LPWA – Giving a Voice to Things

Jeff Apcar, Distinguished Services Engineer
APRICOT 2017
Lots of THINGS Need Connecting

Billions of Devices

World Population

3G/4G, WiFi Not Suitable For “Cheap” Things

Cellular networks generally connect expensive things
In terms of energy available and data usage e.g., cars
Bulk of existing cellular M2M use embedded GPRS modules

Low Cost Sensor Characteristics
- Lossy Communications
  - Low Power Wireless IEEE802.15.4, LPWA
  - LoRa, NB-IoT
  - IEEE 1901.2 NB-PLC (Power Line Comms)
- Narrowband Media
  - Tens to hundreds of kilobits
- Power Consumption is critical
  - Energy efficiency is paramount
  - Battery/Scavenger/Harvest
- Moderate CPU Power
  - Minimise energy use
- Low memory
  - Few tens of kilobytes
  - Embedded OS

M2M Module Cost
- GPRS (2.5G)
- 3G
- LTE

<table>
<thead>
<tr>
<th></th>
<th>1990s</th>
<th>2000s</th>
<th>Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10</td>
<td></td>
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<td>$20</td>
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<tr>
<td>$40</td>
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</tbody>
</table>
Examples Constrained “Cheap” Things

- **Fire Detection**
  - CO₂ Temp, Humidity, Infrared

- **Snow Depth**
  - UltraSound Sensor

- **Street Lighting**
  - Light Sensors, Relays

- **Chemical Leakage**
  - PH Monitor, Oxygen levels

- **Smart Parking**
  - Magnetic Field Sensor

- **River Levels**
  - Level sensor, Ultrasound

- **Urban Air Pollution**
  - NO₂, CO₂ Gas Sensors

- **Earthquake Warning**
  - Accelerometer
LPWA

A new category of low cost network for low powered devices across a wide area

“The IoT contains devices that allow us to sense and control the physical world by making objects smarter and connecting them through an intelligent network”

Connecting a new generation smart objects/devices poses challenges: Pervasive connectivity, Power Availability and Low Cost

This requires a new generation of network to connect the low-powered things: Low Power Wide Area Networks
Low Power Wide Area Networks (LPWA)
What Is An LPWA?

Low Data Throughput
~200 Bytes per day, higher instantaneous
Small packets (12 to 255 Bytes), mostly uplink traffic

Low Power
Devices last several years on battery

Long Range
0-5kms (dense urban), 10-65kms open area

Several LPWA technologies (Licensed vs Unlicensed Spectrum)
LoRa, SIGFOX, Weightless, On-Ramp, NB-IoT, EC-GPRS, eMTC
Trend: Many SP Are Investigating LPWA

Innovative IoT Business Models require different networks
  How to connect millions of devices across a cityscape
  Connect wireless sensors
  Highly constrained devices

Become Knowledge Provider
  Revenue Models?
  Use Cases?
  Data Collection?

Low Power Wide Area (LPWA) is an enabler
LPWA – Enables Innovation & Knowledge Providers

Wisdom

Knowledge

Information

Data

Sensors/Actuators

Connecting Devices

Collecting Information

Correlating Knowledge

Concluding Wisdom

CUSTOMER OUTCOME

KNOWLEDGE PROVIDER

INFORMATION PROVIDER

SERVICE PROVIDER

Wisdom

Knowledge

Information

Data

Sensors/Actuators

Connecting Devices

Collecting Information

Correlating Knowledge

Concluding Wisdom

CUSTOMER OUTCOME

KNOWLEDGE PROVIDER

INFORMATION PROVIDER

SERVICE PROVIDER

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LPWA Device Characteristics & Typical Values

- **Spectrum**: Unlicensed/Licensed, < 1GHz
- **Range**: 10s Km, No Relay
- **Objects**: Many, 1000+
- **Data Volume**: Small, tens kB per day
- **Service Cost**: Low, < $1-3 pm
- **Data Rate**: Low, <100kb/s
- **Latency**: Low-High, Up to minutes
- **Battery Life**: Long Life, Up to 10 years
- **Module Cost**: Low, < $5
- **Installation Cost**: Low, < $5-$10

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Current IoT Wireless vs LPWA

