IoT Network Planning

ITU ASP COE TRAINING ON

"Developing the ICT ecosystem to harness IoTs"

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Summary

I. Introduction

II. IoT Market Assessment

III. IoT Technologies

   A. Fixed & Short Range

   B. Long Range technologies

      1. Non 3GPP Standards (LPWAN)

      2. 3GPP Standards

IV. IoT Network Dimensioning and Planning

   I. Dimensioning Phase

   II. Radio Network Planning

I. Introduction

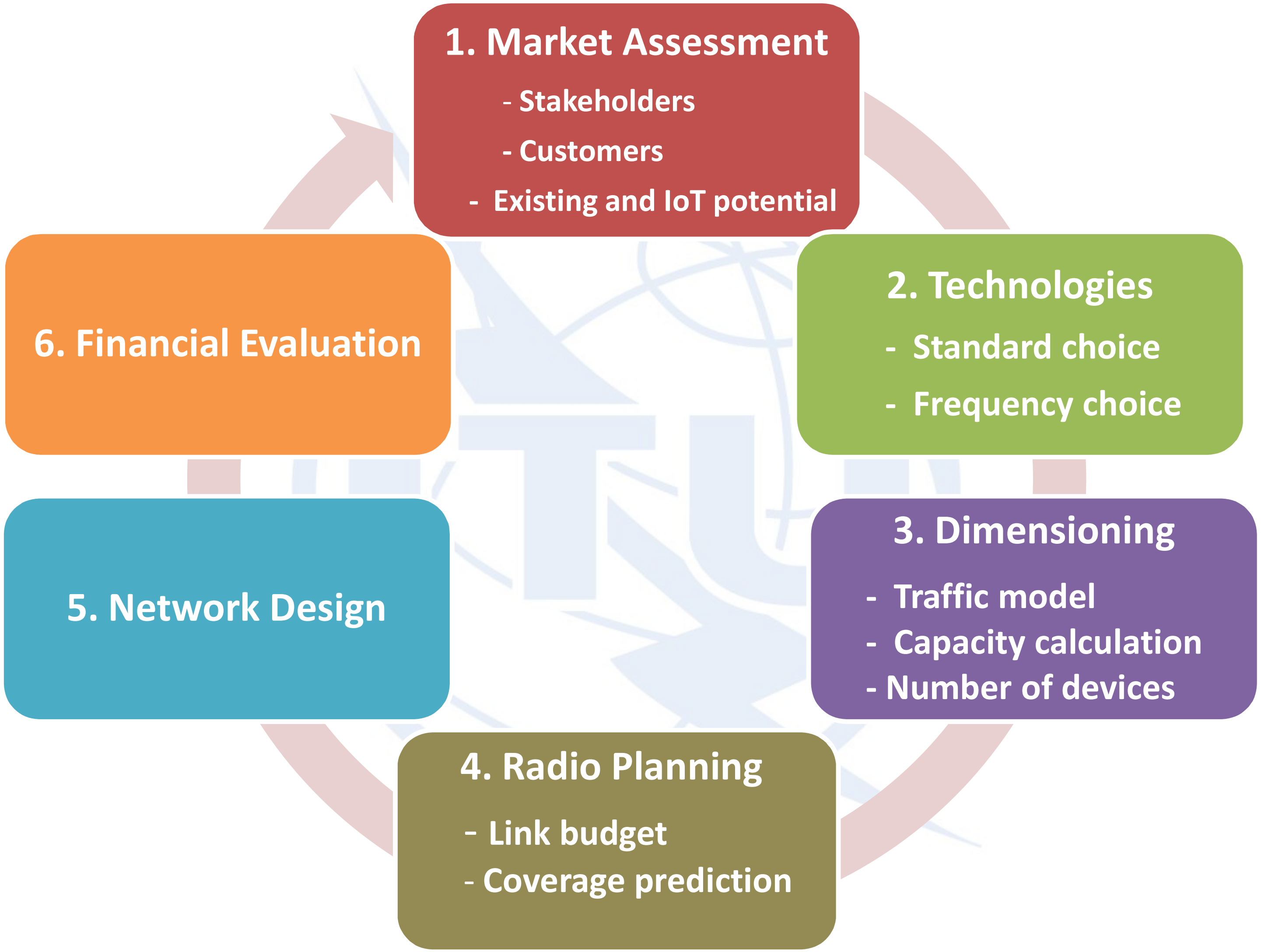
a. Network Planning Process Overview

b. Classical Networks Dimensioning and Planning Process

c. Classical Networks Dimensioning and Planning Tools

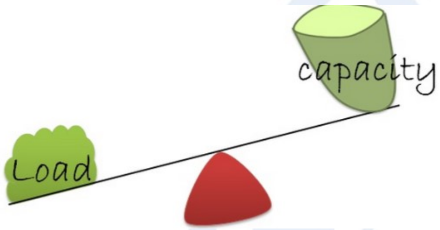
d. IoT Specificities and Impacts on Network Planning

a. Network Planning Process Overview

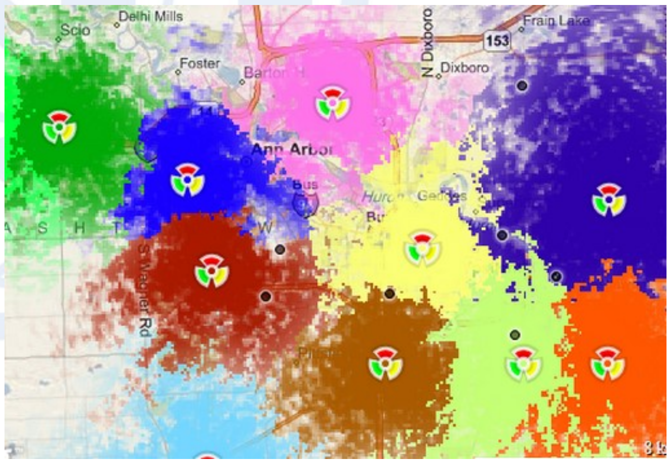


- Cellular systems design is based on 2 phases:

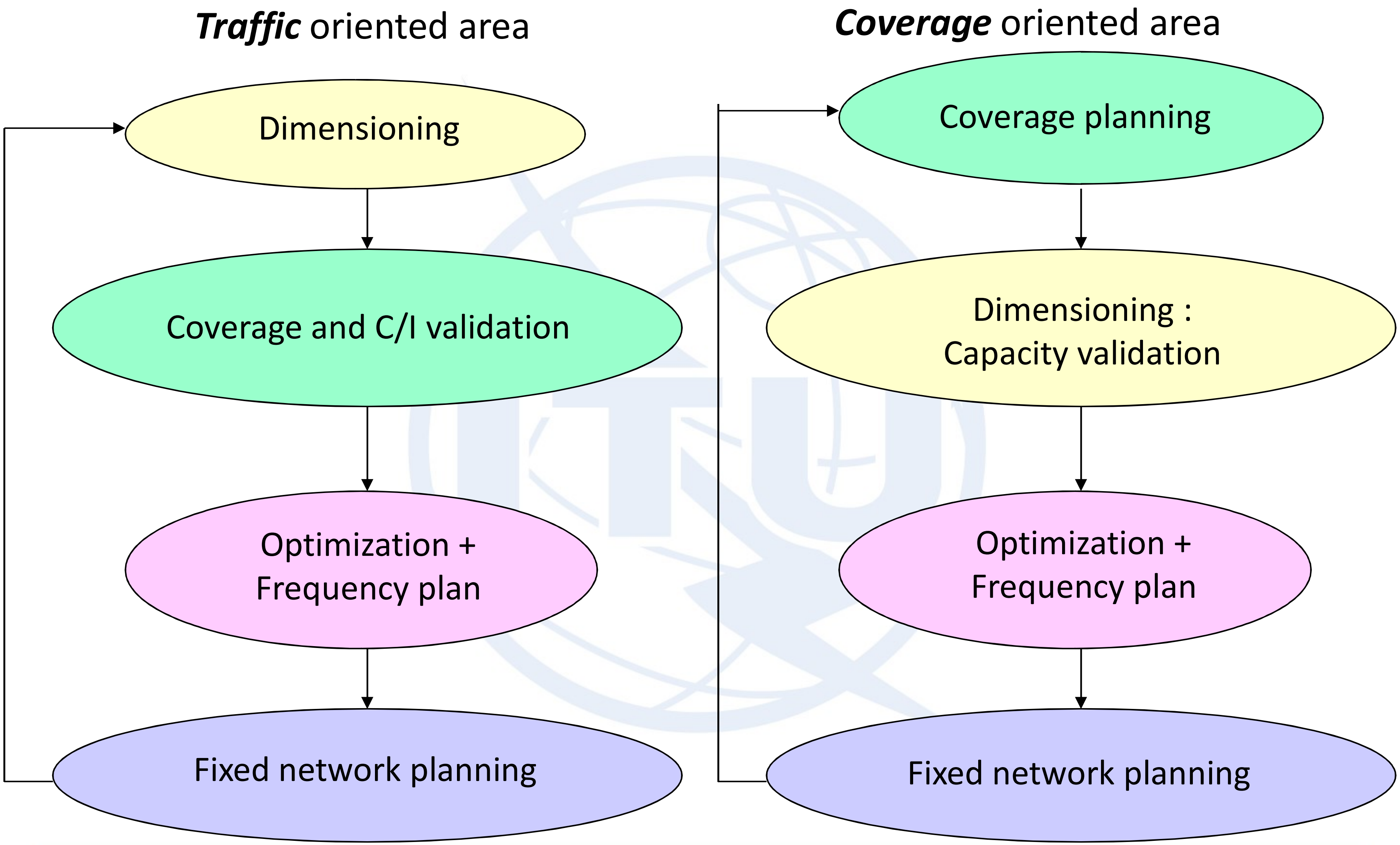
  - **Capacity planning**



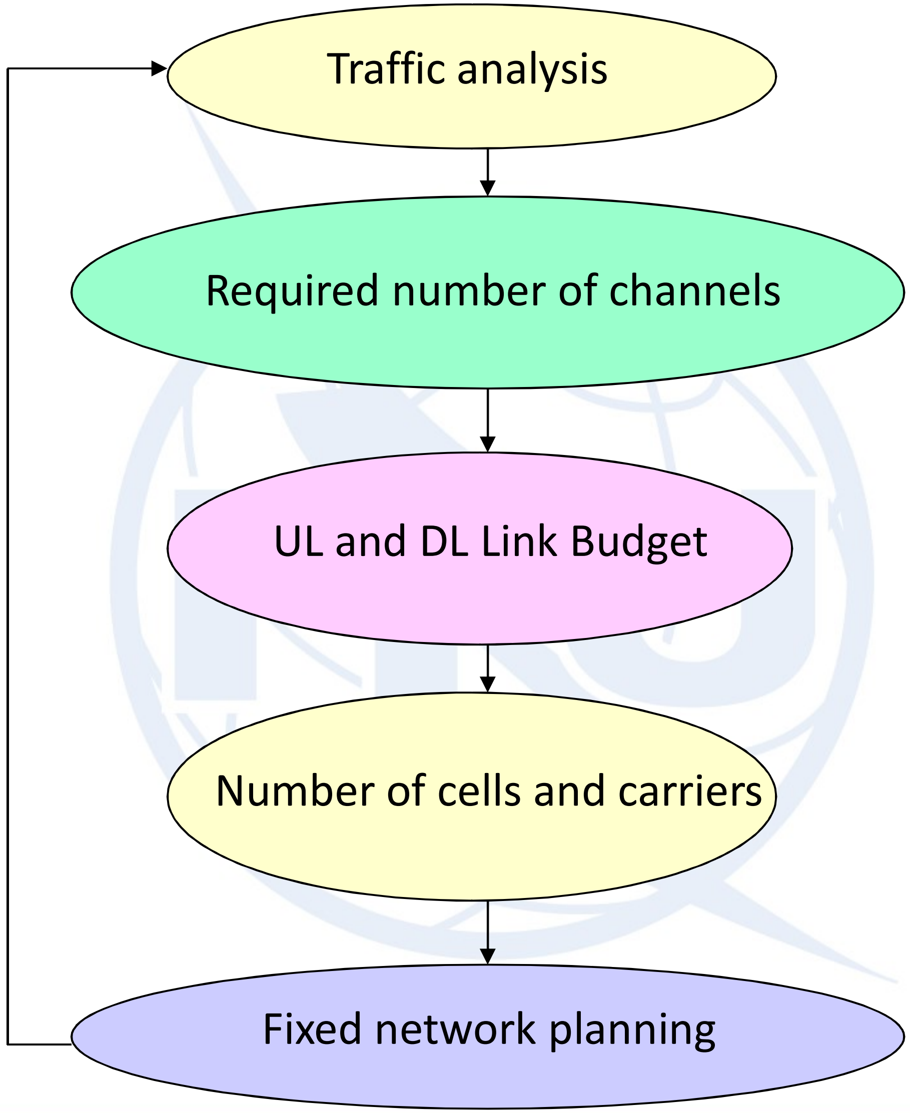
  - **Coverage planning**



Coverage or Traffic Oriented Area Planning (TDMA/FDMA/OFDMA)



CDMA system particular case



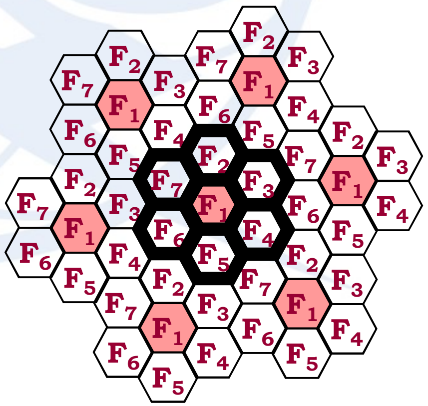
b. Classical Network Dimensioning and Planning

- ***Capacity planning***

  - Number of calls and data sessions that should be carried on in a certain area within a certain period of time

  - Condition: Probability that users will be denied access to the system due to unavailability of network capacity

    - ➢ Define which resources to be assigned to a network element

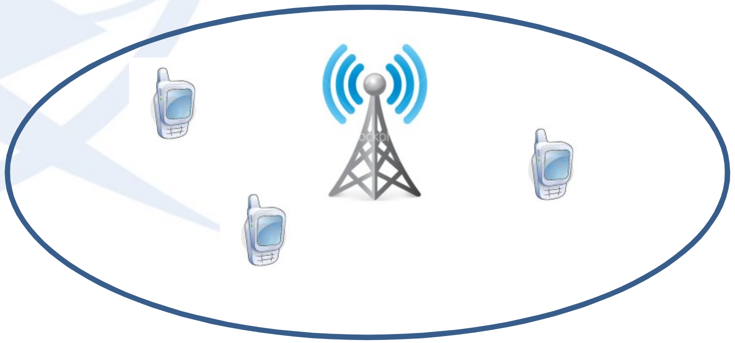


- ***Coverage planning***

  - Percentage of the geographical area covered by the cellular service where mobile services should be available

    - Select where to install base stations
    - Select antenna configurations

➔ Guarantee the signal strength required threshold in the service area



CIRCUIT SWITCHING DIMENSIONING (ERLANG MODEL)

❖ Erlang calculations

Grade of service

Number of Channels

n	0.01	0.02	0.03
1	.01010	.02041	.03093
2	.15259	.22347	.28155
3	.45549	.60221	.71513

Offered traffic

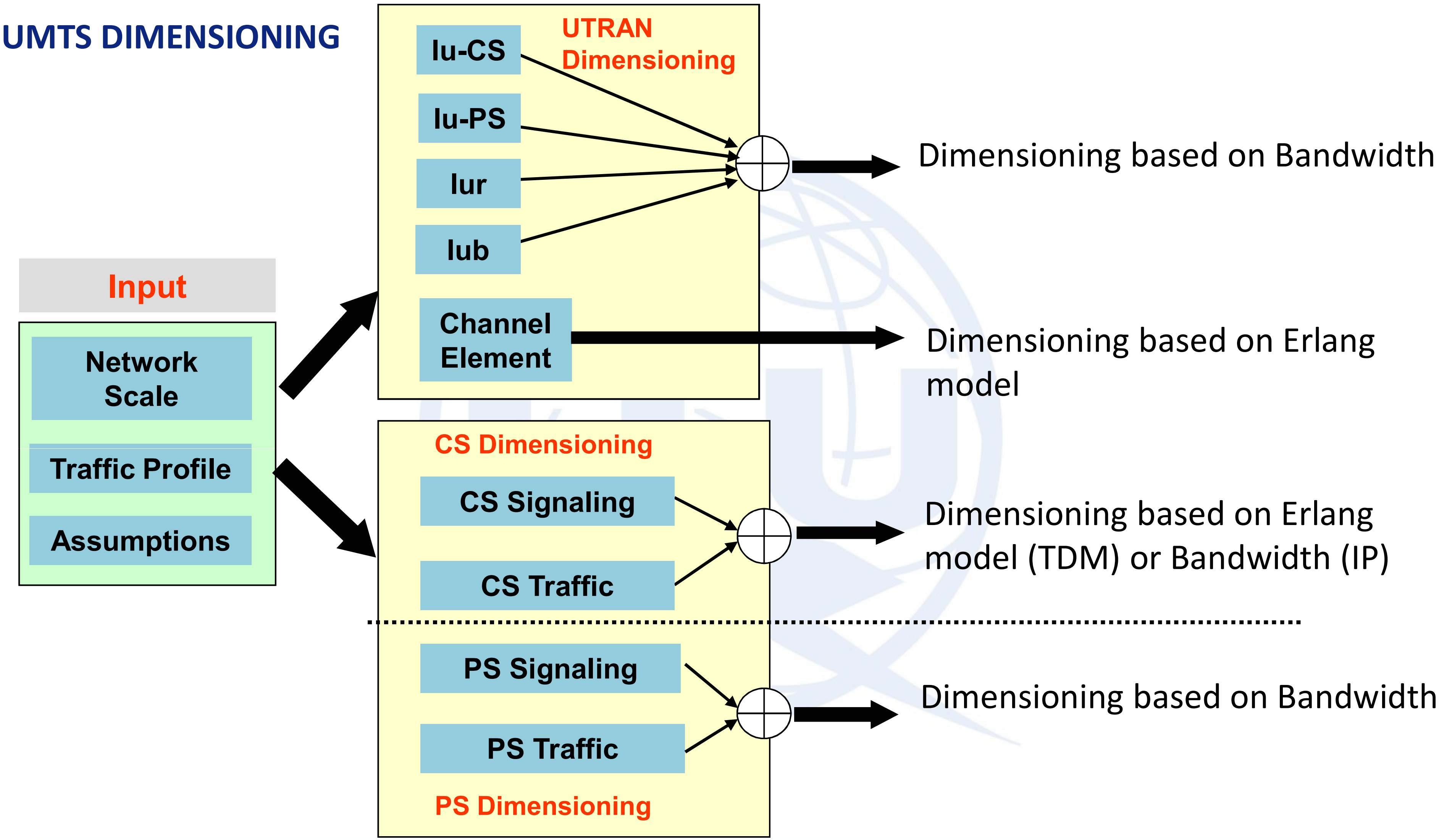
❖ Ressources dimensioning

Erlangs for radio interfaces dimensioning

- **Communications**
  - Traffic (data and voice)
  - Signaling
- **Signaling**

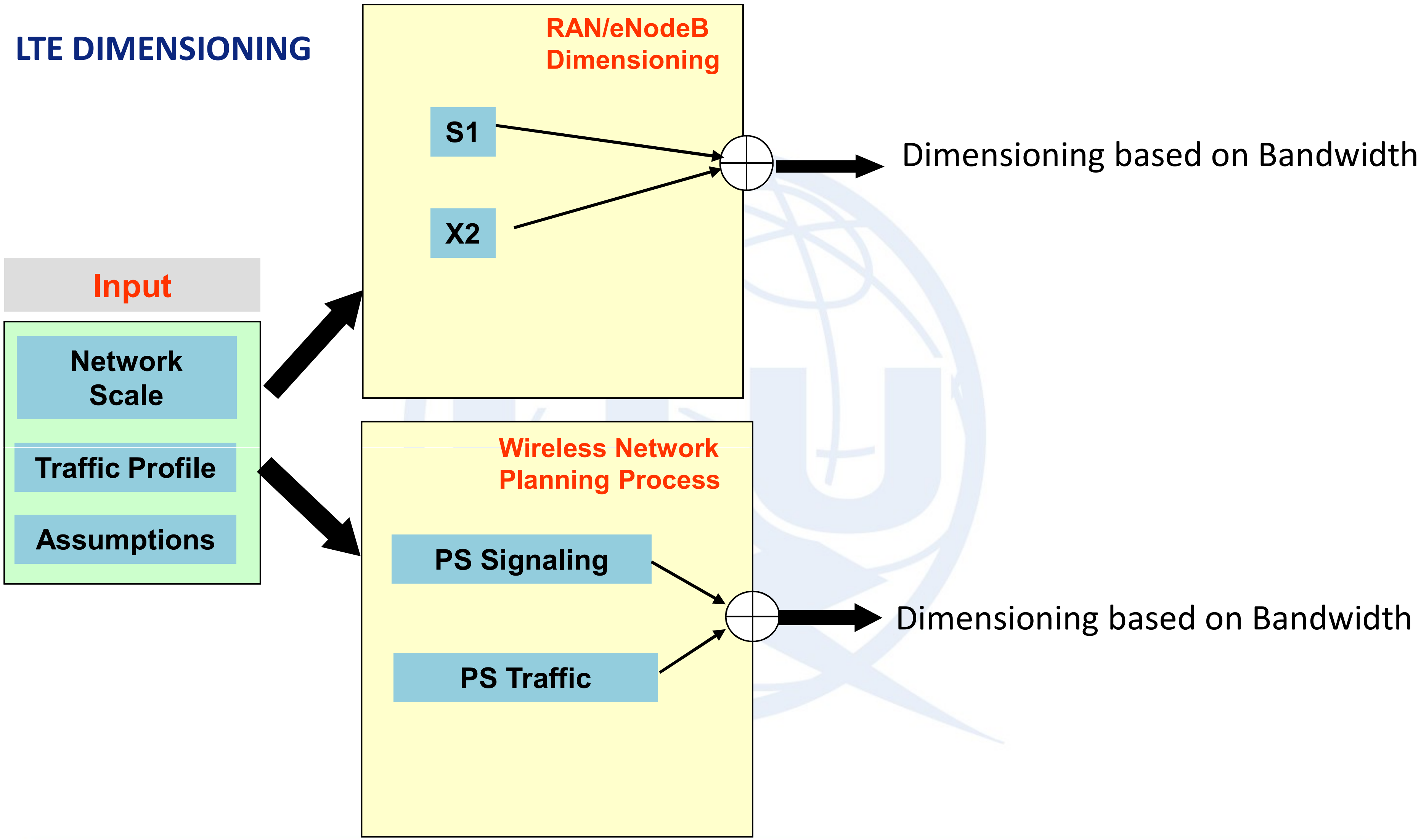
c. Classical Network Planning Tools

UMTS DIMENSIONING



c. Classical Network Planning Tools

LTE DIMENSIONING



d. IoT Specificities and Impacts on Network planning and design

Characteristics	*Impact*
Low power and **Wide Range**	• High sensitivity (Gateways and end-devices with a typical sensitivity around -150 dBm/-125 dBm with Bluetooth) • Low frequency usage ➔ strong signal penetration • Usage of Narrow band ➔ far greater range of reception
Low deployment and **Operational Costs**	• Low gateways cost • Wide range ➔ Extended coverage area + strong signal penetration (deep indoors, Rural) • Low numbers of gateways ➔Link budget: UL: 155 dB (or better), DL: Link budget: 153 dB (or better)
Long Battery life (10mA RX current, 100nA sleep current)	• Low Power • Idle mode most of the time. • Connected mode just for transmission (some mA) • < 100 MHz clock frequency • Embedded memory of a few Mo • Idle mode allowing an energy consumption of around 100 µW

d. IoT Specificities and Impacts on Network planning

Characteristics	*Impact*
Shared Spectrum → Interference Management	- Clear channel assessment - Frequency hopping - OFDM/CDMA access and NOMA technologies - Activity rate around 1% (regulation and energy constraints)
Service diversity	- Diversity of the traffic models - Diversity of the transmission modes
Low bitrates (hundreds to thousands of bits/sec. compared to 250 Kbit/s in ZigBee and 1-2 Mbit/s in Bluetooth)	- Low capacity and lower number of gateways
Simple topology (single-hop links)	- Simplifies the coverage of large areas - Share the existing cellular networks infrastructure

IoT Networks and Services are Very Different from « Classical Networks » in Many Aspects and Especially from a Planning Perspective

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II. IoT Market Assessment

Examples of services per Category

Smart Utilities	Smart Health	Smart Public Services	Smart Building	Smart Transportation
• Intelligent Utility Network • Smart Metering • Energy Optimization • Smart Production • Demand Planning • Advanced Distribution Management • Operations Control • River Basin and Smart Water Management • Wastewater Treatment	• Smart Care Management • Connected Health • Smart Medicine Supply • Mobile Health • Remote Healthcare Management	• Smart Citizen Services • Smart Tax Administration • Smart Customs, Immigration, Border Management • Smart Crime Prevention • Smart Emergency Response • Smart Financial Management	• Energy Optimization • Asset Management • Facility Management • Video Surveillance • Recycling and Power Generation • Automatic Fault Detection Diagnosis • Supervisory Control • Audio / Video Distribution Management	• Intelligent Transportation • Smart Public Transportation • Integrated Fare Management • Fleet Optimization • Tolling Solutions • Real-time Adaptive Traffic Management • Smart Parking • Traveler Information Systems

Smart Education
• Smart Classroom • Performance Man. • Asset Management

All sectors, All types of Things, All Environments taken into account for network design (capacity, coverage)

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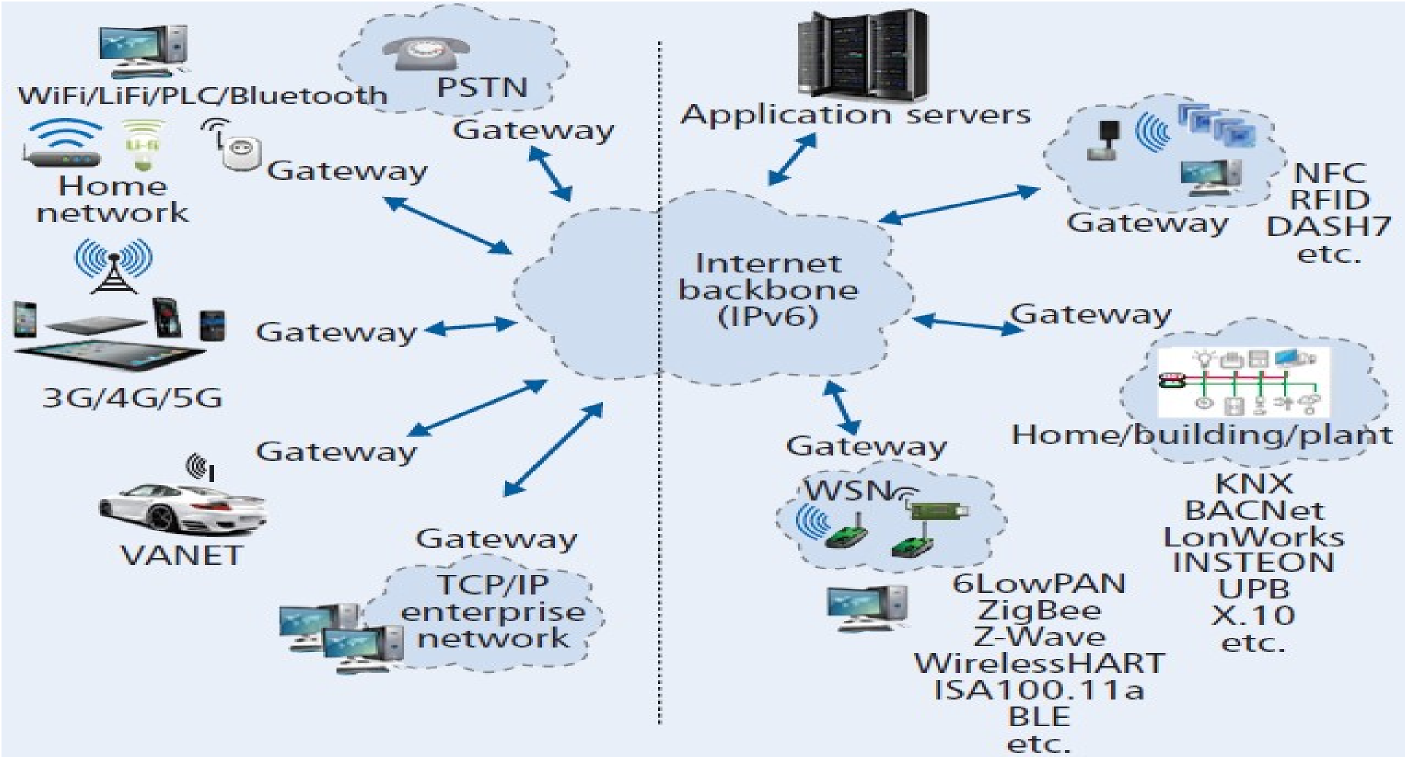
III. IoT Technologies

- *Internet of Things* term
  - First introduced in **1999** by the Auto-ID Labs (autoidlabs.org) (formerly the Auto-ID Center of MIT),
  - Primarily for networked radio frequency identification (**RFID**) devices.
- IoT has included many other technologies including wireless sensor networks (**WSN**), near field communications (**NFC**), biotechnology and body area networks (**BAN**), machine-to-machine (**M2M**) communications, and other “legacy” personal area networks (**PAN**) such as **WiFi**, **Bluetooth**, **cellular**, etc.

IoT stand-alone or “silo” Architecture



- IPv6 over low-power wireless personal area networks (6LoWPAN),
- Zigbee (www.zigbee.org),
- Wireless highway addressable remote transducer (WirelessHART http://en.hartcomm.org),
- ISA100.11a,
- RFID,
- Developers Alliance for Standards Harmonization of ISO/IEC 18000-7 (DASH7),
- Building Automation and Control Network (BACNet, http://bacnet.org),

- Z-Wave (www.z-wave.com),
- KNX (http://knx.org),
- RFID,
- Bluetooth Low Energy (BLE),
- KNX (http://knx.org),
- Local Operating Network (LonWorks),
- INSTEON (www.insteon.com),

Interconnection via an IPv6 backbone to familiar or legacy technologies (3G/4G/5G, WiFi, LiFi, Home Plug, vehicular networks (VANETs), PSTN and IPv4 enterprise networks).

- 3GPP: adapt 2G/GSM to support IoT traffic ➲ **Cellular IoT architecture** (CIoT)
- **Alternative solutions**: between *short range multi-hop technologies* (operating in the ISM) and *long-range cellular-based solutions* (operating in licensed broadband cellular standards frequency bands)

↳ **LPWAN**:

- Sub-GHz **unlicensed frequency bands**
- **Long range** radio links
- **Star topologies** with many islands (sub-nets) using different connectivity protocols
- End devices directly connected to a unique collector node (**gateway**) providing the bridging to the IP world

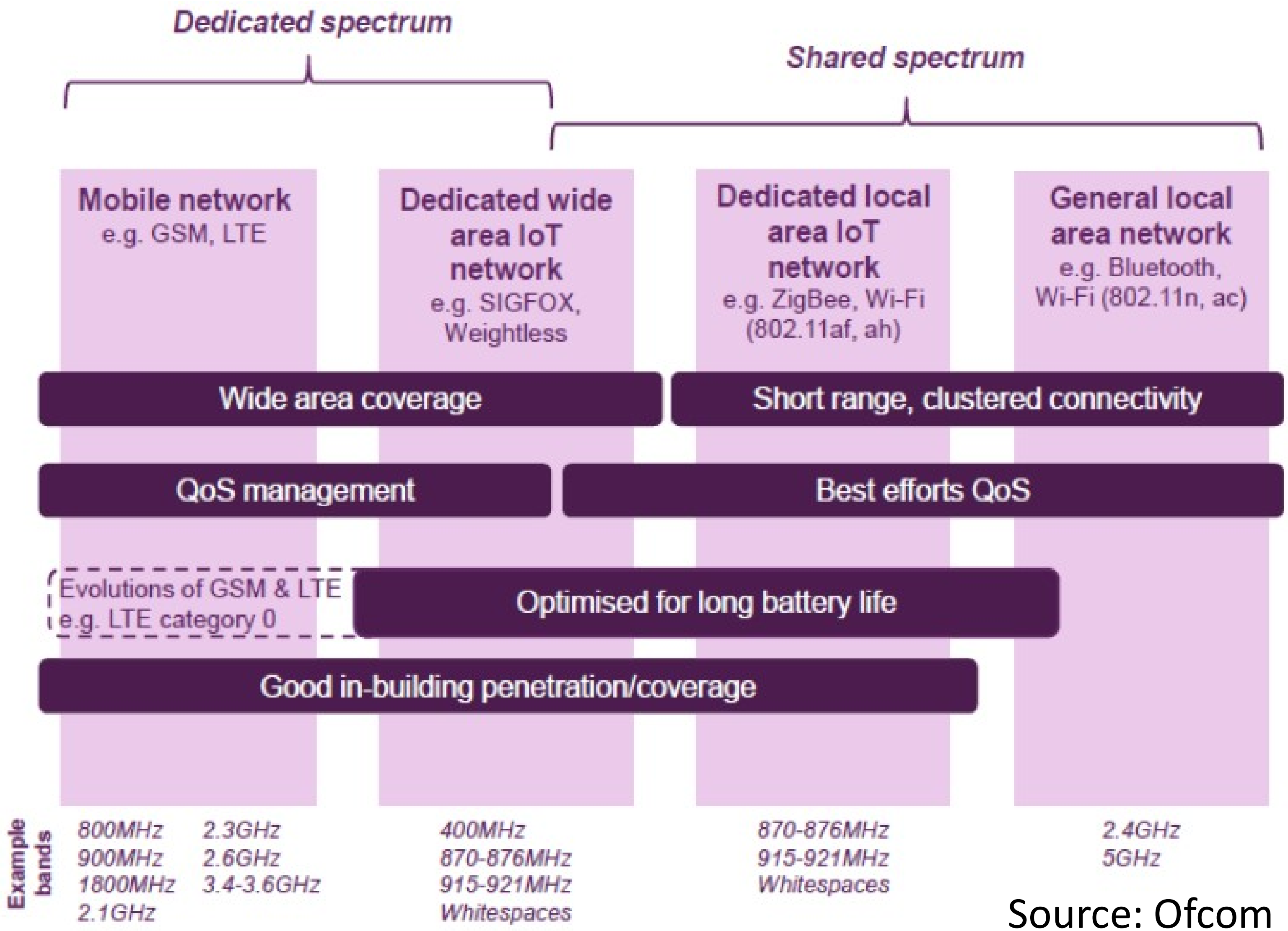
> - Wide area coverage
> - Connectivity to nodes deployed in harsh environments

Applications and ***services*** deployed on top in a **distributed service layer**
Applications may run ***locally*** (sub-net) or in the ***cloud*** (e.g., Smart City)

1. ***Extremely short-range*** systems, e.g., Near Field Communications (NFC) enabled devices;
2. ***Short-range passive*** and ***active RFID*** systems;
3. ***IEEE 802.15.4 standards*** based systems (e.g., ZigBeeTM , 6LoWPAN, Thread-based);
4. ***Bluetooth-based*** systems, including Bluetooth Low Energy (BLE);
5. ***Proprietary systems***, including Z-WaveTM , CSRMeshTM (the Bluetooth mesh by Cambridge Silicon Radio, owned by Qualcomm), EnOceanTM ;
6. ***IEEE 802.11/Wi-Fi based systems*** (e.g., those defined by the "*AllSeen Alliance*" specifications, which explicitly include the gateways, or by the "*Open Interconnect Consortium*").

Most connected things:
- IEEE 802.15.4 based, including ZigBee
- Operate in the 2.4 GHz and optionally 868/915 MHz unlicensed bands
- Mesh topology
- Distance: few meters to 100 meters.

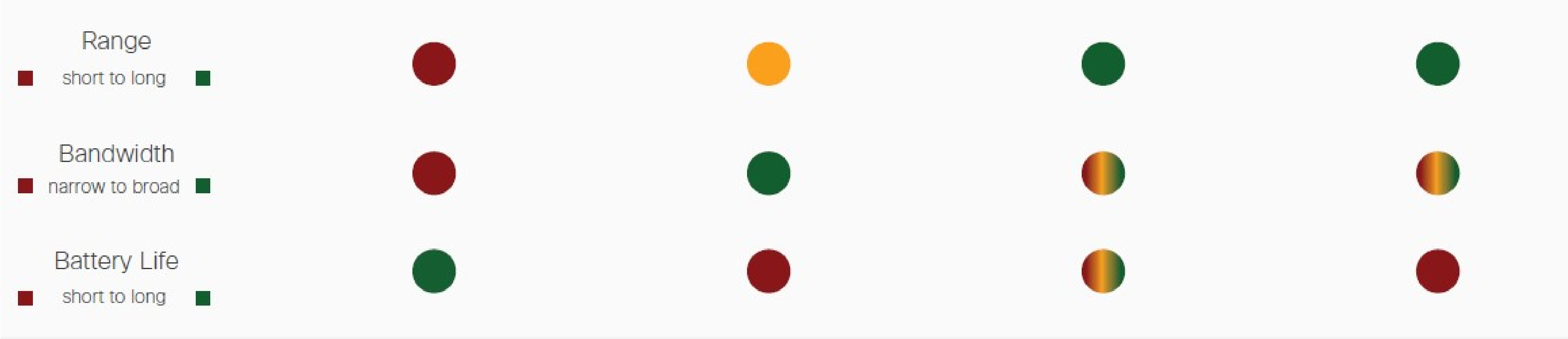
Various IoT Technologies and Characteristics



Source: Ofcom

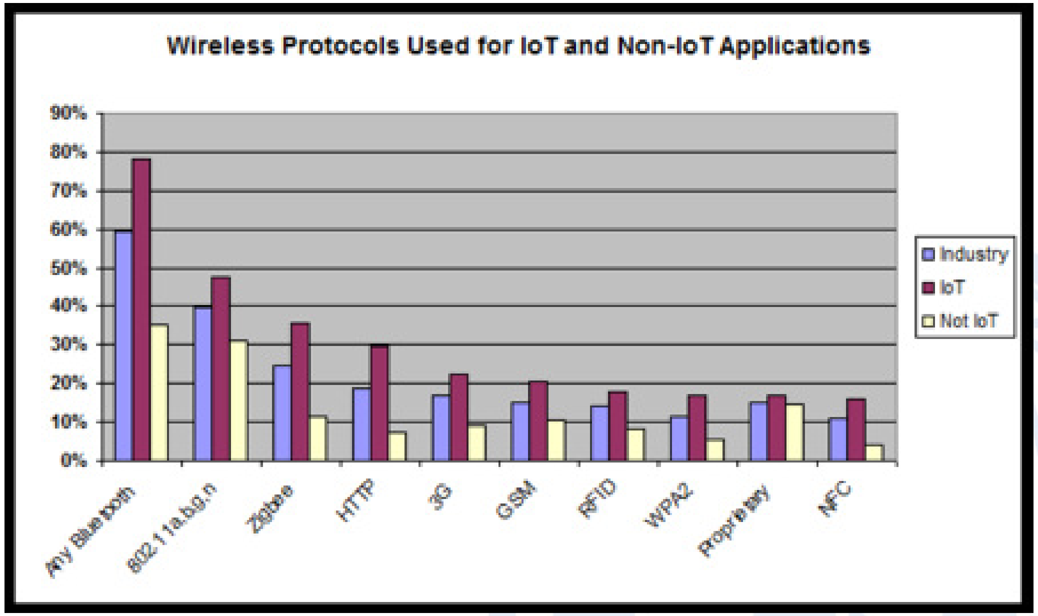
IoT Connectivity Technologies

	Wireless-			Wireline
	Personal Area Networks (WPAN)	Local Area Networks (WLAN)	Wide Area Networks (WWAN)	
	ANT+, Bluetooth, 4.0 LE RFID, NFC 802.11.4, ZigBee	Wi-Fi	LoRa, Weightless, Dash 7 WiMax, 2G, 3G 4G/LTE, Satellite	Copper/DSL Coaxial Fiber

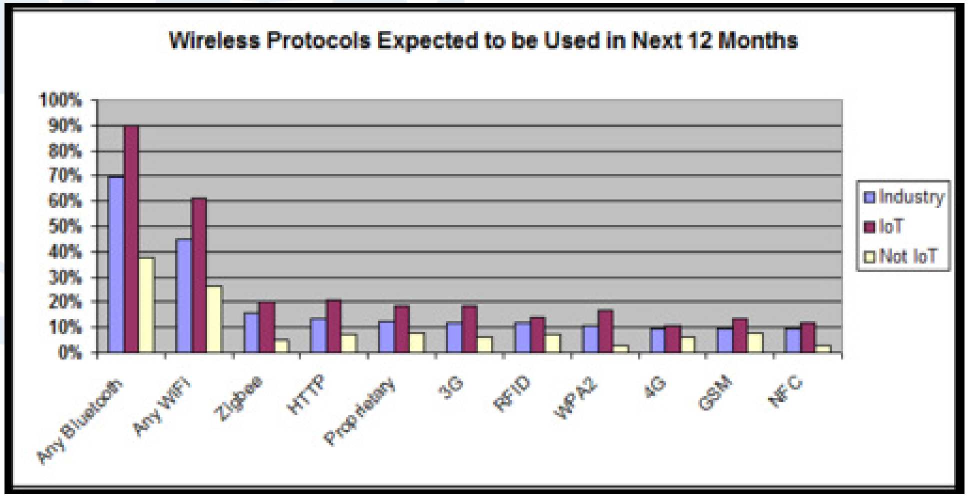


Source: Cisco Systems

Technologies and Standards Used for IoT



Bluetooth and **WiFi** are the most dominant used technologies for IoT applications in 2016. Their main advantages are power use, range, and data throughput.



Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards

A. Fixed & Short Range

i. RFID

ii. Bluetooth

iii. Zigbee

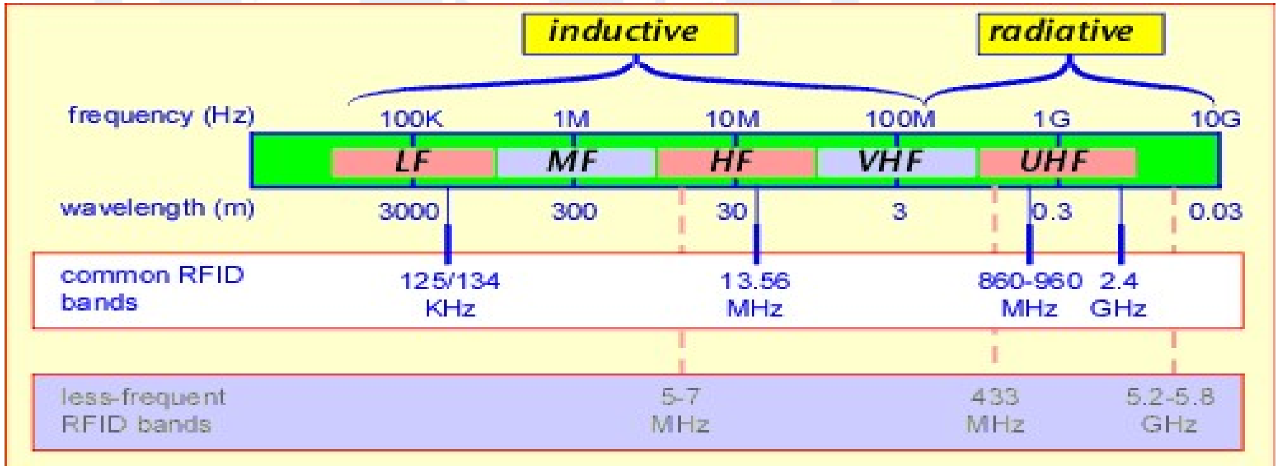
iv. WiFi

i. RFID

RFID (Radio Frequency Identification)

- First appeared in 1945
- *Features*: Identify objects, record metadata or control individual target
- More complex devices (e.g., readers, interrogators, beacons) capable and usually connected to a host computer or network
- Radio frequencies from 100 kHz to 10 GHz
- *Operating*: reading device called a reader, and one or more tags

RFID Frequencies



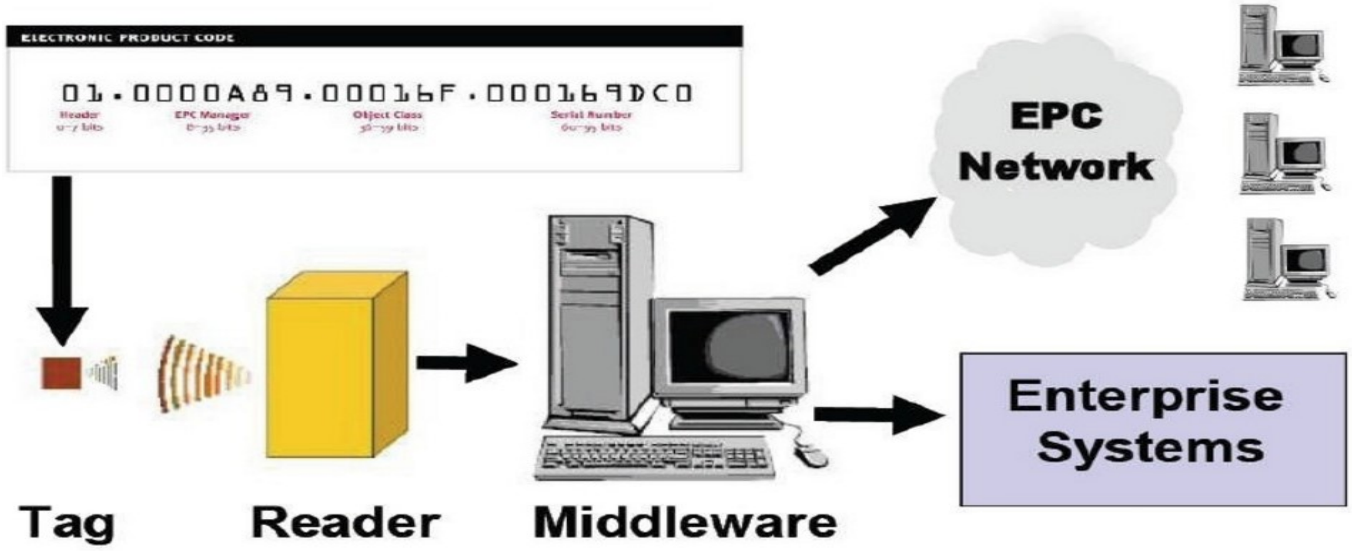
How it works ?

Tag

- Microchip connected with an antenna, which can be attached to an objects as his identifier.

Reader

- RFID reader communicate with the RFID tag using radio wave



Different Types of TAGs

	Passive Tags	Active Tags
Power	Energy Transferred using RF from Reader	Internal to Tag
Battery	No	Yes
Availability	Only in the field of Radar	Continuous
Required Signal Stregth to Tag	Very High	Very Low
Range	Up to 3-5m	Up to 100m
Multi Tag Reading	Few Hundred within 3 metes of reader	1000’s off tags recognized
Data Storage	128 bytes	128 bytes with search and access

Short or very short range technology, most applications are based on manual involvement and limited to presence detection.

ii. Bluetooth

Bluetooth characteristics

- Low Power wireless technology
- Short range radio frequency at 2.4 GHz ISM Band
- Wireless *alternative* to data cables
- Creating PANs (*Personal area networks*)
- Support Data Rate of 1 Mb/s (data traffic, video traffic)
- Use frequency-hopping spread spectrum

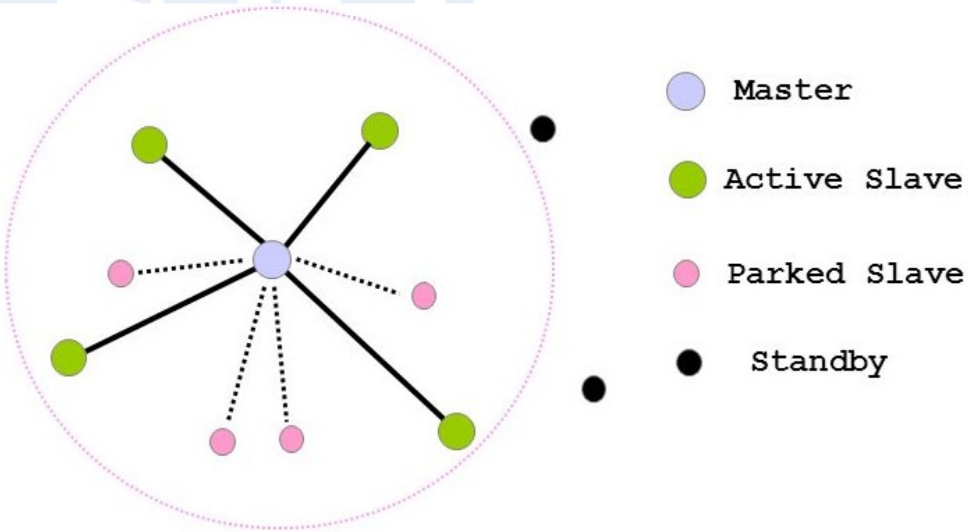
Class	Maximum Permitted Power	Range
1	100 mW (20 dBm)	~100 m
2	2,5 mW (4 dBm)	~10 m
3	1 mW (0 dBm)	~1 m

Bluetooth Piconet

- Created instantly and automatically between Bluetooth devices which are in the same area
- One ***master*** device and others as ***slaves***
- Slaves can not directly send data to each others
- All traffic must go through the ***master***
- Up to 7 active slaves

Bluetooth Scatternets

- Two or more piconets
- Devices that participate in two piconet act as **gateways**



Bluetooth Low Energy

- Enabling the internet of things features
- Designed to be Lowest cost and Easy to implement
- New mechanism for ease of discovery & connection
- Low latency, fast transaction (3 ms from start to finish)
- Data Rate 1 Mb/s: (sending just small chunks of data like state
- **Bluetooth 5**: 4x range, 2x speed and 8x broadcasting message capacity.)

Range	~ 150 m
Output Power	~ 10mW(10 dBm)
Max current	15 mA
Modulation	GFSK at 2.4 GHz
Sleep current	~ 1 µA

Low cost, available, ready to go.

iii. ZigBee

Control and **wireless sensor** network

Based on the **IEEE 802.15.4** Standard

Created by the **Zigbee alliance**

Low data rates and low power consumption

Small packet networks

Operates on unlicensed bands:
- ISM 2.4 GHz at 250 Kbps
- 868 MHz at 20 Kbps
- 915 MHz at 40 Kbps

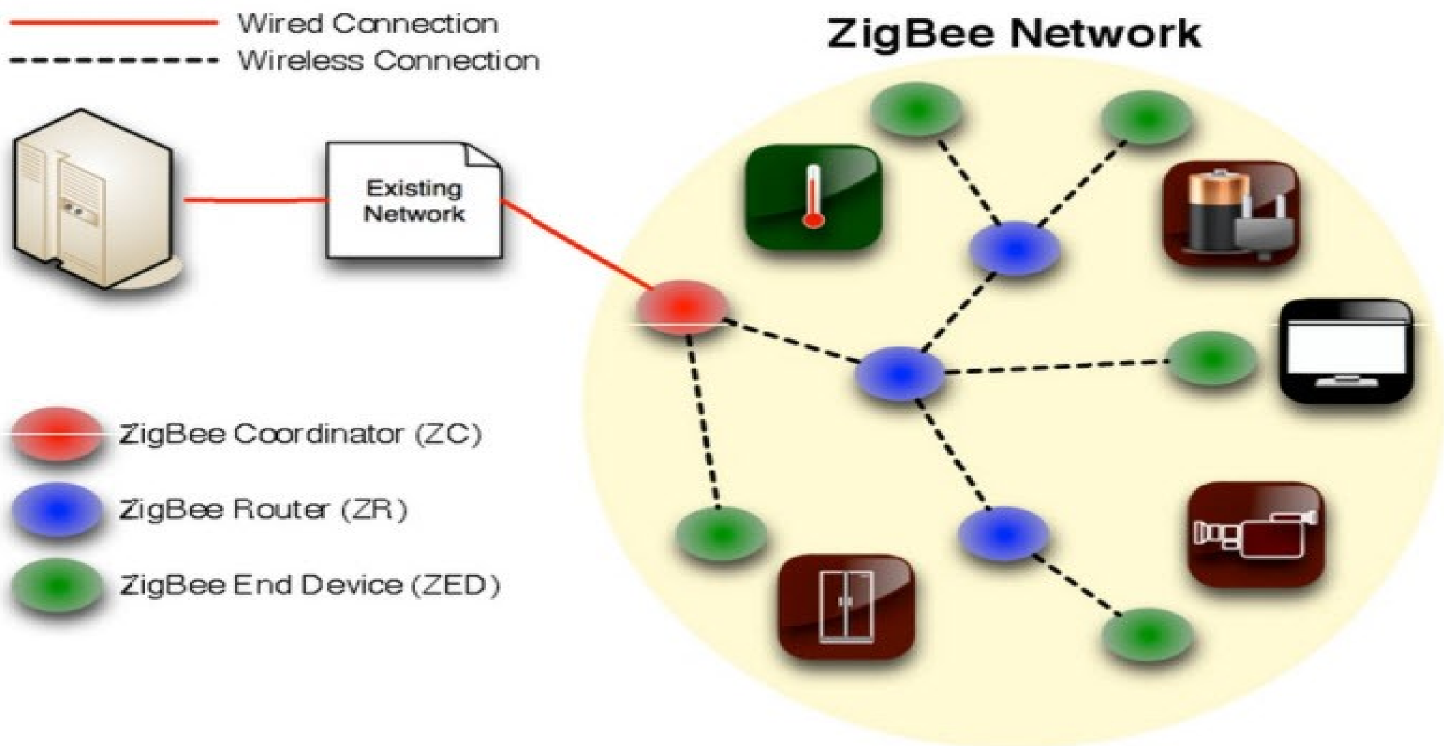
Topology:

Star, Cluster Tree, Mesh

Up to 65 000 nodes on a network

ZigBee™

ZigBee



- **Coordinator**: acts as a root and bridge of the network
- **Router**: intermediary device that permit data to pass to and through them to other devices
- **End Device**: limited functionality to communicate with the parent nodes

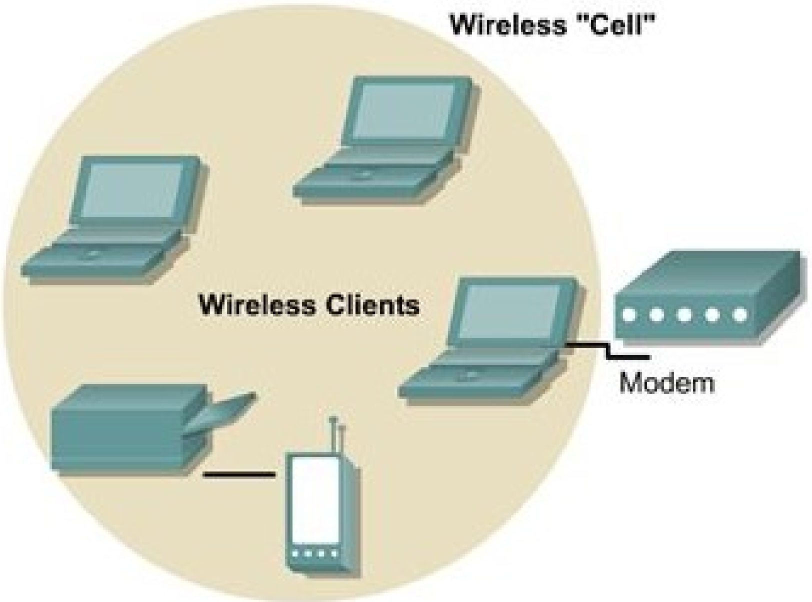
Low cost, available, ready to go.

iv. WiFi

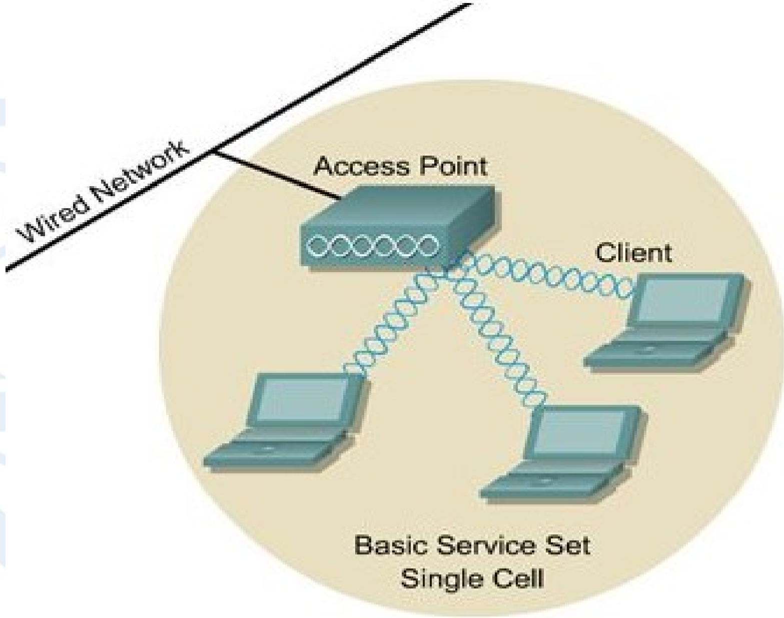
- Wireless technology
- Alternative to Wired Technologies
- IEEE 802.11 standard for WLANs

Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	8 Mbit/s	100 M

Basic Wifi Topologies



Peer-to-peer (Ad Hoc)



Basic Infrastructure (BSS)

Wi-Fi HaLow

- A new low-power, long-range version of **Wi-Fi** that bolsters **IoT** connections, it will be available in 2018
- Wi-Fi HaLow is based on the pending IEEE 802.11ah specification
- Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band
- It will easily penetrate walls and barriers thanks to the propagation capabilities of low-frequency radio waves.
- Its range will be nearly double today's available Wi-Fi (1 kilometer)

- WiFi is longer range than Bluetooth and ZigBee
- More flexible
- Closer to networks

WiFi-based IoT Devices

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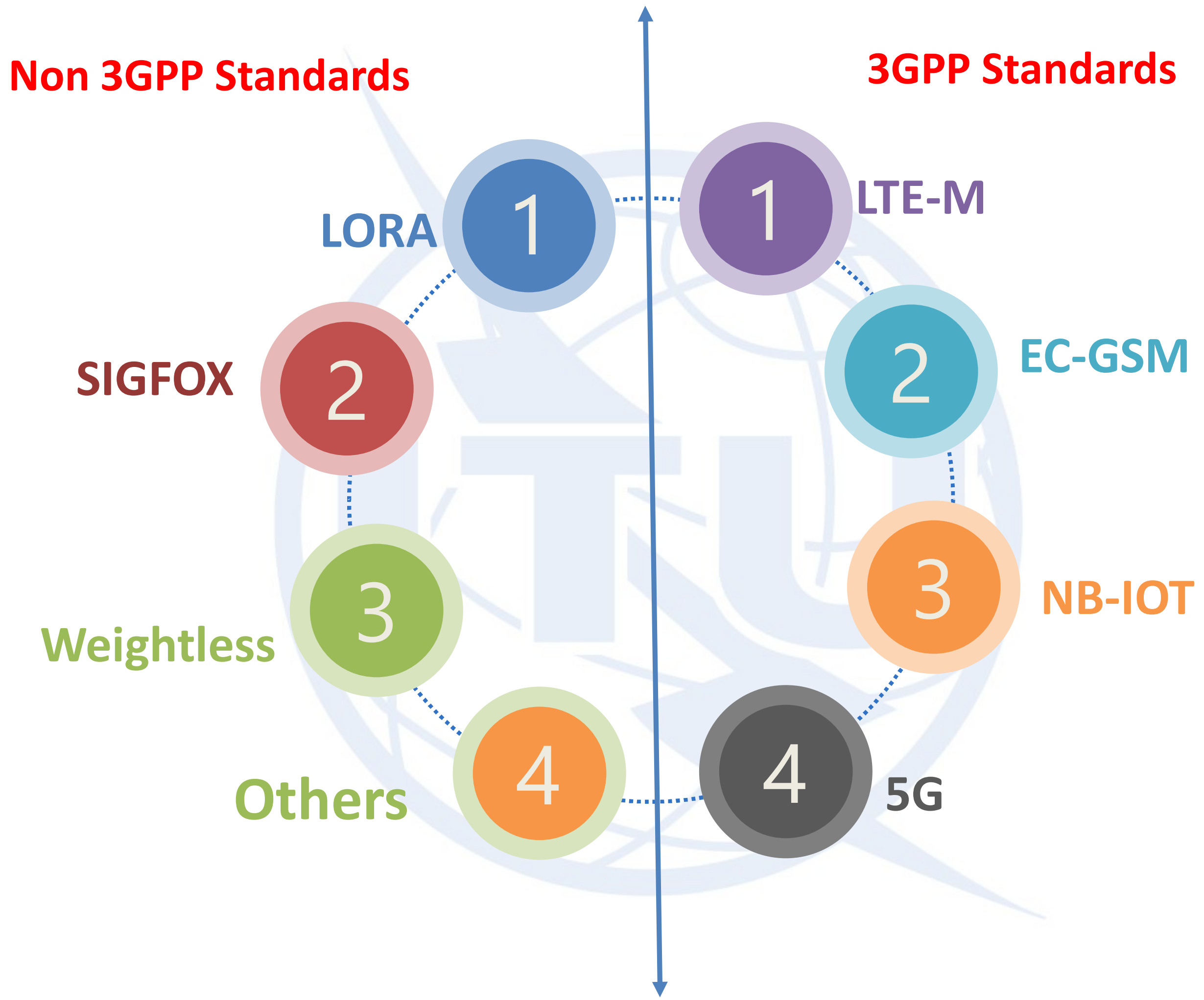


Non 3GPP Standards
3GPP Standards
1 LORA
2 SIGFOX
3 Weightless
4 Others
1 LTE-M
2 EC-GSM
3 NB-IOT
4 5G

B. Non 3GPP Standards (LPWAN)

i. LoRaWAN

ii. Sigfox

iii. Weightless

iv. Others

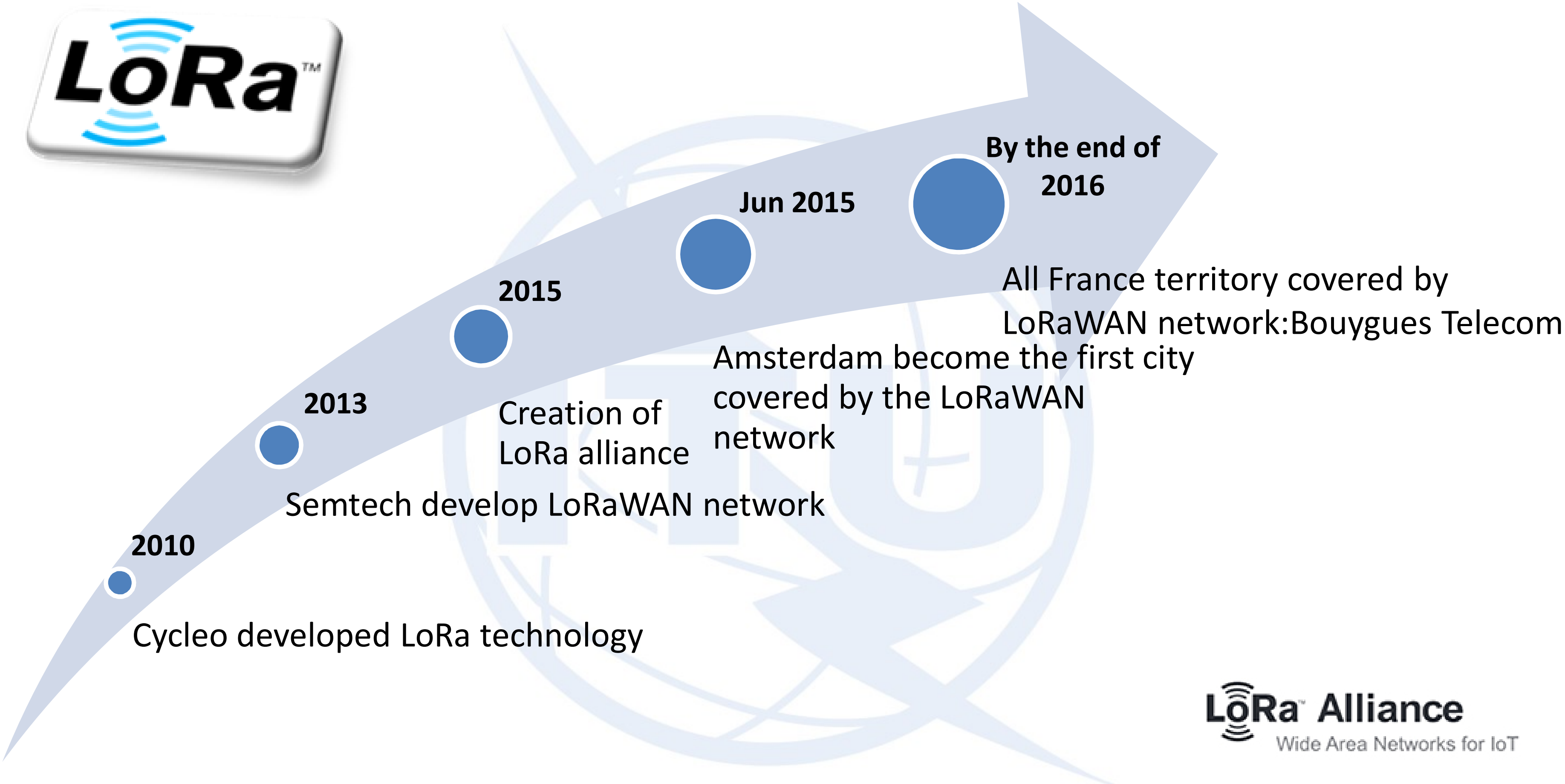
LPWAN REQUIREMENTS

LPWAN

- Long battery life
- Low device cost
- Low cost and easy deployment
- Extended coverage (10-15 km in rural areas, 2-5 km in urban areas)
- Support for a massive number of devices

i. LoRaWAN

Roadmap



LoRa Alliance
Wide Area Networks for IoT

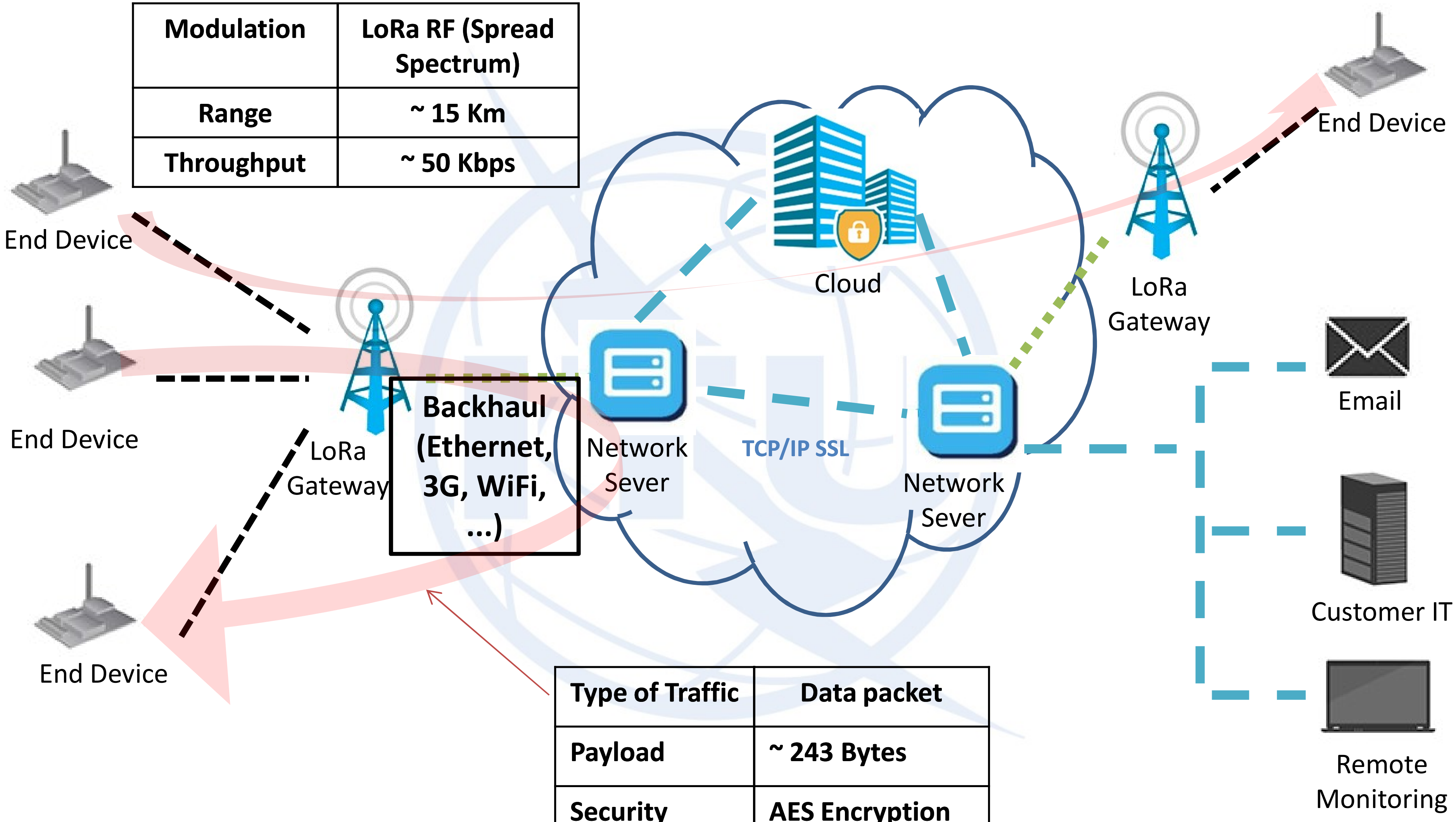
LoRa Alliance

International Operators	International development of the solution
Integrators and industrialists	Appropriate technology and maintain it over time
Manufacturers of End-points	Broadcast end devices
Manufacturers of Semiconductors	Integrate LoRa technology

- LoRaWAN is a *Low Power Wide Area Network*
- LoRa modulation: a version of Chirp **Spread Spectrum** (CSS) with a typical channel **bandwidth of 125KHz**
- High **Sensitivity** (End Nodes: Up to **-137 dBm**, Gateways: up to **-142 dBm**)
- Long range communication (up to **15 Km**)
- Strong indoor penetration: With High Spreading Factor, Up to **20dB** penetration (**deep indoor**)
- Occupies the entire bandwidth of the channel to broadcast a signal, making it **robust** to channel noise.
- **Resistant** to Doppler effect, multi-path and signal weakening.

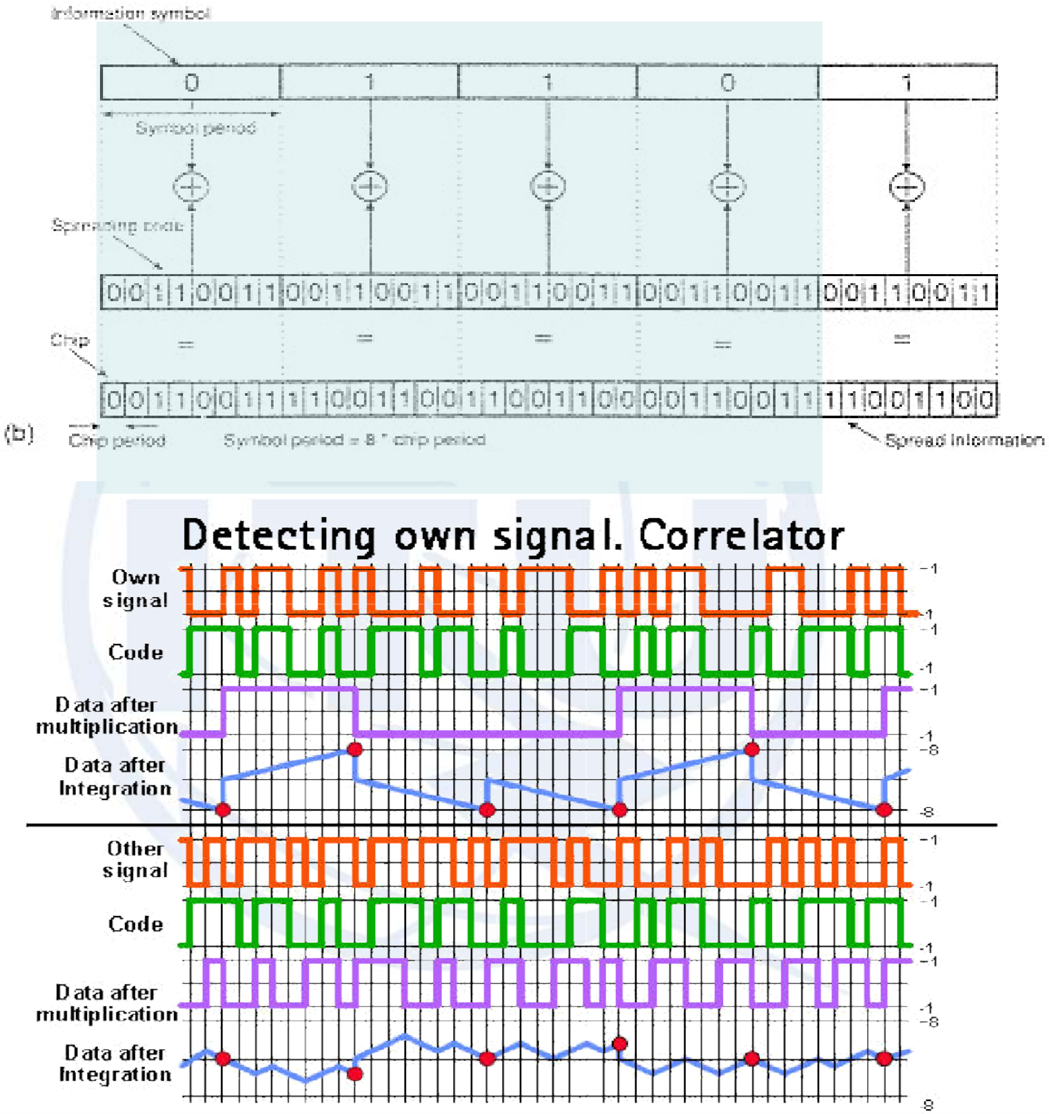
Architecture

Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	~ 50 Kbps



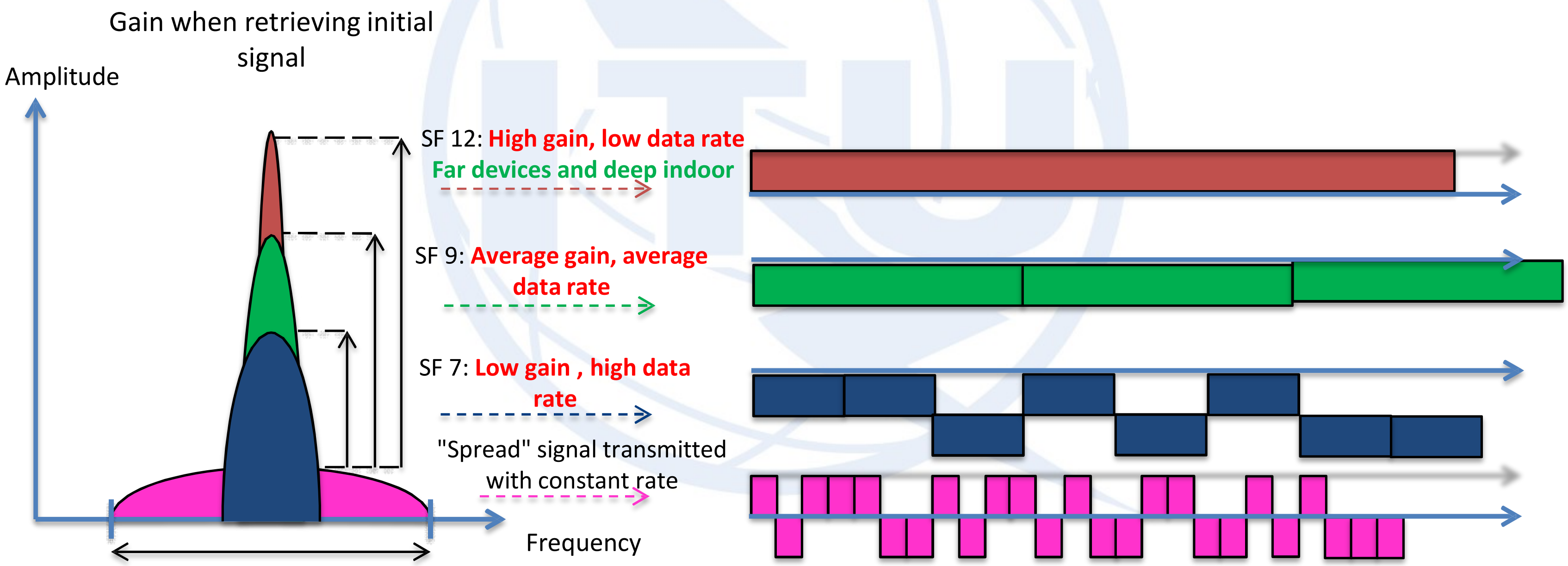
Type of Traffic	Data packet
Payload	~ 243 Bytes
Security	AES Encryption

Spread spectrum basics



Spectrum

- Orthogonal sequences: 2 messages, transmitted by 2 different objects, arriving simultaneously on a GW without interference between them (*Code Division Multiple Access* technique: CDMA , used also in 3G).
- **Spread Spectrum**: Make the signal more robust , the more the signal is spread the more robust. Less sensitive to *interference* and *selective frequency fadings* .



