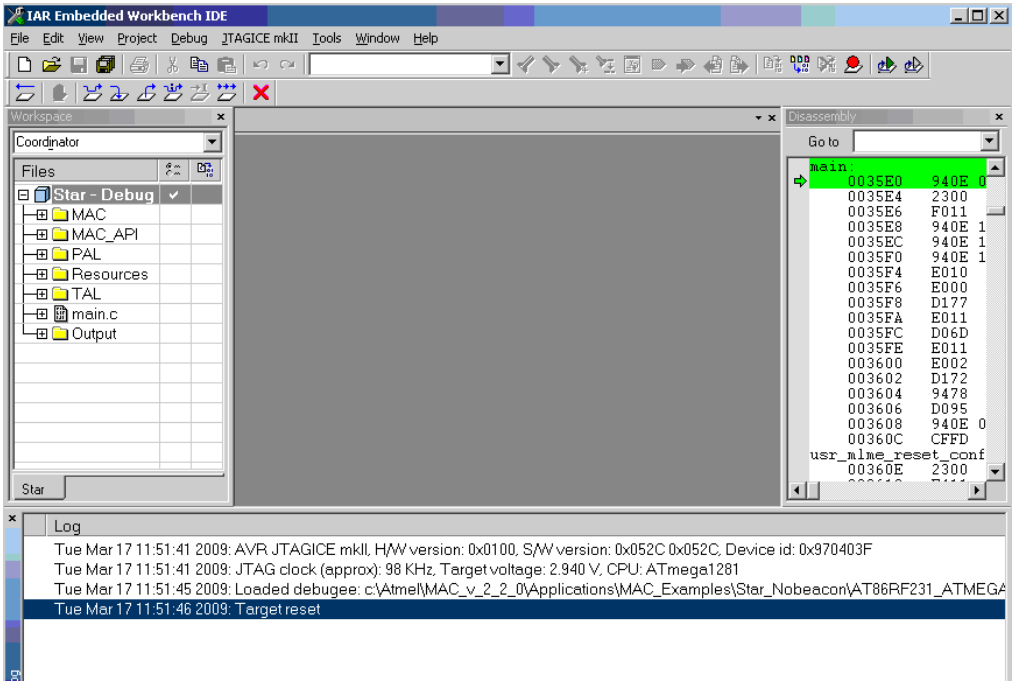
- Press “OK”
- Press the button “Download and Debug”

Figure 8-44. IAR ARM Embedded Workbench – start “Download and Debug”.



- A Window will pop-up indicating the status of the download of the binary
- After successful download the IAR ARM Workbench will looks as shown in Figure 8-5. After the download of the debug build the main function is displayed since all debug and source code information is included in the build

Figure 8-45. IAR ARM Embedded Workbench – successful download of debug build.



- Start the application by pressing the “F5” or the “Go” button

8.3.8 Using Atmel SAM-BA – programming for Atmel SAM3S devices

The application can be downloaded using SAM-BA® software. Change to the directory where the Makefile for the application is located, for example:

cd Applications\ MAC_Examples\Promiscuous_Mode_Demo

cd AT86RF231_AT91SAM3S4C_SAM3SEK

cd GCC

The SAM Boot Assistant (SAM-BA) software provides a means of easily programming different Atmel AT91SAM devices. They are based on a common dynamic linked library (DLL), the SAMBA_DLL.DLL. It is used by SAM-BA tool. SAM-BA now use the DLL to communicate with the target. SAM-PROG™ will remain available in the at91isp v1.13. User who still wants SAM-PROG can download AT91-ISP v1.13.

The user can connect through J-Link/ARM0 if SAM-BA is used or The user can connect to the port as it is detected in the system if SAM-BA CDC is used (Note: The user has to make sure that the device is running in bootloader mode). Select the type of device and then click connect. This is explained in detail in Figure 8-.

Once the device gets connected successfully with the SAM-BA tool, the user has to follow the steps below to enable flash access and to erase the flash and for

downloading the file, the user has to browse for the executable file and then click send file to write into the flash. This is explained in detail in Figure 8-.

Figure 8-46. Atmel SAM-BA – using J-Link Atmel SAM-ICE™.

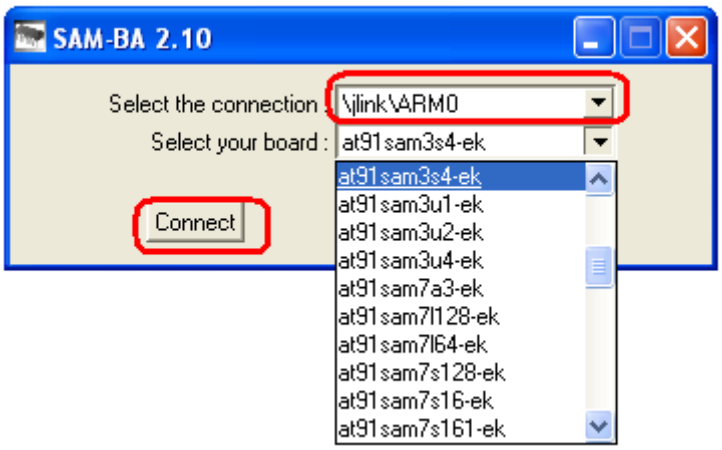


Figure 8-47. SAM-BA – using comport.

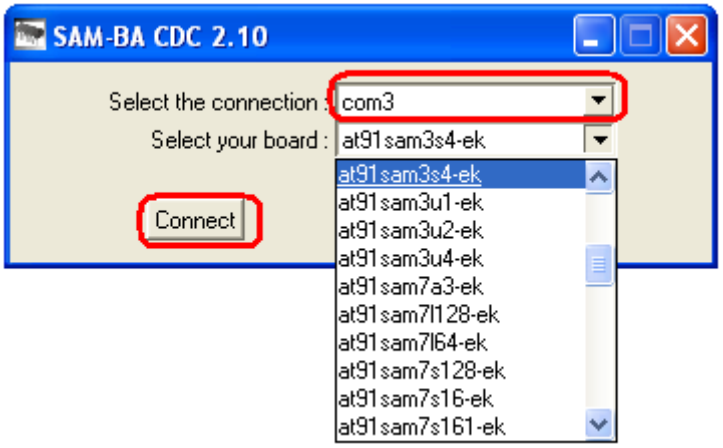


Figure 8-48. Atmel SAM-BA – enabling flash access.

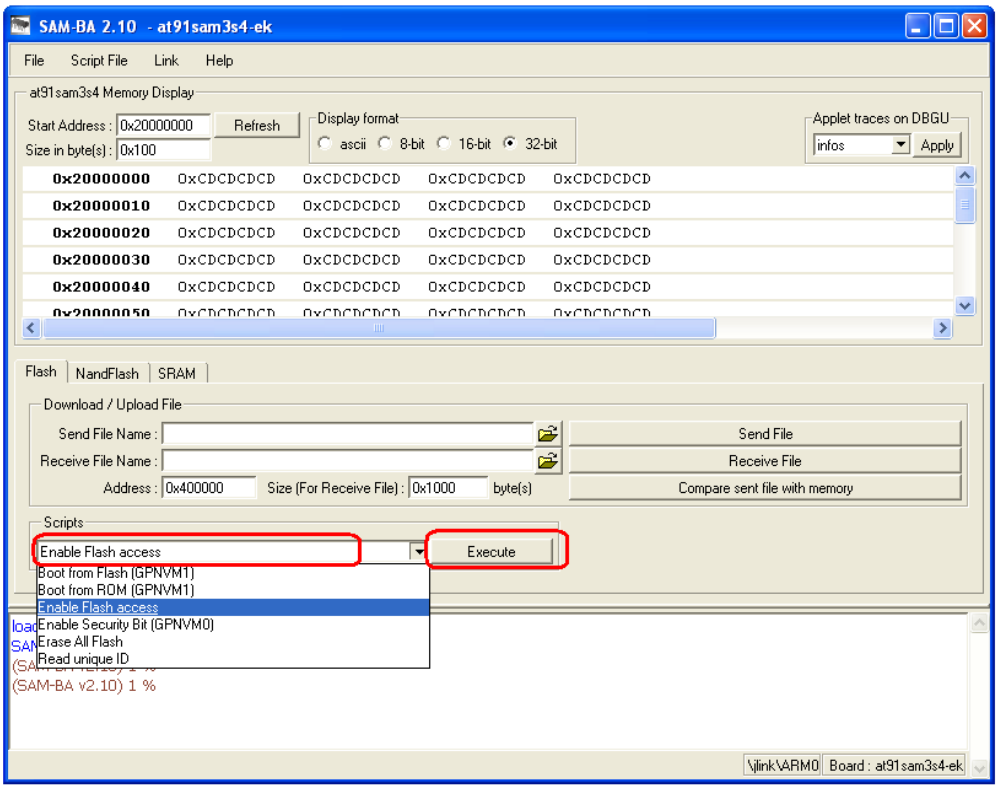
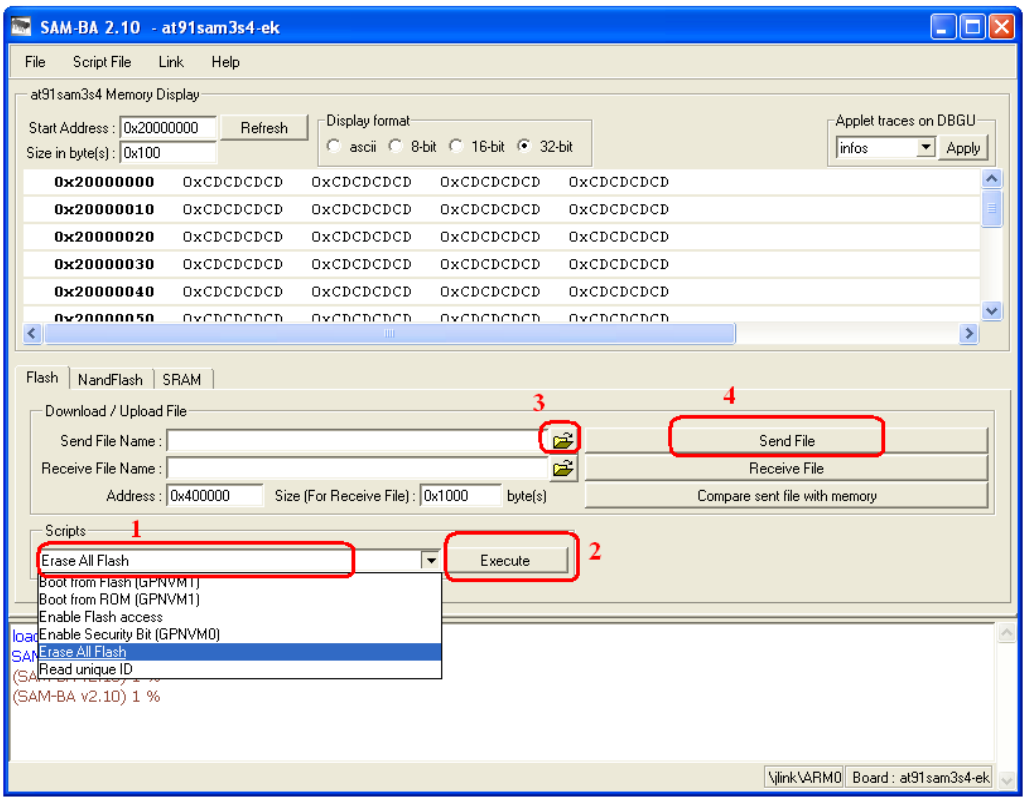


Figure 8-49. Atmel SAM-BA – downloading executable file.



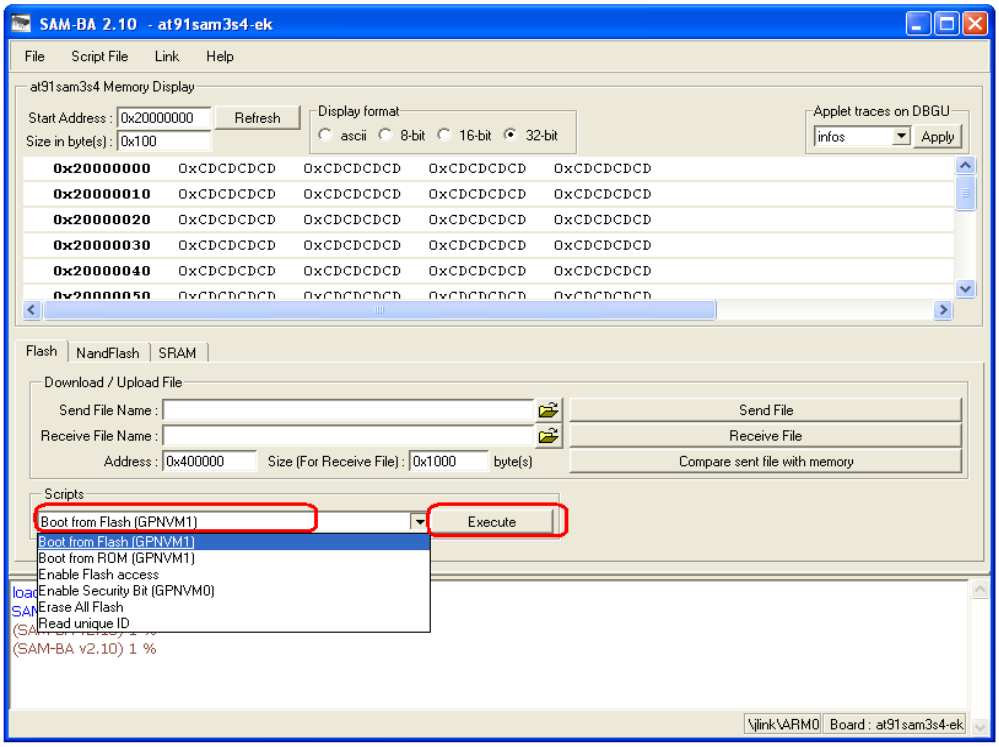
Step 1: Select the Erase All Flash before option

Step 2: Select Execute in order to erase the entire flash contents

Step 3: Browse for the executable file which is to be flashed

Step 4: Select the send file in order to flash the executable file

Figure 8-50. Atmel SAM-BA – boot from flash.



9 Example applications

The MAC package includes a variety of example applications which can be flashed on the supported hardware platforms and be executed immediately. On the other hand the complete source code is provided to help the application developer to more easily understand the proper utilization of the stack and to be able to build its own applications as fast as possible.

The provided example applications can categorized in three main groups (being located in the corresponding subdirectories of directory Applications):

- MAC examples
- TAL examples
- STB examples

These applications will be explained in more detail in the subsequent sections (see Section 9.2). If the example application makes use of the UART interface, the UART is set to 9600 (8,N,1).

9.1 Walking through a basic application

This section describes one basic example application provided with this MAC release (see Section 9.2.1.1) more thoroughly to allow better understanding of all other examples. The example serves as a first introduction on how to control the MAC-API and how to start an 802.15.4 compliant network. It can be used by a developer as a starting point for further designs. The example implements a network with star topology.

There are two types of nodes in the network: PAN Coordinator and device. A PAN Coordinator can be understood as the central hub of a network. It handles association requests from devices and assigns a short address if appropriate.

In this example, the PAN Coordinator does not initiate any data transmissions; it receives data from the associated devices. The usr_mcps_data_ind() callback function is provided only as stub and can be extended by user.

The Devices scan all channels for the PAN Coordinator. If the Coordinator with the default PAN ID is located on the default channel (that is, channel 20), the Device will initiate the association procedure. If the association is also successful, the Device periodically (that is, every two seconds) sends out a data packet to the Coordinator. The data packets contain a random payload. As already mentioned earlier, this example can be extended by the user.

The following sections describe the application code in more detail.

9.1.1 Implementation of the coordinator

The source code of the coordinator is located in:

Applications/MAC_Examples/App_1_Nobeacon_Application/Coordinator/Src/main.c

and the header file in:

Applications/MAC_Examples/App_1_Nobeacon_Application/Coordinator/Inc/app_config.h

Platform related project / Makefiles for GCC (AVR, AVR32, and ARM), AVR Studio, and IAR Workbench are located in the corresponding subdirectories

Applications/MAC_Examples/App_1_Nobeacon_Application/Coordinator/<platform>

The example application can be opened using the Atmel AVR Studio, the IAR EWW or any other editor. To open the example application project from the AVR Studio select the file "Coordinator.aps" or from the IAR EWW select the file "Coordinator.eww". If the AVR Studio is used, the source code can be compiled from the menu "Build" -> "Rebuild All". If the IAR EWW is used, the source code can be compiled from the menu "Project" -> "Rebuild All".

The main function of the coordinator performs the following steps:

Initialize the MAC layer and its underlying layers, like PAL, TAL, BMM:

```
if (wpan_init() != SUCCESS)
{
    /*
     * Stay here; we need a valid IEEE address.
     * Check kit documentation how to create an IEEE address
     * and store it to the EEPROM
     */
    pal_alert();
}
```

Calibrate MCU's RC oscillator:

```
pal_calibrate_rc_osc();
```

Initialize LEDs:

```
pal_led_init();
pal_led(LED_0, LED_ON);    // indicating application is started
pal_led(LED_1, LED_OFF);   // indicating network is started
pal_led(LED_2, LED_OFF);   // indicating data reception
```

Enable the global interrupts:

```
pal_global_irq_enable();
```

Initiate a reset of the MAC layer:

```
wpan_mlme_reset_req(true);
```

Run the main loop:

```
while (1)
{
    wpan_task();
}
```

Once the main loop is running the MAC layer will execute the previously requested reset and call the implementation of usr_mlme_reset_conf() callback function. Depending on the returned status information the program continues either with the request to set the short address of the coordinator or with a new reset request.

```
void usr_mlme_reset_conf(uint8_t status)
{
    if (status == MAC_SUCCESS)
    {
        /*
         * Set the short address of this node.
         */
```

```
        uint8_t short_addr[2];

        short_addr[0] = (uint8_t)COORD_SHORT_ADDR;
        short_addr[1] = (uint8_t)(COORD_SHORT_ADDR >> 8);
        wpan_mlme_set_req(macShortAddress, short_addr);
    }
    else
    {
        // something went wrong; restart
        wpan_mlme_reset_req(true);
    }
}
```

The request to set the short address of the coordinator will be processed once the control flow of the application enters the main loop again. The MAC layer will call the implementation of usr_mlme_set_conf():

```
void usr_mlme_set_conf(uint8_t status, uint8_t PIBAttribute)
{
    if ((status == MAC_SUCCESS) && (PIBAttribute ==
macShortAddress))
    {
        //*
        //* Allow other devices to associate to this coordinator.
        //*/
         uint8_t association_permit = true;

         wpan_mlme_set_req(macAssociationPermit,
                           &association_permit);
    }
    else if ((status == MAC_SUCCESS) &&
             (PIBAttribute == macAssociationPermit))
    {
        //*
        //* Initialize an active scan over all channels to
determine
        //* which channel to use.
        //*/
        wpan_mlme_scan_req(MLME_SCAN_TYPE_ACTIVE,
                           SCAN_ALL_CHANNELS,
                           SCAN_DURATION_COORDINATOR);
    }
    else
    {
        // something went wrong; restart
        wpan_mlme_reset_req(true);
    }
}
```

Depending on the status information, the application will proceed either with the request to set the association permit PIB attribute (see macAssociationPermit for further details).

The MAC layer will process the request and executes the function usr_mlme_set_conf().

Now the PIBAttribute parameter is equal to macAssociationPermit and the scan procedure will be initiated with wpan_mlme_scan_req(). Next time the main loop is running this request is processed by the MAC layer and the usr_mlme_scan_conf() callback function will be called with the result of the scan.

After the scan procedure has finished, a new network is started by invoking the function wpan_mlme_start_req().

```
void usr_mlme_scan_conf(uint8_t status,
                        uint8_t ScanType,
                        uint8_t ChannelPage,
                        uint32_t UnscannedChannels,
                        uint8_t ResultListSize,
                        void *ResultList)
{
    /*
     * We are not interested in the actual scan result,
     * because we start our network on the pre-defined channel
     * anyway.
     * Start a nonbeacon-enabled network
     */
     wpan_mlme_start_req(DEFAULT_PAN_ID,
                         DEFAULT_CHANNEL,
                         DEFAULT_CHANNEL_PAGE,
                         15, 15,
                         true, false, false);
}
```

The wpan_mlme_start_req() will be confirmed with usr_mlme_start_conf().

```
void usr_mlme_start_conf(uint8_t status)
{
    if (status == MAC_SUCCESS)
    {
        /*
         * Network is established.
         * Waiting for association indication from a device.
         */
         pal_led(LED_1, LED_ON);
    }
    else
    {
        // something went wrong; restart
        wpan_mlme_reset_req(true);
```

```
    }
}
```

The PAN Coordinator is waiting for devices to associate. If a device initiates the association procedure, the Coordinator's MAC layer indicates this with the callback function usr_mlme_associate_ind(). The coordinator either responds with a short address for this device passed to wpan_mlme_associate_resp() or denies the request with the error code PAN_AT_CAPACITY. The function get_next_short_addr() is an application specific implementation and checks if an association request is accepted or not.

```
void usr_mlme_associate_ind(uint64_t DeviceAddress,
                            uint8_t CapabilityInformation)
{
    /*
     * Any device is allowed to join the network.
     *
     * Get the next available short address for this device.
     */
    uint16_t associate_short_addr = macShortAddress_def;

    if (get_next_short_addr(DeviceAddress,
                            &associate_short_addr) == true)
    {
        wpan_mlme_associate_resp(DeviceAddress,
                                 associate_short_addr,
                                 ASSOCIATION_SUCCESSFUL);
    }
    else
    {
        wpan_mlme_associate_resp(DeviceAddress,
                                 associate_short_addr,
                                 PAN_AT_CAPACITY);
    }
}
```

As soon as the usr_mlme_comm_status_ind() callback function is called by the coordinator's MAC layer with status MAC_SUCCESS, the device is associated successfully with the coordinator and will periodically (that is, about every two seconds) send data to the coordinator. Received data packets are indicated by the MAC layer to the application by calling the usr_mcps_data_ind() callback function. Further handling of the received (dummy) data can be implemented by the user as desired.

9.1.2 Implementation of the device

The source code of the device is located in:

Applications/MAC_Examples/Nobeacon_Applicatoin/Device/Src/main.c

and the header file in:

Applications/MAC_Examples/Nobeacon_Application/Device/Inc/app_config.h

Platform related project/Makefiles files for AVR GCC, AVR Studio, and IAR Workbench are located in the corresponding subdirectories:

Applications/MAC_Examples/ Nobeacon/Device/<platform>

The example application can be opened using the AVR Studio, the IAR EWW or any other editor. To open the example application project from the AVR Studio select the file "Device.aps" or from the IAR EWW select the file "Device.eww". If the Atmel AVR Studio is used, the source code can be compiled from the menu "Build" -> "Rebuild All". If the IAR EWW is used, the source code can be compiled from the menu "Project" -> "Rebuild All".

The main function of the device performs the following steps:

Initialize the MAC layer and its underlying layers, like PAL, TAL, BMM:

```
if (wpan_init() != SUCCESS)
{
    /*
     * Stay here; we need a valid IEEE address.
     * Check kit documentation how to create an IEEE address
     * and store it to the EEPROM
     */
    pal_alert();
}
```

Calibrate MCU's RC oscillator:

```
pal_calibrate_rc_osc();
```

Initialize LEDs:

```
pal_led_init();
pal_led(LED_0, LED_ON);     // indicating application is
started
pal_led(LED_1, LED_OFF);    // indicating network is started
pal_led(LED_2, LED_OFF);    // indicating data reception
```

Enable the global interrupts:

```
pal_global_irq_enable();
```

Initiate a reset of the MAC layer:

```
wpan_mlme_reset_req(true);
```

Run the main loop:

```
while (1)
{
    wpan_task();
}
```

Once the main loop is running the MAC layer will execute the previously requested reset and call the implementation of usr_mlme_reset_conf() callback function. Depending on the returned status information the program continues either with the request to scan all channels for the coordinator or with a new reset request.

```
void usr_mlme_reset_conf(uint8_t status)
{
    if (status == MAC_SUCCESS)
```

```
        {
            /*
             * Initiate an active scan over all channels to determine
             * which channel is used by the coordinator.
             */
            wpan_mlme_scan_req(MLME_SCAN_TYPE_ACTIVE,
                               SCAN_ALL_CHANNELS,
                               SCAN_DURATION_SHORT,
                               DEFAULT_CHANNEL_PAGE);

            // Indicate network scanning by a LED flashing
            pal_timer_start(TIMER_LED_OFF,
                            500000,
                            TIMEOUT_RELATIVE,
                            (void *)network_search_indication_cb,
                            NULL);
        }
        else
        {
            // something went wrong; restart
            wpan_mlme_reset_req(true);
        }
    }
```

Once the main loop is running this request is processed by the MAC layer and the usr_mlme_scan_conf() callback function is called with the result of the scan. The usr_mlme_scan_conf() function handles three cases:

- A coordinator was found
- No coordinator was found

```
    coordinator = (wpan_pandescriptor_t *)ResultList;
    for (i = 0; i < ResultListSize; i++)
    {
        /*
         * Check if the PAN descriptor belongs to our coordinator.
         * Check if coordinator allows association.
         */
        if ((coordinator->LogicalChannel == DEFAULT_CHANNEL) &&
            (coordinator->ChannelPage == DEFAULT_CHANNEL_PAGE) &&
            (coordinator->CoordAddrSpec.PANId == DEFAULT_PAN_ID) &&
            ((coordinator->SuperframeSpec & 0x8000) == 0x8000))
            // association permit
        {
            // Store the coordinator's address
            if (coordinator->CoordAddrSpec.AddrMode ==
                WPAN_ADDRMODE_SHORT)
            {
                coord_addr.short_addr =
```

```
                (uint16_t)(coordinator->CoordAddrSpec.Addr);
            }
            else if (coordinator->CoordAddrSpec.AddrMode ==
                     WPAN_ADDRMODE_LONG)
            {
                coord_addr.ieee_addr = coordinator->CoordAddrSpec.Addr;
            }
            else
            {
                // Something went wrong; restart
                wpan_mlme_reset_req(true);
                return;
            }

            /*
             * Associate to our coordinator
             */
            wpan_mlme_associate_req(coordinator->LogicalChannel,
                                    coordinator->ChannelPage,
                                    &(coordinator->CoordAddrSpec),
                                    WPAN_CAP_ALLOCADDRESS);
            return;
        }

        // Get the next PAN descriptor
        coordinator++;
    }
```

If the pre-configured coordinator is part of the scan result list, the device's application issues an association request to the coordinator. The association procedure is finished once the callback usr_mlme_associate_conf() is invoked and the corresponding status information is checked.

```
void usr_mlme_associate_conf(uint16_t AssocShortAddress,
                             uint8_t status)
{
    if (status == MAC_SUCCESS)
    {
        // Store own short address
        own_short_addr = AssocShortAddress;

        // Stop timer used for search indication
        // (same as used for data transmission)
        pal_timer_stop(TIMER_LED_OFF);
        pal_led(LED_1, LED_ON);

        // Start a timer that sends some data to the coordinator
        // every 2 seconds.
```

```
            pal_timer_start(TIMER_TX_DATA,
                            DATA_TX_PERIOD,
                            TIMEOUT_RELATIVE,
                            (void *)app_timer_cb,
                            NULL);
        }
        else
        {
            // Something went wrong; restart
            wpan_mlme_reset_req(true);
        }
    }
```

If MAC_SUCCESS is returned, the coordinator has assigned a short address to this device and the application is ready for data transmissions. An application timer is started with two seconds timeout. If the timer triggers, the following callback function is executed. It initiates the data transmission and restarts the timer again.

```
    static void app_timer_cb(void *parameter)
    {
        /*
         * Send some data and restart timer.
         */
        uint8_t src_addr_mode;
        wpan_addr_spec_t dst_addr;
        uint8_t payload;
        static uint8_t msduHandle = 0;

        src_addr_mode = WPAN_ADDRMODE_SHORT;

        dst_addr.AddrMode = WPAN_ADDRMODE_SHORT;
        dst_addr.PANId = DEFAULT_PAN_ID;
        dst_addr.Addr = coord_addr.short_addr;

        payload = (uint8_t)rand();  // any dummy data
        msduHandle++;               // increment handle
        wpan_mcps_data_req(src_addr_mode,
                           &dst_addr,
                           1,
                           &payload,
                           msduHandle,
                           WPAN_TXOPT_ACK);

        pal_timer_start(TIMER_TX_DATA,
                        DATA_TX_PERIOD,
                        TIMEOUT_RELATIVE,
                        (void *)app_timer_cb,
                         NULL);
```

```
}
```

The usr_mcps_data_conf() callback function is a stub indicating the status of the data transmission. It can be adapted to the user's needs.

```
void usr_mcps_data_conf(uint8_t msduHandle,
                        uint8_t status,
                        uint32_t Timestamp)
{
    if (status == MAC_SUCCESS)
    {
        /*
         * Dummy data has been transmitted successfully.
         * Application code could be added here ...
         */
        pal_led(LED_2, LED_ON);
        // Start a timer switching off the LED
        pal_timer_start(TIMER_LED_OFF,
                        500000,
                        TIMEOUT_RELATIVE,
                        (void *)data_exchange_led_off_cb,
                        NULL);
    }
}
```

9.2 Provided examples applications

9.2.1 MAC examples

9.2.1.1 Nobeacon_Application

9.2.1.1.1 Introduction

The basic MAC Example Nobeacon Application deploys a non-beacon enabled network consisting of PAN Coordinator and Device utilizing the mechanism of indirect data transfer between Coordinator and Device.

