LoRaWAN

All of the gateways in a network communicate to the same server, and it decides which gateway should respond to a given transmission.

Any end device transmission can be heard by multiple receivers, but the server chooses one gateway to respond, instructing the others to ignore the transmission.

This process helps to avoid downlink and uplink collisions, because only a single gateway is transmitting, but other end points might nevertheless overlap

LoRaWAN features

Designed for virtualized cloud based networks
All gateways in a network behave like one, so no handover mechanism required and scaling is straightforward
Simplified protocol overhead minimizes energy usage
Downlink message sent by the network server to only one end-device and relayed by a single gateawy

LoRaWAN

LoRa Alliance™ Wide Area Networks for IoT

- Supports
  - Secure bidirectional traffic
  - Mobility
  - Localization
- Star of stars topology
- Collisions prevented by maximum duty cycle limitations per frequency
- If nevertheless, there is a collision, the strongest packet prevails

LoRaWAN regional spectrum usage

Nigeria

Uganda

South Africa

LoRaWAN regional spectrum usage

EU863-870 Preamble Format

Modulation type	Sync word	Preamble length
LoRa	0x34	8 symbols
GFSK	0xC194C1	5 bytes

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

LoRaWAN EU863-870 ISM Band channel frequencies

Network channels can be freely attributed by the network operator, but the three default channels MUST be implemented in every EU868MHz device and all gateways SHOULD always be listening on:

Modulation	Bandwidth, kHz	Channel frequency, MHz	LoRa DR/bitrate	Nb Channels	Duty Cycle
LoRa	125	868.10 868.30 868.50	DR0 to DR5 0.3-5 kbps	3	< 1 %

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

LoRaWAN EU863-870 Channel Sharing

ETSI regulations allow the choice of using either a duty-cycle limitation or a so called **Listen Before Talk Adaptive Frequency Agility** (LBT AFA) transmissions management.

Current LoRaWAN specification uses exclusively duty-cycled limited transmissions.

No dwell time limitation for the EU863-870 PHY layer.

EU863-870 LoRaWAN supports a maximum of 16 channels.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

LoRaWAN EU863-870 Data Rate

Data Rate	Configuration	Indicative physical bit rate, bit/s	Max payload size, bytes
0	SF 2/125 kHz	250	51
1	SF11/125 kHz	440	51
2	SF10/125 kHz	980	51
3	SF9/125 kHz	1760	115
4	SF8/125 kHz	3125	242
5	SF7/125 kHz	5470	242
6	SF7/250 kHz	1100	242
7	FSK	50000	242

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

LoRaWAN EU863-870 Transmitted Power

By default maximum EIRP is 16 dBm, so when directive antennas are used the conducted power should be reduced

