Module IT.2301 - Internet of Things: Low Power Wide Area Networks (LPWAN)

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Part I

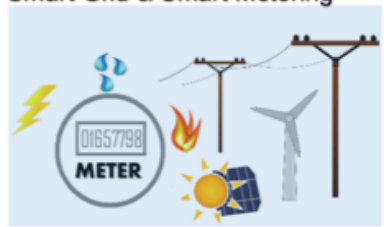
IoT Wide Area Networks

IoT Wide Area Network Use Cases

Smart City Applications

Personal IoT Applications

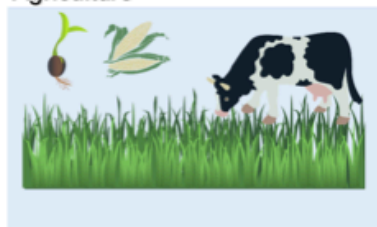
Smart Grid & Smart Metering



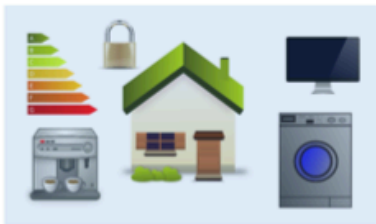
Industrial Assets Monitoring

Critical Infrastructure Monitoring

Agriculture



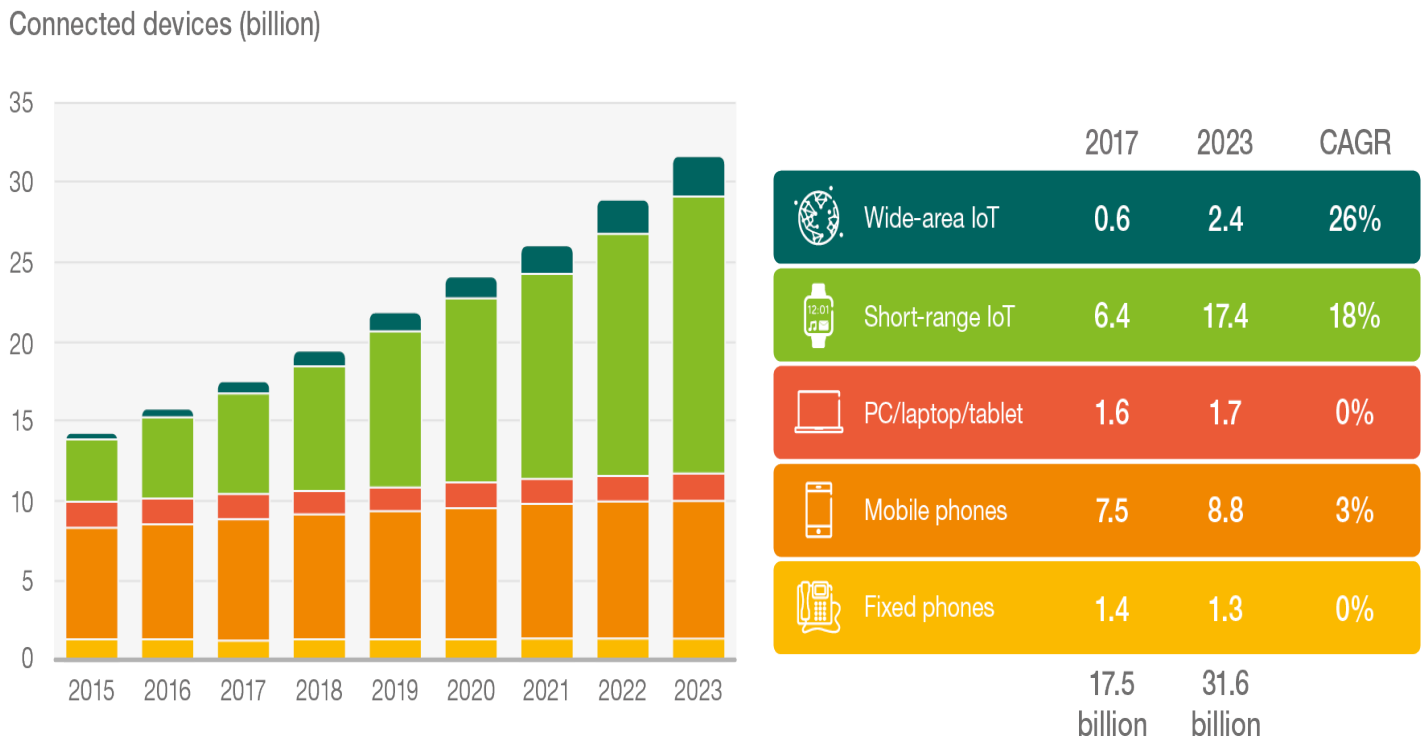
Home Automation & Safety



Logistics

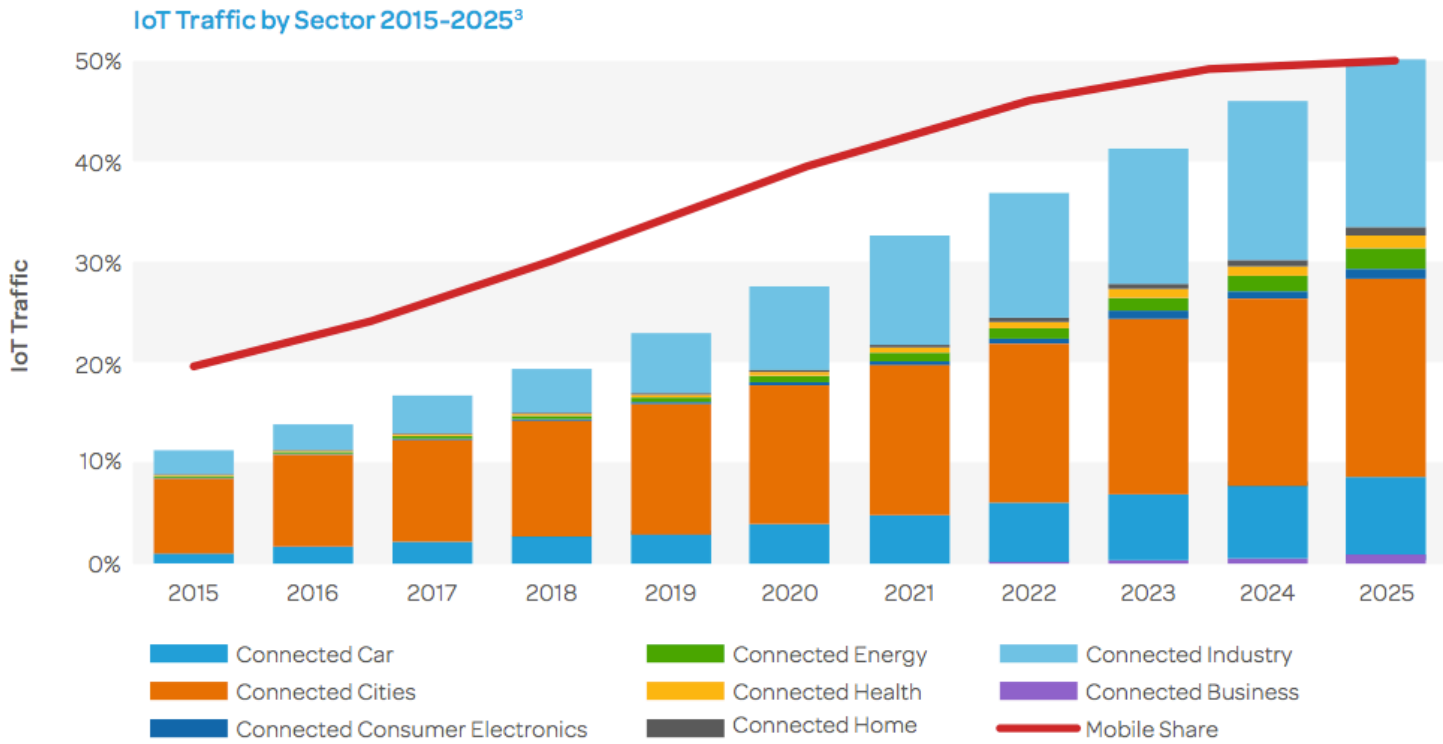
Wildlife Monitoring & Tracking

IoT Traffic and Market Opportunity (1/)