Spectrum: unlicensed, i.e. the 915 MHz ISM band in the US, 868 MHz in Europe

Spectrum (Influence of the Spreading Factor)

Far object from the antenna with obstacles:

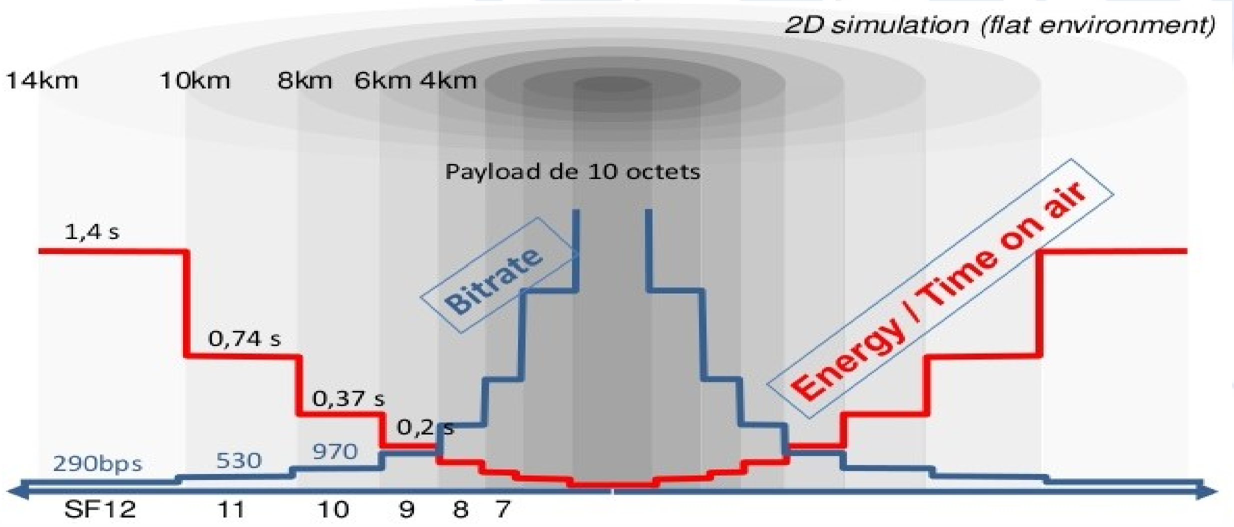
➔ Better sensitivity required

➔ The core network (network server) increases the SF (*Spreading Factor*) ➔ Throughut decreases but **the connection is maintained**

End device close to the antenna:

➔ High sensibility is not required

➔ Decrease of SF (SPREADING FACTOR), **increase of useful flow**

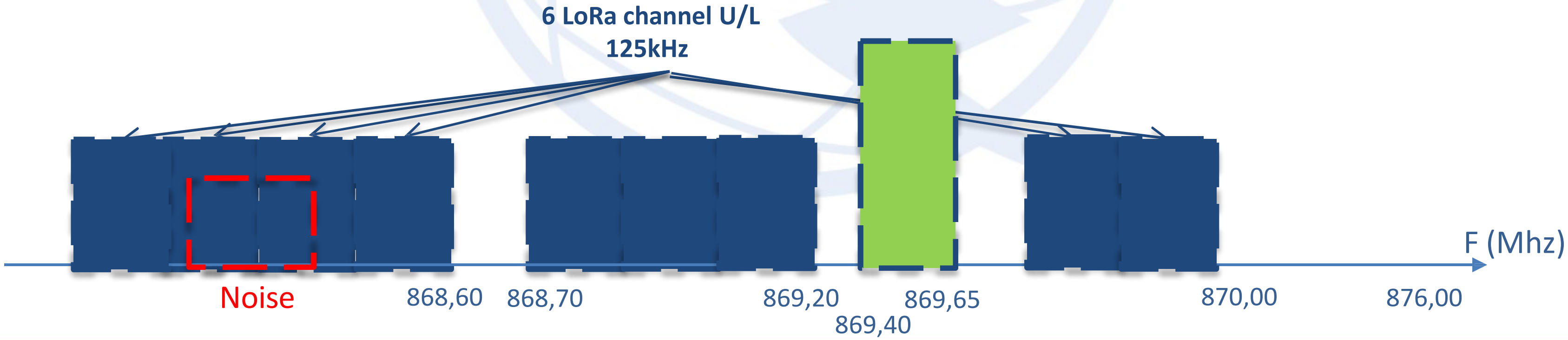


Adaptive throughput

ADR: *Adaptive Data Rate*

Spectrum (Robustness)

- ❑ LoRa demodulate the signal at **-20 dB under thermal noise** thanks to the spread spectrum technique.
- ❑ LoRa is based on a more developed modulation with coding gain mechanisms to improve the robustness of the signal:
  - Spectrum spreading (high SF: penetration up to 20 dB in deep indoor)
  - Forward Error correction to protect the messages
- ► Increase the probability to decode a signal without errors in interfered environments
- ❑ Dynamic channel management (managed network)
- ► Mechanism for pre-selection of non-interfered channels



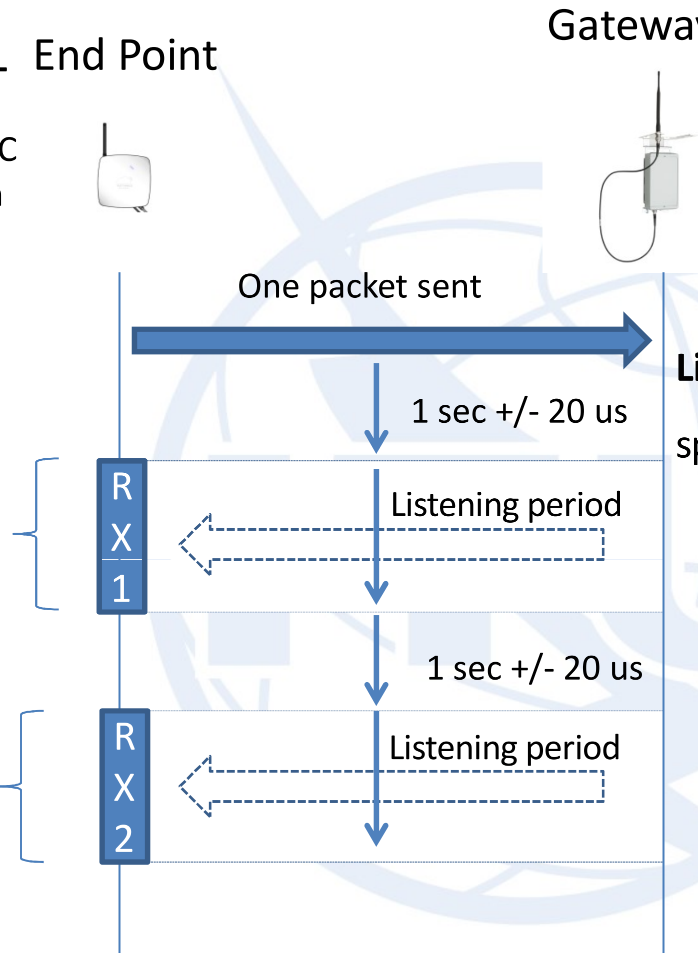
LoRaWAN: device classes

Classes	Description	Intended Use	Consumption	Examples of Services
A (« all »)	The module remains listening after each broadcast from the GTW	Modules with **no latency constraint**	The **most economic** communication Class energetically.. Supported by all modules. Suitable to module on battery	- **Fire Detection** - **Earthquake Early Detection**
B (« **beacon** »)	The module remains listening at a regularly adjustable frequency	Modules with latency constraints concerning the **reception of messages of a few seconds**	Class of communication proposing a **consumption optimized by report** to the aimed application. **Adapted to modules on battery**	- **Smart metering** - **Temperature rise**
C (« continuous »)	Module always listening	Modules with a ***strong reception latency constraint*** (less than one second)	Class of communication adapted to **modules on sector** or having **no constraints of autonomy**.	**- Fleet management** **- Real Time Traffic Management**

➔ Any LoRa object can transmit and receive

Class A

Open **2 windows for DL reception** (acknowledgments, MAC commands, application commands...) **after sending a packet**



1st receive window

2nd receive window

Listening period: varies according to the spreading factor SF

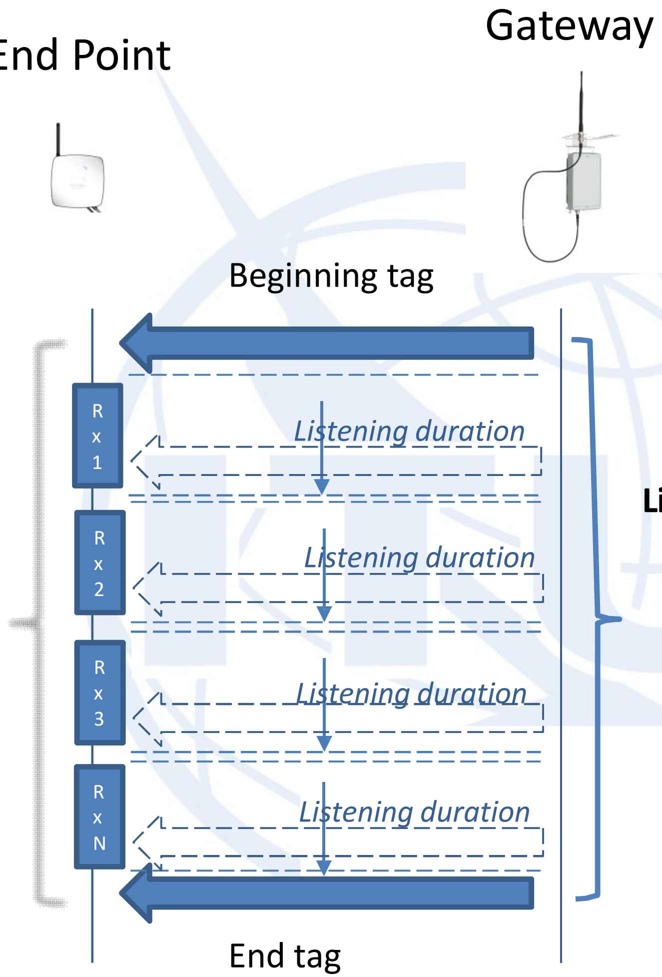
- 5.1 ms at SF7 (outdoor and close devices)
- 10.2 ms at *SF8 …*
- 164 ms at SF12 (deep-indoor or far devices)

Very economic energetically

Class B (Synchronized mode)

- Synchronized with the GW
- Opens listening windows at regular intervals.

Opens N reception windows between the two tags



Listening duration: varies according to the SF

Optimized energy consumption

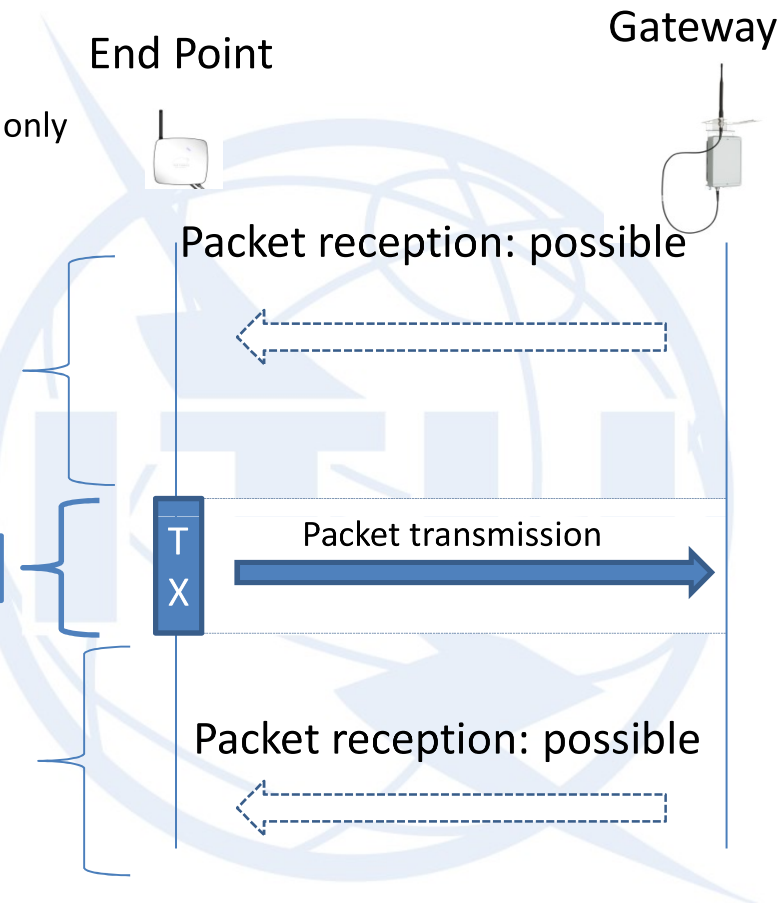
Class C

- **Permanent listening**
- Closes the reception window only during transmissions

Reception window always open

Closed receive window

Reception window is open



Adapted to devices on the power grid

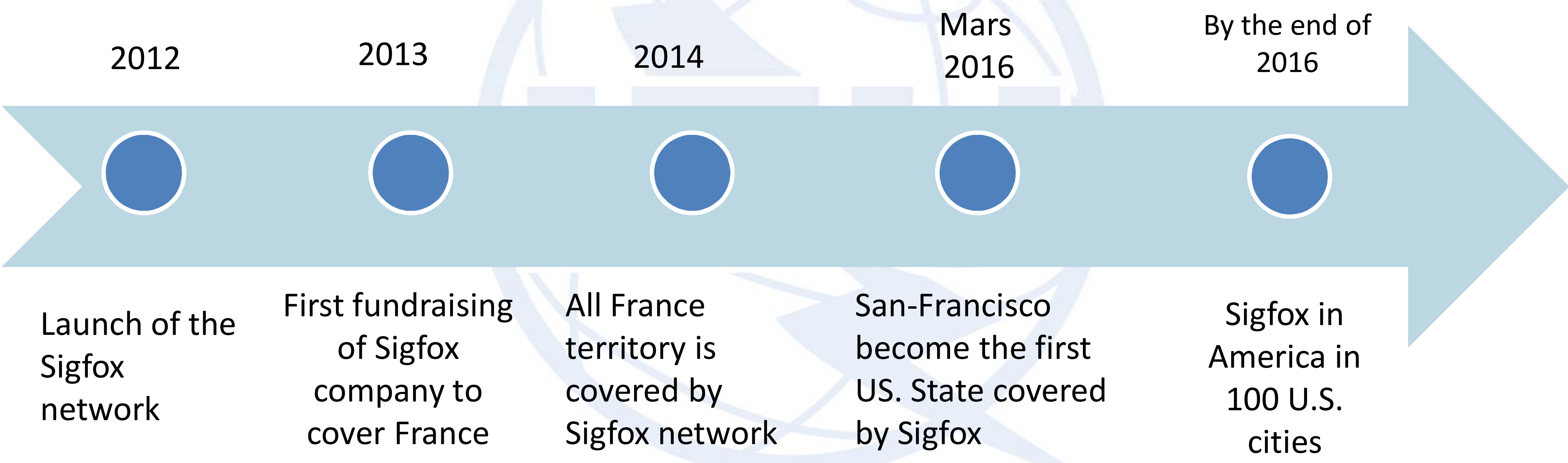
Current state

Amsterdam: was the first city covered by LoRaWAN with only 10 Gateways for the whole city at $ 1200 per unit. Since then, several cities have followed the trend:

By the end of 2016 , France will all be covered by LoRa

ii. Sigfox

Roadmap

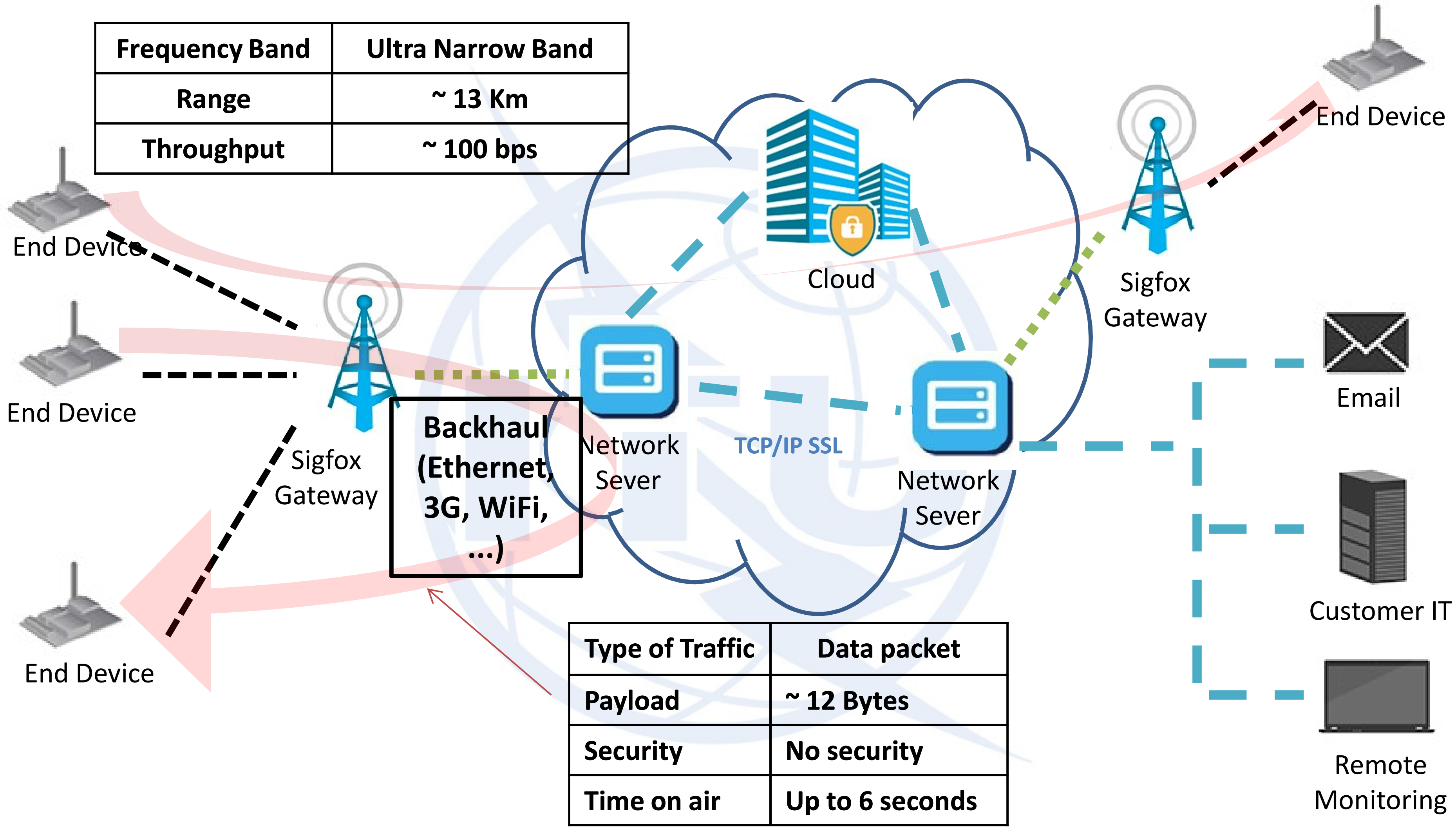

2012
Launch of the Sigfox network
2013
First fundraising of Sigfox company to cover France
2014
All France territory is covered by Sigfox network
Mars 2016
San-Francisco become the first US. State covered by Sigfox
By the end of 2016
Sigfox in America in 100 U.S. cities

Sigfox Overview

- **First LPWAN** Technology
- The physical layer based on &n **Ultra-Narrow band wireless** modulation
- **Proprietary** system
- Low throughput (**~100 bps**)
- Low power
- Extended range (**up to 50 km**)
- **140 messages/day/device**
- Subscription-based model
- **Cloud platform** with Sigfox –defined API for server access
- **Roaming capability**

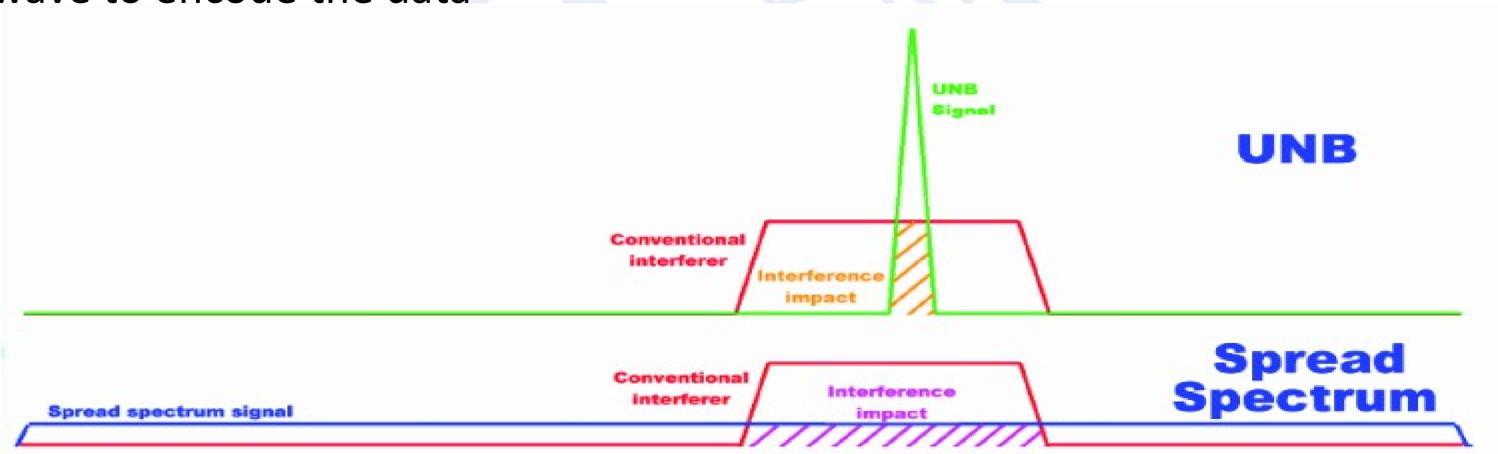
Architecture

Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps



Type of Traffic	Data packet
Payload	~ 12 Bytes
Security	No security
Time on air	Up to 6 seconds

- **Narrowband** technology
- Standard radio transmission method: binary phase-shift keying (**BPSK**)
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data

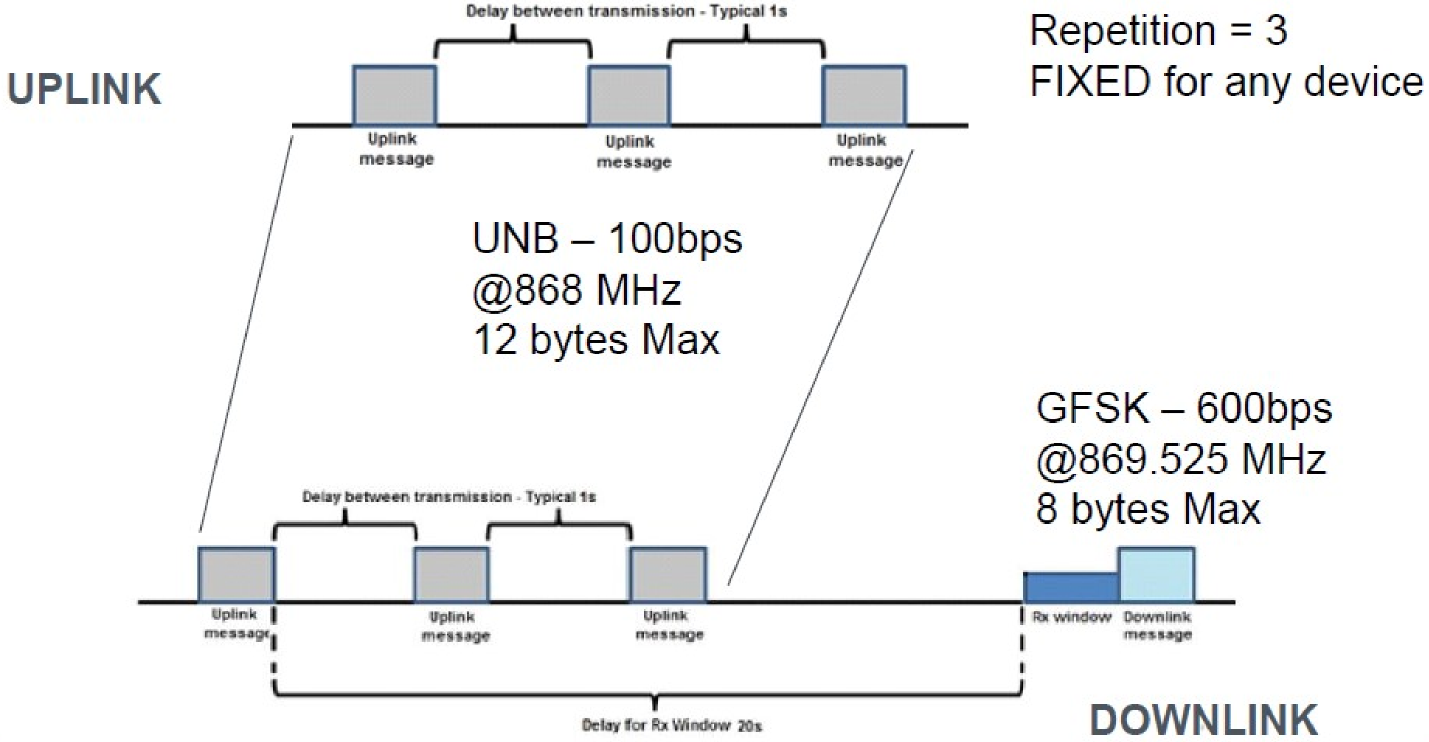


Frequency spectrum:

- 868 MHz in Europe
- 915 MHz in USA

SiFox transmission

- Starts by an **UL transmission**
- Each message is transmitted 3 times
- A **DL message** can be sent (option)
- Maximum payload of **UL messages** = 12 data bytes
- Maximum payload of **DL messages** = 8 bytes



Current state

26 Countries	1.6 million Km²	424 million
Covered countries	**Covered areas**	**End devices**

- SIGFOX LPWAN deployed in France, Spain, Portugal, Netherlands, Luxembourg, and Ireland , Germany, UK, Belgium, Denmark, Czech Republic, Italy, Mauritius Island, Australia, New Zealand, Oman, Brazil, Finland, Malta, Mexico, Singapore and U.S.

Sigfox company objectives:

- ✓ Cover **China** in 2017
- ✓ 60 countries covered by the end of 2018

SIGFOX
One network A billion dreams

iii. Weightless

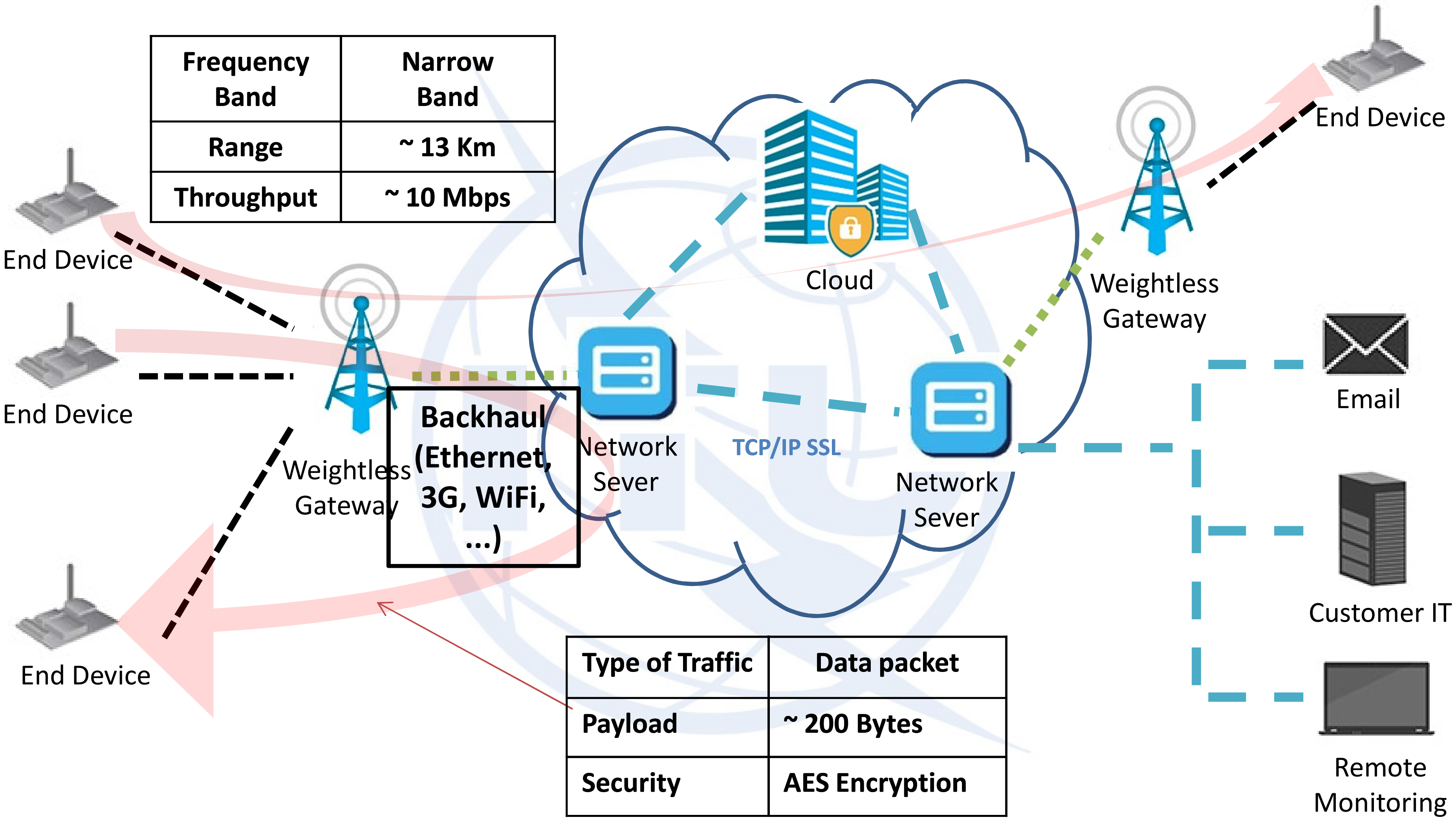
WEIGHTLESS Overview

- **Low cost** technology to be readily integrated into machines
- Operates in an unlicensed environment where the interference caused by others cannot be predicted and must be avoided or overcome.
- Ability to operate effectively in unlicensed spectrum and is optimized for M2M.
- Ability to handle large numbers of terminals efficiently.

Roadmap

- **2012** – Starts specification
- **2012** – Creation of ***Weightless Special Interest Group***
- **2014** – **White Space spectrum** is coming - ratified in USA Q3 2012, UK expected Q2 2014
- **May 2015** – First version released
- **Jun 2015** – First Weightless-N network deployed in London

Architecture



Frequency Band	Narrow Band
Range	~ 13 Km
Throughput	~ 10 Mbps

Type of Traffic	Data packet
Payload	~ 200 Bytes
Security	AES Encryption

Choosing the right Weightless technology

	Weightless-N	**Weightless-P**	**Weightless-W**
Directionality	1-way	2-ways	2-ways
Range	5Km+	2Km+	5Km+
Battery life	10 years	3-8 years	3-5 years
Terminal cost	Very low	Low	Low-medium
Network cost	Very low	Medium	Medium
Data Rate	Up to 10 Mbps	Up to 100 Kbps	Up to 200 Kbps

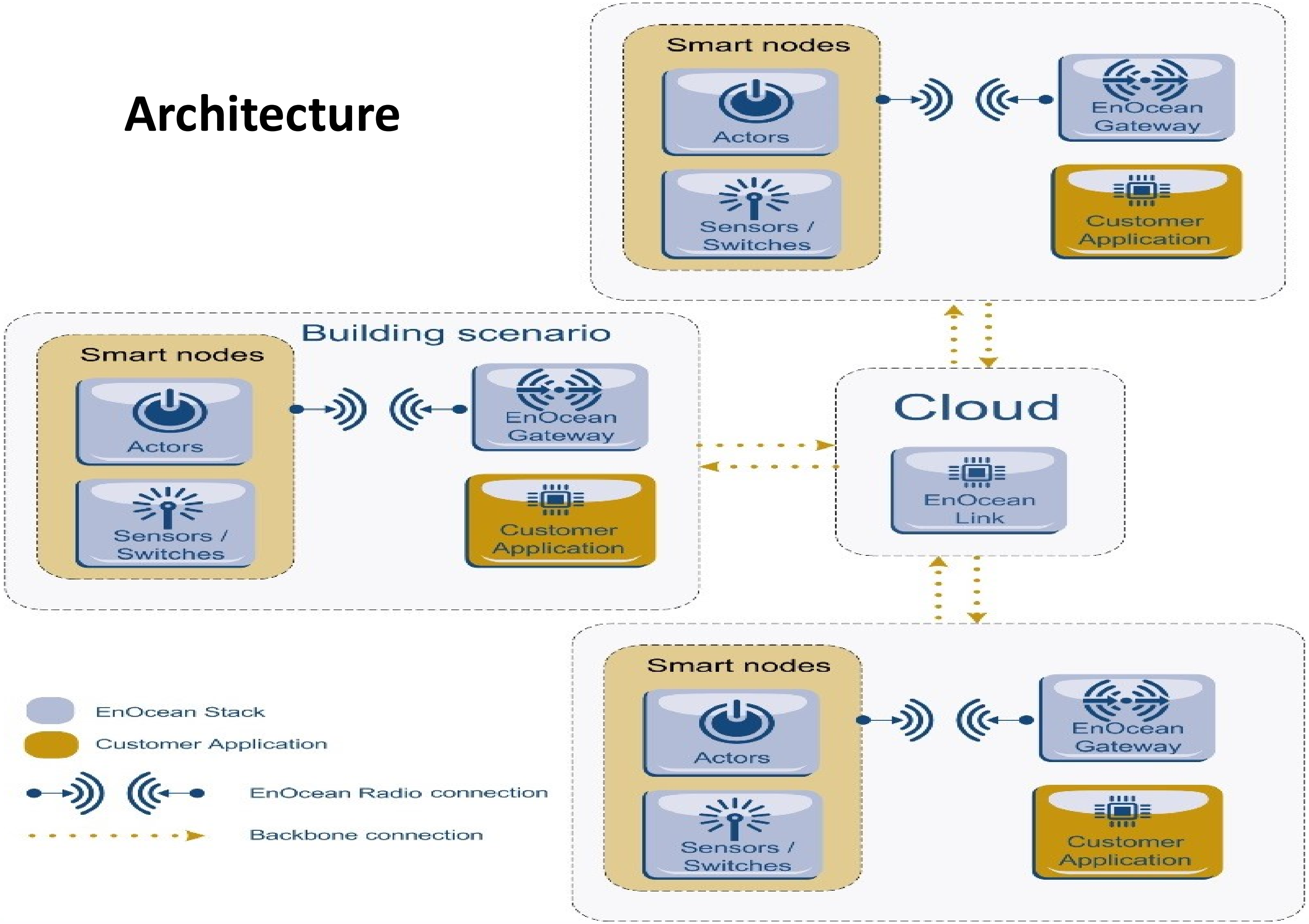
iv. Others

EnOcean

- Based on **miniaturized power converters**
- **Ultra low power** radio technology
- Frequencies: 868 MHz for Europe and 315 MHz for the USA
- Power from pressure on a switch or by photovoltaic cell
- These power sources are sufficient to power each module to transmit wireless and battery-free information.
- EnOcean Alliance in 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)

Green.Smart.Wireless.
enocean®

Architecture



ZWave

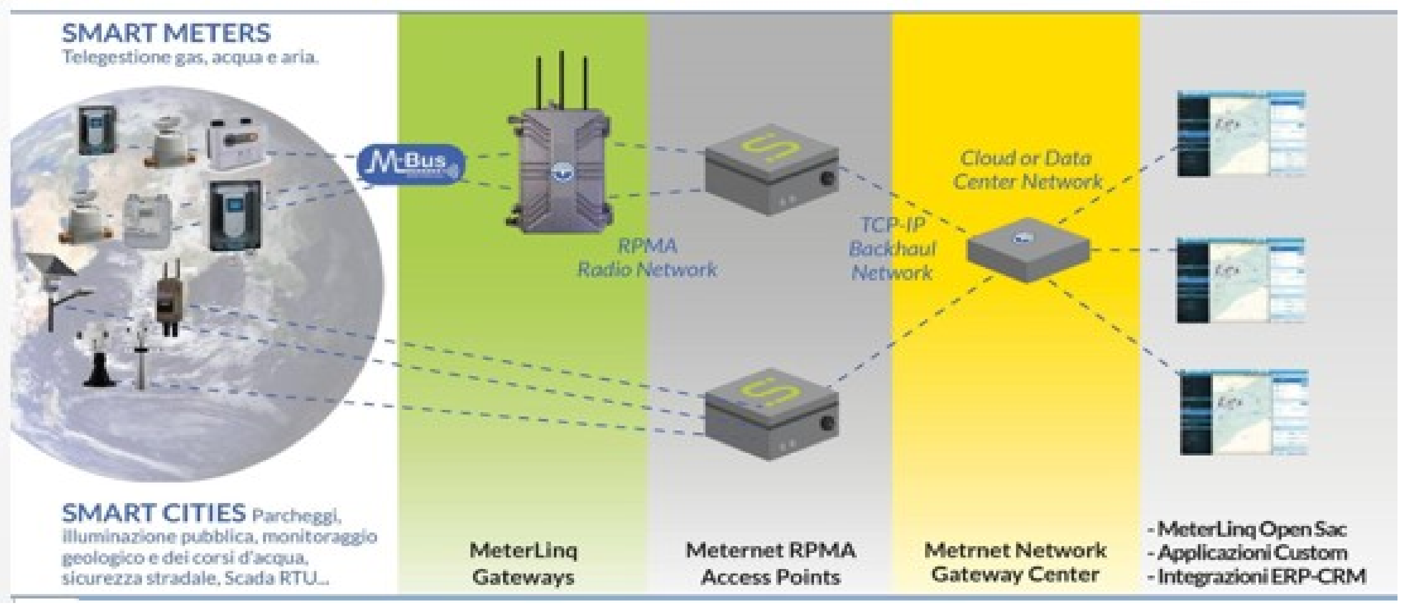
- Low power radio protocol
- Home automation (lighting, heating, ...) applications
- Low-throughput: 9 and 40 kbps
- Battery-operated or electrically powered
- Frequency range: 868 MHz in Europe, 908 MHz in the US
- Range: about 50 m (more **outdoor**, less indoor)
- Mesh architecture possible to increase the coverage
- Access method type CSMA / CA
- Z-Wave Alliance: more than 100 manufacturers in

Services


Home Control
Remote Home Management and Monitoring
Energy Conservation
ZWAVE®
Home Entertainment Control
Safety & Security
Comfort and Convenience

INGENU RPMA

- **Random Phase Multiple Access** (RPMA) technology
- Low-power, wide-area channel access method used exclusively for machine-to-machine (M2M) communication
- RPMA uses the popular 2.4 GHz band
- A single gateway can cover up to 300 square miles ➔ 18 Km range.



Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards

2. 3GPP Standards

i. LTE-M

ii. NB-IOT

iii. EC-GSM

iv. 5G and IoT

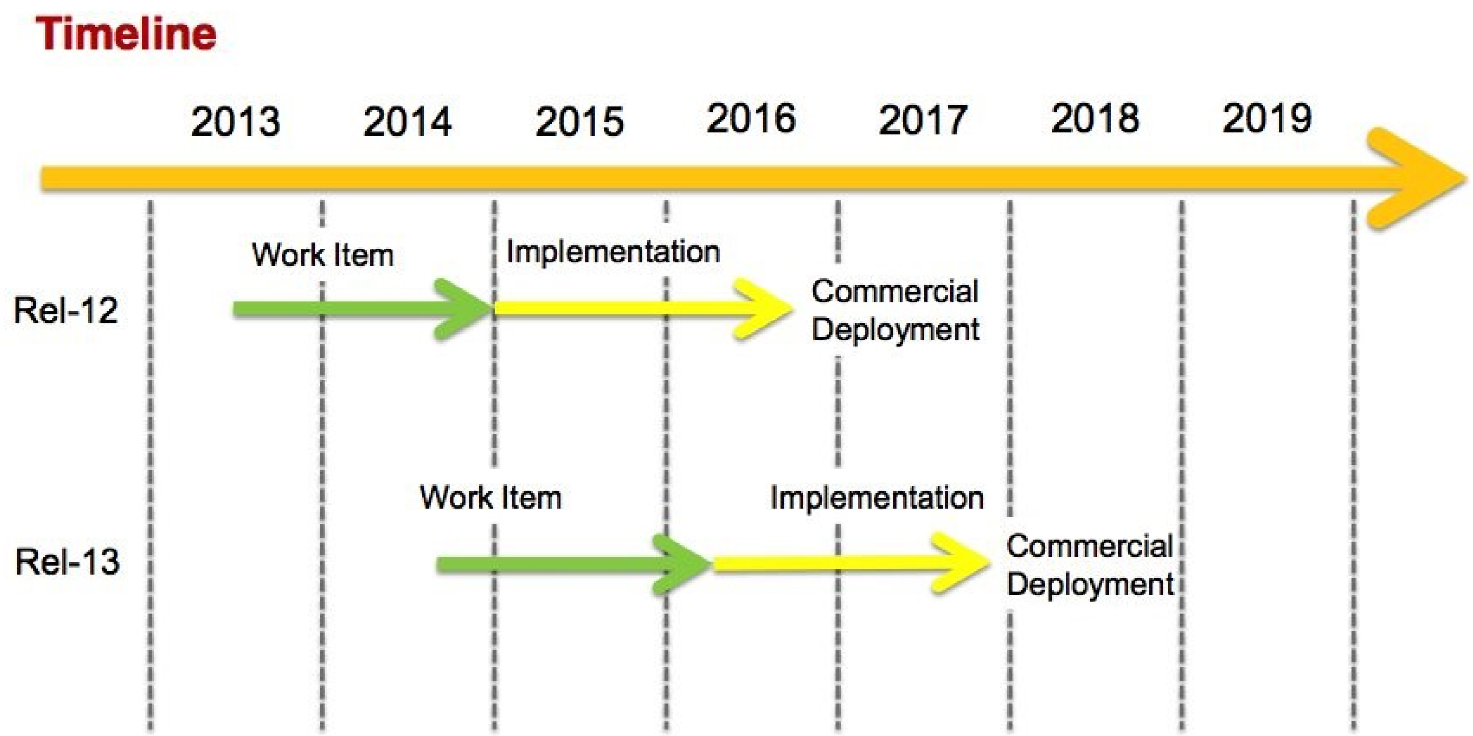
i. LTE-M

- Evolution of LTE optimized for IoT in 3GPP RAN
- **Low power consumption** and autonomy
- **Easy deployment**
- Interoperability
- Low overall **cost**
- Excellent coverage: up to **11 Km**
- Better throughput: up to **1 Mbps**

A GLOBAL INITIATIVE

LTE-M

Roadmap



- First released in Rel.1in 2 Q4 2014
- Optimization in Rel.13
- Specifications completed in Q1 2016

LTE to LTE-M

3GPP Release	8 (Cat.4)	8(Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	1	1
Uplink peak rate (Mbps)	50	5	1	1
Number of antennas	2	2	1	1
Duplex Mode	Full	Full	Half	Half
UE receive bandwidth (MHz)	**20**	**20**	**20**	**1.4**
UE Transmit power (dBm)	**23**	**23**	**23**	**20**

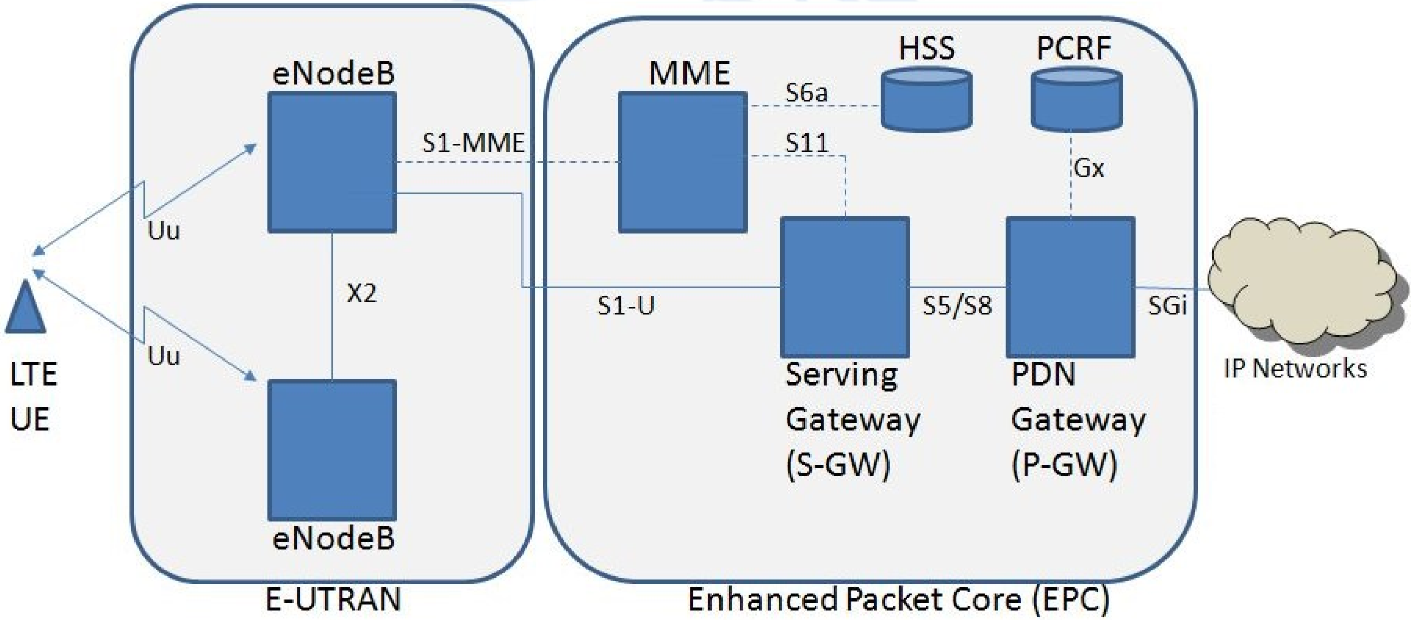
Release 12

- New category of UE (“Cat-0”): **lower complexity** and low cost devices
- **Half duplex FDD** operation allowed
- **Single receive chain**
- Lower data rate requirement (Max: 1 Mbps)

Release 13

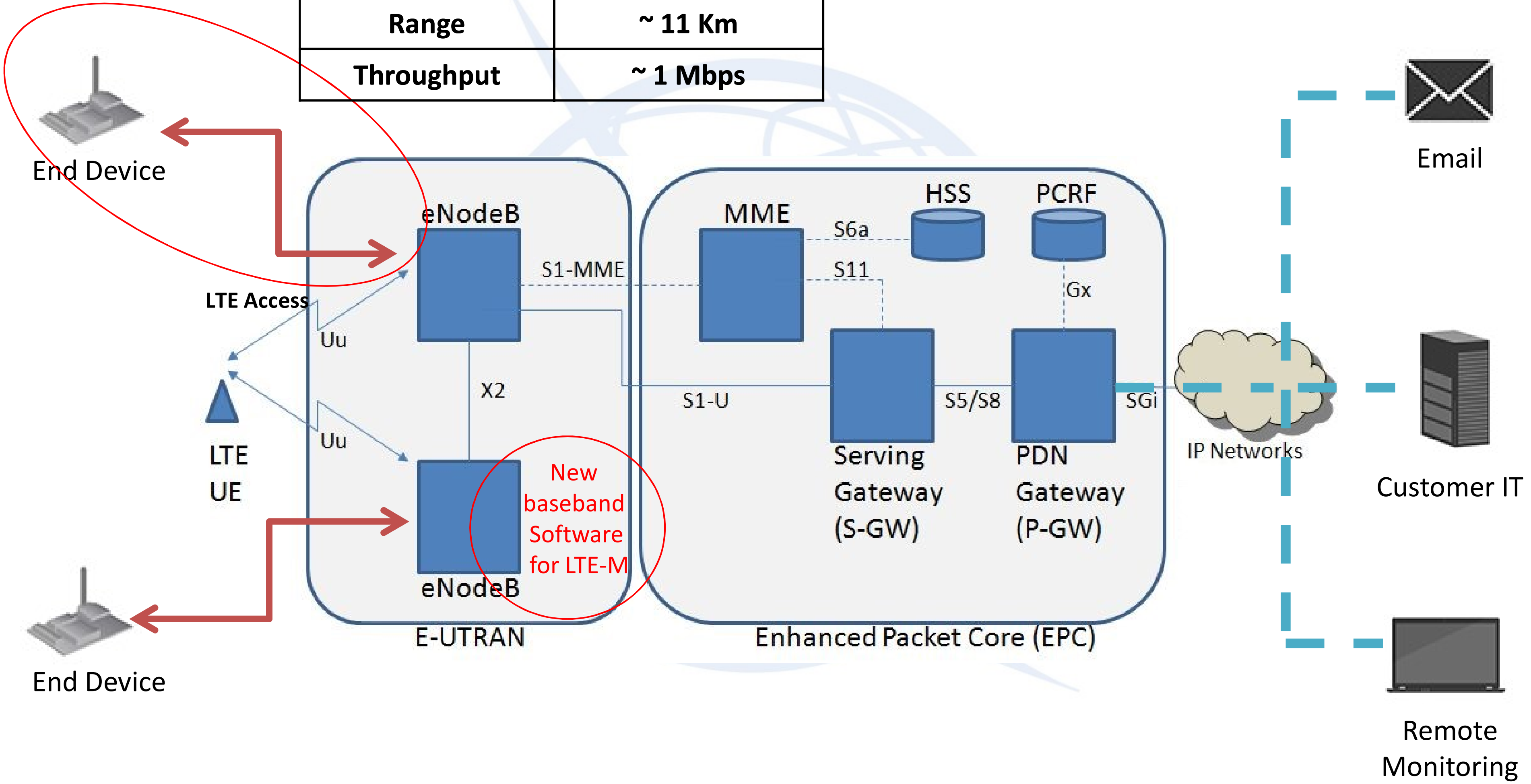
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

Present LTE Architecture

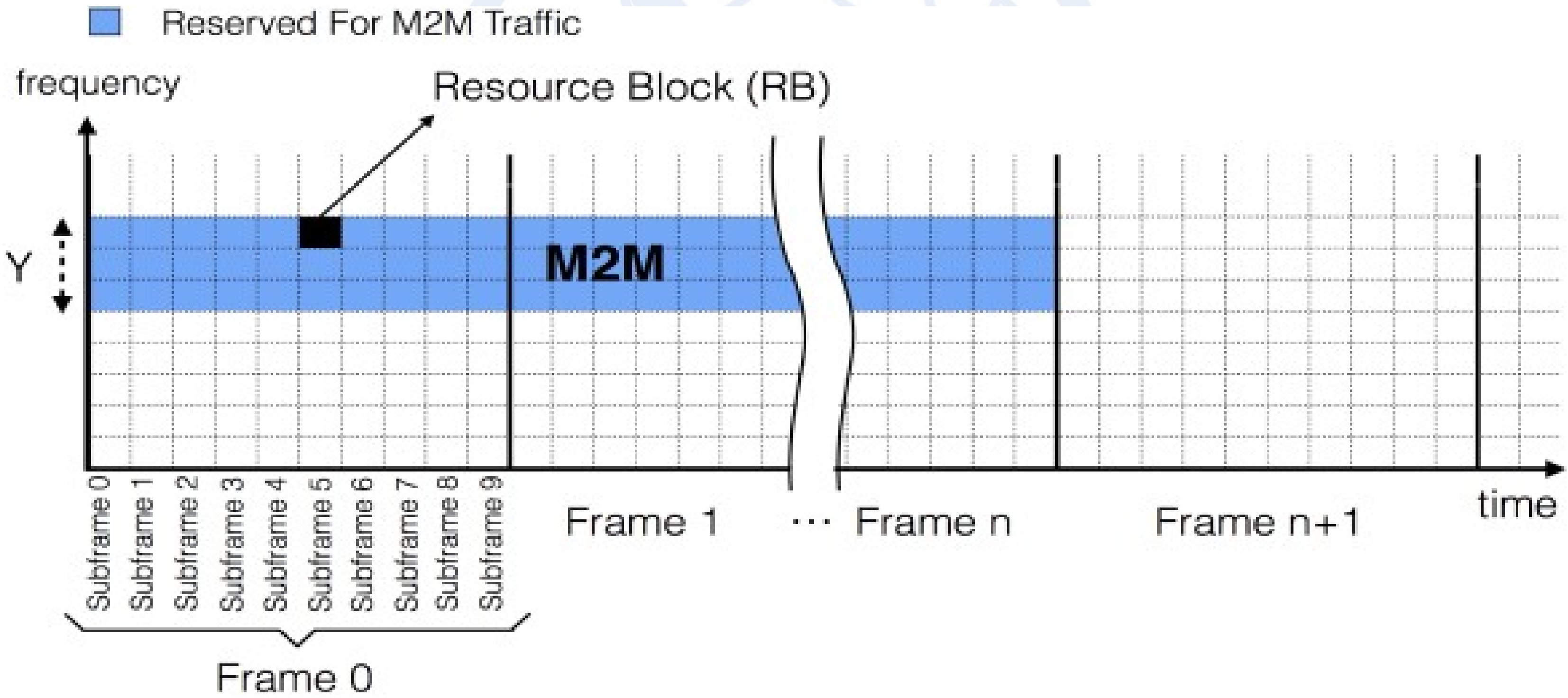


Architecture

Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps



- **Licensed Spectrum**
- **Bandwidth: 700-900 MHz for LTE**
- **Some resource blocks allocated for IoT on LTE frequencies**



ii. NB-IOT

Current state

April 2014	Narrowband proposal to Connected Living
May 2014	3GPP 'Cellular IoT' Study Item
Mars 2015	GSMA Mobile IoT created
August 2015	3GPP alignment on single standard
November 2015	1st live pre-standard NB-IoT message
Jun 2015	Full NB-IoT 3GPP Standard Released
2017+	Commercial rollout

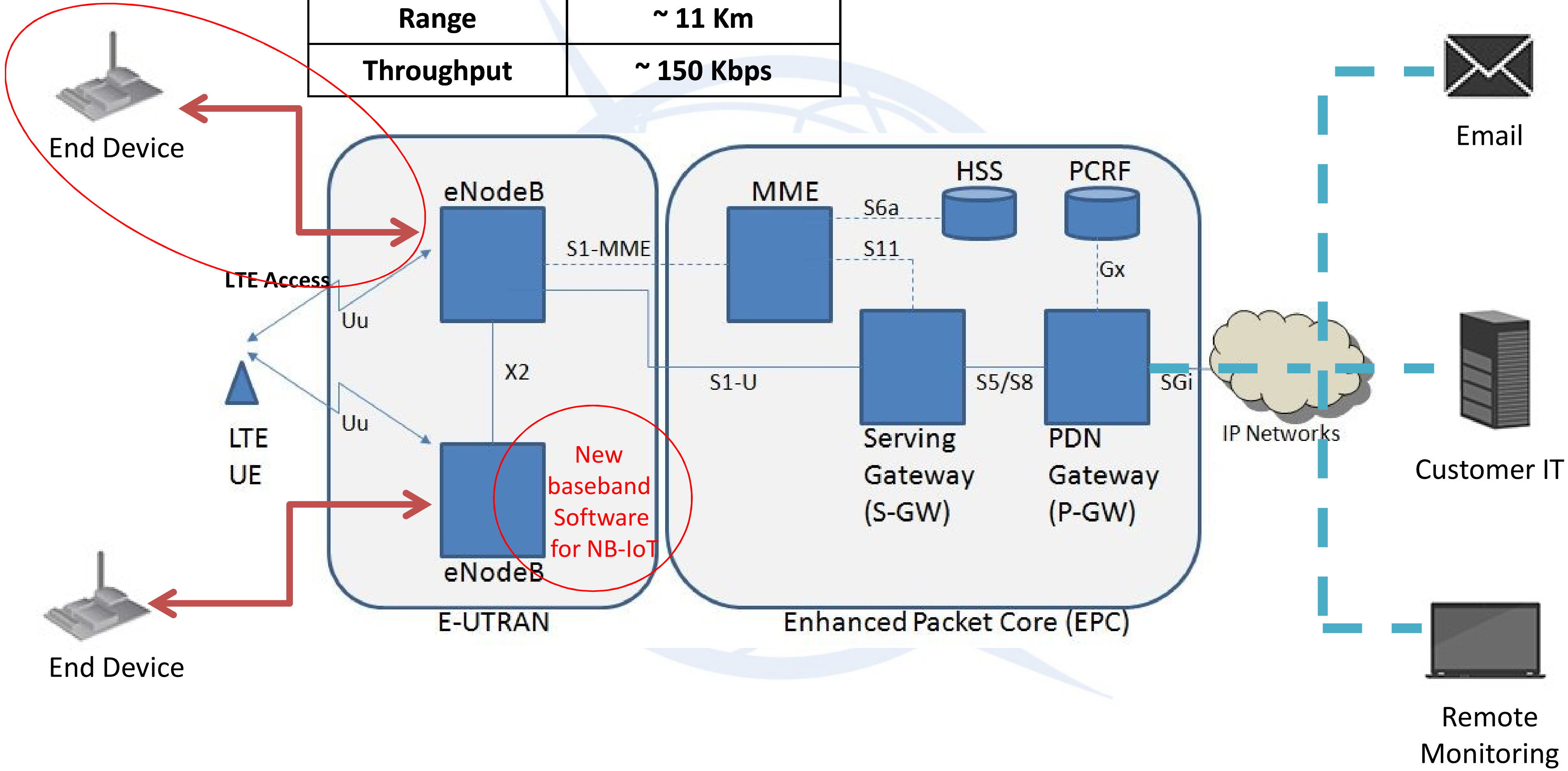
A GLOBAL INITIATIVE

- **Narrowband** radio interface
- Part of RAN **Rel. 13**
- Standardization started in Q4 2015 and specifications completed Q2 2016
- **Improvements over LTE-M**
- Reduced device **bandwidth of 200 kHz** in downlink and uplink
- Reduced throughput based on **single PRB operation**
- Provide **LTE coverage improvement** corresponding to 20 dB.

NB-IoT

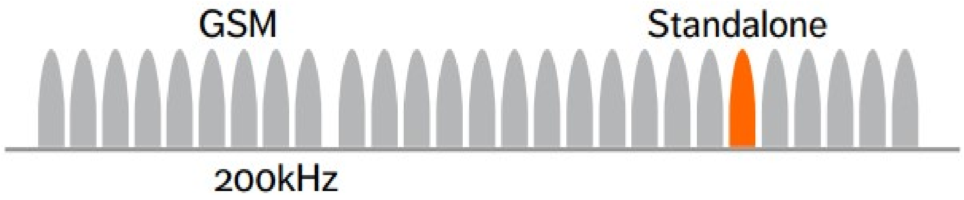
Architecture

Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps



Spectrum and access

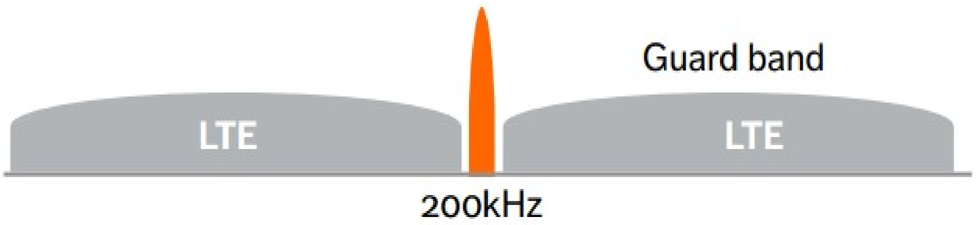
- Designed with a number of deployment options for **GSM ,WCDMA**, or **LTE** spectrum to achieve spectrum efficiency.
- Use **licensed spectrum**.



Stand-alone operation

Dedicated spectrum.

Ex.: By re-farming GSM channels



Guard band operation

Based on the unused RB within a LTE carrier's guard-band

In-band operation

Using resource blocks within a normal LTE carrier

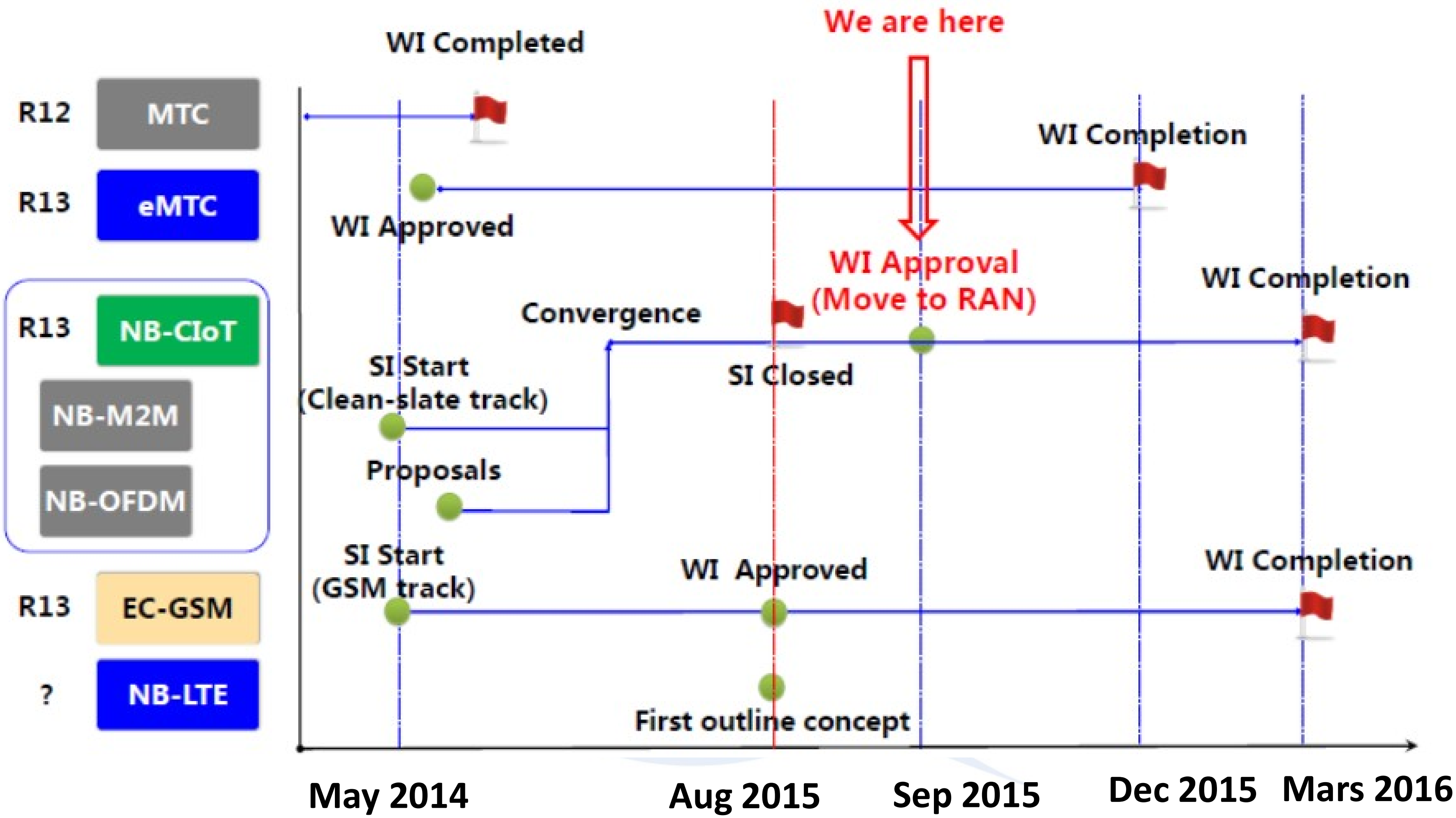
LTE-M to NB-IoT

3GPP Release	12(Cat.0) LTE-M	13(Cat. 1,4 MHz) LTE-M	13(Cat. 200 KHz) NB-IoT
Downlink peak rate	1 Mbps	1 Mbps	200 Kbps
Uplink peak rate	1 Mbps	1 Mbps	144 Kbps
Number of antennas	1	1	1
Duplex Mode	Half	Half	Half
UE receive bandwidth	20 MHz	1.4 MHz	200 KHz
UE Transmit power (dBm)	23	20	23

- **Reduced throughput** based on single PRB operation
- Enables **lower processing and less memory** on the modules
- 20dB additional link budget → **better area coverage**

iii. EC-GSM

Roadmap



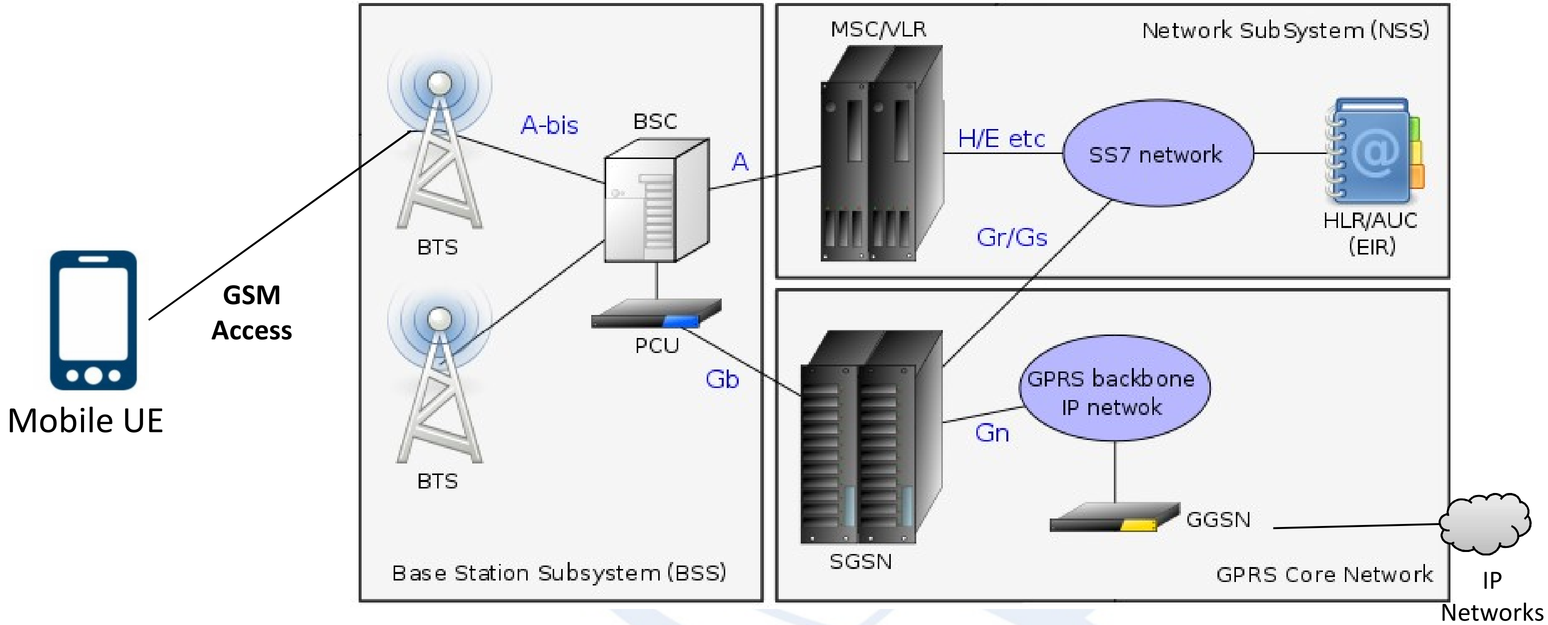
R12
MTC
R13
eMTC
R13
NB-CIoT
NB-M2M
NB-OFDM
R13
EC-GSM
?
NB-LTE
We are here
WI Completed
WI Completion
WI Approved
WI Approval
(Move to RAN)
WI Completion
Convergence
SI Start
(Clean-slate track)
SI Closed
Proposals
SI Start
(GSM track)
WI Approved
WI Completion
First outline concept
May 2014
Aug 2015
Sep 2015
Dec 2015
Mars 2016

- **Extended coverage** GSM IoT (EC-GSM-IoT)
- Standard-based **Low Power Wide Area technology** (long range, low energy)
- Based on **eGPRS**
- Designed as a **high capacity**, **low complexity** cellular system for IoT communications

R13 feature: EC-GSM

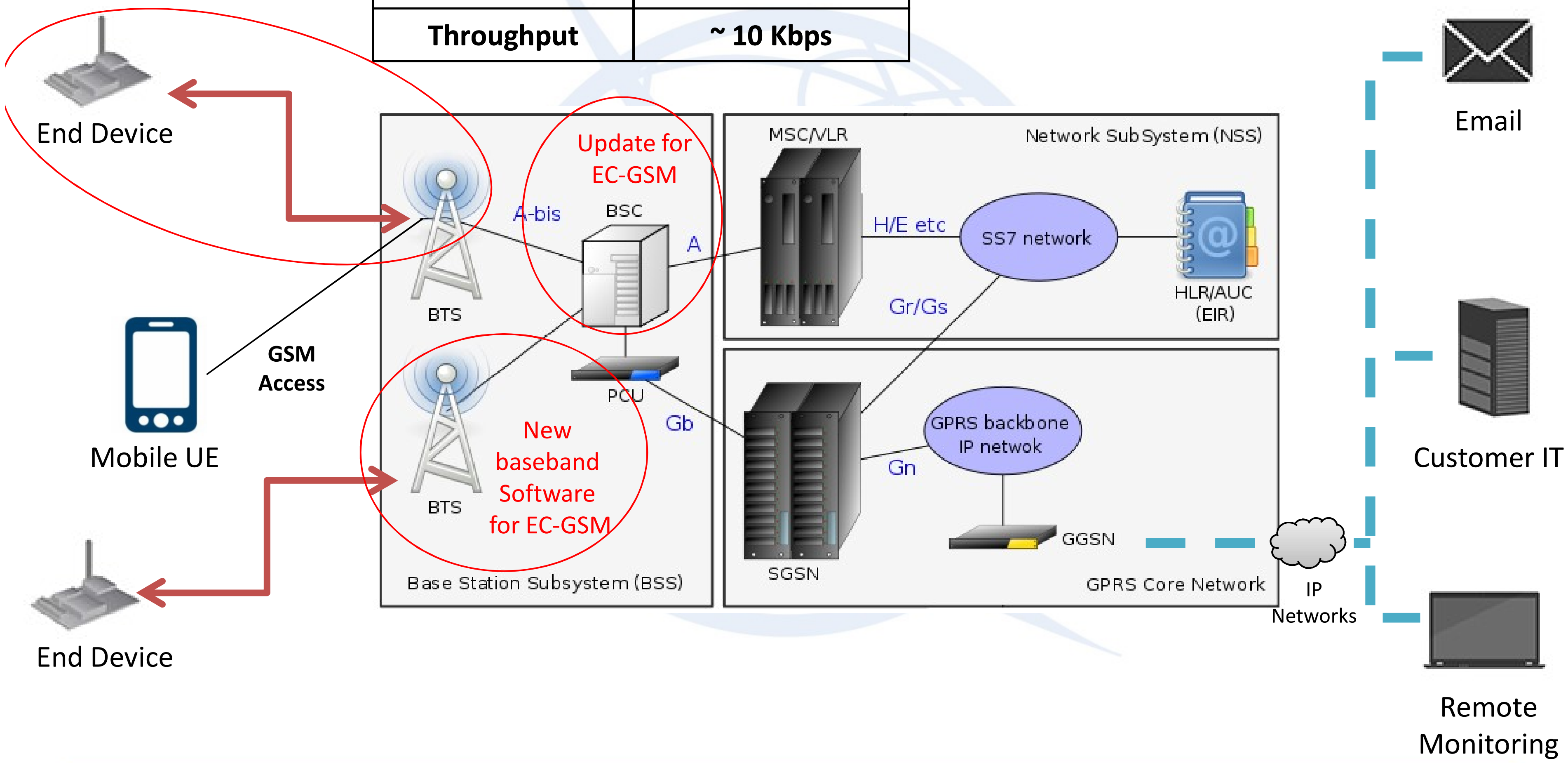
- New single-burst coding schemes
- Blind Physical Layer Repetitions where bursts are repeated up to 28 times without feedback from remote end
- **New logical channel types** (EC-BCCH, EC-PCH, EC-AGC, EC-RACH, ...)
- **New RLC/MAC** layer messages for the EC-PDCH communication
- Introduction of **eDRX** (extended DRX) to allow for PCH listening intervals from minutes up to a hour.

Actual GSM/GPRS Architecture



Architecture

Access	EC-GSM
Frequency Band	Narrow Band
Range	~ 15 Km
Throughput	~ 10 Kbps

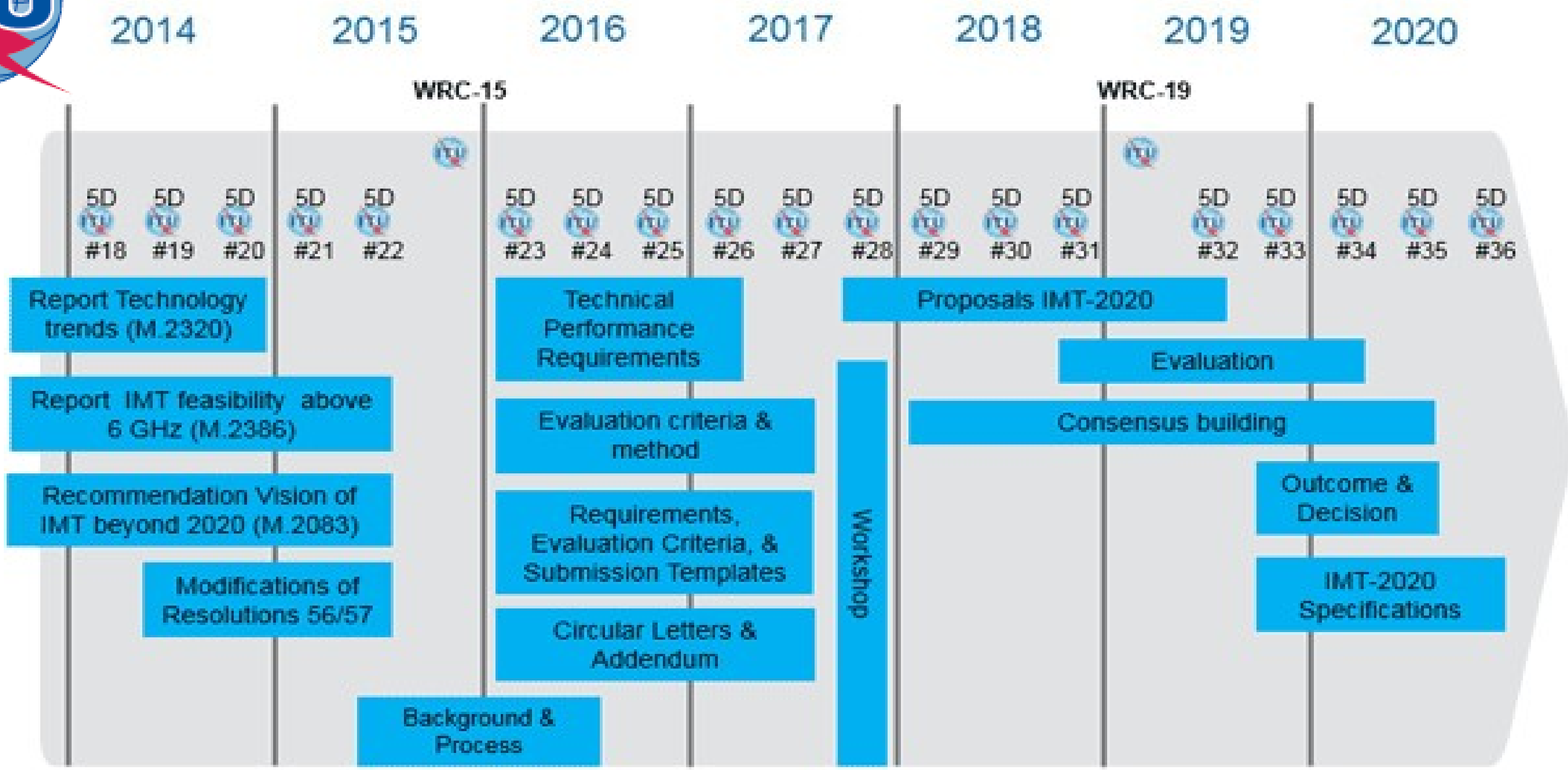


Technologies	EC-GSM
Spectrum	Licensed (800-900MHz)
Bandwidth	2.4 MHz or shared

iv. 5G and IoT

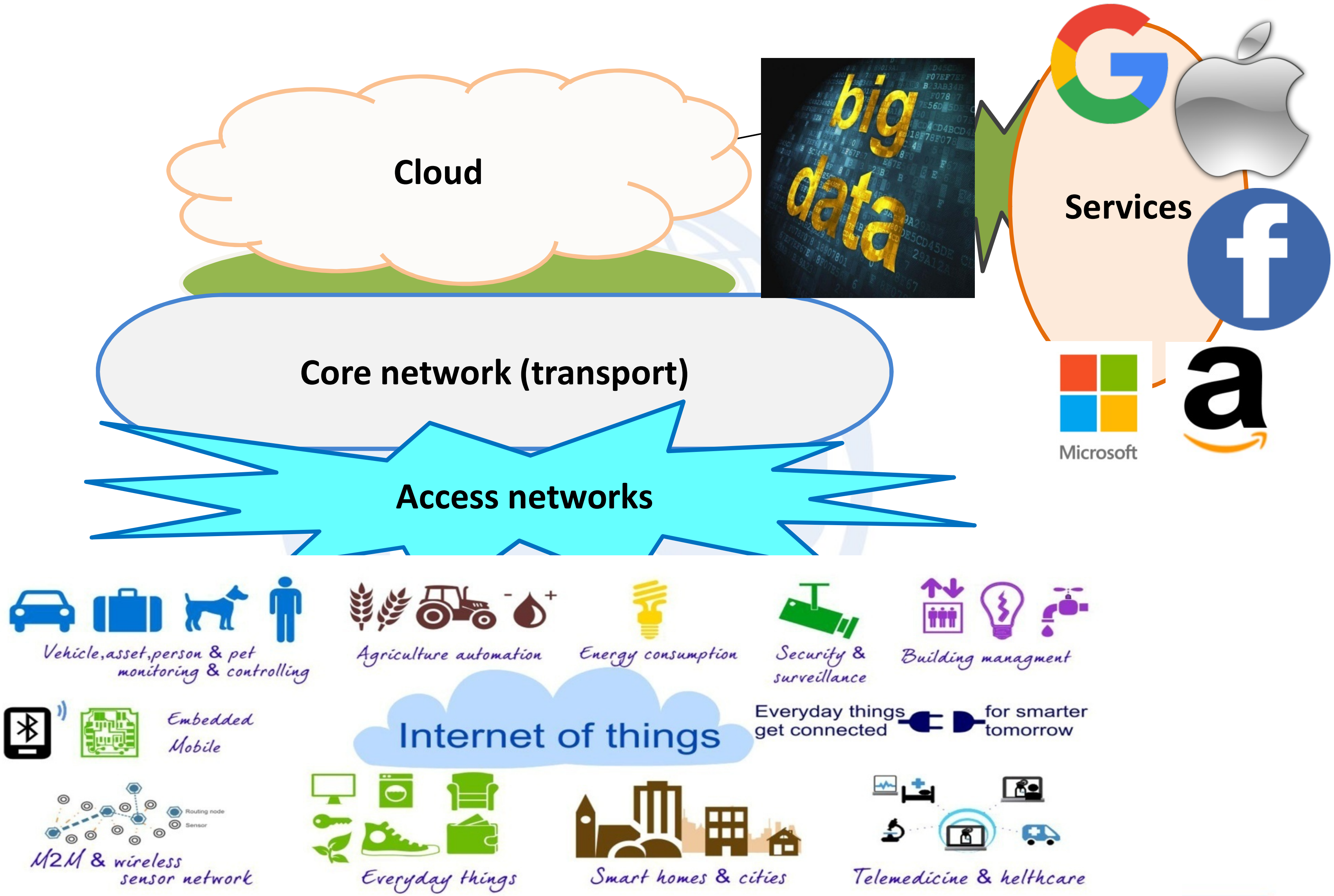
Roadmap

ITU-R WP5D
Detailed Timeline & Process for IMT-2020 in ITU-R



- **Initial technology submission: Meeting 32 (June 2019)**
- **Detailed specification submission: Meeting 36 (October 2020)**

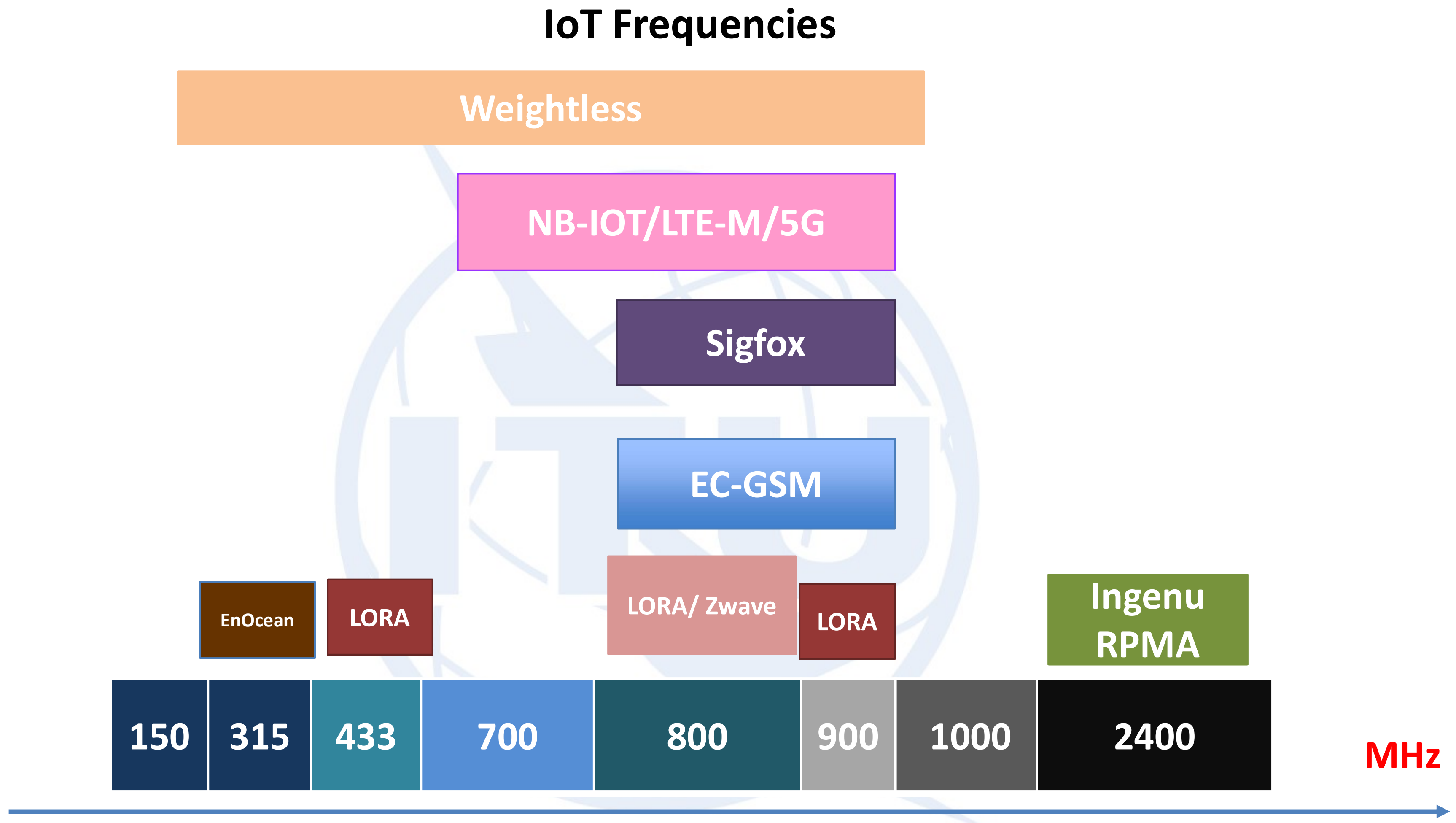
Vision of 5G


Cloud
Core network (transport)
Access networks
big data
Services
Microsoft
Vehicle,asset,person & pet monitoring & controlling
Agriculture automation
Energy consumption
Security & surveillance
Building managment
Embedded Mobile
Internet of things
Everyday things get connected
for smarter tomorrow
M2M & wireless sensor network
Everyday things
Smart homes & cities
Telemedicine & helthcare

IoT Technologies Synthesis

Comparison

Technologies	SIGFOX	LORA	Weightless	NB-IOT	LTE-M	EC-GSM	5G
Range	< 13 km	< 11 km	< 5 km	< 15 km	< 11 km	< 15 km	< 15 km
Spectrum	Unlicensed 868MHz 915MHz	Unlicensed 433MHz	**W:** 470-790MHz **N:**868 - 915 MHz **P:**169/433/470/780/868/915/923 MHz	Licensed 700-900 MHz	Licensed 700-900 MHz	Licensed 800-900 MHz	Licensed 700-900 MHz
bandwidth	100 kHz	< 500 kHz	**W:** 5MHz **N:** Sub-GHz **P:** 12,5 kHz	200 kHz or shared	1.4 MHz or shared	2.4 MHz or shared	Shared
Data Rate	< 100 kbps	<10 kbps	**W:** 1kbits/s to 10Mbits/s **N:** 500 bits/s **P:** 100Kbits to 200Kbits	< 150 kbps	< 1 Mbps	10 kbps	< 1 Mbps
Battery life	>10 years						
Availability	Today	Today	Today	2016 (standard)	2016 (standard)	2016 (standard)	Beyond 2020



Most LPWAN operate in the **2.4 GHz *ISM bands***, **868/915 MHz**, **433 MHz** and **169 MHz**.

