AVR2025: IEEE 802.15.4 MAC Software Package - User Guide -

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, i.e. ATmega128RFA1, AT86RF212, AT86RF231, and AT86RF230**
- **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 MAC software package AVR2025 release 2.5.2.

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 802.15.4 based transceivers and single chips
- Allows easy and quick platform porting
- Provides project files for two supported IDEs (IAR Embedded Workbench, AVR Studio / WinAVR)
- Supports star networks and peer-to-peer communication
- Supports nonbeacon and beacon-enabled networks

The MAC software package is a reference implementation demonstrating the use of Atmel's 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.

AVR E-LINK

MCU Wireless Solutions

Application Note

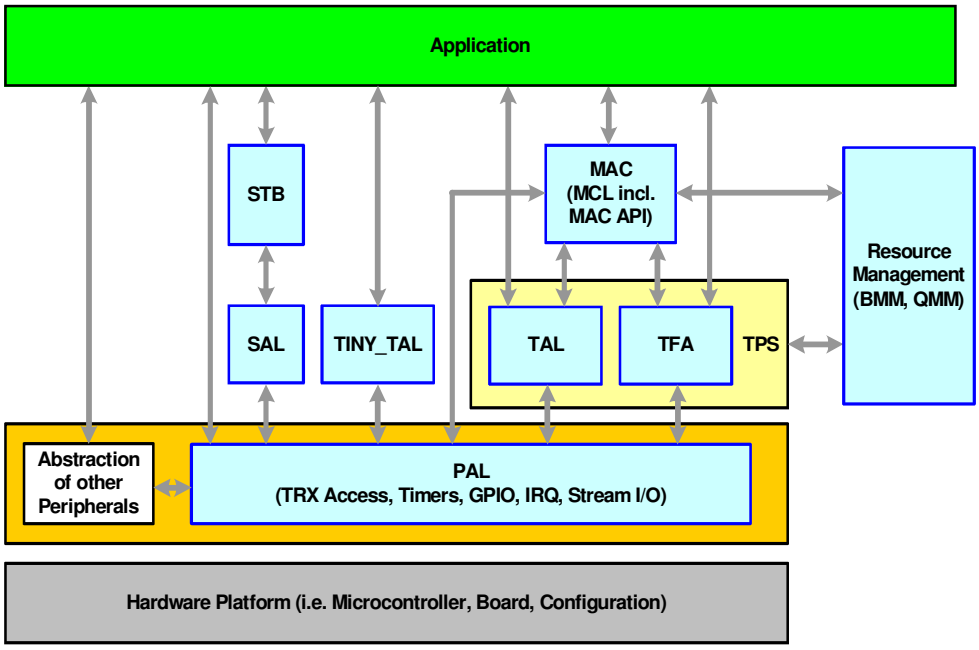
Preliminary

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 section 2.2.2 and 2.2.3)
- Resource Management including Buffer and Queue Management (BMM and QMM) (see section 2.2.1)
- Alternativly the Tiny-TAL with less footprint can be used for simple applications requiring less functionality (see section 2.2.5)

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 (i.e. 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, i.e. 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 (e.g. 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, e.g. 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 nonbeacon-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.

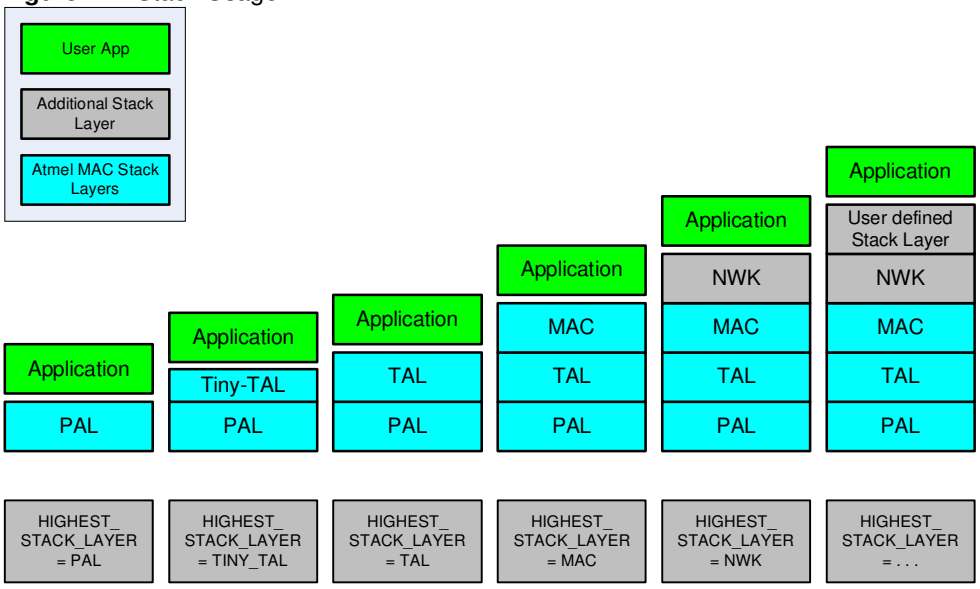
2.1.4 Usage of the Stack

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 (e.g. 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 (i.e. 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 6.1.1.1HIGHEST_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:

1. Queue used by MAC Core Layer
    a. NHLE-MAC-Queue
    b. TAL-MAC-Queue
    c. Indirect-Data-Queue
    d. Broadcast-Queue
2. Queue used by TAL
    a. TAL-Incoming-Frame-Queue

3. 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, e.g. 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 ordet get access to these specific features (see 6.1.4.3).

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
- 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 Measurment (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*).

2.2.5 Tiny Transceiver Abstraction Layer (Tiny-TAL)

2.2.5.1 Introduction

The Tiny-TAL (Tiny Transceiver Abstraction Layer) is a lightweight version of the TAL with less functionality and thus less footprint requirements. While the TAL is mainly used can be used as base layer for the MCL (although it can be used as the highest stack layer as well), the Tiny-TAL is always to be used as the highest stack layer (it cannot serve the MCL as base layer).

The Tiny-TAL contains generally the same functionality as the TAL, except for the following features, which are not available in the Tiny-TAL:

- No beacon mode (function tal_tx_beacon() is not implemented)
- No ED Scanning (functions tal_ed_start() and tal_ed_end_cb() are not implemented),
- No buffer management included, only utilization of simple static memory for frame reception
- Less static variables required
- Removal of frame_info_t structure, handling of simple frame arrays including octets (i.e. type uint8_t) building free format frames
- No internal queue used
- Timestamping not supported
- No filter tuning or PLL calibration supported
- Reduced PIB base (several PIB attributes are not implemented in the Tiny-TAL, such as attributes for beacon support, etc.)
- No API function for reading PIB attributes residing inside the Tiny-TAL

Applications which shall use the Tiny-TAL as base stack layer shall set the build switch

HIGHEST_STACK_LAYER = TINY_TAL in the corresponding Makefiles or project files (see 6.1.1.1).

An example application based on the Tiny-TAL can be found in section 9.2.4.

2.2.5.2 Tiny-TAL Frame Handling

The function for transmitting a frame by an application using the Tiny-TAL is defined as

```
void tal_tx_frame(uint8_t *tx_frame, csma_mode_t csma_mode,
```

```
                                    bool perform_frame_retry)
```

The callback function for indicating a received frame to the application residing on top of the Tiny-TAL is:

```
void tal_rx_frame_cb(uint8_t *rx_frame)
```

Both frame handling functions are simplified compared to the implementation within the original TAL by accepting/providing the frame in a simple array of octets (compare to the filled structure of type frame_info_t in the TAL). This enables easy handling of the fames in the application, especially for non-IEEE-confirm frames and allows for the easy development of applications using free format frames and/or user defined frame exchange protocol. For example, such user defined frame formats do not necessary require the MAC Header information as defined in [4], but instead could create its own frame header scheme.

The callback function after the frame transmission attempt

```
void tal_tx_frame_done_cb(retval_t status)
```

only contains the status of the transmission. The reference to the frame buffer is omitted (compared to the original TAL implementation), since buffer management is not used inside the Tiny-TAL.

2.3 Application

The application uses the services provided by the MAC-API. Besides that, the application can use the resource hooks, like timer functionality of the PAL, buffer and queue management.

It is in the responsibility of the application to implement the callback functions as confirmation and indication primitives for respective MAC data/management services.

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.

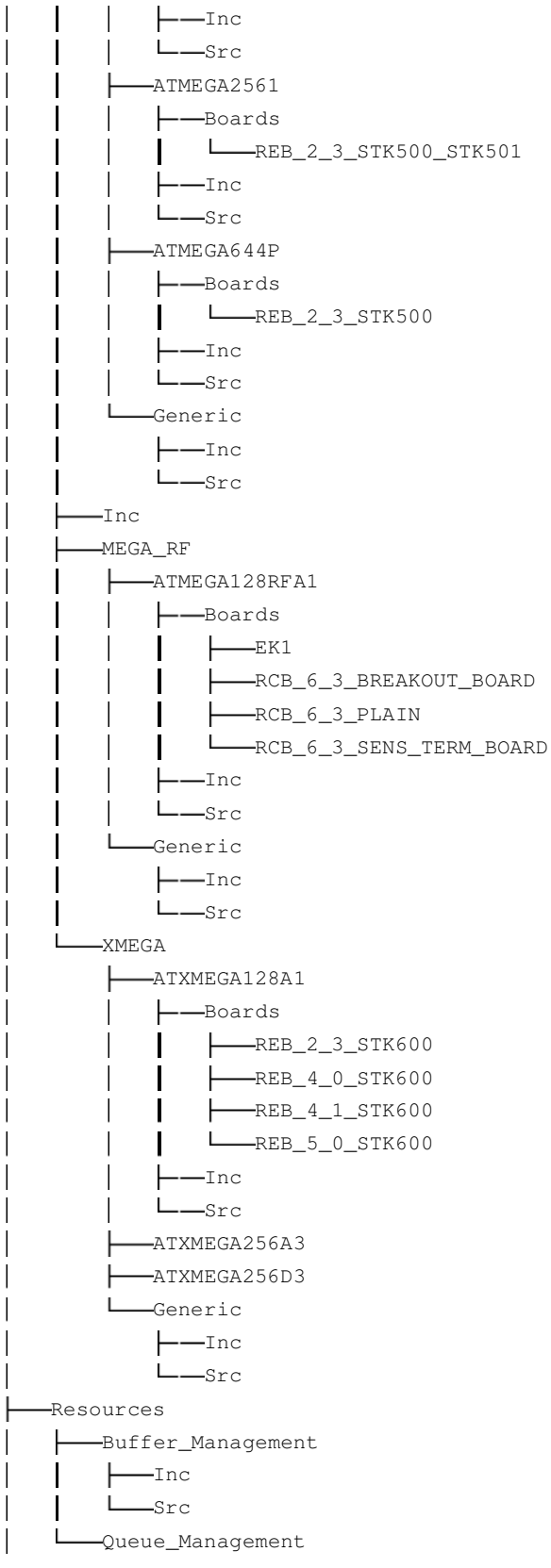
3.1 MAC Package Directory Structure

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

```
MAC_v_2_5_2
├──Applications
│   ├──Helper_Files
│   │   ├──SIO_Support
│   ├──MAC_Examples
│   │   ├──App_1_Nobeacon
│   │   │   ├──Coordinator
│   │   │   │   ├──AT86RF212_ATMEGA1281_RCB_5_3_PLAIN
│   │   │   │   ├──AT86RF212_ATXMEGA128A1_REB_5_0_STK600
│   │   │   │   ├──AT86RF230B_AT90USB1287_USBSTICK_C
│   │   │   │   ├──. . .
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   └──Device
│   │   │       ├──AT86RF212_ATMEGA1281_RCB_5_3_PLAIN
│   │   │       ├──. . .
│   │   │       ├──Inc
│   │   │       └──Src
│   │   ├──App_2_Nobeacon_Indirect_Traffic
│   │   │   ├──Coordinator
│   │   │   │   ├──. . .
│   │   │   │   ├──ATMEGA128RFA1_RCB_6_3_SENS_TERM_BOARD
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   ├──Device
│   │   │   │   ├──. . .
│   │   │   │   ├──Inc
│   │   │   │   └──Src
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Basic_Sensor_Network
│   │   │   ├──. . .
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──Promiscuous_Mode_Demo
│   │   │   ├──. . .
│   │   │   ├──Inc
│   │   │   └──Src
```

```
│   │   └──Star_Nobeacon
│   │       ├──. . .
│   │       ├──Inc
│   │       └──Src
│   ├──PAL_Examples
│   │   └──Simple_Remote_LED_Control
│   │       ├──ATMEGA128RFA1_RCB_6_3_PLAIN
│   │       ├──Inc
│   │       └──Src
│   ├──STB_Examples
│   │   ├──Secure_Remote_Control
│   │   │   ├──. . .
│   │   │   ├──ATMEGA128RFA1_RCB_6_3_PLAIN
│   │   │   ├──ATMEGA128RFA1_RCB_6_3_SENS_TERM_BOARD
│   │   │   ├──Inc
│   │   │   └──Src
│   │   └──Secure_Sensor
│   │       ├──Data_Sink
│   │       │   ├──. . .
│   │       │   ├──ATMEGA128RFA1_RCB_6_3_SENS_TERM_BOARD
│   │       │   ├──Inc
│   │       │   └──Src
│   │       ├──Inc
│   │       ├──Sensor
│   │       │   ├──. . .
│   │       │   ├──Inc
│   │       │   └──Src
│   │       └──Src
│   ├──TAL_Examples
│   │   ├──Performance_Test
│   │       ├──. . .
│   │       ├──Inc
│   │       └──Src
│   └──TINY_TAL_Examples
│       └──Wireless_UART
│           ├──. . .
│           ├──Inc
│           └──Src
├──Build
│   └──Build_MAC
│       ├──GCC
│       │   └──AVR
│       └──IAR
│           ├──ARM
│           └──AVR
├──Doc
│   ├──Application_Guide
```

```
│   ├──Reference_Manual
│   │   ├──MAC
│   │   ├──. . .
│   │   └──PAL_ATMEGA128RFA1_RCB_6_3_PLAIN
│   └──User_Guide
├──Include
├──MAC
│   ├──Inc
│   └──Src
├──PAL
│   ├──ARM7
│   │   ├──AT91SAMX256
│   │   │   ├──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
│   │   ├──AT91SAM7XC256
│   │   ├──Generic
│   │   │   ├──Inc
│   │   │   └──Src
│   ├──AVR
│   │   ├──AT90USB1287
│   │   │   ├──Boards
│   │   │   │   └──USBSTICK_C
│   │   │   ├──Inc
│   │   │   └──Src
│   │   ├──ATMEGA1281
│   │   │   ├──Boards
│   │   │   │   ├──RCB_3_2_BREAKOUT_BOARD
│   │   │   │   ├──RCB_3_2_PLAIN
│   │   │   │   ├──RCB_3_2_SENS_TERM_BOARD
│   │   │   │   ├──RCB_4_0_BREAKOUT_BOARD
│   │   │   │   ├──RCB_4_0_PLAIN
│   │   │   │   ├──RCB_4_0_SENS_TERM_BOARD
│   │   │   │   ├──RCB_4_1_BREAKOUT_BOARD
│   │   │   │   ├──RCB_4_1_PLAIN
│   │   │   │   ├──RCB_4_1_SENS_TERM_BOARD
│   │   │   │   ├──RCB_5_3_BREAKOUT_BOARD
│   │   │   │   ├──RCB_5_3_PLAIN
│   │   │   │   ├──RCB_5_3_SENS_TERM_BOARD
│   │   │   │   ├──REB_2_3_STK500_STK501
│   │   │   │   ├──REB_4_0_STK500_STK501
│   │   │   │   ├──REB_4_1_STK500_STK501
│   │   │   │   └──REB_5_0_STK500_STK501
```


Inc
Src
ATMEGA2561
Boards
REB_2_3_STK500_STK501
Inc
Src
ATMEGA644P
Boards
REB_2_3_STK500
Inc
Src
Generic
Inc
Src
Inc
MEGA_RF
ATMEGA128RFA1
Boards
EK1
RCB_6_3_BREAKOUT_BOARD
RCB_6_3_PLAIN
RCB_6_3_SENS_TERM_BOARD
Inc
Src
Generic
Inc
Src
XMEGA
ATXMEGA128A1
Boards
REB_2_3_STK600
REB_4_0_STK600
REB_4_1_STK600
REB_5_0_STK600
Inc
Src
ATXMEGA256A3
ATXMEGA256D3
Generic
Inc
Src
Resources
Buffer_Management
Inc
Src
Queue_Management

```
│       ├──Inc
│       └──Src
├──SAL
│   ├──AT86RF2xx
│   │   └──Src
│   ├──ATMEGARF_SAL
│   │   └──Src
│   ├──ATXMEGA_SAL
│   │   └──Src
│   ├──Inc
│   └──SW_AES_SAL
├──STB
│   ├──Inc
│   └──Src
├──TAL
│   ├──AT86RF212
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF230B
│   │   ├──Inc
│   │   └──Src
│   ├──AT86RF231
│   │   ├──Inc
│   │   └──Src
│   ├──ATMEGARF_TAL_1
│   │   ├──Inc
│   │   └──Src
│   ├──Inc
│   └──Src
├──TFA
│   ├──AT86RF212
│   │   └──Src
│   ├──AT86RF230B
│   │   └──Src
│   ├──AT86RF231
│   │   └──Src
│   ├──ATMEGARF_TAL_1
│   │   └──Src
│   └──Inc
└──TINY_TAL
    ├──AT86RF212
    │   ├──Inc
    │   └──Src
    ├──AT86RF230B
    │   ├──Inc
    │   └──Src
    ├──AT86RF231
```

```
│   ├──Inc
│   └──Src
├──ATMEGARF_TAL_1
│   ├──Inc
│   └──Src
├──Inc
└──Src
```

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 and AVR Studio and IAR Embedded Workbench project files are available for every supported microcontroller / transceiver / board configuration and can be used as quick start.
    - Hex files 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.
    - Also this MAC User Guide is located here.
- 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.

- TINY_TAL: This directory contains the Tiny Transceiver Abstraction Layer with subdirectories for each supported transceiver providing the lightweight version of the TAL

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
- TINY_TAL/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 (e.g. TAL/AT86RF231/Inc) or each microcontroller family and each single microcontroller have their own Inc directories (e.g. PAL/XMEGA/Generic/Inc or PAL/AVR/ATMEGA1281/Inc).

Generally the following header file naming conventions are followed:

1. 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
2. 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
3. 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
4. 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 Tiny-TAL based on 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.

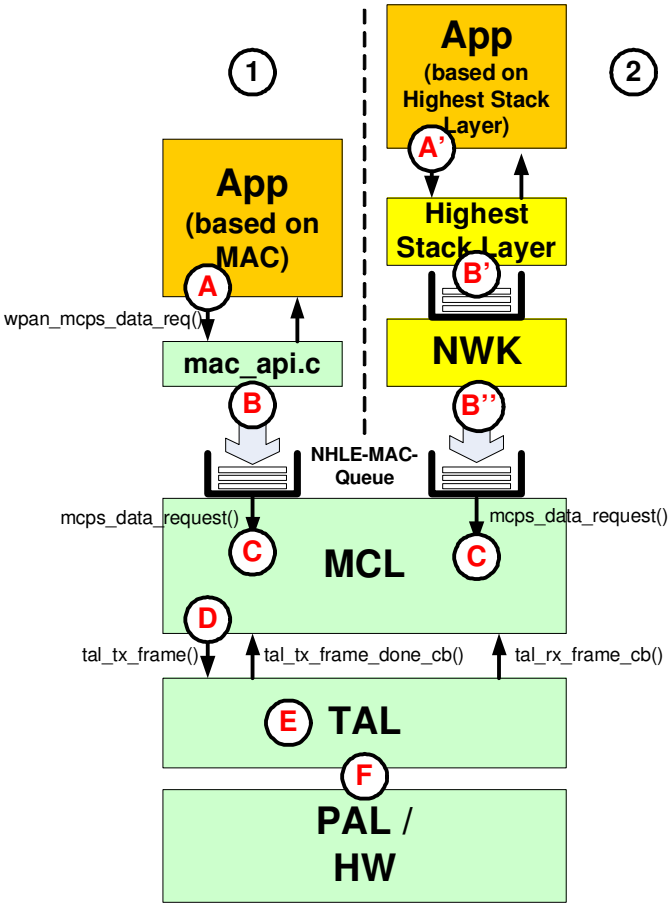
The stack is always separated into a stack domain and an application domain. The application resides on the stack layer called Highest Stack Layer (see section 2.1.4). The AVR2025 software package can be utilized in the following two different archictectures:

(**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 (i.e. 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 initate 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:

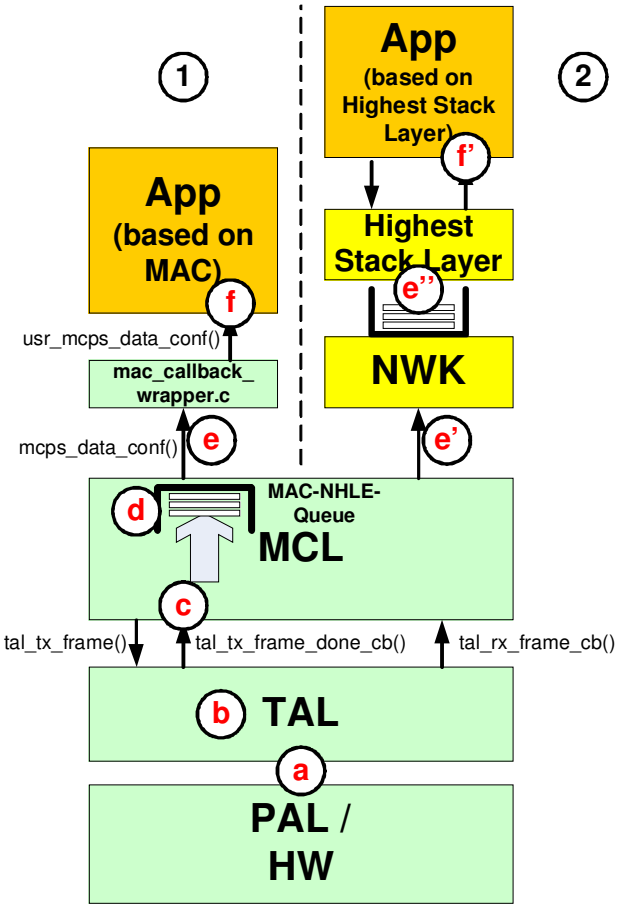
- Parsing of MAC address information
- Creation of the actual MAC frame by filling the information structure (structure ***frame_info_t*** – see file *TAL/Inc/tal.h*)
- The frame_info_t structure for the data frame contains a fully formatted MAC frame including the MAC Header information and the MSDU (i.e. 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''**).

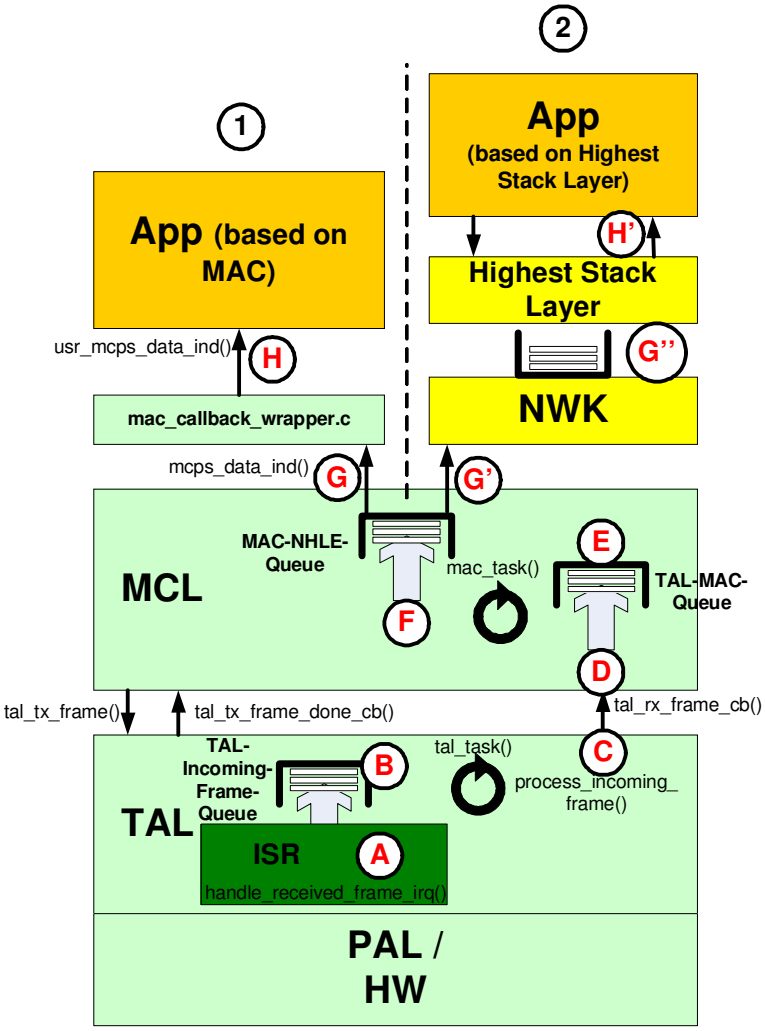
(**f**)(**f'**) Finally the application is notified about the status of the attempt to transmit a data frame by means of the callback function (usr_mcps_data_conf() if the application resides on top of the MAC layer) to be implemented inside the application itself.