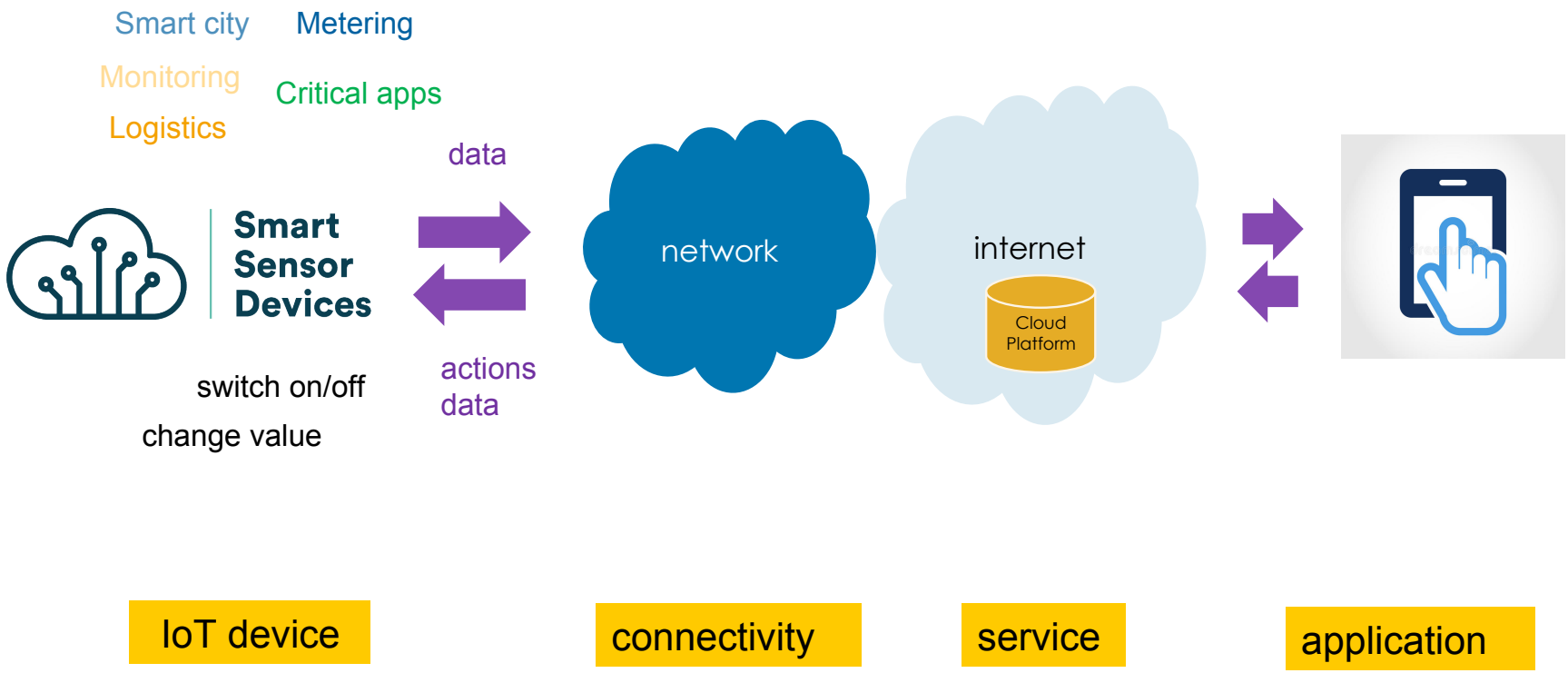
CAGR = Compound Annual Growth Rate

IoT Traffic and Market Opportunity (2/)



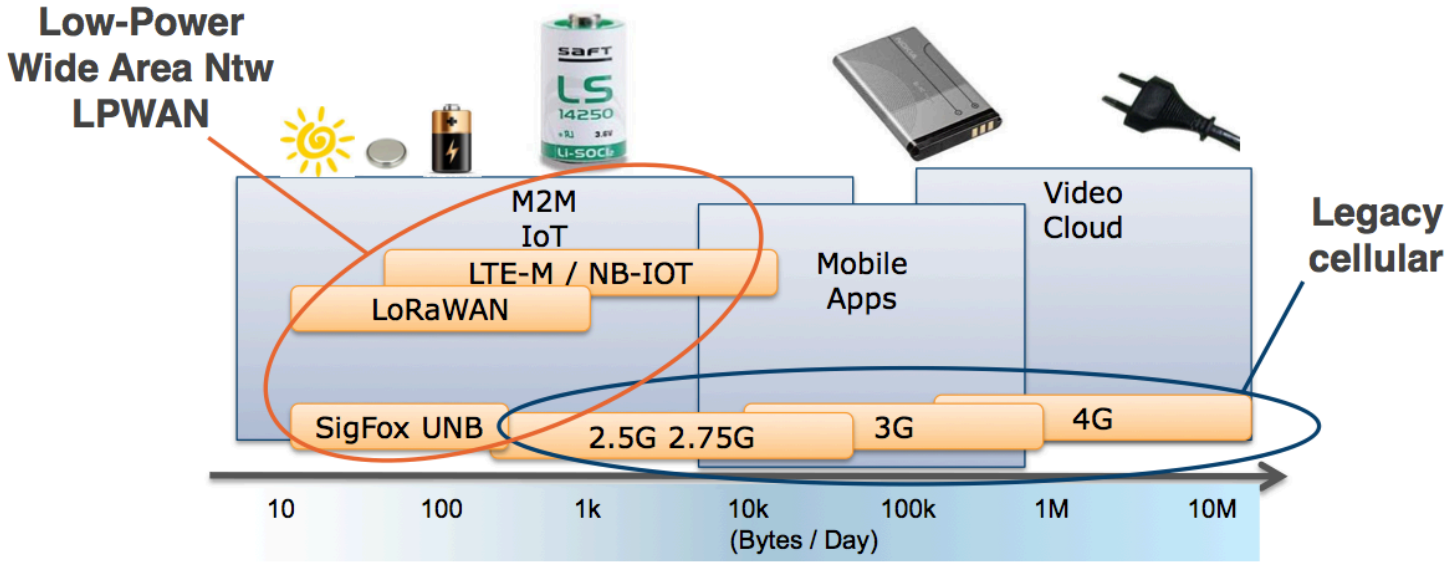
[3] Source: IoT Global Forecast & Analysis 2015-2025, Machina Research, August 2016.

