Information & Communication Technologies for the Internet-of-Things

Cellular Architectures

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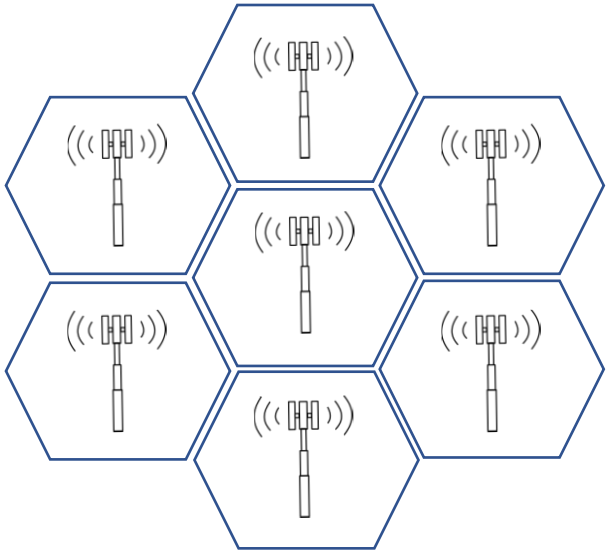
Original content.

Slides under preparation.

Outline

- Cellular Architectures
- Cellular Tecnhological Ecosystem
- Physical Layer of Cellular Communications

Why Cellular?



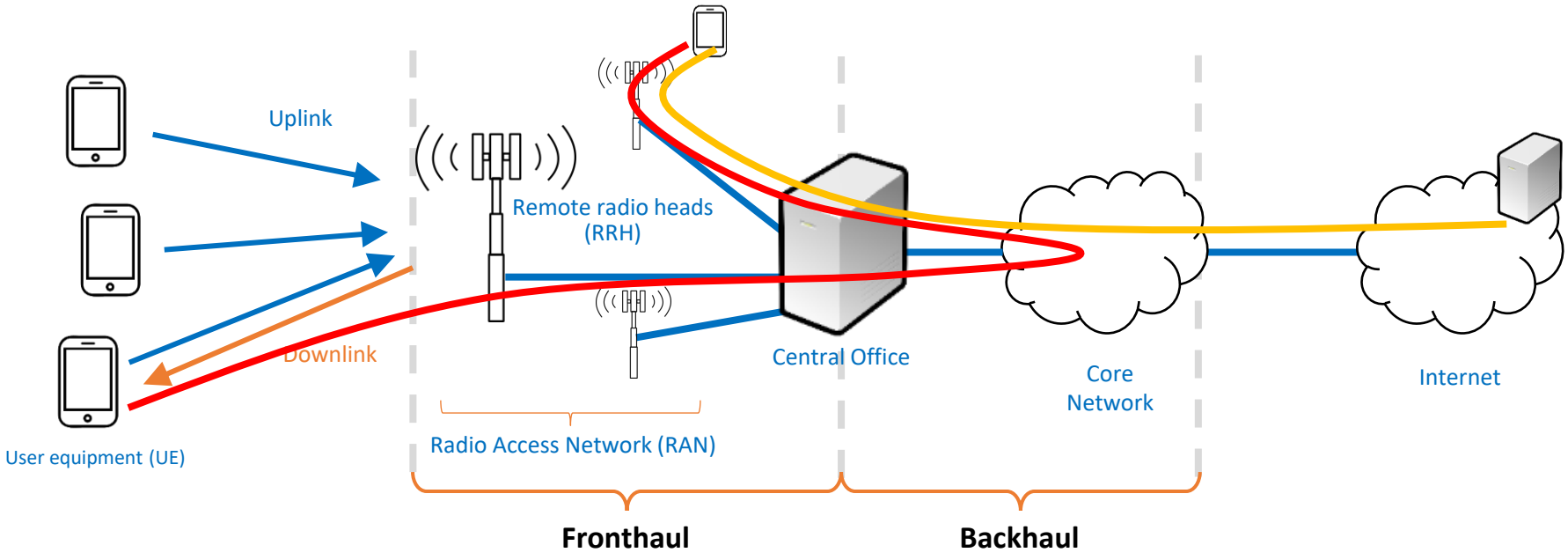
Cellular Technologies

- Technology development for cellular systems
  - Driven by 3GPP – a standardization body that includes most OEMs and operators
  - Cellular specifications are formalized in Releases – currently Release 16
- Massive MIMO
  - Emerging technology
- C-V2X / NR-V2X
  - In cellular terminology, a ‘sidelink’ that complements
- Cellular Service Stack

