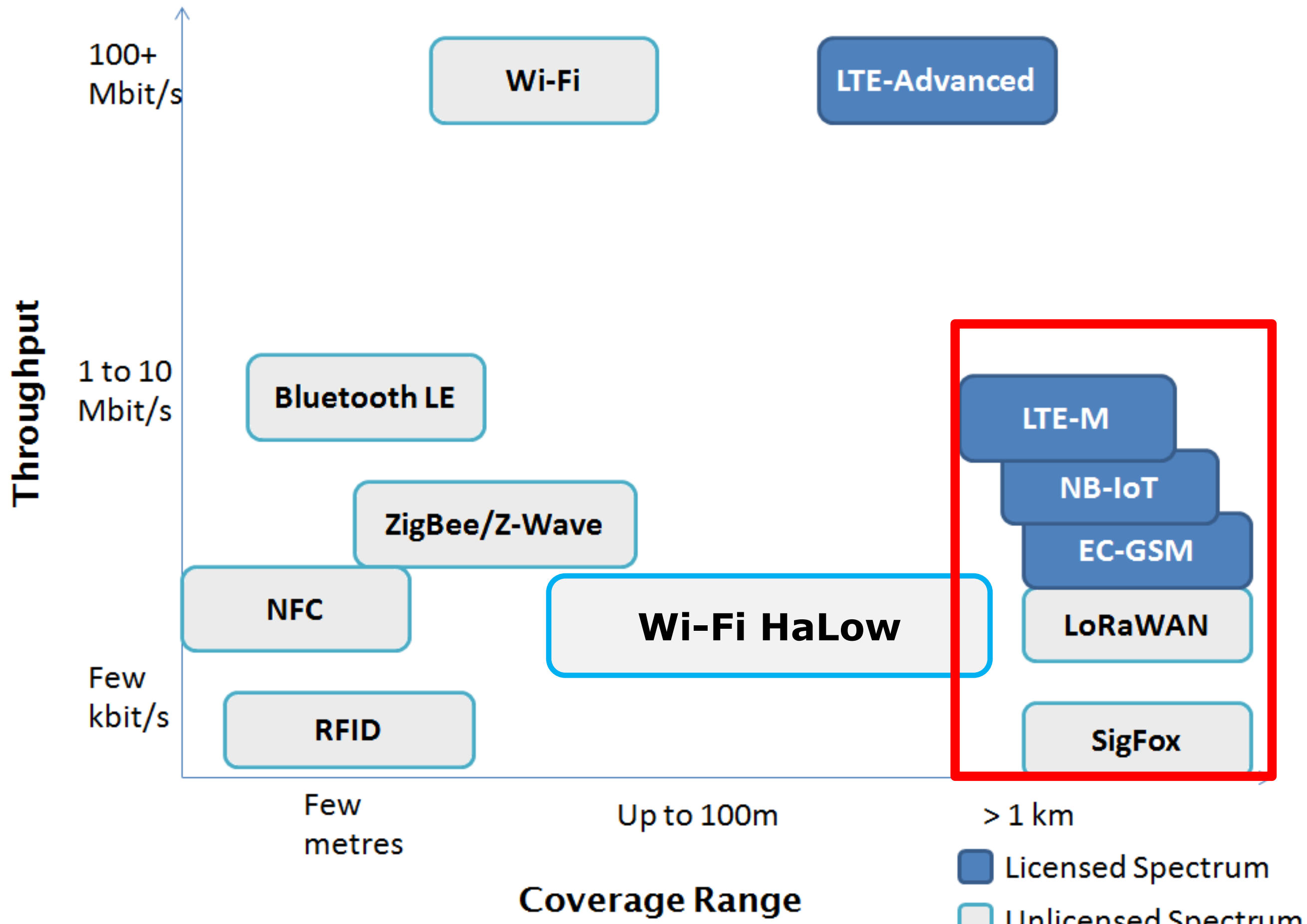
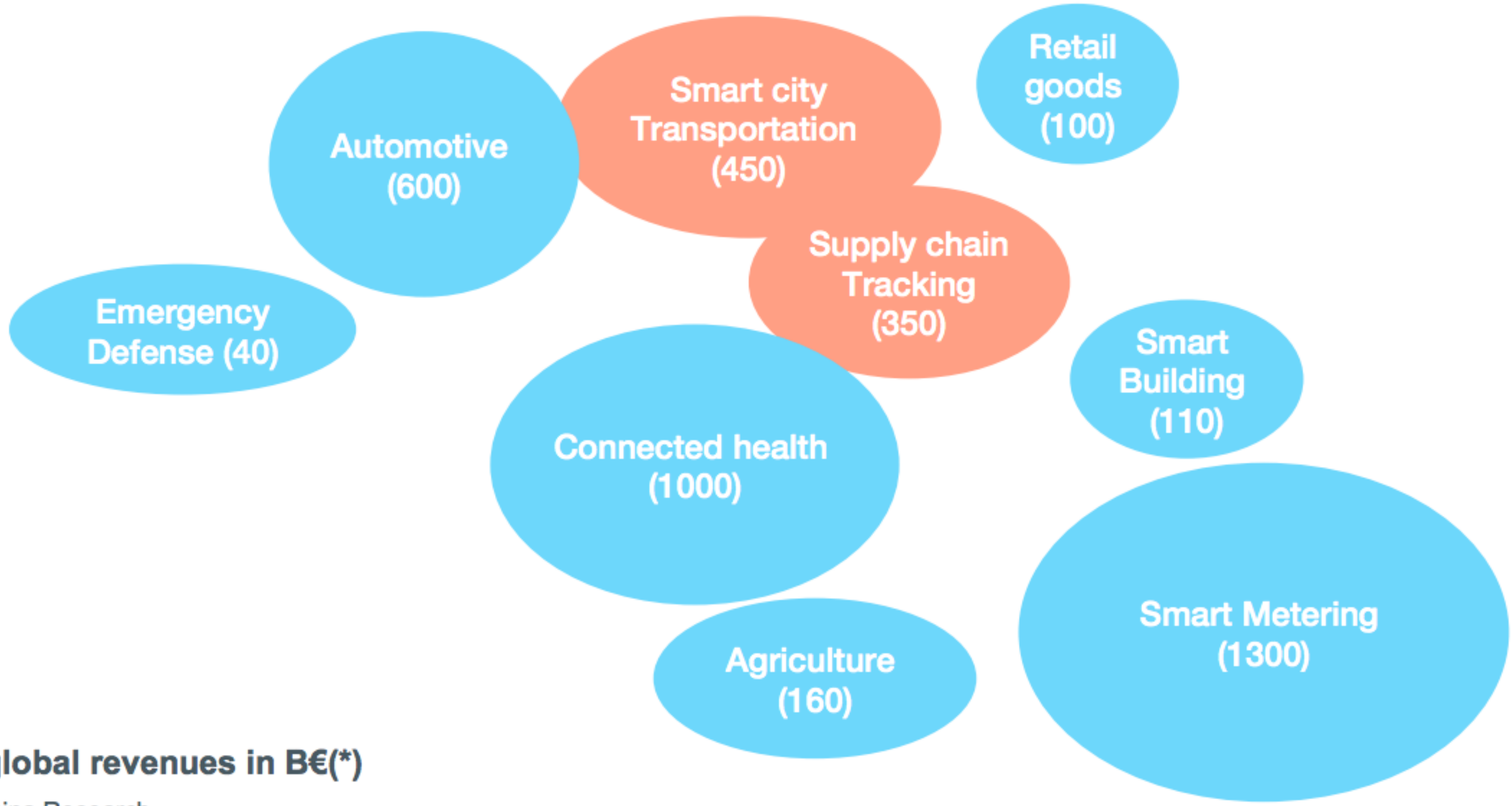
The Long Range Communication Technologies for IoT