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
- Queueing 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 (i.e. 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). Wihtin the stack itself the payload handling is very efficient and the content never needs to be copied.

4.2 Frame Buffer Handling

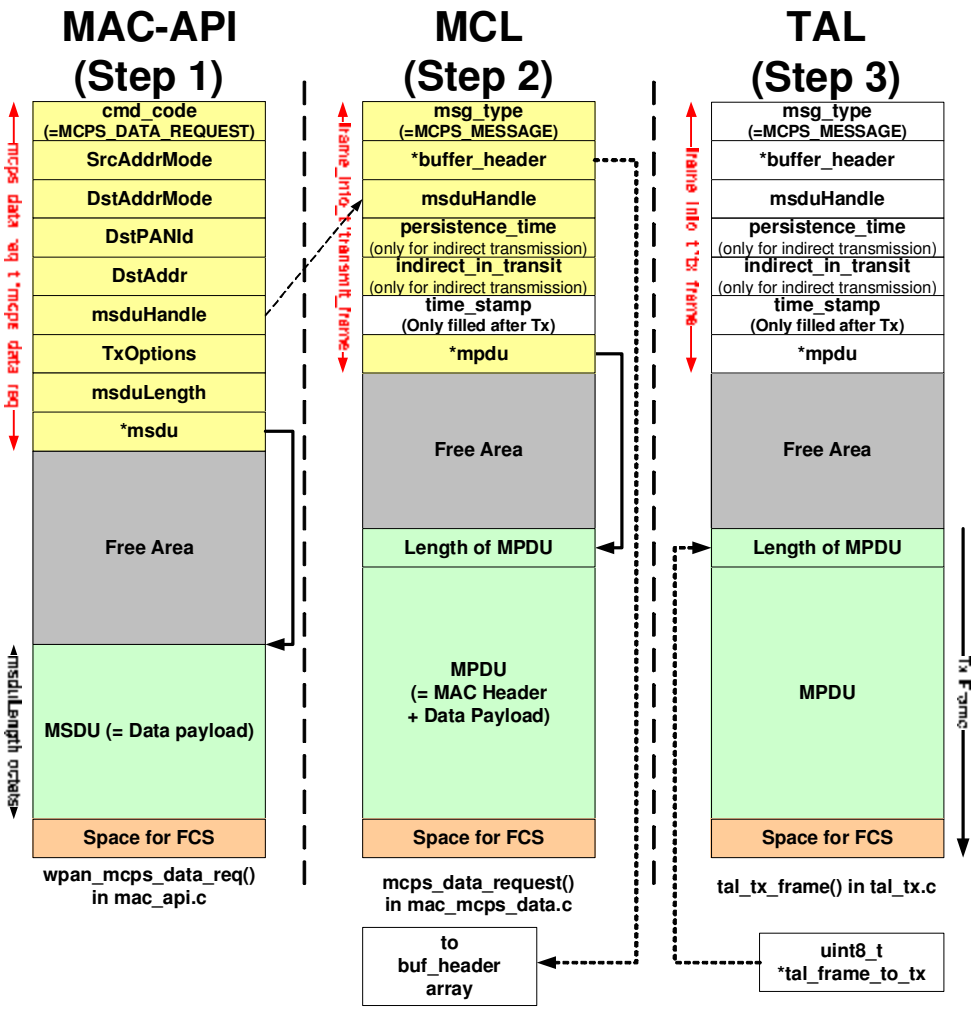
4.2.1 Application on top of MAC-API

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 overlayed 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 MSU 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 dequeued 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 overlayed 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:

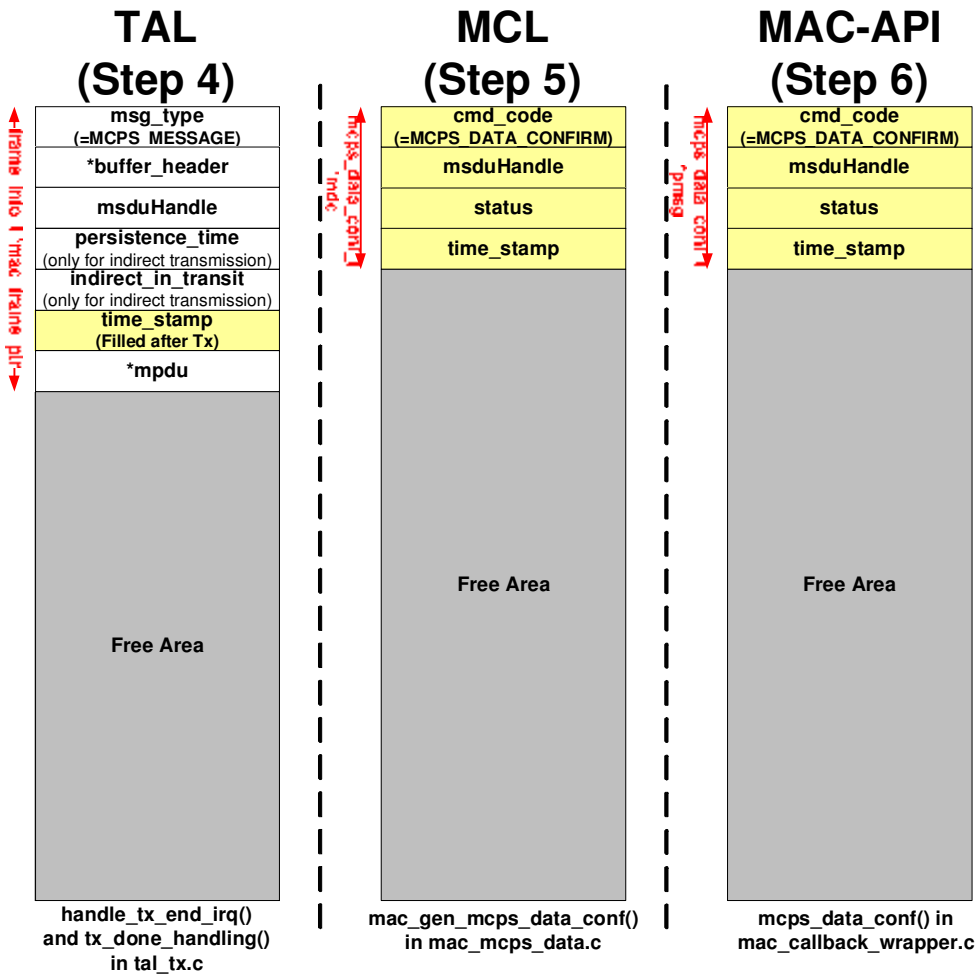
- The message_type parameter is set to MCPS_MESSAGE
- The MSDU handle is copied to the proper place
- The parameter in_transit (only utilized during indirect transmission) is set to the default value
- The buffer_header parameter is set to point to the actual buffer header; this is required once the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

As the last step the complete frame (i.e. 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 (i.e. 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 befinning 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 transveicer 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.

Aferwards 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 overlayed 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 dequeued 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 overlayed over the message (which is the actual buffer body):

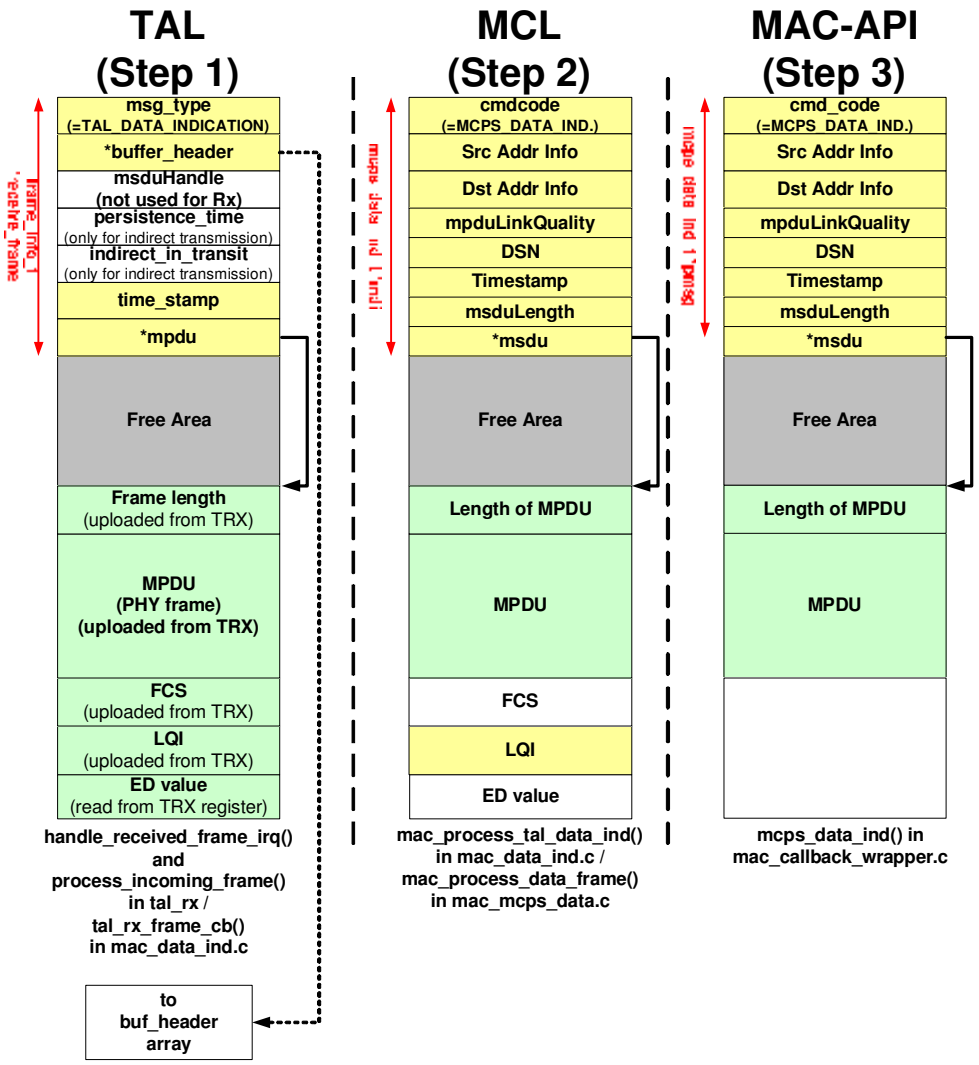
```
pmsg =
    (mcps_data_conf_t *)BMM_BUFFER_POINTER(((buffer_t *)m));
```

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 overlayed 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 overlayed 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 dequeued from the queue the dispatcher calles the corresponding function mac_process_tal_data_ind() (see file *MAC/Src/mac_data_ind.c*). In this function the receveived 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 overlayed 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 overlayed 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 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.

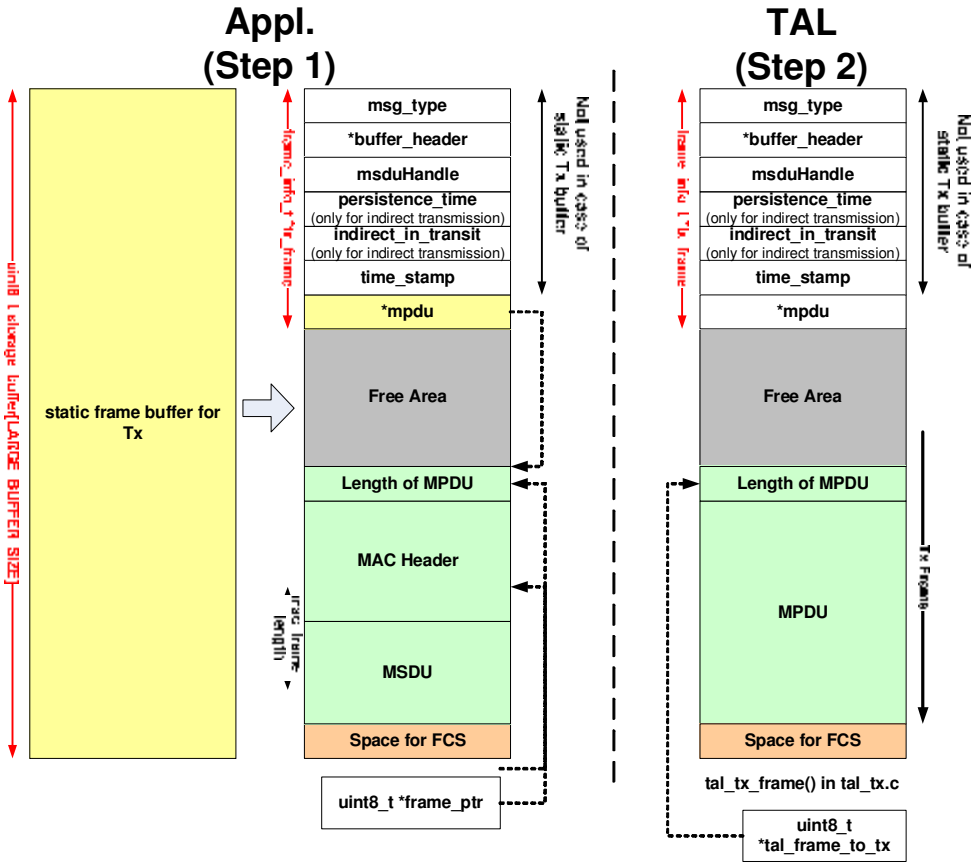
While the application on top of the TAL needs to free buffers received by the frame reception callback function (since these buffers are always alloated inside the TAL automatically), for frame transmission two different approaches are available:

1. Application uses buffer management module provided by stack including allocation and freeing of buffers for frame transmission, or
2. 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 9.2.2.1).

Important Note: Independent from the selected approach regarding the buffer management, it is important that the frame finally presentated to the TAL for transmission follows the scheme in the figure below. 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 overlayed 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 (i.e. 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 (i.e. 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().

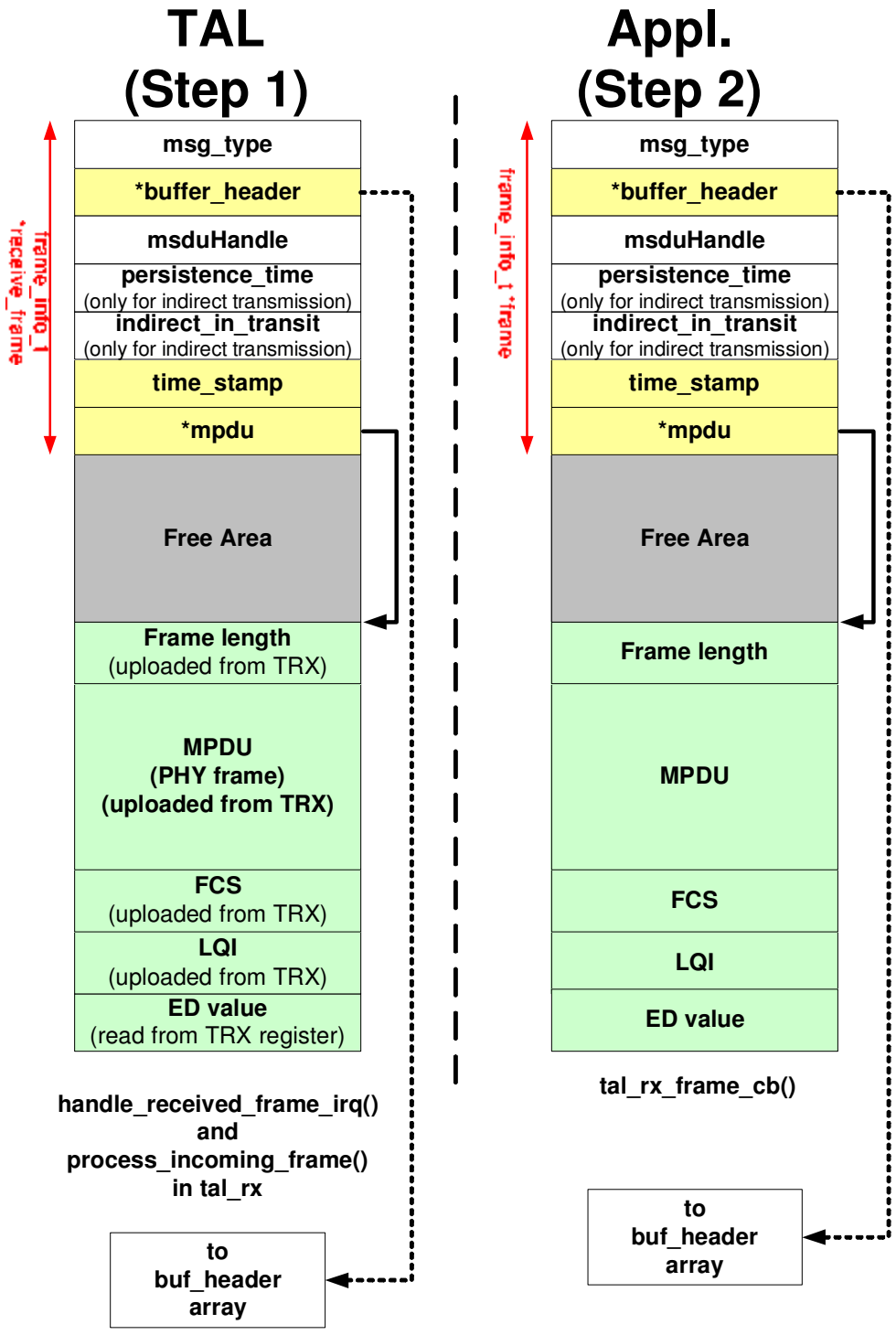
Step 2: Within the TAL in function tal_tx_frame() (see file *TAL/tal_type/Src/tal_tx.c*) a pointer is set to the location of the actual MPDU inside the frame buffer (member *mpdu* of structure *frame_info_t*). This pointer is used for initiating the frame transmission (by means of function send_frame()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

Step 3 (not included in figure above): 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 forther fransmission attempts. In case of dynamic buffer handling the Tx frame buffer needed to be freed addionally 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.

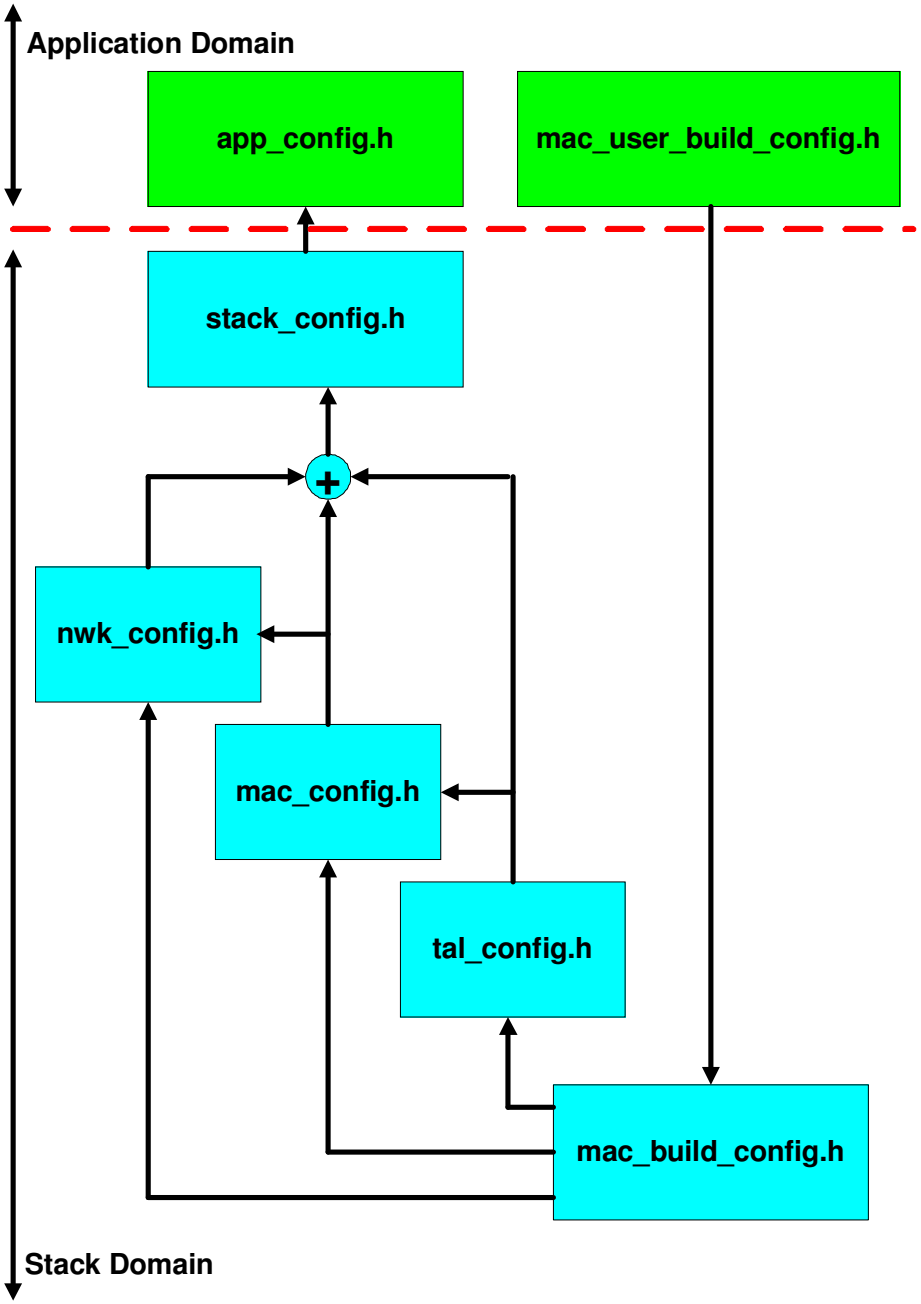
Throughout the various layers and thus directories within the software package the following configuration files are available:

- 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 (e.g. 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 Resource 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.

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 (e.g. 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, i.e. 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
- 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.

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.

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.

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.

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.

