Low-power, Long-range WAN for IoT: a technology overview

ResCom, Lille

Last update: 12th January, 2015

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France
IoT/WSN deployment made easier in single-hop model!
Energy-Range dilemma

Enhanced from M. Dohler “M2M in SmartCities”
## How costly is transmission?

<table>
<thead>
<tr>
<th>Technology</th>
<th>2G</th>
<th>3G</th>
<th>LAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (I=Indoor, O=Outdoor)</td>
<td>N/A</td>
<td>N/A</td>
<td>O: 300m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I: 30m</td>
</tr>
<tr>
<td>Tx current consumption</td>
<td>200mA-500mA</td>
<td>500mA – 1000mA</td>
<td>50mA</td>
</tr>
<tr>
<td>Standby current</td>
<td>2.3mA</td>
<td>3.5mA</td>
<td>NC</td>
</tr>
</tbody>
</table>
Energy consideration

TX power: 500mA

\[ P = I \times V = 500 \times 3.3 = 1650\text{mW} \]

\[ E = P \times t \rightarrow t = \frac{E}{P} \]

11345s or 3h9mins

Haven’t considered:
- Baseline power consumption of the sensor board
- RX consumption!
- Event capture consumption
- Event processing consumption
IEEE 802.15.4 in ISM 2.4GHz

- Low-power radio in the 2.4GHz band offering 250kbps throughput at physical layer
- Power transmission from 1mW to 100mW for range from 100m to about 1km is LOS
- CSMA/CA
- BPSK, used as physical layer in ZigBee
Energy consideration

TX power 0dbm: 17.4mA

\[ P = I \times V = 17.4 \times 3.3 = 57.42\text{mW} \]

\[ E = P \times t \rightarrow t = \frac{E}{P} \]

326018s or 90.5h

Haven’t considered:
- Baseline power consumption of the sensor board
- RX consumption: 18.8mA!
- Event capture consumption
- Event processing consumption
15 YEARS OF MULTI-HOP ROUTING?

Routing over low Power&Lossy Networks (RPL)

RPL is the 4th protocol standardized by IETF (RIP, OSPF, BGP)

6LowPan provides end-to-end IPv6 connectivity

IPv6 edge router

LBR (6lowPAN)

Short range, low power radio

UDP

IPv6 egde router
Academics vs Industries

Let’s go back to reality!

Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …

500 sensors, STATIC deployment, but need to have RELIABILITY, GUARANTEED LATENCY for monitoring and alerting. MUST run for 3 YEARS. No fancy stuff! CAN I HAVE IT?

From Peng Zeng & Qin Wang
Most telemetry applications use the cellular model.
Typical scenarios

**Gateways**
- Gateway – rural environment
- Gateway – urban environment
- Repeater (e.g. femto gateway)

**End points**
- Smart meter
- Smart car
- Smart home
- Smart clothing
- Smart bike (e.g. tracking)

Figure from Siradel
Low-power and long-range?
**Link Budget of LPWAN**

\[
P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_{M} + G_{RX} - L_{RX}
\]

- **\( P_{RX} \)**: Received power (dBm)
- **\( P_{TX} \)**: Sender output power (dBm)
- **\( G_{TX} \)**: Sender antenna gain (dBi)
- **\( L_{TX} \)**: Sender losses (connectors etc.) (dB)
- **\( L_{FS} \)**: Free space loss (dB)
- **\( L_{M} \)**: Misc. losses (multipath etc.) (dB)
- **\( G_{RX} \)**: Receiver antenna gain (dBi)
- **\( L_{RX} \)**: Receiver losses (connectors etc.) (dB)
- **\( S_{RX} \)**: Receiver sensitivity (dBm)

From Peter R. Egli, INDIGOO.COM
Simple loss in signal strength model

- **Free Space Path Loss model**

  \[ L_{(dB)} = 10 \log \left( \frac{P_t}{P_r} \right) = 20 \log \left( \frac{4\pi d}{\lambda} \right) = 20 \log \left( \frac{4\pi f d}{c} \right) \]

  \[ L_{(dB)} = 20 \log (f) + 20 \log (d) - 147.55 \, dB \]

- FSPL assume Gt=Gr=1

- **Rule of thumb**: 6dB = twice the range
LINK BUDGET EXAMPLE

- Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) – Losses (dB)

Example

- Transmitted power is +14dBm (25mw)
- Losses (FSPL) is 120dB (received power is $10^{12}$ less than transmitted power)
- Then Receiver Power (dBm) is -106dBm

If you have a receiver sensitivity of -137dBm you can handle FSPL up to 151dB, i.e. $1.15 \times 10^{15}$ less power than transmitted power!

