Low Power Wide Area Networks for the Internet of Things

Framework, Performance Evaluation, and Challenges

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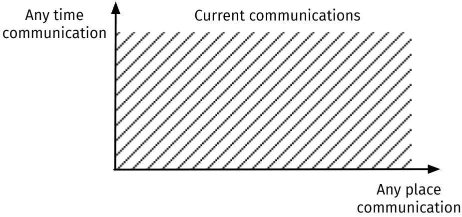
SPECTS 2018, Bordeaux, France

Tutorial Outcomes

- How do LPWAN complement traditional cellular and short-range wireless technologies?
- What are the fundamental mechanisms that enable to meet the LPWAN requirements?
- What are the major design choices made in the LoRaWAN specification?
- How do we evaluate the performance of a LoRaWAN deployment in terms of coverage and capacity?

Outline

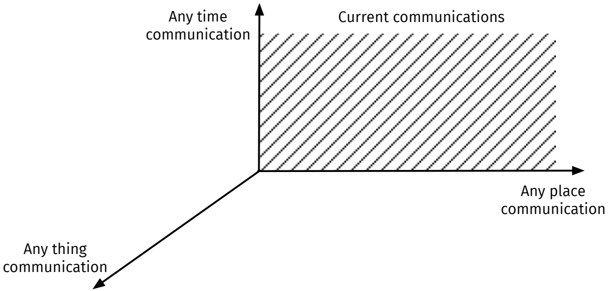
A New Dimension in Communications



Source: The Internet of Things, ITU Internet Reports, 2005

- Current communications brought the ABC (Always Best Connected) paradigm
- The Internet of Things (IoT) explores a new dimension in communications

A New Dimension in Communications



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IoT Scenarios

Internet of Things

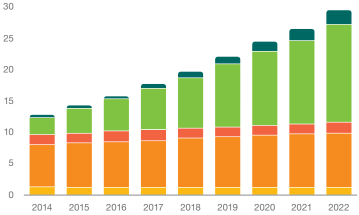
The Internet of Things (IoT) generally refers to scenarios where network connectivity and computing capability extends to devices, sensors, and everyday items (ISOC IoT Overview, 2015).

Scenario	Example
Human	Wearables for health monitoring
Home	Heating, security automation
Retail	Self-checkout, inventory optimization
Vehicles	Condition-based maintenance
Cities	Traffic control, environmental monitoring

Evolution of IoT Devices

- The largest growth is expected for devices connected to a wide-area network

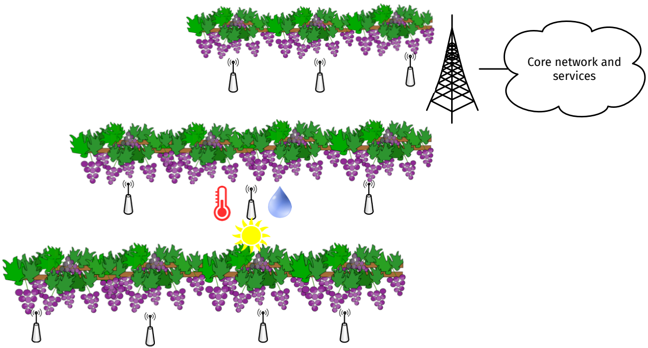
Connected devices (billions)



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	15.5	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	

Source: Ericsson mobility report, 2017

The Case of IoT for Smart Agriculture



- Periodic sensing of microclimates in vineyards

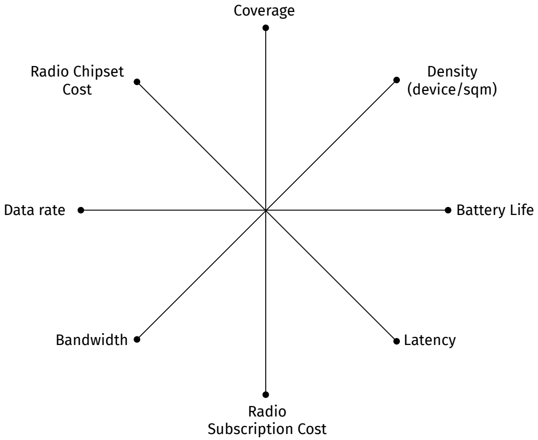
Constraints on the Device and Network Layers

- 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?

LPWAN Sweet Spot



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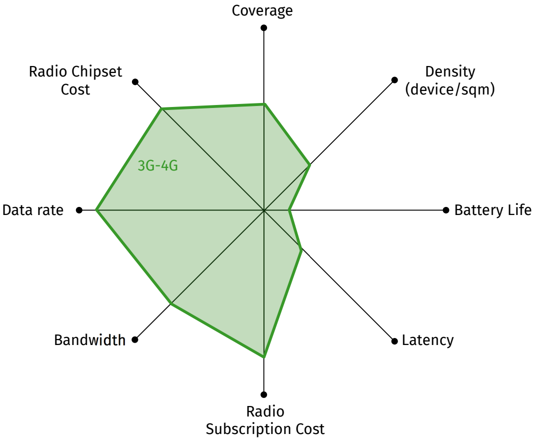
LPWAN Sweet Spot



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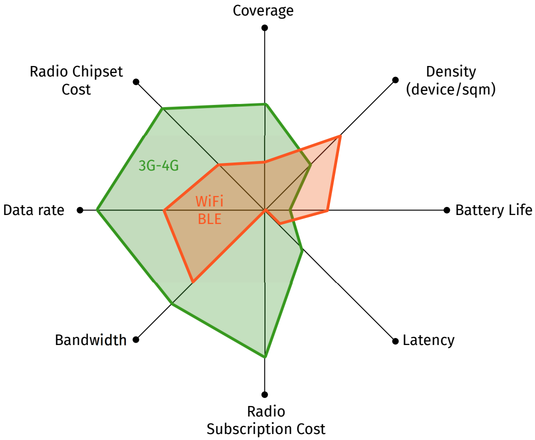