**Long Range**
- 2G
- 3G
- 4G
- 5G

**Medium Range**
- WiFi .p
- WiFi .a
- WiFi .ac
- WiFi .ah
- 802.15.4 g/e
- 6LowPan
- W-HART
- Mesh
- 6Tisch
- Mesh
- ZigBee
- ISA 100.11a

**Short Range**
- B-LE

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**High**
- Cost
- Licensed vs unlicensed
  - Frequency bands, power requirements,
    - Provisioning, i.e. SIM card

**Low**
- Broad Use Cases support
  - Utilities, Industrial (process and discrete manufacturing), Smart Cities (parking, environment,…), Agriculture and rural, Transportations, horizontal/consumers, Assets management

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**TX Power**
- Signal penetration
  - GHz vs sub-GHz
- Frequency bands
- Bandwidth capacity

**Standby Power**
- Use cases applicability
  - Indoor vs Outdoor
- Mobile v Fixed

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**Module Cost**
- Weight
- Less

- 3GPP EC-GPRS
- 3GPP CAT-NB1

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- 2G
- 3G
- 4G
- 5G

---

- 802.15.4 g/e
- 6LowPan
- W-HART
- Mesh
- 6Tisch
- Mesh
- ZigBee
- ISA 100.11a

---

- B-LE

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LPWA Technologies

Radio Coverage Distance

Radio data Rate

- **3GPP NB-IoT/EC-GPRS**
  - MAX power consumption
  - MIN power consumption
  - Byte throughput per hour
- **LoRa**
  - Licensed spectrum
  - License exempt regulated spectrum
- **Ingenu RPMA**
- **Weightless-P**
- **Sigfox**

<table>
<thead>
<tr>
<th>Radio Coverage Distance</th>
<th>500M</th>
<th>1KM</th>
<th>5KM</th>
<th>10KM</th>
<th>15KM</th>
<th>30KM</th>
</tr>
</thead>
<tbody>
<tr>
<td>100bps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1Kps</td>
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<tr>
<td>5Kbps</td>
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<td>10Kbps</td>
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<td>50Kbps</td>
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<tr>
<td>100Kbps</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>200Kbps</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
3GPP IoT Standards Licensed Spectrum

- **LTE MTC (3GPP R12)**
  - Creation of CAT-0

- **CloT (3GPP R13)**
  - **NB-IOT (3GPP R13)**
  - **EC-GSM-IOT**

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**3GPP LPWA Standards**

- **LTE-M/eMTC (3GPP R13)**
  - **UE CAT-M1 (1.4Mhz)**
  - Same LTE air interface
  - Compatible with existing infrastructure
  - Connected cars, telematics…

- **NB-IOT (3GPP R13)**
  - **UE CAT-NB1 (200Khz)**
  - New air interface, Clean slate technology
  - Uses LTE infrastructure (SGW/PGW)
  - Power & parking meters, sensors…

- **EC-GSM-IOT**
  - Based on eGPRS
  - Software upgrade
  - Smart metering, agricultural sensors…

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**Cellular IoT Study**

Coexistence with GSM, UMTS, LTE
LPWA Use Cases
### Some Approaches to Address LP Wireless Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Topology</th>
<th>Outdoor</th>
<th>Use Case</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.15.4g/6lowpan</td>
<td>Mesh</td>
<td>Yes</td>
<td>Smartgrid, Metering, Oil&amp;Gas</td>
<td>Medium</td>
</tr>
<tr>
<td>WirelessHart</td>
<td>Mesh</td>
<td>No</td>
<td>Industrial</td>
<td>Short</td>
</tr>
<tr>
<td>Zigbee/ZigbeePro</td>
<td>Mesh</td>
<td>No</td>
<td>Smart Home/Building</td>
<td>Short</td>
</tr>
<tr>
<td>ISA100</td>
<td>Mesh</td>
<td>No</td>
<td>Industrial</td>
<td>Short</td>
</tr>
<tr>
<td>Proprietary 802.15.4</td>
<td>Point-to-Multipoint</td>
<td>Yes</td>
<td>Smart Parking, Traffic</td>
<td>Short</td>
</tr>
<tr>
<td>Enocean</td>
<td>Mesh</td>
<td>No</td>
<td>Building</td>
<td>Short</td>
</tr>
<tr>
<td>StarSense RF</td>
<td>Mesh</td>
<td>Yes</td>
<td>Smart Lighting</td>
<td>Short</td>
</tr>
<tr>
<td>Z-Wave</td>
<td>Mesh</td>
<td>No</td>
<td>Smart Home</td>
<td>Short</td>
</tr>
</tbody>
</table>

In most cases the technology is tailored to a narrow area/use case and indoor, with some attempts to support other use cases.