IoT Wide Area Architecture



Direct connexion to the network

IoT Wide Area Technologies



Comparison of Wide Area Networks

Comparison	Legacy Cellular	Licensed LPWA	Unlicensed LPWA	Satellite
Range	Global Coverage	Cellular	Regional	Anywhere
Throughput	Medium to High	Low to Medium	Low	Very High
Mobility	yes	yes	varies	varies
Latency	Ultra-low	Low	varies	varies
Battery Life	Days to week	Up to 10+ years	Up to 10+ years	Days to week
Cost	Medium	Low	Low	High

LPWA Network for Battery-Operating Devices

Unlicensed vs Licensed LPWA Technologies

Comparison	Licensed LPWA	Unlicensed LPWA
3GPP-Standard Based	Yes	No
Dedicated spectrum	Yes	No
Benefits from existing networks	Yes	No
Long Battery Life	Yes	Yes
Low Costs Modules	Yes	Yes
Critical applications	Yes	No
Real time application	Yes	No
Coordinated interference	Yes	No

Enabling Licensed LWPA Technologies

- 3GPP Release 13 adds to LTE two categories for Machine Type Communication:
  - **LTE-Cat M1**: Machine Type Communication;
  - **LTE-CatNB1**: Narrow Band NB-IoT.
- Main characteristics of LTE-M: Reduced Complexity, coverage enhancements, channel bandwidth reduction, and a new lower transmit power class
- Main characteristics of NB-IoT: Narrow band (180 kHz); 20dB coverage enhancement w.r.t. 2G

Enabling Unlicensed LWPA Technologies

Technology	Band	Node Power	UL Data Rate
Sigfox	868 MHz ISM	14 dBm	100 bps
LoRa	868 MHz ISM	14 dBm	300 bps - 50 kbps
Weightless	Sub-GHz ISM	17 dBm	100 bps to 100 kbps
IEEE 802.11ah	2.4 GHz	0 - 30 dBm	150 kbps - 300 Mbps
Ingenu	2.4 GHz	20 dBm	624 bps
n-wave	Sub-GHz	14 - 20 dBm	100 bps
Dash7-Alliance	868Mhz ISM	ETSI Reg	10, 55, 166 kps

Comparison between Key Technolgies

Technology	Sigfox	LoRa	LTE-CatM	NB-IoT
Frequency	868 MHz ISM	868 MHz ISM	LTE Bands	GSM Bands, LTE guard band, LTE subcarriers
Bandwidth	2000$\times$100 Hz	8$\times$ 125 KHz	1.4 MHz	180 KHz
Node Power	14 dBm	14 dBm	20 dBm	20 dBm
Ntw sensitivity	-145 dBm	- 142 dBm	-122.7 dBm	-144 dBm
Rural range	30 - 50 km	15 km	cellular	cellular
Urban range	3 - 10 km	2-5 km	cellular	cellular
UL rate	100 bps	0.3 - 50 kbps	200 kbps	0.3 - 300 kbps
DL rate	500 bps	0.3 - 50 kbps	200 kbps	0.2 - 100 kbps
Governing	Sigfox	LoRa Alliance	3GPP	GSMA-3GPP

Part II

Unlicensed LPWA Technologies

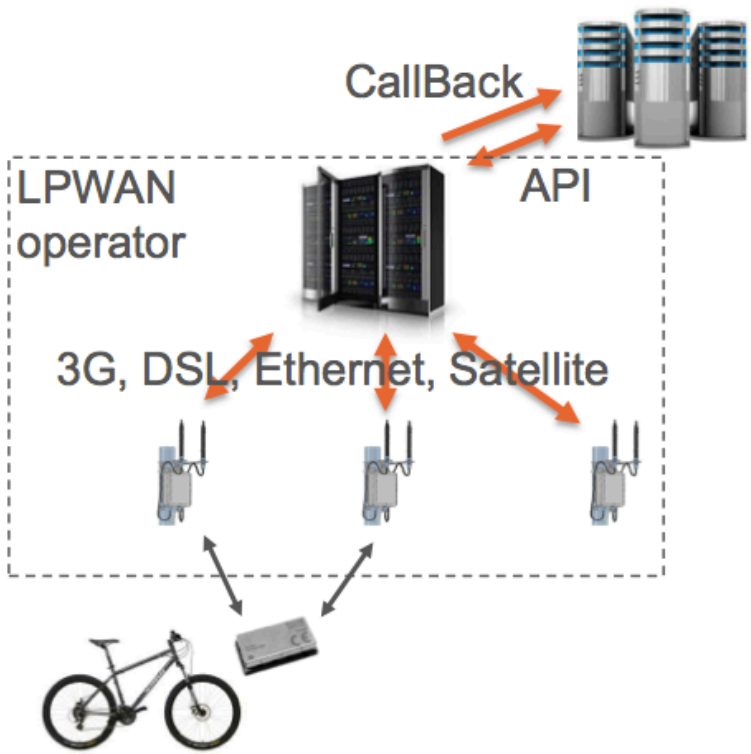
Outline: Unlicensed LPWA Technologies

Outline: Unlicensed LPWA Technologies

Low Data Rate, Low Power and High Ranges

- Low data rate signals stay long time on the air and they travel long distance;
- The bandwidth occupied by the signal is very narrow and the noise power is very low.
- The power of the signal is concentrated in a narrow band and the receiver sensitivity is very high.
- Low data rate is sensitive to quartz oscillation reliability.

Global Architecture (1/)



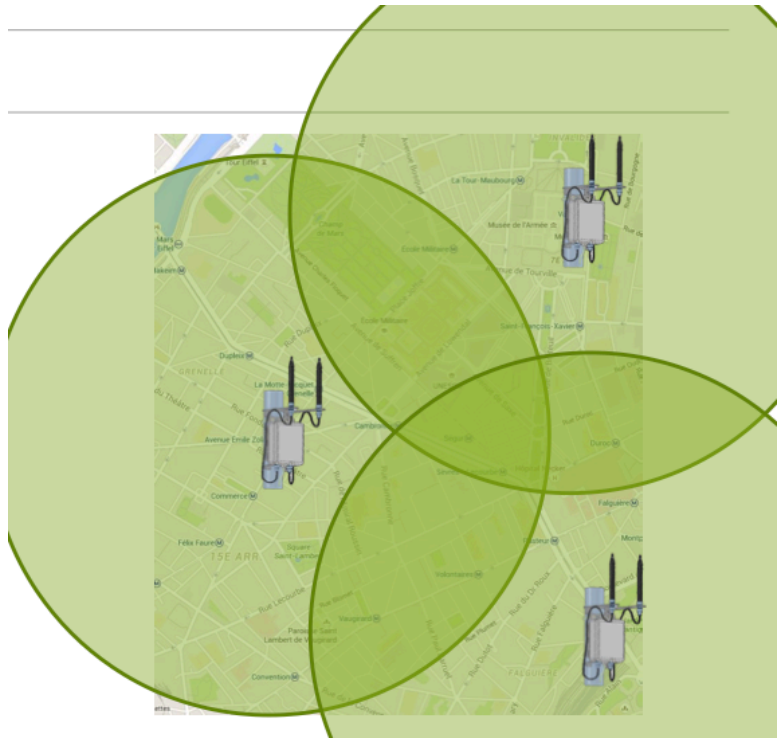
Global Architecture (2/)

- SIGFOX or LoRawAN LPWAN operators are following similar network architectures.
- Base-stations in the field acting as 1 global base-station; The signal is received by all the stations (reception diversity).
- Simplified MAC layer cloud- operated;
- Application Programming Interface (API) or callback interface to retrieve or push messages to customer's application server.

