**LoRa Specification**

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## LoRaWAN™ Specification

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### 1 Introduction

This document describes the LoRaWAN™ network protocol which is optimized for batterypowered end-devices that may be either mobile or mounted at a fixed location.

LoRaWAN networks typically are laid out in a star-of-stars topology in which **gateways[[1]](#footnote-1)** relay messages between **end-devices[[2]](#footnote-2)** and a central **network server** at the backend. Gateways are connected to the network server via standard IP connections while enddevices use single-hop LoRa™ or FSK communication to one or many gateways.3 All communication is generally bi-directional, although uplink communication from an enddevice to the network server is expected to be the predominant traffic.

Communication between end-devices and gateways is spread out on different **frequency** **channels** and **data rates**. The selection of the data rate is a trade-off between communication range and message duration, communications with different data rates do not interfere with each other. LoRa data rates range from 0.3 kbps to 50 kbps. To maximize both battery life of the end-devices and overall network capacity, the LoRa network infrastructure can manage the data rate and RF output for each end-device individually by means of an **adaptive data rate** (ADR) scheme.

End-devices may transmit on any channel available at any time, using any available data rate, as long as the following rules are respected:

* The end-device changes channel in a pseudo-random fashion for every transmission. The resulting frequency diversity makes the system more robust to interferences.
* The end-device respects the maximum transmit duty cycle relative to the sub-band used and local regulations.
* The end-device respects the maximum transmit duration (or dwell time) relative to the sub-band used and local regulations.

**Note:** Maximum transmit duty-cycle and dwell time per sub-band are region specific and are defined in the Chapter 6.

#### 1.1 LoRaWAN 协议类型

所有 LoRaWAN 设备至少要实现文档中描述的A类协议。此外，也可以选择实现文档中描述的B类、C类协议或者其它自定义的协议。在所有实现中必须兼容A类协议。

#### 1.2 规定

MAC命令都写为***LinkCheckReq***,比特位和比特位段都记做**FRMPayload**,常量如RECEIVE\_DELAY1,变量如*N*。

本文档中，

 所有多字节字段的字节顺序都是小端对齐

 EUI是64位整形并且小端对齐传输。

### 2 LoRaWAN 简介

LoRa™是一个由Semtech开发的长距离低功耗低速率应用的无线调制器。在本文中，设备实现了包括A类协议在内的更高级类别协议的II类终端设备。

#### 2.1 LoRaWAN协议类

LoRa网络区分为基本 LoRaWAN (称为Class A)和可选协议(Class B, Class C …):

Application

LoRa

MAC

LoRa

Modulation

Class B

(

beacon

)

Class C

(

Continuous

)

**Application**

**MAC**

**MAC options**

**Modulation**

Class A

(

baseline

)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| EU 868 |  | EU 433 |  | US 915 |  | AS 430 |  | … |

**Regional ISM band**

##### Figure 1: LoRaWAN Classes

**双向终端设备(Class A):**每个终端设备的上行传输必须紧跟两个短的下行接收时间窗，从而保证A类终端设备的双向通讯。传输时隙是由终端设备根据自己的通信需求在基于随机时间基准(ALOHA协议)上进行微小的调整。在终端设备发送完上行数据后仅需要服务器下行传输很短的数据应用场景下，A类操作是最低功耗的终端系统。在其他任何时间服务器下行链路通信将不得不等待，直到下一个预定的上行链路开始。

**固定接收时隙的双向终端设备 (Class B):**B类终端设备允许更多的接收时隙。除了A类随机接收窗口，B类设备开放额外的定时接收窗口。为了使终端设备能在规定的时间打开接收窗，终端会收到来自网关的同步信标。这可以让服务器知道终端设备是否正在监听。

**最大接收时隙的双向通信设备 (Class C):**C类终端设备除了在发送时关闭接收以外几乎能够连续的打开接收窗。C类终端设备比A类或B类设备在操作中要消耗更多的能量，但是它提供了服务器到终端设备的最低延迟通讯。

#### 2.2 Specification scope

LoRaWAN规范描述了附加功能，比A类级别更高的类终端设备也将实现。较高的类终端设备也将实现在LoRaWAN A类规范中描述的所有功能。

|  |
| --- |
| **注:**为避免冗余，在A类和更高等级协议类终端设备中，物理信息格式,MAC消息格式,以及本规范中其它相同的部分仅在LoRaWAN A类规范中有所描述。 |

## A类协议–所有终端设备

所有LoRaWAN 终端设备必须实现A类协议；

### 3 物理信息格式

LoRa术语在上行链路和下行链路数据有所区分。

#### 3.1上行链路数据

**上行消息由终端设备通过一个或多个网关中继的网络服务器发送。**

上行链路消息中包括LORA物理报头（PHDR）加上首部CRC（PHDR\_CRC），使用LoRa无线分组显式模式。1 CRC确保有效载荷的完整性。

物理报头(**PHDR)**,(物理报头CRC)**PHDR\_CRC** 和有效数据**CRC**字段由无线电收发器插入。

*Uplink PHY:*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Preamble | PHDR | PHDR\_CRC | PHYPayload | CRC |

**Figure 2: Uplink PHY structure**

#### 3.2下行链路数据

每个下行链路消息由网络服务器发送到一个只有单个网关中继的终端设备。2

下行链路消息中包括LORA物理报头（PHDR）加上首部CRC（PHDR\_CRC），使用LoRa无线分组显式模式。3

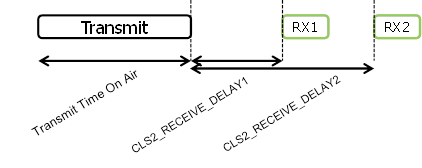
*Downlink PHY:*

|  |  |  |  |
| --- | --- | --- | --- |
| Preamble | PHDR | PHDR\_CRC | PHYPayload |

**Figure 3: Downlink PHY structure**

#### 3.3 接收窗

终端设备在每次上行传输后打开两个短的接收窗口。接收窗口开始时间是从上行数据最后一个比特传输结束后一个配置（固定）周期。



**Figure 4: End-device receive slot timing.**

##### 3.3.1 第一个接收窗的信道、数据速率、启动

第一接收窗RX1使用和上行链路相同的频率信道以及相同的数据速率函数。 RX1在上行链路调制结束后打开RECEIVE\_DELAY1[[3]](#footnote-3)秒（+/- 20微秒）。上行链路和RX1时隙下行链路数据速率之间关系特定描述详见第七节。默认情况下，第一接收窗数据速率和最后的上行链路的数据速率是相同的。

##### 3.3.2第二个接收窗的信道、数据速率、启动

第二接收窗RX2采用固定配置的频率和数据率并在上行链路调制结束后打RECEIVE\_-DELAY2[[4]](#footnote-4)秒（+/- 20微秒）。使用可通过MAC命令（见第5节）进行修改的频率和数据速率。默认频率和数据速率使用的特定区域详见第7节。

##### 3.3.3 接收窗长度

接收窗长度最少为终端设备无线收发器有效探测到下行链路前导码所需的时间。

##### 3.3.4 接收器在接收窗中的活动

如果前导码在一个接收窗中被探测到，无线接收器保持活跃状态直到框架解调完成。如果一个框架被探测到，并随后在第一接收窗内被解调，同时该框架的目的是在寻址和消息完整性代码检查后被用于该终端设备，则该终端设备不会打开第二个接收窗。

##### 3.3.5 网络发送消息到终端设备

如果网络打算发送下行数据到一个终端设备，它总是恰好在两个接收窗中任何一个的起始时刻发起传输。

##### 3.3.6 接收窗的重要注意事项

终端设备在之前的传输中，两个接收窗都未收到下行链路消息并且第二个接收窗未超时，终端设备不得发送另一个上行链路消息。

##### 3.3.7接收或发送其他协议

只要终端设备符合本地法规并兼容LoRaWAN规范，节点可以监听或发送其他协议或者在LoRaWan和接收窗之间做任何传输。

### 4 MAC 消息格式

所有LoRo上行和下行链路消息都携带一个物理有效载荷（**Payload**），该有效载荷以单字节的MAC报头（MHDR）作为开始，后跟一个MAC有效载荷（**MACPayload**），并以4个字节组成的消息完整性代码（MIC）作为结束。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Radio PHY layer:*   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Preamble | PHDR | PHDR\_CRC | PHYPayload | CRC\* |   **Figure 5: Radio PHY structure (CRC\* is only available on uplink messages)** *PHYPayload:*   |  |  |  | | --- | --- | --- | | MHDR | MACPayload | MIC |   **Figure 6: PHY payload structure**  *MACPayload:*   |  |  |  | | --- | --- | --- | | FHDR | FPort | FRMPayload |   **Figure 7: MAC payload structure**  *FHDR:*   |  |  |  |  | | --- | --- | --- | --- | | DevAddr | FCtrl | FCnt | FOpts |   **Figure 8: Frame header structure** |

**figure 9: LoRa message format elements**

#### 4.1 MAC Layer(PHYPayload)

|  |  |  |  |
| --- | --- | --- | --- |
| **Size (bytes)** | 1 | 1..*M* | 4 |
| **PHYPayload** | MHDR | MACPayload | MIC |

**MACPayload**字段的最大长度（**M**）有特定说明，并在19章第6节中指定。

#### 4.2 MAC Header (MHDR field)

|  |  |  |  |
| --- | --- | --- | --- |
| **Bit#** | 7..5 | 4..2 | 1..0 |
| **MHDR bits** | MType | RFU | Major |

MAC报头指定了消息类型（MType），并且根据LoRaWAN层规范下帧格式的不同主版本号（Major）对框架进行了编码。

##### 4.2.1 Message type (MType bit field)

LoRaWAN 区分六种不同的MAC消息类型：**请求加入**、**接受加入**、**未确认的数据上行/下行**、**确认的数据上行/下行**

|  |  |
| --- | --- |
| **MType** | **Description** |
| 000 | Join Request |
| 001 | Join Accept |
| 010 | Unconfirmed Data Up |
| 011 | Unconfirmed Data Down |
| 100 | Confirmed Data Up |
| 101 | Confirmed Data Down |
| 110 | RFU |
| 111 | Proprietary |

**Table 1: MAC message types**

###### 4.2.1.1 Join-request and join-accept messages

请求加入和接收加入消息在空中激活过程中使用，在章节6.2有所描述。

###### 4.2.1.2 Data messages

数据消息被用于传送MAC命令和应用数据，并且两种数据可以整合在一起作为一条消息。一条确定的消息必须有接收器确认，而未确定的消息不需要确认。[[5]](#footnote-5)私有消息可以被用于实现与标准消息没有互操作性的非标消息格式，但是只能在拥有专用扩展的共同理解能力的设备之间使用。

在不同消息格式中有不同的方式确保消息完整性，并且在每一类型消息下面都有描述。

###### 4.2.2 Major version of data message (Major bit field)

|  |  |
| --- | --- |
| **Major bits** | **Description** |
| 00 | LoRaWAN R1 |
| 01..11 | RFU |

**Table 2: Major list**

|  |
| --- |
| 注: 主版本号指定了加入过程（见章节6.2）中信息交换的格式和在第四章描述的MAC Payload的前四个字节。对于每一个主版本，终端设备可实现帧格式的不同次要版本。使用次版本号的终端设备必须事先使用外带消息通知网络服务器（例如，作为设备个性化信息的一部分）。 |

###### 4.3 MAC Payload of Data Messages (MACPayload)

数据消息的MAC有效负载，所谓的数据帧，包含一个后面跟着可选端口字段（FPort）和可选帧负载字段（**FRMPayload**）的帧头（**FHDR**）。

###### 4.3.1 Frame header (FHDR)

该帧头（**FHDR）包含用于传送MAC命令的终端设备短设备地址（DevAddr）、一个帧控制字节（FCtrl）、一个有两个8比特组成的帧计数器（FCnt）和最多可达15个字节的帧选项（FOpts）。**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Size (bytes)** | 4 | 1 | 2 | 0..15 |
| **FHDR** | DevAddr | FCtrl | FCnt | FOpts |

For downlink frames the FCtrl content of the frame header is:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bit#** | 7 | 6 | 5 | 4 | [3..0] |
| **FCtrl bits** | ADR | ADRACKReq | ACK | FPending | FOptsLen |

For uplink frames the FCtrl content of the frame header is:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bit#** | 7 | 6 | 5 | 4 | [3..0] |
| **FCtrl bits** | ADR | ADRACKReq | ACK | RFU | FOptsLen |

4.3.1.1 帧头数据速率自适应控制 (ADR, ADRACKReq in FCtrl)

LoRa网络允许终端设备单独使用任何可能的数据率。此功能被LoRaWAN用于适应和优化静态终端设备的数据速率。这被称为数据速率自适应(ADR)，并且当此功能启用后网络会尽可能向着最快数据速率方向优化。

当移动终端设备移动过程中引起无线环境的快速改变时使用数据速率管理是不切实际的，移动终端设备应当使用固定的默认数据速率。

如果ADR位被设置，网络将通过适当的MAC命令控制终端设备的数据速率。如果ADR没有被置位，网络不会尝试控制终端设备的数据速率而且不管接收到的信号质量如何。ADR位可以由终端设备或者网络按照需要设置或者取消。但是，只要有可能，ADR机制应当被使能以提高终端设备电池寿命和最大限度的提高网络容量。

**注:** 实际上移动终端设备在大部分时间是不移动的。因此，根据设备的流动状态，一个终端设备可以使用ADR请求网络优化其数据速率。

如果一个终端设备的数据速率被网络优化为使用比其默认数据速率更高的数据速率，它需要定期的验证该网络仍能接收上行链路帧。每个上行链路帧计数器递增（对于新的上行链路，重复传输计数器不增加），该设备增加一个ADR\_ACK\_CNT计数器。在上行链路达到最大限制(ADR\_ACK\_CNT >= ADR\_ACK\_LIMIT)而没有收到任何下行链路响应，设置ADR应答请求位（**ADRACKReq**）。网络需要在ADR\_ACK\_DELAY规定的时间内使用下行链路做出回应，任何接收到的紧跟着上行链路帧的下行链路帧复位ADR\_ACK\_CNT计数器。在对终端设备接收时隙中做出的任何响应中，下行ACK位不需要被设置，表明网关仍然可以从该设备接收到上行链路数据。如果没有在接下来的ADR\_ACK\_DELAY上行链路中收到应答（即，在ADR\_ACK\_LIMIT + ADR\_ACK\_DELAY之后），终端设备可以尝试通过切换到下一个较低数据率，提供了一个较长的无线电范围重新连接。终端设备将在每次达到ADR\_ACK\_LIMIT后进一步降低数据速率。如果设备使用其默认的数据速率，**ADRACKReq**不应该设置，因为在这种情况下没有任何可以采取的行动来改善链路范围。

注**:** 不要求立即响应的ADR确认请求对于网络最优的调度其下行链路提供了灵活性。

**注:** 在上行链路传输的**ADRACKReq** 位被置位，如果ADR\_ACK\_CNT >= ADR\_ACK\_LIMIT 并且当前数据速率高于设备定义的最小数据速率，它将在其他条件下被清除。

4.3.1.2 消息确认位和确认过程 (ACK in FCtrl)

