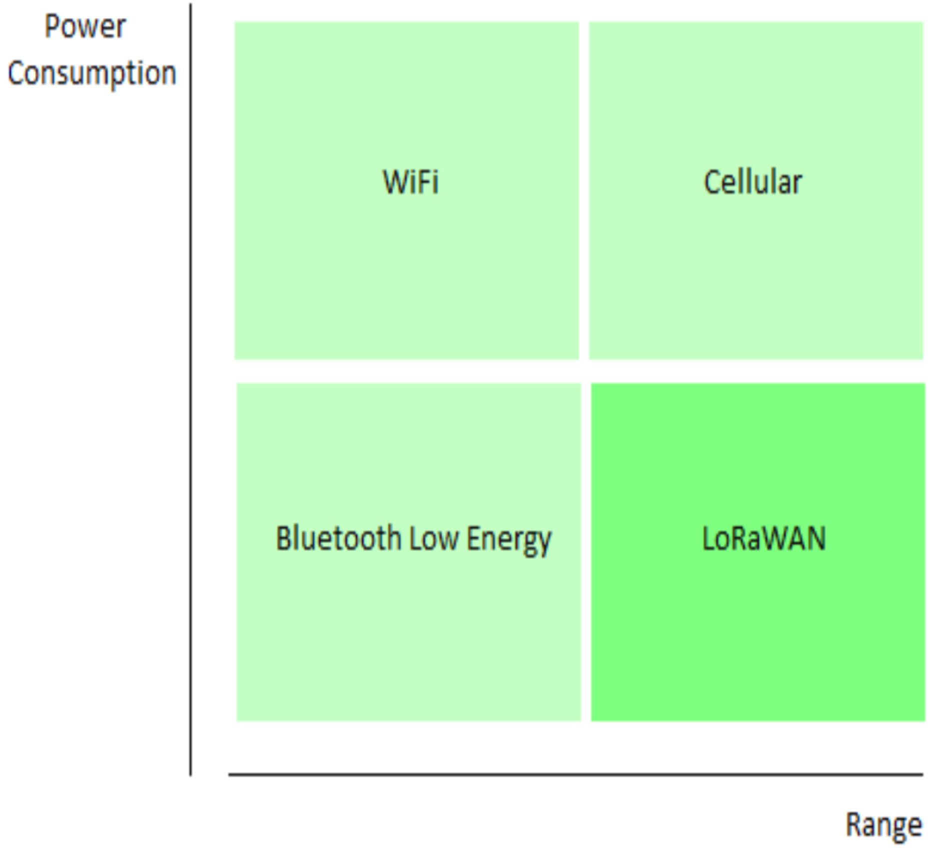
LoRaWAN- Battery Lifetime

- Synchronization network usually **consumes** significant **energy**. In LoRaWAN, nodes are asynchronous and communicate via **events** or in pre**scheduled** opportunities.

- The **ADR** (Adaptive Data Rate) scheme is used for LoRa network infrastructures for manage the individual **data rates** and **maximize** the **battery life** of **each connected device** through RF output.

- A recent research study performed by **Scientific Research Publishing**, Inc revealed that **LoRaWAN** showed an **advantage of 3 up to 5-fold in the energy economy compared** to all the **others LPWAN** technologies.



SigFox

- SigFox
  - The Sigfox technology was developed in 2010 by the startup Sigfox (in Toulouse, France),
  - Sigfox operates and commercializes its own IoT solution in 31 countries and is still under rollout worldwide owing to the partnership with various network operators

SigFox: Technical Specification

- Binary phase-shift keying (BPSK) modulation in an ultra-narrow band (100 Hz) sub- GHZ ISM band carrier

- It causes SigFox experiences
  - very low noise levels,
  - leading to very low power consumption,
  - high receiver sensitivity,
  - and low-cost antenna design
  - all, at the expense of maximum throughput of only 100 bps.

SigFox: Technical Specification

- The downlink communication can only occur following an uplink communication.
- The number of messages over the uplink is limited to 140 messages per day.
- The maximum payload length for each uplink message is 12 bytes.
- However, the number of messages over the downlink is limited to 4 messages per day, which means that the acknowledgment of every uplink message is not supported.

SigFox: Technical Specification

- Without the adequate support of acknowledgments, the uplink communication reliability is ensured using time and frequency diversity as well as transmission duplication.

- Each end-device message is transmitted multiple times (three by default) over different frequency channels (three by default) chosen randomly.

- This simplifies the end device design and reduces its cost

SigFox: Technical Specification

- In Europe for example, the band between 868.180 MHz and 868.220 MHz is divided into 400 orthogonal 100 Hz channels (among them 40 channels are reserved and not used).

- No handover in SigFox

NB-IoT and Other LTE Variations

- Existing cellular technologies,
  - 2G (GPRS, Edge), 3G, and 4G/LTE,
  - are not particularly well adapted to battery-powered devices and small objects specifically developed for the Internet of Things.

