IoT systems overview

CoE Training on Traffic engineering and advanced wireless network planning

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Objectives

• Present the different IoT systems and their classifications
I. Introduction

II. IoT Technologies
   A. Fixed & Short Range
   B. Long Range technologies
      1. Non 3GPP Standards (LPWAN)
      2. 3GPP Standards
**IoT Specificities versus Cellular**

*IoT communications* are or should be:

- Low cost,
- Low power,
- Long battery duration,
- High number of connections,
- Low bitrate,
- Long range,
- Low processing capacity,
- Low storage capacity,
- Small size devices,
- Relaxed latency,
- Simple network architecture and protocols.
IoT Main Characteristics

- **Low power**, 
- **Low cost** (network and end devices), 
- **Short** range (first type of technologies) or **Long** range (second type of technologies), 
- **Low bit rate** (≠ broadband!), 
- **Long battery** duration (years), 
- Located in **any area** (deep indoor, desert, urban areas, moving vehicles ...)

Extended coverage

GPRS

+15 dB

CAT-M1

+20 dB

NB-IoT

+15 dB
IoT Specificities
### IoT Specificities and Impacts on Network planning and design

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Impact</th>
</tr>
</thead>
</table>
| **Low power and Wide Range**             | • High sensitivity (Gateways and end-devices with a typical sensitivity around -150 dBm/-125 dBm with Bluetooth/-95 dBm in 2G/3G/4G)  
   • Low frequencies ➔ strong signal penetration  
   • Narrow band carriers ➔ far greater range of reception  
   • +14 dBm (ETSI in Europe) with the exception of the G3 band with +27 dBm, +30 dBm but for most devices +20 dBm is sufficient (USA) |
| **Low deployment and Operational Costs** | • Low gateways cost  
   • Wide range ➔ Extended coverage + strong signal penetration (deep indoor, Rural)  
   • Low numbers of gateways ➔ Link budget: UL: 155 dB (or better), DL: Link budget: 153 dB (or better) |
| **Long Battery life**                    | • Low Power  
   • Idle mode most of the time.  
   • Connected mode just for transmission (some mA)  
   • < 100 MHz clock frequency  
   • Embedded memory of a few Mo  
   • Idle mode allowing an energy consumption of around 100 µW |

**N.B.**: planning tasks only apply to long range technologies (type 2).
## IoT Specificities and Impacts on Network planning

### Characteristics | Impact
---|---
**Shared Spectrum ➔ Interference Management**<br>- Clear channel assessment<br>- Frequency hopping<br>- OFDM/CDMA access and NOMA technologies<br>- Activity rate around 1% (regulation and energy constraints)<br><br>**Service diversity**<br>- Diversity of the traffic models<br>- Diversity of the transmission modes<br><br>**Low bitrates (hundreds to thousands of bits/sec. compared to 250 Kbit/s in ZigBee and 1-2 Mbit/s in Bluetooth)**<br>- Low capacity and lower number of gateways<br><br>**Small payloads (around 1000 bits): encrypted device ID and measurement or actuation command**<br>- Low capacity and lower number of gateways<br><br>**Simple topology (single-hop links)**<br>- Simplifies the coverage of large areas<br>- Share the existing cellular networks infrastructure

IoT Networks and Services are **Very Different** from « Classical Networks » in Many Aspects and Especially from a Planning Perspective
Tools and Techniques to Meet the Goals

- Communicate with Low Cost and Low Power $\Rightarrow$ Repetition
- Communicate in a Shared Bandwidth $\Rightarrow$ Spread Spectrum + Low Activity Rate
- Communicate in Wide Areas $\Rightarrow$ Low Sensitivity
### IoT components

<table>
<thead>
<tr>
<th>Identification</th>
<th>Sensors</th>
<th>Connection</th>
<th>Integration</th>
<th>Data processing</th>
<th>Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• RFID</td>
<td>• Temperature</td>
<td>• Bluetooth</td>
<td>• Simple middleware</td>
<td>• Databases</td>
<td>• Internet</td>
</tr>
<tr>
<td>• Bar codes</td>
<td>• Hydrometer</td>
<td>• ZigBee</td>
<td>• Decisional analysis of complex systems</td>
<td>• ERP</td>
<td>• EPC</td>
</tr>
<tr>
<td>• AND</td>
<td>• Accelerometer</td>
<td>• Z-Wave</td>
<td></td>
<td>• CRM</td>
<td></td>
</tr>
<tr>
<td>• ...</td>
<td>• Gyro meter</td>
<td>• WiFi</td>
<td></td>
<td>• 3D data warehouse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Nanotechnologies</td>
<td>• Sigfox</td>
<td></td>
<td>• Semantic Web and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• LoRa</td>
<td></td>
<td>ontologies</td>
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<tr>
<td></td>
<td></td>
<td>• NB-IoT</td>
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<td>• ...</td>
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</tr>
</tbody>
</table>
• IoT is a system to collect, store, process, manage, analyze, … information and data from almost any object.

