Technical overview LoRaWAN network

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Spring 2021

HELLO!

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Agenda

1- Big concept	2- Communication technologies	3- LoRaWAN Network	4- CSS modulation	5- RF Factor	6- ALOHA	7- LoRaWAN performance
IoT definition	Defination Communication technologies	Protocol stack	Chrip signal	Link budget	Defination ALOHA	Maximum throughput
IoT architecture	Long Range criteria	LoRaWAN architrcture	Spread factor	Receiving sensitivity	Analysis ALOHA	Maximum Number
Technical research challenges	Compare Long Rage technologies	End to End communication	Symbol rate	SNR		
				Maximum daily packets on LoRaWAN		

1

BIG CONCEPT

Let’s start with big concept about "Internet of Thing" and "Long Range Wide Area Network"

Introduction

- The Internet of Things (IoT) is an extension of the Internet in which large numbers of “things”, including sensors, actuators and processors, in addition to human users, are networked and able to provide high resolution data on their environment and exercise a degree of control over it[1].

- The principal advantage of IoT consists of its ability to enable communication between an infinite amount of machines incorporated into a large-scale wireless network[1].

- These automated devices and sensors together produce and transmit information in real-time, which is useless in the case of incorrect or insufficient filtering and data processing[1].

Introduction

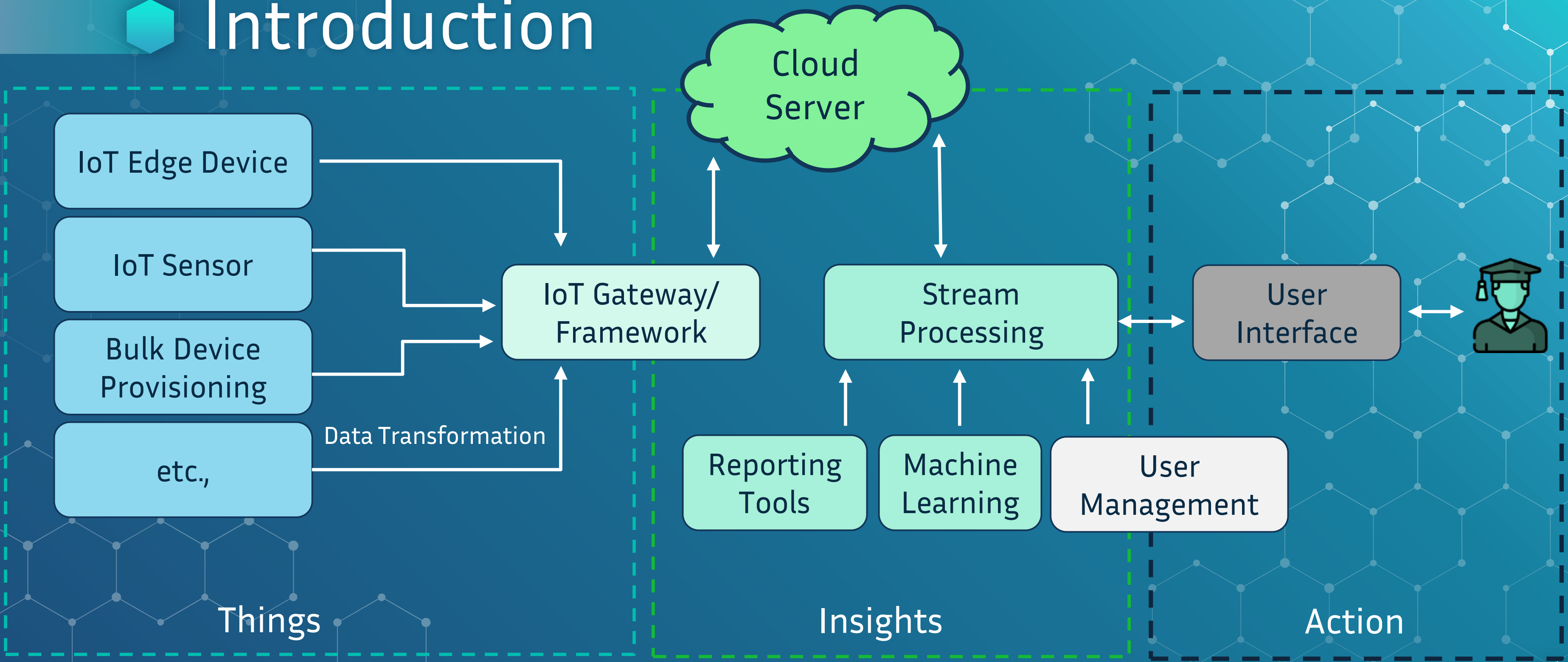


Figure 1: Abstract architectures[2].

Introduction

- Many of these are technical, including interoperability and scalability
- How to invest in the IoT is a challenge for business
- Major social, legal and ethical challenges, including security and privacy
- As the future IoT will be a multi-national, multi-industry, multi-technology infrastructure

[1] Peter J. Ryan 1 and Richard B. Watson, “Research Challenges for the Internet of Things: What Role Can OR Play?”, systems journal, 14 March 2017 .

The main IoT technical research challenges

- **Design**
  - Architecture
  - Interoperability
  - Scalability
  - Mobility
  - Security and Privacy
- **Scientific/Engineering**
  - Energy efficiency/ Power
  - Reliability /Robustness
- **Management/ Operation**
  - Software
  - Development
  - Availability
  - Data management
  - Cloud computing

[1] Peter J. Ryan 1 and Richard B. Watson, "Research Challenges for the Internet of Things: What Role Can OR Play?", systems journal, 14 March 2017 .

2 Communication technologies

Communication and transport technologies

- An essential requirement for implementing a large and cooperating network of devices is the ability to have a flexible, inexpensive and adaptive connectivity layer.

- For these reasons, during the years, several wireless connectivity standards have emerged, ranging from very short-range, low power connections to long-range connectivity solutions based on cellular technologies.

- While short-range protocols can be successfully used for a number of applications (e.g., smart homes, wearable, etc.), for many other applications larger coverage radii become mandatory.

[3] LPWAN white paper, Leverege LLC, 2020 | www.leverege.com

Communication and transport technologies

- We expect that in 2024 more than the 40% of the wide area M2M connections will be LPWAN. That is why several companies are developing different protocols to implement the LPWAN technology.

[3] LPWAN white paper, Leverege LLC, 2020 | www.leverege.com

Communication and transport technologies

- To compare the protocols we keep in mind some of the most important characteristics of the LPWAN and some others important features like:
- **Range**: We all know that the range of any wireless technology can vary based on what is in the way of the signal. A dense urban setting, with walls, buildings, reflections, lots of other people and traffic, means much shorter range than a rural one. And a at, unobstructed rural setting will behave better than a hilly one.
- **Band and spectrum:** As we have explained there are protocols that use the free ISM band and others that use licensed spectrum. We can see also differences into the spectrum use, there are some protocols that use Ultra Narrow Band, some are Narrow Band, and some others like LoRa uses Spread Spectrum (Chirp Spread Spectrum).

[3] LPWAN white paper, Leverege LLC, 2020 | www.leverege.com

Communication and transport technologies

- **Data Rate:** This is another highly variable parameter, it can depend on the distance to the receptor, the obstructions...
- **Over-the-air updates:** This may sound like a random characteristic, but it can be important depending on the application and the deployment of the end-devices. When the number of end-devices is hight or the devices are placed on a remote place, we will get greats advantages of this feature.
- Handover: IoT has an extensive application fields, we will find applications where the end-devices will be static units, in other cases they will be mobile (vehicles in urban or rural areas, for farm implementations for example). So it is natural to wonder whether a protocol that can handle the hand-off a device as it moves between hubs, this matters only to the extent that a "session" of some sort is being maintained.

[3] LPWAN white paper, Leverege LLC, 2020 | www.leverege.com

Communication and transport technologies

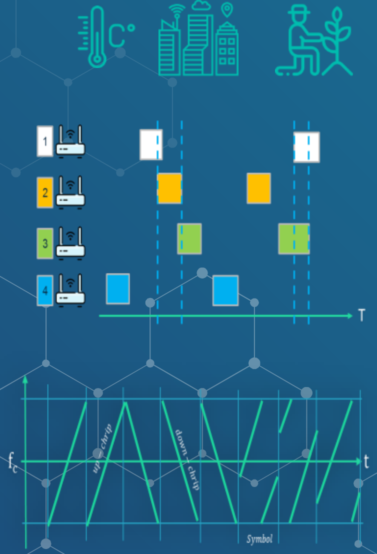
	LoRa	SIGFOX	Telensa	ingenu
Range [km]	3-8 urban 15-20 suburban	3-10 urban 30-50 suburban	Up to 8	4
Band	Sub-GHz	Sub-GHz	Sub-GHz	2.4 GHz
Modulation	Spread Spectrum	Ultra-Narrow Band	Ultra-Narrow Band	Spread Spectrum
Data Rate [kbps]	0.3-22	0.1-0.6	low	20
OTA upgrades	Yes	No	Yes	Yes
Handover	No	Yes	Yes	Yes

Table 1: A Comparison of LPWAN Technologies [3].

3 LoRaWAN Network

LoRaWAN network

- The LoRaWAN network is formed by two core components: LoRa and LoRaWAN, each of which refers to a layer in the protocol stack. LoRa is a physical layer modulation developed by Semtech. LoRaWAN is implemented on top of the LoRa and includes data link and network layers [4].



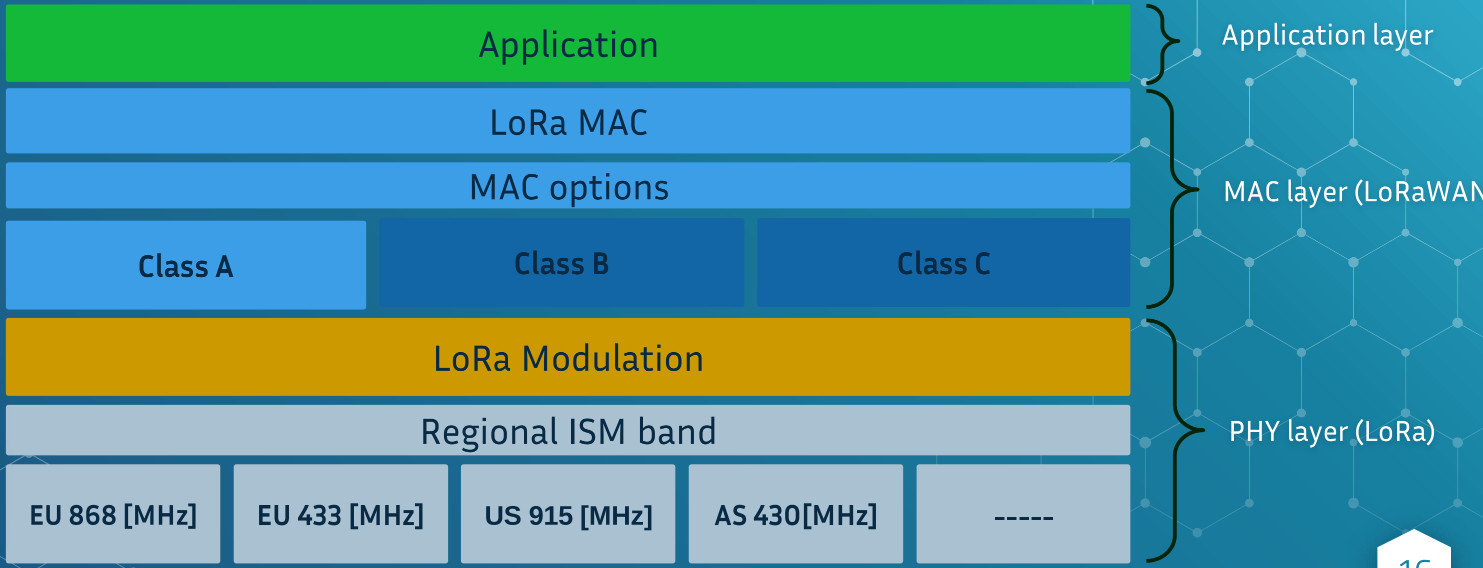


Figure 2: protocol stack.