Rewriting the equation

- Losses (dB) = Transmitted Power (dBm) - Received Power (dBm)
- Losses = link budget & Received Power = max receiver sensitivity
- Link budget = Transmitted Power - max receiver sensitivity
- 151dB=14dBm - (-137dBm)
Link budget example

- Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB)

Example

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Rewriting the equation

- Losses (dB) = Transmitted Power (dBm) - Received Power (dBm)
- Losses = link budget
- Link budget = Transmitted Power - max receiver sensitivity
- 151 dB = 14 dBm - (-137 dBm)
Increasing range?

- Generally, robustness and sensitivity can be increased when transmitting (much) slower.
- A [Sigfox message is sent relatively slowly in a very narrow band of spectrum (hence ultra-narrow-band) using Gaussian Frequency-Shift Keying modulation.]
- LoRa also increases time-on-air when maximum range is needed. But LoRa uses spread spectrum instead of UNB.
WHY THE LPWAN REVOLUTION?

Theoretical capacity of 125kHz and 2MHz radio channels considering a 7.5dB NF receiver.

LoRa SX1272 at 868MHz

433/868 typical

Industry best class at 868MHz

From Peter R. Egli, INDIGOO.COM
VERSATILE LPWAN!

Dense urban areas

Rural areas

Indoor

Underground

Smart Lighting Systems
Wireless DALI
Natural Lighting Control
Signal Conditioning in Airflow, CO₂ and CO Sensors

Security and Intruder Alarms, Access Control Systems
Energy Management: Thermostats, Smart Meters
Extreme long-range!

UK HAB (High Altitude Ballooning) trials gave 2 way LoRa™ coverage at up to 240 km. Lowering the data rate from 1000bps to 100bps should allow coverage all the way to the radio horizon, which is perhaps 600 km at the typical 6000-8000m soaring altitude of these balloons. Balloon tracking can be made.
Sigfox uses ultra-narrow band (UNB) of about 100Hz with GMSK (~BPSK)

Typical throughput is about 100bps

Devices can typically send up to 140 messages of 12-bytes per day (operator limits)

LoRa modulation is more versatile, using CSS variant

Sensitivity and throughput depend on 3 LoRa parameters: BW (bandwidth), CR (coding rate) and SF (spreading factor)

Throughput range is 240bps to 37500bps
What about the throughput?

Sigfox uses ultra-narrow band (UNB) of about 100Hz with GMSK (~BPSK). Typical throughput is about 100bps. Devices can typically send up to 140 messages of 12-bytes per day (operator limits).

LoRa modulation is more versatile, using CSS variant. Sensitivity and throughput depend on 3 LoRa parameters: BW (bandwidth), CR (coding rate) and SF (spreading factor). Throughput range is 240bps to 37500bps.
LoRa’s parameters

- **Parameters**
  - Bandwidth: 62.5kHz, 125kHz, 250kHz, 500kHz
  - Rate code: 4/4+CR (CR=1, 2, 3, 4)
  - Spreading factor: 6 to 12

**Table 1: LoRa Demodulator SNR**

<table>
<thead>
<tr>
<th>Spreading Factor (RegModemConfig2)</th>
<th>Spreading Factor (Chips / symbol)</th>
<th>LoRa Demodulator SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>64</td>
<td>-5 dB</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>-7.5 dB</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
<td>-10 dB</td>
</tr>
<tr>
<td>9</td>
<td>512</td>
<td>-12.5 dB</td>
</tr>
<tr>
<td>10</td>
<td>1024</td>
<td>-15 dB</td>
</tr>
<tr>
<td>11</td>
<td>2048</td>
<td>-17.5 dB</td>
</tr>
<tr>
<td>12</td>
<td>4096</td>
<td>-20 dB</td>
</tr>
</tbody>
</table>

**Table 2: Bandwidth, Spreading Factor, Nominal Rb, and Sensitivity**

<table>
<thead>
<tr>
<th>Bandwidth (kHz)</th>
<th>Spreading Factor</th>
<th>Nominal Rb (bps)</th>
<th>Sensitivity (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>6</td>
<td>9380</td>
<td>-122</td>
</tr>
<tr>
<td>125</td>
<td>12</td>
<td>293</td>
<td>-137</td>
</tr>
<tr>
<td>250</td>
<td>6</td>
<td>18750</td>
<td>-119</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>586</td>
<td>-134</td>
</tr>
<tr>
<td>500</td>
<td>6</td>
<td>3750</td>
<td>-116</td>
</tr>
<tr>
<td>500</td>
<td>12</td>
<td>1172</td>
<td>-131</td>
</tr>
</tbody>
</table>

