Communications & Controls in IoT

LoRaWAN and Cellular Technologies

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INTERNATIONAL INSTITUTE OF
INFORMATION TECHNOLOGY

HYDERABAD

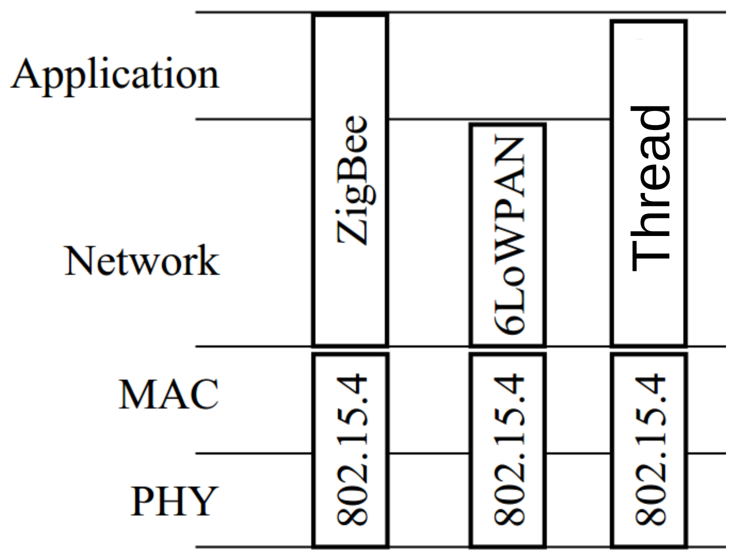
Recap

IEEE 802.15.4

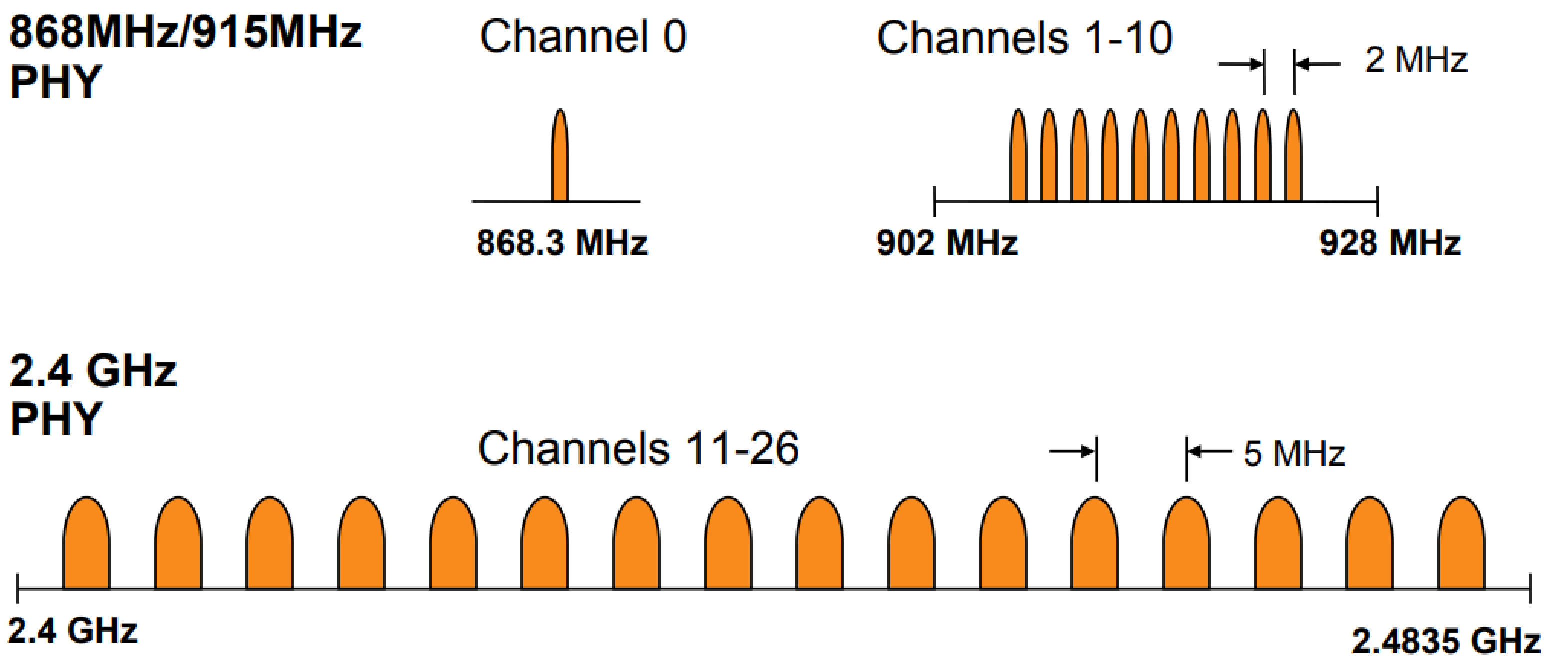
Ref: K. Sohraby, D. Minoli, T. Znati, *Wireless Sensor Networks,* Wiley, 2007

IEEE 802.15.4

- IEEE 802.15.4 defines the operation of low-rate wireless personal area networks (LR-WPANs)
- Widely used in wireless sensor-network (WSN) applications
  - Vast number of industrial, home and medical applications
- It specifies the physical layer (PHY) and media access control (MAC) for LR-WPANs
- Does not have IP address
- Used by several “Internet of Things” protocols:
  - ZigBee, 6LowPAN, Thread, WiSuN etc.



Physical Layer (PHY): *Operating Frequency Bands*



https://people.eecs.berkeley.edu/~prabal/teaching/cs294-11-f05/slides/day21.pdf

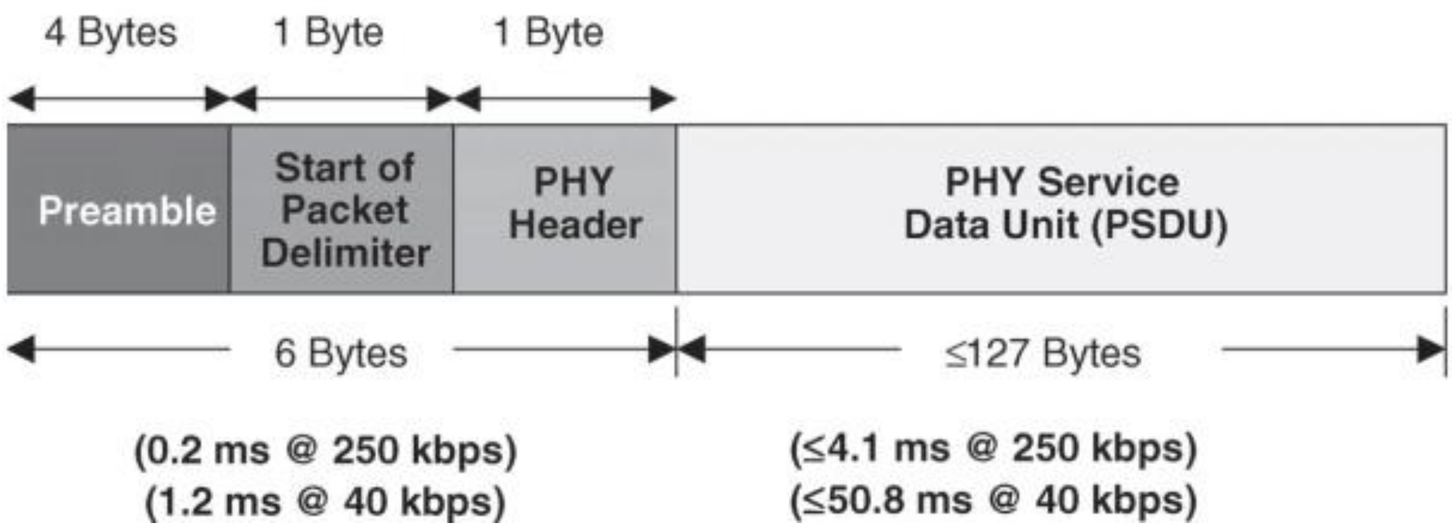
PHY: *Modulation Parameters*

Freq. band (MHz)	Spreading Parameters		Data Parameters		
	Chip rate (kchip/s)	Modulation	Bit rate (kbps)	Symbol rate (ksymbol/s)	Symbols
868	300	BPSK	20	20	Binary
915	600	BPSK	40	40	Binary
2400	2000	O-QPSK	250	62.5	16-ary

[Koubaa2007]

All bands are based on Direct sequence spread spectrum (DSSS), a form of CDMA

PHY-layer packet structure



- Preamble -> Symbol synchronization
- Packet delimiter -> Frame synchronization
- PHY header: length of the PSDU
- PSDU can carry upto 127 bytes

MAC Layer features

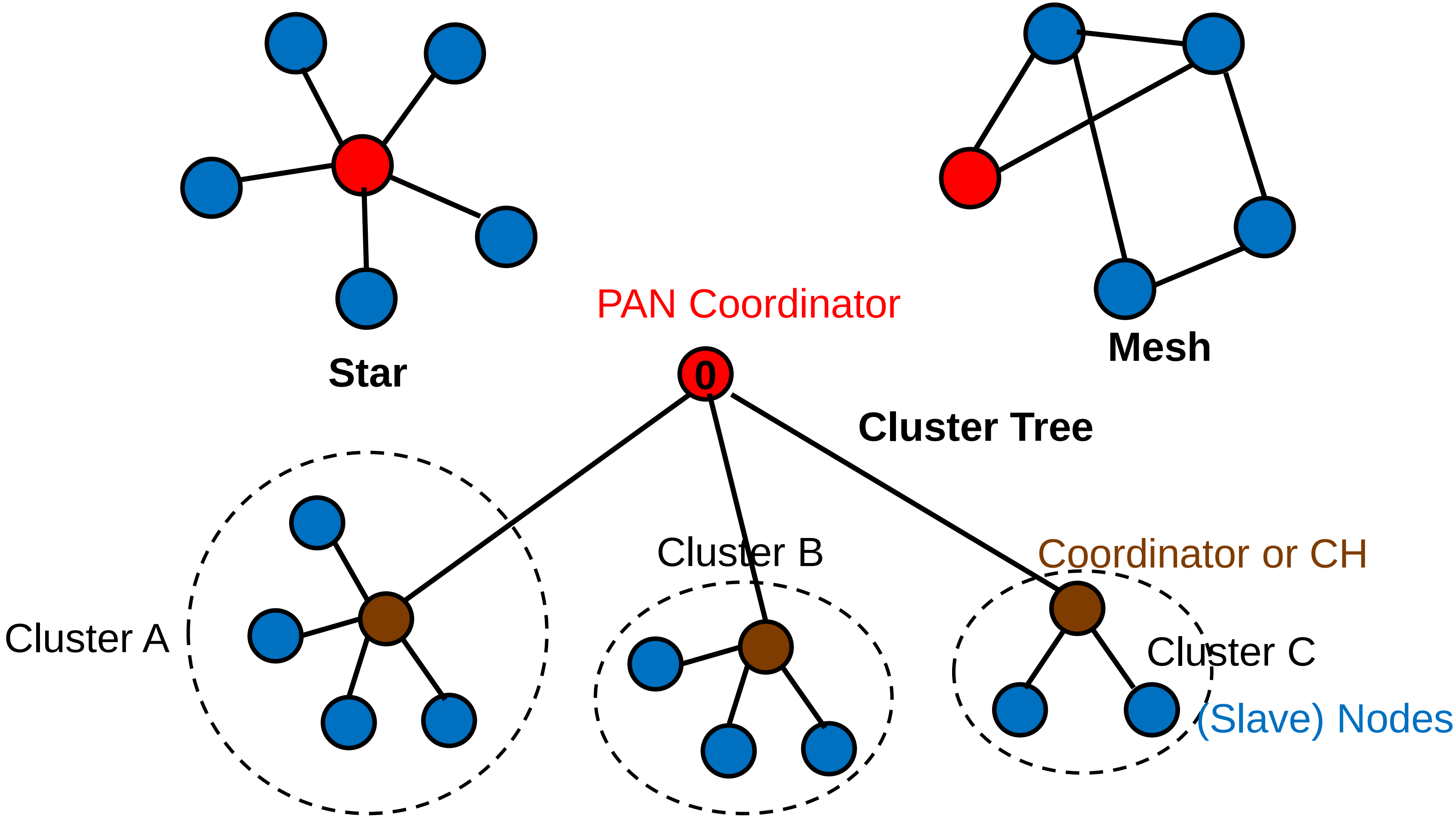
- Designed to support vast number of industrial and home applications for control and monitoring
- Enabling deployment of large number of devices with low cost and complexity
- Several features for flexible network configuration and low-power operation
  - Different topologies and network devices
  - Optional superframe structure with duty-cycle control
  - Both contention and scheduled based MAC protocols
  - Synchronized and non-synchronized operation
  - Efficient energy management
    - Adaptive sleep
    - Extended sleeping time
  - Flexible addressing scheme for large number of nodes

MAC Layer: *Device Types*

Two kind of devices in IEEE 802.15.4 based on complexity and capability

- Fully functional devices (FFD)
  - More resources
  - Multiple network responsibilities
- Reduced functionality devices (RFD)
  - Simple and low-cost device
  - Can only communicate with one FFD

Topologies: *Zigbee (Network Layer)*



- 16 bit addresses support 65536 devices in a PAN. For clusters, 255 clusters with 254 nodes each
- Self recovering ability

