WiMOD LoRaWAN EndNode Modem Firmware

Feature Specification Version 2.4

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IMST GmbH

Carl-Friedrich-Gauß-Str. 2-4

47475 KAMP-LINTFORT

GERMANY

Document Information

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0.2	Draft Version Created For Review
0.3	Preliminary Version
1.0	First Release
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1.7	Chapter 2.9 updated for current consumption diagram
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2.0	Structure of document changed Updated for additional clarifications: e.g. frame counter, RF gain
2.1	Chapter 2.3.2 updated for frame pending bit
2.2	Chapter 2.2.2 and 2.3.4 for RF Gain and EIRP settings Chapter 5.1 added with examples for RF Gain settings

2.3	Chapter 2.2.3 added for RF Sub-bands Configuration Chapter 2.3.3 updated for MAC command reply Chapter 2.3.4 updated for Adaptive Data Rate clarification and Header MAC Cmd capacity
2.4	Firmware V2.0, Build Count 136 Chapter 2.2.4 added for LinkADRReq Handling Configuration Chapter 2.2.5 added for Duty Cycle Configuration Chapter 2.3.2.3 updated for Frame Counter Chapter 2.3.4.1 updated for PowerSaving Feature Chapter 2.3.4.2 added for Class C Implementation

Aim of this Document

This document outlines the WiMOD LoRaWAN EndNode Modem firmware features. This firmware is designed for the WiMOD radio module family (e.g. iM880B-L, iU880B, iM881A).

Table of Contents

1. Overview

The WiMOD LoRaWAN EndNode Modem firmware provides the following features:

- Compliant with LoRaWAN Specification V1.0.2
- LoRaWAN certified for EU868 region in Class A, V1.0.2
- Supports Class A and Class C[1] (only unicast messages supported)
- Over The Air Activation (OTAA) and Activation By Personalization (ABP)
- 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