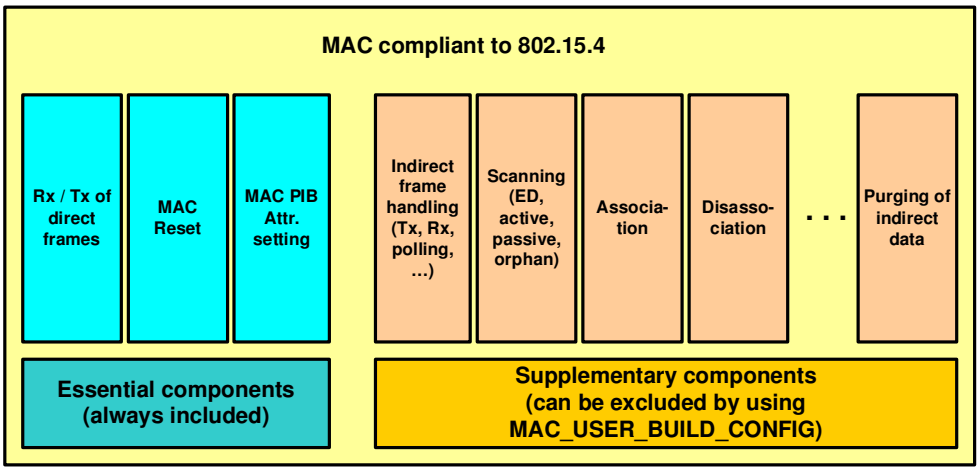
Essential components are required for a minimum reasonable application based on the MAC and are thus always included in a build. These components are:

- 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 (i.e. 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

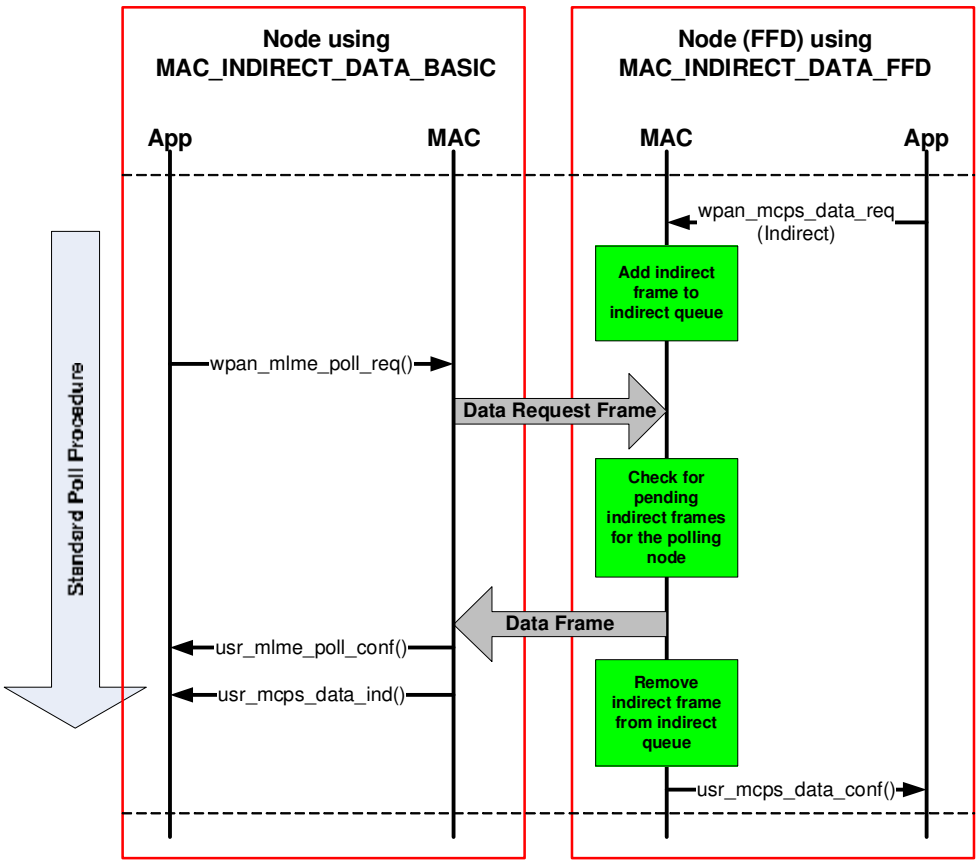
4.4.2 MAC_INDIRECT_DATA_FFD

This feature is a further extension of the feature MAC_INDIRECT_DATA_BASIC (i.e. 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

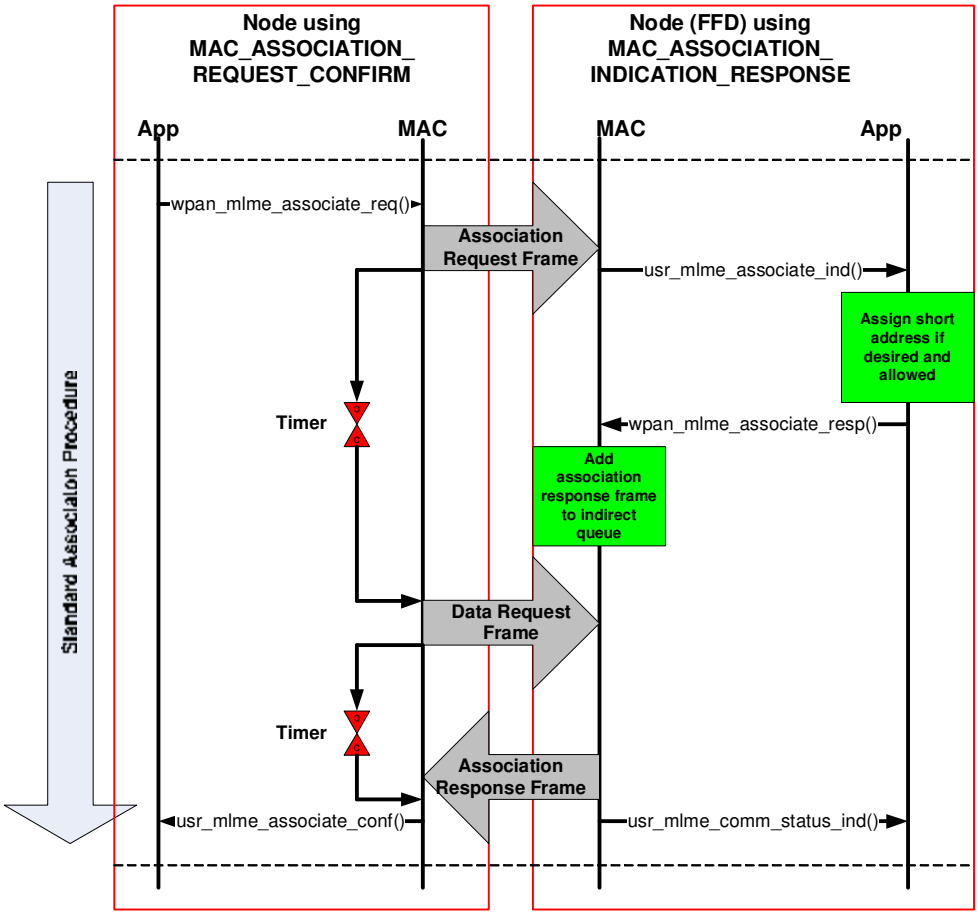
This feature allows a node (both RFD and FFD) to associate to a parent (PAN Coordinator or Coordinator) to initiate an association procedure (by transmitting an association request frame) and handle the reception of an association response frame.

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 (e.g. the network layer) to associate itself to another node (i.e. its parent).

Figure 4-12. Provided Functionality for MAC_ASSOCIATION_INDICATION_ RESPONSE and MAC_ASSOCIATION_REQEUST_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

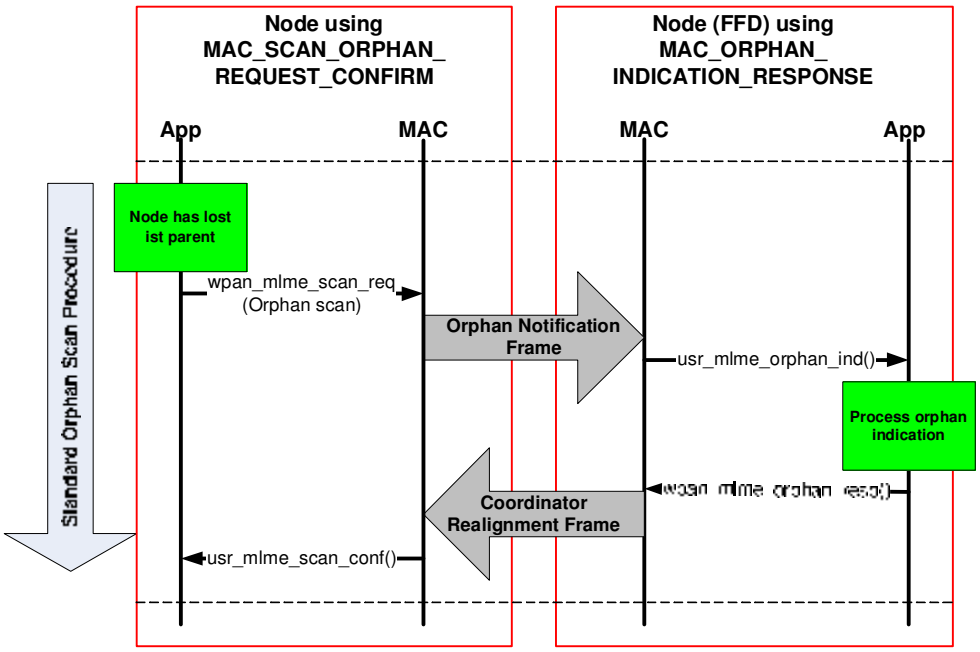
These components allow a node to perform a specific type of scanning.

- 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_REQEUST_CONFIRM (Orphan Scan Procedure)



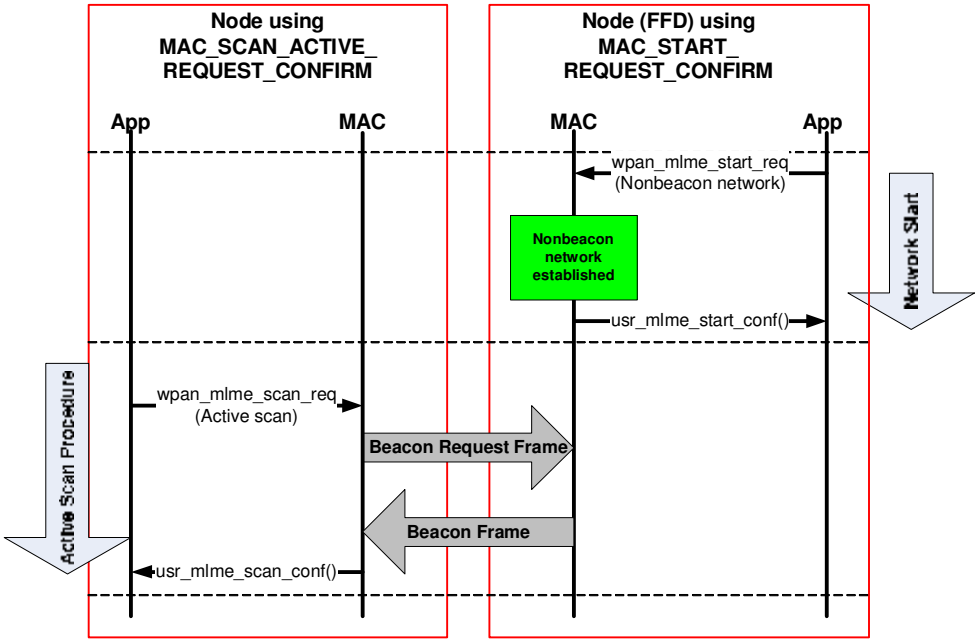
4.4.10 MAC_START_REQUEST_CONFIRM

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 nonbeacon-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)

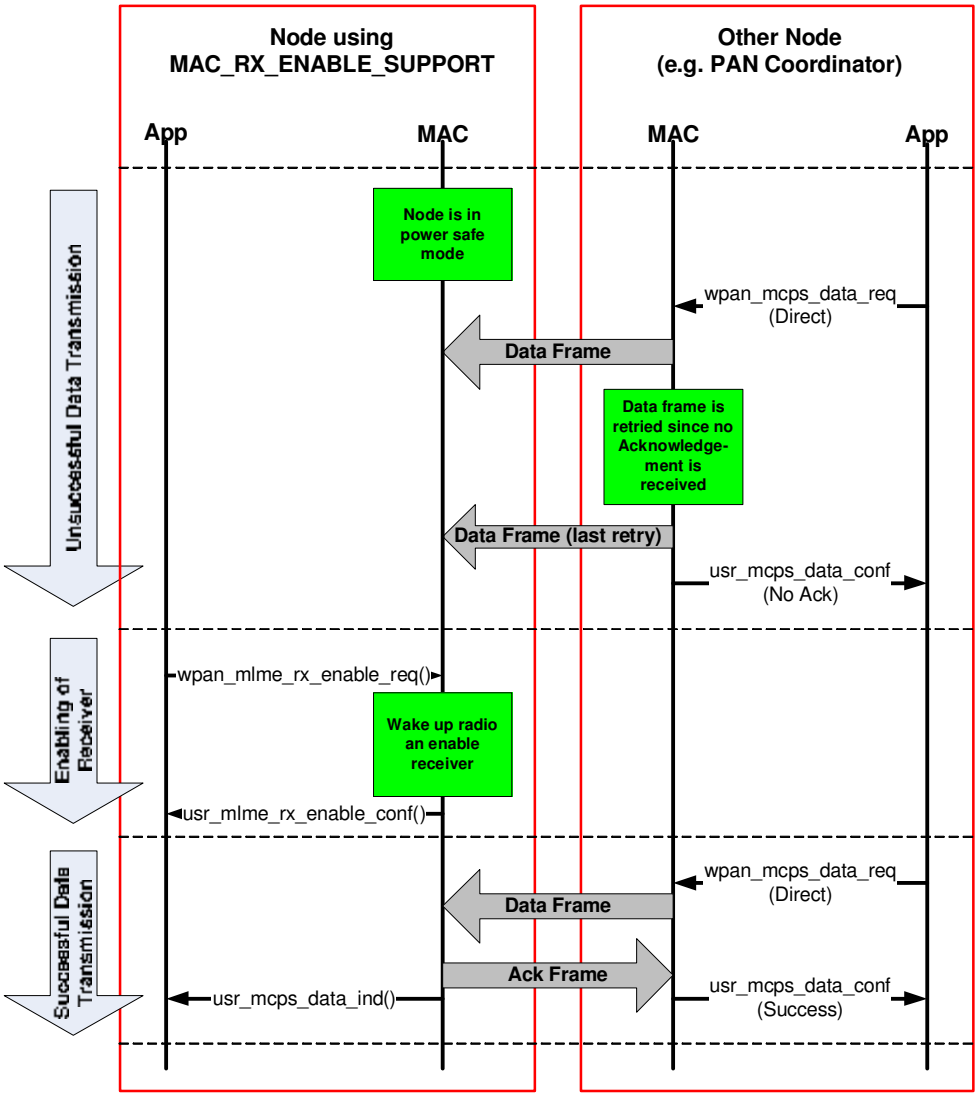
Figure 4-14. Start of Nonbeacon Network and Active Scan



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 9.2.1.3).

Figure 4-15. Enabling of Receiver and proper Data Reception



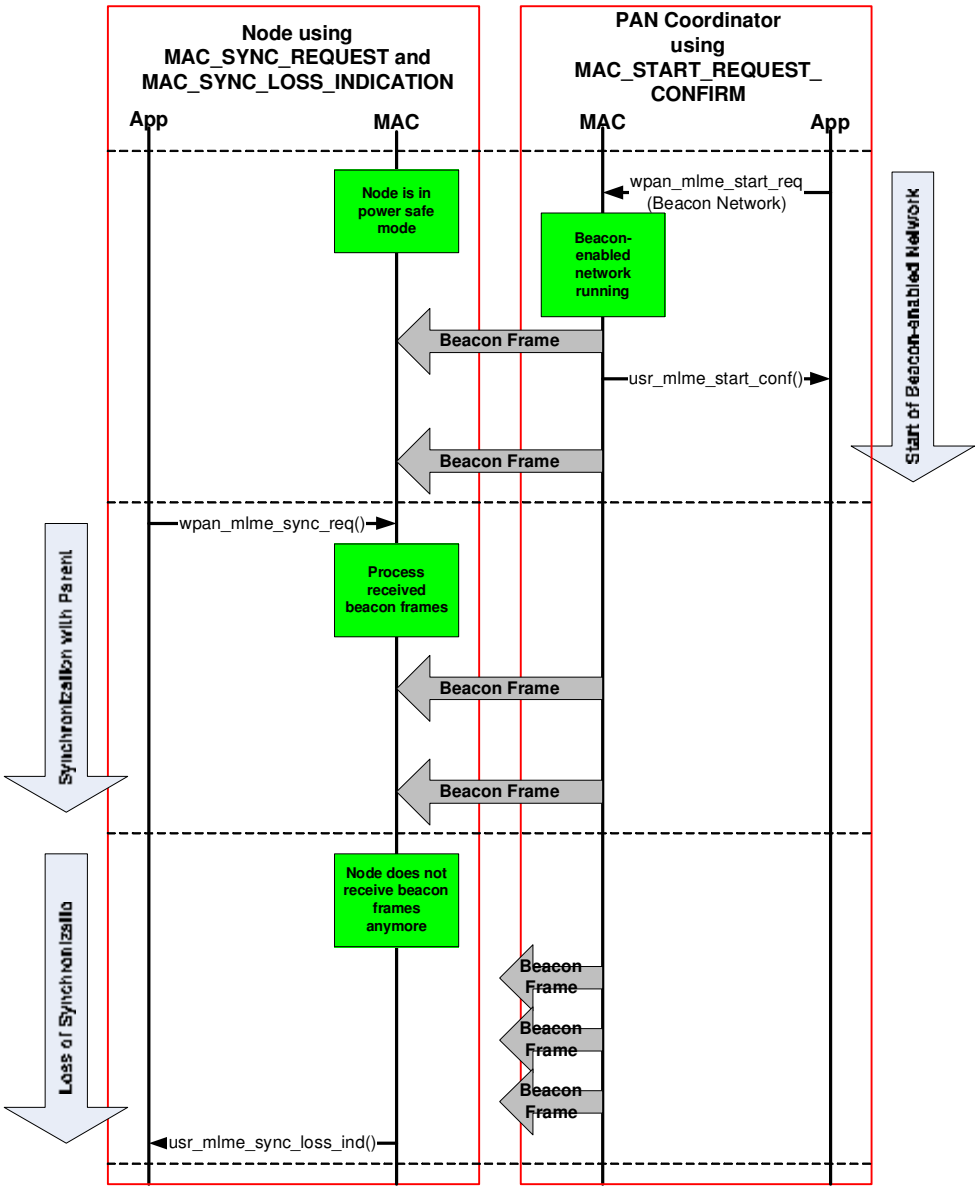
4.4.12 MAC_SYNC_REQUEST

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 128 KByte Program Memory

4.5.1 General

In order to support applications larger than 128 KByte 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 64 KByte of program memory. Functions located in the memory between 64 KByte and 128 KByte 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 127 KByte. So no special care is required for code up to 128 KByte.

In case function pointers shall be used for builds which are larger than 128 KByte (when using for instance the ATxmega256A3 MCU), the function pointers need to be declared as large pointers, i.e. pointers which are 24 Bit. The following section 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 128 KByte 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 128 KByte 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 128 KByte.

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 128 KByte 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 AVR MCUs with more than 128 KByte 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 as 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);
```

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:

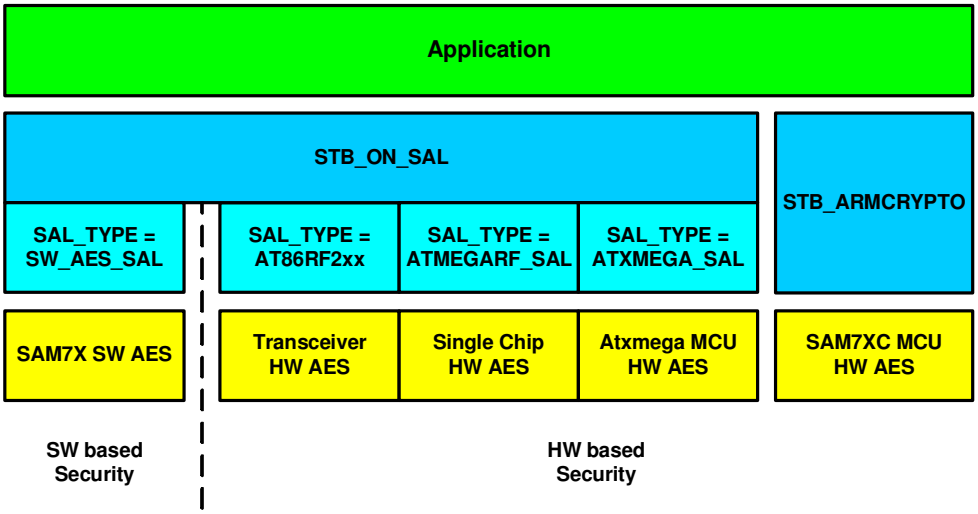
- SAL: Security Abstraction Layer (see section 2.2.2)
- STB: Security Toolbox (see section 2.2.3)

The SAL as low level AES functionality API is supported for various hardware AES engines (in MCUs and transceivers) and software AES (see section 6.1.5.1).

The STB as high level security abstraction API is

- Supported for SAL based systems (the STB requires either one of the SAL implementations, see section 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 AT91SAM7XC256.

Figure 4-17. Usage of the Secuity Layers by an Application



The figure above gives an overview which combinations of the two security layers are meaningful. It can be seen that the following security combinations are supported:

1. Utilization of hardware AES in transceivers, such as AT86RF212 and AT86RF231, by using the STB on top of the SAL (SAL_TYPE = AT86RF2xx); This combinations can be used in conjunction with any MCU
2. Utilization of hardware AES in single chip transceivers, such as ATmega128RFA1, by using the STB on top of the SAL (SAL_TYPE = ATMEGARF_SAL)
3. Utilization of hardware AES in ATxmega MCUs, such as 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 AT86RF230
4. Utilization of software AES, by using the STB on top of the SAL (SAL_TYPE = SW_AES_SAL);
   This combination is recommended only for powerful MCUs, such SAM7X based systems, although theoretically any MCU is supported, and can be used with any transceiver, even with AT86RF230; In order to get the SW AES implementation please contact avr@atmel.com
5. Ulitzation of the ARM hardware crypto engine by using STB_ARMCRYPTO without any SAL;
   This combination is supported for 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 nonbeacon-enabled and beacon-enabled networks. The following PIB attributes can be used to tweak the MAC in this regard:

- Backoff exponent: The PIB attributes *macMinBE* and *macMaxBE* determine the potential length of the backoff 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 backoff 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 3. The IEEE standard allows increasing the number of retries up to 7.
- Maximum CSMA backoffs: The PIB attribute *macMaxCSMABackoffs* defines the number of backoffs that are allowed before the channel is finally determined as busy and no transmission happens. The MAC implementation uses the default value of 4. Increasing the value to 5 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:

1. Enable the build switch HIGH_DATA_RATE_SUPPORT within the corresponding Makefile or project file (see 6.1.4.4)
2. Set the PIB attribute phyCurrentPage to the corresponding value (e.g. 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

The following table 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 4-18. 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**	20 kb/s @ -110 dBm 40 kb/s @ -108 dBm 2)	Channel Page 2 100 kb/s 250 kb/s	Channel Page 16 200 kb/s 500 kb/s 1), 3), 4), 5), 6)	Channel Page 17 400 kb/s 1000 kb/s 1), 3), 4), 5), 6)
Chinese Band **Channel 0-3** **AT86RF212**	N/A	Channel Page 5 250 kb/s	Channel Page 18 500 kb/s 1), 3), 4), 5), 6)	Channel Page 19 1000 kb/s 1), 3), 4), 5), 6)
2.4 GHz **Channel 11-26** **AT86RF231, ATmega128RFA1, …**	250 kb/s @ -101 dBm	Channel Page 2 500 kb/s 1), 3), 5)	Channel Page 16 1000 kb/s 1), 3), 5)	Channel Page 17 2000 kb/s 1), 3), 5)

1) PSDU data rate

2) BPSK

3) Reserved Channel pages are used to address the appropriate mode (non-compliant).
Marked w/ yellow background color. 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 9.2.1.8.

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, i.e. 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, i.e. 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 (e.g. 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, i.e. 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 App_1_Nobeacon (see 9.2.1.1) and Star_Nobeacon (see 9.2.1.7). 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 9.2.1.3).

5.2 Reception of Data at Nodes applying Power Management

When data shall be received by an End Device (i.e. 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, e.g. one symbols is 16us for 2.4 GHz 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 (i.e. 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 (i.e. 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 section 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 (e.g. 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 9.2.1.3):

```
/* 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 9.2.1.3.