• Value is **not in the network** (collection and connectivity) but **it is in the data** itself.

• IoT is an opportunity for countries and people to better have a control of their data and especially, **give value to local information and data**.
Summary

I. Introduction

II. IoT Technologies
   A. Fixed & Short Range
   B. Long Range technologies
      1. Non 3GPP Standards (LPWAN)
      2. 3GPP Standards
II. IoT Technologies
IoT 4 layers model

Integrated Applications

Information Processing

Network Infrastructure

Sensing and Identification
IoT network general architecture

Cloud Storage
Intelligence and Analytics

Cellular
Cable fiber
Satellite

Sensors, actuators
Consumer GTW
Industry GTW

WiFi
Bluetooth
NFC

HSPA+
GSM
GPRS
4G LTE

ZigBee
Thread

LoRa
sigfox
Things classification

• Things/Objects differentiate according to:
  ➢ The **range** (short, medium, long)
  ➢ The **type of interaction** with the system (i.e., service type):

  • **Alarm** (transmission initiated by the end-device only, according to the events, bursty traffic),
  • **Measurements** (triggered either by the end-device or by the system),
  • **Control** (transmissions initiated by the system),
  • **Combination** of these.
Things states and operations

The device can:

- **Publish** or **Subscribe**
- Be **online** or **offline**
- Manage messages of **different formats**
- Have different **types of communication channels**
- Have **one channel** or **several data streams**
Quiz 1 – IoT networks architecture

1. What are the main features of an IoT system?

2. What are the 4 layers of an IoT network?

3. What are the main components of an IoT network?

4. What are the different types of objects in IoT?

5. What are the operations an object (i.e., end-device) can achieve?

6. What kinds of IoT networks can be distinguished?
Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards
A. Fixed & Short Range

i. RFID

ii. Bluetooth

iii. Zigbee

iv. WiFi
i. RFID
RFID (Radio Frequency Identification)

- Appeared first in 1945
- **Features**: Identify objects, record metadata or control individual target
- More complex devices (e.g., readers, interrogators, beacons) usually connected to a host computer or network
- Radio frequencies from 100 kHz to 10 GHz
- **Operating**: reading device called a reader, and one or more tags

**RFID Frequencies**

![RFID Frequency Chart]

- **Inductive**
  - LF: 125/134 KHz
  - HF: 13.56 MHz
  - UHF: 860-950 MHz, 2.4 GHz
- **Radiative**
  - MF: 10 MHz
  - VHF: 50 MHz
  - Lower-frequent RFID bands: 5-7 MHz, 433 MHz, 5.2-5.8 GHz
RFID

How does it work?

**Tag**
- Microchip connected to an antenna
- Can be attached to an object as his identifier

**Reader**
- RFID reader communicating with the **RFID tag** through radio waves

Diagram:
- Tag
- Reader
- Middleware
- EPC Network
- Enterprise Systems
**RFID**

**Different Types of TAGs**

<table>
<thead>
<tr>
<th></th>
<th>Passive Tags</th>
<th>Active Tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Powering through RF <strong>from Reader</strong></td>
<td><strong>Internal</strong> to the Tag</td>
</tr>
<tr>
<td>Battery</td>
<td><strong>No</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td>Availability</td>
<td>Only in the field of Radar</td>
<td>Continuous</td>
</tr>
<tr>
<td>Required Signal Strength to Tag</td>
<td><strong>Very High</strong></td>
<td><strong>Very Low</strong></td>
</tr>
<tr>
<td>Range</td>
<td>Up to <strong>3-5m</strong></td>
<td>Up to <strong>100m</strong></td>
</tr>
<tr>
<td>Multi Tag Reading</td>
<td>Few Hundred within 3 meters from the reader</td>
<td>1000’s of tags recognized</td>
</tr>
<tr>
<td>Data Storage</td>
<td>128 bytes</td>
<td>128 bytes with search and access</td>
</tr>
</tbody>
</table>