- While industry players have been developing unlicensed-band LPWA technologies, 3GPP and associated vendors have been working on evolving cellular technologies to better address IoT requirements.
  - low throughput and low power consumption, and decrease the complexity and cost of the LTE devices.
  - This resulted in the definition of the LTE-M work item.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT and Other LTE Variations

- Because the new LTE-M device category was not sufficiently close to LPWA capabilities, in 2015 3GPP approved a proposal to standardize a new narrowband radio access technology called Narrowband IoT (NB-IoT).

- NB-IoT specifically addresses
  - the requirements of a massive number of low throughput devices,
  - low device power consumption,
  - improved indoor coverage,
  - and optimized network architecture.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT and Other LTE Variations

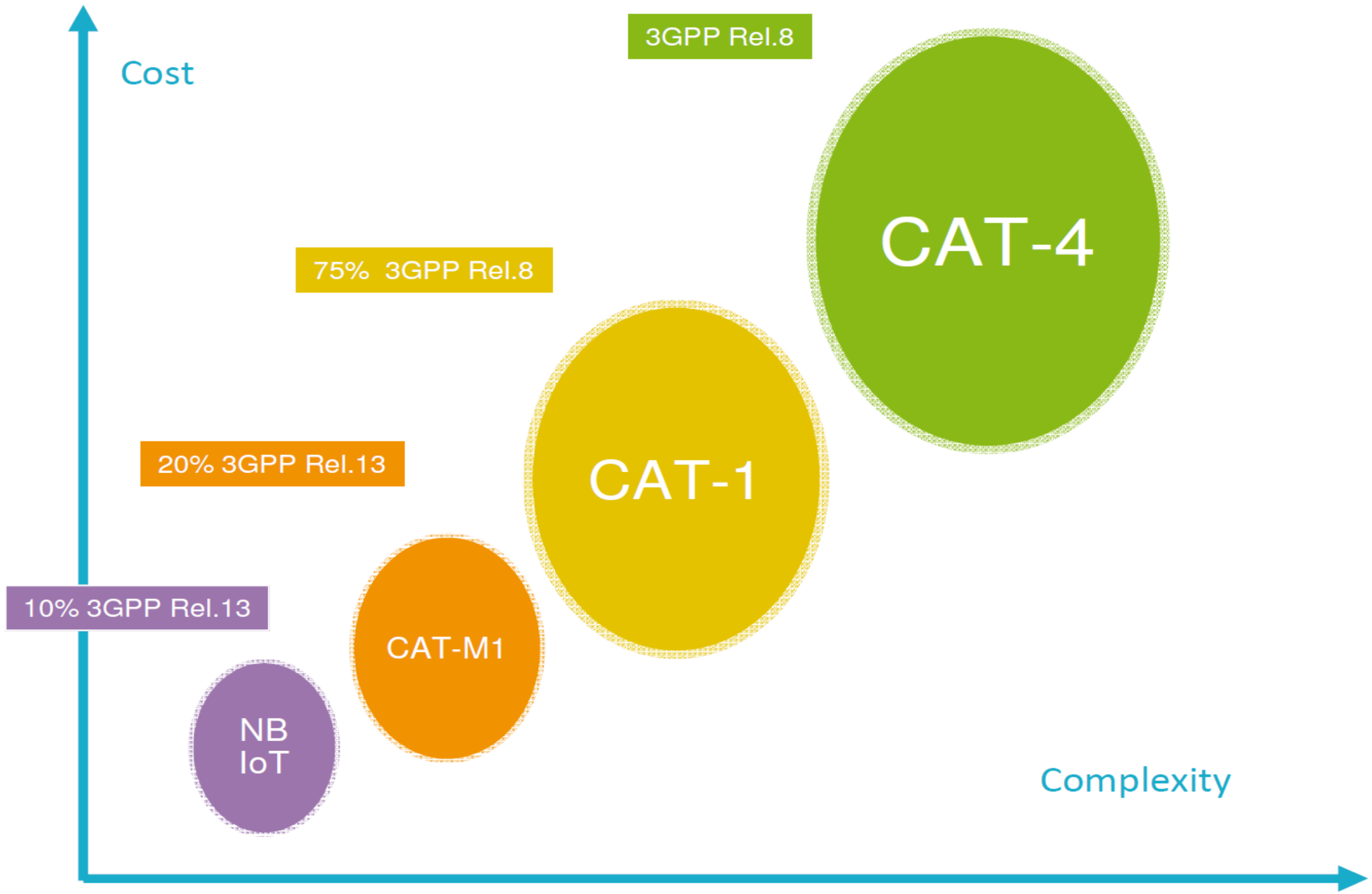
- Mobile vendors and service providers are not willing to lose leadership in this market of connecting IoT devices