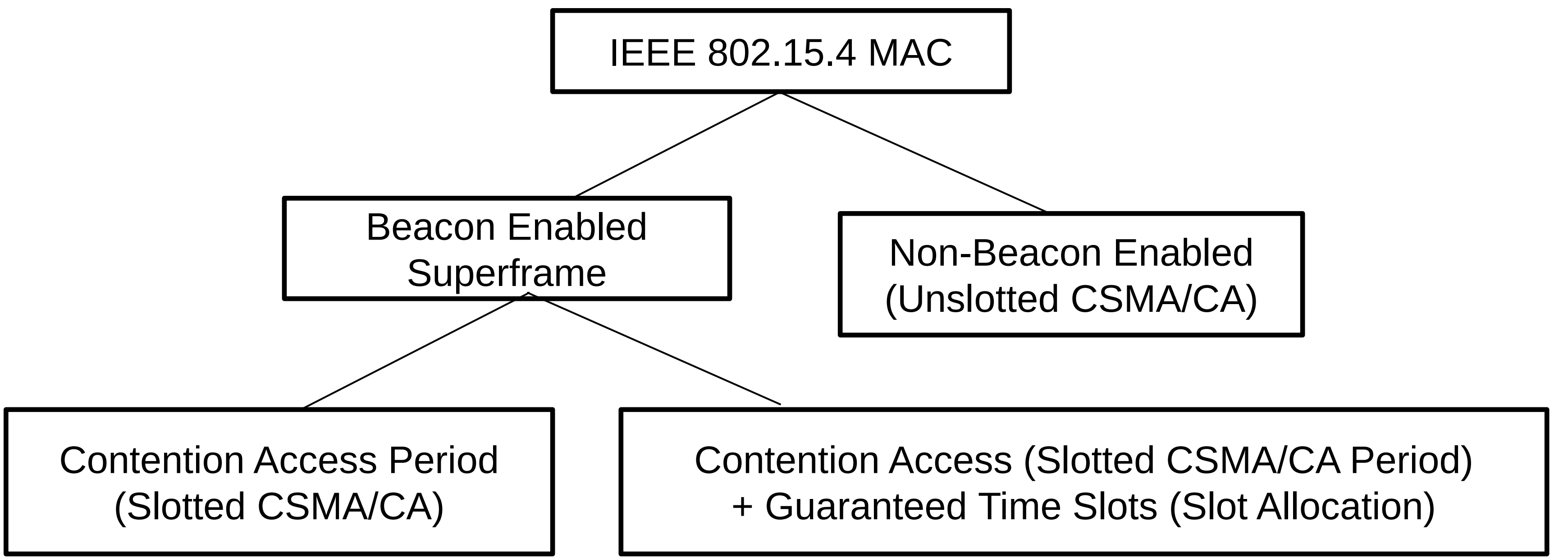
Zigbee Node Types

Zigbee defines three kinds of logical devices

- **PAN coordinator or Master**
  - Principal controller of network
  - Managing list of all network devices or nodes
  - Identifies PAN and nodes associated with it
  - Provides global synchronization by transmitting beacon frames containing relevant information
- **Coordinator or cluster head (CH)**
  - Same functionalities as PAN coordinator locally in cluster
  - Managing association and disassociation of other nodes to PAN
  - Does not create its PAN
- **Simple (Slave) Nodes**
  - No coordination functionalities
- PAN Coordinator and CH are **FFD** while slave nodes are **RFD**

MAC layer functions

- Network association and disassociation
- Two modes of operation
  - Beaconing
  - Non-beaconing



IEEE 802.15.4 Versions

- Since the first version in 2003, new amendments are constantly being introduced.
- Modifications
  - New country specific (frequencies, regulation)
  - New application and network specific:
    - SUN: Smart utility meter monitoring
    - LECIM: Low Energy Critical Infrastructure Monitoring
    - RFID: Radio Frequency Identification
    - RCC: Railway Communications and Control
    - TVWS: TV White Space
    - Medical
  - New PHY specific
    - OFDM, ASK, FSK, QAM, GMSK, MSK, OOK
  - New Protocols
    - TSCH, Aloha, PCA

L. Alkama, L. Medjkoune, “EEE 802.15.4 historical revolution versions: A survey”, Springer Nature 2021

IEEE 802.15.4u-2016: *India specific*

PHY (MHz)	Frequency band (MHz)	Modulation	Data-rate (kb/s)	Number of channels
866	865-867	2-FSK mode 1	50	19
		2-FSK mode 2	100	10
		2-FSK mode 3	150	10

- Needed for M2M/IoT use cases in sub 1 GHz band in India
- Approved in Sept. 2016 as a third amendment to IEEE 802.15.4-2015
  - IEEE 802.15.4n-2016
  - IEEE 802.15.4q-2016
- Defines a new alternate SUN FSK PHY extension in the 866 MHz band

Zigbee Versions

- 2005 – Zigbee 2004 released
- 2006 – Zigbee 2006 released
- 2007 – Zigbee 2007 released (also known as Zigbee Pro)
- 2015 – Zigbee 3.0 version (with IP)
- 2019 – Zigbee Alliance merges into **Connectivity Standards Alliance**
  - Amazon, Apple, Google and Zigbee Alliance
  - Develop a new open standard for smart home device connectivity
  - Connected home over IP (CHIP) project
  - **Matter as home connectivity technology**
    - **In addition to IEEE 802.15.4, Matter also supports Ethernet and WiFi**

Zigbee Green Power

- Integrating battery-less (energy harvesting-based) or life-long battery-operated devices into the Zigbee network

Sensors, open/close detectors, emergency buttons, industrial switches, …

- (Light) switch: flipping the switch generates the energy for data-communication

Key IoT Features

Advantages

Source: Zigbee 3.0

- Low power
  - Zigbee (20 mJ per hour)
  - Zigbee Pro (Green Power: 20 microJ per hour)
- Large coverage of 1Km in Sub-GHz band
  - Even more for boosted modules (3.2 km for Xbee)
- Easy to install and maintain (mesh, self-healing, self-organization)
- Reliable (mesh, multiple channels, demonstrated interference tolerance, automated retransmissions)
- Supports thousands of nodes
- Low cost (many suppliers)
- Long battery life (years on AA battery)
- Secure (AES 128 bit)

Issues

- No mobility support, Scalability
- Less coverage area in 2.4 GHz band

WiFi: IEEE 802.11 family

WLAN Standards

	1G	2/3G	4G		5G	6G
	2000	2004	2008	2012	2016	2020
Standard	11b	11a/g	11n	11ac (wave1)	11ac (wave2)	11ax
MCS	Spread Spectrum	OFDM				OFDM (OFDMA)
Freq	2.4GHz	2.4GHz 5GHz				Same Freq (<7GHz)
Bandwidth	20MHz	20MHz	+40MHz	+80MHz	+160MHz	Same BW (+320M)
Multiple Antenna			MIMO Beamforming		MU-MIMO (DL)	MU-MIMO (UL)
PHY Rate	11Mbps	54Mbps	600Mbps (40M,4SS)	1.7Gbps (80M,4SS)	6.7Gbps (160M,8SS)	9.6GHz (160M,8SS)
MAC	CSMA/CA in DCF	Security QoS	Aggregation			BSS Management

https://www.wlanpedia.org/tech/overview/wlan-standard-in-ieee802-11/

802.11ac (5G of WiFi) and 802.11ah (WiFi-Halow)

	802.11ac	802.11ah
Operating Bands	2.4 and 5 GHz	Sub 1-GHz
Spectrum available	100 + 150 MHz	26 MHz
Use Cases	Broadband wireless	Sensors and Meters Extended WiFi
Data Rate Requirement	20 Mbps - 3 Gbps	100 Kbps
Single Frame Size	Large (e.g., 1500 bytes)	Small (e.g., 100 bytes)
Traffic type	Video Streaming/ Large file transfer	Periodic packet transmission every few to tens minutes
Distance between devices	Up to 60 m	Up to 1 Km
Number of stations	3-20	8191
Location	Mostly indoor	Indoor and outdoor
Backward compatibility	Yes	No

[Park2015, Gonzalvez2016]

PHY parameters for 802.11ah

- Use of orthogonal frequency division multiplexing (OFDM)
- Basically adapted a scaled-down version of 802.11ac
  - Bandwidths of 20-160 MHz to 2-16 MHz
  - Same number of subcarrier
  - Increased symbol duration

[Park2015]

Parameters	Supported Values
Channel Bandwidthds	2, 4, 8, and 16 MHz
Modulation Schemes	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM
Code Rates	1/2 with 2 times repetition 1/2 , 2/3, 3/4 and 5/6 Convolution or low-density parity check (LDPC)
MIMO	Support up to 4 by 4
Data Rates	150 Kbps (1 MHz bandwidth, 1 spatial stream, BPSK, ½ coding rate, repetition) to 347 Mbps (16 MHz bandwidth, 4 spatial streams, 256 QAM, 5/6 coding rate)

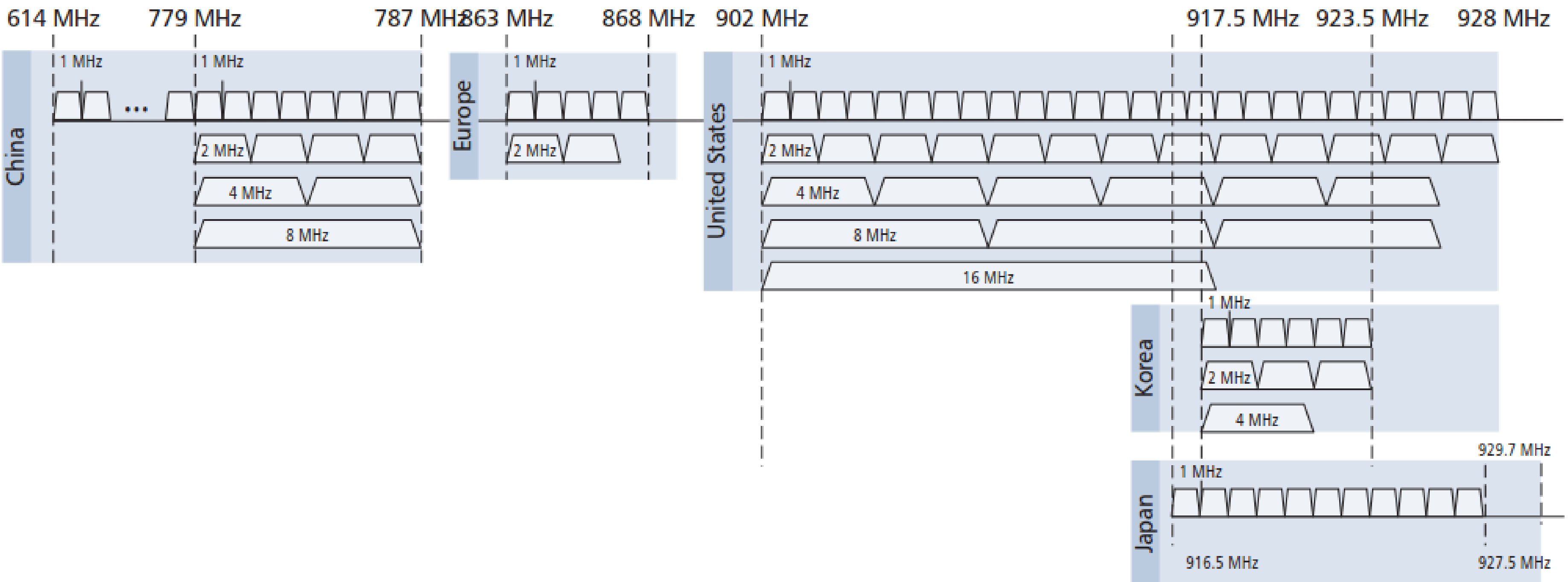
Link Budget Comparison

Parameters	Link budget enhancements of 900 MHz 802.11ah over 2.4 GHz 802.11n
Free space path loss	+8.5 dB
Noise bandwidth	+10 dB
Sub-total link budget gain	+18.5 dB
1 MHz channel width	+3 dB
Repetition coding	+3 dB
Total link budget gain	+24.5 dB

[Park2015]

Low Power and Low Cost Support for Indoor Sensors:
This can reduce the transmit energy consumption and also lower the cost of an 802.11ah radio of a small sensor device.

Frequency Bands in Different Countries



[Park2015]

IEEE 802.11 Network Topologies

Nodes as stations and cluster head as access point

- Basic service set (BSS) or Star
- Extended service set (ESS) or cluster tree
- Independent basic service set (IBSS)
  - Ad-hoc = Mesh without access point
- Mesh basic service set (MBSS)
  - (wired or wireless) Mesh of cluster heads (Hybrid)

802.11ah MAC features

- Hierarchical association identifier
- Access scheme: Hybrid Coordination Function (HCF)
- Optional Restricted Access Window (RAW)
- Increased sleep time
- Target wake-up time
- Bidirectional transmission opportunity
- Short MAC frame
- Null data packet for ACK
- Synchronization frame operation
- And few more!