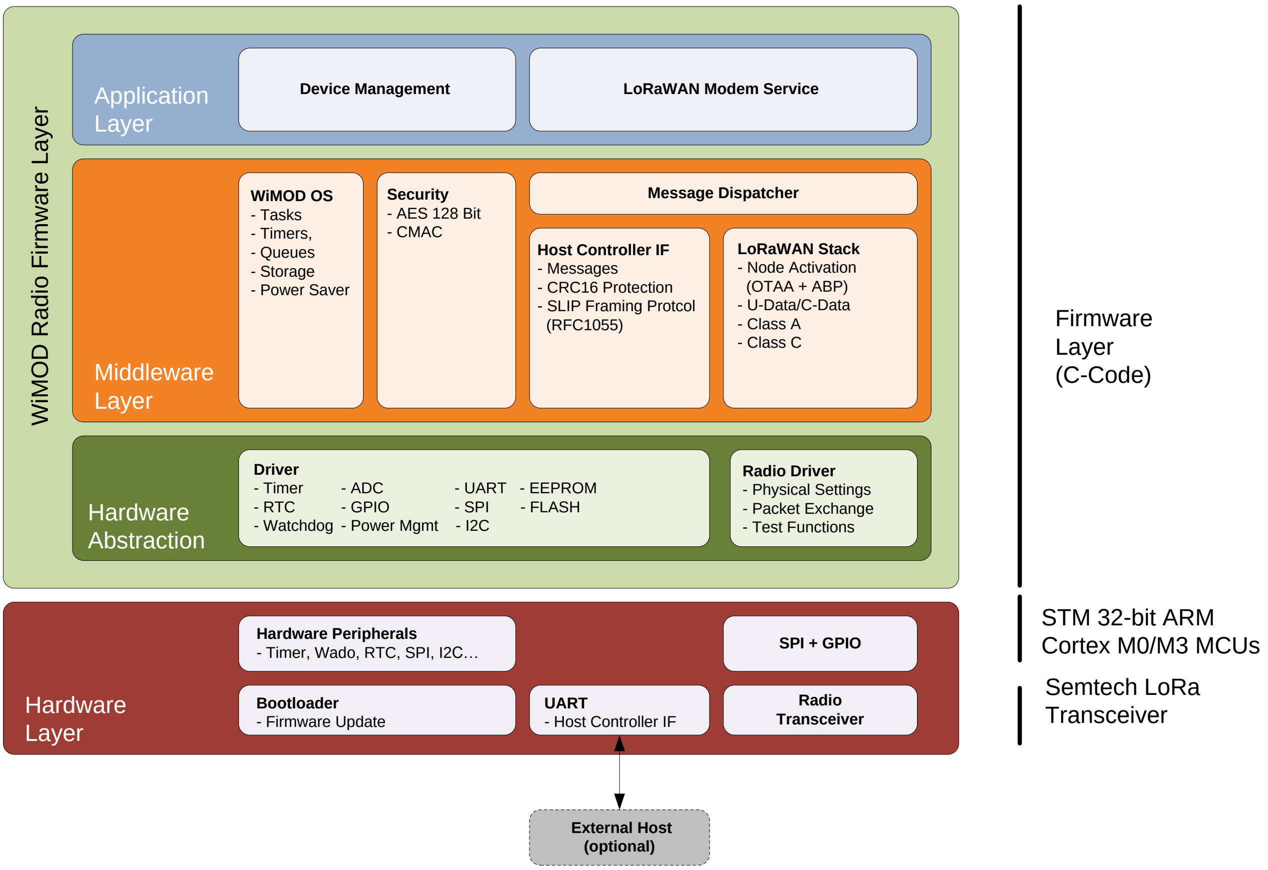

Fig. 1-1: WiMOD LoRaWAN EnNode Modem Firmware Architecture

[1] Within the LoRaWAN specification V1.0.2 Class C is described very rudimentary. Also Class C implementation is currently not covered by the LoRaWAN certification program.

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 *0dBd=2.15dBi*).

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:

  Max. EIRP = MIN (Max. allowed EIRP, Max. RF Power + RF Gain + 2.15dB)

- **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: *EIRP = TRX Power + RF Gain + ~2dB*

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 HCI specification, e.g. [4]).

2.2.4 LinkADRReq Handling Configuration

The end-device supports different options to handle the LinkADRReq MAC Command sent by the LoRaWAN network server. This setting takes place if the Adaptive Data Rate feature is disabled (see 2.3.4). The end-device provides a service to configure this setting with the following possible options:

- **LoRaWAN v1.0.2 compliant**

  any LinkADRReq will be rejected and the uplink settings will not change.

- **Semtech proposal compliant**

  a LinkADRReq with the data rate and tx power parameters set to 0xF will be accepted. Therefore, the channel mask and redundancy parameters could be processed. In this case, the data rate and tx power settings do not change.

  Any other LinkADRReq will be rejected and the uplink settings will not change.

- **KPN/Actility compliant**

  any LinkADRReq will be accepted, but the data rate and tx power parameters will not be processed, therefore they are not modified. The channel mask and redundancy parameters will be interpreted and accordingly modified.

Note that only the *LoRaWAN v1.0.2 compliant* option is conform to the LoRaWAN specification v1.0.2.

2.2.5 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.

2.3 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).

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

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

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*
- Application EUI
- Application Key

The end-device uses the frequencies defined by the corresponding radio band (see corresponding regional HCI specification, e.g. [4], for radio band configuration) to broadcast the JoinReq message. Note that these transmissions follow 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. The first transmission happens with DR5. 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 already stored radio stack configuration (e.g. data rate, tx power) will be used. Note that in case a data rate, which remains invalid in the default channel configuration, is selected, the next lower available data rate will be used (e.g. SF7BW125 instead of FSK or SF7BW250, in EU686 MHz band).

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 to retransmit the unconfirmed data frames 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.

The end-device uses the retransmission procedure recommended in the LoRaWAN specification. In the absence of the acknowledgement the end-device will try to retransmit the same data again, with a maximum number of retries. The frame will be retransmitted on a new randomly selected frequency channel. Each data rate will be used twice and will be lowered after that till DR0 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 transmit an acknowledgement using an empty data message immediately after the reception of a data message requiring a confirmation. A new transmission is not allowed before it either has received a downlink message or the second receive window is expired (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 immediately after the reception of a data message with the frame pending bit set to 1. A new transmission is not allowed before the reception of a data message with a frame pending bit set to 0 (see 3.6). The maximum number of empty frames to be sent is limited to 2.

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.

2.3.3.2 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).

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
- 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. Note: if this feature is disabled the LinkADRReq will be handled as described in 2.2.4.
- 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
- 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.

Some of these parameters, like the uplink data rate and the transmitted power level, are only used for unreliable and confirmed data messages (not join message). These values are used in the next uplink 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 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.

