

# WiMOD LoRaWAN EndNode Modem Firmware

Feature Specification Version 3.2

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3.1	Chapter 2.2.5 added for Band Selection Chapter 2.3.4 updated with Customer Mode clarification
3.2	Updated for Class C

## Aim of this Document

This document outlines the WiMOD LoRaWAN<sup>®1</sup> EndNode Modem firmware features. This firmware is designed for the WiMOD radio module family.

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# 1. Overview

The WiMOD LoRaWAN EndNode Modem firmware provides the following features:

- Compliant with LoRaWAN Specification V1.0.4
- LoRaWAN EU868, IN865, US915, AU915, AS923 and RU868 channel plans supported
- Supports Class A and Class C (unicast/multicast messages supported)
- Over The Air Activation (OTAA) and Activation By Personalization (ABP)<sup>1</sup>
- Multitasking Operating System WiMOD-OS with Automatic Power Saving (APS)
- Host Controller Interface (HCI) for access to radio functions & parameters (see[1])
- EndNode Test Application required for the certification process

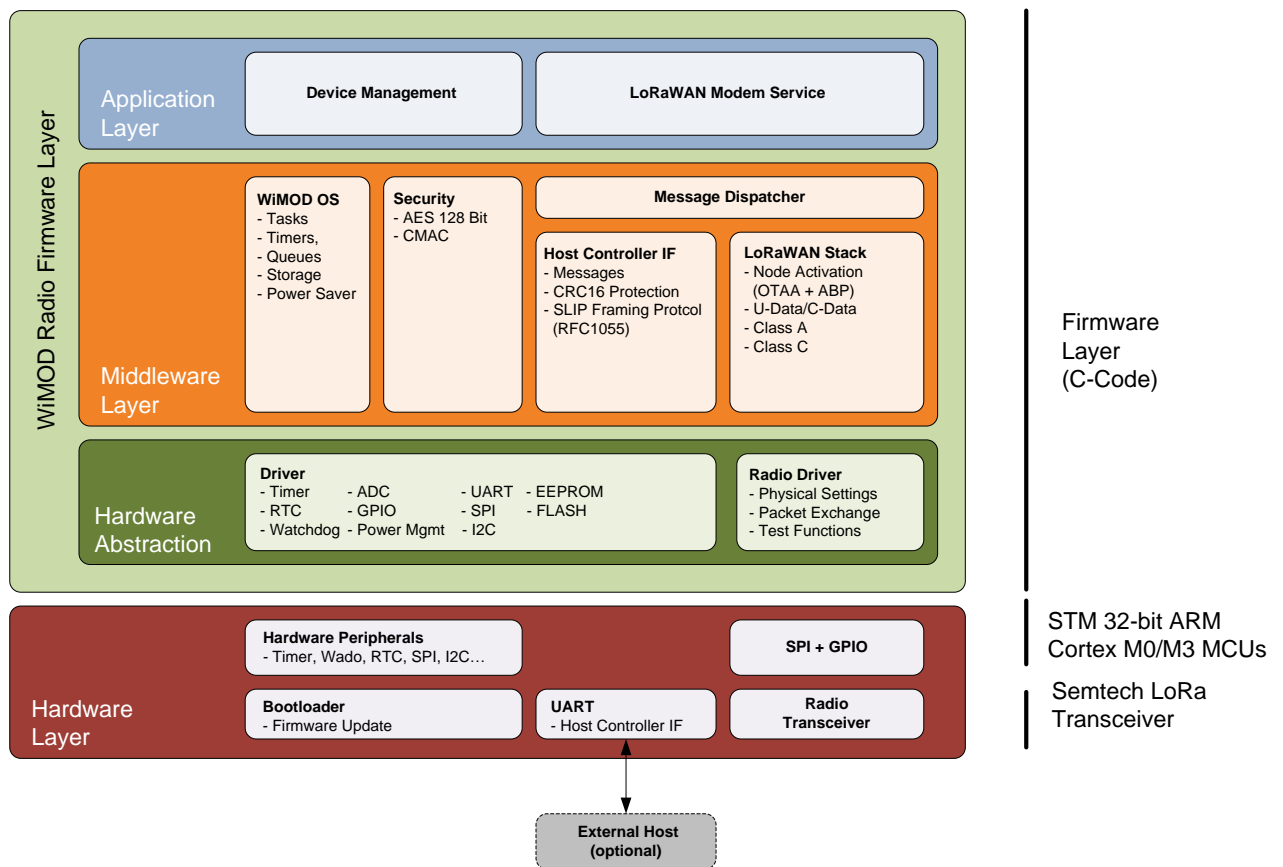


Fig. 1-1: WiMOD LoRaWAN EndNode Modem Firmware Architecture

<sup>1</sup> Activation By Personalization is available only for testing purposes.

## 2. Functional description

This chapter explains several points to clarify the functionality of the WiMOD LoRaWAN EndNode Modem firmware.

### 2.1 General Services

The Device Management component provides general services for module configuration, module identification, and everything which is not related to the radio data exchange.

The main features are:

- Information elements for identification purposes (e.g. module type, device ID)
- Identification of the firmware version (FW version, build count, build date, FW name)
- Real Time Clock handling
- System Operation Modes (e.g. application mode, customer mode)
- Firmware Update

#### 2.1.1 Firmware Update

The end-device offers a fully automatic activation of the bootloader via the HCI interface, which could be used for future firmware updates.

### 2.2 Customization Services

This feature offers the configuration of some customization parameters for the end-device. For this, the Customer Mode should be selected.

#### 2.2.1 Device EUI

The end-device provides the services for read-out and configuration of the 64-bit unique Device EUI required by the LoRaWAN specification.

#### 2.2.2 RF Gain

The RF gain defines an offset used to compensate possible transmission losses/gains in the final product (including circuit, matching, antennas...). This value should be rated in units of dBd (decibels relative to a half-wavelength dipole antenna, where  $0\text{dBd} = 2.15\text{dBi}$ ).

It is recommended to set this constant before the radio stack parameters to ensure a correct configuration of the device.

For more details refer to the appendix (5.1), which contains some examples for possible configurations. The most important parameters related to this feature are:

- **Max. RF Power**

maximum RF output power corresponding to the module to be used (for more information refer to the corresponding hardware datasheet, e.g. see [2]).



- **Max. allowed EIRP**  
maximum allowed EIRP for the selected band, e.g. EU868, IN865. (see [3] for more details).
- **RF Gain**  
configured RF gain related to the final product.
- **Max. EIRP**  
maximum EIRP available for the final product. This value is calculated as following:  
$$\text{Max. EIRP} = \text{MIN} (\text{Max. allowed EIRP}, \text{Max. RF Power} + \text{RF Gain} + 2.15\text{dB})$$
- **Configured EIRP**  
EIRP configured for the next uplink radio message.
- **Configured TRX power**  
transmitted power to be configured in the transceiver to achieve the configured EIRP.  
  
