# Low Power Wide Area Networks for the Internet of Things

## Framework, Performance Evaluation, and Challenges of LoRaWAN and NB-IoT

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# Outline

# Definition of the Internet of Things

**Internet of Things**

The Internet of Things (IoT) generally refers to scenarios where network connectivity and computing capability extends to devices, sensors, and everyday items (ISOC IoT Overview, October 2015).

- IoT devices are also called smart objects or connected objects
  - Physical world interface
  - Computing capability
  - Communication interface
- IoT is referred to as Smart Object Networking (IETF)

# Characteristics of the Devices in IoT

## IoT Devices

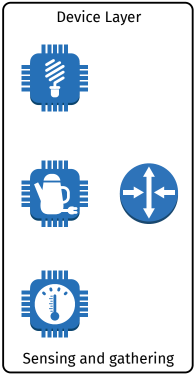
Everyday devices can become IoT devices: cars, HVAC, pollution sensors, street lighting, etc.

- IoT devices are connected to the Internet
  - Implement Internet protocols
  - Require addressing, naming, and routing functions
- IoT devices have stringent constraints on power, memory, bandwidth, and computing capability
  - Limited transmission capacity
  - Limited processing power

# Recent Enablers of IoT

- Ubiquitous connectivity
  - Pervasive wireless connectivity
  - Widespread adoption of IP-based networking
- Computing economics
  - Moore's law
  - Miniaturisation
- Advances in data analytics
  - Data mining
  - Rise of cloud computing

# End-to-End IoT Chain



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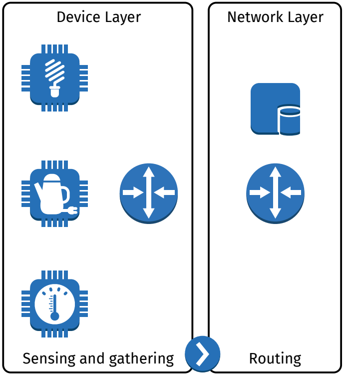

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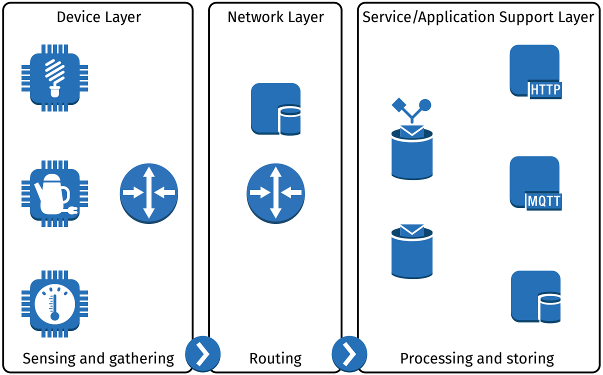

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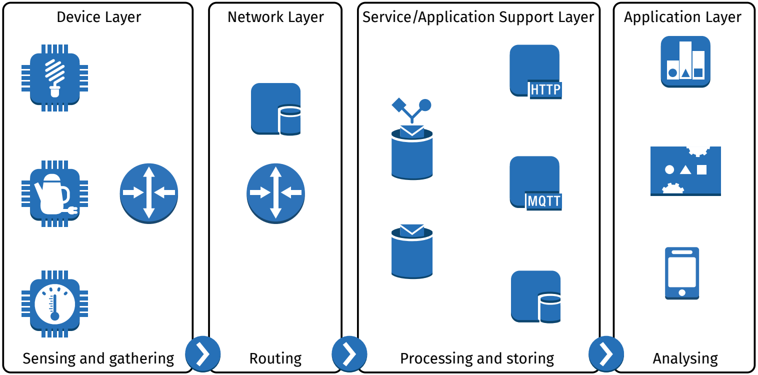