**Table 3: Bandwidth, Spreading Factor, Coding Rate, Nominal Rb, and Sensitivity**

<table>
<thead>
<tr>
<th>Bandwidth (kHz)</th>
<th>Spreading Factor</th>
<th>Coding Rate</th>
<th>Nominal Rb (bps)</th>
<th>Sensitivity (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>12</td>
<td>4/5</td>
<td>293</td>
<td>-136</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>4/5</td>
<td>586</td>
<td>-133</td>
</tr>
<tr>
<td>500</td>
<td>12</td>
<td>4/5</td>
<td>1172</td>
<td>-130</td>
</tr>
</tbody>
</table>

**Rule of thumb**
- 6dB increase = twice the range in LOS
- 12dB needed for urban areas

**Sensitivity**
- Lowest input power with acceptable link quality, typically 1% PER

**Equation**

\[ R_b = SF \times \frac{\text{Rate Code}}{2^{\frac{SF}{BW}}} \text{ bits/sec} \]
## Time on air for various LoRa settings

<table>
<thead>
<tr>
<th>LoRa mode</th>
<th>BW</th>
<th>CR</th>
<th>SF</th>
<th>5 bytes</th>
<th>55 bytes</th>
<th>105 bytes</th>
<th>155 bytes</th>
<th>205 bytes</th>
<th>255 bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125</td>
<td>4/5</td>
<td>12</td>
<td>0.95846</td>
<td>2.59686</td>
<td>4.23526</td>
<td>5.87366</td>
<td>7.51206</td>
<td>9.15046</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>4/5</td>
<td>12</td>
<td>0.47923</td>
<td>1.21651</td>
<td>1.87187</td>
<td>2.52723</td>
<td>3.26451</td>
<td>3.91987</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>4/5</td>
<td>10</td>
<td>0.28058</td>
<td>0.69018</td>
<td>1.09978</td>
<td>1.50938</td>
<td>1.91898</td>
<td>2.32858</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>4/5</td>
<td>12</td>
<td>0.23962</td>
<td>0.60826</td>
<td>0.93594</td>
<td>1.26362</td>
<td>1.63226</td>
<td>1.95994</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td>4/5</td>
<td>10</td>
<td>0.14029</td>
<td>0.34509</td>
<td>0.54989</td>
<td>0.75469</td>
<td>0.95949</td>
<td>1.16429</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
<td>4/5</td>
<td>11</td>
<td>0.11981</td>
<td>0.30413</td>
<td>0.50893</td>
<td>0.69325</td>
<td>0.87757</td>
<td>1.06189</td>
</tr>
<tr>
<td>7</td>
<td>250</td>
<td>4/5</td>
<td>9</td>
<td>0.07014</td>
<td>0.18278</td>
<td>0.29542</td>
<td>0.40806</td>
<td>0.5207</td>
<td>0.63334</td>
</tr>
<tr>
<td>8</td>
<td>500</td>
<td>4/5</td>
<td>9</td>
<td>0.03507</td>
<td>0.09139</td>
<td>0.14771</td>
<td>0.20403</td>
<td>0.26035</td>
<td>0.31667</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>4/5</td>
<td>8</td>
<td>0.01754</td>
<td>0.05082</td>
<td>0.08154</td>
<td>0.11482</td>
<td>0.14554</td>
<td>0.17882</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>4/5</td>
<td>7</td>
<td>0.00877</td>
<td>0.02797</td>
<td>0.04589</td>
<td>0.06381</td>
<td>0.08301</td>
<td>0.10093</td>
</tr>
</tbody>
</table>
LoRa vs Sigfox

Usual (ultra) narrow-band (UNB) vs spread spectrum (SS) arguments

- UNB has lower in-band receive noise and SigFox can have more channels than LoRa
- But UNB needs tighter receiver synchronization and more complex signal processing at receiver (SigFox uses advanced SDR at receiver to analyse the total band)
- SS can more rapidly be saturated so LoRa may have more interference issues in dense environments

From networking guys perspective, LoRa is more versatile with possibility to build ad-hoc mesh networks
LoRa™ technology to be integrated into FLASHNET’s street lighting management solution

From Scoop.it!

