LoRaWAN™

What is it?

A technical overview of LoRa® and LoRaWAN™

Technical Marketing Workgroup 1.0

LoRa® Alliance

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Wide Area Networks for IoT

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INTRODUCTION

The purpose of this document is to give an introductory technical overview to LoRa® and LoRaWAN™. Low–Power, Wide-Area Networks (LPWAN) are projected to support a major portion of the billions of devices forecasted for the Internet of Things (IoT). LoRaWAN™ is designed from the bottom up to optimize LPWANs for battery lifetime, capacity, range, and cost. A summary of the LoRaWAN™ specification for the different regions will be given as well as high level comparison of the different technologies competing in the LPWAN space.

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WHAT IS LoRa®?

LoRa® is the physical layer or the wireless modulation utilized to create the long range communication link. Many legacy wireless systems use frequency shifting keying (FSK) modulation as the physical layer because it is a very efficient modulation for achieving low power. LoRa® is based on chirp spread spectrum modulation, which maintains the same low power characteristics as FSK modulation but significantly increases the communication range. Chirp spread spectrum has been used in military and space communication for decades due to the long communication distances that can be achieved and robustness to interference, but LoRa® is the first low cost implementation for commercial usage.

Long Range (LoRa®)

The advantage of LoRa® is in the technology's long range capability. A single gateway or base station can cover entire cities or hundreds of square kilometers. Range highly depends on the environment or obstructions in a given

location, but LoRa® and LoRaWAN™ have a link budget greater than any other standardized communication technology. The link budget, typically given in decibels (dB), is the primary factor in determining the range in a given environment. Below are the coverage maps from the Proximus network deployed in Belgium. With a minimal amount of infrastructure, entire countries can easily be covered.

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WHERE DOES LPWAN FIT?

One technology cannot serve all of the projected applications and volumes for IoT. WiFi and BTLE are widely adopted standards and serve the applications related to communicating personal devices quite well. Cellular technology is a great fit for applications that need high data throughput and have a power source. LPWAN offers multi-year battery lifetime and is designed for sensors and applications that need to send small amounts of data over long distances a few times per hour from varying environments

Local Area Network Short Range Communication	Low Power Wide Area (LPWAN) Internet of Things	Cellular Network Traditional M2M
40%	45%	15%
Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
Bluetooth 4.0 WiFi	LoRa	GSM 3G+ / H+ 4G

IMPORTANT FACTORS IN LPWAN

The most critical factors in a LPWAN are:

- **Network architecture**

- **Communication range**

- **Battery lifetime or low power**

- **Robustness to interference**

- **Network capacity (maximum number of nodes in a network)**

- **Network security**

- **One-way vs two-way communication**

- **Variety of applications served**

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WHAT IS LoRaWAN™?

LoRaWAN™ defines the communication protocol and system architecture for the network while the LoRa® physical layer enables the long-range communication link. The protocol and network architecture have the most influence in determining the battery lifetime of a node, the network capacity, the quality of service, the security, and the variety of applications served by the network.

Application				
LoRa® MAC				
MAC options				
Class A (Baseline)	Class B (Baseline)		Class C (Continuous)	
LoRa® Modulation				
Regional ISM band				
EU 868	EU 433	US 915	AS 430	—

WHAT IS LoRaWAN™?