Short or very short range technology, most applications are based on manual involvement and limited to presence detection.
ii. Bluetooth
Bluetooth characteristics

- **Low Power** wireless technology
- **Short range** radio frequency at **2.4 GHz** ISM Band
- Wireless *alternative* to wires
- Creating **PANs** (*Personal area networks*)
- Support Data Rate of 1 Mb/s (data traffic, video traffic)
- Uses frequency-hopping spread spectrum

<table>
<thead>
<tr>
<th>Class</th>
<th>Maximum Power</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100 mW (20 dBm)</td>
<td>~100 m</td>
</tr>
<tr>
<td>2</td>
<td>2.5 mW (4 dBm)</td>
<td>~10 m</td>
</tr>
<tr>
<td>3</td>
<td>1 mW (0 dBm)</td>
<td>~1 m</td>
</tr>
</tbody>
</table>
**Bluetooth characteristics**

**Bluetooth Piconet**

- Created instantly and automatically between Bluetooth devices within the same area
- A *master* device and others *slaves*
- Slaves cannot directly send data to each others
- All traffic must go through the *master*
- Up to 7 active slaves

**Bluetooth Scatternets**

- Two or more piconets
- Devices that participate in two piconet act as *gateways*
Bluetooth and IoT

Bluetooth Low Energy

- Enables IoT features
- Lowest cost and Easy to implement
- Improvements for ease of discovery & connection
- Low latency, fast transaction (3 ms from start to finish)
- Data Rate 1 Mb/s: sending just small data packets
- **Bluetooth 5**: 4x range, 2x speed and 8x broadcasting message capacity.

<table>
<thead>
<tr>
<th>Range</th>
<th>~ 150 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power</td>
<td>~ 10mW(10 dBm)</td>
</tr>
<tr>
<td>Max current</td>
<td>15 mA</td>
</tr>
<tr>
<td>Modulation</td>
<td>GFSK at 2.4 GHz</td>
</tr>
<tr>
<td>Sleep current</td>
<td>~ 1 µA</td>
</tr>
</tbody>
</table>

Low cost, available, ready to go.
iii. ZigBee
ZigBee

**Control and wireless sensor network**

Based on the **IEEE 802.15.4 Standard**

Created by the **Zigbee alliance**

- Low data rates and low power consumption
- Small packet networks
- Operates on unlicensed bands:
  - ISM 2.4 GHz at 250 Kbps
  - 868 MHz at 20 Kbps
  - 915 MHz at 40 Kbps

**Topology:**
- Star, Cluster Tree, Mesh

Up to 65 000 nodes on a network
ZigBee

- **Coordinator**: acts as a root and bridge of the network
- **Router**: intermediary device that permit data to pass to and through them to other devices
- **End Device**: limited functionality to communicate with the parent nodes

Low cost, available, ready to go.
iv. WiFi
### WiFi

- **Wireless technology**
- **Alternative to Wired Technologies**
- **IEEE 802.11 standard for WLANs**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Frequency bands</th>
<th>Throughput</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi a (802.11a)</td>
<td>5 GHz</td>
<td>54 Mbit/s</td>
<td>10 m</td>
</tr>
<tr>
<td>WiFi B (802.11b)</td>
<td>2.4 GHz</td>
<td>11 Mbit/s</td>
<td>140 m</td>
</tr>
<tr>
<td>WiFi G (802.11g)</td>
<td>2.4 GHz</td>
<td>54 Mbit/s</td>
<td>140 m</td>
</tr>
<tr>
<td>WiFi N (802.11n)</td>
<td>2.4 GHz / 5 GHz</td>
<td>450 Mbit/s</td>
<td>250 m</td>
</tr>
<tr>
<td>IEEE 802.11ah</td>
<td>900 MHz</td>
<td>8 Mbit/s</td>
<td>1000 m</td>
</tr>
</tbody>
</table>
Wi-Fi HaLow

- A new low-power, long-range version of Wi-Fi that bolsters IoT connections, it will be available in 2018
- Wi-Fi HaLow is based on the IEEE 802.11ah specification
  - Data rates > 100 kbit/s
- Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band
  - MAC is designed to support thousands of connected devices
- It will easily penetrate walls and barriers thanks to the propagation capabilities of low-frequency radio waves.
- Its range will be nearly double today’s available Wi-Fi (1 kilometer)
  - Power Saving mode allows objects to remain inactive during max idle period after which, the STA is disassociated > 5 years sleeping!