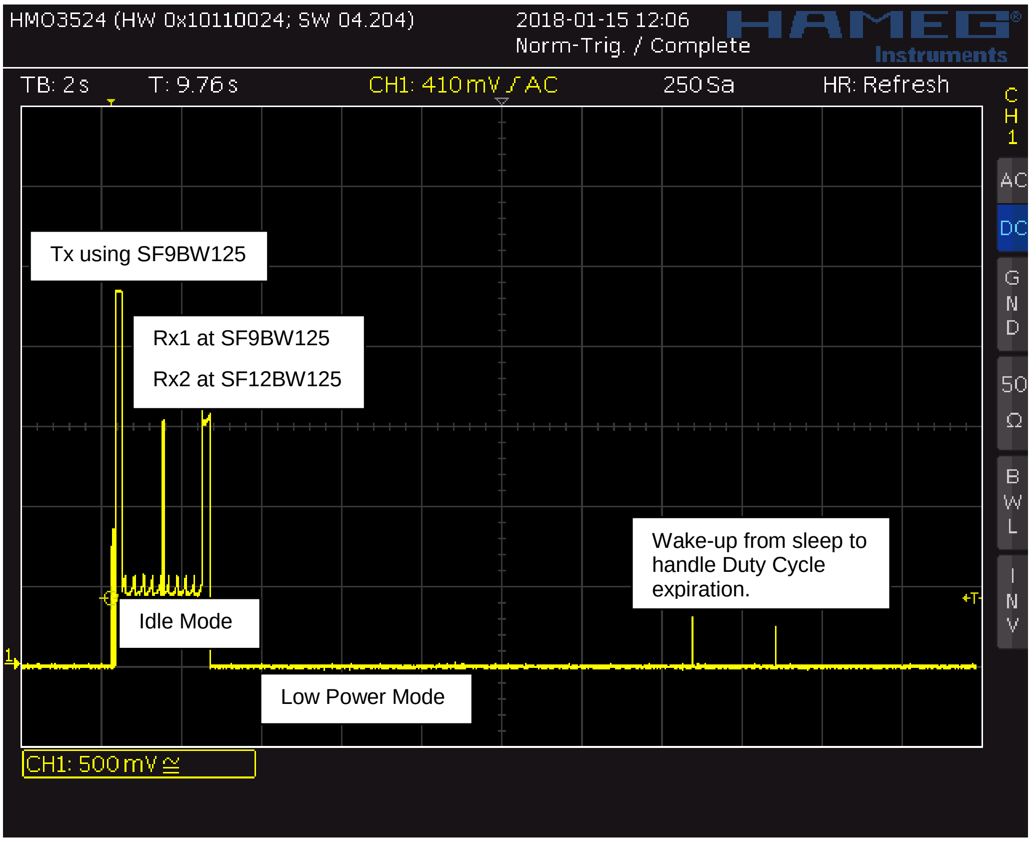

Fig. 2-1: Exemplary current consumption diagram - iM880B-L

2.3.4.2 Class C[1] Implementation

The end-device follows the Class C implementation as defined by the LoRaWAN specification. Additionally, following interpretations are considered by the current implementation:

- If any downlink is correctly processed before the receive windows (as defined by class A) are opened, the receive windows will not be opened. In this case, the end-device could send immediately an uplink if this is required (e.g. ACK to be sent after confirmed downlink).
- 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.

[1] Within the LoRaWAN specification V1.0.2 Class C is described very rudimentary. Also Class C implementation is currently not covered by the LoRaWAN certification program.

