LoRaWAN 1.0.3 Regional Parameters

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LoRaWAN™ 1.0.3 Regional Parameters

This document is a companion document to the LoRaWAN 1.0.3 protocol specification

Authors:
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Revision: A
Date: 2018 January
Status: Released

The authors reserve the right to change specifications without notice.

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1 Introduction

This document describes the LoRaWAN™ regional parameters for different regulatory regions worldwide. This document is a companion document to the LoRaWAN 1.0.3 protocol specification [LORAWAN]. Separating the regional parameters from the protocol specification allows addition of new regions to the former without impacting the latter document.

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1.1 Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", “MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

1.2 Quick cross reference table

In order to support the identification of LoRaWAN channel plans for a given country, the table below provides a quick reference of suggested channel plans listed in priority order for each country.

The authors reserve the right to change specifications without notice.

Country name	Band / channels	Channel Plan
Afghanistan		None
Albania	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Algeria	433.05 - 434.79 MHz	EU433
	870-876MHz	Other
	880-885MHz	Other
	915 - 921 MHz	Other
	925 - 926 MHz	Other
Andorra	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Armenia	863 - 870 MHz	EU863-870
	433.05 - 434.79 MHz	EU433
Argentina	902 - 928 MHz (915-928 MHz usable)	AU915-928, US902-928
Austria	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Australia	915 - 928 MHz	AU915-928, AS923
Azerbaijan	433.05 - 434.79 MHz	EU433
	863 - 868 MHz	Others
Bahrain	862 - 870MHz	EU863-870
Bangladesh	433.05 - 434.79 MHz	EU433
	818 - 824 MHz	Other
	863 - 869 MHz	EU863-870
	925.0 - 927.0 MHz	Other
Belarus	433.05 - 434.79 MHz	EU433
	864.4 - 868.6 MHz	EU863-870
	869-869.2MHz	EU863-870
Belgium	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Burma (Myanmar)	433 - 435 MHz	EU433
	866 - 869MHz	EU863-870
	919 - 923 MHz	Other
Bolivia	915 - 930 MHz	AU915-928, AS923
Bosnia and Herzegovina	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Botswana		None
Brazil	902 - 907.5 MHz	Other
	915 - 928 MHz	AU915-928
	433 - 435 MHz	EU433
Brunei Darussalam	866 - 870 MHz	EU863-870
	920 - 925 MHz	AS923

	433 - 435 MHz	EU433
Bulgaria	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Cambodia	866 - 869 MHz	EU863-870
	923 - 925 MHz	AS923
Cameroon		None
Canada	902 - 928 MHz	US902-928, AU915-928
Chile	902 - 928 MHz (915-928MHz usable)	AU915-928, AS923, US902-928
China	920.5 - 924.5 MHz	AS923
	779 - 787 MHz	CN779-787
	470 - 510 MHz	CN470-510
	433.05 - 434.79 MHz	EU433
	314-316 MHz	Other
	430 - 432 MHz	Other
	840 - 845 MHz	Other
Colombia	902 - 928 MHz	AU915-928, US902-928
Congo Rep.		None
Costa Rica	920.5 - 928 MHz	AS923
Croatia	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Cuba	433.05 - 434.79 MHz	EU433
	915 - 921 MHz	Other
Cyprus	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Czech Republic	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Denmark	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Dominican Republic	915 - 928 MHz	AU915-928
Ecuador	902 - 928 MHz	AU915-928, US902-928, AS923
Egypt	433.05 - 434.79 MHz	EU433
	863 - 876 MHz	EU863-870
Estonia	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Finland	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
France	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Georgia		None
Germany	433.05 - 434.79 MHz	EU433

	863 - 870 MHz	EU863-870
Ghana		None
Greece	433.05 - 434.79 MHz	EU433
	868 - 870 MHz	EU863-870
Guatemala	902 - 928 MHz (915-928 MHz usable)	AU915-928, AS923, US902-928
Haiti		None
Honduras	915-928 MHz	AU915-928
Hong Kong	433.05 - 434.79 MHz	EU433
	865 - 868 MHz	Other
	920 - 925 MHz	AS923
Hungary	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Iceland	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
India	865 - 867 MHz	IN765-867
Indonesia	923 - 925 MHz	AS923
Iraq		None
Iran	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	915 - 918 MHz	Other
Ireland	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Israel	433.05 - 434.79 MHz	EU433
	915 - 917 MHz	Other
Italy	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Ivory Coast		None
Jamaica	902 - 928 MHz (915-928 MHz usable)	AU915-928, US902-928
Japan	920.6 - 928.0 MHz (steps of 200kHz)	AS923
	920.8 - 927.8 MHz (steps of 600kHz)	AS923
Jordan	865 - 868 MHz	Other
Kazakhstan	433.05 - 434.79 MHz	EU433
Kenya		None
Korea (DPR)		None
Kuwait	433.05 - 434.79 MHz	EU433
Kyrgyz Republic		None
Laos	433 - 435 MHz	EU433
	862 - 875 MHz	EU863-870
	923 - 925 MHz	AS923
Latvia	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870

Lebanon	433 - 435 MHz	EU433
	862 - 870 MHz	EU863-870
Liechtenstein	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
Libya		None
Lithuania	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Luxembourg	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Macao		None
Macedonia, FYR	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Malaysia	433 - 435 MHz	EU433
	919 – 924 MHz	AS923
Maldives		None
Malta	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Mauritius		None
Mexico	902 - 928 MHz	US902-928, AU915-928
Moldova	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Mongolia		None
Montenegro	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Morocco	433.05 - 434.79 MHz	EU433
	867.6 - 869 MHz	EU863-870
Netherlands	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
New-Zealand	915 - 928 MHz	AS923, AU915-928
	819 - 824 MHz	Other
	864 - 870MHz	EU863-870
	433.05 - 434.79 MHz	EU433
Nicaragua	902 - 928 MHz (915-928 MHz usable)	AU915-928, US902-928
Nigeria	863 - 870 MHz	EU863-870
Norway	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Oman	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Pakistan	433.05 - 434.79 MHz	EU433
	865 - 869 MHz	EU863-870
	900 - 925 MHz	AS923

Panama	902 - 928 MHz	AU915-928, US902-928, AS923
Paraguay	433.05 - 434.79 MHz	EU433
	915 - 928 MHz	AU915-928, AS923
Peru	915 - 928 MHz	AU915-928, AS923
Papua New Guinea	915 - 925 MHz	AU915-928
Philippines	915 - 918 MHz	Other
	868 – 869.2 MHz	EU863-870
	869.7 - 870 MHz	EU863-870
	433.05 - 434.79 MHz	EU433
Poland	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Portugal	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Qatar	433.05 - 434.79 MHz	EU433
	868 - 868.6 MHz	EU863-870
	868.7 - 869.2 MHz	EU863-870
	869.4 - 869.65 MHz	EU863-870
	869.7 - 870 MHz	EU863-870
Romania	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Russian federation	866 - 868 MHz (Licensed)	RU864-870
	864 - 865 MHz	RU864-870
	868.7 - 869.2 MHz	RU864-870
	433.075 - 434.75 MHz	EU433
	916 - 921 MHz (Licensed)	Other
Salvador	915-928	AU915-928, AS923
Saudi Arabia	863 - 870 MHz	EU863-870
	433.05 - 434.79 MHz	EU433
Senegal		None
Serbia	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Singapore	920 - 925 MHz	AS923
	433.05 - 434.79 MHz	EU433
	866 - 869 MHz	EU863-870
Slovak Republic	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
Slovenia	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
South Africa	433.05 - 434.79 MHz	EU433
	865 – 868.6 MHz	EU863-870

	868.7 – 869.2 MHz	EU863-870
	869.4 – 869.65 MHz	EU863-870
	869.7 – 870 MHz	EU863-870
	915 - 921 MHz	Other
South Korea	917 - 923.5 MHz	KR920-923
Spain	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Sri Lanka	433.05 - 434.79 MHz	EU433
Sudan		None
Sweden	433.05 - 434.79 MHz	EU433
	868 - 870 MHz	EU863-870
Switzerland	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
Syrian Arab Rep.		None
Taiwan	920 - 925 MHz	AS923
Tajikistan		None
Tanzania		None
Thailand	433.05 - 434.79 MHz	EU433
	920 - 925 MHz	AS923
Trinidad and Tobago		None
Tunisia	433.05 - 434.79 MHz	EU433
	868 – 868.6 MHz	EU863-870
	868.7 – 869.2 MHz	EU863-870
	869.4 – 869.65 MHz	EU863-870
	869.7 – 870 MHz	EU863-870
Turkey	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
Turkmenistan		None
Uganda	433.05 - 434.79 MHz	EU433
	865 - 867.6 MHz	Other
	869.25 - 869.7 MHz	Other
	923 - 925 MHz	AS923
Ukraine	433.05 - 434.79 MHz	EU433
	863 - 865 MHz	EU863-870
	868 - 868.6 MHz	EU863-870
United Arab Emirates	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
	870 - 875.8 MHz	Other
	915 - 921 MHz	Other
United Kingdom	433.05 - 434.79 MHz	EU433
	863 - 873 MHz	EU863-870
	918 - 921 MHz	Other
United States	902 - 928 MHz	US902-928, AU915-928

Uruguay	902 - 928 MHz (915 - 928 MHz usable)	AU915-928, AS923, US902-928
Uzbekistan	433.05 - 434.79 MHz	EU433
Venezuela	922 - 928 MHz	AS923
Vietnam	433.05 - 434.79 MHz	EU433
	863 - 870 MHz	EU863-870
	918 - 923 MHz	Other
Yemen, Rep.		None
Zimbabwe		None

293 **Table 1: Channel Plan per Country**

The authors reserve the right to change specifications without notice.