Lang Range Communication Technologies



LPWAN Market Perspectives



In 2020, global revenues in B€(*)

Source: Machina Research

Long Range Connectivity Offer

LPWA

sigfox

LoRaWAN™

Mobile IoT

NB-IoT

LTE-M

5G world

5G eMBB

5G mMTC

5G URLLC

Unlicensed mobile

MULTEFIRE

Lte U

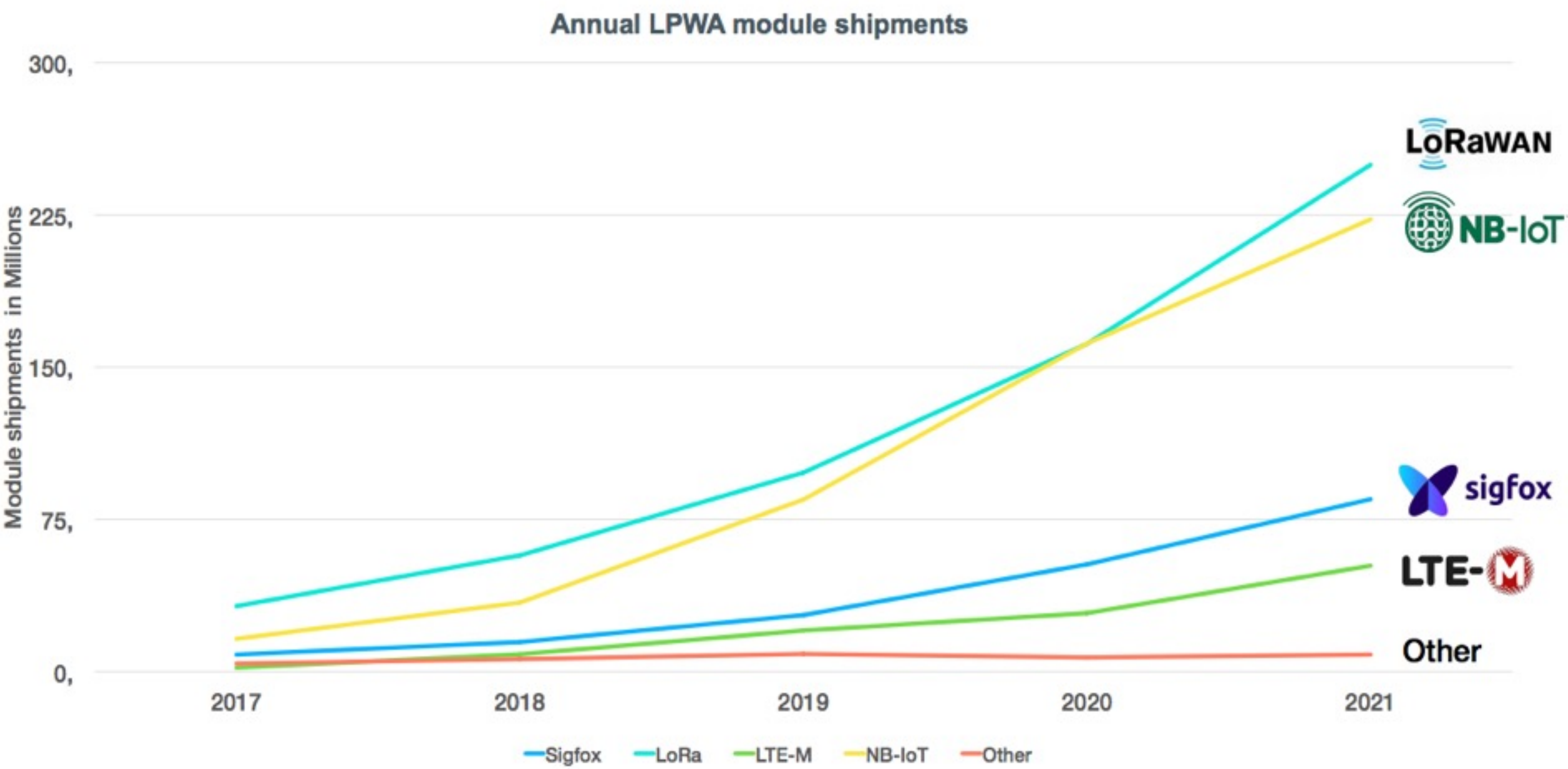
5G NR -U

WLAN

M-Bus wireless

WiFi HaLow

LPWAN Hardware



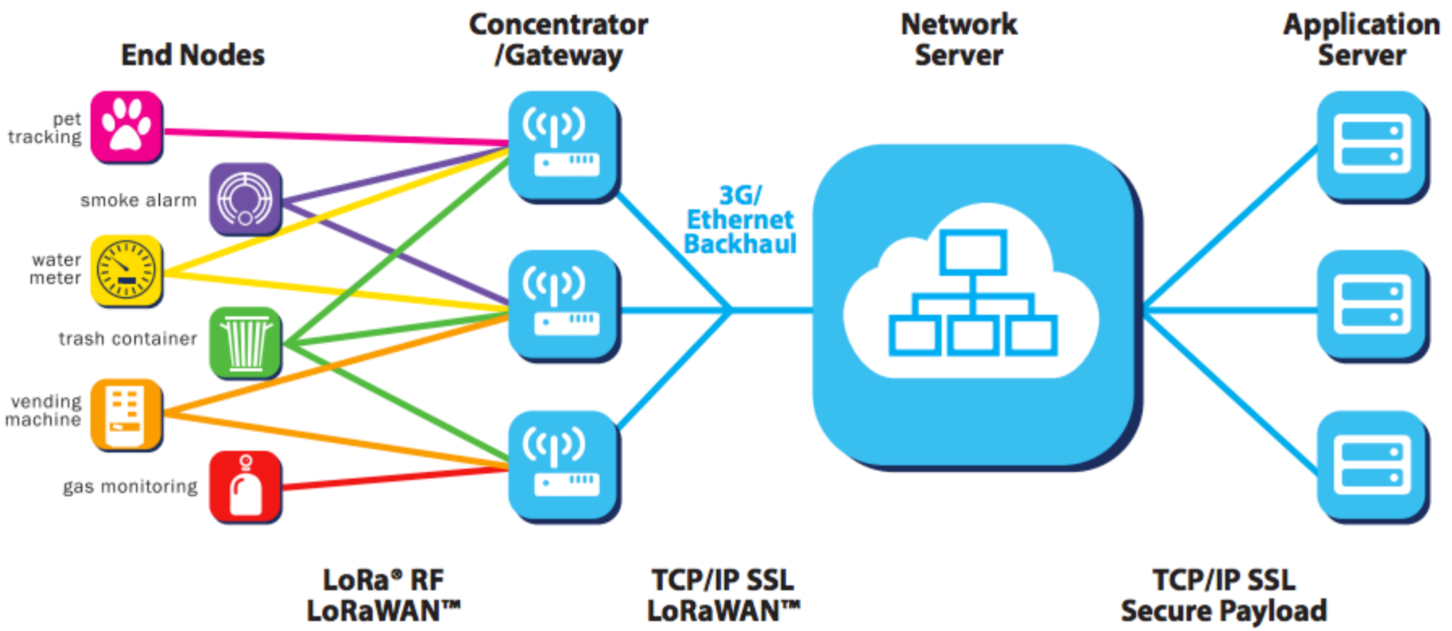
Cellular IoT Operators

- Value proposition
  - Lowest TCO
  - Lowest Energy Consumption
  - Out of the box connectivity
  - Global Reach