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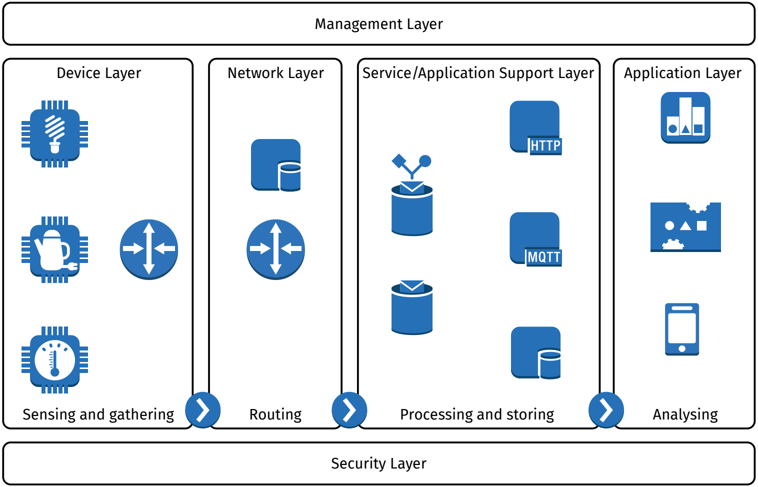
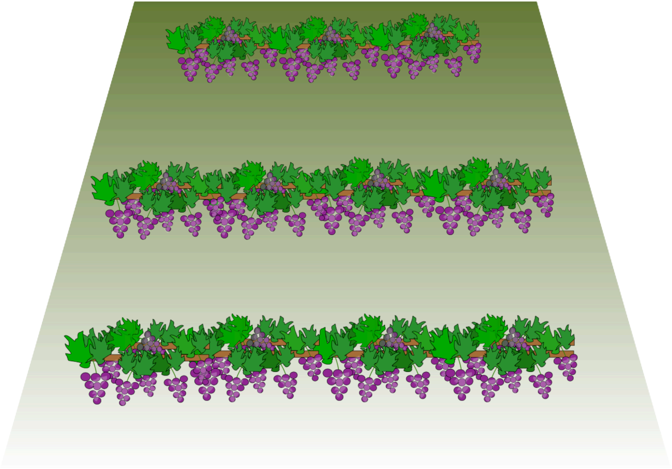


# IoT for Smart Agriculture



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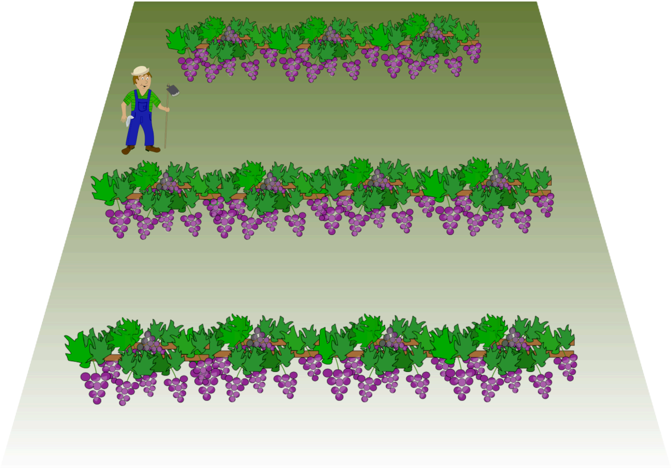

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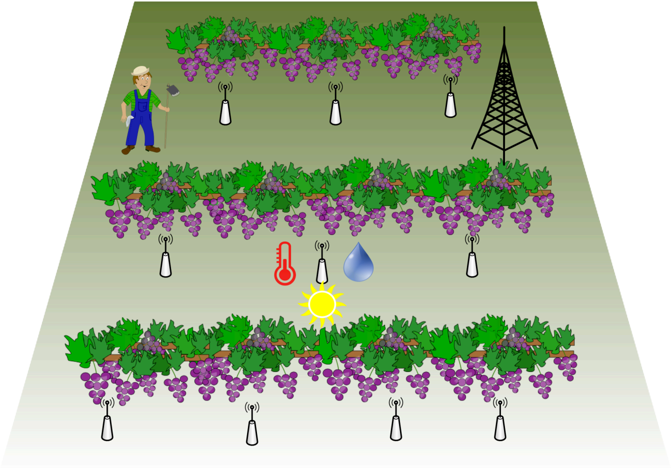


# IoT for Smart Agriculture

# Outline

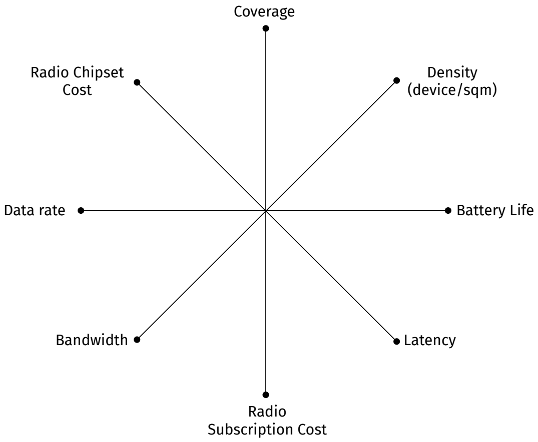
# Constraints on the Device and Network Layers

- Difficult physical accessibility and limited access to power sources
  - Wireless communications
  - Autonomy and long battery life operation
- Wide area coverage with a large number of communicating devices
  - Scalable deployment
  - Cost efficient devices
- Very loose bandwidth and latency constraints
  - Adaptive radio and access mechanisms

**Challenge**

Do existing wireless networking technologies satisfy these constraints?