2 LoRaWAN Regional Parameters

2.1 Regional Parameter Common Names

In order to support the identification of LoRaWAN channel plans referenced by other specification documents, the table below provides a quick reference of common channel plans listed for each formal plan name.

Channel Plan	Common Name
EU863-870	EU868
US902-928	US915
CN779-787	CN779
EU433	EU433
AU915-928	AU915
CN470-510	CN470
AS923	AS923
KR920-923	KR920
IN865-867	IN865
RU864-870	RU864

2.2 EU863-870MHz ISM Band

2.2.1 EU863-870 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 2: EU863-870 synch words

2.2.2 EU863-870 ISM Band channel frequencies

This section applies to any region where the ISM radio spectrum use is defined by the ETSI [EN300.220] standard.

The network channels can be freely attributed by the network operator. However the three following default channels MUST be implemented in every EU868MHz end-device. Those channels are the minimum set that all network gateways SHOULD always be listening on.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	868.10 868.30 868.50	DR0 to DR5 / 0.3-5 kbps	3	<1%

Table 3: EU863-870 default channels

In order to access the physical medium the ETSI regulations impose some restrictions such maximum time the transmitter can be on or the maximum time a transmitter can transmit per

hour. The ETSI regulations allow the choice of using either a duty-cycle limitation or a so-called **Listen Before Talk Adaptive Frequency Agility** (LBT AFA) transmissions management. The current LoRaWAN specification exclusively uses duty-cycled limited transmissions to comply with the ETSI regulations.

EU868MHz end-devices SHALL be capable of operating in the 863 to 870 MHz frequency band and SHALL feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The first three channels correspond to 868.1, 868.3, and 868.5 MHz / DR0 to DR5 and MUST be implemented in every end-device. Those default channels cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and network gateways.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message. The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter "Retransmissions back-off" of the LoRaWAN specification document.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	868.10 868.30 868.50	DR0 – DR5 / 0.3-5 kbps	3

Table 4: EU863-870 JoinReq Channel List

2.2.3 EU863-870 Data Rate and End-device Output Power encoding

There is no dwell time limitation for the EU863-870 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented in EU863-870 devices.

The following encoding is used for Data Rate (DR) and End-device EIRP (TXPower) in the EU863-870 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

Table 5: EU863-870 TX Data rate table

EIRP[1] refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8..15	RFU

Table 6: EU863-870 TX power table

By default MaxEIRP is considered to be +16dBm. If the end-device cannot achieve 16dBm EIRP, the Max EIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.

2.2.4 EU863-870 JoinAccept CFList

The EU 863-870 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of 16 octets in the JoinAccept message.

In this case the CFList is a list of five channel frequencies for the channels three to seven whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125kHz LoRa modulation. The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	Freq Ch7	CFListType

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have a frequency value of 0. The **CFList** is optional and its presence can be detected by the length of the join-accept message. If present, the **CFList** SHALL replace all the previous channels stored in the end-device apart from the three default channels. The newly defined channels are immediately enabled and usable by the end-device for communication.

2.2.5 EU863-870 LinkAdrReq command

The EU863-870 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

[1] *ERP = EIRP – 2.15dB; it is referenced to a half-wave dipole antenna whose gain is expressed in dBd*

The authors reserve the right to change specifications without notice.

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHALL enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 7: EU863-870 ChMaskCntl value table

If the ChMaskCntl field value is one of values meaning RFU, the end-device SHALL reject the command and unset the "**Channel mask ACK**" bit in its response.

2.2.6 EU863-870 Maximum payload size

The maximum **MACPayload** size length (*M)* is given by the following table. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of N MAY be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6	230	222
7	230	222
8:15	Not defined	

Table 8: EU863-870 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6	250	242
7	250	242
8:15	Not defined	

Table 9 : EU863-870 maximum payload size (not repeater compatible)

2.2.7 EU863-870 Receive windows

The RX1 receive window uses the same channel as the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The

allowed values for RX1DROffset are in the [0:5] range. Values in the [6:7] range are reserved for future use.

RX1DROffset Upstream data rate	0	1	2	3	4	5
	Downstream data rate in RX1 slot					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0
DR6	DR6	DR5	DR4	DR3	DR2	DR1
DR7	DR7	DR6	DR5	DR4	DR3	DR2

Table 10: EU863-870 downlink RX1 data rate mapping

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 869.525 MHz / DR0 (SF12, 125 kHz)

2.2.8 EU863-870 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 11: EU863-870 beacon settings

The beacon frame content is:

Size (bytes)	**2**	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 869.525MHz.

The Class B default downlink pingSlot frequency is 869.525MHz

2.2.9 EU863-870 Default Settings

The following parameters are recommended values for the EU863-870MHz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 and RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

The authors reserve the right to change specifications without notice.

2.3 US902-928MHz ISM Band

This section defines the regional parameters for the USA, Canada and all other countries adopting the entire FCC-Part15 regulations in 902-928 ISM band.

2.3.1 US902-928 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols

LoRaWAN does not make use of GFSK modulation in the US902-928 ISM band.

2.3.2 US902-928 Channel Frequencies

The 915 MHz ISM Band SHALL be divided into the following channel plans.

- Upstream – 64 channels numbered 0 to 63 utilizing LoRa 125 kHz BW varying from DR0 to DR3, using coding rate 4/5, starting at 902.3 MHz and incrementing linearly by 200 kHz to 914.9 MHz
- Upstream – 8 channels numbered 64 to 71 utilizing LoRa 500 kHz BW at DR4 starting at 903.0 MHz and incrementing linearly by 1.6 MHz to 914.2 MHz
- Downstream – 8 channels numbered 0 to 7 utilizing LoRa 500 kHz BW at DR8 to DR13, starting at 923.3 MHz and incrementing linearly by 600 kHz to 927.5 MHz

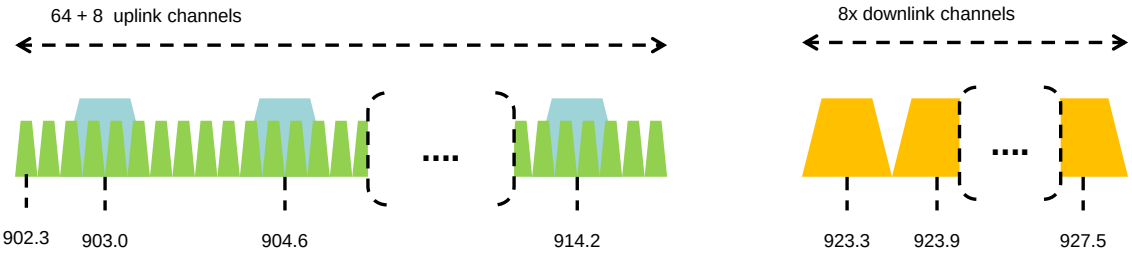

Figure 1: US902-928 channel frequencies

915 MHz ISM band end-devices are required to operate in compliance with the relevant regulatory specifications, the following note summarizes some of the current (March 2017) relevant regulations.

> Frequency-Hopping, Spread-Spectrum (FHSS) mode, which requires the device transmit at a measured conducted power level no greater than +30 dBm, for a period of no more than 400 msec and over at least 50 channels, each of which occupy no greater than 250 kHz of bandwidth.
>
> Digital Transmission System (DTS) mode, which requires that the device use channels greater than or equal to 500 kHz and comply with a conducted Power Spectral Density measurement of no more than +8 dBm per 3 kHz of spectrum. In practice, this limits the conducted output power of an end-device to +26 dBm.
>
> Hybrid mode, which requires that the device transmit over multiple channels (this may be less than the 50 channels required for FHSS mode, but is recommended to be at least 4) while complying with the Power Spectral Density requirements of DTS mode and the 400 msec

dwell time of FHSS mode. In practice this limits the measured conducted power of the end-device to 21 dBm.

Devices which use an antenna system with a directional gain greater than +6 dBi, but reduce the specified conducted output power by the amount in dB of directional gain over +6 dBi.

US902-928 end-devices MUST be capable of operating in the 902 to 928 MHz frequency band and MUST feature a channel data structure to store the parameters for 72 channels. This channel data structure contains a list of frequencies and the set of data rates available for each frequency.

If using the over-the-air activation procedure, the end-device SHALL transmit the Join-request message on random 125 kHz channels amongst the 64 125kHz channels defined using **DR0** and on 500 kHz channels amongst the 8 500kHz channels defined using **DR4**. The end-device SHALL change channels for every transmission.

For rapid network acquisition in mixed gateway channel plan environments, the device SHOULD follow a random channel selection sequence which efficiently probes the octet groups of eight 125 kHz channels followed by probing one 500 kHz channel each pass. Each consecutive pass SHOULD NOT select a channel that was used in a previous pass, until a Join-request is transmitted on every channel, after which the entire process can restart.

Example: First pass: Random channel from [0-7], followed by [8-15]… [56-63], then 64
Second pass: Random channel from [0-7], followed by [8-15]… [56-63], then 65
Last pass: Random channel from [0-7], followed by [8-15]… [56-63], then 71

Personalized devices SHALL have all 72 channels enabled following a reset and shall use the channels for which the device's default data-rate is valid.