802.11ax (6G of WiFi)

- Convergence of high data rates and IoT applications
- Smarter access points for improved outdoor coverage with longer guard intervals
- Target Wake-up Time
- BSS coloring to reduce interference
- Only on 5 GHz
- Comparison with 802.11ac
  - 6 times speed, 7 times battery life with TWT, 4 times range
  - Support much more than 7 devices
- OFDMA instead of OFDM
- MU-MIMO
- 1024 QAM and 160 MHz bandwidth to give multi-giga bit data rates

Key IoT Features (802.11ah)

- High data rates
  - Can handle diverse range of applications including camera
- Longer range
- Scalable to thousands of nodes
- Widely used

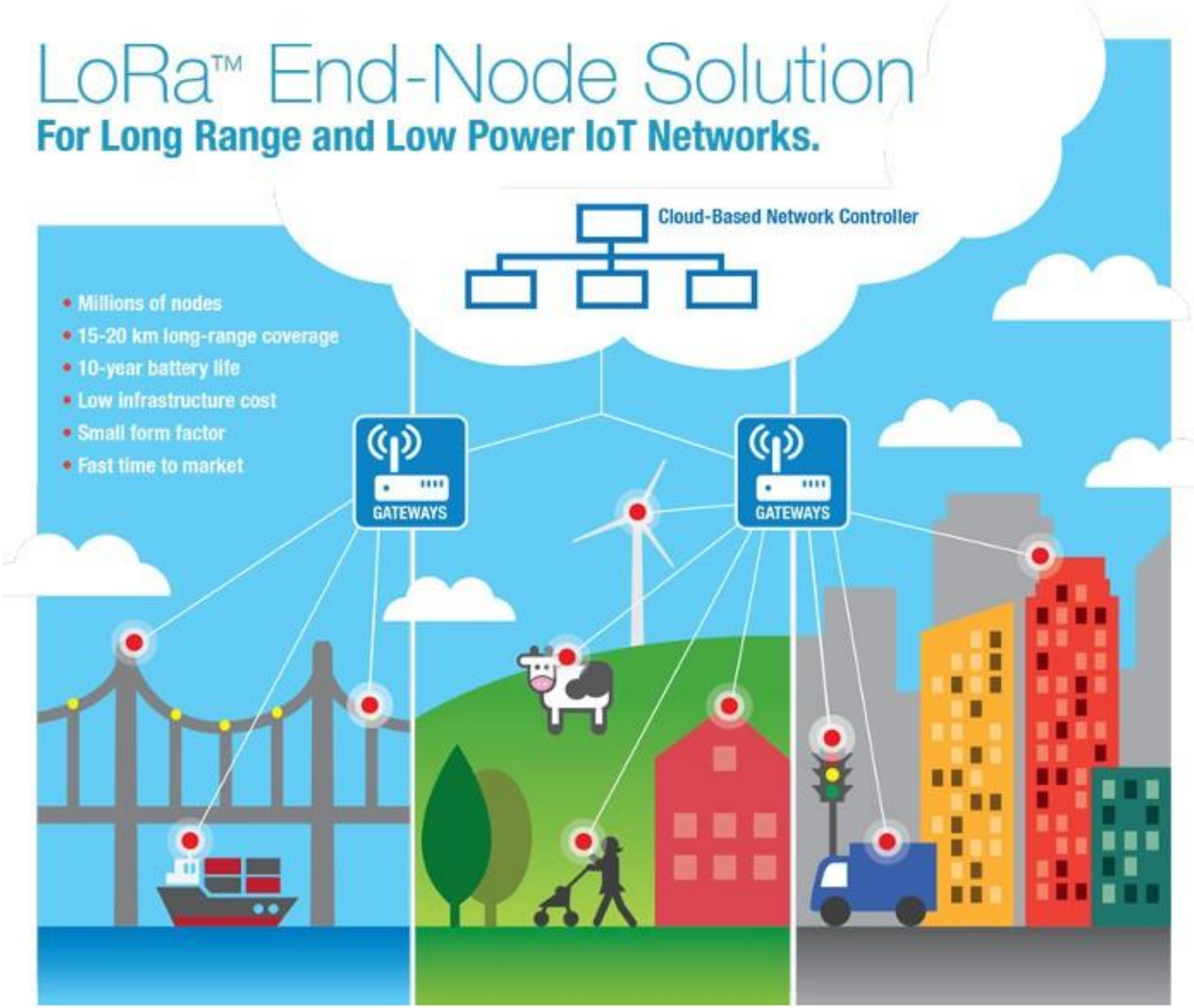
Issues

- Most of the world is using 2.4 GHz
  - Problem for 802.11ah
  - Problem for 802.11ax
- 802.11ah available, but products are hardly there
  - Mostly using 802.11b/g/n
- Security
- High power consumption
- Roaming

Today's Class

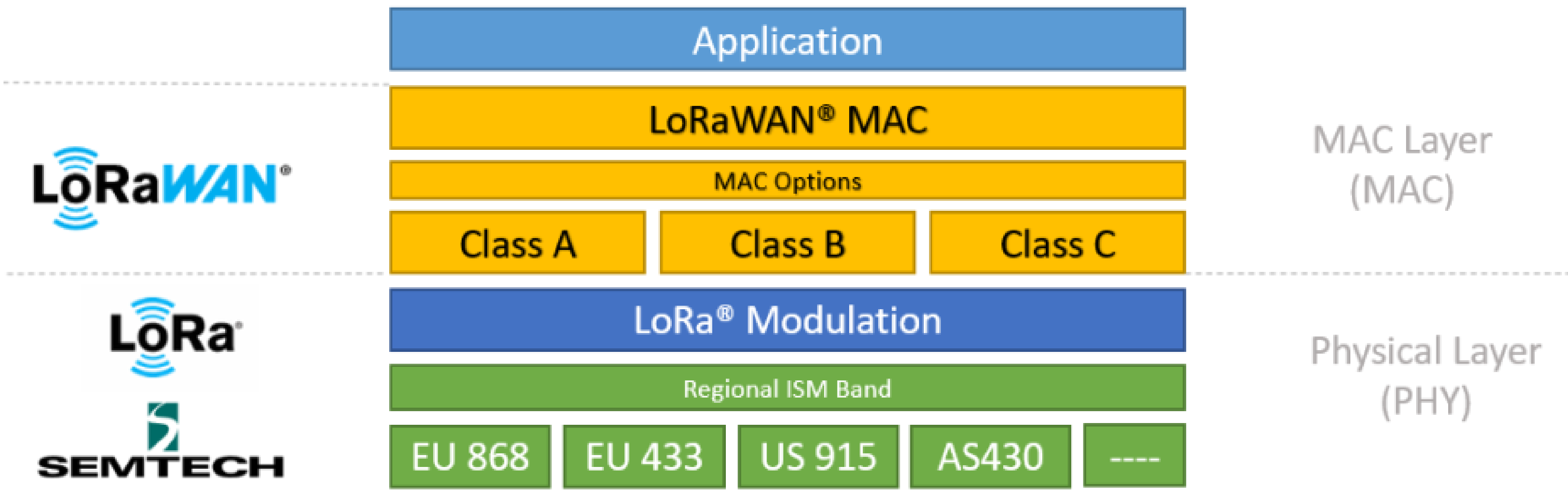
LoRa and LoRaWAN

LoRaWAN



Star of Stars Topology
Data Rate: 0.3-50 kbps
Range: Few Kms

LoRaWAN Technology Stack



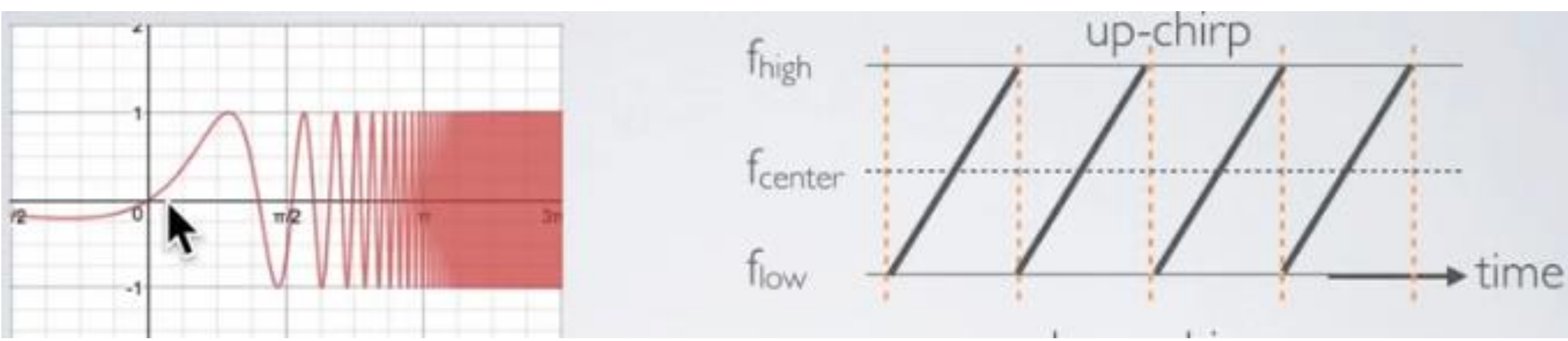
India- 865-867 MHz

- LoRa is a proprietary RF modulation technology at PHY
- Created by Cycleo (acquired by Semtech)
- LoRaWAN is technology stack on top of LoRa
  - LoRaWAN alliance of more than 500 companies
  - Semtech a founding member

LoRa (PHY)

LoRa: Modulation

- A proprietary spread spectrum technique derived out of *Chirp Spread Spectrum*
- Chirp spread spectrum (CSS) is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information
- Chirp
  - *A sinusoidal signal of frequency increase or decrease over time, often with a polynomial expression for the relationship between time and frequency*



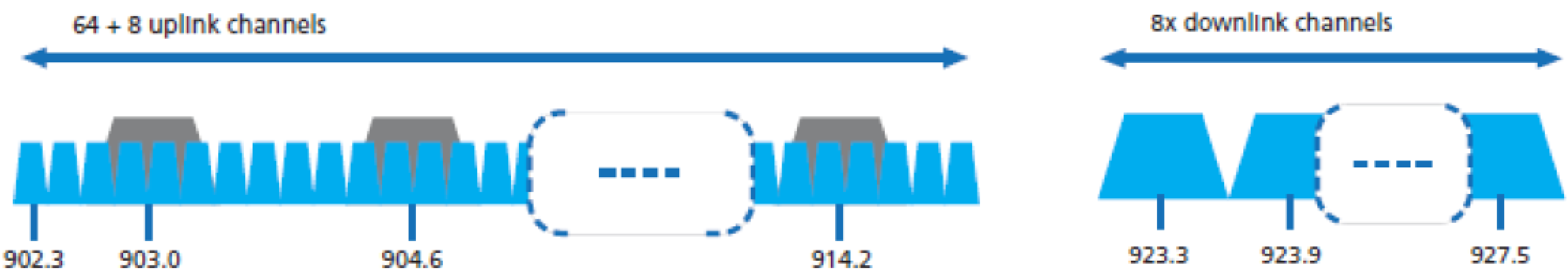
https://www.youtube.com/watch?v=r84GMLeiqg8

LoRa: Frequency and BW

- Unlicensed Sub-GHz frequencies
  - Europe
    - 433.05-434.79 MHz
    - 863-870 MHz
  - Australia: 915–928 MHz
  - North America: 902–928 MHz
  - India: 865–867 MHz
  - Southeast Asia: 433.05-434.79 MHz

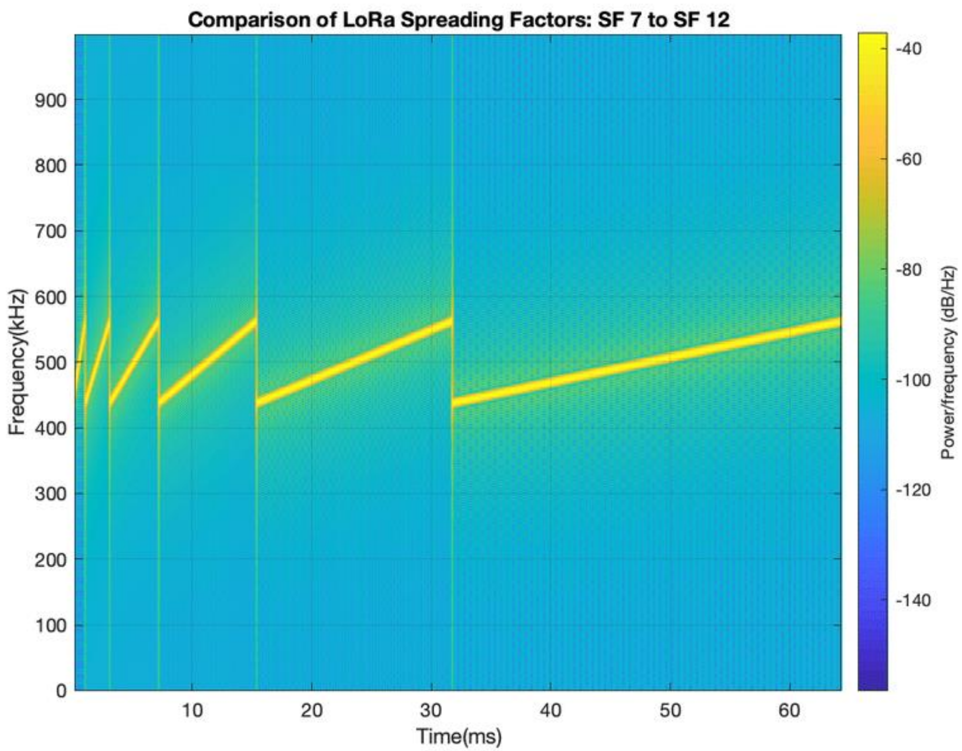
  https://lora-alliance.org/wp-content/uploads/2019/11/rp_2-1.0.0_final_release.pdf

- Fixed bandwidths
  - Uplink: 125 KHz channels or 500 KHz
  - Downlink: 500 KHz



Spreading Factor

- Processing gain by multiplying by spreading code
  - Increase in frequency component
- Six frequency spreading factors (SFs) are possible: 7-12
- Symbol rate is given by $R = BW/2^{SF}$
  - When spreading factor increases from n to $n+1$, the symbol duration ($T = 1/R$) doubles
- Tradeoff l
  - Larger ansmit
- Adaptive
  - End de hould use higher SF



https://www.researchgate.net/figure/LoRa-uses-a-chirp-spread-spectrum-modulation-technique-The-figure-also-shows-that-LoRa_fig3_332151302

Spreading Factor Orthogonality

- LoRa signals in same frequency bands with different SFs are orthogonal
- Two packets with the same SF in same slots will collide
  - However, if one of the two packets is stronger by six dB, it will survive.