# LPWA Sweet Spot



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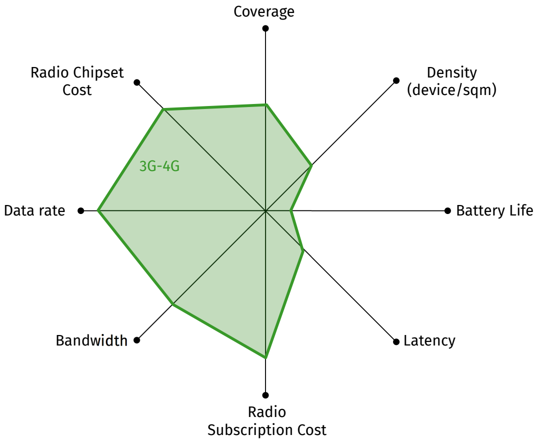

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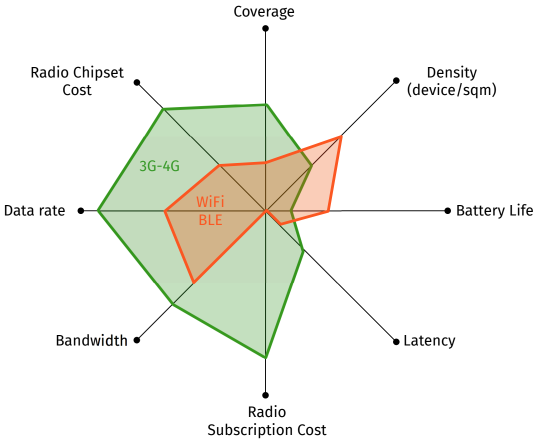

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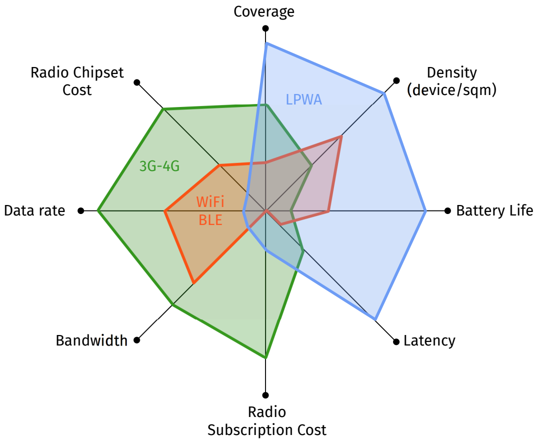
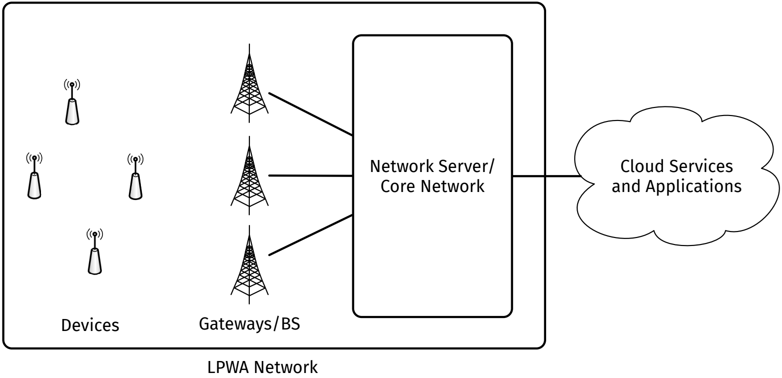


# LPWA Typical Use Cases


Usman Raza *et al.*, Low Power Wide Area Networks: An Overview, IEEE Communications Surveys & Tutorials, Issue 99, 2017