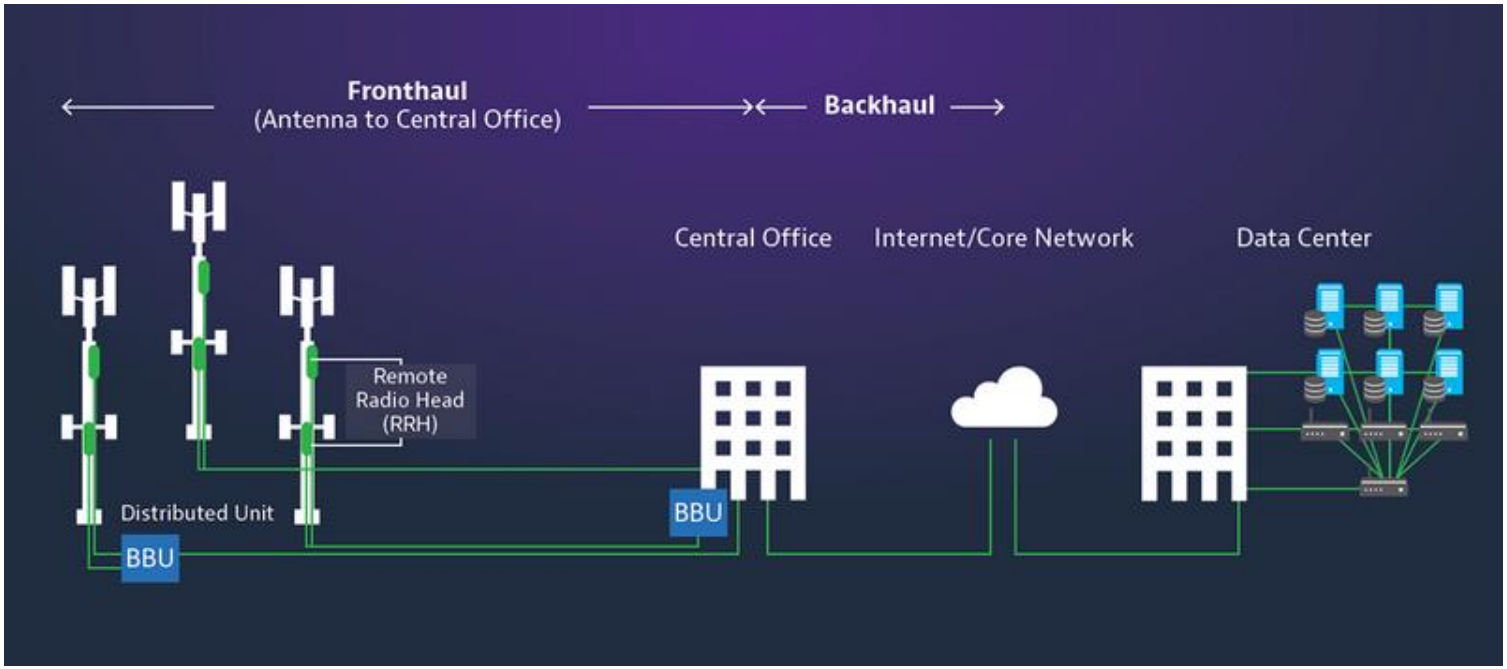
Commercial brand	Name of technical specification	Stand. Body	Time-frame
1G	N/A	N/A	1980
2G	Global System for Mobile Communications **(GSM)**	ETSI	1990
3G	Universal Media Telecom-munications System **(UMTS)**	3GPP	2000
4G	Long-Term Evolution **(LTE)**	3GPP	2010
5G	New Radio **(NR)**	3GPP	2020