LoRa Modulation Characteristics

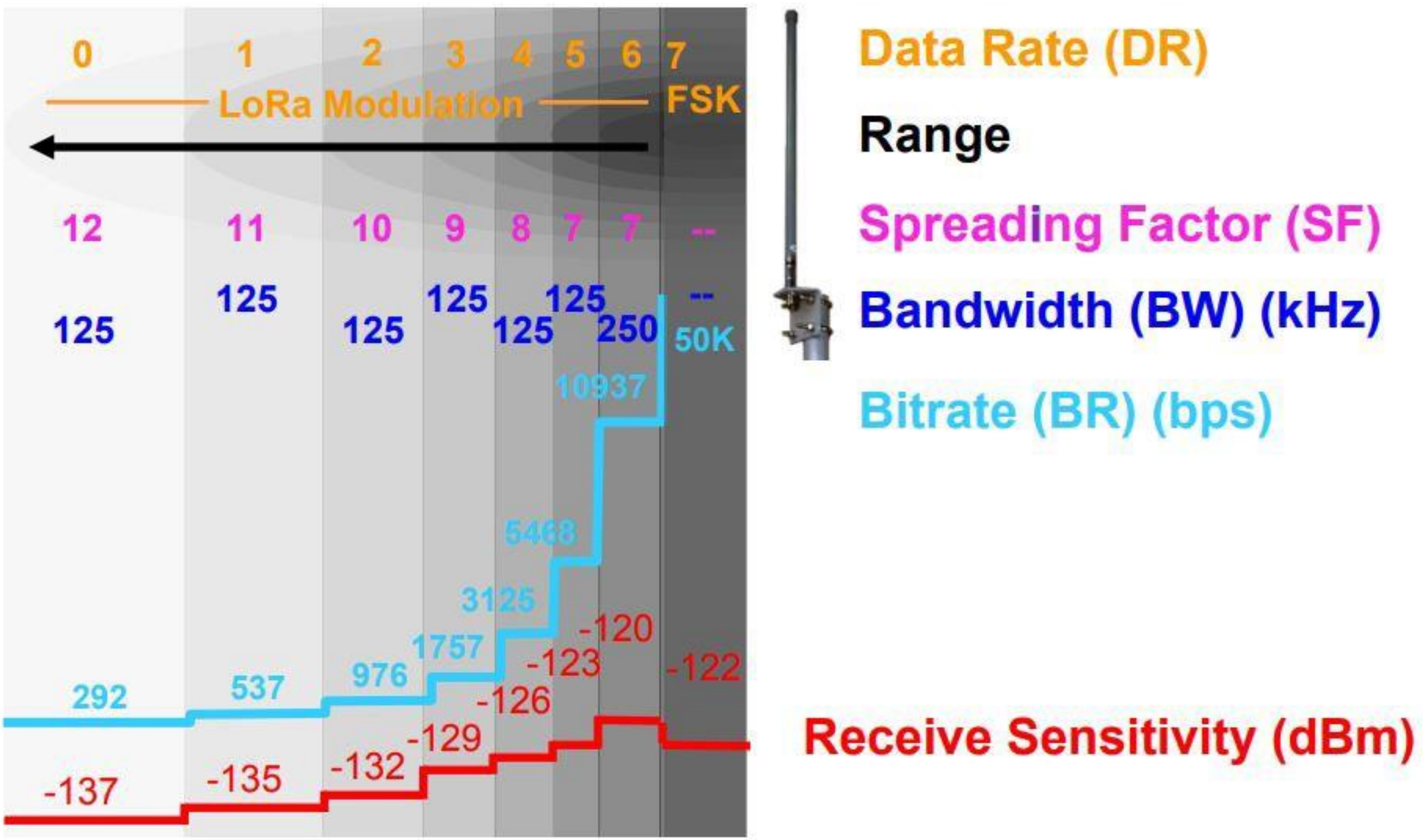
Data Rate (DR)	Spreading Factor (SF)	Channel Frequency	Uplink or Downlink	Bitrate (Bits/Sec)	Maximum User Payload Size (Bytes)
0	SF10	125 kHz	Uplink	980	11
1	SF9	125 kHz	Uplink	1,760	53
2	SF8	125 kHz	Uplink	3,125	125
3	SF7	125 kHz	Uplink	5,470	242
4	SF8	500 kHz	Uplink	12,500	242
5 – 7					
8	SF12	500 kHz	Downlink	980	53
9	SF11	500 kHz	Downlink	1,760	129
10	SF10	500 kHz	Downlink	3,125	242
11	SF9	500 kHz	Downlink	5,470	242
12	SF8	500 kHz	Downlink	12,500	242
13	SF8	500 kHz	Downlink	21,900	242

LoRa Modulation Characteristics

Modulation	Spreading factor	Bandwidth [kHz]	Maximum application throughput per channel [bps]	Maximum application layer throughput per end device per channel [bps]		
				10% duty cycle[1]	1% duty cycle[2]	0.1% duty cycle[3]
LoRa	12	125	146.1	14.61	1.46	0.15
LoRa	11	125	261.4	26.14	2.61	0.26
LoRa	10	125	584.2	58.42	5.84	0.58
LoRa	9	125	1359.2	135.92	13.59	1.36
LoRa	8	125	2738.1	273.81	27.38	2.74
LoRa	7	125	4844.7	484.47	48.45	4.84
LoRa	7	250	9689.3	968.93	96.89	9.69
GFSK	-	150	45660.4	1851.6[4]	456.6	45.66

https://www.researchgate.net/figure/Maximum-throughput-per-LoRaWAN-end-device-per-channel_tbl2_315119434

Spreading factor: Tradeoff

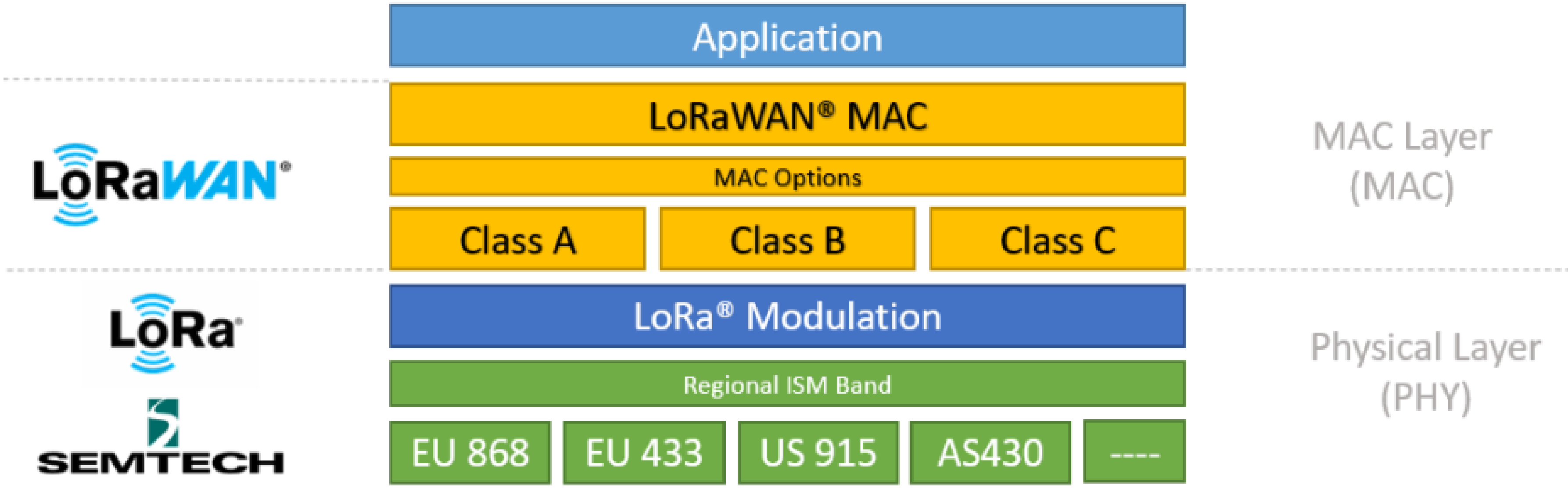


Spreading Factor

Spreading Factor (For UL at 125 KHz)	Bit Rate	Range (Depends on Terrain)	Time on Air for an 11-byte payload
SF10	980 bps	8 km	371 ms
SF9	1760 bps	6 km	185 ms
SF8	3125 bps	4 km	103 ms
SF7	5470 bps	2 km	61 ms

LoRaWAN

LoRaWAN Technology Stack



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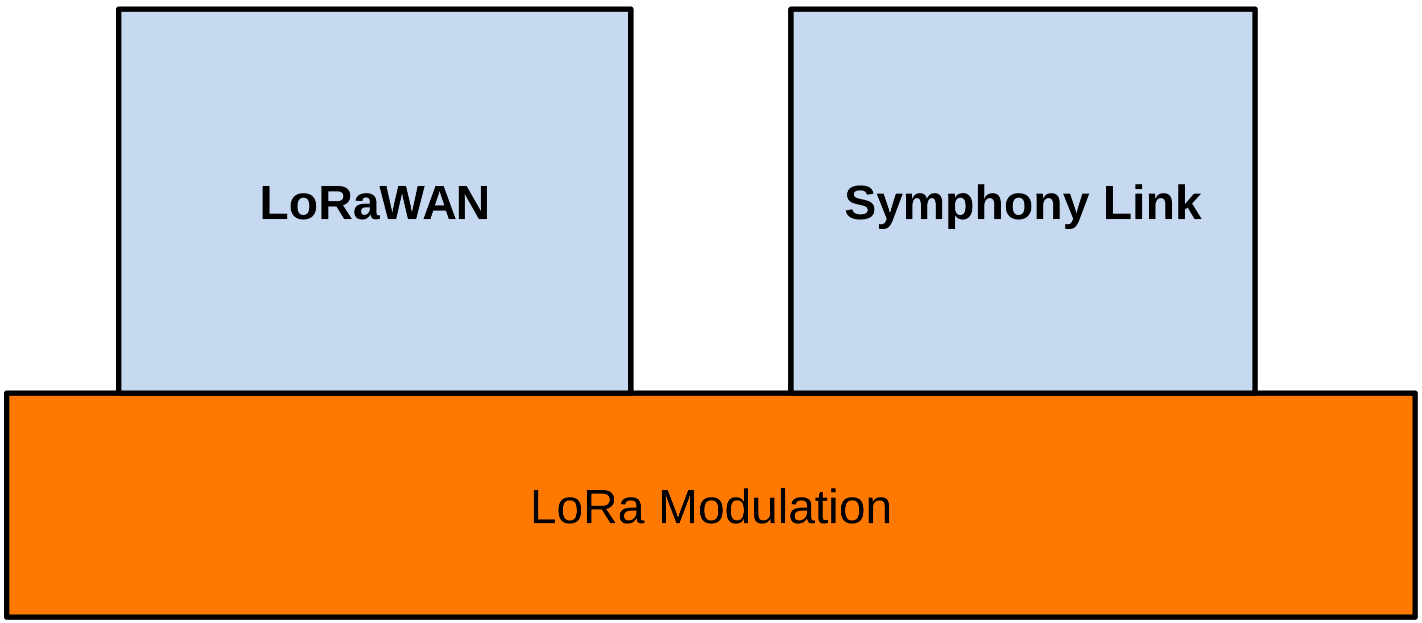
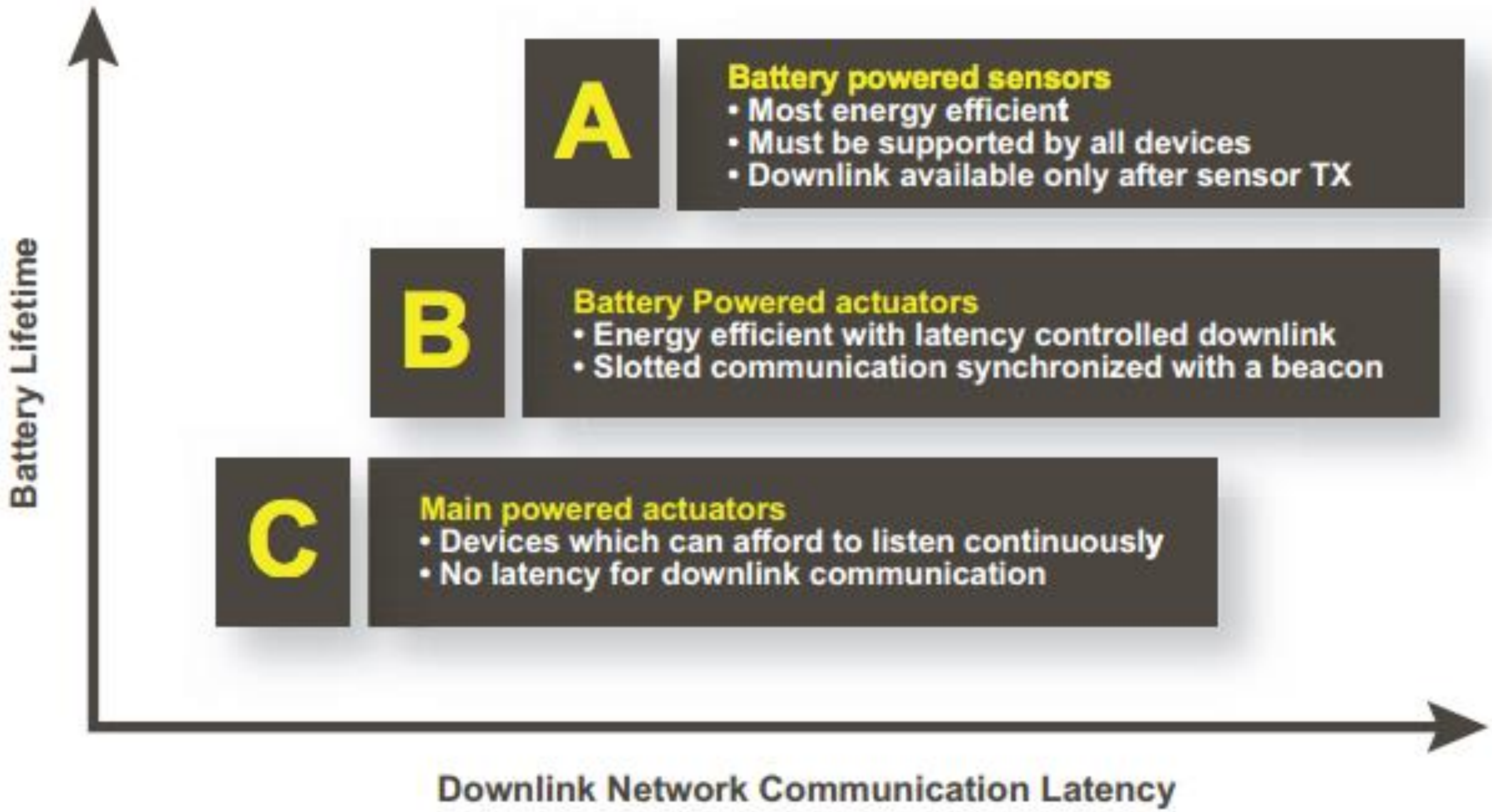
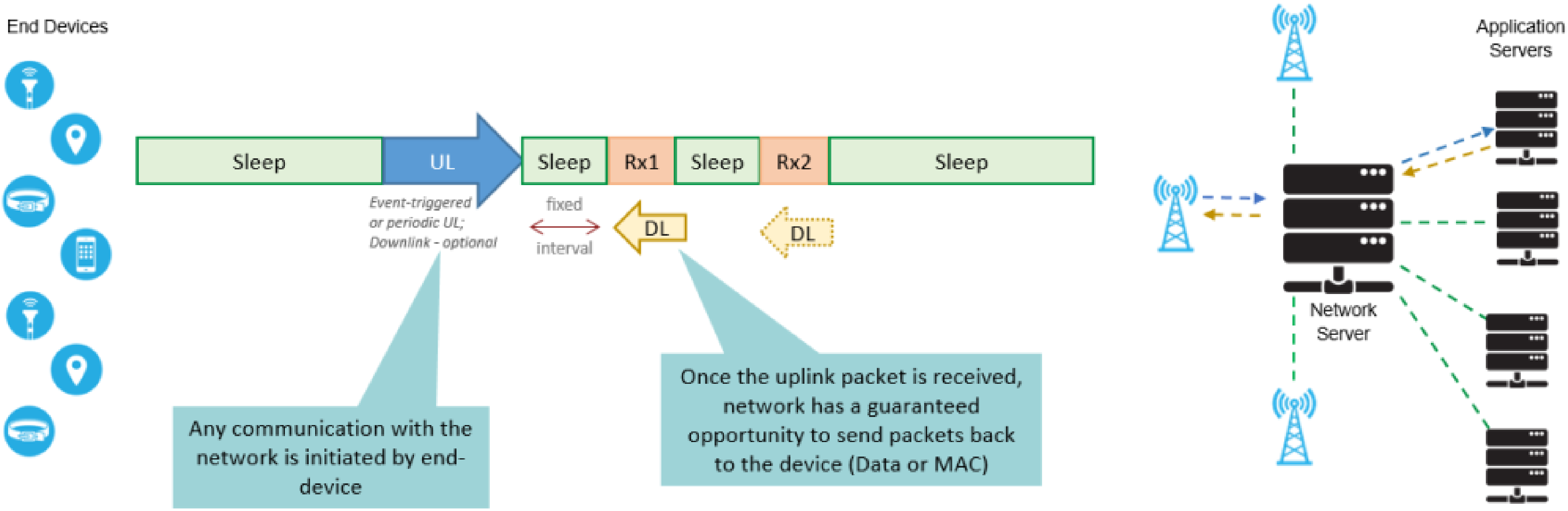
Other solutions possible with LoRa