	SigFOX	LoRaWAN		Weightless			Ingenu
		EU	US	-W	-N	-P	
Spectrum	868-902MHz	863-870MHz 433MHz	902-928MHz	470-790MHz TV white spaces	sub GHz (ISM)	sub GHz (ISM)	2450 MHz
Channel Width	100Hz	125kHz-250kHz	125kHz-500kHz	6-8MHz	200Hz	12.5kHz	1MHz
TX Rate UL	$\leq$100b/s	250b/s-50 b/s	980b/s-kb/s	250b/s-50kb/s	250b/s	200b/s -100kb/s	624kb/s
TX Rate DL	256b/day	250b/s-50 kb/s	980b/s-21.9kb/s	2.5kb/s-16Mb/s	none	200bytes -100kb/s	156[kb/s]
Packet Size	$\leq$ 12bytes	$\leq$ 222bytes	$\leq$ 222 bytes	$\geq$ 10 bytes	$\leq$ 20bytes	$\geq$ 10 bytes	6bytes-10kbytes
Max Range	10-50km	2-15km		5km	3km	2km	100km
TX power UL	10μW-100mW	14dBm	20dBm	17dBm	17dBm	17dBm	20dBm
Standard (if any)	Proprietary	standard available	standard available	standard available	standard available	standard in the works	proprietary

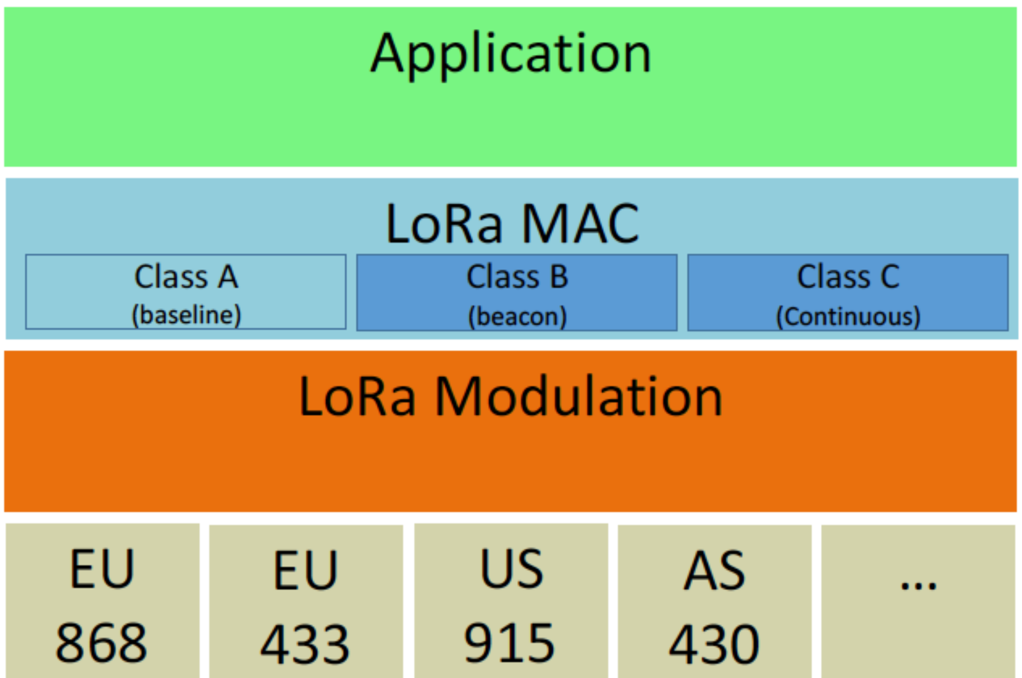
LoraWAN Architecture

A Technical Overview of LoRa and LoraWAN, LoraAlliance



- Association-less, cellular-like architecture
- End devices: field devices
- Gateways: receive and forward messages from end devices (and network server)
- Network server: where all the intelligence is
  - Remove duplicate messages, manages ACKs, manages radio link parameters, etc.

LoraWAN Protocol Stack



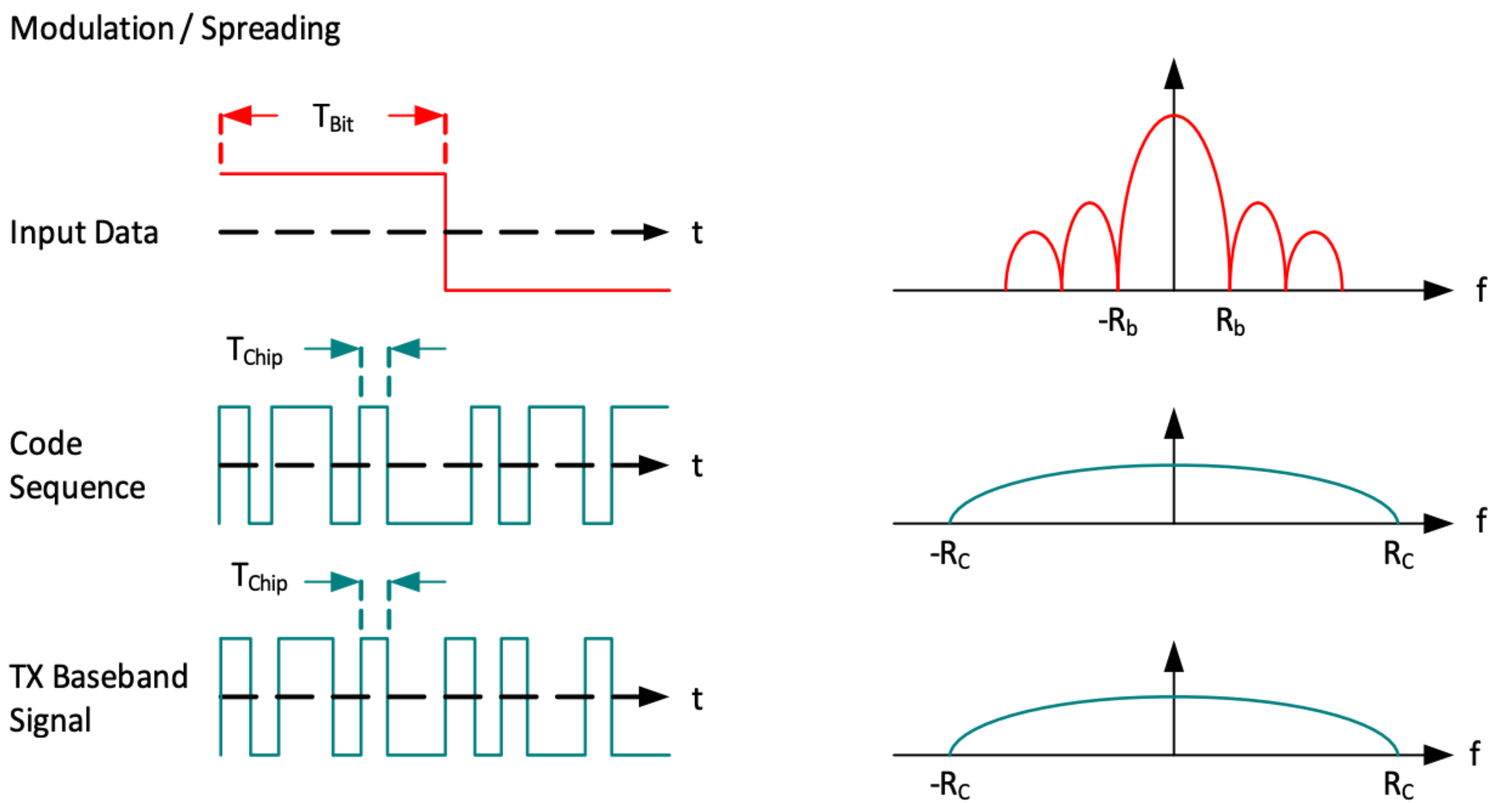
Open source

Proprietary
By SemTech™

Region-specific
Carrier frequency [MHz]

LoRa™ Modulation

- Proprietary chirp-based spread spectrum
- Signal is chipped at a higher data rate and modulated onto a chirp signal



Chip and bit Rates

- The chip rate [chip/s] and the nominal bit rate [bit/s] are related by the following formulas

$$R_c = BW \quad [chips/s]$$

$$R_b = SF \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}} \quad [b/s]$$

- Where BW is the reference bandwidth and SF is the adopted *spreading factor*

How to Choose?