当收到一个确定的消息数据，接收机应当响应一个包含确认位已置位的数据帧。如果发送者是一个终端设备，网络要在终端设备发送完数据后打开的任何一个接收窗内发送确认信息。如果发送者是一个网关，终端设备发送自行决定的确认消息。

确认消息只有在响应接收到的最后消息时发送并且从不重传。

**注:** 以允许终端设备以尽可能简单并且尽可能具有少的状态，它可能需要对接收后需要确认的消息立刻发出一个明确的（可能是空的）确认消息数据。另外，终端设备可以延迟确认的传输，并在其下一个数据消息内携带它。

4.3.1.3 重传过程

对于同一个需要确认却没有收到确认的消息的重传（及其时序）次数由终端设备自己决定，并且每一个终端设备可能不同，它也可以从网络服务器设置或者调整。

**注:** 一些示例确认机制时序图在第18章给出。

**注:** 如果一个终端设备已达到其重传的最大数量却没有收到确认，则可以尝试通过移动到一个能达到更远距离较低的数据速率恢复连接。它是由终端设备重新发送消息或忽略该消息，继续运行。

**Note:** 如果网络服务器已达到它的重传的最大数目而没有接收到确认，它通常会考虑末端装置不可达直到它从终端设备接收到进一步的消息。一旦连接到终端设备问题恢复时，它由网络服务器重传消息或者忽略该消息继续运行。

**Note:** 重传中推荐的数据速率回退策略在章节18.4中有所描述。

4.3.1.4 帧挂起位 (FPending in FCtrl, downlink only)

帧挂起位（FPending）仅在下行链路通信中使用，表示该网关具有更多的数据等待被发送的，因此，要求终端设备尽快通过发送另一个上行链路消息以打开另一个接收窗口。

挂起位的正确使用在章节18.3中进行说明。

4.3.1.5 帧计数器 (FCnt)

每个终端设备具有两个帧计数器来分别跟踪上行链路发送到网络服务器（FCntUp）的数据帧数量和被终端设备接收到的来自网络服务器（FCntDown）的下行数据，FCntUp由终端设备增加，FCntDown由网络服务器增加。网络服务器追踪上行帧计数器并且生成每个终端设备的下行计数器。在接受加入网络后，当前终端设备上的帧计数器和用于该终端设备的网络服务器上的帧计数器被重置为0。接着FCntUp和FCntDown是在发送方随着在各自的方向上发送的每个数据帧加1递增。在接收机侧，相应的计数器和和接收到的值保持同步，并提供加一后的接收到的数值和当前的计数器进行比较，考虑计数器翻转的问题差值应当小于MAX\_FCNT\_GAP[[6]](#footnote-6)规定的数值。如果这个差值比MAX\_FCNT\_GAP规定的数值还要大，那么说明有太多的数据帧丢失，随后的数据帧也将被丢弃。

该LoRaWan允许使用16位或者32位帧计数器。在给定的终端设备中，帧计数器宽度的实现应当在带外通知网络一端。如果使用16位帧计数器，所述FCnt字段可以直接作为计数器值使用。如果需要可以通过8位前导0扩展。如果使用32位帧计数器，所述FCnt字段和32位帧计数器的低16位对应（即，上行数据帧计数器FCntUp和下行数据帧计数器FCntDown）。

在相同的应用和网络会话密钥下，除了重传以外终端设备不得重复使用相同的FCntUp值。

**注:** 由于FCnt字段只携带32位帧计数器的低16位，服务器必须从流量上来观测和推断帧计数器的高16位。

4.3.1.6 帧选项 (FOptsLen in FCtrl, FOpts)

FCtrl字节中的帧选项长度字段（FOptslen）表示此帧中包含的帧选项字段的实际长度。

**FOpts**传送数据帧中携带的最长15个字节的MAC命令；见章节4.4有效的MAC命令的列表。

如果**FOptsLen是0，则FOpts字段不存在。如果FOptsLen不是0，即，如果MAC命令中存在FOpts字段，端口0不能使用（FPort必须不存在或者不为0）。**

MAC命令不能在有效载（数据）字段和帧选项字段同时存在。

###### 4.3.2 端口号字段 (FPort)

如果帧有效载荷字段不为空，则端口字段必须存在。如果存在的话，为0的FPort值表示FRMPayload只包含MAC命令;见章节4.4有效的MAC命令的列表。FPort值1..223（0x01..0xDF）是特定应用。 FPort值224..255（0xE0..0xFF）保留为将来标准化的应用扩展。

|  |  |  |  |
| --- | --- | --- | --- |
| **Size (bytes)** | 7..23 | 0..1 | 0..*N* |
| **MACPayload** | FHDR | FPort | FRMPayload |

*N* 是应用有效数据的字节数。N的有效范围有特别规定，在第7节有定义。

*N*应当≤:

*N* ≤ *M* - 1 - (length of **FHDR** in octets)

*M* 是MAC有效数据最大长度。

###### 4.3.3 MAC 帧有效数据加密 (FRMPayload)

如果数据帧中携带有效数据，在计算消息完整性代码之前有效数据（FRMPayload）必须加密。

使用的加密方案是基于IEEE 802.15.4/ 2006附录B[IEEE802154]中描述的包含 128位的密钥长度的AES通用算法。

默认情况下，加密/解密是由LoRaWAN层为所有FPort完成。如果为了应用更加方便的话，加密/解密可以在LoRaWAN层以上完成，但是只能为除了0以外的特定FPorts进行处理。关于哪一个节点的哪一个FPort在LoRaWAN层以外进行加密或解密，该信息必须通过带外通道传送到服务器（见19章节）。

4.3.3.1 LoRaWAN 中加密

所使用的密钥*K*依赖于数据包中的FPort：

|  |  |
| --- | --- |
| **FPort** | **K** |
| 0 | NwkSKey |
| 1..255 | AppSKey |

**Table 3: FPort list**

被加密的字段是:

***pld* =** FRMPayload

对于每一个数据包，算法定义了一个块序列*Ai* ，其中 *i* = 1..*k* ，*k* = ceil(len(*pld*) / 16):

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 1 | 4 | 1 | 4 | 4 | 1 | 1 |
| ***Ai*** | 0x01 | 4 x 0x00 | **Dir** | DevAddr | FCntUp or  FCntDown | 0x00 | *i* |

方向字段（**Dir**）等于0代表上行链路帧，等于1代表下行链路帧。

块 *Ai* 加密后得到块*Si*的序列 *S*：

*Si* = aes128\_encrypt(K, *Ai*) for *i* = 1..*k*

*S* = *S1* | *S2* | .. | *Sk*

加密和解密有效数据是由截断完成的。

(*pld* | pad16) xor S

to the first len(*pld*) octets.

4.3.3.2 在LoRaWAN 层之上加密

如果在LoRaWAN层之上为LoRaWAN选定的端口提供预加密FRMPayload，LoraWAN从MACPayload到应用传送FRMPayload或者从应用到MACPayload传送FRMPayload不需要对FRMPayload进行任何修改。

##### 4.4 消息完整性代码 (MIC)

消息完整性代码 (**MIC**) 计算消息的所有字段。

*msg* = **MHDR** | **FHDR** | **FPort** | **FRMPayload**

其中len(*msg*) 代表消息的字节长度。

**MIC** 计算如下 [RFC4493]:

*cmac* = aes128\_cmac(**NwkSKey**, *B0* | *msg*)

**MIC** = *cmac*[0..3]

其中块 *B0* 的定义如下:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 1 | 4 | 1 | 4 | 4 | 1 | 1 |
| ***B0*** | 0x49 | 4 x 0x00 | Dir | DevAddr | FCntUp or  FCntDown | 0x00 | len(*msg*) |

方向字段(**Dir**)为0代表上行数据，为1代表下行数据。.

### 5 MAC 命令

为了管理网络，一组MAC命令只在网络服务器和终端设备的MAC层之间交换数据，MAC层命令对于应用程序、用程序服务器或者终端设备上的应用程序是不可见的。

单个数据帧可以包含任意顺序的MAC命令，或者在作为单独数据帧发送时由**FRMPayload** 字段中的FOpts字段携带，同时FPort字段被设置为0。捎带的MAC命令始终无加密发送且最大不超过15个字节。MAC命令作为**FRMPayload**发送则始终加密，且不得超过最大FRMPayload长度。

**注:** MAC命令的内容不应到暴露给窃听者，必须在一个单独数据包的FRMPayload中发送。

一个MAC命令包含一个8位的命令标识符（**CID**）后跟可能为空的8位特殊命令序列。

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CID** | **Command** | **Transmitted by** | | **Short Description** |
|  |  | Enddevice | Gateway |  |
| 0x02 | ***LinkCheckReq*** | x |  | Used by an end-device to validate its connectivity to a network. |
| 0x02 | ***LinkCheckAns*** |  | x | Answer to LinkCheckReq command.  Contains the received signal power estimation indicating to the end-device the quality of reception (link margin). |
| 0x03 | ***LinkADRReq*** |  | x | Requests the end-device to change data rate, transmit power, repetition rate or channel. |
| 0x03 | ***LinkADRAns*** | x |  | Acknowledges the LinkRateReq. |
| 0x04 | ***DutyCycleReq*** |  | x | Sets the maximum aggregated transmit duty-cycle of a device |
| 0x04 | ***DutyCycleAns*** | x |  | Acknowledges a DutyCycleReq command |
| 0x05 | ***RXParamSetupReq*** |  | x | Sets the reception slots parameters |
| 0x05 | ***RXParamSetupAns*** | x |  | Acknowledges a RXSetupReq command |
| 0x06 | ***DevStatusReq*** |  | x | Requests the status of the end-device |
| 0x06 | ***DevStatusAns*** | x |  | Returns the status of the end-device, namely its battery level and its demodulation margin |
| 0x07 | ***NewChannelReq*** |  | x | Creates or modifies the definition of a radio channel |
| 0x07 | ***NewChannelAns*** | x |  | Acknowledges a NewChannelReq command |
| 0x08 | ***RXTimingSetupReq*** |  | x | Sets the timing of the of the reception slots |
| 0x08 | ***RXTimingSetupAns*** | x |  | Acknowledge RXTimingSetupReq command |
| 0x80 to  0xFF | Proprietary | x | x | Reserved for proprietary network command extensions |

#### Table 4: MAC commands

|  |
| --- |
| **注:** MAC的长度没有明确的给出，并且必须由MAC执行过程中隐式得到。因此未知的MAC命令不能跳过并且第一个未知的MAC命令将终止MAC指令序列的处理。因此，根据 LoRaWAN 版本规范说明，首次提出了MAC命令，这是明智的。通过这种方式所有的 LoRaWAN 规范中实行的MAC命令都可以被处理，甚至仅存在于最新的 LoRaWAN规范中的命令都可以被处理。 |

|  |
| --- |
| **注:** 由网络服务器调整的任何值（例如，RX2，新的或经调整的通道定义）在下一个加入的终端设备到来之前依然有效。因此经过每个成功的加入过程结束，设备再次使用默认参数，它由网络服务器根据需要再重新调整值。 |

**5.1 连接检查命令 (***LinkCheckReq, LinkCheckAns***)**

通过 ***LinkCheckReq*** 命令, 终端设备可以确认与网络的连通性。该命令没有有效数据。

当一个 ***LinkCheckReq*** 被网络服务器通过一个或多个网关收到，服务器回应一个***LinkCheckAns*** 命令。

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 1 | 1 |
| **LinkCheckAns Payload** | Margin | GwCnt |

解调范围（**Margin**）是一个范围是0-254的8位的无符号整形，用来识别最后一个成功接收到***LinkCheckReq***命令的以dB为单位的链路范围。如果是0意味着该帧无法解调接收（0dB或无范围），当值为20，该帧可到达20dB以外的网关。值255保留使用。

网关计数器（**GwCnt**）记录成功接收到最后一个***LinkCheckReq***命令的网关数量。

#### 5.2 Link ADR 命令(*LinkADRReq, LinkADRAns*)

根据 ***LinkADRReq*** 命令, 网络服务器请求终端设备执行速率自适应。

|  |  |  |  |
| --- | --- | --- | --- |
| **Size (bytes)** | 1 | 2 | 1 |
| **LinkADRReq Payload** | DataRate\_TXPower | ChMask | Redundancy |

|  |  |  |
| --- | --- | --- |
| **Bits** | [7:4] | [3:0] |
| **DataRate\_TXPower** | DataRate | TXPower |

请求的数据速率（**DataRate**）和发送功率（TXPower）是有特殊规定的，在第7章给出编码。

通道掩膜(**ChMask**) 用于编码上行链路接入的通道，低通道编码从比特0开始。

|  |  |
| --- | --- |
| **Bit#** | **Usable channels** |
| 0 | Channel 1 |
| 1 | Channel 2 |
| .. | .. |
| 15 | Channel 16 |

##### Table 5: Channel state table

**ChMask** 字段的任意比特位设置为1，则表明相应的通道能够被用于上行传输，但前提是该通道允许使用当前终端设备使用的数据速率。如果任意比特位设置为0，意味着应避免使用相应的通道。

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits** | 7 | [6:4] | [3:0] |
| **Redundancy bits** | RFU | ChMaskCntl | NbRep |

冗余比特重复数（**NbRep**）字段表示的是每个上行消息的重复数；这仅适用于未“确认”的上行链路帧；默认值是1；有效范围是[1:15]。如果收到**NbRep**==0，终端设备应当使用默认值。这个字段可以被网络控制器使用来控制节点上行数据的冗余来获得给定的服务质量。终端设备在重复传输时像平常一样执行跳频传输，每次等待接收直到接收窗超时。

通道屏蔽控制(**ChMaskCntl**)字段控制预定义的**ChMask**位掩码的解释。该字段在网络中只能为非0值，其中16以上的信道使用它。它通过作用于**ChMask**来控制16个通道块。它也可以通过使用特殊的调制方式全局打开或者关闭所有通道。该字段用法有特殊说明，在第7章有定义。

通道使用的频率有特殊规定，在第6章有定义。一个终端设备使用***LinkADRAns***命令对***LinkADRReq***做出应答

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **LinkADRAns Payload** | Status |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | [7:3] | 2 | 1 | 0 |
| **Status bits** | RFU | Power ACK | Data rate ACK | Channel mask ACK |

***LinkADRAns*** 状态位有如下含义:

|  |  |  |
| --- | --- | --- |
| **Channel mask ACK** | **Bit = 0** | **Bit = 1** |
| 发送的信道掩码使能了一个尚未定义的信道。该命令被丢弃，终端设备的状态没有改变。 | 发送的信道掩码被成功解析。信道当前所有的状态都根据掩码来设置的。 |
| **Data rate ACK** | 请求的数据速率终端设备不能识别或者不可能给出提供的信道掩码设置（所有使能的信道都不支持）。该命令被丢弃，终端设备的状态没有改变。 | 数据速率成功设置。 |
| **Power ACK** | 请求的功率等级无法被执行。 该命令被丢弃，终端设备的状态没有改变。 | 功率等级成功设置。 |