- Licensed LPWAN:
  - LTE Cat 0
  - LTE-M
  - NB-IoT

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT and Other LTE Variations

Low cost



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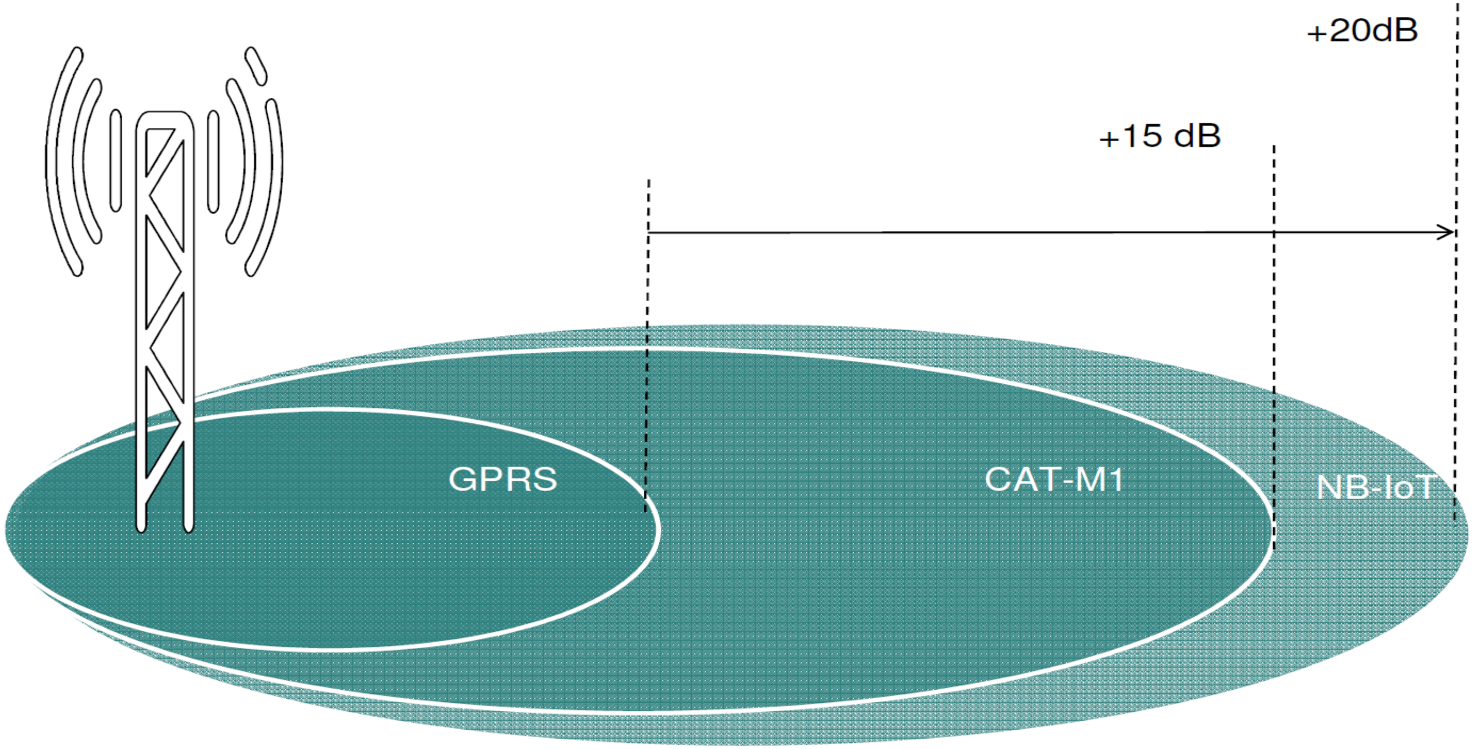
NB-IoT and Other LTE Variations



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LTE Cat 0

- The first enhancements to better support IoT devices in 3GPP occurred in LTE Release 12.
- A new user equipment (UE) category, Category 0, was added, with devices running at a maximum data rate of 1 Mbps.
- Category 0 includes important characteristics to be supported by both the network and end devices.
- Meanwhile, the UE still can operate in existing LTE systems with bandwidths up to 20 MHz.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

LTE Cat 0

These Cat 0 characteristics include the

- **Power saving mode (PSM):**
  - being similar to powered off" mode, but the device stays registered with the network.By staying registered, the device avoids having to reattach or reestablish its network connection.
  - with PSM, a device can be practically powered off but not lose its place in the network

- **Half-duplex mode:**
  - This mode reduces the cost and complexity of a device's implementation because a duplex filter is not needed.
  - Most IoT endpoints are sensors that send low amounts of data that do not have a full-duplex communication requirement.

LTE-M

- Following LTE Cat 0, the next step in making the licensed spectrum more supportive of IoT devices was the introduction of the LTE-M category for 3GPP LTE Release 13.
- LTE-M requires new chipsets and additional software development.
- Commercial deployment is expected in 2017.
- Mobile carriers expect that only new LTE-M software will be required on the base stations, which will prevent re-investment in hardware.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

LTE M

- These are the main characteristics of the LTE-M category in Release 13:
  - **Lower receiver bandwidth:**
    - Bandwidth has been lowered to 1.4 MHz versus the usual 20 MHz, further simplifying the LTE endpoint.
  - **Lower data rate:**
    - Data is around 200 kbps for LTE-M, compared to 1 Mbps for Cat 0.
  - **Half-duplex mode:**
    - Just as with Cat 0, LTE-M offers a half-duplex mode that decreases node complexity and cost.
  - **Enhanced discontinuous reception (eDRX)**
    - This capability increases from seconds to minutes the amount of time an endpoint can "sleep" between paging cycles.
    - A paging cycle is a periodic check-in with the network.
    - This extended "sleep" time between paging cycles extends the battery lifetime for an endpoint significantly.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT

- Recognizing that the definition of new LTE device categories was not sufficient to support LPWA IoT requirement, 3GPP specified Narrowband IoT (NB-IoT).