2.3.3 US902-928 Data Rate and End-device Output Power encoding

FCC regulation imposes a maximum dwell time of 400ms on uplinks. The ***TxParamSetupReq*** MAC command MUST not be implemented by US902-928 devices.

The following encoding is used for Data Rate (**DR**) and End-device conducted Power (**TXPower**) in the US902-928 band:

DataRate	Configuration	Indicative physical bit rate [bit/sec]
0	LoRa: SF10 / 125 kHz	980
1	LoRa: SF9 / 125 kHz	1760
2	LoRa: SF8 / 125 kHz	3125
3	LoRa: SF7 / 125 kHz	5470
4	LoRa: SF8 / 500 kHz	12500
5:7	RFU	
8	LoRa: SF12 / 500 kHz	980
9	LoRa: SF11 / 500 kHz	1760
10	LoRa: SF10 / 500 kHz	3900
11	LoRa: SF9 / 500 kHz	7000
12	LoRa: SF8 / 500 kHz	12500
13	LoRa: SF7 / 500 kHz	21900

The authors reserve the right to change specifications without notice.

14..15	RFU	

Table 12: US902-928 TX Data rate table

Note: DR4 is purposely identical to DR12, DR8..13 MUST be implemented in end-devices and are reserved for future applications

TXPower	Configuration (conducted power)
0	30 dBm – 2*TXpower
1	28 dBm
2	26 dBm
3..15	….

Table 13: US902-928 TX power table

2.3.4 US902-928 JoinAccept CFList

The US902-928 LoRaWAN supports the use of the optional **CFlist** appended to the JoinResp message. If the **CFlist** is not empty then the **CFListType** field SHALL contain the value one (0x01) to indicate the **CFList** contains a series of ChMask fields. The ChMask fields are interpreted as being controlled by a virtual ChMaskCntl that initializes to a value of zero (0) and increments for each ChMask field to a value of four (4). (The first 16 bits controls the channels 0 to 15, ..)

Size (bytes)	[2]	[2]	[2]	[2]	[2]	[2]	[3]	[1]
CFList	***ChMask0***	***ChMask1***	***ChMask2***	***ChMask3***	***ChMask4***	***RFU***	***RFU***	***CFListType***

2.3.5 US902-928 LinkAdrReq command

For the US902-928 version the **ChMaskCntl** field of the ***LinkADRReq*** command has the following meaning:

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	Channels 16 to 31
..	..
4	Channels 64 to 71
5	8LSBs controls Channel Blocks 0 to 7 8MSBs are RFU
6	All 125 kHz ON ChMask applies to channels 64 to 71
7	All 125 kHz OFF ChMask applies to channels 64 to 71

Table 14: US902-928 ChMaskCntl value table

If **ChMaskCntl** = 5 then the corresponding bits in the ChMask enable and disable a bank of 8 125kHz channels and the corresponding 500kHz channel defined by the following calculation: [ChannelMaskBit * 8, ChannelMaskBit * 8 +7],64+ChannelMaskBit.

If **ChMaskCntl** = 6 then 125 kHz channels are enabled, if **ChMaskCntl** = 7 then 125 kHz channels are disabled. Simultaneously the channels 64 to 71 are set according to the **ChMask** bit mask. The DataRate specified in the command need not be valid for channels specified in the ChMask, as it governs the global operational state of the end-device.

> **Note:** FCC regulation requires hopping over at least 50 channels when using maximum output power. It is possible to have end-devices with less channels when limiting the end-device conducted transmit power to 21 dBm.
>
> **Note:** A common network server action may be to reconfigure a device through multiple LinkAdrReq commands in a contiguous block of MAC Commands. For example to reconfigure a device from 64 channel operation to the first 8 channels could contain two LinkAdrReq, the first (ChMaskCntl = 7) to disable all 125kHz channels and the second (ChMaskCntrl = 0) to enable a bank of 8 125kHz channels.

2.3.6 US902-928 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table. It is derived from the maximum allowed transmission time at the PHY layer taking into account a possible repeater encapsulation. The maximum application payload length in the absence of the optional **FOpt** MAC control field (*N*) is also given for information only. The value of *N* MAY be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	19	11
1	61	53
2	133	125
3	250	242
4	250	242
5:7	Not defined	
8	41	33
9	117	109
10	230	222
11	230	222
12	230	222
13	230	222
14:15	Not defined	

Table 15: US902-928 maximum payload size (repeater compatible)

The greyed lines correspond to the data rates that may be used by an end-device behind a repeater.

If the end-device will never operate under a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	*M*	*N*
0	19	11
1	61	53

2	133	125
3	250	242
4	250	242
5:7	Not defined	
8	61	53
9	137	129
10	250	242
11	250	242
12	250	242
13	250	242
14:15	Not defined	

552 Table 16 : US902-928 maximum payload size (not repeater compatible)

553 ### 2.3.7 US902-928 Receive windows

554 • The RX1 receive channel is a function of the upstream channel used to initiate the
555 data exchange. The RX1 receive channel can be determined as follows.
556 ○ RX1 Channel Number = Transmit Channel Number modulo 8
557 • The RX1 window data rate depends on the transmit data rate (see Table 17 below).
558 • The RX2 (second receive window) settings uses a fixed data rate and frequency.
559 Default parameters are 923.3MHz / DR8
560

Upstream data rate	**Downstream data rate**			
RX1DROffset	**0**	**1**	**2**	**3**
DR0	DR10	DR9	DR8	DR8
DR1	DR11	DR10	DR9	DR8
DR2	DR12	DR11	DR10	DR9
DR3	DR13	DR12	DR11	DR10
DR4	DR13	DR13	DR12	DR11

561 Table 17: US902-928 downlink RX1 data rate mapping

562 The allowed values for RX1DROffset are in the [0:3] range. Values in the range [4:7] are
563 reserved for future use.

564 ### 2.3.8 US902-928 Class B beacon

565 The beacons SHALL BE transmitted using the following settings:

DR	8	Corresponds to SF12 spreading factor with 500kHz bw
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity
frequencies	923.3 to 927.5MHz with 600kHz steps	Beaconing is performed on the same channel that normal downstream traffic as defined in the Class A specification

566 Table 18: US902-928 beacon settings

567 The downstream channel used for a given beacon is:

568 $$\text{Channel} = \left[floor\left(\frac{beacon\_time}{beacon\_period}\right)\right] \; modulo\; 8$$

569 • whereby beacon_time is the integer value of the 4 bytes “Time” field of the beacon
570 frame
571 • whereby beacon_period is the periodicity of beacons , 128 seconds
572 • whereby *floor(x)* designates rounding to the integer immediately inferior or equal to x
573

Example: the first beacon will be transmitted on 923.3Mhz , the second on 923.9MHz, the 9th beacon will be on 923.3Mhz again.

Beacon channel nb	Frequency [MHz]
0	923.3
1	923.9
2	924.5
3	925.1
4	925.7
5	926.3
6	926.9
7	927.5

The beacon frame content is:

Size (bytes)	**5**	4	2	7	**3**	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	**RFU**	CRC

2.3.9 US902-928 Default Settings

The following parameters are recommended values for the US902-928 band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 & 2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

2.4 CN779-787 MHz ISM Band

2.4.1 CN779-787 Preamble Format

The following synchronization words SHOULD be used :

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 19: CN779-787 synch words

2.4.2 CN779-787 ISM Band channel frequencies

The LoRaWAN can be used in the Chinese 779-787MHz band as long as the radio device EIRP is less than 12.15dBm.

The end-device transmit duty-cycle SHOULD be lower than 1%.

The LoRaWAN channels center frequency MAY be in the following range:

- Minimum frequency : 779.5MHz
- Maximum frequency : 786.5 MHz

CN780MHz end-devices SHALL be capable of operating in the 779 to 787 MHz frequency band and SHALL feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The first three channels correspond to 779.5, 779.7 and 779.9 MHz with DR0 to DR5 and MUST be implemented in every end-device. Those default channels cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and gateways of all networks. Other channels can be freely distributed across the allowed frequency range on a network per network basis.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter “Retransmissions back-off” of the LoRaWAN specification document.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	779.5 779.7 779.9 780.5 780.7 780.9	DR0 – DR5 / 0.3-5 kbps	6	<0.1%

Table 20: CN779-787 JoinReq Channel List

2.4.3 CN779-787 Data Rate and End-device Output Power encoding

There is no dwell time limitation for the CN779-787 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented by CN779-787 devices.

The following encoding is used for Data Rate (DR) and End-device EIRP (TXPower) in the CN780 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6..15	RFU

Table 21: CN779-787 Data rate and TX power table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default MAxEIRP is considered to be +12.15dBm. If the end-device cannot achieve 12.15dBm EIRP, the Max EIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.

2.4.4 CN779-787 JoinAccept CFList

The CN780 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of 16 octets in the JoinAccept message.

In this case the CFList is a list of five channel frequencies for the channels three to seven whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125kHz LoRa modulation. The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	Freq Ch7	CFListTYpe

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have a frequency value of 0. The **CFList** is optional and its presence can be detected by the length of the join-accept message. If present, the **CFList** SHALL replace all the previous channels stored in the end-device apart from the three default channels.

The newly defined channels are immediately enabled and usable by the end-device for communication.

2.4.5 CN779-787 LinkAdrReq command

The CN780 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device should enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 22: CN779-787 ChMaskCntl value table

If the ChMask field value is one of values meaning RFU, then end-device SHALL reject the command and unset the "**Channel mask ACK**" bit in its response.