##### Table 6: LinkADRAns status bits signification

#### 5.3 终端设备传送工作周期 (*DutyCycleReq*, *DutyCycleAns*)

***DutyCycleReq*** 命令被网络协调器来限制终端设备的最大合计发送占空比。汇总的发射占空比和所有子频带的发射占空比是相关的。

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **DutyCycleReq Payload** | MaxDCycle |

允许的终端设备发送占空比最大值是：



**MaxDutyCycle**的有效范围是[0:15].除了区域的特殊规定外，0值对应“无占空比限制”。

值255意思是终端设备应当立即变得沉默（/转入休眠）;这相当于远程关闭终端设备。

终端设备使用***DutyCycleAns***命令对***DutyCycleReq***做出应答。***DutyCycleAns***的MAC回复不包含任何有效数据。

#### 5.4 接收窗参数 (*RXParamSetupReq*, *RXParamSetupAns*)

***RXParamSetupReq***命令允许改变一个上行传输后紧跟的第二个接收窗的频率和通信速率设定。该命令还允许编程上行链路数据速率和RX1间隙内的下行链路数据速率之间的偏移值。

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 1 | 3 |
| **RX2SetupReq Payload** | DLsettings | Frequency |

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits** | 7 | 6:4 | 3:0 |
| **DLsettings** | RFU | RX1DRoffset | RX2DataRate |

**RX1DRoffset字段设置上行数据速率和下行数据速率之间的偏移值，此下行速率指的是与终端设备通信过程中第一接收时隙（RX1）下的下行速率。默认的偏移值是0。该偏移值用于顾及在某些地区基站的最大功率约束和平衡上下行链路无线电的连接范围。**

数据速率(RX2**DataRate**)字段定义了第二接收窗的下行数据速率，该接收窗是紧跟和***LinkADRReq***命令同一个约定的命令(例如：0表示 DR0/125KhZ)。频率（**Frequency**）字段和用于第二接收窗的信道频率对应，该频率在***NewChannelReq***命令约定定义的之后被编码。

***RXParamSetupAns*** 命令被终端设备用于确认***RXParamSetupReq*** 命令的接收.。有效数据包含单一状态字节。

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **RX2SetupAns Payload** | Status |

状态 (**Status**) 位有如下含义：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bits** |  | 7:3 | 2 | 1 | 0 |
| **Status bits** |  | RFU | RX1DRoffset ACK | RX2 Data rate ACK | Channel ACK |

|  |  |  |
| --- | --- | --- |
| **Channel ACK** | **Bit = 0** | **Bit = 1** |
| 请求的频率不被终端设备使用 | RX2 间隙的信道被设定成功 |
| **RX2 Data rate ACK** | 请求的数据速率对于终端设备未知 | RX2 间隙数据速率设定成功 |
| **RX1DRoffset ACK** | RX1时隙的上下行链路数据速率偏移量不在允许的范围内 | RX1DRoffset 设定成功 |

##### Table 7: RX2SetupAns status bits signification

如果3位中的任一比特等于0，则该命令没有设置成功并且之前的参数将继续保持不变。

**5.5 终端设备状态 (***DevStatusReq***,** *DevStatusAns***)**

网络服务器可以通过***DevStatusReq*** 命令从终端设备请求状态信息。该命令没有有效数据。If a ***DevStatusReq*** 被终端设备接收, 并通过 ***DevStatusAns*** 命令进行响应。

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 1 | 1 |
| **DevStatusAns Payload** | Battery | Margin |

电池(**Battery**)电量报告编码如下：

|  |  |
| --- | --- |
| **Battery** | **Description** |
| 0 | 终端设备连接了一个外部电源。 |
| 1..254 | 电池电量，1代表最小值，254代表最大值。 |
| 255 | 终端设备不能够测量电池电量。 |

##### Table 8: Battery level decoding

范围（**Margin**）是最后一次成功接收到***DevStatusReq***命令时以dB表示并四舍五入后的解调信噪比。他是一个带符号的6位二进制整形数值，最小值是-32，最大值是31.

|  |  |  |
| --- | --- | --- |
| Bits | 7:6 | 5:0 |
| Status | RFU | Margin |

**5.6创建或修改信道（***NewChannelReq，NewChannelAns***)**

***NewChannelReq***命令既可以被用于修改现有的14个信道的参数，也可以用来创建一个新的信道。该命令用于设置新信道15的中心频率和可用的数据速率范围：

|  |  |  |  |
| --- | --- | --- | --- |
| **Size (bytes)** | 1 | 3 | 1 |
| **NewChannelReq Payload** | ChIndex | Freq | DrRange |

信道索引(**ChIndex**)是正在被创建或修改的信道标识。根据使用的区域和频带范围，该LoRaWAN规范规定默认信道对于所有设备是相同的，而且不能被***NewChannelReq***命令修改（参照第6章）。如果默认信道的数目是*N*，怎默认信道编号是0到*N*-1，用于**ChIndex**的可接受范围是*N*到15；一种设备必须能够处理至少16个不同的信道定义。在某些区域中的设备可具有存储16个以上信道的定义。

频率（**Freq**）字段是一个24位的无符号整形变量。实际信道频率等于Freq乘以100，单位是Hz，该值表示的频率低于100MHz的频率保留将来使用。这使得信道频率可以以100Hz为步进单位设置为100Mhz-1.67GHz之间的任意值。**Freq**值为0表示禁用该信道。终端设备必须检查其无线电硬件是否支持该频率，不支持的话返回错误代码。

输速率范围(**DrRange**)字段指定了该信道允许的数据速率范围。该字段被分为两个4比特的索引值：

|  |  |  |
| --- | --- | --- |
| (NewChannelReq, Bits | 7:4 | 3:0 |
| DrRange | MaxDR | MinDR |

根据第5.2章节的定义，最小数据速率(**MinDR**)子域指定了该信道的最低数据速率。例如0指定了DR0/125KHz。同样，最大数据速率 (**MaxDR**)子域指定了该信道的最高数据速率。例如，DrRange = 0x77意味着一个信道只允许50kpbs GFSK调制，DrRange = 0x50意味着支持DR0 / 125 kHz 到DR5 / 125 kHz。

新定义的通道被启用后可立即被用于通信。

终端设备通过发回一个***NewChannelAns***命令来确认***NewChannelReq***的接收。该消息的有效数据包含以下信息：

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **NewChannelAns Payload** | Status |

状态(**Status**) 位拥有以下含义：

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits** | 7:2 | 1 | 0 |
| **Status** | RFU | Data rate range ok | Channel frequency ok |

|  |  |  |
| --- | --- | --- |
| **Data rate range ok** | **Bit = 0** | **Bit = 1** |
| 指定的数据速率范围超出目前为此设备定义的值。 | 该数据速率范围与终端设备的可选项兼容 |
| **Channel frequency ok** | 该设备不能使用该频率 | 该设备可以使用该频率 |

##### Table 9: NewChannelAns status bits signification

如果两个标志位中的任何一个等于0，则该命令没有成功，新的信道没有建立。

##### 5.7 设置TX 和 RX之间的延迟 (*RXTimingSetupReq*, *RXTimingSetupAns*)

命令允许配置TX上行数据结束后和打开第一个接收间隙之间的延时时间。第二个接收时隙在第一个接收时隙之后打开1s。

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **RXTimingSetupReq Payload** | Settings |

延时 (**Delay**) 字段指定了延时。该字段被分为两个4比特索引值：

|  |  |  |
| --- | --- | --- |
| **Bits** | 7:4 | 3:0 |
| **Settings** | RFU | Del |

延时时间以秒表示。**Del**为0表示延时1s。

|  |  |
| --- | --- |
| **Del** | **Delay [s]** |
| 0 | 1 |
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| .. | .. |
| 15 | 15 |

Table 10: Del mapping table

终端设备使用没有有效数据的***RXTimingSetupAns***命令回复***RXTimingSetupReq***命令。

### 6 激活终端设备

要加入一个LoRaWAN网络，每一个终端设备必须被个性化设置和激活。

可以通过两种方式激活终端设备，即可以在终端设备被部署或复位时通过空中激活（OTAA），也可以通过个性化设置激活（APB），从而实现个性化设置和激活一步到位。

#### 6.1 终端设备激活后的数据存储

激活后，终端设备要存储以下信息：设备地址(**DevAddr**)、应用标识符(**AppEUI**)、网络会话密钥(**NwkSKey**)、应用会话密钥(**AppSKey**)。

##### 6.1.1 终端设备地址 (DevAddr)

**DevAddr** 包含32bits 来识别当前网络中的终端设备。它的格式如下:

|  |  |  |
| --- | --- | --- |
| **Bit#** | [31..25] | [24..0] |
| **DevAddr bits** | NwkID | NwkAddr |

高7位用作网络标识符（**NwkID**）以区分不同网络运营商在同一地区重叠网络的地址，同时解决漫游问题。低25位表示终端设备的网络地址（**NwkAddr**），可以由网络管理员任意分配。

##### 6.1.2 应用标识符 (AppEUI)

**AppEUI是一个全球应用ID，在**IEEE EUI64地址空间内唯一标识终端设备应用提供商。

**AppEUI**在终端设备激活过程执行之前备存储在设备中**。**

##### 6.1.3 网络会话密钥 (NwkSKey)

**NwkSKey**是为终端设备特定的网络会话密钥。它被网络服务器和终端设备用于计算和验证所有数据消息的**MIC**以保证数据的正确性。它还用于加密和解密仅包含MAC数据消息中的有效数据。

##### 6.1.4 应用会话密钥 (AppSKey)

**AppSKey** 是为终端设备特定的应用会话密钥。它被网络服务器和终端设备用于加密和解密应用特定数据消息的有效数据区。它也被用于计算和验证应用层的**MIC，该MIC**可能被包含在特定应用数据包中的有效数据中。

#### 6.2 空中激活

对于空中激活，终端设备在和网络服务器交换数据时必须遵循预定的流程进行连接。终端设备当它丢失会话上下文信息时每次必须通过一个新的连接过程。连接过程需要终端设备在连接之前使用如下信息进行个性化配置：终端设备全球唯一标识符（**DevEUI**）、应用标识符（**AppEUI**）h和AES-128密钥（**AppKey**）。 **AppEUI**在上面6.1.2中有所描述**。**

**注:** 对于空中激活，终端设备不能使用任何网络密钥进行个性化配置。相反，每当一个终端设备加入网络时， 该终端设备的特殊网络会话密钥会在网络层加密和验证传输。通过这种方式，在不同网络提供商之间漫游设备变得容易。同时使用网络会话密钥和应用会话密钥进一步将网络服务器联合起来，防止应用数据被网络提供商读取和篡改。

##### 6.2.1 终端设备标识符 (DevEUI)

**DevEUI** 是一个全球终端设备标识符，在IEEE EUI64分配的地址空间中唯一标识终端设备。

##### 6.2.2 应用密钥 (AppKey)

**AppKey** 是一个终端设备的特定的AES-128的应用密钥，它由应用程序所有者分配给终端设备，它最有可能来自于已知的应用特殊的根密钥并由应用提供者控制。每当一个终端设备通过空中激活加入网络，AppKey用于终端设备导出会话密钥NwkSKey和AppSKey，用来加密和验证网络通信和应用数据。

##### 6.2.3 连接过程

从终端设备的角度来看，加入过程包含与服务器进行的两个MAC消息的交换，即加入请求和接受连接。

##### 6.2.4 连接请求消息

连接过程总是从终端设备发送加入请求消息开始。

|  |  |  |  |
| --- | --- | --- | --- |
| **Size (bytes)** | 8 | 8 | 2 |
| **Join Request** | AppEUI | DevEUI | DevNonce |

加入请求消息包含终端设备的**AppEUI 和DevEUI，**另加2字节的随机数（**DevNonce**）

**DevNonce**是一个随机值。2对于每一个终端设备，网络服务器跟踪终端设备在过去使用过的一定数量的**DevNonce**数值， 并且忽略带有以上**DevNonce**数值的终端设备的加入请求。

**Note:这种机制可以阻止故意断开的终端设备采用预先记录的加入请求消息发起的网络攻击。**

加入请求消息的完整性代码（**MIC**）数值（见第4章MAC消息描述）的计算方式如下：[[7]](#footnote-7)

*cmac* = aes128\_cmac(AppKey, MHDR | AppEUI | DevEUI | DevNonce)

MIC = *cmac*[0..3]

加入请求消息没有加密。

##### 6.2.5 加入接受消息

如果终端设备被允许加入网络，网络服务器会使用**join-accept** 消息来响应**join-request** 消息。加入接受消息在发送时除了使用延时JOIN\_ACCEPT\_DELAY1 或 JOIN\_ACCEPT\_DELAY2（而不是RECEIVE\_DELAY1 和RECEIVE\_DELAY2,相应的）以外，其它都和正常的下行链接数据一样。 用于这两个接收窗中的通道频率和数据速率与“物理层”一章中的“接收窗”一节中描述的RX1和RX2接收窗相同。

如果连接请求不被接受，则不会对终端设备做出响应。

加入接受消息包含一个三字节的应用程序随机数（**AppNonce**）、一个网络标识符(**NetID**)、一个终端设备地址(**DevAddr**)、一个TX和RX之间的延时和一个终端设备用于加入网络的信道频率可选项列表(**CFList**)。CFList 选项有特殊说明，在第7节有定义。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 3 | 3 | 4 | 1 | 1 | (16) Optional |
| **Join Accept** | AppNonce | NetID | DevAddr | DLSettings | RxDelay | CFList |

**AppNonce** 是一个随机数或者由网络服务器提供的某种形式的唯一编码（ID），并由终端设备导出两个会话秘钥**NwkSKey** 和**AppSKey，如下所示：**[[8]](#footnote-8)

NwkSKey = aes128\_encrypt(AppKey, 0x01 | AppNonce | NetID | DevNonce | pad16)

AppSKey = aes128\_encrypt(AppKey, 0x02 | AppNonce | NetID | DevNonce | pad16)

加入接受消息的MIC值计算方式如下:4

*cmac* = aes128\_cmac(AppKey,

MHDR | AppNonce | NetID | DevAddr | RFU | RxDelay | CFList) MIC = *cmac*[0..3]

加入接受消息使用**AppKey** 自加密方式如下：

aes128\_decrypt(AppKey, AppNonce | NetID | DevAddr | RFU | RxDelay | CFList | MIC)

**注:** 网络服务器在ECB模式使用一个AES解密操作来加密加入-接受消息，使得终端设备可以使用AES加密运算来解密该消息。这样终端设备只需要执行AES加密操作而不用执行解密操作。

**注:** 建立这两个会话密钥允许联合网络服务器基础架构，其中网络运营商无法窃听应用数据。在这样的设定下，应用程序提供者必须支持网络操作员在终端设备实际加入网络过程中并为终端设备建立NwkSKey。同时，应用提供商向网络运营商承诺，任何由终端设备产生的流量将计费并保留对AppSKey的完全控制权以保护应用程序数据。

**NetID** 的格式如下: **NetID的低7位（LSB）叫做** **NwkID，并且和前面描述的终端设备短地址的高7位(MSB）匹配。相邻或者重叠的网络必须具有不同的NwkID**s。剩下的高17位（MSB）可由网络运营商自由选择。