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

LoRaWAN EU8433 Transmitted Power

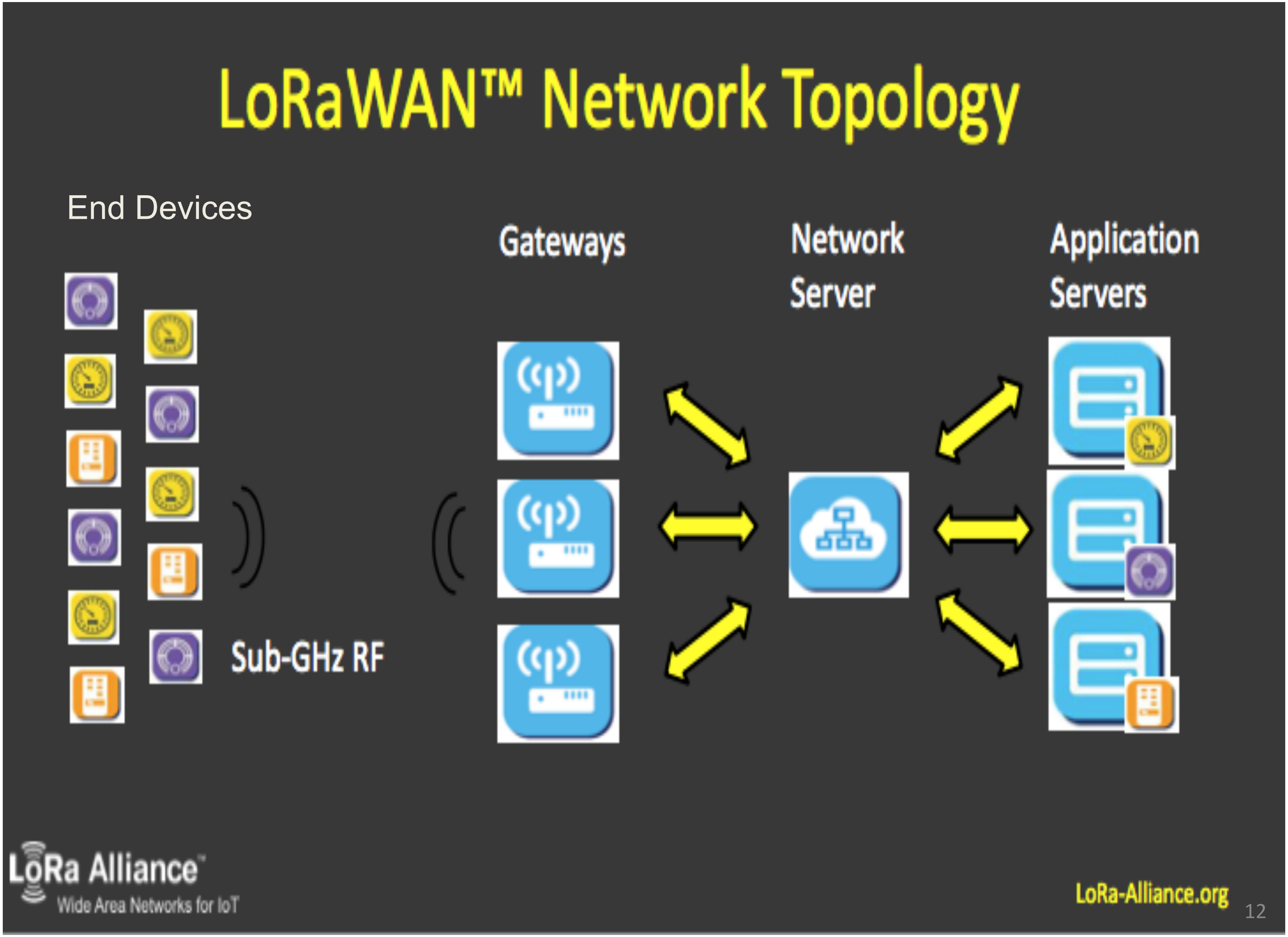
In the frequency from 433.05 to 434.79 MHz
the maximum EIRP is 12.15 dBm.
The end-device duty cycle shall be < 10%.
No dwell time limitation

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

KR920-923 ISM frequencies for LPWA IoT

Center frequency (MHz)	Bandwidth (kHz)	Maximum EIRP output power (dBm)	
		For end-device	For gateway
920.9	125	10	23
921.1	125	10	23
921.3	125	10	23
921.5	125	10	23
921.7	125	10	23
921.9	125	10	23
922.1	125	14	23
922.3	125	14	23
922.5	125	14	23
922.7	125	14	23
922.9	125	14	23
923.1	125	14	23
923.3	125	14	23

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf


LoRaWAN™ Network Topology
End Devices
Gateways
Network Server
Application Servers
Sub-GHz RF
LoRa Alliance™
Wide Area Networks for IoT
LoRa-Alliance.org
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LoRaWAN Communication

- An end device talks to one or more gateways using either LoRa or FSK.
- The GWs communicate to the network server (NW) using some IP based technology.
- The NW interacts to the different application servers to provide the specified services.
- All communication is generally bi-directional, although uplink communication from an end-device to the GW is the predominant traffic.

LoRaWAN Communication

- Current LoRaWAN gateways are all half-duplex, they cannot listen to incoming uplinks while transmitting a downlink packet to a node. When sending it can only transmit on one channel, while for listening it can use 8 channels simultaneously.
- This allows frequency hopping inside the same band which can be used to avoid interfered channels or to cope with the duty cycle limitations; after using the channel an end device can switch to a different frequency without violating the regulation if it needs to continue transmitting.

