Technology: LoRaWAN ® (Long Range Wide Area Network)

Abstract

LoRaWAN (Long Range Wide Area Network) belongs to the low-power wide area network technologies (LPWAN). It operates in the licence free wireless frequency spectrum, usually known as ISM (industrial, scientific and medical) radio band. Due to national legislations, these frequencies can differ from one location to the other.

LoRaWAN takes advantage of the long range characteristics of the LoRa physical layer, allowing a single-hop link between end-devices and one or many gateways. All modes (class A, B, and C) are capable of bi-directional communication, and there is support for multicast addressing groups to make efficient use of spectrum during tasks such as Firmware Over-The-Air (FOTA) upgrades or other mass distribution messages.

The aim of LoRaWAN can be described as a technology which offers wireless transfer of data over longer distances with a minimum of energy and at low costs. The amount of data and the number of transmissions are strictly limited. LoRaWAN is also a mainly uplink oriented technology. It is therefore primarily suited for the transmission of sensor signals with very limited data content (payload) and no real-time requirements.

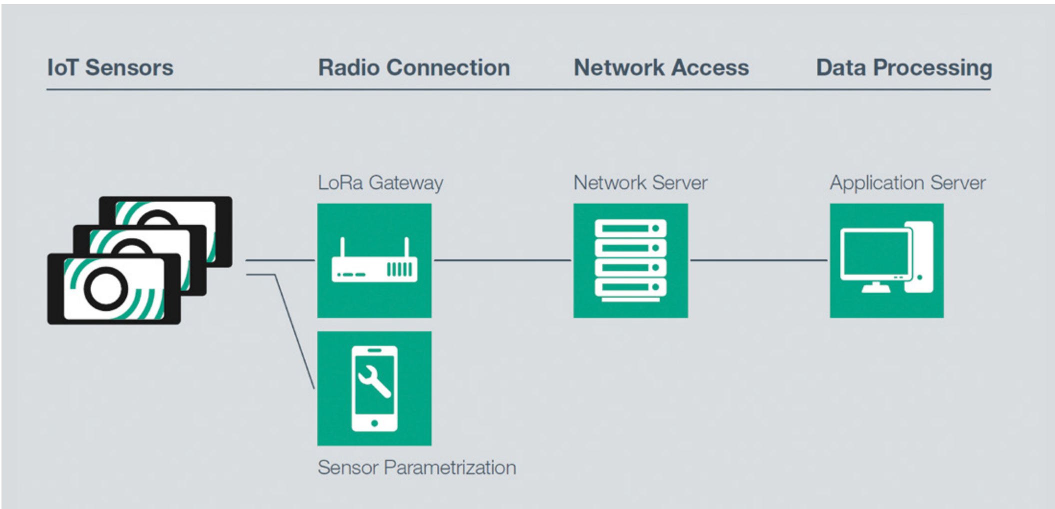
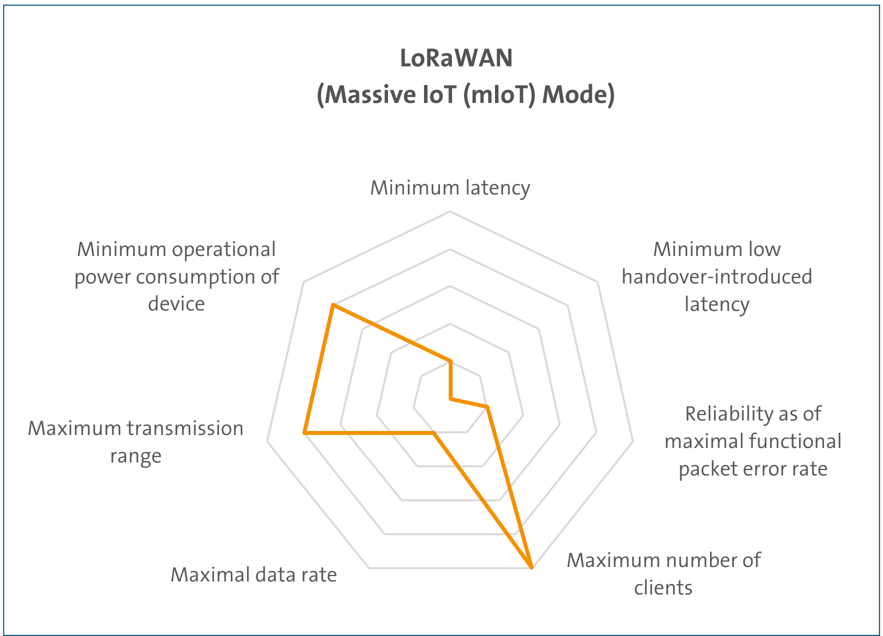


Figure 1 Source: Pepperl+Fuchs SE

Technology Briefly



Note: Scale value "5" = best performance; scale value "0" = not specified. Source: Pepperl+Fuchs SE

The properties in this diagram have been defined by consensus within WCM-Working Group 2.