**DLsettings** 字段包含下行链路配置：

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits** | 7 | 6:4 | 3:0 |
| **DLsettings** | RFU | RX1DRoffset | RX2 Data rate |

RX1DRoffset 字段设置上行和下行数据速率的偏移量，用于在第一接收时隙（RX1）和终端设备通信。此偏移量默认值是0。下行链路数据速率总是低于或等于上行链路数据速率。该偏移用于考虑在某些地区基站的最大功率密度约束，并平衡上行和下行链路无线电连接范围。T

上行和下行链路数据速率的实际关系有特殊规定，并在“物理层”章节详述。

延迟 **RxDelay** 和***RXTimingSetupReq* 命令中的Delay** 字段遵循形同的约定。

#### 6.3 个性化配置激活

在某些情况下，终端设备可以被个性化配置激活。个性化配置激活绕过**join request** - **join accept过程直接一个终端设备到一个特殊网络。**

通过个性化配置配置激活终端设备意味着**DevAddr 和两个会话密钥NwkSKey** 与**AppSKey直接存储到终端设备中而不是通过DevEUI,** 、**AppEUI** 和**AppKey**来获取。终端设备在启动时配置了加入特定LoRa网络所需的信息。

每个设备应该有一个独特的NwkSKey和AppSKey。暴露一个设备的密钥不应当损害其它设备通信的安全性。建立这些密钥的过程不能以任何方式公开其信息（例如，节点地址）。

### 7 Physical Layer

#### 7.1 EU 863-870MHz ISM Band

##### 7.1.1 EU863-870 Preamble Format

应使用下面的同步字：

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

**Table 11: EU863-870 synch words**

##### 7.1.2 EU863-870 ISM Band channel frequencies

在欧洲，无线电频谱是由ETSI [EN300.220]定义的ISM分配的。

网络信道可以由网络运营商自由的组合使用。然而以下三个默认信道不许在每一个EU868MHz 终端设备中实现。这三个信道是所有网络网关应当一直监听最小设定。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 12: EU863-870 default channels

为了访问物理媒介ESTI增加了一些限制，例如最大的发射时间或者每小时传送可发送的次数。ETSI规定中允许选择使用一个占空比限制或者一个称作**Listen Before Talk Adaptive Frequency Agility** (LBT AFA)的传输管理。当前的LoRaWAN规范仅使用占空比限制传输来执行ETSI规定。

LoRaWAN强制对每一个子频带进行限制。每一帧都在给定的子频带内发送，发射时间和帧在空中持续时间被当前子频带记录下来。当前的子频带在接下来的*Toff*秒内不能被再次使用：



在给定的子频带不可用时，该设备仍然能够在另一个子频带传送。如果所有的子频带都不可用，设备必须在传输前等待。设备根据子频带的可用性调整其信道希望的序列。

例如:一个设备在一个默认信道中只能传输0.5s 长的帧。该通道在子频带中允许1%的占空比。因此这整个子频带（868 – 868.6）将有49.5s不可用。

EU868MHz ISM 频段终端设备应当使用如下默认参数。

 默认辐射传输输出功率：14dBm

EU868Mhz 终端设备应当能够在863-870MHz之间进行操作，并且应当设有信道的数据结构来存储至少16个信道的参数。信道的数据结构对应一个频率和一组用于此频率的数据速率。

前三个通道分别对应868.1，868.3，和868.5MHz/ DR0到DR5，并且必须在每一个终端设备中实现。这些默认通道不能够通过***NewChannelReq***命令修改，并保证在终端设备和网络网关之间一个最小的公共信道集合。

下面的表格中给出了终端设备用于广播加入请求数据的频率列表。加入请求消息的发送占空比决不能超过0.1%。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Modulation** | **Bandwidth [kHz]** | **Channel**  **Frequency**  **[MHz]** | **FSK**  **Bitrate or LoRa**  **DR**  **/ Bitrate** | **Nb Channels** | **Duty cycle** |
| LoRa | 125 | 864.10  864.30  864.50  868.10  868.30  868.50 | DR0 – DR5  / 0.3-5 kbps | 6 | <0.1% |

**Table 13: EU863-870 JoinReq Channel List**

###### 7.1.3 EU863-870 Data Rate and End-point Output Power encoding

下面的编码用于EU863-870频带中的数据速率（DR）和终端节点输出功率（TXPower）：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **DataRate** | **Configuration** | **Indicative physicalbit rate [bit/s]** |  | **TXPower** | **Configuration** |
| 0 | LoRa: SF12 / 125 kHz | 250 | 0 | 20 dBm (if supported) |
| 1 | LoRa: SF11 / 125 kHz | 440 | 1 | 14 dBm |
| 2 | LoRa: SF10 / 125 kHz | 980 | 2 | 11 dBm |
| 3 | LoRa: SF9 / 125 kHz | 1760 | 3 | 8 dBm |
| 4 | LoRa: SF8 / 125 kHz | 3125 | 4 | 5 dBm |
| 5 | LoRa: SF7 / 125 kHz | 5470 | 5 | 2 dBm |
| 6 | LoRa: SF7 / 250 kHz | 11000 | 6..15 | RFU |
| 7 | FSK: 50 kbps | 50000 |  |  |
| 8..15 | RFU |  |  |  |

**Table 14: Data rate and TX power table**

###### 7.1.4 EU863-870 JoinAccept CFList

在EU 863-870 ISM 频段LoRaWAN在加入接受消息中实现了16个字节的可选信道频率列表(CFlist)。

在这种情况下，CFList是信道4到8的五个信道频率的列表，因此五个频率被编码城24位的无符号整形值（3字节）。所有这些通道可用于DR0-DR5 125kHzLoRa调制。频率列表加一个RFU字节组成所有的16字节。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Size**  **(bytes)** | 3 | 3 | 3 | 3 | 3 | 1 |
| **CFList** | Freq Ch4 | Freq Ch5 | Freq Ch6 | Freq CN7 | Freq Ch8 | RFU |

实际的信道频率值由100乘以频率值得到，单位是Hz，低于100Mhz被保留将来使用。这允许以100Hz为步进值设置信道频率为100MHz到1.67GHz之间的任意值。未使用的信道频率值为0。**CFList**是一个可选项，并且它可以通过加入接受消息的长短被探测到。如果存在，**CFList**将替换之前存储在终端设备中所有信道，在第6章中定义的三个默认信道除外。新定义的信道立即启用并用于终端设备通信。

##### 7.1.5 EU863-870 LinkAdrReq command

EU863-870 LoRaWAN 仅支持最多16个通道。当**ChMaskCntl** 字段为0时，ChMask 字段单独启用或禁用16信道中的每一个。

|  |  |
| --- | --- |
| **ChMaskCntl** | **ChMask applies to** |
| 0 | 信道1 -16 |
| 1 | RFU |
| .. | .. |
| 4 | RFU |
| 5 | RFU |
| 6 | All channels ON  设备应当独立于ChMask字段值使能所有当前定义的信道。  The device should enable all currently defined channels independently of the ChMask field value. |
| 7 | RFU |

###### Table 15: ChMaskCntl value table

如果ChMask字段值是一个代表RFU的值，终端设备应当拒绝执行命令并在响应中不设置“**Channel mask ACK**”位。

##### 7.1.6 EU863-870 Maximum payload size

最大的 **MACPayload** 大小长度(*M)*由下表给出. 它由PHY层根据有效调制速率导出，用于考虑一个可能的中继封装层。给出的可选**FOpt** 控制字段(*N*) 缺省时最大的应用负载长度仅供参考。**FOpt** 字段如果不为空，N的值可能更小：

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 d | | efined | |

###### Table 16: EU863-870 maximum payload size

如果终端设备从来不和中继器进行操作，则在可选项**FOpt** 控制字段缺省情况下最大应用负载长度应该是：

|  |  |  |  |
| --- | --- | --- | --- |
| **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 d | efined |

**Table 17 : EU863-870 maximum payload size (not repeater compatible)**

##### 7.1.7 EU863-870 Receive windows

RX1接收窗和前述上行链路使用相同的信道。数据速率是一个上行数据速率的函数，RX1DROffset在下表中给出。RX1DROffset的允许值在[0:5]范围，范围[6:7]的值保留将来使用。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 |

RX2接收窗使用固定的频率和数据速率。默认参数是869.525 MHz / DR0 (SF12, 125 kHz)。

##### 7.1.8 EU863-870 Default Settings

以下参数是EU863-870Mhz频段的推荐值。

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)

如果在终端设备中实现的实际参数值和默认值不同（例如，终端设备使用更长的RECEIVE\_DELAY1 和RECEIVE\_DELAY2延迟），这些参数必须在终端设备启动过程中通过频带外信道通知网络服务器。网络服务器可能不会接受和这些默认值不同的参数。

#### 7.2 US 902-928MHz ISM Band

##### 7.2.1 US902-928 Preamble Format

应当使用如下同步关键字：

|  |  |
| --- | --- |
| **Sync word** | **Preamble length** |
| 0x34 | 8 symbols |

**Modulation**

**LORA**

LoRaWAN 在US902-928 ISM频段不会使用 GFSK 调制。

##### 7.2.2 US902-928 Channel Frequencies

915MHz ISM频段将被分为如下信道方案：

 上行数据流– 64 个编号为 0 to 63 的信道使用从DR0 到DR3 的LoRa 125 kHz 带宽（BW），频率从902.3 MHz 开始到914.9MHz 结束以200kHz线性增长

 上行数据流– 8 个编号为 64 to 71 的信道使用从DR4 开始的LoRa 500kHz 带宽（BW），频率从903.0 MHz 开始到914.2 MHz 结束以1.6 MHz线性增长

 下行数据流– 8 个编号为 0 to 7 的信道使用从DR10到DR13的LoRa 500kHz 带宽（BW），频率从923.3 MHz 开始到927.5 MHz 结束以600 kHz线性增长

64 + 8 uplink channels 8x downlink channels

**….**

**….**

902.3 903.0 904.6 914.2 923.3 923.9 927.5

###### Figure 10: US902-928 channel frequencies

915 MHz ISM频段终端设备应当使用如下默认参数：

 默认辐射传输输出功率：20dBm

o 设备在使用125kHz带宽（BW）传送时，可使用的最大的功率为+30 dBm。传输不应该持续400ms以上。

o设备在使用500 kHz带宽（BW）传送时，可使用的最大的功率为+26 dBm。

US902-928 终端设备应当能够在902至928MHz频带内操作，并且提供一个信道数据结构存储72个信道的参数。一个信道数据结构对应一个频率和一组在此频率上使用的数据速率。

如果使用空中激活过程，终端设备应当在使用DR0定义的64个125kHz信道中和使用DR4定义的8个500KHz信道随机进行广播加入请求消息。终端设备应当为每一次传输改变信道。

##### 7.2.3 US902-928 Data Rate and End-point Output Power encoding

在US902-928频带内数据速率(**DR**)和终端节点输出功率编码(**TXPower**)如下：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **DataRate** | **Configuration** | **Indicative physical bit rate [bit/sec]** |  | **TXPower** | **Configuration** |
| 0 | LoRa: SF10 / 125 kHz | 980 |  | 0 | 30 dBm – 2\*TXpower |
| 1 | LoRa: SF9 / 125 kHz | 1760 | 1 | 28 dBm |
| 2 | LoRa: SF8 / 125 kHz | 3125 | 2 | 26 dBm |
| 3 | LoRa: SF7 / 125 kHz | 5470 | 3 : 9 | …. |
| 4 | LoRa: SF8 / 500 kHz | 12500 | 10 | 10 dBm |
| 5:7 | RFU |  | 11:15 | 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 18: Data rate and TX power table (Rem: DR4 is identical to DR12, DR8..13 must be implemented in** 3 **end-devices and are reserved for future applications)**

##### 7.2.4 US902-928 JoinResp CFList

US902-928 LoRaWAN 不支持在加入响应消息中使用可选的**CFlist** 。如果**CFlist** 不为空，它将被终端设备忽略。

##### 7.2.5 US902-928 LinkAdrReq command

对于 US902-928 版本，***LinkADRReq*** 命令中的**ChMaskCntl** 字段有如下含义：

|  |  |
| --- | --- |
| **ChMaskCntl** | **ChMask applies to** |
| 0 | Channels 0 to 15 |
| 1 | Channels 16 to 31 |
| .. | .. |
| 4 | Channels 64 to 71 |
| 5 | RFU |
| 6 | All 125 kHz ON  ChMask applies to channels 65 to 72 |
| 7 | All 125 kHz OFF  ChMask applies to channels 65 to 72 |

###### Table 19: ChMaskCntl value table

如果**ChMaskCntl=6（resp 7），**125kHz信道启用（resp禁用）。同时信道64到71根据**ChMask**位掩码设定。

**注:** FCC 规定当使用最大输出功率时需要至少在50个信道之间跳跃的能力。当限制终端设备传输功率最大为21dBm时，设备可能具有较少的信道（至少6个125kHz信道）。

##### 7.2.6 US902-928 Maximum payload size

最大的**MACPayload** 大小长度(*M*)由下表给出。它是在卡绿岛可能的中继器封装后从PHY(硬件)层允许的最大传输时间导出的。在可选项**FOpt** MAC控制字段缺省的情况下给出的最大应用负载长度（***N***）仅供参考。***N***的值在**FOpt** 字段不为空时可能更小：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DataRate** | ***M*** |  |  | ***N*** |
| 0 | 19 |  |  | 11 |
| 1 | 61 |  |  | 53 |
| 2 | 137 |  |  | 129 |
| 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 20: US902-928 maximum payload size (repeater compatible)

灰色线对应的数据速率可被中继器下面的终端设备使用。

如果该终端设备从来不运行在中继器下面，则在可选**FOpt**控制字段缺省时最大应用负载长度应该是：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DataRate** | ***M*** |  |  | ***N*** |
| 0 | 19 |  |  | 11 |
| 1 | 61 |  |  | 53 |
| 2 | 137 |  |  | 129 |
| 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 | |  |

**Table 21 : US902-928 maximum payload size (not repeater compatible)**

###### 7.2.7 US902-928 接收窗

* RX1接收信道是上行信道用于启动数据交换的功能。RX1接收信道算法如下：
* o RX1 Channel Number = Transmit Channel Number modulo 8

（RX1\_CN =T\_CN+8n）

* RX1 接收窗数据速率取决于发送数据速率（见下表22）。
* RX2 (第二接收窗) 使用固定的数据速率和频率设置。默认参数是923.3Mhz / DR8。

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **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 |
| DR8 | DR8 | DR8 | DR8 | DR8 |
| DR9 | DR9 | DR8 | DR8 | DR8 |
| DR10 | DR10 | DR9 | DR8 | DR8 |
| DR11 | DR11 | DR10 | DR9 | DR8 |
| DR12 | DR12 | DR11 | DR10 | DR9 |
| DR13 | DR13 | DR12 | DR11 | DR10 |

Table 22: Data rate mapping

RX1DROffset的允许值在[0:3]范围内，在[4:7]范围内的值保留将来使用。

###### 7.2.8 US902-928 Default Settings

以下参数是US902-928频带的推荐值。

|  |  |  |
| --- | --- | --- |
| 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) |