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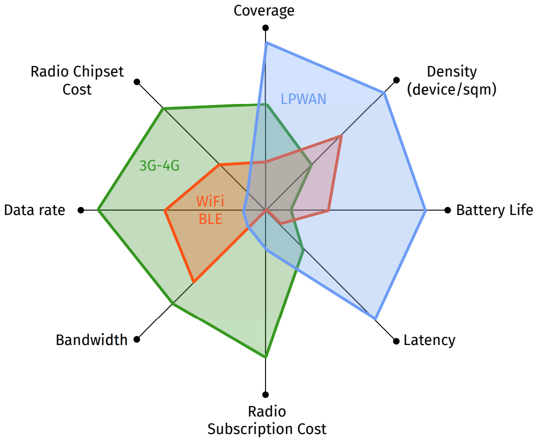

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LPWAN Scenarios

Low Power Wide Area Networks

Low power refers to the ability of an IoT device to function for many years on a single battery charge, while at the same time it is able to communicate from locations where shadowing and path loss would limit the usefulness of more traditional cellular technologies (3GPP Low Power Wide Area Technologies, GSMA White Paper, 2016)

- Typical scenarios for LPWAN (Usman Raza *et al.*, Low Power Wide Area Networks: An Overview, IEEE Communications Surveys & Tutorials, 2017)
  - Smart grid
  - Industrial asset monitoring
  - Critical infrastructure monitoring
  - Agriculture

LPWAN Requirements

Indicator	Requirement
Power consumption	Devices operate for 10 years on a single charge
Device unit cost	Below $5 per module
Dependability	Completely unattended and resilient operation
Coverage	Improved outdoor and indoor penetration coverage
Security	Secure connectivity and strong authentication
Data transfer	Supports small, intermittent blocks of data
Design complexity	Simplified network topology and deployment
Network scalability	Support of high density of devices

LPWAN Technologies

Various technologies are currently being designed to meet the LPWAN requirements: LoRaWAN, NB-IoT, Sigfox, Wi-SUN, Ingenu, etc.

Outline

From LoRa to LoRaWAN

- LoRa
  - Modulation technique for LPWAN
- LoRaWAN
  - Uses LoRa modulation on physical layer
  - Proposes a MAC layer for access control
  - Specified by LoRa Alliance

LoRaWAN Timeline

- Cycleo first introduced LoRa in 2009
  - M2M communications
  - Large coverage
- Semtech acquired Cycleo in 2012
  - Patents filed in 2014
- LoRa Alliance initiated in 2014
  - Actility, Cisco, Bouygues, IBM, Orange, SK Telecom, KPN, ZTE, Semtech, La Poste, SoftBank, Swisscom, etc.
  - LoRaWAN 1.1 specification in 2018

LoRaWAN Radio Interface

Wireless Coverage and Maximum Coupling Loss

- Coverage targets are usually specified in terms of MCL or Maximum Coupling Loss
- MCL defines the maximum loss the system can cope with between a transmitter and a receiver:

$$MCL\,\text{(dB)} = P_{Tx} - \underbrace{(SNR_{threshold} - 174 + 10\log_{10}(B) + NF)}_{\text{Receiver sensitivity}}$$

  - P_{Tx} is the transmit power
  - $SNR_{threshold}$ is the required signal to noise ratio for a given bit error rate
  - B is the signal bandwidth
  - NF is the noise figure caused by RF components

How to Improve Coverage?

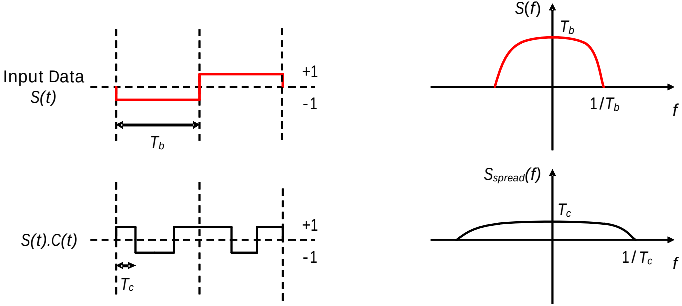
$$MCL\,\text{(dB)} = P_{Tx} - \underbrace{(SNR_{threshold} - 174 + 10\log_{10}(B) + NF)}_{\text{Receiver sensitivity}}$$

- Improving coverage can be achieved by:
  - Increasing P_{Tx}, or lowering NF, leads to higher device complexity and cost $\Rightarrow$ inadequate solutions
  - Reducing B leads to lower network capacity $\Rightarrow$ inadequate solution
  - Reducing $SNR_{threshold}$ through optimized radio modulation that uses spread spectrum $\Rightarrow$ LoRa

Chirp Spread Spectrum in LoRaWAN

What is Spread Spectrum?

- Spread-spectrum techniques deliberately spread a signal in the frequency domain, resulting in a signal with a wider bandwidth



Why Spread Spectrum?

- Spread spectrum compensates for the SNR degradation

$$SNR_{threshold} = \left(\frac{E_b}{N_0}\right)_{threshold} - G_p$$

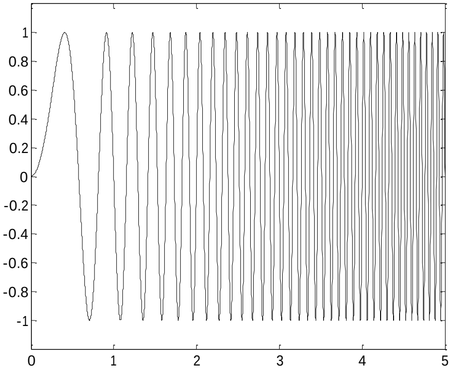
  - E_b is the energy per bit
  - N_0 is the noise power spectral density
  - G_p is the processing gain given by:

$$G_p = 10\log_{10}(T_b B)$$

- The higher G_p is
  - the lower $SNR_{threshold}$ is $\Rightarrow$ larger radio coverage
  - the lower R_b is

Linear Chirp

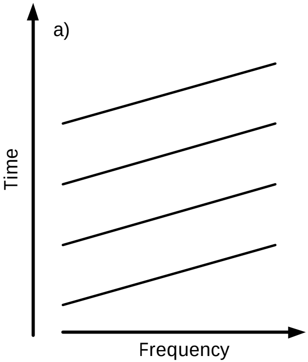
- A linear chirp is a sinusoidal signal whose frequency linearly increases (up-$chirp$) or decreases ($down$-$chirp$) over time