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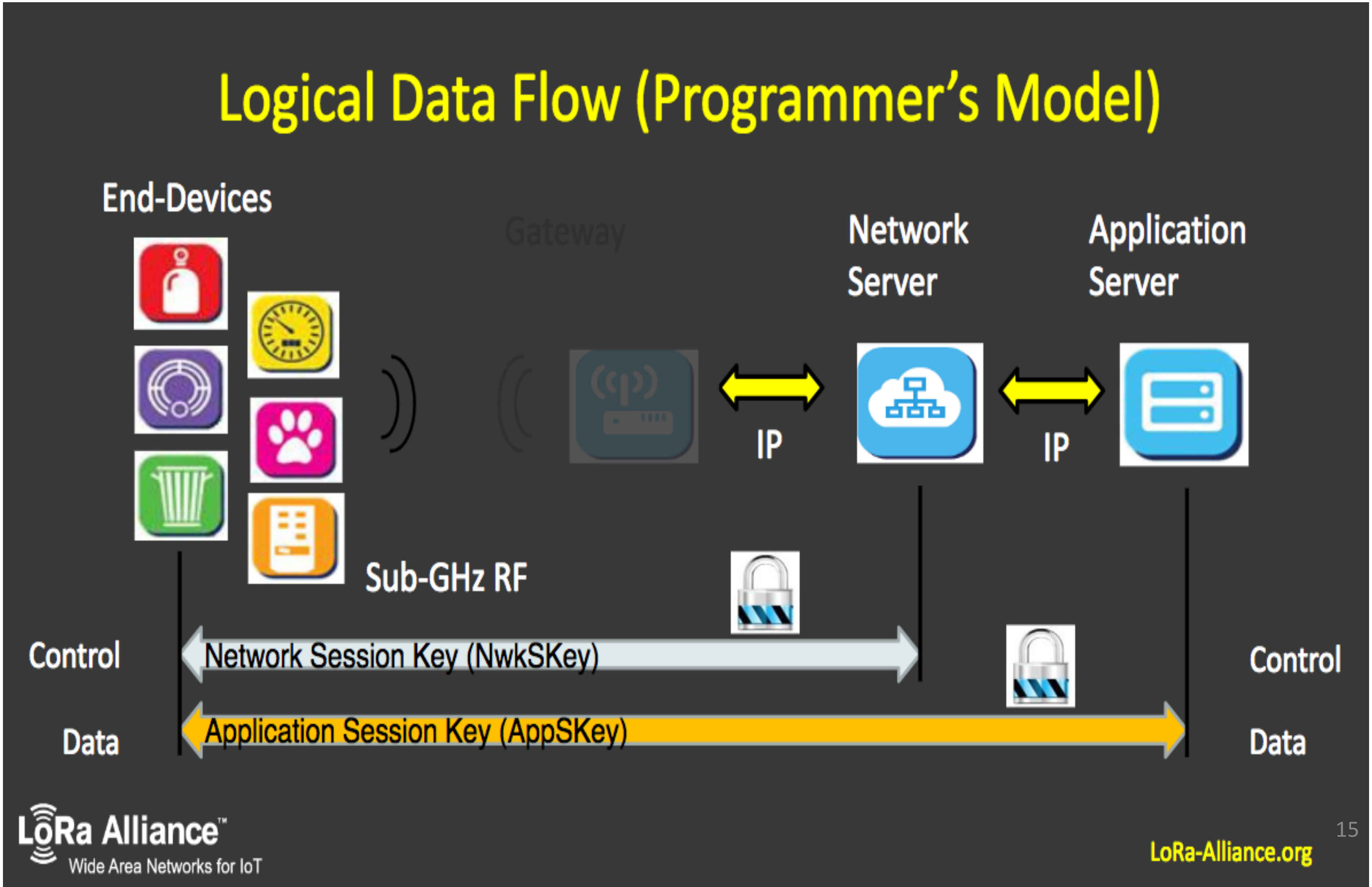
LoRaWAN



Logical Data Flow (Programmer's Model)
End-Devices
Gateway
Network Server
Application Server
IP
IP
Sub-GHz RF
Control
Network Session Key (NwkSKey)
Control
Data
Application Session Key (AppSKey)
Data
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LoRaWAN

- Star-of-stars topology, gateways relay messages between end-devices and the network server.
- Gateways connected to the network server via standard IP connections.
- End devices use single-hop LoRa or FSK. communication to one or many gateways.
- Bi-directional communication, but uplink from an end-device to the network server is expected to predominate.
- Adaptive data rate (ADR).

