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LPWAN Overview
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Abstract

Low Power Wide Area Networks (LPWAN) are wireless technologies with characteristics such as large coverage areas, low bandwidth, possibly very small packet and application layer data sizes and long battery life operation. This memo is an informational overview of the set of LPWAN technologies being considered in the IETF and of the gaps that exist between the needs of those technologies and the goal of running IP in LPWANs.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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Table of Contents

1. Introduction

[[Editor comments/queries are in double square brackets like this.]]

This document provides background material and an overview of the technologies being considered in the IETF's Low Power Wide-Area Networking (LPWAN) working group. We also provide a gap analysis between the needs of these technologies and currently available IETF specifications.

This document is largely the work of the people listed in Section 8. Discussion of this document should take place on the lpwan@ietf.org list.

[[Editor's note: the eventual fate of this draft is a topic for the WG to consider - it might end up as a useful RFC, or it might be best

maintained as a draft only until its utility has dissapated. FWIW, the editor doesn't mind what outcome the WG choose.]]

2. Terminology

[[Not sure if 2119 terms will be needed. Leave it here for now.]] 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 [RFC2119].

[[Extract common terms here. Maybe define and relate technology specific terms, e.g. lora g/w similar to sigfox bs etc. There is text for this in the current "gaps" draft.]]

3. Common Concerns

[[Editors note: We may want a section like this that describes some cross-cutting issues, e.g. duty-cycles, some of the ISM band restrictions. This isn't intended to be a problem statement nor a set of requirements but just to describe some issues that affect more than one of the LPWAN technologies. Such a section might be better before or after Section 4, will see when text's added there. There is some text for this in the current "gaps" draft.]]

Most technologies in this space aim for similar goals of supporting large numbers of low-cost, low-throughput devices at very low-cost and with very-low power consumption, so that even battery-powered devices can be deployed for years. And as the name implies, coverage of large areas is also a common goal. There are some differences however, e.g., the Narrowband IoT specifications Section 4.2 also aim for increased indoor coverage. However, by and large, the different technologies aim for deployment in very similar circumstances.

4. LPWAN Technologies

This section provides an overview of the set of LPWAN technologies that are being considered in the LPWAN working group. The text for each was mainly contributed by proponents of each technology.

Note that this text is not intended to be normative in any sesne, but simply to help the reader in finding the relevant layer 2 specifications and in understanding how those integrate with IETF-defined technologies. Similarly, there is no attempt here to set out the pros and cons of the relevant technologies. [[Editor: I assume that's the right target here. Please comment if you disagree.]]

[[Editor's note: the goal here is 2-3 pages per technology. If there's much more needed then we could add appendices I guess depending on what text the WG find useful to include.]]

4.1. LoRaWAN

[[Text here is from [I-D.farrell-lpwan-lora-overview] And yes, this section is too long right now. Will shorten.]]

4.1.1. Provenance and Documents

LoRaWAN is a wireless technology for long-range low-power low-data-rate applications developed by the LoRa Alliance, a membership consortium. <https://www.lora-alliance.org/> This draft is based on version 1.0.2 [LoRaSpec] of the LoRa specification. (Note that version 1.0.2 is expected to be published in a few weeks. We will update this draft when that has happened. For now, version 1.0 is available at [LoRaSpec1.0])

4.1.2. Characteristics

In LoRaWAN networks, end-device transmissions may be received at multiple gateways, so during nominal operation a network server may see multiple instances of the same uplink message from an end-device.

The LoRaWAN network infrastructure manages the data rate and RF output power for each end-device individually by means of an adaptive data rate (ADR) scheme. End-devices may transmit on any channel allowed by local regulation at any time, using any of the currently available data rates.

LoRaWAN networks are typically organized in a star-of-stars topology in which gateways relay messages between end-devices and a central

"network server" in the backend. Gateways are connected to the network server via IP links while end-devices use single-hop LoRaWAN communication that can be received at one or more gateways. All communication is generally bi-directional, although uplink communication from end-devices to the network server are favoured in terms of overall bandwidth availability.

This section introduces some LoRaWAN terms. Figure 1 shows the entities involved in a LoRaWAN network.