Certification and Hardware Costs

- Both SIGFOX and the LoRa Alliance have a mandatory certification program;
- This is necessary to validate that the implementation of the communication is 100% compliant with the specification;
- In case of communication issues, certificate protects customer against the operator;
- LPWAN data plans cost 10x less than GPRS/3G data plans because 10x less network infrastructure required;
- For volumes higher than 100kbps, cost of communication is 1 euro/node.

Legacy Cellular vs Unlicensed LPWA (1/)



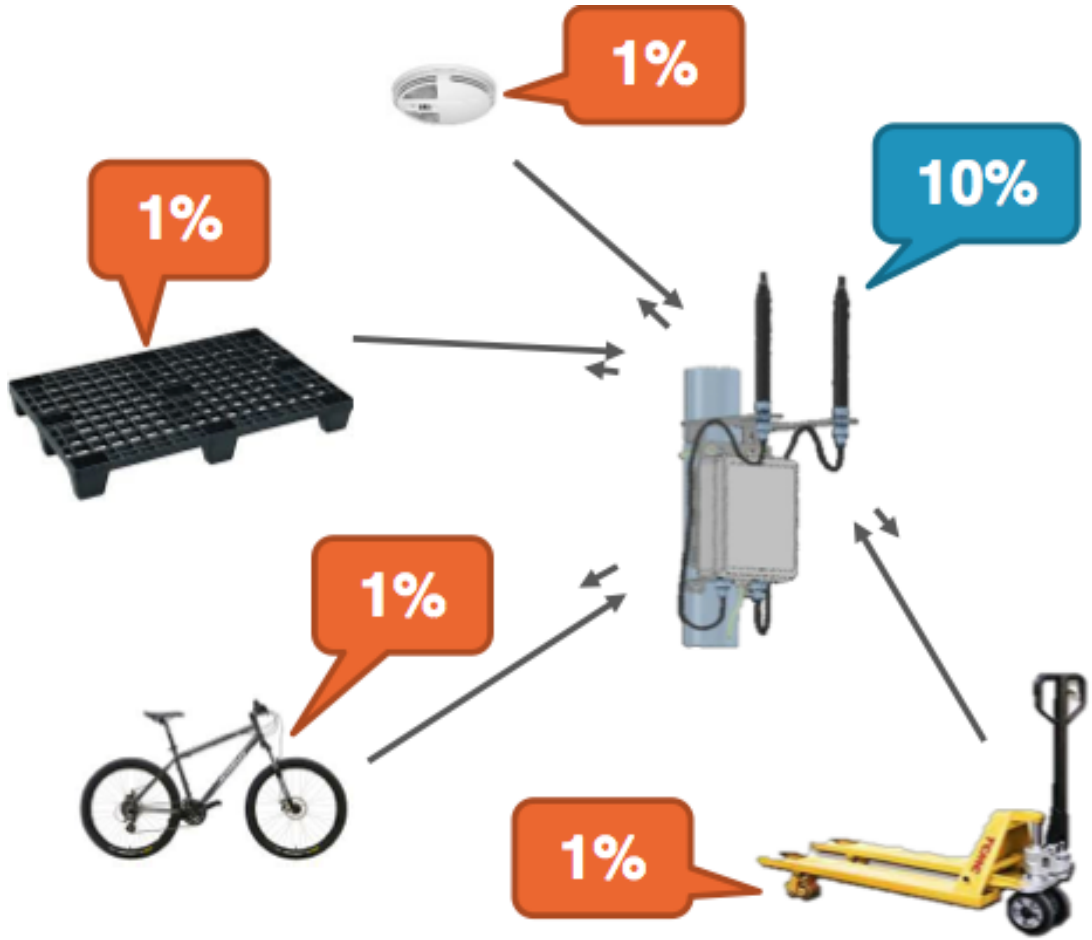
Legacy Cellular Network

- A moving UE (User Equipment) will have to switch to different cells in order to maintain connectivity; The network manages this in real-time: Handover
- Complex mechanism supposing that the UE is updated in real-time with the frequencies/codes of surrounding cells and that the network pre-allocates bandwidth/slots in surrounding cells in case the UE moves.
- 2G networks were designed for voice service: architecture towards limiting latency to a few 10ms and maintaining audio QoS at an average of 5-12kbps full-duplex;
- 3G and 4G networks added the capability to handle transfers of large amount of packetized data at rates up to 50Mbps to serve mobile apps with smartphones.

Unlicensed LPWA

- 5-10x less base-stations than 3G/4G cellular networks;
- All base-stations listen to the same frequencies and act together as 1 global base-station;
- Spatial redundancy helps securing connectivity for objects in harsh environments;
- Filling the blanks is easier: just drop an extra base-station, no modification of the existing network required;
- Very attractive for LPWAN operators: low capex, low opex, low complexity.

Network bi-directionality (1/)

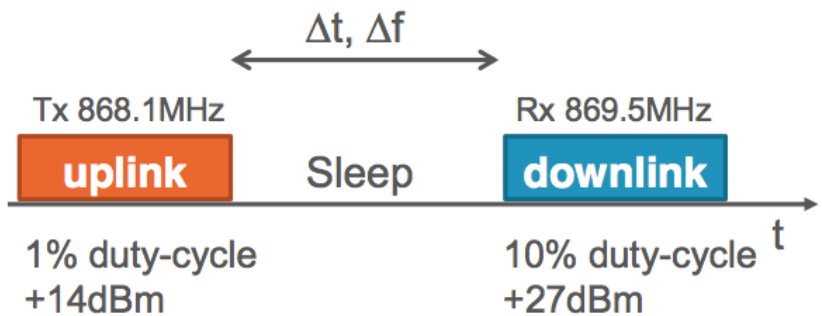


Network bi-directionality (2/)

- Both Up and Down link in same unlicensed 868MHz ISM band;
- European Telecommunications Standards Institute (ETSI) regulates the band usage
- A base-station cannot talk for more than 10% of the time.
- 1 BS serving 100k - 1M objects cannot answer them all!
- Base-Stations operate in half- duplex mode: cannot receive when transmitting
- Network is mostly uplink - downlink used scarcely.