In this example the Coordinator wants to send data to the Device and since a Device in a non-beacon enabled network is in sleep mode as default, direct transmission to the Device is not possible.

In order to enable communication with the Device, indirect data transmission using polling by the device is applied. For further explanation of indirect transmission see section 4.4.1/4.4.2. For power management and indirect transmission see Section 5.2.4.

After the Device receives the data from the Indirect_Data_Queue from the Coordinator,the Device sends back the data received from the Coordinator to the Coordinator itself by direct data transmission

This example application uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Nobeacon_Application. The source code of the

application can be found in the subdirectories Coordinator/Src or Device/Src. The common source code for handling Serial I/O can be found in the subdirectory Src.

9.2.1.1.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes.

For further status information this application requires a serial connection. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin.

9.2.1.1.3 Implementation

The PAN Coordinator starts a PAN at channel DEFAULT_CHANNEL with the PAN ID DEFAULT_PAN_ID. The Device scans for this network and associates to the PAN Coordinator.

Once the device is associated, it uses a timer that fires every 5 seconds to poll for pending data at the coordinator by means of transmitting a data request frame to the coordinator. On the other hand the coordinator every 5 seconds queues a dummy data frame for each associated device into its Indirect-Data-Queue. If the coordinator receives a data request frame from a particular device, it transmits the pending data frame to the device. Device after receiving the data from the Coordinator sends back the data to the Coordinator itself by direct data transmission. While the device is idle (when the timer is running) the transceiver enters sleep in order to save as much power as possible.

9.2.1.1.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file *main.c* and re-built the application.
- Currently only two devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES.

9.2.1.2 Beacon_Application

9.2.1.2.1 Introduction

The basic MAC Example Beacon Application deploys a beacon enabled network consisting of PAN Coordinator and (up to 100 associated) Devices. The application shows how basic MAC features can be utilized within an application using beacon-enabled devices, such as announcement of pending broadcast data at the coordinator within beacon frames (that is, whenever the coordinator has pending broadcast data to be delivered in a beacon-enabled network it sets the Frame Pending Bit in the transmitted beacon frame) and synchronization with the coordinator and utilization of beacon payload by the coordinator. Also the Coordinator in this example wants to send data to the Device using indirect transmission. In order to enable communication with the Device, indirect data transmission using polling by the

device is applied. For further explanation of indirect transmission see Section 4.4.1 /4.4.2. For power management and indirect transmission see Section 5.2.4.

This example application uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Beacon_Application. The source code of the application can be found in the subdirectories Coordinator/Src or Device/Src.

9.2.1.2.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes.

For further status information this application requires a serial connection. Depending on the available serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin.

9.2.1.2.3 Implementation

The coordinator in this application creates a beacon-enabled network and periodically transmits beacon frames with a specific beacon payload. The beacon payload changes after a certain time period.

Each device of this application joins the beacon-enabled network by first attempting to synchronize with the coordinator to be able to receive each beacon frame. Once it has successfully synchronized with the coordinator, the device associates with the coordinator.

The connected devices wake-up whenever a new beacon frame is expected, extract the received payload of each beacon frame from its coordinator. This received payload is printed on the terminal and sent back to the coordinator by means of a direct data frame transmission to the coordinator. After successful beacon reception and data transmission, the devices enter sleep mode until the next beacon is expected.

The coordinator indicates each received data frame from each device on its terminal.

Whenever a device looses synchronization with its parent, it initiates a new synchronization attempt.

Also in this application the coordinator periodically tries to transmit broadcast data frames to all children nodes in its network. When ever broadcast frames are pending at the coordinator, it sets the Frame Pending Bit of the next beacon frame.

The connected devices wake-up whenever a new beacon frame is expected. Once it receives a beacon frame that has the Frame Pending Bit set, it remains awake until a broadcast data frame is received. After successful reception of the expected broadcast data frame the devices enter sleep mode until the next beacon is expected.

Once the device is associated, when it receives a beacon frame that has the data Frame Pending Bit set, the device sends a data request frame to the coordinator. On the other hand the coordinator every 5 seconds queues a dummy data frame for each associated device into its Indirect-Data-Queue. If the coordinator receives a data request frame from a particular device, it transmits the pending data frame to the

device. While the device is idle (when the timer is running) the transceiver enters sleep in order to save as much power as possible.

9.2.1.2.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file *main.c* and re-built the application.
- Currently 100 devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES.

9.2.1.3 Basic_Sensor_Network

9.2.1.3.1 Introduction

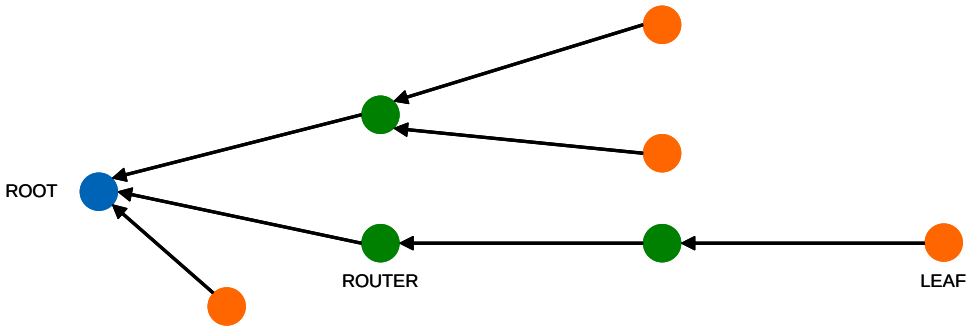
The application Basic_Sensor_Network implements a basic sensor network. The network consists of devices being sensor nodes (called LEAF), nodes (called ROUTER) that provide router functionality and a central node collecting all data (called ROOT).

The network route is a static route. The network and its routing path are configured during network setup. A tree topology is created from ROOT to LEAF nodes during the network setup. The network uses a pre-defined PAN Id (0xBEEF) and channel (1 or 20).

The sensor nodes gather their battery status and another sensor value, like temperature value. Every 10s the node transmits the gather data to its parent. All data is routed/forwarded to the ROOT node where it is printed via UART/USB to a terminal program.

An example network topology is shown in Figure 9-1.

Figure 9-1. Tree network example.



9.2.1.3.2 Implementation

This example application uses MAC-API as interface to the stack.

This application uses the user build configuration feature described in Section 6.2.2. In order to achieve the proper functionality in conjunction with minimal footprint, the actually supported MAC features (that is, MAC primitives) are defined in a

corresponding header file *mac_user_build_config.h* in subdirectory Inc of this application.

In order to use this header file, the build switch "MAC_USER_BUILD_CONFIG" needs to be set in the corresponding Makefiles or IAR project files.

The application and all required build files are located in directory Applications/MAC_Examples/Basic_Sensor_Network. The source code of the application can be found in the subdirectory Src.

9.2.1.3.3 Network setup

The static tree network topology is established by first starting the ROOT node and after that connecting one or more other nodes (ROUTER or LEAF).

The node type (ROOT, ROUTER, or LEAF) is defined during power-up using the push button. If the push button is pressed during power-up, the node is operated as a ROOT node or as a ROUTER node.

To determine that a node acts as a ROOT or ROUTER node, hold the push button pressed during power-up. If the node does not receive any broadcast messages from another node. It configures itself to a ROOT node after 10s and switches LED_0 on. If the node receives a broadcast message within the first 10s after power-up, the node stores its parent address and operates as ROUTER node.

Once the ROOT node has started the network, ROUTER nodes or LEAF nodes can be connected to the ROOT node.

Connecting a node to a parent, for example, a ROUTER node to the ROOT node, during application start broadcast messages need to be received by the child node containing the parent’s address. Broadcast messages can be sent by a ROOT or ROUTER node by pressing the button.

The next node that might be added to the network could be a LEAF node that gets connected to the ROUTER.

A node becomes a LEAF node, if the push button is not pressed during power-up. To connect a LEAF node to a parent, the parent node needs to send broadcast messages (by pressing the push button at the parent node) within the first 10s after start-up of the LEAF node.

Once a LEAF node is connected to a parent, every TX_INTERVAL_S seconds (by default every 10s) the node transmits the sensor data to its parent. An LED is switched on shortly indicating the active period.

Also ROUTER nodes can be connected to already started ROUTER nodes.

A ROUTER node forwards all received data to its parent. The ROOT node prints the received data to the UART/USB output. The ROOT and ROUTER nodes should be mains-powered devices.

9.2.1.3.4 Configuration

The current channel is coded within the application. In order to run the application on another channel, change the default channel in file *main.c* and re-built the application.

9.2.1.4 Promiscuous_Mode_Demo

9.2.1.4.1 Introduction

The application Promiscuous_Mode_Demo provides a simple network diagnostic tool based on the promiscuous mode as described in IEEE 802.15.4-2006 (Section 7.5.6.5 Promiscuous Mode). During the build process the switch PROMISCUOUS_MODE is enabled.

This tool uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Promiscuous_Mode_Demo. The source code of the application can be found in the subdirectory Src.

9.2.1.4.2 Requirements

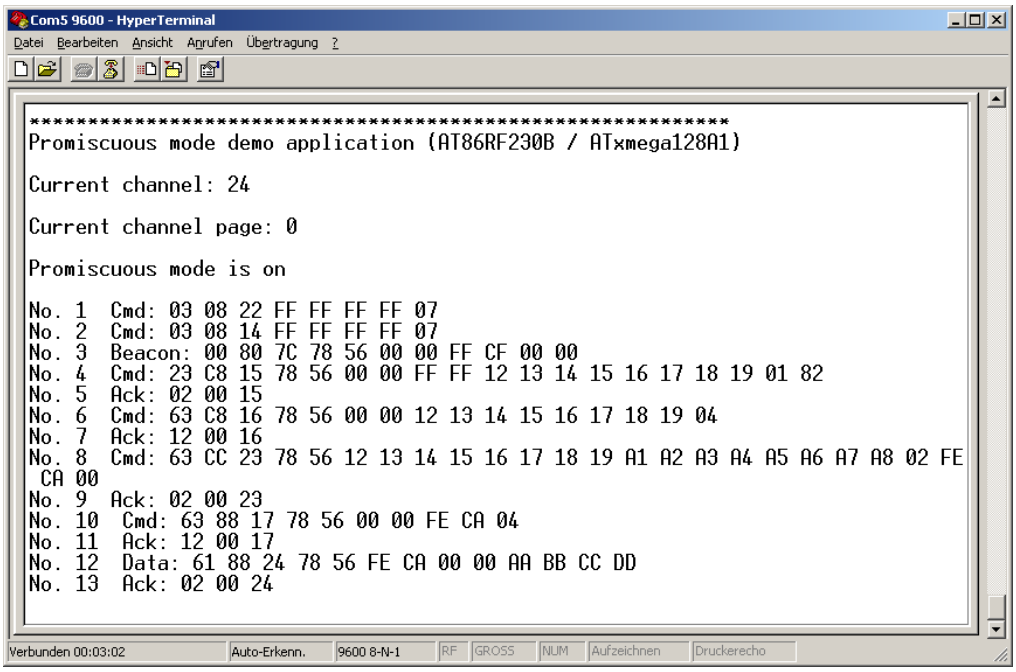
This application requires a serial connection for proper demonstration of the promiscuous mode. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin (For UC3 (32-Bit AVR) Series of devices please press any key other than “Enter Key” from the keyboard).

9.2.1.4.3 Implementation

The application works as described subsequently.

- The node performs a reset of the stack (wpan_mlme_reset_req())
- After successful processing of the reset the channel for operation can be entered by the user
- In case the build switch "HIGH_DATA_RATE_SUPPORT" is set within in the Makefiles or IAR project files, the channel page can also be entered by the user. This allows for using the application also for high rates
- Afterwards the promiscuous mode is switched on immediately
- In the serial terminal on the host system printouts indicate the detected hardware (radio and microcontroller), set channel and channel page, and the status of promiscuous mode
- Now the application will print each received frame (that has a valid CRC) on the terminal. In order to limit the load on the serial connections, currently only the following items are displayed:
    - Number of received frame
    - Type of frame
    - Content of frame (received octets in hexadecimal format), this includes the MAC Header (MHR) of the original frame and the payload within this frame
- In the application itself the received frame is already parsed so that the variable app_parse_data contains all information for the MAC header (that is, addressing information) of the received frame already in a structure of type prom_mode_payload_t

Figure 9-2. Promiscuous_Mode_Demo terminal program snapshot**.**



9.2.1.4.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application
- The processing of each received frame within the application and the corresponding serial output is the limiting factor of this application in terms of throughput
- The actual processing and output implemented within the application for each received frame should be adapted to the end user's requirements

9.2.1.5 Star_Nobeacon

9.2.1.5.1 Introduction

The application Star_Nobeacon provides a simple start network application based on IEEE 802.15.4-2006. The application uses two nodes: a PAN Coordinator (1) and an End Device (2). The firmware is implemented as such that a node can either act as a PAN Coordinator or an End Device.

This application works very similar to the MAC Example Nobeacon Application (see Section 9.2.1.1) but the same source code is used for both types of devices. The type of device is detected by the firmware during run-time.

This example application uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Star_Nobeacon. The source code of the application can be found in the subdirectory Src.

9.2.1.5.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes.

9.2.1.5.3 Implementation

The application works as described subsequently.

Node one:

- Switch on node one
- LED 0 indicates that the node has started properly
- Flashing of LED 1 indicates that the node is scanning its environment. Scanning is done three times on each available channel depending on the radio type
- If no other network with the pre-defined channel and PAN Id is found, the node establishes a new network at the pre-defined channel (channel 20 for 2.4GHz radio). This node now becomes the PAN Coordinator of this network. The successful start of a new network is indicated by switching LED 1 on

Node two:

- Switch on the other node
- LED 0 indicates that the node has started properly. Flashing of LED 1 indicates that the node is scanning its environment. Scanning is again done three times on each available channel depending on the radio type
- If a proper network is discovered, the node joins the existing network and indicates a successful association by switching on LED 1
- Every two seconds this node sends out a dummy data packet. If the packet is acknowledged by the other node the LED 2 is flashing

9.2.1.5.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application
- Currently only two devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES
- The current implementation only provides direct data transmission from device to coordinator. In order to save as much power as possible, the device periodically enters sleep mode between its data transmissions. During these sleeping periods the receiver of the device is not enabled. It is therefore not possible to simply extend the application so that direct data transmission is performed in the other direction (from coordinator to device). In case the data transmission from coordinator to device is required more changes within the application are required. For more information please see Section 4.5. An example where this scenario has been implemented by means of using the feature MAC_RX_ENABLE_SUPPORT can be found in Section 9.2.1.3 (MAC Example Basic_Sensor_Network)

9.2.1.6 Star_High_Rate

9.2.1.6.1 Introduction

The application Star_High_Rate provides a simple start network application based on IEEE 802.15.4-2006 transmitting data frame using a High Data Rate (that is, 2Mbit/s). The application uses two nodes: a PAN Coordinator (1) and an End Device (2). The firmware is implemented as such that a node can either act as a PAN Coordinator or an End Device.

This application works very identical to the MAC Example Star_Nobeacon (see Section 9.2.1.5), but the nodes switch to 2MBit/s data rate once the end device has been associated. In order to see the check functioning of the application the terminal output can be used.

This example application uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Star_High_Rate. The source code of the application can be found in the subdirectory Src.

9.2.1.6.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check the proper association between the two nodes, but in order to see the further data frame exchange a special sniffer is required being capable to except frames at 2Mbit/s.

For further status information this application requires a serial connection. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin.

Also the TAL Example Performance_Test can be used in promiscuous mode to check the proper frame exchange between the two nodes using the same channel and the correct channel page 17 for 2Mbit/s.

9.2.1.6.3 Implementation

The application works as described subsequently.

Node one:

- Switch on node one
- LED 0 indicates that the node has started properly
- Flashing of LED 1 indicates that the node is scanning its environment. Scanning is done three times on each available channel depending on the radio type
- If no other network with the pre-defined channel and PAN Id is found, the node establishes a new network at the pre-defined channel (channel 20 for 2.4GHz radio). This node now becomes the PAN Coordinator of this network. The successful start of a new network is indicated by switching LED 1 on

Node two:

- Switch on the other node

- LED 0 indicates that the node has started properly. Flashing of LED 1 indicates that the node is scanning its environment. Scanning is again done three times on each available channel depending on the radio type
- If a proper network is discovered, the node joins the existing network and indicates a successful association by switching on LED 1
- Every two seconds this node sends out a dummy data packet. If the packet is acknowledged by the other node the LED 2 is flashing

9.2.1.6.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application
- In order to see the further data frame exchange using High Data Rate a special sniffer is required being capable to except frames at 2Mbit/s

9.2.1.7 Star_Push_Button

9.2.1.7.1 Introduction

The application Star_Push_Button provides a simple start network application based on IEEE 802.15.4-2006.The application uses two nodes: a PAN Coordinator (1) and an End Device (2). The firmware is implemented as such that a node can either act as a PAN Coordinator or an End Device.

This application demonstrates how MCU sleep modes can be utilized in the wireless networks inorder to save more power.By default, End Device MCU is full sleep mode and user can wakeup the device and send data to PAN Coordinator anytime by pressing the button.

This example application uses MAC-API as interface to the stack.

The application and all required build files are located in directory Applications/MAC_Examples/Star_Push_Button. The source code of the application can be found in the subdirectory Src.

9.2.1.7.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. A push button is mandatory as it is required to generate an external interrupt to wakeup the MCU from full sleep.A sniffer is suggested in order to check the proper association and the data transfer between the devices.

9.2.1.7.3 Implementation

The application works as described subsequently.

Node one:

- Switch on node one.
- LED 0 indicates that the node has started properly.

- Flashing of LED 1 indicates that the node is scanning its environment. Scanning is done three times on each available channel depending on the radio type.
- If no other network with the pre-defined channel and PAN Id is found, the node establishes a new network at the pre-defined channel (channel 20 for 2.4GHz radio). This node now becomes the PAN Coordinator of this network. The successful start of a new network is indicated by switching LED 1 on.

Node two:

- Switch on the other node.
- LED 0 indicates that the node has started properly. Flashing of LED 1 indicates that the node is scanning its environment. Scanning is again done three times on each available channel depending on the radio type.
- If a proper network is discovered, the node joins the existing network, indicates a successful association by switching on LED 1 and goes both MCU and transceiver to sleep.
- Once the button is pressed, the End Device wake up again and send data frames to the PAN Coordinator every 200ms.If the packet is acknowledged by the PAN Coordinator, the LED 2 is flashing.
- If the button is released, the node goes to full sleep again.

9.2.1.7.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application.
- Currently only 2 devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES.

9.2.1.8 Serial_AT_Interface

9.2.1.8.1 Introduction

The example application enables the use of AT command set with Atmel AVR2025 stack so that the host application can communicate with 802.15.4 network. The AT command set consists of a series of short text strings which combine together to produce complete commands for operations such as dialing, hanging up, and changing the parameters of the connection. A set of basic commands and proprietary extended commands have been defined for the same.

9.2.1.8.2 Requirements

This application requires a serial connection to send AT commands from host and receive responses from the module. Depending on the available Serial I/O interface for each board this can be either UART or USB.

A sniffer is suggested in order to check the proper association and the data transfer between the devices.

9.2.1.8.3 Implementation

The host sends commands to the module, which replies with text messages (information responses), and each of the messages is terminated by a result code (which is mostly OK or ERROR). Each command is prefixed by the AT string followed by the chained commands to be executed consecutively. Any result code relates to the latest command performed in the sequence. In case of any command executed incorrectly, the command sequence is interrupted and the ERROR result code is returned. Information responses for any command are returned in an easily recognizable string format. Each command in a sequence may be of different syntax, depending on whether it is used to execute an action, to read or to write parameter(s) or it is used to test valid parameter range. The standard AT command set is extended to support communicate with 802.15.4 network.

Table 9.1 Example illustrating extended command set

	Command/Response	**Comment**
Command to module	AT+PIB00=0C;+PIB53?	Set the PIB 00 (channel) to 12 (0x0C) and show the PIB 53 (short address) value
Information responses	+PIB 00: 00	PIB 00 value is set successfully
	+PIB 53: 00,FFFF	PIB 53 value is 0xFFFF
Result code	OK	Execution is completed successfully

AT commands for the MLME-SAP is shown in the Table below.

Table 9.2 MLME-SAP listing

MLME-SAP Function	**Request**	**Indication**	**Response**	**Confirm**
MLME-ASSOCIATE	+ASSOC	+INASSOC:	+ASSOCRSP	+ASSOC:
MLME-DISASSOCIATE	+DASSOC	+INDASSOC:		+DASSOC:
MLME-BEACON-NOTIFY		+INBCN:		
MLME-GET	+PIB<>?			+PIB<>:<>
MLME-GTS	Not supported	Not supported	Not supported	Not supported
MLME-ORPHAN		+INORPH:	+ORPHRSP:	
MLME-RESET	+RESET			+RESET:
MLME-RX-ENABLE	+RXEN			+RXEN:
MLME-SCAN	+SCAN			+SCAN:
MLME-COMM-STATUS		+INCOMM:		
MLME-SET	+PIB<>=<>			+PIB<>:<>
MLME-START	+START			+START:
MLME-SYNC	+SYNC			
MLME-SYNC-LOSS		+INSYNL:		
MLME-POLL	+POLL			+POLL:

AT commands for the MCPS-SAP is shown in the Table below.

Table 9.3 MCPS-SAP listing

MCPS-SAP Function	Request	Confirm	Indication
MCPS-DATA	+DATA	+DATA:	+INDATA
MCPS-PURGE	+PURGE	+PURGE:	

Format of the extended command set is shown in the Table below.

Table 9.4 Extended command set

AT Command	Functionalities	Format	Comment
+DATA	Send Data	+DATA<SrcAddrMode,DstAddrMode,DstPANId,DstAddr,msduLength,msdu,msduHandle,TxOptions (all in hex)>	Refer section 7.1.1.1 and 7.1.1.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+PURGE	Data purge request	+PURGE<msdu handle in hex>	Refer section 7.1.1.4 and 7.1.1.5 of IEEE Standard 802.15.4-2006 for request and confirm details
+ASSOC	Send Association Request	+ASSOC<LogicalChannel, ChannelPage, CoordAddrMode,CoordPANId,CoordAddress, CapabilityInformation (all in hex)>	Refer section 7.1.3.1 and 7.1.3.4 of IEEE Standard 802.15.4-2006 for request and confirm details
+ASSOCRSP	Association Response	+ASSOCRSP<DeviceAddr, AssocShortAddr,status (in hex)	Refer section 7.1.3.3 of IEEE Standard 802.15.4-2006 for details
+DASSOC	Disassociate Request	+DASSOC<DeviceAddrMode,DevicePANId,DeviceAddress,DisassociateReason,TxIndirect (all in hex)>	Refer section 7.1.4.1 and 7.1.4.3 of IEEE Standard 802.15.4-2006 for request and confirm details
+PIB<>?	Get or read PIB	+PIB<MAC PIB identifier in Hex>?	Refer section 7.1.6.1 and 7.1.6.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+ORPHRSP	Orphan Response	+ORPHRSP<OrphanAddress,ShortAddress,AssociatedMember>	Refer section 7.1.8.2 of IEEE Standard 802.15.4-2006 for details
+RESET	MAC reset	+RESET<Value in Hex>	Refer section 7.1.9.1 and 7.1.9.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+RXEN	RX enable	+RXEN<DeferPermit,RxOnTime,RxOnDuration (in hex)>	Refer section 7.1.10.1 and 7.1.10.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+SCAN	Active/Passive Scan	+SCAN<ScanType,ScanChannels, ScanDuration, ChannelPage (all in hex)>	Refer section 7.1.11.1 and 7.1.11.2 of IEEE Standard 802.15.4-2006 for request and confirm details

AT Command	Functionalities	Format	Comment
+PIB<>=<>	Set or write PIB	+PIB<MAC PIB identifier in Hex>=<Value>	Refer section 7.1.13.1 and 7.1.13.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+START	Start Request	+START<PANId,LogicalChannel,ChannelPage,BeaconOrder,SuperframeOrder,PANCoordinator,BatteryLifeExtension,CoordRealignment (all in hex)>	Refer section 7.1.14.1 and 7.1.14.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+SYNC	Synch Poll	+SYNC<LogicalChannel,ChannelPage,TrackBeacon>	Refer section 7.1.15.1 of IEEE Standard 802.15.4-2006 for details
+POLL	Poll Request	+POLL<CoordAddrMode,CoordPANId,CoordAddress (all in hex)>	Refer section 7.1.16.1 and 7.1.16.2 of IEEE Standard 802.15.4-2006 for request and confirm details
+AUTOADDR	Auto address allocation	+AUTOADDR=<auto(0 or 1), short address(in hex)>	Auto address allocation is used to allocate address by the AT command interface rater than by user as the time out for association indication is very less. **Auto = 1** enables the functionality and association indication is not passed to the application. Application is notified using Com- status User can **set the address with short address** argument all nodes joining will get address incremented from this value. If **Auto = 0** then short address parameter is ignored

Figure 9-3 Serial_AT_Interface program snapshot on node one.

```
MAC AT Serial Interface v1.0
at
OK
at+reset
+RESET: 00

OK
at+assoc=15,00,02,cafe,0000,80
+ASSOC: 00 0001

OK
at+poll=02,cafe,0000
+POLL: 00

OK

+INDATA: 02,CAFE,0000,02,CAFE,0001,01,AA,FF,29,049152CA
_
```

Figure 9-4 Serial_AT_Interface program snapshot on node two.

```
OK
at+pib52=01
+PIB52: 00

OK
at+autoaddr=01,0001
OK
at+start=cafe,15,00,0f,0f,01,00,00
+START: 00

OK

+INASSOC: 000425FFFF173E34,80

+AUTORSP: 01,0001

+INCOMM: 03,CAFE,000425FFFF173FB6,03,CAFE,000425FFFF173E34,00
at+data=02,02,cafe,0001,01,aa,01,05

+DATA: ,01,00,08C903E0

OK
```

9.2.1.8.4 Limitations

As it is just an interface, no associated device data base shall be maintained in the Coordinator, so primitives like Orphan Response can not be issued even if is just and

interface on which an application sits; association response is sent automatically during the association process by default.

9.2.2 TAL examples

9.2.2.1 Performance_Test_EVK

9.2.2.1.1 Introduction

The TAL example Performance_Test _EVK is a terminal-based application for Range measurement and Packet Error Rate measurement.

The application is targeted to demonstrate the capabilities of Atmel Transceivers, such as:

- Range of the Transceiver for peer-to-peer communication (Range measurement)
- Robust Link Quality
- Packet Error Rate measurement (PER)
- Evaluate features as (with UART connection only)
    - Antenna Diversity
    - Rx Sensitivity
    - CSMA-CA Transmission
    - Read / Write Transceiver Registers
    - TX Power of radio
    - Continuous transmit test modes
    - Reduced Power consumption mode

The different states of the Performance Test EVK application are explained and also the state diagram is shown in Figure 9-5.Each state is represented by a number in the state diagram

1 INIT

- Initializes all underlying layers like TAL, PAL and Resource Management (BMM/QMM).
- Board Identification, if required
- Initializes all board utilities like LEDs and buttons etc.

2 WAIT_FOR_EVENT

- Initializes the TAL PIB attributes PAN Id with 0xCAFE, physical channel with 0x0B on both the nodes, and their radios are kept in receive state.
- Continuously search for the user events like key press or character on UART or a valid frame (Peer Request) received on air.

3 PEER_SEARCH_RANGE_TX

- Enters after key press event is detected from user. Peer Search process in Range Measurement mode as Transmitter node starts here.
- Nodes shall go into different sub states like PEER_INIT, PEER_REQ_SENT, PEER _RSP_RCVD, PEER_SEARCH_SUCCESS.

4 PEER_SEARCH_PER_TX

- Enters after receiving a character on UART event from user. Peer Search process in PER mode as Transmitter node starts here.
- Nodes shall go into different sub states like PEER_INIT, PEER_REQ_SENT, PEER _RSP_RCVD, PEER_SEARCH_SUCCESS.

5 PEER_SEARCH_RANGE_RX

- Enters after receiving a valid frame (Peer Request) from Transmitter. Peer Search process in Range Measurement mode as Reflector node starts here.
- Nodes shall go into different sub states like PEER_INIT, PEER _RSP_SENT, WAIT_FOR_ PEER_CONF, PEER_SEARCH_SUCCESS.

6 PEER_SEARCH_PER_RX

- Enters after receiving a valid frame (Peer Request) from Transmitter. Peer Search process in PER Measurement mode as Reflector node starts here.
- Nodes shall go into different sub states like PEER_INIT, PEER _RSP_SENT, WAIT_FOR_ PEER_CONF, PEER_SEARCH_SUCCESS.