- Two contrasting objectives:
  - Rate: “I want to go fast” (low SF)
  - Reliability: “I want to go safe” (high SF)

How to Choose?

- For a given emitted power level
  - Rate increases as SF decreases

$$R_b = SF \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}} \quad [b/s]$$

DataRate	Configuration	Indicative physical bit rate [bit/s]
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..15	RFU	

How to Choose?

- For a given emitted power level
  - Sensitivity decreases (reliability increases) as SF increases

$$P_{min} = -174 + 10log_{10}BW + NF + SNR$$

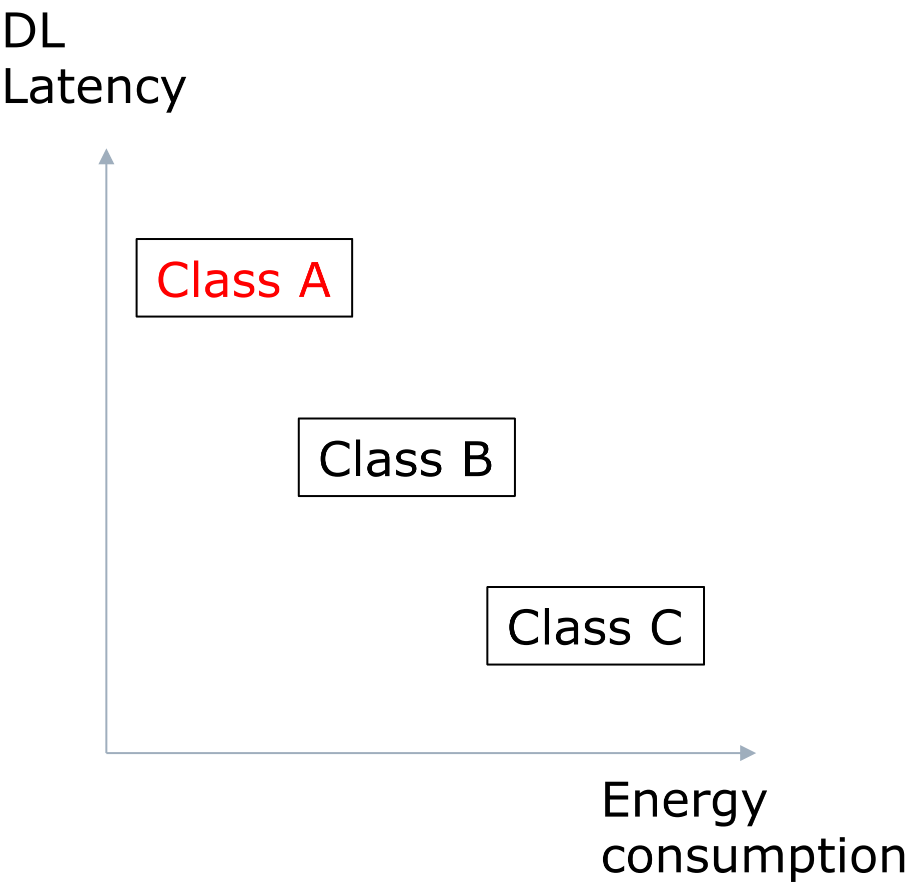
(SNR is inversely proportional to SF)

M. Bor, et al., Do LoRa Low-Power Wide-Area Networks Scale?, Mswim 2016

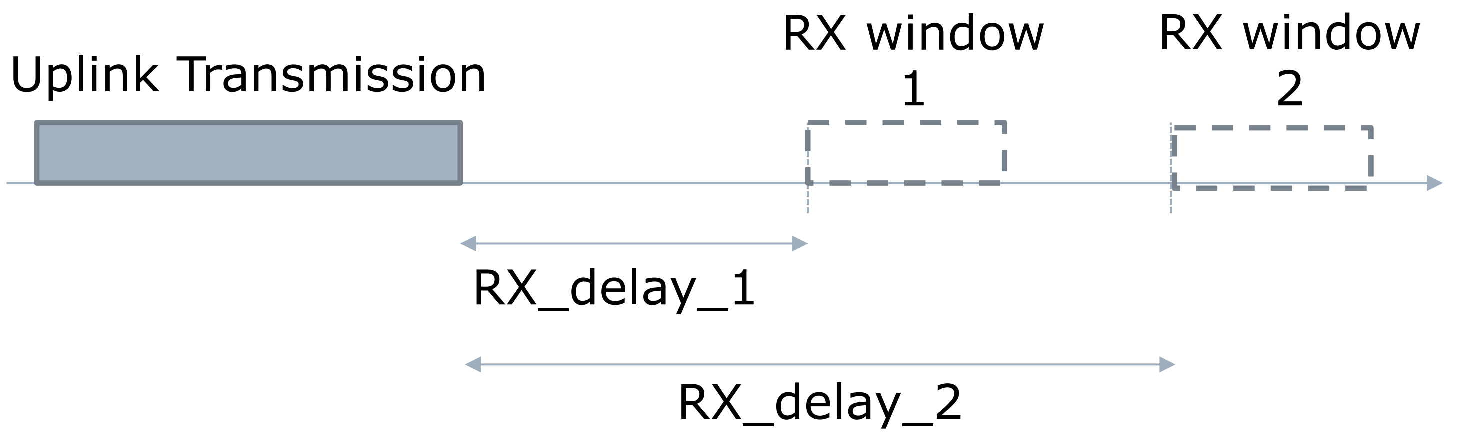
	Bandwidth (kHz)		
SF	125	250	500
7	−126.50	−124.25	−120.75
8	−127.25	−126.75	−124.00
9	−131.25	−128.25	−127.50
10	−132.75	−130.25	−128.75
11	−134.50	−132.75	−128.75
12	−133.25	−132.25	−132.25

LoraWAN End Devices

- *Class A:*
  - Downlink “slots” following uplink transmissions
  - ALOHA-like access in the uplink
- *Class B:*
  - “extra” downlink ”slots” available in a scheduled fashion
- *Class C:*
  - Almost continuous downlink “slots”