A sinusoidal linear up-chirp in the time domain

Spectrograms of Linear Chirps

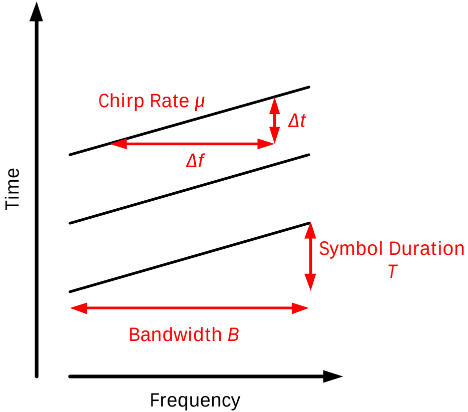
- $\mu > 0 \Rightarrow up\text{-}chirps$, $\mu < 0 \Rightarrow down\text{-}chirps$



Spectrograms of linear $up\text{-}chirp$ (a) and $down\text{-}chirp$ (b)

Bandwidth Spreading

- The bandwidth B is defined as the range of the instantaneous frequency: $B = |\mu|T$
- The processing gain is given by the time-bandwidth product TB



What is LoRa?

Definition of LoRa

LoRa is a wireless modulation technique that uses Chirp Spread Spectrum (CSS) in combination with Pulse-Position Modulation (PPM)

- Processing gain given by $g_p = BT$
- Variable number of bits encoded in a symbol

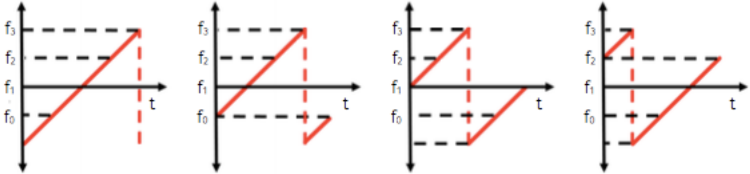
$$R_b = \frac{\log_2(g_p)}{T} = \log_2(g_p) \cdot \frac{B}{g_p}$$

- Spreading factor SF given by $\log_2(g_p)$

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

LoRa Symbols

- $\log_2(g_p)$ bits are encoded by transmitting a single $chirp$ in g_p possible cyclic time shifts
- Example: $g_p = 4 \Rightarrow$ 2 bits/symbol



LoRa Bit-Rate

- LoRa includes a variable error correction scheme based on Hamming code
  - Improve the robustness of the transmitted signal at the expense of redundancy
- Given a coding rate CR, the bit-rate is given by:

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

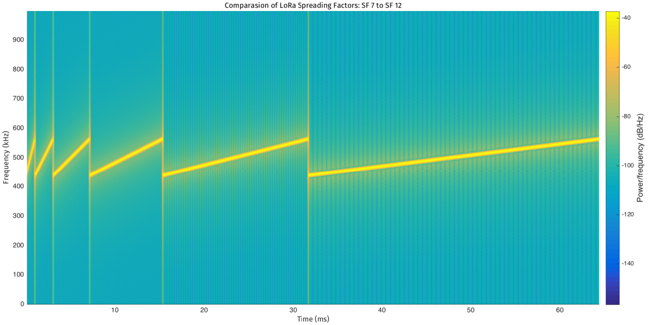
- R_b can also be written as:

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

with $1 \leq CR \leq 4$, and $6 \leq SF \leq 12$

LoRa Spreading Factors

- LoRa uses spreading factors from 6 to 12 (6 is not used in LoRaWAN)



LoRa Radio Performance

Spreading Factor	Bit Rate[1] (kb/s)	Sensitivity (dBm)
6[2]	9.375	-118
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

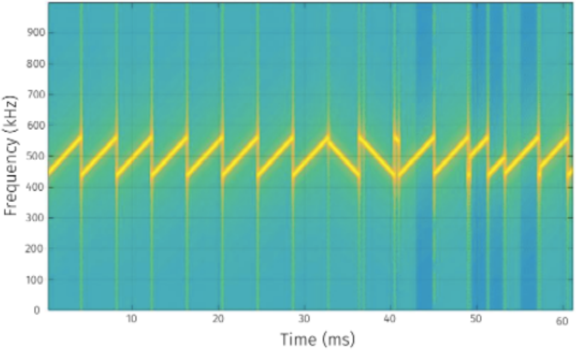
- Higher spreading factors lead to lower sensitivity and larger coverage
- Lower spreading factors lead to higher data rates

[1] CR = 1 and B = 125 kHz

[2] Spreading factor 6 is not used in LoRaWAN

LoRa Physical Layer

- LoRa transmission consists of:
  - 8 preamble (*up-chirp*) symbols
  - 2 synchronization (*down-chirp*) symbols
  - 5 modulated symbols (payload)



LoRaWAN Data Rates

Data rate	Configuration	Indicative Physical Bit Rate
0	LoRa SF12 / 125 kHz	250
1	LoRa SF11 / 125 kHz	440
2	LoRa SF10 / 125 kHz	980
3	LoRa SF9 / 125 kHz	1760
4	LoRa SF8 / 125 kHz	3125
5	LoRa SF7 / 125 kHz	5470
6	LoRa SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8...14	RFU	
15	Defined in LoRaWAN	

LoRaWAN Channels

- Operates in license-free bands all around the world
  - 433, 868 (EU), 915 MHz
- EU 863-870MHz ISM Band
  - Default radiated transmit output power by devices: 14 dBm
  - Minimum set of three channels, maximum of 16 channels

Modulation	Bw [kHz]	Freq [MHz]	Data Rate	Nb Channels	Duty cycle
LoRa	125	868.10 868.30 868.50	DR0 to DR5 0.3-5 kbps	3	<1%

