LEVEREGE

LoRa & LoRaWAN Primer

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Executive Summary

This document serves as an introduction to LoRa and LoRaWAN for those considering Internet of Things (IoT) deployments. The primer provides a basic overview of the technology as well as its variants such as Link Labs's Symphony Link. If you are looking for a more general overview of low-power, wide-area networks (LPWAN), please consider reading Leverege's LPWAN White Paper.

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LPWAN Overview

LPWAN (low-power, wide-area network) is a broad term encompassing various implementations and protocols both proprietary and open-source that share common characteristics:

- **Low power:** Can operate on inexpensive batteries for long periods of time, e.g., 7 - 10 years
- **Wide area:** Has an operating range that can exceed 2 km in urban environments

LPWAN technology works well in situations where devices need to send small packets of data over a wide area while preserving battery life. This distinguishes LPWAN from other wireless network protocols like Bluetooth, RFID, cellular M2M, and ZigBee, shown below with regards to bandwidth and range capability.

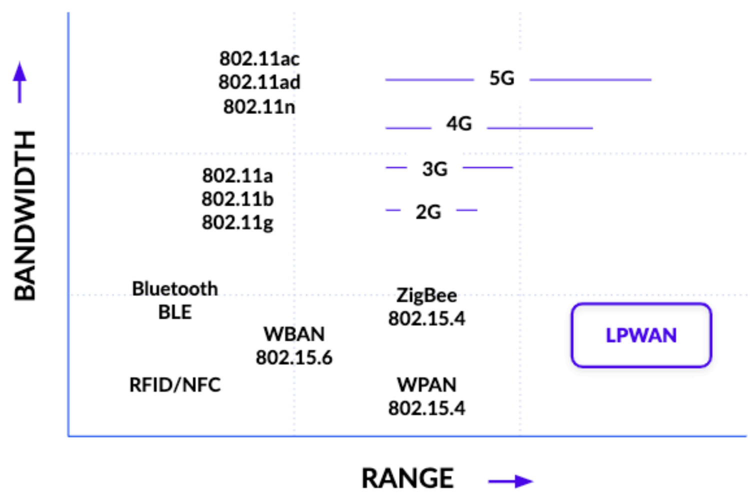

Figure 1, Range vs. Bandwidth for Various Connectivity Protocols

Image Credit: Sanae El Hassani

Market Segmentation for IoT

There are three distinct market segments within IoT based on the amount of bandwidth required for use cases:

High-bandwidth: Cellular (LTE, GSM) are typical connectivity choices for applications that require reliable, high-bandwidth bulk data transfer or real-time streaming of audio and video. Use cases include security applications and surveillance. These networks utilize the licensed spectrum for higher power operation, are more costly to operate, and typically require local power sources for end devices due to shortened battery life.

Medium-bandwidth: WiFi and Zigbee are appropriate for many smart home applications where range is not an issue whereas scaled versions of LTE (Cat-M1 and NB-IoT) are more apt for wide-area applications.

Low-bandwidth: LPWAN technology makes use of the low-cost structure to dominate verticals where long range, small data, and long battery life are required. These applications include sensor monitoring, remote metering, smart infrastructure, agriculture, asset tracking, and environment monitoring.