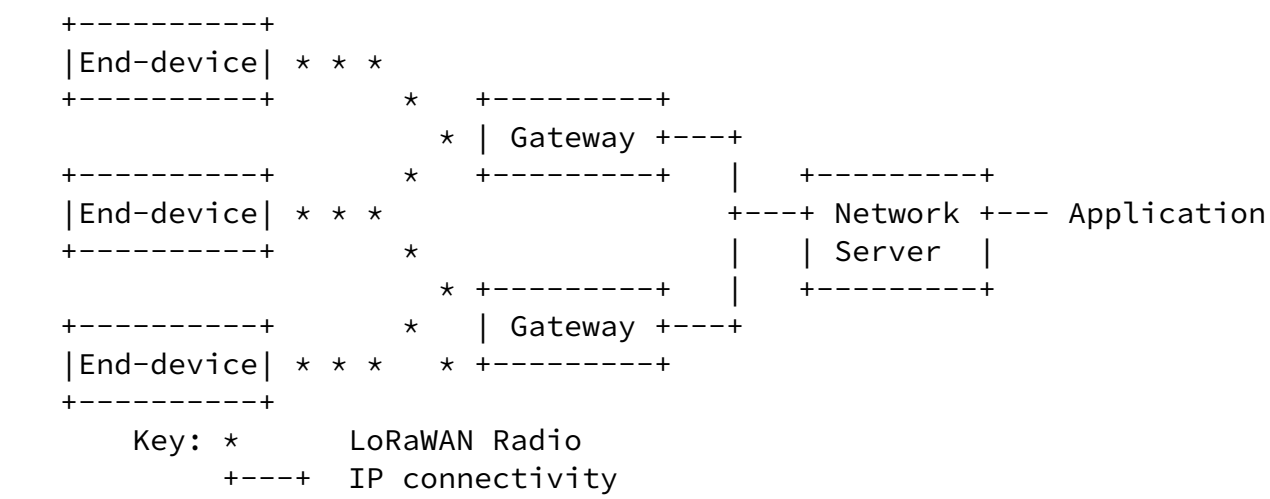


Figure 1: LoRaWAN architecture

- End-device: a LoRa client device, sometimes called a mote. Communicates with gateways.

- Gateway: a radio on the infrastructure-side, sometimes called a concentrator or base-station. Communicates with end-devices and, via IP, with a network server.

- Network Server: The Network Server (NS) terminates the LoRaWAN MAC layer for the end-devices connected to the network. It is the center of the star topology.

- Uplink message: refers to communications from end-device to network server or appliction via one or more gateways.

- Downlink message: refers to communications from network server or application via one gateway to a single end-device or a group of end-devices (considering multicasting).

- Application: refers to application layer code both on the end-device and running "behind" the network server. For LoRaWAN, there will generally only be one application running on most end-devices. Interfaces between the network server and application are not further described here.

- Classes A, B and C define different device capabilities and modes of operation for end-devices. End-devices can transmit uplink messages at any time in any mode of operation (so long as e.g., ISM band restrictions are honoured). An end-device in Class A can only receive downlink messages at predetermined timeslots after each uplink message transmission. Class B allows the end-device to receive downlink messages at periodically scheduled timeslots. Class C allows receipt of downlink messages at anytime. Class

selection is based on the end-devices' application use case and its power supply. (While Classes B and C are not further described here, readers may have seen those terms elsewhere so we include them for clarity.)

LoRaWAN radios make use of ISM bands, for example, 433MHz and 868MHz within the European Union and 915MHz in the Americas.

The end-device changes channel in a pseudo-random fashion for every transmission to help make the system more robust to interference and/or to conform to local regulations.

As with other LPWAN radio technologies, LoRaWAN end-devices respect the frequency, power and maximum transmit duty cycle requirements for the sub-band imposed by local regulators. In most cases, this means

an end-device is only transmitting for 1% of the time, as specified by ISM band regulations. And in some cases the LoRaWAN specification calls for end-devices to transmit less often than is called for by the ISM band regulations in order to avoid congestion.

Figure 2 below shows that after a transmission slot a Class A device turns on its receiver for two short receive windows that are offset from the end of the transmission window. The frequencies and data rate chosen for the first of these receive windows depends on those used for the transmit window. The frequency and data-rate for the second receive window are configurable. If a downlink message preamble is detected during a receive window, then the end-device keeps the radio on in order to receive the frame.

End-devices can only transmit a subsequent uplink frame after the end of the associated receive windows. When a device joins a LoRaWAN network, there are similar timeouts on parts of that process.

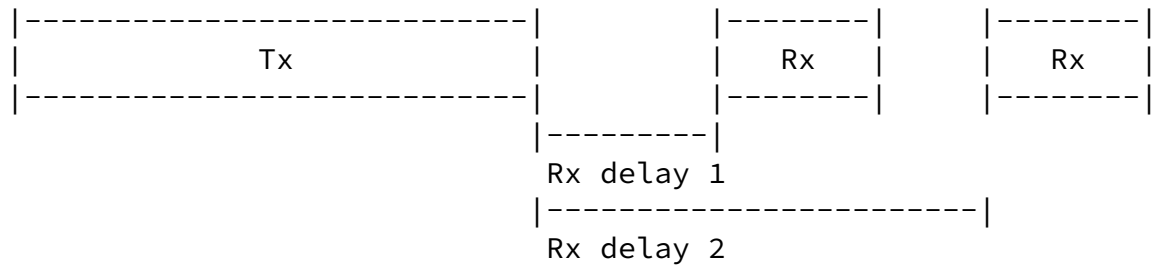


Figure 2: LoRaWAN Class A transmission and reception window

Given the different regional requirements the detailed specification for the LoRaWAN physical layer (taking up more than 30 pages of the specification) is not reproduced here. Instead and mainly to illustrate the kinds of issue encountered, in Table 1 we present some of the default settings for one ISM band (without fully explaining

those here) and in Table 2 we describe maxima and minima for some parameters of interest to those defining ways to use IETF protocols over the LoRaWAN MAC layer.