8 RANGE_TEST_TX_ON

- Starts Range Measurement mode as Transmitter.
- Enters after successful Peer Search on key press event.
- Continuous packet transmission with a period of 200 ms time interval.
- Enters from RANGE_TEST_TX_OFF(7) state on button press

7 RANGE_TEST_TX_OFF

- Starts Range Measurement mode as Reflector.
- Enters after successful Peer Search on a valid frame (Peer Request in Range Measurement mode) received from Transmitter.
- Receives the packets from other node and acknowledges (by an 802.15.4 protocol ACK) each packet received
- Enters from RANGE_TEST_TX_ON(8) state on button press

10 PER_TEST_INITIATOR

- PER Measurement mode as Transmitter
- Enters after successful Peer Search on character received on UART event.
- Node shall go into sub states like TX_PER, TEST_FRAMES_SENT, WAIT_FOR_TEST_RES, SET_PARAMETER, IDENTIFY_PEER, DIVERSITY_SET_REQ, DIVERSITY_STATUS_REQ, CRC_SET_REQ_WAIT, CRC_STATUS_REQ_WAIT, CONTINOUS_TX_MODE, RESULT_RSP, DIV_STAT_RSP etc.

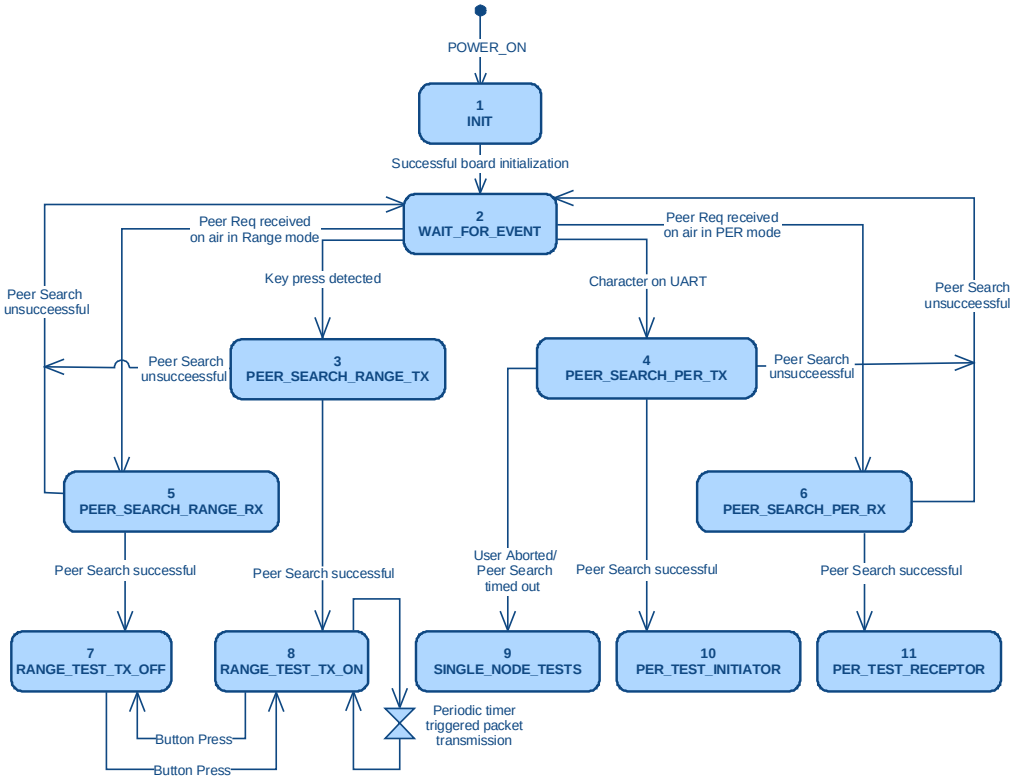
11 PER_TEST_RECEPTOR

- PER Measurement mode as Reflector
- Enters after successful Peer Search on a valid frame (Peer Request) received from Transmitter.
- Node shall respond back for the cmds sent from different states in Transmitter node.

9 SINGLE_NODE_TESTS

- Transmitter node in single node operation.
- Enters on user abort or Peer Search time out, i.e. No Peer Response is received during the Peer Search process.
- Node shall go into sub states similar (but applicable) states in PER_TEST_INITIATOR (10) by considering the Peer Search status as failed.

Figure 9-5. Performance Test EVK Application State Diagram



9.2.2.1.2 Requirements

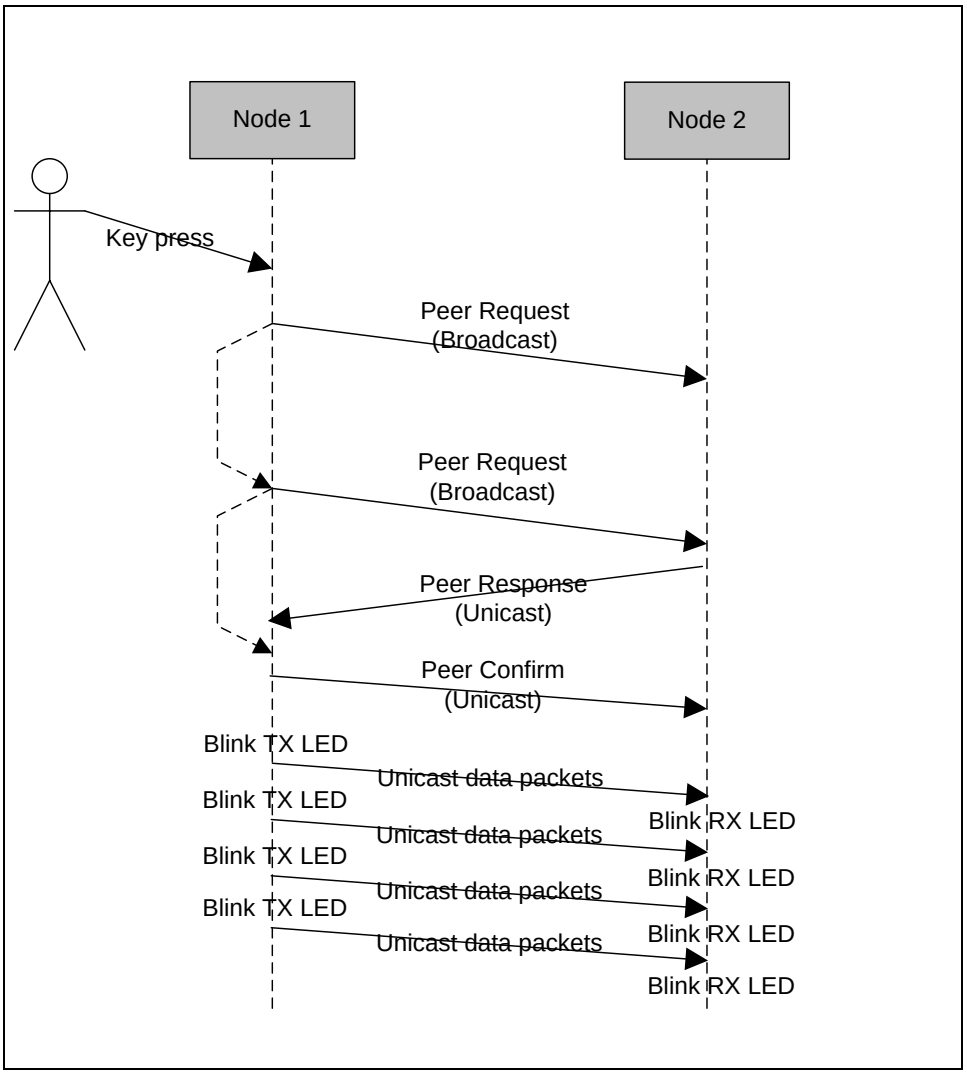
The Packet Error Rate measurement requires a serial connection for controlling the application and displaying the results. Depending on the available serial I/O interface for each board this can be either UART or USB. In order to see the output of the application please start a terminal application on your host system.

9.2.2.1.3 Implementation

9.2.2.1.3.1 Range Measurement mode

During Range measurement, the transmitter node will initiate a sequence to find a peer node. Once peer node is found, packet transmission is initiated by the transmitter to the receiver. The Receiver node acknowledges each packet received. The procedure used for finding the peer node is explained in detail in the Section 9.2.2.1.3.3

Figure 9-6. Sequence diagram of Range measurement



The LED on the receiver will blink sequentially and repeat at the rate at which the packets are received. The LED on the transmitter will blink sequentially & repeat at the rate at which the packets are transmitted. The LED will blink at a constant rate on the transmitter as the packets are transmitted at a constant duration. The packet format is described in the section Packet Format

9.2.2.1.3.1.1 Packet Format

The transmitted packet format and content for the operation mode is customized to suite only the requirements of this application. The format is shown in Table 9-5:

Table 9-5. Packet payload format for Range measurement

Octets	**1**	**1**	**8**
Payload	Command ID	Sequence Number	Packet Count

Field Description is as follows:

- Command-ID:
  (0x00) the value of command ID (DATA FRAME)

- Sequence Number:

  To have a sequence of packets transmitted from the transceiver to the receiver. The range of sequence number is 0x00 ~ 0xFF, will roll-over respectively. This is to track the packet loss for a continuous transmission of packets.

- Packet Count:

  The packet format maintains a 32 bit packet counter to count the number of packets at any instant, by using an external sniffer tool. Once the limit is reached (4294967295) then the counter resets itself to start again from 0x00000000.

9.2.2.1.3.1.2 Debug message support for – Range measurement

Debug prints can be viewed if the node is connected to a UART terminal

The node on which the key was pressed will display a print as shown in Figure 9-7. This node initiates the transmission and calls itself the TX node. For details on Peer Search refer section

Figure 9-7. Initializing Range measurement - transmitter (TX)

```
Key press detected :Range Measurement mode
Search for Peer Device Initiated.................
Peer device found
Starting TX in Range Measurement mode
```

The node connected to the TX node will display a print as shown in Figure 9-8. This node receives the packets and calls itself the RX node.

Figure 9-8. Initializing Range measurement - receiver (RX)

```
Frames Rec on air: Range Measurement
Peer device found
```

On input of any character in the UART Terminal it prints the statistics of the messages received and messages sent as shown in Figure 9-9. Two way communications can be enabled if the button is pressed on both the nodes.

Figure 9-9. Statistics of Range measurement

```
No. of Frames RX: 50
No. of Frames TX: 52
No. of Frames RX: 54
No. of Frames TX: 56
No. of Frames RX: 58
No. of Frames TX: 59
No. of Frames RX: 61
```

9.2.2.1.3.2 PER Measurement mode

The primary intent of this application is PER measurement. One of the nodes should be connected to the UART terminal program. The node connected to the UART is referred as transmitter and other node (need not be connected to the UART) is referred as receiver.

After the boards are turned on if any character is received on the UART then the node (transmitter) tries to find its peer node (i.e. receiver). The procedure to find the peer node is explained in detail in the Section 9.2.2.1.3.3 and the sequence is proprietary.

- Press any character on the UART terminal and the device initiates the procedure to find its peer i.e. Peer Search Process as shown in below

Figure 9-10. Initializing PER measurement

```
 Character received : PER Measurement mode
 Press ENTER to Abort Search for Peer Device and to start single node operation
mode
 Search for Peer Device Initiated.............................................
.............................................._
```

- If the peer node is found then a menu appears as shown in Figure 9-11. The menu is described in Table 9-6.

Figure 9-11. Main Menu after Peer Search Process in PER mode is successful

```
 Character received : PER Measurement mode
 Press ENTER to Abort Search for Peer Device and to start single node operation
mode
 Search for Peer Device Initiated...........
 Peer device found
 Starting PER Measurement mode as Transmitter
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main menu:
(1) Transceiver Configuration
(2) Transceiver State Selection
(3) PER-Test Configuration
(4) Service Functions
(5) Start_test
>_
```

- Press ‘1’ on UART terminal program to configure the transceiver for PER Measurements

Figure 9-12. Transceiver Configuration sub menu

```
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main and Sub-menu:
(1) Transceiver Configuration
    (C) : IEEE Channel = 20
    (P) : Channel page = 0
    (R) : Reduced Power Consumption (RPC) = enabled
    (X) : Receiver Desensitization = disabled
    (W) : Tx power = 4 dBm  (TX_PWR=0x0)
    (A) : ACK request = true
    (F) : Frame retry enabled = false
    (M) : CSMA enabled = true
    (Y) : Antenna diversity - disabled and antenna selected is A1/X2
    (0) : Leave sub-menu
(5) Start_test
>
```

- Press ‘2’ on UART terminal program to select the state of the transceiver in which user is interested. This is useful to evaluate the ultra low power consumption capabilities of transceivers in different states with a specific feature enabled and disabled.

Figure 9-13. Transceiver State Selection sub menu

```
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main and Sub-menu:
(2) Transceiver State Selection
          Present Trx State = PLL_ON
    (R) : Reduced Power Consumption (RPC) = enabled
    (X) : Receiver Desensitization = disabled
    (S) : RESET
    (B) : DEEP_SLEEP
    (T) : SLEEP
    (G) : TRX_OFF = disabled
    (J) : PLL_ON = enabled
    (K) : RX = disabled
    (U) : TX Continuous
    (Y) : Antenna diversity - disabled and antenna selected is A1/X2
    (0) : Leave sub-menu
(5) Start_test
>_
```

- Press ‘3’ on UART terminal program to configure the PER measurement parameters, e.g. setting the frame length, no. of frames, antenna diversity settings on remote node etc.

Figure 9-144. PER-Test Configuration sub menu

```
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main and Sub-menu:
(3) PER-Test Configuration
    (N) : Number of test frames = 100
    (L) : Frame length (PSDU) = 20
    (Q) : Diversity settings on remote node
    (Z) : CRC settings on remote node
    (0) : Leave sub-menu
(5) Start_test
>
```

- Press ‘4’ on UART terminal program to analyze other services of transceivers, e.g. energy scan, Continuous wave Transmission and reading and writing transceiver registers etc.

Figure 9-155. Service Functions sub menu

```
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main and Sub-menu:
(4) Service Functions
    (I) : Identify peer device by blinking
    (E) : Energy scan on all channels
    (U) : Continuous transmission on current channel
    (D) : Transmit a continuous wave pulse on current channel
    (V) : Get sensor data, i.e. supply voltage
    (H) : Read - Write Transceiver Registers
    (0) : Leave sub-menu
(5) Start_test
>_
```

- Press ‘5’ on UART terminal program to start PER measurement test anytime, irrespective of in which sub menu user is in presently.
- If search for peer node is aborted / failed then a minimal set of test can be performed with only single node. The menu shown in **Error! Not a valid bookmark self-reference.**6 describes the test

Figure 9-166. Main menu after Peer Search process aborted/failed

```
Character received on UART: PER Measurement mode
Press ENTER to Abort Search for Peer Device and to start single node operation m
ode
Search for Peer device initiated.............................................
.............................................................................
.............................................................................
...............................................
Search for Peer Device failed
 Starting Performance Test Application in single node operation mode
*****************************************************
Software Version:4.0
Performance test application (AT86RF233 / ATxmega256A3)
Main menu:
(1) Transceiver Configuration
(2) Transceiver State Selection
(3) Service Functions
>
```

Table 9-6. Description for Sub menu – Transceiver Configuration (1)

Menu Option	Functionalities	Default Value	Comment
C	Channel	20	User can change channel Allows the user to enter ISM frequencies also in case of AT86RF233 transceiver
P	Channel Page	0	User can change channel page
R	RPC	Enabled	Toggling RPC (Reduced Power Consumption) .Only available in AT86RF233
X	Desensitization	Disabled	Toggling Receiver Desensitization
W	TX Power	3 dBm (depends on Transceiver)	For changing TX power of the radio transceiver. Allows the user to enter TX power in absolute dBm values or TX_PWR register values.
A	Auto-ACK	Disabled	To enable / disable auto ACK request
F	Retransmission	Disabled	To enable / disable auto re-transmission for no ACK packet
M	CSMA	Enabled	To enable / disable CSMA functionality for TX
Y	Antenna Diversity	Enabled	To toggle the antenna diversity mode on the node connected to the PC

Table 9-7. Description for Sub menu – Transceiver State Selection (2)

Menu Option	Functionalities	Default Value	Comment
S	RESET	--	Allow the user to reset the transceiver

B	DEEP_SLEEP	--	Put the transceiver in DEEP SLEEP (Only available in AT86RF233)
T	SLEEP	--	Put the transceiver in SLEEP
G	TRX_OFF	--	Put the transceiver in TRX_OFF state
J	PLL_ON	--	Put the transceiver in PLL_ON state
K	RX_ON	--	Put the transceiver in RX_ON state

Table 9-8. Description for Sub menu – PER-Test Configuration (3)

Menu Option	Functionalities	Default Value	Comment
N	Test Frames	100	No. of test frames to be transmitted. Max value = 4,294,967,295
L	Frame length	20	The length of frame inclusive of headers limits are (12 - 127)
Q	Diversity	Enabled	To enable / disable the antenna diversity on the remote node
C	CRC	Disabled	To enable/disable the CRC settings on remote node

Table 9-9. Description for Sub menu – Service functions (4)

Menu Option	Functionalities	Default Value	Comment
I	Peer Identify	--	Peer node identifies itself by blinking its LEDs
E	Energy Scan	--	To do energy scan for all channels
U	Continuous Transmission	--	To enable / disable continuous transmission on the current channel
D	Continuous Wave Pulse	--	To enable / disable continuous wave pulse mode from the radio transceiver
V	Sensor Data	--	To read the sensor data in voltage
H	Read / Write	--	To read or write any register set from the radio transceiver

9.2.2.1.3.2.1 Sensitivity testing

In the IEEE 802.15.4 standard, the receiver sensitivity is defined as the lowest received signal power that yields a packet error rate loss of less than 1%. IEEE 802.15.4 requires only -85 dBm of sensitivity for operations in the 2.4 GHz ISM band.

Using the PER test, sensitivity can be tested by configuring one of the nodes as a transmitter and another as a receiver. The number of packets to be transferred is configured on the transmitter and all the packets received by the receiver are acknowledged. The receiver keeps a count of the packets received. At end of the test the transmitter asks the receiver for the test results. The test results are displayed on the UART terminal at the end of the test.

For this test, unicast with ACK is used. Since the boards are not factory connected they are field connected by the method described in the Section **Error! Reference source not found.**. Please refer the Atmel Transceiver datasheet for expected sensitivity.

9.2.2.1.3.2.2 TX Power handling

The Atmel AT86RF231 provides the programmable TX output power from -17dBm to 3dBm. The output power of the transmitter can be controlled over a range of 20 dB. Default TX power is set to 3dBm. The PER measurement mode gives an option to configure the TX out power in the form of absolute power in dBm or TX PWR register value. If the AT86RF231 is connected with front end module (e.g.REB231FE2 –EK kit), TX power can be extended till 21dBm.

The control of an external RF front-end is done via digital control pins DIG3/DIG4. The function of this pin pair is enabled with register bit PA_EXT_EN (register 0x04, TRX_CTRL_1). While the transmitter is turned off pin 1 (DIG3) is set to low level and pin 2 (DIG4) to high level. If the radio transceiver starts to transmit, the two pins change the polarity. This differential pin pair can be used to control PA, LNA, and RF switches.

If the AT86RF231 is not in a receive or transmit state, register bit PA_EXT_EN (register 0x04, TRX_CTRL_1) is disabled to reduce the power consumption or avoid leakage current of external RF switches and other building blocks, especially during SLEEP state. If register bits PA_EXT_EN = 0, output pins DIG3/DIG4 are pulled-down to analog ground.

If AT86RF231 is connected with RF front end module (i.e.REB231FE2 –EK kit), default TX power is 20dBm.To ensure FCC compliance TX Power of CH26 has to be limited to 13dBm (TX_PWR = 0x0d).So if user changes the channel to 26 and the default TX power is more than 13dBm, it shall be automatically changed to 13dBm.For CH26 the allowed range of TX power is 4dbm to 13dBm, for other channels it is 4dBm to 21dBm.

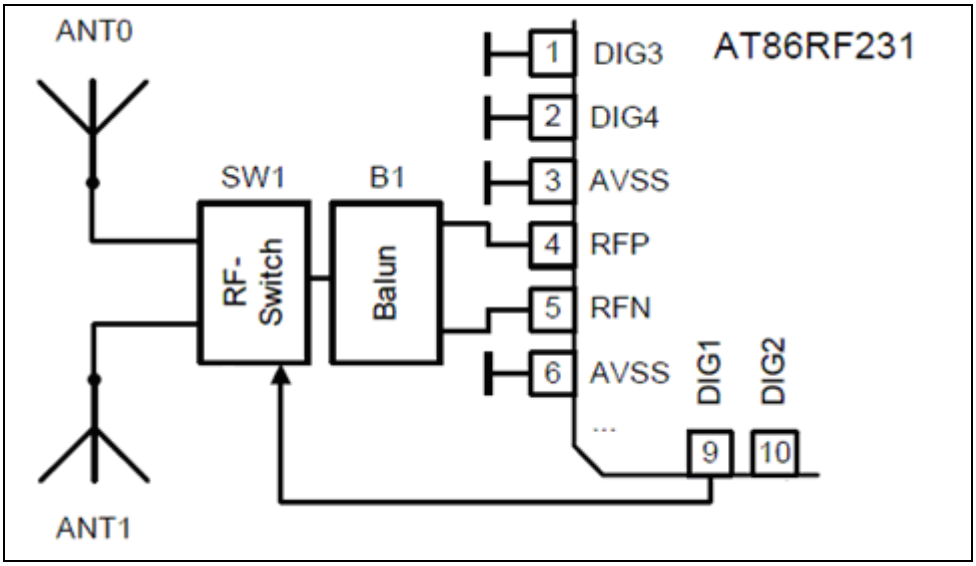
9.2.2.1.3.2.3 Diversity feature testing

In a multi-path environment, several versions of the same signal with different phases, delays, and attenuations will be added together at the receiver location, so there is always the possibility that at some locations, the signals could cancel each other out almost entirely. One way to overcome the multi-path issue is to use the *receiver antenna diversity* technique. In this method, two antennas are used instead of one in the receiver. This way if one antenna is in a multi-path null (also known as *deep-fading region)*, the other antenna has a good chance of being outside the deep-fading region. The receiver can switch between these two antennas to escape from a multi-path null.

Enable Diversity in the radio by using the main menu. Diversity can also be configured in the reflector node by using the main menu. (By default diversity is enabled). AT86RF231 has a built-in antenna diversity feature. Upon reception of a frame the AT86RF231 selects one antenna during preamble field detection. The REB Rx path is shown in the Figure 9-17.

The antenna diversity feature can be tested by doing the PER measurement on conductive medium.

Figure 9-17. REB Rx path



9.2.2.1.3.2.4 Read Write Radio Registers

The Atmel AT86RF231 provides a register space of 64, 8-bit registers, used to configure, control and monitor the radio transceiver. The PER measurement mode gives an option to write / read or Dump the content of range of these registers. Please note that when writing to a register, any reserved bits shall be overwritten only with their reset value.

NOTE If the nodes are connected each other and registers related to channel selection (0x08-PHY_CC_CCA) or channel page selection (0x0C-TRX_CTRL_2) or transmission power setting (0x05-PHY_TX_PWR) are changed, the changes will be reverted to the old setting to prevent loss of connection with remote node. To test these registers use the PER measurement mode with Peer Search aborted.

9.2.2.1.3.2.5 Debug message support for – PER Measurement mode

Debug support is enabled on the receiver node which need not be connected to the PC. If UART Terminal is connected, debug logs are printed on the terminal as shown in Figure 9-188

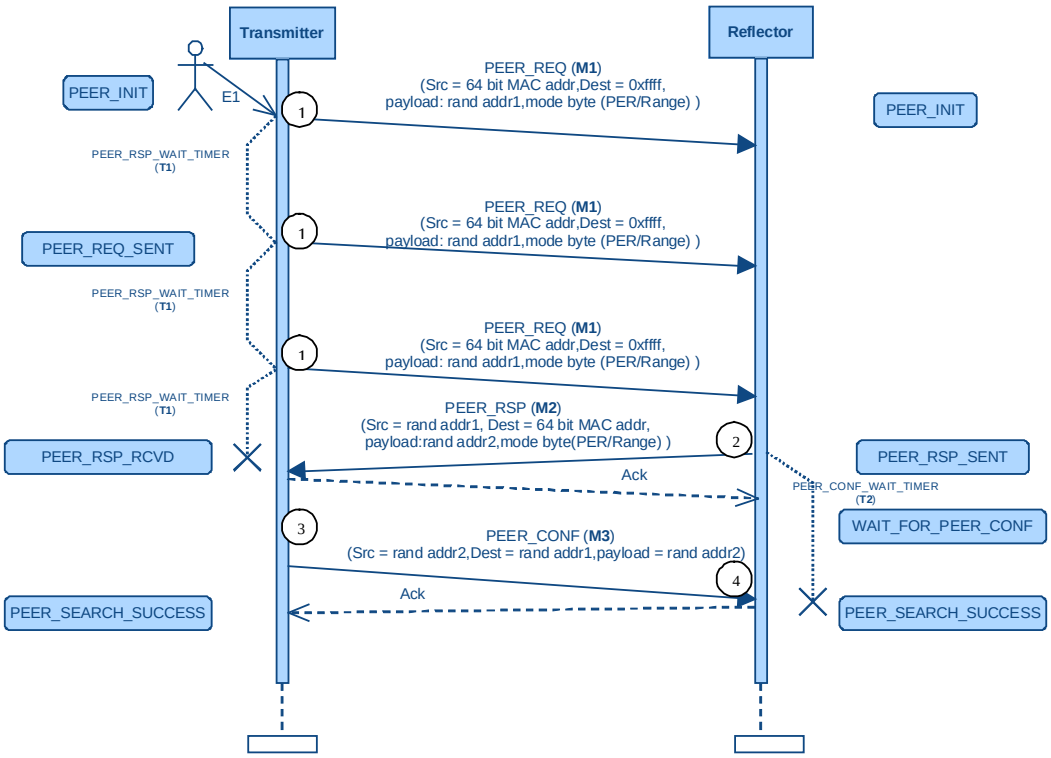
Figure 9-188. Debug prints on reflector

```
 Frames Rec on air: PER Measurement mode
 Peer device found
 Starting PER Measurement mode as Reflector
Receiving..
Number of received frames = 100; average LQI = 255, average RSSI = -41 dBm
 Frames Rec on air: PER Measurement mode
 Peer device found
 Starting PER Measurement mode as Reflector
Receiving..
Number of received frames = 100; average LQI = 255, average RSSI = -41 dBm
Receiving..
Number of received frames = 100; average LQI = 255, average RSSI = -40 dBm
```

9.2.2.1.3.3 Peer Search Process

The Peer Search process is described in detail below and is illustrated by a sequence diagram. Initially the nodes uses their 64-bit MAC address as source address during the Peer Search Process to get connected each other. During the Peer search process 16-bit random address shall be assigned to both the devices.

Figure 9-199. Sequence Diagram for Peer Search process



1. On pressing the button T1 or receiving a valid character on UART, which is shown as an event E1, the node becomes Transmitter and sends a **Peer Request (M1)** as broadcast at a constant period. Then the node enters into PEER_REQ_SENT state. A timer PEER_RSP_WAIT_TIMER (T1) is started to send the Peer Requests with 50ms time interval. A counter is started to count the no. of Peer Requests sent. On every expiry of the timer T1, count value is incremented by one. The Transmitter stops sending the Peer Request if the count reaches to 0xff and the node goes to the WAIT_FOR_EVENT state again. The Peer Request packet payload consists of a 16 bit random number and used as source address (rand addr1) of the receiving node and the mode byte to indicate in which mode (PER/Range) this Peer Request has been sent.

2. If any other node is in power on state and it receives this Peer Request packet, it becomes Reflector, assigns itself this address (rand addr1) as its source address (IEEE 802.15.4 protocol) and sends a **Peer Response (M2)** which is a unicast to Transmitter as destination address using extended MAC address. The Reflector node then enters into PEER_RSP_SENT state. After receiving the

acknowledgement for Peer Response from Transmitter node, Reflector node enters into WAIT_FOR_PEER_CONF state, and a timer called PEER_CONF_WAIT_TIMER (T2) is started with a timeout value of 200ms. If the Peer confirm is not received within this time, the node goes to the WAIT_FOR_EVENT state again. Peer Response payload consists of a random generated 16 bit number used as source address (rand addr2) of the receiving node i.e. Transmitter and the mode byte to indicate in which mode (PER/Range) this Peer Response has been sent.

3. On receipt of the Peer Response packet, the Transmitter node assigns itself the address received in the frame(rand addr2) as its source address (IEEE 802.15.4 protocol) and the node sends a **Peer Confirm (M3)** which is a unicast to Reflector (source address = rand addr2 and destination address = rand addr1). Peer Confirm frame consists of the address (rand addr2) sent to the Transmitter node in the payload of Peer Response. After receiving the acknowledgement for Peer confirm from Reflector, Transmitter node enters into PEER_SEARCH_SUCCESS state.