LoRaWAN network

- As seen in this figure, the nodes send data to the platform through the gateways. Note that the nodes are not assigned to a specific gateway. Rather, all the gateways in the transmission range of a node receive its data and send it to the platform.

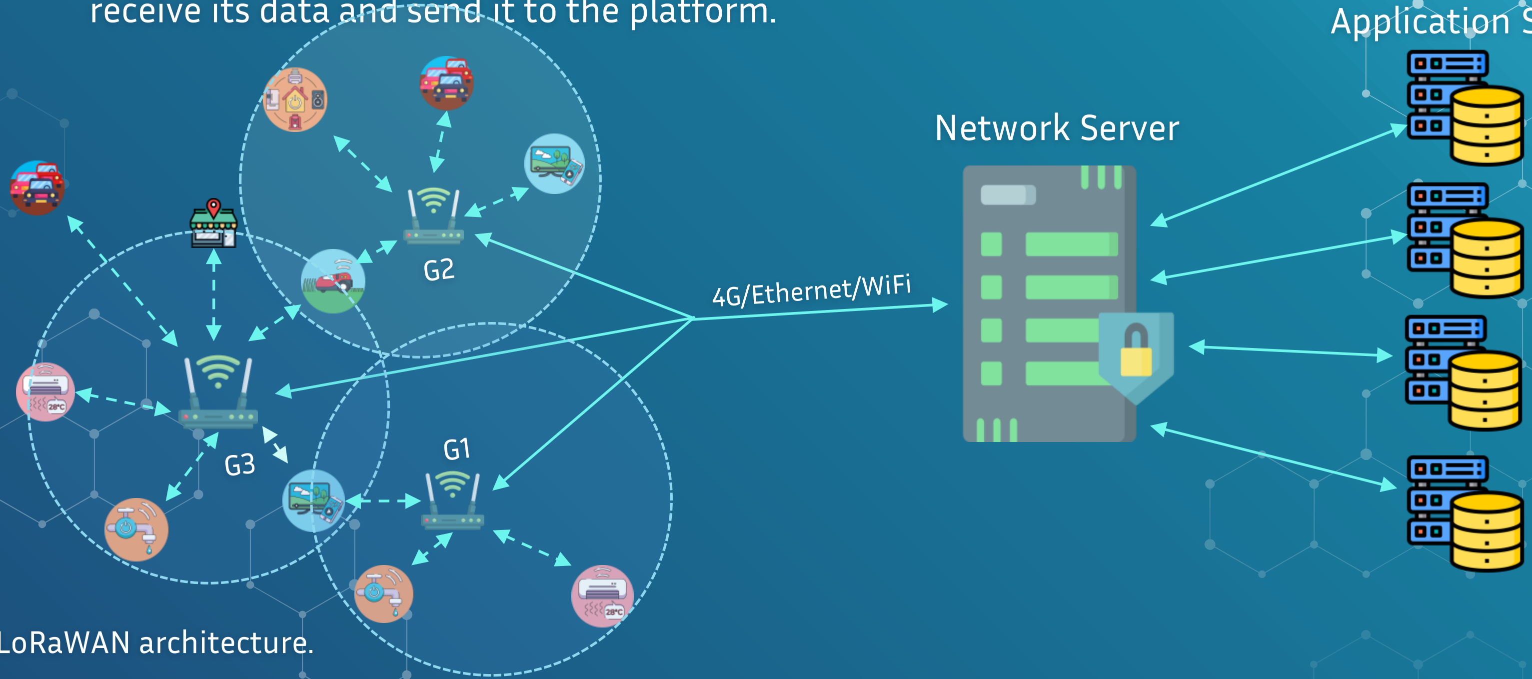


Figure 3: LoRaWAN architecture.

LoRaWAN network

- The gateways are connected to the network server via standard IP connections and act as a transparent bridge, simply converting RF packets to IP packets and vice versa.

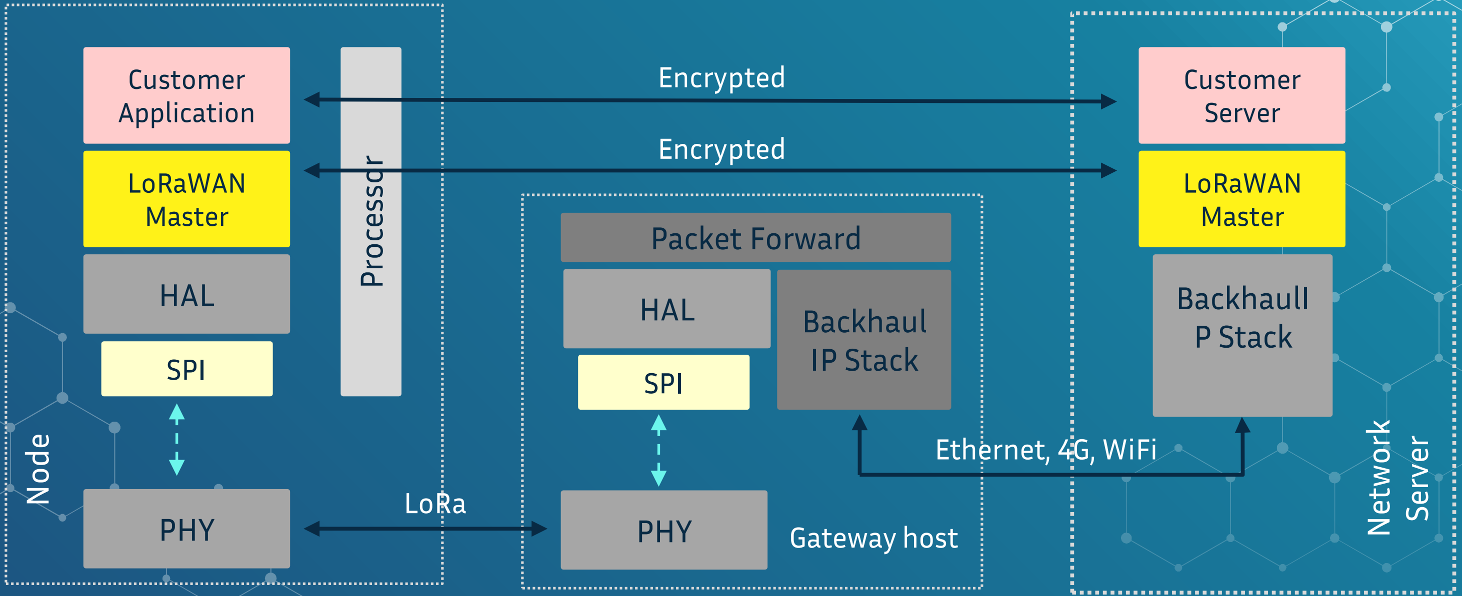


Figure 4: End-to-End communication[5].

4 CSS as a modulation for Long Range

Technical overview CSS as a modulation for Long Range Communication

- Long range low power is a family of technologies promising to connect thousands of sensors to the future internet of things. Within this family of possible technology choices, two different branches have emerged

  - Spread wideband communication

  - Narrowband communication

[6] V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. R. Smith, S. Gollakota, "LoRa Backscer: EnabalingThe Vision of Ubiquitous Connectivity", Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2017/9/11.

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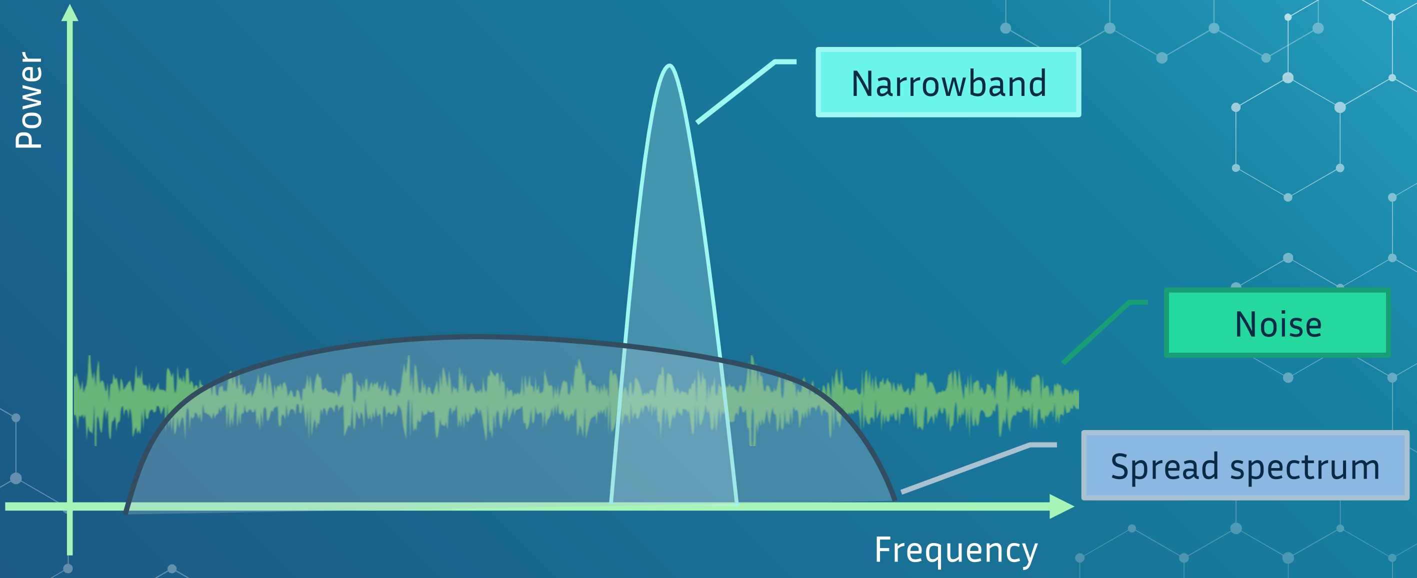

[6] V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. R. Smith, S. Gollakota, “LoRa Backscatter: Enabling The Vision of Ubiquitous Connectivity”, Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2017/9/11.

Technical overview CSS as a modulation for Long Range Communication

- Band of signals occupy a narrow/wide range of frequencies
- Power density is high/very low(max power SigFox and LoRa equal 20dBm).

- Frequency-hopping spread spectrum (FHSS)
- Direct-sequence spread spectrum (DSSS)
- Time-hopping spread spectrum (THSS)
- Chirp spread spectrum (CSS)

[6] V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. R. Smith, S. Gollakota, “LoRa Backscatter: Enabling The Vision of Ubiquitous Connectivity”, Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2017/9/11.