Tata Communications, world’s largest IoT network in India

Cofely Services, a subsidiary of ENGIE (SUEZ group), integrates SIGFOX solution to expand services it provides for buildings

Bengaluru Is 8th City To Provide Internet Of Things Network from SIGFOX

Sigfox and Glen Canyon Corp. to Connect 1 Million Smart Meters to Internet of Things

From intelligible
* Brasov, 2015

Semtech and STMicroelectronics Collaborate to Scale LoRa Technology to Meet High-Volume Demands of Internet of Things Applications

From www.st.com - December 14, 2015 7:27 AM

ST to offer complete line of solutions including LoRa systems on chips (SoCs) to accelerate deployments of low-power wide-area networks by mobile network operators (MNOs)

Lenovo Announces The Lenovo Mobile World Congress In Enevo

From www.enevo.com - March 6, 4:12 PM

French Telecom to deploy its own domestic IoT and M2M network.

* "French Telecom LoRa radio technology for its own domestic IoT and M2M network."

T-Mobile to cover Czech Republic with the network for the Internet of Things

From www.thetimesofnewyork.com - September 10, 4:47 PM

Following a pilot open in the Czech Republic that met expectations, T-Mobile SimpleCell Networks and SIGFOX’s Internet of Things network throughout the country.

Sogedo et Sigfox lancent les compteurs d’eau intelligents

From www.sudouest.fr - December 16, 2015 2:24 PM

"Gestionnaire de réseaux dans les Landes, en Gironde et en Dordogne, Sogedo utilise les ondes radio de Sigfox pour relever les compteurs et surveiller l’état des canalisations."

Le compteur..."

Mobile World Congress In Enevo

From www.enevo.com - March 6, 4:12 PM

"French Telecom LoRa radio technology for its own domestic IoT and M2M network."

T-Mobile to deploy its own domestic IoT and M2M network.

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Some SigFox radio modules

- TD120x serie from Telecom Design
- SigFox module from CookingHack (Libelium)
- SigBee module from ATIM
- ARM-Nano N8 SigFox module from ATIM
- Adeunis SI868
- Nemeus MM002-LS-EU LoRa/SigFox
- AXSEM SigFox module
- SIGT002 from CG-Wireless
- RC1682-SIG from RadioCraft
- SigFox module from Snoc
Some ready-to-use SigFox devices

Snootlab Akeru is Arduino-like

SigFox ready sensor by ATIM

Sens’it from Axible Technologies

SigFox demonstrator by Adeunis

HidNSeek

Universal push button from Bttn Inc
LoRaA modules from Semtech’s SX127x chips

- DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz
- HopeRF HM-TRLR-D
- HopeRF RFM series
- Multi-Tech MultiConnect mDot
- LinkLabs Symphony module
- IMST IM880A-L is based on Semtech SX1272 LoRa 863-870 MHz for Europe
- Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe
- habSupplies
- AMIHO AM093
- ARM-Nano N8 LoRa module from ATIM
- SODAQ LoRaBee
- SODAQ LoRaBee RN2483
- inAir9 based on SX1276
- Froggy Factory LoRa module (Arduino)
- Microchip RN2483
**LoRa modules from Semtech’s SX127x chips**

Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe

<table>
<thead>
<tr>
<th>LoRa® Transceivers</th>
<th>Part Number</th>
<th>Frequency Range (MHz)</th>
<th>Link Budget (dB)</th>
<th>Rx Current (mA)</th>
<th>FSK max DR (kbps)</th>
<th>LoRa DR (kbps)</th>
<th>Max Sensitivity (dBm)</th>
<th>Tx Power (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SX1272</td>
<td>860 – 1020</td>
<td>158</td>
<td>10</td>
<td>300</td>
<td>0.3 – 37.5</td>
<td>-137</td>
<td>+ 20</td>
<td></td>
</tr>
<tr>
<td>SX1273</td>
<td>860 – 1020</td>
<td>150</td>
<td>10</td>
<td>300</td>
<td>1.7 – 37.5</td>
<td>-130</td>
<td>+ 20</td>
<td></td>
</tr>
<tr>
<td>SX1276</td>
<td>137 – 1020</td>
<td>168</td>
<td>9.9</td>
<td>300</td>
<td>0.018 – 37.5</td>
<td>-148</td>
<td>+ 20</td>
<td></td>
</tr>
<tr>
<td>SX1277</td>
<td>137 – 1020</td>
<td>158</td>
<td>9.9</td>
<td>300</td>
<td>1.7 – 37.5</td>
<td>-139</td>
<td>+ 20</td>
<td></td>
</tr>
<tr>
<td>SX1278</td>
<td>137 – 525</td>
<td>168</td>
<td>9.9</td>
<td>300</td>
<td>0.018 – 37.5</td>
<td>-148</td>
<td>+ 20</td>
<td></td>
</tr>
</tbody>
</table>