4. On receipt of the Peer Confirm, Reflector node stops the timer T2, checks the packet and verifies the address is the same as the address it sent to the Transmitter node in the Peer Response (rand addr2). If it is the same, Reflector node enters into PEER_SEARCH_SUCCESS, and the nodes are connected each other. If Reflector node does not receive any Peer Confirm within timeout the node goes into WAIT_FOR_EVENT state. This process is followed to connect only a pair of nodes if two nodes are in the powered on state.

The boards are assigned random addresses and if the Peer Search process is successful then the test commences and the nodes operate in the respective operation modes.

9.2.2.1.3.4 Configuration mode

Configuration mode is the startup mode in which two nodes (i.e. Transmitter and Reflector) can connect each other if they are only within in the vicinity of one meter approximately. This is to restrict the distance range for connecting devices. This is used generally in seminars where there are no. of participants may start the Performance test at the same time. With configuration mode provided, each individual participant can make sure that his/her two devices are only getting connected without disturbing the other devices. Once the Peer Search is done successfully, the nodes shall come to the normal mode where the nodes can be kept afar.

User can enter into configuration mode by pressing the button T1 while Power on /reset. The serial terminal prompts "Button press while power-on - CONFIGURATION_MODE". Then user can initiate Peer Search by key press for PER measurement or button press for Range measurement. Then the device (transmitter) shall go to the low TX level (TX_PWR = 0x0F) and sends the peer request with the config_mode bit set to true. On the other device (reflector), if the peer request received with config_mode bit true, it checks the ED level and if it is above defined threshold, it will connect with the transmitter device. This ED threshold is defined to allow connecting with the devices which are approximately below one meter range. In configuration mode Transmitter node works with lowest TX power and the Reflector sends the received packets to the application layer if it is above ED threshold.

After successful Peer Search, devices shall come to the normal mode, which means Transmitter node work with default TX power and the receiver node shall not do any filtering based on the ED threshold value

Figure 9-200. Debug prints for Configuration mode followed by PER Measuremnt

```
 Button press while poweron - CONFIGURATION_MODE
 Character received : PER Measurement mode
 Press ENTER to Abort Search for Peer Device and to start single node operation
mode
 Search for Peer Device Initiated.............................................
.........................................._
```

Figure 9-211. Debug prints for Configuration mode followed by Range Measuremnt

```
 Button press while poweron - CONFIGURATION_MODE
 Key press detected :Range Measurement mode
 Search for Peer Device Initiated.............................................
.......................................................................................
......................._
```

9.2.2.1.3.5 Application Contents

Using the PAL and TAL package for the corresponding controller and radio transceiver, the entire implementation of the Performance Test Application requires an additional set of following files.

Table 9-10. File list for Performance Test application

File name	Short description of contents
main.c	Main application task ,TX-done handler & Rx callback functions (represents entire state machine)
user_interface.c	User interface related functions like LED, Serial prints, buttons
init_state.c	Board and startup application initialization functions (represents INIT State)
wait_for_event.c	Functions for waiting for events like character on UART, Key press etc (represents WAIT_FOR_EVENT state)
peer_search_initiator.c	Proprietary Peer Search related functions as Initiator (represents PEER_SEARCH_ PER_TX & PEER_SEARCH_RANGE_TX states)
peer_search_receptor.c	Proprietary Peer Search related functions as Receptor (represents PEER_SEARCH_ PER_RX & PEER_SEARCH_RANGE_RX states)
range_measure.c	Range measurement related functions (represents RANGE_TEST_TX_OFF & RANGE_TET_TX_OFF states)
per_mode_initiator.c	PER measurement related functions as Initiator (represents PER_TEST_INITIATOR & SINGLE_NODE_TESTS states)
per_mode_receptor.c	PER measurement related functions as Receptor (represents PER_TEST_RECEPTOR state)
per_mode_common_utils.c	Common utility function related to all PER mode states

9.2.2.1.4 Limitations

Only two devices are allowed connecting each other and communicating.

A switch on the board is required to enter into Range Measurement mode and configuration mode

In case of the ATREB231FE2-EK, two nodes should be kept at least 50cm apart to avoid the distortion due to high TX Power levels.

9.2.2.2 Accelerometer_Display_App

9.2.2.2.1 Introduction

The TAL example Accelerometer_Display_App demonstrates the LCD and accelerometer present on the key remote controller board.

The application is targeted to demonstrate the capabilities of Atmel Transceivers, on chip peripherals such as LCD and accelerometer.

9.2.2.2.2 Requirements

This application requires two or one of the key remote controller board(s). The following observations user has to keep in mind before testing this application

- During application startup the LCD will display the ATMEL logo.
- Then the user will get the message 'calibrating'.
- Now remote controller board must be placed on a flat surface undisturbed so that the application can take the current accelerometer reading as reference and output the values accordingly.
- After the application has finished the calibration the LCD will display 'calibration done'.
- After this the user can make use of the remote and tilt it to any position to see the logo slide across the LCD.
- If two or more remotes are used the user can see the transition in all of them.

A sniffer is suggested in order to check the proper association and the data transfer between the devices.

9.2.2.2.3 Implementation

The application works as described subsequently.

- Each remote will transmit its current position and will update it on the LCD as well. If the other remote is used its position is also updated on the LCD. Since a remote updates its own position as well as the other remotes position on the LCD, the following effects can be observed on the LCD.

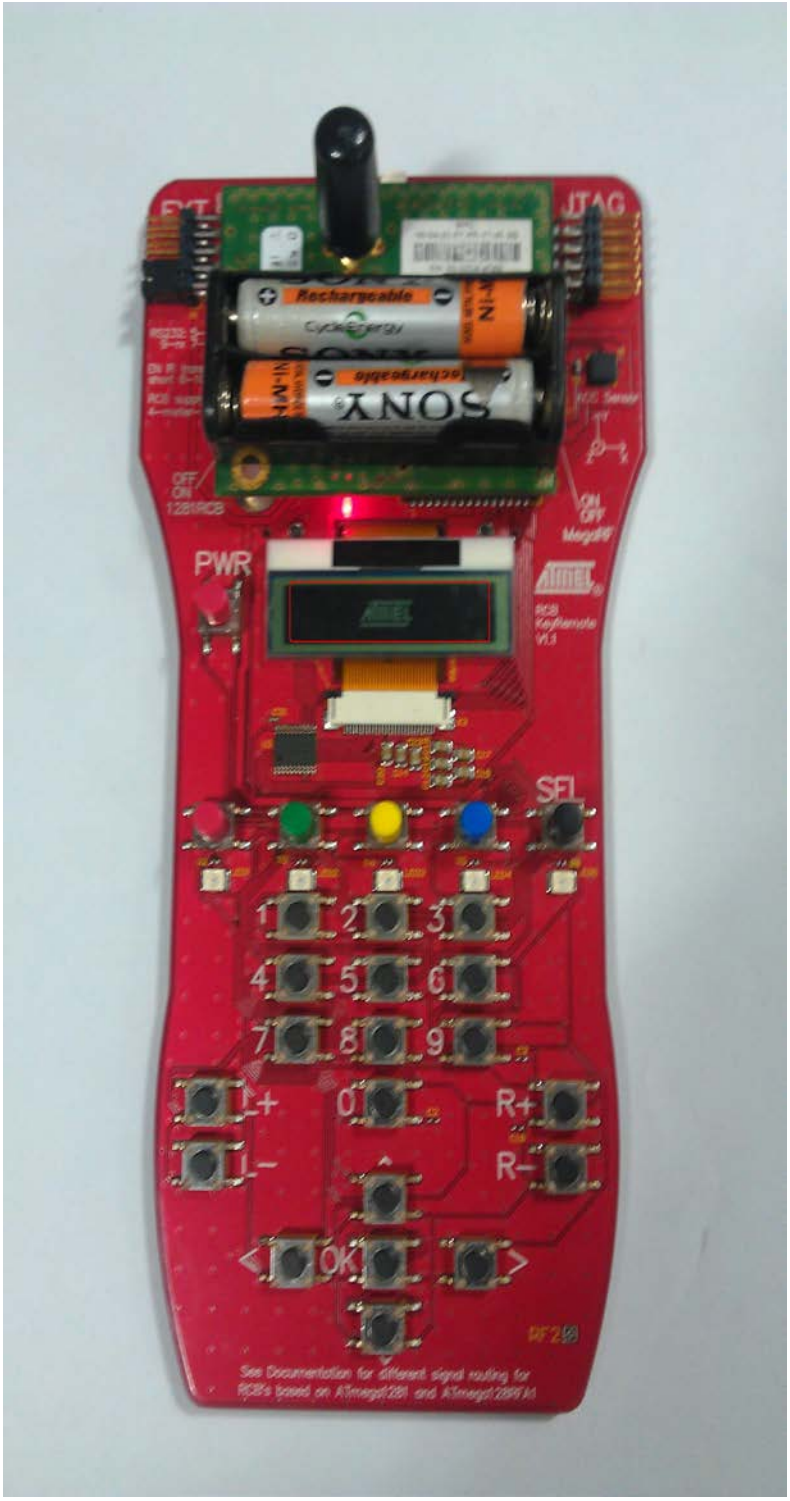
    1. If only one remote is used the LCD will update its position.

2. If two remotes are used and if one is kept undisturbed and the other is used, both the remotes will update the position of the active remote on the LCD.

3. If both the remotes are positioned in the same direction, the logo will move twice as fast in that direction, than it normally would.

4. But if the remotes are positioned in opposing direction like one positioned left and the other towards the right, these two actions will cancel eachother. The logo will not move in either of directions but will remain stationary.

Figure 9-222. Accelerometer Display Application



9.2.2.2.4 Limitations

The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application.

9.2.3 STB examples

9.2.3.1 Secure_Remote_Control

9.2.3.1.1 Introduction

The STB example Secure_Remote_Control is an application demonstrating application security for a remote control acting as a light switch. It deploys a nonbeacon-enabled network using ZigBee/CCM* security.

This example application uses both STB and TAL API as interface to the stack. The STB is used to secure and unsecure application data, and the TAL is used to transmit or receive (secured or unsecured) frames.

The application and all required build files are located in directory Applications/STB_Examples/ Secure_Remote_Control. The source code of the application can be found in the subdirectory Src.

9.2.3.1.2 Requirements

This application requires

- (Up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes
- One button on the board in order to determine whether the node starts in secure or unsecure mode, and in order to initiate an action by the remote control
- A serial connection for typing messages and displaying the received data from the other device. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin

9.2.3.1.3 Implementation

The application involves exactly two nodes. Both nodes operate at channel DEFAULT_CHANNEL with the PAN ID DEFAULT_PAN_ID and use the same short address settings. More than two nodes should not be operated with the same settings.

The application uses a button to determine the mode of operation (secure or unsecure mode) or to initiate frame transmissions, and (up to three) LEDs to indicate the current status of the node.

Once the node is powered up the LED_0 switched on permanently. If the node is powered while the button is pressed (until the LED_0 is switched on), the application runs in unsecured mode (LED_1 is off). Otherwise (that is, button is not pressed during system start-up) the application runs in secured mode (LED_1 is on).

If the button is pressed during operation, the node sends a frame which contains the message "Toggle light!“. This message is either to be seen in plaintext or it is encrypted.

A node in secured mode only transmits frames being encrypted using ZigBee/CCM* security, and also expects frames being encrypted. A node in unsecured mode only transmits frames with plaintext, and also expects frames with plaintext.

If the transmitter has received an Acknowledgment frame as response to its frame transmission, it indicates the successful transmission by toggling the LED_2. If the transmission is not successfully, the LED_2 is flashing for a short time.

Receiver is in secured mode: If the node has received a secured frame, that could be decrypted properly, the LED_2 is toggled. If the received frame is either unsecured or has a security error (for example, incorrect key), the LED_2 is flashing for a short time.

Receiver is in unsecured mode: If the node has received a plaintext frame, the LED_2 is toggled. If the received frame is secured, the LED_2 is flashing for a short time.

If a serial terminal is used, the used mode (security on or off) and the status of the last frame transmission or reception are printed.

The following pictures show the printouts on the serial terminal depending whether the nodes are started in secure or unsecure mode.

Figure 9-17. Secure remote control application – both nodes in secure mode.

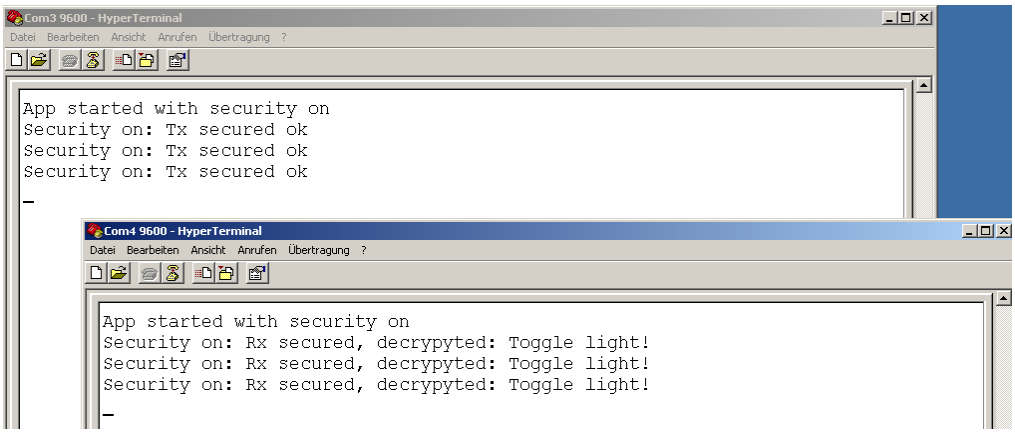


Figure 9-18. Secure remote control application – both nodes in unsecure mode.

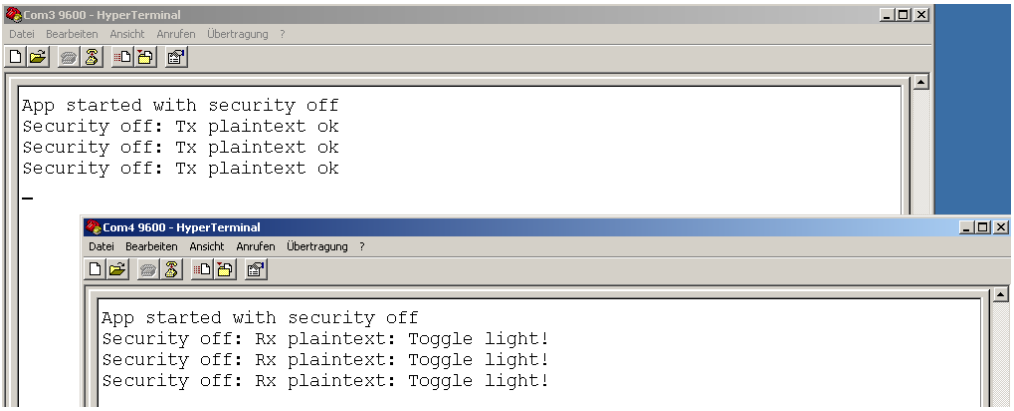


Figure 9-19. Secure remote control application – transmitter in secure mode, receiver in unsecure mode.

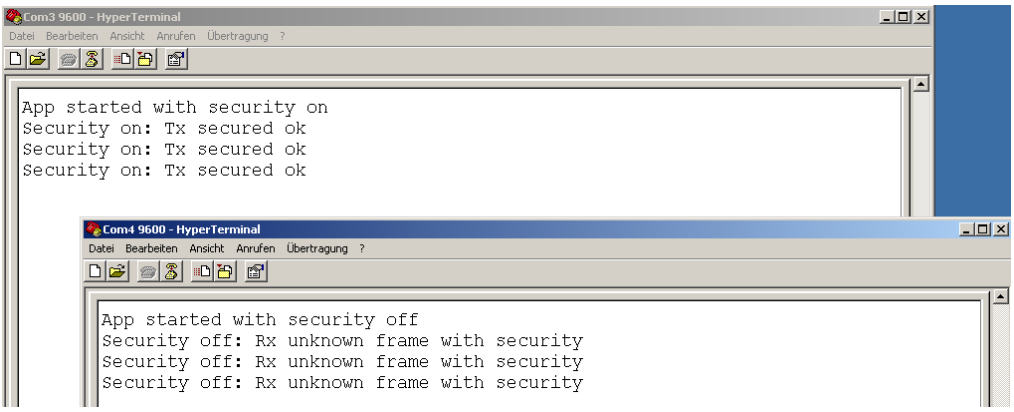
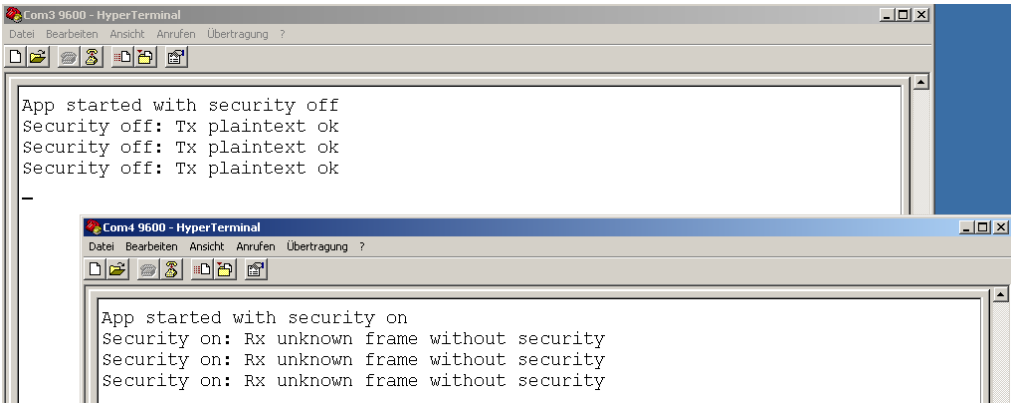


Figure 9-20. Secure remote control application – transmitter in unsecure mode, receiver in secure mode.



9.2.3.1.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application
- It is not recommended operating more than two nodes with the application simultaneously

9.2.3.2 Secure_Sensor

9.2.3.2.1 Introduction

The STB example Secure_Sensor deploys a nonbeacon-enabled network with encrypted and authenticated frames. It is using ZigBee/CCM* security. The application consists of Sensor (that is, End Devices) and a Data Sink (that is, a PAN Coordinator) collecting data from the sensors.

This example application uses both STB and MAC-API as interface to the stack. The STB is used to secure and unsecure application data, and the MAC is used to set up a nonbeacon-enabled network, perform scanning and network association, and to transmit or receive (secured or unsecured) frames.

The application and all required build files are located in directory Applications/STB_Examples/ Secure_Sensor. The source code of the application can be found in the subdirectory Data_Sink/Src and Sensor/Src.

9.2.3.2.2 Requirements

This application requires:

- (Up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes
- A serial connection for typing messages and displaying the received data from the other device. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to start the application and to see the output of the application please start a terminal application on your host system and press any key for the application to begin

9.2.3.2.3 Implementation

The node acting as data sink (PAN Coordinator) starts a non-beacon enabled PAN at channel DEFAULT_CHANNEL with the PAN ID DEFAULT_PAN_ID. The sensor (Device) scans for this network and associates to the data sink (PAN Coordinator). Once the sensor (Device) is associated, it uses a timer that fires every two seconds to transmit a random payload (sensor measurement data) to the data sink.

The frames are secured according to ZigBee/CCM* network layer security:

- The network header is omitted, only the auxiliary security header is constructed (14 byte long)
- The applied security level is 0x06, that is, encrypted payload, authentication applied, MIC 8 byte long
- The random payload has 13 byte length

The LEDs signal the following status:

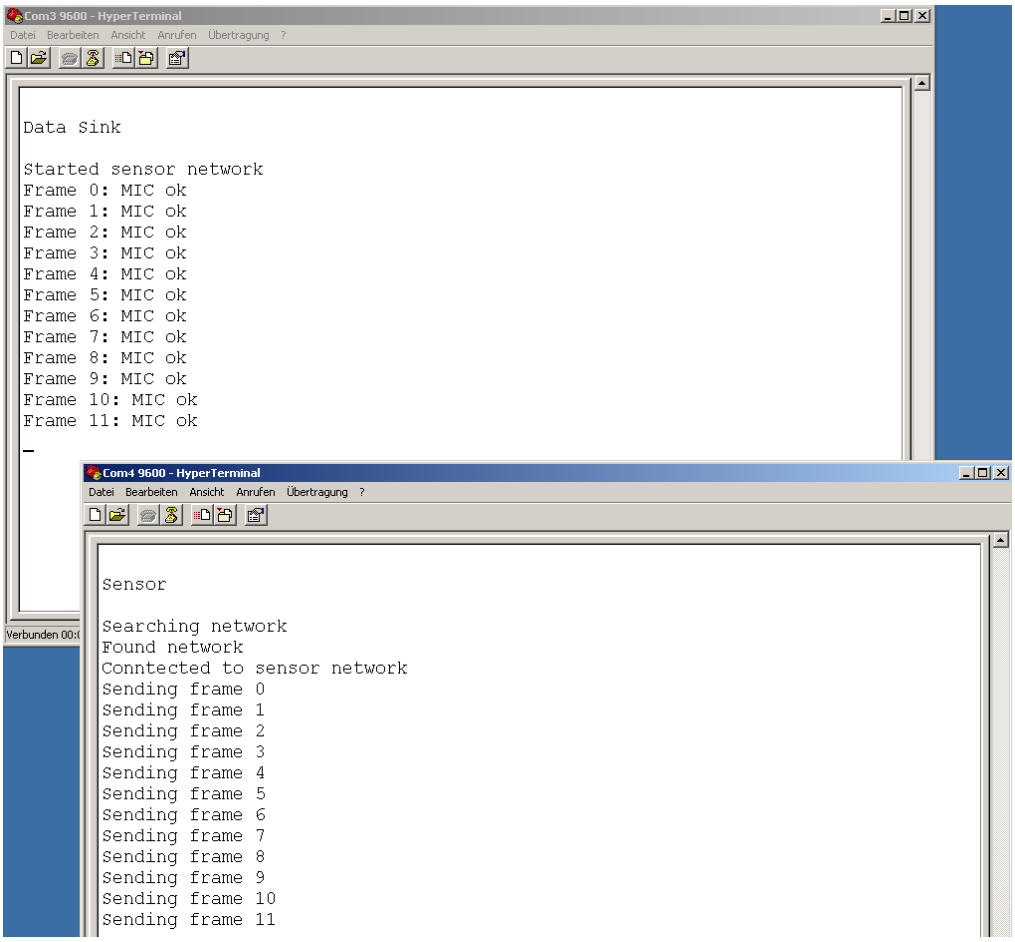
Sensor (Device):

- LED 0 on: Application is running
- LED 1 on: Sensor (Device) is associated to Data Sink (Coordinator)
- LED 2 blinking slowly: Data frames are sent (one every two seconds)

Data Sink (Coordinator):

- LED 0 on: Application is running
- LED 1 on: Network is started
- LED 2 blinking slowly: Data frames are received (one every two seconds)
- LED 0 blinking fast: Format error on received frame - wrong payload length, or security control byte has a wrong value
- LED 1 blinking fast: Frame with too small frame counter received
- LED 2 blinking fast: MIC of received frame is wrong

Figure 9-21. Snapshot of secure sensor application.



9.2.3.2.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file main.c and re-built the application
- It is not recommended operating more than two nodes with the application simultaneously

9.2.3.3 Secure_Star_Network

9.2.3.3.1 Introduction

The STB example Secure_Star_Network deploys a non-beacon enabled network with encrypted and authenticated frames. It is using CCM* security. The application consisting of PAN Coordinator and Device utilizing the mechanism of transmitting secured data frames from the Device to the Coordinator after successful joining of the Device to the Coordinator.

This example application uses both STB and MAC-API as interface to the stack. The STB is used to secure application data, and the MAC is used to set-up a non-beacon enabled network, perform scanning and network association, and to transmit or receive secured frames.

The application and all required build files are located in directory Applications/STB_Examples/ Secure_star_Network. The source code of the application can be found in the subdirectory Coordinator/Src and Device/Src.

9.2.3.3.2 Requirements

This application requires

- (Up to three) LEDs on the board in order to indicate the proper working status. A sniffer is suggested in order to check frame transmission between the nodes.

9.2.3.3.3 Implementation

The node acting as a Coordinator (PAN Coordinator) starts a non-beacon enabled PAN at channel DEFAULT_CHANNEL with the PAN ID DEFAULT_PAN_ID. The Device scans for this network and associates to the PAN Coordinator. Once the Device is associated, it uses a timer that fires every 2 seconds to transmit an encrypted packet to the Coordinator.

The frames are secured according to ZigBee/CCM* network layer security:

- The network header is omitted, only the auxiliary security header is constructed (14 byte long).
- The applied security level is 0x05, i.e. encrypted payload, authentication applied, MIC 8 byte long.
- The random payload has 23 byte length.

The LEDs signal the following status:

Device:

- LED 0 on: Application is running.
- LED 1 on: Device is associated to Coordinator.
- LED 2 on: Data frames are sent (one every 2 seconds).

Coordinator:

- LED 0 on: Application is running.
- LED 1 on: Network is started.
- LED 2 on: Data frames are received (one every 2 seconds).

9.2.3.3.4 Limitations

- The current channel is coded within the application. In order to run the application on another channel, change the default channel in file *main.c* and re-build the application.
- It is not recommended operating more than two nodes with the application simultaneously

9.3 Common SIO handler

Applications that require SIO input or output (via UART or USB) in order to print data on a terminal or to get input from the end user can utilize a common SIO handler that

provides helper functions for platform independent processing of serial information. These helper functions are

- sio_putchar(): print one character
- sio_getchar(): read one character via SIO (blocking function)
- sio_getchar_nowait(): read one character via SIO without blocking

The helper functions in return make use of the PAL related SIO functions such as pal_sio_tx() and pal_sio_rx(). This allows for easy implementation of SIO functionality in the application.

The SIO handler is located in directory

```
Applications/Helper_Files/SIO_Support
```

The implementation is located in file sio_handler.c in the Src directory, whereas the corresponding function declaration is located in file sio_handler.h in the Inc directory.

For the IAR compiler the file write.c located in the IAR_Support needs to be added as well.

In order to use these helper functions, the application needs to do the following things:

- Include the header file in its source files
  ```
  #include "sio_handler.h"
  ```
- Extend the include search path for GCC Makefiles, for example
  ```
  PATH_SIO_SUPPORT = $(MAIN_DIR)/Applications/Helper_Files/SIO_Support
  . . .
  ## Include directories for SIO support
  INCLUDES += -I $(PATH_SIO_SUPPORT)/Inc
  ```
- Extend the include search path for IAR project files, for example
  ```
  <name>newCCIncludePaths</name>
  . . .
  <state>$PROJ_DIR$\..\..\..\..\Helper_Files\SIO_Support\Inc</state>
  ```
- Add file sio_handler.c to the list of source and object files in GCC Makefiles, for example
  ```
  ...
  $(TARGET_DIR)/sio_handler.o\
  ...
  $(TARGET_DIR)/sio_handler.o: $(PATH_SIO_SUPPORT)/Src/sio_handler.c
  $(CC) -c $(CFLAGS) $(INCLUDES) -o $@ $<
  ```

```
Add file sio_handler.c to the list of source and object files in
GCC Makefiles, e.g.
<file>
<name>
$PROJ_DIR$\..\..\..\..\Helper_Files\SIO_Support\Src\sio_handler.c
</name>
</file>
<file>
<name>
```

```
$PROJ_DIR$\..\..\..\..\Helper_Files\SIO_Support\IAR_Support\write.c
</name>
</file>
```

9.4 Handling of callback stubs

The MAC stack must support asynchronous operation by all layers, for instance to allow for callbacks from lower layers back to higher layers without blocking the control flow. This is required to implement the request/confirm or indication/response primitive handling. A common way of implementing asynchrony operation by lower layers is the installation of callback functions, which are called a lower layer, but actually implemented in the higher layer. Callbacks are required by both the TAL and the MAC layer.

9.4.1 MAC callbacks

The MAC Core layer (MCL) requires the following callback functions:

- usr_mcps_data_conf
- usr_mcps_data_ind
- usr_mcps_purge_conf
- usr_mlme_associate_conf
- usr_mlme_associate_ind
- usr_mlme_beacon_notify_ind
- usr_mlme_comm_status_ind
- usr_mlme_disassociate_conf
- usr_mlme_disassociate_ind
- usr_mlme_get_conf
- usr_mlme_orphan_ind
- usr_mlme_poll_conf
- usr_mlme_reset_conf
- usr_mlme_rx_enable_conf
- usr_mlme_scan_conf
- usr_mlme_set_conf
- usr_mlme_start_conf
- usr_mlme_sync_loss_ind

These callback functions are declared in file *MAC/Inc/mac_api.h*. Each MAC based application (HIGHEST_STACK_LAYER = MAC) needs to implement these usr_...() callback functions.

For example an application that uses data transmission mechanisms, will call a function wpan_mcps_data_request, which in return requires the implementation of the corresponding asynchronous callback function usr_mcps_data_conf() to indicate the status of the requested data transmission.