- WiFi is longer range than Bluetooth and ZigBee
- More flexible
- Closer to networks
WiFi-based IoT Devices

Home & Building Automation
- Bringing intelligence, convenience and lifestyle

Smart Energy
- Adding power awareness to products and helping to save energy

Multimedia
- Wireless audio streaming and advanced remote controls

Security and Safety
- Improving remote control and home monitoring

Industrial M2M Communication
- Internet enhanced M2M communication using existing Wi-Fi infrastructure

Small Size | Low Cost | Low Power
Long Range Technologies

Non 3GPP Standards
- LORA
- SIGFOX
- Weightless
- Others

3GPP Standards
- LTE-M
- EC-GSM
- NB-IOT
- 5G

Others

3GPP Standards

Others

Non 3GPP Standards
# Wide-area M2M technologies and IoT

<table>
<thead>
<tr>
<th>Carrier frequency</th>
<th>Technology</th>
<th>Channel bandwidth</th>
<th>Representative data rate</th>
<th>Link budget target or max. range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Licensed cellular</td>
<td><strong>LTE Cat. 0</strong></td>
<td>20 MHz</td>
<td>DL: 1 Mb/s UL: 1 Mb/s</td>
<td>140 dB</td>
</tr>
<tr>
<td></td>
<td><strong>LTE Cat. M</strong></td>
<td>1.4 MHz</td>
<td>DL: 1 Mb/s UL: 1 Mb/s</td>
<td>155 dB</td>
</tr>
<tr>
<td></td>
<td><strong>NB-IoT</strong></td>
<td>200 kHz</td>
<td>DL: 128 kb/s UL: 64 kb/s</td>
<td>164 dB</td>
</tr>
<tr>
<td></td>
<td><strong>EC-GSM</strong></td>
<td>200 kHz</td>
<td>DL: 74 kb/s UL: 74 kb/s</td>
<td>164 dB</td>
</tr>
<tr>
<td>Unlicensed</td>
<td><strong>2.4 GHz</strong></td>
<td>Ingenu RPMA</td>
<td>UL: 624 kb/s DL: 156 kb/s</td>
<td>500 km line of sight</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-1 GHz</strong></td>
<td>LoRa chirp spread spectrum</td>
<td>UL: 100 kb/s DL: 100 kb/s</td>
<td>15 km rural 5 km urban</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-1 GHz</strong></td>
<td>Weightless-N</td>
<td>UL: 100 b/s</td>
<td>3 km urban</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-1 GHz</strong></td>
<td>Sigfox</td>
<td>UL: 100 b/s</td>
<td>50 km rural 10 km urban</td>
</tr>
</tbody>
</table>

Quiz 2 – Short range IoT systems

1. What are the main 2 technologies used for IoT short range?

2. What are the main changes introduced in existing short range system to allow IoT communications?

3. What are the main advantage of using existing systems?

4. What are the offered bitrates with these systems?

5. What are the maximum ranges these systems can offer?
Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards
B. Non 3GPP Standards (LPWAN)

i. LoRaWAN
ii. Sigfox
iii. RPMA
iv. Others
LPWAN Requirements

- Long battery life
- Support for a massive number of devices
- Extended coverage (10-15 km in rural areas, 2-5 km in urban areas)
- Low device cost
- Low cost and easy deployment
i. LoRaWAN
Differences between LoRa and LoRaWAN

- **LoRa** contains only the link layer protocol. LoRa modules are a little cheaper than the LoRaWAN ones.
- **LoRaWAN** includes the network layer too so it is possible to send the information to any Base Station already connected to a Cloud platform. LoRaWAN modules may work in different frequencies by just connecting the right antenna to its socket.
LoRa Alliance

International Operators
- International development of the solution

Integrators and industrialists
- Appropriate technology and maintain it over time

Manufacturers of End-points
- Broadcast end devices

Manufacturers of Semiconductors
- Integrate LoRa technology
LoRa technology Overview