# LPWA Architecture



# Common Characteristics of LPWA Technologies

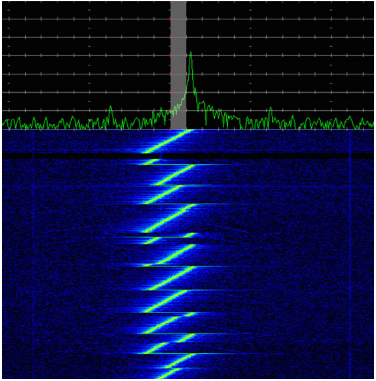
- Optimised radio modulation
- Star topology
- Frame sizes in the order of tens of bytes
- Frames transmitted a few times per day at ultra-low speeds
- Mostly upstream transmission pattern
- Devices spend most of their time in low-energy deep-sleep mode

**LPWA Technologies**

Various technologies are currently candidating for LPWA: LoRaWAN, NB-IoT, Sigfox, Wi-SUN, Ingenu, etc.

# Outline

# What is LoRa?



- Wireless modulation technology
  - Variation of Chirp Spread Spectrum (CSS)
  - Robust to interference, multipath, and fading

# LoRa Characteristics

- Operates in license-free bands all around the world
  - 433, 868 (EU), 915 MHz
- Spectrum regulation for EU (including Lebanon)
  - Transmit power is limited to 14 dBm (25 mW)
  - 1% per sub-band duty-cycle limitation (per hour)
- Receiver sensitivity: -142 dBm
- Link budget: 156 dB
- Uses Spreading Factors to set the modulation rate (SF7 to SF12)

# LoRa Radio Optimization

| Spreading Factor | Bit Rate (kb/s) | Sensitivity (dBm) |
|---|---|---|
| 7 | 5.468 | -123 |
| 8 | 3.125 | -126 |
| 9 | 1.757 | -129 |
| 10 | 0.976 | -132 |
| 11 | 0.537 | -134.5 |
| 12 | 0.293 | -137 |

- Higher spreading factors lead to better sensitivity and larger coverage
- Lower spreading factors lead to higher data rates

# What is LoRaWAN?

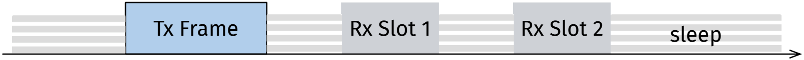
- Communication protocol and architecture that utilizes the LoRa physical layer
- Data rates ranging from 300 bps to 5.5 kbps
  - Two high-speed channels at 11 kbps and 50 kbps (FSK modulation)
  - Eight channels: bandwidth 125 kHz or 250 kHz
  - Support for adaptive data rate (power and spreading factor control)
- Secure bi-directional communication, mobility, and localization
  - Device authentication, message encryption, and frame counter
- Uncoordinated data transmission
  - Devices transmit without any coordination on a randomly chosen channel

## LoRaWAN Access Method

LoRaWAN is an ALOHA-type protocol: transmission by the device is based on its own communication needs with a small variation based on a random time basis.

# LoRaWAN Device Classes

- Class A: Each device's uplink transmission is followed by two short downlink receive windows.

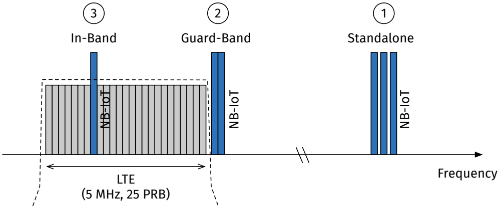



- Class B: In addition to the Class A functionality, Class B devices open extra receive windows at scheduled times.
- Class C: These devices have a continuous open receive widow, except when transmitting.

# Outline

# What is NB-IoT?

- Radio technology standard by 3GPP
- Reutilizes cellular telecommunication bands
    - Three possible operation modes: in-band, guard-band, or standalone
- Reutilizes cellular telecommunication infrastructure
- Shares common characteristics with LTE networks
    - Modulation technique
    - Access method
    - Core network functions



# NB-IoT Characteristics

- LTE FDD frequency bands
- Bandwidth: 180 kHz
  - 12 subcarriers separated by 15 kHz
- Duration: 1 slot of 0.5 ms
- Multiple access: Downlink OFDMA, Uplink SC-FDMA
- Modulation scheme
  - Downlink: QPSK
  - Uplink: Single Tone: $\pi/4$-QPSK, $\pi/2$-BPSK, Multi Tone: QPSK
- Link budget: 164 dB
- Data rate: ~250 kbps in DL and ~250 kbps in UL (multi-tone)

# Leveraging LTE Mechanisms in NB-IoT

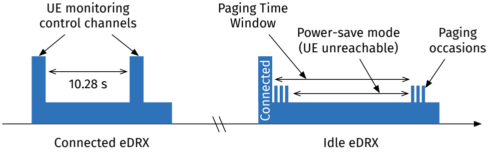
- Communication channels
  - Broadcast channel
  - Shared control channels (uplink and downlink)
- Access method
  - Cell acquisition and registration
  - Random access procedure
  - Scheduling of uplink and downlink transmissions
- Localization and mobility management (idle mode)

**NB-IoT Access Method**

NB-IoT access is performed in two steps: random access then scheduled transmission.