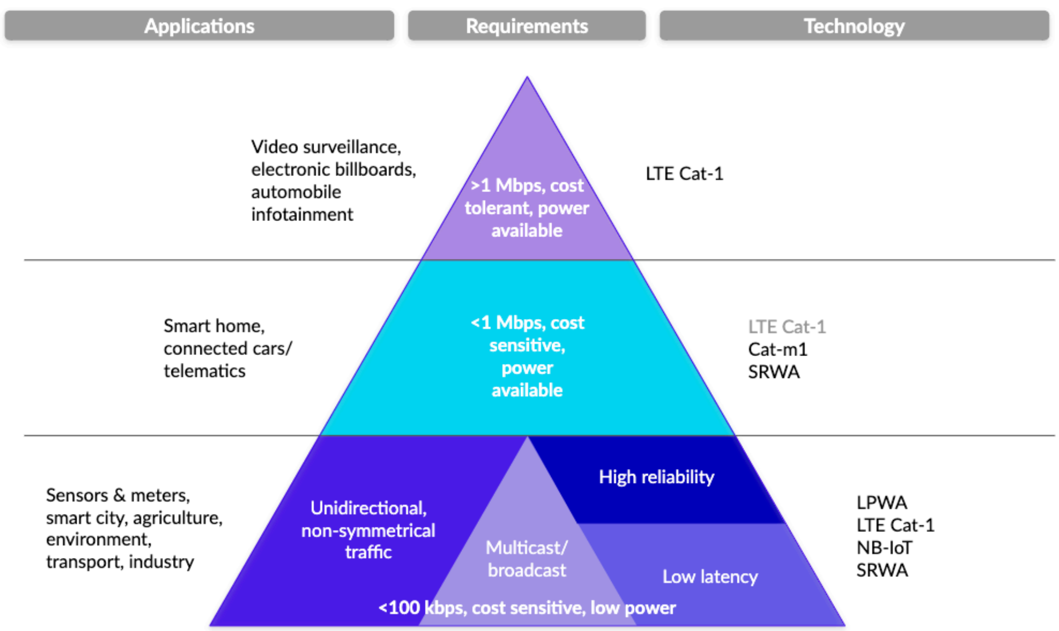

Figure 2, Applications Segmentation per Bandwidth

Image Credit: LPWAN Technology Decisions: 17 critical features

Within the LPWAN market, there exists several competing standards: SigFox, Weightless, RPMA, UNB, and LoRa/LoRaWAN. For in-depth comparison of each of these standards, refer to the Leverege White Paper on LPWAN.

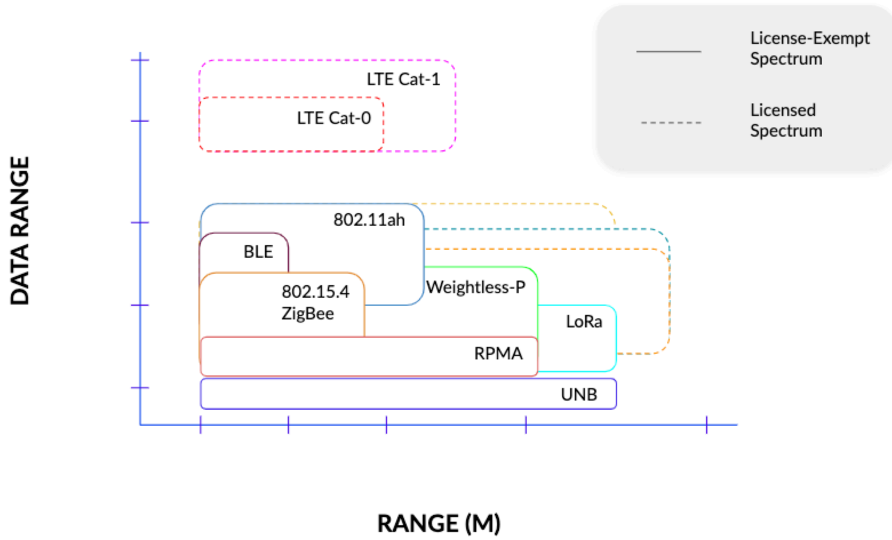

Figure 3, Range vs. Data Range for LPWAN Protocols

Image Credit: LPWAN Technology Decisions: 17 critical features

LoRa

LoRa is the physical layer (PHY) of the LPWAN technology stack. It is implemented on a proprietary chip made by Semtech that modulates wireless signals over a long range. Specifically, it uses a technique called chirp spread spectrum (CSS) that allows for a robust and low-power communication protocol over a wide area. For an in-depth discussion on the underlying technology, refer to Appendix A.

Terminology Clarification

It is critical to understand that LoRa, by itself, does not make it an implementation of LPWAN technology. LoRa is simply the chip that enables modulation. To create a network, a media access control (MAC) layer is also required. The MAC layer associated with LoRa chips is called LoRaWAN, maintained by the LoRa Alliance. LoRa is sometimes used to refer to this entire protocol, but to differentiate Link Labs' Symphony Link that uses a proprietary MAC layer on top of a LoRa chip, this document will take a strict definition of LoRa.