The firmware considers that:  $\text{EIRP} = \text{TRX Power} + \text{RF Gain} + \sim 2\text{dB}$

### 2.2.3 RF Sub-bands Configuration

In some regions, the ISM band is divided in several frequency sub-bands with different regulatory limitations. The end-device allows to modify the default settings in order to configure different values if required.

The parameters related to this feature are:

- **Tx Power Limit**  
configuration of the maximum allowed transmit power for each frequency sub-band (see corresponding regional HCl specification, e.g. [4]).

### 2.2.4 Duty Cycle Control

The duty cycle limitation may be disabled for testing purposes. Please refer to 2.3.4 for the configuration of this parameter.

### 2.2.5 Band Selection

This parameter allows to configure the radio band to be used. Please refer to 2.3.4 for the configuration of this parameter.

## 2.3 LoRaWAN Services

### 2.3.1 Device Activation

An end-device must be activated before it can communicate with a server. Two activation options are supported: Activation By Personalization (ABP) and Over The Air Activation (OTAA).

After a successful activation (ABP or OTAA), the end-device will send an empty unconfirmed uplink message ("alive" message) over the air.

Note that after a reset of the radio module the firmware will automatically restore the last activation status stored in the non-volatile memory. Therefore, in case the end-device was previously ABP activated an unconfirmed uplink message will be sent. On the other side, the join procedure will be started if the end-device was OTAA activated or the join procedure was already initiated.

#### 2.3.1.1 Activation By Personalization (ABP)

The activation parameters must be known on both sides - the end-device and the LoRaWAN network. The following parameters are required:

- Device Address
- Network Session Key: used for MIC calculation and verification
- Application Session Key: used to encrypt and decrypt the payload field of application specific messages

Note that this activation is available only for testing purposes, as the frame counters and other parameters are not stored persistently.

#### 2.3.1.2 Over The Air Activation (OTAA)

The end-device can be configured and triggered to execute the so called join procedure defined in the LoRaWAN specification. The result of a successful join procedure is a new device address, a new network session key and a new application session key.

The following parameters are required:

- Device EUI: this parameter can only be written in *Customer Mode*
- Join EUI
- Application Key

The end-device uses the frequencies defined by the corresponding radio band (see corresponding regional HCl specification, e.g. [4], for radio band configuration) to broadcast the Join Request message. Note that these transmissions follow the retransmissions backoff defined in the LoRaWAN specification and the duty-cycle requirements, even if this is deactivated.

The join request will be retransmitted on a new randomly selected frequency channel if no join accept message is received. For this, the maximum number of retries for a join request is fixed to 12.

### 2.3.1.3 Activation Parameters

The parameters required for Over The Air Activation and Activation By Personalization are configurable via HCI interface. These parameters are not readable and they are stored in encrypted form in a non-volatile memory to resist a power cycle.

## 2.3.2 Data Exchange

### 2.3.2.1 Uplink Services

#### 2.3.2.1.1 Uplink Unreliable Data Transmission

The end-device could send data in an unreliable way to the network server. This requires no acknowledgement from the network server.

If the end-device is configured by the network server to retransmit the unconfirmed/confirmed data frames (NbTrans) and an unconfirmed data frame is sent, a new transmission is not allowed before it either has received a downlink message or the second receive window of the last retransmission is expired.

The data frame will be retransmitted on a new frequency but using the same data rate (see 3.2).

#### 2.3.2.1.2 Reliable Data Transmission

The end-device could send data in a reliable way to the network server. The server will acknowledge the received packet within the defined downlink timeslots. Note that if a downlink with the acknowledge bit unset is received, the end-device will ignore it.

If the end-device is configured by the network server to retransmit the unconfirmed/confirmed data frames (NbTrans) and a confirmed uplink has been sent, a new transmission is not allowed before it either has received an acknowledge or the second receive window of the last retransmission is expired.

In the absence of the acknowledgement the end-device will try to retransmit the same application payload, with a maximum number of retries (stored in the radio stack configuration). The same application payload will be retransmitted on a new uplink frame using a new randomly selected frequency channel. In case the ADR feature is enabled, each data rate will be used twice and will be lowered after that till the minimum data rate is achieved (see 3.3). The maximum number of retransmissions to be sent can be changed in the end-device configuration (see [1]). The maximum value allowed is 254.

If the retransmission procedure finishes without success (e.g. maximum number of retransmission achieved or maximum payload size exceeded for the selected data rate), the corresponding error code will be sent (see [1]).

#### 2.3.2.1.3 Duty Cycle

A new transmission is not allowed if all channels are blocked by duty cycle. The application should try to send the data again (see 3.4).

#### 2.3.2.1.4 Payload Size

The maximum length of the LoRaWAN message is limited according to the maximum payload size defined in the LoRaWAN specification (see [3]). In case the application data exceeds these

limits the corresponding error code will be returned (see [1]).

### 2.3.2.2 Downlink Service

The end-device is able to receive packets within dedicated Rx timeslots scheduled as defined in the LoRaWAN specification.

Depending on the type of received or not received data, the corresponding messages will be sent to the Host.

#### 2.3.2.2.1 Message Acknowledge Bit

The end-device will automatically transmit an acknowledgement using an empty data message after the reception of a data message requiring a confirmation. This uplink is delayed 60 seconds, allowing the user to send piggybacked application payload if desired (see 3.5).

#### 2.3.2.2.2 Frame Pending Bit

The frame pending bit functionality is implemented according to the LoRaWAN specification. An empty frame will be sent after the reception of a data message with the frame pending bit set to 1. This uplink is delayed 60 seconds, allowing the user to send piggybacked application payload if desired (see 3.6).

### 2.3.2.3 Frame Counter

The end-device implements a 32 bit frame counter.

## 2.3.3 MAC Commands

The end-device supports the MAC commands defined in the LoRaWAN specification.

### 2.3.3.1 MAC Commands Request

The end-device allows the transmission of a MAC command request, either piggybacked in the header or in the Payload field with the Port field being set to 0.

#### 2.3.3.1.1 Device Time Request

The firmware supports the DevTimeReq MAC command with following limitations:

- The end-device will automatically synchronize its RTC if a DeviceTimeAns is received in any unicast class A downlink.
- The GPS epoch time is used for the time synchronization on the end-device.  
Note that there is a small time different between the GPS epoch and the UTC time (leap seconds).  
Moreover, the configuration of the time zone is not available on the end-device and therefore no correction is performed.

Note that the LoRaWAN network server must support the DeviceTimeReq/DeviceTimeAns MAC command to manage a successful time synchronization on the end-device.

### 2.3.3.2 MAC Commands Response

The end-device will send the answer to the MAC commands piggybacked within the next uplink. If this is not possible because they exceed the maximum length set under the radio stack configuration (max. 15 bytes), they will be sent immediately using the port 0 (see 3.7).