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LoRaWAN

- Messages from the end devices are received by every gateway in range.
- If an end device wishes to communicate with another end device must reach first the network server thus involving two transits through the GW.
- Adaptive data rate (ADR) can accommodate different transmission distances.

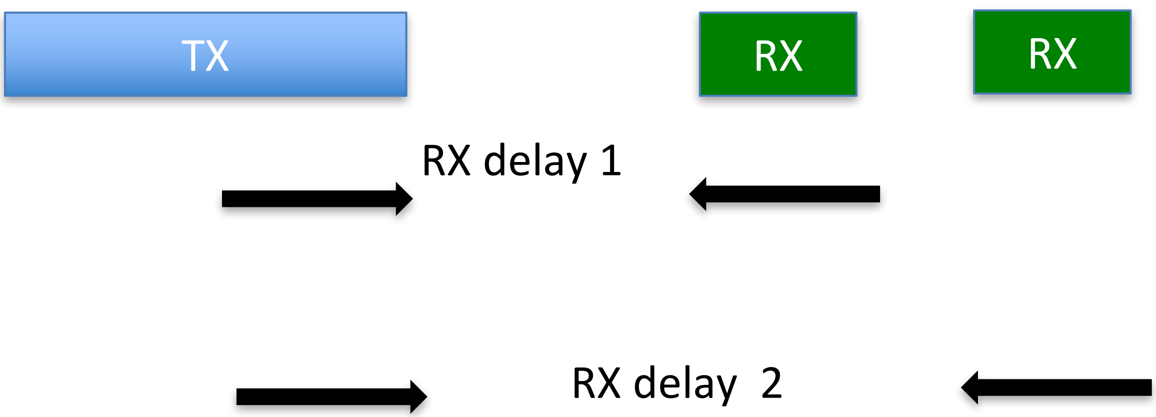
LoRaWAN

- Uplink messages from end-devices are relayed by one or more gateways to the network server.
- Downlink message sent by the network server to only one end-device, relayed by a single gateway.
- A confirmed-data message has to be acknowledged by the receiver, whereas an unconfirmed one does not require an acknowledgment.
- End devices can hop in frequency to alleviate duty cycle constraints

LoRaWAN

- Confirmed messages will increase channel occupancy which is a drawback in countries where there is a duty cycle limitation.
- Duty cycle is calculated per channel frequency, so moving to another channel will reset the occupancy clock.
- Gateways listen to 8 channels simultaneously.
- LoRaWAN cannot using SF 6 because the header and CRC are mandatory thus restricting the payload size.

Down-stream transmission modes



Class A : Following upstream transmission two receive windows are opened after the delay to account for the transmission times.
Gateway must transmit in one of these windows.
Mandatory mode, saves energy but introduces latency.

Down-stream transmission modes

Class B: Gateway transmits periodically a beacon that elicits a receive window in the end device.
Reduced latency
For no latency, use class C in which the node is always receiving when is not transmitting. High energy consumption