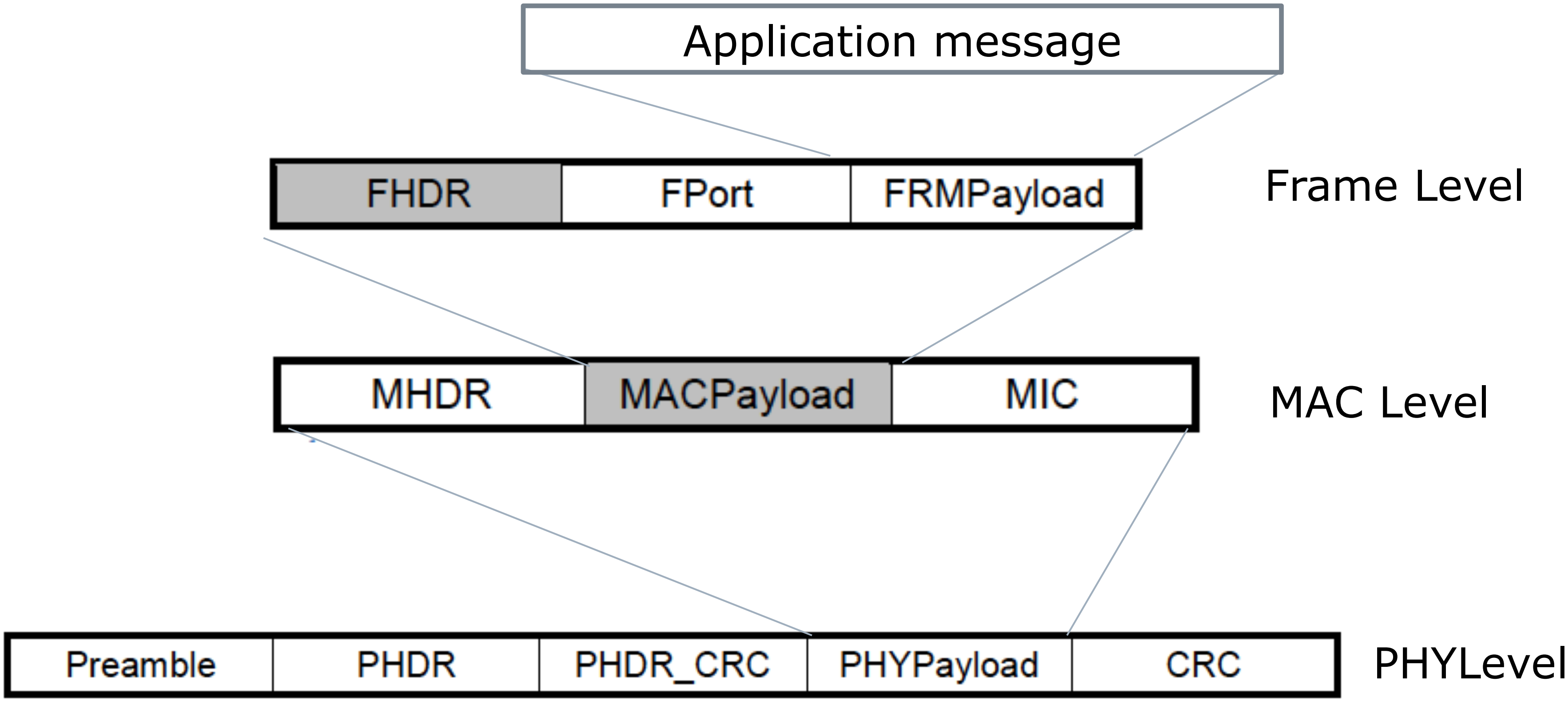


LoraWAN Class A Devices



- In EU: RX_delay_1 = 1[s]; RX_delay_2= RX_delay_1 + 1[s]
- If a preamble is detected during one of the receive windows, the radio receiver stays active until the downlink frame is demodulated
- If a frame was detected and subsequently demodulated during the first receive window and the frame was intended for this end-device after address and MIC (message integrity code) checks, the end-device does not open the second receive window

LoraWAN Encapsulation

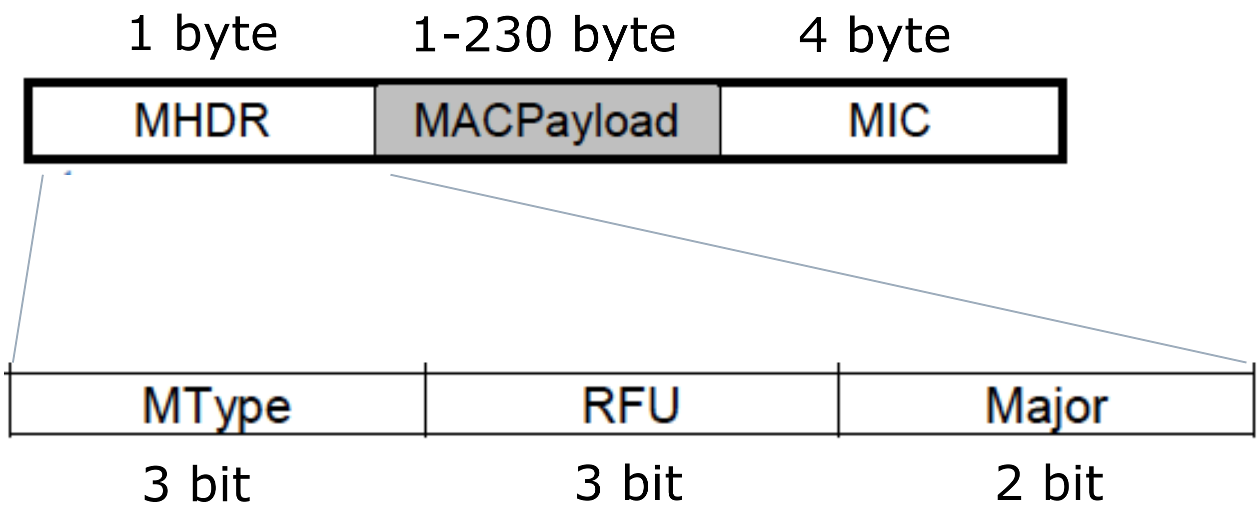


PHY Message structure

Preamble	PHDR	PHDR_CRC	PHYPayload	CRC

- *Preamble*
- *Physical HeaDeR (PHDR)*
- *PHDR_CRC, CRC*: fields used for integrity check
- *PHYPayload:* PHY message content