LoRaWAN classes

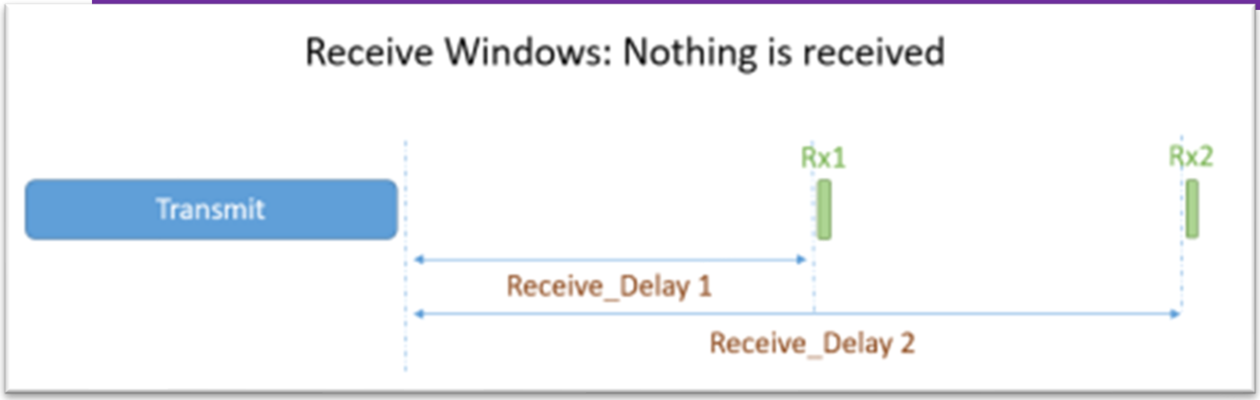


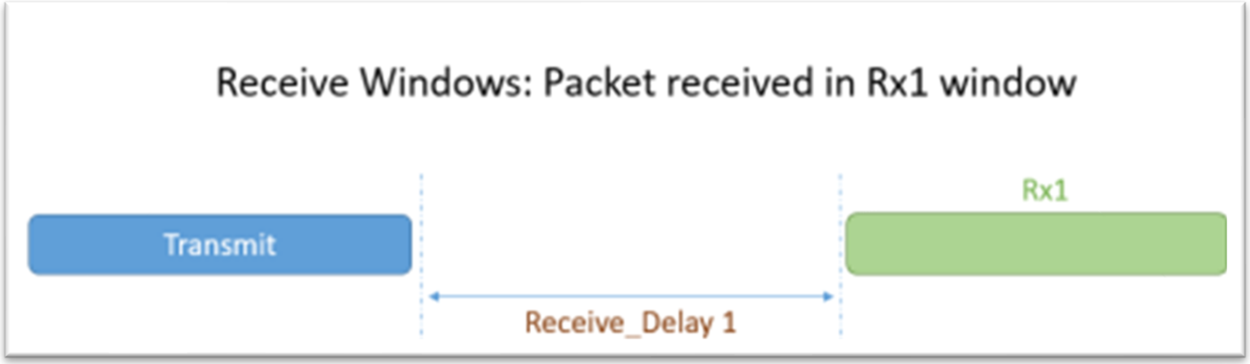
Class A operation



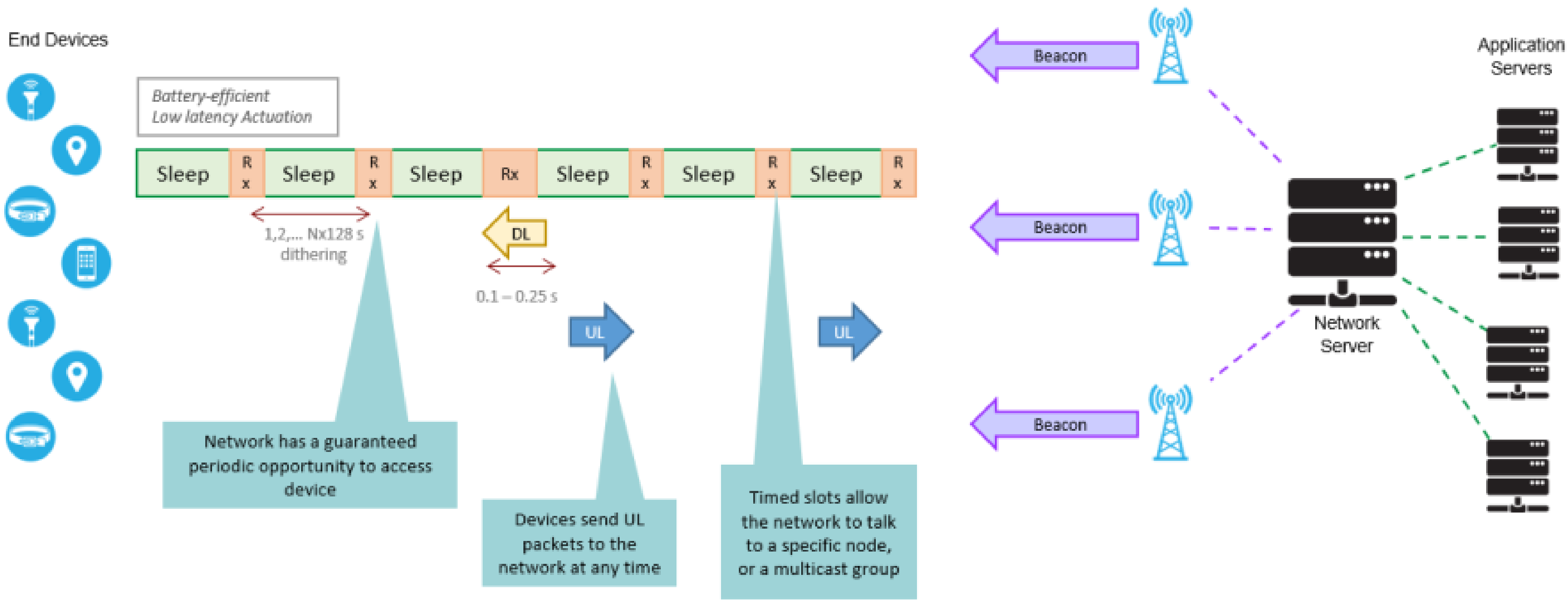
- Downlink only after uplink transmission
- Any communication is initiated by end-device
- Most energy efficient
- All devices should support this
- Default mode
- No way application can wakeup the end-device
  - Serious latency issues
  - Not suitable for actuators

Class A operation



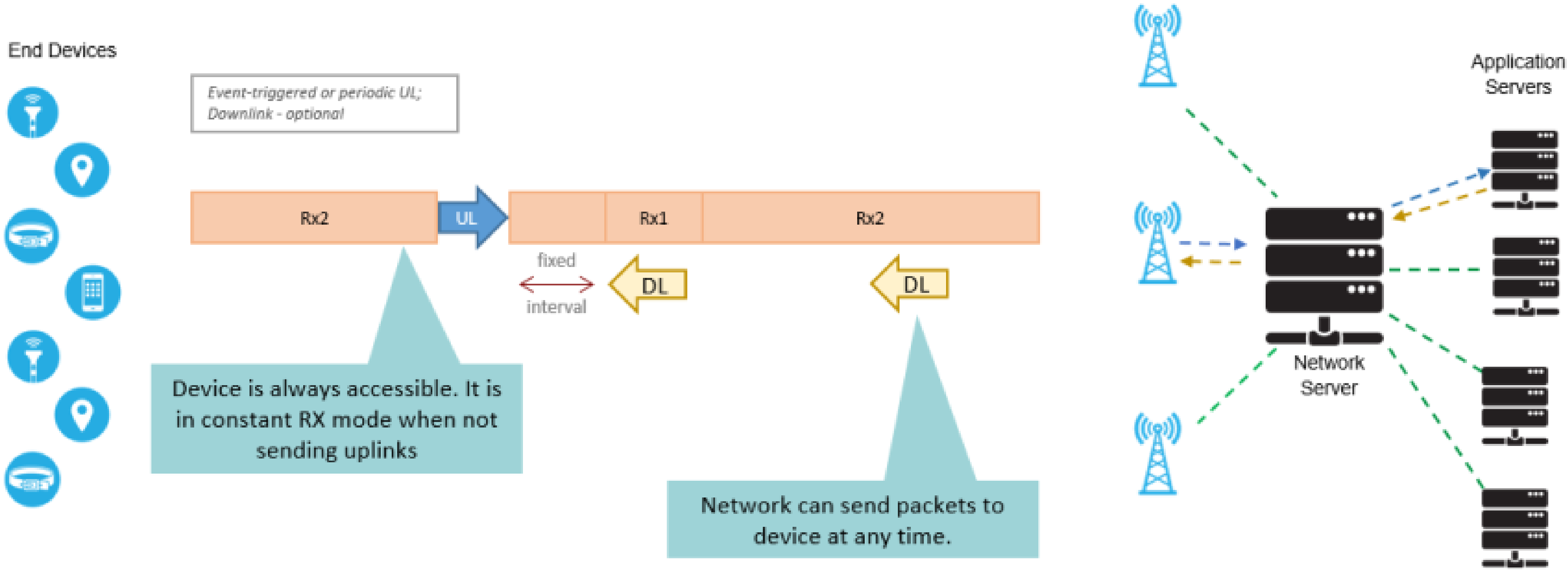


Class B operation



- Fixed time slots for an end device to receive downlinks
- Beacon required to synchronize the nodes
- Gateways need GPS timing source
- Beacon interval of 128 s (675 beacons in day)
- Suitable for battery powered actuators

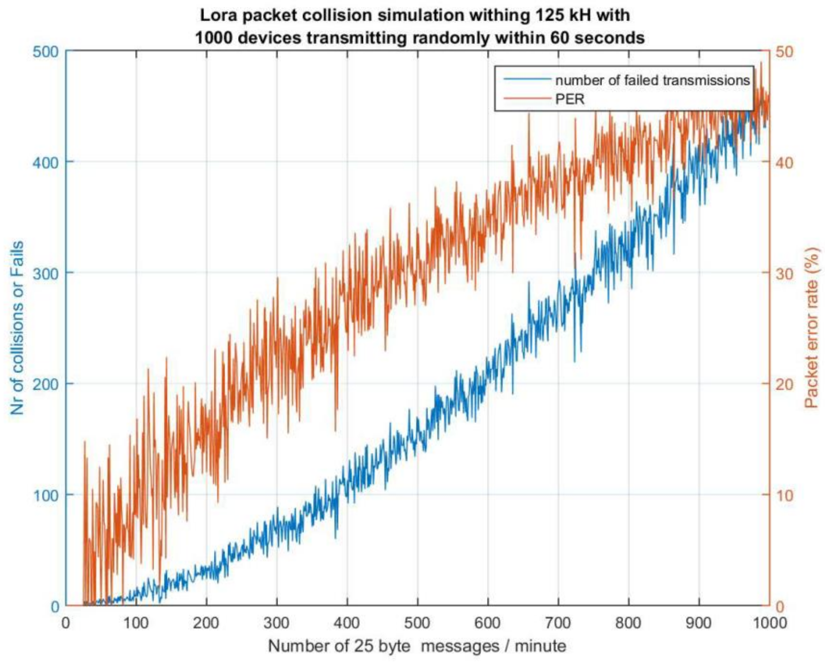
Class C Operation



- Class C devices are always ON
  - Streetlights, electrical meters
- Devices are always listening for downlink messages, unless they are transmitting an uplink
  - Lowest latency for communication from the server to an end device.