In addition to a consensual definition, the property values refer to requirements described in reference use cases. This is done to ensure a degree of comparability between wireless communication systems.

The reference use cases have been described by the WCM-Working Group 1, providing specific requirements for:

- Realtime / Ultra low latency communication (e.g. discrete manufacturing)
- Streaming/high data rate (e.g. video streaming)
- Massive Industrial Internet of Things (mIIoT) / Sensor Networks (e.g. valve status)

Property Definitions

Minimum Latency

Nominal achievable latency for the given reference use case and the associated functional packet error rate (FPER) property.

- Assuming that all clients are able to fulfill this latency requirement at the same time
- The latency is measured from reference input interface to reference output interface of the wireless communication system (e.g. Layer2/3)
- The latency and FPER of the spider diagram need to be achievable at the same time as they are linked together

Minimum Handover-Introduced latency

Minimum latency added to the nominal latency when a handover of a single device occurs for the given use case. Handover assumes operation of all devices of the usecase with the associated FPER.

Reliability as of maximal Functional Packet Error Rate, where Functional PER:

Percentage of data that is delivered later than the nominal latency for a given reference use case due to errors on the channel, late channel access, scheduling, or whatever other reason.

- Assuming that all clients are at the maximum range and at line of sight
- Assuming that all devices have to fulfill the same latency requirement (provided by the minimum latency property)
- Assuming that all clients fulfill the same FPER requirement
- FPER and latency of the spiderdiagram need to be achievable at the same time as they are linked together

Maximum number of clients

The maximum supportable number of clients for the given reference use case. This means the number of clients servable by one access point/base station/node in a meshed network/ relay.

- Assuming that all devices in that scenario have the same communication requirements
- The available spectrum for the property is defined by the maximum bandwidth supported by the technology.
  It needs to be in line with the data rate property
- Per default the frequency regulation of Germany is referenced

Maximum Data Rate

The maximum/peak user data rate (payload) achievable per device for the given reference use case. Assuming that all devices in that scenario have the same communication requirements.

Minimum Operational Power Consumption of Device

Mean power consumption in Watt [W] for the given reference use case.

- This references the power consumption of a known device/node for that use case
- The time duration for the averaging is defined by the use case

Maximum Transmission Range

Maximum distance from a single transmitter to a single receiver

- Assuming maximum allowed transmission power (EIRP)
- Assuming typical receive antennas for the application
- The frequency band is also defined by the application
- Assuming line of sight communication

The “Technical Parameters” chart in the “Detailed Technology Description” section provides further information on these properties and other Key Performance Indicators (KIPs).

A brief description of the reference use cases can be found in the Appendix.

Disclaimer: This graph is based on the information provided by the authors of this chapter – a list of authors can be found at the end of the publication – available at the time of publication. It reflects an approximate performance of the communications system at a high level, based on the requirements specified in reference use cases.

This performance may of course vary depending on the degree of customization possible in defining the specific requirements for each industrial application and on the specific implementation. Thus, dialogue between the industrial user and wireless experts is encouraged to explore all possibilities.

High-level Technology Description

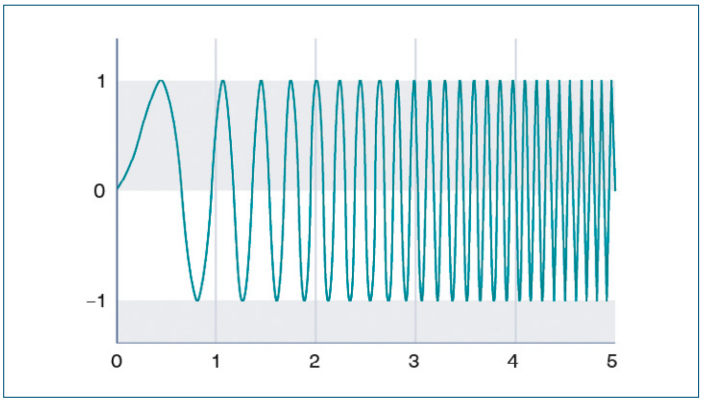


Figure 2: Chip signal for the transmission of LoRa signals Source: Pepperl+Fuchs SE