To cover a wide area a hybrid approach is required.

**Hybrid LPWA**: low power wireless short range and cellular/wire backhaul
Hybrid LPWA Approach

Current Hybrid Approaches

Long Range
- Cellular Backhaul
- Pub/Priv WiFi
- Pub/Priv WiFi

Medium Range
- RF Mesh
- RF Mesh
- Serial WiFi
- ISA 100
- Wireless HART
- 2G
- 3G WiFi
- RF Mesh
- PLC

Short Range
- Wearables
- Smart Home
- Smart City
- Industrial
- Agriculture Mining etc..
- Smart Grid

LPWA Approach

Pub/Priv WiFi

Multiple Services

B-LE
LPWA Market Research

**TAM - 2023**
- Will reach 3 Billion Connections
- $10B Connectivity Revenues
- $10B in Device and Apps sales
- ??B in Knowledge Sales

**Complementary Technology**
- Complements Cellular – only 4% overlap
- LPWA will create new market opportunities that can’t be addressed with Cellular, LAN

**Impacts Many Vertical Markets**
- Suitable for any vertical with low power, low-bandwidth requirements
- Immediate use cases in Smart Cities, Utilities, Agriculture
- Many use cases to be discovered

**Sustainable Business Models**
- Low/Predictable lifetime costs help reduce barriers to adoption, drive market growth
- Bundling infrastructure to services to enable sustainable business

Source: [Analysys Mason](https://www.analysysmason.com)
LPWA Connection TAM By 2023

USD34 billion accumulated connectivity revenue by 2023

Connections Revenue

Cellular M2M

LPWA IoT

Other IoT (WiFi etc)

Source: Analysys Mason, 2014

Connections

Revenues

Source:

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Sample Use Cases

Utilities
- Water, Gas, Electricity Monitoring & distribution
- Water, Gas, Electricity transport
- Road/traffic management
- Acoustic, Pollution monitoring
- Smart Lighting

Waste
- Waste container monitoring

City Traffic
- Bike sharing, City asset tracking
- Short msg digital signage, parking

Environment
- Livestock monitoring, soil quality
- Irrigation, crop monitoring

Building
- Commercial & residential monitoring

Health
- Independent living, Out of area
- Dosage monitoring, fall detection
- Asset tracking, wearables
- Asset tracking