LoRaWAN

- Gateways listen on 8 frequencies on all spreading factor
- Collision prevented by maximum duty cycle



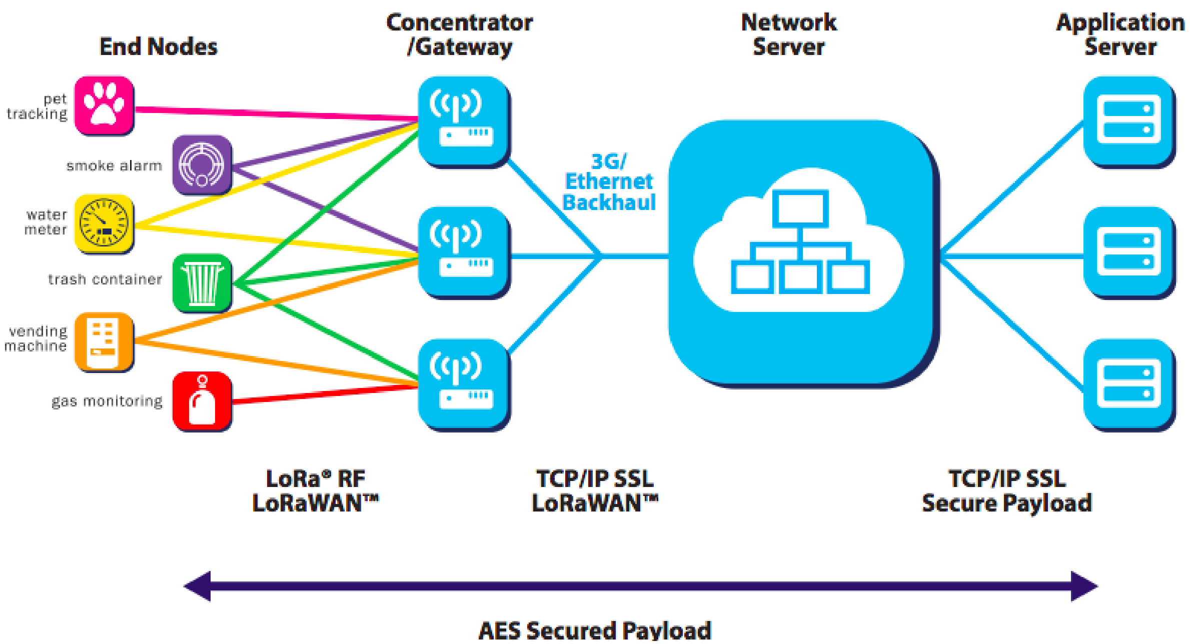
Source: https://sites.google.com/a/wesdec.be/mweyn/lpwan

Capacity of network

- LoRaWAN network can support millions of message
- A single gateway of 8 channels can support 1.5 Million messages over a day
  - If each device sends data every hour, a gateway can support 60,000 devices
- Add new gateway for more capacity and coverage
- Alternatively, we can use 16- or 64-channel gateway
- 64-channel is only used outdoors while others can be used indoors as well

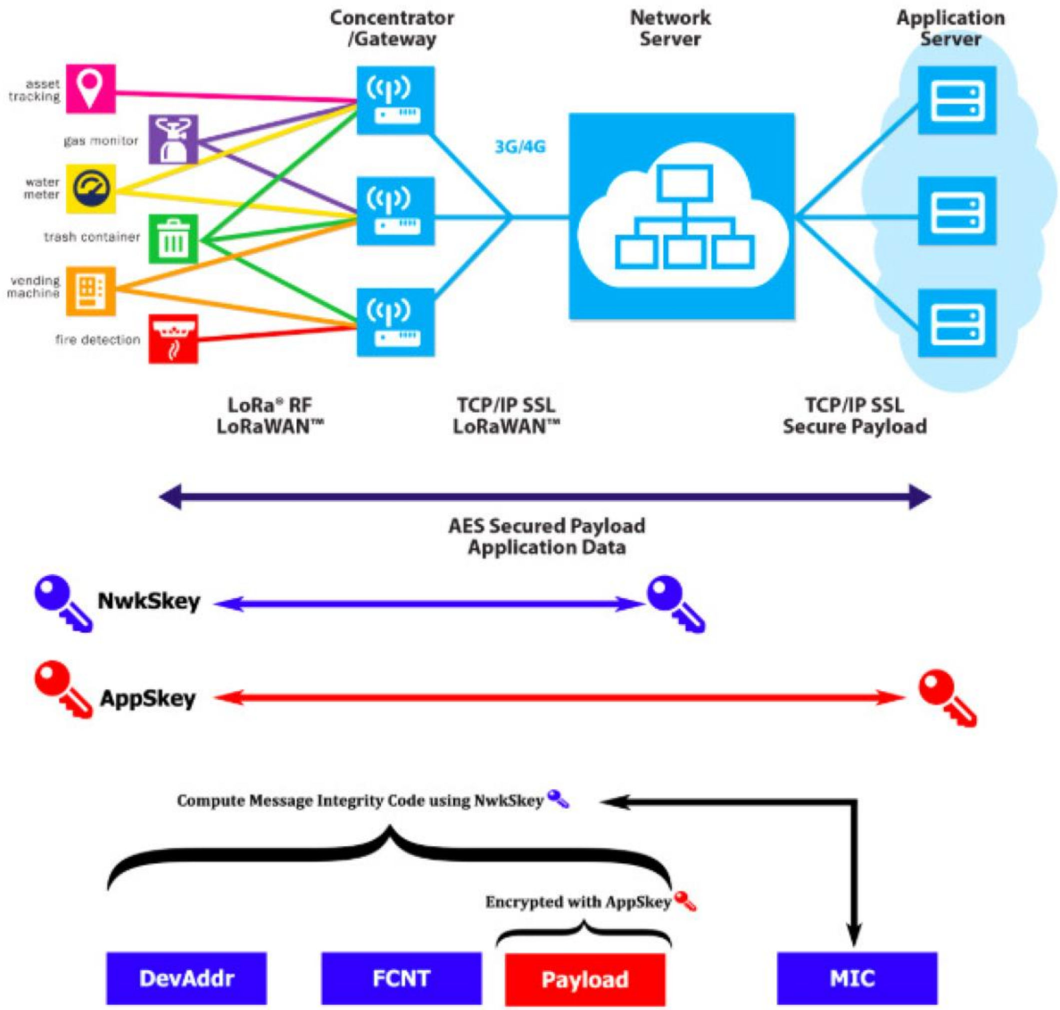
LoRaWAN

- LoRaWAN is a software layer above LoRa
  - Pure Aloha (18.4% efficiency) + CSS
  - Dumb Gateways and Smart Server: *Filters data at server*
  - Makes transmission reliable by allowing retransmissions
  - Transposes data on IP network
  - Adds security as LoRa does not have security



https://medium.com/coinmonks/lpwan-lora-lorawan-and-the-internet-of-things-aed7d5975d5d

LoRaWAN security



NwkSkey to guarantee the message integrity from the device to LoRa server

AppSKey to used for end to end AES-128 bit encryption from device to application server

https://medium.com/coinmonks/lpwan-lora-lorawan-and-the-internet-of-things-aed7d5975d5d

IoT Features: *Advantages*

- Designed for majority of IoT applications
- Low powered sensors (Battery life of 2-5 years)
  - Class A and B
- Wide coverage area up to 15 Kms
- Low Costs
  - free(unlicensed) frequencies
- One gateway can support thousands of end devices
- Simple Architecture
- Security: a layer of security for the network and one for the application with AES encryption.
- Localization without GPS
- Roaming
- LoRa Alliance: 500+ members companies including IBM and Cisco

IoT Features: *Disadvantages*

- Payload limited to 100 bytes
- High latency (actuators are not possible)
- Low data rates
  - Does not support voice or video
- Low duty cycles (1% in EU)
- Interference issues
  - Unlicensed frequency for other technology users
  - Crowding of LoRaWAN gateways increase interference
  - High packet error rate
- Cost in terms of cloud-based servers for network and applications
  - Things Network, LoRIoT
- Needs fair amount of development work
  - DIY
  - Not a complete protocol stack

IoT Features: *Disadvantages*

- Not for continuous or real-time monitoring and actuations (most of low-latency industry cases)
  - High latency (actuators are not possible)
  - High packet error rate
  - Low data rates
  - Low duty cycles

Few Use Cases

- Utility monitoring
  - Water, Electricity, Gas
- Environment monitoring
  - Air Pollution, Water Quality, Soil Detection
- Animal Tracking
- Farming
- Smart building
  - Temperature, humidity sensors
- Smart Cities
  - Street Lights, Parking, Dustbins

References

- P. Lea, *Internet of Things for Architect*, Packt, 2018
- Semtech, “LoRa and LoRaWAN: A Technical Overview,” Feb. 11, 2020
  - [Online: https://lora-developers.semtech.com/uploads/documents/files/LoRa_and_LoRaWAN-A_Tech_Overview-Downloadable.pdf]

Questions?

Ungraded Quiz

1. Arrange in the order of lower to higher latency? ABC, CBA, CAB, BAC
2. Data rates increase with increasing spreading factor? Yes, No, Does not depend of SF
3. LoRaWAN can be used for low-latency industrial IoT applications? Yes, No

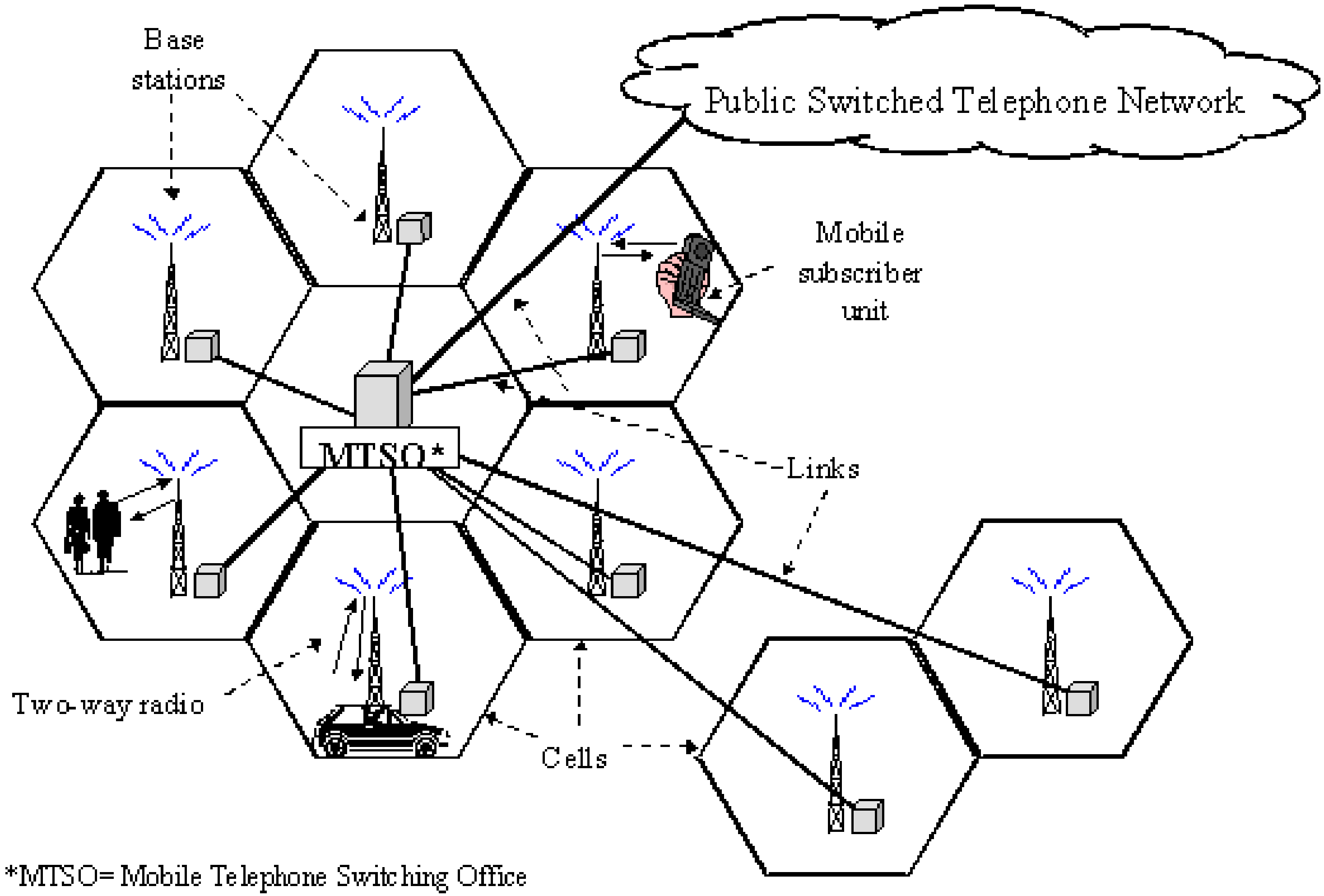
Cellular Technologies: 2G, 3G, 4G, 5G

Cellular Technologies

- Licensed
  - 2G, 3G, 4G
  - LTE-MTC: Cat-1, Cat-0, LTE-CatM1, NB-IoT, 5G
    - low-power, long-range applications
- Unlicensed
  - Example: Sigfox, LoRa, Weightless
  - +ves: Extremely low-power, low data rate, long coverage
  - -ves: Unlicensed band, deployment should exist in region of interest, gateways,