- **Multi-Tech MultiConnect mDot**
- **DORJI DRF1278DM** is based on Semtech SX1278 LoRa 433MHz
- **Microship RN2483**
- **Libelium LoRa** is based on Semtech SX1272 LoRa 863-870 MHz for Europe
- **HopeRF RFM series**
- **Embit LoRa**
- **SODAQ LoRaBee RN2483**
- **ARM-Nano N8 LoRa module from ATIM**
- **IMST IM880A-L** is based on Semtech SX1272 LoRa 863-870 MHz for Europe
- **inAir9 based on SX1276**
- **habSupplies**
- **Adeunis ARF8030AA- Lo868**
Some ready-to-use LoRa devices

- LoRa Mote from Semtech
- Microchip LoRa mote
- NetBlocks XRange
- LoRa Alliance
- HopeRF/Ideetron motes
- SODAQ Tatu with LoraBee (Embit)
Sigfox’s model for M2M: the « operator » (all-in-one) approach

Figures from SigFox

http://www.scoop.it/t/toulouse-networks/?tag=SigFox
vs PRIVATE LONG RANGE NETWORKS WITH LoRa

Add LoRa radio module to your preferred dev platform

Install a LoRa gateway and start collecting data

- 100mW = cellular @1W
- Battery Friendly
- Small Size
- Market Priced

Figure from Semtech
LoRa Gateways
(Non exhaustive list)

- Multi-Tech Conduit
- Embedded Planet EP-M2M-LORA
- PicoWAN from Archos
- Kerlink IoT Station
- TheThingNetwork
- Ideetron Lorank 8
- LinkLabs Symphony
- Or build your own one: Arduino, Raspberry PI, …
Gateways/BS = Cloud
## OTHER LONG-RANGE TECHNOLOGIES

<table>
<thead>
<tr>
<th>Technology</th>
<th>LoRa</th>
<th>NWave</th>
<th>OnRamp</th>
<th>Platanus</th>
<th>SIGFOX</th>
<th>Telensa</th>
<th>Weightless-N</th>
<th>Weightless-P</th>
<th>Amber Wireless</th>
<th>M2M Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAVIoT: Nb-Fi with -154dBm (50km LOS, 10-15km urban)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range (km)</td>
<td>15-45 flat; 15-22 suburban; 3.8 urban</td>
<td>10</td>
<td>4 (but claims 25x competition)</td>
<td>Several hundred meters</td>
<td>50 rural; 10 urban</td>
<td>Up to 8</td>
<td>5+</td>
<td>2+ urban</td>
<td>Up to 20</td>
<td></td>
</tr>
<tr>
<td>Band (MHz)</td>
<td>Spread; varies by region</td>
<td>Sub-GHz</td>
<td>2.4 GHz</td>
<td>Sub-GHz</td>
<td>868; 902</td>
<td>868/915 470 (China)</td>
<td>Sub-GHz</td>
<td>Sub-GHz</td>
<td>434, 868, 2.4 GHz</td>
<td>800/900</td>
</tr>
<tr>
<td>ISM?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Symmetric up/down?</td>
<td>No</td>
<td>No</td>
<td>No (4:1)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Uplink only</td>
<td>Not yet determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data rate (Caveat)</td>
<td>0.3-50 kbps (adaptive)</td>
<td>100 (close)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Up to 500 kbps**</td>
</tr>
<tr>
<td>Max nodes</td>
<td>Depends; 200K-300K/hub</td>
<td>1000 (close)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>255 networks of 255 nodes</td>
</tr>
<tr>
<td>OTA upgrades?</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handoff?</td>
<td>No; no node/hub association</td>
<td>No; it’s being considered</td>
<td>Yes</td>
<td>Yes</td>
<td>Doubtful</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational model</td>
<td>Public or private (expect 80% public)</td>
<td>Public or private</td>
<td>Public or private</td>
<td>Public or private</td>
<td>Public</td>
<td>Public</td>
<td>Public or private</td>
<td>Public or private</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard status (if any)</td>
<td>No</td>
<td>Weightless-N</td>
<td>IEEE; in process</td>
<td>Weightless-P</td>
<td>No</td>
<td>No (perhaps in future)</td>
<td>Yes</td>
<td>In process; spec later this yr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