- LoRaWAN is a *Low Power Wide Area Network*
- LoRa modulation: a version of Chirp *Spread Spectrum* (CSS) with a typical channel **bandwidth of 125KHz**
- High **Sensitivity** (End Nodes: Up to -137 dBm, Gateways: up to -142 dBm)
- Long range communication (up to **15 Km**)
- Strong indoor penetration: With High Spreading Factor, Up to **20dB** penetration (**deep indoor**)
- Occupies the entire bandwidth of the channel to broadcast a signal, making it **robust** to channel noise.
- **Resistant** to Doppler effect, multi-path and signal weakening.
### Architecture

<table>
<thead>
<tr>
<th>Modulation</th>
<th>LoRa RF (Spread Spectrum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>~ 15 Km</td>
</tr>
<tr>
<td>Throughput</td>
<td>0.3 to 27 Kbps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Traffic</th>
<th>Data packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>~ 243 Bytes</td>
</tr>
<tr>
<td>Security</td>
<td>AES Encryption</td>
</tr>
</tbody>
</table>

- **End Device**
- **LoRa Gateway**
- **Network Server**
- **Application Server**
- **Cloud**
- **Email**
- **Customer IT**
- **Remote Monitoring**
Spread spectrum basics

Diagram showing spread spectrum basics with labeled parts:
- Information symbol
- Symbol period
- Spreading code
- Chip

Graph titled "Detecting own signal. Correlator" showing:
- Own signal
- Code
- Data after multiplication
- Data after integration

Another graph showing:
- Other signal
- Code
- Data after multiplication
- Data after integration
**Spectrum**

- **Orthogonal sequences:** 2 messages, transmitted by 2 different objects, arriving simultaneously on a GW without interference between them (*Code Division Multiple Access* technique: CDMA, used also in 3G).
- **Spread Spectrum:** Make the signal more robust, the more the signal is spread the more robust. Less sensitive to *interference* and *selective frequency fadings*.

**Diagram:**
- **SF 12:** High gain, low data rate. Far devices and deep indoor.
- **SF 9:** Average gain, average data rate.
- **SF 7:** Low gain, high data rate. "Spread" signal transmitted with constant rate.

**Spectrum:** unlicensed, i.e. the 915 MHz ISM band in the US, 868 MHz in Europe.
Spectrum (Influence of the Spreading Factor)

Far with obstacles:

- **High sensitivity** required
- The network increases the SF (Spreading Factor)

  Throughput decreases but the connection is maintained

Close:

- **Low sensitivity** sufficient
- **Decrease** of SF (SPREADING FACTOR), **increase of throughput**

Adaptive throughput

ADR: Adaptive Data Rate
### RSSI and SF versus BW

<table>
<thead>
<tr>
<th>BW</th>
<th>SF 7</th>
<th>SF 8</th>
<th>SF 9</th>
<th>SF 10</th>
<th>SF 11</th>
<th>SF 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 kHz</td>
<td>-123</td>
<td>-126</td>
<td>-129</td>
<td>-132</td>
<td>-133</td>
<td>-136</td>
</tr>
<tr>
<td>250 kHz</td>
<td>-120</td>
<td>-123</td>
<td>-125</td>
<td>-128</td>
<td>-130</td>
<td>-133</td>
</tr>
<tr>
<td>500 kHz</td>
<td>-116</td>
<td>-119</td>
<td>-122</td>
<td>-125</td>
<td>-128</td>
<td>-130</td>
</tr>
</tbody>
</table>

**Bar Chart**

- **Specified RSSI**
- **Observed RSSI**

Spread factor values:

- 7
- 8
- 9
- 10
- 11
- 12
### SF, bitrate, sensitivity and SNR for a 125 kHz channel

<table>
<thead>
<tr>
<th>Spreading factor</th>
<th>Bitrate (bit/sec)</th>
<th>Sensitivity (dBm)</th>
<th>LoRa demodulator SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (128)</td>
<td>5 469</td>
<td>-124 dBm</td>
<td>-7.5 dB</td>
</tr>
<tr>
<td>8 (256)</td>
<td>3 125</td>
<td>-127 dBm</td>
<td>-10 dB</td>
</tr>
<tr>
<td>9 (512)</td>
<td>1 758</td>
<td>-130 dBm</td>
<td>-12.5 dB</td>
</tr>
<tr>
<td>10 (1024)</td>
<td>977</td>
<td>-133 dBm</td>
<td>-15 dB</td>
</tr>
<tr>
<td>11 (2048)</td>
<td>537</td>
<td>-135 dBm</td>
<td>-17.5 dB</td>
</tr>
<tr>
<td>12 (4096)</td>
<td>293</td>
<td>-137 dBm</td>
<td>-20 dB</td>
</tr>
</tbody>
</table>