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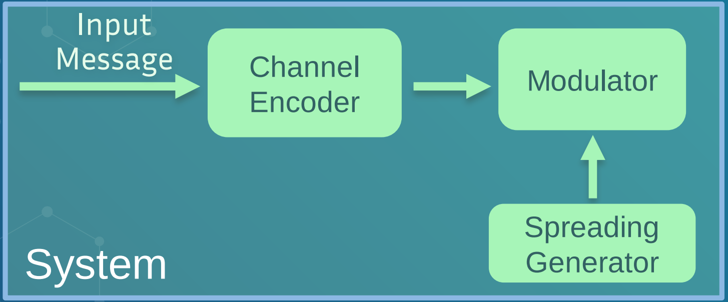

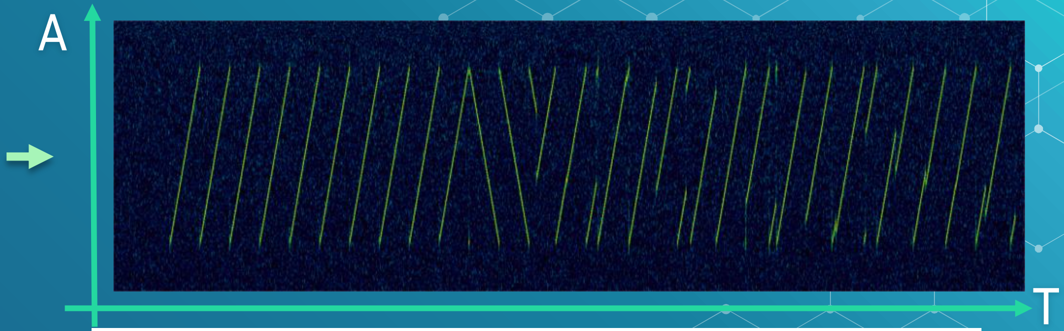

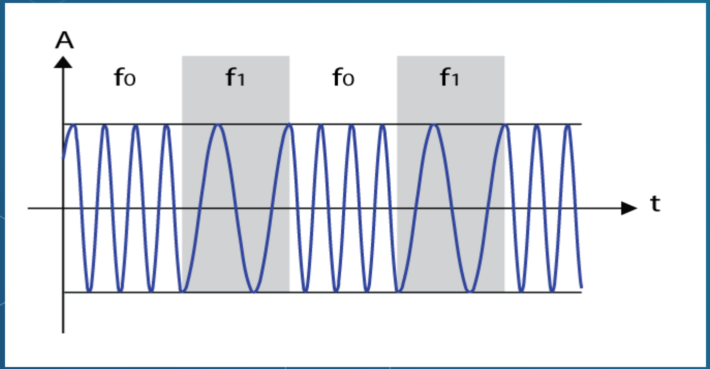

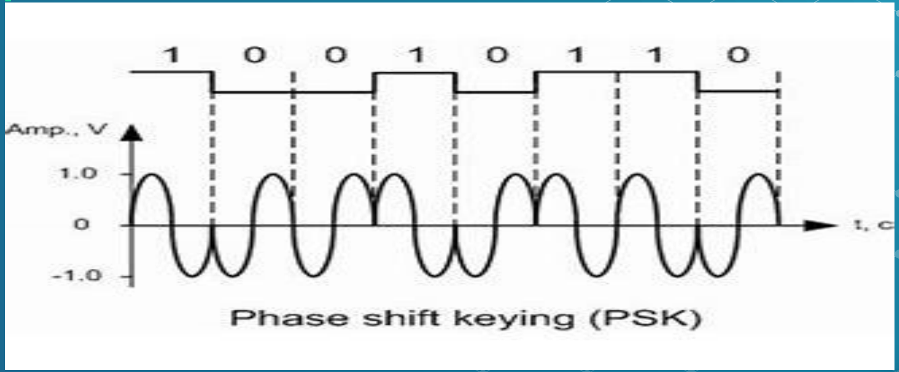

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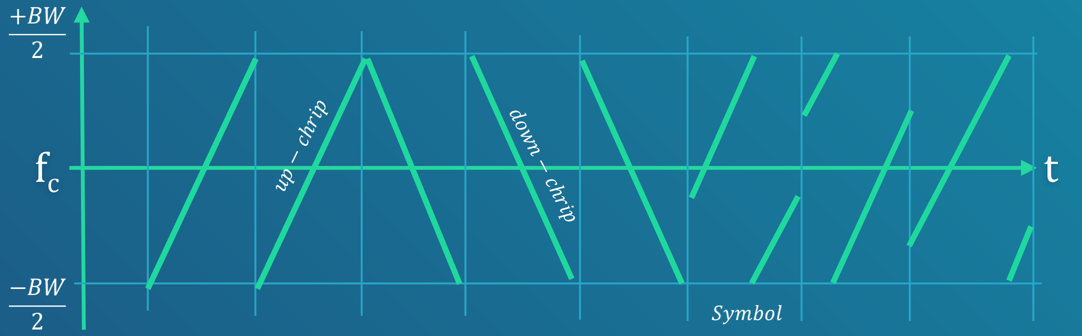

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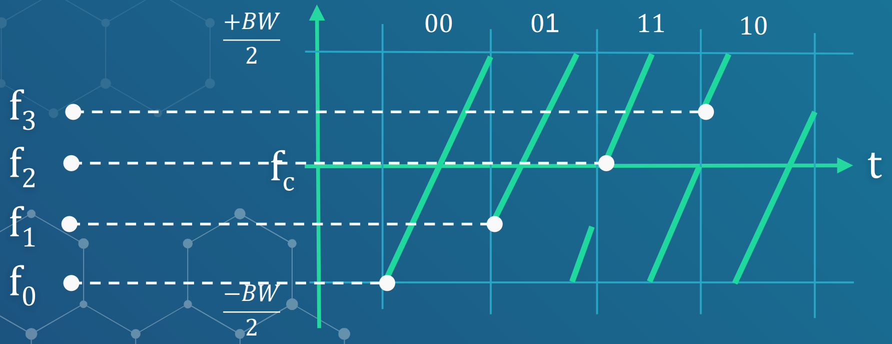
Technical overview CSS as a modulation for Long Range Communication

- The spreading factor, SF , is the number of bits encoded in each chirp duration.

$SF = 2$

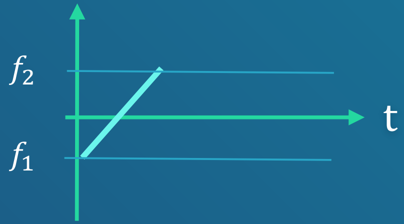


$SF = 2$	$SF = s$
$N = 2^2 \quad sample$	$N = 2^s \quad sample$
$chrip\ symbol = \quad \log_2 4$	$chrip\ symbol = \quad \log_2 N$
$frequencies = f_0 \ldots . f_3$	$frequencies = 2^s$

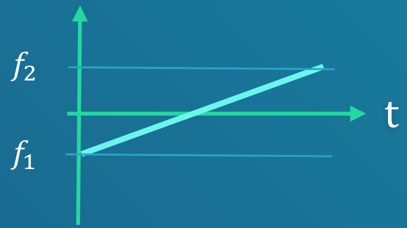
[6] V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. R. Smith, S. Gollakota, "LoRa Backscatter: Enabling The Vision of Ubiquitous Connectivity", Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2017/9/11.

Technical overview CSS as a modulation for Long Range Communication

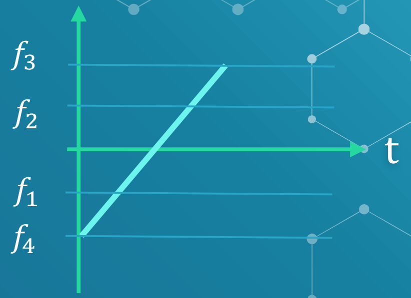
$SF = 7 \quad BW = 125kHz$



$SF = 8 \quad BW = 125kHz$



$SF = 8 \quad BW = 250kHz$



$SF = s$

$N = 2^s \quad sample$

$chrip\ symbol = \log_2 N$

$frequencies = 2^s$

$$symbol\ time(s) = \frac{2^s}{BW}$$

$$symbol\ rate(s) = \frac{BW}{2^s}$$

$$bit\ rate(s) = \frac{BW}{2^s} s$$

$CR?$

$energy\ consumption?$

$PSS = symbol\ time \times E_s$

[6] V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. R. Smith, S. Gollakota, "LoRa Backscatter: Enabling The Vision of Ubiquitous Connectivity", Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2017/9/11.

5 Factors determine RF range

Decibel

- A unit of measurement is a definite magnitude of a quantity, defined and adopted by convention or by law, that is used as a standard for measurement of the same kind of quantity.

- If a person is listening to a radio with a sound power of 10 watts, the volume will not be doubled when it increases the output power to 20 watts.

- The decibel (symbol: dB) is a relative unit of measurement corresponding to one tenth of a bel (B). It is used to express the ratio of one value of a power or root-power quantity to another, on a logarithmic scale.

$$\mathrm{x}_{dB} = 10 \times \log_{10}\left(\frac{signal}{ref.signal}\right) \qquad \mathrm{x}_{dB} = 10 \times \log_{10}\left(\frac{20}{10}\right) = 3\ dB\ of\ gain$$

Decibel

- What if we want to measure an absolute power with dB? We have to define a reference.
- The reference point that relates the logarithmic dB scale to the linear watt scale may be for example this:

$$1mW = 0\ dBm$$

- The new m in dBm refers to the fact that the reference is one mW, and therefore a dBm measurement is a measurement of absolute power with reference to 1 mW.
- To convert power in mW to dBm:

$$P_{dBm} = 10 \times \log_{10} P_{mW}$$

- To convert power in dBm to mW:

$$P_{mW} = 10^{\frac{P_{dBm}}{10}}$$

[11] WIRELESS NETWORKING IN THE DEVELOPING WORLD, http://wndw.net

Decibel

- Example: mW to dBm, Radio signal power: 100mW

$$P_{dBm} = 10 \times \log_{10}(100) \qquad 100mW = 20dBm$$

- Example: dBm to mW, Radio signal power: 17dBm

$$P_{mW} = 10^{\frac{17}{10}} \qquad 17dBm = 50\ mW$$

- You can now imagine situations in which:

$$10\ mW + 10\ dB\ of\ gain = ?\ dBm, ?\ mW \qquad 10\ dB = 10 \times Log_{10}(\frac{x_{mW}}{10mW}) \qquad 100\ mW = 20\ dBm$$

$$20\ dBm - 10\ dB\ of\ loss = ?\ dBm, ?\ mW \qquad 10\ dBm = 10mW$$

$$50\ mW + 3\ dB = 100\ mW = 20\ dBm$$

$$17\ dBm + 3\ dB = 20\ dBm = 100\ mW$$

[11] WIRELESS NETWORKING IN THE DEVELOPING WORLD, http://wndw.net

What factors determine RF range and performance?

- **Link budget** : The link budget is the difference between the strength of the transmitted signal and the minimum required signal at the receiver

$$\textit{Link budget} = \mathrm{TransmitPower}(\mathrm{P}_t) - \mathrm{Receiver\ Sensitivity}(\mathrm{S}_r)$$

$$\textit{For a typical LoRa radio}: P_t = 13\ dBm, S_r = -137\ dBm$$

$$\textit{Link budget} = 13 - (-137) = 150dBm$$

[7] LoRa™ Modulation Basics, SEMTECH

What factors determine RF range and performance?