Cellular Architectures and Asymmetric

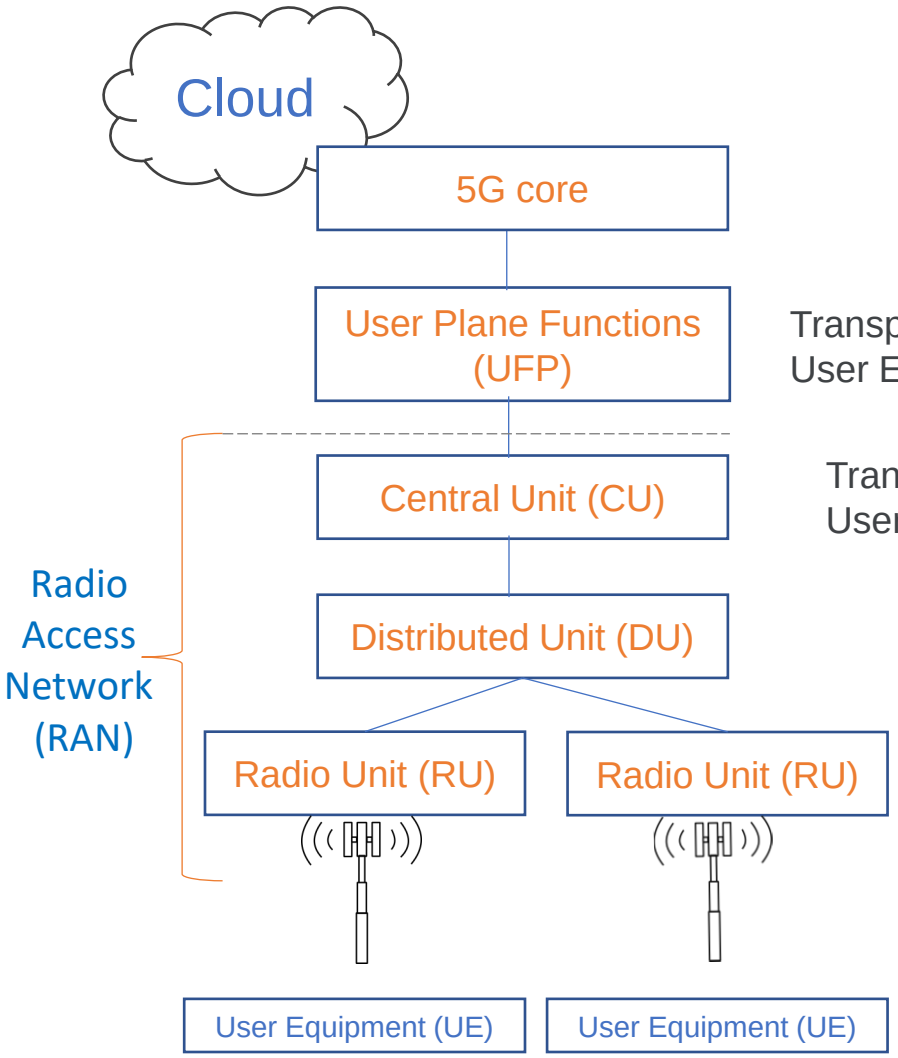
- The most prominent example of Wide-Area Networks (WAN) are **cellular** networks (and thus sometimes the terms WAN and cellular are used interchangeably)



Cellular Architectures



Vertical Architecture



Transports the IP data traffic (user plane) between the User Equipment (UE) and the external networks.