- The work on NB-IoT started with multiple proposals pushed by the involved vendors, including the following:
  - Extended Coverage GSM (EC-GSM), Ericsson proposal
  - Narrowband GSM (N-GSM), Nokia proposal
  - Narrowband M2M (NB-M2M), Huawei/Neul proposal
  - Narrowband OFDMA (orthogonal frequency-division multiple access), Qualcomm proposal
  - Narrowband Cellular IoT (NB-CIoT), combined proposal of NB-M2M and NB-OFDMA
  - Narrowband LTE (NB-LTE), Alcatel-Lucent, Ericsson, and Nokia proposal
  - Cooperative Ultra Narrowband (C-UNB), Sigfox proposal

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT

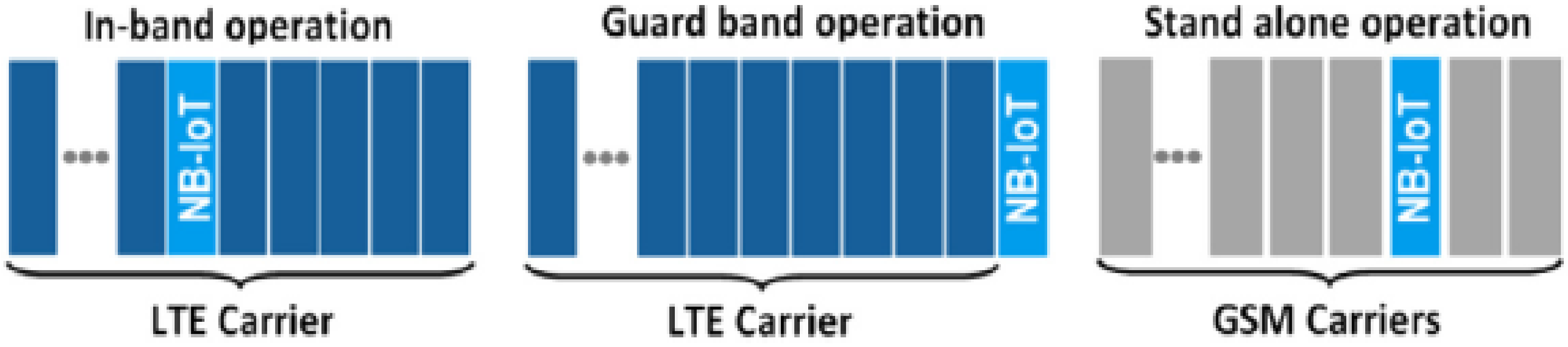
- Three modes of operation are applicable to NB-IoT:
  - **Standalone**
    - A GSM carrier is used as an NB-IoT carrier, enabling reuse of 900 MHz or 1800 MHz.
  - **In-band**
    - Part of an LTE carrier frequency band is allocated for use as an NB-IoT frequency.
  - **Guard band**
    - An NB-IoT carrier is between the LTE or WCDMA bands.
    - This requires coexistence between LTE and NB-IoT bands.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