Summary

I. Introduction

II. IoT Market Assessment

III. IoT Technologies

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)

2. 3GPP Standards

IV. IoT Network Dimensioning and Planning

I. Dimensioning Phase

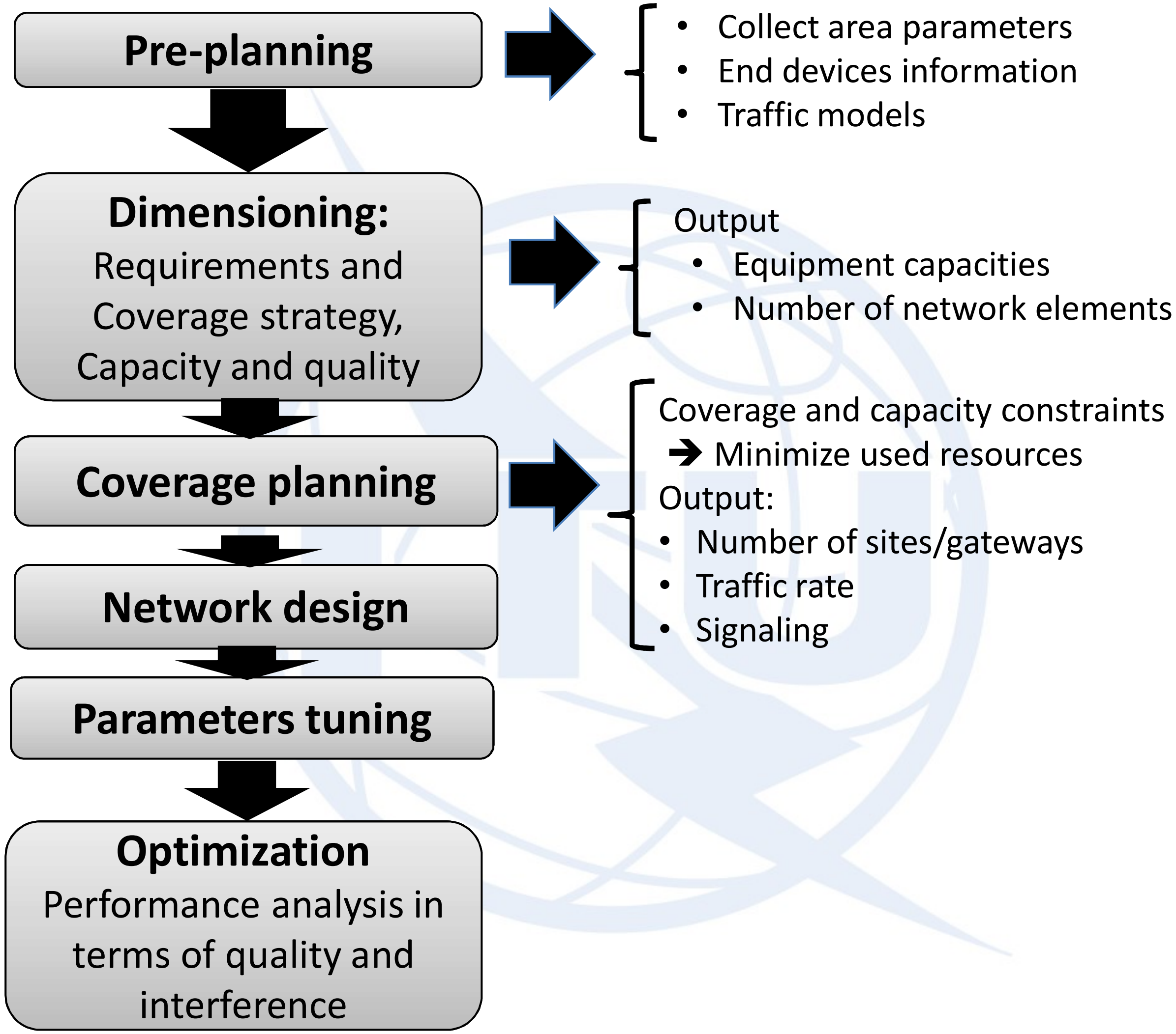
II. Radio Network Planning

IV. IoT Network Dimensioning and Planning

A. Network Dimensioning

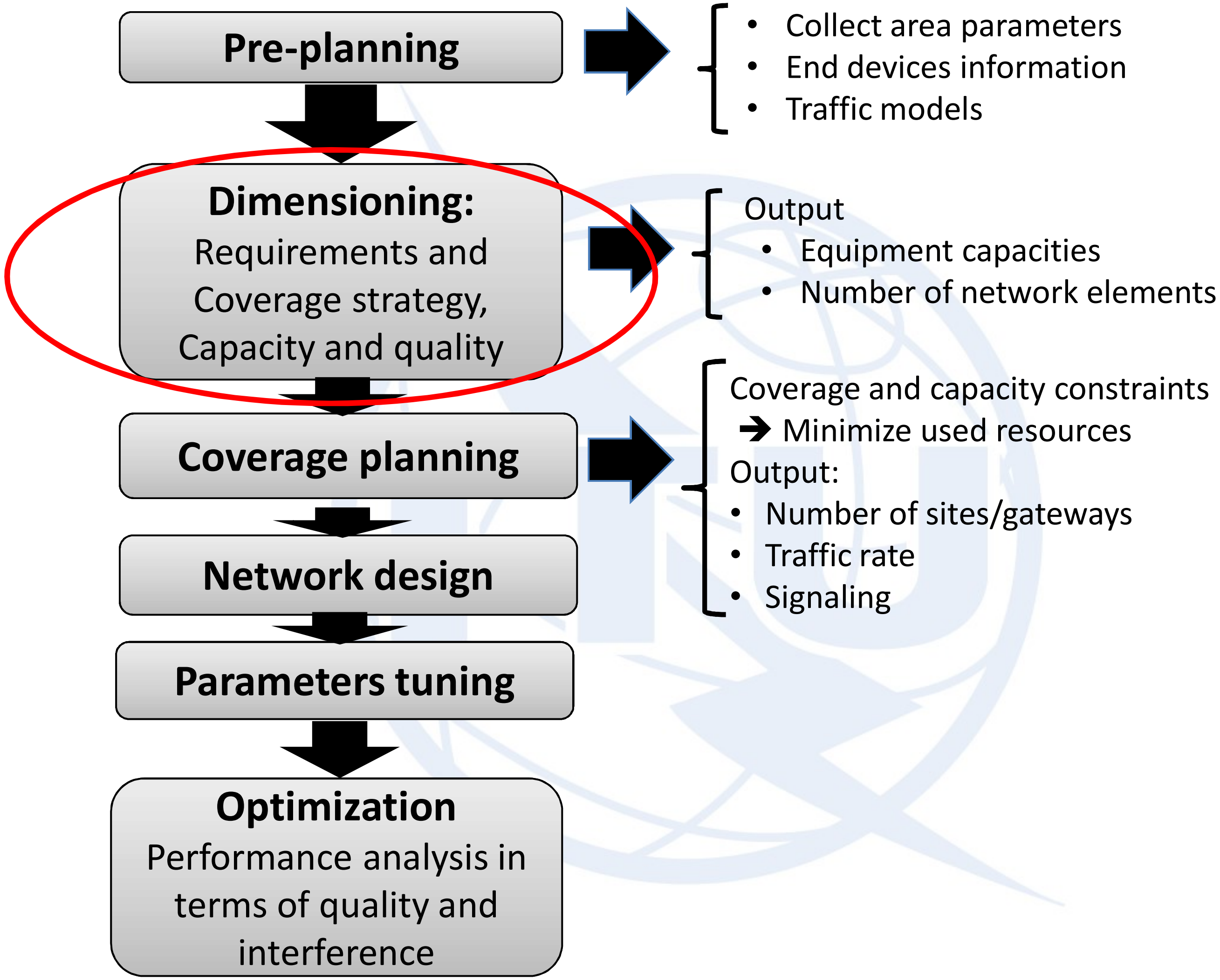
B. Network planning

Wireless Network Planning Process



A. NETWORK DIMENSIONNING

Wireless Network Planning Process

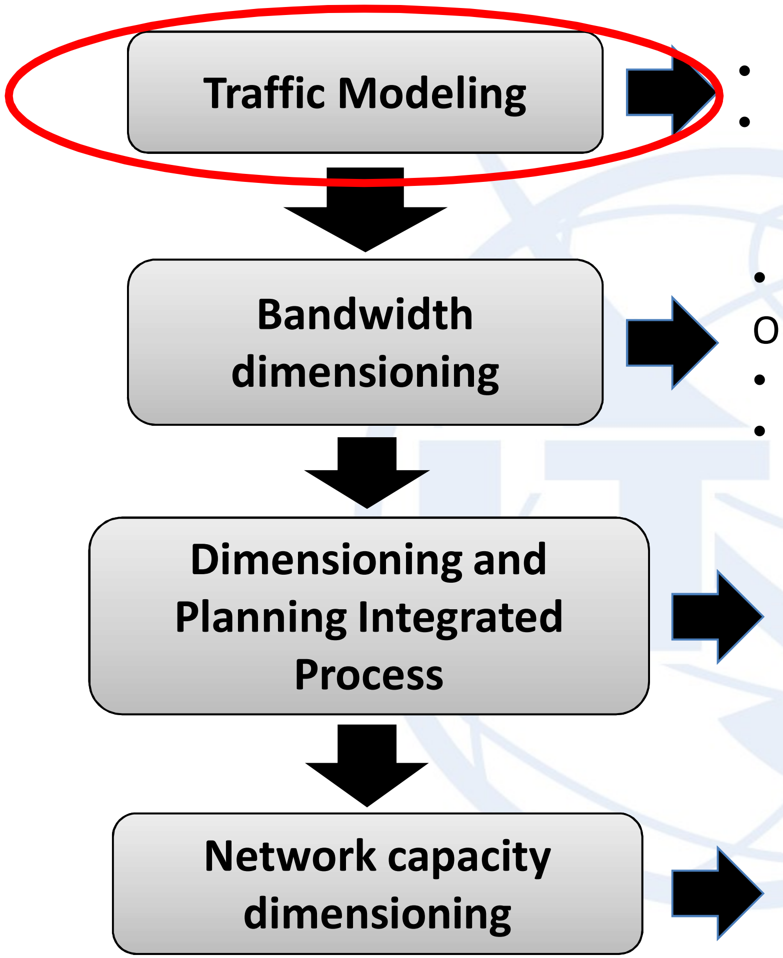


- 2 types of traffic considered for dimensioning:
    - Circuit switched traffic (CS),
    - Packet switched traffic (PS)

IoT type of traffic is **PS-like.**

Traffic models

Dimensioning Steps and Process



- Traffic models selection/elaboration
- Traffic models parameters setting

- Models application

Output:

- Aggregated capacity
- Number of network elements

- Simulation of coverage and capacity
- Revision of the initial assumptions

Output:

- Network design
- Gateways parameters

- Traffic models have least three major uses:

1. Properly ***dimension network resources*** for a target level of QoS. **Erlang** developed models voice calls to estimate *telephone switch* capacity with a target call blocking probability. **Packet traffic models** are needed to estimate the *bandwidth* and *buffer resources* for target packet delays and packet loss probability. Knowledge of the average traffic rate is not sufficient. Queueing theory indicates that queue lengths increase with the variability of traffic. Understanding of *traffic burstiness* or variability is needed to determine ***buffer sizes*** and ***link capacities***.
2. Verify network performance under specific ***traffic controls***.
3. ***Admission control.***

- Data traffic is often modeled by:
  - **Packet size**
  - **Packet inter-arrival time**
- Some classical models:
  - White random process,
  - ARMA auto regressive moving average (Gauss),
  - Markov-modulated processes,
  - Fractional Brownian Motion (Long-range dependence),
  - Wavelets (self-similar),
  - TES (*Transform Expand Sample*) models (used for example to model MPEG4 video traffic).

- Common email models (Paxson, FUNET, Stuckmann) – Server pushes email according to a CDF
- No client requests
- No login process
- Less TCP ACKs

Adaptation to the model –10-12 packets as login process

– Similar size (40-60 Bytes)

– CDF from traces.

• Mobitex model

Statistics collected in the Mobitex network. Models measurement type of traffic.

Frequent short packets transmission with a Poisson type call arrival law:

- Average rate *l* = 300 calls/mobile/hour.
- Uniform packet size distribution:

Uplink = 30 ± 15 *bytes*

Downlink = 115 ± 57 *bytes*

Close to IoT type of traffic?

• Railway model

Used in the railway area. Models email traffic type without attached files.

- Average packet size: exponential negative distribution with an average equal to 170 bytes and a maximum size of 1 000 bytes.
- Packets arrival rate: Poisson law (λ = 53 calls/mobile/hour).
- Distribution function: $F(x) = 1 - e^{[-x/170]}$

• Funet model

Data traffic observations in Finland universities. Efficient for FTP type of traffic.

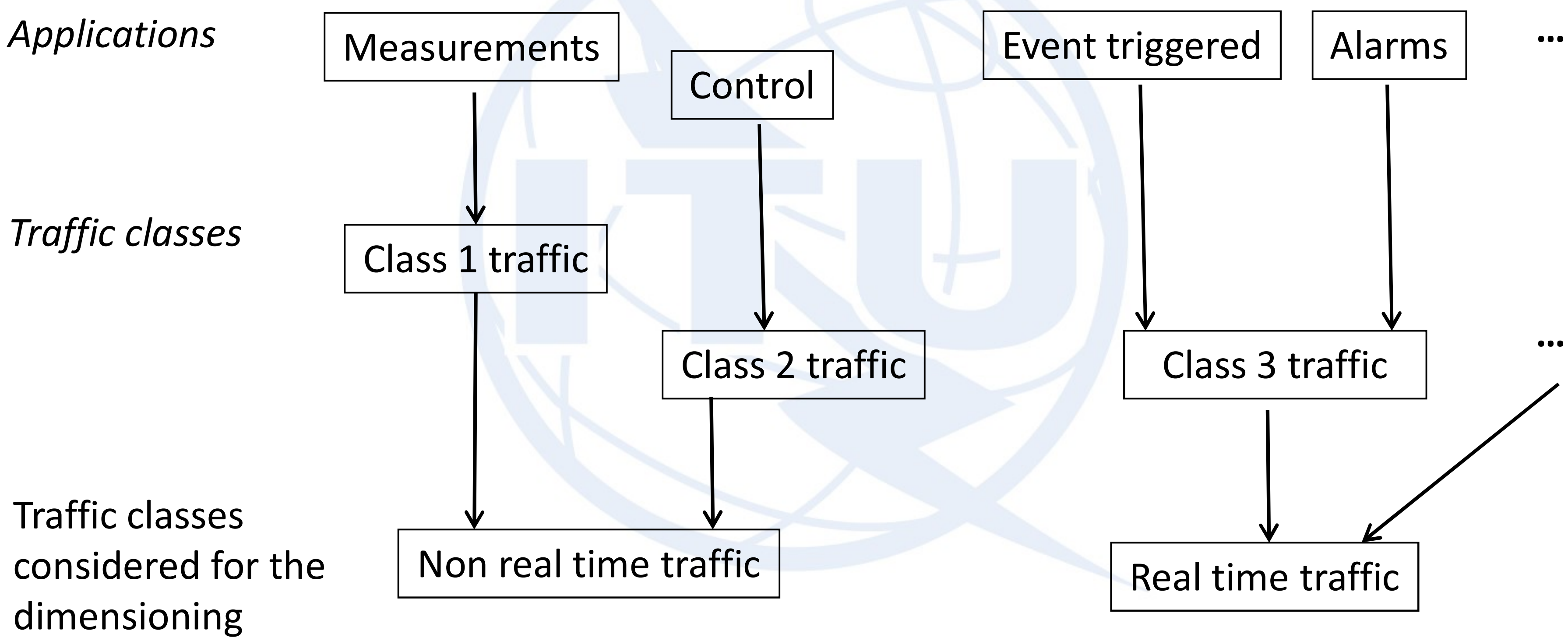
- Cauchy probability distribution function.
- Packet maximum size: 10 kbytes with an average value of 1 770 bytes.
- Packets arrival rate: Poisson law (λ = 5 calls/mobile/hour).

$$Cauchy\ (0,8\ ;\ 1) = f(x) = \frac{1}{\pi.(1+(x-0,8)^2)}$$

• WWW model

- Sessions arrival: Poisson law,
- Number of packet flows per session N_{pc}: geometric distribution of mean μ_{Npc}.
- Read time between 2 consecutive sessions, D_{pc}: geometric distribution with mean μ_{Dpc}.
- Number of packets during a session, N_d: geometric distribution with mean μ_{Nd}.
- Inter-arrival between 2 packets, D_d: geometric distribution with mean μ_{Dd}.

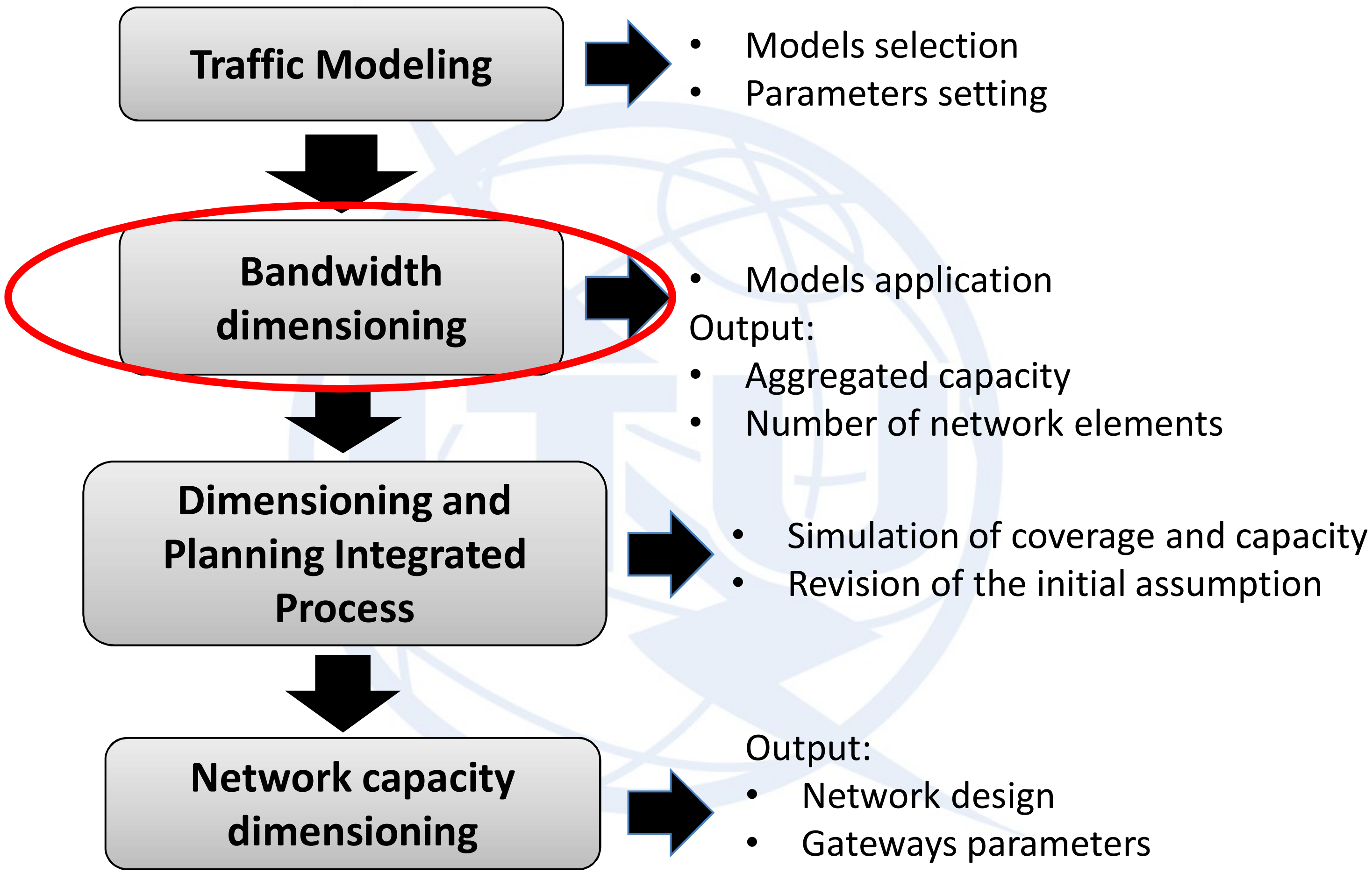
Classification of the traffic for priority handling



- Models are embedded within a **simulator** to generate, for different scenarios (e.g., service usage, end devices types, coding type, …) an aggregated traffic volume used to dimension the capacity of the nodes and/or the interfaces.
- ***Drawback***: complex, time consuming and requires accurate estimations.

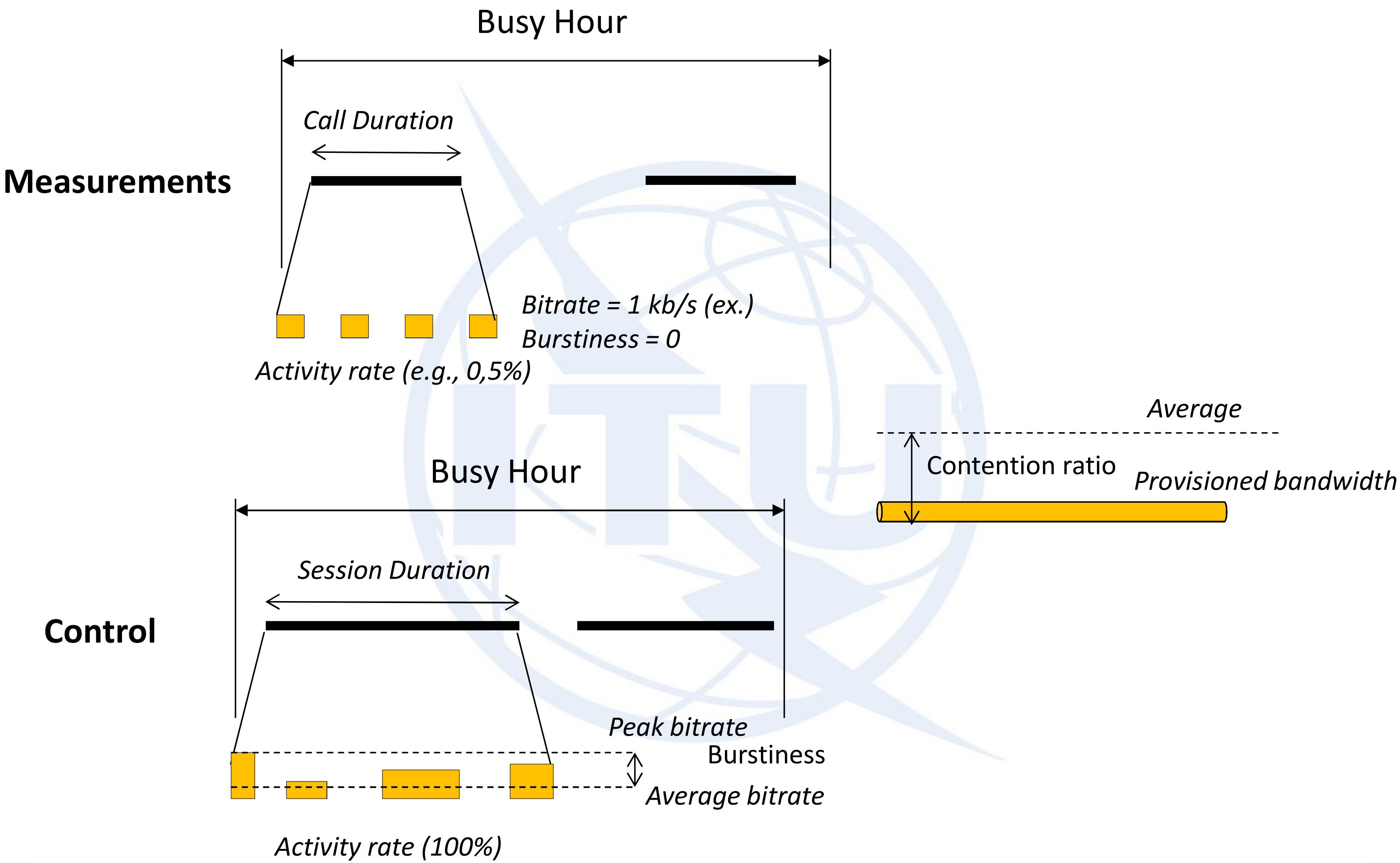
Bandwidth based dimensioning

Dimensioning Steps and Process



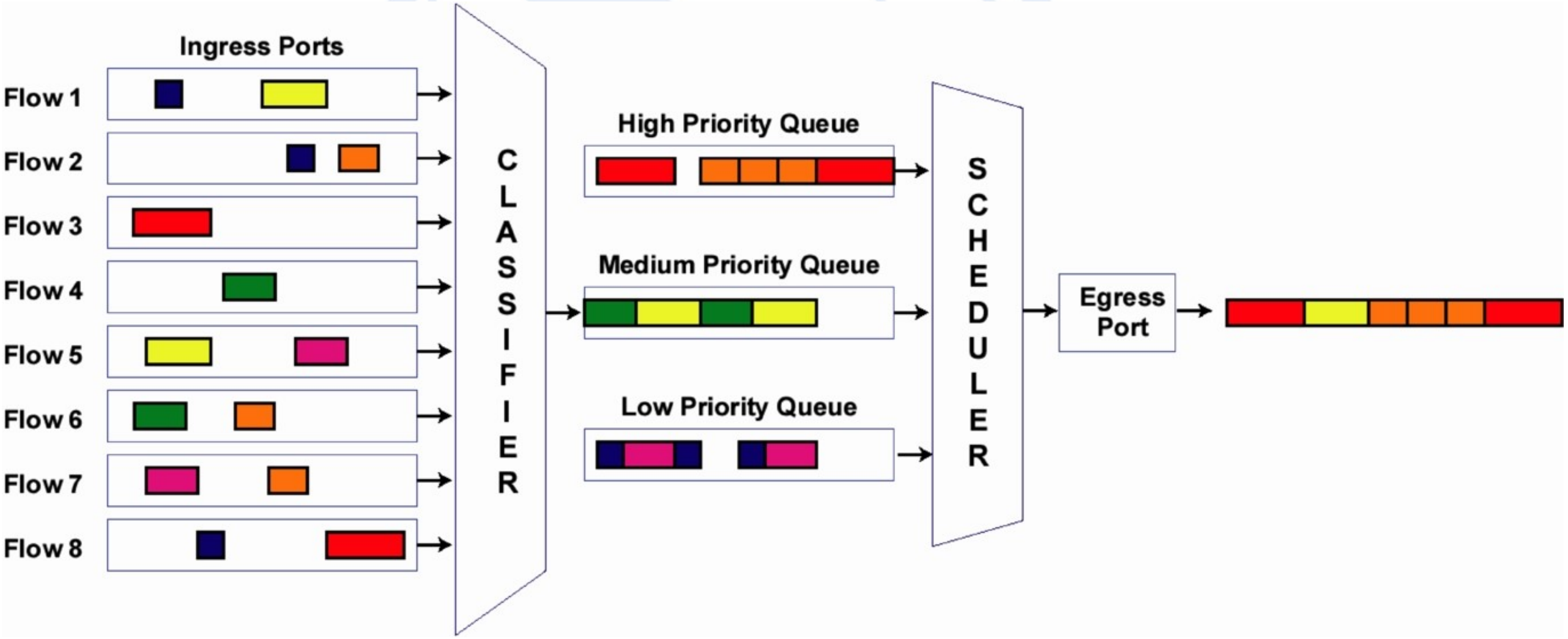
- Dimensioning (UL or DL): based on the services required bandwidth estimation.
- **Contention ratios**: reflect the bursty nature of the ***traffic*** and of the ***service activity*** as well as the **services *priorities***.
- **Aggregation of the traffic** flows bitrates: to estimate the ***total link*** or ***gateways capacities***.
- In case of overload due to unpredicted end devices and applications behavior: ***scheduling*** and ***queuing*** mechanisms allow to maintain the QoS of high priority traffic. Degradation of QoS parameters (e.g., bitrate, jitter, delay, BLER, …) occurs.

Burtsiness, Activity Rate, Contention Ratio



- Common queue examples for IP routers
  - FIFO : First In First Out
  - PQ : Priority Queuing
  - WFQ : Weighted Fair Queuing
  - Combinations of the above
- Service types from a queuing theory standpoint
  - Single server (one queue - one transmission line)
  - Multiple server (one queue - several transmission lines)
  - Priority server (several queues with hard priorities - one transmission line)
  - Shared server (several queues with soft priorities - one transmission line)

- **Packets are classified into separate queues**
  - E.g., based on source/destination IP address, source/destination port, etc.
- **All packets in a higher priority queue are served before a lower priority queue is served**



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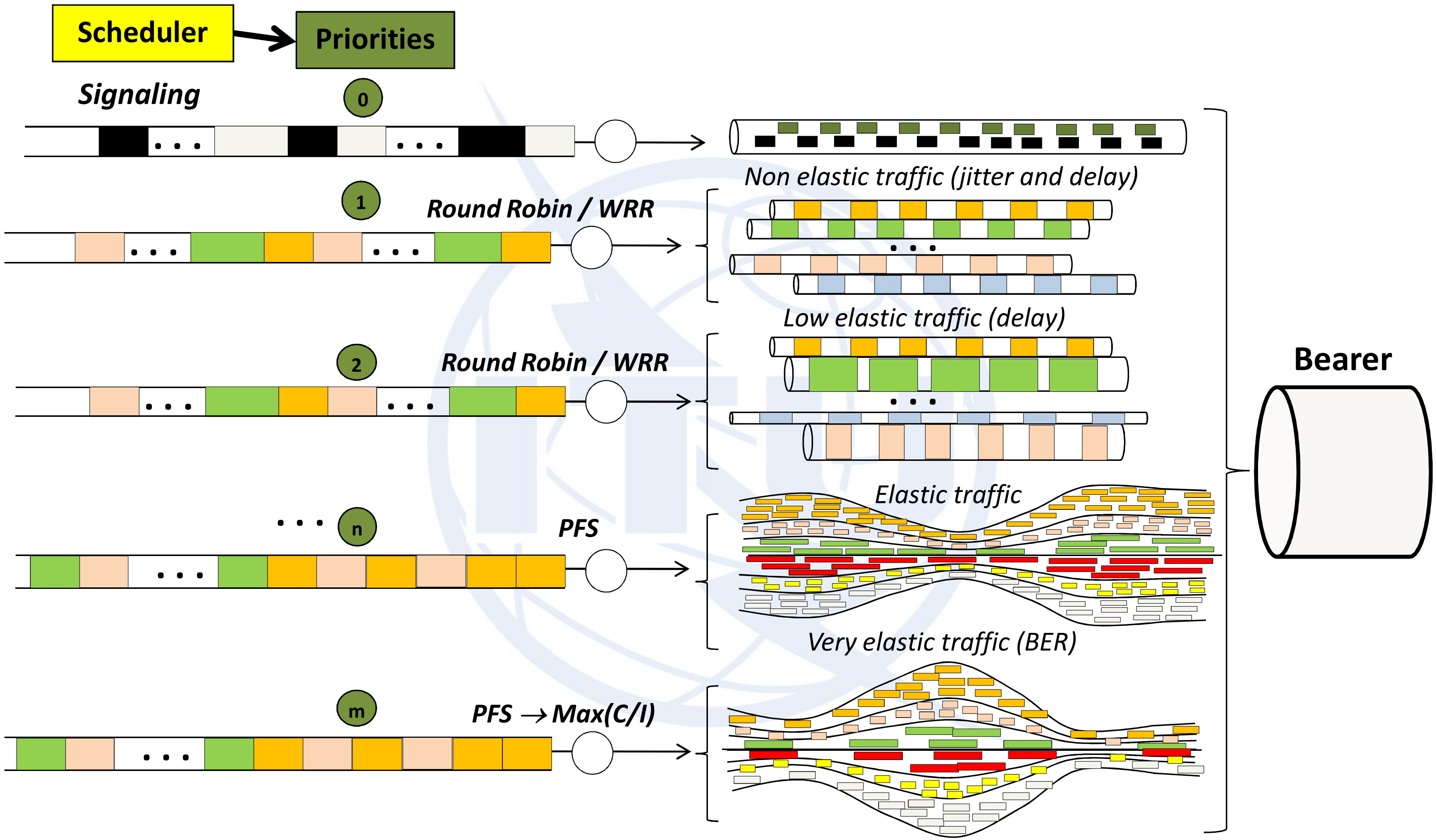
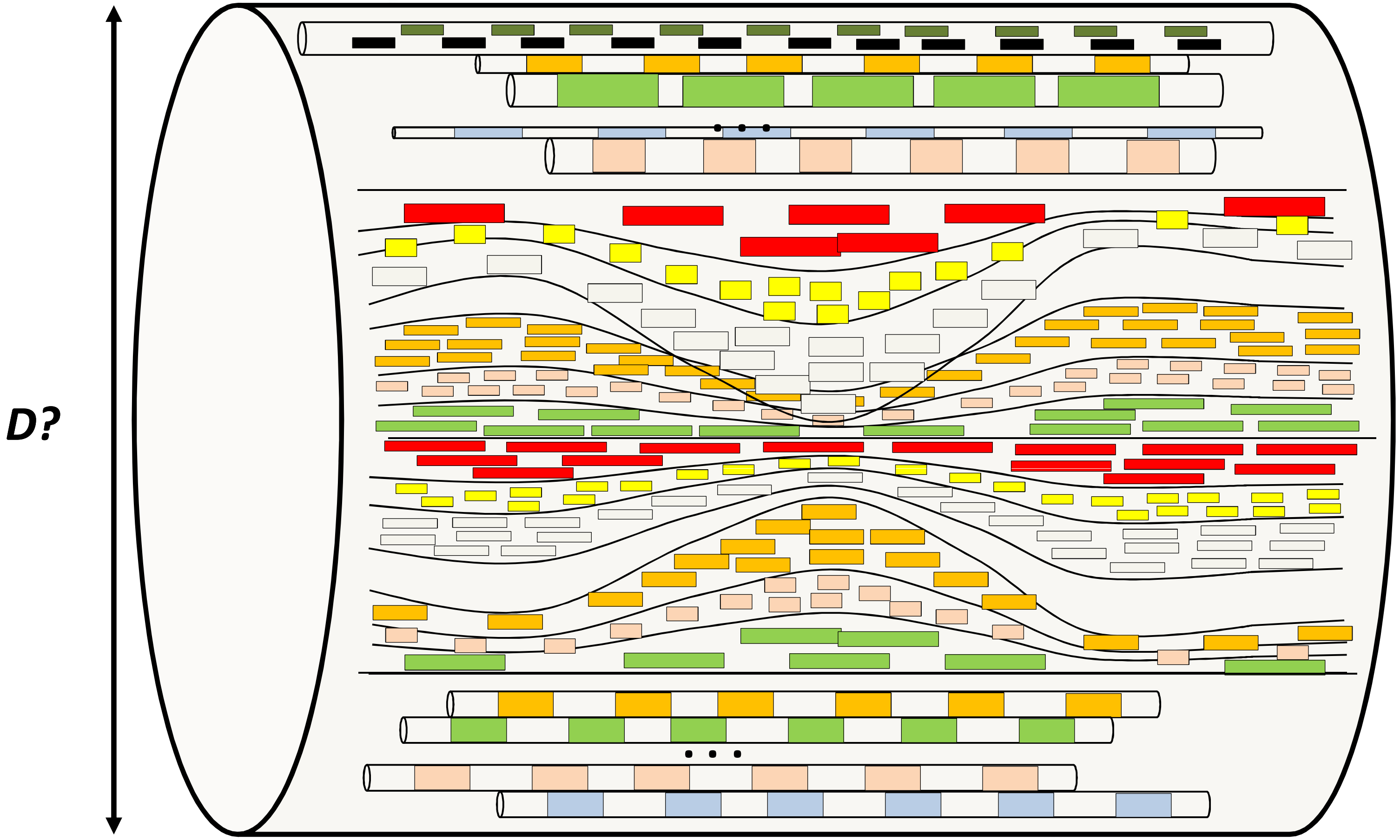
Services traffic aggregation and prioritization example



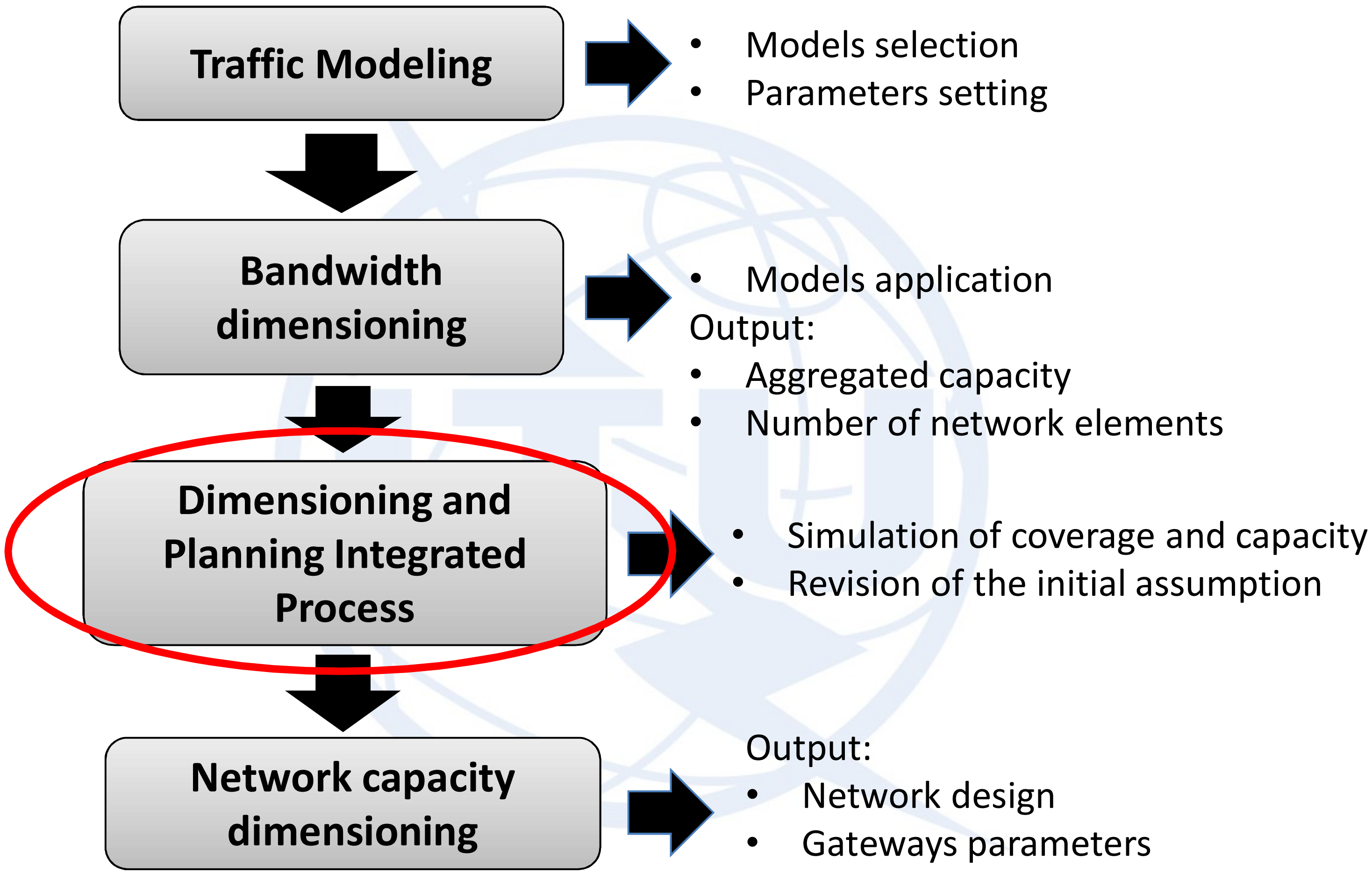
Aggregated bearers



Dimensioning purpose: determine the bearer bitrate ***D***

Dimensioning and Planning Integrated Process

Dimensioning Steps and Process



Step 1: initial configuration (dimensioning and planning)

Traffic and mobility model
End devices classes
Services QoS characteristics
Services contention ratios
Transmission and protocols overheads

→ **Aggregate required capacity (Mb/s)**

Theoretical cell available bandwidth

→ **Initial number of required GTWs**

Radio planning

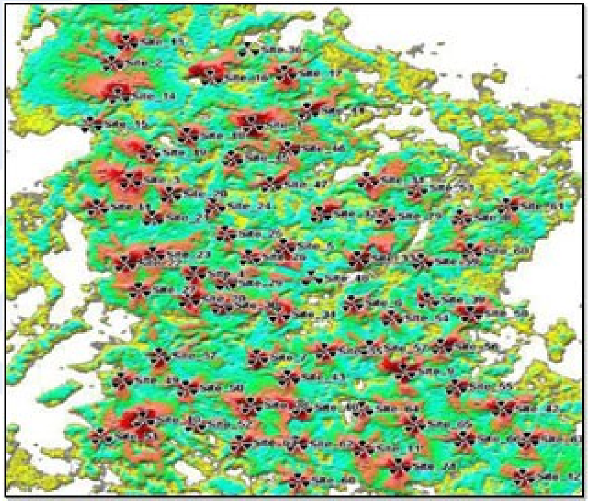
Radio interface characteristics
Coverage and interference requirements
End devices geographic distribution
Allocated spectrum