Smart City
- Transportation
- Transportation

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## LPWA Use Cases (Part 1)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Sub-domain</th>
<th>Use case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utilities</strong></td>
<td>Water &amp; Gas distribution</td>
<td>Collect 3-4 times daily water and gas usage data</td>
</tr>
<tr>
<td></td>
<td>Water Network monitoring</td>
<td>Collect 3-4 times daily water flow, pressure data</td>
</tr>
<tr>
<td></td>
<td>Electricity distribution</td>
<td>Collect daily or hourly electricity usage data</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td>Water &amp; Gas transportation</td>
<td>Water and Gas infrastructure network surveillance (alarm, metering parameters)</td>
</tr>
<tr>
<td></td>
<td>Electricity transportation</td>
<td>Electricity transport status monitoring and command/control</td>
</tr>
<tr>
<td></td>
<td>Road / traffic management</td>
<td>Traffic light control, traffic level monitoring, emergency gate status control, digital signage status and updates</td>
</tr>
<tr>
<td><strong>Environment</strong> (City)</td>
<td>Acoustic Noise Monitoring</td>
<td>Collect data on Levels, location</td>
</tr>
<tr>
<td></td>
<td>Humidity, Temperature</td>
<td>Collect data on humidity, temperature, rain, luminosity</td>
</tr>
<tr>
<td></td>
<td>Air pollution monitoring and alerting</td>
<td>Collect data on different gas CO2, CO, NO, SO</td>
</tr>
<tr>
<td>Domain</td>
<td>Sub-domain</td>
<td>Use case</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>City Traffic/Mobility</td>
<td>Parking</td>
<td>Collect data on parking sensors</td>
</tr>
<tr>
<td></td>
<td>Traffic</td>
<td>Collect Data on traffic sensors</td>
</tr>
<tr>
<td></td>
<td>Bike Sharing/Bike</td>
<td>Bike &amp; rack availability, status monitoring, location</td>
</tr>
<tr>
<td></td>
<td>City Asset tracking</td>
<td>Collect data on asset: e.g. manhole</td>
</tr>
<tr>
<td></td>
<td>Digital Signage</td>
<td>Display short message on Digital Signage</td>
</tr>
<tr>
<td>Waste Management</td>
<td>Waste Container monitoring</td>
<td>Collect data on waste containers: level, temperature</td>
</tr>
<tr>
<td>Consumer Services</td>
<td>Pet tracking</td>
<td>Monitor location of pets</td>
</tr>
<tr>
<td></td>
<td>Personal asset tracking</td>
<td>Monitor location/usage of personal items</td>
</tr>
<tr>
<td></td>
<td>Wearables</td>
<td>Collect data from wearables</td>
</tr>
</tbody>
</table>
## LPWA Use Cases (3/3)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Sub-domain</th>
<th>Use case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Soil quality monitoring</td>
<td>Acidity, humidity, nitrogen, landslide prevention,</td>
</tr>
<tr>
<td>(Country side)</td>
<td>Livestock surveillance</td>
<td>Geolocation, health status, wolf prevention (accelerometer), geofencing,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>teleguidance</td>
</tr>
<tr>
<td></td>
<td>Cattle &amp; pet monitoring</td>
<td>Geolocation</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>Rain, wind, temperature, humidity, (pressure)</td>
</tr>
<tr>
<td></td>
<td>Irrigation</td>
<td>Leakage</td>
</tr>
<tr>
<td></td>
<td>Building Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>Fire detection, smoke, CO, flood, leakage, intrusion, temperature, home</td>
</tr>
<tr>
<td></td>
<td></td>
<td>automation (blinds etc.)</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>Fire detection, smoke, CO, flood, leakage, intrusion, temperature, building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>automation (blinds, heating, air conditioning etc), telesurveillance,</td>
</tr>
<tr>
<td></td>
<td>Healthcare</td>
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</tr>
<tr>
<td></td>
<td>Patient monitoring</td>
<td>Fall down detection, out of area detection, ECG monitoring, activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>monitoring, Alert</td>
</tr>
<tr>
<td></td>
<td>Home Medical Equipment status</td>
<td>Control of correct usage of medical equipment and status</td>
</tr>
<tr>
<td></td>
<td>and usage</td>
<td></td>
</tr>
</tbody>
</table>
LPWA Architecture
LPWA Architecture Value Proposition

- **Low Power Wide Area IoT as a Service**
  Managed IoT using for example, LoRaWAN technology

- **Shift from CAPEX to OPEX**
  Low CAPEX deployment, Subscription based revenue model

- **Shift from HW to SW**
  All intelligence is in the Cloud implemented in software

- **Application Centric**
  Application/Data based routing/forwarding and services
Low Power Wide Area Architecture

- Cloud Data Centre
- Per App Processing
- Radio & Packet Mgmt
- Secure Aggregation
- WAN Backhaul
- LPWA RF
- Constrained Devices

LPWA Service Provider

Applications

LPWA App Router

LPWA Network Server

Security Firewall

LPWA APs

LPWA Sensors

Separate Network & Application Servers

Allows scale, provisioning, management, SLA
Allows distinction between SP and AP
Ensures confidentiality of data per application
# LPWA Architectural Component Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPWA Device</td>
<td>Smart devices (sensor, actuator) with LPWA RF</td>
<td>Support a given use cases/applications: (e.g. metering). Send or receive data to/from LPWA</td>
</tr>
<tr>
<td>LPWA AP</td>
<td>LPWA Access Point</td>
<td>LPWA RF interface to devices, Packet Relay, WAN backhaul: 3G, wifi, fiber, Security</td>
</tr>
<tr>
<td>LPWA NS</td>
<td>LPWA Network Server</td>
<td>Terminate MAC layer, Relay Packet to Application server, Collect data from multiple AP, Security: MAC layer, communication to AP and App Server, Application based routing to AP server, Collect data for network management, billing, optimization, Location Services</td>
</tr>
<tr>
<td>LPWA App Server</td>
<td>LPWA Application Server or Router (can be collocated with NS)</td>
<td>One per application, Relay Packet network server and application Interface with end-to-end application Mapping from IPv6 to NS</td>
</tr>
<tr>
<td>WAN Aggregation</td>
<td>WAN aggregation</td>
<td>Secure Tunnel termination, Firewall, IDS/IPS, Load-Balancing</td>
</tr>
<tr>
<td>AAA and Security</td>
<td>Authorization, Authentication, Accounting</td>
<td>Authenticate users, device, accounting, etc.</td>
</tr>
<tr>
<td>Network/Device</td>
<td>Network/Device Management</td>
<td>Device provisioning, activation, End-to-end Network management</td>
</tr>
<tr>
<td>Management</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LoRa Physical Layer (PHY)
An LPWA technology
Semtech **Long Range (LoRa) PHY**