But the same application might, for example, not want to use the MAC primitive MLME-SYNC-LOSS.indication. Nevertheless the callback function usr_mlme_sync_loss_ind() needs to be available or the linker generates a build error. This can be solved by either implementing an empty stub function in the application, or, more conveniently, use an already existing stub function. All required MAC stub

functions are already implemented in the files *usr_mcps_*.c* or *usr_mlme_*.c* in directory *MAC/Src*.

So whenever such a callback is not used by the application, simply add the required usr_*.c stub files to your Makefiles or IAR project files.

9.4.2 TAL callbacks

The TAL requires the following callback functions:

- tal_ed_end_cb
- tal_rx_frame_cb
- tal_tx_frame_done_cb

These callback functions are declared in file *TAL/Inc/tal.h*. Each TAL based application (HIGHEST_STACK_LAYER = TAL) needs to implement these tal_..._cb() callback functions. The MAC layer (residing on top of the TAL) has also implemented these callback functions.

In case these callbacks are not used within the TAL based application, the existing stub functions can easily be used. All required TAL stub functions are already implemented in the files *tal_*_cb.c* in directory TAL/*Src*.

So whenever such a callback is not used by the TAL based application, simply add the required tal_*.c stub files to your Makefiles or IAR project files.

9.4.3 Example for MAC callbacks

The handling of callback stub functions shall be more illustrated by the example of the MAC based application Star_Nobeacon. When opening the main source file of this application Applications/MAC_Examples/Star_Nobeacon/Src/main.c, the source code indicates that the following used MAC callback functions are actually used and filled with dedicated application code:

- usr_mlme_reset_conf – Node can perform a MAC reset
- usr_mlme_scan_conf – Node can perform scanning
- usr_mlme_set_conf – Node can change PIB attributes
- usr_mlme_start_conf – Node can set up a new network
- usr_mlme_associate_ind – Node can accept associations from other nodes
- usr_mlme_comm_status_ind – Required to accept associations from other nodes
- usr_mcps_data_ind – Node can receive data frames
- usr_mlme_associate_conf – Node can perform association to other nodes
- usr_mcps_data_conf – Node can transmit data frames

The remaining callbacks

- usr_mcps_purge_conf
- usr_mlme_beacon_notify_ind
- usr_mlme_disassociate_conf
- usr_mlme_disassociate_ind
- usr_mlme_get_conf
- usr_mlme_orphan_ind
- usr_mlme_poll_conf

- usr_mlme_rx_enable_conf
- usr_mlme_sync_loss_ind

are not used by the application, since this example does not deal with this functionality. In order to avoid implementing empty stubs in the application, the way of using the delivered stub functions in the files usr_*.c shall be used. This is done by adding these stub files to the GCC Makefiles or IAR project files.

In the corresponding GCC Makefile (Applications/MAC_Examples/Star_Nobeacon/any_platform/GCC/Makefile) the following lines can be found in order to add the required object files to the link process:

```
## Objects that must be built in order to link
OBJECTS = $(TARGET_DIR)/main.o\
    $(TARGET_DIR)/pal_uart.o\
    $(TARGET_DIR)/mac_api.o \
    $(TARGET_DIR)/usr_mcps_purge_conf.o \
    $(TARGET_DIR)/usr_mlme_beacon_notify_ind.o \
    $(TARGET_DIR)/usr_mlme_disassociate_conf.o \
    $(TARGET_DIR)/usr_mlme_disassociate_ind.o \
    $(TARGET_DIR)/usr_mlme_get_conf.o \
    $(TARGET_DIR)/usr_mlme_orphan_ind.o \
    $(TARGET_DIR)/usr_mlme_poll_conf.o \
    $(TARGET_DIR)/usr_mlme_rx_enable_conf.o \
    $(TARGET_DIR)/usr_mlme_sync_loss_ind.o
```

In the corresponding IAR project file (*Applications/MAC_Examples/Star_Nobeacon/any_platform/Star.ewp*) the following lines can be found in order to add the required source files to the build process:

```
  <group>
    <name>MAC_API</name>
    <file>
    <name>$PROJ_DIR$\..\..\..\..\MAC\Src\mac_api.c</name>
    </file>
    <file>

<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mcps_purge_conf.c</name>
    </file>
    <file>
    <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_beacon_notify_ind.c
    </name>
    </file>
    <file>
    <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_conf.c
    </name>
    </file>
    <file>
```

```
     <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_ind.c
    </name>
    </file>
    <file>

<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_get_conf.c</name>
    </file>
    <file>
    <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_orphan_ind.c
    </name>
    </file>
    <file>

<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_poll_conf.c</name>
    </file>
    <file>
    <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_rx_enable_conf.c
    </name>
    </file>
    <file>
    <name>
        $PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_sync_loss_ind.c
    </name>
    </file>
  </group>
```

10 Supported platforms

This chapter describes which hardware platforms are currently supported with the Atmel AVR2025 software package. A platform usually comprises of three major components:

- An MCU,
- A transceiver chip (this may be integrated into the MCU for Single Chips)
- A specific Board or even several boards that contain the MCU or the transceiver chip

The supported software for each platform can be found in the directory PAL.

10.1 Supported MCU families

Currently the following generic MCU families are supported:

- AVR32: Atmel AVR32 platforms
- SAM3: Atmel SAM3S platforms
- ARM7: Atmel ARM7 platforms
- AVR: Atmel AVR 8-bit ATmega platforms
- MEGA_RF: Atmel AVR 8-bit ATmega RF Single Chip platforms
- XMEGA: Atmel AVR 8-bit ATxmega platforms

The dedicated code for each platform family can be found in the corresponding subdirectories.

10.2 Supported MCUs

Within each platform family a number of MCUs are supported. These are for example the Atmel AT32UC3X, Atmel ATmega1281, Atmel ATxmega128A1, Atmel ATmega128RFA1, Atmel AT90SAM7X256, Atmel AT91SAM3S4X etc.

For a complete list of the actually supported MCUs please refer to the Atmel AVR2025 release notes (*MAC_Release_Notes.txt* in directory *MAC_v_x_y_z\Doc*) or directly look into the various subdirectories as mentioned in Section 10.1.

10.3 Supported transceivers

For a complete list of all supported transceivers please refer to the AVR2025 release notes (*Release_Notes.txt* in directory *MAC_v_x_y_z\Doc*).

10.4 Supported boards

The actually supported boards can be found in the corresponding PAL Boards directories *MAC_v_x_y_z/PAL/pal_family_name/mcu_name/Boards*. For example all supported boards for the ATmega128RFA1 Single Chip are located in directory *PAL/MEGA_RF/ATMEGA128RFA1/Boards*. Each board directory contains a file *pal_boardtypes.h* (or *vendor_boardtypes.h*), which contains a list of all supported boards based on this specific MCU together with a short description.

The following sections describe the currently supported hardware platforms in more detail. All described hardware boards are available from Atmel (see [1]) or third party vendors (for example, see [2]).

For a short list of the supported peripherals of each board see Section 10.4.5.

10.4.1 Radio controller boards (RCB) based platforms

The Radio Controller Board (RCB) is a radio module containing either a MCU (for example, Atmel ATmega1281) and an Atmel transceiver, or an Atmel Single Chip. RCBs can be used stand alone as plain RCB or in conjunction with a base board providing additional peripheral capabilities.

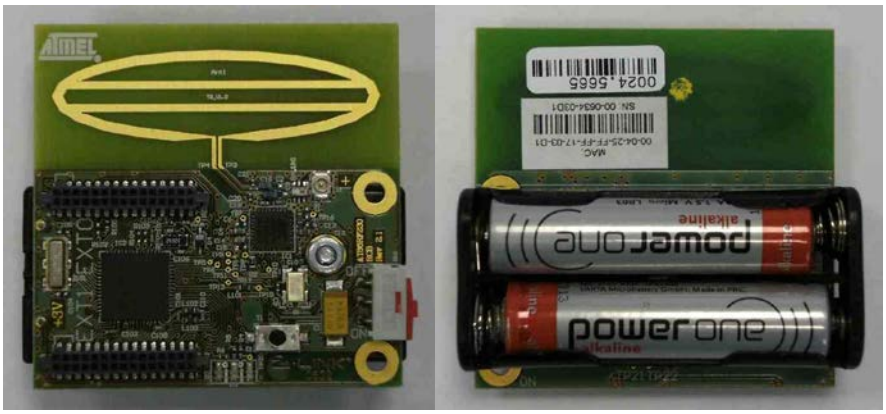
10.4.1.1 Plain radio controller board RCB230 V3.1

For more information about earlier versions of the Plain Radio Controller Boards prior to V3.2 please contact Atmel support ([3]).

10.4.1.2 Plain radio controller board RCB230 V3.2

- Atmel AT86RF230B and ATmega1281
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_3_2_PLAIN

Figure 10-1. RCB V3.2 with AT86RF230B and ATmega1281.



10.4.1.3 Plain radio controller board RCB231 V4.0

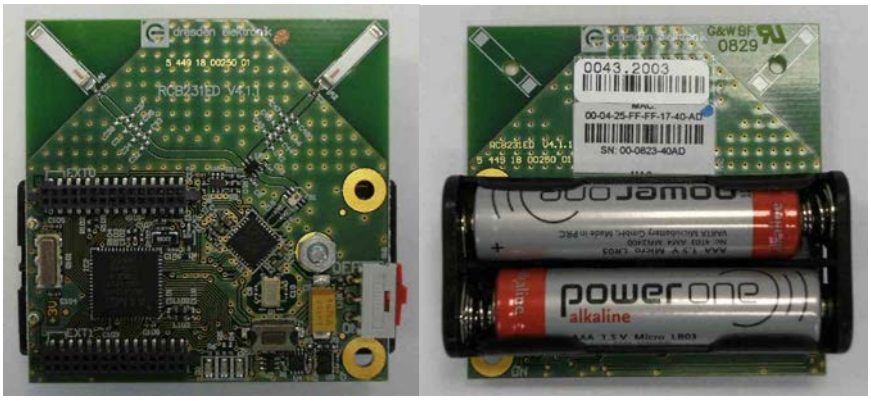
- Atmel AT86RF231 with and ATmega1281
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_4_0_PLAIN

Figure 10-2. RCB V4.0 with AT86RF231 and ATmega1281.

10.4.1.4 Plain radio controller board RCB231ED V4.1.1

- Atmel AT86RF231 with Antenna Diversity and Atmel ATmega1281
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_4_1_PLAIN

Figure 10-3. RCB V4.1 with AT86RF231 and ATmega1281.



10.4.1.5 Plain radio controller board RCB231SMA V5.3.2

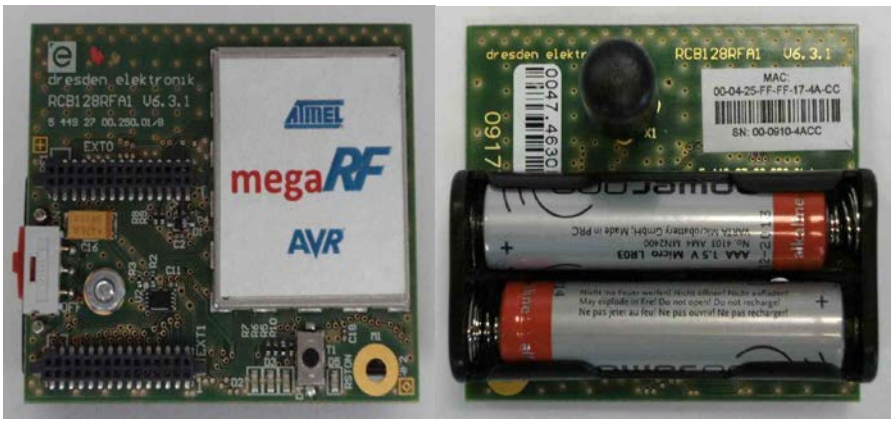
- Atmel AT86RF212 with and ATmega1281
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_5_3_PLAIN

Figure 10-4. RCB V5.3 with AT86RF212 and ATmega1281.

10.4.1.6 Plain radio controller board RCB V6.3 with Atmel ATmega128RFA1

- Atmel ATmega128RFA1 Single Chip only
- See PAL\MEGA_RF\ATMEGA128RFA1\Boards\RCB_6_3_PLAIN

Figure 10-5. RCB V6.3 with Atmel ATmega128RFA1.



10.4.1.7 Plain radio controller board RCB V6.3.2 with Atmel ATmega256RFR2

- Atmel ATmega256RFR2 Single Chip only
- See PAL\MEGA_RF\ATMEGA256RFR2\Boards\ RCB_6_3_2_SENS_TERM_BOARD

Figure 10-6. RCB V6.3.2 with Atmel ATmega256RFR2.

10.4.1.8 Sensor terminal board

The Sensor Terminal Board can be used as baseboard for a Plain RCB to enable SIO capabilities via USB. It provides one button and two LEDs for user interaction. It can be used for existing RCBs mentioned in Section 10.4.1.

The following pictures depict a Sensor Terminal Board with and without an RCB, and also indicate how the Sensor Terminal Board is connected to the Atmel AVR JTAGICE.

Figure 10-7. Sensor terminal board without RCB.

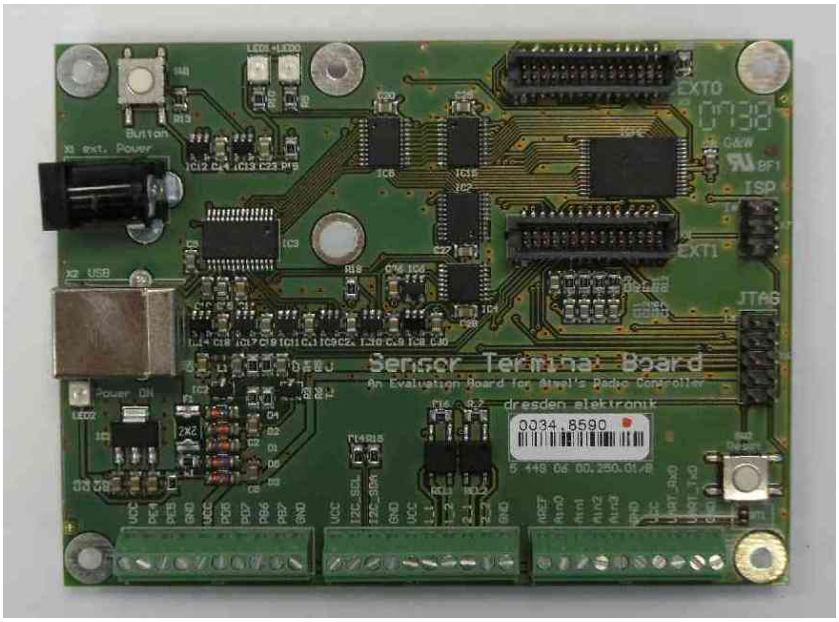


Figure 10-8. Sensor terminal board with RCB V6.3 with Atmel ATmega128RFA1.

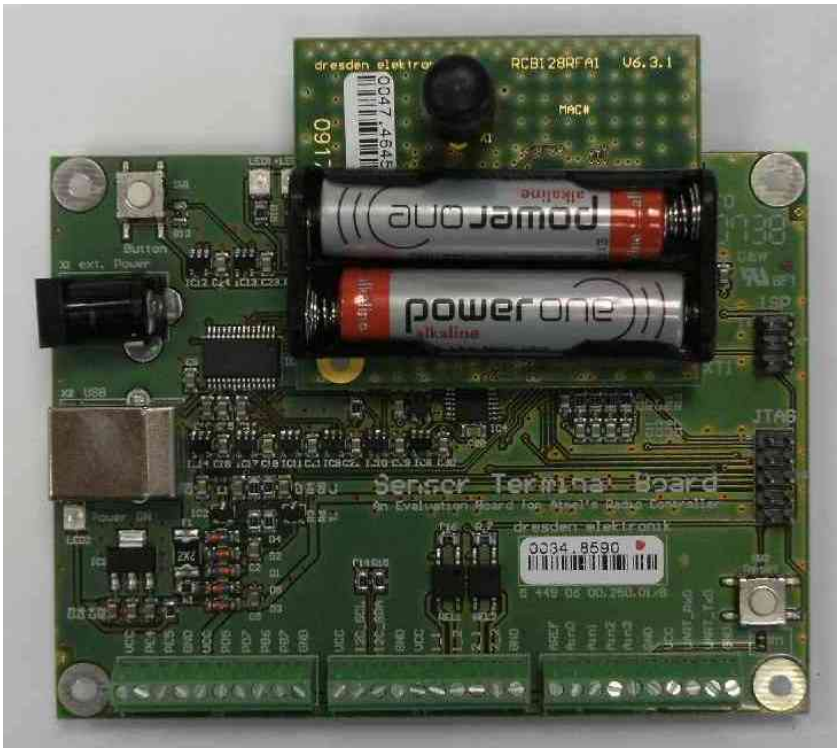
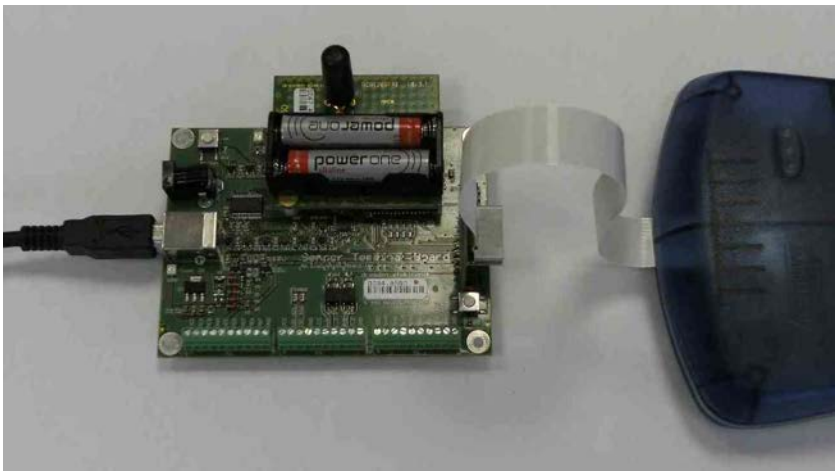


Figure 10-9. Sensor terminal board connected to Atmel AVR JTAGICE and USB.



The Sensor Terminal Board can be powered with USB, although it is recommended to use a powered hub in case the board is not directly connected to a PC.

10.4.2 Radio extender boards (REB)

The Radio Extender Board (REB) is a radio module containing an Atmel transceiver. REBs cannot be used stand alone but require an additional baseboard for the MCU, such as Atmel STK600, Atmel AT91SAM7X-EK, Atmel AT91SAM7XC-EK, etc.

10.4.2.1 Radio extender board REB230 V2.1

For more information about earlier versions of the Radio Extender Boards prior to V2.3 please contact Atmel support ([3]).

10.4.2.2 Radio extender board REB230 V2.3

- Atmel transceiver: Atmel AT86RF230B
- The REB230B V2.3 is supported on several platforms:
    - See PAL\XMEGA\ATXMEGA256A3\Boards\REB_2_3_CBB
    - See PAL\AVR32\AT32UC3B1128\Boards\REB_2_3_STK600
    - See ARM7\AT91SAM7X256\Boards\REB_2_3_REX_ARM_REV_2

Figure 10-6. REB V2.3 with Atmel AT86RF230B.

10.4.2.3 Radio extender board REB231 V4.0.1

- Atmel transceiver: Atmel AT86RF231
- The REB231 V4.0 is supported on several platforms:
    - See PAL\AVR32\AT32UC3B1128\Boards\REB_2_3_STK600
    - See PAL\XMEGA\ATXMEGA256A3\Boards\REB_4_0_CBB

Figure 10-7. REB V4.0.1 with AT86RF231.

10.4.2.4 Radio extender board REB231ED V4.1.1

- Atmel transceiver: AT86RF231 using Antenna Diversity
- The REB231ED V4.1 is supported on several platforms:

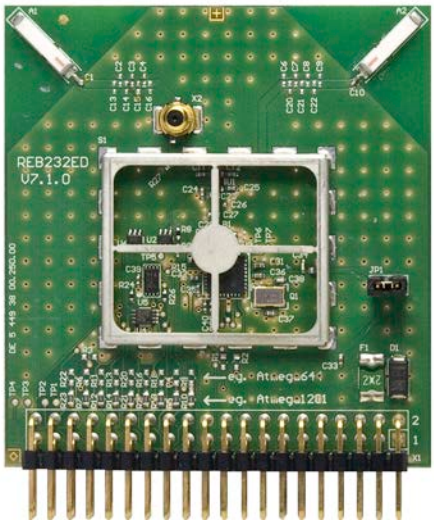
- See PAL\XMEGA\ATXMEGA256A3\Boards\REB_4_1_CBB

Figure 10-8. REB231ED V4.1.1 with Atmel AT86RF231.

10.4.2.5 Radio extender board REB232 V7.1.0

- Atmel transceiver: Atmel AT86RF232
- The REB232 V7.1 is supported on several platforms:
  - See PAL\XMEGA\ATXMEGA256A3\Boards\REB_7_1_CBB

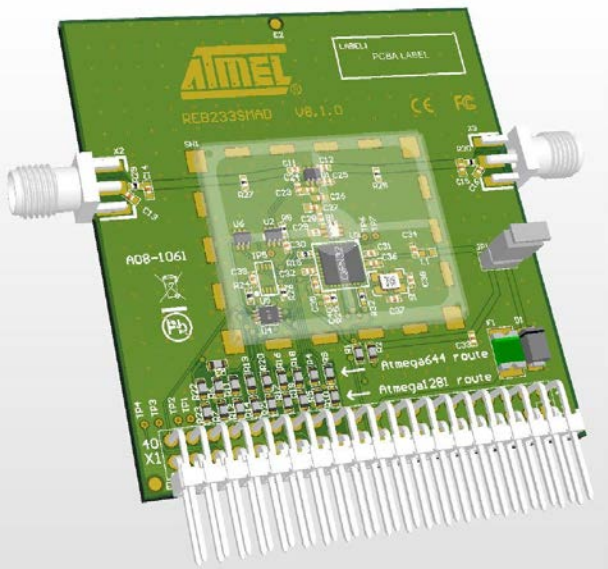
Figure 10-9. REB V7.1.0 with AT86RF232.



10.4.2.6 Radio extender board REB233 V8.1.0

- Atmel transceiver: Atmel AT86RF233
- The REB233 V8.1 is supported on several platforms:
  - See PAL\XMEGA\ATXMEGA256A3\Boards\REB_8_1_CBB

Figure 10-10. REB V8.1.0 with AT86RF233.



10.4.2.7 Radio extender board REB212 V5.0.2

- Atmel transceiver: Atmel AT86RF212
- The REB212 V5.0 is supported on several platforms:
    - See PAL\AVR32\AT32UC3B1128\Boards\REB_5_0_STK600
    - See PAL\XMEGA\ATXMEGA256A3\Boards\REB_5_0_CBB

Figure 10-11. REB212 V5.0.2 with Atmel AT86RF212.

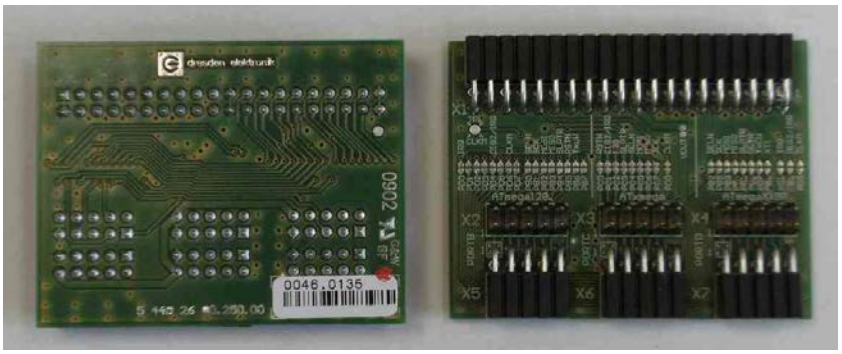
10.4.3 Radio extender boards (REB) based platforms

10.4.3.1 STK600 and REB to STK600 Adapter

The Atmel STK600 in conjunction with an REB to STK600 Adapter can be used as a baseboard for an REB to create platforms using AVR 8-bit MCUs (such as Atmel ATxmega or Atmel ATmega MCUs). It provides eight buttons and LEDs for user interaction. It can be used for existing REBs mentioned in Section 10.4.2.

The following pictures depict an REB to STK600 Adapter and an STK600 with an REB with REB to STK600 Adapter.

Figure 10-12. REB to STK600 adapter.



10.4.3.2 CBB-REB

The CBB in conjunction with an REB can be used as a baseboard for an REB to create platforms using Atmel XMEGA MCUs (such as Atmel ATxmega256A3 MCUs). It provides currently three LEDs and two buttons for user interaction.

Currently supported are:

- REB230B V2.3 (with Atmel AT86RF230) in conjunction with CBB (with ATxmega256A3 MCU)
- REB231 V4.1.1 (with Atmel AT86RF231) in conjunction (with ATxmega256A3 MCU)
- REB232 V7.1.0 (with Atmel AT86RF232) in conjuction with CBB (with ATxmega256A3 MCU)
- REB212 V5.0.2 (with Atmel AT86RF212) in conjunction with CBB (with ATxmega256A3 MCU)

The following pictures depict an Atmel ATxmega256A3 CBB board with REB231 V4.1.1 (with Atmel AT86RF231).

Figure 10-17. REB-CBB assembly.

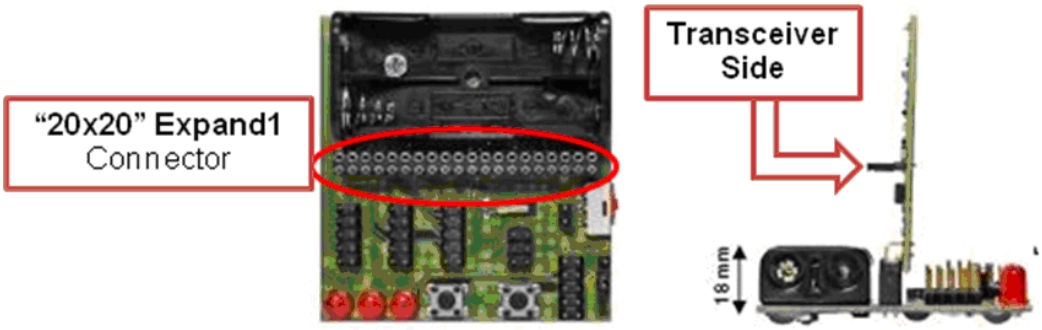


Figure 10-18. REB-CBB with UART cable.

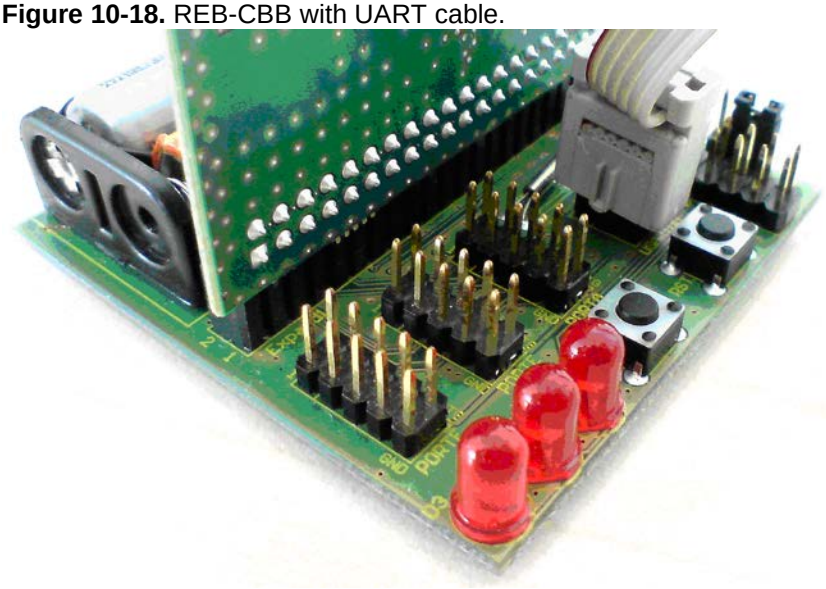


Figure 10-19. Connecting UART cable and JTAG to CBB.

10.4.3.3 AT91SAM7X-EK

The Atmel AT91SAM7X-EK in conjunction with an REB to ARM Adapter can be used as a baseboard for an REB to create platforms using Atmel ARM7 MCUs (such as Atmel AT91SAM7X256 MCUs). It provides currently four LEDs and a joystick for user interaction.

Currently supported are:

- REB230B V2.3 (with Atmel AT86RF230) in conjunction with REB to ARM Adapter Rev. 2 (REV_ARM REV 2)
- REB231 V4.0.1/V4.0.2 (with Atmel AT86RF231) in conjunction with REB to ARM Adapter Rev. 3 (REV_ARM REV 3)
- REB212 V5.0.2 (with Atmel AT86RF212) in conjunction with REB to ARM Adapter Rev. 3 (REV_ARM REV 3)

The following pictures depict an AT91SAM7X-EK board with Atmel AT91SAM7X256 and an AT91SAM7X-E with an REV_ARM REV 2 with REB230B V2.3.