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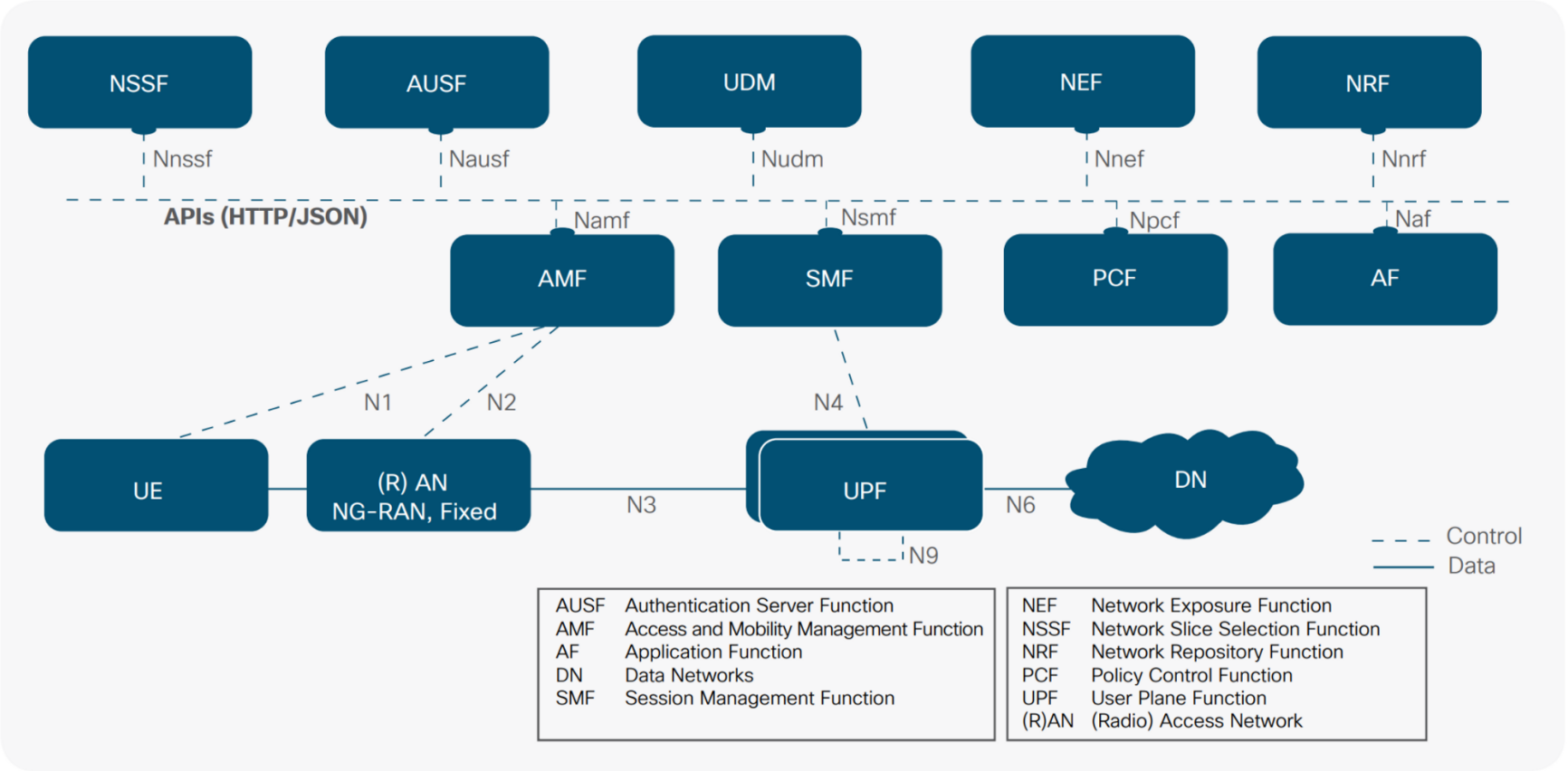
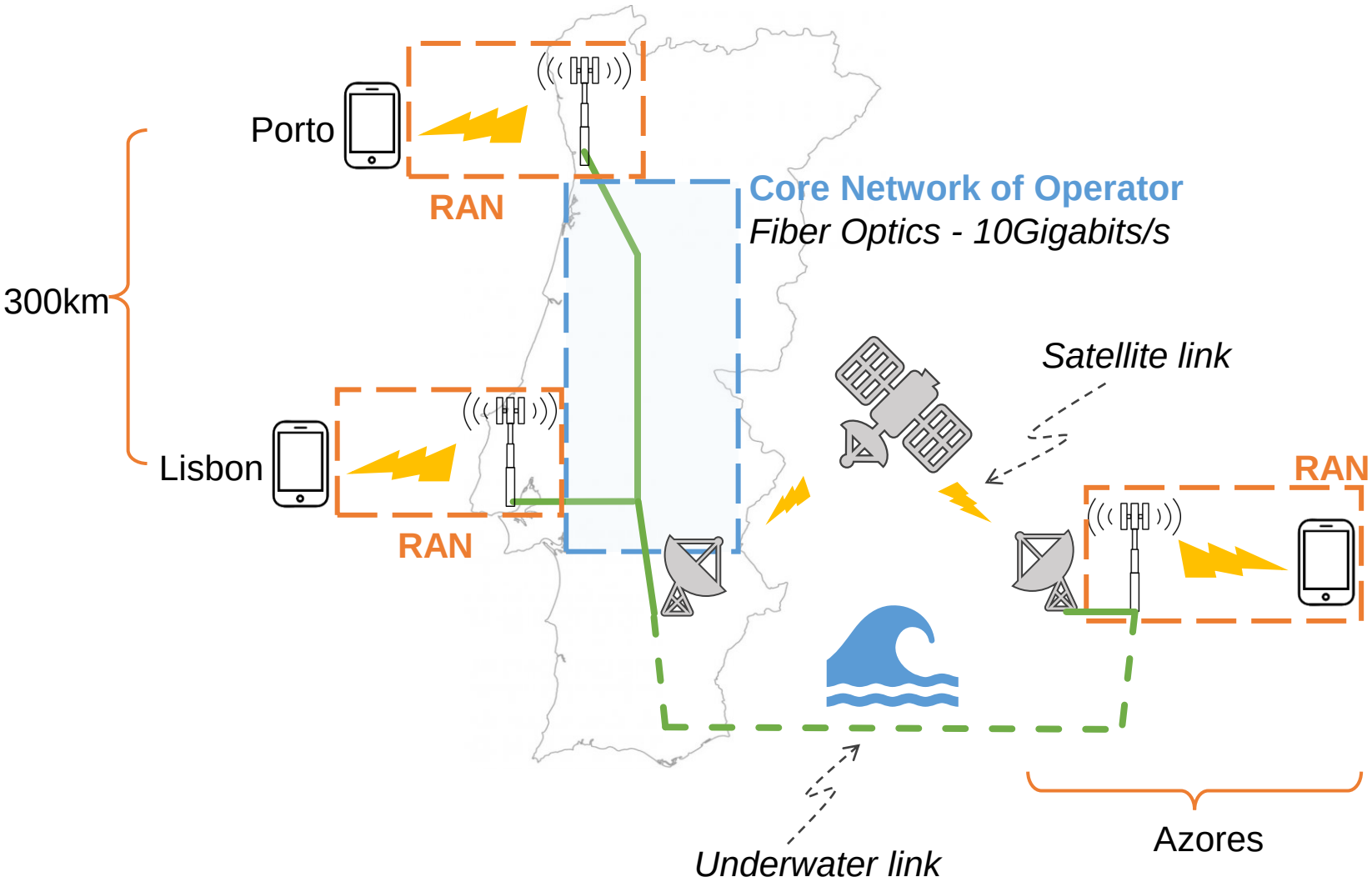