2.4.6 CN779-787 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of *N* MAY be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6	250	242
7	230	222
8:15	Not defined	

Table 23: CN779-787 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6	250	242
7	250	242
8:15	Not defined	

Table 24 : CN779-787 maximum payload size (not repeater compatible)

2.4.7 CN779-787 Receive windows

The RX1 receive window uses the same channel than the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The allowed values for RX1DROffset are in the [0:5] range. Values in the range [6:7] are reserved for future use

RX1DROffset **Upstream data rate**	**0**	**1**	**2**	**3**	**4**	**5**
	Downstream data rate in RX1 slot					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0
DR6	DR6	DR5	DR4	DR3	DR2	DR1
DR7	DR7	DR6	DR5	DR4	DR3	DR2

Table 25: CN779-787 downlink RX1 data rate mapping

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 786 MHz / DR0.

2.4.8 CN779-787 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 26: CN779-787 beacon settings

The beacon frame content is:

Size (bytes)	**2**	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 785MHz.

The class B default downlink pingSlot frequency is 785MHz

2.4.9 CN779-787 Default Settings

The following parameters are recommended values for the CN779-787MHz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32

707	ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

708 If the actual parameter values implemented in the end-device are different from those default
709 values (for example the end-device uses a longer RECEIVE_DELAY1 and
710 RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network
711 server using an out-of-band channel during the end-device commissioning process. The
712 network server may not accept parameters different from those default values.

The authors reserve the right to change specifications without notice.

2.5 EU433MHz ISM Band

2.5.1 EU433 Preamble Format

The following synchronization words SHOULD be used :

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 27: EU433 synch words

2.5.2 EU433 ISM Band channel frequencies

The LoRaWAN can be used in the ETSI 433-434 MHz band as long as the radio device EIRP is less than 12.15dBm.

The end-device transmit duty-cycle SHALL be lower than 10%[1]

The LoRaWAN channels center frequency can be in the following range:

- Minimum frequency : 433.175 MHz
- Maximum frequency : 434.665 MHz

EU433 end-devices SHALL be capable of operating in the 433.05 to 434.79 MHz frequency band and SHALL feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The first three channels correspond to 433.175, 433.375 and 433.575 MHz with DR0 to DR5 and MUST be implemented in every end-device. Those default channels cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and gateways of all networks. Other channels can be freely distributed across the allowed frequency range on a network per network basis.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message. The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter “Retransmissions back-off” of the LoRaWAN specification document.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	433.175 433.375 433.575	DR0 – DR5 / 0.3-5 kbps	3	<1%

Table 28: EU433 JoinReq Channel List

2.5.3 EU433 Data Rate and End-device Output Power encoding

There is no dwell time limitation for the EU433 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented by EU433 devices.

[1] The EN300220 ETSI standard limits to 10% the maximum transmit duty-cycle in the 433MHz ISM band. The LoRaWAN requires a 1% transmit duty-cycle lower than the legal limit to avoid network congestion.

744 The following encoding is used for Data Rate (DR) and End-device EIRP (TXPower) in the
745 EU433 band:

746

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6..15	RFU

747 **Table 29: EU433 Data rate and TX power table**

748

749 EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output
750 power referenced to an isotropic antenna radiating power equally in all directions and whose
751 gain is expressed in dBi.

752

753 By default MAxEIRP is considered to be +12.15dBm. If the end-device cannot achieve
754 12.15dBm EIRP, the Max EIRP SHALL be communicated to the network server using an
755 out-of-band channel during the end-device commissioning process.
756
757

758 2.5.4 EU433 JoinAccept CFList

759

760 The EU433 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of
761 16 octets in the JoinAccept message.

762 In this case the CFList is a list of five channel frequencies for the channels three to seven
763 whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these
764 channels are usable for DR0 to DR5 125 kHz LoRa modulation. The list of frequencies is
765 followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal
766 to zero (0) to indicate that the CFList contains a list of frequencies.

767

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	Freq Ch7	CFListType

768 The actual channel frequency in Hz is 100 x frequency whereby values representing
769 frequencies below 100 MHz are reserved for future use. This allows setting the frequency of
770 a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have
771 a frequency value of 0. The **CFList** is optional and its presence can be detected by the length
772 of the join-accept message. If present, the **CFList** MUST replace all the previous channels
773 stored in the end-device apart from the three default channels.

774 The newly defined channels are immediately enabled and usable by the end-device for
775 communication.

2.5.5 EU433 LinkAdrReq command

The EU433 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 30: EU433 ChMaskCntl value table

If the ChMask field value is one of the values meaning RFU, then end-device SHALL reject the command and unset the "**Channel mask ACK**" bit in its response.

2.5.6 EU433 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of N might be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6	230	222
7	230	222
8:15	Not defined	

Table 31: EU433 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6	250	242
7	250	242
8:15	Not defined	

Table 32 : EU433 maximum payload size (not repeater compatible)

2.5.7 EU433 Receive windows

The RX1 receive window uses the same channel than the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The allowed values for RX1DROffset are in the [0:5] range. Values in the range [6:7] are reserved for future use.

RX1DROffset	**0**	**1**	**2**	**3**	**4**	**5**
Upstream data rate	**Downstream data rate in RX1 slot**					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0
DR6	DR6	DR5	DR4	DR3	DR2	DR1
DR7	DR7	DR6	DR5	DR4	DR3	DR2

Table 33 : EU433 downlink RX1 data rate mapping

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 434.665MHz / DR0 (SF12, 125kHz).

2.5.8 EU433 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 34 : EU433 beacon settings

The beacon frame content is:

Size (bytes)	**2**	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 434.665MHz.

The class B default downlink pingSlot frequency is 434.665MHz

2.5.9 EU433 Default Settings

The following parameters are recommended values for the EU433band.

RECEIVE_DELAY1 1 s
RECEIVE_DELAY2 2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1 5 s
JOIN_ACCEPT_DELAY2 6 s
MAX_FCNT_GAP 16384

ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 & 2 latency) , those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

The authors reserve the right to change specifications without notice.

2.6 AU915-928MHz ISM Band

This section defines the regional parameters for Australia and all other countries whose ISM band extends from 915 to 928MHz spectrum.

2.6.1 AU915-928 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols

LoRaWAN does not make use of GFSK modulation in the AU915-928 ISM band.

2.6.2 AU915-928 Channel Frequencies

The AU ISM Band SHALL be divided into the following channel plans.

- Upstream – 64 channels numbered 0 to 63 utilizing LoRa 125 kHz BW varying from DR0 to DR5, using coding rate 4/5, starting at 915.2 MHz and incrementing linearly by 200 kHz to 927.8 MHz
- Upstream – 8 channels numbered 64 to 71 utilizing LoRa 500 kHz BW at DR6 starting at 915.9 MHz and incrementing linearly by 1.6 MHz to 927.1 MHz
- Downstream – 8 channels numbered 0 to 7 utilizing LoRa 500 kHz BW at DR8 to DR13) starting at 923.3 MHz and incrementing linearly by 600 kHz to 927.5 MHz

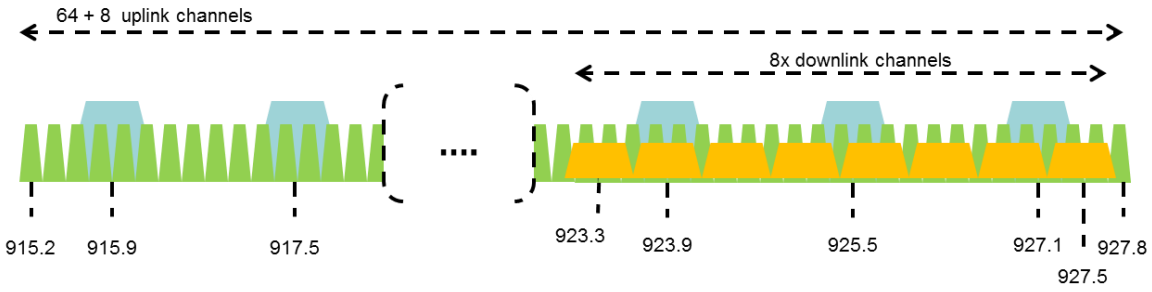

Figure 2: AU915-928 channel frequencies

AU ISM band end-devices may use a maximum EIRP of +30 dBm.

AU915-928 end-devices SHALL be capable of operating in the 915 to 928 MHz frequency band and SHALL feature a channel data structure to store the parameters of 72 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

If using the over-the-air activation procedure, the end-device SHALL broadcast the JoinReq message alternatively on a random 125 kHz channel amongst the 64 channels defined using **DR2** and a random 500 kHz channel amongst the 8 channels defined using **DR6**. The end-device SHOULD change channel for every transmission.

Personalized devices SHALL have all 72 channels enabled following a reset.

> The default JoinReq Data Rate is DR2 (SF10/125KHz), this setting ensures that end-devices are compatible with the 400ms dwell time limitation until the actual dwell time limit is notified to the end-device by the network server via the MAC command ***TxParamSetupReq***.

AU915-928 end-devices MUST consider UplinkDwellTime = 1 during boot stage until reception of the ***TxParamSetupReq*** command.

AU915-928 end-devices MUST always consider DownlinkDwellTime = 0, since downlink channels use 500KHz bandwidth without any dwell time limit.

2.6.3 AU915-928 Data Rate and End-point Output Power encoding

The "TxParamSetupReq/Ans" MAC commands MUST be implemented by AU915-928 devices.