NB-IoT

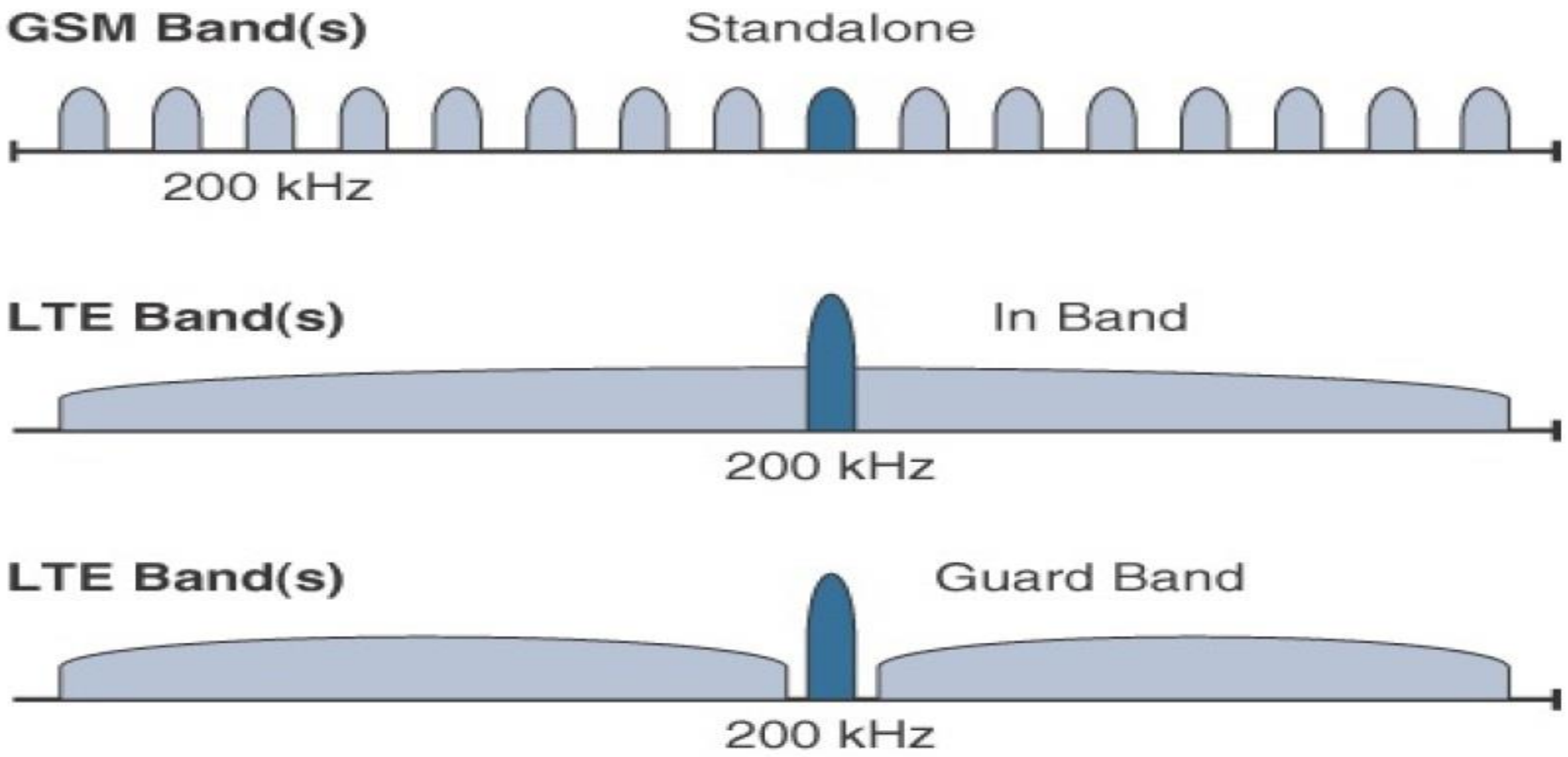
- NB-IoT occupies a frequency band width of 200 KHz, which corresponds to one resource block in GSM and LTE transmission

- Operation Modes of NB-IoT



Physical and Link Layers Protocols- NB-IoT

- NB-IoT



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Physical and Link Layers Protocols- NB-IoT

- NB-IoT uses the single-carrier FDMA in the uplink and orthogonal FDMA (OFDMA) in the downlink, and employs the QPSK modulation (QPSK)
- The data rate is limited to 200 kbps for the downlink and to 20 kbps for the uplink.
- The maximum payload size for each message is 1600 bytes.

Physical and Link Layers Protocols- NB-IoT

- Based on the LTE protocol, bust with minimal functionalities
  - LTE backend system is used to broadcast information that is valid for all end devices within a cell.
    - As the broadcasting backend system obtains resources and consumes battery power from each end device, it is kept to a minimum, in size as well as in its occurrence.
  - It was optimized to small and infrequent data messages and avoids the features not required for the IoT purpose, e.g., measurements to monitor the channel quality, carrier aggregation, and dual connectivity.

Physical and Link Layers Protocols- NB-IoT

- NB-IoT technology is a new air interface from the protocol stack point of view, while being built on the well-established LTE infrastructure
  - NB-IoT can be supported with only a software upgrade in addition to the existing LTE infrastructure

- NB-IoT allows connectivity of up to 100 K end devices per cell with the potential for scaling up the capacity by adding more NB-IoT carriers.

- 10 years of battery lifetime when transmitting 200 bytes per day on average.

Physical and Link Layers Protocols- NB-IoT

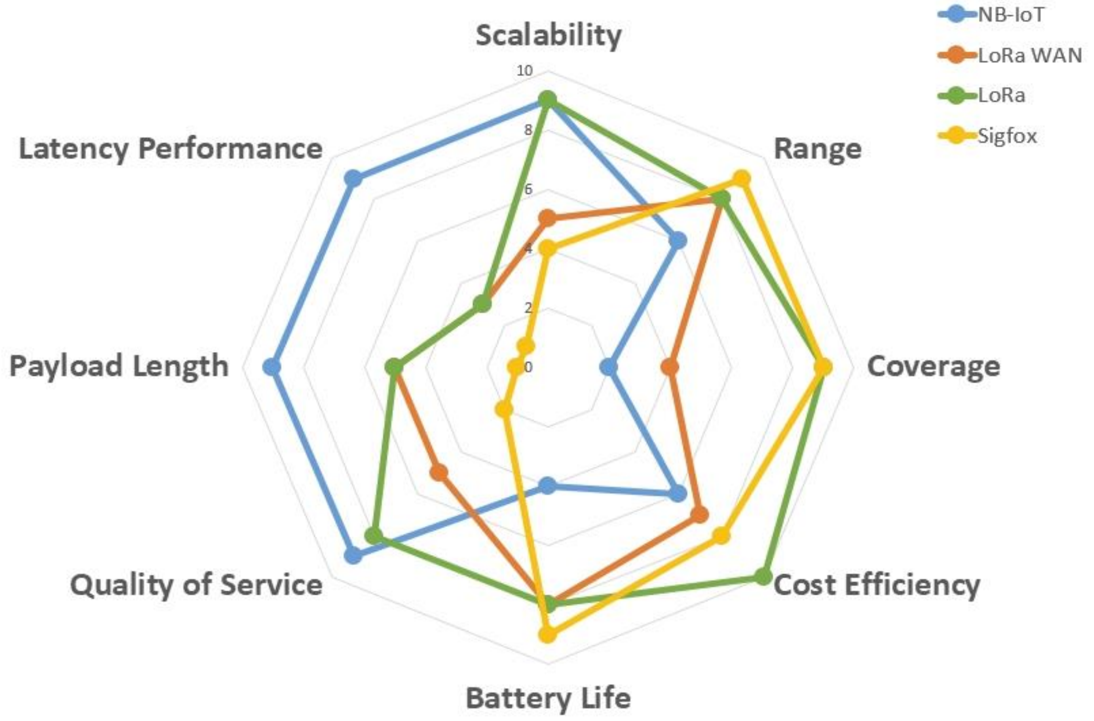
- According to the 3GPP's current plan (Release 15), the NB IoT will be extended to include:
  - localization methods,
  - multicast services (e.g., end-devices software update and messages concerning a whole group of end devices)
  - mobility,
  - as well as further technical details to enhance the applications of the NB-IoT technology.