Note that the answers to the MAC commands that need to be retransmitted by the end-device until a Class A downlink is received, will be sent piggybacked in the header of the following uplinks.

### 2.3.4 Device Configuration

The end-device provides several features and parameters which can be configured under the radio stack configuration. The main parameters are:

- Band Selection: e.g. EU868.  
Note that the *Customer Mode* is required for the modification of this parameter
- Uplink Data Rate
- Tx Power Level (EIRP): radiated power (EIRP) to be configured
- Adaptive Data Rate: used to allow an automatic data rate adaption from server side (described in 2.3.4.1)
- Automatic Power Saving
- Duty Cycle Control: the duty cycle may be disabled for testing purposes. Note that the *Customer Mode* is required for any modification of this parameter
- Class A & Class C Selection
- Number of Retransmissions: this value sets the maximum number of retries for a reliable radio packet where an acknowledgment is not received. Note that these retransmissions are additional to the frame retransmissions configured by the LoRaWAN network server via the LinkADRReq MAC Command (NbTrans)
- Header MAC Cmd capacity: this value is used to configure the maximum length of the MAC commands to be piggybacked in the header within the next uplink. If the length of the reply exceeds this value, they will be sent immediately using the port 0. This parameter could be used to ensure a minimum desired payload size available for the user application
- Private LoRaWAN network configuration: this feature enables the configuration of a private LoRaWAN network, which implies a change on the sync word

Some of these parameters, like the uplink data rate and the transmitted power level, are only used in certain situations (described in 2.3.4.1) and may change automatically during runtime or via LoRaWAN MAC commands from network server side.

If the configured parameters are not allowed an error code will indicate that there is a wrong parameter. In this case, it is recommended to check that the uplink data rate and the transmitted power level are compatible with the selected band.

### 2.3.4.1 Adaptive Data Rate (ADR)

This feature allows an automatic data rate adaption from server side. Therefore the behaviour of the end-device depends on its configuration as defined in the following sections.

#### 2.3.4.1.1 ADR enabled

According to the LoRaWAN specification, if the end-device is configured with Activation By Personalization, the minimum data rate is used until the LoRaWAN network requests a higher data rate through the LinkADRRReq MAC command. In this case, the stored settings for data rate and the transmitted power level under the radio stack configuration will not be applied.

On the other hand, if the Over The Air Activation is selected and no special behaviour is established in the Regional Parameter document [3], the first transmission of the Join Request happens with the already stored data rate under the radio stack configuration. Each data rate will be used twice and will be lowered after that (see 3.1). After a successful activation of the end-device, it will send an empty LoRaWAN frame. For this, the data rate of the last Join Request will be used.

#### 2.3.4.1.2 ADR disabled

If the ADR feature is disabled the data rate used by the end-device to send the application data will always remain unchanged and therefore the stored values for the data rate and tx power under the radio stack configuration will be applied.

In this case, if a LinkADRRReq MAC Command from the LoRaWAN network server is received, the end-device will accept it, where only the channel mask and tx power will be interpreted and accordingly modified. The data rate and redundancy parameters do not change.

Furthermore, the end-device will check for connectivity loss and therefore it sets the ADRAckReq bit after 64 successive uplinks without any Class A downlink response. In case no downlink is received in the following 32 uplinks, a link disconnect indication is sent to the host application via HCI, the ADRAckReq bit is reset to 0 and the data rate remains unchanged.

### 2.3.4.2 Automatic Power Saving

In case the Automatic Power Saving is enabled, the end-device will enter low power mode whenever possible and the current consumption will be reduced to a typical low power current depending on the given hardware module, where the RTC remains running (for more information refer to the corresponding hardware datasheet, e.g. see [2]).

Note that if class C support is enabled the current consumption will increase to the value which corresponds to the continuously listening mode.

The end-device does not enter low power mode direct after a transmission and this is not enabled before it either has received a downlink message or the second receive window is expired (no Rx indication).

The following picture shows an example of a voltage graph (multiplied by 10) measured at a 10 Ohm resistor on an iM880B-L module.

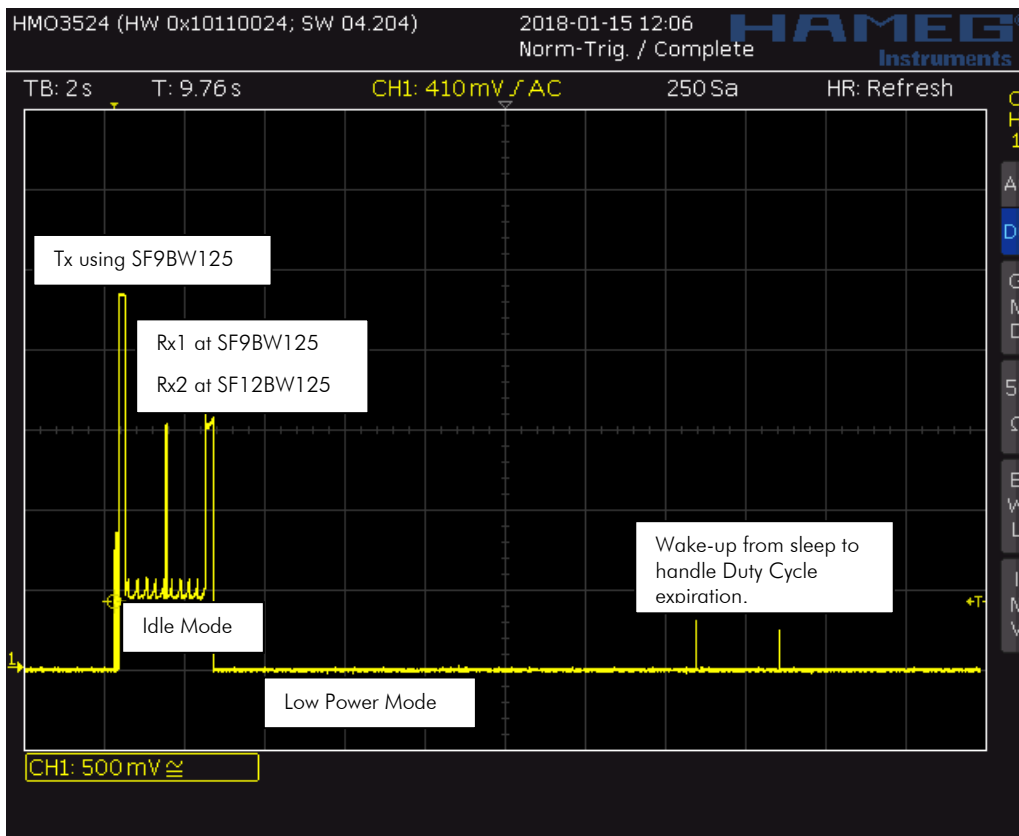


Fig. 2-1: Exemplary current consumption diagram - iM880B-L

### 2.3.4.3 Class C Implementation

The end-device follows the Class C implementation as defined by the LoRaWAN specification.