If the field UplinkDwellTime is set to 1 by the network server in the ***TxParamSetupReq*** command, AU915-928 end-devices SHALL adjust the time between two consecutive uplink transmissions to meet the local regulation. Twenty seconds (20s) are recommended between 2 uplink transmissions when UplinkDwellTime = 1 but this value MAY be adjusted depending on local regulation.

There is no such constraint on time between two consecutive transmissions when UplinkDwellTime = 0.

The following encoding is used for Data Rate (**DR**) and End-point EIRP (**TXPower**) in the AU915-928 band:

DataRate	Configuration	Indicative physical bit rate [bit/sec]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF8 / 500 kHz	12500
7	RFU	
8	LoRa: SF12 / 500 kHz	980
9	LoRa: SF11 / 500 kHz	1760
10	LoRa: SF10 / 500 kHz	3900
11	LoRa: SF9 / 500 kHz	7000
12	LoRa: SF8 / 500 kHz	12500
13	LoRa: SF7 / 500 kHz	21900
14..15	RFU	

Table 35: AU915-928 Data rate table

DR6 is identical to DR12, DR8...13 MUST be implemented in end-devices and are reserved for future applications.

TXPower	Configuration (EIRP)
0	Max EIRP
1..15	Max EIRP – 2*TXPower

Table 36 : AU915-928 TX power table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default MaxEIRP is considered to be +30dBm. The Max EIRP can be modified by the network server through the ***TxParamSetupReq*** MAC command and SHOULD be used by both the end-device and the network server once ***TxParamSetupReq*** is acknowledged by the device via ***TxParamSetupAns***.

2.6.4 AU915-928 JoinAccept CFList

The AU915-928 LoRaWAN supports the use of the optional **CFlist** appended to the JoinResp message. If the **CFlist** is not empty then the CFListType field SHALL contain the value one (0x01) to indicate the CFList contains a series of ChMask fields. The ChMask fields are interpreted as being controlled by a virtual ChMaskCntl that initializes to a value of zero (0) and increments for each ChMask field to a value of four(4). (The first 16 bits controls the channels 1 to 16, ..)

Size (bytes)	[2]	[2]	[2]	[2]	[2]	[2]	[3]	[1]
CFList	***ChMask0***	***ChMask1***	***ChMask2***	***ChMask3***	***ChMask4***	***RFU***	***RFU***	***CFListType***

2.6.5 AU915-928 LinkAdrReq command

For the AU915-928 version the **ChMaskCntl** field of the ***LinkADRReq*** command has the following meaning:

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	Channels 16 to 31
..	..
4	Channels 64 to 71
5	8LSBs controls Channel Blocks 0 to 7 8MSBs are RFU
6	All 125 kHz ON ChMask applies to channels 64 to 71
7	All 125 kHz OFF ChMask applies to channels 64 to 71

Table 37: AU915-928 ChMaskCntl value table

If **ChMaskCntl** = 5 then the corresponding bits in the ChMask enable and disable a bank of 8 125kHz channels and the corresponding 500kHz channel defined by the following calculation: [ChannelMaskBit * 8, ChannelMaskBit * 8 +7],64+ChannelMaskBit.

If **ChMaskCntl** = 6 then 125 kHz channels are enabled, if **ChMaskCntl** = 7 then 125 kHz channels are disabled. Simultaneously the channels 64 to 71 are set according to the **ChMask** bit mask. The DataRate specified in the command need not be valid for channels specified in the ChMask, as it governs the global operational state of the end-device.

2.6.6 AU915-928 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table for both uplink dwell time configurations: No Limit and 400ms. It is derived from the maximum allowed transmission time at the PHY layer taking into account a possible repeater encapsulation. The maximum application payload length in the absence of the optional **FOpt** MAC control field (*N*) is also given for information only. The value of *N* might be smaller if the **FOpt** field is not empty:

DataRate	UplinkDwellTime=0		UplinkDwellTime=1	
	M	***N***	***M***	***N***
0	59	51	N/A	N/A
1	59	51	N/A	N/A
2	59	51	19	11
3	123	115	61	53
4	230	222	133	125
5	230	222	250	242
6	230	222	250	242
7	Not defined		Not defined	
8	41	33	41	33
9	117	109	117	109
10	230	222	230	222
11	230	222	230	222
12	230	222	230	222
13	230	222	230	222
14:15	Not defined		Not defined	

Table 38: AU915-928 maximum payload size

The greyed lines correspond to the data rates that may be used by an end-device behind a repeater.

> For AU915-928, DownlinkDwellTime MUST be set to 0 (no limit). The 400ms dwell time MAY only apply to uplink channels depending on the local regulations.

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	UplinkDwellTime=0		UplinkDwellTime=1	
	M	***N***	***M***	***N***
0	59	51	N/A	N/A
1	59	51	N/A	N/A
2	59	51	19	11
3	123	115	61	53
4	250	242	133	125
5	250	242	250	242
6	250	242	250	242

7	Not defined		Not defined	
8	61	53	61	53
9	137	129	137	129
10	250	242	250	242
11	250	242	250	242
12	250	242	250	242
13	250	242	250	242
14:15	Not defined		Not defined	

Table 39: AU915-928 maximum payload size (not repeater compatible)

2.6.7 AU915-928 Receive windows

- The RX1 receive channel is a function of the upstream channel used to initiate the data exchange. The RX1 receive channel can be determined as follows.
  - RX1 Channel Number = Transmit Channel Number modulo 8
- The RX1 window data rate depends on the transmit data rate (see Table 17 below).
- The RX2 (second receive window) settings uses a fixed data rate and frequency. Default parameters are 923.3Mhz / DR8

Upstream data rate RX1DROffset	Downstream data rate 0	1	2	3	4	5
DR0	DR8	DR8	DR8	DR8	DR8	DR8
DR1	DR9	DR8	DR8	DR8	DR8	DR8
DR2	DR10	DR9	DR8	DR8	DR8	DR8
DR3	DR11	DR10	DR9	DR8	DR8	DR8
DR4	DR12	DR11	DR10	DR9	DR8	DR8
DR5	DR13	DR12	DR11	DR10	DR9	DR8
DR6	DR13	DR13	DR12	DR11	DR10	DR9

Table 40 : AU915-928 downlink RX1 data rate mapping

The allowed values for RX1DROffset are in the [0:5] range. Values in the range [6:7] are reserved for future use.

2.6.8 AU915-928 Class B beacon

The beacons are transmitted using the following settings:

DR	8	Corresponds to SF12 spreading factor with 500kHz bw
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity
frequencies	923.3 to 927.5MHz with 600kHz steps	Beaconing is performed on the same channel that normal downstream traffic as defined in the Class A specification

Table 41 : AU915-928 beacon settings

The downstream channel used for a given beacon is:

$$\text{Channel} = \left[floor\left(\frac{beacon\_time}{beacon\_period}\right)\right] \ modulo\ 8$$

- whereby beacon_time is the integer value of the 4 bytes “Time” field of the beacon frame
- whereby beacon_period is the periodicity of beacons , 128 seconds
- whereby *floor(x)* designates rounding to the integer immediately inferior or equal to x

> Example: the first beacon will be transmitted on 923.3Mhz , the second on 923.9MHz, the 9th beacon will be on 923.3Mhz again.

Beacon channel nb	Frequency [MHz]
0	923.3
1	923.9
2	924.5
3	925.1
4	925.7
5	926.3
6	926.9
7	927.5

The beacon frame content is:

Size (bytes)	**3**	4	2	7	**1**	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	**RFU**	CRC

2.6.9 AU915-928 Default Settings

The following parameters are recommended values for the AU915-928 band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 & 2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

2.7 CN470-510MHz Band

2.7.1 CN470-510 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols

2.7.2 CN470-510 Channel Frequencies

In China, this band is defined by SRRC to be used for civil metering applications.

The 470 MHz ISM Band SHALL be divided into the following channel plans:

- Upstream – 96 channels numbered 0 to 95 utilizing LoRa 125 kHz BW varying from DR0 to DR5, using coding rate 4/5, starting at 470.3 MHz and incrementing linearly by 200 kHz to 489.3 MHz.

> Channel Index 6 to 38 and 45 to 77 are mainly used by China Electric Power. In the areas where these channels are used by China Electric Power, they should be disabled.

- Downstream – 48 channels numbered 0 to 47 utilizing LoRa 125 kHz BW varying from DR0 to DR5, using coding rate 4/5, starting at 500.3 MHz and incrementing linearly by 200 kHz to 509.7 MHz

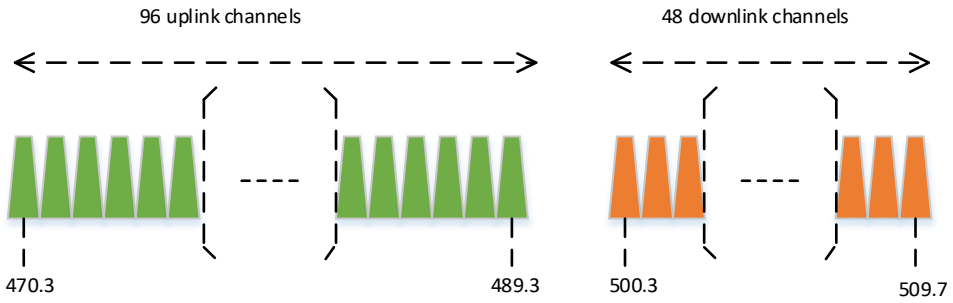

Figure 3: CN470-510 channel frequencies

The LoRaWAN can be used in the Chinese 470-510MHz band as long as

- The radio device EIRP is less than 19.15dBm
- The transmission never lasts more than 5000 ms.