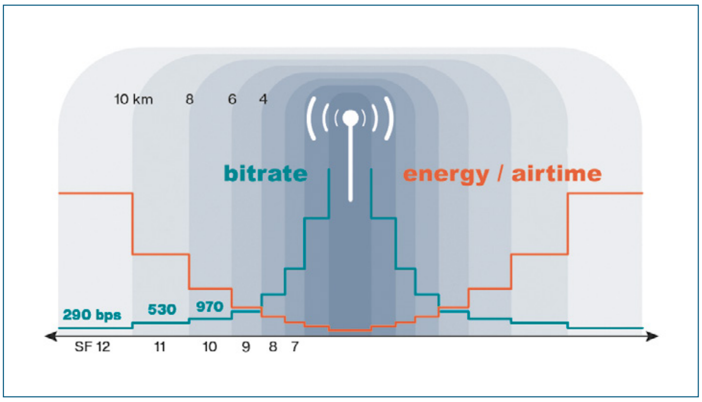


Figure 3: LoRa Spreading Factor (SF), Bitrates and Time on Air Source: Pepperl+Fuchs SE

Topology

LoRaWAN is a star transmission technology. The so called end-device sends its data (payload) to a local gateway. The number of gateways corresponds to the required connectivity in a certain area. In a free field the coverage is much better than in a very congested area, especially if end-devices must be reached in the basement of buildings.

The gateway transfers the messages to a server. The so-called LoRaWAN Network-Server (LNS) is handling the communication with the end-devices. Therefore, an end-device can transmit messages via several gateways in the reach of the signal, if they belong to the same server. The Network-Server incorporates a Join-Server, which is handling the join process of an end-device and the generation of the encryption keys. The Network-Server delivers the messages to an Application-Server, which is usually already part of the end-user infrastructure.

Interfaces

The communication between an end-device and the LNS is defined by the LoRaWAN specification issued by the LoRa Alliance. The payload of the end-device is of course specific to the respective task of the end-device and needs to be decoded. Since there is an end-to-end encryption of the payload, the decoding usually happens on the Application-Server side. But the protocol between Network-Server and Application-Server depends on customer requirements. Typical formats are MQTT or Rest API.

Time Behaviour

Since LoRaWAN operates in a licence free spectrum, there are strong legal limitation. In this case the use of air-time is limited to 1% in the preference channels. Since LoRaWAN allows for 6 different transmission cycles this leads also to a restriction of the payload, as described in the table. These values are right for Europe regulation, but there are other limitations outside Europe, especially in the USA.

LoRaWAN defines 3 classes of devices.

Class A is primarily up-link oriented. It can receive down-link information from a server only directly after a sent message. After sending there comes a small message receive window, which may be used to send messages to the end-device. Class A devices represent approx. 90% of the market.

Class B devices can receive down-links in defined time intervals which are independent from the up-link messages. This needs a time synchronization with the server. This version is rarely used on the market.

Class C device may communicate bi-directional any time. As a consequence such units cannot be operated by batteries anymore, since the power consumption is much too high.

Therefore, one of the most important advantages of LoRaWAN applications is lost, but in cases, where power is available but no wired communication infrastructure is existing, this is an alternative to other wireless communication networks, because of the long range feature.

Spectrum

The base technology of LoRaWAN is called CSS (Chirp Spread Spectrum). That means the radio signals are using an increasing (up-chirp) or decreasing (down-chirp) frequency at a constant amplitude. This method has proven to provide a very good range for the given low power and it can receive messages even under the noise level.

Spreading Factor	Data-/Bit Rate	Range (depending on terrain)	Time on Air (for a 11-byte payload)
SF7	5470 bps	2km	60ms
SF8	3125bps	4km	100 ms
SF9	1760 bp s	6 km	200ms
SF10	970bps	8km	370ms
SF11	530bps	10 km	740 ms
SF12	290bps	14km	1400 ms

Figure 4: LoRa Spreading Factor (SF), Bitrates and Time on Air Source: Pepperl+Fuchs SE

To adapt to different transmission qualities, there are 6 Spreading Factors (SF) available. Spreading means, that the transmission time is expanded to improve the range (see table below). A higher spreading factor increase the air-time and allows for a longer range of the signals, but also reduces the data-rate.

The frequencies (ISM band) depend on the region respectively local legislation and rules.

Typical examples are:

868 MHz (Europe),
915 MHz (USA),
950 MHz (Japan),
430 MHz (Asia)

Coexistence

LoRaWAN used the ALOHA principle. ALOHA is a multiple access protocol for transmission of data via a shared network channel. That means, an end-device can send out data any time without synchronization with other end-device or the receiving gateway.

If several end-devices send data at the same time using identical data rates, then collisions may happen and data will be lost.

Using different spreading factors allows the gateway to receive data from different end-devices simultaneously. Additionally, there are different channels available (the three default channels are 868.10, 868.30, 868.50 MHz).