In summary:

- **LoRa** = PHY Layer
- **LoRaWAN** = MAC Layer
- **LoRa + LoRaWAN** = LPWAN

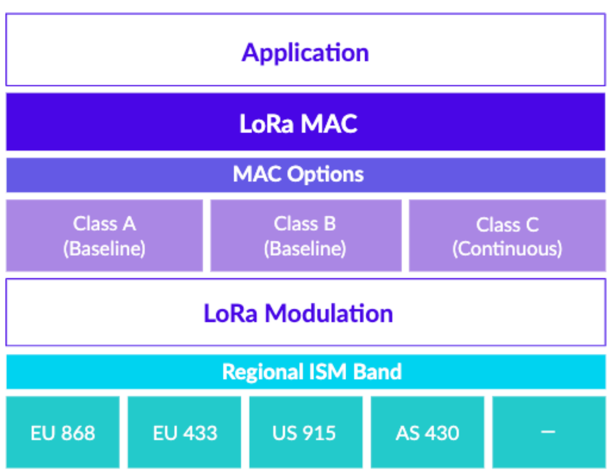

Figure 4, OSI Model for LoRa

Image Credit: LoRa Alliance

LoRaWAN

LoRaWAN is an open-standard that defines the communication protocol for LPWAN technology using a LoRa chip. Since CSS modulation does not mitigate collisions very well, LoRAWAN uses a multiple access protocol to handle this issue.

Network Architecture

LoRaWAN implements a star-on-star topology to relay messages to a central server using gateways. This topology preserves battery power while increasing the communication range. Each end node transmits the data to multiple gateways. The gateway will then forward the data to the network server where redundancy detection, security checks, and message scheduling are performed.

This design choice has the following implications:

- Easier asset tracking: Since the end node sends data to multiple gateways, there is no need for gateway-to-gateway communication. This simplifies the logic for asset tracking applications where the end nodes are mobile.
- Better for public networks: Having a central server mitigating collision issues means that LoRaWAN might not be a good fit for private/customer-deployed networks.

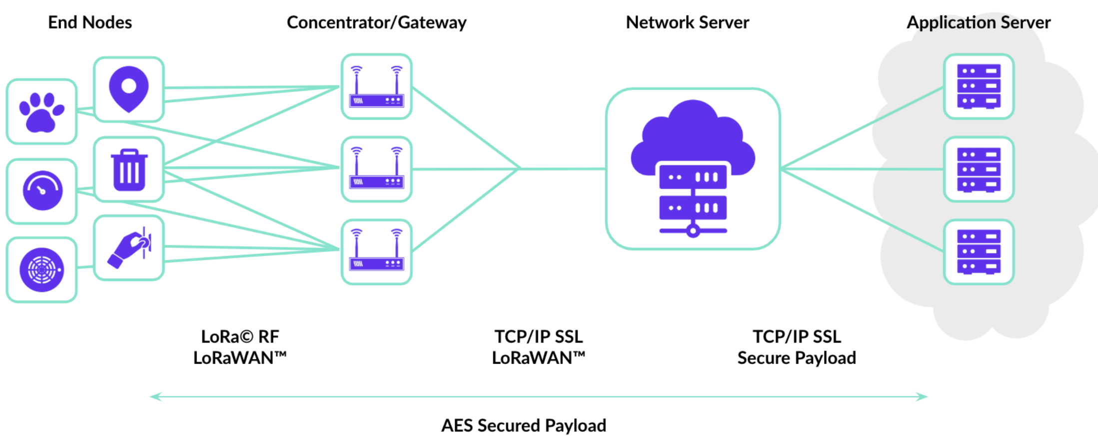

Figure 5, LoRaWAN End-to-End Communication Architecture

Image Credit: Mouser Electronics

Long communication range can also be achieved with a mesh network. However, mesh networks require a synchronous protocol to check for messages constantly, which consumes significant energy. The end nodes in a star-on-stars LoRaWAN network use an asynchronous protocol called ALOHA to only communicate when the data is ready or scheduled. This limits downlink capabilities but extends battery life.

Also, since gateways aggregate messages from many nodes, network capacity must expand to handle large amounts of data. The gateway achieves this by taking advantage of orthogonality and adaptive data rates. CSS modulation of LoRa chips makes signals orthogonal when different spreading factors are used. The gateway then receives simultaneous messages on multiple channels. For example, if a node is close to a gateway, it shifts the data rate higher to reduce the time the signal is in air; allowing for data from further nodes to transmit at a slower rate. (Communication range is inversely proportional to data rate. For a detailed technical discussion, please refer to Leverege's LPWAN White Paper).

Device Classes

LoRaWAN actually has three classes to cover a wide range of applications:

- **Class A** (Bi-directional end-devices): Each uplink transmission is followed by two short downlink receive windows. Class A devices use the lowest power and are useful for applications where downlink communication is not critical (similar to SigFox)
- **Class B** (Bi-directional end-devices with scheduled receive slots): In addition to the two downlink receive windows, Class B devices schedule a synchronized beacon to let the server know that the end-device is listening.
- **Class C** (Bi-directional end-devices with maximal receive slots): Class C devices have open receive windows that are only closed when transmitting. This uses a lot of power and renders it unfit for long battery-life applications.