Secure Sub-GHz (ISM bands) bi-directional point-to-point wireless link

Proprietary digital and chirp spread-spectrum modulation with FEC

Data rates 300bps and 10kbps, 50 kbps via FSK, Packet size up to 250 Bytes

Can trade data rate against range, up to +20dBm TX power, 168dB link budget

10 mA RX current, < 200 nA sleep current

Allow localization of end devices via a combination of time-of-flight and RSSI

Capacity can be incrementally increased by reducing cell size

Physical layer supports ISM bands (915/868/433/169)

  Upper layer protocols (LoRaWAN) may not necessarily supports all the bands the PHY does
RF Signal Primer

**dBm – Decibel-milliwatts**

<table>
<thead>
<tr>
<th>dBm</th>
<th>Power</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 Milliwatt</td>
<td>Bluetooth at 1m</td>
</tr>
<tr>
<td>30</td>
<td>1 Watt</td>
<td>GSM Mobile Phone</td>
</tr>
<tr>
<td>-127</td>
<td>0.178 FemtoWatt</td>
<td>GPS Satellite Signal</td>
</tr>
</tbody>
</table>

**RSSI – Received Strength Signal Indicator**

-60dBm – 70dBm – 80dBm – 90dBm – 100dBm – 110dBm – 120dBm – 130dBm – 140dBm – 150dBm

Excellent | Good | Weak | Poor | None

LoRa can RX below noise floor

**SNR – Signal to Noise ratio**

Signal Propagation

Signal Attenuation

RX Signal

SNR
Rural Drive Test (Australian Countryside)

RSSI (5cm TX Antenna, +6dB gain RX antenna)

SNR

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CBD Walk Test (5th Ave New York 4.5km)

Walker reported real-time location via text messages. SNR and RSSI were measured on valid packets received by roof-top gateway.

Source: Semtech
Semtech Indoor Penetration test

Source: Semtech
Semtech Long Range Test

Node Location: Community Center – 10 miles away

16,115 meters = 10 Miles

Source: Semtech
Semtech LoRa Chips (modules by Dorji)

- SPI Interface Module (Sophisticated)
- UART Interface Module (Simple)
- Battery not Included

LoRa transceiver

17mm
LoRaWAN™ (MAC)
LoRa Alliance (What is above the PHY?)

Non-profit association that believes the IoT era is now

Mission: Standardize LPWA Networks with a first focus on LoRaWAN

Initial Members: IoT solution providers: Actility, Cisco, Eolane, IBM, Kerlink, IMST, MultiTech, Sagemcom, Semtech, and Microchip Technology. SP: Bouygues Telecom, KPN, SingTel, Proximus, Swisscom, and FastNet (part of Telkom South Africa)

LoRaWAN specification 1.0.2 is available from LoRA alliance

(http://lora-alliance.org)
# LoRaWAN™ Layered Architecture

## Applications

<table>
<thead>
<tr>
<th>CoAP</th>
<th>MQTT</th>
<th>IPv6/6LoWPAN (IETF 6LPWA WG)</th>
<th>Raw</th>
<th>others</th>
</tr>
</thead>
</table>

## LoRaWAN™ MAC

- **Class A** (Baseline)
- **Class B** (Beacon)
- **Class C** (Continuous)

## LoRa Modulation

<table>
<thead>
<tr>
<th>EU868</th>
<th>EU433</th>
<th>US915</th>
<th>CN779</th>
<th>AU915</th>
<th>Others</th>
</tr>
</thead>
</table>

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LoRaWAN 1.0.2 Released Specification