Comparison of Main LPWAN Technologies

	Sigfox	LoRaWAN	NB-IoT
Modulation	BPSK	CSS	QPSK
Frequency	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Licensed LTE frequency bands
Bandwidth	100 Hz	250 kHz and 125 kHz	200 kHz
Maximum data rate	100 bps	50 kbps	200 kbps
Bidirectional	Limited / Half-duplex	Yes / Half-duplex	Yes / Half-duplex
Maximum messages/day	140 (UL), 4 (DL)	Unlimited	Unlimited
Maximum payload length	12 bytes (UL), 8 bytes (DL)	243 bytes	1600 bytes
Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference immunity	Very high	Very high	Low
Authentication & encryption	Not supported	Yes (AES 128b)	Yes (LTE encryption)
Adaptive data rate	No	Yes	No
Handover	End-devices do not join a single base station	End-devices do not join a single base station	End-devices join a single base station
Localization	Yes (RSSI)	Yes (TDOA)	No (under specification)
Allow private network	No	Yes	No
Standardization	Sigfox company is collaborating with ETSI on the standardization of Sigfox-based network	LoRa-Alliance	3GPP

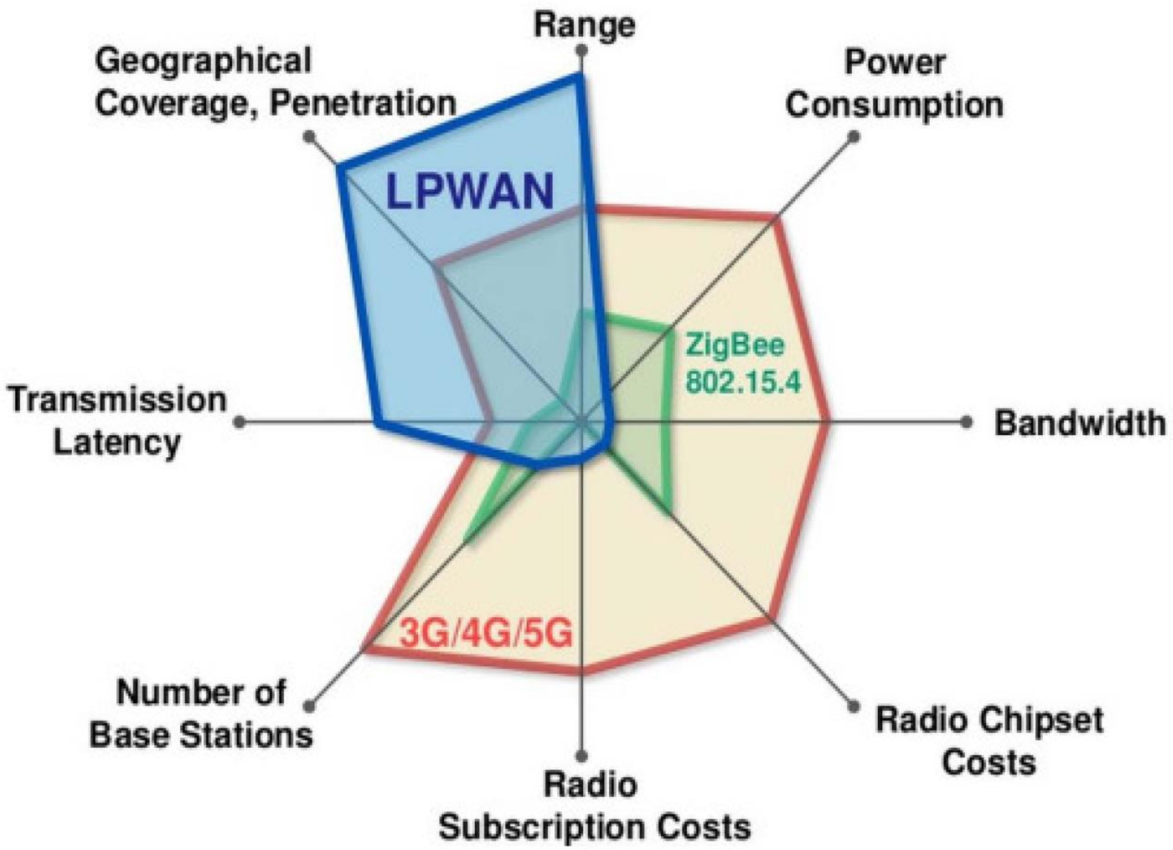
Communication Technologies Comparison

- Comparison of SigFox, LoRa, LoRaWAN, and NB-IoT in terms of different criteria



* https://www.betasolutions.co.nz/Blog/25/20-Things-to-Consider-When-Planning-an-IoT-Solution-_-Part-2

NB-IoT and Other LTE Variations



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Comparison of Main LPWAN Technologies

Feature	LORAWAN	SIGFOX	LTE Cat 1	LTE M	NB - LTE
Modulation	SS chip	UNB / GFSK / BPSK	OFDMA	OFDMA	OFDMA
Rx Bandwith	500 – 125 KHz	100 Hz	20 MHz	20 – 1.4 MHz	200 KHz
Data Rate	290bps – 50Kbps	100 bit / sec 12 / 8 bytes Max	10 Mbit /sec	200 kbps – 1 Mbps	Average 20K bit / sec
Max. # Msgs/day	Unlimited	UL: 140 msgs / day	Unlimited	Unlimited	Unlimited
Max Outpu Power	20 dBm	20 dBm	23 – 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Battery lifetime – 2000 mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very High	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes Oui	Yes	Yes
Mobility / localization	Yes	Limited mobility, No localization	Mobility	Mobility	Limited mobility, No localization

Source: LoRAWAN Alliance, 2015

www.vertical-m2m.com

Technical Specification of Various LPWA Proprietary Technologies

	SigFox	LoRaWAN
Modulation	UNB DBPSK(UL), GFSK(DL)	CSS
Band	Sub-GHz ISM:EU (868MHz), US(902MHz)	Sub-GHz ISM:EU (433MHz 868MHz), US (915MHz), Asia (430MHz)
Data rate	100 bps(UL), 600 bps(DL)	0.3-37.5 kbps (LoRa), 50 kbps (FSK)