3. Sequence Charts

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

3.1 Join Procedure

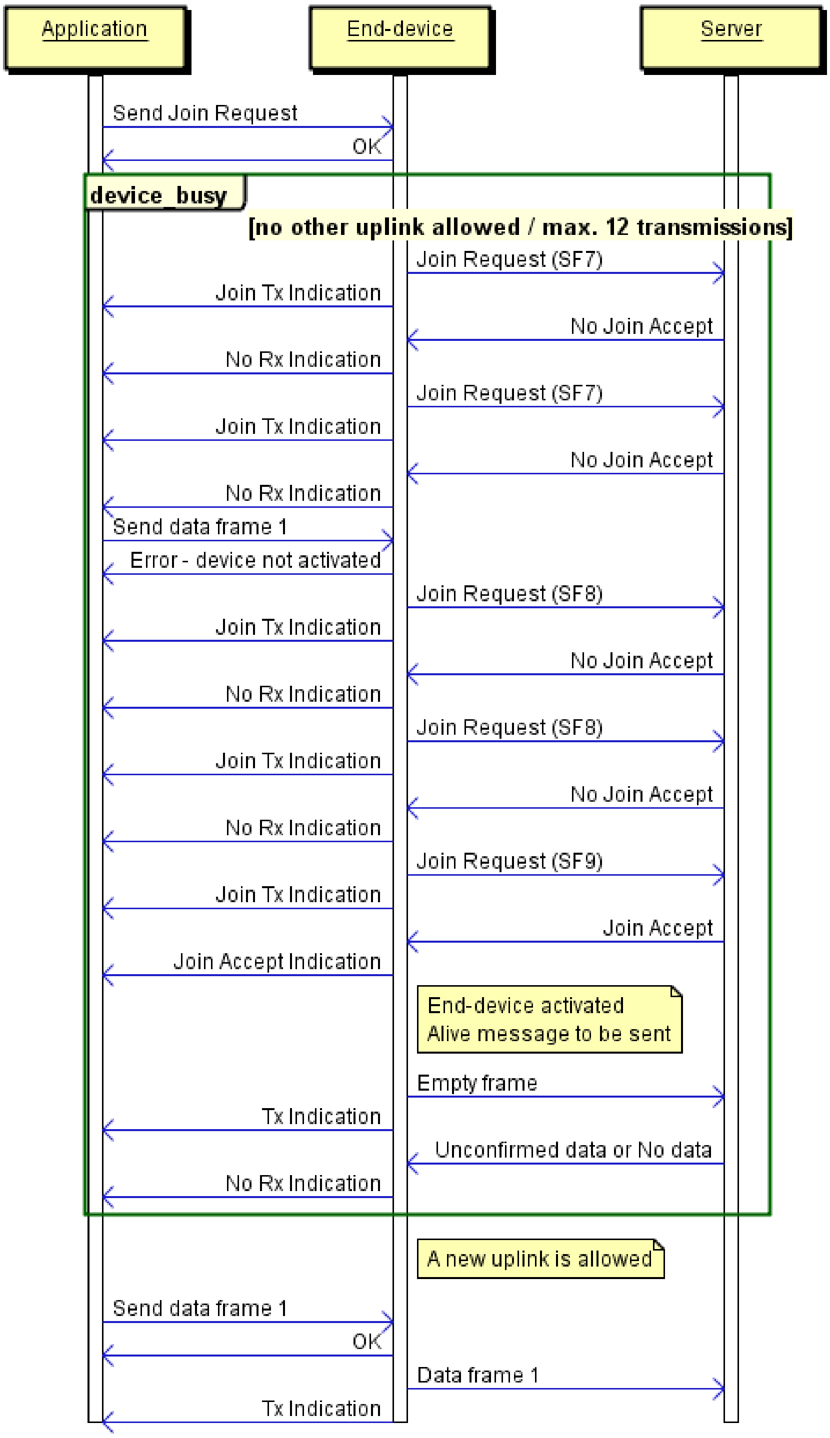

Fig. 3-1: Sequence chart - Join procedure

3.2 Unconfirmed Data Retransmission

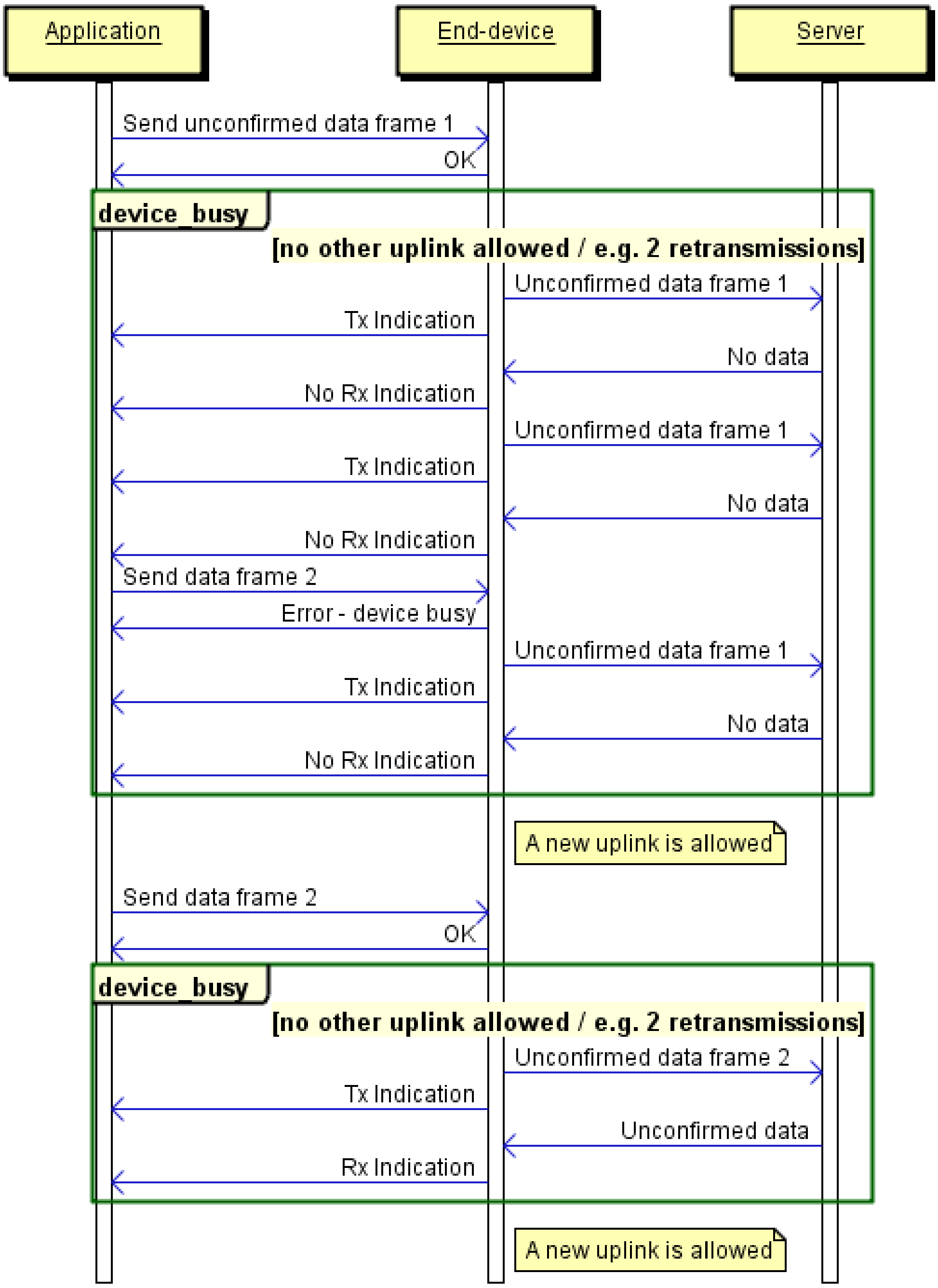