Authored by Semtech, Actility, IBM

LoRaWAN Specification Document
Identifiers definition, Security procedures
Data and Control messages
Class A, B & C procedures

Regional Parameters Document (Join Freq, Duty Cycles Dwell times…)
900Mhz, 800Mhz, 700Mhz and 433Mhz bands
Europe, US, China, Australia, South Korea defined
Australia: 915Mhz – 928Mhz (13MHz available)
Special AS923Mhz plan (intersection of ISM frequencies)
Brunei, Cambodia, Hong Kong, Indonesia, Japan, Laos,
NZ, Singapore, Taiwan, Thailand, Vietnam
LoRaWAN End-to-End Architecture

- **LoRaWAN Sensor**: Standards Compliant, Low power sensor
- **Access Point**: Contains Radios, RF Termination of 1000s
- **Network Server**: MAC decaps, Security, Network/Radio management, Message scheduling, ZTD etc...
- **Application Server**: Platform for ASP, e.g., Parking, Air quality, Meter reading

Cloud Based Sensor Platform
This is where data can be stored and monetized
Data → Information → Knowledge → Wisdom

**Cisco IXM LoRaWAN Interface Module**

**RF**
**Backhaul**
**Cloud**

**LoRaWAN Radio PHY**
**LoRaWAN MAC**
**IP Tunnel**
**IP Transport**

**AppData**

Data à Information à Knowledge à Wisdom
LoRaWAN Description

Star-of-stars topology
  Gateways (AP) act as transparent bridge relaying messages between end-devices and a cloud based network server (NS)

Sensors use single-hop wireless communication
  To one or many gateways

Communication between sensors and Gateway is spread
  Different frequency channels and data rates

NS manages the data rate and RF output for each sensor
  Using adaptive data rate (ADR) scheme
LoRaWAN is a Simple Network

Any device can transmit to any channel at any time

No synchronization between devices required
   Easy to implement devices

Mote changes channel randomly for each transmission
   Robust to interferers and collisions

Piggy-backing for gateway to node/mote communication
   Acknowledgement may be sent in the next data packet
   Predictable battery-life
Simple & Secure Cloud-Based Radio Access

1. Application data encrypted
2. Message integrity calculated
3. Device transmits a packet
4. All APs in range RX packet
5. NS receives & checks MIC
6. NS forwards packet to AS
7. AS decrypts using app key
8. NS selects best AP for return TX

Encrypted App Data

Payload Message Integrity (MIC)
Three Important LoRa Parameters

- **Modulation Bandwidth**: 7.8, 10.4, 156.6, 20.8, 31.25, 41.7, 62.5, 125, 500 kHz
- **Spreading Factor**: 6, 7, 8, 9, 10, 11, 12
- **Coding Rate**: 4+1, 4+2, 4+3, 4+4 bits

**Design trade off**

- **Link Budget**
- **Spectral Occupancy**
- **Interference Immunity**
- **Nominal data rate**

Configuring these parameters influences these properties.
### Spreading Factor Example

Bandwidth: 125Khz, Coding Rate: 4/5, Payload: 4 bytes, Preamble: 12 symbols

<table>
<thead>
<tr>
<th>Spreading Factor</th>
<th>Chips/Symbol</th>
<th>Bit rate (bps)</th>
<th>Sensitivity (dBm)</th>
<th>Time on Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>64</td>
<td>9375 bps</td>
<td>-118 dBm</td>
<td>17 ms</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>5469 bps</td>
<td>-123 dBm</td>
<td>30 ms</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
<td>3125 bps</td>
<td>-126 dBm</td>
<td>60 ms</td>
</tr>
<tr>
<td>9</td>
<td>512</td>
<td>1758 bps</td>
<td>-129 dBm</td>
<td>120 ms</td>
</tr>
<tr>
<td>10</td>
<td>1024</td>
<td>977 bps</td>
<td>-132 dBm</td>
<td>240 ms</td>
</tr>
<tr>
<td>11</td>
<td>2048</td>
<td>537 bps</td>
<td>-134 dBm</td>
<td>479 ms</td>
</tr>
<tr>
<td>12</td>
<td>4096</td>
<td>293 bps</td>
<td>-137 dBm</td>
<td>958 ms</td>
</tr>
</tbody>
</table>

Each spreading factor is orthogonal on the same transmission channel.
Adaptive Data Rate (ADR)