CN470-510 end-devices SHALL be capable of operating in the 470 to 510 MHz frequency band and SHALL feature a channel data structure to store the parameters of 96 uplink channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

If using the over-the-air activation procedure, the end-device SHALL broadcast the JoinReq message on a random 125 kHz channel amongst the 96 uplink channels defined using **DR5 to DR0**.

Personalized devices SHALL have all 96 channels enabled following a reset.

2.7.3 CN470-510 Data Rate and End-point Output Power encoding

There is no dwell time limitation for the CN470-510 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented by CN470-510 devices.

The following encoding is used for Data Rate (**DR**) and End-point EIRP (**TXPower**) in the CN470-510 band:

DataRate	Configuration	Indicative physical bit rate [bit/sec]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa:SF7 / 125 kHz	5470
6..15	RFU	

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8…15	RFU

Table 42: CN470-510 Data rate and TX power table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default MaxEIRP is considered to be +19.15dBm. If the end-device cannot achieve 19.15dBm EIRP, the Max EIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.

2.7.4 CN470-510 JoinResp CFList

The CN470-510 LoRaWAN supports the use of the optional **CFlist** appended to the JoinResp message. If the **CFlist** is not empty then the CFListType field SHALL contain the value one (0x01) to indicate the CFList contains a series of ChMask fields. The ChMask fields are interpreted as being controlled by a virtual ChMaskCntl that initializes to a value of zero (0) and increments for each ChMask field to a value of five (5). (The first 16 bits controls the channels 1 to 16, ..)

Size (bytes)	[2]	[2]	[2]	[2]	[2]	[2]	[3]	[1]
CFList	***ChMask0***	***ChMask1***	***ChMask2***	***ChMask3***	***ChMask4***	***ChMask5***	***RFU***	***CFListType***

2.7.5 CN470-510 LinkAdrReq command

For the CN470-510 version the **ChMaskCntl** field of the ***LinkADRReq*** command has the following meaning:

ChMaskCntl	ChMask applies to
0	Channels 0 to 15
1	Channels 16 to 31
2	Channels 32 to 47
3	Channels 48 to 63
4	Channels 64 to 79
5	Channels 80 to 95
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 43: CN470-510 ChMaskCntl value table

If the ChMask field value is one of the values meaning RFU, then end-device SHOULD reject the command and unset the "**Channel mask ACK**" bit in its response.

2.7.6 CN470-510 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table. It is derived from the maximum allowed transmission time at the PHY layer taking into account a possible repeater encapsulation. The maximum application payload length in the absence of the optional **FOpt** MAC control field (*N*) is also given for information only. The value of *N* might be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6:15	Not defined	

Table 44: CN470-510 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6:15	Not defined	

Table 45 : CN470-510 maximum payload size (not repeater compatible)

2.7.7 CN470-510 Receive windows

- The RX1 receive channel is a function of the upstream channel used to initiate the data exchange. The RX1 receive channel can be determined as follows.
  - RX1 Channel Number = Uplink Channel Number modulo 48, for example, when transmitting channel number is 49, the rx1 channel number is 1.
- The RX1 window data rate depends on the transmit data rate (see Table below).
- The RX2 (second receive window) settings uses a fixed data rate and frequency. Default parameters are 505.3 MHz / DR0

RX1DROffset	0	1	2	3	4	5
Upstream data rate	**Downstream data rate in RX1 slot**					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0

Table 46: CN470-510 downlink RX1 data rate mapping

The allowed values for RX1DROffset are in the [0:5] range. Values in the range [6:7] are reserved for future use.

2.7.8 CN470-510 Class B beacon

The beacons are transmitted using the following settings:

DR	2	Corresponds to SF10 spreading factor with 125kHz bw
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity
frequencies	508.3 to 509.7MHz with 200kHz steps	

Table 47 : CN470-510 beacon settings

The downstream channel used for a given beacon is:

$$\text{BeaconChannel} = \left[floor\left(\frac{beacon\_time}{beacon\_period}\right)\right] \ modulo\ 8$$

- whereby beacon_time is the integer value of the 4 bytes “Time” field of the beacon frame
- whereby beacon_period is the periodicity of beacons , 128 seconds
- whereby *floor(x)* designates rounding to the integer immediately inferior or equal to x

> Example: the first beacon will be transmitted on 508.3Mhz, the second on 508.5MHz, the 9th beacon will be on 508.3Mhz again.

Beacon channel nb	Frequency [MHz]
0	508.3
1	508.5
2	508.7
3	508.9
4	509.1
5	509.3
6	509.5
7	509.7

The beacon frame content is:

Size (bytes)	**3**	4	2	7	**1**	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	**RFU**	CRC

The authors reserve the right to change specifications without notice.

2.7.9 CN470-510 Default Settings

The following parameters are recommended values for the CN470-510 band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 & 2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

2.8 AS923MHz ISM Band

2.8.1 AS923 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 48: AS923 synch words

2.8.2 AS923 ISM Band channel frequencies

This section applies to regions where the frequencies [923…923.5MHz] are comprised in the ISM band.

The network channels can be freely attributed by the network operator. However the two following default channels MUST be implemented in every AS923MHz end-device. Those channels are the minimum set that all network gateways SHOULD always be listening on.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	923.20 923.40	DR0 to DR5 / 0.3-5 kbps	2	< 1%

Table 49: AS923 default channels

Those default channels MUST be implemented in every end-device and cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and network gateways.

AS923MHz ISM band end-devices should use the following default parameters

- Default EIRP: 16 dBm

AS923MHz end-devices SHALL feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	923.20 923.40	DR2 to DR5	2	< 1%

Table 50: AS923 JoinReq Channel List

The default JoinReq Data Rate utilizes the range DR2-DR5 (SF10/125 kHz – SF7/125 kHz), this setting ensures that end-devices are compatible with the 400ms dwell time limitation until the actual dwell time limit is notified to the end-device by the network server via the MAC command “TxParamSetupReq”.

The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter

"Retransmissions back-off" of the LoRaWAN specification document.

2.8.3 AS923 Data Rate and End-point Output Power encoding

The "TxParamSetupReq/Ans" MAC command MUST be implemented by the AS923 devices.

The following encoding is used for Data Rate (DR) in the AS923 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

Table 51: AS923 Data rate table

The TXPower table indicates power levels relative to the Max EIRP level of the end-device, as per the following table:

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8..15	RFU

Table 52: AS923 TxPower table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default Max EIRP SHALL be 16dBm.The Max EIRP can be modified by the network server through the ***TxParamSetupReq*** MAC command and SHOULD be used by both the end-device and the network server once ***TxParamSetupReq*** is acknowledged by the device via ***TxParamSetupAns***,

The authors reserve the right to change specifications without notice.

2.8.4 AS923 JoinAccept CFList

The AS923 LoRaWAN implements an optional channel frequency list (CFlist) of 16 octets in the JoinAccept message.

In this case the CFList is a list of five channel frequencies for the channels two to six whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125 KHz LoRa modulation. The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch2	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	CFListType

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 915 and 928MHz in 100 Hz steps. Unused channels have a frequency value of 0. The CFList is optional and its presence can be detected by the length of the join-accept message. If present, the CFList replaces all the previous channels stored in the end-device apart from the two default channels. The newly defined channels are immediately enabled and usable by the end-device for communication.

2.8.5 AS923 LinkAdrReq command

The AS923 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	**ChMask applies to**
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 53: AS923 ChMaskCntl value table

If the ChMask field value is one of values meaning RFU, the end-device SHOULD reject the command and unset the "**Channel mask ACK**" bit in its response.

2.8.6 AS923 Maximum payload size

The maximum **MACPayload** size length (*M)* is given by the following table for both dwell time configurations: No Limit and 400ms. It is derived from the PHY layer limitation depending on the effective modulation rate used taking into account a possible repeater encapsulation layer.

DataRate	***Uplink MAC Payload Size (M)***	***Downlink MAC Payload Size (M)***

	UplinkDwellTime = 0	UplinkDwellTime = 1	DownlinkDwellTime = 0	DownlinkDwellTime = 1
0	59	N/A	59	N/A
1	59	N/A	59	N/A
2	59	19	59	19
3	123	61	123	61
4	230	133	230	133
5	230	250	230	250
6	230	250	230	250
7	230	250	230	250
8:15	RFU		RFU	

Table 54: AS923 maximum payload size

If the end-device will never operate with a repeater then the maximum MAC payload length should be:

DataRate	*Uplink MAC Payload Size (M)*		*Downlink MAC Payload Size (M)*	
	UplinkDwellTime = 0	UplinkDwellTime = 1	DownlinkDwellTime = 0	DownlinkDwellTime = 1
0	59	N/A	59	N/A
1	59	N/A	59	N/A
2	59	19	59	19
3	123	61	123	61
4	250	133	250	133
5	250	250	250	250
6	250	250	250	250
7	250	250	250	250
8:15	RFU		RFU	

Table 55: AS923 maximum payload size (not repeater compatible)

The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is eight bytes lower than the MACPayload value in the above table. The value of N might be smaller if the **FOpt** field is not empty.