# Optimizing LTE Mechanisms for NB-IoT

- Energy saving
  - DRX (Discontinuous Reception) cycles extended from 2.56 seconds to 10.28 seconds in NB-IoT
  - Paging Time Window of 3 hours allowing longer paging cycles




- Coverage extension
  - Repeating the same transmission several times, available on all channels
  - Achieves extra coverage (up to 20 dB compared to GPRS)

# NB-IoT vs LoRaWAN

| | LoRaWAN | NB-IoT |
|---|---|---|
| Spectrum | Licence-free | Licensed |
| Deployment | Private/Operator | Operator |
| Signalling | Very low | High |
| QoS | Delay insensitive | Delay bounded |
| Data Volume | Low | High |

# Outline

# Comparison of LPWA Technologies

- Evaluation scenario
  - Dynamic device arrival/departure
  - Single and multiple cell deployment
  - Variable demand per node
  - Variable radio conditions
- Performance indicators
  - Network capacity and throughput
  - Collision/interference level
  - Power consumption
  - Transmission delay

**Research Project**

Devise analytical models and simulation tools to assess and compare the performance of LoRaWAN and NB-IoT.

# Radio Resource Management in LPWA

- Adaptation of the radio propagation models
  - Antenna height
  - (Sub)Urban vs agriculture land
- Interference mitigation
  - Frequency allocation
- Scheduling for NB-IoT
  - Max-SNR vs energy efficient scheduling
- Support for quality of service
  - Delay bounded transmission
- Maximisation of the energy efficiency
  - Power control
  - Rate adaptation

# Naming and Addressing in LPWA

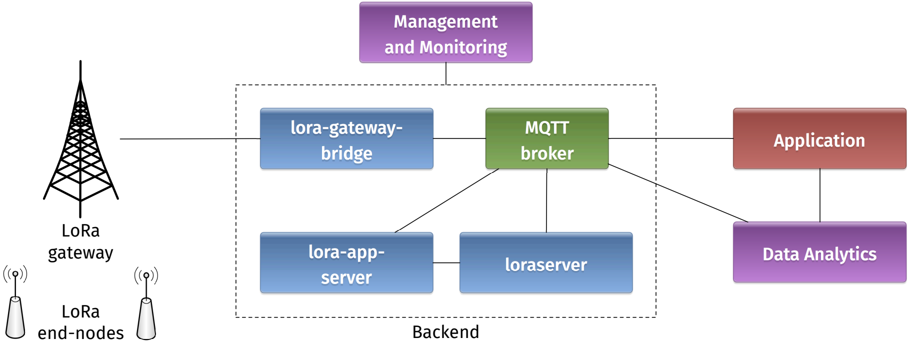
- IoT devices are connected to the Internet
  - Implement Internet protocols
  - Require addressing, naming, and routing functions
- Current work by the IETF lpwan working group
  - Providing IPv6 connectivity to the devices
  - Proposing technologies to secure the operations and manage the devices and their gateways
- Proposed standard expected in July 2017
  - Compression and fragmentation of a CoAP/UDP/IPv6 packet over LPWA networks