NSSF
AUSF
UDM
NEF
NRF
Nnssf
Nausf
Nudm
Nnef
Nnrf
APIs (HTTP/JSON)
Namf
Nsmf
Npcf
Naf
AMF
SMF
PCF
AF
N1
N2
N4
UE
(R) AN
NG-RAN, Fixed
N3
UPF
N6
DN
N9
Control
Data
AUSF Authentication Server Function
AMF Access and Mobility Management Function
AF Application Function
DN Data Networks
SMF Session Management Function
NEF Network Exposure Function
NSSF Network Slice Selection Function
NRF Network Repository Function
PCF Policy Control Function
UPF User Plane Function
(R)AN (Radio) Access Network

Core Network & RANs – Spatial Relation



Spectrum Assignment in LTE

- Spectrum usage in LTE
  - LTE carriers can be [1.4, 3, 5, 10, 15, 20] MHz wide (defined in the standard)
  - **Physical Resource Blocks** (PRBs) are 180kHz sub-divisions that correspond to smallest chunk of data
  - For 10MHz carrier, we get 50 PRBs

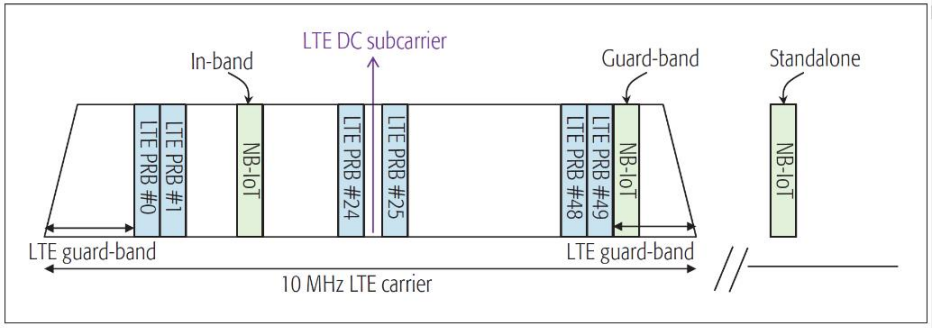


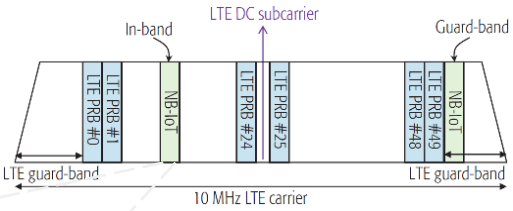
Figure 1. Examples of NB-IoT stand-alone deployment and LTE in-band and guard-band deployments.

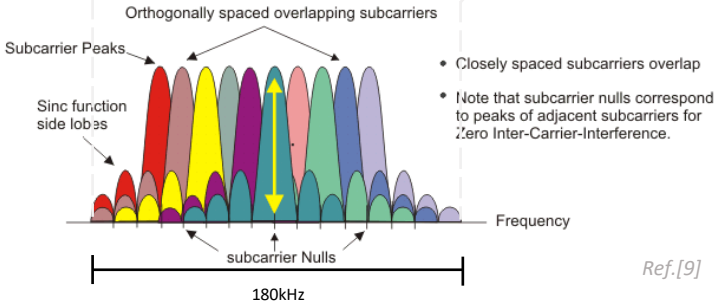
- NB-IoT was designed to be compatible with GSM and LTE
  - NB-IoT requires a bandwidth of 180 kHz for downlink and uplink
  - In GSM: Replace one GSM carrier (200 kHz) with NB-IoT
  - In LTE: Allocate one PRB of 180 kHz to NB-IoT
    - In-band: using one of the regular PRBs
    - Guard-band: using unused space that borders the PRBs of that carrier

A Primer on Cellular Physical Layer

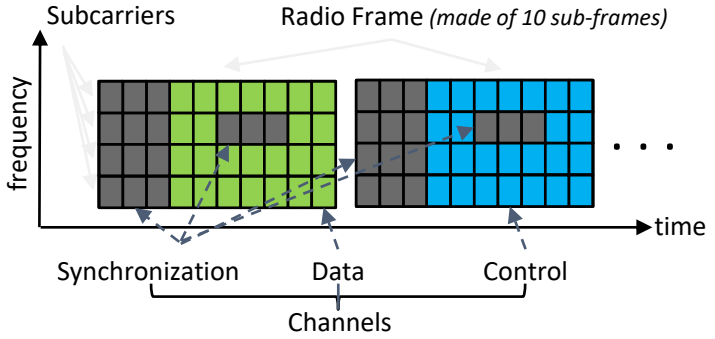
Inside a PRB

- Modulation: **OFDM**
  - *Orthogonal Frequency Division Multiple Access*
  - Number of subcarriers can vary, e.g., 12, 48, 64
  - Different modulations are possible, e.g., QPSK, 16QAM, 64QAM
- Time: **Frame**
  - Frames are composed of 10 sub-frames
- **Channels:**
  - For synchronization, control, and data
  - Channels are **logical,** i.e.: their implementation is mapped into well defined physical resources (frequencies and sub-frames)
  - Synchronism between UE and BE is a key aspect of cellular operation (unlike SigFox)



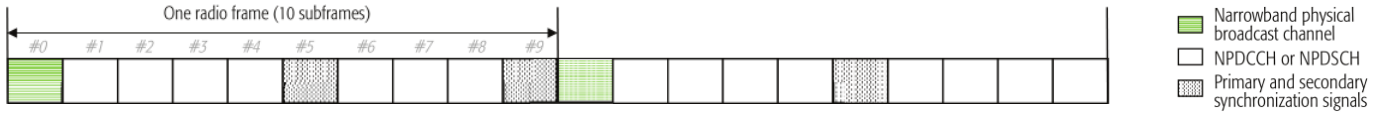


Ref.[9]