Duty Cycle Limitation

- The LoRaWAN enforces a per sub-band duty-cycle limitation (ETSI regulation)
  - Each time a frame is transmitted in a given sub-band, the time of emission and the on-air duration of the frame are recorded for this sub-band
  - The same sub-band cannot be used again during the next T_{off} seconds where:

$$T_{off} = \frac{TimeOnAir}{DutyCyleSubband} - TimeOnAir$$

  - During the unavailable time of a given sub-band, the device may still be able to transmit on another sub-band
  - The device adapts its channel hopping sequence according to the sub-band availability

Example

A device just transmitted a 0.5 s long frame on one default channel. This channel is in a sub-band allowing 1% duty-cycle. Therefore this whole sub-band (868 – 868.6) will be unavailable for 49.5 s

How LoRaWAN Supports Massive Number of Low-Rate Devices

- Trading off data rate for coverage
  - Higher spreading factors lead to lower sensitivity and larger coverage
  - Lower spreading factors lead to higher data rates
- How to increase network capacity?
  - LoRaWAN uses multiple orthogonal spreading factors simultaneously on the same channel

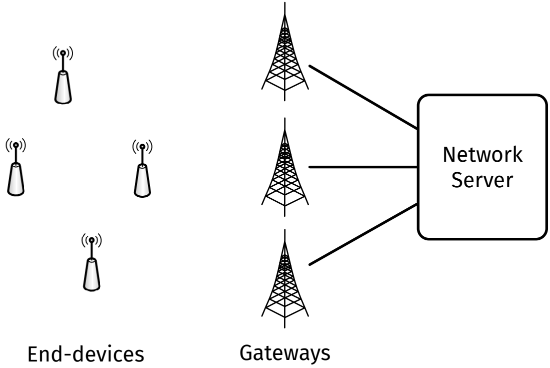
How LoRa Enables Low Device Complexity and Cost?

- Reduce baseband processing complexity through:
  - limiting message size: maximum application payload size between 51 and 222 bytes, depending on the spreading factor
  - using simple channel codes: Hamming code
  - simple modulation: LoRa
  - supporting only half-duplex operation: no simultaneous transmission and reception
- Reduce RF processing complexity and cost through:
  - using one transmit-and-receive antenna
  - not using a duplexer (since only half-duplex operation is supported)
  - on-chip integrating power amplifier $\Rightarrow$ single-chip modem implementation (since transmit power is limited)

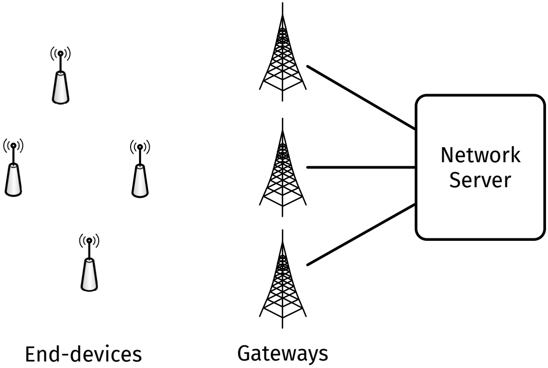
LoRaWAN Physical Architecture

LoRaWAN General Architecture

- LoRaWAN network architecture is typically laid out in a star-of-stars topology
  - End-devices
  - Gateways
  - Network server
- LoRaWAN has a simple network architecture and operates in license-free bands $\Rightarrow$ low-cost deployment

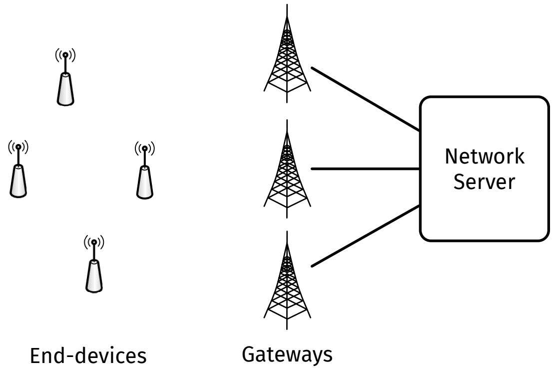


End-Devices



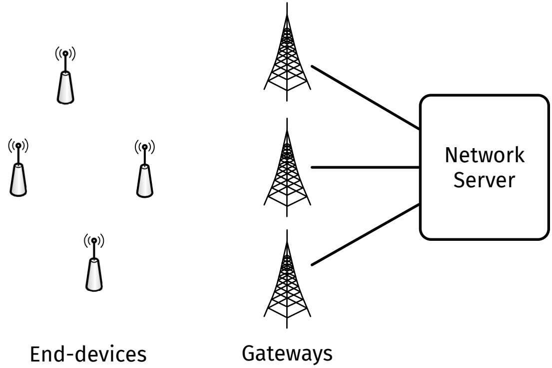
- End-devices are also called motes or devices
  - Communicate to one or more gateways via a wireless interface using single hop LoRa or FSK

Gateways



- Gateways are also called concentrators or base stations
  - Forward Frames between devices and network server
  - Connected to the network server via IP interfaces

Network Server



- Network server is a central server located at the backend
  - Provides mobility, frame control, and security functions
  - Adapts data transmission rates

LoRaWAN Protocol Architecture

How LoRaWAN Saves Power?

- Most of the IoT applications require infrequent transmission of small data volumes
- Idle devices may enter a deep sleep mode and shut down their transceiver
- Devices wake up from deep sleep mode to:
  - transmit data
  - open receive windows
- Battery lifetime is increased through:
  - optimizing device reachability
  - reducing signaling messages when a device needs to transmit data

Uplink transmission

- Uncoordinated data transmission
  - Devices transmit without any coordination on a randomly chosen channel
  - Regulated maximum transmit duty cycle
  - Regulated maximum transmit duration (or dwell time)
- Collisions occur in LoRaWAN
  - Simultaneous transmissions on the same channel and spreading factor collide
- Two types of messages: unconfirmed and confirmed

LoRaWAN Access Method

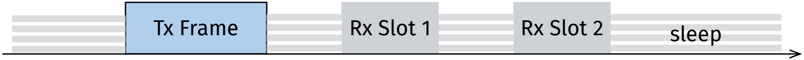
LoRaWAN is an ALOHA-type protocol: transmission by the device is based on its own communication needs with a small variation based on a random time basis