如果在终端设备中实现的实际参数值和默认值不同（例如，终端设备使用更长的RECEIVE\_DELAY1 和RECEIVE\_DELAY2延迟），这些参数必须在终端设备启动过程中通过频带外信道通知网络服务器。网络服务器可能不会接受和这些默认值不同的参数。

#### 7.3 China 779-787MHz ISM Band

##### 7.3.1 CN779-787 Preamble Format

以下同步关键字应当被使用：

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

**Table 23: CN779-787 synch words**

###### 7.3.2 CN779-787 ISM Band channel frequencies

LoRaWAN 可以在中国 779-787MHz 频段使用，只要无线设备EIRP少于10mW（或10dBm）即可。

终端设备发送占空比应当低于1%。

LoRaWAN 信道的中心频率可以在如下范围内：

* 最小频率 : 779.5Mhz
* 最大频率 : 786.5 MHz

CN780Mhz终端设备应当能够在779-787 MHz之间进行操作，并且应当设有信道的数据结构来存储至少16个信道的参数。信道的数据结构对应一个频率和一组用于此频率的数据速率。

前三个信道分别对应779.5，779.7，和779.9MHz/ DR0到DR5，并且必须在每一个终端设备中实现。这些默认信道不能够通过***NewChannelReq***命令修改，并保证在终端设备和网络网关之间一个最小的公共信道集合。其它信道可以在每个基础网的网络允许的频率范围内自由分配。

下面的表格中给出了终端设备用于广播加入请求消息的频率列表。加入请求消息的发送占空比决不能超过0.1%。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 24: CN780 JoinReq Channel List**

##### 7.3.3 CN779-787 Data Rate and End-point Output Power encoding

下面的编码用于CN780频带中的数据速率（DR）和终端节点输出功率（TXPower）：

**DataRate Configuration Indicative physical TXPower Configuration**

**bit rate [bit/s]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 0 | LoRa: SF12 / 125 kHz | 250 |  | 0 | 10 dBm |
| 1 | LoRa: SF11 / 125 kHz | 440 | 1 | 7 dBm |
| 2 | LoRa: SF10 / 125 kHz | 980 | 2 | 4 dBm |
| 3 | LoRa: SF9 / 125 kHz | 1760 | 3 | 1 dBm |
| 4 | LoRa: SF8 / 125 kHz | 3125 | 4 | -2 dBm |
| 5 | LoRa: SF7 / 125 kHz | 5470 | 5 | -5 dBm |
| 6 | LoRa: SF7 / 250 kHz | 11000 | 6..15 | RFU |
| 7 | FSK: 50 kbps | 50000 |  |  |
| 8..15 | RFU |  |  |  |

**Table 25: Data rate and TX power table**

##### 7.3.4 CN779-787 JoinAccept CFList

CN780 ISM 频段LoRaWAN在加入接受消息中实现了16个字节的可选信道频率列表(CFlist)。

在这种情况下，CFList是信道4到8的五个信道频率的列表，因此五个频率被编码成24位的无符号整形值（3字节）。所有这些通道可用于DR0-DR5 125kHzLoRa调制。频率列表加一个RFU字节组成所有的16字节。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Size**  **(bytes)** | 3 | 3 | 3 | 3 | 3 | 1 |
| **CFList** | Freq Ch4 | Freq Ch5 | Freq Ch6 | Freq CN7 | Freq Ch8 | RFU |

实际的信道频率值由100乘以频率值得到，单位是Hz，低于100Mhz被保留将来使用。这允许以100Hz为步进值设置信道频率为100MHz到1.67GHz之间的任意值。未使用的信道频率值为0。**CFList**是一个可选项，并且它可以通过加入接受消息的长短被探测到。如果存在，**CFList**将替换之前存储在终端设备中所有信道，在第6章中定义的三个默认信道除外。新定义的信道立即启用并用于终端设备通信。

##### 7.3.5 CN779-787 LinkAdrReq command

CN780 LoRaWAN仅支持最多16个通道。当**ChMaskCntl** 字段为0时，ChMask 字段单独启用或禁用16信道中的每一个。

|  |  |
| --- | --- |
| **ChMaskCntl** | **ChMask applies to** |
| 0 | Channels 1 to 16 |
| 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 26: ChMaskCntl value table

如果ChMask字段值是一个代表RFU的值，终端设备应当拒绝执行命令并在响应中不设置“**Channel mask ACK**”位。

###### 7.3.6 CN779-787 Maximum payload size

最大的 **MACPayload** 大小长度(*M)*由下表给出. 它由PHY层根据有效调制速率导出，用于考虑一个可能的中继封装层。给出的可选**FOpt** 控制字段(*N*) 缺省时最大的应用负载长度仅供参考。**FOpt** 字段如果不为空，N的值可能更小：

|  |  |  |  |
| --- | --- | --- | --- |
| **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 d | efined |

16 Table 27: CN780 maximum payload size

如果终端设备从来不和中继器进行操作，则在可选项**FOpt** 控制字段缺省情况下最大应用负载长度应该是：

|  |  |  |
| --- | --- | --- |
| **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 28 : CN780 maximum payload size (not repeater compatible)**

##### 7.3.7 CN779-787 Receive windows

RX1接收窗和前述上行链路使用相同的信道。数据速率是一个上行数据速率额函数，RX1DROffset在下表中给出。RX1DROffset的允许值在[0:5]范围，范围[6:7]的值保留将来使用。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 |

RX2接收窗使用固定的频率和数据速率。默认参数是786 MHz / DR0 。

###### 7.3.8 CN779-787 Default Settings

|  |  |  |
| --- | --- | --- |
| 以下参数是CN779-787MHz频段的推荐值。 | | |
| 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) |

如果在终端设备中实现的实际参数值和默认值不同（例如，终端设备使用更长的RECEIVE\_DELAY1 和RECEIVE\_DELAY2延迟），这些参数必须在终端设备启动过程中通过频带外信道通知网络服务器。网络服务器可能不会接受来自这些和默认值不同的参数。

#### 7.4 EU 433MHz ISM Band

##### 7.4.1 EU433 Preamble Format

应当使用如下的同步关键字：

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

**Table 29: EU433 synch words**

###### 7.4.2 EU433 ISM Band channel frequencies

LoRaWAN 可以使用 ETSI 433-434 MHz 频带，只要无线设备EIRP少于10mW（或10dBm）即可.

终端设备发送占空比应当低于1%[[9]](#footnote-9)。

LoRaWAN 信道的中心频率可以在如下范围内：

* 最小频率 : 433.175 MHz
* 最大频率 : 434.665 MHz

EU433终端设备应当能够在433.05-434.79 MHz之间进行操作，并且应当设有信道的数据结构来存储至少16个信道的参数。信道的数据结构对应一个频率和一组用于此频率的数据速率。

前三个信道分别对应433.175，433.375，和433.575/ DR0到DR5，并且必须在每一个终端设备中实现。这些默认信道不能够通过***NewChannelReq***命令修改，并保证在终端设备和网络网关之间一个最小的公共信道集合。其它信道可以在每个基础网的网络允许的频率范围内自由分配。

下面的表格中给出了终端设备用于广播加入请求消息的频率列表。加入请求消息的发送占空比决不能超过0.1%。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 30: EU433 JoinReq Channel List**

##### 7.4.3 EU433 Data Rate and End-point Output Power encoding

下面的编码用于EU433频带中的数据速率（DR）和终端节点输出功率（TXPower）：

**DataRate Configuration Indicative physical TXPower Configuration**

**bit rate [bit/s]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 0 | LoRa: SF12 / 125 kHz | 250 |  | 0 | 10 dBm |
| 1 | LoRa: SF11 / 125 kHz | 440 | 1 | 7 dBm |
| 2 | LoRa: SF10 / 125 kHz | 980 | 2 | 4 dBm |
| 3 | LoRa: SF9 / 125 kHz | 1760 | 3 | 1 dBm |
| 4 | LoRa: SF8 / 125 kHz | 3125 | 4 | -2 dBm |
| 5 | LoRa: SF7 / 125 kHz | 5470 | 5 | -5 dBm |
| 6 | LoRa: SF7 / 250 kHz | 11000 | 6..15 | RFU |
| 7 | FSK: 50 kbps | 50000 |  |  |
| 8..15 | RFU |  |  |  |

**Table 31: Data rate and TX power table**

##### 7.4.4 EU433 JoinAccept CFList

在EU433 ISM 频段LoRaWAN在加入接受消息中实现了16个字节的可选信道频率列表(CFlist)。

在这种情况下，CFList是信道4到8的五个信道频率的列表，因此五个频率被编码成24位的无符号整形值（3字节）。所有这些通道可用于DR0-DR5 125kHzLoRa调制。频率列表加1个RFU字节组成所有的16字节。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 3 | 3 | 3 | 3 | 3 | 1 |
| **CFList** | Freq Ch4 | Freq Ch5 | Freq Ch6 | Freq CN7 | Freq Ch8 | RFU |

实际的信道频率值由100乘以频率值得到，单位是Hz，低于100Mhz被保留将来使用。这允许以100Hz为步进值设置信道频率为100MHz到1.67GHz之间的任意值。未使用的信道频率值为0。**CFList**是一个可选项，并且它可以通过加入接受消息的长短被探测到。如果存在，**CFList**将替换之前存储在终端设备中所有信道，在第6章中定义的三个默认信道除外。新定义的信道立即启用并用于终端设备通信。

##### 7.4.5 EU433 LinkAdrReq command

CN780 LoRaWAN 仅支持最多16个通道。当**ChMaskCntl** 字段为0时，ChMask 字段单独启用或禁用16信道中的每一个。

|  |  |
| --- | --- |
| **ChMaskCntl** | **ChMask applies to** |
| 0 | Channels 1 to 16 |
| 1 | RFU |
| .. | .. |
| 4 | RFU |
| 5 | RFU |
| 6 | All channels ON  The device should enable all currently defined channels independently of the ChMask field value. |

###### Table 32: ChMaskCntl value table

如果ChMask字段值是一个代表RFU的值，终端设备应当拒绝执行命令并在响应中不设置“**Channel mask ACK**”位。

###### 7.4.6 EU433 Maximum payload size

最大的 **MACPayload** 大小长度(*M)*由下表给出. 它由PHY层根据有效调制速率导出，用于考虑一个可能的中继封装层。给出的可选**FOpt** 控制字段(*N*) 缺省时最大的应用负载长度仅供参考。**FOpt** 字段如果不为空，N的值可能更小：

|  |  |  |  |
| --- | --- | --- | --- |
| **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 d | efined |

Table 33: EU433 maximum payload size

如果终端设备从来不和中继器进行操作，则在可选项**FOpt** 控制字段缺省情况下最大应用负载长度应该是：

|  |  |  |
| --- | --- | --- |
| **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 34 : EU433 maximum payload size (not repeater compatible)**

##### 7.4.7 EU433 Receive windows

RX1接收窗和前述上行链路使用相同的信道。数据速率是一个上行数据速率额函数，RX1DROffset在下表中给出。RX1DROffset的允许值在[0:5]范围，范围[6:7]的值保留将来使用。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 |

RX2接收窗使用固定的频率和数据速率。默认参数是434.665MHz / DR0 (SF12 , 125kHz)

###### 7.4.8 EU433 Default Settings

以下参数是 EU863-870Mhz 频段的推荐值：

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)

如果在终端设备中实现的实际参数值和默认值不同（例如，终端设备使用更长的RECEIVE\_DELAY1 和RECEIVE\_DELAY2延迟），这些参数必须在终端设备启动过程中通过频带外信道通知网络服务器。网络服务器可能不会接受来自这些和默认值不同的参数。

## CLASS B – BEACON

### 8 B类协议介绍

本节将介绍LoRaWAN B类协议层，一个专门为由电池供电的在移动中或挂在某个固定地方的终端设备优化的协议。

当需要在固定时间间隔打开接收窗以使能服务器启动下行链路数据传输时，终端设备应当实现B类操作协议。

LoRaWAN B类选项在终端设备中增加了一个同步接收窗。

LoRaWAN A类协议的一个限制是从终端设备发送数据的Aloha方法；当客户应用程序或者服务器想要联系终端设备时，它不能够得到一个确切的反应时间。B类协议的目的是有一个终端设备在可预见的时间内可以接收，除了遵循A类终端设备随机上行传输的接收窗以外。B类协通过具有的网关发送一个基本的常规信标来同步网络中所有的终端设备，这样使得终端设备能够在周期性的时隙内以可预测的时间打开一个短的额外接收窗（叫“ping slot”）。

**注:** 从A类转到B类协议是由终端设备的应用才来决定的。如果需要从网络侧控制A类协议转向B类协议的开关，客户应用程序必须使用终端设备的A类协议上行传输从而得到发回的下行应用层指令，并且需要终端设备在应用层识别这种请求-该过程没有在LoRaWAN 层进行管理。

### 9 启动下行传输同步网络的原理 (Class-B option)

对于一个支持B类协议的终端设备，所有的网关必须同步广播一个信标来向终端设备提供时间参考。基于该时基参考的终端设备能够周期性的打开接收窗，以下称作“ping slot”，可用于基础网络设施启动下行传输通信。网络使用这些称作“ping”网络探测时隙启动下行链路。网关被选中启动下行链路传输是由网络服务器根据终端设备最后上行传输的信号质量标识符进行选择的。出于这个原因，如果一个终端设备移动并且探测到在接收到的信标中广播的身份发生了变化，它必须向网络服务器发送一个上行链路数据使得服务器能够更新下行路由路径数据库：

所有终端设备以A类协议终端设备启动和加入网络。终端设备应用程序可以决定切换到B类协议。这通过一下过程完成：

* 终端设备应用请求LoRaWAN层切换到B类协议模式。终端设备内的LoRaWAN层搜索信标并在发现并锁定网络信标信标时向应用层简单的返回一个BEACON\_LOCKED服务，或者返回BEACON\_NOT\_FOUND服务。为了加快发现信标，LoRaWAN层可以使用后述的“BeaconTimingReq”消息。
* 根据信标的强度和电池寿命的限制，终端设备应用选择一个网络探测间隙数据速率和周期，然后从终端设备的LoRaWAN层请求它们。
* 一旦进入B类协议模式，MAC层将每一个发送的上行链路帧的FCTRL字段中的*Class B位*设置为1。该位通知服务器该设备切换到了B类协议模式。MAC层将自动为每一个信标和网络探测时隙调度一个接收时隙。 当信标接收成功，终端设备的LoRaWAN层转发信标内容和测量到的无线电信号强度。终端设备LoRaWAN层在信标接收时隙和网络搜索时隙的调度中考虑最大可能的时钟漂移。当在一个网络搜索间隙中一个下行连接数据被成功解调，它以和LoRaWAN A类规范中描述的相同的方式处理它。
* 一个移动终端设备必须周期行的通知网络服务器他的位置以更新下行链路路由。这是由发送一个正常的（可能为空）“未确认”或者“确认的”上行数据来完成的。 终端设备LoRaWAN层将适当的设置 *Class B*位为1。如果应用通过分析信标内容探测到节点移动，这可以更有效率的完成。这种情况下，终端设备必须在信标接收和上行链路传输之间应用一个随机延时（如章节15.5定义）以避免系统的上行链路数据发生冲突。
* 如果在给定的时间（如章节12.2定义）内没收到信标，和网络的同步将丢失。MAC层必须通知应用程序它必须切换回A类协议。 作为结果，终端设备的LoRaWAN层在所有上行链路中停止设置*Class* B位，同事这也通知网络服务器终端设备不再是B类协议模式。终端设备应用可以周期性的尝试切换到B类协议模式。这将会从起开始搜索信标的过程。