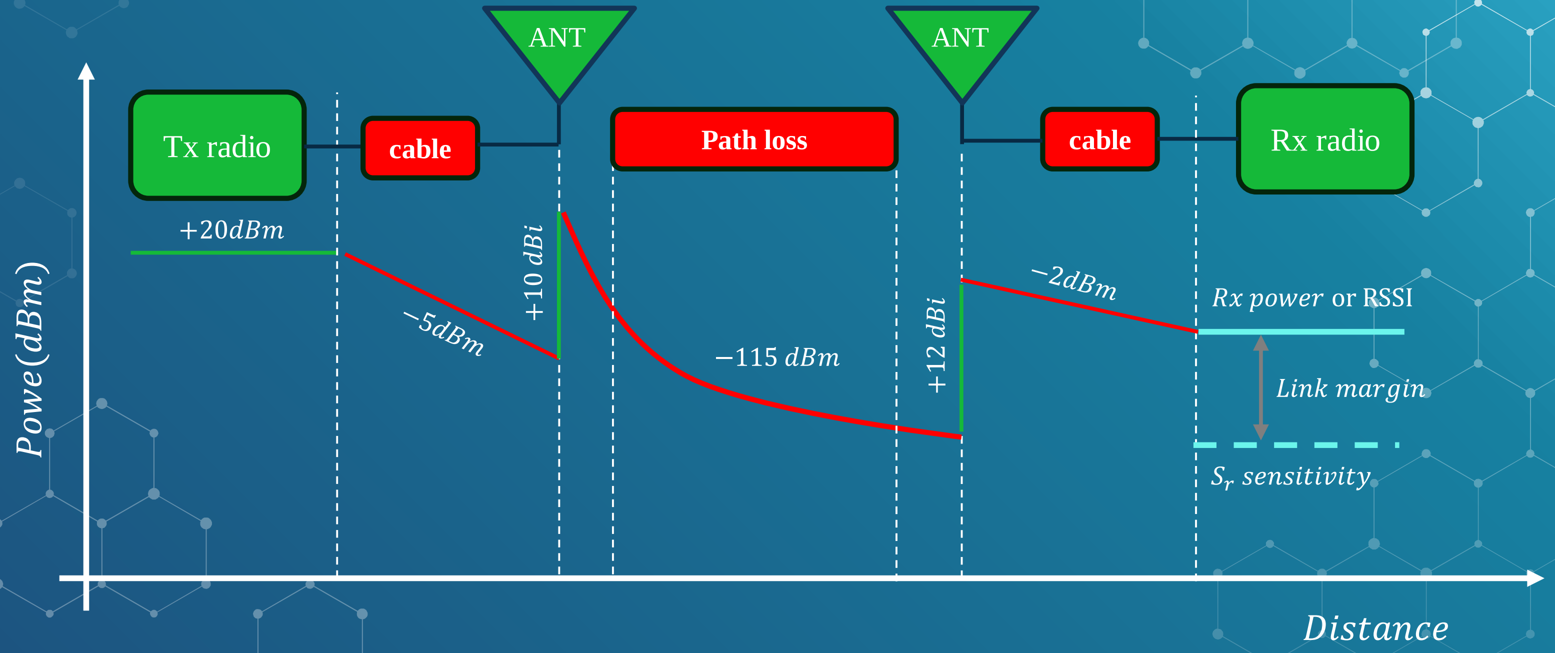


Figure 5: Example link budget calculation [8].

What factors determine RF range and performance?

- **Receiving sensitivity**: refers to the smallest modulated signal that can be demodulated at the receiving end.

$$Receiving\ sensitivity = \text{NF} + \text{SNR}$$

$$NF = \underbrace{-174}_{\text{Thermal noise for a 1 Hz bandwidth}} + \overbrace{\text{NF} + 10\log\ BW}^{\text{Noise figure}}$$

[7] LoRa™ Modulation Basics, SEMTECH

What factors determine RF range and performance?

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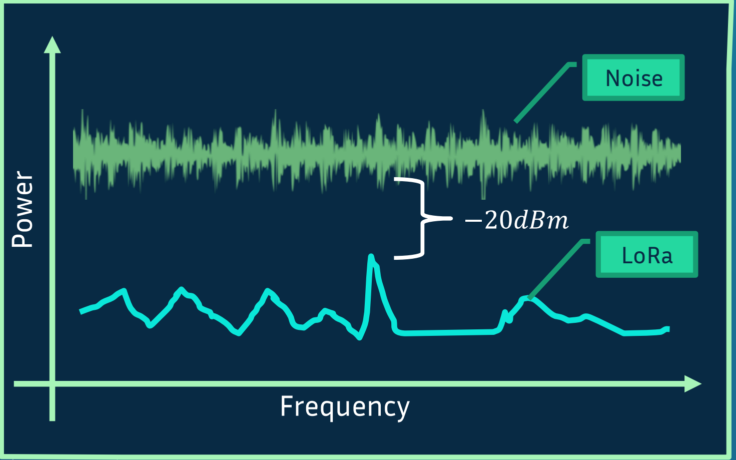


- *Tx power = 14 dBm*
- *BW = 125KHz = 10log10(125000) = 51*
- *NF = 6 dBm*
- *SNR = -20 dBm(for SF=12)*
- Rx sensitivity = - 174 + 51 + 6 - 20 = -137 dBm
- *Link budget = 14dBm +(-137dBm)= 151dBm*

[7] LoRa™ Modulation Basics, SEMTECH

What factors determine RF range and performance?

SNR is key measure in wireless network.

- In LoRa network SNR include Noise, SF, BW, TP, CR, Interference

[7] LoRa™ Modulation Basics, SEMTECH

What factors determine RF range and performance?

- **Signal-to-Noise Ratio (SNR)** : is the ratio between the received power signal and the noise floor power level.

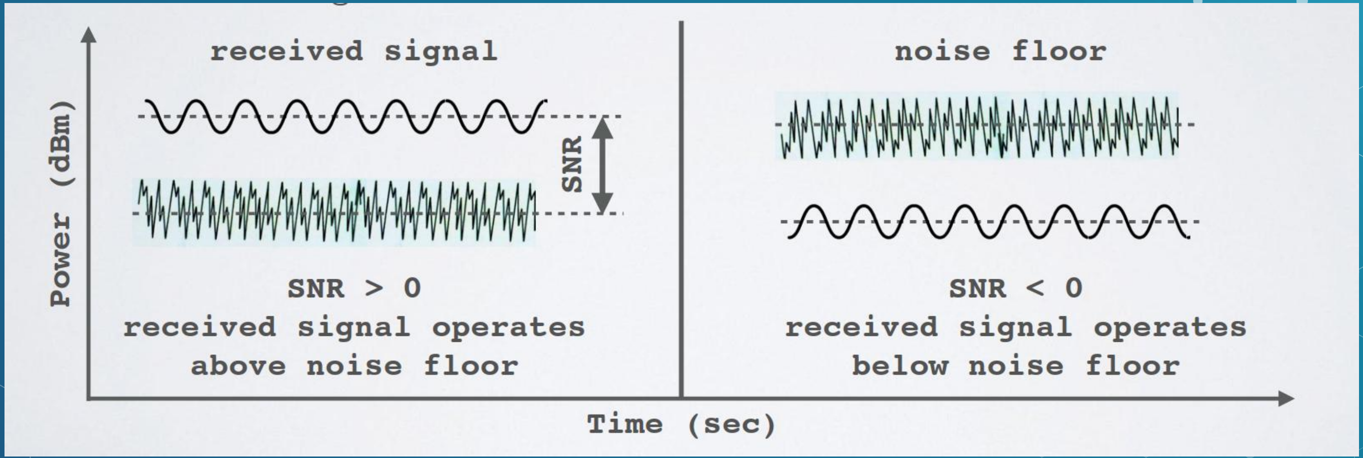


Figure 6: Signal-to-Noise Ratio (SNR) [8].

What factors determine RF range and performance?

Accurate calculation of SNR:

$$SNR = \frac{P_s}{P_w}$$

$P_s = The\ average\ power\ of\ s(t)$

$P_w = The\ average\ power\ of\ noise$

Calculate minimum SNR in terms of SF:

$$SNR_0 = \frac{E_{bit}}{NF}$$

$$\left.\begin{aligned} E_{bit} &= RSSI \times T_{bit} \\ T_{bit} &= \frac{1}{BW} \times 2^{SF} \end{aligned}\right\} \quad SNR_0 = \frac{RSSI \times 2^{SF}}{NF \times BW}$$

$$\left.\begin{aligned} RSSI &= \frac{SNR_0 \times NF \times BW}{2^{SF}} \\ S_r &= BW \times NF \times SNR(SF) \end{aligned}\right\} \quad SNR(SF) = \frac{SNR_0}{2^{SF}}$$

$$SNR(12) = \frac{31}{2^{12}} = 0.007mW = -21dBm$$

[9] T. Bouguera, J.F. Diouris , J.J Chaillout, R.Jaouadi, G. Andrieux, *"Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN", sensors, 30 June 2018.*

What factors determine RF range and performance?

- ***Path loss* (PL):** Path loss (or path attenuation) delineates a decline in power density of any given electromagnetic wave as it propagates through space.

- Path loss models are developed using a combination of numerical methods and empirical approximations of measured data collected in channel sounding experiments.

- In general, propagation path loss increases with **frequency** as well as **distance**:

$$L_{path} = (\frac{4.\pi.f}{c})^2.d^n$$

$$d = distance\ (meter)$$
$$f = signal\ frequency\ (MHz)$$
$$n = is\ 2\ for\ free\ space$$

$$L_{\ path(dB)} = 10Log_{10}((\frac{4 \times 3.14 \times 868}{300})^2.1000^2) = \ 91\ dB$$

[9] T. Bouguera, J.F. Diouris , J.J Chaillout, R.Jaouadi, G. Andrieux, *“Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN”, sensors, 30 June 2018.*

What factors determine RF range and performance?

Calculate maximun distance in terms of SF:

$$d = \left(\frac{L_{path}}{(\frac{4.\pi.f}{c})^2} \right)^{\frac{1}{n}}$$

We assume that there are no antenna gains and set the path loss L_{path} equal to L_{budget}

$$d = \left(\frac{L_{budget}}{(\frac{4.\pi.f}{c})^2} \right)^{\frac{1}{n}}$$

[9] T. Bouguera, J.F. Diouris , J.J Chaillout, R.Jaouadi, G. Andrieux, *“Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN”, sensors, 30 June 2018.*

What factors determine RF range and performance?

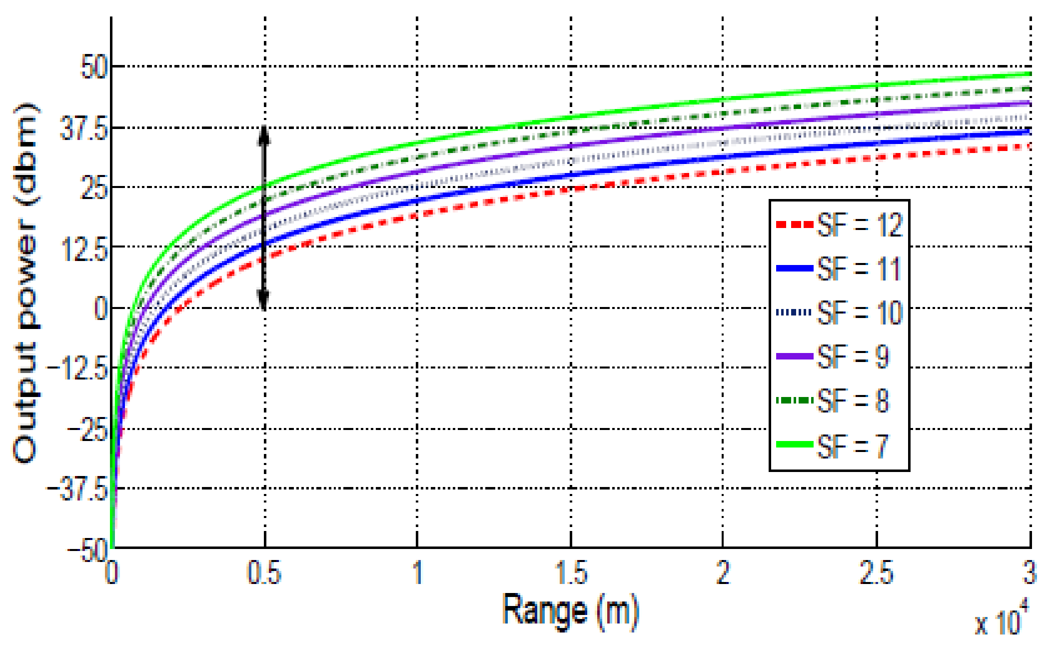


Figure 11. Required output power vs. LoRaWAN range.