→ **GTW available bandwidth (Mb/s)**

Step 2: final configuration

- Cell available bandwidth (Mb/s)
- Aggregate required capacity (Mb/s)
- Coverage and interference characteristics
- Radio interface characteristics
- New radio planning: optimization

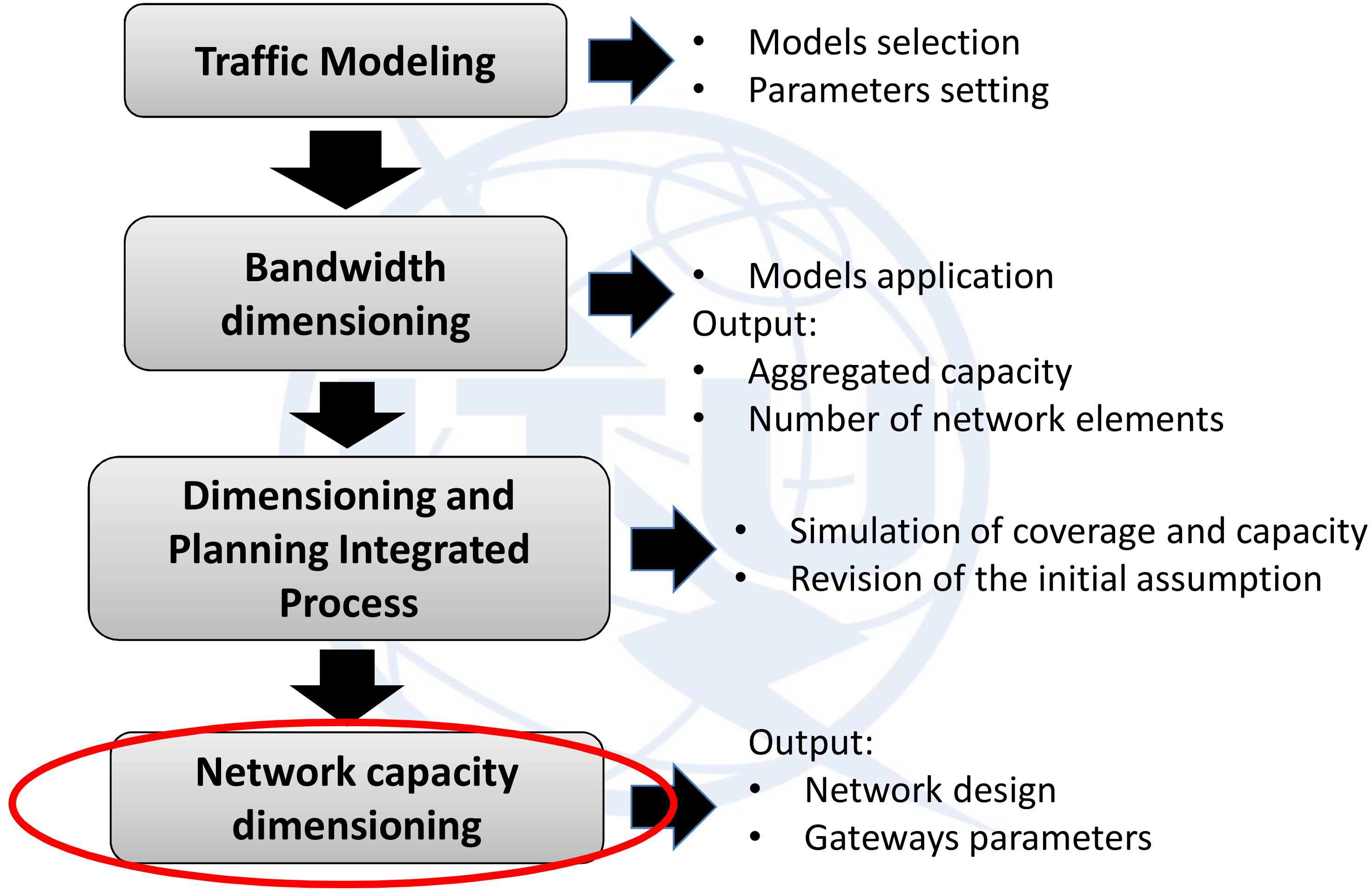
→ **Final number of required cells and gateway configuration**



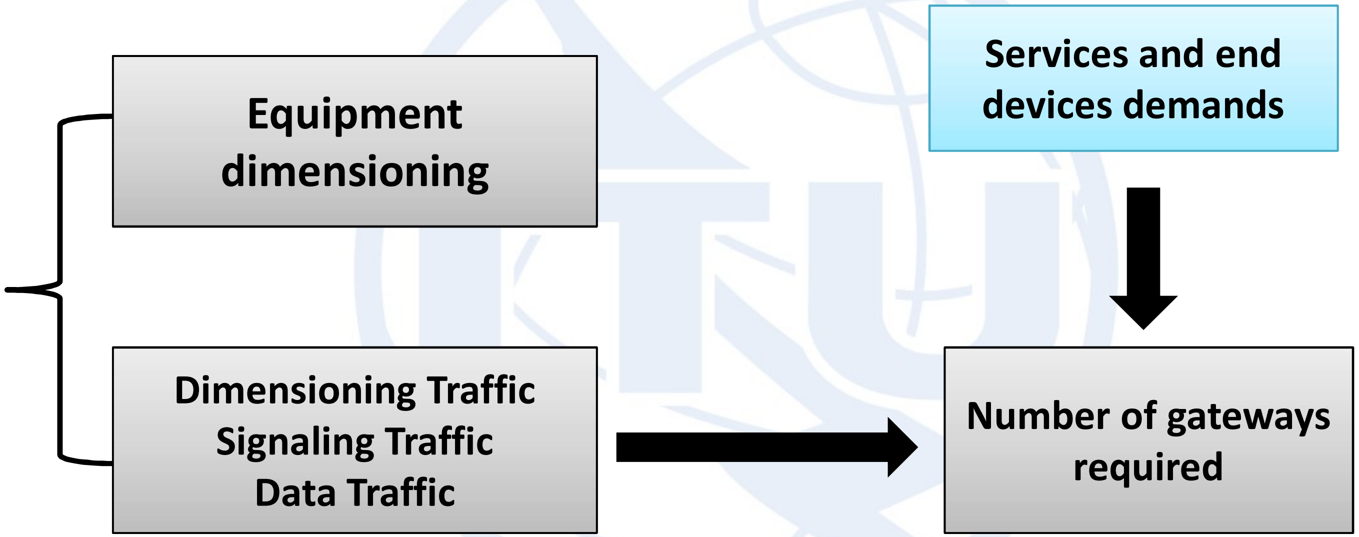
- End devices types,
- Service usage/end devices class,
- Contention ratios/end devices class,
- End devices geographic distribution,
- Services packet sizes,
- Services and protocols overheads.

Network capacity dimensioning

Dimensioning Steps and Process



- **Traffic Dimensioning**



- ***Dimensioning preliminary phases***

Initial parameters configuration

End devices profiles configuration

- Number of end devices, N
- Number of end devices type 1
- …
- Number of end devices type k

Traffic at Busy hour

- Packets sizes
- Packet arrival rates
- Traffic percentage in DL/UL

Signaling Traffic

- Control DL
- ACK
- …

- ***Initial parameters (Number of end devices of each type)***

$$N_1 = N_A * P_1$$

$$N_2 = N_A * P_2$$

$$\ldots$$

$$N_k = N_A * P_k$$

Where:

N_i: Number of end devices of type *i*

N_A: Total end devices number

P_i: Type *i* end devices percentage

- ***End devices profile at Busy hour***

Accesses of end devices to the network are for:

- Measurements reporting,
- Alarms,
- Control,
- …

Service characteristics:

- Activity rate per end device,
- Packets sizes.

➔ **Traffic at busy hour:**

$$\rho^{S}_{BH\text{-}DL/UL} = (T_{session} * N_{session})$$

Where

$\rho^{S}_{BH\text{-}DL/UL}$: Traffic volume in UL/ DL at Busy hour

$T_{session}$: Data volume transmitted per exchange (i.e., session)

$N_{session}$: Number of exchanges at BH

➔ **Traffic on the DL:**

$$\rho^{S}_{BH\text{-}DL} = (\rho^{S}_{BH\text{-}DL/UL}) * \rho_{DL}$$

Where:

- $\rho^{S}_{BH\text{-}DL/U}$: Traffic volume at Busy hour
- $\rho^{S}_{BH\text{-}DL}$: Traffic volume on the DL
- ρ_{DL} : Percentage of DL traffic

- ***Traffic at BH***

➔ **Type *i* end devices total traffic at BH**

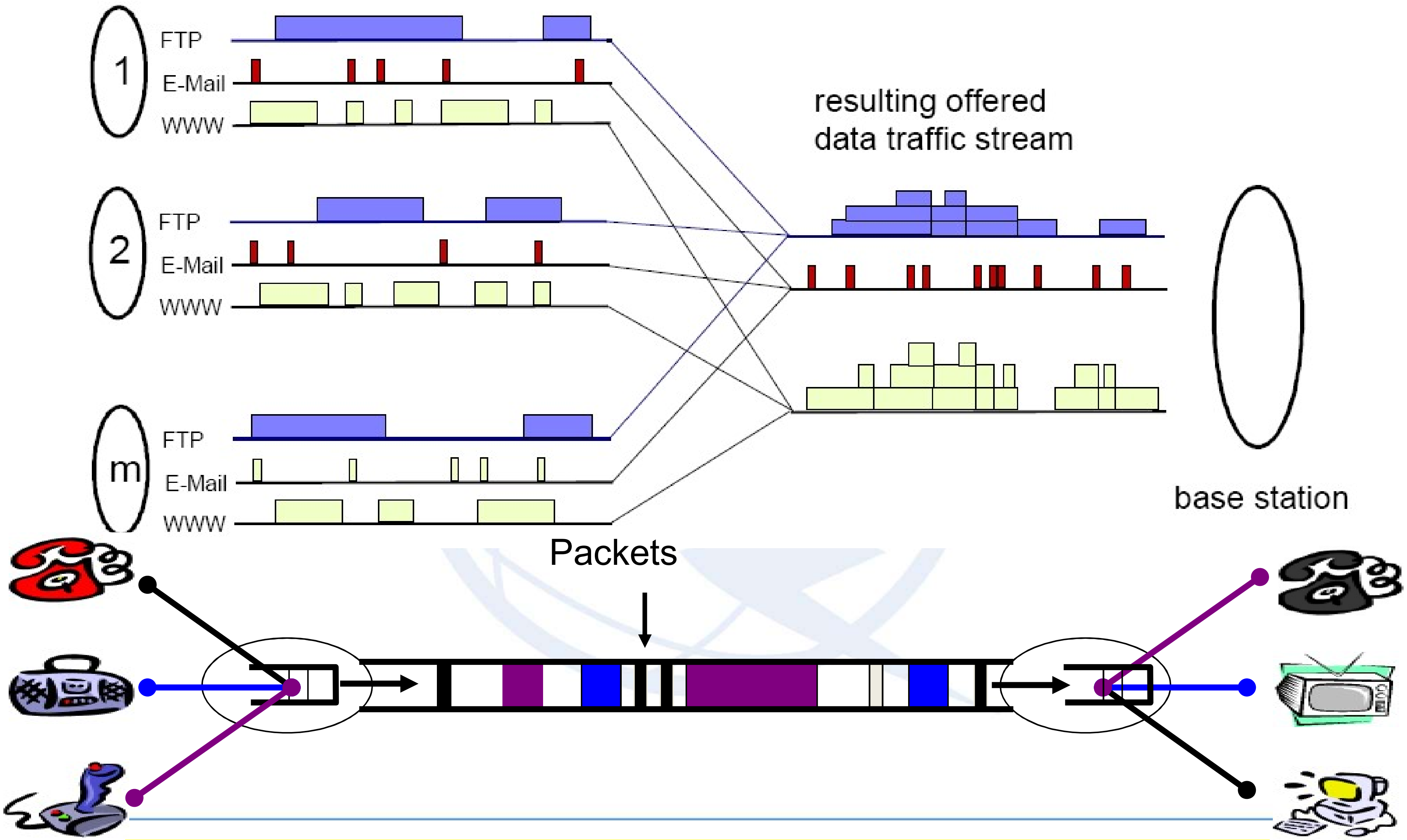
$$\rho^{i}_{DL/UL} = \rho^{i}_{BH\text{-}DL/UL} * N_i$$

$\rho^{i}_{DL/UL:}$ type *i* end devices total traffic at Busy hour

➔ **Type *i* end devices throughput at BH**

$$TH_{i\ BH\text{-}DL/UL} = (\rho_{i\ DL/UL}) / 3600$$

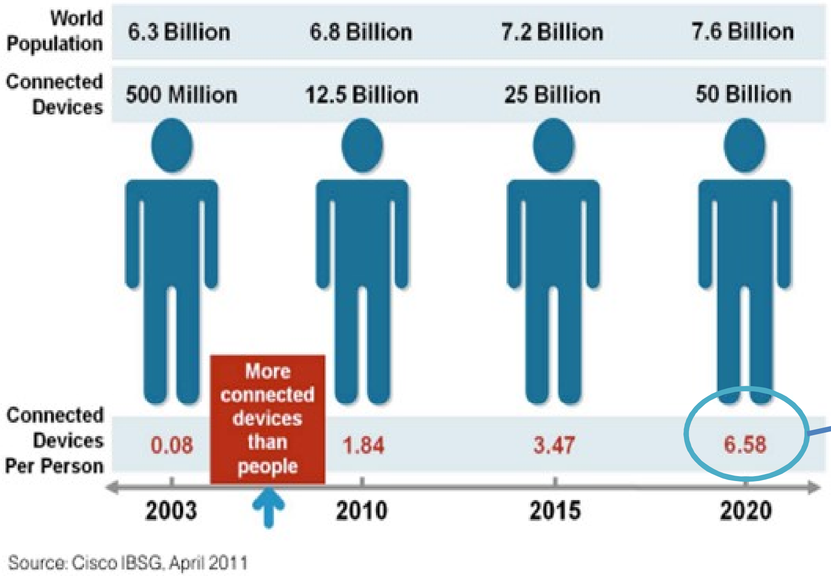
Traffic aggregation



Dimensioning objective: determine the total required bandwidth to carry the aggregated traffic with related QoS targets

Dimensioning Use Case

The capacity of the planned network must comply with the requirements of the terms of traffic to be handled.



For **1 million people**

We can predict **7 million devices**

Possible distribution in the different areas according to the number of people and the penetration

End devices	Urban area (60 %)	Suburban area (30 %)	Rural area (10 %)
7 million	4.2 million	2.1 million	0.7 million

Modeling of:
- End devices (type, technology used, …)
- Sensors
- Other connected things

→ Modeling the services

❖ *Fleet Management:* The end device can send a packet in the network every **30 second** to track a vehicle

❖ *Logistic*: an end device can send a packet in the network every **5 min** to report his occupation state

❖ *Water meter*: can send a packet **once a day** to inform the water consumption

Several parameters to consider depending on the technology

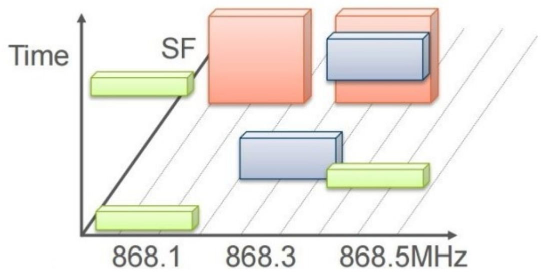
Packet size

Preamble	Payload	CRC

↓ (Payload) Change according the services

Number of available channels

More channels ➔ More simultaneous connections



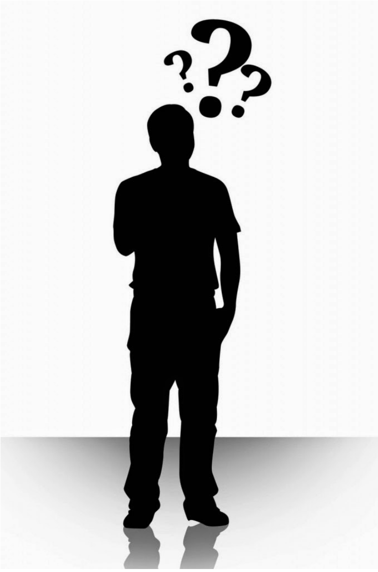
Throughput

Determine the time on Air ➔ Packets inter-arrival time

Gateway Capacity

Gateway capacity (packets/day, maximum throughput, …)

Assumptions



- Big City
- **Public LoRaWAN Network Dimensioning**
- Number of devices increase every year
- Total Bandwidth: **1 MHz**

- **LoRa SX1301 Chipset**
- **Bandwidth: 125 KHz**
- **8 channels**
- **Central Frequency: 868 MHz**
- CRC enabled
- Low data rate optimization enabled

Traffic Modeling

Services	Packet transmission frequency (per hour)
Sensor	1
Metering	0,04
Alarm	1/365/24
Tracking Logistic	2
Vehicle Tracking	6
Traffic Control	60
Agriculture	1
Wearables	2
Home Automation	0,50

Gateway Capacity

Lora Gateway **Capacity**: given in terms of **number of packets per day**.

LoRa Packet
(maximum size: 256 bytes)

Preamble	Payload	CRC
Up to 5 bytes	Min: 2 bytes	Up to 2 bytes

Payload Size (byte)	Spreading Factor	Symbol Rate	Programmed Preamble (Symbol)	Preamble Duration (ms)	Coding Rate	Number of payload Symbol	Payload Duration (ms)	Duration of packet (ms)	Single Gateway with 8 channels Capacity (Packets per day)
10	7	0,98	6	10	2	32	32	43	1 997 041
10	8	0,49	6	20	1	23	47	68	1 268 797
5	9	0,24	6	41	2	14	57	99	869 845
15	10	0,12	6	83	4	40	327	411	209 888
15	11	0,06	6	167	1	23	376	544	158 600
10	7	0,98	6	10	4	40	40	51	1 679 104
15	8	0,49	6	20	1	33	67	88	975 434
12	9	0,24	6	41	3	29	118	160	537 420
12	10	0,12	6	83	1	23	188	272	317 199

IoT Applications with Different Characteristics

Example Applications	Data volume	Quality of Service	Amount of signaling	Time sensitivity	Mobility	Server initiated Communication	Packet switched only
Smart energy meters	low	low	intermediate	very low	no	yes	yes
Red charging	low	low	low	low	yes	no	yes
eCall	very low	very high	very low	very high	yes	no	no
Remote maintenance	low	low	high	high	no	yes	yes
Fleet management	low	low	very high	intermediate	yes	yes	no
Photo frames	intermediate	low	high	low	no	yes	yes
Assets tracking	low	low	very high	high	yes	yes	no
Mobile payments	intermediate	low	high	very high	yes	no	yes
Media synchronisation	high	low	high	intermediate	yes	yes	yes
Surveillance cameras	very high	very high	low	very high	no	yes	yes
Health monitoring	high	high	high	very high	yes	yes	yes

very low   low   intermediate   high   very high

Source: www.itu.int/md/T09-SG11-120611-TD-GEN-0844/en

Use case

First Year

Gateway **Capacity: 1 500 000 packets per day**

Services	Packet transmission frequency (at BH)	End devices Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packets
Sensor	1	200	24	20%	10%	152 064
Metering	0,04	100,00	1	20%	10%	132
Alarm	0,00	100,00	1	20%	10%	132
Tracking Logistic	2	100	48	20%	10%	304 128
Vehicle Tracking	6	70	144	20%	10%	1 916 007
Traffic Control	10	150	240	20%	10%	11 404 800
Agriculture	1	200,00	24	20%	10%	152 064
Wearables	0,5	1000,00	12	20%	10%	190 080
Home Automation	0,5	300	12	20%	10%	57 024
Total Packets per day						14 176 431

Number of Gateways: **10**

Second Year

Gateway **Capacity: 1 500 000 packets per day**

Services	Packet transmission frequency (at BH)	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packet
Sensor	1	400	24	20%	10%	304 128
Metering	0,04	200	1	20%	10%	264
Alarm	0,00	200	1	20%	10%	264
Tracking Logistic	2	200	48	20%	10%	608 256
Vehicle Tracking	6	140	144	20%	10%	3 832 013
Traffic Control	10	300	240	20%	10%	22 809 600
Agriculture	1	400	24	20%	10%	304 128
Wearables	0,5	2000	12	20%	10%	380 160
Home Automation	0,5	600	12	20%	10%	114 048
Total Packets per day						28 352 861

Number of Gateways: **19**

Use case

Third Year

Services	Packet transmission frequency (at BH)	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packets
Sensor	1	800	24	20%	10%	608 256
Metering	0,04	400	1	20%	10%	528
Alarm	0,00	400	1	20%	10%	528
Tracking Logistic	2	400	48	20%	10%	1 216 512
Vehicle Tracking	6	300	144	20%	10%	8 211 456
Traffic Control	10	600	240	20%	10%	45 619 200
Agriculture	1	800	24	20%	10%	608 256
Wearables	0,5	3000	12	20%	10%	570 240
Home Automation	0,5	1200	12	20%	10%	228 096
Total Packets per day						57 063 072

Number of Gateways: **39**

B. NETWORK PLANNING

Wireless Network Planning Process

Pre-planning

- Collect area parameters
- End devices information
- Traffic models

Dimensioning: Requirements and Coverage strategy, Capacity and quality

Output
- Equipment capacities
- Number of network elements

Coverage planning

Network design

Coverage and capacity constraints
➔ Minimize used resources

Output:
- Number of sites/gateways
- Traffic rate
- Signaling

Parameters tuning

Optimization Performance analysis in terms of quality and interference

1. Pre-planning of radio network: ***Initial Site Selection***

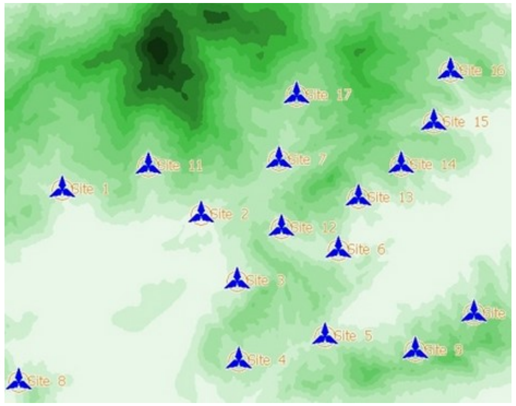
Determine:

- Theoretical location of sites
- Implementation parameters (antenna type / azimuth / tilt / altitude / feeder type / length)
- Gateway parameters (as transmission power, transmission periodicity, …)

1. Based on the **network dimensioning** and **site information**.

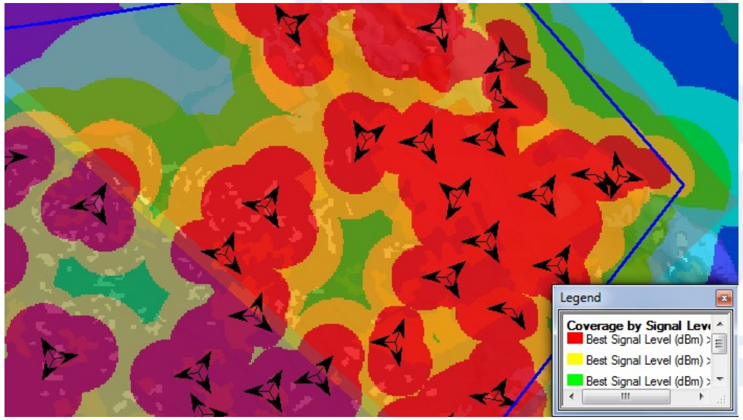
2. An **analysis** is made to check whether the **coverage** of the system meets the requirements → the height and tilt of the antenna and the GTWs number are adjusted to optimize the coverage.

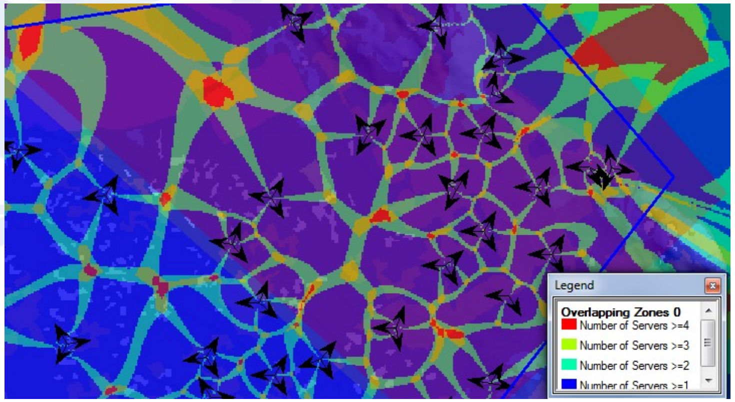
3. The system capacity is analyzed to check whether it meets the requirement.



2. Pre-planning of radio network: ***Prediction***

- Predict coverage results such as best serving cell, overlapping area …
- Carry out detailed adjustments (such as gateway number, gateway configuration, antenna parameters) after analyzing the coverage prediction results
- Obtain proper site location and parameters that should satisfy coverage requirements

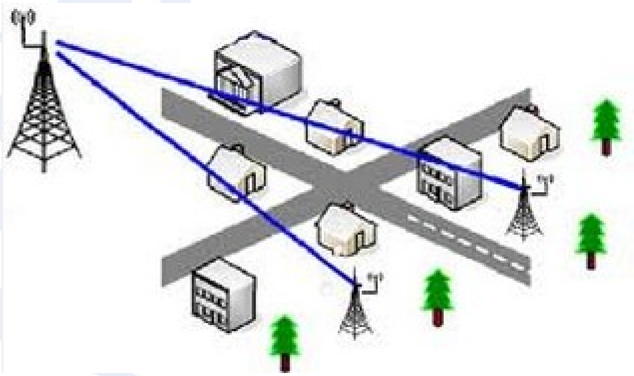




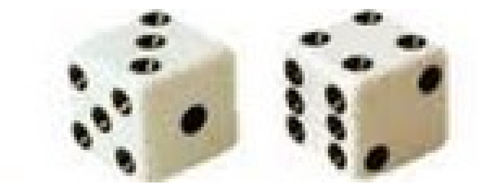
3. Cell planning of radio network: ***Site survey***

- Select backup location for site if theoretical location is not available

- Take into account:
  - Radio propagation factor: situation / height / surrounding /
  - Implementation factor: space / antenna installation / transmission / power supply

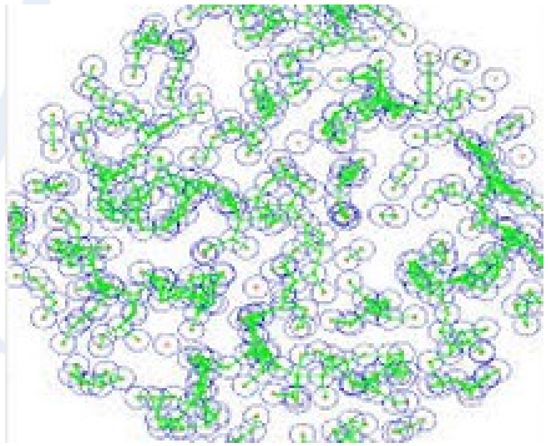


3. Cell planning of radio network: **Simulation**



- Generate certain quantity of network instantaneous state (snapshots)
- By iteration
- Determinate gateway load, connection status and rejected reason for each end device

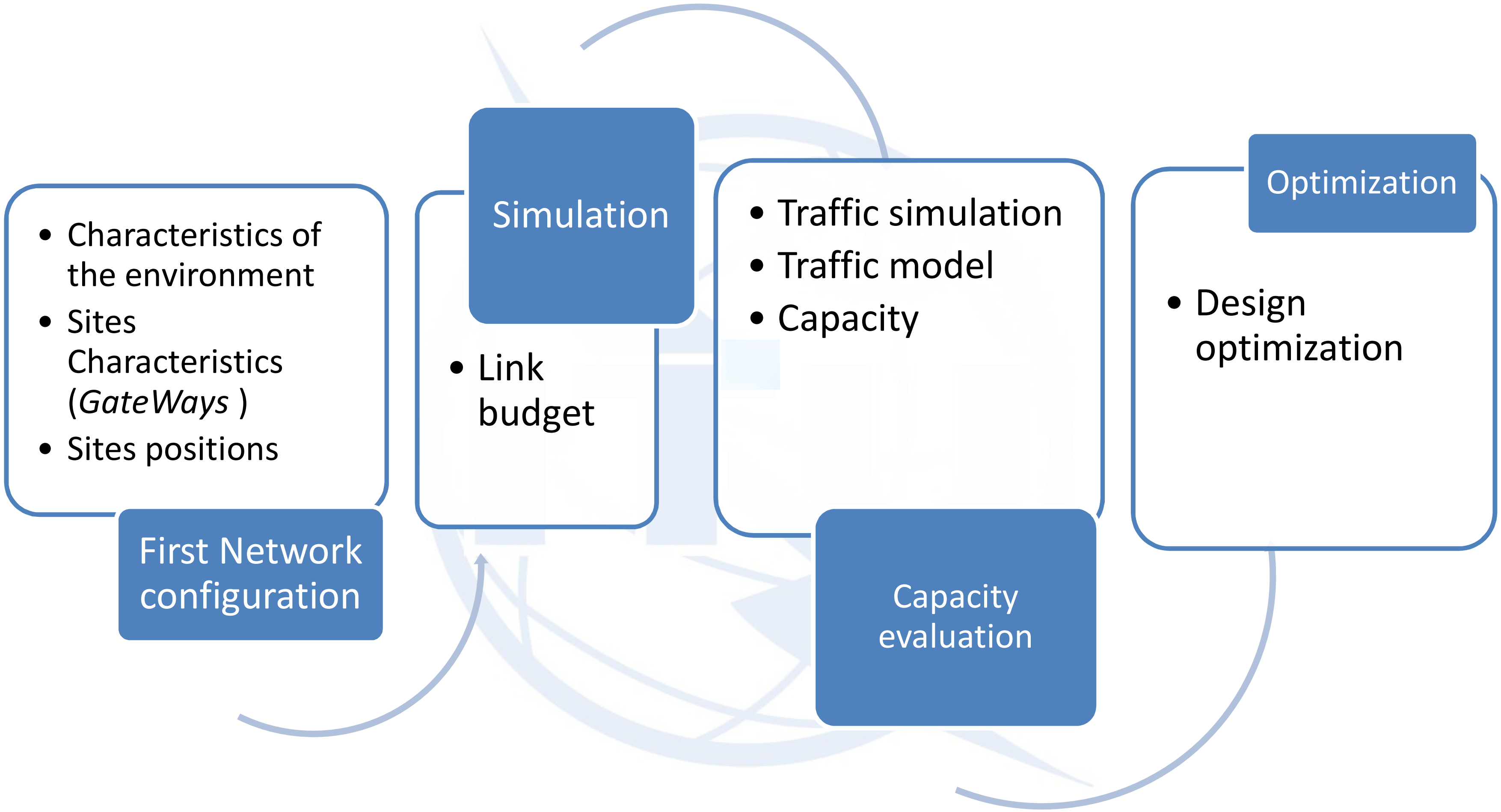
➔ understand network performance



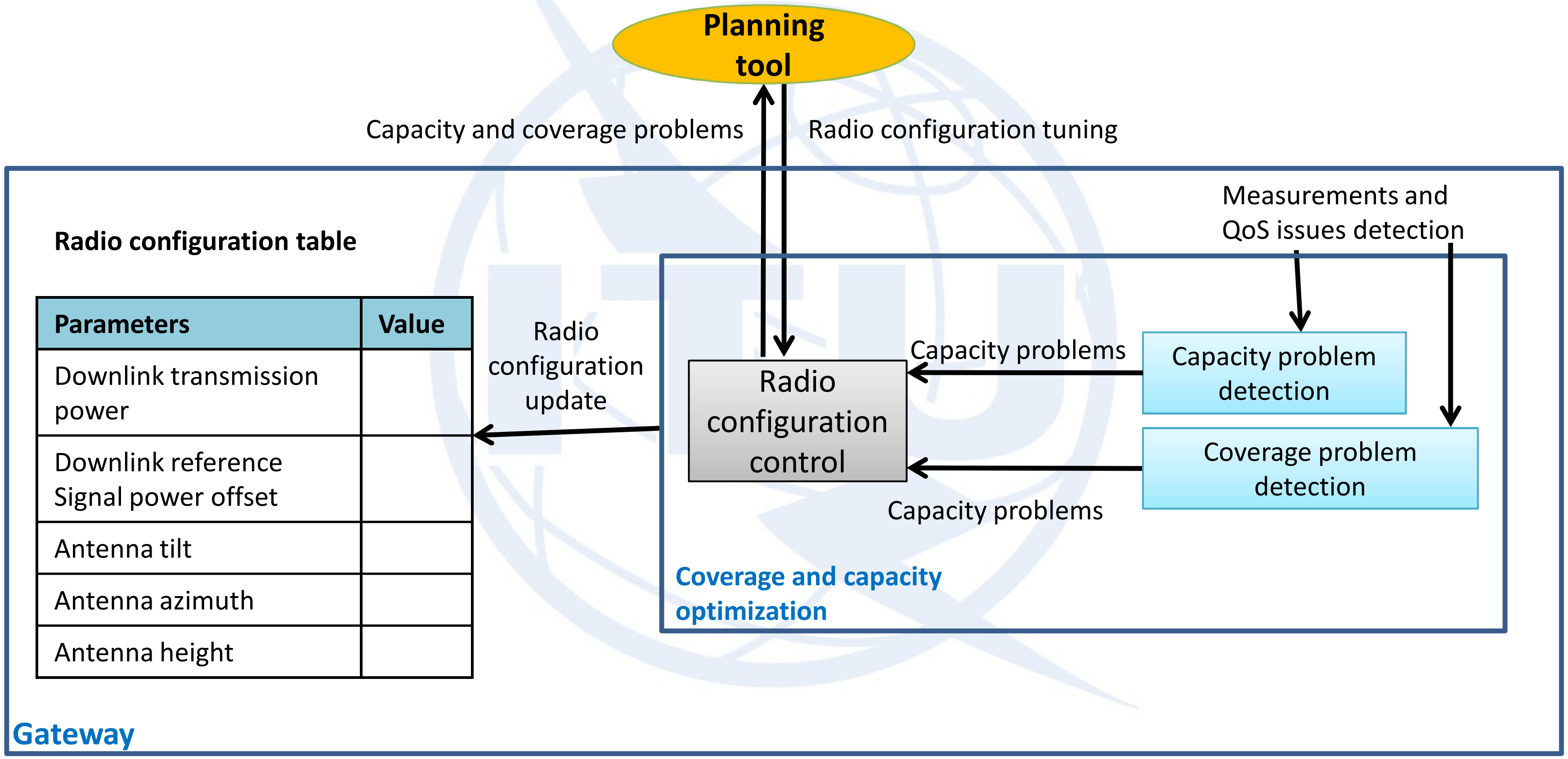
PRE-PLANNING

- Choice of the area
- Choice of antennas
- Choice of equipment (GW and sensor)
- Choice of propagation model
- Frequencies choice

PLANNING PROCEDURE

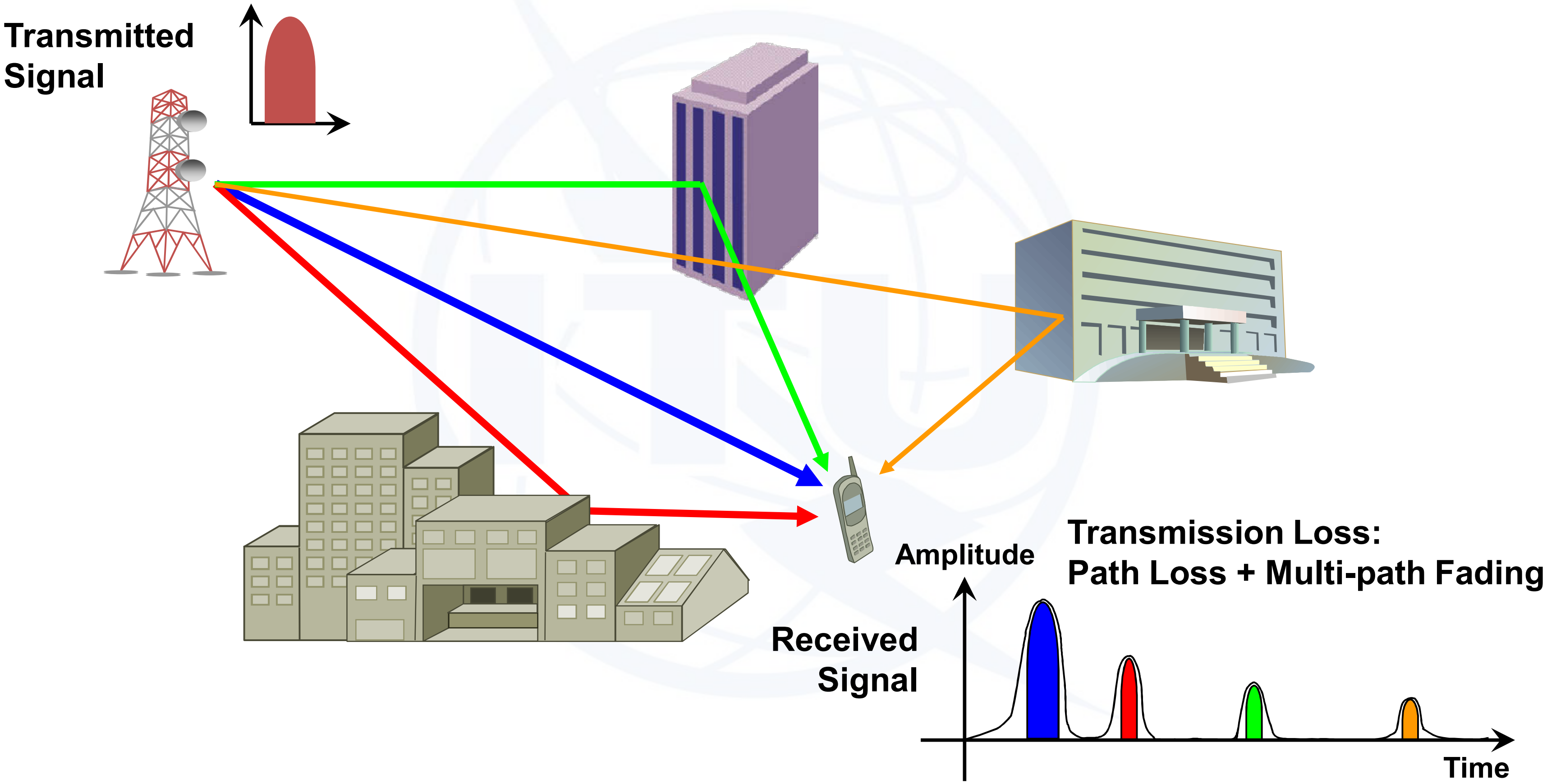


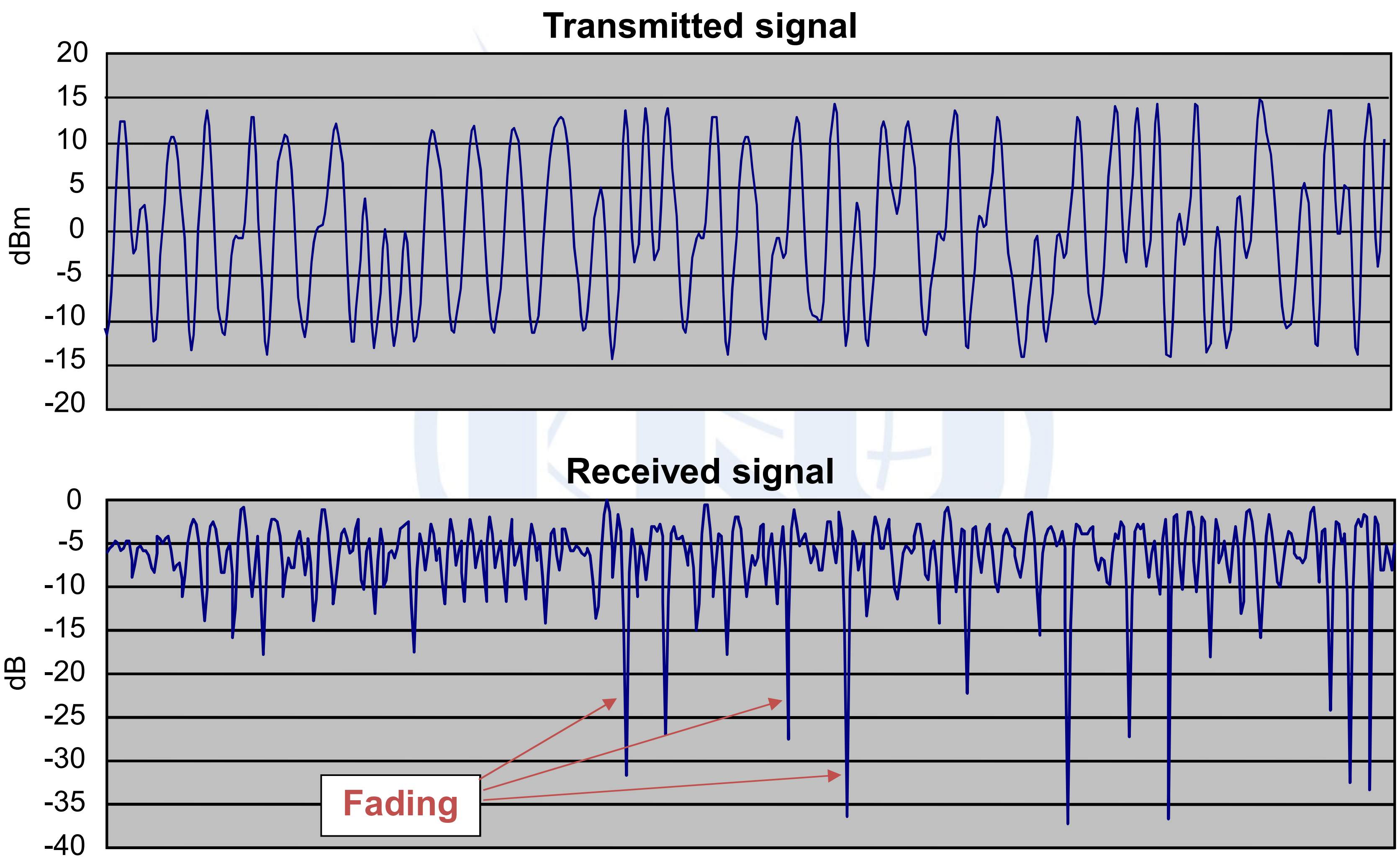
- **Radio Planning Overview**



Parameters	Value
Downlink transmission power	
Downlink reference Signal power offset	
Antenna tilt	
Antenna azimuth	
Antenna height	