Device Classes

- Class A
  - Each uplink transmission is followed by two short downlink receive windows
  - Adapted for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission
- Class B
  - In addition to class A, receive windows are opened at scheduled times
  - A time synchronized Beacon is sent by the gateway
- Class C
  - Nearly always open receive windows (unless transmitting)

Receive Windows for Class A Devices

- First receive window
  - Same channel (and data rate) as the uplink
- Second receive window
  - Predefined channel and data rate, and possibility to modify it by MAC commands



Adaptive Data Rate

- Objectives
  - Increase battery life
  - Maximize network capacity
- Data rate validation
  - A device periodically sets the ADR acknowledgment bit and waits for an acknowledgment from the network
  - If an ACK is not received, the device switches to the next lower data rate that provides a longer radio range

Outline

Link Budget Analysis

Link Budget

- The link budget is a measure of all the gains and losses from the transmitter, through the propagation channel, to the target receiver
- The link budget of a network wireless link can be expressed as:

$$P_{Rx} = P_{Tx} + G_{System} - L_{System} - L_{Channel} - M$$

where:

P_{Rx} = the expected received power
P_{Tx} = the transmitted power
G_{System} = system gains such as antenna gains
L_{System} = system losses such as feed-line losses
$L_{Channel}$ = path loss
M = additional margins

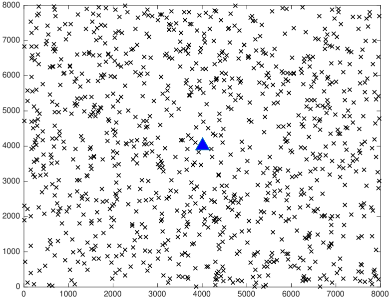
Additional Margins

- Fading margin
- Interference margin
- Penetration margin:
  - indoor penetration loss (first wall): ~ 18 dB (in dense urban environment), ~ 15 dB (in urban environment), and $\sim 10 - 12$ dB (in rural environment)
  - deep indoor penetration loss (second wall): +3 dB
- Protection margin

Coverage of LoRaWAN

Evaluation Scenario

- Area
  - Surface: square of 8 Km $\times$ 8 Km
  - Number of end-devices: 1000
  - Distribution of end-devices: uniform
  - Single gateway
  - Environment type: urban
- Radio link
  - Bandwidth: 125 kHz
  - Transmit power: 14 dBm
  - Gateway height: 30 m
  - End-device height: 1.5 m
  - Antenna gains: 6 dBi
  - Noise floor: -153 dBm
  - Pathloss: Okumura-Hata
  - Shadow fading: lognormal $\mathcal{N}(0, 8)$



Pathloss Model

- Using the Okumura-Hata urban model, the pathloss between device i and the gateway is proportional to the logarithm of the distance $d(i,g)$ in Km:

$$L_{Channel}(i) = A + B\log_{10}(d(i,g))$$

- The two parameters A and B depend on the antenna heights ($h_b = 30$ m for the gateway and $h_d = 1.5$ m for the end-device) and the central frequency $f_c = 868$ MHz

$$A = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - 3.2(\log 10(11.75h_d))^2 + 4.$$

$$B = 44.9 - 6.55\log_{10}(h_b)$$

Link Budget

- We consider the following parameters:
  - Transmit power: $P_{Tx} = 14$ dBm
  - Antenna gain: $G_{System} = 6$ dBi
  - Fading and protection margin: $M = 10$ dB
  - Noise floor: $N = -153$ dBm
- We can now compute the received power $P_{RX}(i)$ and SNR(i) at the gateway for end-device i:

$$P_{Rx}(i) = P_{Tx} + G_{System} - L_{Channel}(i) - M$$

$$\text{SNR}(i) = P_{Rx}(i) - N$$

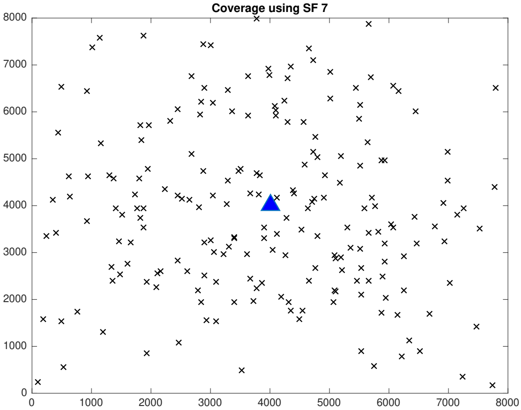
Spreading Factor Selection

- The spreading factor for each end-device is selected using the following matching table (Source: SX1276/77/78/79 Semtech datasheet):

SNR Interval (dB)	Spreading Factor
[-7.5, $+\infty$[	7
[-10, -7.5[	8
[-12.5, -10[	9
[-15, -12.5[	10
[-17.5, -15[	11
[-20, -17.5[	12

- Note that for SNR values lower that -20 dB, the end-device is considered out of coverage of the gateway

Coverage Study



Spreading Factor	7	8	9	10	11	12
Cumulative coverage (%)	40.50	51.60	61.60	70.40	77.70	86.10

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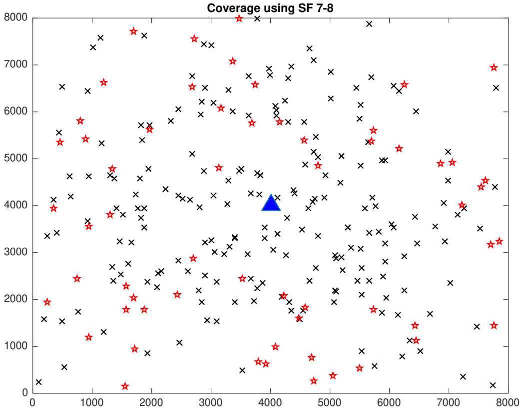