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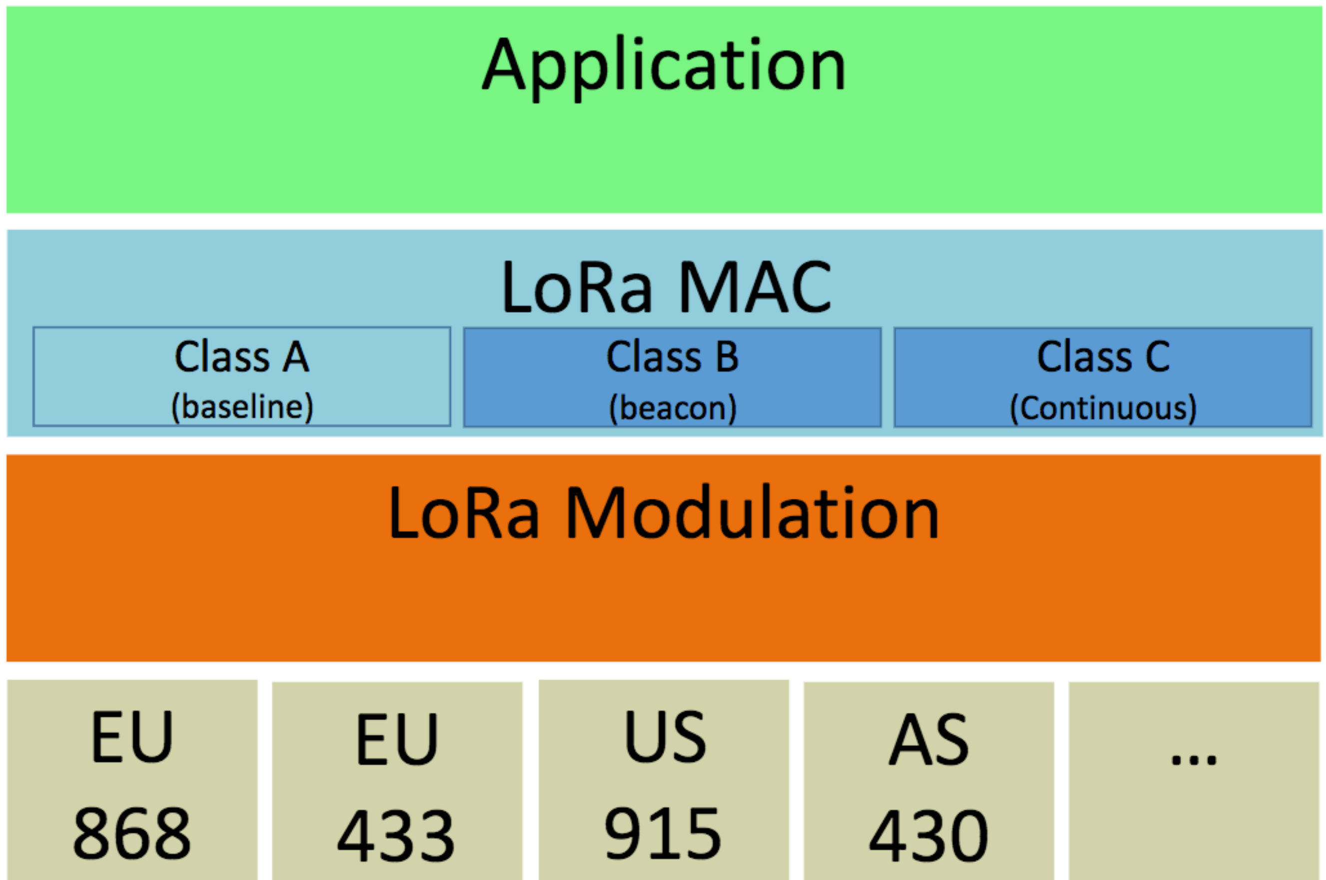
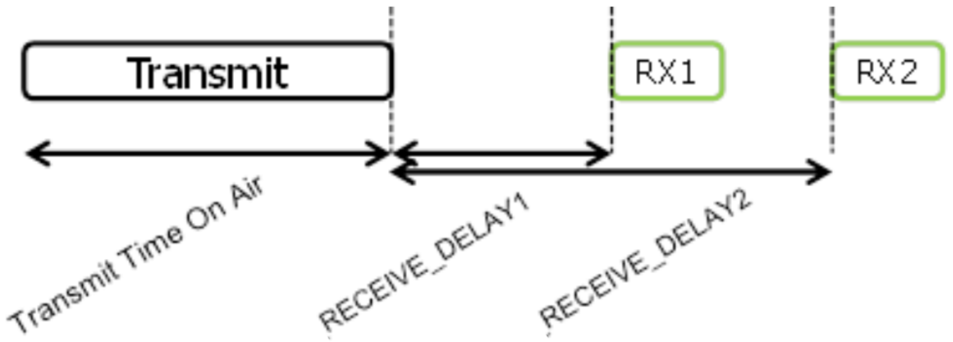
LoRaWAN Classes



https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN Receive Windows

Following each uplink transmission the end-device MUST open two short receive windows. The receive window start times are defined using the end of the transmission as a reference.