Range	10 km (URBAN), 50 km (RURAL)	5 km(URBAN), 15 km (RURAL)
Num. of channels / orthogonal signals	360 channels	10 in EU, 64+8(UL) and 8(DL) in US plus multiple SFs
Link symmetry	✗	✓
Forward error correction	✗	✓
MAC	unslotted ALOHA	unslotted ALOHA
Topology	star	star of stars
Adaptive Data Rate	✗	✓
Payload length	12B(UL), 8B(DL)	up to 250B (depends on SF & region)
Handover	end devices do not join a single base station	end devices do not join a single base station
Authentication & encryption	encryption not supported	AES 128b
Over the air updates	✗	✓
SLA support	✗	✗
Localization	✗	✓

Physical and Link Layers Protocols- IEEE 1901-2a: PLC

- Power Line Communication (PLC) is the use of electrical wires to provide data transmission capabilities
- PLC networks provide a number of advantages that make them both a useful complement and a strong competitor to wireless networking solutions.
  - low deployment cost when an electrical wired infrastructure is already in place.
  - PLC networks allow communication through obstacles that commonly degrade wireless signals, while delivering high data rates.
  - PLC also provides a low-cost alternative to complement existing technologies when aiming for ubiquitous coverage.
  - PLC provides the possibility of re-using the existing wired electrical network to provide communication capabilities

* State-of-the-art in Power Line Communications: from the Applications to the Medium, IEEE Journal on Selected Areas in Communications, 2016

Physical and Link Layers Protocols- IEEE 1901-2a: PLC

- A classification of PLC systems is according to frequency bands:
  - ultra-narrowband (UNB) operating between about 125–3000 Hz,
  - narrowband (NB) operating between about 3–500 kHz , and
  - broadband (BB) operating between about 1.8–100 MHz

* State-of-the-art in Power Line Communications: from the Applications to the Medium, IEEE Journal on Selected Areas in Communications, 2016

Physical and Link Layers Protocols- PLC

- *Main Characteristics of IoT Access Technologies*

Characteristic	IEEE 802.15.4	IEEE 802.15.4g and IEEE 802.15.4e	IEEE 1901.2a	IEEE 802.11ah	LoRaWAN	NB-IoT
Wired or wireless	Wireless	Wireless	Wired	Wireless	Wireless	Wireless
Frequency bands	Unlicensed 2.4 GHz and sub-GHz	Unlicensed 2.4 GHz and sub-GHz	Unlicensed CENELEC A and B, FCC, ARIB	Unlicensed sub-GHz	Unlicensed sub-GHz	Licensed
Topology	Star, mesh	Star, mesh	Mesh	Star	Star	Star
Range	Medium	Medium	Medium	Medium	Long	Long
Data rate	Low	Low	Low	Low–high	Low	Low