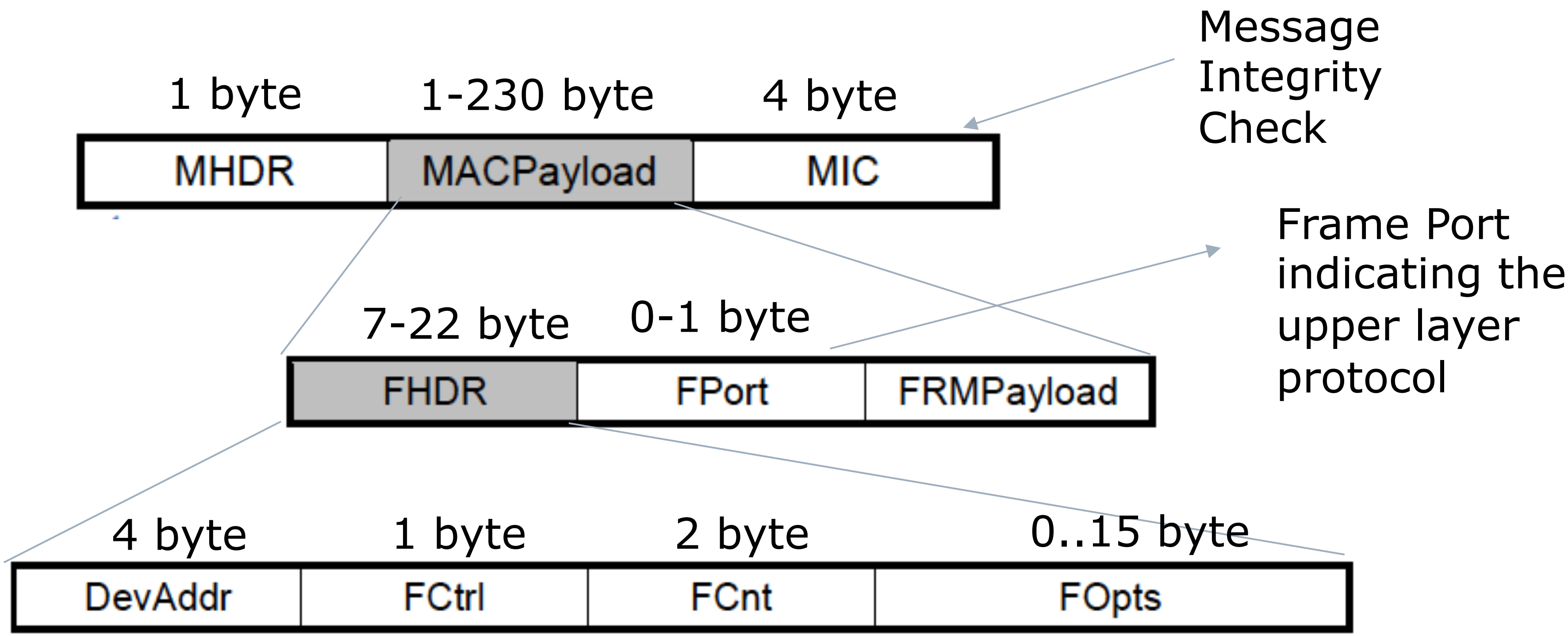
MAC Message Header



- *Mtype*: message type
- *RFU*: reserved for future use
- *Major*: tells the message format

MType	Description
000	Join Request
001	Join Accept
010	Unconfirmed Data Up
011	Unconfirmed Data Down
100	Confirmed Data Up
101	Confirmed Data Down
110	RFU
111	Proprietary

MAC message payload



- *DevAddr*: end device address
- *FCtrl*: frame control field to manage adaptive data rate, ACK and MAC commands
- *FCnt*: frame counter to count up each transmitted frame
- *Fopts*: frame options containing MAC commands

Frame Control Field

4 byte	1 byte	2 byte	0..15 byte
DevAddr	FCtrl	FCnt	FOpts

	1 bit	1 bit	1 bit	1 bit	4 bits
DL	ADR	ADRACKReq	ACK	FPending	FOptsLen

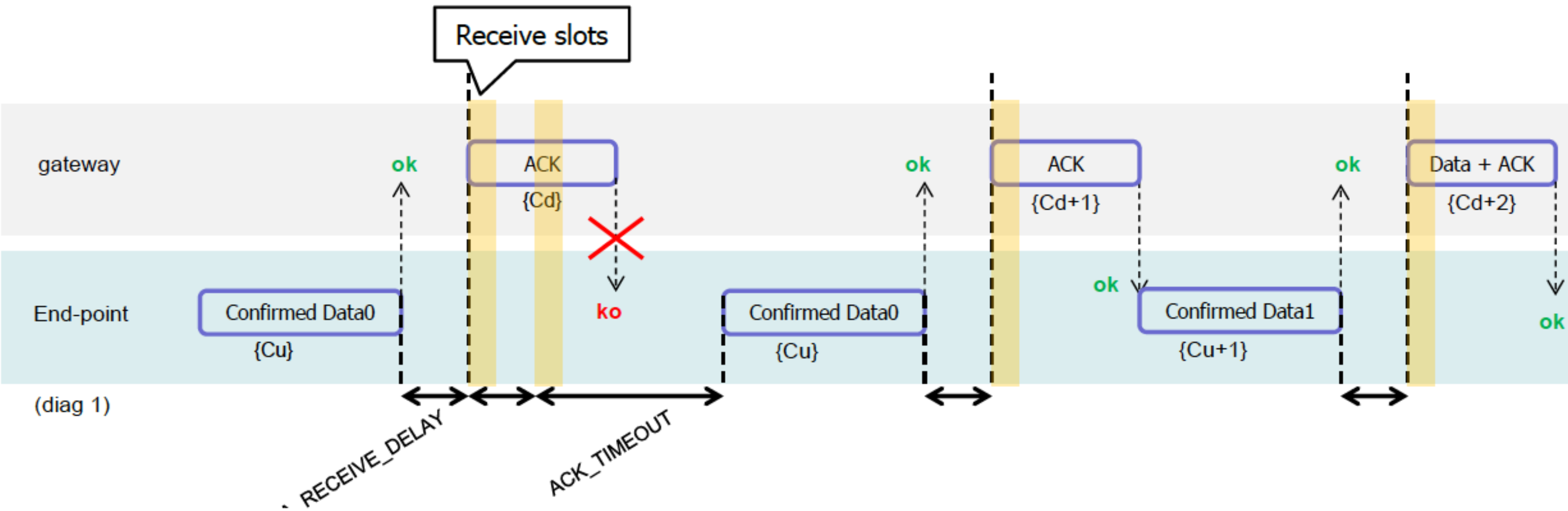
	1 bit	1 bit	1 bit	1 bit	4 bits
UL	ADR	ADRACKReq	ACK	RFU	FOptsLen

- *ADR (adaptive data rate)* and *ADRACKReq* are used to manage adaptively the uplink/downlink data rate
- ACK: is used as valid acknowledgement
- *Fpending* is used to signal (in DL) the presence of additional frame to be delivered to the device
- *FOptsLen* indicates the size (in bytes) of the *FOpts*

Frame Options, aka MAC Commands

CID	Command	Transmitted by		Short Description
		End-device	Gateway	
0x02	***LinkCheckReq***	x		Used by an end-device to validate its connectivity to a network.
0x02	***LinkCheckAns***		x	Answer to LinkCheckReq command. Contains the received signal power estimation indicating to the end-device the quality of reception (link margin).
0x03	***LinkADRReq***		x	Requests the end-device to change data rate, transmit power, repetition rate or channel.
0x03	***LinkADRAns***	x		Acknowledges the LinkRateReq.
0x04	***DutyCycleReq***		x	Sets the maximum aggregated transmit duty-cycle of a device
0x04	***DutyCycleAns***	x		Acknowledges a DutyCycleReq command
0x05	***RXParamSetupReq***		x	Sets the reception slots parameters
0x05	***RXParamSetupAns***	x		Acknowledges a RXSetupReq command
0x06	***DevStatusReq***		x	Requests the status of the end-device
0x06	***DevStatusAns***	x		Returns the status of the end-device, namely its battery level and its demodulation margin
0x07	***NewChannelReq***		x	Creates or modifies the definition of a radio channel
0x07	***NewChannelAns***	x		Acknowledges a NewChannelReq command
0x08	***RXTimingSetupReq***		x	Sets the timing of the of the reception slots
0x08	***RXTimingSetupAns***	x		Acknowledge RXTimingSetupReq command
0x80 to 0xFF	Proprietary	x	x	Reserved for proprietary network command extensions