2.8.7 AS923 Receive windows

The RX1 receive window uses the same channel than the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as following:

Downstream data rate in RX1 slot = *MIN* (5, *MAX* (MinDR, Upstream data rate – Effective_RX1DROffset))

MinDR depends on the DownlinkDwellTime bit sent to the device in the ***TxParamSetupReq*** command:

- Case DownlinkDwellTime = 0 (No limit): MinDR = 0
- Case DownlinkDwellTime = 1 (400ms): MinDR = 2

The allowed values for RX1DROffset are in the [0:7] range, encoded as per the below table:

RX1DROffset (Coded value)	0	1	2	3	4	5	6	7
Effective_RX1DROffset	0	1	2	3	4	5	-1	-2

Values in the [6:7] range allow setting the Downstream RX1 data rate higher than Upstream data rate.

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 923.2 MHz / DR2 (SF10/125KHz).

2.8.8 AS923 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 56 : AS923 beacon settings

The beacon frame content is:

Size (bytes)	**2**	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 923.4MHz.

The class B default downlink pingSlot frequency is 923.4MHz

2.8.9 AS923 Default Settings

The following parameters are recommended values for the AS923MHz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 and RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

2.9 KR920-923MHz ISM Band

2.9.1 KR920-923 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols

2.9.2 KR920-923 ISM Band channel frequencies

The center frequency, bandwidth and maximum EIRP output power for the South Korea RFID/USN frequency band are already defined by Korean Government. Basically Korean Government allocated LPWA based IoT network frequency band from 920.9 to 923.3MHz.

Center frequency (MHz)	Bandwidth (kHz)	Maximum EIRP output power (dBm)	
		For end-device	For gateway
920.9	125	10	23
921.1	125	10	23
921.3	125	10	23
921.5	125	10	23
921.7	125	10	23
921.9	125	10	23
922.1	125	14	23
922.3	125	14	23
922.5	125	14	23
922.7	125	14	23
922.9	125	14	23
923.1	125	14	23
923.3	125	14	23

Table 57: KR920-923 Center frequency, bandwidth, maximum EIRP output power table

The three following default channels (922.1, 922.3 and 922.5MHz / DR0 to DR5) determined by the network operator from the set of available channels as defined by the South Korean regulation MUST be implemented in every KR920-923MHz end-device, and cannot be alterable by the ***NewChannelReq*** command. Those channels are the minimum set that all network gateways SHOULD always be listening on to guarantee a minimal common channel set between end-devices and network gateways.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	922.10 922.30 922.50	DR0 to DR5 / 0.3-5 kbps	3

Table 58: KR920-923 default channels

In order to access the physical medium the South Korea regulations impose some restrictions. The South Korea regulations allow the choice of using either a duty-cycle limitation or a so-called Listen Before Talk Adaptive Frequency Agility (LBT AFA) transmissions management. The current LoRaWAN specification for the KR920-923 ISM band exclusively uses LBT channel access rule to maximize MACPayload size length and comply with the South Korea regulations.

KR920-923MHz ISM band end-devices SHALL use the following default parameters

- Default EIRP output power for end-device(920.9~921.9MHz): 10 dBm
- Default EIRP output power for end-device(922.1~923.3MHz): 14 dBm
- Default EIRP output power for gateway: 23 dBm

KR920-923MHz end-devices SHALL be capable of operating in the 920 to 923MHz frequency band and SHALL feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	922.10 922.30 922.50	DR0 to DR5 / 0.3-5 kbps	3

Table 59: KR920-923 JoinReq Channel List

2.9.3 KR920-923 Data Rate and End-device Output Power encoding

There is no dwell time limitation for the KR920-923 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented by KR920-923 devices.

The following encoding is used for Data Rate (DR), and EIRP Output Power (TXPower) in the KR920-923 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6..15	RFU	

Table 60: KR920-923 TX Data rate table

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8..15	RFU

Table 61: KR920-923 TX power table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default MaxEIRP is considered to be +14dBm. If the end-device cannot achieve 14dBm EIRP, the MaxEIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.
When the device transmits in a channel whose frequency is <922MHz, the transmit power SHALL be limited to +10dBm EIRP even if the current transmit power level set by the network server is higher.

2.9.4 KR920-923 JoinAccept CFList

The KR920-923 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of 16 octets in the JoinAccept message.

In this case the CFList is a list of five channel frequencies for the channels three to seven whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125kHz LoRa modulation.

The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	Freq Ch7	CFListType

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have a frequency value of 0. The **CFList** is optional and its presence can be detected by the length of the join-accept message. If present, the **CFList** replaces all the previous channels stored in the end-device apart from the three default channels. The newly defined channels are immediately enabled and usable by the end-device for communication.

2.9.5 KR920-923 LinkAdrReq command

The KR920-923 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	**ChMask applies to**
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 62: KR920-923 ChMaskCntl value table

If the ChMaskCntl field value is one of values meaning RFU, the end-device SHOULD reject the command and unset the "**Channel mask ACK**" bit in its response.

2.9.6 KR920-923 Maximum payload size

The maximum **MACPayload** size length (*M*) is given by the following table for the regulation of dwell time; less than 4 sec with LBT. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of N might be smaller if the **FOpt** field is not empty:

DataRate	*M*	*N*
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6:15	Not defined	

Table 63: KR920-923 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6:15	Not defined	

Table 64 : KR920-923 maximum payload size (not repeater compatible)

2.9.7 KR920-923 Receive windows

The RX1 receive window uses the same channel than the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The allowed values for RX1DROffset are in the [0:5] range. Values in the [6:7] range are reserved for future use.

RX1DROffset **Upstream data rate**	**0**	**1**	**2**	**3**	**4**	**5**
	Downstream data rate in RX1 slot					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0

Table 65 : KR920-923 downlink RX1 data rate mapping

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 921.90MHz / DR0 (SF12, 125 kHz).

2.9.8 KR920-923 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 66 : KR920-923 beacon settings

The beacon frame content is:

Size (bytes)	**2**	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 923.1MHz.

The class B default downlink pingSlot frequency is 923.1MHz

2.9.9 KR920-923 Default Settings

The following parameters are recommended values for the KR920-923Mhz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 and RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

2.10 IN865-867 MHz ISM Band

2.10.1 IN865-867 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 67: IN865-867 synch words

2.10.2 IN865-867 ISM Band channel frequencies

This section applies to the Indian sub-continent.

The network channels can be freely attributed by the network operator. However the three following default channels MUST be implemented in every India 865-867MHz end-device. Those channels are the minimum set that all network gateways SHOULD always be listening on.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	865.0625 865.4025 865.985	DR0 to DR5 / 0.3-5 kbps	3

Table 68: IN865-867 default channels

End-devices SHALL be capable of operating in the 865 to 867 MHz frequency band and should feature a channel data structure to store the parameters of at least 16 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The first three channels correspond to 865.0625, 865.4025, and 865.985 MHz / DR0 to DR5 and MUST be implemented in every end-device. Those default channels cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and network gateways.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message. The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter “Retransmissions back-off” of the LoRaWAN specification document.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	865.0625 865.4025 865.9850	DR0 – DR5 / 0.3-5 kbps	3

Table 69: IN865-867 JoinReq Channel List

2.10.3 IN865-867 Data Rate and End-device Output Power Encoding

There is no dwell time or duty-cycle limitation for the INDIA 865-867 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented by INDIA 865-867 devices.

The following encoding is used for Data Rate (DR) and End-device Output Power (TXPower) in the INDIA 865-867 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	RFU	RFU
7	FSK: 50 kbps	50000
8..15	RFU	

Table 70: IN865-867 TX Data rate table

The TXPower table indicates power levels relative to the Max EIRP level of the end-device, as per the following table:

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8	Max EIRP – 16dB
9	Max EIRP – 18dB
10	Max EIRP – 20dB
11..15	RFU

Table 71: IN865-867 TxPower table

EIRP refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

By default MaxEIRP is considered to be 30dBm. If the end-device cannot achieve 30dBm EIRP, the Max EIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.

2.10.4 IN865-867 JoinAccept CFList

The India 865-867 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of 16 octets in the JoinAccept message.

In this case the CFList is a list of five channel frequencies for the channels three to seven whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125kHz LoRa modulation.

The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	Freq Ch7	CFListType

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have a frequency value of 0. The **CFList** is optional and its presence can be detected by the length of the join-accept message. If present, the **CFList** replaces all the previous channels stored in the end-device apart from the three default channels. The newly defined channels are immediately enabled and usable by the end-device for communication.

2.10.5 IN865-867 LinkAdrReq command

The INDIA 865-867 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	**ChMask applies to**
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 72: IN865-867 ChMaskCntl value table

If the ChMaskCntl field value is one of values meaning RFU, the end-device SHOULD reject the command and unset the "**Channel mask ACK**" bit in its response.

2.10.6 IN865-867 Maximum payload size

The maximum **MACPayload** size length (*M)* is given by the following table. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of N might be smaller if the **FOpt** field is not empty:

DataRate	***M***	***N***
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6	230	222
7	230	222
8:15	Not defined	

The authors reserve the right to change specifications without notice.

Table 73: IN865-867 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6	250	242
7	250	242
8:15	Not defined	

Table 74 : IN865-867 maximum payload size (not repeater compatible)

2.10.7 IN865-867 Receive windows

The RX1 receive window uses the same channel than the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The allowed values for RX1DROffset are in the [0:7] range. Values in the [6:7] range allow setting the Downstream RX1 data rate higher than Upstream data rate.

The allowed values for RX1DROffset are in the [0:7] range, encoded as per the below table:

RX1DROffset (Coded value)	0	1	2	3	4	5	6	7
Effective_RX1DROffset	0	1	2	3	4	5	-1	-2

Downstream data rate in RX1 slot = *MIN* (5, *MAX* (0, Upstream data rate – Effective_RX1DROffset))

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 866.550 MHz / DR2 (SF10, 125 kHz).