Network Architecture

Many existing deployed networks utilize a mesh network architecture. In a mesh network, the individual end-nodes forward the information of other nodes to increase the communication range and cell size of the network. While this increases the range, it also adds complexity, reduces network capacity, and reduces battery lifetime as nodes receive and forward information from other nodes that is likely irrelevant for them. Long range star architecture makes the most sense for preserving battery lifetime when long-range connectivity can be achieved.
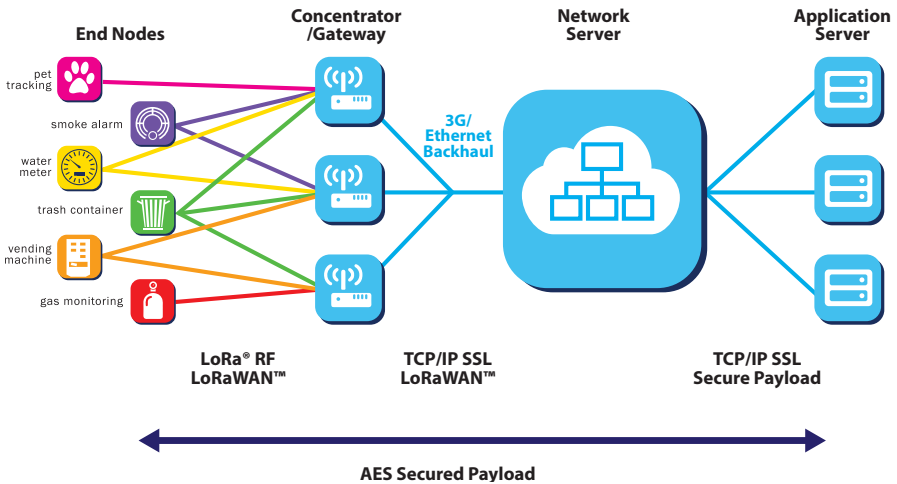
WHAT IS LoRaWAN™?

In a LoRaWAN™ network nodes are not associated with a specific gateway. Instead, data transmitted by a node is typically received by multiple gateways. Each gateway will forward the received packet from the end-node to the cloud-based network server via some backhaul (either cellular, Ethernet, satellite, or Wi-Fi). The intelligence and complexity is pushed to the network server, which manages the network and will filter redundant received packets, perform security checks, schedule acknowledgments through the optimal gateway, and perform adaptive data rate, etc. If a node is mobile or moving there is no handover needed from gateway to gateway, which is a critical feature to enable asset tracking applications–a major target application vertical for IoT.

Battery Lifetime

The nodes in a LoRaWAN™ network are asynchronous and communicate when they have data ready to send whether event-driven or scheduled. This type of protocol is typically referred to as the Aloha method. In a mesh network or with a synchronous network, such as cellular, the nodes frequently have to 'wake up' to synchronize with the network and check for messages. This synchronization consumes significant energy and is the number one driver of battery lifetime reduction. In a recent study and comparison done by GSMA of the various technologies addressing the LPWAN space, LoRaWAN™ showed a 3 to 5 times advantage compared to all other technology options.
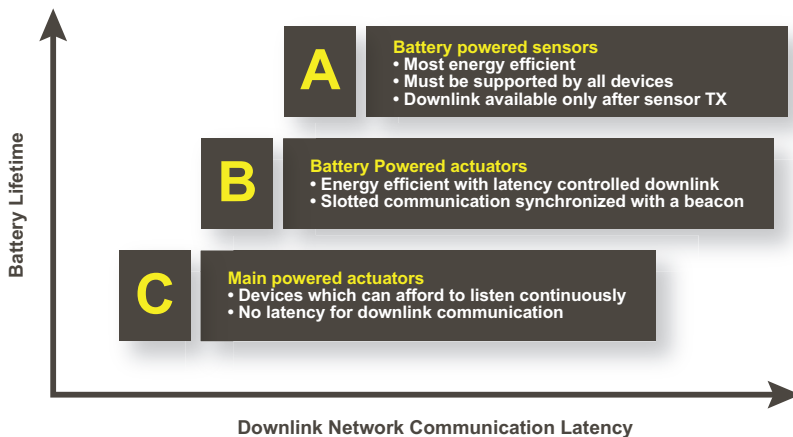
Network Capacity

In order to make a long range star network viable, the gateway must have a very high capacity or capability to receive messages from a very high volume of nodes. High network capacity in a LoRaWAN™ network is achieved by utilizing adaptive data rate and by using a multichannel multi-modem transceiver in the gateway so that simultaneous messages on multiple channels can be received. The critical factors effecting capacity are the number of concurrent channels, data rate (time on air), the payload length, and how often nodes transmit. Since LoRa® is a spread spectrum-based modulation, the signals are practically orthogonal to each other when different spreading factors are utilized. As the spreading factor changes, the effective data rate also changes. The gateway takes advantage of this property by being able to receive multiple different data rates on the same channel at the same time. If a node has a

WHAT IS LoRaWAN™?

good link and is close to a gateway, there is no reason for it to always use the lowest data rate and fill up the available spectrum longer than it needs to. By shifting the data rate higher, the time on air is shortened opening up more potential space for other nodes to transmit. Adaptive data rate also optimizes the battery lifetime of a node. In order to make adaptive data rate work, symmetrical up link and down link is required with sufficient downlink capacity. These features enable a LoRaWAN™ network to have a very high capacity and make the network scalable. A network can be deployed with a minimal amount of infrastructure, and as capacity is needed, more gateways can be added, shifting up the data rates, reducing the amount of overhearing to other gateways, and scaling the capacity by 6-8x. Other LPWAN alternatives do not have the scalability of LoRaWAN™ due to technology trade-offs, which limit downlink capacity or make the downlink range asymmetrical to the uplink range.