ADR maximises battery life overall & network capacity

ADR manages the data rate and RF output for each device

Acknowledgement: Actility for diagrammatic representation
LoRaWAN Device Classes

Class A Bi-directional (Baseline)
Generally battery powered
Device UL TX followed by 2 short DL RX windows (TX from NS)
Class A must initiate a TX before listening on RX windows
Very suitable for lowest powered devices

Class B Bi-directional with scheduled receive slots (Beacons)
Generally battery powered
Implements Class A plus…
Open extra receive windows at scheduled times
Scheduled time synchronised with Beacon frames from gateway

Class C Bi-directional with maximum receive slots (Continuous RX)
Mains powered
Implements Class A RX¹ window plus…
Continually listens on RX² channel, only closed when TX
Uses most power, provides low latency
LoRaWAN Device Channel Access

End device may use listen-before-talk

Adhere to max transmit dwell time

Adhere to max transmit Duty Cycle

TX on any channel available, anytime

Changes channel in pseudo random fashion

Requirements are subject to local regulation
Not all are necessarily required in a local region
LoRaWAN Over-The-Air Activation (OTAA)

Global Dev ID (DevEUI)  
Application ID (AppEUI)  
Application Key (AppKey)  
Net Session Key (NwkSKey)  
App Session Key (AppSKey)  
End Device Addr (DevAddr)

Join Request
Network Server

Key generation algorithm

DevNonce  
DevEUI  
AppEUI  
AppNonce  
NetID  
DevAddr  
DLSettings  
RXDelay  
ChanList
LoRaWAN Activation-By-Personalisation (ABP)

ABP pre-provisions keys and device address
Join procedure is bypassed
# LoRaWAN Key Information Element (IE)

<table>
<thead>
<tr>
<th>IE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DevUI</td>
<td>A globally unique device ID in EUI64 format</td>
</tr>
<tr>
<td>DevAddr</td>
<td>A device ID of 32 bits that uniquely identifies the end device. Dev is composed of NetworkID (7 bits) and NetworkAddr (25 bits)</td>
</tr>
<tr>
<td>AppEUI</td>
<td>A globally unique application ID in EUI64 format that uniquely identifies the application provider (i.e., owner) of the end device</td>
</tr>
<tr>
<td>NwkSKey</td>
<td>A device-specific network session key used by both the network server and the end device to calculate and verify the Message Integrity Check (MIC) of all data messages to ensure data integrity. It is further used to encrypt and decrypt the payload field of MAC-only data messages.</td>
</tr>
<tr>
<td>AppSKey</td>
<td>A device-specific application session key used by both the network/app server and the end device to encrypt and decrypt the payload field of application-specific data messages. It may also be used to calculate and verify an application-level MIC to be optionally included in the payload of application-specific data.</td>
</tr>
<tr>
<td>AppKey</td>
<td>The AppKey is an AES-128 root key specific to the end-device. Whenever an end-device joins a network via over-the-air activation, the AppKey is used to derive the session keys NwkSKey and AppSKey specific for that end-device to encrypt and verify network communication and application data.</td>
</tr>
</tbody>
</table>
LoRaWAN™ Band Plan
## AU915MHz - 928MHz Band Example

### Parameter

<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX Power 125kHz</td>
<td>+30dBm (20dBm +10dBm gain) +26dBm (20dBm + 6dBm gain)</td>
</tr>
<tr>
<td>TX Power 500kHz</td>
<td>+26dBm (20dBm + 6dBm gain)</td>
</tr>
<tr>
<td>Transmit</td>
<td>Any available channel DR0-DR4</td>
</tr>
<tr>
<td>Frequency Hop</td>
<td>Min 20 channels on 125kHz</td>
</tr>
<tr>
<td>Dwell Time</td>
<td>400ms</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>&lt;1% per hour (~32 packets)</td>
</tr>
</tbody>
</table>

### 125kHz UL Data Rates

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>SF</th>
<th>Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR0</td>
<td>SF10</td>
<td>980bps</td>
</tr>
<tr>
<td>DR1</td>
<td>SF9</td>
<td>1760bps</td>
</tr>
<tr>
<td>DR2</td>
<td>SF8</td>
<td>3125bps</td>
</tr>
<tr>
<td>DR3</td>
<td>SF7</td>
<td>5470bps</td>
</tr>
</tbody>
</table>