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:

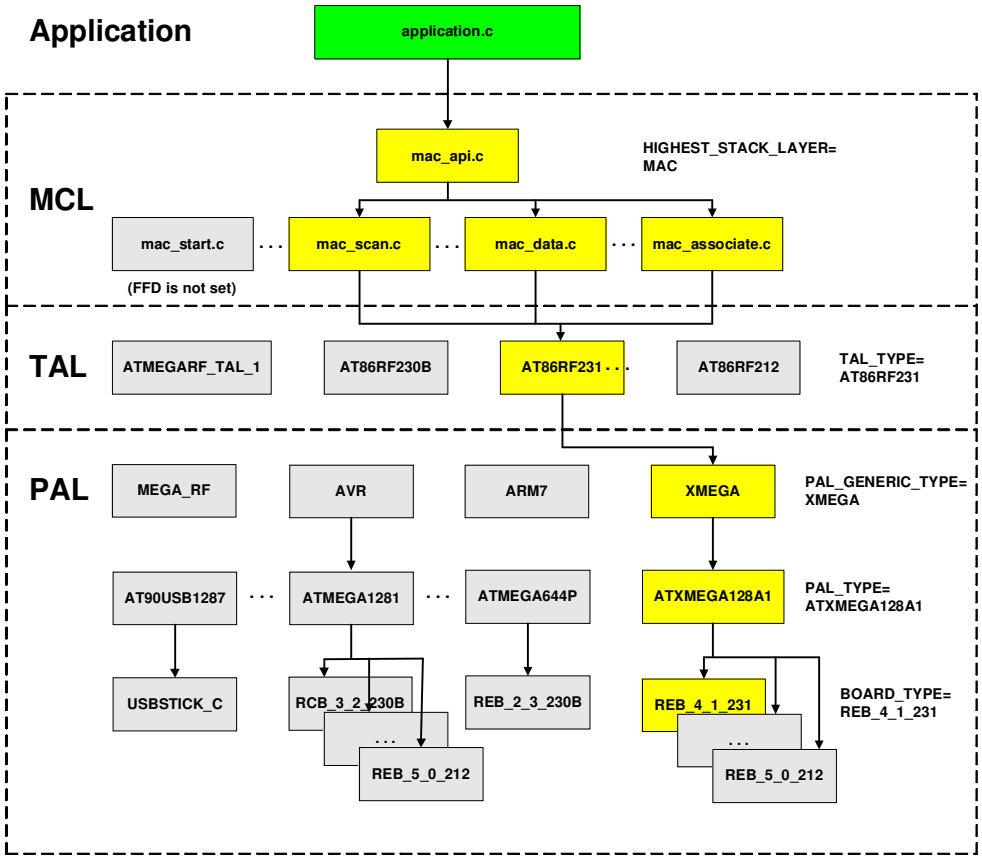
1. Global stack switches
    - HIGHEST_STACK_LAYER
    - REDUCED_PARAM_CHECK
    - PROMISCUOUS_MODE
    - ENABLE_TSTAMP
2. Standard or user build configuration switches
    - BEACON_SUPPORT
    - FFD
    - MAC_USER_BUILD_CONFIG
3. Platform switches
    - PAL_TYPE
    - PAL_GENERIC_TYPE
    - BOARD_TYPE
    - 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)

4. Transceiver specific switches
   - TAL_TYPE
   - ANTENNA_DIVERSITY
   - ENABLE_TFA
   - HIGH_DATA_RATE_SUPPORT
   - CHINESE_BAND
   - RSSI_TO_LQI_MAPPING
   - ENABLE_FTN_PLL_CALIBRATION
   - DISABLE_IEEE_ADDR_CHECK
5. Security switches
   - SAL_TYPE
   - STB_ON_SAL (formerly ENABLE_STB)
   - STB_ARMCRYPTO
6. 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 (e.g. 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 (i.e. which API it is using). If an application for instance only uses the PAL and TAL layers (i.e. 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 Tiny-TAL layer, this build switch shall be set to „HIGHEST_STACK_LAYER = TINY_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, i.e. 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.

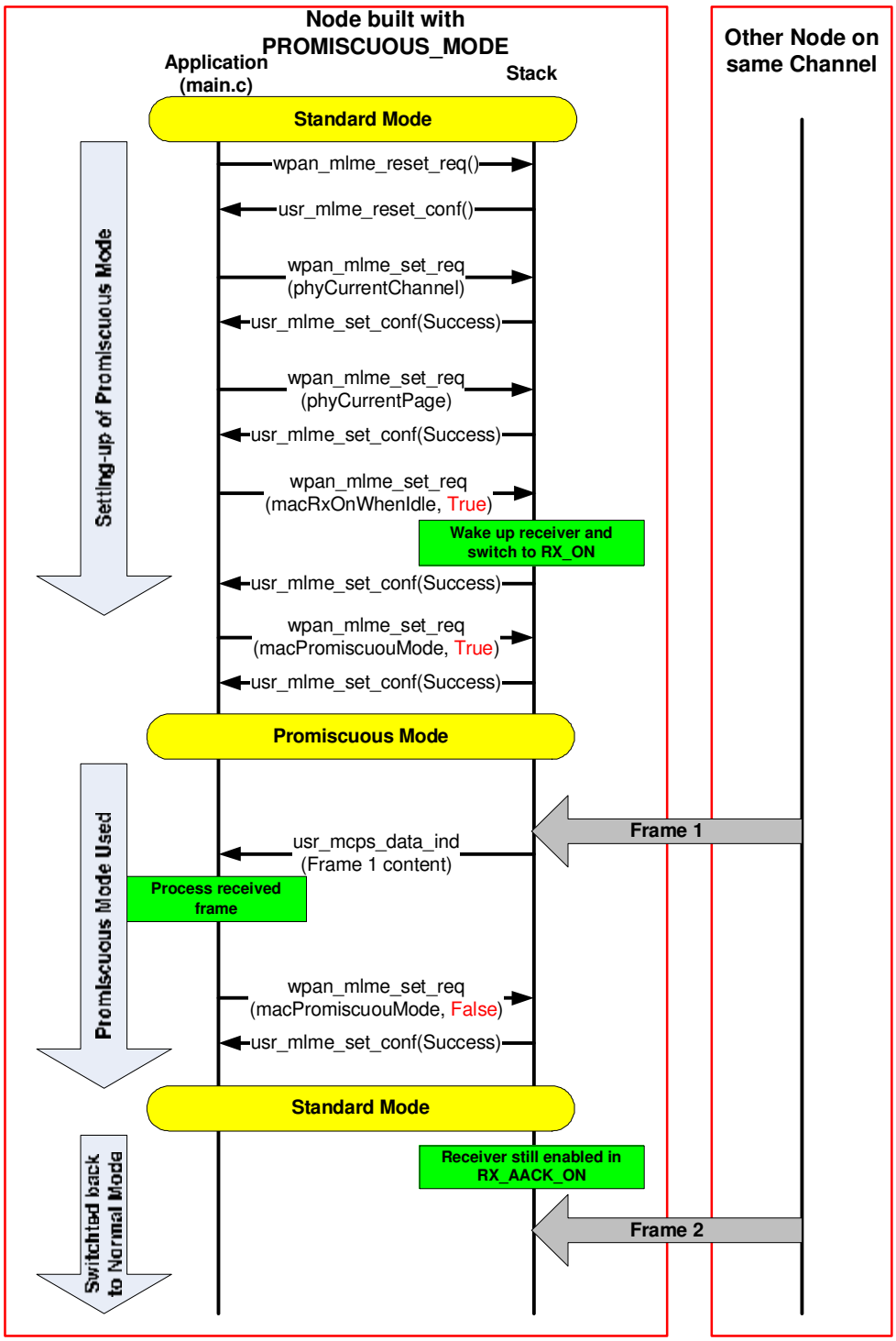
An example application presenting all received frames on a serial terminal can be found in the directory Applications/MAC_Examples/Promiscuous_Mode_Demo (see section 9.2.1.6).

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, e.g. 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 platform (i.e. MCU and board) based functionality and provides 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 AVR 8-bit controller (see file AVR\Generic\Src\pal_trx_access.c), or using Event System of 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:

- AVR
- XMEGA
- AVR32
- 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 AVR 8-bit 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:

- AT90USB1287
- ATmega1281
- ATmega2561
- ATmega644p
- ATxmega128A1

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

Usage in Makefiles:

```
CFLAGS += -DPAL_TYPE=ATXMEGA128A1
```

selects the ATxmega128A1 microcontroller.

Usage in IAR ewp files:

```
PAL_TYPE=ATMEGA644P
```

selects the ATmega644p 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, e.g. for ATmega2561 this file is located in directory PAL\AVR\ATMEGA2561\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 6.1.3.11 or 11.3.1.111.3.1).

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 AT86RF231 microcontroller.

6.1.3.4 SIO_HUB, UART0, UART1, USB0

Certain applications (e.g. TAL example Wireless_UART) 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 / demultiplexer 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.

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);
```

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 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 (AT86RF231 or 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 8 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, i.e. 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 (i.e. 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 ATxmega128A1 with 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 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
```

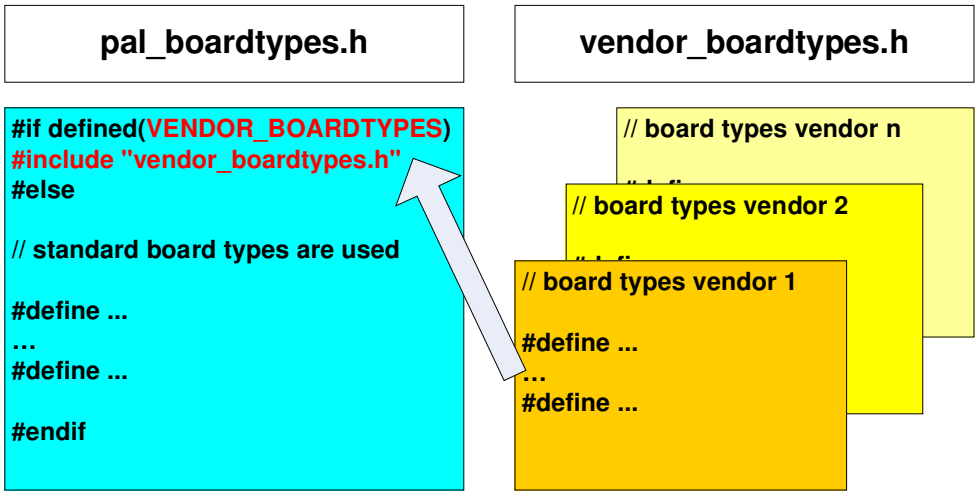
or

```
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 speficic 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 reqruiements, 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 Atmega128RFA1 provides up to usable 10 transceiver interrupts.

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

1. TX END IRQ (i.e. the main transceiver interrupt),
2. RX END IRQ, and
3. CCA ED IRQ,

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

The other enhanced transceiver interrupts of MEGA_RF platforms

1. AMI IRQ
2. Batmon IRQ
3. Awake IRQ
4. PLL Lock IRQ
5. PLL Unlock IRQ
6. AES Ready IRQ

are not used within the 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.

6.1.4 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:

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

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

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 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 this build switch has to be set.

For AT86RF230 transceivers this switch is not used.

Usage in Makefiles:

```
CFLAGS += -DANTENNA_DIVERSITY
```

enables the usage of antenna diversity.

Usage in IAR ewp files:

```
ANTENNA_DIVERSITY
```

enables the usage of antenna diversity.

6.1.4.3 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 of current temperature (only 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 ewp files:

```
ENABLE_TFA
```

enables the usage of the TFA.

6.1.4.4 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.

6.1.4.5 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 (e.g. 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_ATMEGA1281_RCB_5_3_SENS_TERM_BOARD.

6.1.4.6 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*.

6.1.4.7 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 (i.e. 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 5 minutes, i.e. 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.

6.1.4.8 DISABLE_IEEE_ADDR_CHECK

This build switch is used to disable the check whether the node has a valid IEEE address (i.e. 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 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 (i.e. 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.

6.1.4.9 DISABLE_TSTAMP_IRQ

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

The TAL for AT86RF231 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 AT86RF230 based systems.

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 (e.g. 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
- SW_AES_SAL - AES software implementation

For more information please check file SAL/Inc/*sal_types.h* 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, e.g. 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 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 crpto 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 (e.g. End Devices) vs. Full Functional Devices – FFD (PAN Coordinators, Coordinators)

The Atmel MAC provides 2 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, i.e. nonbeacon-enabled networks
- Setting of this build switch additionally enables functionality required for a network using a superframe structure, i.e. beacon-enabled networks

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 nonbeacon- and beacon-enabled networks has to use an application built with BEACON_SUPPORT.

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 (e.g. the network layer) to associate itself to another node (i.e. 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 nonbeacon-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 (e.g. the network layer) to associate itself to another node (i.e. 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.

6.2.2 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 bound 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 9.2.1.3.

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, i.e. 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 (e.g. MLME_ASSOCIATE-request and MLME_ASSOCIATE.confirm, or (2) Indication / Response (e.g. 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 (e.g. 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 Guide from Version 2.4.x to 2.5.x

With the release of AVR2026 version 2.5.x a number of significant improvement 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.

7.1 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

7.1.1 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 6.1.1.4.

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 an application using timestamping can be found in 9.2.1.3.

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 at /MAC/Inc/mac_api.h.

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*.

7.1.2 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 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:

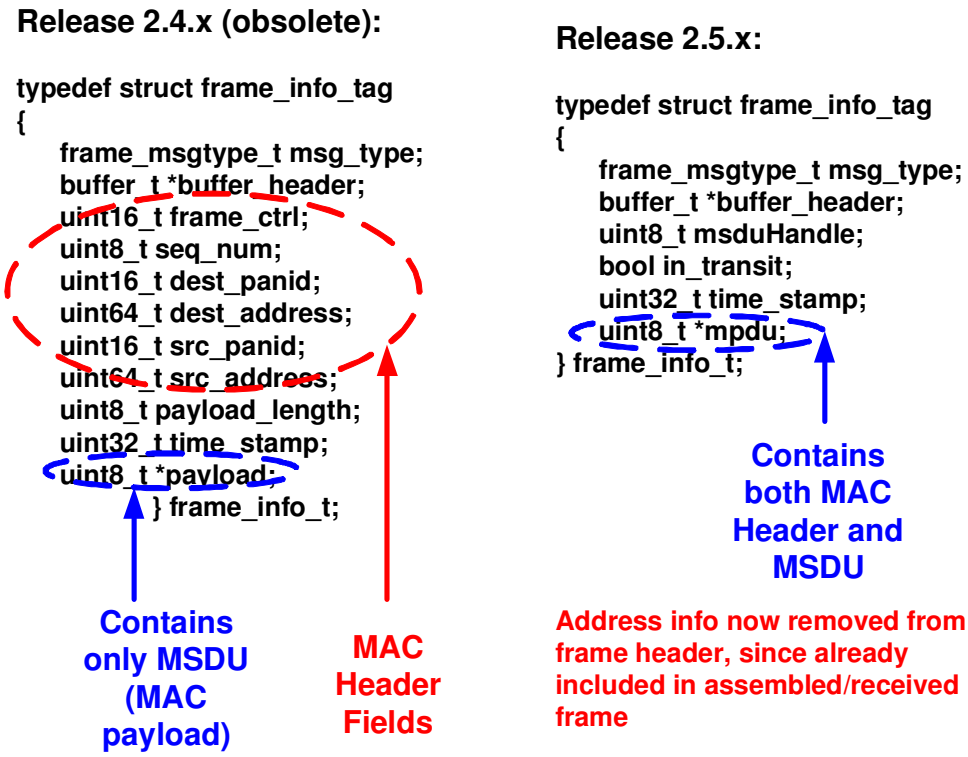
- Simplification of structure frame_info_t used within the TAL frame handling functions
- Simplification of frame indication callback function tal_rx_frame_cb()
- Simplification of Beacon handling API

7.2.1 Simplification of Structure frame_info_t

Frames being exchanged between the MCL and the TAL layer (i.e. 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



The MAC header information previously included by means of several structure elements mas 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 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.

7.2.3 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:

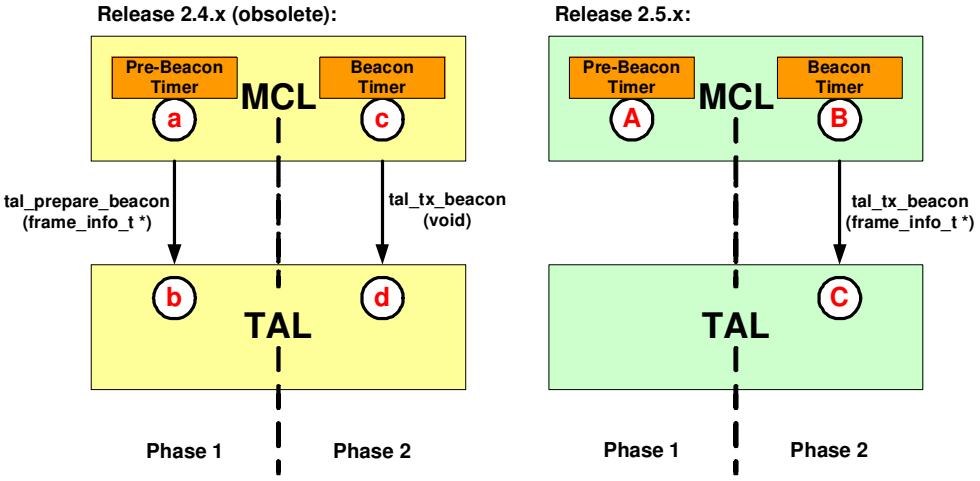
(**a**) Expiration of Pre-Beacon timer in MCL - Preparation of next Beacon frame within MCL

(**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

7.3 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.

7.3.1 TRX IRQ Initialization

7.3.1.1 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.

7.3.1.2 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.

7.3.2 TRX IRQ Enabling and Disabling

7.3.2.1 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.

7.3.2.2 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.

7.3.3 TRX IRQ Flag Clearing

7.3.3.1 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.

7.3.3.2 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 file *PAL/Inc/ptal.h* and the corresponding *pal_config.h* file for each platform implementation.

8 Tool Chain

The following chapter describes the used tool chain 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:

- AVR Studio 4.18
  (see http://www.atmel.com/dyn/products/tools_card.asp?tool_id=2725)
- WinAVR 20100110 including AVR-GCC for Windows
  (see http://sourceforge.net/projects/winavr)
- IAR Embedded Workbench for Atmel AVR V5.50.2
  (see http://www.iar.com/)
- IAR Embedded Workbench for Atmel ARM V5.50.3
  (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, e.g.

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

- Run the desired Makefile, e.g.

  ```
  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).

8.2.2 Using AVR Studio

Each application can be rebuilt using the 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, e.g.