下图说明了信标接收时隙和网络探测时隙的该念。

gateway

End

-

device

End

-

device

RX windows

Network beacon

transmission

Network beacon

transmission

ping

End

-

device

response

**Figure 11: Beacon reception slot and ping slots**

在这个例子中，给定的信标周期是128s，终端设备每隔32s开启一个网络探测时隙。大多数情况下该网络探测时隙未被服务器使用，因此，只要无线电收发器评估到当前无限电信道没有前导码终端设备就会立即关闭接收窗。如果一个前导码被探测到，无线电收发器将运行至下行连接帧解调完成。然后MAC层将会处理该帧数据，在将数据转发到应用层之前检查地址字段是否匹配终端设备地址和消息正确性检查是否有效。

### 10 Uplink frame in Class B mode

在B类协议模式下上行链路帧和A类协议模式下上行链路相同，帧头中FCtrl字段内的RFU位除外。在A类协议中该位不使用（RFU）。该位用于B类协议上行链路。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bit#** | 7 | 6 | 5 | 4 | 3..0 |
| **FCtrl** | ADR | ADRACKReq | ACK | Class B | FOptsLen |

上行链路中*Class B*位设为 1 示意设备已经前换位B类协议模式并且准备好接收调度下行链接网络探测 。

FPending位的意义对于下行链接来书不变，仍然预示着一个或多个下行帧在服务器中排队等待发送到终端设备，该设备应当像A类协议规范中描述的一样保持接收器开启 。

### 11 Downlink Ping frame format (Class B option)

#### 11.1 Physical frame format

下行链路网络探测（Ping）和A类协议下行链路数据帧使用相同的格式，但是可能遵循不同的信道频率规划。

#### 11.2 Unicast & Multicast MAC messages

消息可以是“单播”或“组播”。单播消息发送到单一的终端设备，组播消息发送到多个终端设备。一个组播组内所有设备必须共享相同的组播地址和相关的加密密钥。LoRaWAN B类协议规范没有指定方法来远程设置这样的广播组或者安全的分发所需的组播密钥数据。这必须在节点进行个性化配置或在应用层执行。

##### 11.2.1 Unicast MAC message format

单播下行链路**Ping**的MAC有效数据使用A类协议规范中定义的格式，它由终端设备以完全相同的方式进行处理。相同的帧计数器被使用并增加，无论下行链路使用B类协议的网络探测（ping）时隙还是A类协议的“携带”时隙。

##### 11.2.2 Multicast MAC message format

组播帧共享大多数的单播帧格式，除了少量例外：

* 它们不允许携带MAC指令，在端口0上既不能存在于**FOpt**字段也不能在有效数据上，因为组播下行链路不具有和单播数据帧相同的认证稳定性。
* **ACK**和**ADRACKReq位必须为0。MType字段必须携带记录未经确认的数据的值。**
* **FPending**位表示有更多的广播数据需要发送。如果它被设置则下一个组播接收时隙将会携带一个数据帧。如果它没有被设置则下一个时隙可能携带也可能不携带数据。这一位可被终端设备用于冲突的接收时隙优先级评估。

### 12 Beacon acquisition and tracking

在从A类协议切换到B类协议之前，终端设备必须首先接收一个网络信标来对其它内部的时钟与网络的参考。

一旦切换到B类协议，终端设备必须周期性的搜索和接收一个网络信标来修正它内部基准时钟相对于网络时间之间产生的任何漂移。

一个B类协议设备可能暂时无法接收信标（超出网关的范围，存在干扰等等）。在这种情况下，考虑到终端设备内部时钟可能的漂移，终端设备必须逐渐的扩大其信标和网络探测时隙接收窗。

**注:例如，一个内部时钟限定精度为+/-10ppm的终端设备在每一个信标周期内可能产生+/-1.3ms的漂移。**

#### 12.1 Minimal beacon-less operation time

在信标丢失的情况下，设备在接收到最后一个信标后应当能够继续维持B类协议操作2小时（120分钟）。这种没有信标的临时的B类协议操作称作“beacon-less”操作。它依赖于终端设备自身的时钟保持定时。

在丢失信标的操作下，单播、组播和信标接收时隙必须全部逐渐扩大来迁就终端设备可能的时钟漂移。

End

-

device

End

-

device

receives the

beacon

Beacon reception

window

End

-

device

temporarily stop

receiving beacon

End

-

device receives a

beacon and resets the

reception window length

Reception window

enlarges to

accommodate clock drift

**Figure 12 : beacon-less temporary operation**

#### 12.2 Extension of beacon-less operation upon reception

在这120分钟时间间隔之内任何针对于该设备的信标被接受到，应当通过下一个120分钟来进一步延长B类无信标操作，若它允许修正任何时钟漂移和复位接收时隙长短。

#### 12.3 Minimizing timing drift

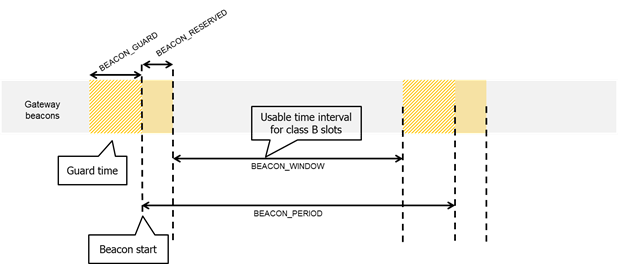
终端设备可以使用信标（如果可用）精确地周期来校准自己的内部时钟，因而降低初始时钟的不精确。作为时钟振荡器表现出可预测的频率温漂，可以使用温度传感器来进一步最小化定时器的温漂。

### 13 Class B Downlink slot timing

#### 13.1 Definitions

终端设备要想在B类协议下成功操作，必须在相对于基础设施信标的精准时刻打开接收时隙。

两个连续的信标的开始之间的间隔被称作信标周期。信标帧发送与BEACON\_RESERVED间隔的开始对齐。每一个信标是由没有网络探测（ping）时隙放置的保护时间间隔之后。保护的间隔长度和在空中最大允许的帧对应。这是为了确保恰巧在保护时间之前在网络探测（ping）间隙内下行链路启动不会和信标传输冲突。这使得网络探测（ping）时隙的时间间隔因此跨越了信标结束后保留时间间隔到下一个信标守护间隔的开始。



**Figure 13: Beacon timing**

|  |  |
| --- | --- |
| Beacon\_period | 128 s |
| Beacon\_reserved | 2.120 s |
| Beacon\_guard | 3.000 s |
| Beacon-window | 122.880 s |

**Table 35: Beacon timing**

空中的信标帧时间相比信标保留时间间隔来说实际上很短，这允许在将来增加网络控制广播帧。

信标窗口间隔被分成212 = 4096 份网络探测（ping）时隙，每一个30ms，编号为0到4095。

使用时隙编号N的终端设备必须在信标开始后正好*Ton*秒后打开其接收器:

*Ton* = *beacon*\_*reserved* + *N* \* 30 ms N 称为时隙索引（ *slot index）。*

最后一个网络探测（ping）时隙在信标开始后的 *beacon*\_*reserved* + 4095 \* 30 ms = 124 970 ms时刻或者在下一个信标开始之前的3030ms时刻开始。

#### 13.2 Slot randomization

为了避免系统冲突或者过度监听问题，时隙索引是随机的并且在每一个信标周期都会改变。

使用如下参数:

|  |  |
| --- | --- |
| **DevAddr** | Device 32 bit network unicast or multicast address |
| *pingNb* | Number of ping slots per beacon period. This must be a power of 2 integer: *pingNb* = 2k where 1 <= k <=7 |
| *pingPeriod* | Period of the device receiver wake-up expressed in number of slots: *pingPeriod* = 212 / *pingNb* |
| *pingOffset* | Randomized offset computed at each beacon period start. Values can range from 0 to (pingPeriod-1) |
| *beaconTime* | The time carried in the field **BCNPayload**.Time of the immediately preceding beacon frame |
| *slotLen* | Length of a unit ping slot = 30 ms |

在每一个信标周期，终端设备和服务器计算一个新的伪随机偏移量来对齐接收时隙。AES加密使用一个所有都是0的密钥用于随机化：

*Key* = 16 x 0x00

*Rand* = aes128\_encrypt(Key, beaconTime | DevAddr | pad16) *pingOffset* = (*Rand*[0] + *Rand*[1]x 256) modulo *pingPeriod*

The slots used for this beacon period will be:

*pingOffset* + *N* x *pingPeriod* with *N*=[0:*pingNb*-1]

The node therefore opens receive slots starting at :

|  |  |
| --- | --- |
| First slot | Beacon\_reserved + pingOffset x slotLen |
| Slot 2 | Beacon\_reserved + (pingOffset + pingPeriod) x slotLen |
| Slot 3 | Beacon\_reserved + (pingOffset + 2 x pingPeriod) x slotLen |
| … | … |

如果该终端设备服务同时提供单播和一个或多组组播时隙，这将在一个新的信标周期开始的时执行多次运算。一次为了单播地址（节点网络地址），一次为了每一个组播组地址。

在组播网络探测（ping）时隙和单播网络探测（ping）时隙冲突并导致终端设备接收器无法服务的情况下，终端设备应当优先监听组播时隙。如果在组播接收时隙之间有冲突，先前组播帧的FPending位可以用于设置一个优先级。

随机化调度防止单播和组播时隙之间的系统冲突。如果在一个信标周期内发生冲突，那么它不太可能在下一个信标周期内发生冲突。

### 14 Class B MAC commands

所有A类协议规范内描述的指令都应当在B类协议设备内实现。B类协议规范增加了如下MAC指令。

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CID** | **Command** | **Transmitted by** | | **Short Description** |
|  |  | Enddevice | Gateway |  |
| 0x10 | ***PingSlotInfoReq*** | x |  | Used by the end-device to communicate the ping unicast slot data rate and periodicity to the network server |
| 0x10 | ***PingSlotInfoAns*** |  | x | Used by the network to acknowledge a PingInfoSlotReq command |
| 0x11 | ***PingSlotChannelReq*** |  | x | Used by the network server to set the unicast ping channel of an end-device |
| 0x11 | ***PingSlotFreqAns*** | x |  | Used by the end-device to acknowledge a  ***PingSlotChannelReq***command |
| 0x12 | ***BeaconTimingReq*** | x |  | Used by end-device to request next beacon timing & channel to network |
| 0x12 | ***BeaconTimingAns*** |  | x | Used by network to answer a ***BeaconTimingReq*** uplink |
| 0x13 | ***BeaconFreqReq*** |  | x | Command used by the network server to modify the frequency at which the enddevice expects to receive beacon broadcast |
| 0x13 | ***BeaconFreqAns*** | x |  | Used by the end-device to acknowledge a BeaconFreqReq command |

#### 14.1 PingSlotInfoReq

终端设备通过***PingSlotInfoReq***命令通知服务器它的单播网络探测（ping）时隙周期和预期的数据速率。该命令智能用于通知服务器UNICAST（单播）网络探测时隙参数。组播时隙完全由应用程序定义并且不应该使用此命令。

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **PingSlotInfoReq Payload** | Periodicity & data rate |

|  |  |  |  |
| --- | --- | --- | --- |
| **Bit#** | 7 | [6:4] | [3:0] |
| **Periodicity & data rate** | RFU | Periodicity | Data rate |

**Periodicity** 子字段是一个无符号3位整形，被终端设备使用如下方程用来编码当前的网络探测（ping）时隙周期。  in seconds

* **Periodicity** = 0 表示终端设备在每一秒打开一个网络探测（ping）时隙
* **Periodicity** = 7 , 每个128秒，LoRaWAN B类协议规范支持的最大网络探测（ping）周期

**Data rate子字段编码终端节点期望的任何网络探测（ping）的数据速率。这使用了和A类协议规范中描述的*LinkAdrReq*命令相同的编码机制。**

The server needs to be aware of the end-device ping slot periodicity or expected data rate else Class B downlinks will not happen successfully. For that purpose the ***PingSlotInfoReq*** MAC command **must be acknowledged** with a ***PingSlotInfoAns*** before the device can switch from class A to Class B**.** To change its ping slot scheduling or data rate a device should first revert to Class A , send the new parameters through a ***PingSlotInfoReq*** command and get an acknowledge from the server through a ***PinSlotInfoAns*** . It can then switch back to Class B with the new parameters.

This command can be concatenated with any other MAC command in the **FHDRFOpt** field as described in the Class A specification frame format.

#### 14.2 BeaconFreqReq

This command is sent by the server to the end-device to modify the frequency on which this end-device expects the beacon.

|  |  |
| --- | --- |
| **Octets** | 3 |
| **PingSlotChannelReqPay load** | Frequency |

The Frequency coding is identical to the ***NewChannelReq*** MAC command defined in the Class A.

**Frequency** is a 24bits unsigned integer. The actual beacon channel frequency in Hz is 100 x frequ. This allows defining the beacon channel anywhere between 100 MHz to 1.67 GHz by 100 Hz step. The end-device has to check that the frequency is actually allowed by its radio hardware and return an error otherwise.

A valid non-zero Frequency will force the device to listen to the beacon on a fixed frequency channel even if the default behavior specifies a frequency hopping beacon (i.e US ISM band).

A value of 0 instructs the end-device to use the default beacon frequency plan as defined in the ―Beacon physical layer‖ section. Where applicable the device resumes frequency hopping beacon search.

#### 14.3 PingSlotChannelReq

This command is sent by the server to the end-device to modify the frequency on which this end-device expects the downlink pings.

|  |  |  |
| --- | --- | --- |
| **Octets** | 3 | 1 |
| **PingSlotChannelReq**  **Payload** | Frequency | DrRange |

The Frequency coding is identical to the ***NewChannelReq*** MAC command defined in the Class A.

**Frequency** is a 24bits unsigned integer. The actual ping channel frequency in Hz is 100 x frequ. This allows defining the ping channel anywhere between 100MHz to 1.67GHz by 100Hz step. The end-device has to check that the frequency is actually allowed by its radio hardware and return an error otherwise.

A value of 0 instructs the end-device to use the default frequency plan.

**DrRange** is the data rate range allowed on this channel. This byte is split in two 4-bit 2 indexes.

|  |  |  |
| --- | --- | --- |
| **Bits** | 7:4 | 3:0 |
| **DrRange** | Max data rate | Min data rate |

Following the convention defined in the ―Physical layer‖ section of the Class A specification, the ―Min data rate‖ subfield designates the lowest data rate allowed on this channel. For example 0 designates DR0 / 125 kHz in the EU physical layer. Similarly “Max data rate” designates the highest data rate. For example in the EU spec, DrRange = 0x77 means that only 50 kbps GFSK is allowed on a channel and DrRange = 0x50 means that DR0 / 125 kHz 10 to DR5 / 125 kHz are supported.