### 500kHz UL Data Rates

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>SF</th>
<th>Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR4</td>
<td>SF8</td>
<td>12500bps</td>
</tr>
</tbody>
</table>

### 500kHz DL Data Rates

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>SF</th>
<th>Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR8</td>
<td>SF12</td>
<td>980bps</td>
</tr>
<tr>
<td>DR9</td>
<td>SF11</td>
<td>1760bps</td>
</tr>
<tr>
<td>DR10</td>
<td>SF10</td>
<td>3900bps</td>
</tr>
<tr>
<td>DR11</td>
<td>SF9</td>
<td>7000bps</td>
</tr>
<tr>
<td>DR12</td>
<td>SF8</td>
<td>12500bps</td>
</tr>
<tr>
<td>DR13</td>
<td>SF7</td>
<td>21900bps</td>
</tr>
</tbody>
</table>

### TX Power

- 125kHz: +30dBm (20dBm +10dBm gain) +26dBm (20dBm + 6dBm gain)
- 500kHz: +26dBm (20dBm + 6dBm gain)

### Transmit

Any available channel DR0-DR4

### Frequency Hop

Min 20 channels on 125kHz

### Dwell Time

400ms

### Duty Cycle

<1% per hour (~32 packets)

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Cisco LoRaWAN Gateway
Cisco LoRaWAN Interface Module

Part of IoT eXtension Module Series (IXM)
LoRaWAN Gateway Deployment

Connect to IR809/829 LAN via PoE cable

Carrier-grade LoRa gateway function

Semtech v2 reference design

Integrate with Actility (LoRa Network Server)

Support ZTD via Field Network Director

FCS - 16-ch for EU (868MHz), US (915Mhz)

Post FCS – Australia, Singapore

Omni LoRa Gateway – IR809 with single LoRa modem

3-sectors LoRa Gateway – IR829 with 3 LoRa modems

Multiple backhaul options – Ethernet, 4G and Wi-Fi
LoRaWAN Applications
Multi-Purpose Tester: IMST LoRa Mote

LoRaMote is perfect for testing, demo, prototyping LoRa transceiver and Cortex-M3 controller

GPS

Various sensors
  - proximity, magnetic, three axis accelerometer, pressure and temperature sensors

Schematics and source code are available on https://github.com/Lora-net
Smart Parking – Worldsensing Fastpark with LoRa

Cisco IR900 with Semtech LoRa Card

When a car parks over the sensor, it is detected and the sensor relays that information wirelessly to the gateway.

The system relies on embedded sensors in each parking bay in the street.

When connected to the payment method system, the authority can identify non-paying cars and with the use of a tablet app, parking wardens can work more effectively.

One single gateway covers an area of about 1km².

The gateway sends the information via the Internet to the database in real time.

The occupancy is instantly reported to users via apps and illuminated panels in the street.

Guidance

Reporting

The central control can get real time analytics about parking bays occupancy per areas and times of the day.
Asset Tracking : Abeeway

Tracker for people, pet, assets, cows…
Up to 1 year of battery autonomy
Small and handy size (starts at 6cm / 2,4in)
Leverage GPS for location and LoRa to communicate
Application: any asset, amusement park, ski resort, farm, children tracking, pet tracking, etc.
Waste Management

Sensor measuring the level of large containers
   Key to optimising waste collection

Long term (years) battery life, Long range transmission

Several vendors with waste collection sensors
   Enevo, BH Technologies and Homerider
Water Metering: Home Rider Systems

HOMERIDER has developed integrated end points
  In partnership with manufacturers: Actaris/Itron, Sappel, Elster, Sensus

Comprehensive data collection
  Up to 96 indexes per day
  Maximum & minimum debit by 6 hour slot
  Back flow: Number, Volume
  28 day consumption histogram
  Continuous flow by debit period
  Alarms: leaks, back flow, battery, fraud.
Summary

LPWA is a hot topic amongst network vendors/startups globally

Provides a “low cost network for low cost devices”
  - Looks like a cellular network, operates like a WiFi network
  - Simple access architecture, intelligence in the cloud

Many applicable use cases

Revenue models formulating
  - Subscription; Data Volume, Number of devices, Storage, Analytics?

Enables the Knowledge Provider
References

LoRa MAC Specification (Semtech, Actility, IBM)
  http://lora-alliance.org

LoRa net Github:
  https://github.com/Lora-net