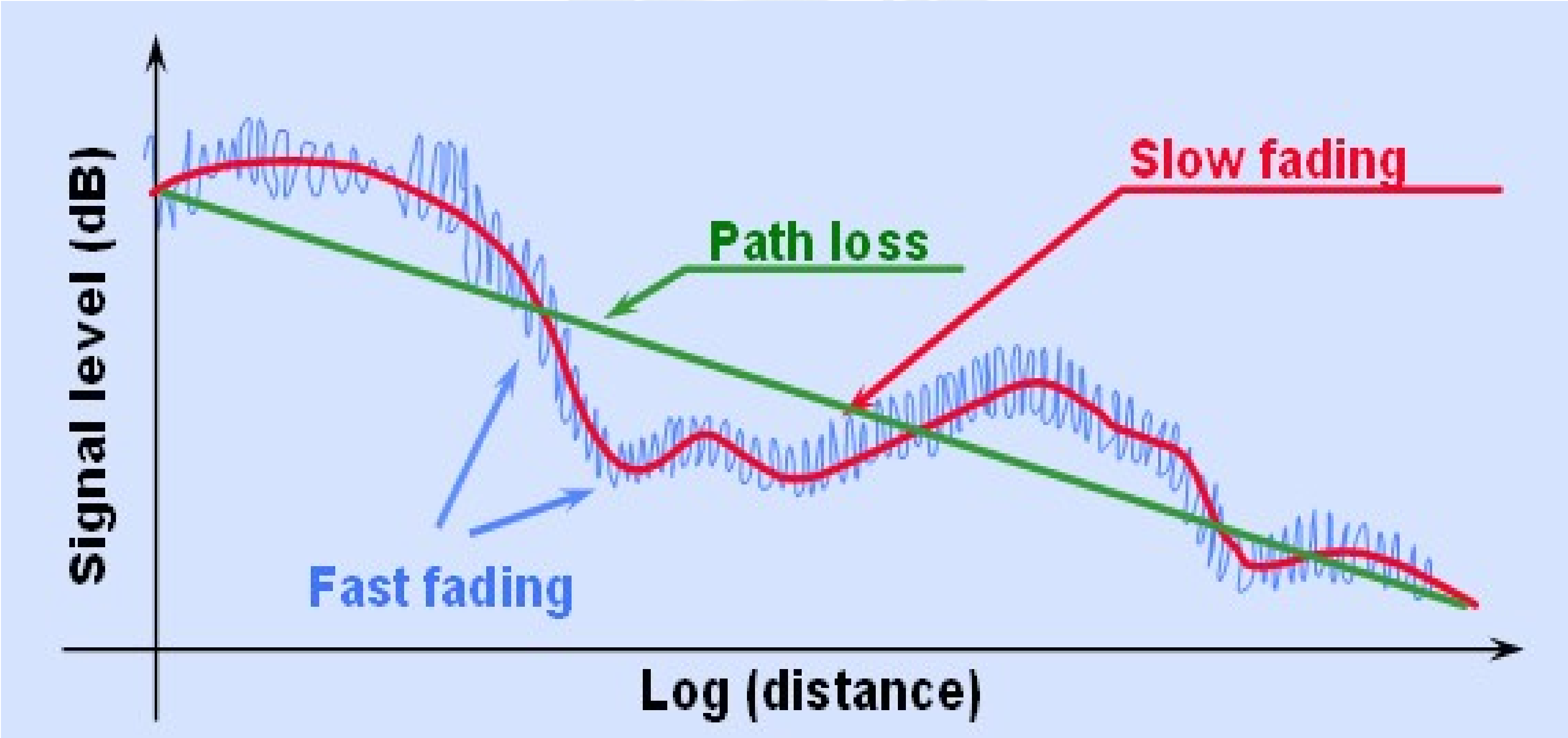
Wireless propagation




Transmitted signal
20
15
10
5
0
-5
-10
-15
-20
dBm
Received signal
0
-5
-10
-15
-20
-25
-30
-35
-40
dB
Fading

Three-stage propagation model

- Fading Categories
  - Fast fading caused by multi-path
  - Slow fading caused by shadowing



Propagation Model	Characteristics
Cost 231_Hata Model	- Band 150-1500 MHz - Hb: 30-300 m - Hm: 1 à 20 m - Cell radius 1-20 Km
Cost_WI Model	- Band 800-2000 MHz - Hb: 4-50m - Hm:1-3 m - Cell Radius 0.02-0.5 Km
Okumura_Hata Model	- Band 150–1920 MHz - Hb: 30-1000m - Hm: 1-3 m - Cell radius 1-100 Km
SPM Model	- All frequencies bands after calibration

Propagation models: SPM (Standard Propagation Model)

Ploss=K1+K2log(d)+K3*(Hms)+K4*(Hms)+K5*log(Heff)+K6*(Heff)*log(d)+K7diffn +Clutter_Loss

K	Value
K1	-29.41
K2	55.51
K3	5.83
K4	0
K5	-6.55
K6	0
Kclutter=1	1

Propagation model

Effecttive antenna height	
Method	0-Height above ground
Distance min(m)	0
Distance max(m)	15000
Diffraction	
Method	2-Epsten-Peterson

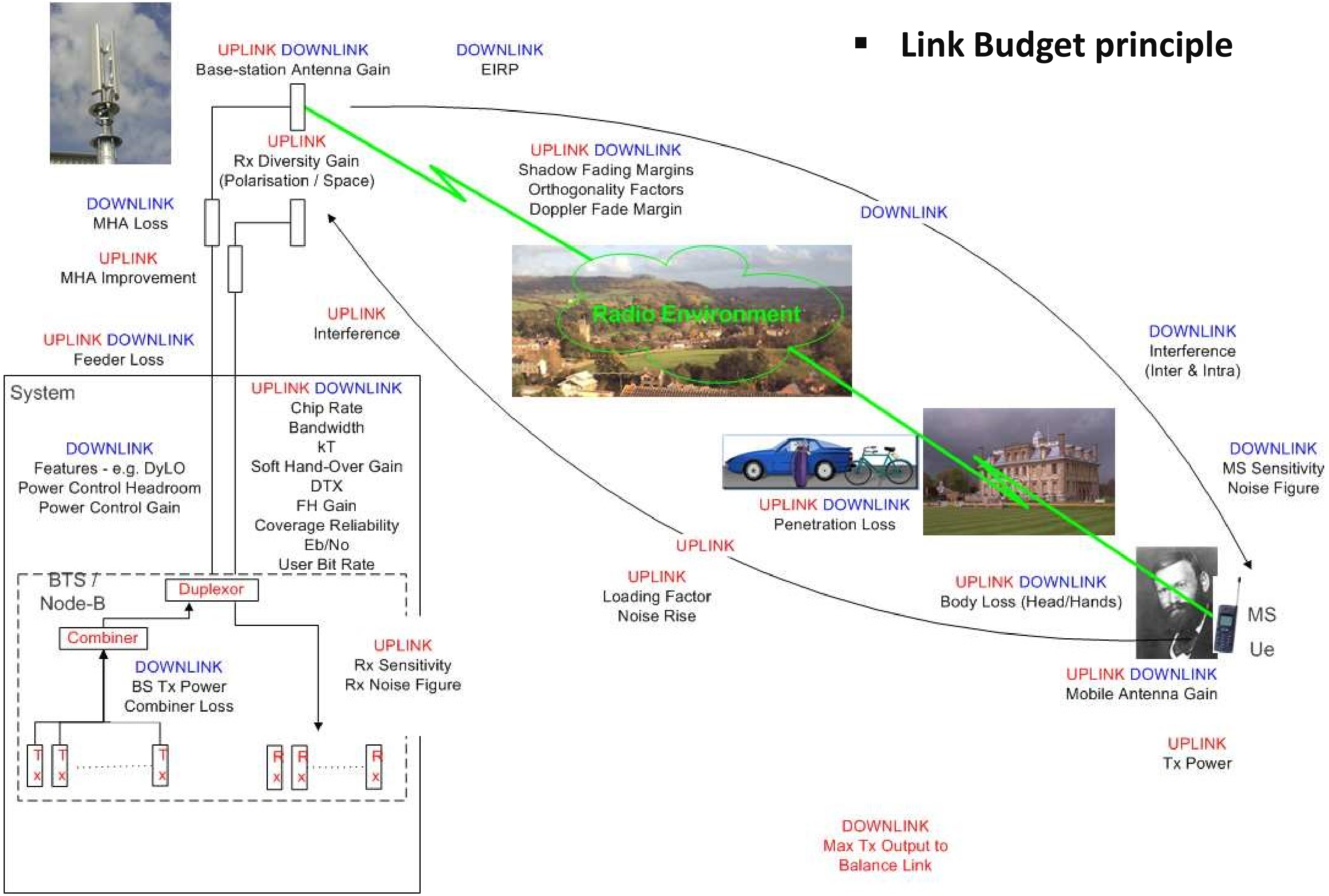
Propagation model related parameter

Clutter	Offset(dB)
OPEN	0
INLAND WATER	-1
MEAN INDIVIDUAL	4
MEAN COLLECTIVE	6
BUILDING	15
VILLAGE	-0.9
INDUSTRIAL	12
OPEN IN URBAN	0
FOREST	15
PARK	2
DENSE INDIVIDUAL	5
BLOCK BUILDING	18
SCATTERED URBAN	10

Clutter loss clutter

Cell Characteristics and Planning Assumptions

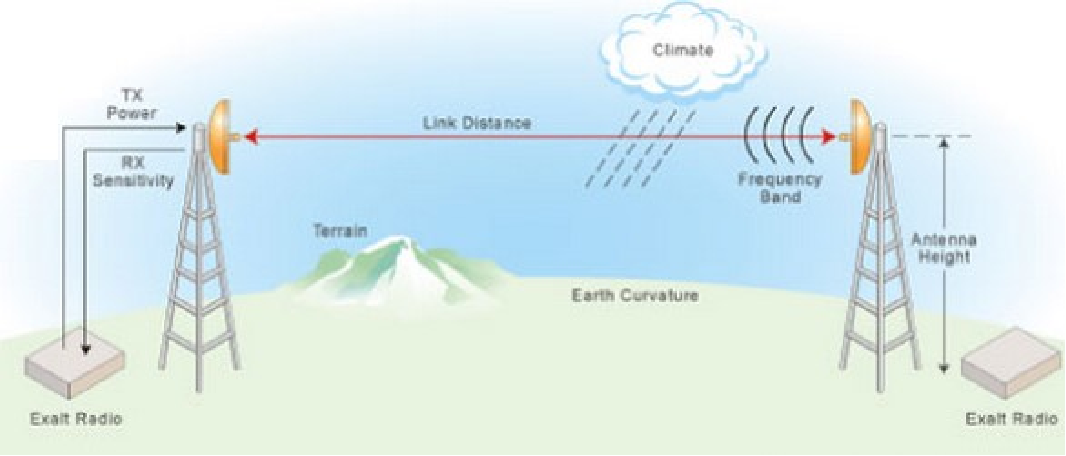
- **Link Budget principle**



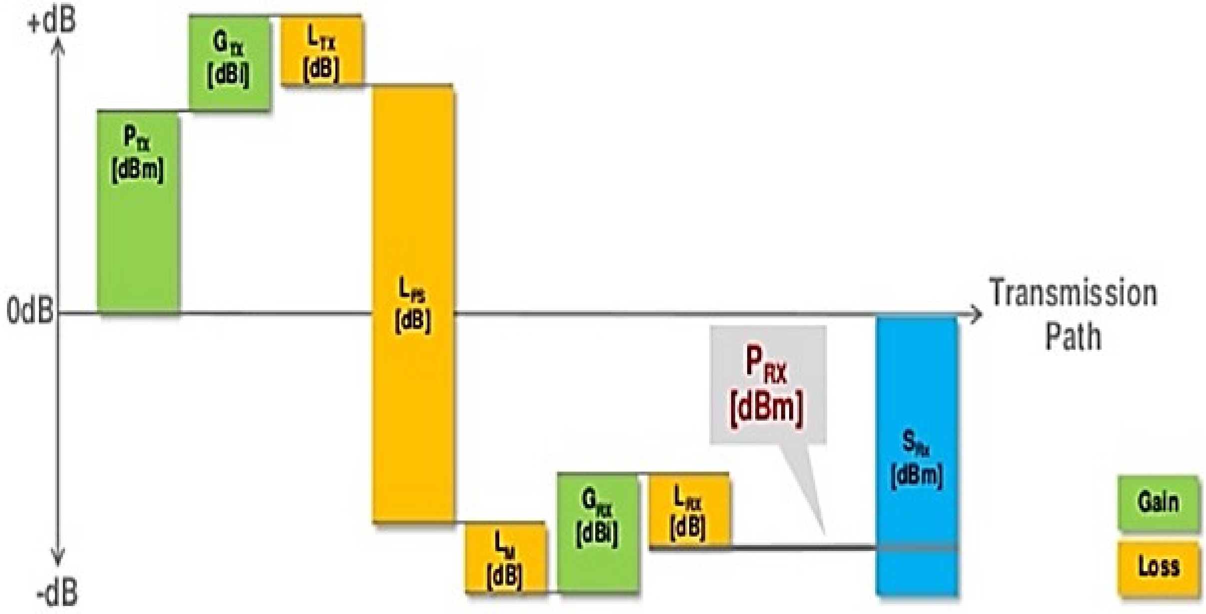
- Link budget calculation
  - Signal strength loss on the path between gateway and the end device

- Define the cell ranges along with the coverage thresholds

- Important components
  - Sensitivity, Fade margin, Connector and cable losses, Antenna gain



$$P_{RX} = P_{TX} + G_{TX} - L_{Tx} - L_{FS} - L_{M} + G_{RX} - L_{RX}$$



P_{RX} = Received power (dBm)

P_{TX} = Sender output power (dBm)

G_{TX}= Sender antenna gain (dBi)

L_{TX} = Sender losses (connectors etc) (dB)

L_{FS} = Free space loss (dB)

L_{M} = Misc. losses (multipath etc.) (dB)

G_{RX}= Receiver antenna gain (dBi)

L_{RX}= Receiver losses (connectors etc.) (dB)

S_{RX}= Receiver sensitivity (dBm)

DL Link Budget

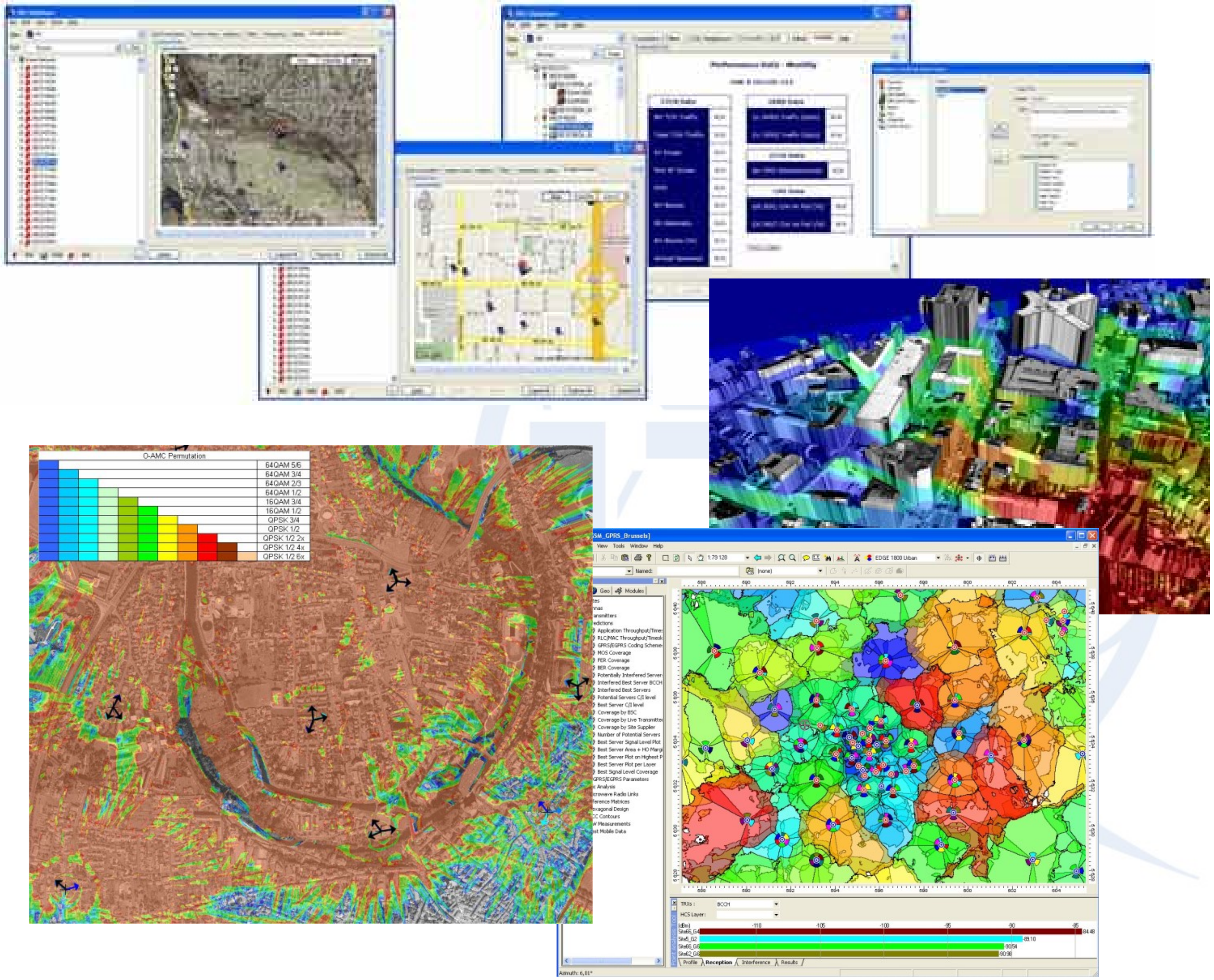
Technologies	WAVIoT NB-Fi	LORA	Sigfox	LTE-M
TX power (dBm)	30	21	24	40
TX Cable loss (dB)	-3	-3	-6	-3
TX Antenna gain, dBi	0	9	9	10
TX subtotal (dBm)	27	27	27	47
RX Sensitivity (dBm)	-147	-137	-129	-129
Rx Environment noise (dB)	0	0	0	0
RX Antenna gain diversity (dBi)	0	0	0	0
RX SubTotal (dBm)	-147	-137	-129	-129
Maximum Allowable Pathloss (dB)	174	164	156	176

UL Link Budget

Technologies	WAVIoT NB-Fi	LORA	Sigfox	LTE-M
TX power (dBm)	15	15	15	20
TX Cable loss (dB)	-1	-1	-1	-1
TX Antenna gain, dBi	0	0	0	0
TX subtotal (dBm)	14	14	14	19
RX Sensitivity (dBm)	-152	-137	-142	-129
Rx Environment noise (dB)	-10	-10	-10	-10
RX Antenna gain diversity (dBi)	10	10	10	10
RX SubTotal (dBm)	152	137	142	129
Maximum Allowable Pathloss (dB)	166	151	156	148

Planning Tools

Tools for Radio planning



Main Planning Tools:

- Aircom Asset
- Mentum Planet
- Atoll FORSK
- ATDI
- WinProp
- EDX Signal Pro
- CelPlan
- Siradel
- Pathloss

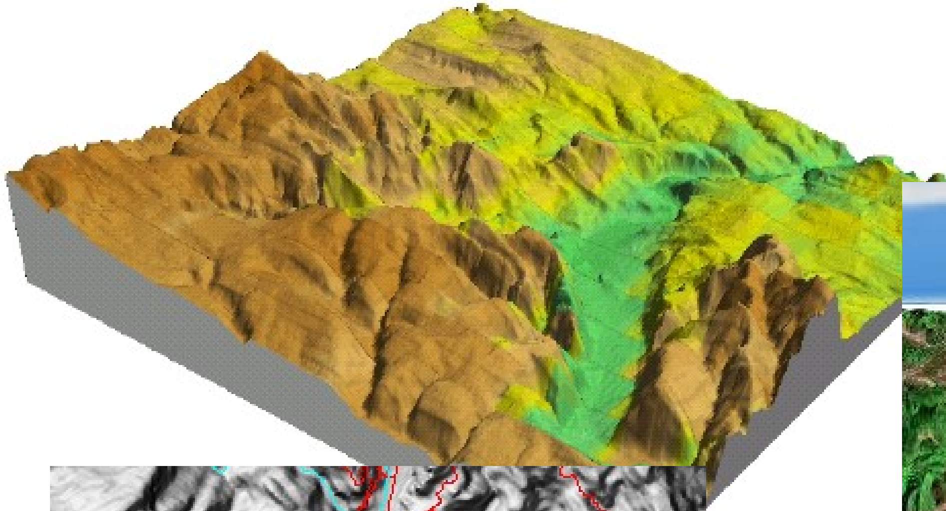
Main Optimization Engines

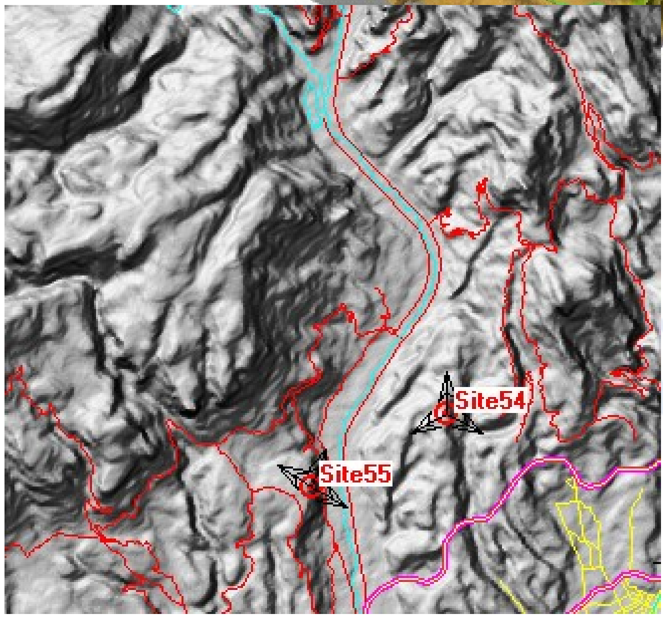
- Actix
- Capesso

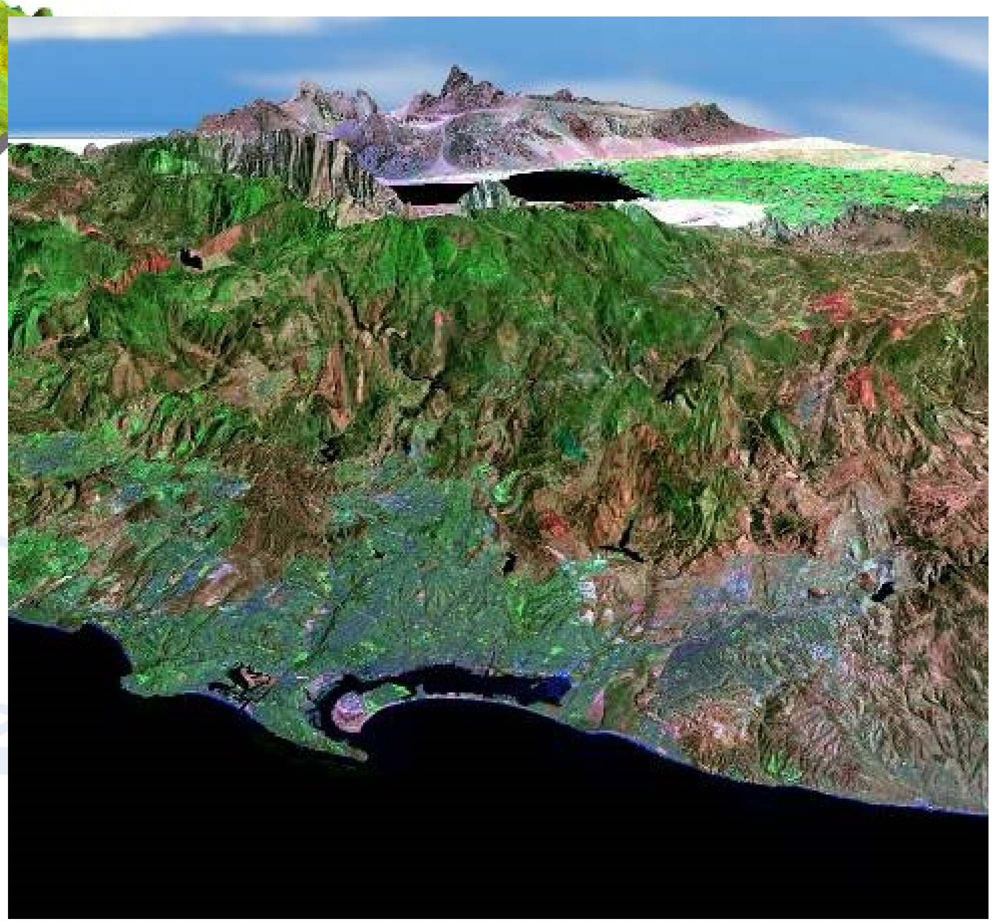
- Used to design and optimize the network by:
  - Prediction of coverage
  - Frequency planning automatically
  - Creating neighboring list
- With a data base takes into account:
  - Clutter
  - Antenna radiation
  - Terrain
  - Number of end devices
  - Supported services

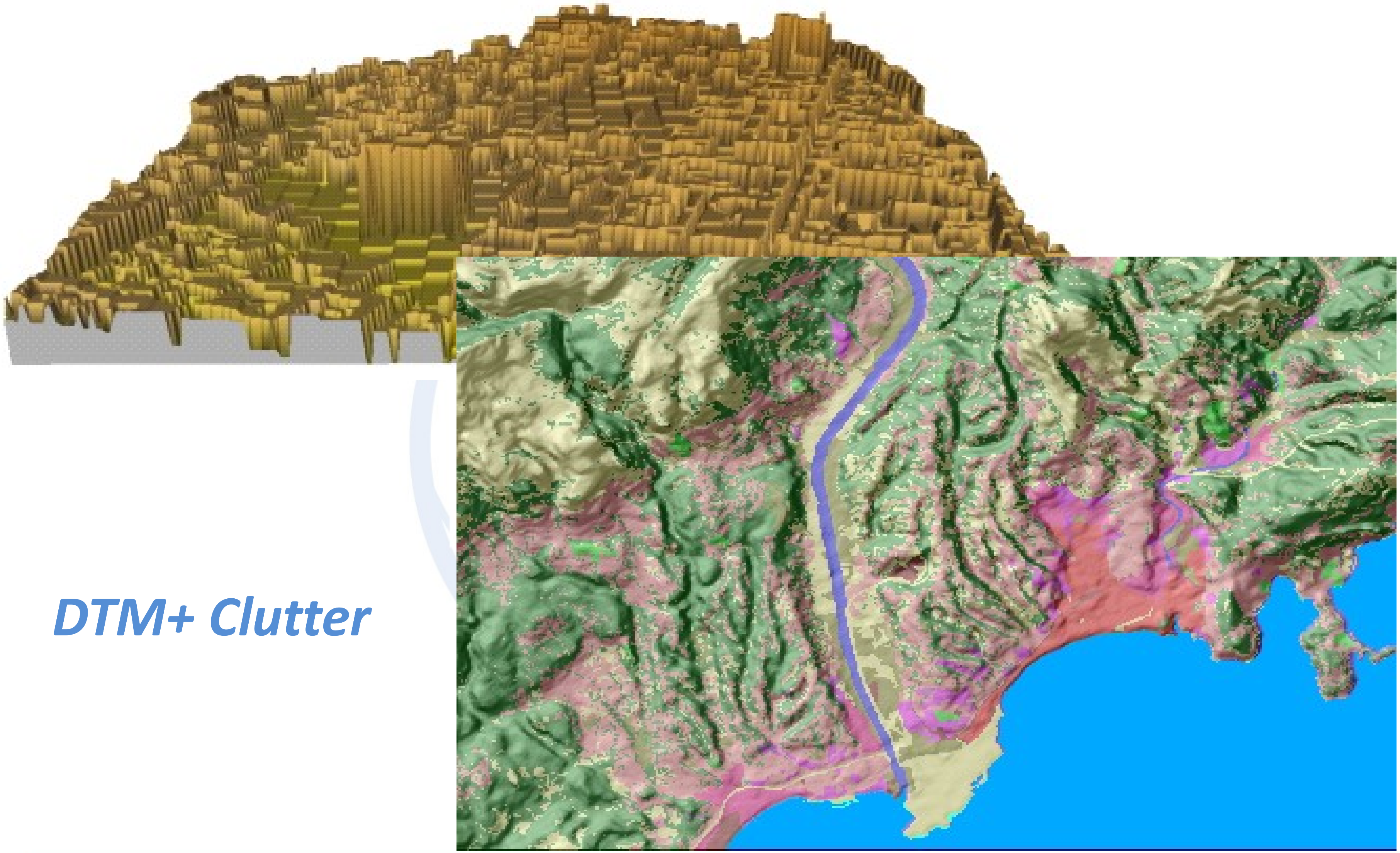
- ***Geographical databases***
  - Digital terrain map (DTM).
  - Clutter.
  - 3D databases.
  - Indoor architecture.

Digital terrain map



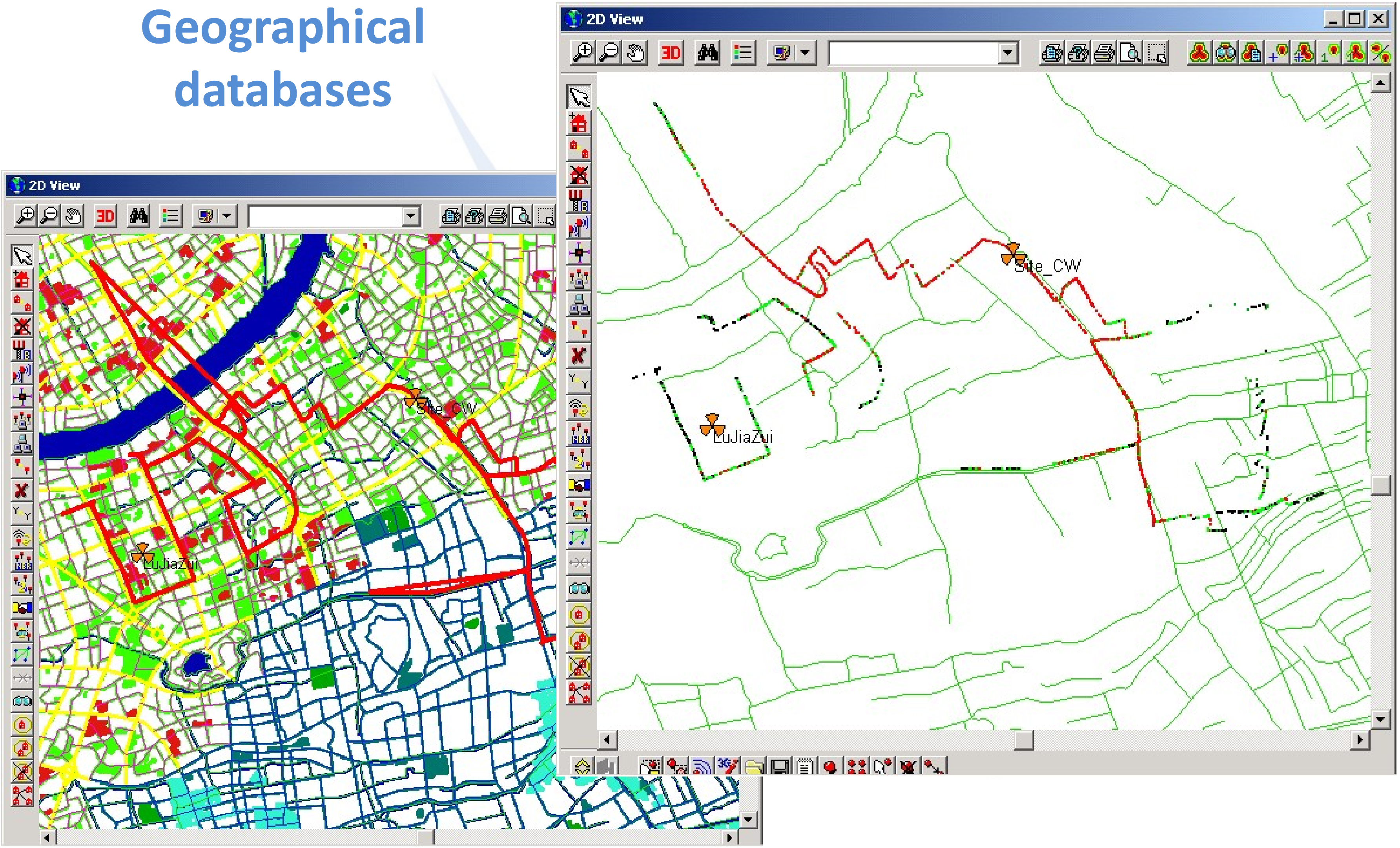






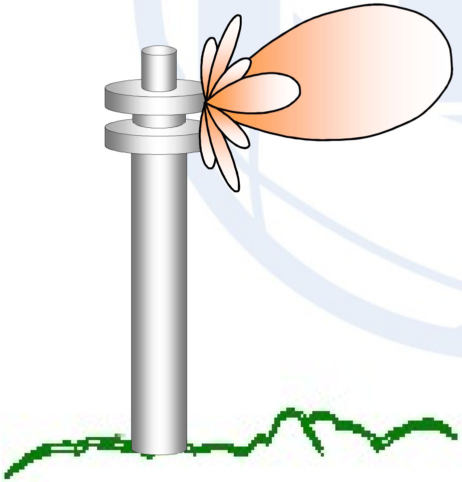
DTM+ Clutter

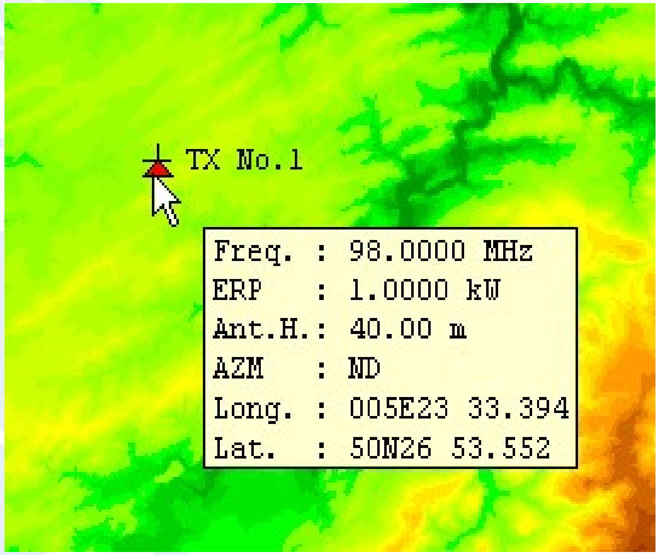
Geographical databases



Parameters used for coverage prediction

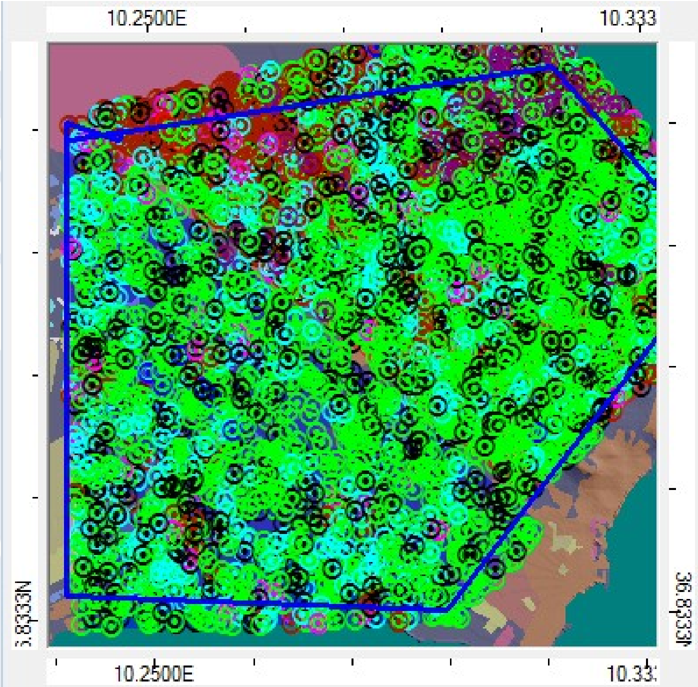
- Coordinates of the transmitter
- Radiated power
- Frequency
- Antenna diagram





Coverage simulation

- Static/Dynamic simulation
- Distributions (snapshots)
- By iteration,



➔ UL/DL cell load, connection status and rejected reason for each mobile

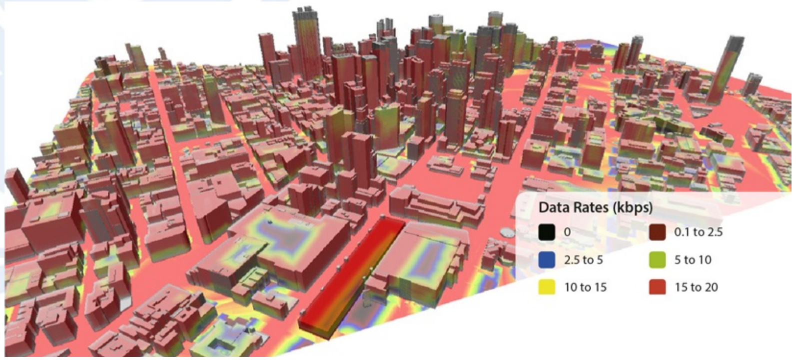
C. Use cases

IoT planning with Mentum Planet

- Introduction to Planet
- **Use case 1: LoRa network planning in Tunis area**
- **Use case 2: Patavina Technologies network in Italy**

IoT Planning

- Create demand forecasts and determine best technology options
- Dimension and simulate LPWA networks
- Optimize deployment of IoT technologies



- **New IoT capabilities**. Support for IoT technologies SIGFOX and LoRa is delivered through an optional module. Network analyses (best server, signal strength, SIGFOX diversity levels, Uplink LoRa, best available modulation based on spreading factors) are all available.
- **MapInfo geographic information system**. Operators planning their network and related demand forecasts are trying to solve an RF geospatial problem. Planet is includes a leading geographic information system — MapInfo Professional™ — native to the application.
- An open platform. Planet offers multiple means to integrate 3rd-party solutions or key systems through application programming interfaces (APIs).