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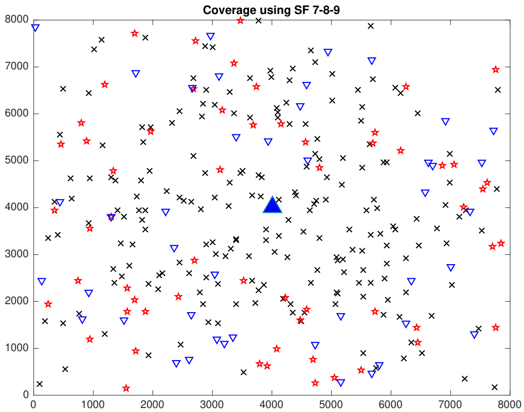

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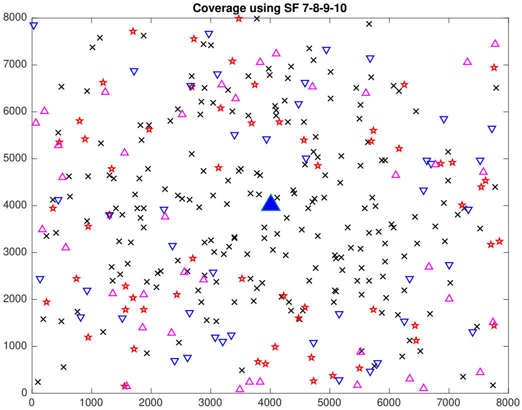

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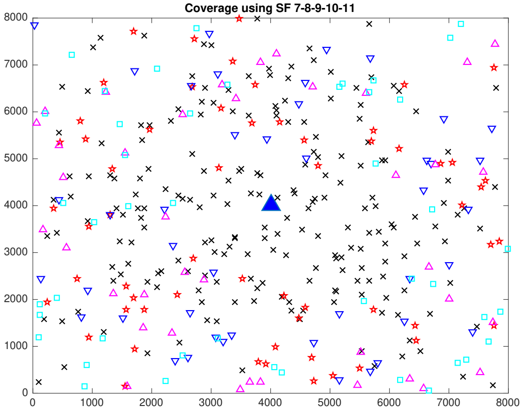

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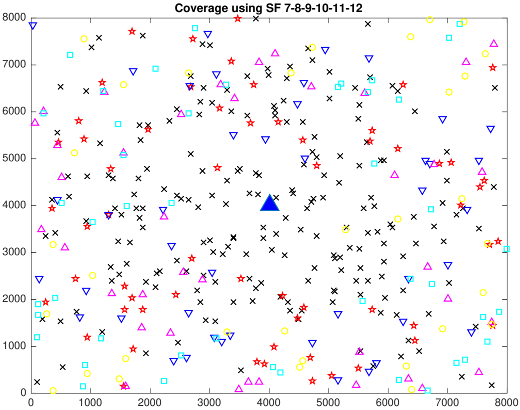

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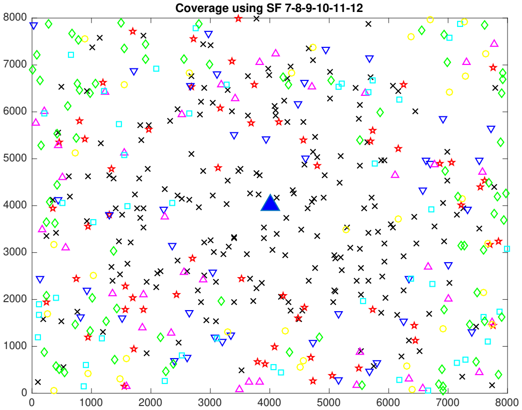

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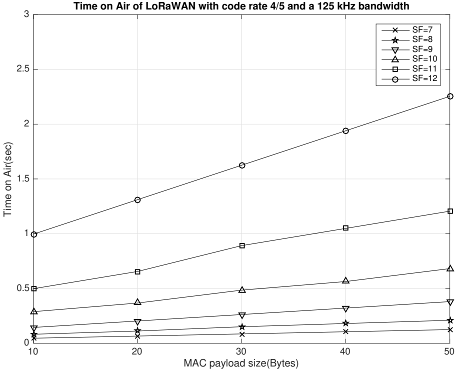
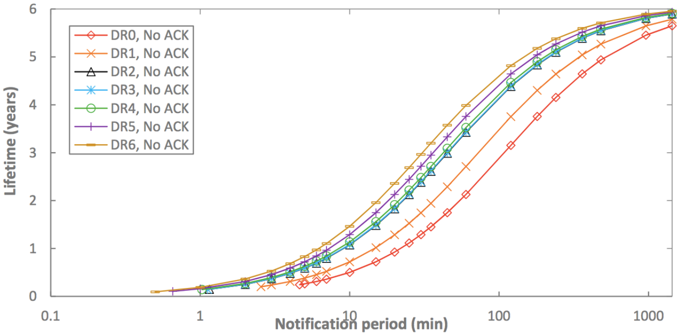
Spreading Factor and Time on Air

- The Time on Air is defined as the time required to transmit a packet in a sub-band
- The selection of the spreading factor impacts the Time on Air and consequently determines the duty cycle limitation



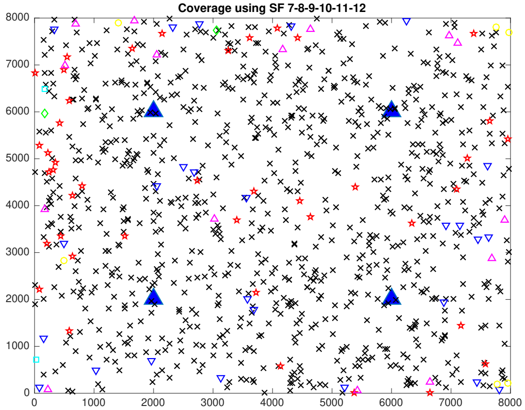
Spreading Factor and Energy Consumption



Source: Lluís Casals *et al.*, Modeling the Energy Performance of LoRaWAN, Sensors, 2017

- DR0 to DR5 correspond to spreading factors 12 to 7 with a bandwidth of 125 kHz. DR6 correspond to spreading factor 7 and a bandwidth of 250 kHz
- For an end-device sending packets every 100 minutes, changing the spreading factor from 12 to 7 increases its lifetime by almost 1.5 years