Communication Protocols

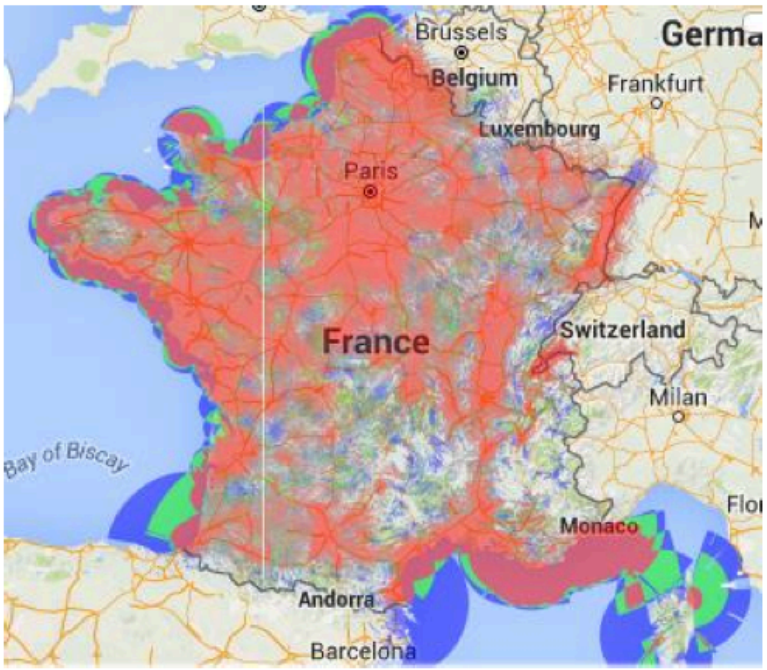
- **SIGFOX**: Sensor-initiated bi-directionnal communication
- **LoRaWAN Class-A**: Equivalent to SIGFOX with same constraints (ETSI)
- **LoRaWAN Class-B**:
  - Sensors are synchronized by network beaconing - TDMA;
  - Useful in private networks for throughput optimization.
- **LoRaWAN Class-C**: Powered sensors/actuators can be in listen-mode full-time



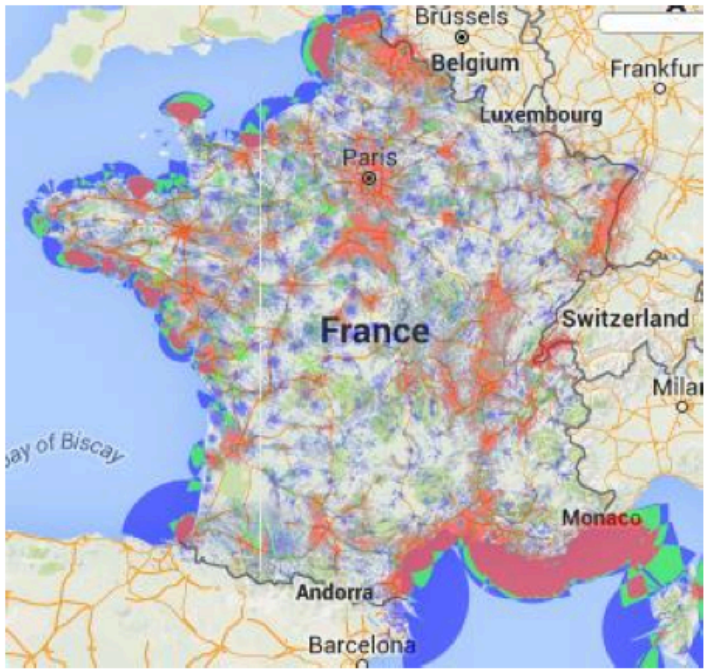
Outline: Unlicensed LPWA Technologies

French Sigfox Deployment

Outdoor



Indoor = Outdoor – 20dB

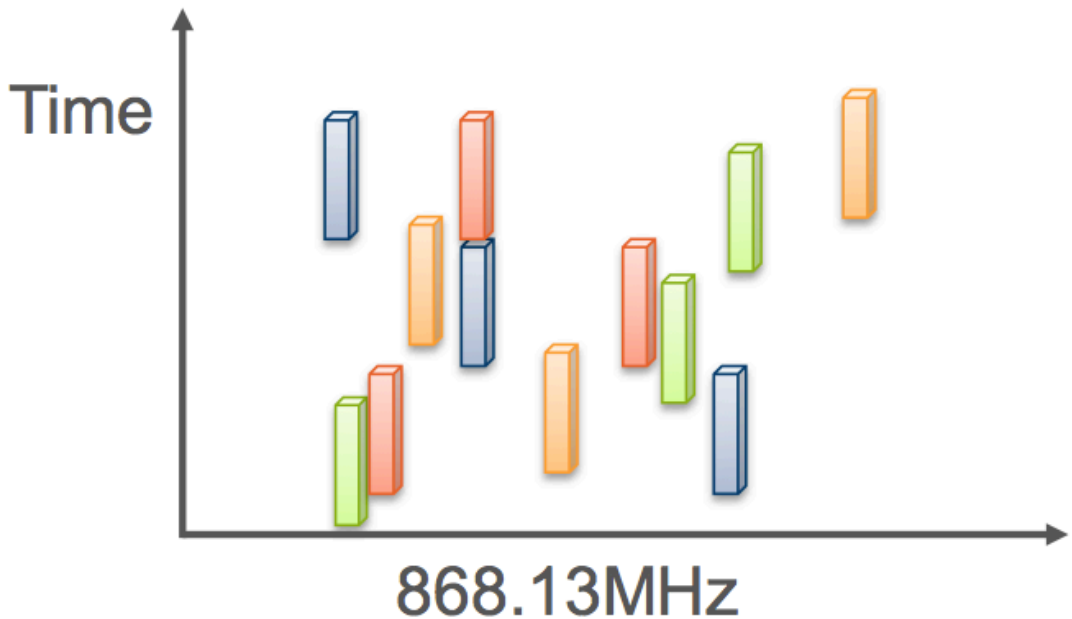


Sigfox Network Operators

- France: SIGFOX
- Spain: CELLNEX
- NL: AEREA / TELE2
- UK: ARQIVA
- Portugal: NARROW NET
- Belgium: ENGIE M2M
- Luxemburg: RMS / POST
- Italy: NETTROTTER
- Denmark: IoT DENMARK
- Ireland: VIZOR
- Poland: EED USA: SIGFOX

Ultra Narrow Band Modulation in Uplink

- 200kHz allocated BW in current implementation
- Simultaneous frequency capacity = 200kHz / 100Hz x 10% = 200 simultaneous messages. Only 10% are used to avoid collisions.
- Messages is repeated 3 times on 3 random frequencies.



Sigfox Node UNB Modulation Limits

- DBPSK modulation @ 100 bps;
- Frequency: 868.13MHz +/- 100kHz
- Link budget = +14dBm (Tx) - (-145dBm) (ntw sensitivity) = 159dB $\gg$ GPRS
- 12-byte payload per message
- Message duration = 3$\times$2s
- Repeated 3 times on 3 random frequencies within band;
- Energy spent per message Etx = 3 x 2s x 50mA = 300mAs = 83μAh

Dowlink PHY Layer

- FSK modulation @ 500 bps
- Frequency: Uplink + 1.4MHz (869.5MHz +27dBm sub-band)
- Link budget = +27dBm (Tx) - (-126dBm) (node sensitivity) = 154dB $\gg$ GPRS
- 8-byte payload per message
- Message duration = 300ms with average latency of 10s
- Energy spent per message Erx = 10.3s x 15mA = 154mAs = 43μAh

Sigfox Network Capacity

- Simultaneous frequency capacity = 200kHz / 100Hz x 10% = 200 simultaneous messages with 10% is max limit for collisions;
- Message = 208bits (2.08s) repeated 3 times on 3 random frequencies
- Base-station capacity = 200 x 24h x 3600s/h / 6.24s = 2.7M mess/day @ max link budget