After a successful activation (ABP or OTAA), the end-device will send an empty confirmed uplink message ("alive" message) over the air, as defined in the LoRaWAN specification.

In difference to the Class A implementation, the end-device will transmit an acknowledgement using an empty data message immediately after the reception of a data message requiring a confirmation.

Additionally, following interpretations are considered by the current implementation:

- If any downlink which requires an uplink from the end-device (e.g. confirmed downlink) is received, the end-device will not listen in continuous mode until the pending uplink is sent.
- The indication with the information that no data has been received (including the corresponding error code if required) will only be forwarded to the application if the received downlink was addressed to the selected end-device. This is valid for the downlinks received during continuous listening mode.
- The firmware supports the configuration of up to three different multicast configurations. The end-device will use the multicast configuration once it is successful activated (by ABP or OTAA) and the class C support is enabled. The end-device will use the sequence counter included in the first received multicast downlink to synchronize its internal downlink sequence counter.

#### **2.3.4.4 Battery Level Status**

The firmware offers the possibility to update the status of the battery level of the end-device. This will be sent to the LoRaWAN server in the reply to the DevStatusReq MAC command (see [1]).

#### **2.3.4.5 Non-Volatile Memory Handling**

After a reset of the radio module the firmware will automatically restore the configuration available in the non-volatile memory. If this information is not available or corrupted, the initial firmware settings stored during production time will be used. In case the factory settings are missing or corrupted, the firmware will use its default settings (see [1]).

In the same way, the DevNonce is stored in the non-volatile memory to ensure that this is incremented, which is required for a successful Over The Air Activation. If this information is not available or corrupted, a corresponding indication will be sent to the host application via HCI. Therefore it is recommended that the host application implements a restoring mechanism for this situation.

#### **2.3.4.6 Test Mode**

The firmware includes a Test Mode, selectable as an Operation Mode, which enables the test application required for the LoRaWAN certification.



### 3. Sequence Charts

This chapter contains exemplary sequence charts which show the typical behavior of the firmware.

#### 3.1 Join Procedure

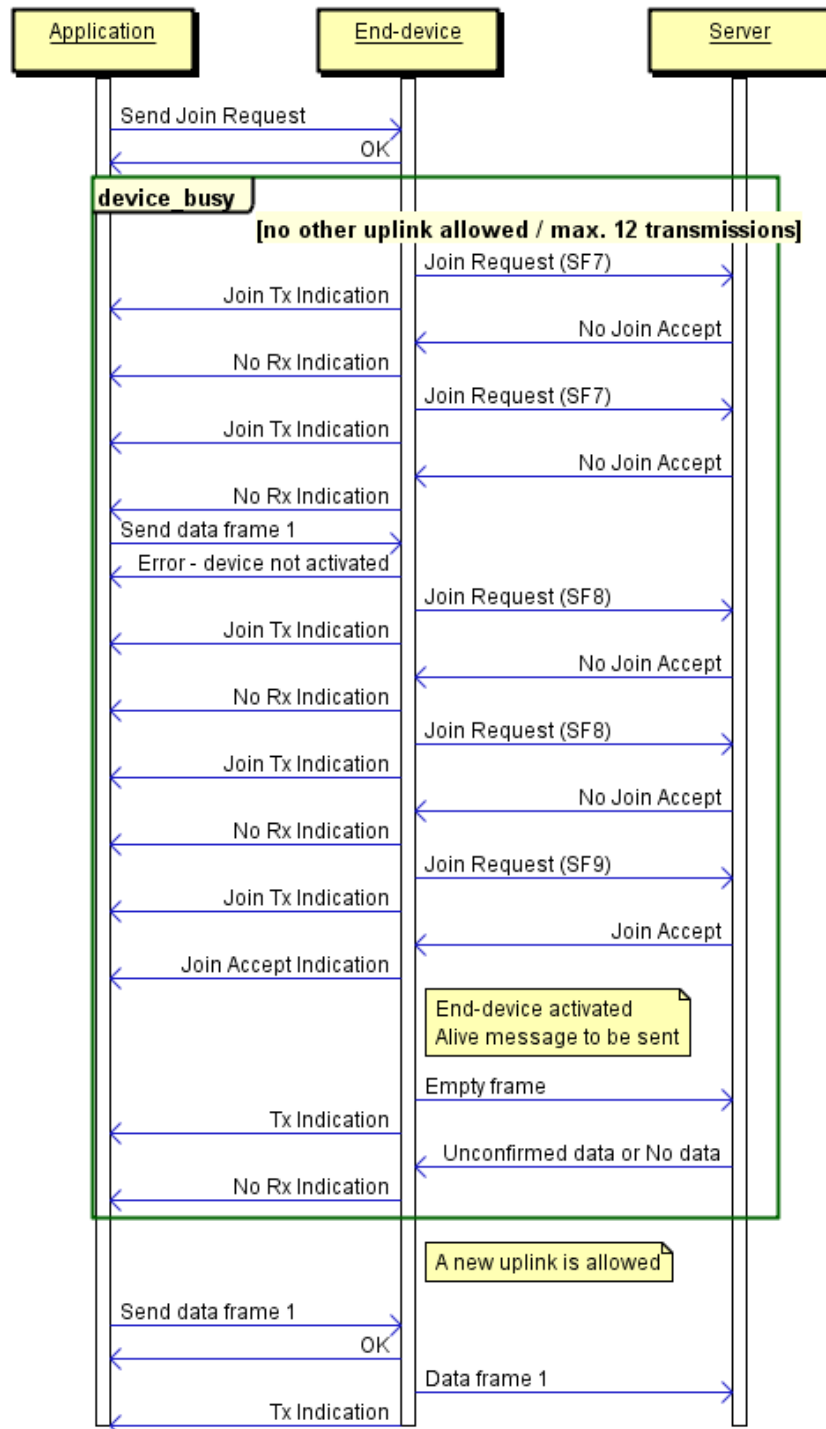


Fig. 3-1: Sequence chart - Join procedure example (ADR enabled/SF7BW125 configured)