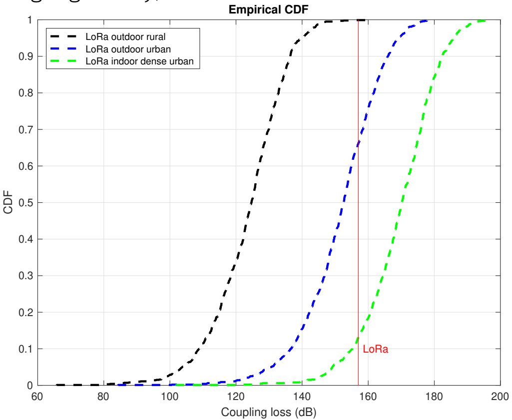
Enhancing the Coverage with Multiple Gateways



Spreading Factor	7	8	9	10	11	12
Cumulative coverage (%)	88.70	94.50	97.60	99.20	99.60	100.00

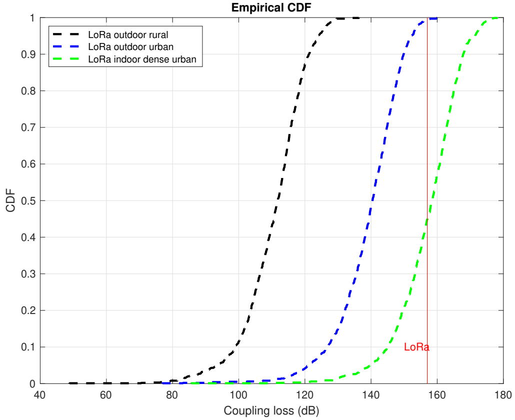
Coverage in Different Environments

- Coverage outage $\Rightarrow$ coupling loss $> MCL$ (LoRaWAN: 157 dB)
- In indoor dense urban environments, the outage probability of LoRaWAN is 87% (with a single gateway)



Densification and Coverage Limitation

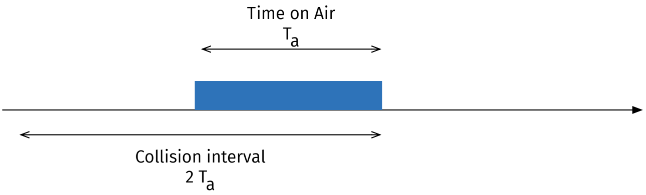
- Network densification decreases the outage probability of LoRaWAN to 55%
- LoRaWAN has coverage limitations especially in indoor dense urban



Capacity of LoRaWAN

Pure ALOHA Model

- The start times of the packets in an ALOHA channel is modeled as a Poisson point process with parameter λ packets/second



- If each packet in the channel lasts T_a seconds, the normalized channel traffic can be defined as

$$G = \lambda T_a$$

- The normalized throughput of the ALOHA random access channel is given by

$$S = G \exp(-2G)$$

ALOHA Model for LoRaWAN

- We consider the case where only *one* spreading factor and *one* sub-channel are available
- The general case of multiple sub-channels and spreading factors can be easily inferred
  - Multiple spreading factors are orthogonal
  - Packets are uniformly transmitted on available sub-channels
- The time to transmit a packet of l bytes (size of MAC payload) on spreading factor s is denoted $T_a(l, s)$
- Given a duty cycle limitation of $d = 1\%$, the packet generation rate for each end-device operating on spreading factor s must verify:

$$\lambda(s) \leq \frac{d}{T_a(l, s)}$$

- The normalized channel traffic for N end-devices is obtained as follows:

$$G = N.\lambda(s).T_a(s)$$

Capacity Formulas for LoRaWAN

- We consider a LoRaWAN network with N end-devices and one gateway
  - One spreading factor s and one sub-channel are available
  - Transmit attempts are done according to a Poisson distribution
  - All end-devices have the same packet generation rate $\lambda(s)$
  - All packets have the same length of l bytes
- The normalized throughput of the LoRaWAN network is given by:

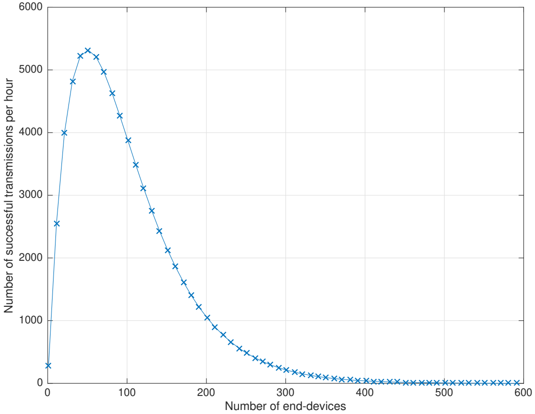
$$S = G\exp(-2G) = N\lambda(s)T_a(l,s)\exp(-2N\lambda(s)T_a(l,s))$$

- The total number of transmitted packets per second that are successfully received by the gateway (referred to as successful transmissions in the following) is obtained by:

$$\frac{1}{T_a(l,s)} \times S$$

Successful Transmissions per Hour

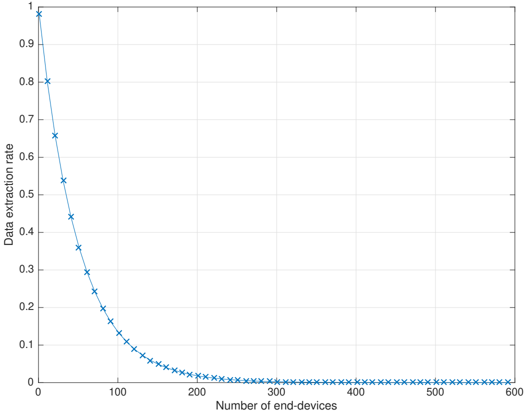
- The number of successful transmissions per hour decreases for more than 50 end-devices