SF and repetition can be either **manual** (i.e., determined by the end-device) or **automatic** (i.e., managed by the network)
## LoRaWAN: device classes

<table>
<thead>
<tr>
<th>Classes</th>
<th>Description</th>
<th>Intended Use</th>
<th>Consumption</th>
<th>Examples of Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(« all »)</td>
<td>Listens only after end device transmission</td>
<td>Modules with no latency constraint</td>
<td>The most economic communication Class energetically. Supported by all modules. Adapted to battery powered modules</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Fire Detection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Earthquake Early Detection</td>
</tr>
<tr>
<td>B</td>
<td>(« beacon »)</td>
<td>The module listens at a regularly adjustable frequency</td>
<td>Modules with latency constraints for the reception of messages of a few seconds</td>
<td>Consumption optimized. Adapted to battery powered modules</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Smart metering</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Temperature rise</td>
</tr>
<tr>
<td>C</td>
<td>(« continuous »)</td>
<td>Module always listening</td>
<td>Modules with a strong reception latency constraint (less than one second)</td>
<td>Adapted to modules on the grid or with no power constraints</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Fleet management</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Real Time Traffic Management</td>
</tr>
</tbody>
</table>

⇒ Any LoRa object can transmit and receive data
Class A

One packet sent

RX1

1st receive window

Listening period: varies according to the spreading factor SF
- 5.1 ms at SF7 (outdoor and close devices)
- 10.2 ms at SF8 ...
- 164 ms at SF12 (deep-indoor or far devices)

RX2

2nd receive window

Open 2 windows for DL reception (acknowledgments, MAC commands, application commands...) after sending a packet

Gateway

End Point

Listening period

1 sec +/- 20 us

Very economic energetically

Communication triggered by the end device
Class B (Synchronized mode)

- **Synchronized** with the GTW
- **Opens listening windows** at regular intervals.

Opens N reception windows between the two tags

Listening duration: varies according to the SF

- Optimized energy consumption
- Communication initiated by the GTW
**Class C**

- **Permanent listening**
- Closes the reception window only during transmissions

- Reception window always open
- Closed receive window
- Reception window is open

End Point

Gateway

Packet reception: possible

Adapted to devices on the power grid
Identification of an end device in LORA

- **End-device address (DevAddr):**
  
  - | Network identifier | network address of the end-device |
  - | 7 bits | 25 bits |

- **Application identifier (AppEUI):** A global application ID in the IEEE EUI64 address space that uniquely identifies the owner of the end-device.

- **Network session key (NwkSKey):** A key used by the network server and the end-device to calculate and verify the message integrity code of all data messages to ensure data integrity.

- **Application session key (AppSKey):** A key used by the network server and end-device to encrypt and decrypt the payload field of data messages.
Current state

83 Network Operators

57 Alliance Member Operators

49 Countries operating in

95 Countries with LoRaWAN Deployments

- Alliance Member Public Networks
- Other LoRaWAN Deployment
ii. Sigfox
Roadmap

- 2012: Launch of the Sigfox network
- 2013: First fundraising of Sigfox company to cover France
- 2014: All France territory is covered by Sigfox network
- Mars 2016: San-Francisco become the first US. State covered by Sigfox
- By the end of 2016: Sigfox in America in 100 U.S. cities
First LPWAN Technology

- The physical layer based on an **Ultra-Narrow band wireless** modulation
- **Proprietary** system
- Low throughput (\(~100 \text{ bps}\))
- Low power
- Extended range (up to 50 km)
- **140 messages/day/device**
- Subscription-based model
- **Cloud platform** with Sigfox –defined API for server access
- **Roaming capability**
By default, data is conveyed over the air interface without any encryption. Sigfox gives customers the option to either implement their own end-to-end encryption solutions.
Spectrum and access

- **Narrowband** technology
- Standard radio transmission method: binary phase-shift keying (**BPSK**)
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data

**Frequency spectrum:**
- 868 MHz in Europe
- 915 MHz in USA
Sigfox transmission

- Starts by an UL transmission
- Each message is transmitted 3 times
- A DL message can be sent (option)
- Maximum payload of UL messages = 12 data bytes
- Maximum payload of DL messages = 8 bytes
Current state
iii. RPMA
RPMA was developed by On-Ramp Wireless to provide connectivity to oil and gas actors.