### 3.2 Unconfirmed Data Retransmission

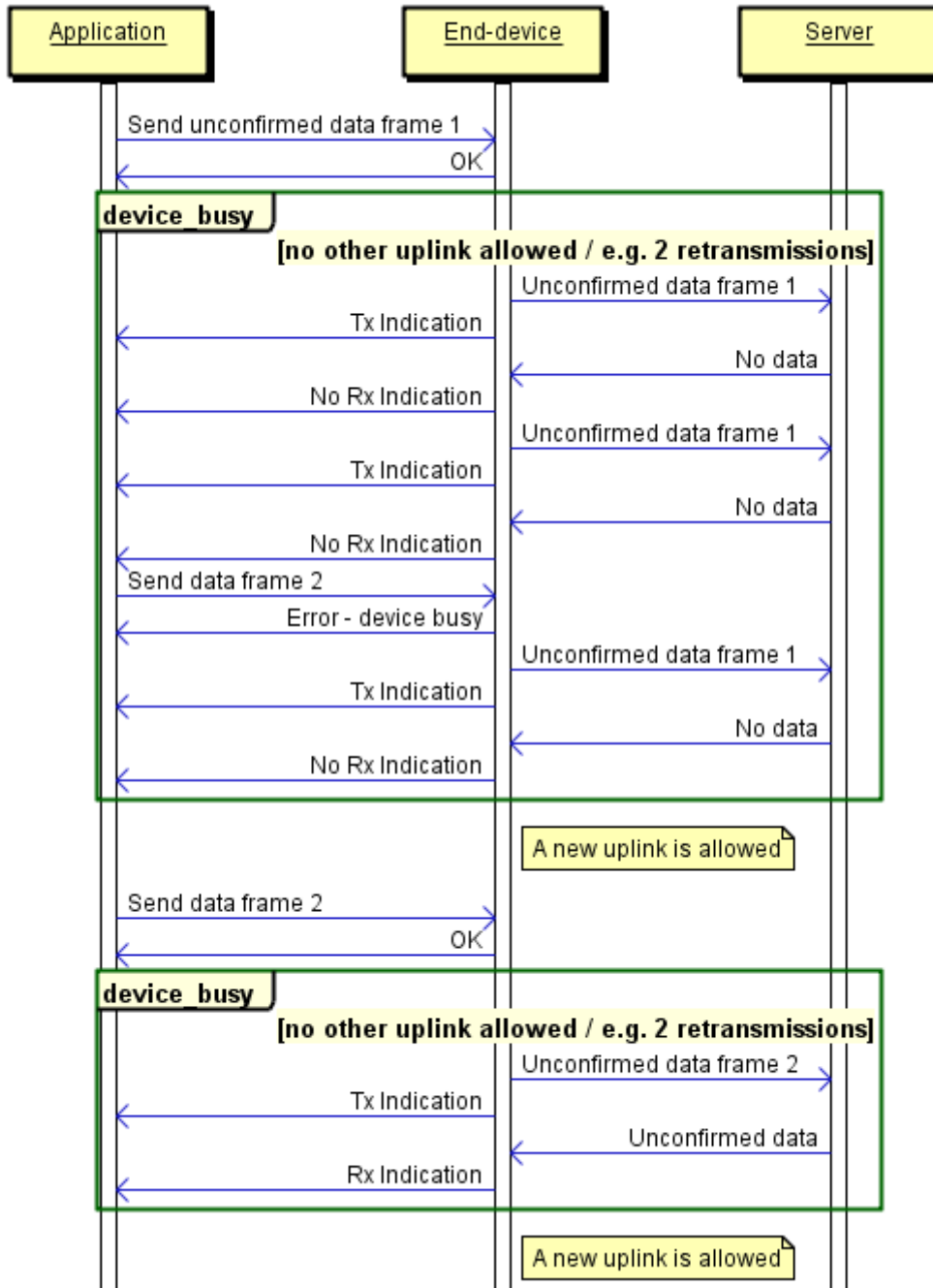


Fig. 3-2: Sequence chart - Unconfirmed data retransmission example (NbTrans=2)

### 3.3 Confirmed Data Retransmission

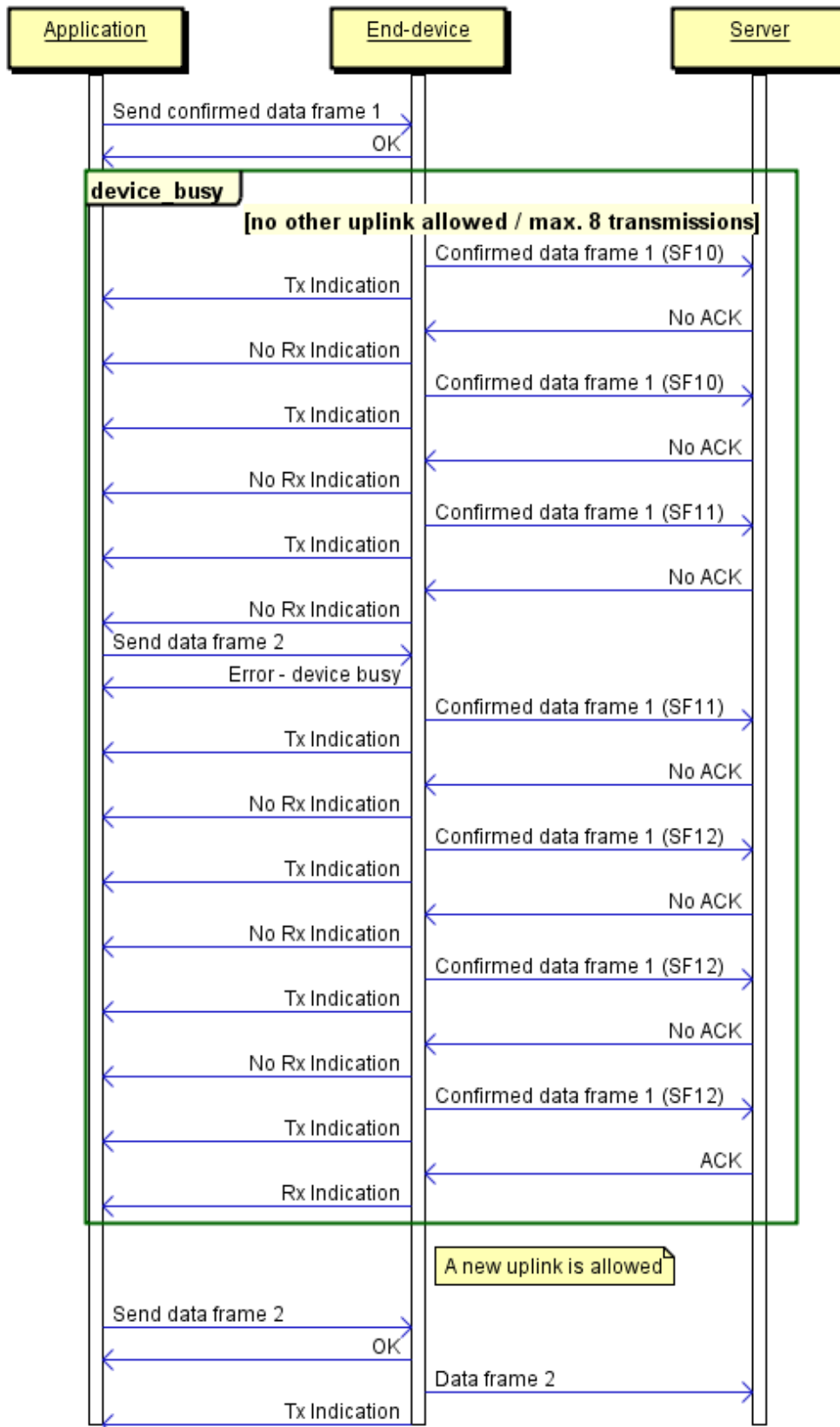


Fig. 3-3: Sequence chart - Retransmission procedure example (NbTrans=1)