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

- Double click on the corresponding AVR Studio Project file (aps-file), e.g. *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.
- 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 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, e.g.

```
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), e.g. *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 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 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

8.2.4 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, i.e. 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 run-time.

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

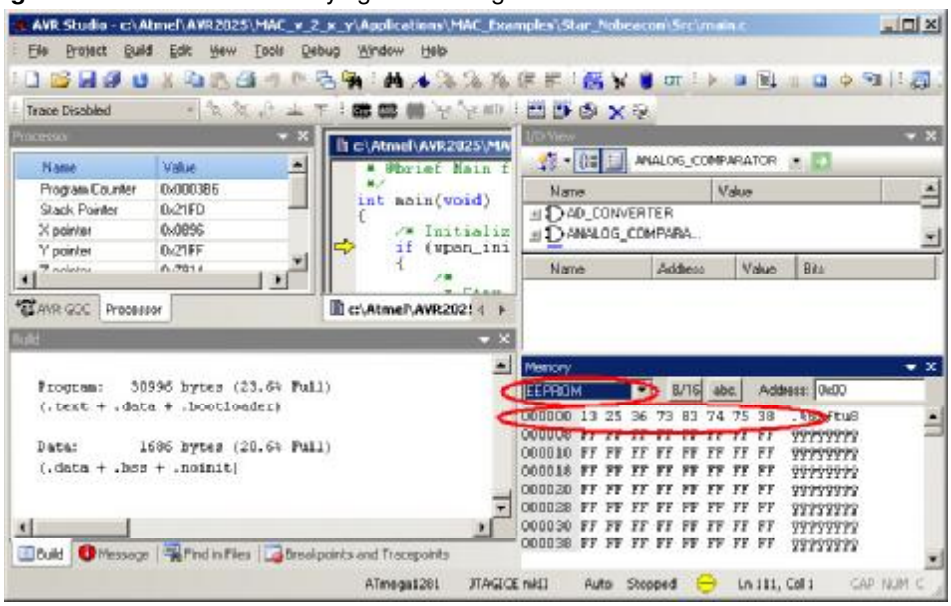
8.3.1 Using AVR Studio directly

When the application has been built using AVR Studio 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 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 8 octets of the EEPROM (see picture below).
- Start the application by pressing “F5” or clicking the “Run” button.

Figure 8-1. AVR Studio - Verifying and Setting of IEEE Address



8.3.2 Using AVR Studio after Command Line Build of Application

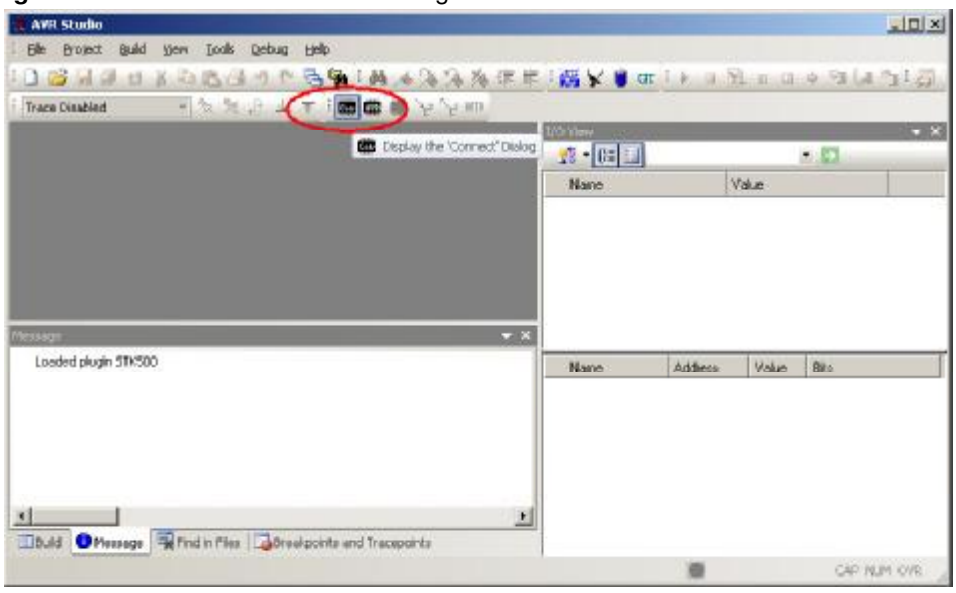
When the application has been built using external Makefiles from the command line, the application can be started following the steps described below.

8.3.2.1 Starting the Release Build

The release build can simply be started as follows:

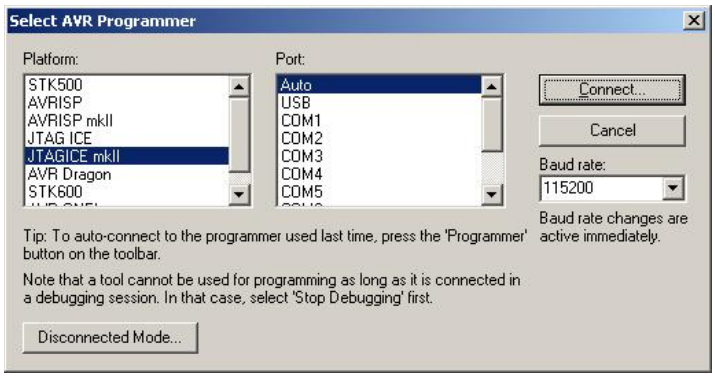
- Start AVR Studio.
- Display the “Connect” dialog.

Figure 8-2. AVR Studio “Connect” Dialog



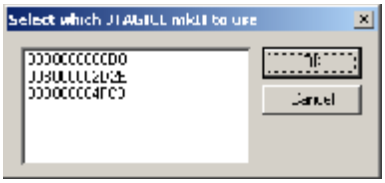
- Select the proper AVR Programmer (e.g. JTAGICE mkII) and press “Connect”.

Figure 8-3. AVR Studio “Select AVR Programmer” Dialog



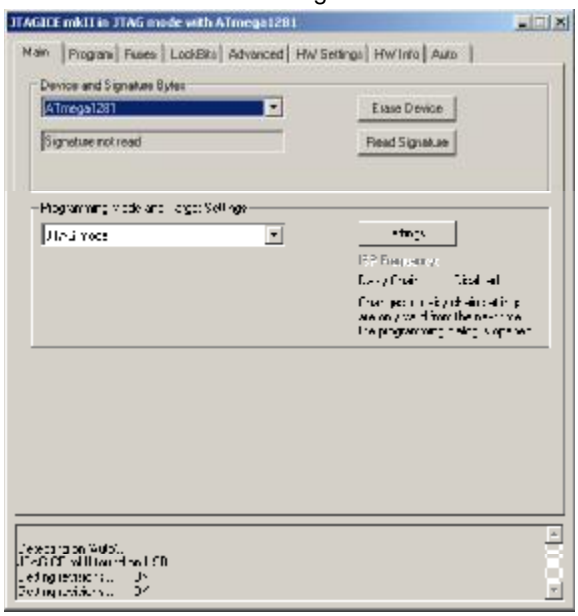
- In case more than one JTAGICE mkII are detected by AVR Studio select the proper Id.

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



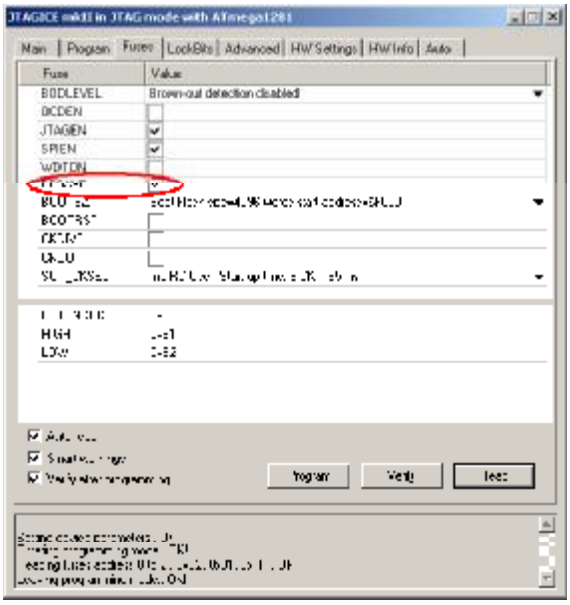
- After the JTAGICE selection the “JTAGICE mkII” dialog opens. Select the “Main” tab. Within this tab select the proper “Device and Signature Bytes” (e.g. “ATmega1281”) and the proper “Programming Mode and Target Settings” (e.g. “JTAG mode”).

Figure 8-5. AVR Studio “JTAGICE mkII” Dialog with “Main” Tab



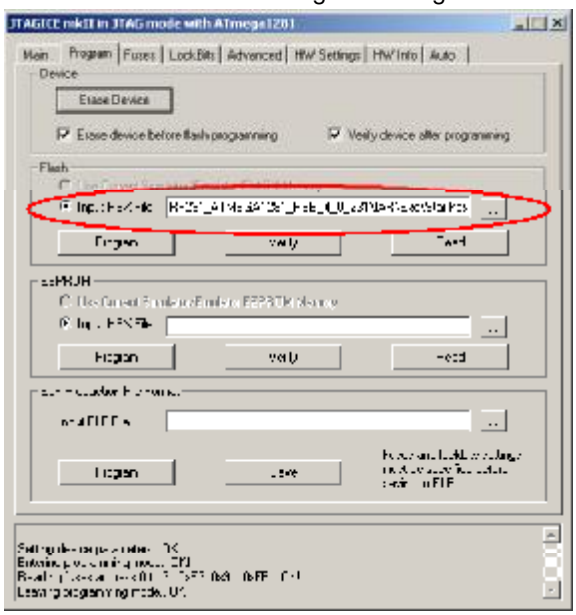
- Select the “Fuses” tab. Within this tab make sure that the EESAVE fuse is selected. This preserves the EEPROM through the Chip Erase cycle.

Figure 8-6. AVR Studio “JTAGICE mkII” Dialog with “Fuses” Tab



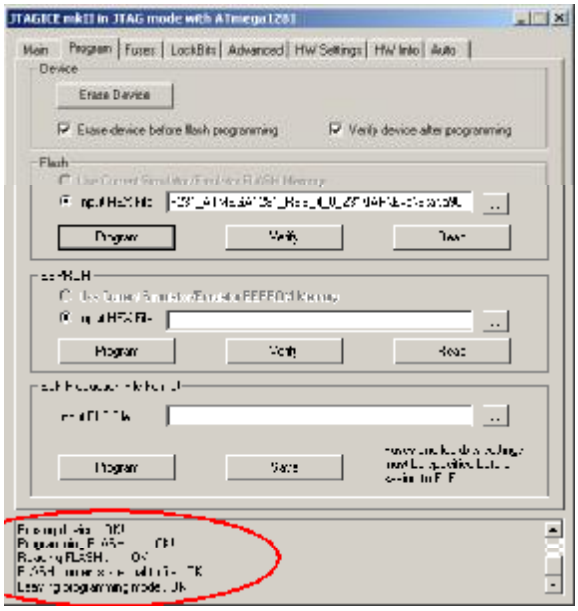
- Select the “Program” tab. Within this tab select the “Flash” section selection the proper Intel Hex File in either hex- or a90-format. Afterwards press button “Program”.

Figure 8-7. AVR Studio “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

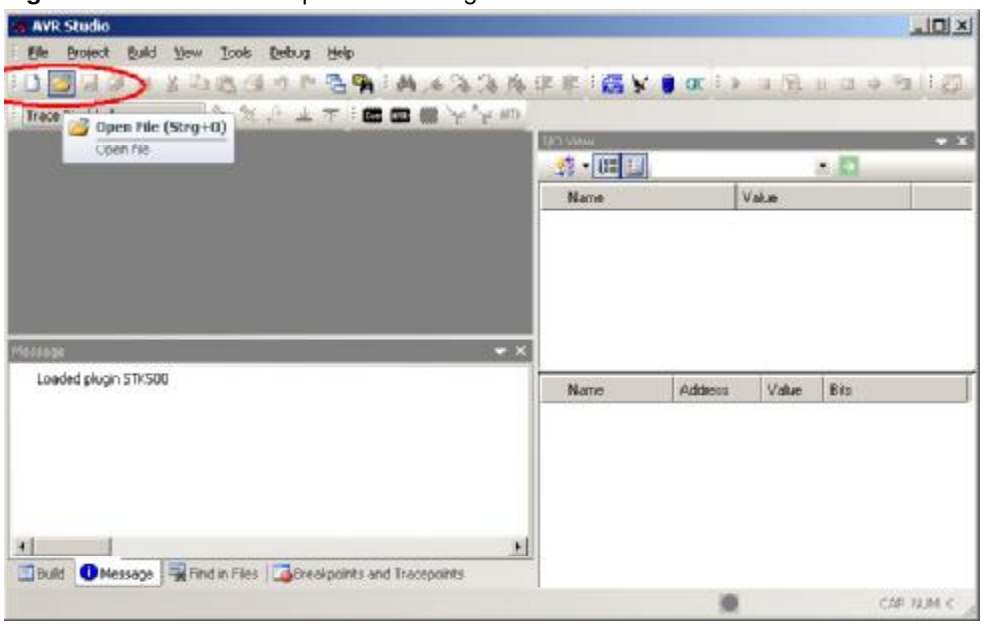
(see section 8.3.1 or section 8.3.2.2), or whether the proper binary has been selected (selection of transceiver type, microcontroller type, and board type).

8.3.2.2 Starting the Debug Build

The debug build can simply be started as follows:

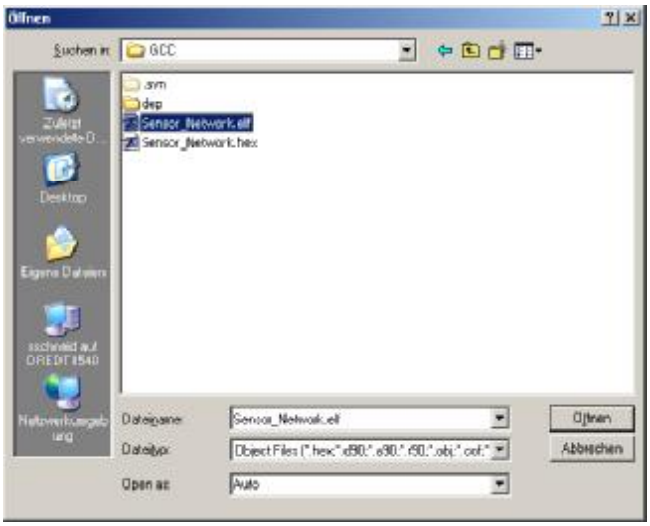
- Start AVR Studio.
- Display the “Open File” dialog.

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



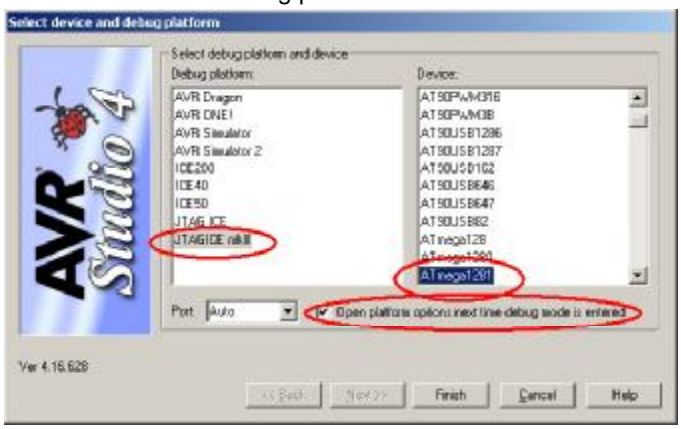
- Select the proper elf-file.

Figure 8-10. AVR Studio – Select elf-File



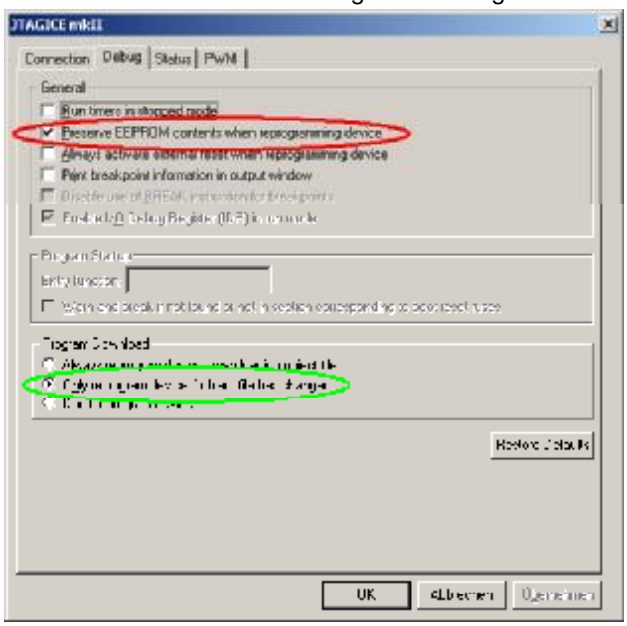
- In case a windows pops-up asking whether to save changes to a specific project press “Yes” and select the proper place to store the existing project file.
- The “Select device and debug platform” window opens. Select the proper “Debug platform” (e.g. JTAGICE mkII) and “Device” (e.g. ATmega1281). Make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

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



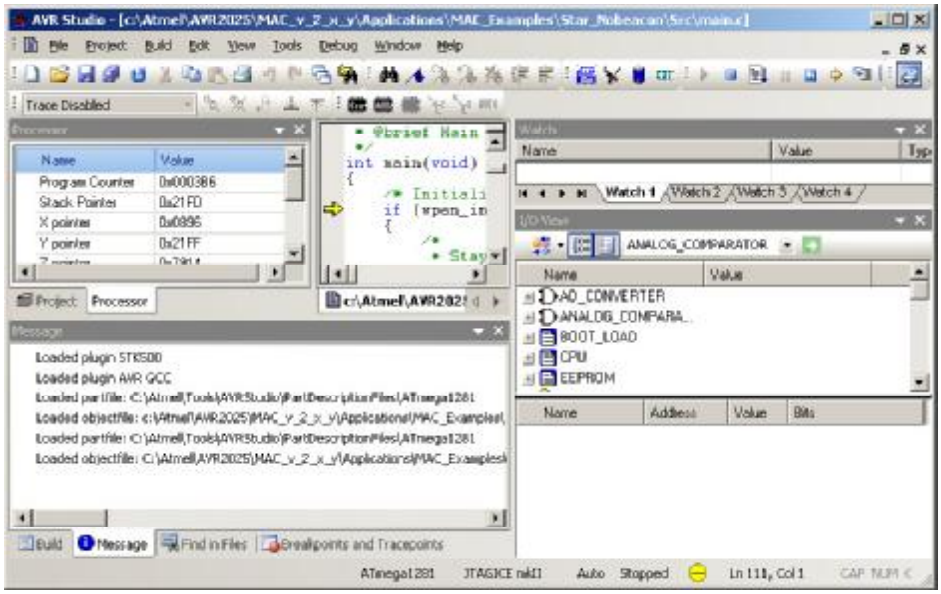
- Press “Finish”.
- In case there has been more than one JTAGICE mkII detected a window pops up asking to select the proper JTAGICE mkII to be used.
- The JTAGICE mkII Dialog opens. Select the “Debug” tab. Within the “Debug” tab make sure that “Preserve EEPROM contents when reprogramming device” is selected.

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 AVR Studio.
- Now AVR Studio looks like below.

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:
  - Check whether a valid IEEE address (different from 0xFFFFFFFFFFFFFFFFand 0x0000000000000000) is stored in the internal EEPROM. Select menu “View” item “Memory”.
  - If the IEEE address is not set properly, add the correct IEEE to the first 8 octets of the EEPROM (see section 8.3.1).
- Start the application by pressing “F5” or clicking the “Run” button.

8.3.3 Using IAR Embedded Workbench

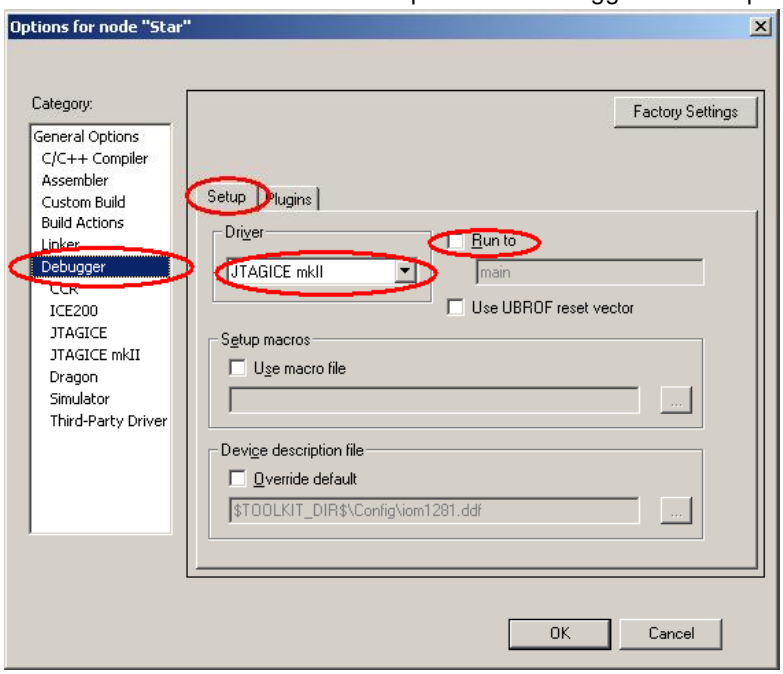
When using IAR Embedded Workbench directly by double clicking the corresponding eww-file, the application can be downloaded onto the desired hardware platform as described below.

8.3.3.1 Starting the Release Build

The release build can simply be started as follows:

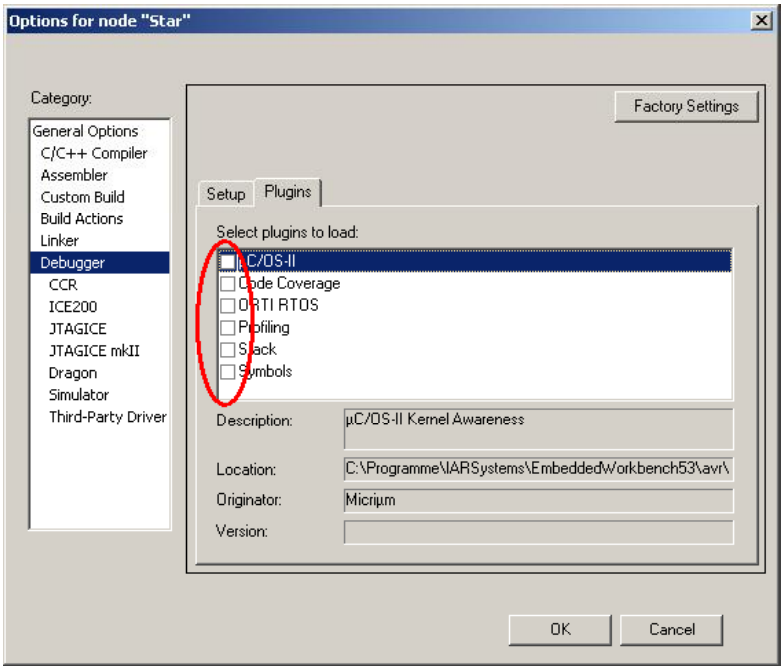
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE.
- Open IAR Workbench by double clicking the desired eww-file.
- Select the “Release” Workspace.
- Open the “Options” window for the “Release” Workspace. Select the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

Figure 8-14. IAR Embedded Workbench – “Options” -> “Debugger” -> “Setup”



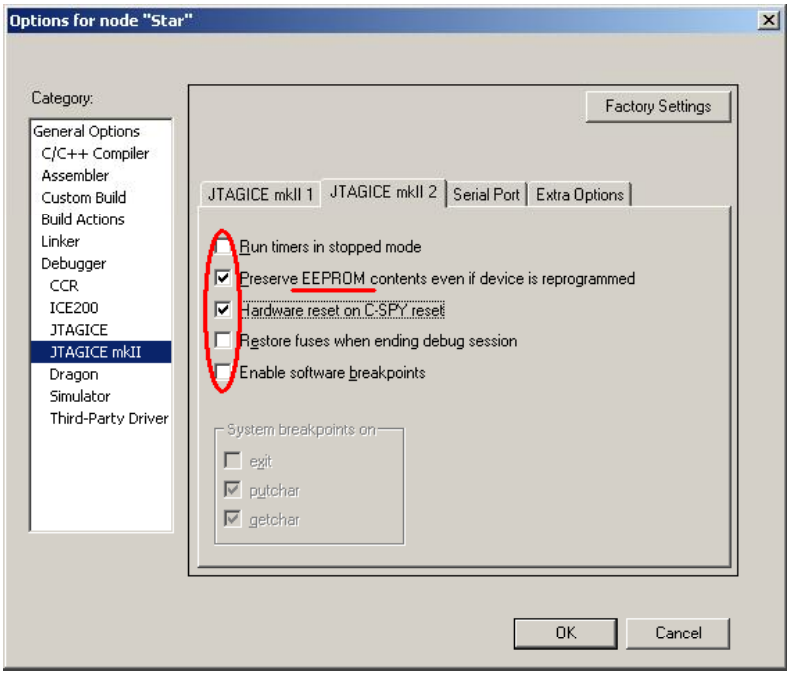
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and deselect “Run to (main)”.
- Change to the “Plugins” tab and deselect all entries.

Figure 8-15. 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 8-16. IAR Embedded Workbench – “Options” -> “JTAGICE mkII” -> “JTAGICE mkII 2”



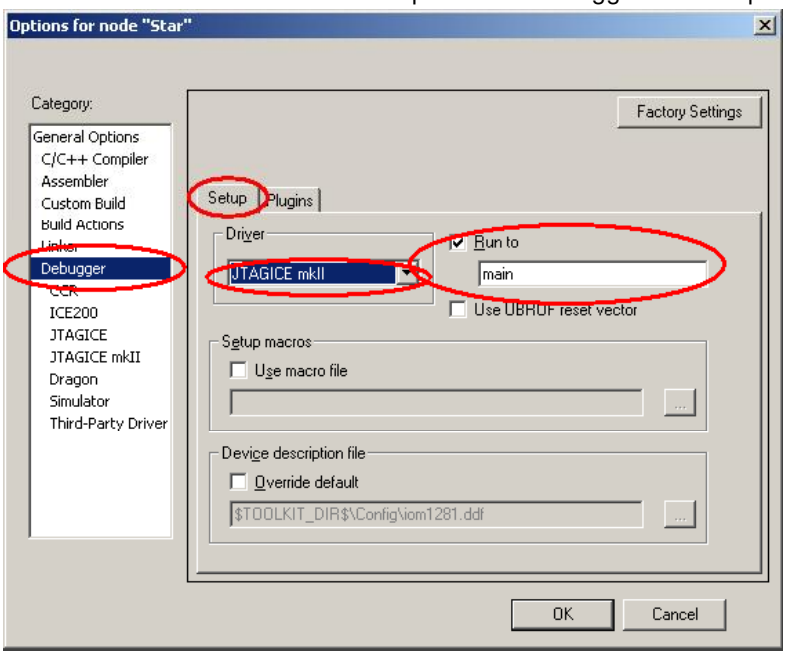
- Within the “JTAGICE mkII 2” tab check the items as shown above. Especially make sure that the EEPROM will be preserved if the device is reprogrammed.
- Press “Ok”.
- Press the button “Download and Debug”.

8.3.3.2 Starting the Debug Build

The debug build can simply be started as follows:

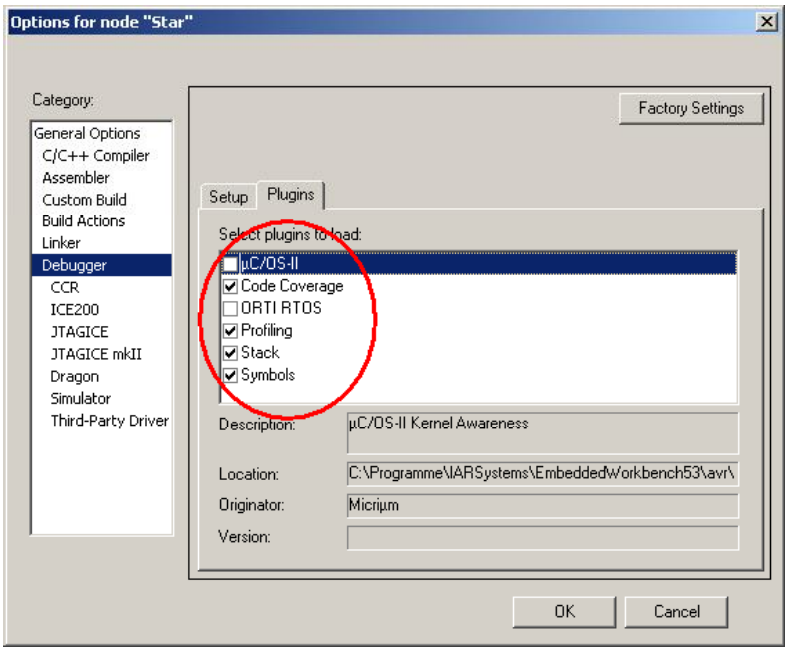
- Make sure that only the JTAGICE of the node where the current build shall be downloaded to is switched on. Switch off all other JTAGICE.
- Open IAR Workbench by double clicking the desired eww-file.
- Select the “Debug” Workspace.
- Open the “Options” window for the “Debug” Workspace. Select the “Debugger”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

Figure 8-17. IAR Embedded Workbench – “Options” -> “Debugger” -> “Setup”



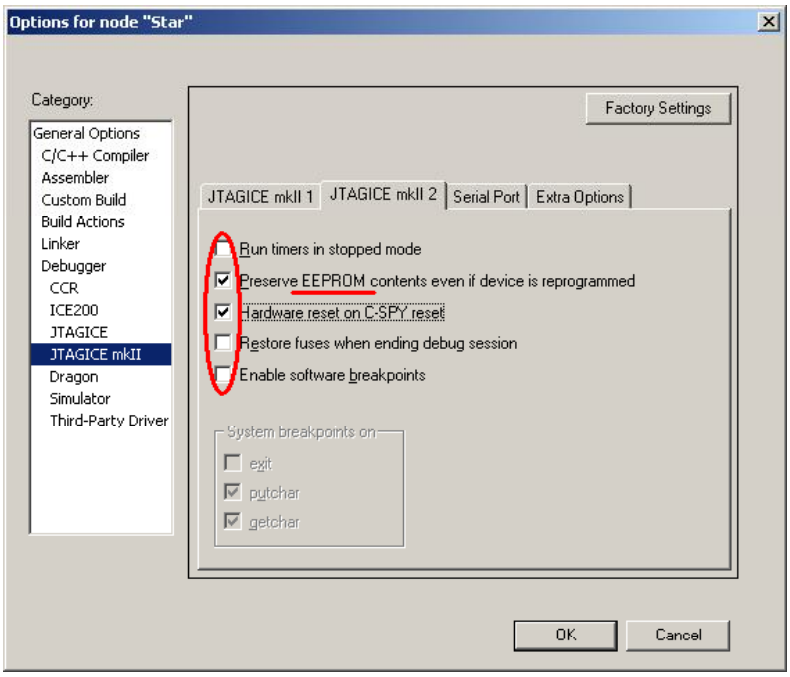
- Within the “Setup” tab select the “Driver” “JTAGICE mkII” and select “Run to (main)” (this is different to “Release” build).
- Change to the “Plugins” tab and select the entries as below.

Figure 8-18. IAR Embedded Workbench – “Options” -> “Debugger” -> “Plugins”



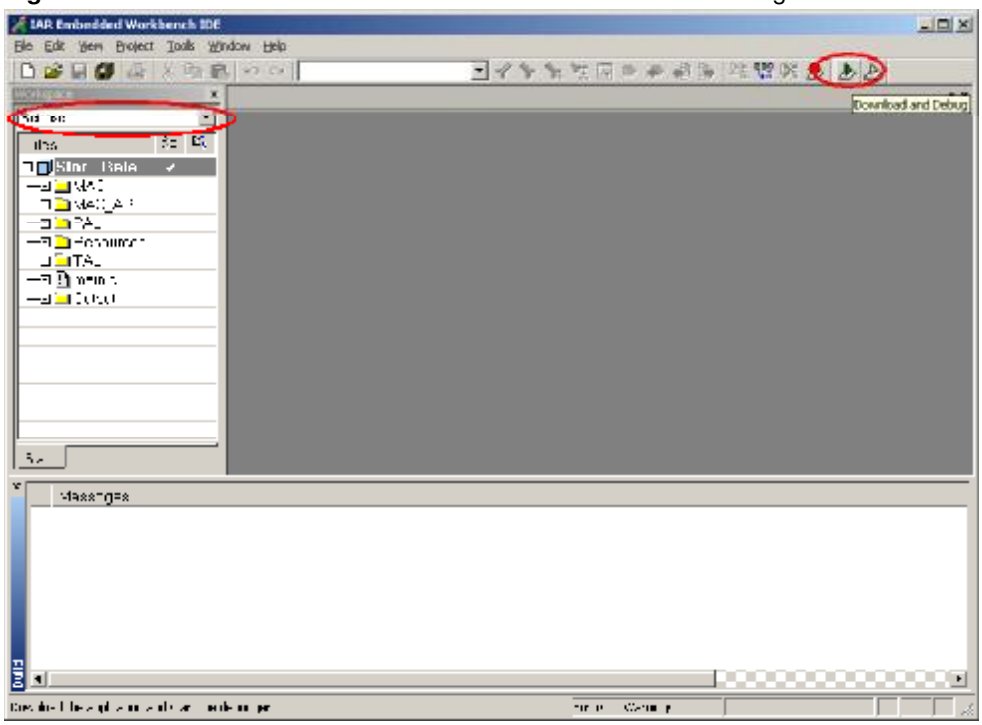
- Within the “Options” window for the “Release” Workspace select now the “JTAGICE mkII” window and within this window select the “JTAGICE mkII 2” tab.

Figure 8-19. IAR Embedded Workbench – “Options” -> “JTAGICE mkII” -> “JTAGICE mkII 2”



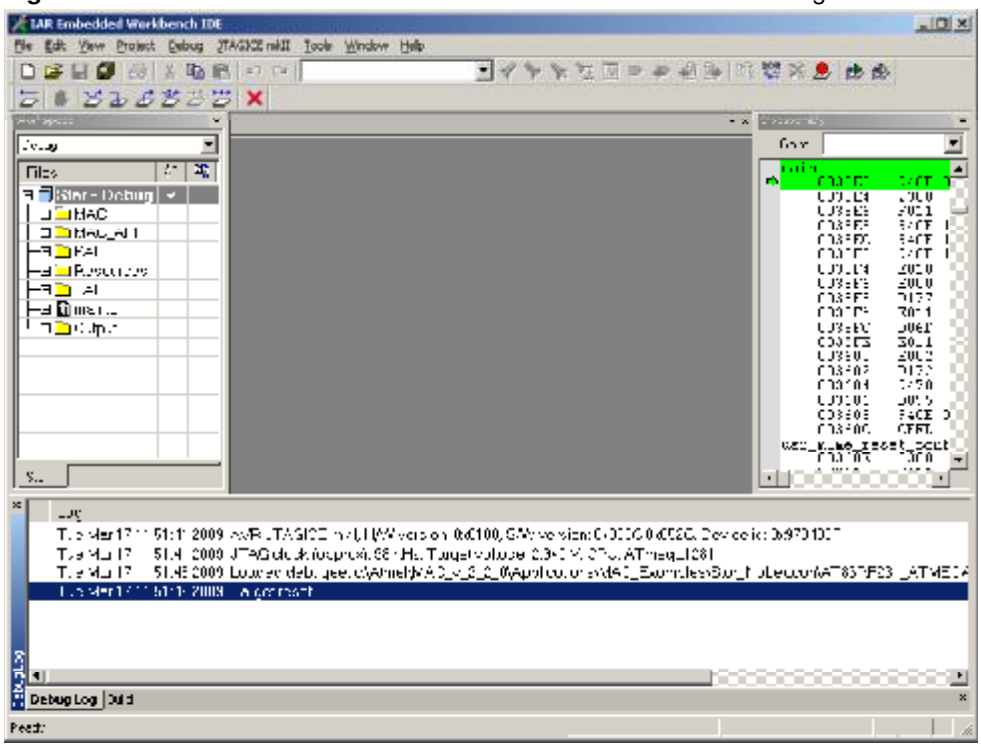
- Within the “JTAGICE mkII 2” tab check the items as shown above. Especially make sure that the EEPROM will be preserved if the device is reprogrammed.
- Press “Ok”.
- Press the button “Download and Debug”.

Figure 8-20. IAR Embedded Workbench - Start “Download and Debug”



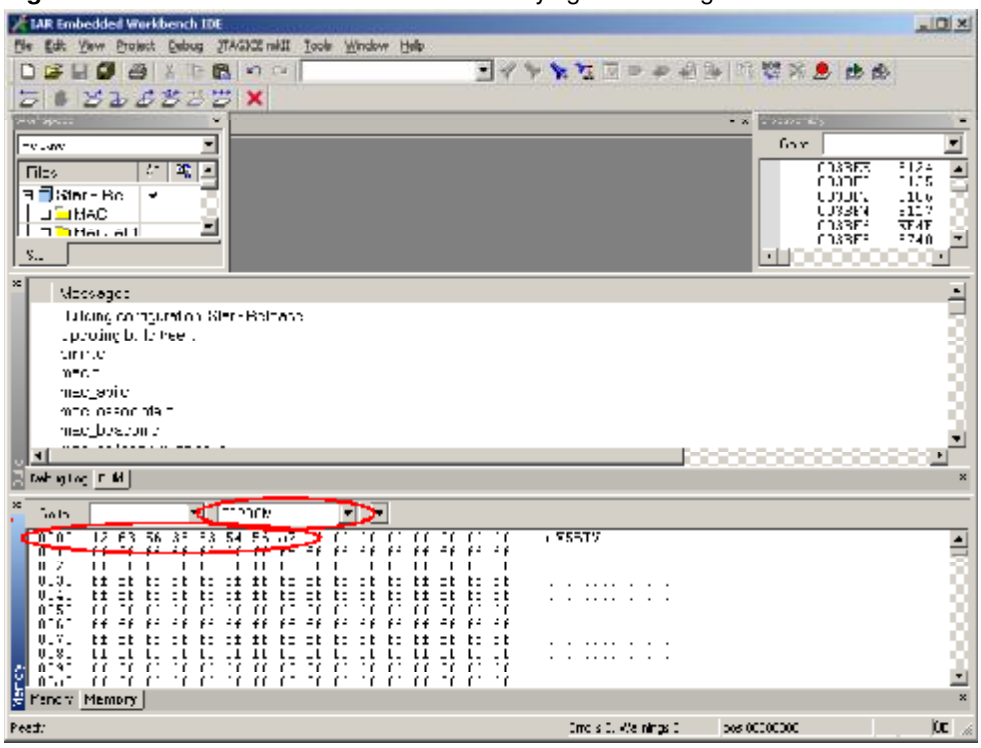
- A Window will pop-up indicating the status of the download of the binary.
- After successful download the IAR Workbench will looks as shown below. After the download of the debug build the main function is displayed since all debug and source code information is included in the build.

Figure 8-21. 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:
    - 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 8 octets of the EEPROM.

Figure 8-22. IAR Embedded Workbench – Verifying and Setting of IEEE Address



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

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 (i.e. channel 20), the Device will initiate the association procedure. If the association is also successful, the Device periodically (i.e. every 2 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/Coordinator/Src/main.c

and the header file in

Applications/MAC_Examples/App_1_Nobeacon/Coordinator/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/App_1_Nobeacon/Coordinator/<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

"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 (i.e. about every 2 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/App_1_Nobeacon/Device/Src/main.c

and the header file in

Applications/MAC_Examples/App_1_Nobeacon/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/App_1_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 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 2 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 App_1_Nobeacon

9.2.1.1.1 Introduction

The basic MAC Example 1 deploys a nonbeacon-enabled network consisting of PAN Coordinator and Device. The application shows how basic MAC features can be utilized within an application (Scanning for network, starting a network, association procedure, data transmission from Device to PAN Coordinator).

This application works very similar to the MAC Example Star_Nobeacon (see section 9.2.1.7) but different source code implementations are provided for both types of devices. A node is either a PAN Coordinator or a Device.

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/App_1_Nobeacon. The source code of the application can be found in the subdirectories Coordinator/Src or Device/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.

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 2 seconds to transmit a random payload to the PAN Coordinator. While the device is idle (when the timer is running) the transceiver enters sleep in order to safe 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 2 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 using indirect data transmission to the Device can be found in 9.2.1.2. Another example implementing the feature MAC_RX_ENABLE_SUPPORT can be found in 9.2.1.3 (MAC Example Basic_Sensor_Network).

9.2.1.2 App_2_Nobeacon_Indirect_Traffic

9.2.1.2.1 Introduction

The basic MAC Example 2 (Indirect Traffic) deploys a nonbeacon-enabled network consisting of PAN Coordinator and Device utilizing the mechanism of indirect data transfer between Coordinator and Device. In terms of setting up the basic network (network start, scanning, association) the application operates similar to the basic MAC Example 1 (see 9.2.1.1).