Figure 10-20. Atmel AT91SAM7X-EK board with Atmel AT91SAM7X256.

Figure 10-21. AT91SAM7X-EK board with AT91SAM7X256.

Figure 10-22. Atmel AT91SAM7X-EK board with Atmel AT91SAM7X256 connected to Atmel SAM-ICE and UART.

10.4.4 Atmel AT91SAM7XC-EK

The AT91SAM7XC-EK is handled similar to the AT91SAM7X-EK.

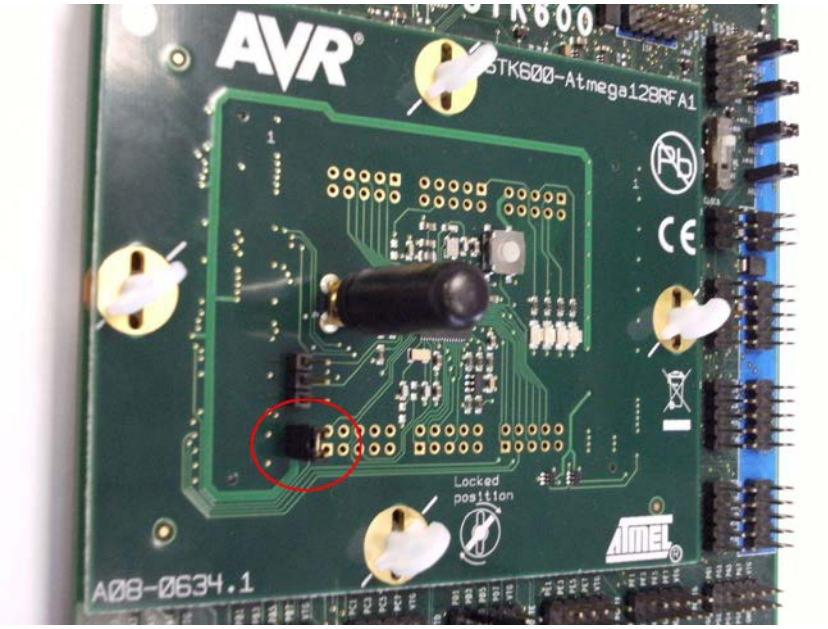
10.4.5 ATmega128RFA1-EK1 evaluation kit

The Atmel ATmega128RFA1-EK1 Evaluation Kit provides an Atmel STK600-ATmega128RFA1 Top Card that can be used in conjunction with the STK600 board. No further Routing Cards are required.

- See PAL\MEGA_RF\ATMEGA128RFA1\Boards\EK1
- It provides currently three LEDs and one button for user interaction (similar to RCBs)
- The buttons and LEDs from the STK600 base board are not supported
- Both UART0 and UART1 are supported (UART1 is default in provided example applications)

The following picture depicts an Atmel ATmega128RFA-EK1 Top Card placed on an Atmel STK600 base board and the board setup connected to an Atmel AVR JTAGICE and setup for utilization of UART1.

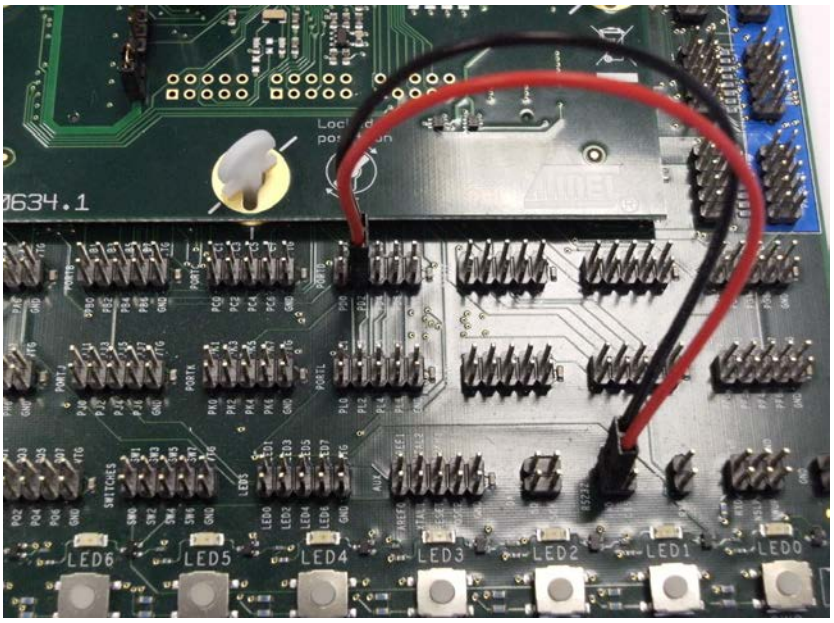
Figure 10-23. ATmega128RFA1-EK1 on STK600.



Please note that jumper J11 (see red circle in Figure 10-) needs to be placed as shown in Figure 10- (if no current measurements are done) in order to provide the proper voltage to the board.

Figure 10-24. ATmega128RFA1-EK1 on STK600 with JTAGICE using UART1.

Figure 10-25. Atmel ATmega128RFA1-EK1 wiring for UART1.



NOTE The ATmega128RFA1-EK1 is not optimized for RF performance.

10.4.6 Atmel RZ600 on Atmel AT32UC3L-EK

The RZ600 Evaluation board (as part of the RZ600 evaluation kit) is supported on top of an AT32UC3L-EK evaluation and demonstration kit (based on Atmel AT32UC3L064):

- See PAL\AVR32\AT32UC3L064\Boards\RZ600_2XX_UC3LEK
- Images need to be flashed using Atmel AVR JTAGICE and the JTAG connector
- Images can also be downloaded using Atmel AVR ONE!
- A USB driver providing a virtual COM port for the AT32UC3L-EK board (based on the CDC Driver) is provided in the software package (see at32uc3xxx_cdc.inf in directory: PAL\Board_Utils\AVR32_USB_Driver)

The debugger connections are explained in the sections below, using a squid cable with Atmel AVR JTAGICE mkII or Atmel AVR ONE! debugger.

Figure 10-26. Atmel AT32UC3L-EK board with Atmel AVR JTAGICE mkII.

JTAGICE mkII with AT32UC3L-EK connection details:

- White – Pin 2 of JTAG Header of AT32UC3L-EK
- Purple – Pin 4 of JTAG Header of AT32UC3L-EK
- Red – Pin 6 of JTAG Header of AT32UC3L-EK

Figure 10-27. AT32UC3L-EK board with Atmel AVR ONE!.

AVR ONE! with AT32UC3L-EK connection details:

- White – Pin 2 of JTAG Header of AT32UC3L-EK
- Purple – Pin 4 of JTAG Header of AT32UC3L-EK
- Grey – Pin 6 of JTAG Header of AT32UC3L-EK

10.4.7 Atmel STK600 (Atmel AT32UC3B1128) with REB

The STK600 is supported with REB in conjunction with an REB to Atmel STK600 Adapter can be used as a baseboard for an REB to create platforms using AVR 8-bit MCUs (such as Atmel ATxmega or Atmel ATmega MCUs). But for Atmel AVR32 (AT32UC3B1128) the STK600 can be connected to the REB by using the connection details given below, that is, Table 10-1.

- See PAL\AVR32\AT32UCB1128\Boards\REB_X_X_STK600
- Images need to be flashed using Atmel AVR JTAGICE and the JTAG connector given on the STK600
- A USB driver providing a virtual COM port for the AT32UC3B1128 (based on the CDC Driver) is provided in the software package (see at32uc3xxx_cdc.inf in directory: PAL\Board_Utils\AVR32_USB_Driver)

It provides eight buttons and LEDs for user interaction. Table 10-1 depicts the socket and routing card needed for Atmel AT32UC3B1128 MCU and Atmel REB231 to STK600 connection details. Similar connection can be made for Atmel REB230B and Atmel REB212.

Table 10-1. STK600 (AT32UC3B1128) with REB connection details.

AT32UC3B1128 CONNECTION WITH AT86RF231		
Routing Card	STK600 - RCuC3B48-27	
Socket Card	STK600-TQFP48	
No	STK-600	RF231
1	PA6	38
2	PA7	25
3	PB0	26
4	PD1	27
5	PB6	28
6	PB7	29
7	PC0	30
8	VTG	20
9	GND	21
No	STK-600	STK600-RS232 SPACE
10	PC7	TXD
11	PD0	RXD

10.4.8 RZ600 kit

The Atmel RZ600 Kit which is based on Atmel AT32UC3S3256S MCU is also supported on this release:

- See PAL\AVR32\AT32UC3A3256\Boards\RZ600_2XX
- Images need to be flashed using JTAGICE and the 10-pin JTAG connector

- A USB driver providing a virtual COM port for the Atmel RZ600 board (based on the CDC driver) is provided in the software package (see at32uc3xxx_cdc.inf in directory: PAL\Board_Utils\AVR32_USB_Driver)

The debugger connections are explained in the sections below, using a 10-pin JTAG connector.

Figure 10-28. RZ600 (Atmel AT32UC3A3256S) connection details.

10.4.9 Atmel AT91SAM3S-EK

The AT91SAM3S-EK can be used to create platforms using Atmel SAM3S MCUs (such as Atmel AT91SAM3S4C MCUs). It provides currently three LEDs and Atmel QTouch for user interaction.

- See PAL\SAM3\AT91SAM3S4C\Boards\RZ600_2XX_SAM3SEK
- Images need to be flashed using SAM-ICE
- Images can also be downloaded using SAM-BA CDC
- A USB driver providing a virtual COM port for the AT91SAM3S-EK board (based on the CDC Driver) is provided in the software package (see *AT91SAM3S-EK.inf* in directory: *PAL\Board_Utils\SAM3SEK_USB_Driver*)

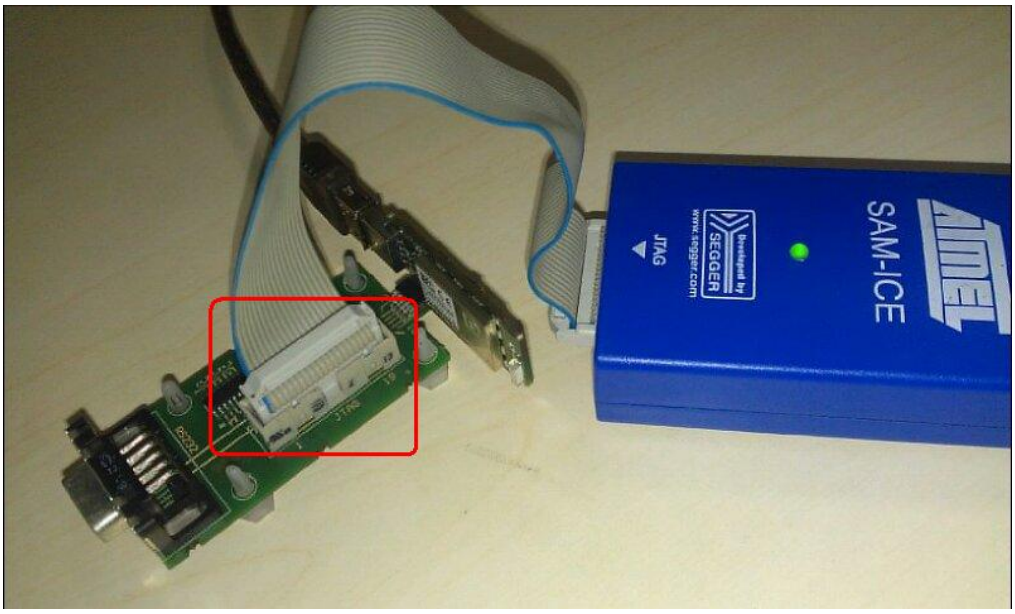
Figure 10-29. Atmel AT91SAM3S-EK connection details.

10.4.10 Atmel SAM3S USB sticks

The SAM3S USB sticks are based on Atmel AT91SAM3S4B. It provides currently three LEDs for user interaction.

- See PAL\SAM3\AT91SAM3S4B\Boards\DERF_USB_XXEXX
- Images need to be flashed using Atmel SAM-ICE and SAM-ICE adaptor
- Images can also be downloaded using Atmel SAM-BA CDC
- A USB driver providing a virtual COM port for the SAM3S USB sticks (based on the CDC Driver) is provided in the software package (see *deRFusbXXEXX.inf.inf* in directory: *PAL\Board_Utils\SAM3S_USB_Stick_Driver*)

Figure 10-30. SAM3S USB sticks (Atmel AT91SAM3S4B) connection details.



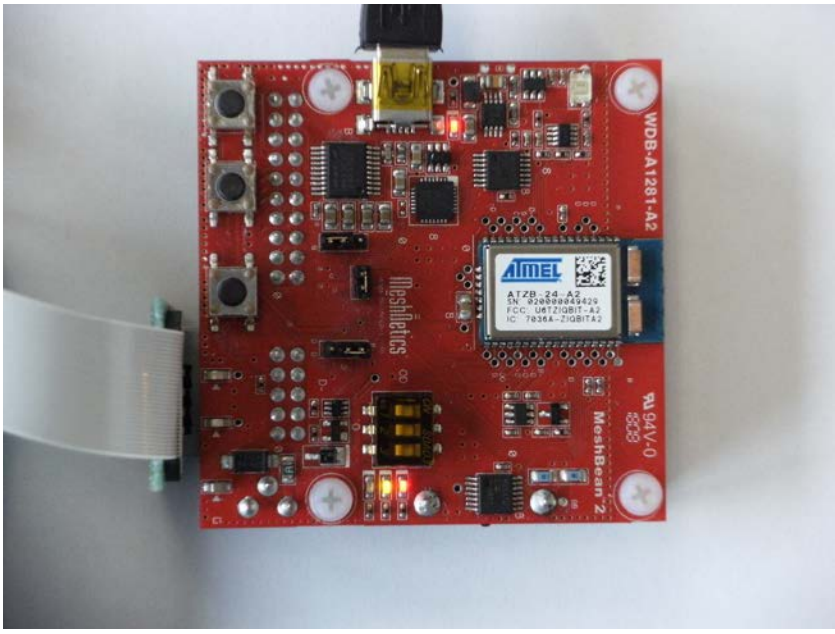
10.4.11 ZigBit Modules on Top of Meshbean2 Board

The ZigBit Modules are supported on top of a MeshBean2 board (based on ATmega1281):

- See PAL\AVR\ATMEGA1281\Boards\ATZB_24_MN2 for the ZigBit 2.4 GHz support based on AT86RF230B
- Images need to be flashed using JTAG-ICE and the JTAG connector
- An installation programm for the USB driver providing a virtual COM port for the MeshBean2 board is provided in the software package (see CP210x_VCP_Win2K_XP_S2K3.exe in directory PAL\Board_Utils\MeshBean2)
- For more information about the ATZB ZigBit Modules refer to [8]

The following picture depicts an ATZB ZIgBit Module on top of the MeshBean2 board conntected to a JTAG_ICE.

Figure 10-31. ATZB ZIgBit Module on Top of MeshBean2 Board with JTAG-ICE and USB



10.4.12 Peripherals

Each board or combination of boards provides a variety of peripherals that determine which application can be executed to which extent of this board. This section provides an overview about the differences for the various platforms for the following peripherals:

- Buttons
- LEDs
- SIO support (UART, USB)

Table 10-2. Peripherals supported by platform type.

	Buttons	LEDs	SIO support
Plain RCB	1	3	No

	Buttons	LEDs	SIO support
Sensor terminal board + RCB	1	2	USB
Atmel STK600 + REB to STK600 Adapter + REB	8	8	UART
Atmel AT91SAM7X(C)-EK + REX_ARM + REB	Joystick	4	UART
Atmel ATmega128RFA1-EK1	1	3	UART
Atmel AT32UC3LEK + RZ600	1	4	USB
RZ600	0	2	USB
STK600(AVR32)+REB	8	8	UART & USB
Atmel AT91SAM3S-EK+RZ600 Radio	2	3	UART & USB
Atmel SAM3S USB sticks	0	3	USB

11 Platform porting

11.1 Porting to a new platform

In case a new platform that is not supported yet needs to be utilized, the task to bring-up the new platform can be performed as described in the following section. Generally this task can be split into different subtasks:

35. Bring-up of a new PAL or of a board within an already existing PAL.
36. Bring-up of an existing application on the new platform.
37. Bring-up of new applications on the new platform (if required).

Each of these subtasks will be explained subsequently and described on an example.

Before the actual porting is described a number of terms need to be defined:

- Target MCU: MCU that is not yet supported and shall be utilized within a new platform
- Base MCU: MCU that is already supported within the MAC package and it's PAL implementation is used as base code for the target MCU
- Target board: Board based on the target MCU that is not yet supported and shall be utilized within a new platform
- Base board: Board that is already supported within the base MCU PAL directory and is used as base code for the target board
- Target platform: Platform consisting of target MCU and target board
- Base platform: Platform consisting of base MCU and base board

11.2 Bring-up of a new PAL

If the target platform is not provided by the MAC software package this platform needs to be brought-up. A new target platform can be one of the following cases:

a) Bring-up of a new customized board for an already supported MCU: This is usually the case of the customer has designed its own hardware board using a standard Atmel MCU (for example, Atmel ATmega1281). This is the simplest case and is described in Section 11.3.

b) Bring-up of a new platform based on a not yet supported MCU but within a supported MCU family: This is usually the case if the customer wants to use a dedicated MCU (for example, with different memory resources such as using the Atmel ATxmega256A3), that is based on an existing MCU family (Atmel ATxmega family). This case is described in more detail in Section 11.4.

c) Bring-up of a new platform based on a not yet supported MCU within a not yet supported MCU family, such as an ARM device not based on the ARM7 family.

11.3 Bring-up of a new hardware board

11.3.1 Implementation of PAL for target platform

The task of bringing-up a new platform ("target platform") for an already supported MCU is explained in general within this section and furthermore by the example of a platform based on the Atmel AT91SAM7X256 in Section 11.3.2. The same steps are to be performed for all other platforms or boards respectively that shall be used.

11.3.1.1 Phase1: General preparation for target platform

The first phase is a simple preparation phase. It provides the required directory and file-structure for the target platform/board and defines proper build switches required for this target platform.

- Step 1: Identify the MCU for the target board
    - Each supported MCU is identified by a specific value of the build switch PAL_TYPE (and is part of a specific MCU family specified by the build switch PAL_GENERIC_TYPE)
    - For a list of all currently supported MCUs with a given MCU family check file PAL/Inc/pal_types.h for defined values of PAL_TYPE for each MCU family
    - For more information see also Section 10.2
- Step 2: Add the target board to the selected MCU (that is, PAL_TYPE) in the corresponding file containing the supported hardware platforms for the target MCU. This can be done using one of the following approaches:
    a. Add the board type to the existing file PAL/*MCU_FAMILY_NAME*/*MCU_NAME*/Boards/pal_boardtypes.h. As an example for a new board for the Atmel AT81SAM7X256, add the target board to file PAL/ARM7/AT91SAM7X256/Boards/pal_boardtypes.h (see Section 11.3.2). Make sure that the new board type gets a unique reasonable number in its definition. The actually selected number for the board definition itself can be deliberately selected, as long as it is unique in this particular board definition header file.
    b. Or create a new file vendor_boardtypes.h and add the new hardware platform with its own ID in this file. An example of such a vendor specific file can be found at *PAL/AVR/ATMEGA1281/Boards/vendor_boardtype_example.h*. Copy this file into your board directory and rename it to *vendor_boardtype.h*. Added the boardtype into this file. Also make sure that the build switch “VENDOR_BOARDTYPES” is used within your application project files.
- Step 3: Identify an already supported board that best fits the target board to start the porting (“base platform”):
    - Each supported board based on a given MCU is identified by a specific value of the build switch BOARD_TYPE
    - For a list of all currently supported boards check file PAL/*MCU_FAMILY_NAME*/*MCU_NAME*/Boards/pal_boardtypes.h for defined values of BOARD_TYPE
    - For more information see also Section 10.4
- Step 4: Copy the PAL board directory of the base platform in a separate directory within the same board directory (of the target MCU) and name it according to the target platform
- Step 5: Rename all occurrences of base platform to target platform

11.3.1.2 Phase2: Actual porting to target platform

This section describes the actual porting phase once the directory and file structure of the target platform has been established.

The board directory of the target platform contains currently three files (same as for the base platform):

- pal_board.c
- pal_irq.c
- pal_config.h

Within the next phase all hardware resources need to be adjusted from the base platform to fit the resources of the target platform, such as timers, IRQs, ports, LEDs, buttons, ports and registers for SIO support, etc. This is explained in the subsequent steps.

All of these files are now adapted to the target platform needs step by step.

- Step 6: File pal_irq.c

  This source file contains functions to initialize, enable, disable and install handler for the transceiver interrupts. It needs to be updated to match the requirements of the target board when handling the transceiver interrupts (see examples in Section 11.3.2.6 and in Section 11.4.2.8).

- Step 7: File pal_board.c

  This source file contains board specific functions to initialize and handle peripherals (such as LEDs, buttons, GPIO to the transceiver). It needs to be updated to match the requirements of the target board when handling these peripherals (see Section 11.3.2.7).

- Step 8: File pal_config.h

  This header file contains configuration parameters for the target platform such as CPU frequency for this particular board, IRQ pins, pins between transceiver and MCU, LED pins, button pins, timer clock source definitions, debug macros, etc. It needs to be updated to match the requirements of the target board (see example in Section 11.3.2.8)

11.3.2 Example implementation of PAL for Atmel AT91SAM7X256 based platform

This section describes the porting activities explained in the previous sections in general more specifically for the example of porting an existing software package based on the AT91SAM7X256 ARM 7 MCU to the new target board Atmel AT91SAM7X-EK with Radio Extender board REB231 V4.0 on REX_ARM adapter Revision 3 (REB_4_0_2_REX_ARM_REV_3) in order to support the Atmel AT86RF231 transceiver on this MCU.

11.3.2.1 Step 1 – Identify the MCU of the new board

The target board is based on the MCU AT91SAM7X256. It is a member of the ARM7 family. Therefore new code of the target board is based on the PAL_GENERIC_TYPE=ARM7 and PAL_TYPE= AT91SAM7X256.

11.3.2.2 Step 2 – Add the new board to file pal_boardtypes.h

To add support for the target board “AT91SAM7X-EK with Radio Extender board REB231 V4.0 on REX_ARM adapter Revision 3”, open file PAL/ARM7/AT91SAM7X256/Boards/pal_boardtypes.h and add the target board definition to the proper section of this file. Since the REB_4_0_2_REX_ARM_REV_3 is based on the transceiver Atmel AT86RF231, the new target board shall be added to the section “Boards for AT86RF231” where all AT86RF231 based boards for this MCU are listed. Use a not existing unique value for the target board. Make sure that

the new target board type gets a unique reasonable number in its definition. The actually selected number for the board definition itself can be deliberately selected, as long as it is unique in this particular board definition header file.

Example:

```
/* Boards for AT86RF230B */
#define REB_2_3_REB_TO_SAM7EK       (0x01)
#define REB_2_3_REX_ARM_REV_2       (0x02)

/* Boards for AT86RF231 */
#define REB_4_0_2_REB_TO_SAM7EK3    (0x11)
/* AT91SAM7X-EK and AT91SAM7XC-EK boards with Radio Extender board
REB231 V4.0 on REX_ARM adapter Revision 3 */
#define REB_4_0_2_REX_ARM_REV_3     (0x12)
```

The actual numerical value of each define is not important, as long as each board within a specific PAL_ TYPE has a unique value.

Alternatively create a new board type in a customer specific board type file called *vendor_boardtypes.h* (see 11.3.1.1).

11.3.2.3 Step 3 – Identify an already supported board that best fits the new board as base platform

From all currently supported boards based on the Atmel AT91SAM7X256 MCU the board “REB_2_3_REX_ARM_REV_2” (Atmel AT91SAM7X-EK boards with Radio Extender board REB230B V2.3 on REX_ARM adapter Revision 2) is selected as base platform to start the porting to the target platform “REB_4_0_2_REX_ARM_REV_3”.

11.3.2.4 Step 4 – Copy the board directory of the base platform

Example:

Copy the entire board directory
PAL/ARM7/AT91SAM7X256/Boards/REB_2_3_REX_ARM_REV_2
and rename it to directory
PAL/ARM7/AT91SAM7X256/Boards/REB_4_0_2_REX_ARM_REV_3.
Your directory PAL/ARM7/AT91SAM7X256/Boards now contains the following entries:

```
REB_2_3_REX_ARM_REV_2
…
REB_4_0_2_REX_ARM_REV_3
…
```

The directory REB_4_0_2_REX_ARM_REV_3 currently contains the identical code from the directory REB_2_3_REX_ARM_REV_2 (from the base platform). It comprises of the following files:

```
pal_board.c
pal_irq.c
pal_config.h
```

11.3.2.5 Step 5 – Rename all occurrences of base platform to target platform

Within the entire directory

PAL/ARM7/AT91SAM7X256/Boards/REB_4_0_2_REX_ARM_REV_3 all occurrences of the string “REB_2_3_REX_ARM_REV_2” are searched and replaced by the target Platform “REB_4_0_2_REX_ARM_REV_3”. In this example this needs to be done in the following files:

- pal_board.c
- pal_irq.c
- pal_config.h

11.3.2.6 Step 6 – File pal_irq.c

This file contains functions to initialize, enable, disable and install handler for the transceiver interrupts. In this porting example it is a file dedicated to a board utilizing the transceiver Atmel AT86RF231, but is derived from a board utilizing the transceiver Atmel AT86RF230B.

While the AT86RF230B provides only one transceiver interrupt, the AT86RF231 provides usually two transceivers interrupt. This approach is followed fore most boards for the Atmel AVR and Atmel XMEGA MCU family.

Since the Atmel AT91SAM7X256 provides on a limited number of external interrupts, this approach is not followed in this example. The AT86RF231 is only used with one transceiver interrupt enabled. The Timestamp interrupt (based on DIG2 pin from the transceiver) is not used. Timestamping is done similar for AT86RF230B systems.

Because of this limitation for this particular board, no changes within file pal_irq.c during the porting from the base platform to the target platform are to be done (except the board name change explained in Section 11.3.2.5).

11.3.2.7 Step 7 – File pal_board.c

This source file contains board specific functions to initialize and handle peripherals (such as LEDs, buttons, GPIO to the transceiver).

The following items within this file need to be updated according to the target board’s needs or at least checked for correctness.

- Function pal_generate_rand_seed()
    - Each board needs a random seed value for:
        - The random seed for the CSMA-CA algorithm
        - The generation of a random IEEE address for demo applications in case no valid IEEE address is provided for this board (for example, by means of an external EEPROM)
    - While the AT86RF230B does not provide a random number generator (and thus this random seed needs to be generated for the corresponding board by different means), the AT86RF231 provides such a feature that is automatically enabled within the TAL for AT86RF231
    - This implies the mechanism used for the base platform to generate a random seed by utilizing the ADC of the MCU, is not required for the target platform
    - Therefore function pal_generate_rand_seed() can be removed entirely for this platform
- Functions
    - adc_irq_handler()

- adc_get_data()
- adc_is_channel_irq_status_set()
- adc_initialize()
- These functions are helper functions for the obsolete function pal_generate_rand_seed() and can be removed completely as well

- Function timer_init_non_generic()
- Function trx_interface_init()
  - While the board of the base platform connects the transceiver to the MCU via SPI0, the target platform uses SPI1. The pins of the Atmel AT91SAM7X256 used for SPI1 are still controlled via PIO-A, but used as "Peripheral A". For more information about the used pins for the SPI see Section 11.3.2.8. In order to use SPI1, change

```
/**
 * @brief Initializes the transceiver interface
 *
 * This function initializes the transceiver interface.
 * This board uses SPI0.
 */
void trx_interface_init(void)
{
    /*
     …
     * Peripheral A.
     */
    AT91C_BASE_PIOA->PIO_ASR = (MISO | MOSI | SCK);
    AT91C_BASE_PIOA->PIO_PDR = (MISO | MOSI | SCK);

    AT91C_BASE_PIOA->PIO_ASR = TRX_INTERRUPT_PIN;
    AT91C_BASE_PIOA->PIO_PDR = TRX_INTERRUPT_PIN;
    …
    /* Set SEL as output pin. */
    AT91C_BASE_PIOA->PIO_OER = SEL;
    AT91C_BASE_PIOA->PIO_PER = SEL;

    /*
     * Used peripheral interface is SPI0.
     * The clock to the utilized SPI 0 peripheral is enabled.
     */
    AT91C_BASE_PMC->PMC_PCER = _BV(AT91C_ID_SPI0);
```

to

```
/**
 * @brief Initializes the transceiver interface
 *
 * This function initializes the transceiver interface.
 * This board uses SPI1.
 */
```

```
void trx_interface_init(void)
{
    /*
     …
     * Peripheral B.
     */
    AT91C_BASE_PIOA->PIO_BSR = (MISO | MOSI | SCK);
    AT91C_BASE_PIOA->PIO_PDR = (MISO | MOSI | SCK);

    AT91C_BASE_PIOA->PIO_ASR = TRX_INTERRUPT_PIN;
    AT91C_BASE_PIOA->PIO_PDR = TRX_INTERRUPT_PIN;
    …
    /* Set SEL as output pin. */
    AT91C_BASE_PIOA->PIO_OER = SEL;
    AT91C_BASE_PIOA->PIO_PER = SEL;

    /*
     * Used peripheral interface is SPI1.
     * The clock to the utilized SPI 1 peripheral is enabled.
     */
    AT91C_BASE_PMC->PMC_PCER = _BV(AT91C_ID_SPI1);
```

11.3.2.8 Step 8 – File pal_config.h

This header file contains configuration parameters for the target platform such as CPU frequency for this particular board, IRQ pins, pins between transceiver and MCU, LED pins, button pins, timer clock source definitions, debug macros, etc.