Device Classes – Not All Nodes Are Created Equal

End-devices serve different applications and have different requirements. In order to optimize a variety of end application profiles, LoRaWAN™ utilizes different device classes. The device classes trade off network downlink communication latency versus battery lifetime. In a control or actuator-type application, the downlink communication latency is an important factor.

A — Battery powered sensors
• Most energy efficient
• Must be supported by all devices
• Downlink available only after sensor TX

B — Battery Powered actuators
• Energy efficient with latency controlled downlink
• Slotted communication synchronized with a beacon

C — Main powered actuators
• Devices which can afford to listen continuously
• No latency for downlink communication

Battery Lifetime

Downlink Network Communication Latency

WHAT IS LoRaWAN™?

Bi-directional end-devices (Class A): End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.

Bi-directional end-devices with scheduled receive slots (Class B): In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. In order for the end-device to open its receive window at the scheduled time, it receives a time-synchronized beacon from the gateway. This allows the server to know when the end-device is listening.

Bi-directional end-devices with maximal receive slots (Class C): End-devices of Class C have almost continuously open receive windows, only closed when transmitting.

Security

It is extremely important for any LPWAN to incorporate security. LoRaWAN™ utilizes two layers of security: one for the network and one for the application. The network security ensures authenticity of the node in the network while the application layer of security ensures the network operator does not have access to the end user's application data. AES encryption is used with the key exchange utilizing an IEEE EUI64 identifier.

There are trade-offs in every technology choice but the LoRaWAN™ features in network architecture, device classes, security, scalability for capacity, and optimization for mobility address the widest variety of potential IoT applications.

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LoRaWAN™ REGIONAL SUMMARY

The LoRaWAN™ specification varies slightly from region to region based on the different regional spectrum allocations and regulatory requirements. The LoRaWAN™ specification for Europe and North America are defined, but other regions are still being defined by the technical committee. Joining the LoRa® Alliance as a contributor member and participating in the technical committee can have significant advantages to companies targeting solutions for the Asia market.

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

LoRaWAN™ for Europe

LoRaWAN™ defines ten channels, eight of which are multi data rate from 250bps to 5.5 kbps, a single high data rate LoRa® channel at 11kbps, and a single FSK channel at 50kbps. The maximum output power allowed by ETSI in Europe is +14dBM, with the exception of the G3 band which allows +27dBm. There are duty cycle restrictions under ETSI but no max transmission or channel dwell time limitations.

LoRaWAN™ for North America

The ISM band for North America is from 902-928MHz. LoRaWAN™ defines 64, 125kHz uplink channels from 902.3 to 914.9MHz in 200kHz increments. There are an additional eight 500KHz uplink channels in 1.6MHz increments from 903MHz to 914.9MHz. The eight downlink channels are 500kHz wide starting from 923.3MHz to 927.5MHz. The maximum output power in North America 902-928MHz band is +30dBm but for most devices +20dBm is sufficient. Under FCC there are no duty cycle limitations but there is a 400msec max dwell time per channel.

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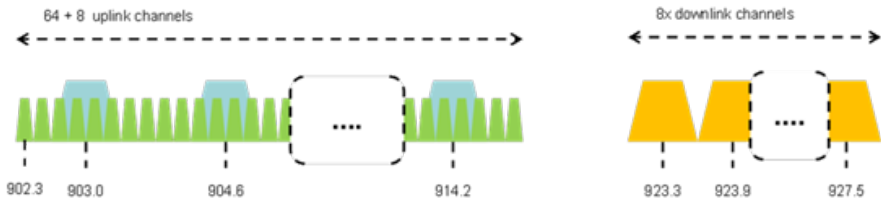
LoRaWAN™ Hybrid mode for North America

Most people are familiar with the frequency hopping requirements for FCC, which require greater than 50 channels to be utilized equally in the ISM band. LoRaWAN™ is defined with more than 50 channels to take advantage of the available spectrum and allow maximum output power.