[9] T. Bouguera, J.F. Diouris , J.J Chaillout, R.Jaouadi, G. Andrieux, *"Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN", sensors, 30 June 2018.*

Maximum daily packets on LoRaWAN

- Duration of the packet transmission

$$T_{on\_the\_air} = (N_{payload} + N_{preamble}) \times T_{symbol}$$

$$T_{symbol} = \frac{2^{SF}}{BW}$$

$$N_{payload} = 8 + max\left[Ceil\left(\frac{8PL - 4SF + 28 + 16 - 20IH}{SF - 2DE} \times \frac{CR + 4}{4}, 0\right)\right]$$

$$N_{preamble} = 8$$

	Description
SF	Spreading Factor
PL	Payload Length
CRC	The use of the Cyclic Redundancy Check (CRC, 1 when enabled 0 when not)
IH	The use of explicit header or not (IH, 1 when enabled 0 when not)
CR	Coding Rate
DE	The Low Data Rate Optimization (DE, 1 when used 0 when not).

[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

Maximum daily packets on LoRaWAN

- The time that the LoRa Mote has to wait before send the next packet is called T_{off}

$$T_{off} = T_{on\_the\_air} \times (1 - \frac{1}{DCycle})$$

- So we can calculate the maximum daily packets

$$Daily\ packets = \frac{Seconds\ in\ a\ day}{T_{off}}$$

[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

Maximum daily packets on LoRaWAN

- we can calculate theoretical $T_{on\text{-}the\text{-}air}$ *and maximum number of daily packets* with variable payload, 8 symbols of preamble, CRC activated with a value of 4/5, Implicit Header deactivated, bandwidth of 125 kHz and Low Data Rate optimization activated for high spreading factors (SF11 and SF12).

	16B	32B	51B
7	60ms	90ms	110ms
8			
9			
10			
11			
12	161ms	213ms	276ms

	16B	32B	51B
7	13061	9657	7394
8			
9			
10			
11			
12	540	408	316

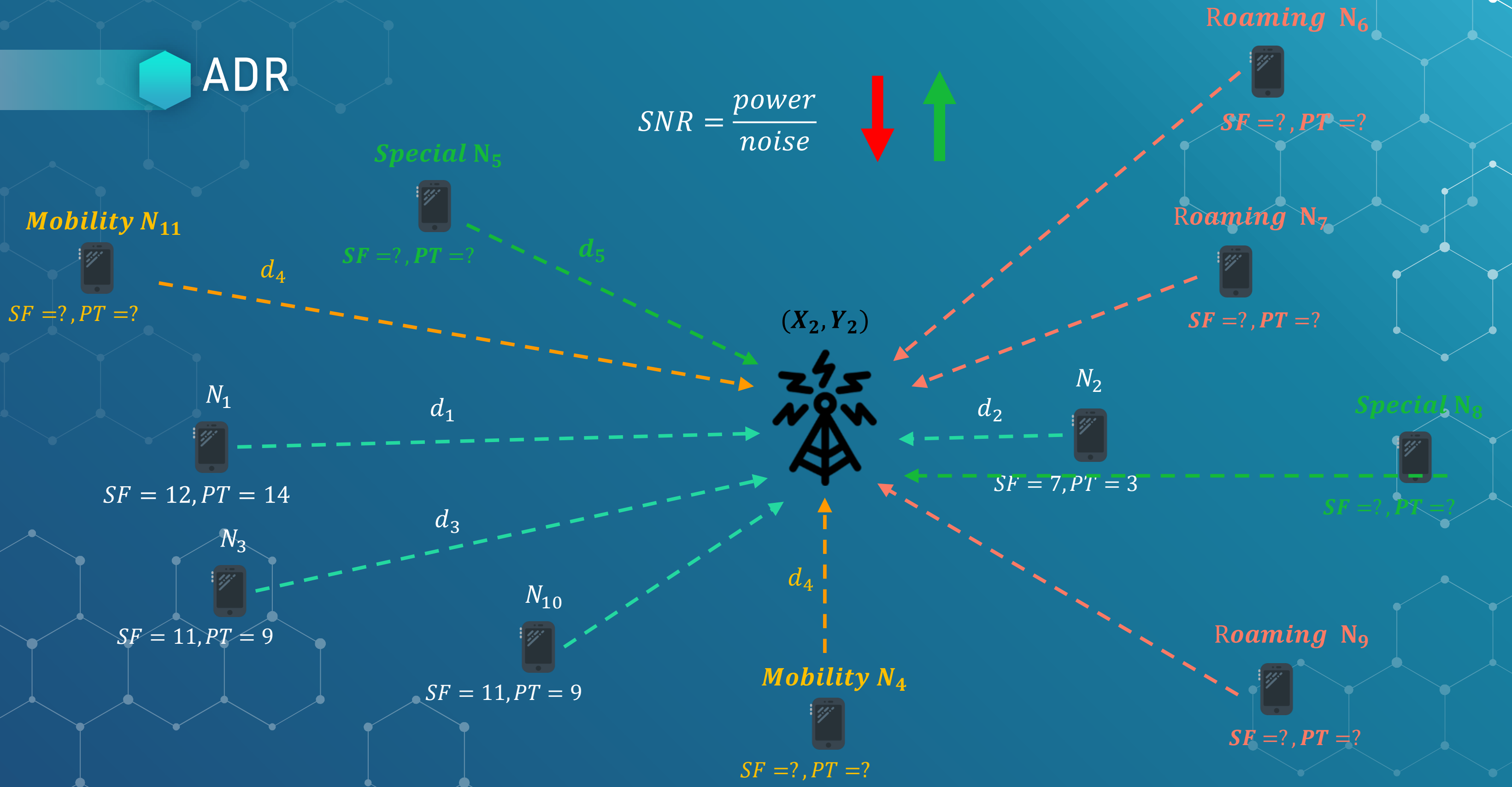
Table 2: Theoretical Time on-the-air and maximum number of daily packets [10].

What factors determine RF range and performance?

SF	125 (kHz)			250 (kHz)			500 (kHz)			SNR (dBm)	Range (Km)
	Bit rate (kb/s)	Sensitivity (dBm)	ToA (ms)	Bit rate (kb/s)	Sensitivity (dBm)	ToA (ms)	Bit rate (kb/s)	Sensitivity (dBm)	ToA (ms)		
7	5.4	-124	56	110	-122	20	219	-116	10	-7.5	2
8											
9											
10											
11											
12	0.29	-137	1483	0.5	-135	495	0.98	-129	247	-20	15

- Code rate: 4/5 Payload:10 byte

ADR

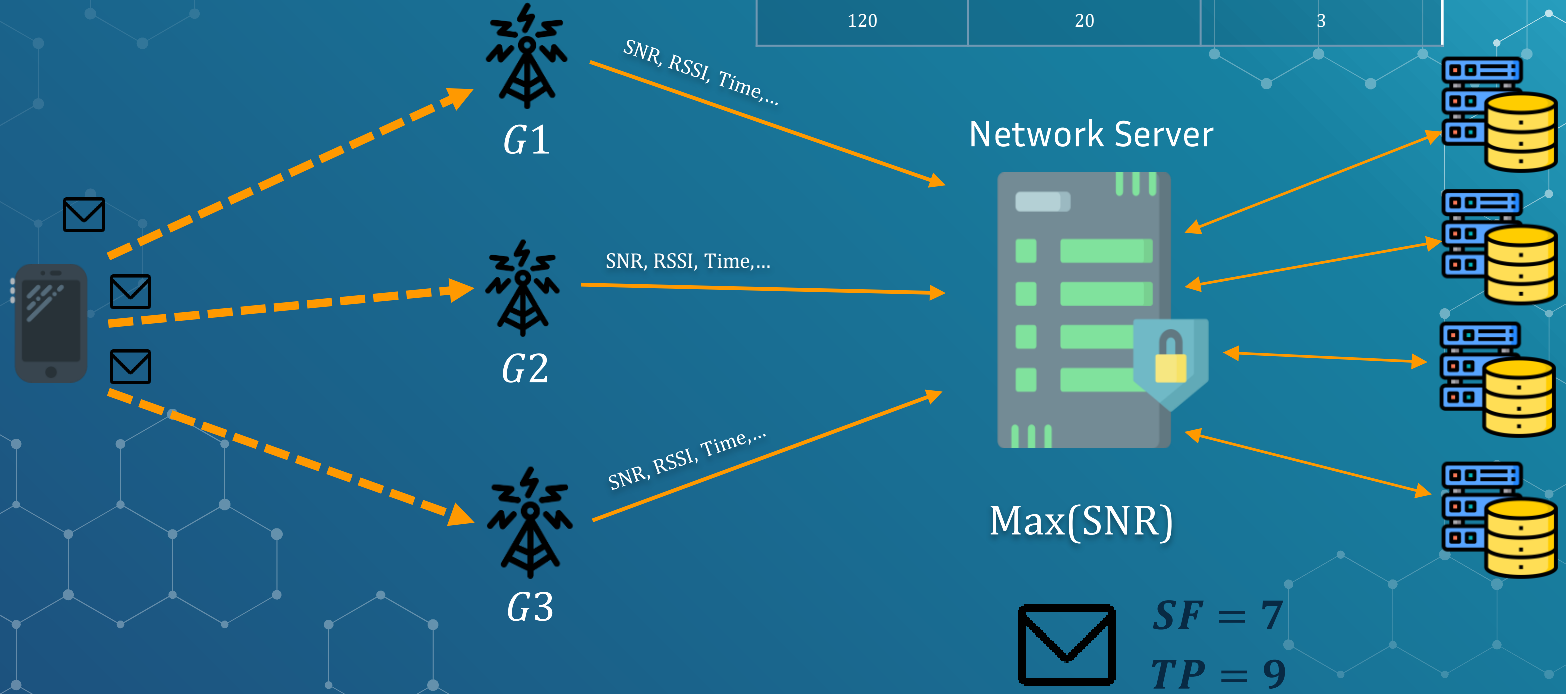


$SNR = \frac{power}{noise}$
(X_2, Y_2)
Roaming N_6
$SF = ?, PT = ?$
Roaming N_7
$SF = ?, PT = ?$
Special N_5
$SF = ?, PT = ?$
d_5
Mobility N_{11}
$SF = ?, PT = ?$
d_4
N_1
d_1
$SF = 12, PT = 14$
N_2
d_2
$SF = 7, PT = 3$
Special N_8
$SF = ?, PT = ?$
N_3
d_3
$SF = 11, PT = 9$
N_{10}
$SF = 11, PT = 9$
d_4
Mobility N_4
$SF = ?, PT = ?$
Roaming N_9
$SF = ?, PT = ?$