LoraWAN Class A Uplink TX example

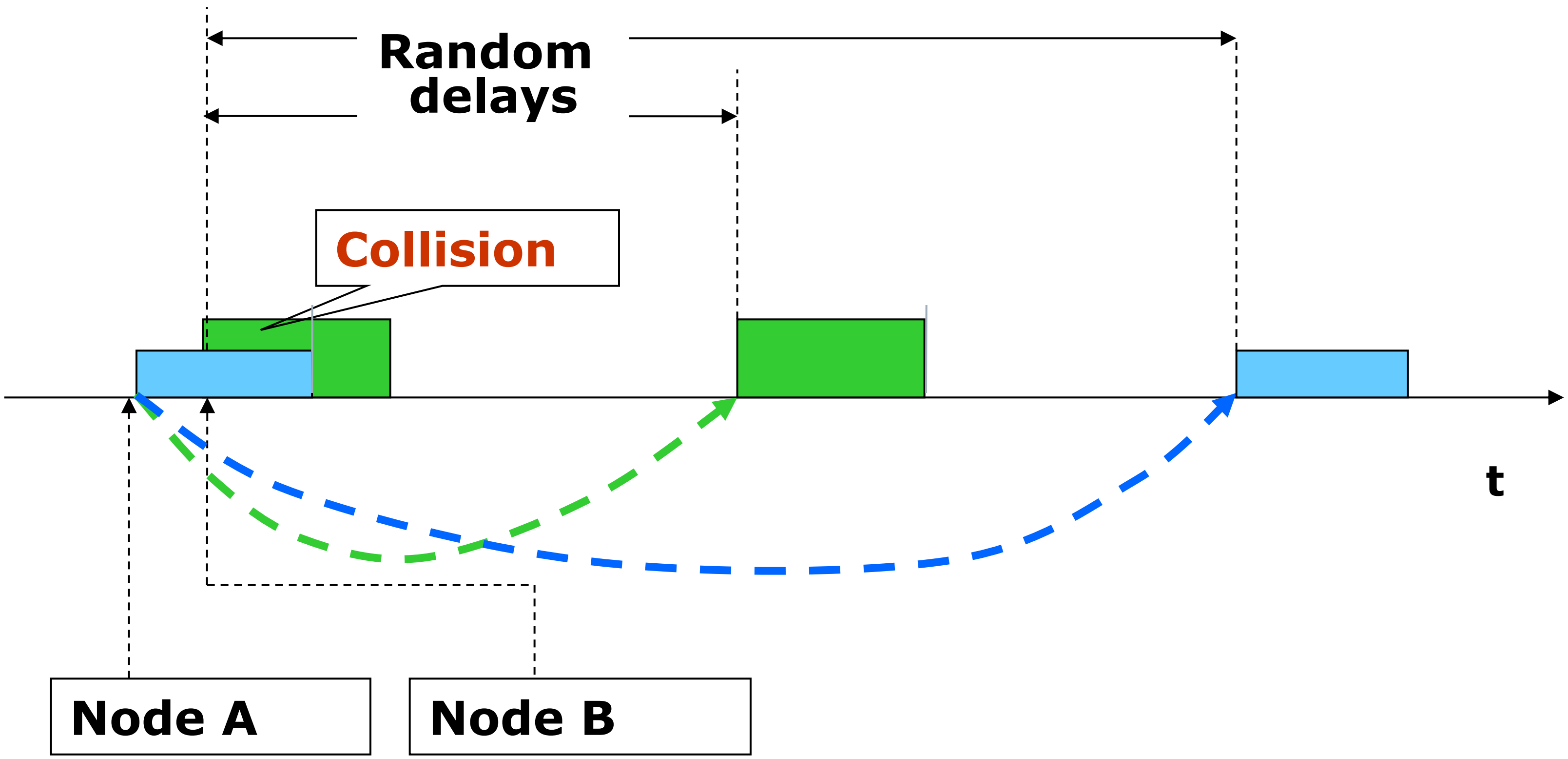


- ALOHA-like procedure to handle channel access and retransmissions
  - If a confirmed message is not acknowledged, the message is retransmitted after a random time-out (ACK_TIMEOUT)
  - ACK_TIMEOUT is randomly drawn in the interval 1[s]-3[s] and starts at the end of Receive_window2

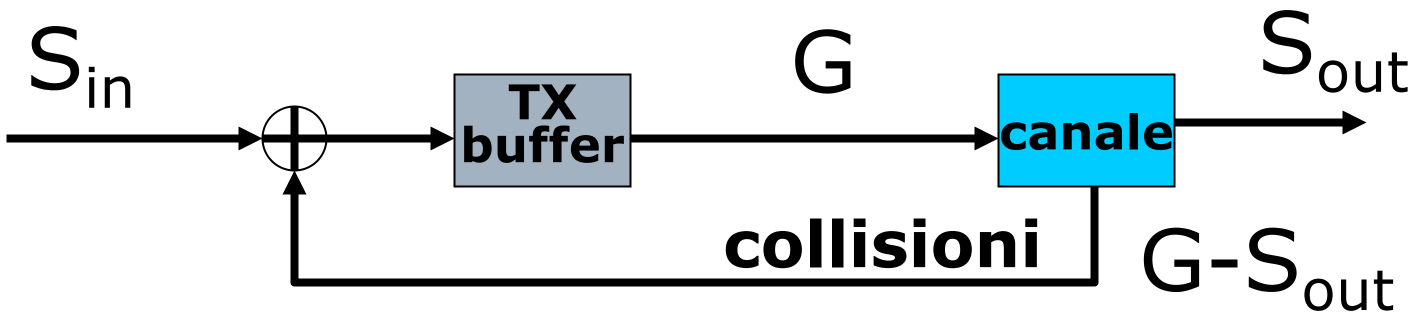
ALOHA Protocol

- No channel feedback required, only the ACK
- Time is continuous
- Protocol:
  - The first packet in the transmission queue is transmitted as soon as ready
  - If the ACK does not come, the transmission is re-attempted after a random number of slots X

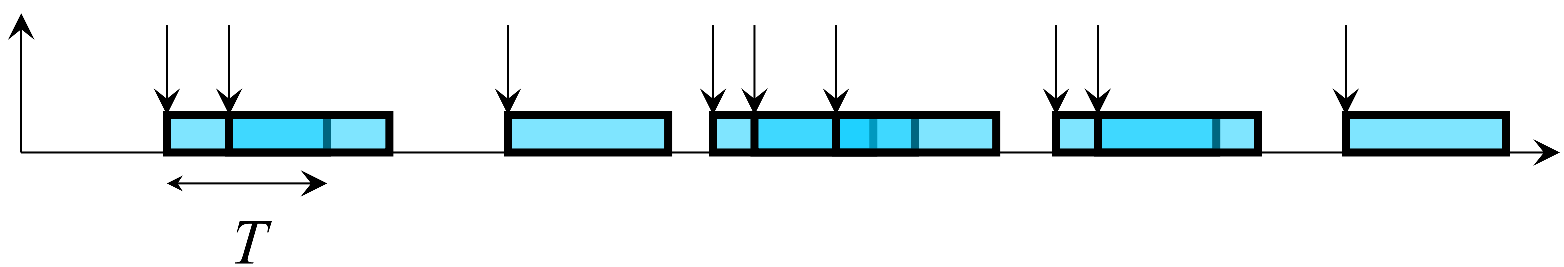
ALOHA retransmissions



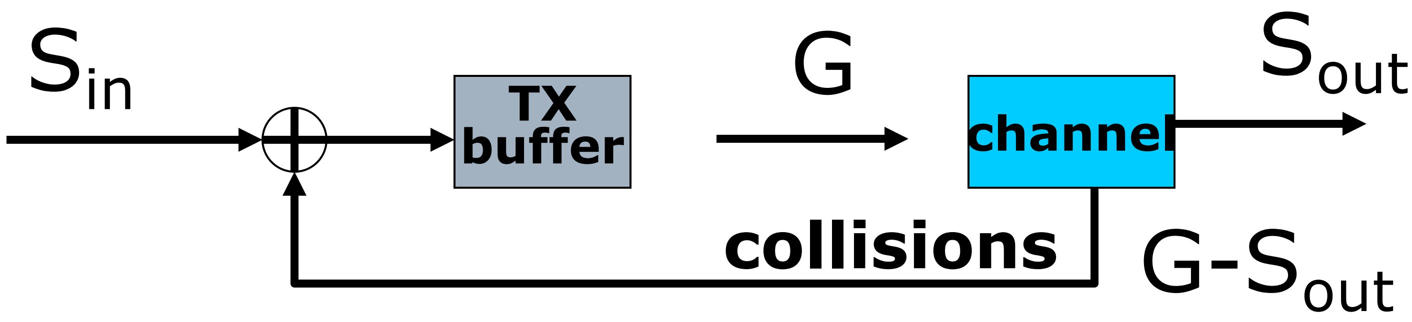
ALOHA performances



- Assumptions:
  - Stationarity: $S_{in}=S_{out}$
  - Traffic G distributed according to Poisson process
    - Packet arrivals is a Poisson point process with parameter λ
    - Transmissions last T
    - $G=T \times \lambda$