Parameters	Default Value
Rx delay 1	1 s

Rx delay 2	2 s (must be RECEIVE_DELAY1 + 1s)
join delay 1	5 s
join delay 2	6 s
868MHz Default channels	3 (868.1,868.2,868.3), date rate: 0.3-5 kbps

Table 1: Default settings for EU868MHz band

Parameter/Notes	Min	Max
Duty Cycle: some but not all ISM bands impose a limit in terms of how often an end-device can transmit. In some cases LoRaWAN is more stringent in an attempt to avoid congestion.	1%	no-limit
EU 868MHz band data rate/frame-size	250 bits/s : 59 octets	50000 bits/s : 250 octets
US 915MHz band data rate/frame-size	980 bits/s : 19 octets	21900 bits/s : 250 octets

Table 2: Minima and Maxima for various LoRaWAN Parameters

Note that in the case of the smallest frame size (19 octets), 8 octets are required for LoRa MAC layer headers leaving only 11 octets for payload (including MAC layer options). However, those settings do not apply for the join procedure - end-devices are required to use a channel that can send the 23 byte Join-request message for the join procedure.

Uplink and downlink higher layer data is carried in a MACPayload.

There is a concept of "ports" (an optional 8 bit value) to handle different applications on an end-device. Port zero is reserved for LoRaWAN specific messaging, such as the join procedure.

The header also distinguishes the uplink/downlink directions and whether or not an acknowledgement ("confirmation") is required from the peer.

All payloads are encrypted and ciphertexts are protected with a cryptographic Message Integrity Check (MIC) - see Section 6 for details.

In addition to carrying higher layer PDUs there are Join-Request and Join-Response (aka Join-Accept) messages for handling network access. And so-called "MAC commands" (see below) up to 15 bytes long can be piggybacked in an options field ("FOpts").

LoRaWAN end-devices can choose various different data rates from a menu of available rates (dependent on the frequencies in use). It is however, recommended that end-devices set the Adaptive Data Rate ("ADR") bit in the MAC layer which is a signal that the network should control the data rate (via MAC commands to the end-device). The network can also assert the ADR bit and control data rates at it's discretion. The goal is to ensure minimal on-time for radios whilst increasing throughput and reliability when possible. Other things being equal, the effect should be that end-devices closer to a gateway can successfully use higher data rates, whereas end-devices further from all gateways still receive connectivity though at a lower data rate.

Data rate changes can be validated via a scheme of acks from the network with a fall-back to lower rates in the event that downlink acks go missing.

There are 16 (or 32) bit frame counters maintained in each direction that are incremented on each transmission (but not re-transmissions) that are not re-used for a given key. When the device supports a 32 bit counter, then only the least significant 16 bits are sent in the MAC header, but all 32 bits are used in cryptographic operations. (If an end-device only supports a 16 bit counter internally, then the topmost 16 bits are set to zero.)

There are a number of MAC commands for: Link and device status checking, ADR and duty-cycle negotiation, managing the RX windows and radio channel settings. For example, the link check response message allows the network server (in response to a request from an end-device) to inform an end-device about the signal attenuation seen

most recently at a gateway, and to also tell the end-device how many gateways received the corresponding link request MAC command.

Some MAC commands are initiated by the network server. For example, one command allows the network server to ask an end-device to reduce it's duty-cycle to only use a proportion of the maximum allowed in a region. Another allows the network server to query the end-device's power status with the response from the end-device specifying whether it has an external power source or is battery powered (in which case a relative battery level is also sent to the network server).

The network server can also inform an end-device about channel assignments (mid-point frequencies and data rates). Of course, these must also remain within the bands assigned by local regulation.

A LoRaWAN network has a short network identifier ("NwkID") which is a seven bit value. A private network (common for LoRaWAN) can use the value zero. If a network wishes to support "foreign" end-devices then the NwkID needs to be registered with the LoRA Alliance, in which case the NwkID is the seven least significant bits of a registered 24-bit NetID. (Note however, that the methods for "roaming" are currently being enhanced within the LoRA Alliance, so the situation here is somewhat fluid.)

In order to operate nominally on a LoRaWAN network, a device needs a 32-bit device address, which is the catentation of the NwkID and a 25-bit device-specific network address that is assigned when the device "joins" the network (see below for the join procedure) or that is pre-provisioned into the device.

End-devices are assumed to work with one or a quite limited number of applications, which matches most LoRaWAN use-cases. The applications are identified by a 64-bit AppEUI, which is assumed to be a registered IEEE EUI64 value.

In addition, a device needs to have two symmetric session keys, one for protecting network artefacts (port=0), the NwkSKey, and another for protecting appliction layer traffic, the AppSKey. Both keys are used for 128 bit AES cryptpgraphic operations. (See Section 6 for details.)

So, one option is for an end-device to have all of the above, plus channel information, somehow (pre-)provisioned, in which case the end-device can simply start transmitting. This is achievable in many cases via out-of-band means given the nature of LoRaWAN networks. Table 3 summarises these values.

Value	Description
DevAddr	DevAddr (32-bits) = NwkId (7-bits) + device-specific network address (25 bits)
AppEUI	IEEE EUI64 naming the application
NwkSKey	128 bit network session key for use with AES
AppSKey	128 bit application session key for use with AES

Table 3: Values required for nominal operation

As an alternative, end-devices can use the LoRaWAN join procedure in order to setup some of these values and dynamically gain access to the network.

To use the join procedure, an end-device must still know the AppEUI. In addition to the AppEUI, end-devices using the join procedure need to also know a different (long-term) symmetric key that is bound to the AppEUI - this is the application key (AppKey), and is distinct from the application session key (AppSKey). The AppKey is required to be specific to the device, that is, each end-device should have a different AppKey value. And finally the end-device also needs a long-term identifier for itself, syntactically also an EUI-64, and known as the device EUI or DevEUI. Table 4 summarises these values.