THE ISM/SRD LICENSE-FREE FREQUENCY BANDS

- 315/915MHz in USA
- 2.4GHz
- 433/868MHz
- 315/426MHz
- 315/433MHz
- 433MHz
- 433/915MHz
License-free Sub-GHz constraints

- Shared medium so long-range transmission in dense environments can create lots of interference!
- Activity time is constrained from 0.1%, 1% 10% duty-cycle depending on frequency: 3.6s, 36s/hour to 360s/hour

<table>
<thead>
<tr>
<th>Band</th>
<th>Edge Frequencies</th>
<th>Field / Power</th>
<th>Spectrum Access</th>
<th>Band Width</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe-</td>
<td>Fe+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g(Note 7)</td>
<td>865 MHz</td>
<td>868 MHz</td>
<td>+6.2 dBm /100 kHz</td>
<td>1 % or LBT AFA</td>
</tr>
<tr>
<td>g(Note 7)</td>
<td>865 MHz</td>
<td>870 MHz</td>
<td>-0.8 dBm / 100 kHz</td>
<td>0.1 % or LBT AFA</td>
</tr>
<tr>
<td>g1</td>
<td>868 MHz</td>
<td>868.6</td>
<td>14 dBm</td>
<td>1 % or LBT AFA</td>
</tr>
<tr>
<td>g2</td>
<td>868.7 MHz</td>
<td>869.2 MHz</td>
<td>14 dBm</td>
<td>0.1 % or LBT AFA</td>
</tr>
<tr>
<td>g3</td>
<td>869.4 MHz</td>
<td>869.65 MHz</td>
<td>27 dBm</td>
<td>10 % or LBT AFA</td>
</tr>
<tr>
<td>g4</td>
<td>869.7 MHz</td>
<td>870 MHz</td>
<td>7 dBm</td>
<td>No requirement</td>
</tr>
<tr>
<td>g4</td>
<td>869.7 MHz</td>
<td>870 MHz</td>
<td>14 dBm</td>
<td>1 % or LBT AFA</td>
</tr>
</tbody>
</table>

For SigFox, the operator typically limits the number of messages per day (140) with penalty for over usage. e.g. new messages/day = 140 – (2 * «#msg_overuse») applied during «#msg_overuse» days
LBT+AFA

- Listen Before Talk and Adaptive Frequency Agility can relax the duty-cycle constraints...

- ... but still
  - 100s / hour on every 200kHz BW
  - no more than 1s for a single transmission 😞😞

- ... so may not be that interesting!
What about reliability?

- Using the g3 band, 10% duty cycle can be achieved for the gateway on the downlink.
- However, handling ACKs for a large number of devices is not possible.
- SigFox uses repetition.

LoRa uses coding gain (with the coding rate) and spread spectrum higher immunity to interferences.

ACKs may be reserved for critical transactions.
What is LoRaWAN?

**Class A: Receiver Initiated Transmission strategy (RIT)**
- **END DEVICE**
  - **PACKET**
  - **END DEVICE SLEEPS**
  - **Rx slot 1**
  - **Rx slot 2**
  - Received by ALL base stations in range
  - Cloud Network Server (MAC Controller) selects best base station

**Class B: Coordinated Sampled Listening (CSL)**
- **END DEVICE**
  - **Rx**
  - **Rx**
  - **Rx**
  - **Rx**
  - **Rx**
  - **Rx**
  - **Rx**
  - **Rx**
  - 128 seconds

**Class C: Continuous Listening**
- **Transmit**
- **RX1**
- **RX2**
- **RECEIVE_DELAY1**
- **RECEIVE_DELAY2**
- **Extends to next uplink**

LoRa® Alliance
Wide Area Networks for IoT

<table>
<thead>
<tr>
<th>Application</th>
<th>LoRa® MAC</th>
<th>LoRa® Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAC options</strong></td>
<td>Class A</td>
<td>Class B</td>
</tr>
<tr>
<td>Class A (Baseline)</td>
<td>Class B</td>
<td>Class C (Continuous)</td>
</tr>
<tr>
<td><strong>LoRa® Modulation</strong></td>
<td>Regional ISM band</td>
<td></td>
</tr>
<tr>
<td>EU 868</td>
<td>EU 433</td>
<td>US 915</td>
</tr>
<tr>
<td>AS 430</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LoRa™ Long-Range Sub-GHz Module (Part # RN2483)
LoRaWAN architecture
# LoRaWAN Channels