While in MAC Example 1 always the Device is transmitting data frames to the Coordinator directly, in this example the Coordinator wants to send data to the Device. Since a Device in a nonbeacon-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.

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/App_2_Nobeacon_Indirect_Traffic. 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.

9.2.1.2.2 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 see the output of the application please start a terminal application on your host system.

9.2.1.2.3 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. While the device is idle (when the timer is running) the transceiver enters sleep in order to safe 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 only 2 devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES.

9.2.1.3 App_3_App_3_Beacon_Payload

9.2.1.3.1 Introduction

The basic MAC Example 3 Beacon Payload 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 synchronization with the coordinator and utilization of beacon payload by the coordinator.

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/App_3_App_3_Beacon_Payload. The source code of the application can be found in the subdirectories Coordinator/Src or Device/Src.

9.2.1.3.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. Also 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 see the output of the application please start a terminal application on your host system.

9.2.1.3.3 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 mean 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.

9.2.1.3.4 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-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.

9.2.1.4 App_4_Beacon_Broadcast_Data

9.2.1.4.1 Introduction

The basic MAC Example 3 Beacon Broadcast 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 (i.e. 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).

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/App_4_Beacon_Broadcast_Data. The source code of the application can be found in the subdirectories Coordinator/Src or Device/Src.

9.2.1.4.2 Requirements

The application requires (up to three) LEDs on the board in order to indicate the proper working status. Also 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 see the output of the application please start a terminal application on your host system.

9.2.1.4.3 Implementation

The coordinator in this application creates a beacon-enabled network. Periodically the application of the coordinator try 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.

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. 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.

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.
- Currently 100 devices are allowed to associate to the PAN Coordinator. This can be easily extended by increasing the define MAX_NUMBER_OF_DEVICES.

9.2.1.5 Basic_Sensor_Network

9.2.1.5.1 Introduction

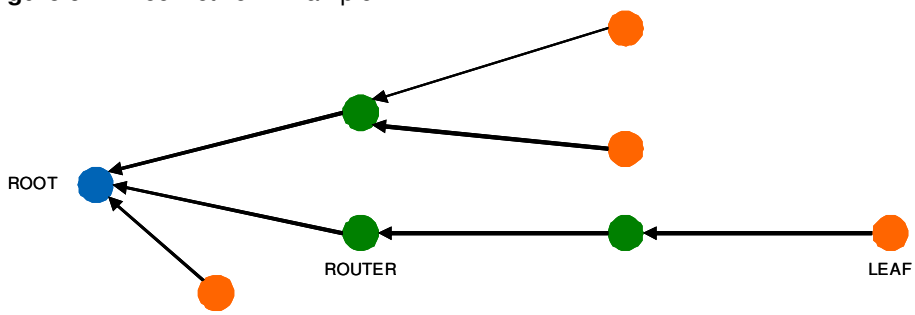
The application Basic_Sensor_Network implements a basic sensor network. The network consists of devices being sensor nodes (called LEAF), nodes (called ROUTER) that provide router functionality and a central node collecting all data (called ROOT).

The network route is a static route. The network and its routing path is 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 by Figure 9-1.

Figure 9-1. Tree Network Example



9.2.1.5.2 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 (i.e. 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.

9.2.1.5.3 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, e.g. 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.

9.2.1.5.4 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.

9.2.1.6 Promiscuous_Mode_Demo

9.2.1.6.1 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.

9.2.1.6.2 Requirements

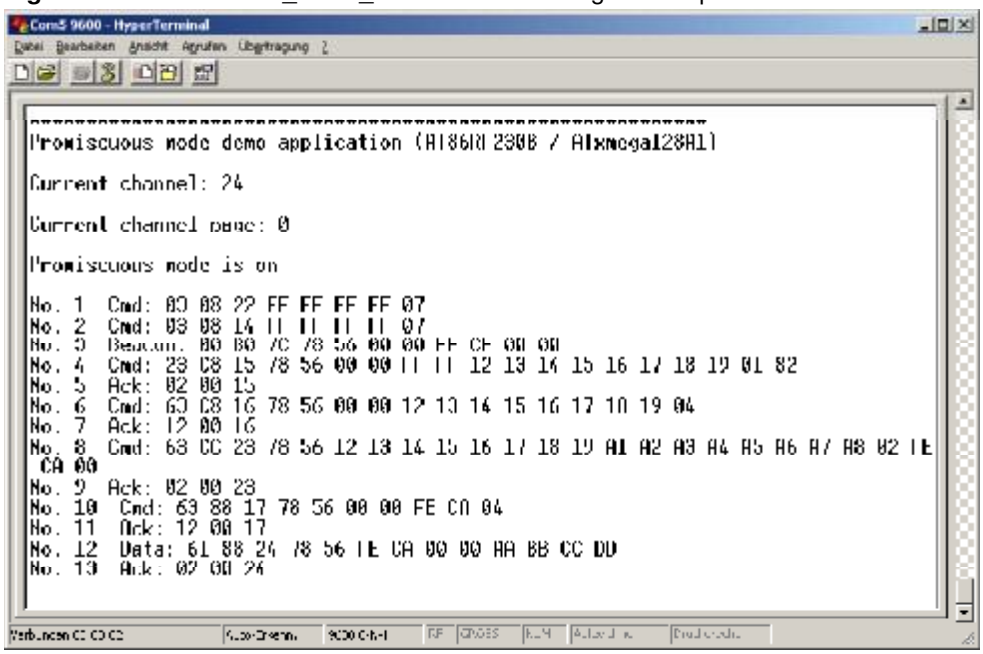
This application requires a serial connection for proper demonstration of the promiscuous mode. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to see the output of the application please start a terminal application on your host system.

9.2.1.6.3 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 (i.e. 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



9.2.1.6.4 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.
- 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.

9.2.1.7 Star_Nobeacon

9.2.1.7.1 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 App_1_Nobeacon (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.

9.2.1.7.2 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.

9.2.1.7.3 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 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.

9.2.1.7.4 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.
- 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 9.2.1.3 (MAC Example Basic_Sensor_Network).

9.2.1.8 Star_High_Rate

9.2.1.8.1 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 (i.e. 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 9.2.1.7), 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.

9.2.1.8.2 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 see the output of the application please start a terminal application on your host system.

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.

9.2.1.8.3 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.

9.2.1.8.4 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.

9.2.2 TAL Examples

9.2.2.1 Performance_Test

9.2.2.1.1 Introduction

The TAL example Performance_Test is a terminal-based application. It demonstrates transceiver performance including high data rate modes. Configuration parameters are set using a terminal program, like

- Channel
- Channel page
- Transmit power
- Number of frames sent during a test
- Frame length (PSDU)
- ACK request enable/disable
- CSMA enable/disable
- Frame retry enable/disable

This allows to measure throughput performance and PER testing with different radios, data rates and transmits powers. In addition to that the following features are supported:

- ED scan over all channels
- Continuous wave (CW) transmission
- Promiscuous mode

This example application uses TAL API as interface to the stack.

The application and all required build files are located in directory Applications/TAL_Examples/ Performance_Test. The source code of the application can be found in the subdirectory Src.

9.2.2.1.2 Requirements

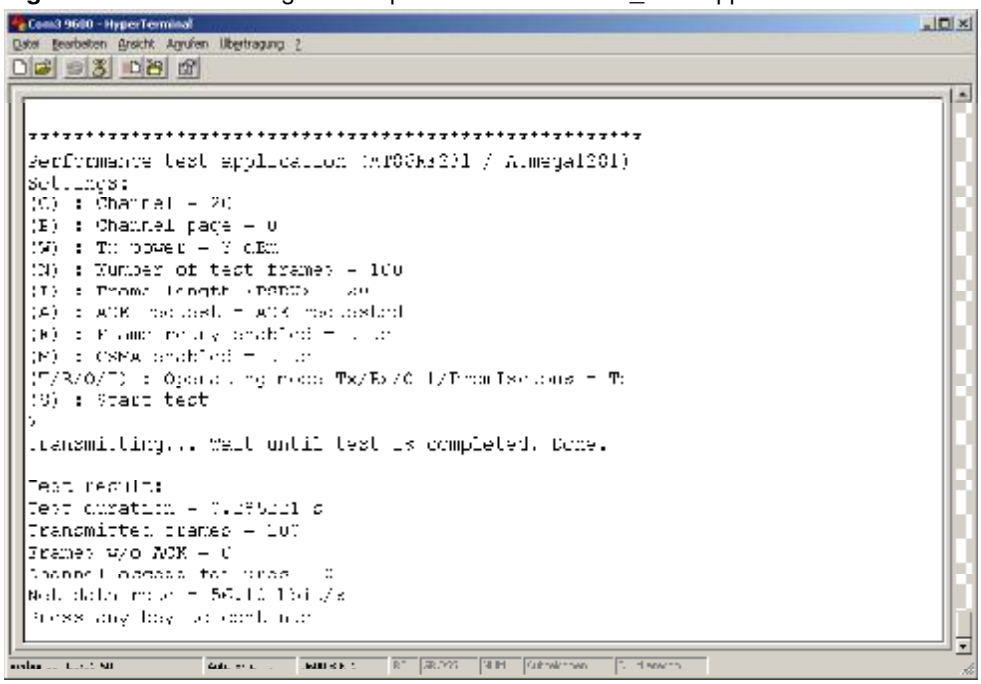
This application requires a serial connection for controlling the application and displaying the results. Depending on the available Serial I/O interface for each board this can be either UART or USB. In order to see the output of the application please start a terminal application on your host system.

9.2.2.1.3 Implementation

Once the application is started hit any key to display the initial screen. A menu indicates which options are currently available (such as channel, Tx power, CSMA usage, etc.).

After the desired parameters have been set, chose the proper operating mode. The performance application requires a node acting as receiver (“R”) and another node acting as transmitter (“T”). An additional node can operate in promiscuous mode (“I”) as diagnostic tool.

Figure 9-3. Terminal Program Snapshot of Performance_Test 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 see the output of the application, please start a terminal application on your host system.

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 (i.e. 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 (e.g. 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 9-4. Secure Remote Control Application – Both Nodes in Secure Mode

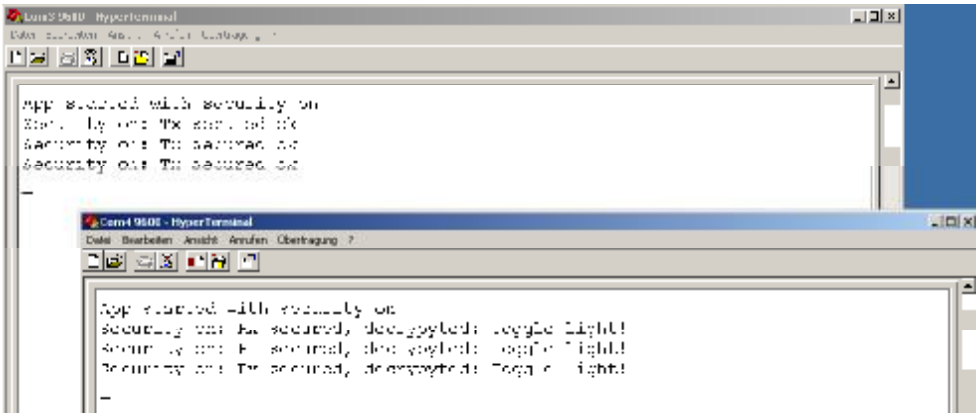


Figure 9-5. Secure Remote Control Application – Both Nodes in Unsecure Mode

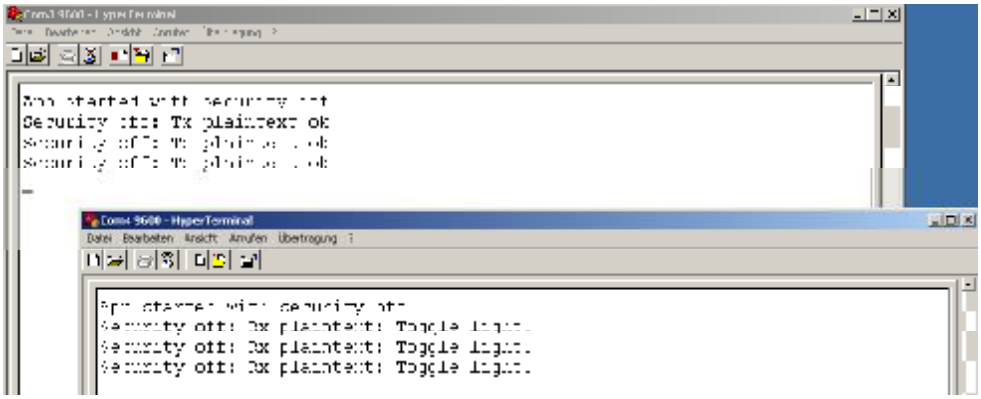


Figure 9-6. Secure Remote Control Application – Transmitter in Secure Mode, Receiver in Unsecure Mode

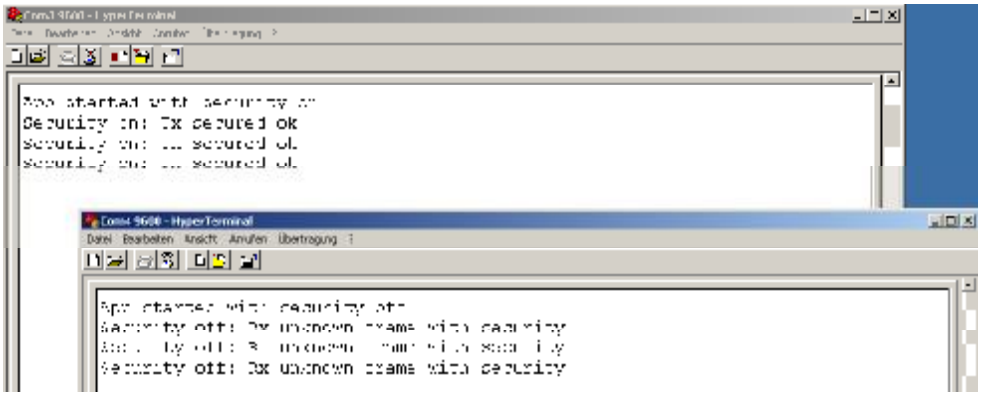
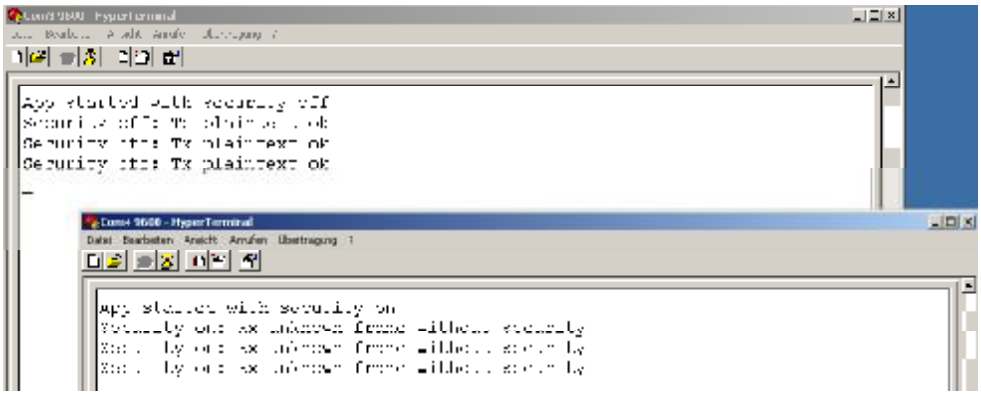


Figure 9-7. Secure Remote Control Application – Transmitter in Unsecure Mode, Receiver in Secure Mode



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 (i.e. End Devices) and a Data Sink (i.e. 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 see the output of the application, please start a terminal application on your host system.

9.2.3.2.3 Implementation

The node acting as data sink (PAN Coordinator) starts a nonbeacon-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 2 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, i.e. encrypted payload, authentication applied, MIC 8 byte long.
- The random payload has 13 byte length.

The LEDs signal the following status:

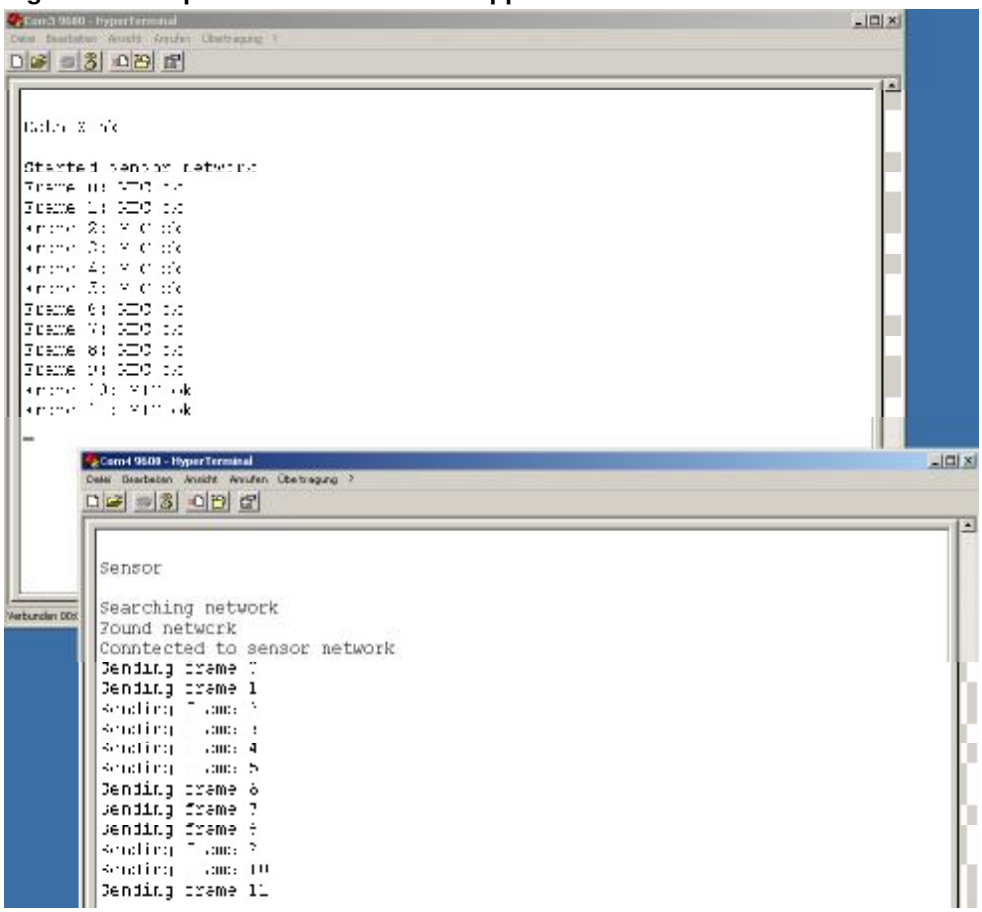
Sensor (Device):

- 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 2 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 2 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 9-8. 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.

9.2.4 Tiny-TAL Examples

9.2.4.1 Wireless_UART

9.2.4.1.1 Introduction

The Tiny-TAL example Wireless_UART is a terminal-based application. It acts as a simple communication program between nodes (i.e. a wireless UART connection).

This example application uses Tiny-TAL API as interface to the stack.

The application and all required build files are located in directory Applications/TINY_TAL_Examples/ Wireless_UART. The source code of the application can be found in the subdirectory Src.

9.2.4.1.2 Requirements

This application requires 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 type input or the see the output of the application, please start a terminal application on your host system.

9.2.4.1.3 Implementation

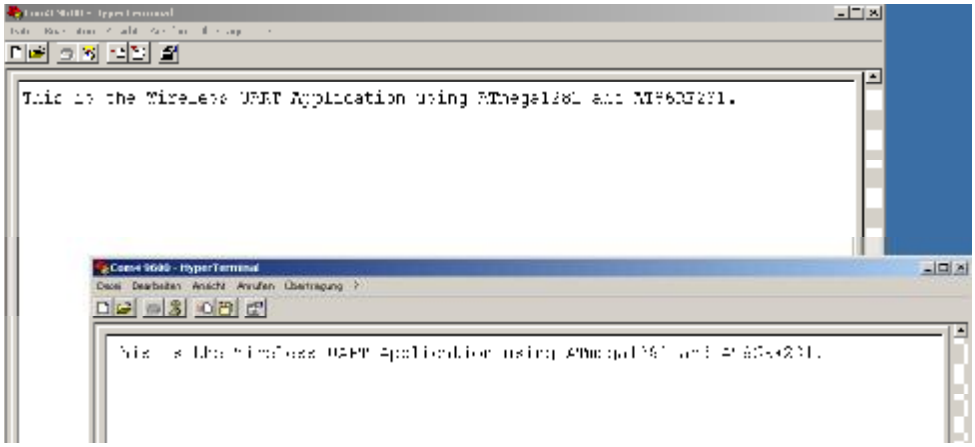
The basic Tiny-TAL Example Wireless_UART deploys a nonbeacon-enabled network. The example application is based on the TAL.

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.

A terminal program (Terminal program settings: No flow control and local echo should be disabled) can be used to enter text on both nodes.

If a byte is received via the serial connection from one node, the node transmits the byte to the other node. If the transmission was successful, the entered bytes are forwarded to the terminal indicating successful transmission.

Figure 9-9. Terminal Program Snapshots of Performance_Test Application



9.2.4.1.4 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.

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 are 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, e.g.