RxDelay1 is configurable, default is 1s. RxDelay2 default is 2s.
First receive window data rate is the same as that of the last uplink by default, but it is region specific.
Second receive window frequency and data rate are region specific.
Receive window duration must be at least long enough to detect the downlink preamble.
Second Receive window must not be opened if a successful reception was achieved during RX1

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

Consumption example

Assume:

- 10 packets/day
- Sleep current 1 microampere
- Microcontroller is essentially off during TX
- No ACK received during the two RX windows
- 32 mA consumption transmitting at 14 dBm over 125 kHz

Payload (bytes)	SF 12	SF 10	SF 17
16	7 uA	2.5 uA	1.3 uA
30	9 uA	3 uA	1.4 uA

LoRaWAN Message types

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	Rejoin-request
111	Proprietary

Data messages are used to transfer both MAC commands and application data, and can be combined in a single message.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN Adaptive Data Rate (ADR)

Static end-devices can use any of the possible data rates and TX power to achieve the highest throughput.
This might not be possible if the the channel attenuation changes constantly, as might in a mobile device.
The application layer should always try to minimize the aggregate air time given the network conditions.
If the uplink ADR bit is set, the network will control the data rate and TX power through MAC commands, otherwise the network will NOT attempt to control these parameters, regardless of the received signal quality.
When the downlink ADR bit is set, the device will receive control commands from the application layer, but it can can set/unset the uplink ADR bit.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN Adaptive Data Rate (ADR)

When the downlink ADR bit is is unset, the device has the choice of:

- unset the ADR uplink bit and control the data rate following its own strategy. This should be the behaviour of a mobile device.
- keep the the uplink ADR bit set and apply the normal data rate decay in the absence of ADR downlink commands. This should be the behaviour of a stationary device.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN uplink retransmission

Both uplink "confirmed" and "unconfirmed" frames are transmitted "NbTrans" times, except if a valid downlink is received following one of the transmissions.

The "NbTrans" parameter can be used by the network manager to control the redundancy in order to achieve a given Quality of Service.

End-device performs frequency hopping between repeated transmissions.

The delay between transmissions is at the discretion of the end-device.

If the network receives more than NbTrans transmissions of the same frame, a replay attack or a malfunctioning device might be the culprit and the network shall not process the extra frames and might reduce the NbTrans parameter to 1.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN End-device Activation

To participate in a LoRaWAN network each end device has to be personalized and activated. This can be achieved by either of these two methods:

- Over The Air Activation (OTAA)
  - JoinEUI is a global application ID in IEEE EUI64 address space that uniquely identifies the Join Server that assists in the Join procedure and the session keys derivation. JoinEUI must be stored in the end-device before the procedure is executed. Dev EUI is a global end-device ID in IEEE EUI64 address space that uniquely identifies the end-device and must be stored in it for OTAA devices but is only recommended (not required to be stored) for ABP devices.
- Activation By Personalization (ABP)
  - JoinEUI is not required for ABP only devices

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

LoRaWAN End-device Activation

Device root keys

NwkKey and AppKey are AES root keys specific to the end-device that are assigned to the end-device during fabrication. Whenever an end-device joins a network via over-the-air activation, the NwkKey is used to derive the FNwkSIntKey, SNwkSIntKey and NwkSEncKey session keys, and AppKey is used to derive the AppSKey session key.

LoRaWAN 1.0 supports only one root key while LoRaWAN 1.1 requires two network keys.

- A NwkKey MUST be stored on a OTAA end-device.
- A NwkKey is not required for ABP only end-devices.
- An AppKey MUST be stored on an end-device that uses OTAA.
- An Appkey is not required for ABP only end-devices.

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_specification_-v1.1.pdf

Geolocation capability

Second generation LoRaWAN gateways can provide geolocation of the end nodes by relaying on an accurate time source shared by several gateways and then adding a high-resolution time stamp to each received LoRa packet. The node position can then be determined using time differential of arriving (TDoA) algorithms.