### 3.4 Duty Cycle

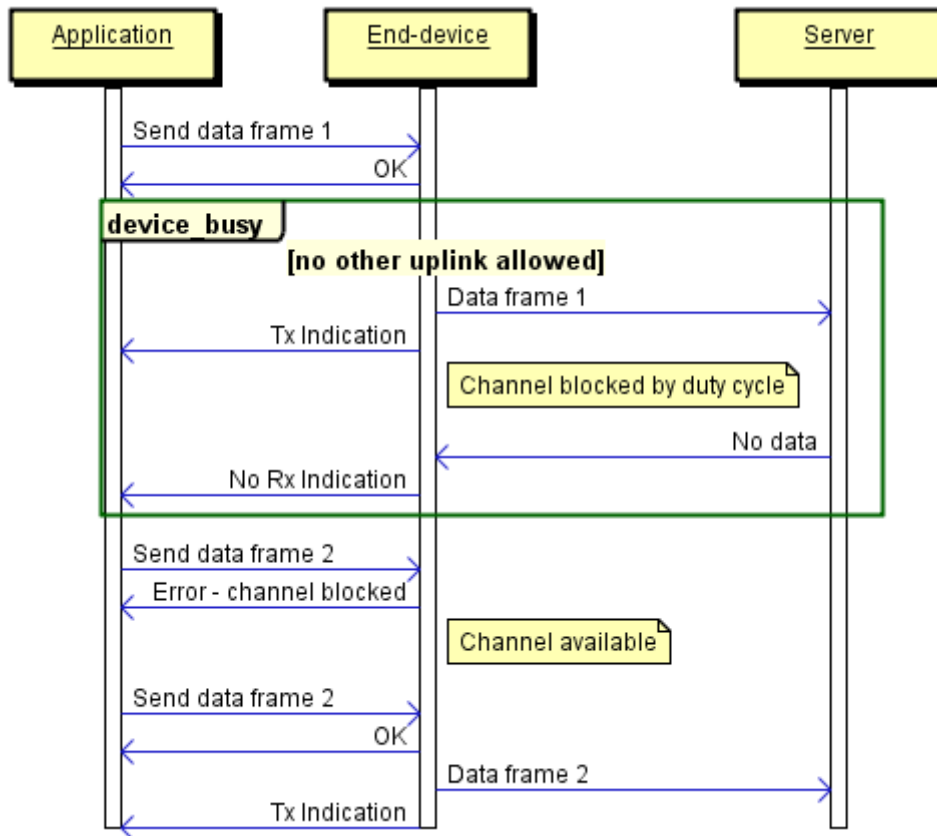


Fig. 3-4: Sequence chart - Duty Cycle

### 3.5 Message Acknowledge Procedure

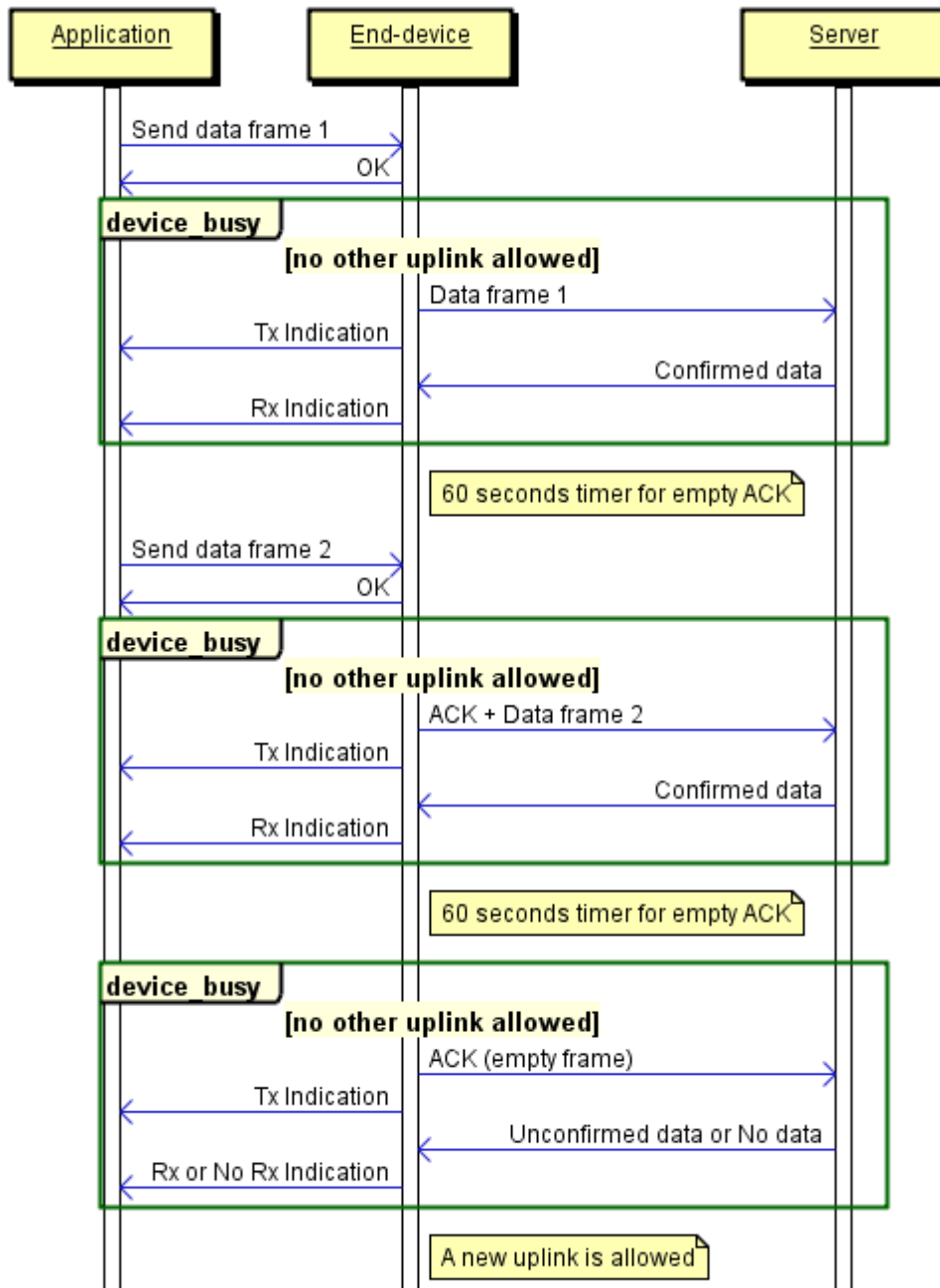


Fig. 3-5: Sequence chart - Acknowledgement procedure (Class A)