Upon reception of this command the end-device answers with a ***PingSlotFreqAns*** message. The MAC payload of this message contains the following information:

|  |  |
| --- | --- |
| **Size (bytes)** | 1 |
| **pingSlotFreqAns Payload** | Status |

The **Status** bits have the following meaning:

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits** | 7:2 | 1 | 0 |
| **Status** | RFU | Data rate range ok | Channel frequency ok |

|  |  |  |
| --- | --- | --- |
|  | **Bit = 0** | **Bit = 1** |
| **Data rate range ok** | The designated data rate range exceeds the ones currently defined for this end device, the previous range is kept | The data rate range is compatible with the  possibilities of the end device |
| **Channel frequency ok** | The device cannot use this frequency, the previous ping frequency is kept | The device is able to use this frequency. |

#### 14.4 BeaconTimingReq

This command is sent by the end-device to request the next beacon timing and channel.

This MAC command has no payload. The ***BeaconTimingReq*** & ***BeaconTimingAns*** 19 mechanism is only meant to accelerate the initial beacon search to lower the end-device 20 energy requirement.

The network may answer only a limited number of requests per a given time period. An end device must not expect that ***BeaconTimingReq*** is answered immediately with a ***BeaconTimingAns***. Class A end-devices wanting to switch to Class B should not transmit more than one ***BeaconTimingReq*** per hour.

End-devices requiring a fast beacon lock must implement an autonomous beacon finding algorithm.

#### 14.5 BeaconTimingAns

This command is sent by the network to answer a ***BeaconInfoReq*** request.

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 2 | 1 |
| **BeaconInfoReqPayload** | Delay | Channel |

The “**Delay**” field is a 16bits unsigned integer. If the remaining time between the end of the current downlink frame and the start of the next beacon frame is noted *RTime* then:

*30 ms x (****Delay****+1) > RTime* >= 30 ms x **Delay**

In networks where the beacon uses alternatively several channels, the “**Channel**” field is the index of the beaconing channel on which the next beacon will be broadcasted. For networks where the beacon broadcast frequency is fixed then this field content is 0.

### 15 Beaconing (Class B option)

#### 15.1 Beacon physical layer

Besides relaying messages between end-devices and network servers, all gateways participate in providing a time-synchronization mechanisms by sending beacons at regular fixed intervals configurable per network (BEACON\_INTERVAL). All beacons are transmitted in radio packet implicit mode, that is, without a LoRa physical header and with no CRC being appended by the radio.

|  |  |
| --- | --- |
| Preamble | BCNPayload |

**PHY**

The beacon Preamble begins with (a longer than default) 10 unmodulated symbols. This allows end-devices to implement a low power duty-cycled beacon search.

The beacon frame length is tightly coupled to the operation of the radio Physical layer. Therefore the actual frame length might change from one region implementation to another. The changing fields are highlighted in **Bold** in the following sections.

##### 15.1.1 EU 863-870MHz ISM Band

The beacons are transmitted using the following settings

|  |  |  |
| --- | --- | --- |
| DR | 3 | Corresponds to SF9 spreading factor with  125 kHz BW |
| CR | 1 | Coding rate = 4/5 |
| frequency | 869.525 MHz | This is the recommended frequency allowing  +27 dBm EIRP. Network operators may use a different frequency as long as ETSI  compliance is achieved |

The beacon frame content is:

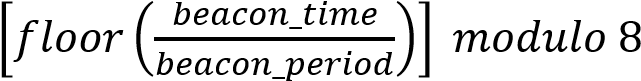
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 3 | 4 | **1** | 7 | **2** |
| **BCNPayload** | NetID | Time | **CRC** | GwSpecific | **CRC** |

##### 15.1.2 US 902-928MHz ISM Band

The beacons are transmitted using the following settings:

|  |  |  |
| --- | --- | --- |
| DR | 10 | Corresponds to SF10 spreading factor with 500kHz bw |
| CR | 1 | Coding rate = 4/5 |
| 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 |

The downstream channel used for a given beacon is:

Channel = 

 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 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** | NetID | Time | **CRC** | GwSpecific | **RFU** | **CRC** |

#### 15.2 Beacon frame content

The beacon payload **BCNPayload** consists of a network common part and a gateway specific part.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Size (bytes)** | 3 | 4 | 1/2 | 7 | 0/1 | 2 |
| **BCNPayload** | NetID | Time | CRC | GwSpecific | RFU | CRC |

The network common part contains a network identifier **NetID** to uniquely identify the network for which the beacon is sent, and a timestamp **Time** in seconds since 00:00:00

[Coordinated Universal Time](http://en.wikipedia.org/wiki/Coordinated_Universal_Time) (UTC), 1 January 1970. The integrity of the beacon‘s network common part is protected by an 8 or 16 bits CRC depending on PHY layer parameters. The CRC-16 is computed on the NetID+Time fields as defined in the IEEE 802.15.4-2003 section 7.2.1.8. When an 8 bits CRC is required then the 8 LSBs of the computed CRC-16 are used.

For example: This is a valid EU868 beacon frame:

AA BB CC | 00 00 02 CC | 7E | 00 | 01 20 00 | 00 81 03 | DE 55

Bytes are transmitted left to right. The corresponding field values are:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Field** | NetID | Time | **CRC** | InfoDesc | lat | long | **CRC** |
| **Value Hex** | CCBBAA | CC020000 | **7E** | 0 | 002001 | 038100 | **55DE** |

The CRC-16 of the NetID+Time fields is 0xC87E but only the 8LSBs are used in that case

The seven LSB of the **NetID** are called **NwkID** and match the seven MSB of the short address of an end-device. Neighboring or overlapping networks **must have** different **NwkIDs**.

The gateway specific part provides additional information regarding the gateway sending a beacon and therefore may differ for each gateway. The RFU field when applicable (region specific) should be equal to 0. The optional part is protected by a CRC-16 computed on the GwSpecific+RFU fields. The CRC-16 definition is the same as for the mandatory part.

For example: This is a valid US900 beacon:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Field** | NetID | Time | **CRC** | InfoDesc | lat | long | **RFU** | **CRC** |
| **Value Hex** | CCBBAA | CC020000 | **C87E** | 0 | 002001 | 038100 | **00** | **D450** |

Over the air the bytes are sent in the following order:

AA BB CC | 00 00 02 CC | 7E C8 | 00 | 01 20 00 | 00 81 03 |00 | 50 D4

Listening and synchronizing to the network common part is sufficient to operate a stationary end-device in Class B mode. A mobile end-device should also demodulate the gateway specific part of the beacon to be able to signal to the network server whenever he is moving from one cell to another.

**Note:** As mentioned before, all gateways send their beacon at exactly the same point in time (i.e., time-synchronously) so that for network common part there are no visible on-air collisions for a listening enddevice even if the end-device simultaneously receives beacons from several gateways. With respect to the gateway specific part, collision occurs but an end-device within the proximity of more than one gateway will still be able to decode the strongest beacon with high probability.

##### 15.3 Beacon GwSpecific field format

The content of the **GwSpecific** field is as follow:

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 1 | 6 |
| **GwSpecific** | InfoDesc | Info |

The information descriptor**InfoDesc** describes how the information field **Info** shall be interpreted.

|  |  |
| --- | --- |
| **InfoDesc** | **Meaning** |
| 0 | GPS coordinate of the gateway first antenna |
| 1 | GPS coordinate of the gateway second antenna |
| 2 | GPS coordinate of the gateway third antenna |
| 3:127 | RFU |
| 128:255 | Reserved for custom network specific broadcasts |
|  |  |

For a single omnidirectional antenna gateway the **InfoDesc** value is 0 when broadcasting GPS coordinates. For a site featuring 3 sectored antennas for example, the first antenna broadcasts the beacon with **InfoDesc** equals 0, the second antenna with **InfoDesc** field 28 equals 1, etc …

###### 15.3.1 Gateway GPS coordinate:InfoDesc = 0, 1 or 2

For **InfoDesc** = 0 ,1 or 2, the content of the **Info** field encodes the GPS coordinates of the 3 antenna broadcasting the beacon

|  |  |  |
| --- | --- | --- |
| **Size (bytes)** | 3 | 3 |
| **Info** | Lat | Lng |

The latitude and longitude fields (**Lat** and **Lng**, respectively) encode the geographical location of the gateway as follows:

* The north-south latitude is encoded using a signed 24 bit word where -223 corresponds to 90° south (the South Pole) and 223 corresponds to 90° north (the North Pole). The equator corresponds to 0.
* The east-west longitude is encoded using a signed 24 bit word where - 223corresponds to 180° west and 223 corresponds to 180° east. The Greenwich meridian corresponds to 0.

##### 15.4 Beaconing precise timing

The beacon is sent every 128 seconds starting at 00:00:00 Coordinated Universal Time (UTC), 1 January 1970 plus **NwkID plus** TBeaconDelay. Therefore the beacon is sent at

BT = *k* \* 128 + **NwkID** + TBeaconDelay seconds after 00:00:00 Coordinated Universal Time (UTC), 1 January 1970 whereby*k* is the smallest integer for which

*k* \* 128 + **NwkID**>*T* whereby

*T* = seconds since 00:00:00 Coordinated Universal Time (UTC), 1 January 1970.

**Note:** *T* is not (!) Unix time. Similar to GPS time and unlike Unix time, *T* is strictly monotonically increasing and is not influenced by leap seconds.

Whereby TBeaconDelay is a network specific delay in the [0:50] ms range. TBeaconDelay may vary from one network to another and is meant to allow a slight transmission delay of the gateways. TBeaconDelay must be the same for all gateways of a given network. TBeaconDelay must be smaller than 50 ms. All end-devices ping slots use the beacon transmission time as a timing reference, therefore the network server as to take TBeaconDelay into account when scheduling the class B downlinks.

##### 15.5 Network downlink route update requirements

When the network attempts to communicate with an end-device using a Class B downlink slot, it transmits the downlink from the gateway which was closest to the end-device when the last uplink was received. Therefore the network server needs to keep track of the rough position of every Class B device.

Whenever a Class B device moves and changes cell, it needs to communicate with the network server in order to update its downlink route. This update can be performed simply by sending a ―confirmed‖ or ―unconfirmed‖ uplink, possibly without applicative payload.

The end-device has the choice between 2 basic strategies:

* Systematic periodic uplink: simplest method that doesn‘t require demodulation of the

―gateway specific‖ field of the beacon. Only applicable to slowly moving or stationery end-devices. There are no requirements on those periodic uplinks.

* Uplink on cell change: The end-device demodulates the ―gateway specific‖ field of the beacon, detects that the ID of the gateway broadcasting the beacon it demodulates has changed, and sends an uplink. In that case the device should respect a pseudo random delay in the [0:120] seconds range between the beacon demodulation and the uplink transmission. This is required to insure that the uplinks of multiple Class B devices entering or leaving a cell during the same beacon period will not systematically occur at the same time immediately after the beacon broadcast.

Failure to report cell change will result in Class B downlink being temporary not operational. The network server may have to wait for the next end-device uplink to transmit downlink traffic.

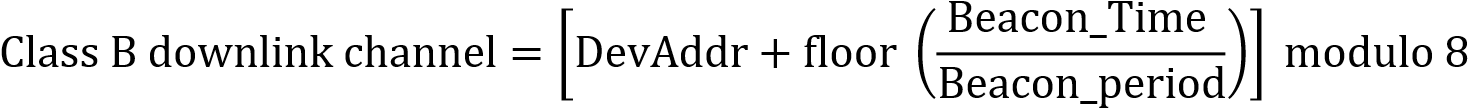
### 16 Class B unicast & multicast downlink channel frequencies

#### 16.1 EU 863-870MHz ISM Band

All unicast&multicastClass B downlinks use a single frequency channel defined by the “***PingSlotChannelReq”*** MAC command. The default frequency is 869.525MHz

#### 16.2 US 902-928MHz ISM Band

By default Class B downlinks use a channel function of the Time field of the last beacon (see Beacon Frame content) and the DevAddr.



* Whereby Beacon\_Time is the 32 bit Time field of the current beacon period
* Beacon\_period is the length of the beacon period (defined as 128sec in the specification)
* Floor designates rounding to the immediately lower integer value
* DevAddr is the 32 bits network address of the device

Class B downlinks therefore hop across 8 channels in the ISM band and all Class B end-devices are equally spread amongst the 8 downlink channels.

If the “***PingSlotChannelReq”*** command with a valid non-zero argument is used to set the Class B downlink frequency then all subsequent ping slots should be opened on this single frequency independently of the last beacon frequency.

If the “***PingSlotChannelReq”*** command with a zero argument is sent, the end-device should resume the default frequency plan, id Class B ping slots hoping across 8 channels.

The underlying idea is to allow network operators to configure end-devices to use a single proprietary dedicated frequency band for the Class B downlinks if available, and to keep as much frequency diversity as possible when the ISM band is used.

## CLASS C – CONTINUOUSLY LISTENING

### 17 Class C: Continuously listening end-device

The end-devices implanting the Class C option are used for applications that have sufficient power available and thus do not need to minimize reception time.

Class C end-devices cannot implement Class B option.

The Class C end-device will listen with RX2 windows parameters as often as possible. The end-device listens on RX2 when it is not either (a) sending or (b) receiving on RX1, according to Class A definition. To do so, it will open a short window on RX2 parameters between the end of the uplink transmission and the beginning of the RX1 reception window and it will switch to RX2 reception parameters as soon as the RX1 reception window is closed; the RX2 reception window will remain open until the end-device has to send another message.

**Note:** There is not specific message for a node to tell the server that it is a Class C node. It is up to the application on server side to know that it manages Class C nodes based on the contract passed during the join procedure.

#### 17.1 Second receive window duration for Class C

Class C devices implement the same two receive windows as Class A devices, but they do not close RX2 window until they need to send again. Therefore they may receive a downlink in the RX2 window at nearly any time. A short listening window on RX2 frequency and data rate is also opened between the end of the transmission and the beginning of the RX1 receive window.

Transmit

RX

1

RX

2

RX

2

Transmit On Air Time

RECEIVE

\_

DELAY

1

RECEIVE

\_

DELAY

2

Extends to next uplink

**Figure 14: Class C end-device receive slot timing.**

#### 17.2 Class C Multicast downlinks

Similarly to Class B, Class C devices may receive multicast downlink frames. The multicast address and associated network session key and application session key must come from the application layer. The same limitations apply for Class C multicast downlink frames:

* They are not allowed to carry MAC commands, neither in the **FOpt** field, nor in the payload on port 0 because a multicast downlink does not have the same authentication robustness as a unicast frame.
* The **ACK** and **ADRACKReq** bits must be zero. The **MType** field must carry the value for Unconfirmed Data Down.
* The **FPending** bit indicates there is more multicast data to be sent. Given that a Class C device keeps its receiver active most of the time, the **FPending** bit does not trigger any specific behavior of the end-device.