The following items within this file need to be updated according to the target board's needs or at least checked for correctness.

- Enum definition for PIOs, LEDs, and buttons: Remain unchanged
- Clock frequency selection (F_CPU) and corresponding defines: Remain unchanged
- Mapping of TRX IRQs to MCU pins (TRX_INTERRUPT_PIN)
    - This defines the interrupt pin used for the transceiver interrupt and is derived from the actual pin on the MCU where the transceiver interrupt line is connected to
    - In case the transceiver interrupt is routed to a different MCU pin (providing interrupt handling) this interrupt vector needs to be updated too
    - Remain unchanged
- Configuration of Advanced Interrupt Controller (AIC_CPONFIGURE()): Remain unchanged
- IRQ Macros: Change the comments

```
/*
 * AT86RF230B:
 *
 * TRX_MAIN_IRQ_HDLR_IDX
```

```
 *         TRX interrupt mapped to MCU IRQ0 pin and TIOA line of
 *         timer channel 0
 * TRX_TSTAMP_IRQ_HDLR_IDX
 *         Not used
 */
```

to

```
/*
 * AT86RF231:
 *
 * TRX_MAIN_IRQ_HDLR_IDX
 *         TRX interrupt mapped to MCU IRQ0 pin and TIOA line of
 *         timer channel 0
 * TRX_TSTAMP_IRQ_HDLR_IDX
 *         Time stamping interrupt, not used for this board,
 *         since the DIG2 pin of the 231 transceiver is not routed
 *         as an additional interrupt to the MCU.
 *         Timestamping is done similar to the 230 implementation.
 *         Make sure that the build switch "DISABLE_TSTAMP_IRQ"
 *         is set in the corresponding project files.
 */
```

- Number of transceiver interrupts (NO_OF_TRX_IRQS):
  This is set to 1 for all Atmel AT86RF230B platforms and remains unchanged. Add the following comment:

```
/* Number of used TRX IRQs in this implementation */
/*
 * Even if the 231 transceiver generally provides
 * an additional interrupt for convenient timestamping,
 * it is not used for this board.
 */
#define NO_OF_TRX_IRQS                  (1)
```

- Macros for handling transceiver interrupts (enabling, disabling, clearing of transceiver interrupts): Remain unchanged
- Macro for critical region with respect to transceiver interrupts: Remain unchanged
- PAL_USE_SPI_TRX: Remains unchanged, since Atmel AT91SAM7X256 uses SPI as interface to the transceiver
- SPI registers and pins: In case the transceiver is connected differently than on the base platform, these SPI registers and pins used on the MCU need to be updated. Change:

```
/*
 * SPI Base Register:
 * SPI0 is used with REX ARM Rev. 2.
 */
#define AT91C_BASE_SPI_USED             (AT91C_BASE_SPI0)
/* RESET pin is pin 9 of PIOA. */
#define RST                             (AT91C_PIO_PA9)
/* Sleep Transceiver pin is pin 8 of PIOA. */
```

```
#define SLP_TR                          (AT91C_PIO_PA8)
/*
 * Slave select pin is PA14
 */
#define SEL                             (AT91C_PA14_SPI0_NPCS2)
/*
 * SPI Bus Master Output/Slave Input pin is PA17
 */
#define MOSI                            (AT91C_PA17_SPI0_MOSI)
/*
 * SPI Bus Master Input/Slave Output pin is PA16
 */
#define MISO                            (AT91C_PA16_SPI0_MISO)
/*
 * SPI serial clock pin is PA18
 */
#define SCK                             (AT91C_PA18_SPI0_SPCK)
```

to

```
/*
 * SPI Base Register:
 * SPI1 is used with REX ARM Rev. 3.
 */
#define AT91C_BASE_SPI_USED             (AT91C_BASE_SPI1)
/* RESET pin is pin 9 of PIOA. */
#define RST                             (AT91C_PIO_PA9)
/* Sleep Transceiver pin is pin 8 of PIOA. */
#define SLP_TR                          (AT91C_PIO_PA8)
/*
 * Slave select pin is PA21
 */
#define SEL                             (AT91C_PA21_SPI1_NPCS0)
/*
 * SPI Bus Master Output/Slave Input pin is PA23
 */
#define MOSI                            (AT91C_PA23_SPI1_MOSI)
/*
 * SPI Bus Master Input/Slave Output pin is PA24
 */
#define MISO                            (AT91C_PA24_SPI1_MISO)
/*
 * SPI serial clock pin is PA22
 */
#define SCK                             (AT91C_PA22_SPI1_SPCK)
```

in order to reflect the utilization of SPI as transceiver interface.

- TRX GPIO pins: Remain unchanged

- Short PAL waiting delays (PAL_WAIT_65_NS(),PAL_WAIT_500_NS, PAL_WAIT_1_US): Remains unchanged
- Timeout macros (MIN_TIMEOUT, MAX_TIMEOUT, MIN_DELAY_VAL): Remains unchanged since this platform uses the same timer implementation as the base platform
- Timer source macros:
    - TIMER_SRC_DURING_TRX_AWAKE
    - TIMER_SRC_DURING_TRX_SLEEP
    - These macros specify which timer source is used on this system when the transceiver is awake or sleeping
    - Remains unchanged for this platform since the same timer sources are used as for the base platform
- TIME_STAMP_REGISTER: Remains unchanged, since the target platform uses the same register for time stamping as the base platform
- TRX Access macros for SPI: Remain unchanged
- LED pins and joystick: Remains unchanged
- Alert initialization and indication macros: Remain unchanged since the same ports for the LEDs are used as for the base platform
- ADC Initialization values: Remove completely since ADC is not used for random number generation
- ANTENNA_DIVERSITY: Some IEEE 802.15.4 Atmel transceivers allow for the utilization of antenna diversity as hardware feature (e.g. AT86RF231) if the board also does support this feature. The current MAC release supports antenna diversity where applicable. In order to use antenna diversity the definition is included in this file as
    - #define ANTENNA_DIVERSITY (0) – Boards do not support
    - #define ANTENNA_DIVERSITY (1) – Boards do support

11.3.3 Bring-up of an existing (MAC) application on the target platform

The task of bringing-up an already existing application on the new target platform is explained in this section by the example of a target platform “REB_4_0_2_REX_ARM_REV_3” based on the Atmel AT91SAM7X256 ARM7 MCU. A similar example based on the Atmel ATxmega256A3 MCU during the course of bringing-up a new MCU is explained in detail in Section 11.5.

The same steps are to be performed for all other target platforms/boards that shall be used. Each step is first described generally and then specifically described in detail for porting the existing code from the base platform “REB_2_3_REX_ARM_REV_2” (using Atmel AT86RF230B with AT91SAM7X256) to the target platform “REB_4_0_2_REX_ARM_REV_3” using Atmel AT86RF231 with AT91SAM7X256.

- Step 1: Identify the application that shall be ported. This requires that all peripherals required by the application need to be supported (such as SIO support, LEDs, buttons). For more information about the requirements of existing applications see Section 9.2
- Step 2: Identify the best matching base platform already supported within this application. Duplicate the directory of the base platform within this application and rename it according to your target platform
- Step 3: Update the GCC Makefile. Independent from whether the target application is built from command line using make or Atmel AVR Studio project file (APS-files),

which also use external Makefiles themselves, the Makefile needs to be updated to cope with the target platform. This includes:

- Build specific properties such as
  - TAL_TYPE
  - PAL_TYPE
  - PAL_GENERIC_TYPE
  - BOARD_TYPE
- The MCU type
- The selected SIO channel in case stream I/O is used within the particular application
  - If the build switch SIO_HUB is set in the Makefile (-DSIO_HUB), also one of the following (currently supported) SIO channels needs to be enabled as well:
    -DUART0
    -DUART1
    -DUSB0
  - If the build switch SIO_HUB is not set, no further SIO channel needs to be defined
- Other specific build and link options if required

- Step 4: Update the IAR project files. Usually all required changes for the IAR Workbench are to done in the ewp-file. This includes changing of the paths for includes and source files referring to the proper MCU. Also the proper MCU needs to be selected within the options for this project. Other changes may include updating the proper SIO channel, etc.

11.3.3.1 Step 1 – Identify the application to be ported to the target platform

The MAC application Star_Nobeacon shall be enabled on the target board Atmel AT91SAM7X-EK with Radio Extender board REB231 V4.0 on REX_ARM adapter Revision 3 (REB_4_0_2_REX_ARM_REV_3). For more information about the platform bring-up for this target platform see the previous sections. This MAC application is located in directory

```
Application/MAC_Examples/Star_Nobeacon.
```

11.3.3.2 Step 2 – Identify the best matching base platform

The best matching base platform for the target board AT91SAM7X-EK with Radio Extender board REB231 V4.0 on REX_ARM adapter Revision 3 (REB_4_0_2_REX_ARM_REV_3) is the AT91SAM7X-EK with Radio Extender board REB230B V2.3 on REX_ARM adapter Revision 2 (REB_2_3_REX_ARM_REV_2). This entire build files for this particular base platform are located in directory

```
AT86RF230B_AT91SAM7X256_REB_2_3_REX_ARM_REV_2
```

within the application directory

```
Applications/MAC_Examples/Star_Nobeacon/.
```

The entire directory

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF230B_AT91SAM7X256_REB_2_3_REX_ARM_REV_2
```

is copied and renamed

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_AT91SAM7X256_REB_4_0_2_REX_ARM_REV_3
```

Usually the directory name for applications consists of the following items to uniquely identify the target platform:

- TAL_TYPE (=AT86RF231)
- PAL_TYPE (=AT91SAMX256)
- PAL_GENERIC_TYPE (= ARM7)
- BOARD_TYPE (= REB_4_0_2_REX_ARM_REV_3)

IMPORTANT

Make sure that the build switch “HIGHEST_STACK_LAYER” is not changed. This build switch always needs to reflect the proper highest stack layer that the application is residing on. In case of a MAC application (such as the Star_Nobeacon) the application is residing on top of the MAC, so “HIGHEST_STACK_LAYER” needs to be MAC. If this is not properly set, this leads to undefined behavior during the build process or during application usage.

11.3.3.3 Step 3 – Update the GCC Makefile

Currently the GCC build is not supported for ARM7 based boards. For an example how to port applications for MCU families with GCC support within this software package (such as AVR or XMEGA MCUs), see Section 11.4.3.3.

11.3.3.4 Step 4 – Update the IAR project files

The IAR project files for an ARM7 based project (Star.ewd, Star.ewp, Star.eww, and flash.icf) of the target board which were duplicated from the base platform/board are now located in the application build directory of the target platform, that is,

`Applications/`MAC_Examples/Star_Nobeacon/
AT86RF231_AT91SAM7X256_REB_4_0_2_REX_ARM_REV_3.

In order to support the target platform the file Star.ewp needs to be updated as follows:

- Change the TAL_TYPE from

  ```
  <state>TAL_TYPE=AT86RF230B</state>
  ```

  to

  ```
  <state>TAL_TYPE=AT86RF231</state>
  ```

- Change the BOARD_TYPE from

  ```
  <state>BOARD_TYPE=REB_2_3_REX_ARM_REV_2</state>
  ```

  to

  ```
  <state>BOARD_TYPE=REB_4_0_2_REX_ARM_REV_3</state>
  ```

- Since the target board does not use the Timestamp interrupt from the Atmel AT86RF231 add the following build option

  ```
  <state>DISABLE_TSTAMP_IRQ</state>
  ```

- Change all occurrences of

  ```
  REB_2_3_REX_ARM_REV_2
  ```

  to

  ```
  REB_4_0_2_REX_ARM_REV_3
  ```

- Change all occurrences of

```
AT86RF230B
```

to

```
AT86RF231
```

Since the MCU type is note changed, the build switches PAL_GENERIC_TYPE and PAL_TYPE remain unchanged.

11.4 Bring-up of a new MCU based on a supported MCU family

11.4.1 Implementation of PAL for target platform

The task of bringing-up a new MCU ("target MCU") within an already supported MCU family is explained in general within this section and furthermore by the example of a platform based on the Atmel ATxmega256A3 in Section 11.4.2. The same steps are to be performed for all other MCUs that shall be used.

11.4.1.1 Phase1: General preparation for target platform

The first phase is a simple preparation phase. It provides the required directory and file-structure for the target MCU and defines proper build switches required for the target platform.

- Step 1: Identify the MCU family for the target MCU
    - Each supported MCU family is identified by a specific value of the build switch PAL_GENERIC_TYPE
    - For a list of all currently supported MCU families check file PAL/Inc/pal_types.h for defined values of PAL_GENERIC_TYPE
    - For more information see also Section 10.1
- Step 2: Add the target MCU to the selected PAL_GENERIC_TYPE in file PAL/Inc/pal_types.h
- Step 3: Identify an already supported MCU that best fits the target MCU to start the porting ("base MCU")
    - Each supported MCU is identified by a specific value of the build switch PAL_TYPE
    - For a list of all currently supported MCU check file PAL/Inc/pal_types.h for defined values of PAL_TYPE within the selected PAL_GENERIC_TYPE
    - For more information see also Section 10.2
- Step 4: Copy the PAL directory of the base MCU in a separate directory within the same MCU family and name it according to the target MCU
- Step 5: Identify an already existing board type ("base board") within the directory of the target MCU that best fits the new board to be supported ("target board")
    - Each supported board with the newly created directory contains a "board" directory including file pal_boardtypes.h and least one specific board directory
    - Select the base board for the target board
    - Other boards within target board directory that are obsolete may be removed
- Step 6: Rename the target board (optional)
    - In case the selected target board shall to be renamed, file pal_boardtypes.h with in target MCU directory needs to be updated

with the new board type. Also the target directory needs to be renamed matching the new board type. For more information see Section 11.3

- Step 7: Rename all occurrences of base MCU to target MCU

11.4.1.2 Phase2: Actual porting to target platform

This section describes the actual porting phase once the directory and file structure of the target platform has been established.

The directory of the target platform contains currently three directories (same as for the base platform):

- Boards
- Inc
- Src

Within the next phase all hardware resources need to be adjusted from the base platform to fit the resources of the target platform, such as timers, IRQs, ports, LEDs, buttons, ports and registers for SIO support, etc. This is explained in the subsequent steps.

The main changes for a new platform need to be done in directory Boards in the subdirectory for the target board. In the current example change to directory

PAL/XMEGA/ATXMEGA256A3/Boards/REB_4_1_CBB.

In this directory the following three files are located:

- pal_board.c
- pal_irq.c
- pal_config.h

All of these files are now adapted to the target platform needs step by step.

- Step 8: File pal_irq.c

  This source file contains functions to initialize, enable, disable and install handler for the transceiver interrupts. It needs to be updated to match the requirements of the target board when handling the transceiver interrupts (see example in Section 11.4.2.8).

- Step 9: File pal_board.c

  This source file contains board specific functions to initialize and handle peripherals (such as LEDs, buttons, GPIO to the transceiver). It needs to be updated to match the requirements of the target board when handling these peripherals.

- Step 10: File pal_config.h

  This header file contains configuration parameters for the target platform such as CPU frequency for this particular board, IRQ pins, pins between transceiver and MCU, LED pins, button pins, timer clock source definitions, debug macros, etc. It needs to be updated to match the requirements of the target board (see example in Section 11.4.2.10).

- Step 11: File pal_sio_hub.c in directory Src
  - The file pal_sio_hub.c within the Src directory of the target MCU is a source containing the hub functionality for all serial I/O related functionality. This included currently UART and/or USB

- Depending on the available and utilized serial I/O peripherals on the target MCU (please check the corresponding data sheet of the target MCU) and board this file needs to be updated

11.4.2 Example implementation of PAL for Atmel ATxmega256A3

This section describes the porting activities explained in the previous sections in general more specifically for the example of porting an existing software package to the new target MCU, ATxmega256A3, (on CBB board with radio extender board REB231ED V4.1.1).

11.4.2.1 Step 1 – Identify the MCU family of the new MCU

The target MCU is the ATxmega256A3. It is a member of the Atmel AVR ATxmega family. Therefore new code of this MCU is based on the PAL_GENERIC_TYPE=XMEGA.

11.4.2.2 Step 2 – Add the new MCU to file pal_types.h

To add support for ATxmega256A3, open file PAL/Inc/pal_types.h and add the ATxmega256A3 to the section where all ATxmega MCUs are listed. Use a non-existing unique value for the target MCU.

Example:

```
#elif (PAL_GENERIC_TYPE == XMEGA)
    /* PAL_TYPE for XMEGA MCUs */
    #define ATXMEGA128A1                (0x01)
    #define ATXMEGA256A3                (0x02)

#elif (PAL_GENERIC_TYPE == AVR32)
```

For better readability the target MCU has been added to reflect the alphabetical order of the MCU directory name. Also the existing values of the defines have been updated. The actual numerical value of each define is not important, as long as each MCU within a specific PAL_GENERIC_TYPE has a unique value.

11.4.2.3 Step 3 – Identify an already supported MCU that best fits the new MCU as base MCU

From all currently supported MCUs within the Atmel ATxmega family the Atmel ATxmega128A1 is selected as base MCU to start the porting to the target MCU, ATxmega256A3.

11.4.2.4 Step 4 – Copy the PAL directory of the base MCU

Example:

Copy the entire directory PAL/XMEGA/ATXMEGA128A1 and rename it to directory PAL/XMEGA/ATXMEGA256A3. Your directory PAL/XMEGA now contains the following entries:

```
ATXMEGA128A1
ATxmega256A3
Generic
```

The directory ATxmega256A3 currently contains the identical code from the directory ATXMEGA128A1 (from the base MCU). It comprises of the following directories:

```
Boards
Inc
Src
```

11.4.2.5 Step 5 – Identify the base board best fitting the target board

Within the board directory of the target MCU (PAL/XMEGA/ATXMEGA256A3/Boards) a variety of subdirectories are existing. Please remove all directories except REB_4_1_CBB. Now the following entries exist:

- Directory REB_4_1_CBB
- File pal_boardtypes.h

The directory REB_4_1_CBB contains the board implementation for the Atmel AT86RF231 transceiver based on the board REB231ED V4.1.1 on top of a CBB board. For more information about this platform see Sections 10.4.2.4 and 10.4.3.2.

For simplicity reason it is assumed that the same platform is used, and only the MCU shall be replaced. For more information about how to bring-up a new board, see also Section 11.3.

11.4.2.6 Step 6 – Rename the target board

The file pal_boardtypes.h contains entries inherited form the base platform. All obsolete entries (except of REB_4_1_CBB) may be removed if desired. In this example all entries are kept since this allows for the easy extension of the boards later.

11.4.2.7 Step 7 – Rename all occurrences of base MCU to target MCU

Within the entire directory PAL/XMEGA/ATXMEGA256A3 all occurrences of the string “ATXMEGA128A1” are searched and replaced by the target MCU “ATXMEGA256A3”. In this example this needs to be done in the following files:

- PAL/XMEGA /ATXMEGA256A3/Boards/pal_boardtypes.h
- PAL/XMEGA /ATXMEGA256A3/Boards/REB_4_1_CBB/pal_config.h

11.4.2.8 Step 8 – File pal_irq.c

Since the target platform is close very close to the base platform, no changes need to be done in this file.

11.4.2.9 Step 9 – File pal_board.c

Since the target platform is close very close to the base platform, no changes need to be done in this file.

11.4.2.10 Step 10 – Fila pal_config.h

Since the target platform is close very close to the base platform, no changes need to be done in this file.

11.4.2.11 Step 11 – File pal_sio_hub.c in directory Src

No changes need to be done in this file.

11.4.3 Bring-up of an existing application on the target platform

The task of bringing-up an already existing application on a new target platform is explained by the example of a platform based on the Atmel ATxmega256A3. The same steps are to be performed for all other MCUs that shall be used. Each step is first described generally and then specifically described in detail for porting the existing code to the Atmel ATxmega256A3.

Please note that the opposite task of bringing up a new application for an existing platform is explained in Section 11.5.

- Step 1: Identify the application that shall be ported. This requires that all peripherals required by the application need to be supported (such as SIO support, LEDs, buttons). For more information about the requirements of existing applications see Section 9.2
- Step 2: Identify the best matching base platform already supported within this application. Duplicate the directory of the base platform within this application and rename it according to your target platform
- Step 3: Update the GCC Makefile. Independent from whether the target application is built from command line using make or Atmel AVR Studio project file (APS-files), which also use external Makefiles themselves, the Makefile needs to be updated to cope with the target platform. This includes:
  - Build specific properties such as
    - TAL_TYPE
    - PAL_TYPE
    - PAL_GENERIC_TYPE
    - BOARD_TYPE
  - The MCU type
  - The selected SIO channel in case stream I/O is used within the particular application
    - If the build switch SIO_HUB is set in the Makefile (-DSIO_HUB), also one of the following (currently supported) SIO channels needs to be enabled as well:
      -DUART0
      -DUART1
      -DUSB0
    - If the build switch SIO_HUB is not set, no further SIO channel needs to be defined
  - Other specific build and link options if required
- Step 4: Update the IAR project files. Usually all required changes for the IAR Workbench are to done in the ewp-file. This includes changing of the paths for includes and source files referring to the proper MCU. Also the proper MCU needs to be selected within the options for this project. Other changes may include updating the proper SIO channel, etc.
- Step 5: Update the AVR Studio Project files (aps-files). This includes changing of the paths for includes and source files referring to the proper MCU. All other items are already within the external Makefiles that are called during the build process

11.4.3.1 Step 1 – Identify the application to be ported to the target platform

The MAC application Star_Nobeacon shall be enabled on the target platform ATxmega256A3 MCU based on REB231ED V4.1.1 on top of a CBB board. For more information about the platform bring-up for this target platform see the previous sections. The MAC or TAL must not be changed, since these layers residing on top of the PAL are completely independent from the selected platform. This MAC application is located in directory

```
Application/MAC_Examples/Star_Nobeacon.
```

11.4.3.2 Step 2 – Identify the best matching base platform

The best matching base platform for an Atmel ATxmega256A3 placed on the CBB board with Radio Extender board REB231ED V4.1.1 (with Atmel AT86RF231) is the Atmel ATxmega128A1 on the same hardware setup (CBB board with REB231ED V4.0, see Sections 10.4.2.4 and 10.4.3.2). This entire build files for GCC and IAR for this particular base platform are located in directory

```
AT86RF231_ATXMEGA256A3_REB_4_0_CBB
```

within the application directory

```
Applications/MAC_Examples/Star_Nobeacon/.
```

The entire directory

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA128A1_REB_4_1_STK600
```

is copied and renamed to

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_0_CBB
```

Usually the directory name for applications consists of the following items to uniquely identify the target platform:

- TAL_TYPE (= AT86RF230B)
- PAL_TYPE (= ATXMEGA256A3)
- PAL_GENERIC_TYPE (= XMEGA)
- BOARD_TYPE (= REB_4_0_CBB)

IMPORTANT

Make sure that the build switch “HIGHEST_STACK_LAYER” is not changed. This build switch always needs to reflect the proper highest stack layer that the application is residing on. In case of a MAC application (such as the Star_Nobeacon example) the application is residing on top of the MAC, so “HIGHEST_STACK_LAYER” needs to be MAC. If this is not properly set, this leads to undefined behavior during the build process or during application usage.

11.4.3.3 Step 3 – Update the GCC Makefile

The Makefile of the target platform which was duplicated from the base platform is now located in the GCC directory of the target platform, that is,

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.
```

In order to support the target platform this Makefile needs to be updated as follows:

- Update the build specific properties from

```
_TAL_TYPE = AT86RF231
_PAL_TYPE = ATXMEGA128A1
_PAL_GENERIC_TYPE = XMEGA
_BOARD_TYPE = REB_4_1_CBB
```

to

```
_TAL_TYPE = AT86RF231
_PAL_TYPE = ATXMEGA256A3
_PAL_GENERIC_TYPE = XMEGA
_BOARD_TYPE = REB_4_1_CBB
```

In the described example only the PAL_TYPE needs to be changed. Make sure that the PAL_TYPE (that is, the variable in the Makefile) is set identical to the target directory in the PAL that was created for the new platform (see Sections 11.4.2.2 and 11.4.2.4), since the PAL_TYPE is used within directory names.

- Update the MCU type from

  ```
  MCU = atxmega128a1
  ```

  to

  ```
  MCU = atxmega256a3
  ```

- Updating the SIO channel (for example, UART1, etc.) is not required here, since this application does not use SIO functionality

11.4.3.4 Step 4 – Update the IAR project files

The IAR project files (Star.eww and Star.ewp) of the target platform which were duplicated from the base platform are now located in the application build directory of the target platform, that is:

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.
```

In order to support the target platform the Star.ewp-file needs to be updated as follows:

- Select the proper MCU (Atmel ATxmega256A3) for this project within IAR Workbench
- Correct the proper used SIO channel is not required for here, since this application does not use SIO functionality. This can be done using an XML editor or within IAR Workbench
- Change all occurrences of “ATXMEGA128A1”, which are used as path names for directories and files to “ATXMEGA256A3”. This can be done using an XML editor, a regular text editor, or within IAR Workbench

11.4.3.5 Step 5 – Update the Atmel AVR Studio project files

The AVR Studio project file (that is, aps-file) of the target platform which were duplicated from the base platform are now located in the application build directory of the target platform, that is,

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.
```

In order to support the target platform the file Star.aps needs to be updated as follows:

- Change all occurrences of “ATXMEGA128A1”, which are used as path names for directories and files to “ATXMEGA256A3”. This can be done using an XML editor or a regular text editor

11.5 Bring-up of a new application on an existing platform

The task of bringing-up a new application on an existing platform is explained by the MAC example application Promiscuous_Mode_Demo for a supported platform based on the Atmel ATxmega256A3. The same steps are to be performed for all other MCUs that shall be used, or all other applications respectively. Each step is first described generally and then specifically explained in detail for bringing-up the Promiscuous_Mode_Demo.

Please note that the opposite task of bringing up a new platform on an existing application is explained in Section 11.4.3.

- Step 1: Identify a matching base application already supported for this platform. Duplicate the directory of the base application for this platform to the corresponding target platform
- Step 2: Update the GCC Makefiles. Independent from whether the target application is built from command line using make or Atmel AVR Studio Project file (APS-files), which also use external Makefiles themselves, the Makefile needs to be updated to cope with the target application. This includes the following steps:
    - Replace occurrences of the name of base application with the target application (for example, replace “Star” with “Promiscuous_Mode_Demo”)
    - Update the required path variables (“# Path variables”)
    - Update the required compiler options (“CFLAGS”); this includes updating the required SIO handling switches
    - Update the required include directories (“INCLUDES”)
    - Update the required list of object files for the linker (“OBJECTS”)
    - Update the compile section for the source files (“## Compile”)
- Step 3: Update the IAR project files. Usually all required changes for the IAR Workbench are to done in the ewp file. This includes updating of the paths for includes and updating of the required source files. Other changes may include updating the proper SIO channel, etc.
- Step 4: Update the Atmel AVR Studio Project files (aps files). This includes replacing occurrences of the name of base application with the target application (for example, replace “Star” with “Promiscuous_Mode_Demo”). All other items are already within the external Makefiles that are called during the build process

11.5.1 Step 1 – Identify a matching base application

The MAC application Promiscuous_Mode_Demo (target application) shall be enabled on the existing platform ATxmega256A3 MCU based on REB231ED V4.1.1 on top of an STK600 board. For more information about the platform bring-up for this target platform see Section 11.4. This target application is located in directory

```
Application/MAC_Examples/Promiscuous_Mode_Demo.
```

A matching base application for this MAC application is the Star_Nobeacon application. The platform ATxmega256A3 MCU based on REB231ED V4.1.1 is already supported for this base application.

All required build files for GCC and IAR for this particular base application are located in directory

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ ATXMEGA256A3_REB_4_1_CBB.
```

This entire directory is copied to the target application directory. Now the following directory exists:

```
Applications/MAC_Examples/Promiscuous_Mode_Demo/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB.
```

This directory now contains the following entries:

- GCC/Makefile
- GCC/Makefile_Debug
- Star.aps
- Star.ewp
- Star.eww

Now rename the project files as required for the target application, that is, rename all files Star.* to Promiscuous_Mode_Demo.*.