LoRa® modulation qualifies as a digital modulation technique so it is exempt from having to comply with all the frequency hopping requirements specified by FCC under a Hybrid mode of operation. In Hybrid mode, the maximum output power is limited to +21dBm and only a subset of eight channels out of the 64 uplink channels is utilized under Hybrid mode.

From the FCC:

"A hybrid system uses both digital modulation and frequency hopping techniques at the same time on the same carrier. As shown in Section 15.247(f), a hybrid system must comply with the power density standard of 8 dBm in any 3 kHz band when the frequency hopping function is turned off. The transmission also must comply with a 0.4 second / channel maximum dwell time when the hopping function is turned on. There is no requirement for this type of hybrid system to comply with the 500 kHz minimum bandwidth normally associated with a DTS transmission; and, there is no minimum number of hopping channels associated with this type of hybrid system."

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COMPARING LPWAN TECHNOLOGY OPTIONS

There is a lot of activity in the IoT sector comparing LPWAN options both from a technical comparison but also from a business model perspective. LPWAN networks are being deployed now because there is a strong business case to support immediate deployment, and the cost to deploy the network in unlicensed bands requires much less capital than even a 3G software upgrade. The questions that should be answered to compare different LPWAN technologies are:

- Flexibility to target a large variety of applications

- Is the communication protocol secure?

- Technical aspects – range, capacity, two-way communication, robustness to interference

- Cost of network deployment, cost of end-node BOM, cost of battery (largest BOM contributor)

- Ecosystem of solutions providers for flexible business models

- Availability of end-products to ensure ROI of network deployment

- Strength of ecosystem to ensure quality and longevity of the solution

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019(Rel13+)
Modulation	SS Chirp	UNB / GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500 - 125 KHz	100 Hz	20 MHz	20 - 1.4 MHz	200 KHz
Data Rate	290bps - 50Kbps	100 bit/sec 12 / 8 bytes Max	10 Mbit/sec	200kbps – 1Mbps	~20K bit/sec
Max. # Msgs/day	Unlimited	UL: 140 msgs/day	Unlimited	Unlimited	Unlimited
Max Output Power	20 dBm	20 dBm	23 - 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Batery lifetime - 2000mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, No loc	Mobility	Mobility	Limited Mobility No Loc

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LPWAN COST VS LEGACY SYSTEMS

LoRaWAN™ has significant cost savings in the deployment and required infrastructure compared to existing systems. The below analysis is done by Talkpool who have significant experience in deploying both WMBus and LoRa® based solutions.

| 2000 apartments | 80 buildings/staircases | Sensor cost equal | An average of 5 sensors/apartment (temperature, humidity and warm water consumption). Fire detection optional. Potential IoT revenue with LoRa. |

WM-Bus

CAPEX			
Design, prep	4 000	€100/hour
Repeaters	32 000	€80/each
Concentrators	20 000	€250/each
Installation	24 200	€55/hour
SUM	€ 80 200	

REVENUE			
Business logic & Statistics	36 842	Yearly occuring
Billing, Invoice		

LoRa Network Operator

CAPEX			
Design, prep	1 600	€100/hour
GW	6 000	€1500/each (500apts/GW)
Installation	880	€55/hour
SUM	€ 8 480	

REVENUE		
Business logic & Statistics		Yearly occuring
Billing, Invoice		Yearly occuring
Other IoT services		Occuring

This Whitepaper is sponsored by the LoRa® Alliance Members, and in particular, our Platinum Sponsors of the November 2015 All Member Meeting.

Long Range

- **Greater than cellular**
- **Deep indoor coverage**
- **Star topology**

Max Lifetime

- **Low power optimized**
- **10-20yr lifetime**
- **>10x vs cellular M2M**

Multi-Usage

- **High capacity**
- **Multi-tenant**
- **Public network**

Low Cost

- **Minimal infrastructure**
- **Low cost end node**
- **Open SW**

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Wide Area Networks for IoT