### 3.6 Frame Pending Bit

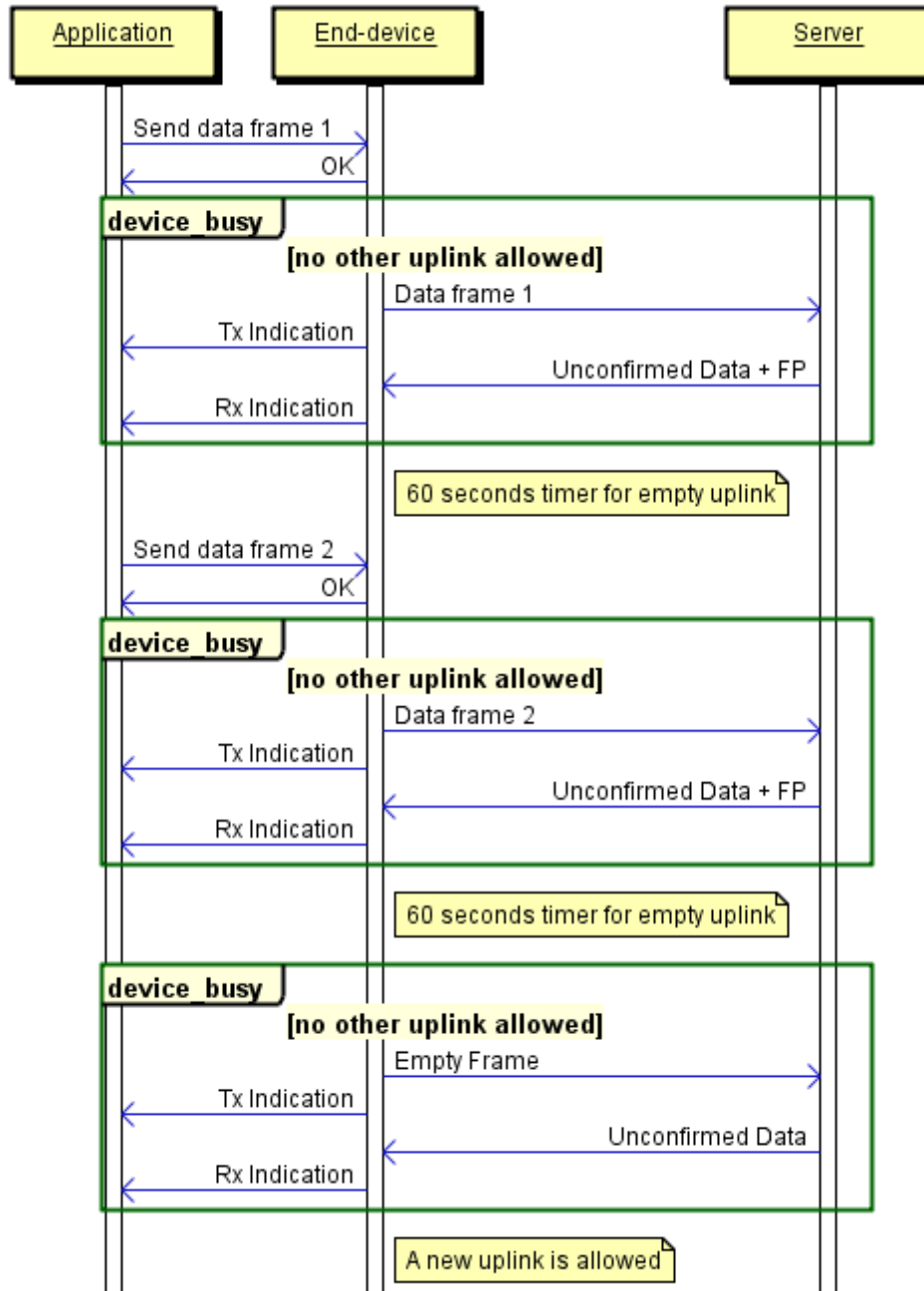


Fig. 3-6: Sequence chart - Frame pending bit

### 3.7 MAC Commands

#### 3.7.1 MAC Commands - Piggybacked in Header

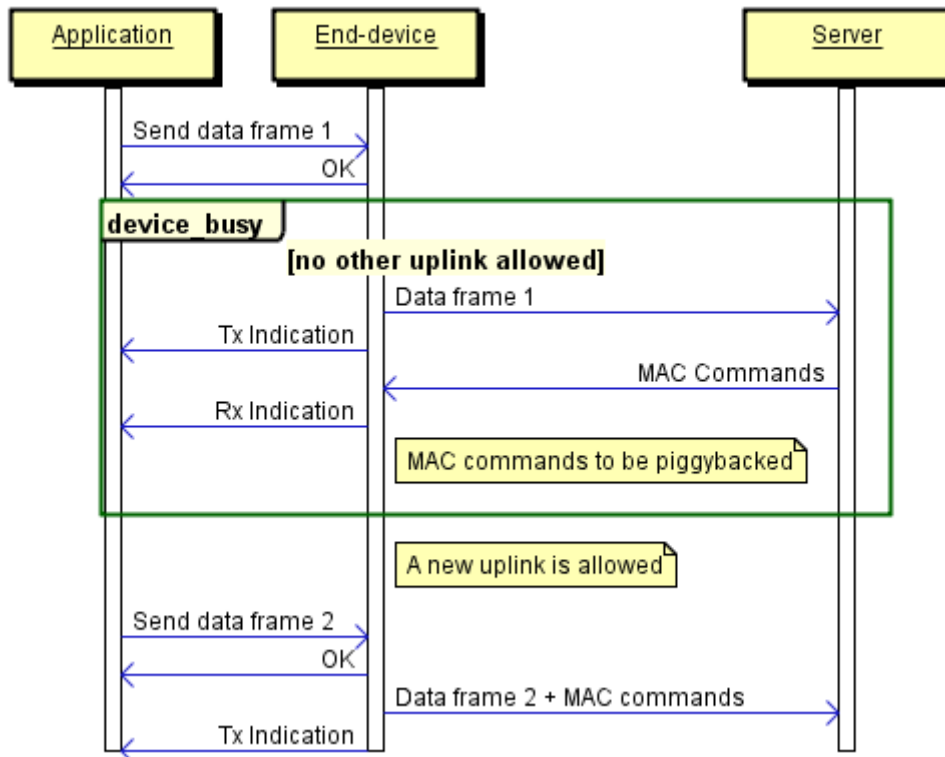


Fig. 3-7: Sequence chart - MAC Commands (piggybacked in header)