2.10.8 IN865-867 Class B beacon and default downlink channel

The beacons are transmitted using the following settings

DR	4	Corresponds to SF8 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

The beacon frame content is:

Size (bytes)	1	4	**2**	7	**3**	**2**
BCNPayload	RFU	Time	**CRC**	GwSpecific	**RFU**	**CRC**

The beacon default broadcast frequency is 866.550MHz.

The class B default downlink pingSlot frequency is 866.550MHz

The authors reserve the right to change specifications without notice.

2.10.9 IN865-867 Default Settings

The following parameters are recommended values for the INDIA 865-867MHz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 and RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

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The authors reserve the right to change specifications without notice.

2.11 RU864-870 MHz ISM Band

2.11.1 RU864-870 Preamble Format

The following synchronization words SHOULD be used:

Modulation	Sync word	Preamble length
LORA	0x34	8 symbols
GFSK	0xC194C1	5 bytes

Table 75: RU864-870 synch words

2.11.2 RU864-870 ISM Band channel frequencies

The network channels can be freely attributed by the network operator in compliance with the allowed sub-bands defined by the Russian regulation. However the two following default channels MUST be implemented in every RU864-870 MHz end-device. Those channels are the minimum set that all network gateways SHOULD always be listening on.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	868.9 869.1	DR0 to DR5 / 0.3-5 kbps	2	<1%

Table 76: RU864-870 default channels

RU864-870 MHz end-devices SHALL be capable of operating in the 864 to 870 MHz frequency band and SHALL feature a channel data structure to store the parameters of at least 8 channels. A channel data structure corresponds to a frequency and a set of data rates usable on this frequency.

The first two channels correspond to 868.9 and 869.1 MHz / DR0 to DR5 and MUST be implemented in every end-device. Those default channels cannot be modified through the ***NewChannelReq*** command and guarantee a minimal common channel set between end-devices and network gateways.

The following table gives the list of frequencies that SHALL be used by end-devices to broadcast the JoinReq message. The JoinReq message transmit duty-cycle SHALL follow the rules described in chapter “Retransmissions back-off” of the LoRaWAN specification document.

Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels
LoRa	125	868.9 869.1	DR0 – DR5 / 0.3-5 kbps	2

The authors reserve the right to change specifications without notice.

Table 77: RU864-870 JoinReq Channel List

2.11.3 RU864-870 Data Rate and End-device Output Power encoding

There is no dwell time limitation for the RU864-870 PHY layer. The ***TxParamSetupReq*** MAC command is not implemented in RU864-870 devices.

The following encoding is used for Data Rate (DR) and End-device EIRP (TXPower) in the RU864-870 band:

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

Table 78: RU864-870 TX Data rate table

EIRP[1] refers to the Equivalent Isotropically Radiated Power, which is the radiated output power referenced to an isotropic antenna radiating power equally in all directions and whose gain is expressed in dBi.

TXPower	Configuration (EIRP)
0	Max EIRP
1	Max EIRP – 2dB
2	Max EIRP – 4dB
3	Max EIRP – 6dB
4	Max EIRP – 8dB
5	Max EIRP – 10dB
6	Max EIRP – 12dB
7	Max EIRP – 14dB
8..15	RFU

Table 79: RU864-870 TX power table

By default MaxEIRP is considered to be +16dBm. If the end-device cannot achieve +16dBm EIRP, the Max EIRP SHOULD be communicated to the network server using an out-of-band channel during the end-device commissioning process.

2.11.4 RU864-870 JoinAccept CFList

The RU 864-870 ISM band LoRaWAN implements an optional **channel frequency list** (CFlist) of 16 octets in the JoinAccept message.

[1] *ERP = EIRP – 2.15dB; it is referenced to a half-wave dipole antenna whose gain is expressed in dBd*

The authors reserve the right to change specifications without notice.

In this case the CFList is a list of five channel frequencies for the channels two to six whereby each frequency is encoded as a 24 bits unsigned integer (three octets). All these channels are usable for DR0 to DR5 125kHz LoRa modulation. The list of frequencies is followed by a single CFListType octet for a total of 16 octets. The CFListType SHALL be equal to zero (0) to indicate that the CFList contains a list of frequencies.

Size (bytes)	3	3	3	3	3	1
CFList	Freq Ch2	Freq Ch3	Freq Ch4	Freq Ch5	Freq Ch6	CFListType

The actual channel frequency in Hz is 100 x frequency whereby values representing frequencies below 100 MHz are reserved for future use. This allows setting the frequency of a channel anywhere between 100 MHz to 1.67 GHz in 100 Hz steps. Unused channels have a frequency value of 0. The **CFList** is optional and its presence can be detected by the length of the join-accept message. If present, the **CFList** replaces all the previous channels stored in the end-device apart from the two default channels. The newly defined channels are immediately enabled and usable by the end-device for communication.

2.11.5 RU864-870 LinkAdrReq command

The RU864-870 LoRaWAN only supports a maximum of 16 channels. When **ChMaskCntl** field is 0 the ChMask field individually enables/disables each of the 16 channels.

ChMaskCntl	**ChMask applies to**
0	Channels 0 to 15
1	RFU
..	..
4	RFU
5	RFU
6	All channels ON The device SHOULD enable all currently defined channels independently of the ChMask field value.
7	RFU

Table 80: RU864-870 ChMaskCntl value table

If the ChMaskCntl field value is one of values meaning RFU, the end-device SHOULD reject the command and unset the "**Channel mask ACK**" bit in its response.

2.11.6 RU864-870 Maximum payload size

The maximum **MACPayload** size length (*M)* is given by the following table. It is derived from limitation of the PHY layer depending on the effective modulation rate used taking into account a possible repeater encapsulation layer. The maximum application payload length in the absence of the optional **FOpt** control field (*N*) is also given for information only. The value of N might be smaller if the **FOpt** field is not empty:

DataRate	***M***	***N***
0	59	51
1	59	51
2	59	51
3	123	115
4	230	222
5	230	222
6	230	222

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7	230	222
8:15	Not defined	

Table 81: RU864-870 maximum payload size

If the end-device will never operate with a repeater then the maximum application payload length in the absence of the optional **FOpt** control field SHOULD be:

DataRate	M	N
0	59	51
1	59	51
2	59	51
3	123	115
4	250	242
5	250	242
6	250	242
7	250	242
8:15	Not defined	

Table 82 : RU864-870 maximum payload size (not repeater compatible)

2.11.7 RU864-870 Receive windows

The RX1 receive window uses the same channel as the preceding uplink. The data rate is a function of the uplink data rate and the RX1DROffset as given by the following table. The allowed values for RX1DROffset are in the [0:5] range. Values in the [6:7] range are reserved for future use.

RX1DROffset **Upstream data rate**	**0**	**1**	**2**	**3**	**4**	**5**
	Downstream data rate in RX1 slot					
DR0	DR0	DR0	DR0	DR0	DR0	DR0
DR1	DR1	DR0	DR0	DR0	DR0	DR0
DR2	DR2	DR1	DR0	DR0	DR0	DR0
DR3	DR3	DR2	DR1	DR0	DR0	DR0
DR4	DR4	DR3	DR2	DR1	DR0	DR0
DR5	DR5	DR4	DR3	DR2	DR1	DR0
DR6	DR6	DR5	DR4	DR3	DR2	DR1
DR7	DR7	DR6	DR5	DR4	DR3	DR2

Table 83: RU864-870 downlink RX1 data rate mapping

The RX2 receive window uses a fixed frequency and data rate. The default parameters are 869.1MHz / DR0 (SF12, 125 kHz)

2.11.8 RU864-870 Class B beacon and default downlink channel

The beacons SHALL be transmitted using the following settings

DR	3	Corresponds to SF9 spreading factor with 125 kHz BW
CR	1	Coding rate = 4/5
Signal polarity	Non-inverted	As opposed to normal downlink traffic which uses inverted signal polarity

Table 84: RU864-870 beacon settings

The beacon frame content is:

Size (bytes)	2	4	2	7	2
BCNPayload	**RFU**	Time	CRC	GwSpecific	CRC

The beacon default broadcast frequency is 869.1 MHz.

The class B default downlink pingSlot frequency is 868.9 MHz.

2.11.9 RU864-870 Default Settings

The following parameters are recommended values for the RU864-870 MHz band.

RECEIVE_DELAY1	1 s
RECEIVE_DELAY2	2 s (MUST be RECEIVE_DELAY1 + 1s)
JOIN_ACCEPT_DELAY1	5 s
JOIN_ACCEPT_DELAY2	6 s
MAX_FCNT_GAP	16384
ADR_ACK_LIMIT	64
ADR_ACK_DELAY	32
ACK_TIMEOUT	2 +/- 1 s (random delay between 1 and 3 seconds)

If the actual parameter values implemented in the end-device are different from those default values (for example the end-device uses a longer RECEIVE_DELAY1 and RECEIVE_DELAY2 latency), those parameters MUST be communicated to the network server using an out-of-band channel during the end-device commissioning process. The network server may not accept parameters different from those default values.

3 Revisions

3.1 Revision A

- Initial 1.0.3 revision, the regional parameters were extracted from the LoRaWANV1.0.3 revision A.

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4 Bibliography

4.1 References

[LORAWAN] LoRaWAN Specification, V1.0.3, the LoRa Alliance, January 2018.

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