Fig. 3-2: Sequence chart - Unconfirmed data retransmission

3.3 Confirmed Data Retransmission

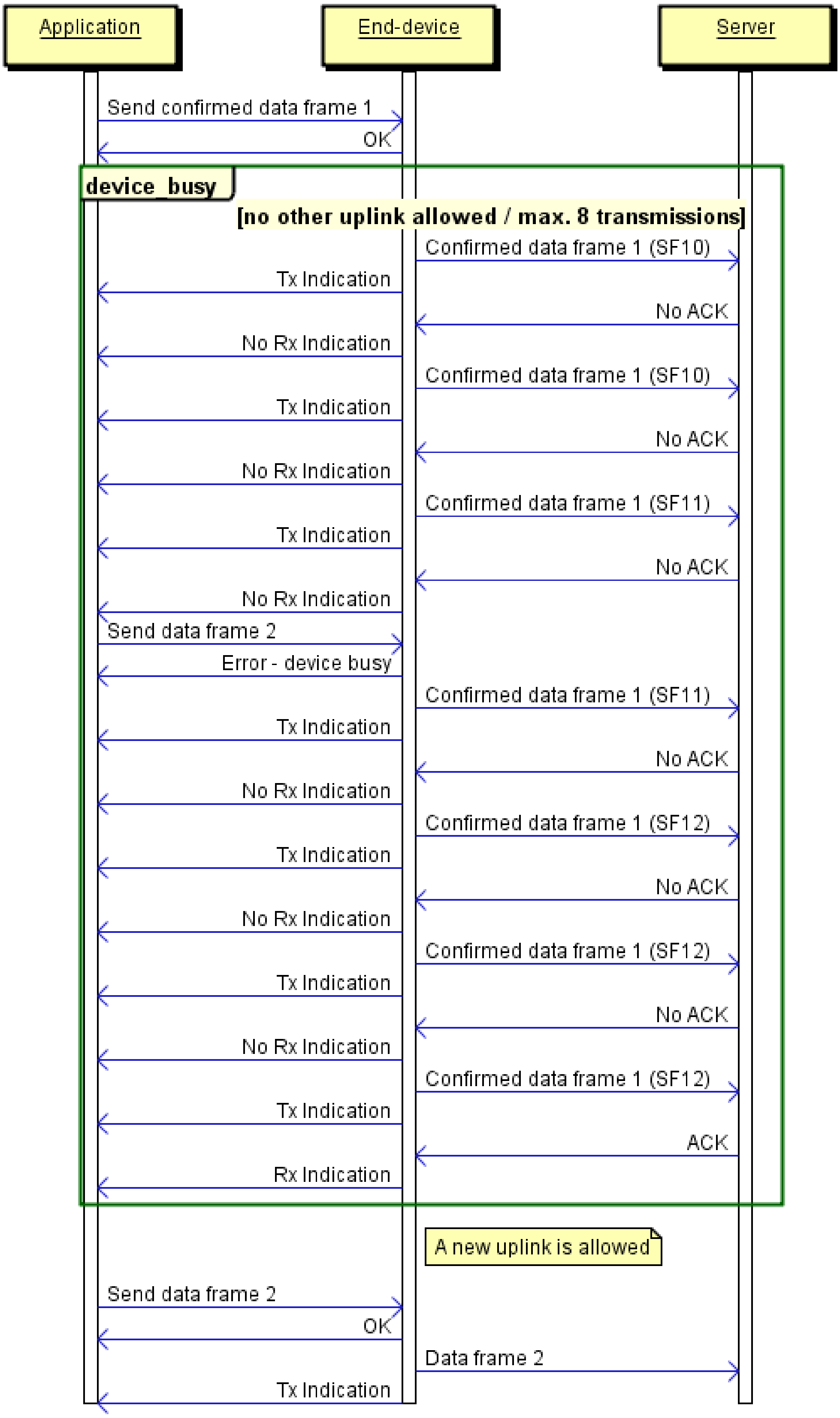

Fig. 3-3: Sequence chart - Retransmission procedure

3.4 Duty Cycle