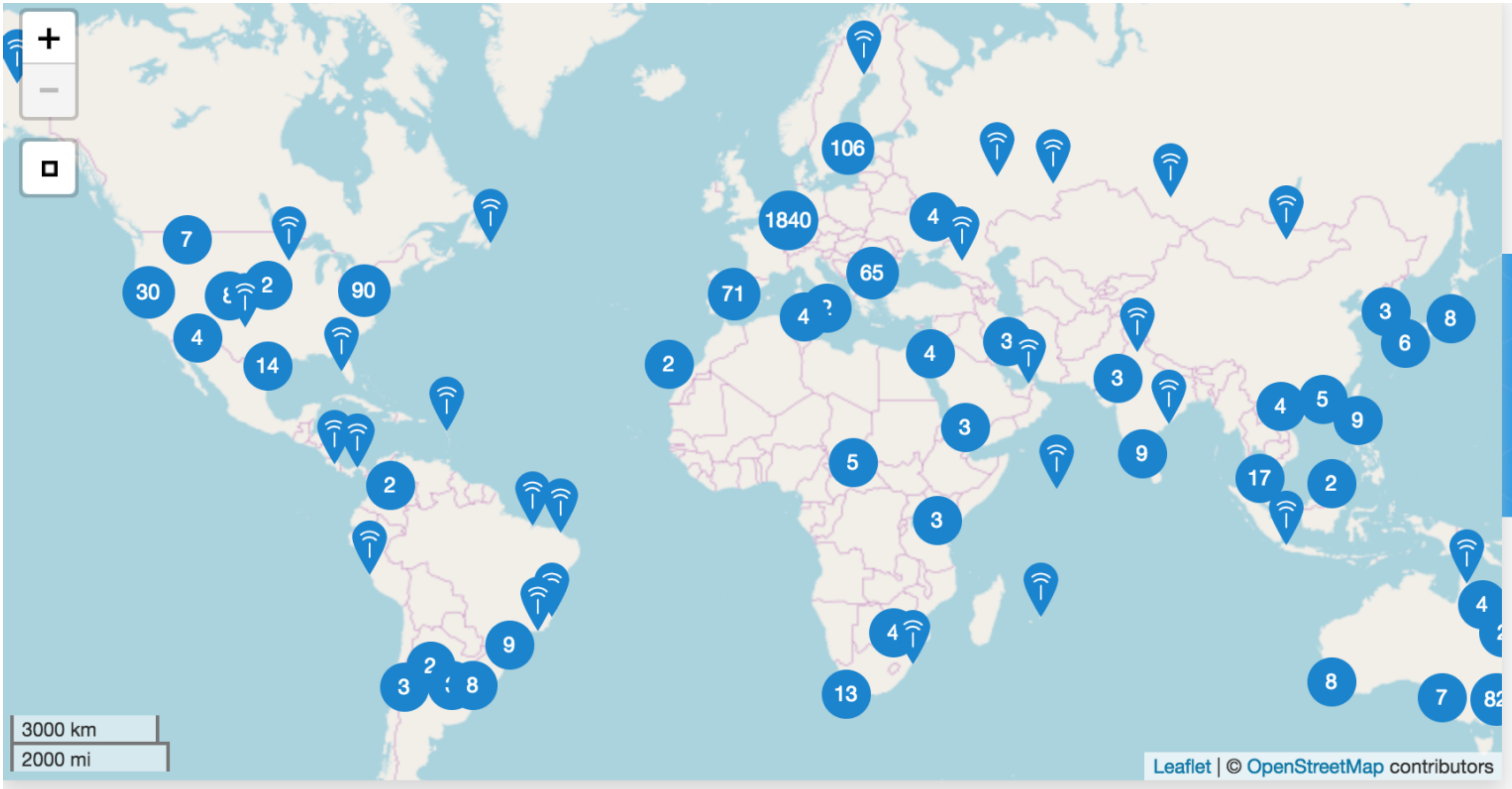
The Thing Network

Open source LoRaWAN server with end-to-end encryption. Anyone can:

- Connect devices to The Things Network (TTN)
- Extend TTN by installing a Gateway
- Build a GW using low cost hardware
- Manage own applications and devices or build new applications
- Free trial subscription can be used to assess the technology