# Outline

# LISA: Long-range IoT for Smart Agriculture

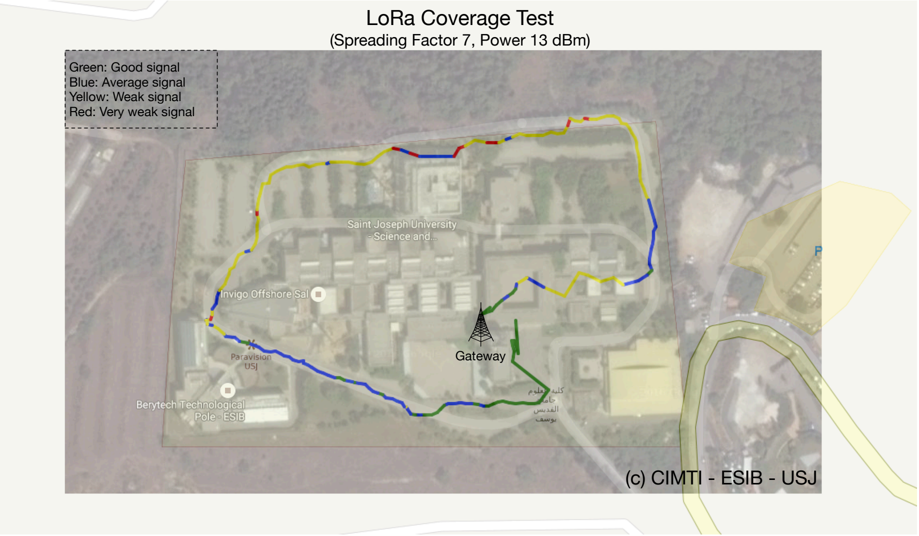
- Project launched at ESIB-USJ in Sept. 2016
- Scientific objectives cover networking and agriculture topics
  - Deploy and test LoRa for agriculture
  - Automate measurement process of microclimates under vines
  - Test and assess different pruning lengths
- LISA will deploy a LoRa based IoT network in Bekaa in 2018

# First LoRaWAN Pilot in Lebanon at ESIB

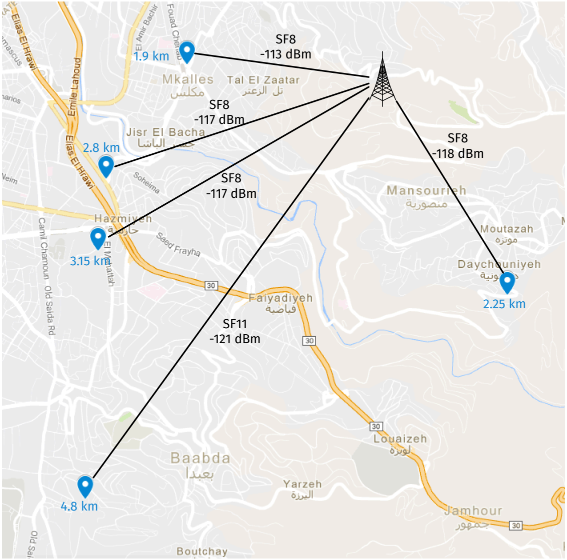



- Lab prototype: Arduino + Dragino (HopeRF) LoRa shield, Raspberry Pi based DIY gateway
- Deployment: Sodaq autonomo with (Microchip) LoRabee devices, Kerlink Wirnet gateway

# LoRa Campus Coverage



# LoRa Drive Test



# IoT Cool Services

- View the live dashboard
  - https://emoncms.org/dashboard/view&id=42658
- Play with MQTT and receive LoRa messages
  - Install a MQTT app (MQTT Dashboard on Android)
  - Connect to 212.98.137.194 port 1883
  - Subscribe to topic #
- Connect with our plants
  - Twitter: @allo_laplante
  - Hangout: rt.laplante@gmail.com and type `/bot eguz`

# LoRa Modulation Basics

## LoRa Modulation

Wireless modulation technology that uses CSS in combination with Pulse-Position Modulation (PPM)

- Chip rate: $R_c = B$
  Symbol rate: $R_s = 1/T$
  $\Rightarrow$ Processing gain $g_p = R_c/R_s = BT$
- Important aspect of LoRa related to PPM: the number of possible bits that can be encoded in a symbol is variable $= log_2(g_p)$

$$R_b = \frac{log_2(g_p)}{T} = log_2(g_p) \cdot R_s = log_2(g_p) \cdot \frac{R_c}{g_p} = log_2(g_p) \cdot \frac{B}{g_p}$$

- LoRa defines the spreading factor $SF$ as equal to $log_2(g_p)$

$$\Rightarrow R_b = SF \cdot \frac{B}{2^{SF}}$$

# LoRa Bit-Rate

- LoRa modulation includes a variable error correction scheme that improves the robustness of the transmitted signal at the expense of redundancy

$$\Rightarrow R_b = SF \cdot \frac{B}{2^{SF}} \cdot CR$$

where $CR$ represents the coding rate

- $R_b$ can also be written as follows:

$$\Rightarrow R_b = SF \cdot \frac{B}{2^{SF}} \cdot \frac{4}{4 + CR}$$

where $1 \leq CR \leq 4$ and $7 \leq SF \leq 12$