Cellular Architecture: an example of 2G

https://www.itu.int/osg/spu/ni/3G/technology/index.html



Good introduction to cellular communication: https://www.youtube.com/watch?v=1JZG9x_VOwA

Spectrum Chart in India

- 2G: GSM 900 / GSM 1800
- 3G: UMTS 900, UMTS 2100
- 4G: LTE 850, 1800, 2100, 2300, 2500

https://www.gsmarena.com/network-bands.php3?sCountry=INDIA

Exact allocation:
https://dot.gov.in/sites/default/files/NFAP%202018.pdf?download=1

Spectrum Chart in India

				Uplink Frequency (MHz)	Downlink Frequency (MHz)
700 MHz	FDD	x2	B28 - n28	703-748 MHz	758-803 MHz
800 MHz	FDD	x2	B5	824-844 MHz	869-889 MHz
ISM Band	Industrial, Scientific and Medical - License Free Band. *T&C Apply. 200 kHz carrier bandwidth. Currently used in India for LoRa etc.				
900 MHz	FDD	x2	B8	890-915 MHz	935-960 MHz
1800 MHz	FDD	x2	B3	1710-1785 MHz	1805-1880 MHz
2100 MHz	FDD	x2	B1	1920-1980 MHz	2110-2170 MHz
2300 MHz	TDD		B40	2300-2400 MHz	

https://telecomtalk.info/india-spectrum-data-sheet/134245/

Cellular Spectrum Chart in India

Band	Circle	AP	AS	BH	DL	GU	HA	HP	JK	KA	KE	KO	MP	MH	MU	NE	OD	PU	RA	TN	UPE	WB	AGG.
	Type	A	C	C	M	A	B	C	C	A	B	M	B	A	M	C	C	B	B	A	B	B	
	Telco																						Telco AGG.
B5 800MHz	AIRTEL	3.75			1.25		1.25							2.5	2.5								11.25
	JIO	3.75	5	5	7.5	8.75	5	5	5	7.5	7.5	8.75	5	3.75	5	5	5	7.5	7.5	7.5	6.25	7.5	137.5
	RCOMM	1.25	5	5	1.25	2.5	5	5	5	1.25	1.25	1.25	5	1.25	5	5	5	2.5	1.25	1.25	3.75	1.25	66.25
	TSP AGG.	8.75	10	10	10	11.25	11.25	10	10	8.75	8.75	10	10	7.5	12.5	10	10	10	8.75	8.75	10	8.75	
	BAL	13.75	2.5	12.5	12.5	6.25	10	10	2.5	13.75	13.75	12.5	12.5	15	10	2.5	11.25	11.25	12.5	13.75	12.5	12.5	236.25
	CB AGG.																						
B8 900MHz	AIRCEL		4.4						4.4							4.4							13.2
	AIRTEL	9	8	7.8	6			7.4	6.2	8.8		7			5	8.8	7.4	10	6	6.2	6.2	6.6	116.4
	BSNL	6.2	6.2	6.2	6.2	6.2	6.2	6.2	8	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	138.2
	JIO																						0
	RCOMM							5					5										10
	Vi	5			10	11	12.2			5	12.4	7	7.4	14	11		5	5.6	6.4	6.2	5.6	6.6	141.6
	TSP AGG.	20.2	18.6	14	22.2	17.2	18.4	18.6	18.6	20	18.6	20.2	18.6	20.2	22.2	19.4	18.6	21.8	18.6	18.6	18	19.4	
	BAL	3	4.6	9.2	1	3	0.2	4.6	0	3.2	4.6	3	4.6	3	1	3.8	4.6	0	0	17	5.2	4.6	81.4
	CB AGG.																						
B3 1800MHz	AIRCEL	4.4	1.8	6.2	4.4				1.8	4.4	4.4	4.4			4.4	1.8	4.4	4.4	6	10	6.2	5.6	74.6
	AIRTEL	21.4	15.45	15.2	7	16.2	16.2	10.2	5	8.8	11.2	9	17	23.2	20.2	10	11.8	10	10	8	12.8	6.2	283.05
	BSNL	3.8	3.8				3.8	3.8		3.8	3.8		3.8			3.8	3.8			3.8	3.8	1.8	47.4
	JIO	5.8	5.4	5	5.4	6	5	10.4	10	5	5	10	6.4	5	6.6	6.4	5	5.2	10	6.8	6.4	10.6	146.4
	RCOMM						0.6		5	0.6					0.6	5	5	0.6					17.4
	Vi	11	25	17.8	18.6	20.8	15.8	15.6	17	19	20	15	18.6	12.4	14.6	25.8	17	21.2	16.2	12.4	14.8	23.4	386.4
	TSP AGG.	46.4	51.45	44.2	35.4	43	41.4	40	38.8	41.6	44.4	38.4	45.8	40.6	46.4	52.8	47	41.4	42.2	41	44	47.6	
	BAL	12.6	3	8.6	25.4	17.8	19.4	19	14	21	16.4	14.4	15	22.2	15.6	0	5.8	19.4	16.8	17.6	15	5.2	323.6

https://telecomtalk.info/india-spectrum-data-sheet/134245/

Cat-1, Cat-0, eMTC, NB-IoT and EC-GSM-IoT

LTE-M or LTE-MTC or LTE Cat M1

	LTE Cat 1	LTE Cat 0	LTE Cat M1 (eMTC)	LTE Cat NB1 (NB-IoT)	EC-GSM-IoT
3GPP Release	Release 8	Release 12	Release 13	Release 13	Release 13
Downlink Peak Rate	10 Mbit/s	1 Mbit/s	1 Mbit/s	250 kbit/s	474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Uplink Peak Rate	5 Mbit/s	1 Mbit/s	1 Mbit/s	250 kbit/s (multi-tone) 20 kbit/s (single-tone)	474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Latency	50–100ms	not deployed	10ms–15ms	1.6s–10s	700ms–2s
Number of Antennas	2	1	1	1	1–2
Duplex Mode	Full Duplex	Full or Half Duplex	Full or Half Duplex	Half Duplex	Half Duplex
Device Receive Bandwidth	1.08 – 18 MHz	1.08 – 18 MHz	1.08 MHz	180 kHz	200 kHz
Receiver Chains	2 (MIMO)	1 (SISO)	1 (SISO)	1 (SISO)	1–2
Device Transmit Power	23 dBm	23 dBm	20 / 23 dBm	20 / 23 dBm	23 / 33 dBm

LTE-M and NB-IoT enhanced in Release 14

http://www.3gpp.org/images/articleimages/iot_summary_large.jpg

Cat-1, Cat-0, and EC-GSM-IoT

- Cat-1
  - IoT support in LTE 3G (Release 8)
  - Already standardized
  - Premium IoT applications

- Cat-0
  - IoT support in LTE-A 4G (Release 12)
  - Optimized cost as compared to Cat-1

- EC-GSM
  - IoT support in GSM networks
  - Extended Coverage

Cat-M1 (eMTC)

- IoT support in LTE-A 4G (Release 13)
- Compatible with existing LTE network (only software upgrade)
- 1.4 MHz bandwidth
- Supports mobility and voice-over LTE (VoLTE)
- Asset tracking and wearables

NB-IoT or Cat-M2

- Competing against Sigfox, LoRa (Release 13)
- Support of massive number of low throughput devices, ultra-low device cost, low device power consumption and optimized network architecture
- Improved indoor coverage
  – Power boosting
  – Repetition
- flexible spectrum: in-band and guard band in LTE; standalone deployment; GSM re-farming possible
- Not backward compatible with other 3G/4G devices
- No mobility support and not suitable for latency low applications
- LPWAN applications like smart metering

NB-IoT deployment

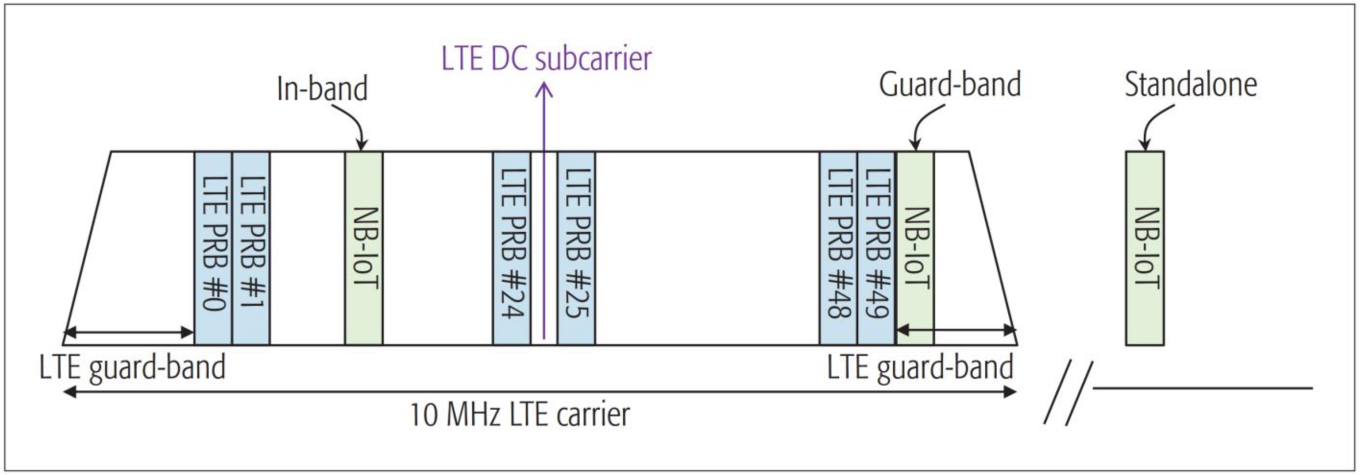


Figure 1. Examples of NB-IoT stand-alone deployment and LTE in-band and guard-band deployments.

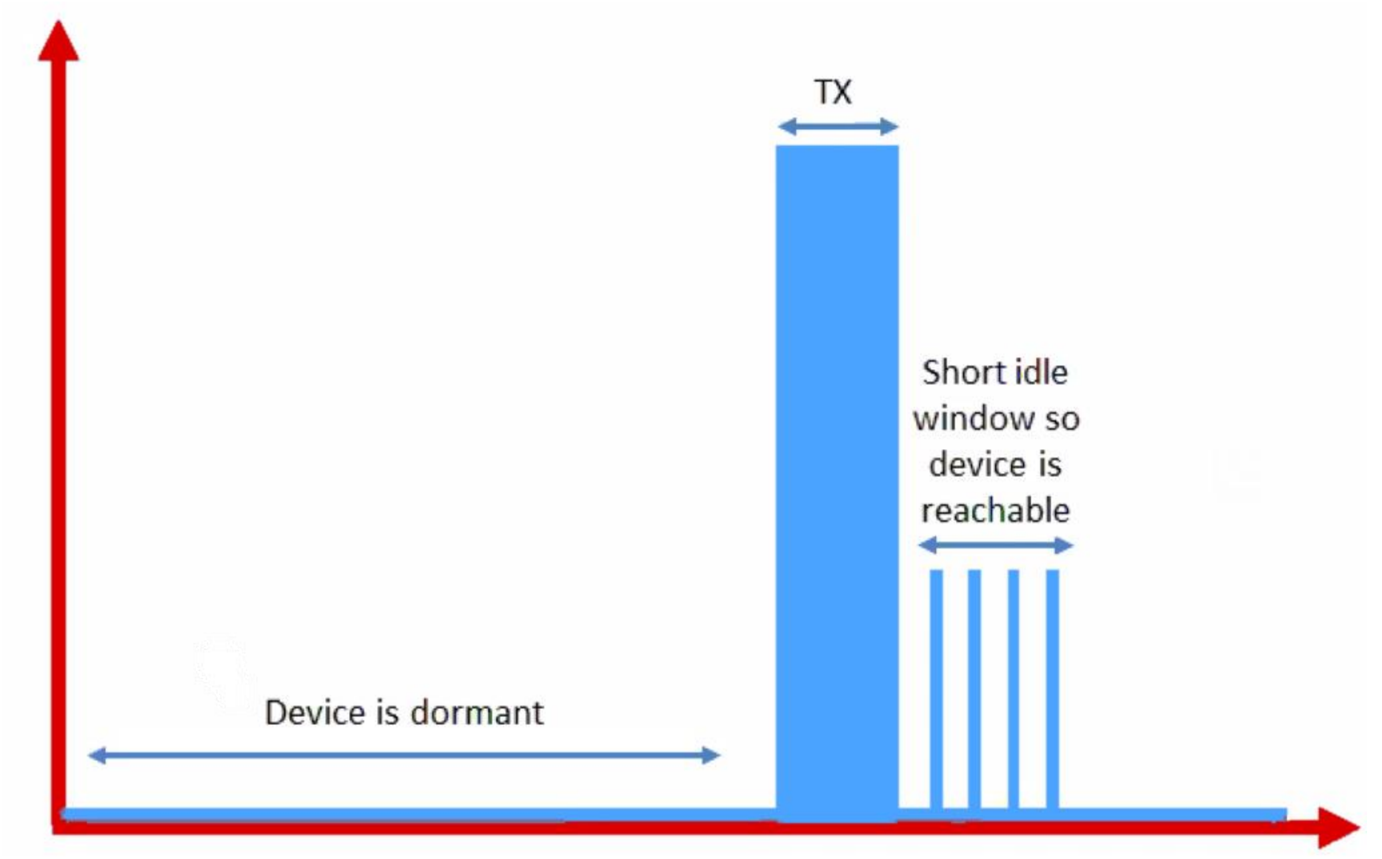
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7876968