Value	Description
DevEUI	IEEE EUI64 naming the device
AppEUI	IEEE EUI64 naming the application
AppKey	128 bit long term application key for use with AES

Table 4: Values required for join procedure

The join procedure involves a special exchange where the end-device asserts the AppEUI and DevEUI (integrity protected with the long-term AppKey, but not encrypted) in a Join-request uplink message. This is then routed to the network server which interacts with an entity that knows that AppKey to verify the Join-request. All going well, a Join-accept downlink message is returned from the network server to the end-device that specifies the 24-bit NetID, 32-bit DevAddr and

channel information and from which the AppSKey and NwkSKey can be derived based on knowledge of the AppKey. This provides the end-device with all the values listed in Table 3.

There is some special handling related to which channels to use and for multiple transmissions for the join-request which is intended to ensure a successful join in as many cases as possible. Join-request and Join-accept messages also include some random values (nonces) to both provide some replay protection and to help ensure the session keys are unique per run of the join procedure. If a Join-request fails validation, then no Join-accept message (indeed no message at all) is returned to the end-device. For example, if an end-device is factory-reset then it should end up in a state in which it can re-do the join procedure.

In this section we describe the use of cryptography in LoRaWAN. This section is not intended as a full specification but to be sufficient so that future IETF specifications can encompass the required security considerations. The emphasis is on describing the externally visible characteristics of LoRaWAN.

All payloads are encrypted and have data integrity. Frame options (used for MAC commands) when sent as a payload (port zero) are therefore protected. MAC commands piggy-backed as frame options ("FOpts") are however sent in clear. Since MAC commands may be sent as options and not only as payload, any values sent in that manner are visible to a passive attacker but are not malleable for an active attacker due to the use of the MIC.

For LoRaWAN version 1.0.x, the NWkSkey session key is used to provide data integrity between the end-device and the network server. The AppSKey is used to provide data confidentiality between the end-

device and network server, or to the application "behind" the network server, depending on the implementation of the network.

All MAC layer messages have an outer 32-bit Message Integrity Code (MIC) calculated using AES-CMAC calculated over the ciphertext payload and other headers and using the NwkSkey.

Payloads are encrypted using AES-128, with a counter-mode derived from IEEE 802.15.4 using the AppSKey.

Gateways are not expected to be provided with the AppSKey or NwkSKey, all of the infrastructure-side cryptography happens in (or "behind") the network server.

When session keys are derived from the AppKey as a result of the join procedure the Join-accept message payload is specially handled.

The long-term AppKey is directly used to protect the Join-accept message content, but the function used is not an aes-encrypt operation, but rather an aes-decrypt operation. The justification is that this means that the end-device only needs to implement the aes-encrypt operation. (The counter mode variant used for payload decryption means the end-device doesn't need an aes-decrypt primitive.)

The Join-accept plaintext is always less than 16 bytes long, so electronic code book (ECB) mode is used for protecting Join-accept messages.

The Join-accept contains an AppNonce (a 24 bit value) that is recovered on the end-device along with the other Join-accept content (e.g. DevAddr) using the aes-encrypt operation.

Once the Join-accept payload is available to the end-device the session keys are derived from the AppKey, AppNonce and other values, again using an ECB mode aes-encrypt operation, with the plaintext input being a maximum of 16 octets.

4.2. Narrowband IoT (NB-IoT)

[[Text here is from [I-D.ratilainen-lpwan-nb-iot].]]

4.2.1. Provenance and Documents

Narrowband Internet of Things (NB-IoT) is developed and standardized by 3GPP. The standardization of NB-IoT was finalized with 3GPP Release-13 in June 2016, but further enhancements for NB-IoT are worked on in the following releases, for example in the form of multicast support. For more information of what has been specified for NB-IoT, 3GPP specification 36.300 [TGPP36300] provides an overview and overall description of the E-UTRAN radio interface protocol architecture, while specifications 36.321 [TGPP36321], 36.322 [TGPP36322], 36.323 [TGPP36323] and 36.331 [TGPP36331] give more detailed description of MAC, RLC, PDCP and RRC protocol layers respectively.

4.2.2. Characteristics

[[Editor notes: Not clear if all the radio info here is needed. Not clear what minimum MTU might be. Many 3GPP acronyms/terms to eliminate or explain.]]

Specific targets for NB-IoT include: Less than 5$ module cost, extended coverage of 164 dB maximum coupling loss, battery life of

over 10 years, ~55000 devices per cell and uplink reporting latency of less than 10 seconds.

NB-IoT supports Half Duplex FDD operation mode with 60 kbps peak rate in uplink and 30 kbps peak rate in downlink, and a maximum size MTU of 1600 bytes. As the name suggests, NB-IoT uses narrowbands with the bandwidth of 180 kHz in both, downlink and uplink. The multiple access scheme used in the downlink is OFDMA with 15 kHz sub-carrier spacing. On uplink multi-tone SC-FDMA is used with 15 kHz tone spacing or as a special case of SC-FDMA single tone with either 15kHz or 3.75 kHz tone spacing may be used.