ADR

ADR-List

FrmCun	SNR	NumGat
1	7.5	3
10	-10	2
...	-13.5	3
120	20	3



ADR

$SNR_m \leftarrow \max(\text{SNR of last 20 frames})$

$SNR_{req} \leftarrow \text{demodulation floor(current data rate)}$

$\text{SNR}_{margin} \leftarrow (SNR_m - SNR_{req} - 10)$

$step \leftarrow floor(SNR_{margin}/3)$

while steps > 0 **and** SF $>$ SF_{min} ***do***

$\quad \text{SF} \leftarrow \text{SF} - 1$

$\quad \text{steps} \leftarrow \text{steps} - 1$

while steps > 0 **and** TP $>$ TP_{min} ***do***

$\quad \text{TP} \leftarrow \text{TP} - 3$

$\quad \text{steps} \leftarrow \text{steps} - 1$

while steps < 0 **and** TP $<$ TP_{max} ***do***

$\quad \text{TP} \leftarrow \text{TP} + 3$

$\quad \text{steps} \leftarrow \text{steps} + 1$

$SF = 9 \quad TP = 14$

$SNR_{MIN} = -12.5$

$SNR_m = 10$

$SNR_{req} = -12.5$

$SNR_{req} = 12 - (-12.5) - 10 = 12.5$

$step = 4$

$step = 4 \quad 3 \quad 2$

$SF = 9 \quad 8 \quad 7$

$step = 2 \quad 1 \quad 0$

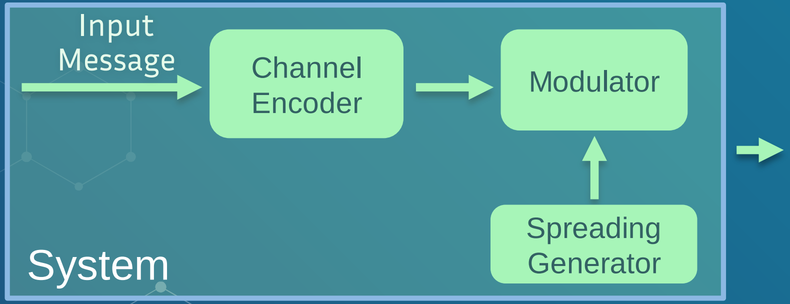
$TP = 14 \quad 11 \quad 9$

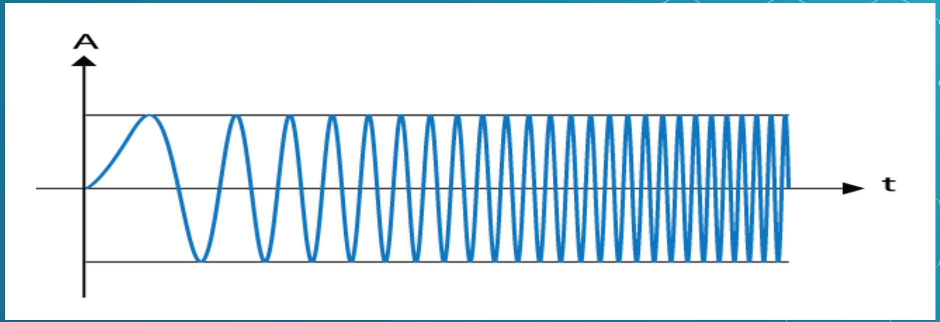
$SF = 7$

$TP = 9$

6 ALOHA protocol

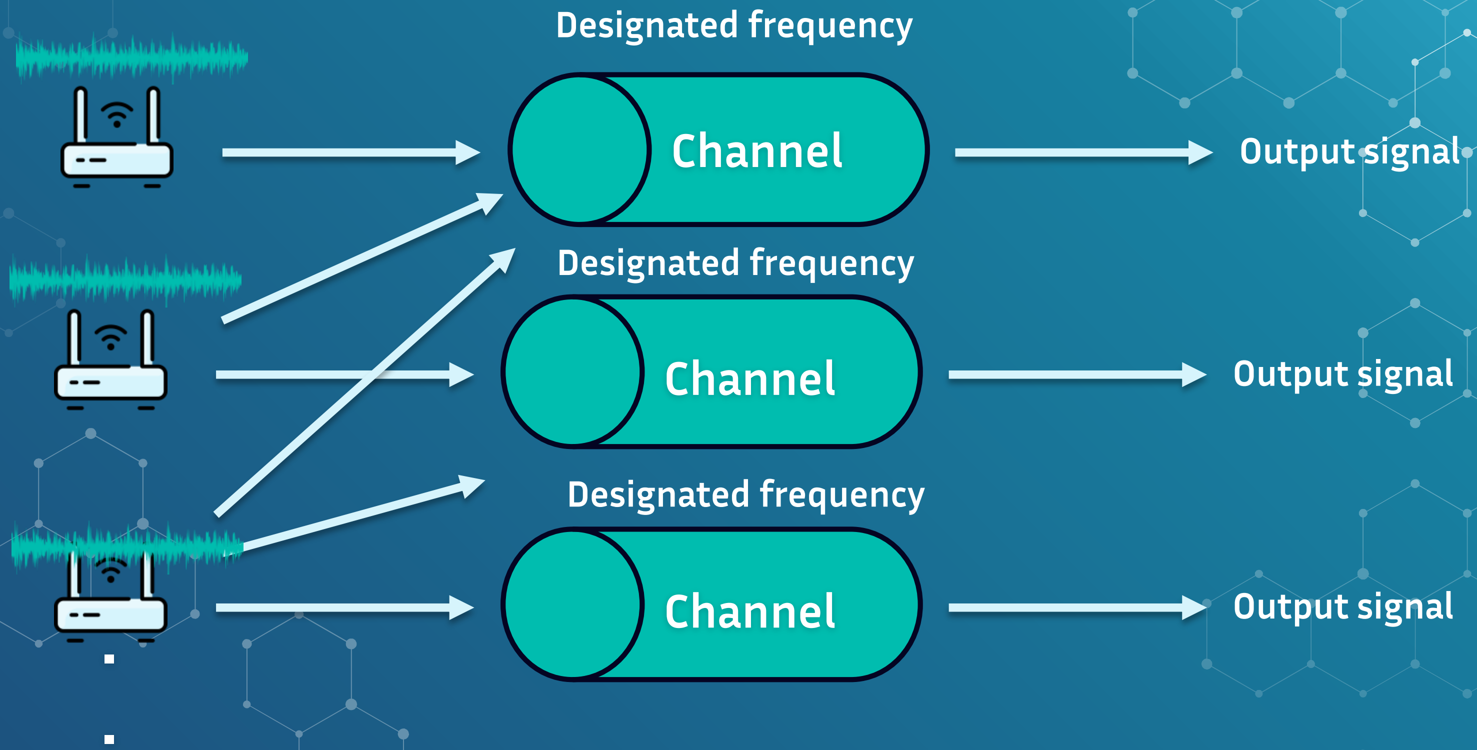
ALOHA protocol





[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

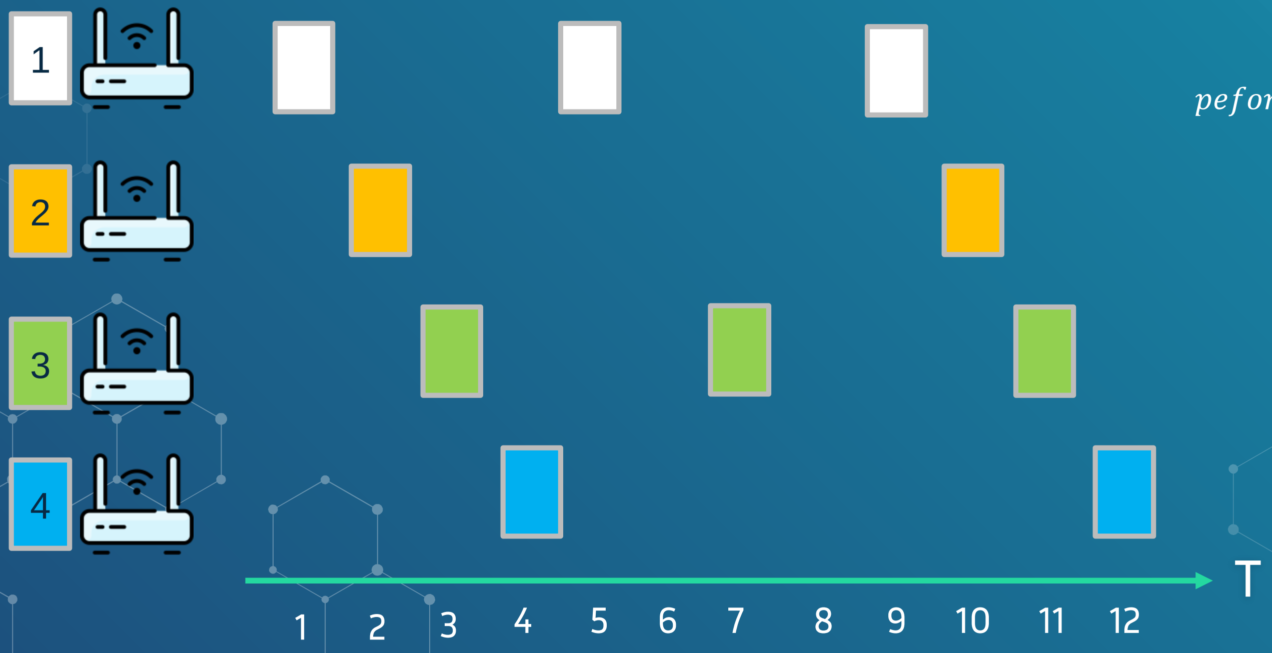
ALOHA protocol



[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

ALOHA protocol

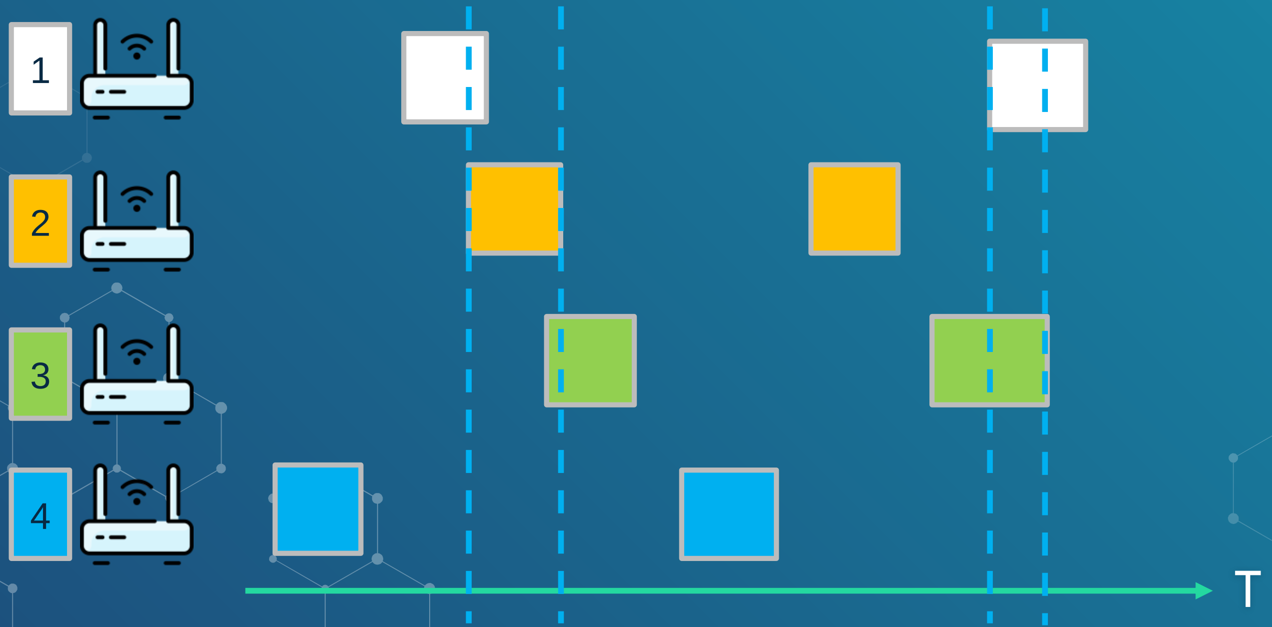
- TDMA creates channels by assigning users nonoverlapping time slots. In a system with N users, each user can thus use the total bandwidth W, but only a fraction 1/N of the time