September 2015

RPMA was renamed Ingenu, and targets to extend its technology to the IoT and M2M market.

2016

RPMA was implemented in many places: Austin, Dallas/Ft. worth, Houston, TX, Phenix, AZ, ....

2017

RPMA will be invaded in many others countries: Los Angeles, San Francisco-West Bay, CA, Washington, D C, Baltimore, MD, Kanasas City.
INGENU RPMA overview

- Random Phase Multiple Access (RPMA) technology is a low-power, wide-area channel access method used exclusively for machine-to-machine (M2M) communication
- RPMA uses the 2.4 GHz band
- Offer extreme coverage
- High capacity
- Allow handover (channel change)
- Excellent link capacity
INGENU RPMA Overview

- RPMA is a Direct Sequence Spread Spectrum (DSSS) using:
  - Convolutional channel coding, gold codes for spreading
  - 1 MHz bandwidth
  - Using TDD frame with power control:
    - **Closed Loop Power Control:** the access point/base station measures the uplink received power and periodically sends a one bit indication for the endpoint to turn up transmit power (1) or turn down power (0).
    - **Open Loop Power Control:** the endpoint measures the downlink received power and uses that to determine the uplink transmit power without any explicit signaling from the access point/base station.

![TDD frame diagram](image-url)
Specifications of RPMA Solution

- **Time/Frequency Synchronization**

- **Uplink Power Control**
  - Creating a very tightly power controlled system in free-spectrum and presence of interference which reduces the amount of required endpoint transmit power by a factor of >50,000 and mitigates the near-far effect.
  - Frame structure to allow continuous channel tracking.
  - Adaptive spreading factor on uplink to optimize battery consumption.

- **Handover**
  - Configurable gold codes per access point to eliminate ambiguity of link communication.
  - Frequency reuse of 3 to eliminate any inter-cell interference degradation.
  - Background scan with handover to allow continuous selection of the best access point
Specifications of RPMA Solution

**Downlink Data Rate Optimization**

- Very high downlink capacity by use of adaptive downlink spreading factors.
- Open loop forward error correction for extremely reliable firmware download.
- Open loop forward error correction to optimize ARQ signaling. Signaling only needs to indicate completion, not which particular PDUs are lost.
Random multiple access is performed by delaying the signal to transmit at each end-device.

Support up to 1000 end devices simultaneously.

For the uplink, or the downlink broadcast transmission, a unique Gold code is used.

For unicast downlink transmission, the Gold code is built with the end-device ID, such that no other end-device is able to decode the data.
INGENU RPMA architecture

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>2.4 GHZ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>5-6 Km</td>
</tr>
<tr>
<td><strong>Throughput</strong></td>
<td>624 kb/s (UL) and 156 kb/s (DL)</td>
</tr>
</tbody>
</table>

**Type of Traffic** | **Data packet**
---|---
Payload | ~ 16 Bytes (one end point) ~ 1600 Bytes (for 1000 end points)
Security | AES Encryption
## Uplink Subslot Structure

**Uplink Subslot Structure Supporting Flexible Data Rate**

<table>
<thead>
<tr>
<th>Spreading Factor 8192 Subslot 0</th>
<th>SF 4096 Subslot 0</th>
<th>SF 2048 Subslot 0</th>
<th>SF 1024 Subslot 0</th>
<th>SF 512 SS 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF 4096 Subslot 0</td>
<td>SF 2048 Subslot 1</td>
<td>SF 1024 Subslot 1</td>
<td>SF 512 SS 1</td>
<td></td>
</tr>
<tr>
<td>SF 2048 Subslot 0</td>
<td>SF 1024 Subslot 2</td>
<td>SF 512 SS 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 1024 Subslot 0</td>
<td>SF 512 SS 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 0</td>
<td>SF 512 SS 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 1</td>
<td>SF 512 SS 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 2</td>
<td>SF 512 SS 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 3</td>
<td>SF 512 SS 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 4</td>
<td>SF 512 SS 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 5</td>
<td>SF 512 SS 9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 6</td>
<td>SF 512 SS 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 7</td>
<td>SF 512 SS 11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 8</td>
<td>SF 512 SS 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 9</td>
<td>SF 512 SS 13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 10</td>
<td>SF 512 SS 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF 512 SS 11</td>
<td>SF 512 SS 15</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Step 1:** Choose Spreading factor from 512 to 8192