NB-IoT can be deployed in three ways. In-band deployment means that the narrowband is multiplexed within normal LTE carrier. In Guard-band deployment the narrowband uses the unused resource blocks between two adjacent LTE carriers. Also standalone deployment is supported, where the narrowband can be located alone in dedicated spectrum, which makes it possible for example to refarm the GSM

carrier at 850/900 MHz for NB-IoT. All three deployment modes are meant to be used in licensed bands. The maximum transmission power is either 20 or 23 dBm for uplink transmissions, while for downlink transmission the eNodeB may use higher transmission power, up to 46 dBm depending on the deployment.

For signaling optimization, two options are introduced in addition to legacy RRC connection setup, mandatory Data-over-NAS (Control Plane optimization, solution 2 in [TGPP23720]) and optional RRC Suspend/ Resume (User Plane optimization, solution 18 in [TGPP23720]). In the control plane optimization the data is sent over Non Access Stratum, directly from Mobility Management Entity (MME) in core network to the UE without interaction from base station. This means there are no Access Stratum security or header compression, as the Access Stratum is bypassed, and only limited RRC procedures.

The RRC Suspend/Resume procedures reduce the signaling overhead required for UE state transition from Idle to Connected mode in order to have a user plane transaction with the network and back to Idle state by reducing the signaling messages required compared to legacy operation

With extended DRX the RRC Connected mode DRX cycle is up to 10.24 seconds and in RRC Idle the DRX cycle can be up to 3 hours.

NB-IoT has no channel access restrictions allowing up to a 100% duty-cycle.

3GPP access security is specified in [TGPP33203].

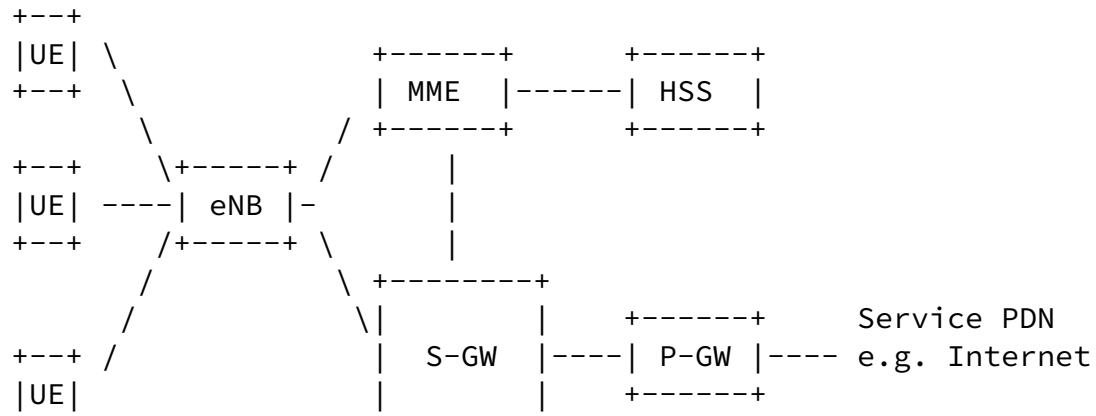


Figure 3: 3GPP network architecture

Mobility Management Entity (MME) is responsible for handling the mobility of the UE. MME tasks include tracking and paging UEs, session management, choosing the Serving gateway for the UE during initial attachment and authenticating the user. At MME, the Non Access Stratum (NAS) signaling from the UE is terminated.

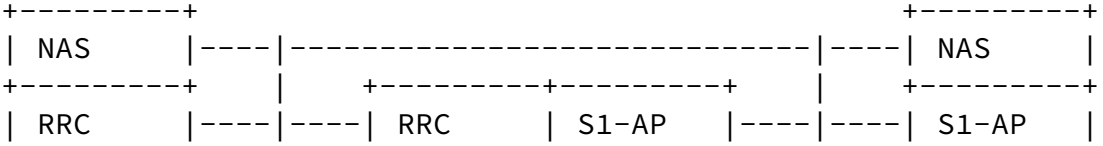
Serving Gateway (S-GW) routes and forwards the user data packets through the access network and acts as a mobility anchor for UEs during handover between base stations known as eNodeBs and also during handovers between other 3GPP technologies.

Packet Data Node Gateway (P-GW) works as an interface between 3GPP network and external networks.

Home Subscriber Server (HSS) contains user-related and subscription-related information. It is a database, which performs mobility management, session establishment support, user authentication and access authorization.

E-UTRAN consists of components of a single type, eNodeB. eNodeB is a base station, which controls the UEs in one or several cells.

The illustration of 3GPP radio protocol architecture can be seen from Figure 4.