```
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, e.g.

```
<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, e.g.

```
. . .
$(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 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), and
- 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:

- ARM7: Atmel ARM7 platforms
- AVR: Atmel AVR 8-bit ATmega platforms
- MEGA_RF: Atmel AVR 8-bit ATmegaRF 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 ATmega1281, ATxmega128A1, ATmega128RFA1, AT90SAM7X256, etc.

For a complete list of the actually supported MCUs please refer to the 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 (e.g. see [2]).

For a short list of the supported peripherals of each board see section 10.4.6.

10.4.1 Radio Controller Boards (RCB) based Platforms

The Radio Controller Board (RCB) is a radio module containing either a MCU (e.g. 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.

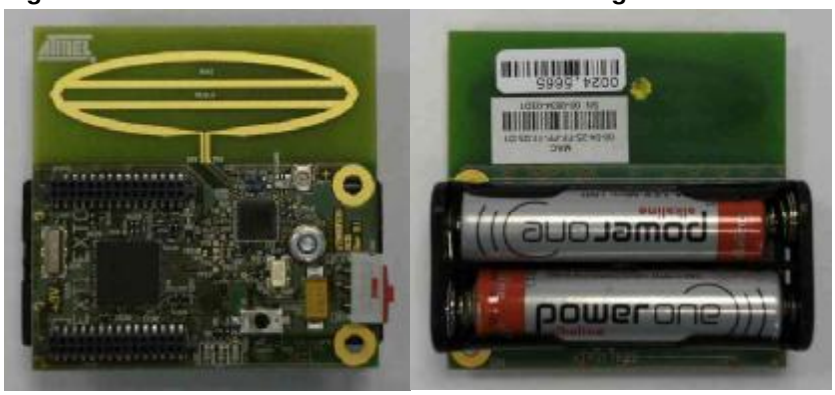
10.4.1.1 Plain Radio Controller Board RCB230 V3.1

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

- 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

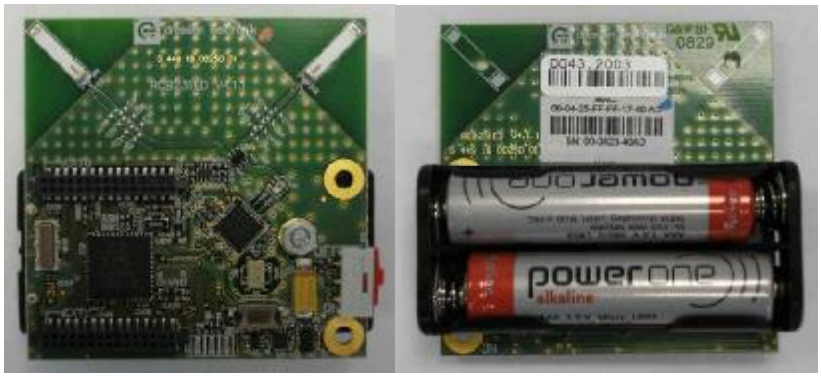
- AT86RF231 with and ATmega1281
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_4_0_PLAIN

Figure 10-2. RCB V4.0 with AT86RF231 and ATmega1281

10.4.1.4 Plain Radio Controller Board RCB231ED V4.1.1

- AT86RF231 with Antenna Diversity and 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 RCB212SMA V5.3.2

- 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 ATmega128RFA1

- ATmega128RFA1 Single Chip only
- See PAL\AVR\ATMEGA1281\BOARDS\RCB_5_3_PLAIN

Figure 10-5. RCB V6.3 with ATmega128RFA1

10.4.1.7 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 JTAG-ICE.

Figure 10-6. Sensor Terminal Board without RCB

Figure 10-7. Sensor Terminal Board with RCB V6.3 with ATmega128RFA1

Figure 10-8. Sensor Terminal Board connected to JTAG-ICE 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.

10.4.1.8 Breakout Board (Light)

The Breakout Board (Light) can be used as baseboard for a Plain RCB to enable SIO capabilities via UART. It can be used for existing RCBs mentioned in section 10.4.1**Error! Reference source not found.**. Its main purpose is to be a simple baseboard for the RCB for image flashing and debugging purpose.

The following pictures depict a Breakout Board Light with and without an RCB, and also indicate how the Breakout Board Light is connected to the JTAG-ICE.

Figure 10-9. Breakout Board Light without RCB

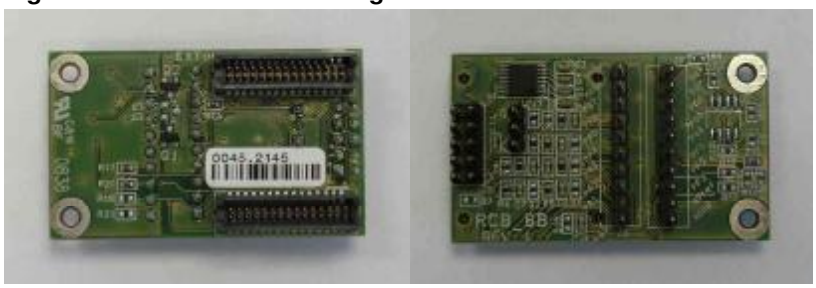


Figure 10-10. Breakout Board Light with RCB

Figure 10-11. Breakout Board Light connected to JTAG-ICE and UART

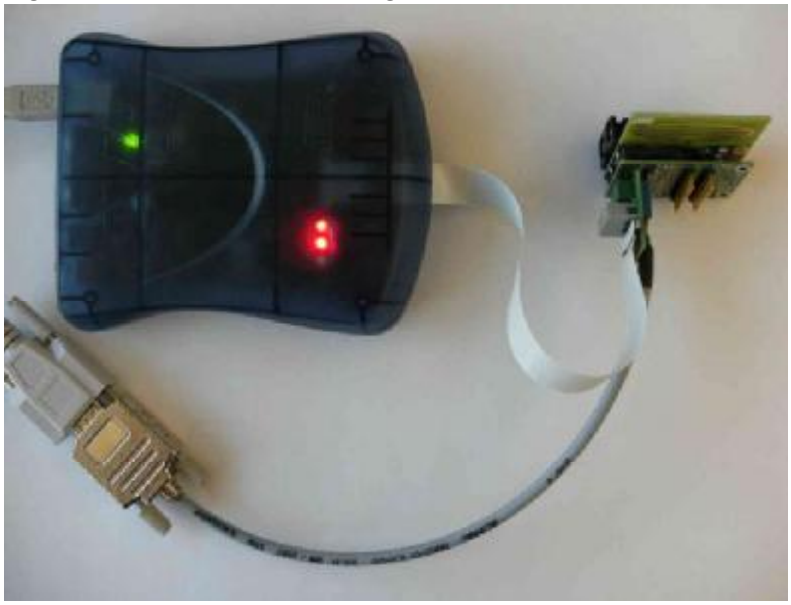


Figure 10-12. Close-up View of Breakout Board Light connected to JTAG-ICE and UART

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 STK600, STK500, AT91SAM7X-EK, 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: AT86RF230B
- The REB230B V2.3 is supported on several platforms:
    - See PAL\AVR\ATMEGA1281\Boards\REB_2_3_STK500_STK501
    - See PAL\AVR\ATMEGA2561\Boards\REB_2_3_STK500_STK501
    - See PAL\AVR\ATMEGA644P\Boards\REB_2_3_STK500
    - See PAL\XMEGA\ATXMEGA128A1\Boards\REB_2_3_STK600
    - See ARM7\AT91SAM7X256\Boards\REB_2_3_REX_ARM_REV_2
    - See ARM7\AT91SAM7XC256\Boards\REB_2_3_REX_ARM_REV_2

Figure 10-13. REB V2.3 with AT86RF230B

10.4.2.3 Radio Extender Board REB231 V4.0.1

- Atmel transceiver: AT86RF231
- The REB231 V4.0 is supported on several platforms:
    - See PAL\AVR\ATMEGA1281\Boards\REB_4_0_STK500_STK501
    - See PAL\XMEGA\ATXMEGA128A1\Boards\REB_4_0_STK600

Figure 10-14. 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\AVR\ATMEGA1281\Boards\REB_4_1_STK500_STK501

- See PAL\XMEGA\ATXMEGA128A1\Boards\REB_4_1_STK600
- See PAL\XMEGA\ATXMEGA256A3\Boards\REB_4_1_STK600
- See PAL\XMEGA\ATXMEGA256D3\Boards\REB_4_1_STK600

Figure 10-15. REB231ED V4.1.1 with AT86RF231

10.4.2.5 Radio Extender Board REB212 V5.0.2

- Atmel transceiver: AT86RF212
- The REB212 V5.0 is supported on several platforms:
  - See PAL\AVR\ATMEGA1281\Boards\REB_5_0_STK500_STK501
  - See PAL\XMEGA\ATXMEGA128A1\Boards\REB_5_0_STK600

Figure 10-16. REB212 V5.0.2 with AT86RF212

10.4.3 Radio Extender Boards (REB) based Platforms

10.4.3.1 STK600 and REB to STK600 Adapter

The 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 ATxmega or 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 10-17. REB to STK600 Adapter

Figure 10-18. STK600 with REB to STK600 Adapter and REB231ED V4.1.1

The next pictures indicates how the STK600 is connected to the JTAG-ICE and UART, and how the LEDs and buttons are enabled.

Figure 10-19. STK600 (with ATxmega128A1) with REB to STK600 Adapter and REB connected to JTAG-ICE and UART, and LED and Button Cable

10.4.3.2 STK500

The STK500 can be used as a baseboard for an REB to create platforms using AVR 8-bit MCUs with a 40-pin PDIP package (such as ATmega644p MCUs). It provides two buttons (there are actually eight buttons but only the first two are used for this platform) and eight LEDs for user interaction. It can be used for existing REBs mentioned in section 10.4.2.

The following picture depicts an STK500 with an ATmega644p.

Figure 10-20. STK500

The next pictures indicates how the STK500 is connected to the JTAG-ICE and UART, and how the LEDs and buttons are enabled.

Figure 10-21. STK500 (with ATmega644p) with REB connected to JTAG-ICE and UART, and LED and Button Cable

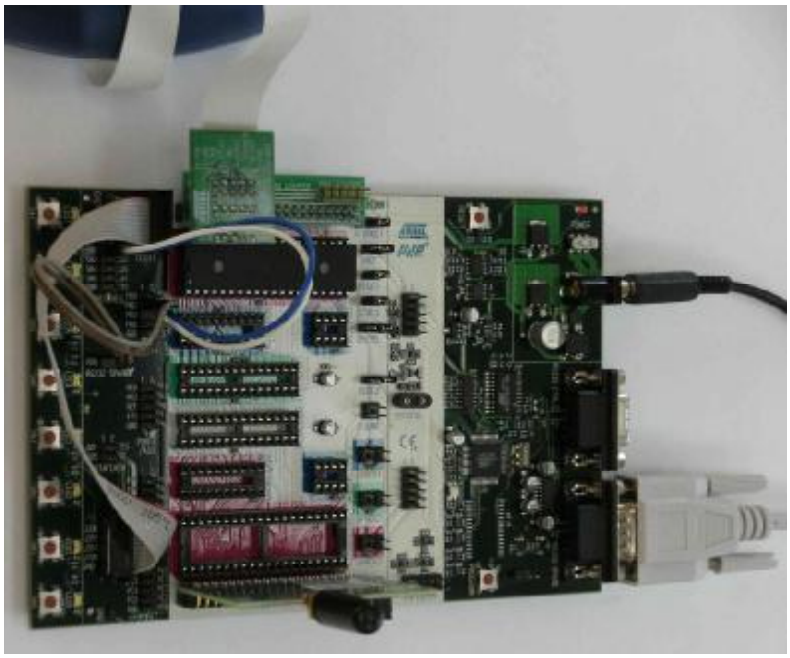
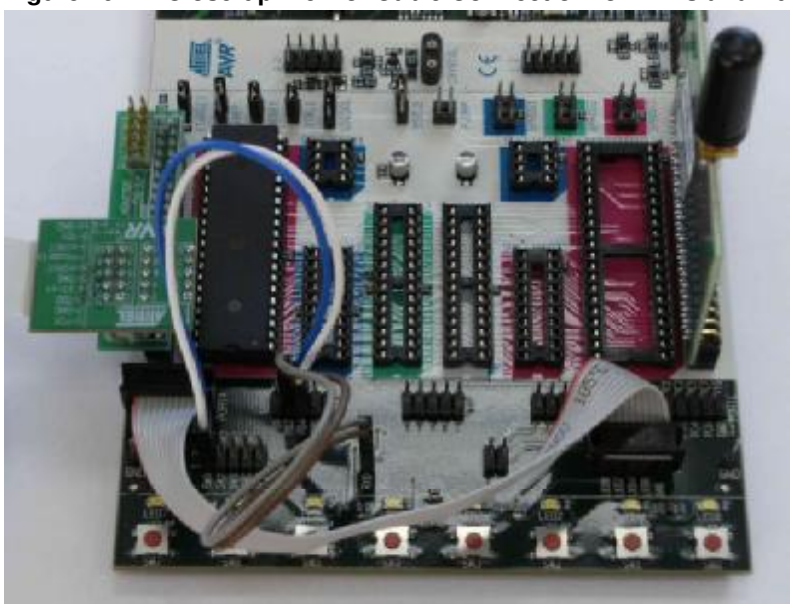


Figure 10-22. Close-up View of Cable Connection for LEDs and Buttons



10.4.3.3 STK500 + STK501

The STK500 in conjunction with an STK501 can be used as a baseboard for an REB to create platforms using AVR 8-bit MCUs with a 64-pin TQFP package (such as

ATmega1281 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 picture depicts an STK500 with an STK501.

Figure 10-23. STK500 with STK501

Figure 10-24. STK500 with STK501 (with ATmega1281) and REB connected to JTAG-ICE and UART, and LED and Button Cable

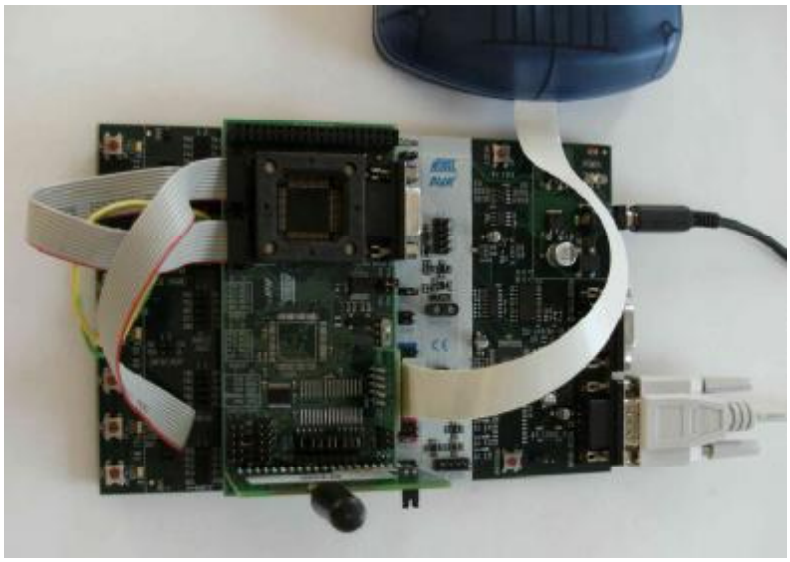
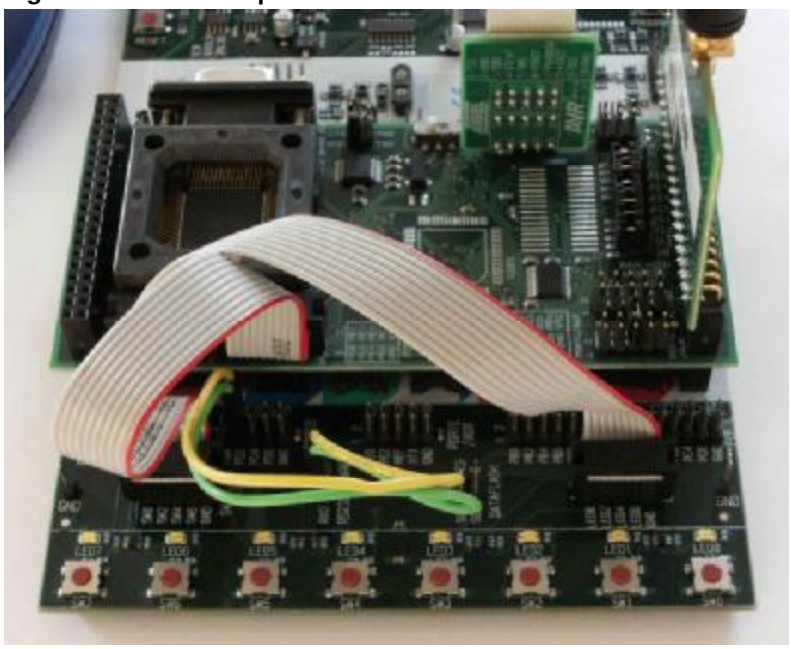
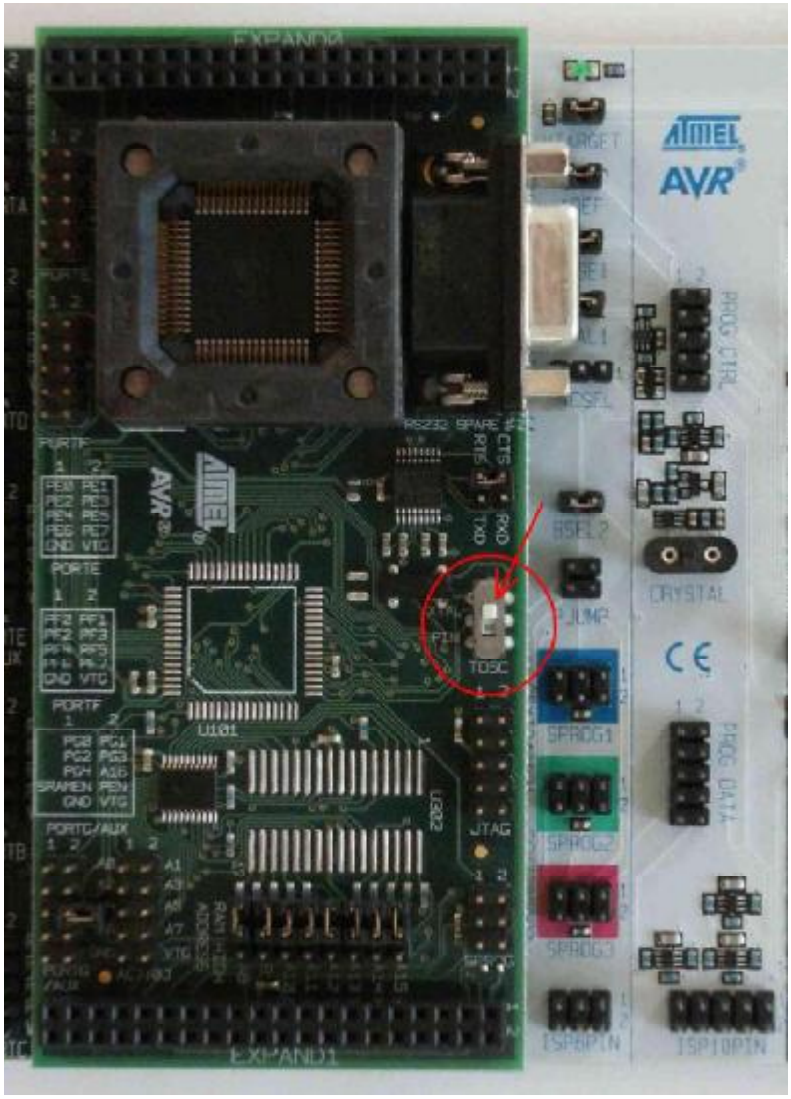


Figure 10-25. Close-up View of Cable Connection for LEDs and Buttons



The following picture indicates how the TOSC switch on the STK501 needs to set correctly to “XTAL” in order to allow proper operation for this platform using the provided software package.