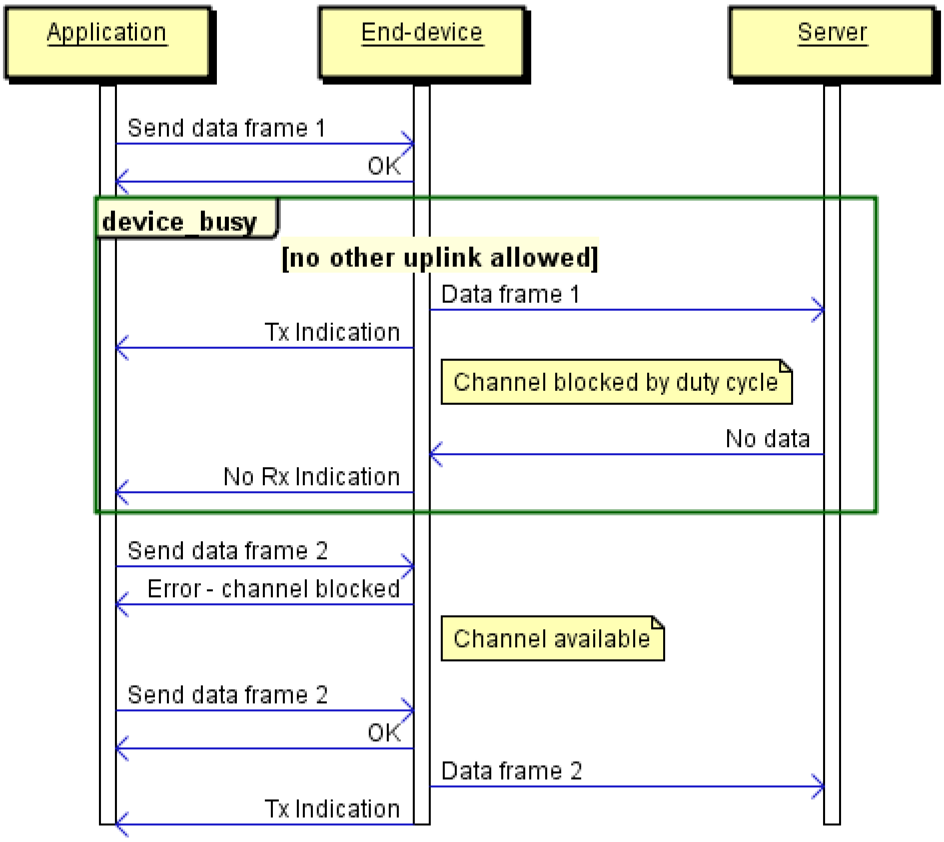

Fig. 3-4: Sequence chart - Duty Cycle

3.5 Message Acknowledge Procedure

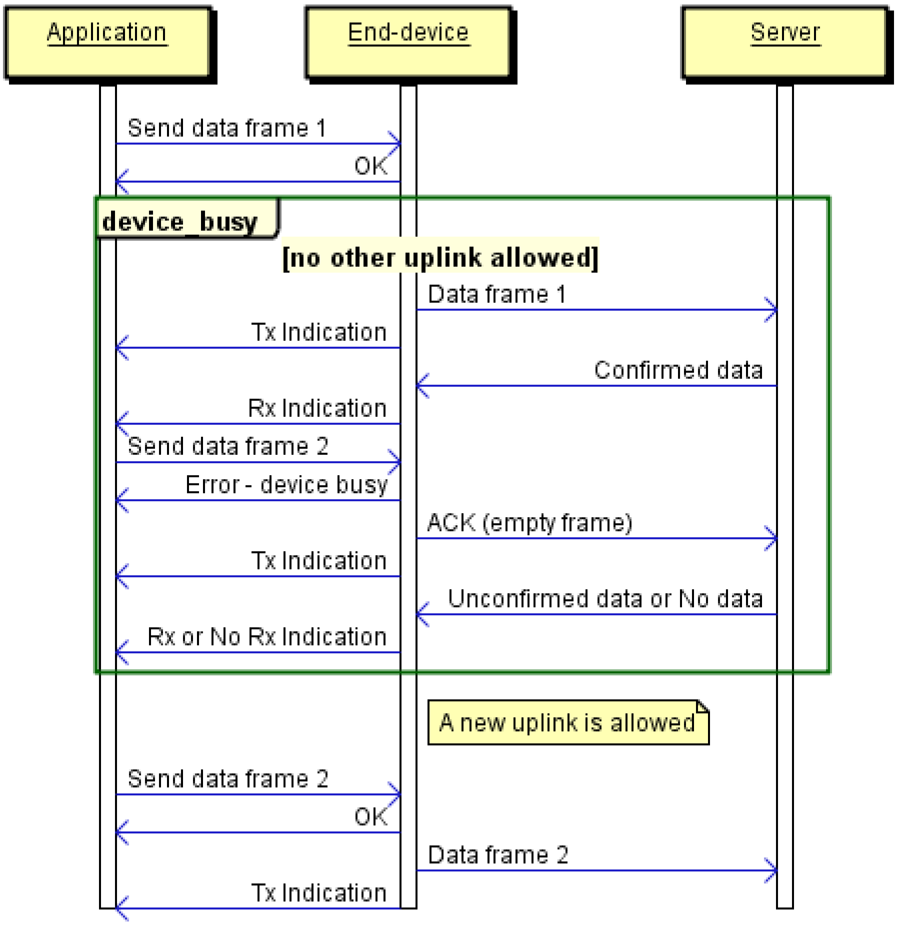

Fig. 3-5: Sequence chart - Acknowledgement procedure

3.6 Frame Pending Bit