11.5.2 Step 2 – Update the GCC Makefile

The Makefiles of the target application which was duplicated from the base application is now located in the GCC directory of the target application, that is

```
Applications/MAC_Examples/Promiscuous_Mode_Demo/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.
```

In order to support the target application these Makefiles need to be updated as follows:

- Replace occurrences of the name of base application “Star” with the name of the target application Promiscuous_Mode_Demo “Promiscuous_Mode_Demo”. This is required in comments and for specifying the generated output files (“PROJECT = …”)
- Add the path for the generic SIO support functions (see Section 9.3):

  ```
  PATH_SIO_SUPPORT =
  $(MAIN_DIR)/Applications/Helper_Files/SIO_Support
  ```

- Enable SIO support for this application via the supported SIO channel. In this example UART1 is used. Change

  ```
  CFLAGS += -Wall -Werror -g -Wundef -std=c99 –Os
  ```

  to

  ```
  CFLAGS += -Wall -Werror -g -Wundef -std=c99 -DSIO_HUB -DUART1 –
  Os
  ```

- Update the used and/or unused compiler flags. The base example application (Star_Nobeacon) used the compiler switches FFD and REDUCED_PARAM_CHECK that are not required anymore for the target application. On the other hand the target application requires the build switch PROMISCUOUS_MODE. Therefore change

  ```
  CFLAGS += -DDEBUG=0
  ```

```
CFLAGS += -DFFD
CFLAGS += -DREDUCED_PARAM_CHECK
CFLAGS += -DTAL_TYPE=$(_TAL_TYPE)
CFLAGS += -DPAL_GENERIC_TYPE=$(_PAL_GENERIC_TYPE)
CFLAGS += -DPAL_TYPE=$(_PAL_TYPE)
CFLAGS += -DBOARD_TYPE=$(_BOARD_TYPE)
CFLAGS += -DHIGHEST_STACK_LAYER=$(_HIGHEST_STACK_LAYER)
```

to

```
CFLAGS += -DDEBUG=0
CFLAGS += -DPROMISCUOUS_MODE
CFLAGS += -DTAL_TYPE=$(_TAL_TYPE)
CFLAGS += -DPAL_GENERIC_TYPE=$(_PAL_GENERIC_TYPE)
CFLAGS += -DPAL_TYPE=$(_PAL_TYPE)
CFLAGS += -DBOARD_TYPE=$(_BOARD_TYPE)
CFLAGS += -DHIGHEST_STACK_LAYER=$(_HIGHEST_STACK_LAYER)
```

- Update the used and/or unused include directories in the Makefile. The base example application (Star_Nobeacon) did not use SIO support, so this needs to be added to the target application in order to allow for the inclusion of sio_handler.h. Add the following include path by changing

```
## Include directories for application
INCLUDES = -I $(APP_DIR)/Inc
## Include directories for general includes
INCLUDES += -I $(MAIN_DIR)/Include
```

to

```
## Include directories for application
INCLUDES = -I $(APP_DIR)/Inc
## Include directories for SIO support
INCLUDES += -I $(PATH_SIO_SUPPORT)/Inc
## Include directories for general includes
INCLUDES += -I $(MAIN_DIR)/Include
```

- Update the used and/or unused object files to the list of OBJECTS in the Makefile. Since the Promiscuous_Mode_Demo application only uses three MAC callback functions itself (usr_mcps_data_ind(), usr_mlme_reset_conf(), and usr_mlme_set_conf()), all other callbacks need to be added as stubs by adding the following lines. For more information about MAC stub functions see Section 9.4. Change

```
## Objects that must be built in order to link
OBJECTS = $(TARGET_DIR)/main.o\
        $(TARGET_DIR)/pal_uart.o\
        . . .
        $(TARGET_DIR)/mac_api.o \
        $(TARGET_DIR)/usr_mcps_purge_conf.o \
        $(TARGET_DIR)/usr_mlme_beacon_notify_ind.o \
        $(TARGET_DIR)/usr_mlme_disassociate_conf.o \
        $(TARGET_DIR)/usr_mlme_disassociate_ind.o \
        $(TARGET_DIR)/usr_mlme_get_conf.o \
```

```
        $(TARGET_DIR)/usr_mlme_orphan_ind.o \
        $(TARGET_DIR)/usr_mlme_poll_conf.o \
        $(TARGET_DIR)/usr_mlme_rx_enable_conf.o \
        $(TARGET_DIR)/usr_mlme_sync_loss_ind.o
```

to

```
## Objects that must be built in order to link
OBJECTS = $(TARGET_DIR)/main.o\
        $(TARGET_DIR)/sio_handler.o\
        $(TARGET_DIR)/pal_uart.o\
        . . .
        $(TARGET_DIR)/mac_api.o \
        $(TARGET_DIR)/usr_mcps_data_conf.o \
        $(TARGET_DIR)/usr_mcps_purge_conf.o \
        $(TARGET_DIR)/usr_mlme_associate_conf.o \
        $(TARGET_DIR)/usr_mlme_associate_ind.o \
        $(TARGET_DIR)/usr_mlme_beacon_notify_ind.o \
        $(TARGET_DIR)/usr_mlme_comm_status_ind.o \
        $(TARGET_DIR)/usr_mlme_disassociate_conf.o \
        $(TARGET_DIR)/usr_mlme_disassociate_ind.o \
        $(TARGET_DIR)/usr_mlme_get_conf.o \
        $(TARGET_DIR)/usr_mlme_orphan_ind.o \
        $(TARGET_DIR)/usr_mlme_poll_conf.o \
        $(TARGET_DIR)/usr_mlme_rx_enable_conf.o \
        $(TARGET_DIR)/usr_mlme_scan_conf.o \
        $(TARGET_DIR)/usr_mlme_start_conf.o \
        $(TARGET_DIR)/usr_mlme_sync_loss_ind.o
```

- Update the used and/or unused list of files to be compiled. Change

```
## Compile
$(TARGET_DIR)/main.o: $(APP_DIR)/Src/main.c
        $(CC) $(INCLUDES) $(CFLAGS) -c  -o $@ $<
$(TARGET_DIR)/pal_uart.o:
$(PATH_PAL)/$(_PAL_GENERIC_TYPE)/Generic/Src/pal_uart.c
        $(CC) -c $(CFLAGS) $(INCLUDES) -o $@ $<
```

to

```
## Compile
$(TARGET_DIR)/main.o: $(APP_DIR)/Src/main.c
        $(CC) $(INCLUDES) $(CFLAGS) -c  -o $@ $<
$(TARGET_DIR)/sio_handler.o:
$(PATH_SIO_SUPPORT)/Src/sio_handler.c
        $(CC) $(INCLUDES) $(CFLAGS) -c  -o $@ $<
$(TARGET_DIR)/pal_uart.o:
$(PATH_PAL)/$(_PAL_GENERIC_TYPE)/Generic/Src/pal_uart.c
        $(CC) -c $(CFLAGS) $(INCLUDES) -o $@ $<
```

11.5.3 Step 3 – Update the IAR project files

The IAR project files (Promiscuous_Mode_Demo.eww and Promiscuous_Mode_Demo.ewp) of the target application are now located in the directory

```
Applications/MAC_Examples/Promiscuous_Mode_Demo/
AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.
```

In order to support the target application these project files need to be updated as follows:

- Replace occurrences of the name of base application “Star” with the name of the target application Promiscuous_Mode_Demo “Promiscuous_Mode_Demo”. This is required in both project files
- Enable SIO support for this application via the supported SIO channel. In this example UART1 is used. Also update the used and/or unused compiler flags. The base example application (Star_Nobeacon) used the compiler switches FFD and REDUCED_PARAM_CHECK that are not required anymore for the target application. On the other hand the target application requires the build switch PROMISCUOUS_MODE. In file Promiscuous_Mode_Demo.ewp change

```
<name>CCDefines</name>
<state>DEBUG=0</state>
<state>FFD</state>
<state>REDUCED_PARAM_CHECK</state>
<state>TAL_TYPE=AT86RF231</state>
<state>PAL_TYPE=ATXMEGA256A3</state>
<state>PAL_GENERIC_TYPE=XMEGA</state>
<state>BOARD_TYPE=REB_4_1_CBB</state>
<state>HIGHEST_STACK_LAYER=MAC</state>
```

  to

```
<name>CCDefines</name>
<state>DEBUG=0</state>
<state>PROMISCUOUS_MODE</state>
<state>SIO_HUB</state>
<state>UART1</state>
<state>TAL_TYPE=AT86RF231</state>
<state>PAL_TYPE=ATXMEGA256A3</state>
<state>PAL_GENERIC_TYPE=XMEGA</state>
<state>BOARD_TYPE=REB_4_1_CBB</state>
<state>HIGHEST_STACK_LAYER=MAC</state>
```

- Update the used and/or unused included directories in file Promiscuous_Mode_Demo.ewp. The base example application (Star_Nobeacon) did not use SIO support, so this needs to be added to the target application in order to allow for the inclusion of sio_handler.h. Add the following include path by changing

```
<name>newCCIncludePaths</name>
<state>$PROJ_DIR$\..\Inc</state>
<state>$PROJ_DIR$\..\..\..\..\Include</state>
```

to

```
<name>newCCIncludePaths</name>
<state>$PROJ_DIR$\..\Inc</state>
<state>$PROJ_DIR$\..\..\..\Helper_Files\SIO_Support\Inc</state>
<state>$PROJ_DIR$\..\..\..\..\Include</state>
```

- Update the used and/or unused list of source files. Add the following callback stub files in file Promiscuous_Mode_Demo.ewp (for more information about MAC stub functions, see Section 9.4.)

```
<name>MAC_API</name>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\mac_api.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mcps_purge_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_beacon_notify_ind.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_ind.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_get_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_orphan_ind.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_poll_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_rx_enable_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_sync_loss_ind.c</name>
```

```
</file>
```

to

```
<name>MAC_API</name>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\mac_api.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mcps_data_conf.c</name
>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mcps_purge_conf.c</nam
e>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_associate_conf.c<
/name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_associate_ind.c</
name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_beacon_notify_ind
.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_comm_status_ind.c
</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_conf
.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_disassociate_ind.
c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_get_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_orphan_ind.c</nam
e>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_poll_conf.c</name
>
</file>
```

```
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_rx_enable_conf.c<
/name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_scan_conf.c</name
>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_start_conf.c</nam
e>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_sync_loss_ind.c</
name>
</file>
```

- Add the sio_handler source files in file Promiscuous_Mode_Demo.ewp

```
<file>
<name>$PROJ_DIR$\..\Src\main.c</name>
</file>
```

to

```
<file>
<name>$PROJ_DIR$\..\Src\main.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\Helper_Files\SIO_Support\Src\sio_hand
ler.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\Helper_Files\SIO_Support\IAR_Support\
write.c</name>
</file>
```

11.5.4 Step 4 – Update the Atmel AVR Studio project files

The AVR Studio project file (that is, aps file) of the target application is located in the directory of the target platform, that is,

`Applications/MAC_Examples/Promiscuous_Mode_Demo/AT86RF231_ATXMEGA256A3_REB_4_1_CBB/GCC.`

In order to support the target application the file Promiscuous_Mode_Demo.aps needs to be updated as follows:

- Replace all occurrences of the name of base application with the target application (for example, replace “Star” with “Promiscuous_Mode_Demo”). All other items are already within the external Makefiles that are called during the build process

11.6 Customizing the platform clock speed

11.6.1 Customizing Atmel ATxmega128A1 platforms

The following section describes how a specific ATxmega128A1 based platform can be customized to run at various clock speeds. The default clock speed for these platforms is currently 16MHz, but user may want to adapt this to their specific needs. Due to the platform abstraction implemented within the MAC Software package, this is very simple and straightforward.

11.6.1.1 Introduction to the ATxmega128A1 platform software design

The system clock (that is, the MCU clock frequency) controls a variety of blocks within the MCU.

The MCU for the Atmel ATxmega128A1 platform is always clocked by the 32MHz internal RC oscillator in conjunction with the corresponding System Clock Prescaler to derive the selected system clock.

The event system is always selected as source for the hardware timer used by software. Since the hardware timer requires a tick of 1µs (that is, timer runs at speed of 1MHZ), the event system channel used as timer source, is divided to the proper speed by means of the event system Prescaler.

The SPI speed is derived from the system clock with the constraint that the SPI speed in asynchronous mode (that is, the MCU is not clocked by the CLKM from the transceiver, see the data sheet for the corresponding transceiver) must be smaller than 8MHz. This implies that the largest usable SPI speed is 4MHz.

So based on this design and depending on the selected clock speed the following hardware blocks need to be initialized accordingly:

- MCU clock setting
- Event System initialization and thus setting proper timer source
- SPI speed between MCU and transceiver
- UART baud rate

In order to change the implementation of the ATxmega128A1 platform and to select a specific system clock, the Platform Abstraction Layer (PAL) for this platform needs to be customized.

11.6.1.2 Customizing the ATxmega128A1 platform abstraction

The PAL for all ATxmega128A1 based platforms can be found in directory *MAC_v_x_y_z\PAL\XMEGA\ATXMEGA128A1*.

The directory *PAL\XMEGA* contains the code that is common to all Atmel ATxmega family based systems.

The directory *PAL\XMEGA\ATXMEGA128A1* contains the code that is common to all ATxmega128A1 MCU platforms.

The entire code that is dedicated to a specific hardware platform (based on a specific MCU and on a specific board with specific settings) is located in the board directory for this particular hardware configuration. All supported platforms (that is, boards with specific settings) can be found in directory *PAL\XMEGA\ATXMEGA128A1/Boards*.

The selectable clock speed will be explained for the board ***REB_4_1_STK600***, which implements the platform abstraction for a Radio Extender Board version 4.1 with

Atmel AT86RF231 (with Antenna Diversity), placed on an Atmel STK600 (with ATxmega128A1). The explanations given for this board apply for each board configuration and can easily be adapted to other boards as well.

The directory for the specific board implementation for ***REB_4_1_STK600*** contains three files:

- pal_board.c
- pal_irq.c
- pal_config.h

Whenever a configuration parameter (such as system clock speed) is changed, only these files shall be adapted. All other files generally remain unchanged.

In the case of the selectable system clock speed, only *pal_board.c* and *pal_config.h* are customized.

11.6.1.2.1 MCU clock setting

Depending on the selected system clock, the MCU clock needs to be set. As described for Atmel ATxmega128A1 based platforms currently always the 32MHz Internal RC Oscillator is utilized. In order to gain the proper system clock, the corresponding prescaler needs to be set.

The corresponding implementation can be found in file *pal_board.c* in function clock_init() which is called during PAL initialization.

11.6.1.3 Event system initialization

The hardware timer used for this board is always driven by the event system. This is implemented in file *pal_board.c* in function timer_init_non_generic() by using the macro TIMER_SRC_DURING_TRX_SLEEP(). This macro is implemented in file *pal_config.h*. Currently always the Event Channel 0 is used as timer source.

Since the timer runs at 1MHz speed, the Event Channel 0 is configured to provide events at 1µs rate. The is implemented in file *pal_board.c* in function event_system_init() where the proper Prescaler for this particular Event Channel is set.

11.6.1.3.1 SPI speed selection

As already mentioned the SPI between the MCU and the transceiver needs to be initialized properly with the border condition that the SPI rate must not reach 8MHz. Thus the largest (trivially) selectable SPI speed is 4MHz.

The SPI is initialized in *file pal_config.h* in function macro TRX_INIT(). This macro is called by function trx_interface_init() (see file pal_trx_access.c for the ATxmega family).

11.6.1.3.2 Small blocking delays

In order to comply whit he data sheet for the transceivers and the corresponding Software Programming Model, certain very small delays are required (such as 1µs or even 500ns). Since it is not reasonable for such small delays to call the function pal_timer_delay(), these delays are implemented as macros in file *pal_config.h*: PAL_WAIT_1_US and PAL_WAIT_500_NS., These macros are based on nop

operations, which depend on the MCU clock. This is implemented in file *pal_config.h* as well.

11.6.1.3.3 UART baud rate

The UART baud rate is selected by properly setting the USART baud rate register, which in return is depending on the MCU clock speed. This is implemented in file *pal_uart.h* in macro UART_BAUD(). This macro does not have to be updated if the clock speed changes.

11.6.1.4 Selecting the proper system clock speed

The desired clock speed can be selected at compile time by using the build switch **F_CPU**. It is not intended to change the clock during operation, since this would add additional code size.

The currently supported clock speed is 32MHz, 16MHZ, 8MHz, or 4MHz.

The standard frequency of the system clock is 16MHz. If the build switch F_CPU is not set during the build process, the clock speed of 16MHz will be applied. In case other clock speed shall be selected, the build switch needs to be set accordingly.

For the GCC tool chain example Makefiles for changing the system clock are provided for the MAC application *Star_Nobeacon* for the above described hardware platform. Please check directory

MAC_v_x_y_z\Applications\MAC_Examples\Star_Nobeacon\ AT86RF231_ATXMEGA128A1_REB_4_1_STK600

for the following Makefiles:

- Makefile: Standard clock speed of 16MHz
- Makefile_32/8/4_MHZ: Makefiles for customized clock speed with proper build switch F_CPU

For the IAR tool chain Example project files for changing the system clock are provided for the MAC application *Star_Nobeacon* for the above described hardware platform. Please check directory

```
MAC_v_x_y_z\Applications\MAC_Examples\Star_Nobeacon\
AT86RF231_ATXMEGA128A1_REB_4_1_STK600
```

for the following IAR project files:

- Star.eww: Standard clock speed of 16MHz
- Star_32/8/4_MHZ.eww/ewp: IAR project files for customized clock speed with proper build switch F_CPU

In order to review the changes for the selectable clock speed feature, search for occurrences of this build switch in the corresponding files *pal_board.c* and *pal_config.h*.

Other clock speeds than the currently supported speed (such as 1MHz or 2MHz) could be implemented easily by updated the dedicated code snippets pointed out by F_CPU.

12 Protocol implementation conformance statement (PICS)

This chapter lists the conformance of the Atmel AVR2025 MAC implementation with the requirements and optional features as defined by the standard specified in [4] in Section D.7.

12.1 Major roles for devices compliant with IEEE Std 802.15.4-2006

Table 12-1. Functional device types.

Item number	Item description	Status	Support		
			N/A	Yes	No
FD1	Is this a full function device (FFD)	O.1		X	
FD2	Is this a reduced function device (RFD)	O.1		X	
FD3	Support of 64 bit IEEE address	M		X	
FD4	Assignment of short network address (16 bit)	FD1:M		X (FFD only)	
FD5	Support of short network address (16 bit)	M		X	
O1: At least one of these features shall be supported.					

12.2 Major capabilities for the PHY

Table 12-2. PHY functions.

Item number	Item description	Status	Support		
			N/A	Yes	No
PLF1	Transmission of packets	M		X	
PLF2	Reception of packets	M		X	
PLF3	Activation of radio transceiver	M		X	
PLF4	Deactivation of radio transceiver	M		X	
PLF5	Energy detection (ED)	FD1:MO		X (FFD only)	
PLF6	Link quality indication (LQI)	M		X	
PLF7	Channel selection	M		X	
PLF8	Clear channel assessment (CCA)	M		X	
PLF8.1	Mode 1	O.2		X	
PLF8.2	Mode 2	O.2		X	
PLF8.3	Mode 3	O.2		X	
O2: At least one of these features shall be supported.					

12.3 Major capabilities for the MAC sub-layer

12.3.1 MAC sub-layer functions

Table 12-3. MAC sub-layer functions.

Item number	Item description	Status	Support		
			N/A	Yes	No
MLF1	Transmission of data	M		X	
MLF1.1	Purge data	FD1: M FD2: O		X (FFD only)	
MLF2	Reception of data	M		X	
MLF2.1	Promiscuous mode	FD1: M FD2: O		X (FFD only)	
MLF2.2	Control of PHY receiver	O		X	
MLF2.3	Timestamp of incoming data	O		X	
MLF3	Beacon management	M		X	
MLF3.1	Transmit beacons	FD1: M FD2: O		X (FFD only)	
MLF3.2	Receive beacons	M		X	
MLF4	Channel access mechanism	M		X	
MLF5	Guaranteed time slot (GTS) management	O			X
MLF5.1	GTS management (allocation)	O			X
MLF5.2	GTS management (request)	O			X
MLF6	Frame validation	M		X	
MLF7	Acknowledged frame delivery	M		X	
MLF8	Association and disassociation	M		X	
MLF9	Security	M		X (data frames)	
MLF9.1	Unsecured mode	M		X	
MLF9.2	Secured mode	O			X
MLF9.2.1	Data encryption	O.4			X
MLF9.2.2	Frame integrity	O.4			X
MLF10.1	ED	FD1: M FD2: O		X (FFD only)	
MLF10.2	Active scanning	FD1: M FD2: O		X	
MLF10.3	Passive scanning	M		X	
MLF10.4	Orphan scanning	M		X	
MLF11	Control/define/determine/declare superframe structure	FD1: O		X (FFD only)	
MLF12	Follow/use superframe structure	O		X	
MLF13	Store one transaction	FD1: M		X (FFD only)	

Item number	Item description	Status	Support		
			N/A	Yes	No
O4: At least one of these features shall be supported.					

12.3.2 MAC frames

Table 12-4. MAC frames.

Item number	Item description	Transmitter		Receiver	
		Status	Support N/A Yes/No	Status	Support N/A Yes/No
MF1	Beacon	FD1: M	Yes (FFD only)	M	Yes
MF2	Data	M	Yes	M	Yes
MF3	Acknowledgment	M	Yes	M	Yes
MF4	Command	M	Yes	M	Yes
MF4.1	Association request	M	Yes	FD1: M	Yes (FFD only)
MF4.2	Association response	FD1: M	Yes (FFD only)	M	Yes
MF4.3	Disassociation notification	M	Yes	M	Yes
MF4.4	Data request	M	Yes	FD1: M	Yes
MF4.5	PAN identifier conflict notification	M	Yes	FD1: M	Yes
MF4.6	Orphaned device notification	M	Yes	FD1: M	Yes (FFD only)
MF4.7	Beacon request	FD1: M	Yes	FD1: M	Yes
MF4.8	Coordinator realignment	FD1: M	Yes (FFD only)	M	Yes
MF4.9	GTS request	MLF5: O	No	MLF5: O	No

13 Abbreviations

API	Application Programming Interface
BMM	Buffer Management Module
GPIO	General Purpose Input/Output
IRQ	Interrupt Request
ISR	Interrupt Service Routine
MAC	Medium Access Control
MCL	MAC Core Layer
MCPS	MAC Common Part Sub-layer
MCU	Microcontroller Unit
MHR	MAC Header
MIC	Message Integrity Code
MLME	MAC Sub-layer Management Entity
MPDU	MAC Protocol Data Unit
MSDU	MAC Service Data Unit
NHLE	Next Higher Layer Entity
NWK	Network Layer
PAL	Platform Abstraction Layer
PAN	Personal Area Network
PIB	PAN Information Base
QMM	Queue Management
RCB	Radio Controller Board
REB	Radio Extender board
SAL	Security Abstraction Layer
SIO	Serial I/O
SPI	Serial Peripheral Interface
STB	Security Toolbox
TAL	Transceiver Abstraction Layer
TFA	Transceiver Feature Access
TPS	Transceiver Programming Suite
TRX	Transceiver
WPAN	Wireless Personal Area Network

14 References

[1] Atmel Wireless MCU Software Website
http://www.atmel.com/dyn/products/tools_card.asp?tool_id=4373

[2] Dresden Elektronik Wireless data transmission 802.15.4 Website
http://www.dresden-elektronik.de/shop/cat4.html?language=en

[3] Atmel Wireless Support avr@atmel.com

[4] IEEE Std 802.15.4™-2006 Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)

[5] AVR2025 IEEE 802.15.4 MAC Reference Manual
MAC_readme.htm located in the AVR2025 top directory

[6] RZ600 Evaluation Kit Website
http://www.atmel.com/dyn/products/tools_card.asp?tool_id=4702

[7] ATAVRXPLAIN Evaluation and Demonstration Kit Website
http://www.atmel.com/dyn/products/tools_card.asp?tool_id=4506&source=xplain_page

[8] ATZB ZigBit Module Website
http://www.atmel.com/products/zigbee/zigbit_modules.asp?family_id=676

15 User guide revision history

Please note that the referring page numbers in this section are referring to this document. The referring revisions in this section are referring to the document revision.

15.1 Rev. 2025M-MCU Wireless-06/12

Released with AVR2025 MAC Version 2.8.0

1. AT86RF233 TAL support and demonstrated with TAL and MAC Examples
2. ATMEGARFR2 TAL support and demonstrated with TAL and MAC Examples
3. Platform support added for ATmega1281_REB_4_1_STK600 and ATZB_24_MN2
4. MAC examples and TAL examples added for ATZB_24_MN2
5. Pal_nvm_multi_write functionality added for AVR32
6. Watchdog support added for SAM3S
7. MAC Application Power Management Support – Star Push Button, a MAC Example demonstrates the feature.
8. Accelerometer_Display_App added for KEY_RC platform as a part of TAL Example to demonstrate the LCD and Motion Sensor on it

15.2 Rev. 2025M-MCU Wireless-10/11

Released with AVR2025 MAC Version 2.7.1

9. Performance_Test_EVK and Performance Test Application merged as a single application
10. Serial_AT_Interface added as a MAC application
11. Atmel AT86RF232 Radio support added for Atmel ATXmega256A3 and Atmel AT32UC3B1128 as a part of MAC & TAL applications

15.3 Rev. 2025L-MCU Wireless-07/11

Released with AVR2025 MAC Version 2.7.0

12. New applications added along with this release namely,
    a. Beacon_Application
    b. Nobeacon_Applications
13. Added Security Example Application to demonstrate MAC security
14. Atmel AVRStudio 5 Support for all AVR 8bit & AVR 32bit
15. Filtered and removed some of the platforms & MCU families
16. Added Performance_Test_EVK application description

15.4 Rev. 2025K-MCU Wireless-08/11

Released with AVR2025 MAC Version 2.6.1

17. mac_security.c file contents are completely removed for the web release
18. UART software driver issue working on SAM3S-EK Platform got fixed

15.5 Rev. 2025J-MCU Wireless-03/11

Released with AVR2025 MAC Version 2.6.0

19. Platform description for AVR32, SAM3S, CBB boards added

20. Tool Chain section is updated for AVR32, SAM.
21. Build Switches WATCHDOG,SLEEPING_TIMER for AVR32, XMEGA Platforms added

15.6 Rev. 2025I-MCU Wireless-10/10

Released with AVR2025 MAC Version 2.5.3

22. Build switch ENABLE_RC_OSC_CALIBRATION for Mega-RF platforms added

15.7 Rev. 2025H-MCU Wireless-08/10

Released with AVR2025 MAC Version 2.5.2

23. MAC Example Star_High_Rate added
24. High Data Rate support added
25. Platform description for RZ600 on top of Xplain board added
26. Platform description for ATZB ZigBit Modules on top of MeshBean2 board added

15.8 Rev. 2025G-MCU Wireless-08/10

Released with AVR2025 MAC Version 2.5.1

27. Description of new design of TAL and MCL added
28. Description of Tiny-TAL added
29. Support for ZigBit 212 added
30. New compiler switches added
31. Support for ATxmega256A3 added
32. Migration Guide from 2.4.x to 2.5.x added
33. High-density Network Configuration added
34. Frame transmission and reception procedure added
35. Buffer handling description added

15.9 Rev. 2025F-MCU Wireless-02/10

Released with AVR2025 MAC Version 2.4.2

36. Support of program code larger than 128KByte added
37. PAN-Id conflict detection handling added
38. Support for AT91SAM7XC added
39. Description of application security added
40. Description of security build switches updated

15.10 Rev. 2025E-MCU Wireless-01/10

Released with AVR2025 MAC Version 2.4.0

41. Support for AT86RF231 and AT86RF212 with AT91SAM7X256 added
42. Support for ATmega128RFA1-EK1 added
43. Build switch DISABLE_TSTAMP_IRQ added
44. Support for ATmega1284P removed
45. Support for ATxmega256A3
46. MAC Porting Guide using ATxmega256A3 as example added
47. MAC Examples App 3 (Beacon Payload) and App 4 (Beacon Broadcast Data) added
48. Build switch SYSTEM_CLOCK_MHZ renamed to F_CPU
49. Updated handling of MAC PIB attribute macRxOnWhenIdle and MAC power management

50. New build switch BAUD_RATE added
51. Support for AT86RF230A and related hardware platforms discontinued
52. Handling of callback stub functions added Handling of callback stub functions added
53. PICS Table added

15.11 Rev. 2025B-MCU Wireless-09/09

Released with AVR2025 MAC Version 2.3.1

54. Name of Radio Controller Board (RCB) changed: transceiver number suffix is replaced by board suffix
55. Support for ATmega128RFA1 added
56. Handling of Promiscuous Mode updated.
57. Migration Guide for previous MAC versions removed
58. Filter tuning section added
59. Description of Performance test application extended
60. Support for ATxmega MCU based AES within SAL
61. Handling of MAC components updated
62. Initial Support for AT91SAM7X256 added
63. DISABLE_IEEE_ADDR_CHECK added
64. Chapter Supported Platforms added
65. Chapter Topics on Platforms Porting added

15.12 Rev. 2025-AVR-04/09

Released with AVR2025 MAC Version 2.2.0

66. Initial Version

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