Few Power Saving Features

- Power Saving Mode
- Extended Discontinuous Reception

Power Saving Mode

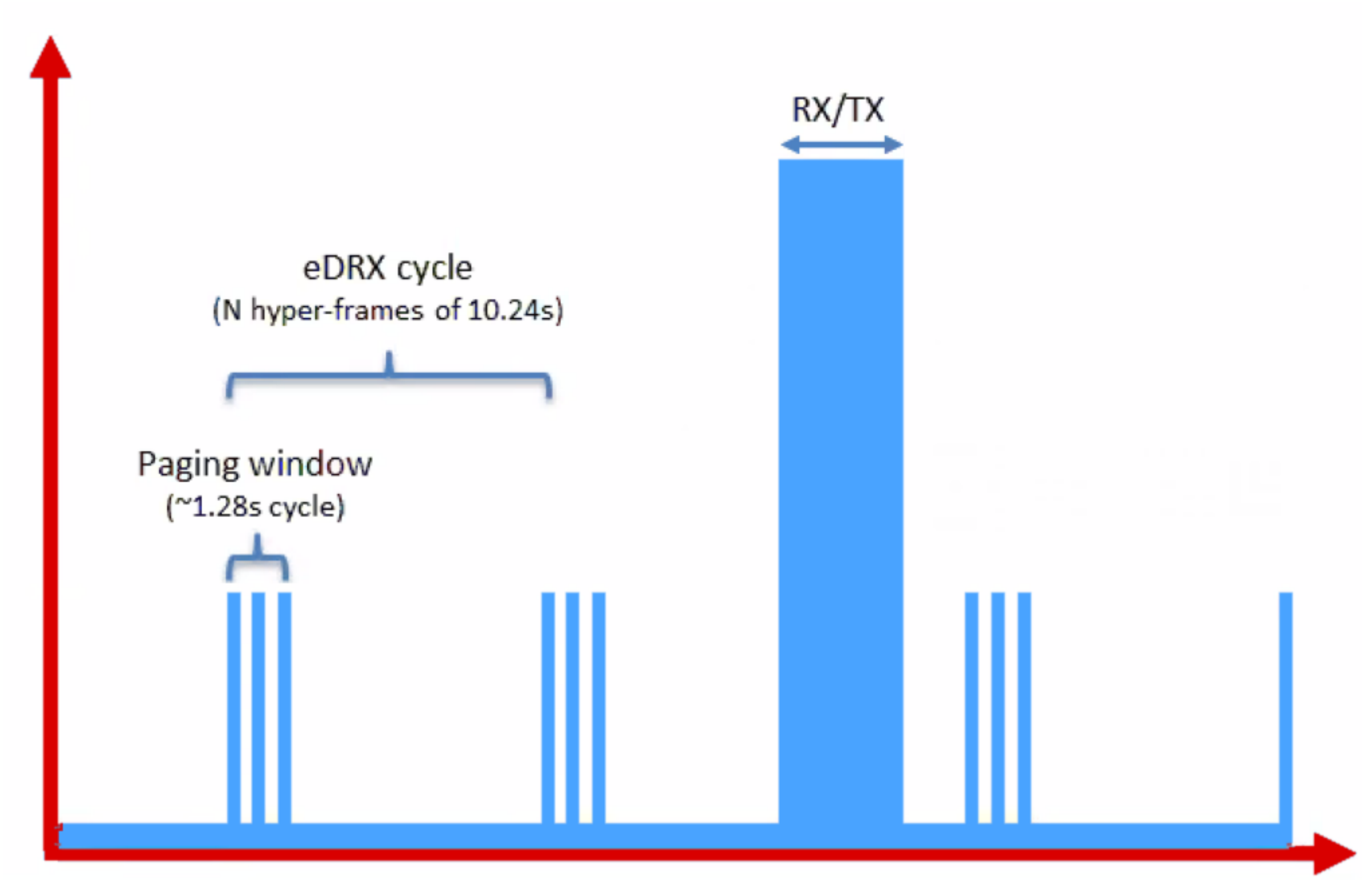
PSM allows LTE-M devices to go idle without having to re-join the network when they wake up.



https://www.link-labs.com/blog/lte-e-drx-psm-explained-for-lte-m1

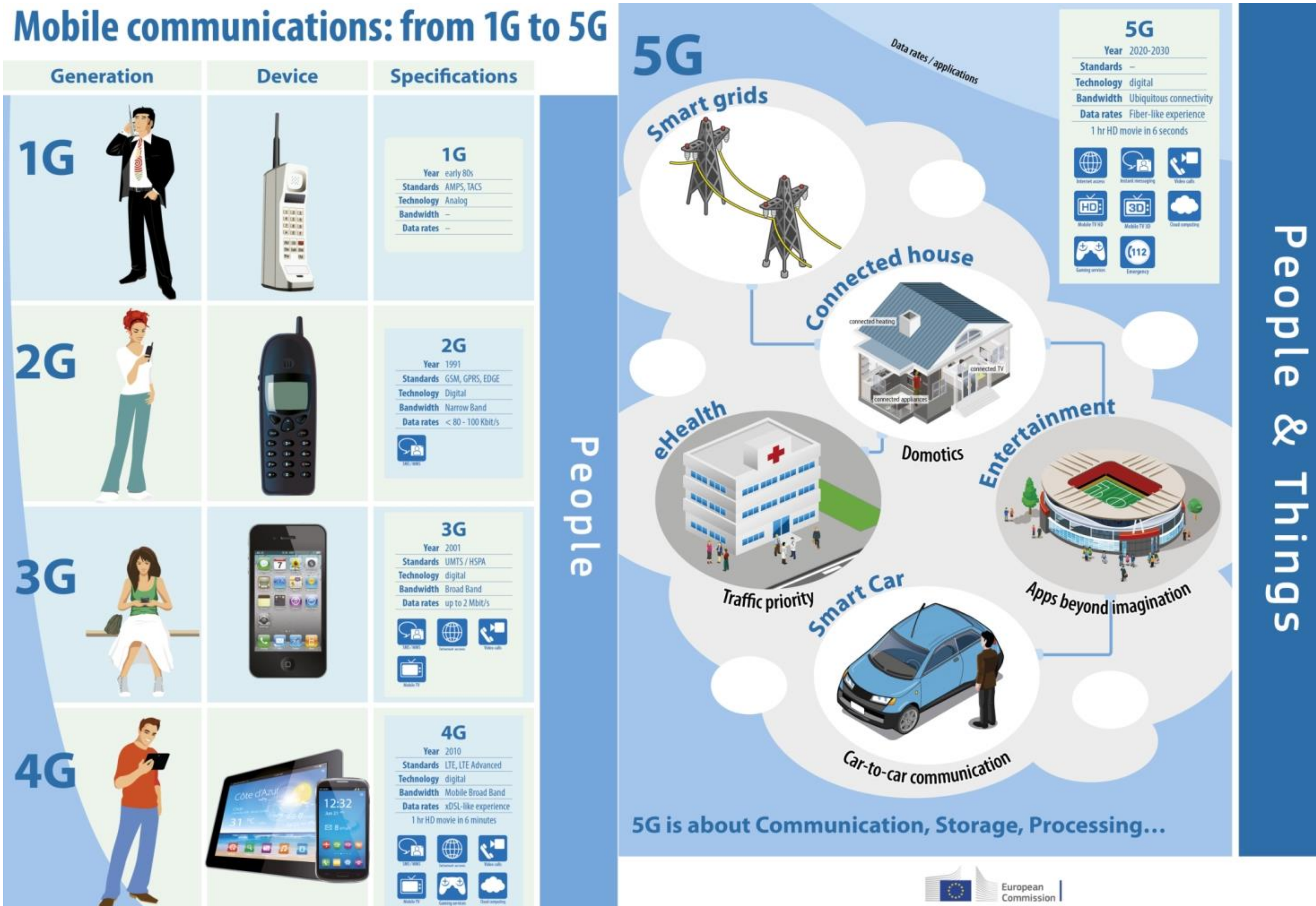
Extended Discountinous Reception (eDRX)

Node can skip several paging cycles



https://www.link-labs.com/blog/lte-e-drx-psm-explained-for-lte-m1

1G to 5G



https://www.ng-voice.com/the-evolution-of-wireless-generations/

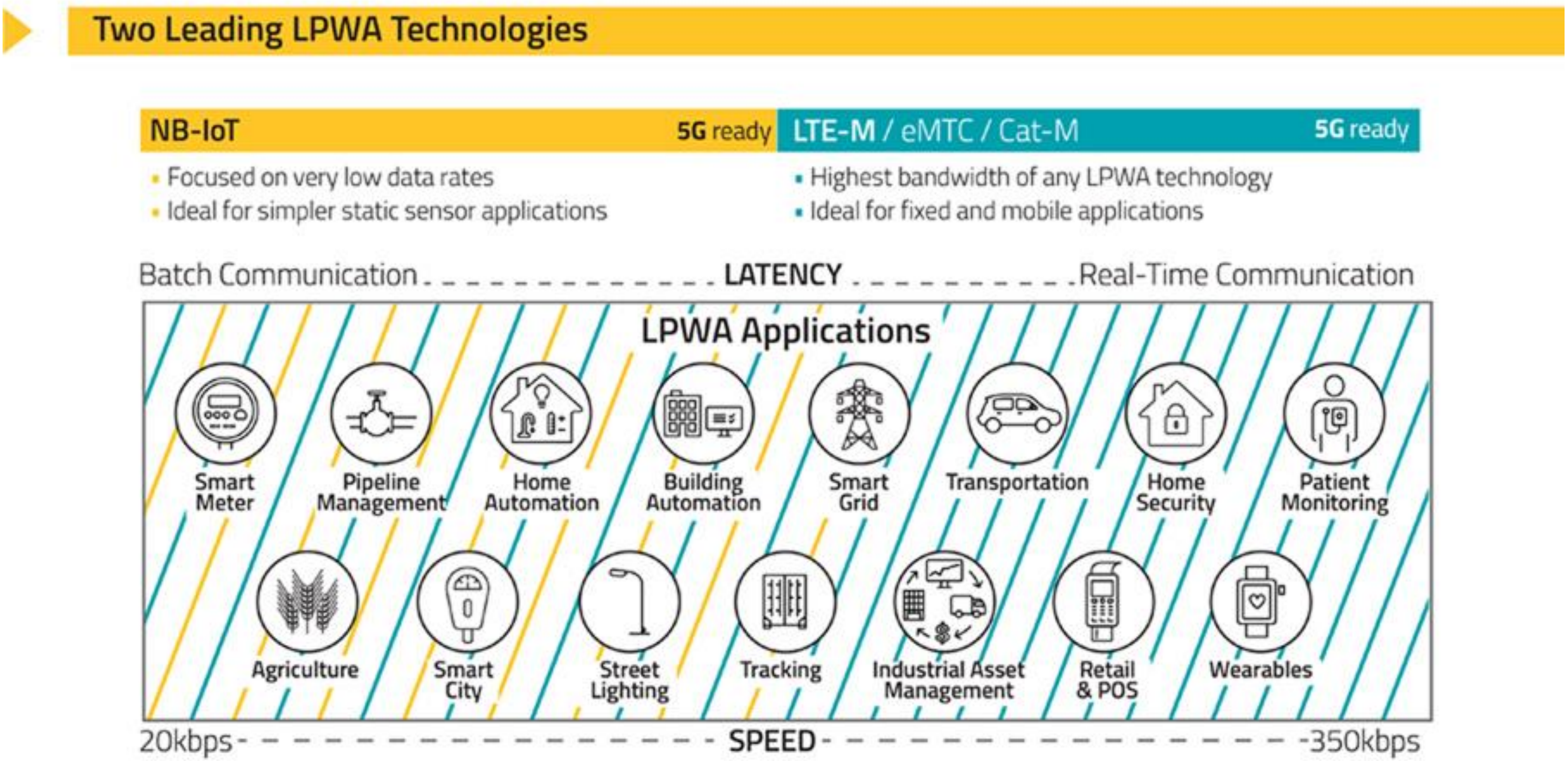
IoT in 5G Era

- ❑ **Mobile IoT/Massive IoT/LPWA:** improved network coverage, long device operational lifetime and a high density of connections. This is also known as mMTC (Massive MTC)
- ❑ **Enhanced Mobile Broadband:** improved performance and a more seamless user experience accessing multimedia content for human-centric
- ❑ **Critical Communications:** high performance, ultra-reliable, low latency industrial IoT and mission critical applications. This is also known as Critical IoT, URLLC (Ultra Reliable Low Latency Communications)

Source: GSMA

LTE-M and NB-IoT=Massive IoT

IoT in 5G era



https://www.iotforall.com/cellular-iot-explained-nb-iot-vs-lte-m/

Key IoT features

Advantages

- Quality of service
  - Licensed band
  - Low latency
- Ubiquitous
- Security: SIM card protection + AES 256 bit (best)
- Great coverage: 2 km (LTE), 10 km (NB-IoT), 35 km (GSM)
- Global mobility and roaming support
- Scalable
- Connected even during power failure

Issues

- Cost: License, Capex and Opex, subscription
- High power
- Not possible to make your own network

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That's all for today!

Thank You!