### 3.7.2 MAC Commands - Port 0

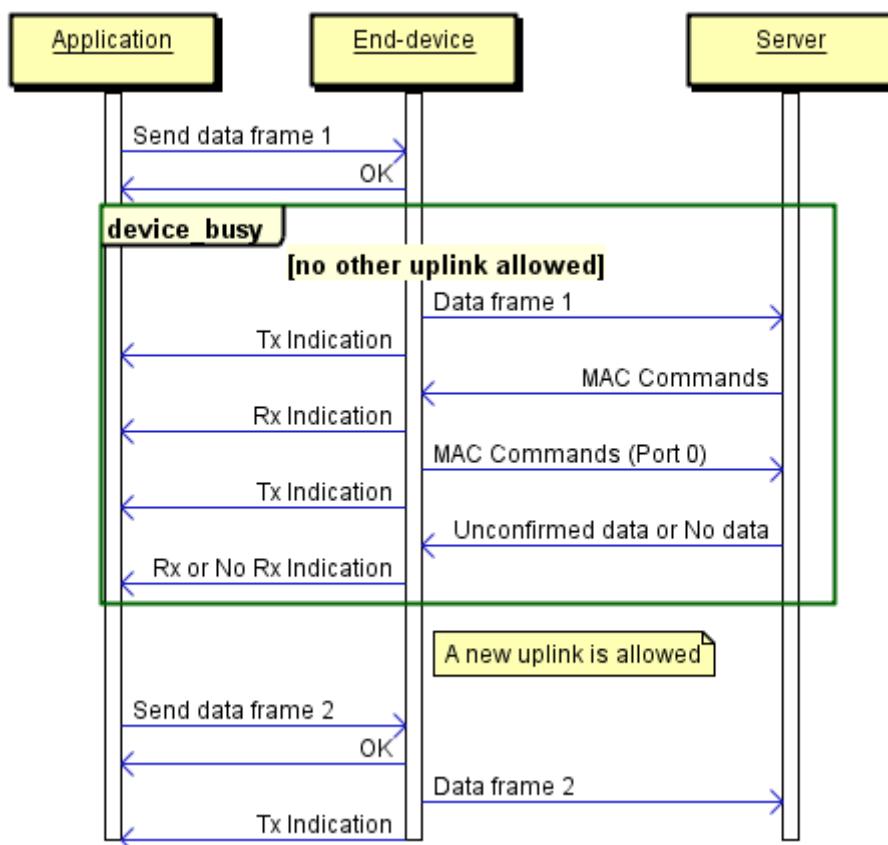


Fig. 3-8: Sequence chart - MAC Commands (using port 0)



## 4. Known Limitations

This chapter lists the current known limitations related to the WiMOD LoRaWAN EndNode Modem firmware:

- No official LoRaWAN certification for multicast class C, V1.0.4
- Note that a new configuration request may require access to the non-volatile memory, therefore a power loss or HW reset must be avoided in the next 500 ms to ensure that the stored parameters are correct
- Automatic activation of the bootloader via the HCI interface (for future firmware updates) not supported by iM881A-XL
- Activation By Personalization only available for testing purposes

## 5. Appendix

### 5.1 RF Gain Examples

#### 5.1.1 iM880B-L Radio Module configured in EU868 Band<sup>1</sup>

For this example a maximum RF power (limited by the radio module) of 20dBm and a maximum allowed EIRP of 16dBm have been considered.

Max. RF power	Max. allowed EIRP	RF Gain	Max. EIRP	Configured EIRP	Configured TRX power
20dBm	16dBm	0dBd	16dBm	16dBm	14dBm
20dBm	16dBm	+6dBd	16dBm	16dBm	8dBm
20dBm	16dBm	-6dBd	16dBm	16dBm	20dBm

Table. 5-1: Example for RF Gain settings - iM880B-L & EU868

#### 5.1.2 iM880B-L Radio Module configured in IN865 Band<sup>2</sup>

For this example a maximum RF power (limited by the radio module) of 20dBm and a maximum allowed EIRP of 30dBm have been considered.

Max. RF power	Max. allowed EIRP	RF Gain	Max. EIRP	Configured EIRP	Configured TRX power
20dBm	30dBm	0dBd	22dBm	22dBm	20dBm
20dBm	30dBm	+6dBd	28dBm	28dBm	20dBm
20dBm	30dBm	-6dBd	16dBm	16dBm	20dBm

Table. 5-2: Example for RF Gain settings - iM880B-L & IN865

#### 5.1.3 iM881A Radio Module configured in EU868 Band

For this example a maximum RF power (limited by the radio module) of 14dBm and a maximum allowed EIRP of 16dBm have been considered.

Max. RF power	Max. allowed EIRP	RF Gain	Max. EIRP	Configured EIRP	Configured TRX power
14dBm	16dBm	0dBd	16dBm	16dBm	14dBm
14dBm	16dBm	+6dBd	16dBm	16dBm	8dBm
14dBm	16dBm	-6dBd	10dBm	10dBm	14dBm

Table. 5-3: Example for RF Gain settings - iM881A & EU868

<sup>1</sup> AS923 and RU868 channel plans similar to EU868

<sup>2</sup> US915 and AU915 channel plans similar to IN865

### 5.1.4 iM881A Radio Module configured in IN865 Band

For this example a maximum RF power (limited by the radio module) of 14dBm and a maximum allowed EIRP of 30dBm have been considered.

Max. RF power	Max. allowed EIRP	RF Gain	Max. EIRP	Configured EIRP	Configured TRX power
14dBm	30dBm	0dBd	16dBm	16dBm	14dBm
14dBm	30dBm	+6dBd	22dBm	22dBm	14dBm
14dBm	30dBm	-6dBd	10dBm	10dBm	14dBm

Table. 5-4: Example for RF Gain settings - iM881A & IN865

## 5.2 List of Abbreviations

ABP	Activation By Personalization
FW	Firmware
HCI	Host Controller Interface
HW	Hardware
EIRP	Effective Isotropic Radiated Power
ERP	Effective Radiated Power
LR	Long Range
LoRa	Long Range
LPM	Low Power Mode
OTAA	Over The Air Activation
RAM	Random Access Memory
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RTC	Real Time Clock
SW	Software
TRX	Transceiver
UART	Universal Asynchronous Receiver/Transmitter
WiMOD	Wireless Module by IMST

## 5.3 List of References

- [1] WiMOD\_LoRaWAN\_EndNode\_Modem\_HCI\_Spec.pdf
- [2] iM880B\_Datasheet.pdf
- [3] LoRaWAN Regional Parameters, LoRa Alliance
- [4] WiMOD\_LoRaWAN\_EndNode\_Modem\_EU868\_HCI\_Spec.pdf

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## 6. Regulatory Compliance Information

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