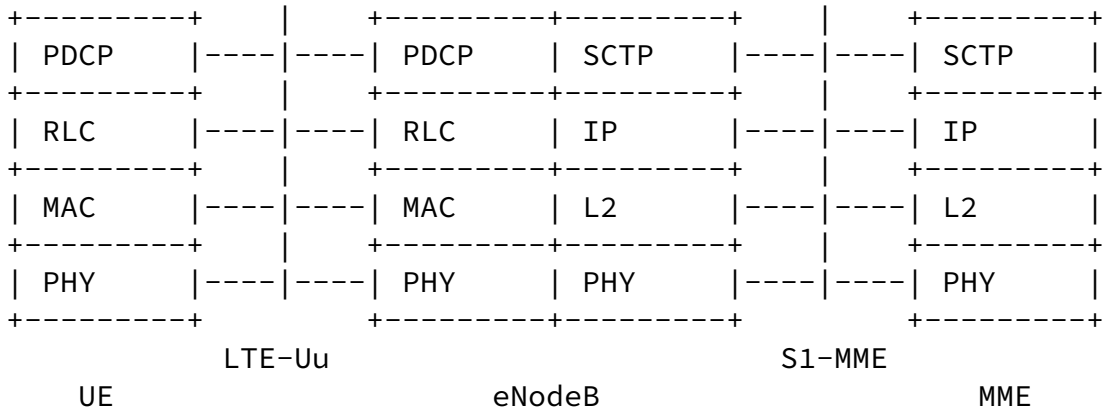


Figure 4: 3GPP radio protocol architecture

The radio protocol architecture of NB-IoT (and LTE) is separated into control plane and user plane. Control plane consists of protocols which control the radio access bearers and the connection between the UE and the network. The highest layer of control plane is called Non-Access Stratum (NAS), which conveys the radio signaling between the UE and the EPC, passing transparently through radio network. It is responsible for authentication, security control, mobility management and bearer management.

Access Stratum (AS) is the functional layer below NAS, and in control plane it consists of Radio Resource Control protocol (RRC) [TGPP36331], which handles connection establishment and release functions, broadcast of system information, radio bearer establishment, reconfiguration and release. RRC configures the user and control planes according to the network status. There exists two RRC states, RRC_Idle or RRC_Connected, and RRC entity controls the switching between these states. In RRC_Idle, the network knows that the UE is present in the network and the UE can be reached in case of incoming call. In this state the UE monitors paging, performs cell measurements and cell selection and acquires system information. Also the UE can receive broadcast and multicast data, but it is not expected to transmit or receive singlecast data. In RRC_Connected the UE has a connection to the eNodeB, the network knows the UE location on cell level and the UE may receive and transmit singlecast data. RRC_Connected mode is established, when the UE is expected to be active in the network, to transmit or receive data. Connection is released, switching to RRC_Idle, when there is no traffic to save the UE battery and radio resources. However, a new feature was introduced for NB-IoT, as mentioned earlier, which allows data to be

transmitted from the MME directly to the UE, while the UE is in RRC_Idle transparently to the eNodeB.

Packet Data Convergence Protocol's (PDCP) [TGPP36323] main services in control plane are transfer of control plane data, ciphering and integrity protection.

Radio Link Control protocol (RLC) [TGPP36322] performs transfer of upper layer PDUs and optionally error correction with Automatic Repeat reQuest (ARQ), concatenation, segmentation and reassembly of RLC SDUs, in-sequence delivery of upper layer PDUs, duplicate detection, RLC SDU discard, RLC-re-establishment and protocol error detection and recovery.

Medium Access Control protocol (MAC) [TGPP36321] provides mapping between logical channels and transport channels, multiplexing of MAC SDUs, scheduling information reporting, error correction with HARQ, priority handling and transport format selection.

Physical layer [TGPP36201] provides data transport services to higher layers. These include error detection and indication to higher layers, FEC encoding, HARQ soft-combining. Rate matching and mapping of the transport channels onto physical channels, power weighting and modulation of physical channels, frequency and time synchronization and radio characteristics measurements.

User plane is responsible for transferring the user data through the Access Stratum. It interfaces with IP and consists of PDCP, which in user plane performs header compression using Robust Header Compression (RoHC), transfer of user plane data between eNodeB and UE, ciphering and integrity protection. Lower layers in user plane are similarly RLC, MAC and physical layer performing tasks mentioned above.

Under worst-case conditions, NB-IoT may achieve data rate of roughly 200 bps. For downlink with 164 dB coupling loss, NB-IoT may achieve higher data rates, depending on the deployment mode. Stand-alone operation may achieve the highest data rates, up to few kbps, while in-band and guard-band operations may reach several hundreds of bps. NB-IoT may even operate with higher maximum coupling loss than 170 dB with very low bit rates.

4.3. SIGFOX

[[Text here is from [I-D.zuniga-lpwan-sigfox-system-description].]]

4.3.1. Provenance and Documents

The SIGFOX LPWAN is in line with the terminology and specifications being defined by the ETSI ERM TG28 Low Throughput Networks (LTN) group [etsi_ltn]. As of today, the SIGFOX LPWAN/LTN has been fully deployed in 6 countries, with ongoing deployments on 14 other countries, which in total will reach 316M people.

4.3.2. Characteristics

SIGFOX LPWAN autonomous battery-operated devices send only a few bytes per day, week or month, allowing them to remain on a single battery for up to 10-15 years.

The radio interface is compliant with the following regulations:

Spectrum allocation in the USA [fcc_ref]

Spectrum allocation in Europe [etsi_ref]

Spectrum allocation in Japan [arib_ref]

The SIGFOX LTN radio interface is also compliant with the local regulations of the following countries: Australia, Brazil, Canada, Kenya, Lebanon, Mauritius, Mexico, New Zealand, Oman, Peru, Singapore, South Africa, South Korea, and Thailand.

The radio interface is based on Ultra Narrow Band (UNB) communications, which allow an increased transmission range by spending a limited amount of energy at the device. Moreover, UNB allows a large number of devices to coexist in a given cell without significantly increasing the spectrum interference.