Different Steps

Project Setup

- Network Settings: Frequency, bands, …
- Site Editor: Propagation, antenna, PA Power, …
- IoT Device Editor: PA Power, Noise Figure, …

Propagation Modeling

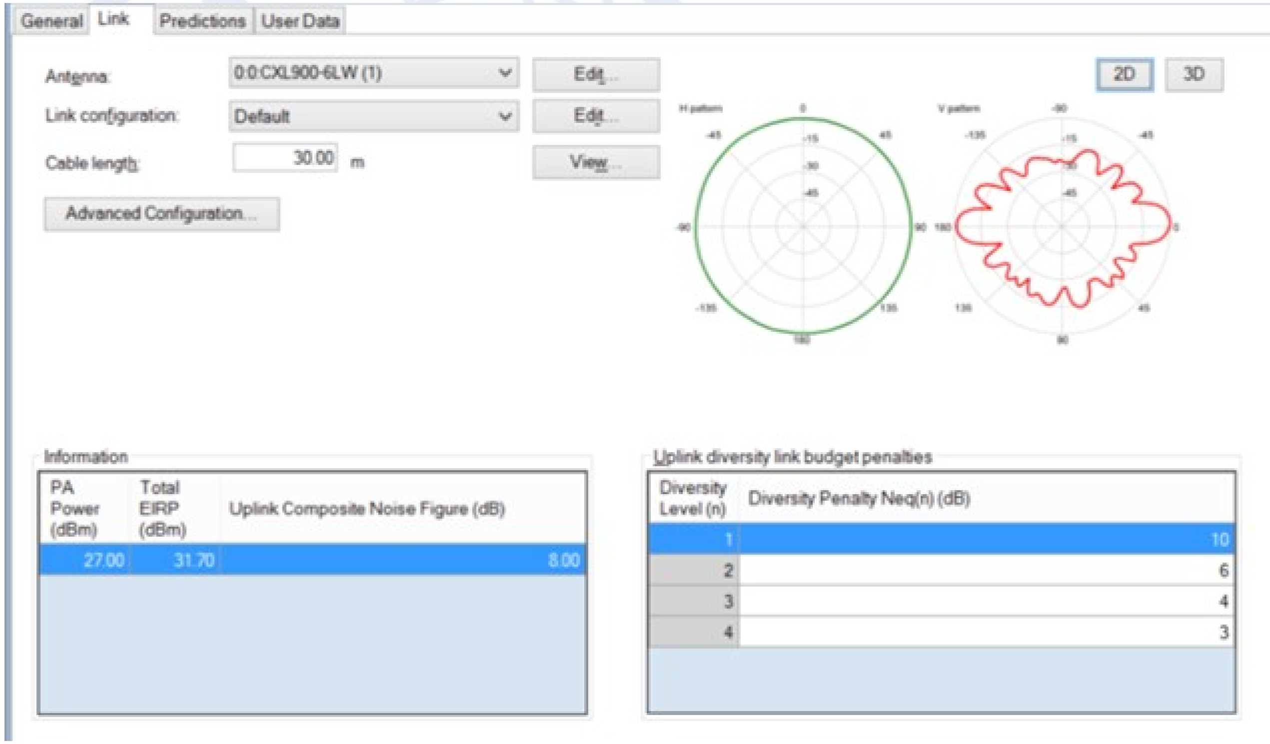
- Geographical Data support (Elevation, clutter, height, buildings, forest, polygons, …)
- Intelligent antenna management and modeling

Network Analyses

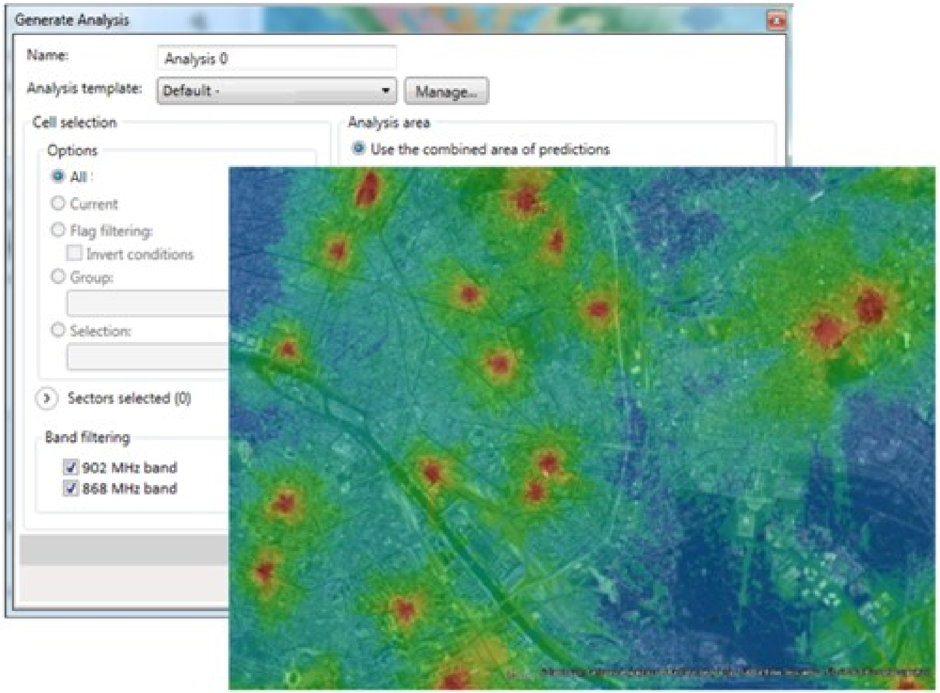
- Signal Strength, best available modulation, …
- Data analytics and statistics
- Scheduling and automating

Site Editor

- Antenna's property
- Radiation pattern
- HBA
- Tilt
- Azimuth, …



- IoT-specific simulation engine with downlink and uplink analysis
  - DL/UL best server
  - DL/UL received signal strength
  - DL/UL S/(N+I)
  - DL/UL coverage (Including diversity requirement)
  - Number of servers
  - Nth Best Server
  - LoRa Uplink capacity
- Multi-threaded



- **Introduction to Planet**
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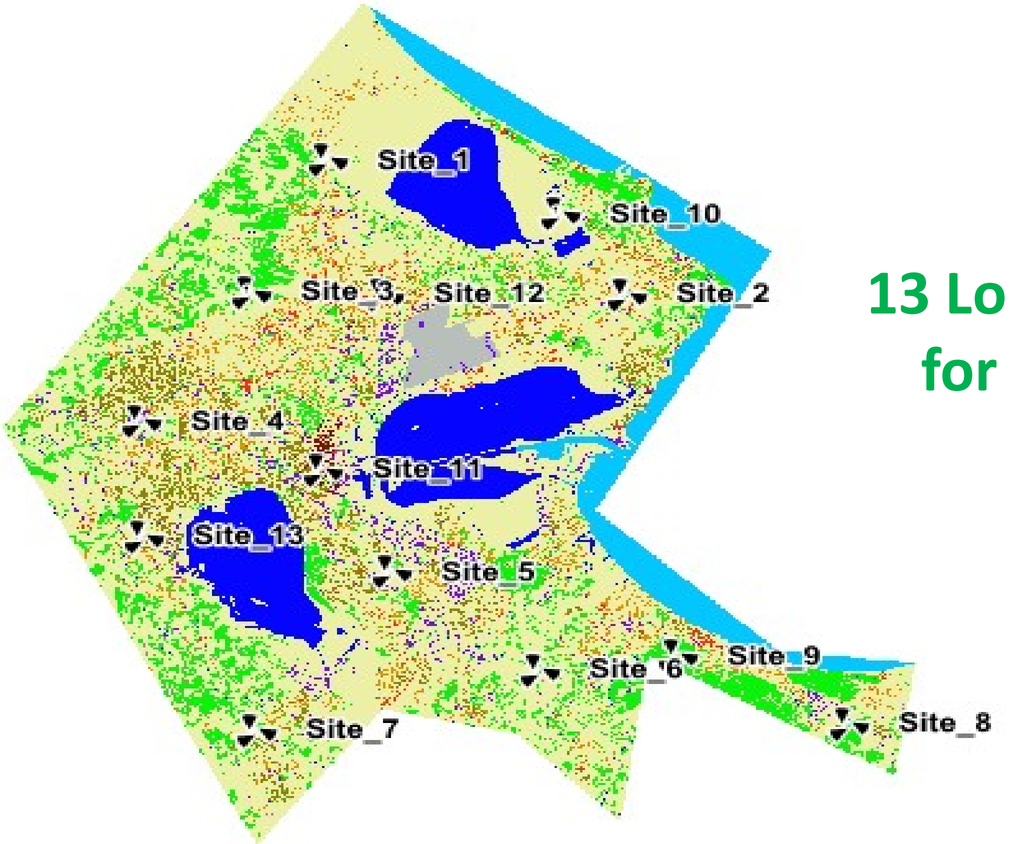
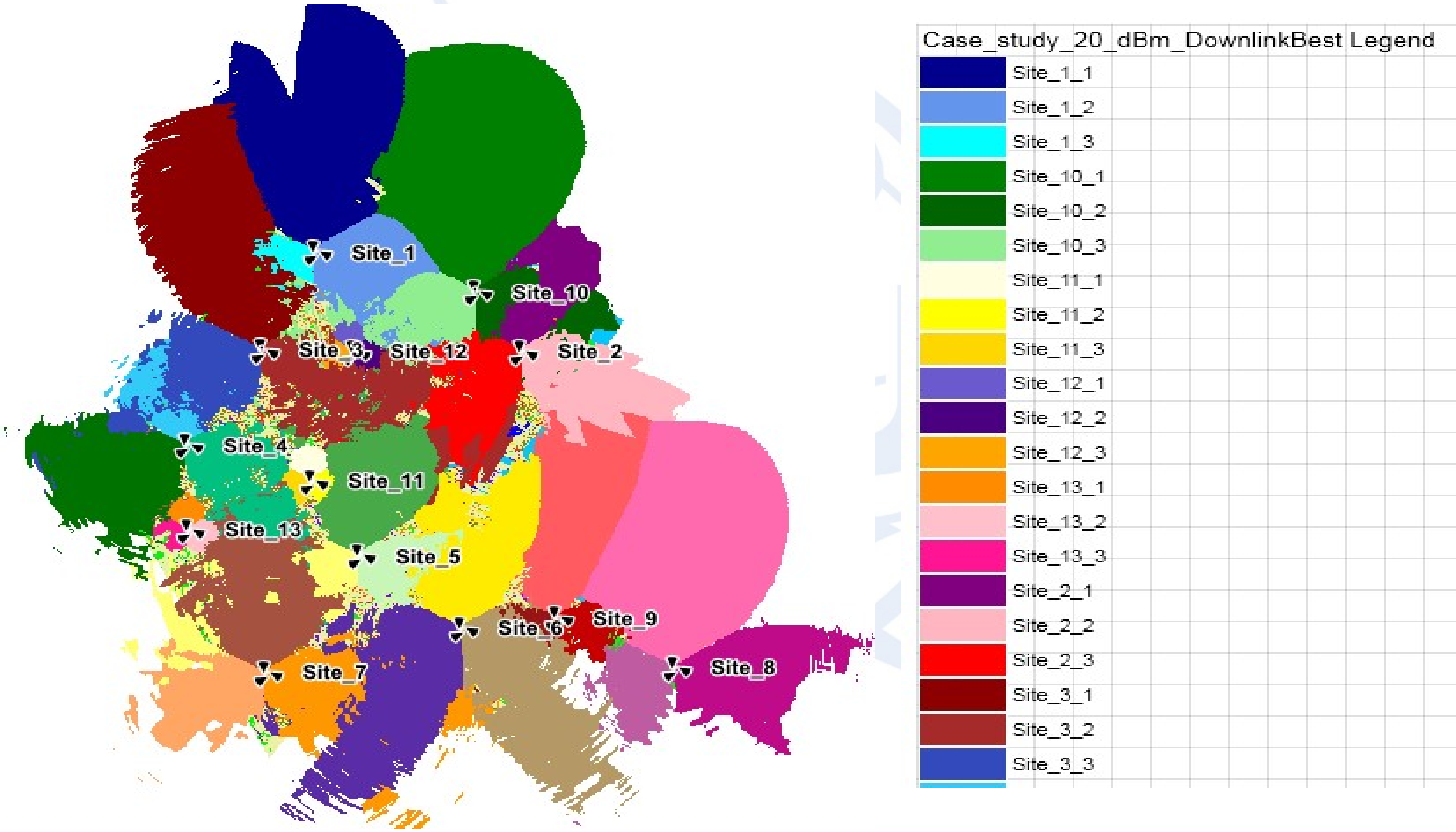
Area choice



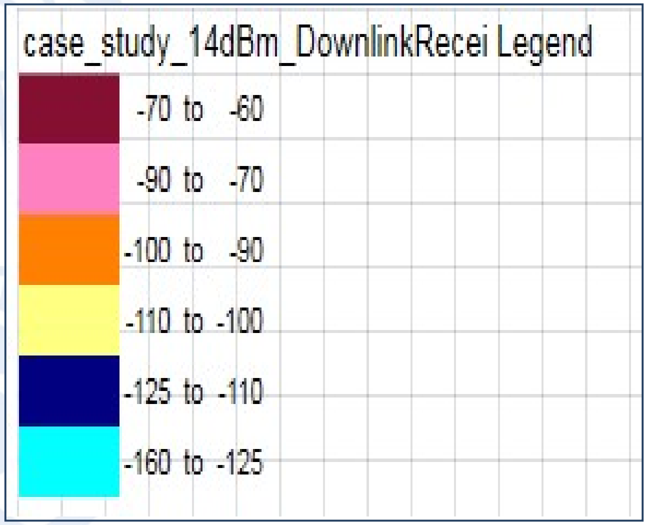
13 LoRa Gateways for simulation

1 227.3 Km^2

Downlink Best Server

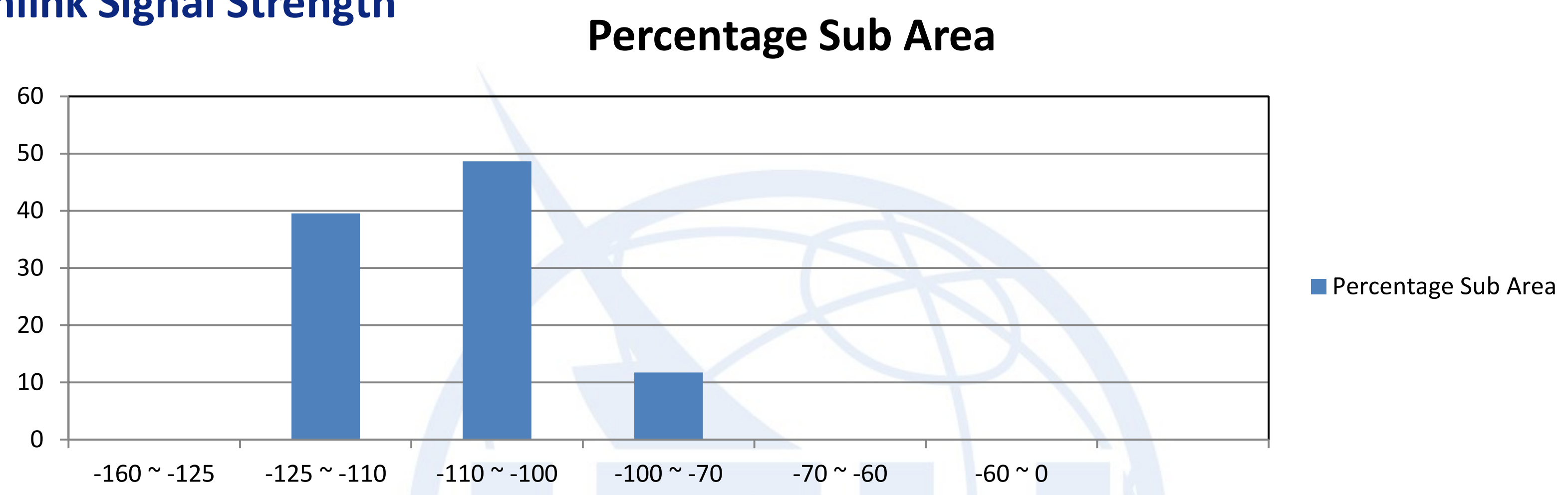


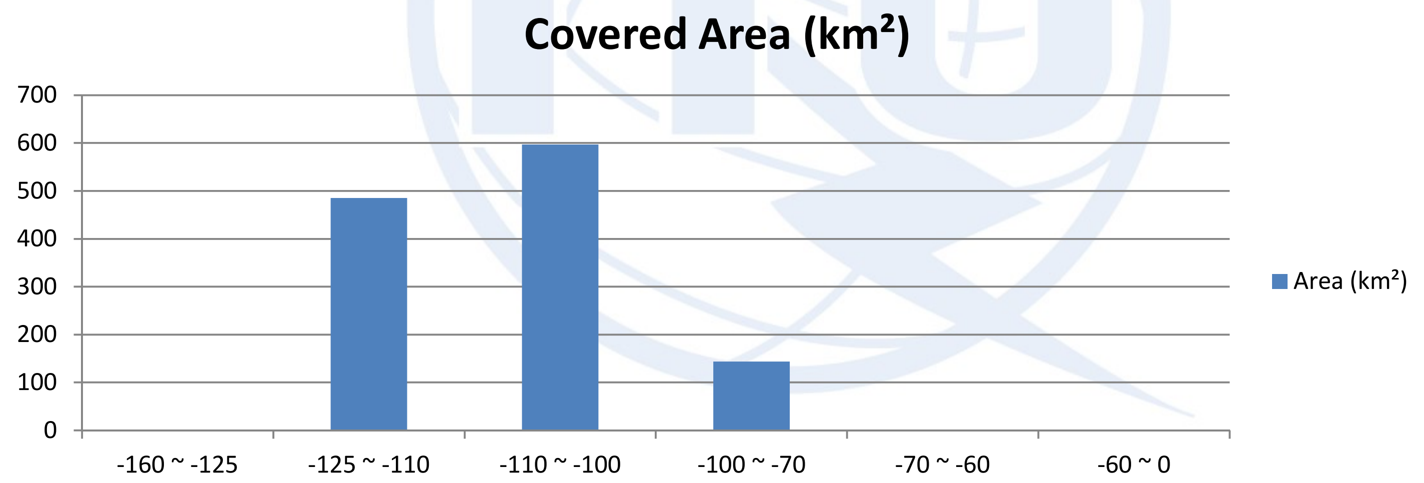
Downlink Signal Strength



Use case 1

Downlink Signal Strength





Uplink Signal Strength

- More important to consider
- IoT devices send more packets to gateway than they receive
- LoRa End Devices Transmit Power: **14 dBm to 20 dBm**

Two use cases

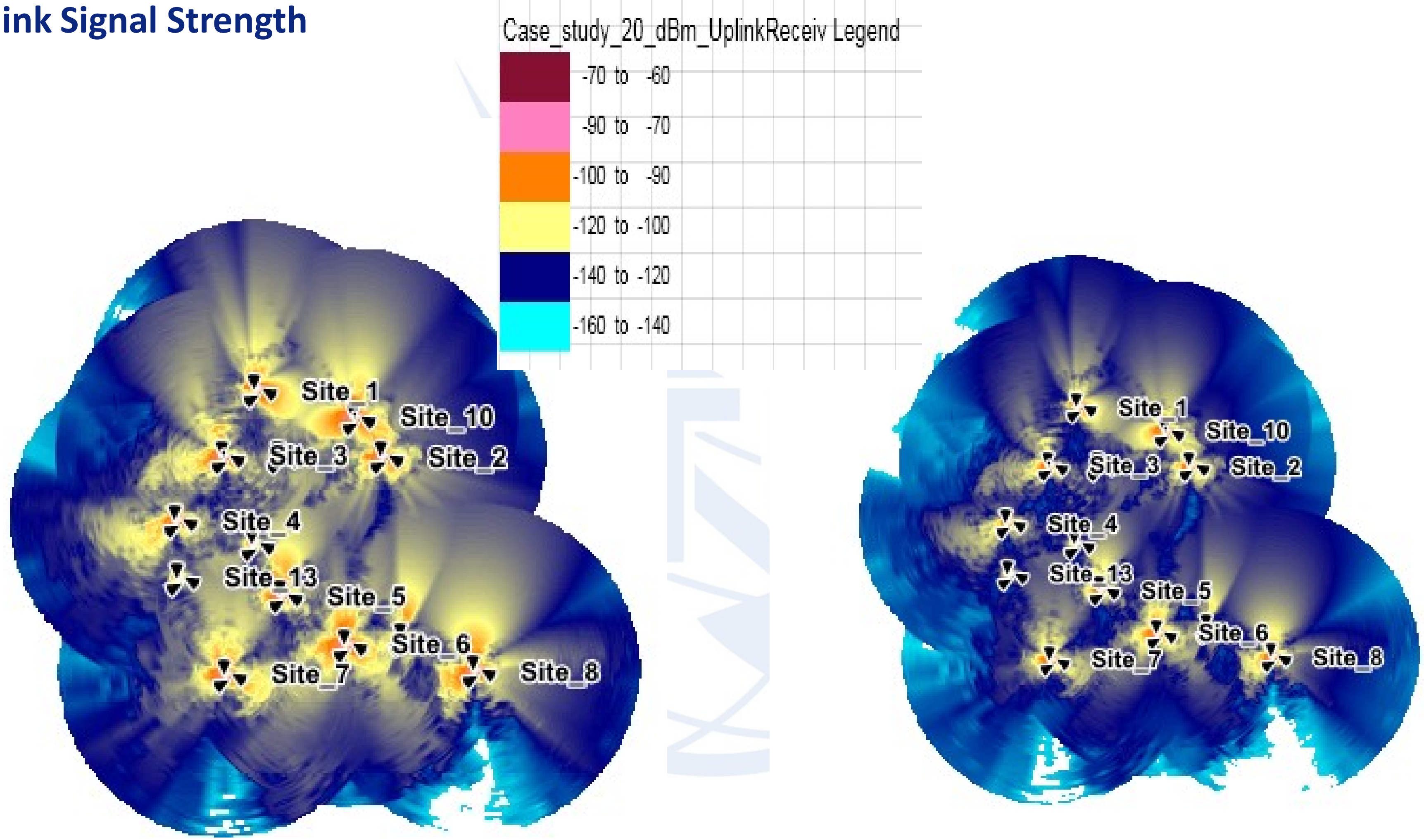
14 dBm

Better battery economy for end devices

20 dBm

Better for end devices on the grid

Uplink Signal Strength



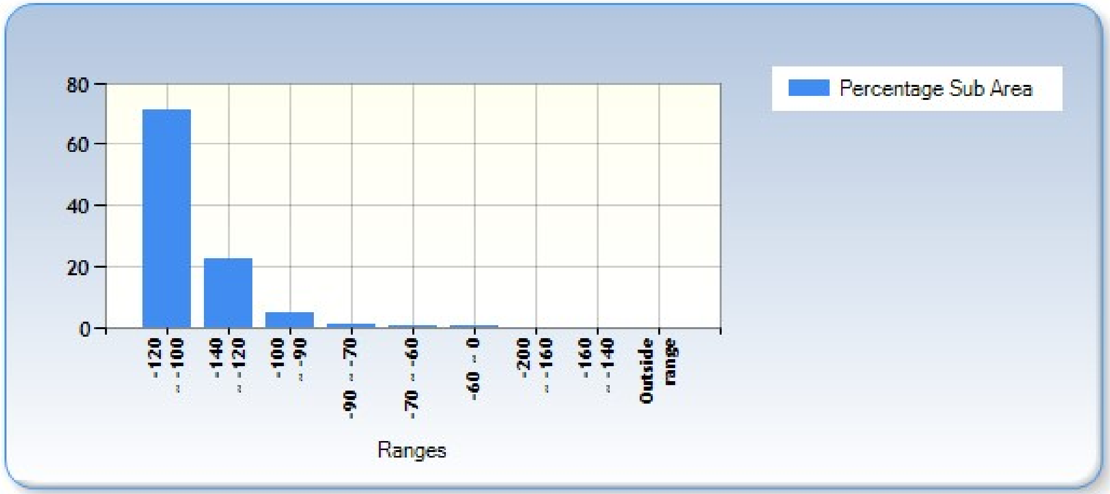
End Device Power: 20 dBm

End Device Power: 14 dBm

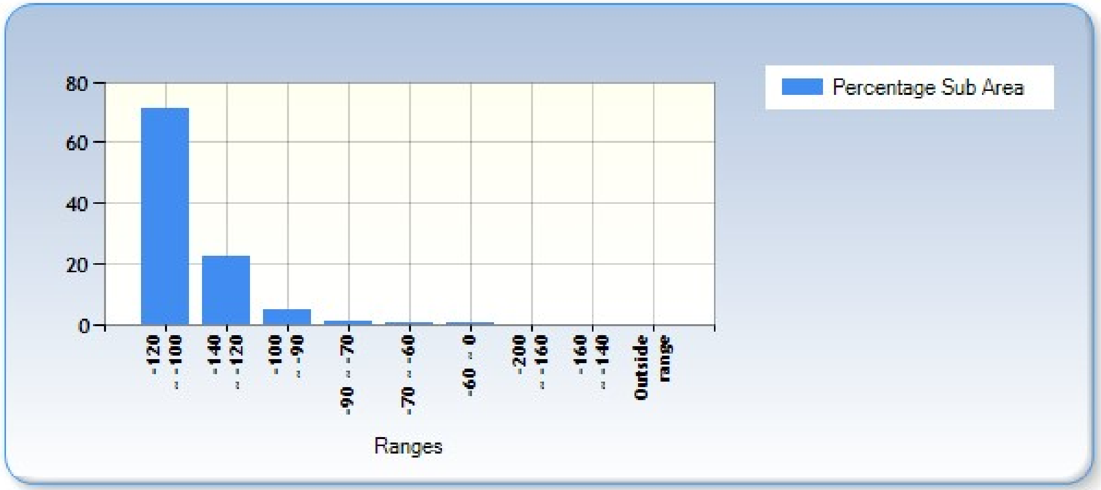
Use case 1

Uplink Signal Strength

End Device Power: 20 dBm

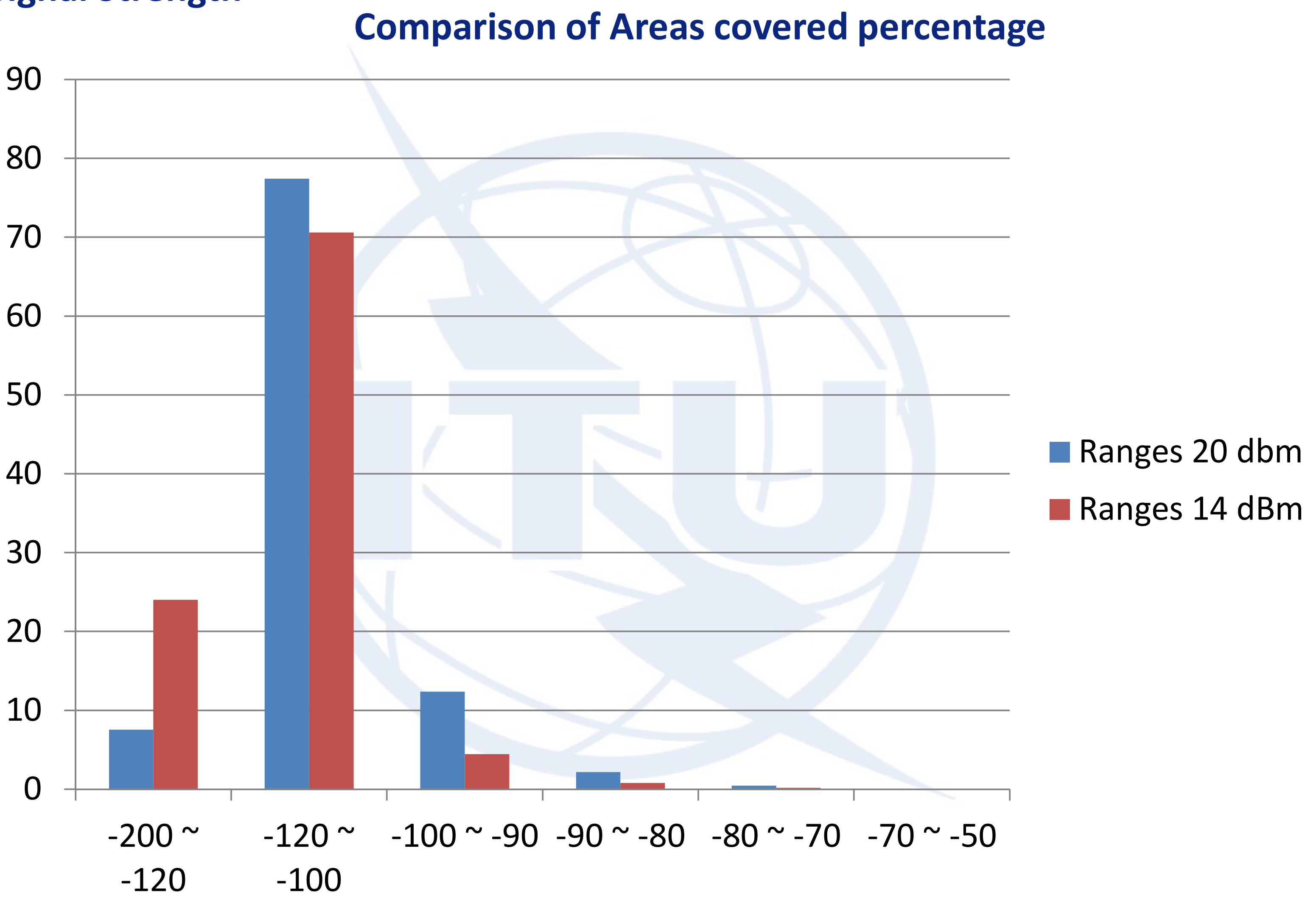


End Device Power: 14 dBm



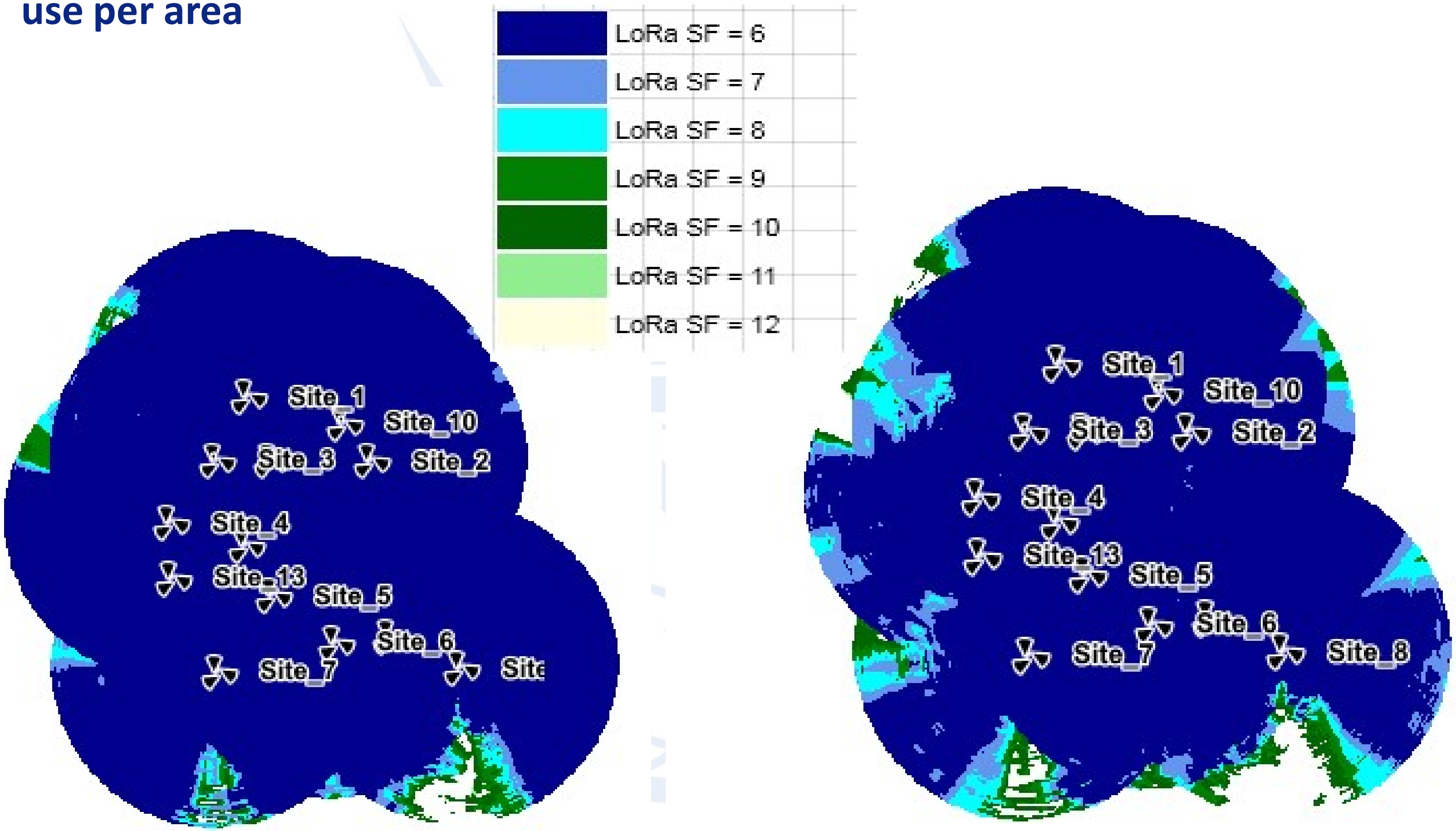
Use case 1

Uplink Signal Strength



Use case 1

Lora Spreading Factor use per area

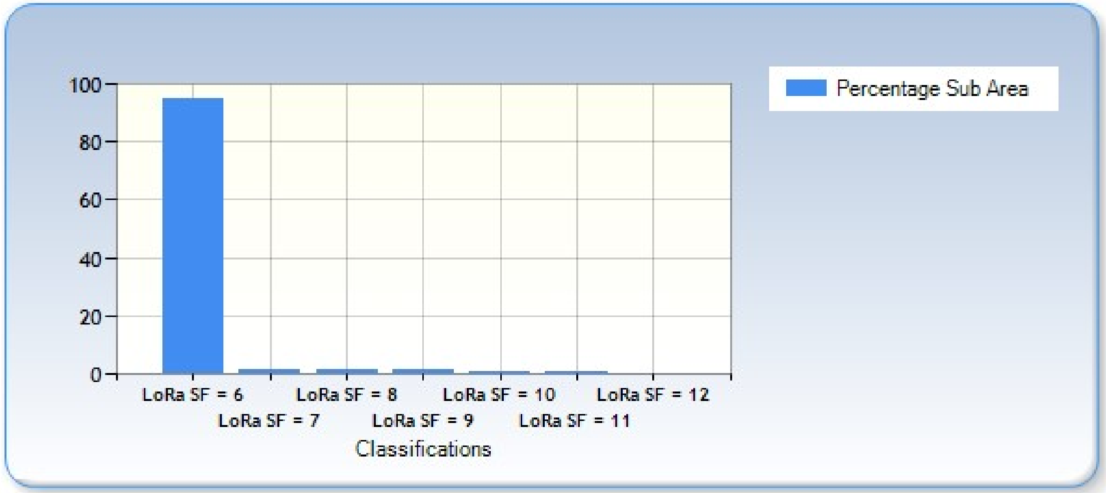


End Device Power: 20 dBm **End Device Power: 14 dBm**

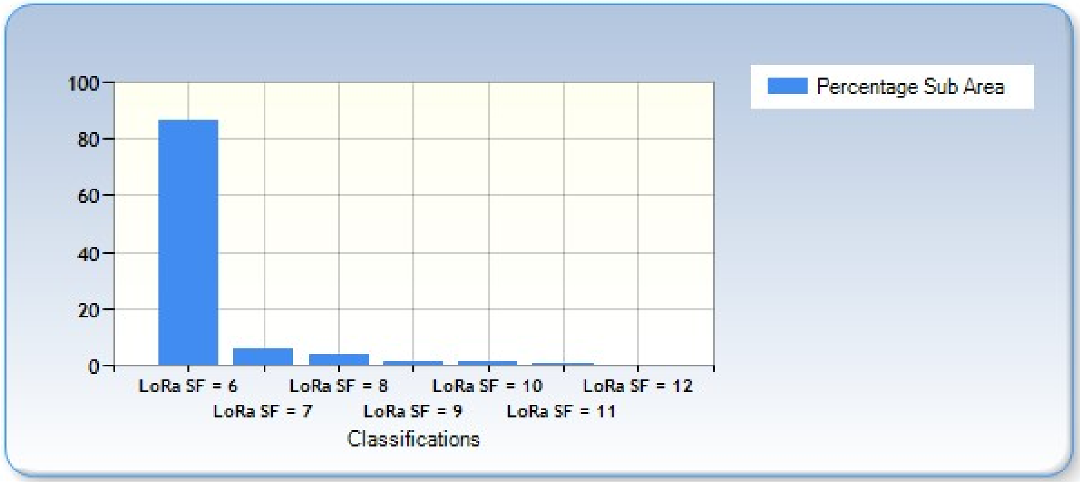
Use case 1

Lora Spreading Factor use per area

End Device Power: 20 dBm



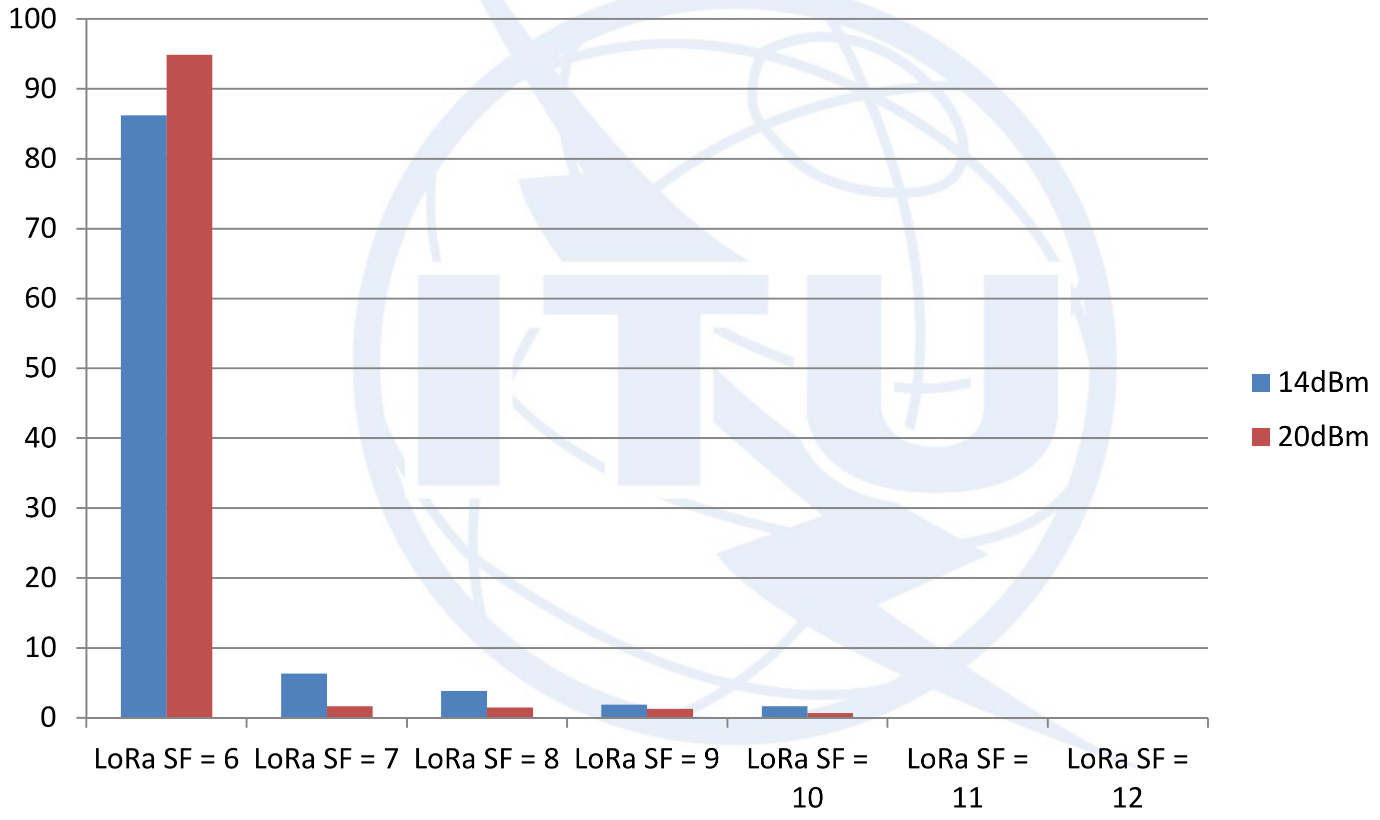
End Device Power: 14 dBm



Use case 1

Lora Spreading Factor use per area

Comparison of SF use per device transmit Power



Distribute End Nodes per area according the different services

Calculate possible number of packets to be send in every area simultaneously

Calculate the number of gateways according the capacity of one gateway

Final Numbers of Gateways = Maximum {

Number of Gateways (coverage),

Number of Gateways (capacity) }

- **Introduction to Planet**
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Use case 2

- Private Network by Patavina Technologies in Italy
- Building with **19 floors**
- **LoRaWAN** Network
- Goal:
  - ➢ Reduce the cost related to heating, ventilation and air conditioning
  - ➢ Temperature and Humidity control

Installation

Single gateway on **ninth** floor

32 nodes

All over the building

- Open places
- Stress test

(elevators, …)

All nodes **successfully** covered

- Coverage analysis by Patavina Technologies in Italy
- Padova, Italy
- **LoRaWAN** Network
- Goal:
  - Assess **“worst case” coverage** (Harsh propagation conditions)
  - Conservative estimate number of gateways to cover the whole city

Results

Single gateway
Max radius: **2 Km**
Nominal Radius: **1.2 Km**

Padova system cell overage

- **30** gateways
- 200 000 inhabitants ➔ 7 000 per gateway
- **Adequate** for most smart city applications

Thank you!