## EU 863-870MHz ISM Band

<table>
<thead>
<tr>
<th>DataRate</th>
<th>Configuration</th>
<th>Indicative physical bit rate [bit/s]</th>
<th>TXPower</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>LoRa: SF12 / 125 kHz</td>
<td>250</td>
<td>0</td>
<td>20 dBm (if supported)</td>
</tr>
<tr>
<td>1</td>
<td>LoRa: SF11 / 125 kHz</td>
<td>440</td>
<td>1</td>
<td>14 dBm</td>
</tr>
<tr>
<td>2</td>
<td>LoRa: SF10 / 125 kHz</td>
<td>980</td>
<td>2</td>
<td>11 dBm</td>
</tr>
<tr>
<td>3</td>
<td>LoRa: SF9 / 125 kHz</td>
<td>1760</td>
<td>3</td>
<td>8 dBm</td>
</tr>
<tr>
<td>4</td>
<td>LoRa: SF8 / 125 kHz</td>
<td>3125</td>
<td>4</td>
<td>5 dBm</td>
</tr>
<tr>
<td>5</td>
<td>LoRa: SF7 / 125 kHz</td>
<td>5470</td>
<td>5</td>
<td>2 dBm</td>
</tr>
<tr>
<td>6</td>
<td>LoRa: SF7 / 250 kHz</td>
<td>11000</td>
<td>6..15</td>
<td>RFU</td>
</tr>
<tr>
<td>7</td>
<td>FSK: 50 kbps</td>
<td>50000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Data rate and TX power table

## Minimum set

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Bandwidth [kHz]</th>
<th>Channel Frequency [MHz]</th>
<th>FSK Bitrate or LoRa DR / Bitrate</th>
<th>Nb Channels</th>
<th>Duty cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoRa</td>
<td>125</td>
<td>868.10 868.30 868.50</td>
<td>DR0 to DR5 0.3-5 kbps</td>
<td>3</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

Table 12: EU863-870 default channels
Will main market be operator based?

Long Range

- Greater than cellular
- Deep indoor coverage
- Star topology

bouygues telecom
orange
swisscom
KPN
...COMMUNITY BASED?
OR FROM LOCAL ACTORS?

Irrigation

Livestock farming

Fish farming & aquaculture

Storage & logistic

Agriculture

Fresh water
What about Quality of Service?

Regulations stipulate that radio activity duty-cycle should be enforced at devices and that end-users should not be able to modify it « easily ».

LoRaWAN specification from LoRa Alliance is a first attempt to standardize LoRa networks but no issues on quality of service.

What if I still need to send more than 36s in the current hour because of an emergency situation?

☐ stop transmitting?
☐ violate regulation?
LONG-RANGE VERSION OF OUR IMAGE SENSOR
What if I want to transmit images?

Optimized image encoding at medium quality: 16384b down to 1366b (ratio 12).

Will generate 7 pkts using 250 max payload.

<table>
<thead>
<tr>
<th>LoRa mode</th>
<th>BW</th>
<th>CR</th>
<th>SF</th>
<th>5 bytes</th>
<th>55 bytes</th>
<th>105 bytes</th>
<th>155 Bytes</th>
<th>205 Bytes</th>
<th>255 Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125</td>
<td>4/5</td>
<td>12</td>
<td>0.95846</td>
<td>2.59686</td>
<td>4.23526</td>
<td>5.87366</td>
<td>7.51206</td>
<td>9.15046</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>4/5</td>
<td>12</td>
<td>0.47923</td>
<td>1.21651</td>
<td>1.87187</td>
<td>2.52723</td>
<td>3.26451</td>
<td>3.91987</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>4/5</td>
<td>10</td>
<td>0.28058</td>
<td>0.69018</td>
<td>1.09978</td>
<td>1.50938</td>
<td>1.91898</td>
<td>2.32858</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>4/5</td>
<td>12</td>
<td>0.23962</td>
<td>0.60826</td>
<td>0.93594</td>
<td>1.26362</td>
<td>1.63226</td>
<td>1.95994</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td>4/5</td>
<td>10</td>
<td>0.14029</td>
<td>0.34509</td>
<td>0.54989</td>
<td>0.75469</td>
<td>0.95949</td>
<td>1.16429</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
<td>4/5</td>
<td>11</td>
<td>0.11981</td>
<td>0.30413</td>
<td>0.50893</td>
<td>0.69325</td>
<td>0.87757</td>
<td>1.06189</td>
</tr>
<tr>
<td>7</td>
<td>250</td>
<td>4/5</td>
<td>9</td>
<td>0.07014</td>
<td>0.18278</td>
<td>0.29542</td>
<td>0.40806</td>
<td>0.5207</td>
<td>0.63334</td>
</tr>
<tr>
<td>8</td>
<td>500</td>
<td>4/5</td>
<td>9</td>
<td>0.03507</td>
<td>0.09139</td>
<td>0.14771</td>
<td>0.20403</td>
<td>0.26035</td>
<td>0.31667</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>4/5</td>
<td>8</td>
<td>0.01754</td>
<td>0.05082</td>
<td>0.08154</td>
<td>0.11482</td>
<td>0.14554</td>
<td>0.17882</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>4/5</td>
<td>7</td>
<td>0.00877</td>
<td>0.02797</td>
<td>0.04589</td>
<td>0.06381</td>
<td>0.08301</td>
<td>0.10093</td>
</tr>
</tbody>
</table>