Both uplink and downlink communications are possible with the UNB solution. Due to spectrum optimizations, different uplink and downlink frames and time synchronization methods are needed.

The main radio characteristics of the UNB uplink transmission are:

- Channelization mask: 100 Hz (600 Hz in the USA)

- Uplink baud rate: 100 baud (600 baud in the USA)
- Modulation scheme: DBPSK
- Uplink transmission power: compliant with local regulation
- Link budget: 155 dB (or better)

- Central frequency accuracy: not relevant, provided there is no significant frequency drift within an uplink packet

In Europe, the UNB uplink frequency band is limited to 868,00 to 868,60 MHz, with a maximum output power of 25 mW and a maximum mean transmission time of 1%.

The format of the uplink frame is the following:

Figure 5: Uplink Frame Format

The uplink frame is composed of the following fields:

- Preamble: 19 bits
- Frame sync and header: 29 bits
- Device ID: 32 bits
- Payload: 0-96 bits
- Authentication: 16-40 bits
- Frame check sequence: 16 bits (CRC)

The main radio characteristics of the UNB downlink transmission are:

- Channelization mask: 1.5 kHz
- Downlink baud rate: 600 baud
- Modulation scheme: GFSK
- Downlink transmission power: 500 mW (4W in the USA)
- Link budget: 153 dB (or better)
- Central frequency accuracy: Centre frequency of downlink transmission are set by the network according to the corresponding uplink transmission.

In Europe, the UNB downlink frequency band is limited to 869,40 to 869,65 MHz, with a maximum output power of 500 mW with 10% duty cycle.

The format of the downlink frame is the following:

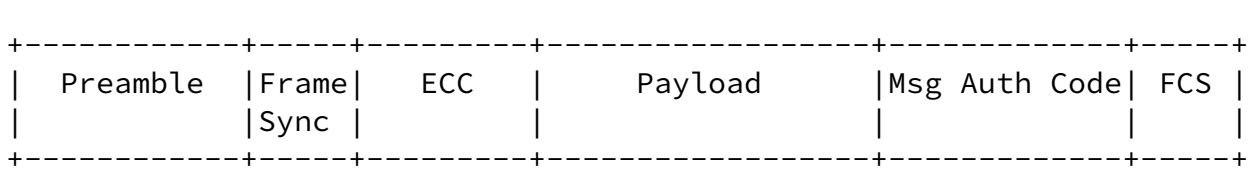


Figure 6: Downlink Frame Format

The downlink frame is composed of the following fields:

- Preamble: 91 bits
- Frame sync and header: 13 bits
- Error Correcting Code (ECC): 32 bits
- Payload: 0-64 bits
- Authentication: 16 bits

o Frame check sequence: 8 bits (CRC)

The radio interface is optimized for uplink transmissions, which are asynchronous. Downlink communications are achieved by querying the network for existing data from the device.

A device willing to receive downlink messages opens a fixed window for reception after sending an uplink transmission. The delay and duration of this window have fixed values. The LTN network transmits the downlink message for a given device during the reception window. The LTN network selects the BS for transmitting the corresponding downlink message.

Uplink and downlink transmissions are unbalanced due to the regulatory constraints on the ISM bands. Under the strictest regulations, the system can allow a maximum of 140 uplink messages and 4 downlink messages per device. These restrictions can be slightly relaxed depending on system conditions and the specific regulatory domain of operation.

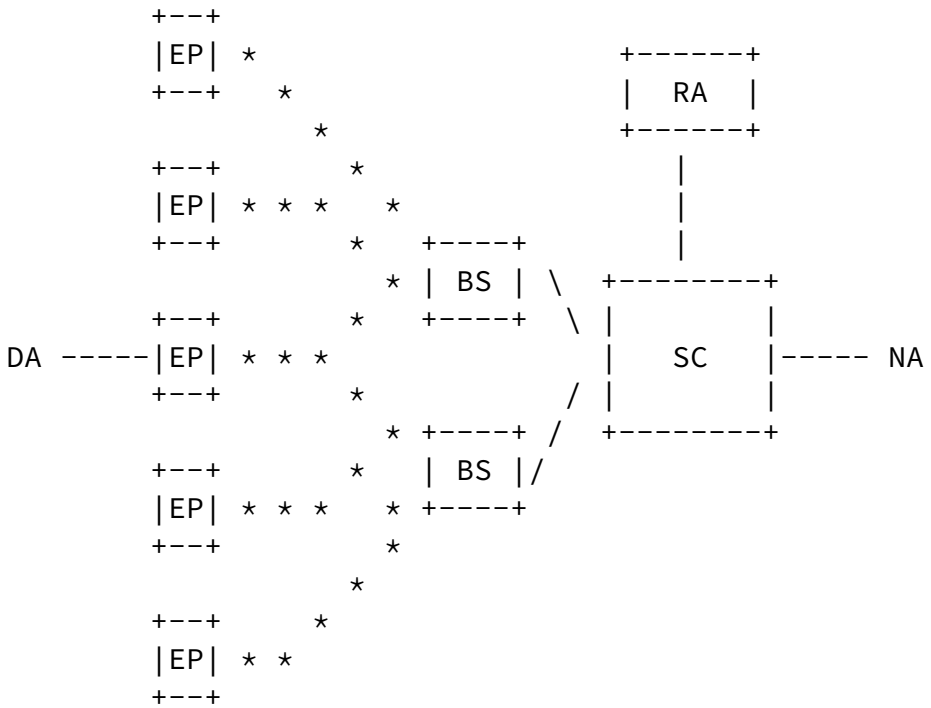


Figure 7: ETSI LTN architecture

Figure 7 depicts the different elements of the SIGFOX architecture.