Figure 10-26. Close-up View of STK501 TOSC Switch



10.4.3.4 AT91SAM7X-EK

The 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 AT91SAM7X256 MCUs). It provides currently 4 LEDs and a Joystick for user interaction.

Currently supported are:

- REB230B V2.3 (with AT86RF230) in conjunction with REB to ARM Adapter Rev. 2 (REV_ARM REV 2).
- REB231 V4.0.1/V4.0.2 (with AT86RF231) in conjunction with REB to ARM Adapter Rev. 3 (REV_ARM REV 3)
- REB212 V5.0.2 (with AT86RF212) in conjunction with REB to ARM Adapter Rev. 3 (REV_ARM REV 3)

The following pictures depict an AT91SAM7X-EK board with AT91SAM7X256 and an AT91SAM7X-E with an REV_ARM REV 2 with REB230B V2.3.

Figure 10-27. AT91SAM7X-EK Board with AT91SAM7X256

Figure 10-28. AT91SAM7X-EK Board with AT91SAM7X256

Figure 10-29. AT91SAM7X-EK Board with AT91SAM7X256 connected to SAM-ICE and UART

10.4.4 AT91SAM7XC-EK

The AT91SAM7XC-EK is handled similar to the AT91SAM7X-EK.

10.4.5 RZ USBstick

The RZ USBstick (as part of the ATAVRRZRAVEN 2.4 GHz Evaluation and Starter Kit) is based on AT90USB1287:

- See PAL\AVR\AT90USB1287\Boards\USBSTICK_C
- The USB Bootloader is currently not supported
- Images need to be flashed using JTAG-ICE and the JTAG connector
- In case the 10 pin header for the JTAG connector (included in the ATAVRRZRAVEN kit) is not on the board, this needs to be added
- A USB driver providing a virtual COM port for the USBstick is provided in the software package (see *rzusbstick_cdc.inf* in directory PAL\Board_Utils\RZ_USB_Stick)

The following picture depicts an RZ USBstick with the 10 pin header for the JTAG connector and the JTAG-ICE.

Figure 10-30. RZ USBstick with 10 Pin Header for JTAG Connector

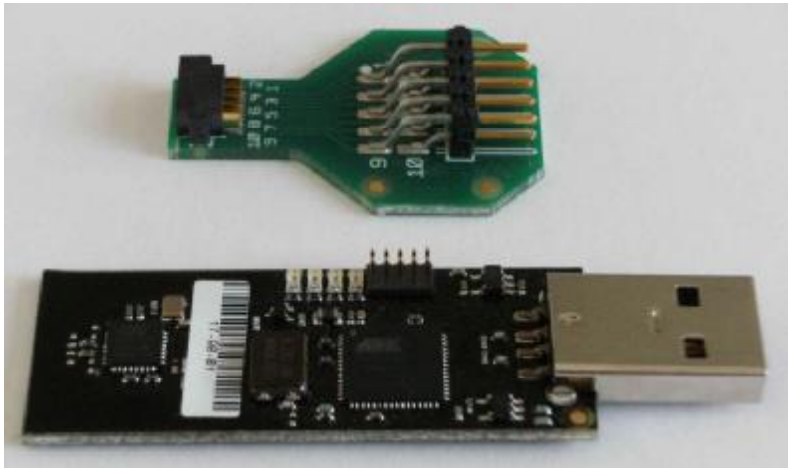
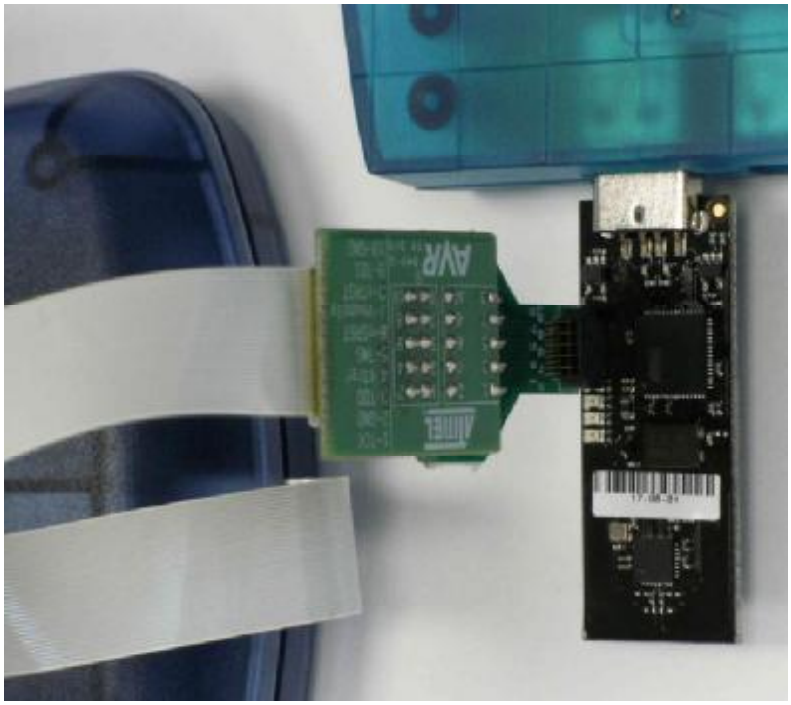


Figure 10-31. RZ USBstick with JTAG-ICE and USB Connection



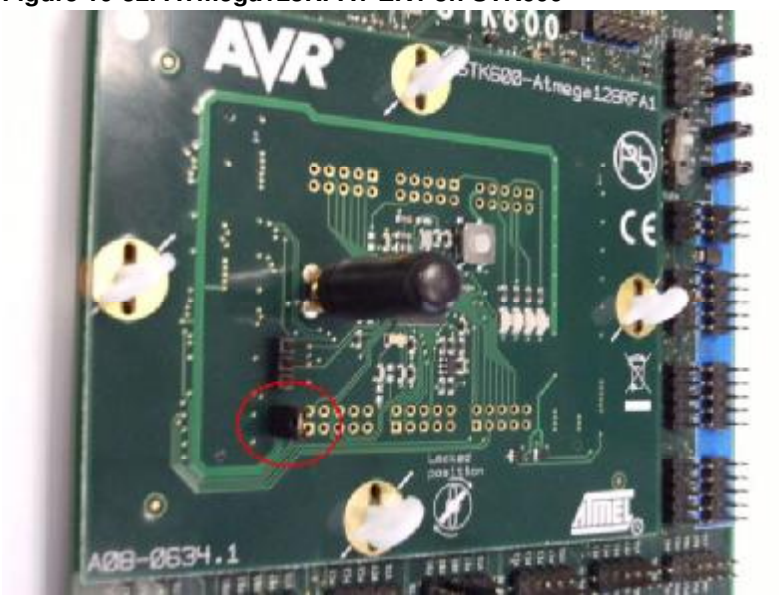
10.4.6 ATmega128RFA1-EK1 Evaluation Kit

The ATmega128RFA1-EK1 Evaluation Kit provides an 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 3 LEDs and 1 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 ATmega128RFA-EK1 Top Card placed on an STK600 base board and the board setup connected to a JTAG-ICE and set-up for utilization of UART1.

Figure 10-32. ATmega128RFA1-EK1 on STK600



Please note that jumper J11 (see red circle) needs to be placed as shown above (if no current measurements are done) in order to provide the proper voltage to the board.

Figure 10-33. ATmega128RFA1-EK1 on STK600 with JTAG-ICE using UART1

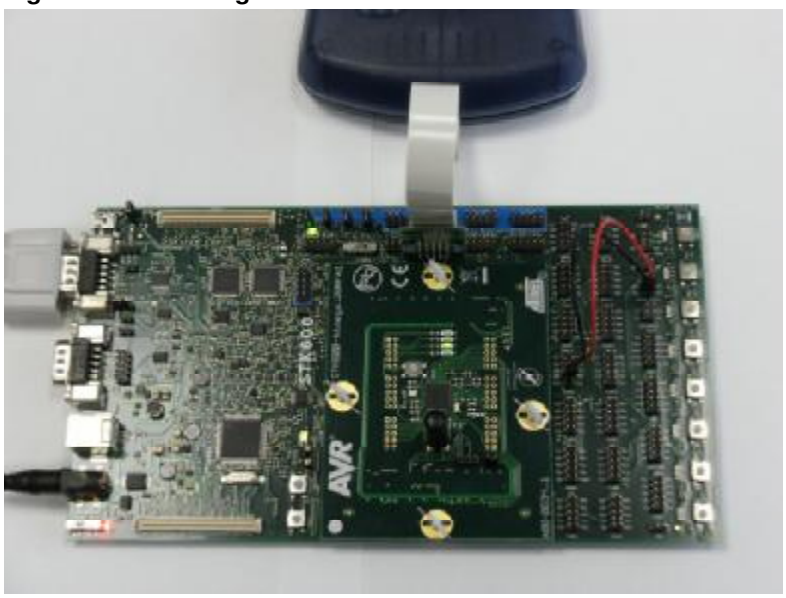
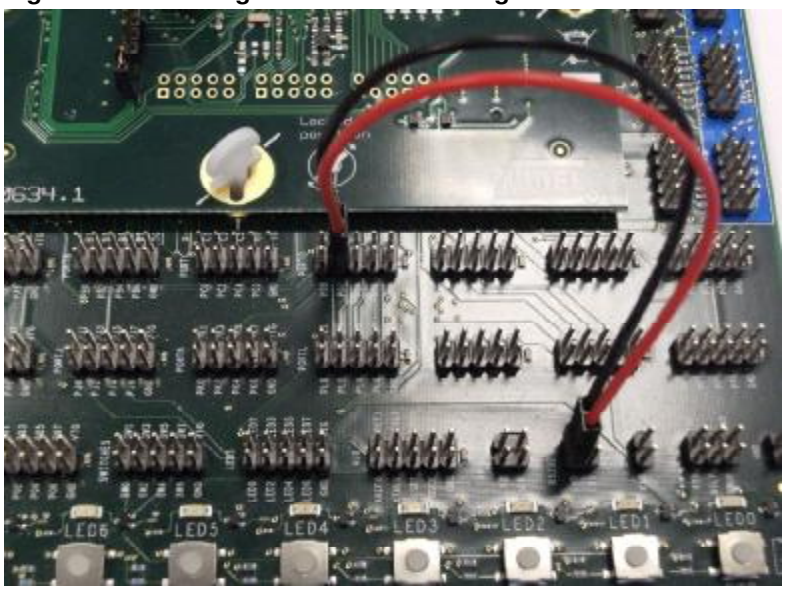


Figure 10-34. ATmega128RFA1-EK1 wiring for UART1



Please note that the ATmega128RFA1-EK1 is not optimized for RF performance.

10.4.7 RZ600 on Top of Xplain Board

The RZ600 Evaluation boards (as part of the RZ600 evaluation kit) is supported on top of an ATAVRXPLAIN evaluation and demonstration kit (based on ATxmega128A1):

- See PAL\XMEGA\ATXMEGA128A1\Boards\RZ600_230B_XPLAIN
- Images need to be flashed using JTAG-ICE and the JTAG connector
- A USB driver providing a virtual COM port for the Xplain board (based on the AT90USB1287) is provided in the software package (see *Xplain_CDC_install.inf* in directory PAL\Board_Utils\XPLAIN\AT90USB1287\revision_2_and_above\USB_driver\)
- For more information about the RF600 evaluation kit refer to [6] and the corresponding Application Notes
- For more information about the ATAVRXPLAIN desing and evaluation kit refer to [7] and the corresponding Application Notes

The following picture depicts an RZ600 on top of the Xplain board conntected to a JTAG_ICE.

Figure 10-35. RZ600 on Top of Xplain Board with JTAG-ICE and USB

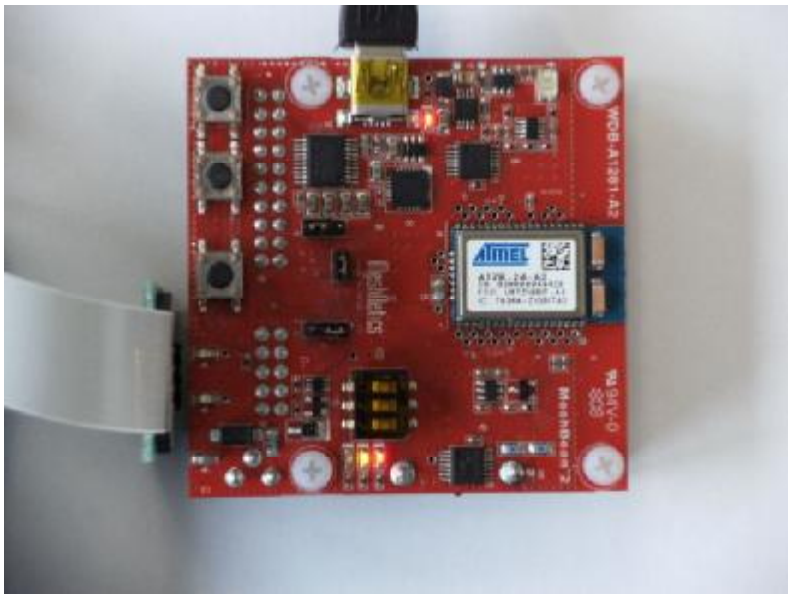
10.4.8 ZigBit Modules on Top of Meshbean2 Board

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
- See PAL\AVR\ATMEGA1281\Boards\ATZB_900_MN2 for the ZigBit 900 MHz support based on AT86RF212
- 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 ZlgBit Module on top of the MeshBean2 board conntected to a JTAG_ICE.

Figure 10-36. ATZB ZIgBit Module on Top of MeshBean2 Board with JTAG-ICE and USB



10.4.9 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 10-37. Peripherals supported by Platform Type

	Buttons	LEDs	SIO Support
Plain RCB	1	3	No
Sensor Terminal Board + RCB	1	2	USB
Breakout Board + RCB	0	0	UART
Breakout Board (Light) + RCB	0	0	UART
STK600 + REB to STK600 Adapter + REB	8	8	UART
STK500 + REB	2	8	UART
STK500 + STK501 + REB	8	8	UART
AT91SAM7X(C)-EK + REX_ARM + REB	Joystick	4	UART
RZ USBstick	0	4	USB
ATmega128RFA1-EK1	1	3	UART
RZ600 + Xplain	8	8	USB
ZigBit + Meshbean	2	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:

1. Bring-up of a new PAL or of a board within an already existing PAL
2. Bring-up of an existing application on the new platform
3. 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 (e.g. 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 (e.g. with different memory resources such as using the ATxmega256A3), that is based on an existing MCU family (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 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 (i.e. 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 boardtype to the existing file PAL/*MCU_FAMILY_NAME*/*MCU_NAME*/Boards/pal_boardtypes.h. As an example for a new board for the AT81SAM7X256, add the target board to file PAL/ARM7/AT91SAM7X256/Boards/pal_boardtypes.h (see 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 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 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 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 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 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.

Alternativly create a new boardtype in a customer specific boardtype 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 AT91SAM7X256 MCU the board “REB_2_3_REX_ARM_REV_2” (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 AT86RF231, but is derived from a board utilizing the transceiver AT86RF230B.

While the AT86RF230B provides only one transceiver interrupt, the AT86RF231 provides usually two transceiver interrupts. This approach is followed fore most boards for the AVR and Xmega MCU family.

Since the 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 (e.g. 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 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 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 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 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

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 ARM7 MCU AT91SAM7X256. A similar example based on the MCU ATxmega256A3 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 AT86RF230B with AT91SAM7X256) to the target platform "REB_4_0_2_REX_ARM_REV_3" using 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 AVRStudio 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 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)

Attention: 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, i.e.

`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 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 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_STK600.

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 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 the STK600 board with REB to STK600 Adapter and 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 ATxmega AVR 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 ATxmega family the 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_STK600. Now the following entries are existing:

- Directory REB_4_1_STK600
- File pal_boardtypes.h

The directory REB_4_1_STK600 contains the board implementation for the transceiver AT86RF231 based on the board REB231ED V4.1.1 on top of an STK600 board with REB to STK600 Adapter. For more information about this platform see sections 10.4.2.4 and 10.4.3.1.

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_STK600) 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_STK600/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 - File 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 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 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 AVRStudio 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 an STK600 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 ATxmega256A3 placed on the STK600 board with REB to STK600 Adapter and Radio Extender board REB231ED V4.1.1 (with AT86RF231) is the ATxmega128A1 on the same hardware setup (STK600 board with REB to STK600 Adapter and Radio Extender board REB231ED V4.1.1, see section 10.4.2.4 and 10.4.3.1). This entire build files for GCC and IAR for this particular base platform are located in directory

```
AT86RF231_ATXMEGA128A1_REB_4_1_STK600
```

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_1_STK600
```

Usually the directory name for applications consists of the following items to uniquely identify the target platform:

- TAL_TYPE (= AT86RF231)
- PAL_TYPE (= ATXMEGA128A1)
- PAL_GENERIC_TYPE (= XMEGA)
- BOARD_TYPE (= REB_4_1_STK600)

Attention: 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, i.e.

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_STK600/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_STK600
  ```

  to

  ```
  _TAL_TYPE = AT86RF231
  _PAL_TYPE = ATXMEGA256A3
  _PAL_GENERIC_TYPE = XMEGA
  _BOARD_TYPE = REB_4_1_STK600
  ```

In the described example only the PAL_TYPE needs to be changed. Make sure that the PAL_TYPE (i.e. 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 (e.g. 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, i.e.

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_STK600/GCC.
```

In order to support the target platform the file Star.ewp needs to be updated as follows:

- Select the proper MCU (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 AVR Studio Project files

The AVR Studio project file (i.e. 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, i.e.

```
Applications/MAC_Examples/Star_Nobeacon/
AT86RF231_ATXMEGA256A3_REB_4_1_STK600/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 an 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 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 AVRStudio 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 (e.g. 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 AVR Studio Project files (aps files). This includes replacing occurrences of the name of base application with the target application (e.g. 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_STK600.
```

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_STK600.
```

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, i.e. 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, i.e.

```
Applications/MAC_Examples/Promiscuous_Mode_Demo/
AT86RF231_ATXMEGA256A3_REB_4_1_STK600/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 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_STK600/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_STK600</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_STK600</state>
<state>HIGHEST_STACK_LAYER=MAC</state>
```

- Update the used and/or unused include 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 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</n
ame>
```

```
</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</name>
</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</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_scan_conf.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\..\MAC\Src\usr_mlme_start_conf.c</name>
</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_handler.c</name>
</file>
<file>
<name>$PROJ_DIR$\..\..\..\Helper_Files\SIO_Support\IAR_Support\write.c</name>
</file>
```

11.5.4 Step 4 - Update the AVR Studio Project files

The AVR Studio project file (i.e. aps file) of the target application is located in the directory of the target platform, i.e.

`Applications/MAC_Examples/Promiscuous_Mode_Demo/AT86RF231_ATXMEGA256A3_REB_4_1_STK600/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 (e.g. 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 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 (i.e. the MCU clock frequency) controls a variety of blocks within the MCU.

The MCU for the 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 (i.e. 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 (i.e. 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 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 (i.e. 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 AT86RF231 (with Antenna Diversity) placed on a 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 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 AVR2025 MAC implementation with the requirements and optional features as defined by the standard specified in 196] 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: M O		X (FFD only)	
PLF6	Link quality indication (LQI)	M		X	
PLF7	Channel selection	M		X	

			Support		
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 Sublayer

12.3.1 MAC Sublayer Functions

Table 12-3. MAC Sublayer 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	

			Support		
MLF8	Association and disassociation	M		X	
MLF9	Security	M			X (No MAC security, only application security)
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)	
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)

		Transmitter		Receiver	
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 Sublayer
• MCU	Microcontroller Unit
• MHR	MAC Header
• MIC	Message Integrity Code
• MLME	MAC Sublayer 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

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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. 2025H-MCU Wireless-08/10

Released with AVR2025 MAC Version 2.5.2

1. MAC Example Star_High_Rate added
2. High Data Rate support added
3. Platform description for RZ600 on top of Xplain board added
4. Platform description for ATZB ZigBit Modules on top of MeshBean2 board added

15.2 Rev. 2025G-MCU Wireless-08/10

Released with AVR2025 MAC Version 2.5.1

1. Description of new design of TAL and MCL added
2. Description of Tiny-TAL added
3. Support for ZigBit 212 added
4. New compiler switches added
5. Support for ATxmega256A3 added
6. Migration Guide from 2.4.x to 2.5.x added
7. High-density Network Configuration added
8. Frame transmission and reception procedure added
9. Buffer handling description added

15.3 Rev. 2025F-MCU Wireless-02/10

Released with AVR2025 MAC Version 2.4.2

1. Support of program code larger than 128 KByte added
2. PAN-Id conflict detection handling added
3. Support for AT91SAM7XC added
4. Description of application security added
5. Description of security build switches updated

15.4 Rev. 2025E-MCU Wireless-01/10

Released with AVR2025 MAC Version 2.4.0

1. Support for AT86RF231 and AT86RF212 with AT91SAM7X256 added
2. Support for ATmega128RFA1-EK1 added
3. Build switch DISABLE_TSTAMP_IRQ added
4. Support for ATmega1284P removed
5. Support for ATxmega256A3
6. MAC Porting Guide using ATxmega256A3 as example added
7. MAC Examples App 3 (Beacon Payload) and App 4 (Beacon Broadcast Data) added
8. Build switch SYSTEM_CLOCK_MHZ renamed to F_CPU

9. Updated handling of MAC PIB attribute macRxOnWhenIdle and MAC power management
10. New build switch BAUD_RATE added
11. Support for AT86RF230A and related hardware platforms discontinued
12. Handling of callback stub functions added Handling of callback stub functions added
13. PICS Table added

15.5 Rev. 2025B-MCU Wireless-09/09

Released with AVR2025 MAC Version 2.3.1

1. Name of Radio Controller Board (RCB) changed: transceiver number suffix is replaced by board suffix
2. Support for ATmega128RFA1 added
3. Handling of Promiscuous Mode updated.
4. Migration Guide for previous MAC versions removed
5. Filter tuning section added
6. Description of Performance test application extended
7. Support for ATxmega MCU based AES within SAL
8. Handling of MAC components updated
9. Initial Support for AT91SAM7X256 added
10. DISABLE_IEEE_ADDR_CHECK added
11. Chapter Supported Platforms added
12. Chapter Topics on Platforms Porting added

15.6 Rev. 2025-AVR-04/09

Released with AVR2025 MAC Version 2.2.0

1. Initial Version

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