7*9.15 = 64.05s

7*1.96 = 13.72s
A device can transmit more if needed, provided that other devices will decrease their radio activity time accordingly.
Distributing Remote Activity Time Usage

\[ l_RAT^4 = 0 \]
\[ r_{ATU}^4 = l_{TAT}^4 - l_RAT^4 \]

\[ \text{G}^4_{AT} = 360000 \]

\[ l_RAT^4 = 0 \]
\[ r_{ATU}^4 = l_{TAT}^4 - l_RAT^0 \]

\[ \text{AT}^4 = -3196 - 36000 = -39196 \]

\[ \text{G}^5_{AI} = 360000 - 39196 + 3196 = 324000 \]

\[ G^6_{AI} = 360000 - 39196 + 3196 = 324000 \]

\[ \text{G}^j_{AT} = 360000 - 39196 = 320804 \]
OTHER ISSUES TO TAKE INTO ACCOUNT

- Minimise the number of UPDT messages sent by the gateway because the gateway’s radio time is also limited
  - UPDT can have cumulative behavior if no remote activity time has been used
- Support sleep periods of end-devices
  - The network is synchronized for control messages (REG, INIT, UPDT). UPDT msg that cannot use cumulative behavior are queued for transmission at next transmission slot. At rcv, UPDT have to be applied sequentially.
- Maintain (loose) synchronization
  - If no UDPT are scheduled, the gateway periodically sends a BEACON. Clock drift is limited to a BEACON period
- Dynamic insertion of new end-devices
  - New devices can either stay out of the managed pool (then only 36s of activity time/h is allowed), or join by waiting for the next UPDT/BEACON msg
  - Every hour, end-devices decide if they want to join the pool or not
- Give priority to control msg
  - SIFS/DIFS mechanism are implemented using LoRa Channel Activity Detection
- Avoid interleaving of several image transmissions
  - Use DIFS for first image packet, then SIFS
- Improve LoRa network efficiency
  - Move from pure ALOHA to CSMA mechanism with CAD+RSSI tests prior to any transmission
IMPLEMENTATION AVAILABLE
Sending message under LAS services
WAZIUP is an EU H2020 project (2016-2019) contributes to long-range networks for rural applications with WP2
Design and adaptation

- Build low-cost, low-power, Long-range enabled generic platform
- Methodology for low-cost platform design
- Technology transfers to user communities, economic actors, stakeholders,...
Design and adaptation

- Build low-cost, low-power, Long-range enabled generic platform
- Methodology for low-cost platform design
- Technology transfers to user communities, economic actors, stakeholders,…
LOW-COST LoRa gateway: less than 50€
**Low-cost LoRa Gateway:**
Less than 50€

Kept as simple as possible

Most of user or application specific logics is done here!
We provide some basic features, up to you to enhance them

Radio bridge program

Post processing

stdout
stdin

stdout

lora_gateway program

SX1272 lib

ArduPi lib

Raspbian

```
g++ -lpthread -lrt lora_gateway.cpp arduPi.cpp SX1272.cpp -o lora_gateway
```
LONG-RANGE TEST-BED & BENCHMARK
Conclusions

- Low-power, long-range (LR) transmission is a break-through technology for IoT and large-scale deployment of wireless (sensor) devices
- With a large variety of applications, products & actors the low-power WAN (LPWAN) eco-system is becoming mature
- New technologies will certainly emerge but the LPWAN «philosophy» is now settled firmly: out-of-the-box connectivity is now the standard.
- Is multi-hop routing for low-power device still interesting in the IoT domain?
- Mostly driven by industrials, research & development around long-range technologies should also attract the academic research community