The architecture consists of a single core network, which allows global connectivity with minimal impact on the end device and radio access network. The core network elements are the Service Center (SC) and the Registration Authority (RA). The SC is in charge of the data connectivity between the Base Station (BS) and the Internet, as well as the control and management of the BSs and End Points. The RA is in charge of the End Point network access authorization.

The radio access network is comprised of several BSs connected directly to the SC. Each BS performs complex L1/L2 functions, leaving some L2 and L3 functionalities to the SC.

The devices or End Points (EPs) are the objects that communicate application data between local device applications (DAs) and network applications (NAs).

EPs (or devices) can be static or nomadic, as they associate with the SC and they do not attach to a specific BS. Hence, they can communicate with the SC through one or many BSs.

Due to constraints in the complexity of the EP, it is assumed that EPs host only one or very few device applications, which communicate to one single network application at a time.

The radio protocol provides mechanisms to authenticate and ensure integrity of the message. This is achieved by using a unique device ID and a message authentication code, which allow ensuring that the message has been generated and sent by the device with the ID claimed in the message.

Security keys are independent for each device. These keys are associated with the device ID and they are pre-provisioned. Application data can be encrypted by the application provider.

4.4. WI-SUN

[[Add text here when available. Source = bheile@ieee.org]]

5. Gap Analysis

[[Add text here from [I-D.minaburo-lpwan-gap-analysis].]]

6. Security Considerations

7. IANA Considerations

There are no IANA considerations related to this memo.

8. Contributors

As stated above this document is mainly a collection of content developed by the full set of contributors listed below. The main input documents and their authors were:

- The text on LoRaWAN was based on [I-D.farrell-lpwan-lora-overview] co-authored by Alper Yegin and Stephen Farrell.
- Text for Section 4.2 was provided by Antti Ratilainen in [I-D.ratilainen-lpwan-nb-iot].
- Text for Section 4.3 was provided by Juan Carlos Zuniga and Benoit Ponsard in [I-D.zuniga-lpwan-sigfox-system-description].
- Text for Section 5 was provided by Ana Minabiru, Carles Gomez, Laurent Toutain, Josep Paradells and Jon Crowcroft in [I-D.minaburo-lpwan-gap-analysis]. Additional text from that draft is also used elsewhere above.

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Errors in the handling of that are solely the editor's fault.

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10. Informative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

[I-D.farrell-lpwan-lora-overview] Farrell, S. and A. Yegin, "LoRaWAN Overview", draft-farrell-lpwan-lora-overview-01 (work in progress), October 2016.

[I-D.minaburo-lpwan-gap-analysis] Minaburo, A., Gomez, C., Toutain, L., Paradells, J., and J. Crowcroft, "LPWAN Survey and GAP Analysis", draft-minaburo-lpwan-gap-analysis-02 (work in progress), October 2016.

[I-D.zuniga-lpwan-sigfox-system-description] Zuniga, J. and B. PONSARD, "SIGFOX System Description", draft-zuniga-lpwan-sigfox-system-description-00 (work in progress), July 2016.

[I-D.ratilainen-lpwan-nb-iot] Ratilainen, A., "NB-IoT characteristics", draft-ratilainen-lpwan-nb-iot-00 (work in progress), July 2016.

[TGPP36300] 3GPP, "TS 36.300 v13.4.0 Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2", 2016, <http://www.3gpp.org/ftp/Specs/2016-09/Rel-14/36_series/>.

[TGPP36321] 3GPP, "TS 36.321 v13.2.0 Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification", 2016.

[TGPP36322] 3GPP, "TS 36.322 v13.2.0 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol

specification", 2016.

[TGPP36323]
3GPP, "TS 36.323 v13.2.0 Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification (Not yet available)", 2016.

[TGPP36331]
3GPP, "TS 36.331 v13.2.0 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification", 2016.

[TGPP36201]
3GPP, "TS 36.201 v13.2.0 - Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description", 2016.

[TGPP23720]
3GPP, "TR 23.720 v13.0.0 - Study on architecture enhancements for Cellular Internet of Things", 2016.

[TGPP33203]
3GPP, "TS 33.203 v13.1.0 - 3G security; Access security for IP-based services", 2016.

[etsi_ltn]
"ETSI Technical Committee on EMC and Radio Spectrum Matters (ERM) TG28 Low Throughput Networks (LTN)", February 2015.

[fcc_ref] "FCC CFR 47 Part 15.247 Telecommunication Radio Frequency Devices - Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz.", June 2016.

[etsi_ref]
"ETSI EN 300-220 (Parts 1 and 2): Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW", May 2016.

[arib_ref]

"ARIB STD-T108 (Version 1.0): 920MHz-Band Telemeter, Telecontrol and data transmission radio equipment.", February 2012.

[LoRaSpec]
LoRa Alliance, "LoRaWAN Specification Version V1.0.2", Nov 2016, <URL TBD>.

[LoRaSpec1.0]
LoRa Alliance, "LoRaWAN Specification Version V1.0", Jan 2015, <https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pdf>.

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