Outline: Unlicensed LPWA Technologies

LoRaWAN Deployment in France

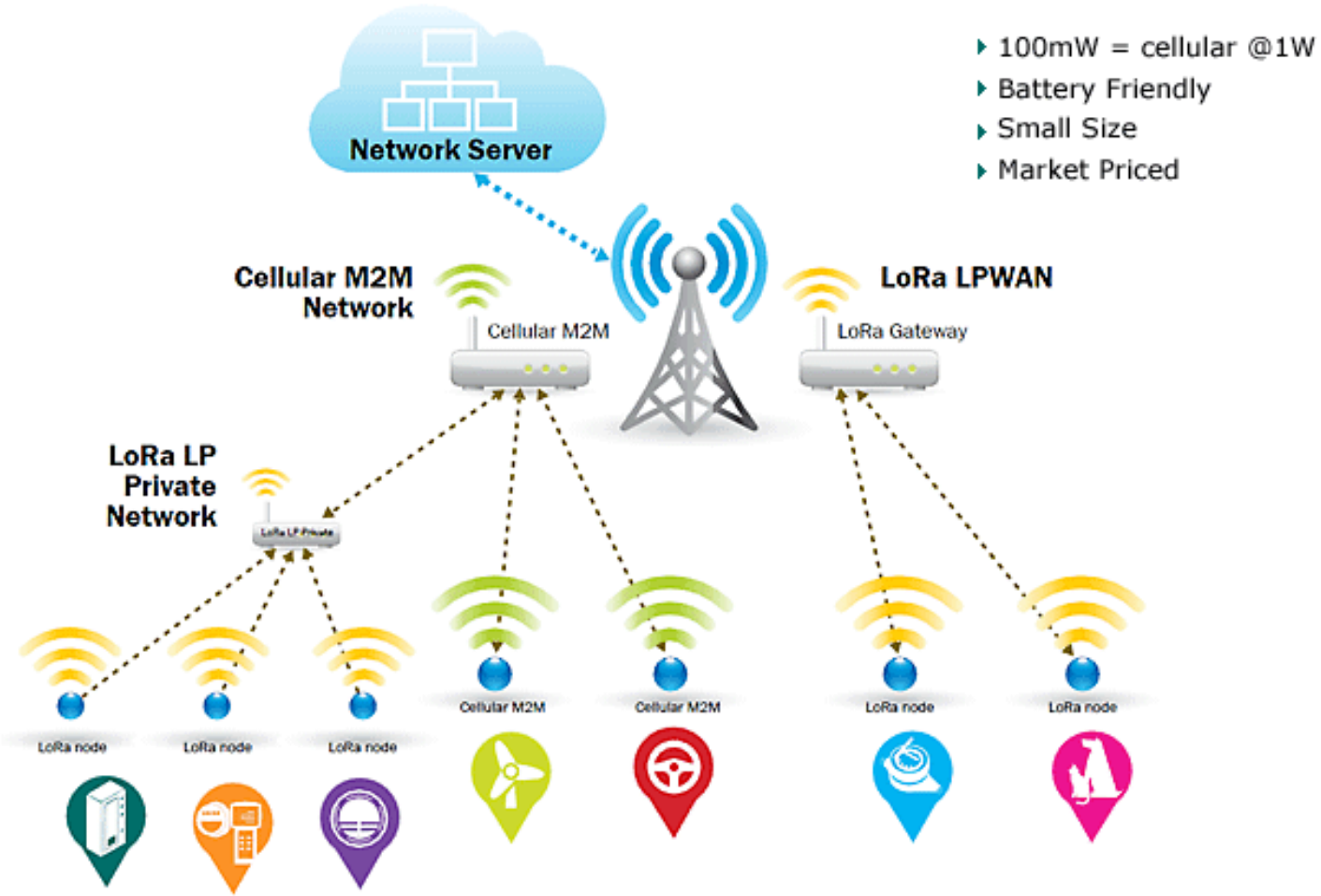
- **Bouygues Telecom**:
  - End 2015 : 30 urban areas over 200k people, ie 1500 towns;
  - H1 2016 : 80% population;
  - End 2016 : Full nationwide coverage;
  - Total planned number of BS = 400-500
  - To be compared with SIGFOX's current 1400 BS.

- **Orange**:
  - Current pilot in Grenoble
  - H1 2016: nationwide deployment
  - End 2016: full nationwide coverage.

LoRaWAN Operators

- France: BOUYGUES TEL, ORANGE;
- NL: KPN
- Belgium: PROXIMUS
- Switzerland: SWISSCOM
- South Africa: FASTNET
- Russia: LACE
- USA: SENET
- India: TATA

LoRaWAN Private Network (1/)



LoRaWAN Private Network (2/)

- Customer owns, installs and administrates his private network across his buildings and campuses;
- LoRaWAN private network connects sensors, actuators, machines inside Intranet;
- LoRaWAN private network is compatible with public networks when available;
- LoRaWAN private network is also useful to strengthen / complement a public network in harsh industrial environments.
- Private network is not in the business model of Sigfox.

LoRA Chirp Spread Spectrum (CSS) (1/)

- LoRa uses 8 frequency channels of 125kHz in the 867- 868.5MHz sub-band
- In each band, chirp Spread Spectrum with a spreading coefficient of SF is used to spread the information on a larger bandwidth to mitigate the interference.
- There is 6 Spreading Factors (SF) orthogonal between them yielding bit rates from 0.3 to 5 kbps.
- Adaptive data rate is used with respect to the distance btw the tx and the Rx.

Uplink PHY Layer

- LoRa CSS (Chirp Spread Spectrum)
- 0.3-5 kbits per second (Adaptive Data Rate)
- Link budget = +14dBm (Tx) - (-142dBm) (ntw sensitivity) = 156dB $\gg$ GPRS
- 0-250 bytes/message payload
- Message duration = 40ms - 1.2s
- Energy spent per message Etx = 1.2s x 32mA = 11μAh at full sensitivity
- Energy spent per message Etx = 40ms x 32mA = 0.36μAh at min sensitivity.

LoRa Modes and Data Rate

Mode SF	Bit Rate (kbps)	Sensitivity (dBm)
12	0.293	-137
11	0.537	-134.5
10	0.976	-132
9	1.757	-129
8	3.125	-126
7	5.468	-123
6	9.375	- 118

Dowlink PHY Layer

- LoRa CSS (Chirp Spread Spectrum)
- 0.3-5 kbits per second (Adaptive Data Rate)
- Link budget = +27dBm (Tx) - (-137dBm) (node sensitivity) = 164dB $\gg$ GPRS
- 8dB higher link budget than uplink allowing reducing SF by 3 for downlink (9dB)
- 8x shorter message, 8x increased capacity, 8x lower power consumption @ sensor
- 0-250 bytes/message payload
- Message duration = 20-160ms with average latency of 2s
- Energy per message Erx = 160ms x 11mA = 0.5μAh at uplink-equivalent link budget

LoRaWAN Network Capacity

- Base-station capacity = 8 x 24 x 3600 x 20% = 138k mess/day @ max link budget (SF12) & 20- byte payload
- Base-station capacity = 8 x 32 x 24 x 3600 x 20% = 3.3M mess/day @ min link budget (SF7) (= max - 15dB) & 20-byte payload
- Capacity optimization with ADR (Adaptive Data Rate) - network controlled
- Nodes close to BS are told to communicate at higher bit rate with shorter messages in time
- Capacity can be increased with infrastructure densification and depends on application