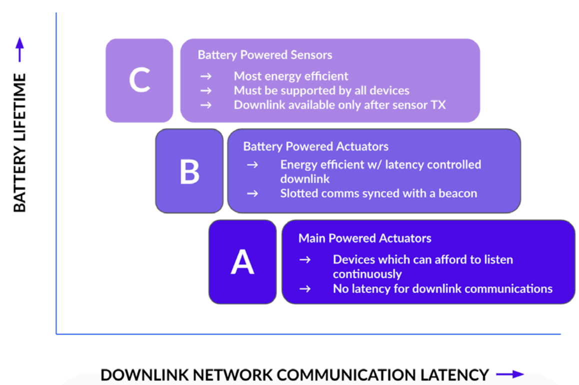

Figure 6, Three Classes of LoRaWAN

Image Credit: Silva Sammelsaar and Gunnar Kotkasets

Regional Differences

LoRaWAN specifications are only completely defined for Europe and North America. In the United States, LoRaWAN uses 64, 125 kHz uplink channels in 902.3 - 914.9 MHz in 200 kHz increments. An additional eight 500 kHz uplink channels exist in 1.6 Mhz increments in 903 - 914.9 MHz. Eight downlink channels are defined in 923.3 - 927.5 MHz, each 500 kHz wide. Since LoRa's CSS modulation qualifies as a digital modulation technique, it is exempt from the frequency hopping requirements of the FCC under Hybrid mode of operation.

Symphony Link (Link Labs)

Link Labs is a LoRa Alliance member that built their proprietary MAC protocol on top of Semtech's LoRa PHY. It added the following features on top of the LoRaWAN protocols:

- Guaranteed message receipt
- Firmware upgrade over-the-air
- Removes duty cycle limit
- Repeater capability
- Dynamic range

In summary, the biggest difference is that it adds a synchronous layer to allow repeaters and ac-acknowledgment messages. Also, before every transmission, the end device calculates the reverse link to the gateway and dynamically adjusts its parameters.

Pros:

- High sensitivity: -137 dBm
- Flexible frequency/no duty cycle limit: 150 MHz to 1 GHz (both unlicensed and licensed)
- Added features to LoRaWAN protocol

Cons:

- Requires Symphony Link software (added dependency)
- Smaller community of users

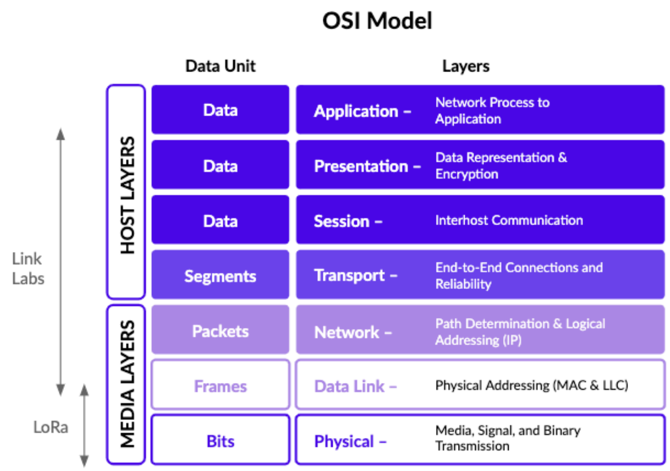

Figure 7, OSI Model

Image Credit: Link Labs

Appendix A: LoRa Technology

LoRa is a proprietary PHY layer made by Semtech. Therefore, the underlying technology is not fully open. This section will analyze open parts of LoRa and include empirical analysis from other re- searchers and vendors.

Overview[1]

LoRa is a modulation technique that uses chirp spread spectrum technology. LoRa chips generate a stable chirp using a frac-N phase lock loop (PLL), which is a linear variation of frequency over time. Due to this linearity, LoRa receivers are not affected by the Doppler effect and can be built inexpensively since extreme accuracy to account for frequency offsets are not necessary. LoRa receivers can achieve a sensitivity in the order of - 130 dBm even with cheap crystals.