https://www.thethingsnetwork.org/

The Thing Network: GWs installed



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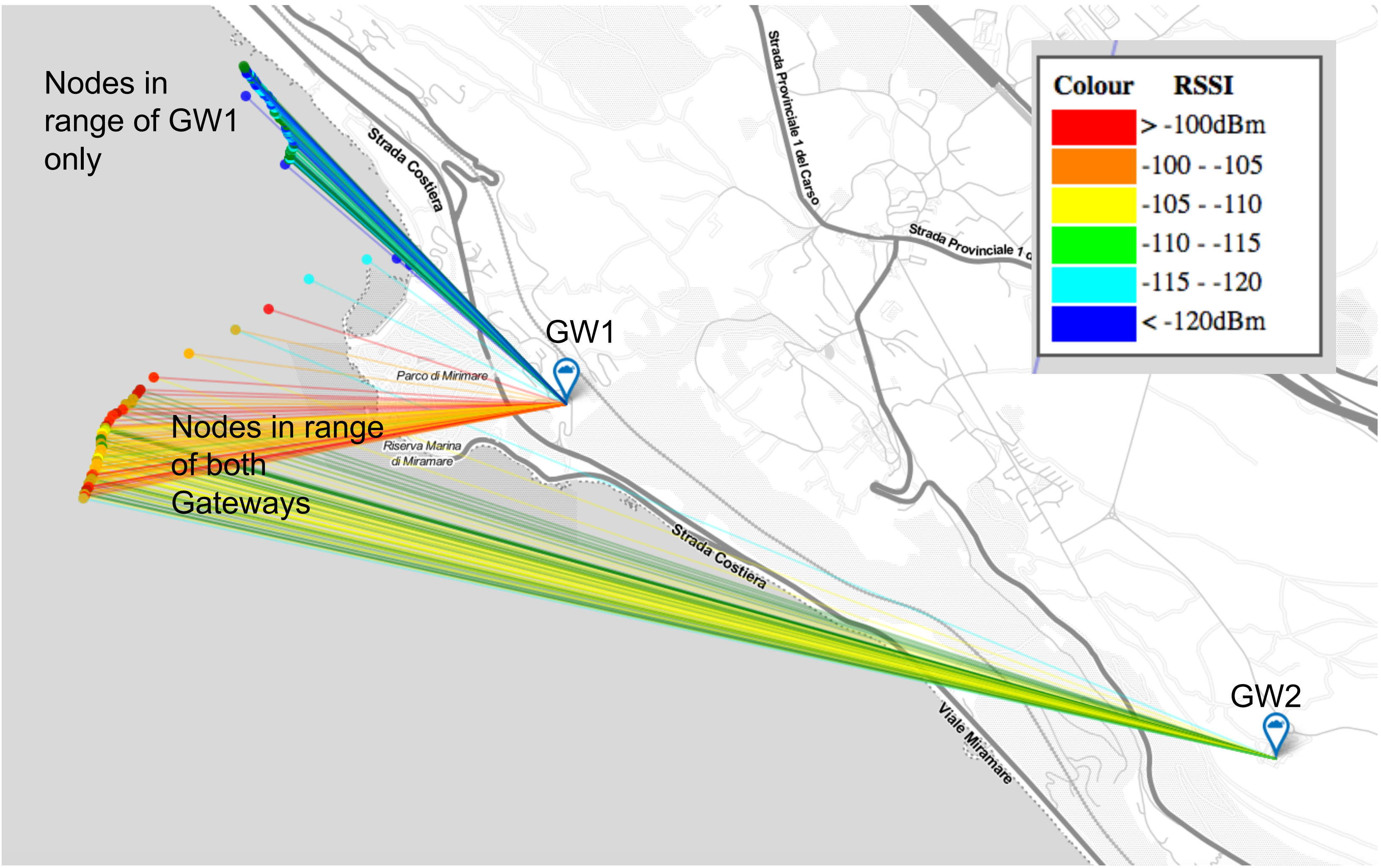
Two LoRaWAN Gateways



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LinkLabs Symphony link

Uses LoRa PHY layer but with an alternative MAC layer, different from LoRaWAN, claiming the following advantages:

- Guaranteed message receipt
- Over-the-air firmware upgrade
- Repeater capability to extend the range
- Management of frequencies, time slots, node privilege and throughput to insure QoS.

www.link-labs.com

2018 update

- GSMA announced that 23 mobile operators have commercially launched 41 mobile IoT networks worldwide across both NB-IoT and LTE-M technologies.
- According to a Juniper Research report, by 2022 the number of M2M connections leveraging unlicensed spectrum will reach 400 million, while cellular based ones will approach 100 millions.

https://enterpriseiotinsights.com/20180222/nb-iot/gsma-says-41-mobile-iot-networks-available-worldwide-tag23

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Conclusions

- IoT requires specific standards.
- Legacy cellular technologies not efficient.
- Cellular based on Release 13 address most of the shortcomings but the cost is high and availability limited.
- WiFi , Zigbee and BLE have limited range.
- Several vendors offer alternatives.
- LoRa and SigFox are widely used worldwide for long distance but with limited data rate.
- LoRaWAN is an open standard that can be leveraged to build your own network.

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