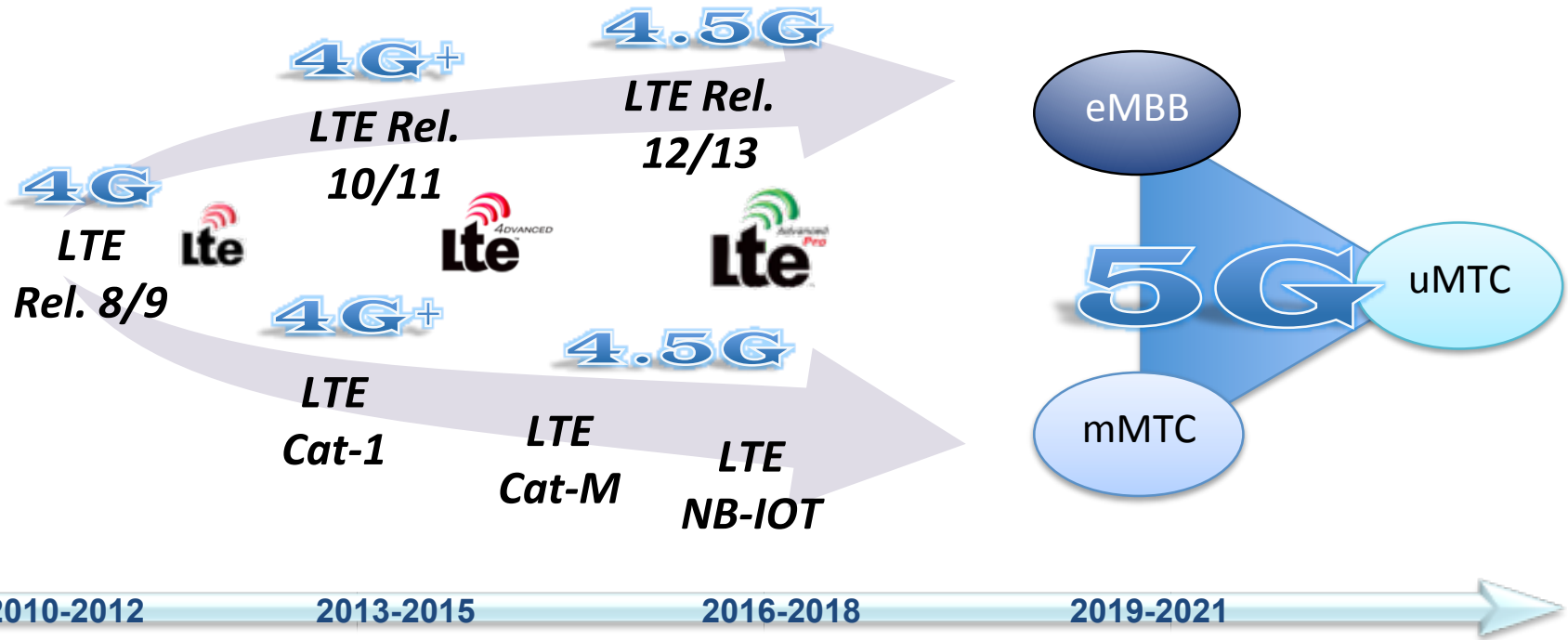
Part III

Licensed LPWA Technologies

GSMA and 3GPP

- 3GPP has launched a NB-IoT initiative in order to normalize LPWAN in licensed spectrum worldwide
- Backed by 20+ operators inside GSMA, including VODAFONE, TELEFONICA, AT&T, VERIZON, T-MOBILE, DEUTSCHE TELECOM, TELECOM ITALIA...
- Backed by base-station manufacturers, including HUAWEI, NOKIA, ERICSSON, ZTE...
- Backed by cellular chipset vendors such as INTEL and QUALCOMM

Standardization Status (1/)



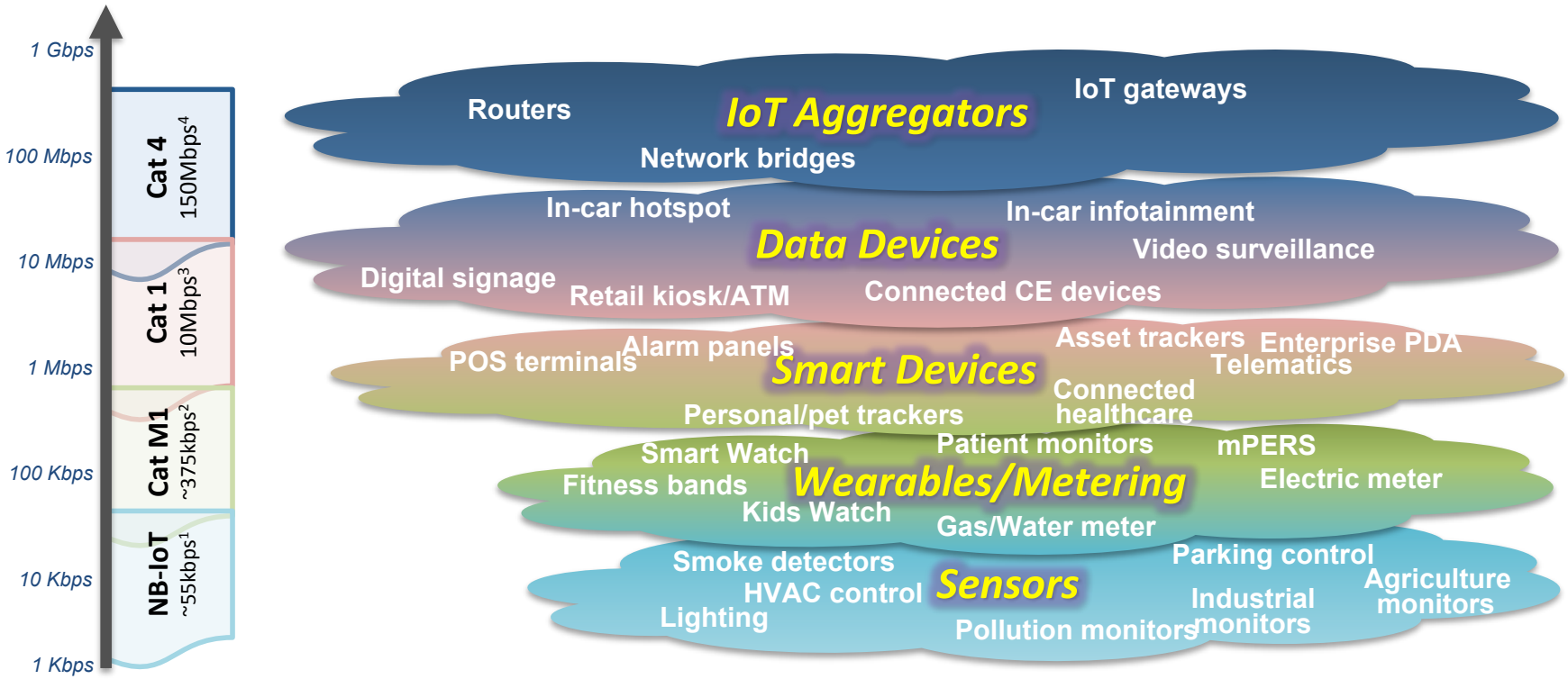
Standardization Status (2/)