$$peformance = \frac{10}{12} \times 100 = 83.3\,\%$$

ALOHA protocol

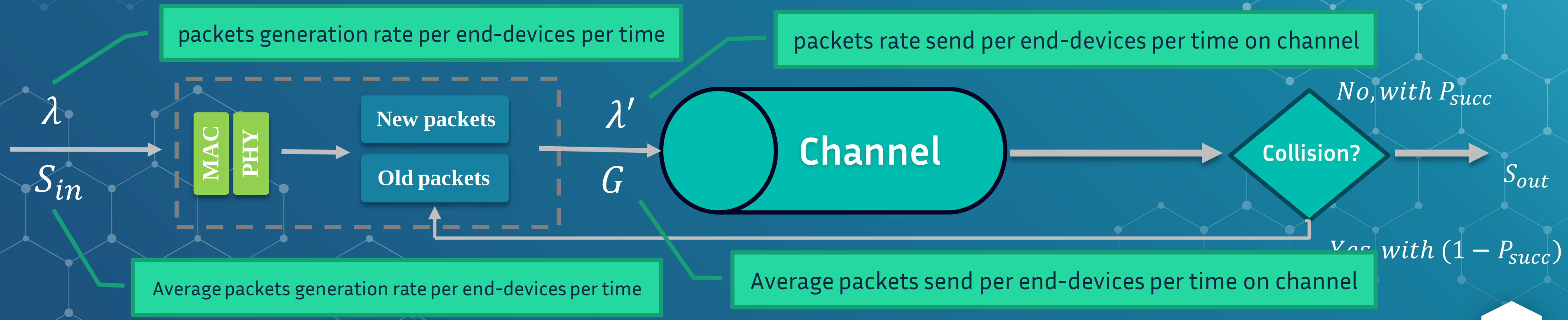
- Node transmits as soon as it has a frame.
- If a collision is detected, it waits for a random time interval and then retransmits.



ALOHA protocol

- Node transmits as soon as it has a frame.
- If a collision is detected, it waits for a random time interval and then retransmits.

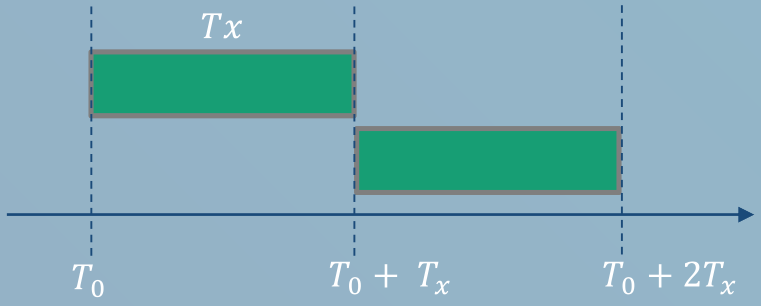
$$S_{out} = S_{in} \qquad\qquad S_{out} = P_{succ} \times G$$



[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

ALOHA protocol implemented on LoRaWAN

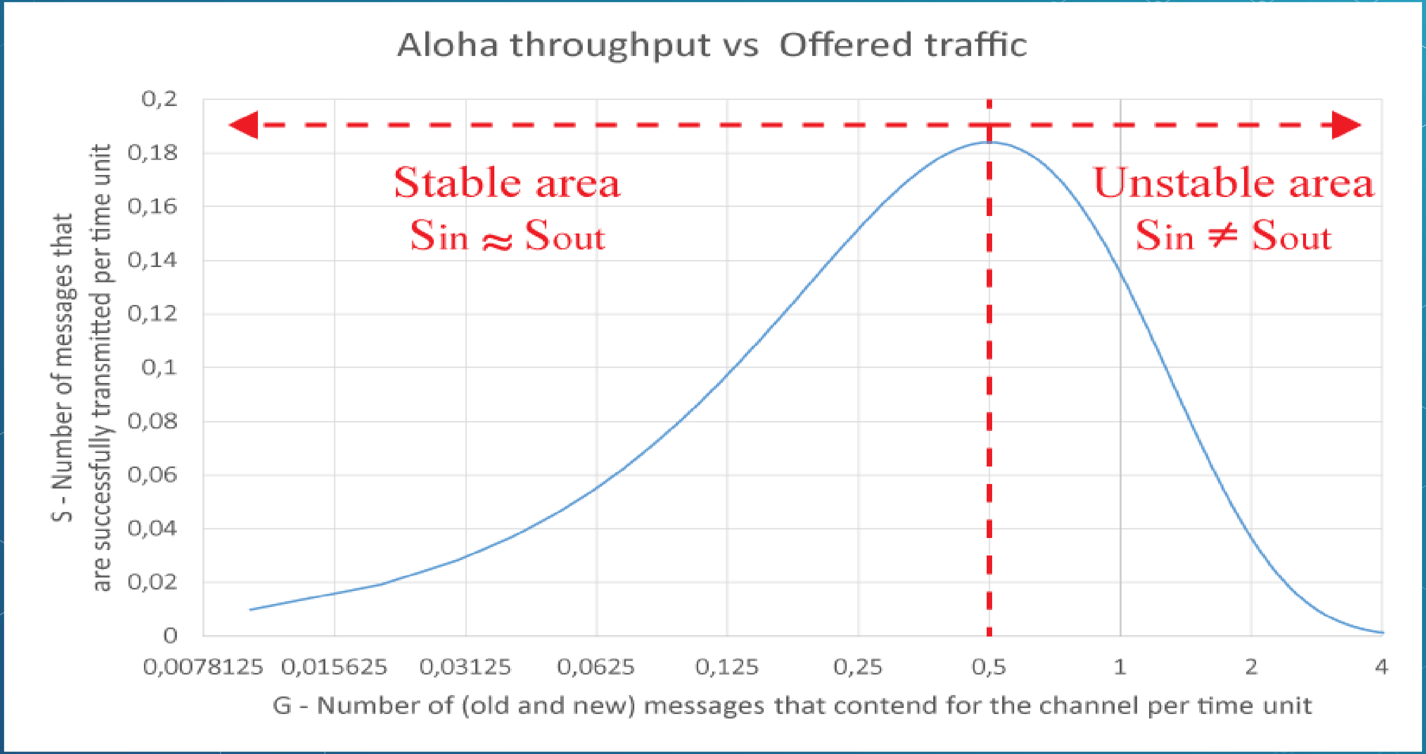
$$P[k\ occur\ in\ G\ time] = \frac{G^{k}}{k!}e^{-G}$$



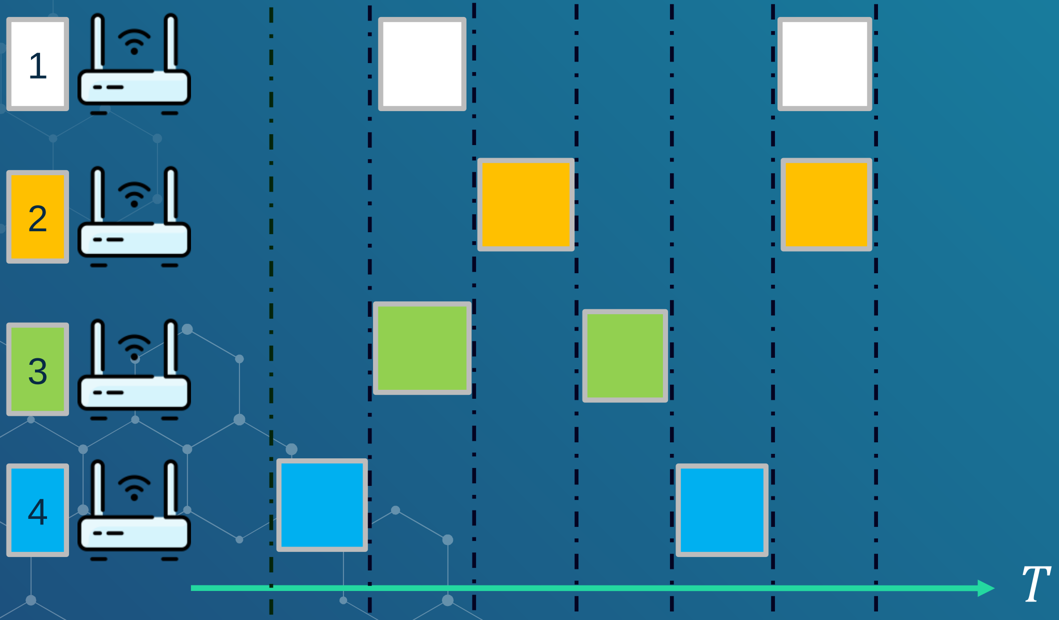
$$P[k=0] = \frac{G^{0}}{0!}e^{-2G} \qquad P[k=0] = e^{-2G}$$

$$S_{out} = Ge^{-2G}$$

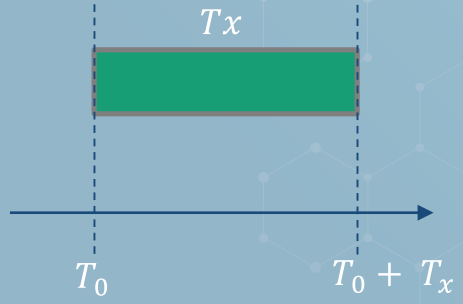
ALOHA protocol



Slotted-ALOHA protocol



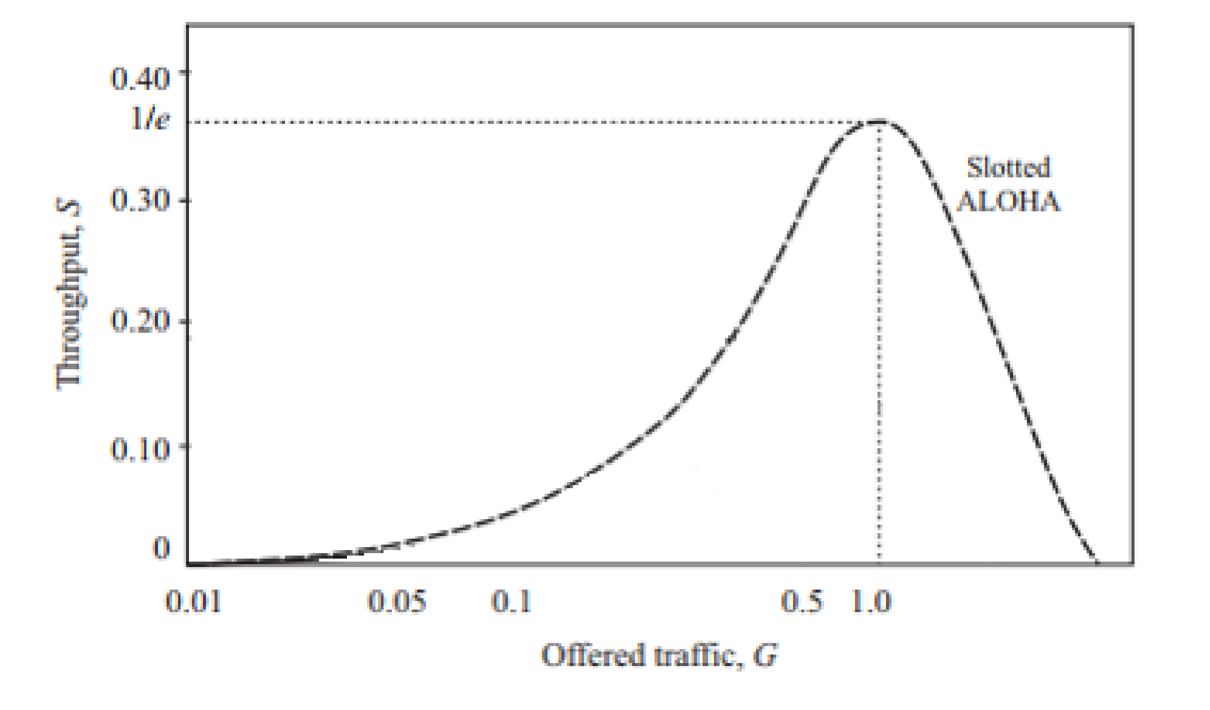
$$P[k\ occur\ in\ G\ time] = \frac{G^{k}}{k!}e^{-G}$$