## SUPPORT INFORMATION

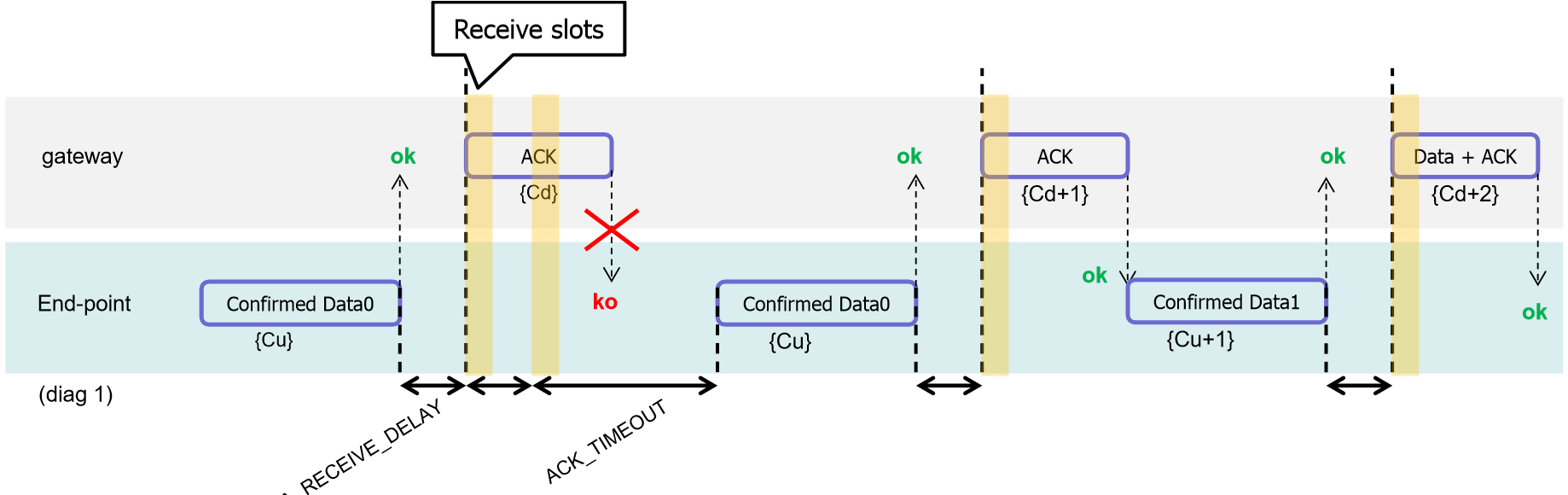
This sub-section is only a recommendation.

### 18 Examples and Application Information

Examples are illustrations of the LoRaWAN spec for information, but they are not part of the formal specification.

#### 18.1 Uplink Timing Diagram for Confirmed Data Messages

The following diagram illustrates the steps followed by an end-device trying to transmit two confirmed data frames (Data0 and Data1):



##### Figure 15: Uplink timing diagram for confirmed data messages

The end-device first transmits a confirmed data frame containing the Data0 payload at an arbitrary instant and on an arbitrary channel. The frame counter Cu is simply derived by adding 1 to the previous uplink frame counter. The network receives the frame and generates a downlink frame with the ACK bit set exactly RECEIVE\_DELAY1 seconds later, using the first receive window of the end-device. This downlink frame uses the same data rate and the same channel as the Data0 uplink. The downlink frame counter Cd is also derived by adding 1 to the last downlink towards that specific end-device. If there is no downlink payload pending the network shall generate a frame without a payload. In this example the frame carrying the ACK bit is not received.

If an end-point does not receive a frame with the ACK bit set in one of the two receive windows immediately following the uplink transmission it may resend the same frame with the same payload and frame counter again at least ACK\_TIMEOUT seconds after the second reception window. This resend must be done on another channel and must obey the duty cycle limitation as any other normal transmission. If this time the network receives the ACK downlink during its first receive window, as soon as the ACK frame is demodulated, the end-device is free to transmit a new frame on a new channel.

#### 18.2 The third ACK frame in this example also carries an application payload. A downlink frame can carry any combination of ACK, MAC control commands and payload. Downlink Diagram for Confirmed Data Messages

The following diagram illustrates the basic sequence of a ―confirmed‖ downlink.

gateway

End

-

point

Unconfirmed data

}

Cu

{

Confirmed Data

}

Cd

{

**ok**

**ok**

Receive slots

**ok**

ACK

{

Cu

+1}

##### Figure 16: Downlink timing diagram for confirmed data messages

The frame exchange is initiated by the end-device transmitting an ―unconfirmed‖ application payload or any other frame on channel A. The network uses the downlink receive window to transmit a ―confirmed‖ data frame towards the end-device on the same channel A. Upon reception of this data frame requiring an acknowledgement, the end-device transmits a frame with the ACK bit set at its own discretion. This frame might also contain piggybacked data or MAC commands as its payload. This ACK uplink is treated like any standard uplink, and as such is transmitted on a random channel that might be different from channel A.

**Note:** To allow theend-devices to be as simple as possible and have keep as few states as possible it may transmit an explicit (possibly empty) acknowledgement data message immediately after the reception of a data message requiring an acknowledgment. Alternatively the end-device may defer the transmission of an acknowledgement to piggyback it with its next data message.

#### 18.3 Downlink Timing for Frame-Pending Messages

The next diagram illustrates the use of the **frame pending** (FPending) bit on a downlink. The FPending bit can only be set on a downlink frame and informs the end-device that the network has several frames pending for him; the bit is ignored for all uplink frames.

If a frame with the FPending bit set requires an acknowledgement, the end-device shall do so as described before. If no acknowledgment is required, the end-device may send an empty data message to open additional receive windows at its own discretion, or wait until it has some data to transmit itself and open receive windows as usual.

**Note:** The FPending bit is independent to the acknowledgment scheme.

gateway

End

-

point

Data uplink

}

cu

{

Confirmed

Data0

+

F\_P

cd

}

{

ACK

+1}

cu

{

Confirmed

Data1

+1}

cd

{

ACK

{

+2}

cu

**ok**

**ok**

**ok**

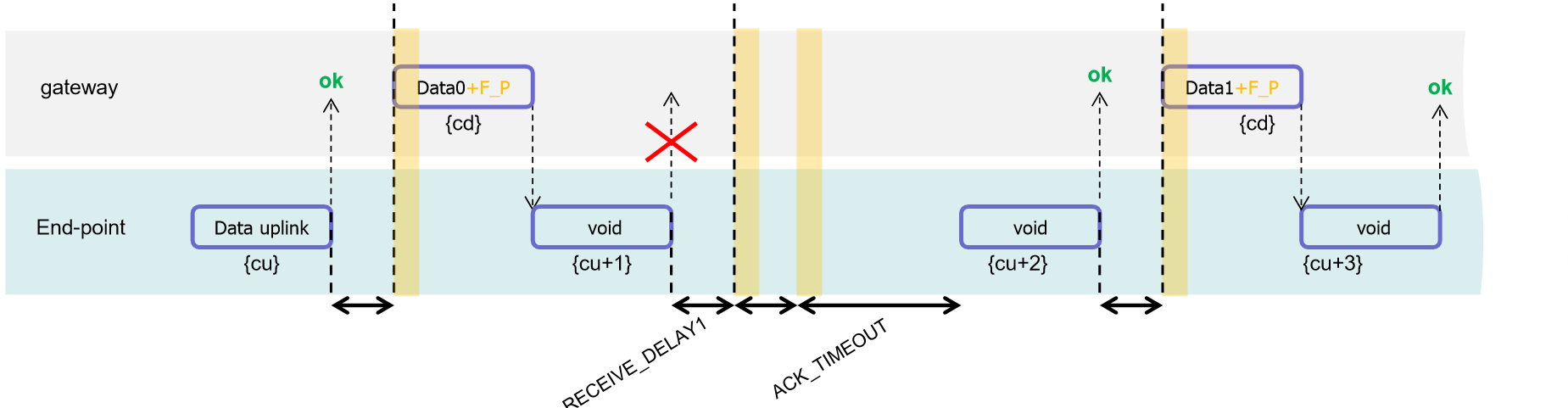
F\_P means ‗frame pending‘ bit set

(\*)

Receive slots

##### Figure 17: Downlink timing diagram for frame-pending messages, example 1

In this example the network has two confirmed data frames to transmit to the end-device. The frame exchange is initiated by the end-device via a normal ―unconfirmed‖ uplink message on channel A. The network uses the first receive window to transmit the Data0 with the bit FPending set as a confirmed data message. The device acknowledges the reception of the frame by transmitting back an empty frame with the ACK bit set on a new channel B. RECEIVE\_DELAY1 seconds later, the network transmits the second frame Data1 on channel B, again using a confirmed data message but with the FPending bit cleared. The end-device acknowledges on channel C.



##### Figure 18: Downlink timing diagram for frame-pending messages, example 2

In this example, the downlink frames are ―unconfirmed‖ frames, the end-device does not need to send back and acknowledge. Receiving the Data0 unconfirmed frame with the FPending bit set the end-device sends an empty data frame. This first uplink is not received by the network. If no downlink is received during the two receive windows, the network has to wait for the next spontaneous uplink of the end-device to retry the transfer. The enddevice can speed up the procedure by sending a new empty data frame.

**Note:** An acknowledgement is never sent twice.

The FPending bit, the ACK bit, and payload data can all be present in the same downlink. For example, the following frame exchange is perfectly valid.



##### Figure 19: Downlink timing diagram for frame-pending messages, example 3

The end-device sends a ―confirmed data‖ uplink. The network can answer with a confirmed downlink containing Data + ACK + ―Frame pending‖ then the exchange continues as previously described.

#### 18.4 Data-Rate Adaptation during Message Retransmissions

When an end-device attempts the transmission of a “confirmed” frame toward the network it expects to receive an acknowledgement in one of the subsequent reception slot. In the absence of the acknowledgement it will try to re-transmit the same data again. This re transmission happens on a new frequency channel, but can also happen at a different data rate (preferable lower) than the previous one. It is strongly recommended to adopt the following re-transmission strategy.

The first transmission of the ―confirmed‖ frame happens with a data rate DR.

|  |  |  |
| --- | --- | --- |
| **Transmission nb** |  | **Data Rate** |
| 1 (first) | DR |  |
| 2 | DR |  |
| 3 | max(DR-1,0) |  |
| 4 | max(DR-1,0) |  |
| 5 | max(DR-2,0) |  |
| 6 | max(DR-2,0) |  |
| 7 | max(DR-3,0) |  |
| 8 | max(DR-3,0) |  |

The Data Rate max(a,b) stands for maximum of a and b values.

If after a recommended 8 transmissions, the frame has not been acknowledged the MAC layer should return an error code to the application layer.

**Note:** For each re-transmission, the frequency channel is selected randomly as for normal transmissions.

Any further transmission uses the last data rate used.

For example if an end-device sends a ―confirmed‖ frame first using DR5 and has to retransmit 3 times (twice at DR5 then twice at DR4), the next frame transmitted will use DR4 Other example, if an end-device sends a “confirmed” frame first using DR5 and does not receive an acknowledge after 8 transmissions (2 at DR5, 2 at DR4, … , 2 at DR2), and the application of this end-device re-initiates a ―confirmed‖ transmission a little later, the first two transmission will be tentatively at DR2, then switch to DR1, then to DR0.

### 19 Recommendation on contract to be provided to the network server by the end-device provider at the time of provisioning

Configuration data related to the end-device and its characteristics must be known by the network server at the time of provisioning. –This provisioned data is called the ―contract‖. This contract cannot be provided by the end-device and must be supplied by the end-device provider using another channel (out-of-band communication).

This end-device contract is stored in the network server. It can be used by the application server and the network controller to adapt the algorithms.

This data will include:

* End-device specific radio parameters (device frequency range, device maximal output power, device communication settings - RECEIVE\_DELAY1, RECEIVE\_DELAY2)
* Application type (Alarm, Metering, Asset Tracking, Supervision, Network Control)

### 20 Recommendation on finding the locally used channels

End-devices that can be activated in territories that are using different frequencies for LoRaWAN will have to identify what frequencies are supported for join message at their current location before they send any message. The following methods are proposed:

* A GPS enabled end-device can use its GPS location to identify which frequency band to use.
* End-device can search for a beacon and use its frequency to identify its region
* End-device can search for a beacon and if this one is sending the antenna GPS coordinate, it can use this to identify its region
* End-device can search for a beacon and if this one is sending a list of join frequencies, it can use this to send its join message

### 21 Revisions

#### 21.1 Revision 1.0

 LoRaWAN 草案版本

### 22 词汇表

|  |  |
| --- | --- |
| ADR | Adaptive Data Rate |
| AES | Advanced Encryption Standard |
| AFA | Adaptive Frequency Agility |
| AR | Acknowledgement Request |
| CBC | Cipher Block Chaining |
| CMAC | Cipher-based Message Authentication Code |
| CR | Coding Rate |
| CRC | Cyclic Redundancy Check |
| DR | Data Rate |
| ECB | Electronic Code Book |
| ETSI | European Telecommunications Standards Institute |
| EIRP | Equivalent Isotropically Radiated Power |
| FSK | Frequency Shift Keying modulation technique |
| GPRS | General Packet Radio Service |
| HAL | Hardware Abstraction Layer |
| IP | Internet Protocol |
| LBT | Listen Before Talk |
| LoRa™ | Long Range modulation technique |
| LoRaWAN™ | Long Range Network protocol |
| MAC | Medium Access Control |
| MIC | Message Integrity Code |
| RF | Radio Frequency |
| RFU | Reserved for Future Usage |
| Rx | Receiver |
| RSSI | Received Signal Strength Indicator |
| SF | Spreading Factor |
| SNR | Signal Noise Ratio |
| SPI | Serial Peripheral Interface |
| SSL | Secure Socket Layer |
| Tx | Transmitter |
| USB | Universal Serial Bus |

### 23 参考书目

#### 23.1 References

[IEEE802154]: IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low Rate Wireless Personal Area Networks (LR-WPANs), IEEE Std 802.15.4TM-2011 (Revision of IEEE Std 802.15.4-2006), September 2011.

[RFC4493]: The AES-CMAC Algorithm, June 2006.

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1. 网关也被称为集中器或基站。 [↑](#footnote-ref-1)
2. 终端设备又被称作子节点。

   3 对于中继器本文档中没有描述, 但是有效载荷限制的封装开销包括在本规范。中继器被规定为使用LoRaWAN 作为其返回机制。 [↑](#footnote-ref-2)
3. RECEIVE\_DELAY1 和 RECEIVE\_DELAY2 在第6章有描述。 [↑](#footnote-ref-3)
4. RECEIVE\_DELAY1 和 RECEIVE\_DELAY2 在第6章有描述。 [↑](#footnote-ref-4)
5. 在18节给出了确认机制的详细时序图。 [↑](#footnote-ref-5)
6. Actual value for MAX\_FCNT\_GAP, RECEIVE\_DELAY1 and RECEIVE\_DELAY2 can be found at

   7.1.7 for EU863-870 or 7.2.7 for US902-928. [↑](#footnote-ref-6)
7. [RFC4493] [↑](#footnote-ref-7)
8. The pad16 function appends zero octets so that the length of the data is a multiple of 16. 4

   [RFC4493] [↑](#footnote-ref-8)
9. 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. [↑](#footnote-ref-9)