- Classification of 5G services:
  1. Enhanced Mobile Broadband (eMBB)
  2. Ultra-Reliable Low-Latency Machine Type Communications (uMTC)
  3. Massive Machine Type Communications (mMTC)
- Exemple of 5G use-cases:
  1. Crowded venue (public, sport event, concert): high user density and mostly uplink network
  2. Dynamic hotspots (afternoon coffee shops, workplace): dense temporary cluster
  3. 50+ Mbps everywhere: wide coverage range
  4. V2X communications to assist drivers, enhance awareness, etc

Objectives of Licensed LPWA

- provide improved LPWAN services in licensed cellular spectrum
- Premium bi-directional service
- Higher bit rates
- Lower power
- Standardized across all operators and countries
- No extra LPWAN-dedicated infrastructure: native in 5G base- stations
- Deployed over full countries overnight

Licensed LPWA Use Cases



Benefit of using 3GPP Cellular MTC

Source: GSA, April 2016

Licensed spectrum, Carrier grade QoS, Flexibility, Privacy, Capacity, Coverage, Ecosystem (certification, price, openness), Ease of use, Worldwide roaming

Licensed LPWA Motivations

3GPP has defined « machine-type communications » MTC extension to LTE standard

MTC is fully integrated in the standard with new device categories

Both regular and MTC devices can coexist on the same network

Longer battery life: ***10 years on AA battery***

- New power modes
- Optimized signaling

Lower device cost: ***Comparable to 2G***

- Simpler/cheaper chipset
- Overall simpler BOM

Improved network coverage: ***>160dB***

- More robust modulation & coding schemes
- 20 dB better than GSM/ GPRS

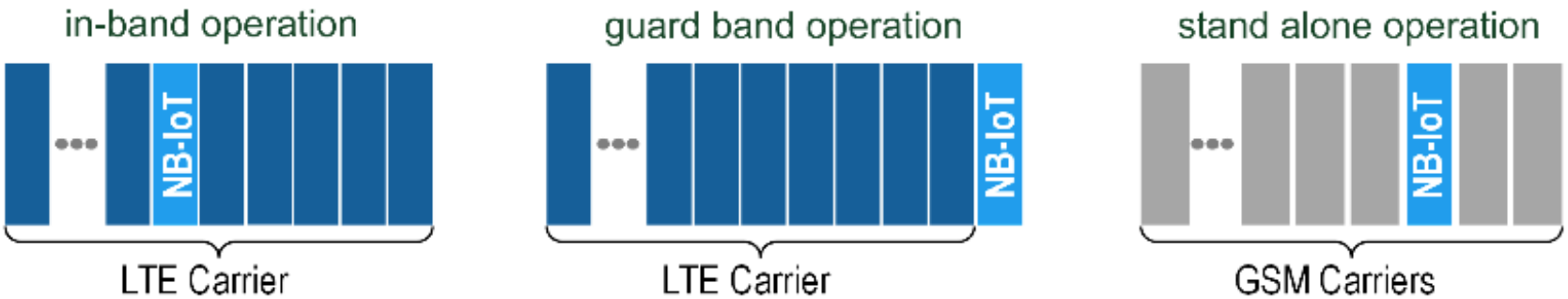
Licensed LPWA

UE Category	3GPP Release	Max DL/UL (Mbps)
"NB1"	**13**	**~0.01**
"M1"	**13**	<1
0	*12*	*1/1*
1	**8**	10/5
2	8	50/25
3	8	100/50
4	8	150/50
6	10	300/50
9	11	450/50
10	11	450/100

NB-IoT: On Going Proposals

- Licensed cellular spectrum: Reuse of 2G channels, LTE guard-bands, LTE sub-carriers;
- NB-IoT technology occupies a frequency band of 180 kHz bandwidth;
- Uplink: 300bps - 300kbps;
- UL modulation: FDMA - GMSK (NEUL/HUAWEI) and SC-FDMA (Single Carrier FDMA).
- Downlink: 200bps - 100kbps, OFDMA
- Full balanced bidirectional service
- +23dBm sensor Tx power

NB-IoT: Modes

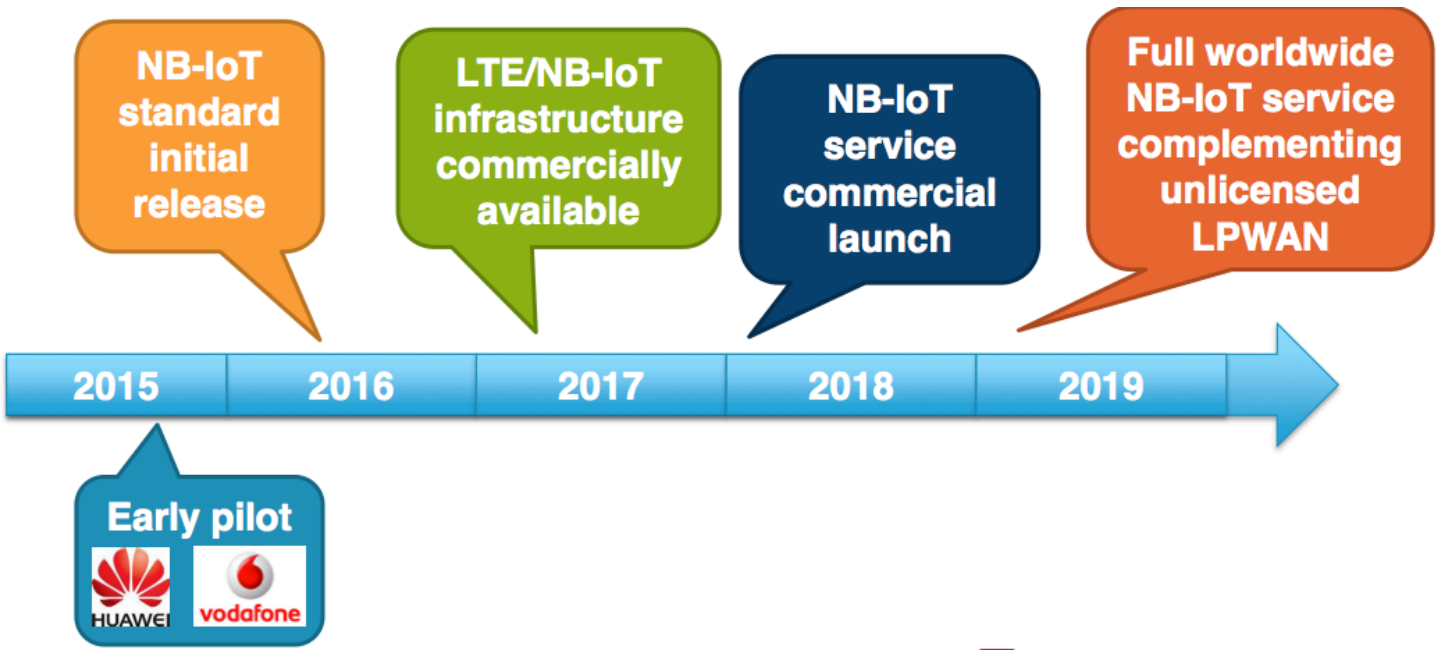


- Stand-alone operation: reuse of 200 kHz GSM band, a guard interval of 10 kHz is left on both side.

  Guard band operation, utilizing the unused resource blocks within an LTE carrier's guard-band;

- In-band operation utilizing resource blocks within an LTE carrier.

NB-IoT: Standard Status



Questions?