$$P[k = 0] = \frac{G^{0}}{0!}e^{-G}$$

$$S_{out-slotted} = Ge^{-G}$$

Slotted-ALOHA



7 ALOHA protocol implemented on LoRaWAN

ALOHA protocol implemented on LoRaWAN

- λ represents all the packets sent to the network by all the LoRa devices in the same coverage area, so we can rewrite λ as:

$$\lambda = N.\lambda_i$$

$$\lambda_i = Represents\ the\ throughput\ of\ one\ device$$

$$N = The\ number\ of\ devices\ on\ the\ coverage\ area$$

- Each packet sent by one LoRa device, will select randomly one channel from the 8 available, so the total throughput sent by one LoRa devices per channel will be:

$$\lambda_{i\ per\ channel} = \frac{\lambda_i}{8\ channel}$$

[10] E. Ruano, LoRaTM protocol Evaluations, limitations and practical test, May 11, 2016

Maximum throughput per end-device and per channel

- Considering packets of 16B payload, a bandwidth of 125 kHz and two available sub-bands on LoRaWAN (Band0 from 868.1 MHz to 868.5 MHz and Band1 from 867.1 MHz to 867.9 MHz).

	Max. daily packets per end-device [packets/day]	Max. λ_i per end-device [packets/sec]	Max. $\lambda_{i\ \text{per channel}}$ [packets/sec]
SF7	26122	0,302	0,037
SF8			
SF9			
SF10			
SF11			
SF12	1080	0,012	0,001

Table 3: Theoretical Ton-the-air and maximum number of daily packets [10].

$$Max.\lambda_i = \frac{26122}{86400} = 0{,}302$$

Maximum throughput per end-device and per channel

$$G = T_{tx} \times \lambda \qquad S(G = 0.5) = 18.4\ \%$$

$$G_{SF7} = 0.302 \times 0.037 = 0.011174 \qquad G_{SF7} < 0.5 \qquad 0.5 - G_{SF7} = 0.488826$$

- We can obtain the maximum number of end-devices N.

$$N = \frac{0.5}{T_{tx} \times \lambda}$$

Maximum throughput per end-device and per channel

We can obtain the maximum number of end-devices in two different Scenario:

Scenario 1: maximizing the packets send by the end-devices and throughput of network.

Scenario 2: considering 1 packet per end-device and per day.

Maximum throughput per end-device and per channel Scenario 1

	Max. daily packets per end-device [packets/day]	$T_{\text{on-the-air}}$ [sec]	Max. $\lambda_{i \text{ per channel}}$ [packets/sec]
SF7	26122	0,302	0.00825
SF8			
SF9			
SF10			
SF11			
SF12	1080	0,012	0.201625

N
198
198

Table 4: Theoretical Ton-the-air and maximum number of daily packets [10].

$$T_{tx\_SF7\_125kHz\_16B} = 0.066$$

$$\lambda_{i\ per\ channel} = \frac{0.066}{8} = 0.00825$$

$$N = \frac{0.5}{0,302 \times 0.00825} = 198$$

Maximum throughput per end-device and per channel Scenario 1

	Max. daily packets per end-device [packets/day]	$T_{\text{on-the-air}}$ [sec]	Max. $\lambda_{i \text{ per channel}}$ [packets/sec]
SF7	1	0,066	0.00000144
SF8			
SF9			
SF10			
SF11			
SF12	1	1,613	0.00000144

N
5172000
214149

$$N = \frac{0.5}{0{,}066 \times 0.00000144} = 5172000$$

Table 5: Theoretical Ton-the-air and maximum number of daily packets [10].

Maximum throughput per end-device and per channel

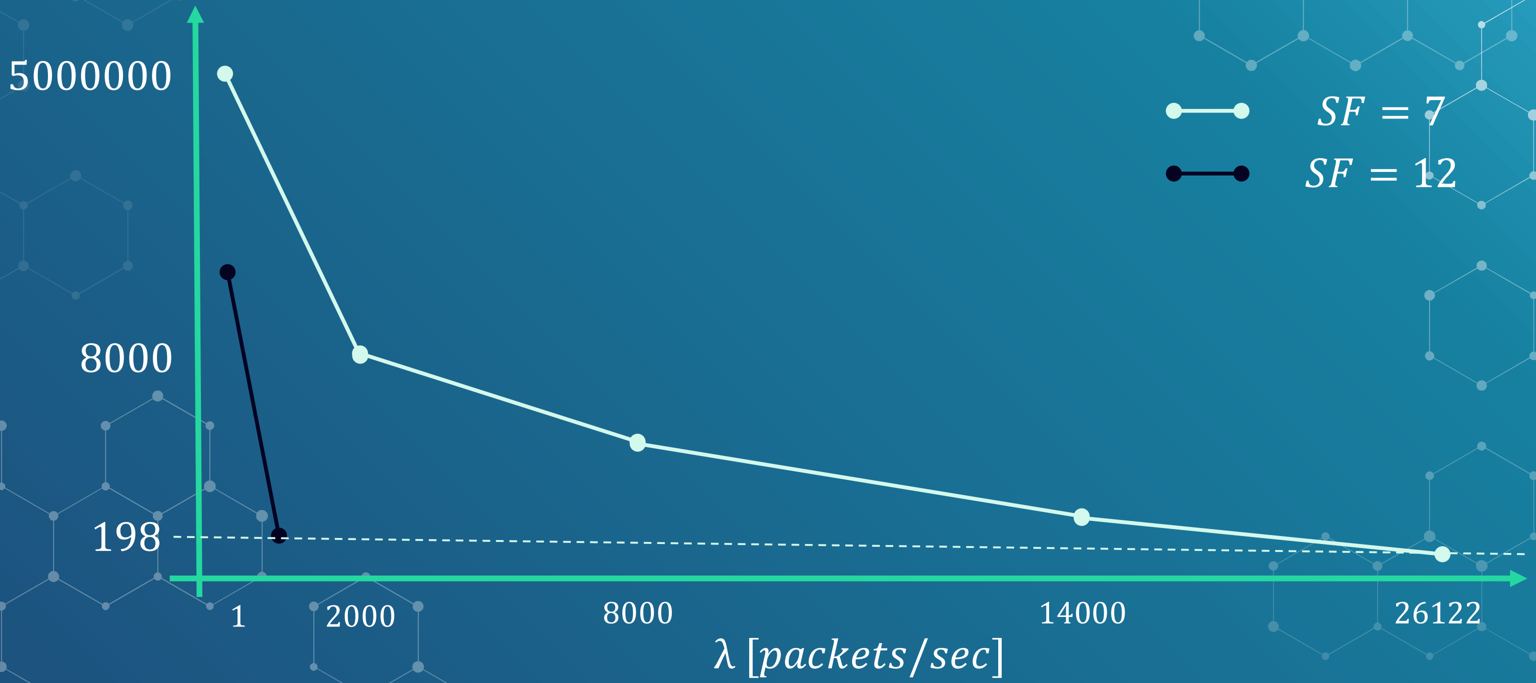
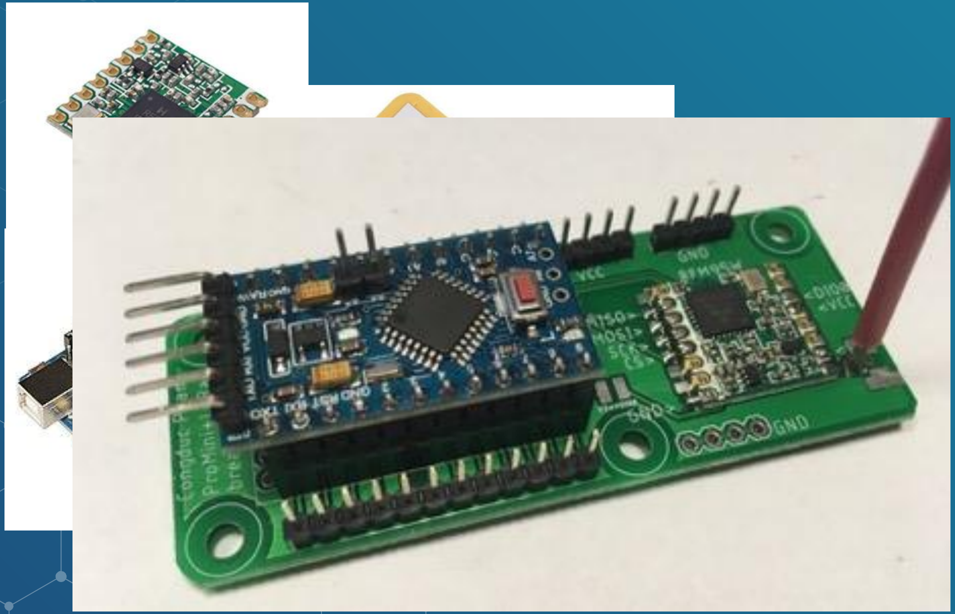
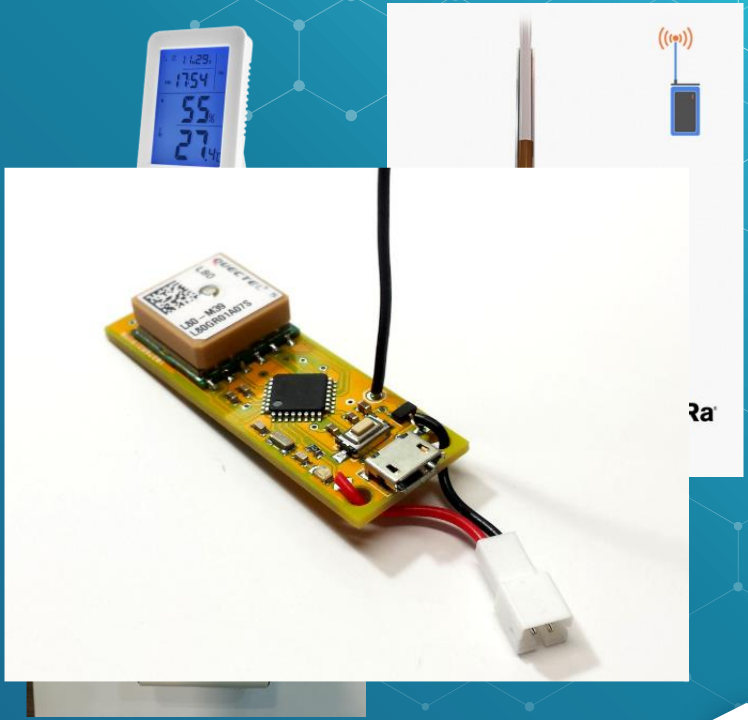


Figure 7: Maximum throughput per end-device and per channel [10].

PCB design

PCB design





PLATFORM

https://www.chirpstack.io/

ChirpStack

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THANKS!

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