* State-of-the-art in Power Line Communications: from the Applications to the Medium, IEEE Journal on Selected Areas in Communications, 2016

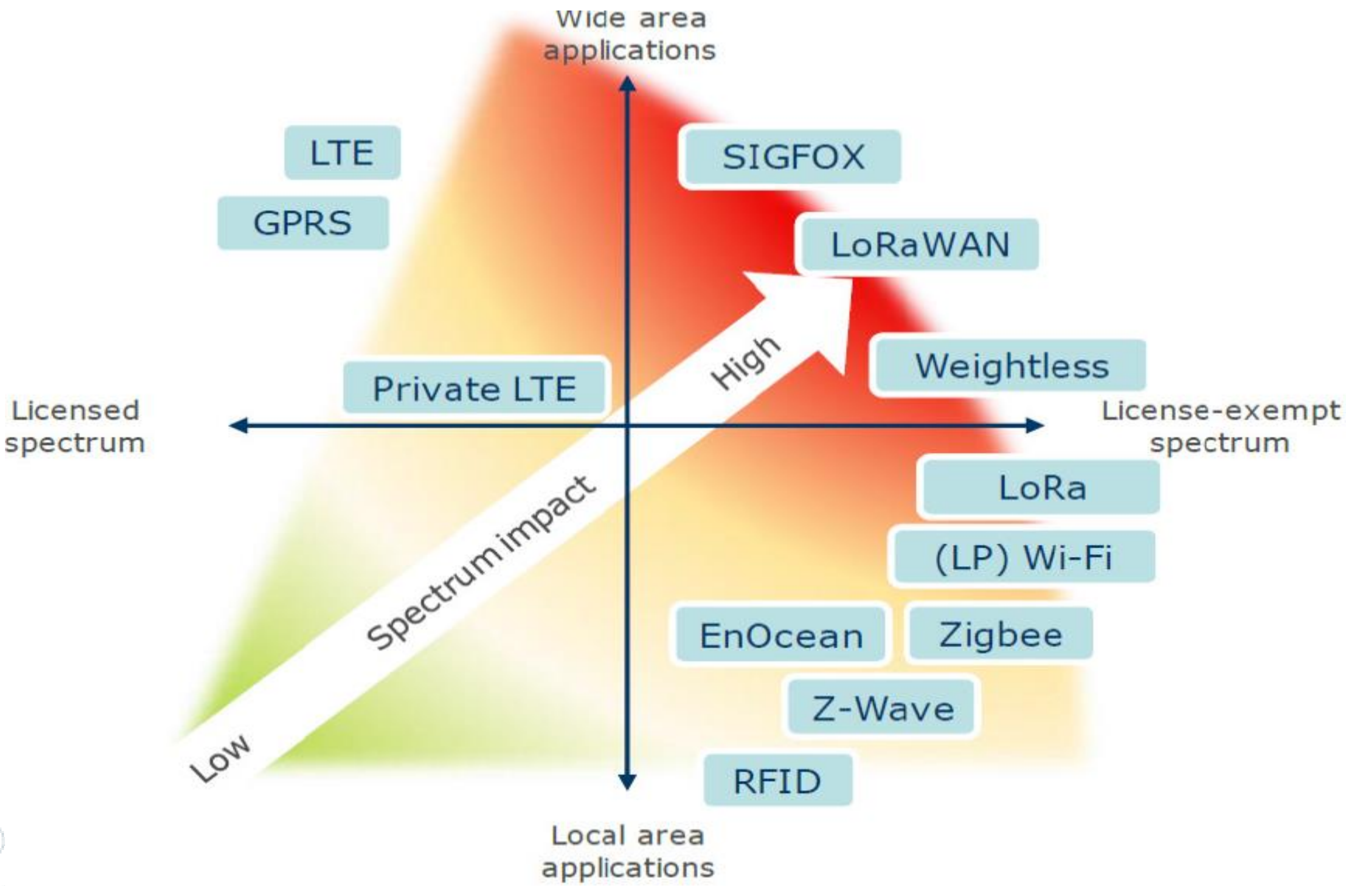
Physical and Link Layers Protocols- use cases

Key IoT Verticals	LPWAN (Star)	Cellular (Star)	Zigbee (Mostly Mesh)	BLE (Star & Mesh)	Wi-Fi (Star & Mesh)	RFID (Point-to-point)
Industrial IoT	●	○	○			
Smart Meter	●					
Smart City	●					
Smart Building	●		○	○		
Smart Home			●	●	●	
Wearables	○			●		
Connected Car					○	
Connected Health		●		●		
Smart Retail		○		●	○	●
Logistics & Asset Tracking	○	●				●
Smart Agriculture	●					

● Highly applicable ○ Moderately applicable

* https://behrtech.com/blog/6-leading-types-of-iot-wireless-tech-and-their-best-use-cases/

IoT wireless technologies overview



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Contents

Mostly adopted from Chapters 4, 5, and 6 of IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

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- Introduction
  - Connecting Smart Objects
  - IoT Protocol Stack (Standards, Protocols and Technologies)
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