Maturity

LoRaWAN is a mature technology. The specifications are provided by the LoRa Alliance. Gateways and a great number of end-devices are available. There are more than 170 LoRaWAN network operators active worldwide.

Detailed Technology Description

Technical Parameters

Parameter	General KPIs
Protocol	Low Power, Wide Area proprietary
Frequency bands	430/868/915 MHz
Un-licensed frequency band	Yes (ISM)
International coverage	Worldwide
Real-Time capability	No
Network topology	Star
Handover (mobility) support	Yes
Voice support	No
Localization support	No
Coexistence mitigation mode	Multi-channel use, spreading factor
MiMo capability	Yes
Typical range BS - MS	1.5 to 14 km
Typical latency BS - MS	100 ms to 3 s
Typical data rate	0.29 to 5.47 kbps
Maximal number of active clients	Unlimited
Maximal lifetime when using a battery	10 years, max.
Expected interference immunity	Good
Likelihood of coexistence	Frequency dependent
Signal bandwidth	125 KHz
Coexistence relevant bandwidth	CSS modulation
Technology maturity level	Mature (TRL 9...10)
Product availability	Available
Standardization	LoRa Alliance
Standard availability	Available
Required Infrastructure on site	Gateway
Massive IoT Mode (mIoT)	
Nominal latency	3 s
Handover introduced latency	n.s.
Cycle time	Duty cycle 0,1% / 1%
Roundtrip time	Part of LoRa protocol

Parameter	General KPIs
Maximal Functional Packet Error Rate	10^{-2}
Maximum number of clients	No Limit
Telegram size	64 Byte max.
Maximal data rate MS downlink	5,47 kbps
Maximal data rate MS uplink	5,47 kbps
Data payload per MS downlink (net)	51 Byte (SF12, 1% airtime)
Data payload per MS uplink (net)	51 Byte (EU)
Maximal RF power [EIRP] downlink	16 dBm EIRP (40 mW in EU)
Maximal RF power [EIRP] uplink	16 dBm EIRP (40 mW in EU)
Required SNR	-20 dB min.
Mean power consumption in usecase	10 mA / 100 nA (sleep mode)
Maximum transmission range	14 km
Maximum velocity of an MS	n/a

Technology Description

LoRaWAN belongs to the low-power wide area network technologies. It operates in the licence free wireless frequency spectrum, usually known as ISM (industrial, scientific and medical) radio band. Due to national legislations, these frequencies can differ from one location to the other.

The aim of LoRaWAN can be described as a technology which offers wireless transfer of data over longer distances with a minimum of energy and at low costs. The amount of data and the number of transmissions are strictly limited. LoRaWAN is also a mainly uplink oriented technology. It is therefore primarily suited for the transmission of signals with very limited data content (payload) and no real-time requirements.

LoRaWAN provide ADR (adaptable data rate) by changing the spreading factor SF. A low SF leads to a high data rates and vice versa. This has significant influence on the range of the signals (see technical parameters chart). The adaptation of the date rate is performed by an algorithm in the network server, using Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) values to evaluate the transmission quality. A higher date rate also saves air-time, which reduces the probability of collisions.

Application Reference

Application Specific Technology Description

Smart Waste Applications and Metering

Current Situation
Besides metering another typical application can be found in the smart waste applications.

Waste bins are objects with no electrical supply or wired data connection. Therefore, a sensor must operate autonomously. In this specific case that means a maintenance free operation of up to six years and a radio communication even out of a metal container is required.

These applications are usually restricted to a clearly defined area. A waste collection service is always operating within a fixed area like a city or an industrial park. Therefore, local networks which could easily be scaled according to the specific environmental conditions, are absolutely feasible.

The amount of data is very limited and there are also no real-time requirements. Something like 3 messages per day are usually completely sufficient. On the other side, a lifetime of the battery of 6 or more years is demanded, since permanent maintenance of the sensors would generate unacceptable costs. In many cases the network is operated by the customer, which means that there are no fees for the transmission of data.

Pain Point
The general motivation hereby is the optimization of the services around the waste collection and the avoidance of dirt. This requires information about the individual fill level of each container, which is normally not available.

Wireless Solution
LoRaWAN has proven that its technology can fulfil the requirements very well, because the long range capability allows also for the integration of sensors in metal containers, which have a heavy damping effect on the radio signals. Nevertheless, the amount of gateways needed to provide connectivity at every location in a city stays within a very acceptable amount. This again has a major influence on the investment, which is needed to establish a LoRaWAN.

Real World Example
Meanwhile we find the first cities which are using local LoRaWAN networks to collect data from various end-devices. Especially glass container are often equipped with fill-level sensors to optimize the collection. This reduces unnecessary driving on the one side and avoids anger on the side of the citizen who stands in front of a completely filled container.