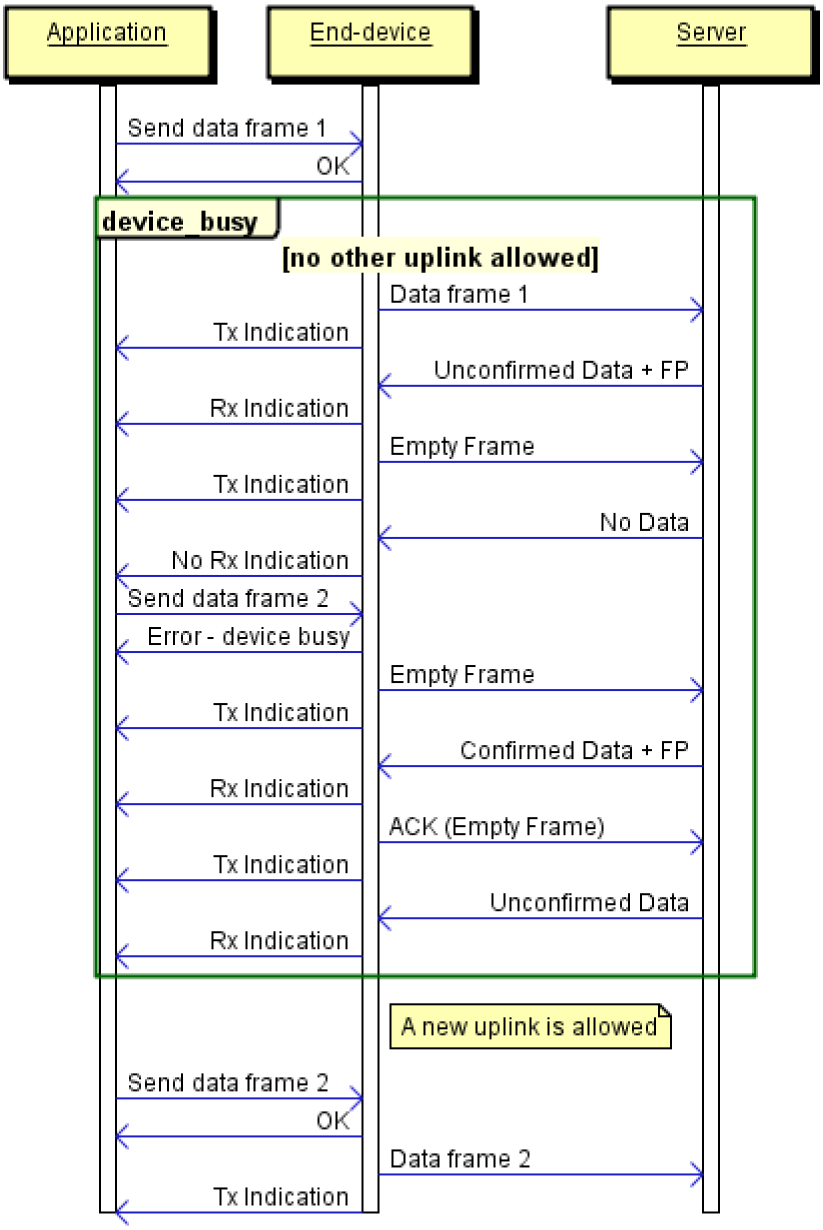

Fig. 3-6: Sequence chart - Frame pending bit

3.7 MAC Commands

3.7.1 MAC Commands – Piggybacked in Header

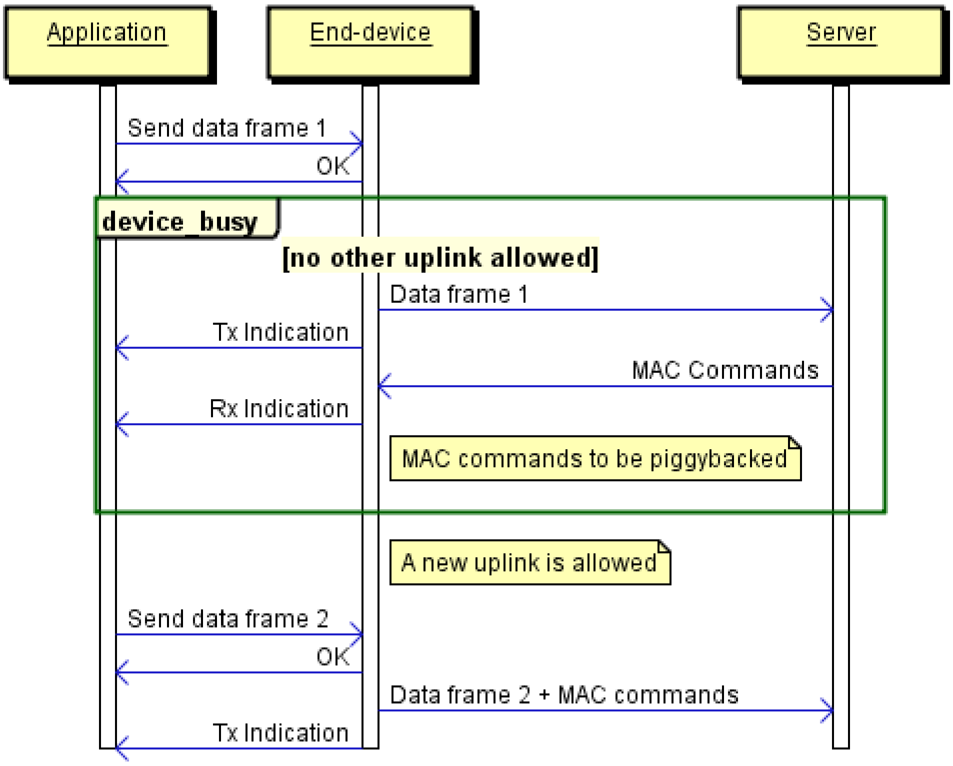

Fig. 3-7: Sequence chart - MAC Commands (piggybacked in header)