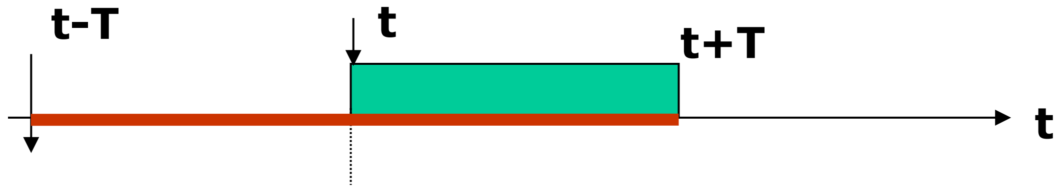
ALOHA performances



- S_{in} incoming traffic
- S_{out} outgoing traffic
- G traffic on the channel: transmissions + retransmissions
- $S_{out}<=G$

ALOHA performances

- The probability P_s for a packet transmission to be successful is the probability that no other packet starts transmission in "conflict" period of 2T



$$P_s = P(N(t-T, t+T) = 0) = e^{-2G}$$

- The throughput is:

$$S = GP_s = Ge^{-2G}$$

LoraWAN Performance Evaluation

- LoraWAN stations may have different SF -> transmission durations
- Setting
  - N_1 stations, with arrival frequency λ_1 and transmission duration T_1
  - N_2 stations, with arrival frequency λ_2 and transmission duration T_2

LoraWAN Performance Evaluation

- The probability that a transmission of type *i* (1,2) collides, P_i is:

$$P_1 \approx 1 - e^{-(N_1\lambda_1)2T_1} e^{-N_2\lambda_2(T_1+T_2)}$$

$$P_2 \approx 1 - e^{-(N_2\lambda_2)2T_2} e^{-N_1\lambda_1(T_1+T_2)}$$

- The probability that a generic transmission collides is:

$$P = \frac{\lambda_1 N_1}{\lambda_1 N_1 + \lambda_2 N_2} P_1 + \frac{\lambda_2 N_2}{\lambda_1 N_1 + \lambda_2 N_2} P_1$$

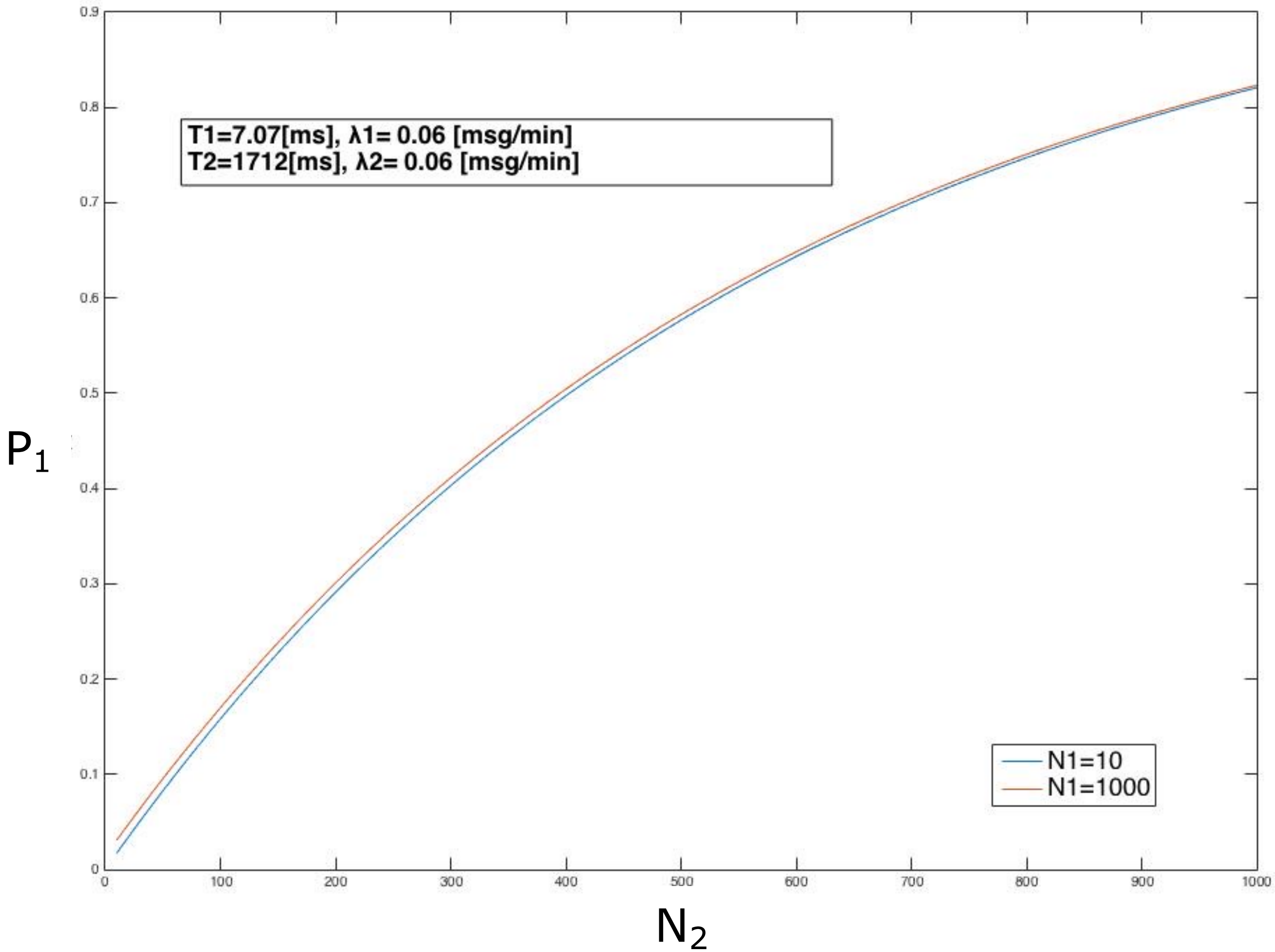
LoraWAN Performance Evaluation

- The previous expressions can be generalized in case of *n* different classes of stations with transmission duration T_i, scale N_i and arrival frequency λ_i

$$P_i \approx 1 - \prod_{k=1}^{n} e^{-(N_k \lambda_k)(T_i + T_k)}$$

$$P = \sum_{i=1}^{n} \frac{\lambda_i N_i}{\sum_{i=1}^{n} \lambda_i N_i} P_i$$

Example


T1=7.07[ms], λ1= 0.06 [msg/min]
T2=1712[ms], λ2= 0.06 [msg/min]
N1=10
N1=1000
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
900
1000
P1
N2

LoRaWAN Ecosystem

- ***Devices***: Any
- ***Gateways***: Kerlink, Multitech, Lorrier, CISCO, Gemtek, Advantech, TTI, Loriot, Lorix
- ***Network Servers***: TTI, Actility, Patavina (A2A), Loriot
- ***(ITA) Public Network Operators****: A2A Smart City, Telemar, UNIDATA*