**Step 2:** randomly select subslot

**Step 3:** Randomly select delay to add to subslot start from 0 to 2048 chips
How end point can transfer a data?

- **End Point**
  - Registration request (how often the EP will communicate)
  - Assigned a bit on the BCH channel (enable to send or No)
  - Send the message (payload 16 bytes)
- **Access Point**
  - AP response (Ack or NACK): Successful transaction
  - Not OK send again
  - Send the message
  - Send Acknowledge
RPMA security

- Message confidentiality: use of powerful encryption
- Message integrity & Replay protection
- Mutual Authentication
- Device Anonymity
- Authentic firmware Upgrades
- Secure Multicasts
Presence in Texas, with networks in Dallas, Austin, San Antonio, Houston, and large white space areas.

Ingenu offer the connectivity to more 50% of the Texas state population.

Three densely populated Texas markets are served by only 27 RPMA access points.

RPMA currently provides more than 100,000 square miles of wireless coverage for a host of IoT applications.
## RPMA’s current and future presence

<table>
<thead>
<tr>
<th>Currently live</th>
<th>Coverage Rollout Q3</th>
<th>Coverage ROLLOUT Q4 2016</th>
<th>Coverage planned 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Austin, TX</td>
<td>• Columbus, OH</td>
<td>• Atlanta, GA</td>
<td>• Los Angeles, CA</td>
</tr>
<tr>
<td>• Dallas/Ft.worth, TX</td>
<td>• Indianapolis, IN</td>
<td>• Jacksonville, FL</td>
<td>• San Fransisco-West Bay, CA</td>
</tr>
<tr>
<td>• Houston, TX</td>
<td></td>
<td>• Miami, FL</td>
<td>• Washington, DC</td>
</tr>
<tr>
<td>• Phoenix, AZ</td>
<td></td>
<td>• Orlando, FL</td>
<td>• Baltimore, MD</td>
</tr>
<tr>
<td>• Riverside, CA</td>
<td></td>
<td>• New Orleans, LA</td>
<td>• Kansas City</td>
</tr>
<tr>
<td>• San Antonio, TX</td>
<td></td>
<td>• Charlotte, NC</td>
<td>• Greensboro, NC</td>
</tr>
<tr>
<td>• San Diego, CA</td>
<td></td>
<td>• Albuquerque</td>
<td>• Las Vegas, NV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Memphis, TN</td>
<td>• Oklahoma City, OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nashville, TN EL paso, TX</td>
<td>• And many more cities</td>
</tr>
</tbody>
</table>

• And many more cities
v. Others
EnOcean

- Based on miniaturized power converters
- Ultra low power radio technology
- Frequencies: 868 MHz for Europe and 315 MHz for the USA
- Power from pressure on a switch or by photovoltaic cell
- These power sources are sufficient to power each module to transmit wireless and battery-free information.
- EnOcean Alliance in 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)
EnOcean

Architecture

Smart nodes

Building scenario

Cloud

Smart nodes

- Actors
- Sensors / Switches

EnOcean Stack
- Customer Application

EnOcean Radio connection
Backbone connection

EnOcean Gateway
Customer Application

83
ZWave

- Low power radio protocol
- Home automation (lighting, heating, ...) applications
- Low-throughput: 9 and 40 kbps
- Battery-operated or electrically powered
- Frequency range: 868 MHz in Europe, 908 MHz in the US
- Range: about 50 m (more outdoor, less indoor)
- Mesh architecture possible to increase the coverage
- Access method type CSMA / CA
- Z-Wave Alliance: more than 100 manufacturers in...
Quiz 3 – LPWAN

1. What are the main 2 IoT non-3GPP networks?

2. What are the main characteristics of LPWAN?

3. What are the 3 classes defined in LoRaWAN?

4. What is the particular SigFox model proposed for the users?

5. How many times a SigFox message is transmitted?

6. What multiple access technique is used in LoRa and SigFox?

7. What is the advantage of this multiple access technique in LPWAN communications?
Thank you!