3.7.2 MAC Commands – Port 0

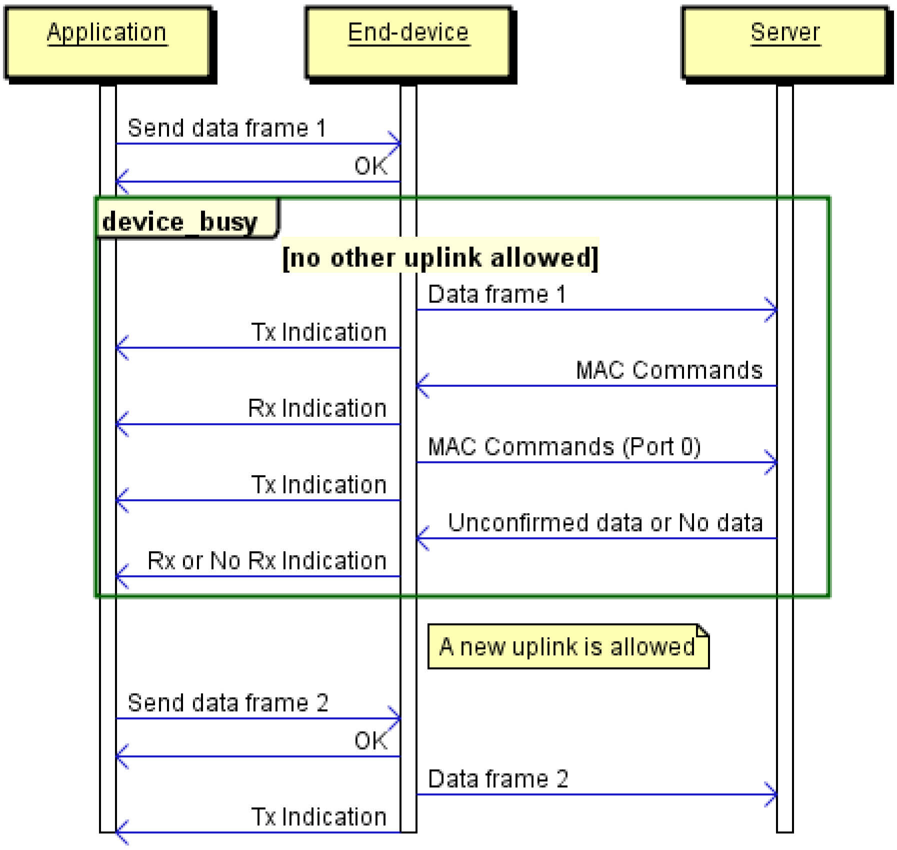

Fig. 3-8: Sequence chart - MAC Commands (using port 0)

4. Known Limitations

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

- No official LoRaWAN certification for class C, V1.0.2
- No multicast messages implemented (Class C)
- FSK mode not supported during continuously listening (Class C)

5. Appendix

5.1 RF Gain Examples

5.1.1 iM880B-L Radio Module configured in EU868 Band

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

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

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.doc

[4] WiMOD_LoRaWAN_EndNode_Modem_EU868_HCI_Spec.pdf

5.4 List of Figures

6. Regulatory Compliance Information

The use of radio frequencies is limited by national regulations. The radio module has been designed to comply with the European Union's R&TTE (Radio & Telecommunications Terminal Equipment) directive 1999/5/EC and can be used free of charge within the European Union. Nevertheless, restrictions in terms of maximum allowed RF power or duty cycle may apply.

The radio module has been designed to be embedded into other products (referred as "final products"). According to the R&TTE directive, the declaration of compliance with essential requirements of the R&TTE directive is within the responsibility of the manufacturer of the final product. A declaration of conformity for the radio module is available from IMST GmbH on request.

The applicable regulation requirements are subject to change. IMST GmbH does not take any responsibility for the correctness and accuracy of the aforementioned information. National laws and regulations, as well as their interpretation can vary with the country. In case of uncertainty, it is recommended to contact either IMST's accredited Test Center or to consult the local authorities of the relevant countries.

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7.2 Contact Information

IMST GmbH

Carl-Friedrich-Gauss-Str. 2-4
47475 Kamp-Lintfort
Germany

T +49 2842 981 0
F +49 2842 981 299
E wimod@imst.de
I www.wireless-solutions.de