l=50 bytes, SF=7, $\lambda(s) = \frac{d}{T_a(l,s)}$

Data Extraction Rate

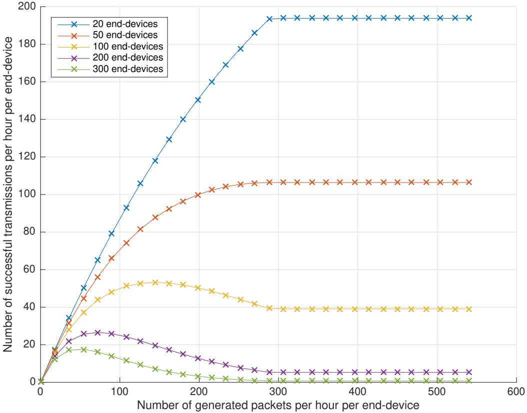
- For 100 end-devices the percentage of successful transmissions is equal to 14% (the average number of successfully transmitted packets per end-device equals 40 per hour, out of 289 generated packets)



l=50 bytes, SF=7, $\lambda(s) = \frac{d}{T_a(l,s)}$

Packet Generation Rate

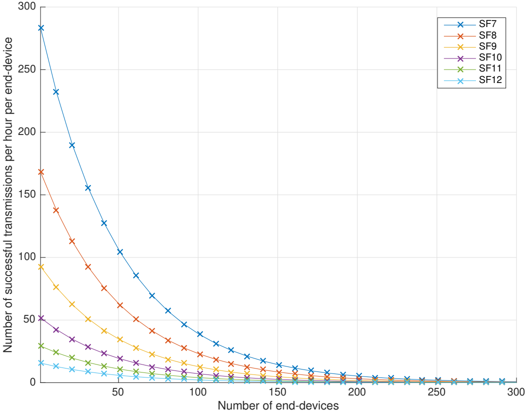
- For small number of end-devices, the throughput is limited by the duty cycle
- For large number of end-devices, the throughput is limited by collisions



l=50 bytes, SF=7

Spreading Factors and Successful Transmissions

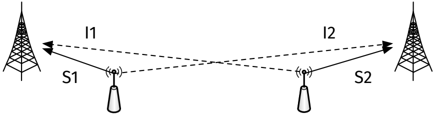
- For 50 end-devices, the average number of successful transmissions per end-device per hour increases from 6 to 106 when SF decreases from 12 to 7



l=50 bytes, $\lambda(s) = \frac{d}{T_a(l,s)}$

Collisions and Capture Effect

- It is assumed by default that all transmitted signals that collide will fail to be received
- In practice, the strongest received signal may be successfully received despite the presence of interfering signals $\Rightarrow$ capture effect
- The capture effect depends on:
  - The receiver sensitivity
  - The signal to noise plus interference ratio SINR
- The presence of multiple receivers favors the capture effect



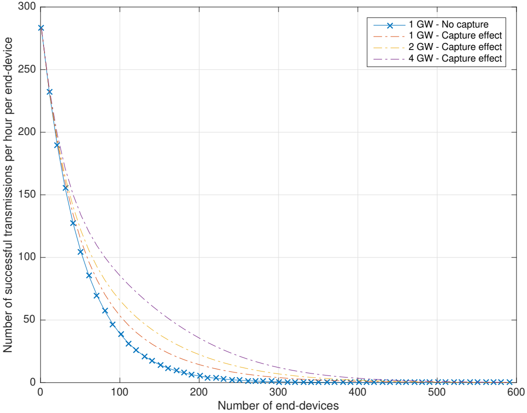
Applying the Capture Effect for LoRaWAN

- We consider a LoRaWAN network with N end-devices and r gateways
- We take $G = N\lambda(s)T_a(l,s)$, where $\lambda(s)$ is the packet generation rate of each end-device, and $T_a(l,s)$ the time to transmit a packet of l bytes
- We assume that a packet is successfully received by one gateway if the corresponding received signal power is higher than the maximum interferer
  - We consider an additional margin of Δ dB (Δ equals 3 dB or 6 dB in practice)
- The probability of successful transmission of one packet when n collisions occur is denoted by $P_{cap}(n,\Delta)$
- The normalized throughput of the LoRaWAN network is given by:

$$S = G\exp(-2G)(1 + \sum_{n=2}^{N} \frac{(2G)^n}{n!}(1-(1-P_{cap}(n,\Delta))^r))$$

Successful Transmissions with Capture Effect

- For 100 end-devices, the number of successful transmissions per hour per end-device increases from 38 to 52 when considering the capture effect with one gateway, and reaches 84 with 4 gateways



l=50 bytes, SF=7, $\lambda(s) = \frac{d}{T_a(l,s)}$, $\Delta = 6$ dB

Conclusions (1/4)

- How do LPWAN complement traditional cellular and short-range wireless technologies?
  - LPWAN devices function for many years on a single battery charge
  - LPWAN devices communicate from locations where shadowing and path loss would limit the usefulness of more traditional cellular technologies
- What are the fundamental mechanisms that enable to meet the LPWAN requirements?
  - Short messages, low complexity codes and modulations
  - Low receiver sensitivity
  - Optimized reachability and low signaling
  - Multiple transmissions on the same channel
  - Simplified architecture

Conclusions (2/4)

- What are the major design choices made in the LoRaWAN and NB-IoT specifications?

	LoRaWAN
Reliability	CSS-based LoRa
Power consumption	Short receive windows
Capacity	Multiple SFs
Deployment	Simple architecture

Conclusions (3/4)

- How do we evaluate the performance of a LoRaWAN deployment in terms of coverage and capacity?
  - Combination of simulation, mathematical modeling and measurement campaigns
  - Performance evaluations should take into account collisions and duty cycle in LoRaWAN

Global performance

- LoRaWAN shows coverage limitations especially in indoor dense urban environments
- Collisions hinder the performance of LoRaWAN in heavy loaded networks

Conclusions (4/4)

- What are the recent research directions for radio resource management in LoRaWAN?
  - Adaptation of the radio propagation models
  - Interference mitigation
  - Support for quality of service such as delay bounded transmission
  - Maximization of the energy efficiency
  - Providing IPv6 connectivity to the device (IETF lpwan working group)

Feedback and Tutorial Material

- We made the tutorial sources available under Creative Common license CC BY-NC-SA 4.0

  https://github.com/samerlahoud/tutorial-lpwan-iot
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