Compared to traditional frequency shift keying (FSK) and phase shift keying (PSK) modulation schemes, LoRa receivers have a higher out-of-channel selectivity and co-channel rejection of 90 dB and 20 dB respectively. LoRa can also demodulate several orthogonal signals at the same frequency if they have different chirp rates (spreading factors with higher spreading factors denoting slower chirps).

Parameters

LoRa chirp rate is only dependent on the bandwidth. In fact, the chirp rate is equal to the bandwidth. Knowing that a LoRa symbol is encoded by 2S F chirps (where SF is the log2 spreading factor) that covers the entire frequency band, the relationship between the chirp rate and bandwidth brings several important consequences:

1. Spreading factor is inversely proportional to the frequency span of a chirp and directly proportional to the duration of a symbol.
2. Spreading factor does not affect the bit rate.
3. Bit rate at a spreading factor is proportional to the frequency bandwidth.

1 A. Augustin, J. Yi, T. Clausen, and W. M. Townsley. “A Study of LoRa: Long Range & Low Power Networks for the Internet of Things.” Sensors (Basel). 2016 Sep; 16(9): 1466.

LoRa also includes forward error correction code where the code rate is 4/(4+n) with n {1, 2, 3, 4}. So the useful bit rate is given by the following:

$$BitRate = SF \times BW/2^{sf} \times Code\ Rate$$

In general, receiver sensitivity increases with spreading factor and decreases with more bandwidth. So the theoretical receiver sensitivity per spreading factor and bandwidth are tabulated as following from the SX1276 datasheet:

Format

LoRa uses a specific structure to transmit physical frames:

1. Each message begins with a preamble where the up-chirps cover the entire frequency band and encodes a sync word. The sync word differentiates the LoRa network from others in the same frequency band.
2. The optional header provides the size of the payload, code rate, and the presence of payload CRC
3. Payload and the optional CRC follows the header

Appendix B: Symphony Link Protocol in 900MHz

1. Scan the band and create an interference profile
2. Gateway selects a 500 kHz channel for its downlink
3. Systems begins transmitting every 2 seconds
    a. Encrypted with the network ID - makes network private with application token
    b. uplink/downlink time boundary (LoRA is half-duplex technology, so important to prevent up/down collisions)
    c. Uplink channel frequencies

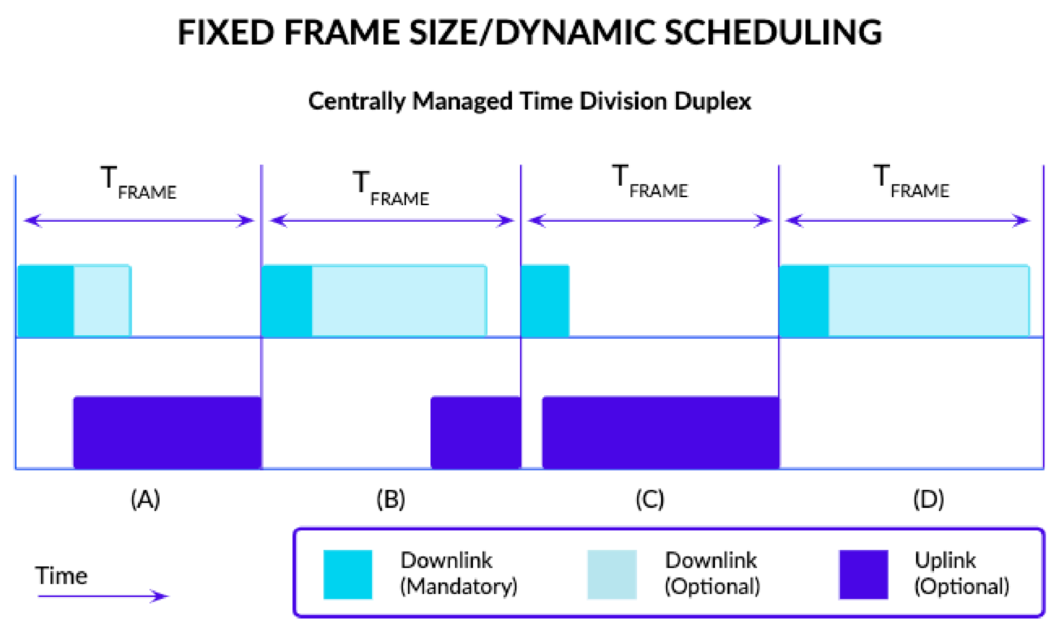

Figure 8, Fixed Frame Size/Dynamic Scheduling

Image Credit: Links Labs LPWA Webinar