NB-IoT Physical Layer – Downlink (BS to UE)

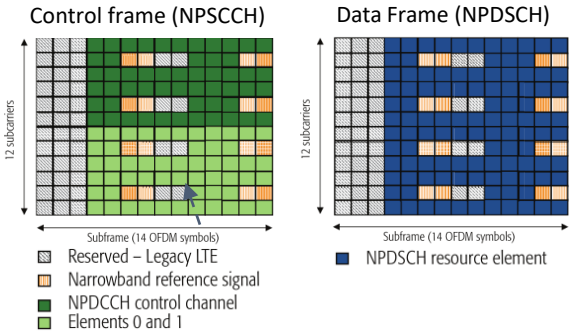
- Modulation: orthogonal frequency-division multiple access (OFDMA)
- Two consecutive DL frames have the following structure:



- Three channels:
  - **Synchronization** (NPSS/NSSS – *NB primary/ secondary sync. signals*)

– *(The following can be transmitted at any white sub-frame.)*

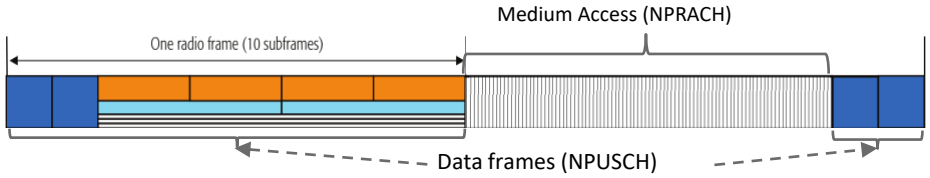
  - **Control channel** (NPDCCH - *NB physical downlink control channel*)
  - **Data channel** (NPDSCH - *NB physical downlink shared channel*)



Ref.[6]

NB-IoT Physical Layer – Uplink (UE to BS)

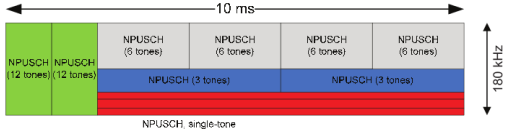
- Modulation: single-carrier frequency-division multiple access (SC-FDMA)
- Two consecutive UL frames have the following structure:



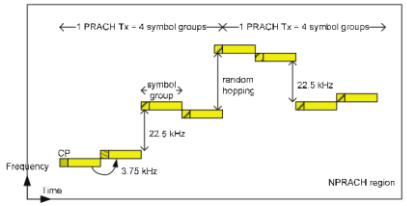
Two channels:

- **Data frames** (NPUSCH - *NB physical uplink shared channel*)
  - A data package can be split per multiple sub-carriers and/or subframes
- **Random Medium Access** (NPRACH - *NB physical random access channel*)
  - Allows UE to request a uplink to BS by sending a random tone sequence
  - If correctly received, BS schedules transmissions for that UE

Data Frame (NPUSCH)



Random Medium Access Channel (NPRACH)



Ref.[6]

6G vs 5G.

COMPARISON OF FEATURES OF 5G AND 6G NETWORK

Features	5G NR	6G
Peak data rates	20Gbps	~1 Tbps
Latency	1ms	Less than 1ms
Area traffic capacity	10Mb/s/m^2	1Gb/s/m^2
Frequency bands	Sub 6GHz mmWave (24-52.6 GHz)	Sub 6GHz mmWave band Terahertz band (Visible light band)
Connection density	1M devices/Km^2	10M devices/Km^2
Device Services	Reliable connectivity of devices.	Physical interaction in real-time scenarios.
Network Type	SDN, NFV, Slicing	SDN, NFV, Intelligent cloud, AI-based Slicing. Machine Learning, Deep Learning.
Computing Technique	Fog Computing, cloud computing	Quantum Computing, Edge computing
Mobility	500 Km/h	> 700 Km/h
Technology	D2D communication, Ultra-dense Network, Relaying, Small Cell Access, NOMA.	Visible Light Communication, Quantum Communication, Hybrid Access, Haptic technology, Adaptive Resource Allocation.
Applications	360º Video, UHD video, AR, VR, IoT, Smart city, Smart Home.	Holographic imaging, Haptic communication, Telerobotics, Teledriving, AR/VR/XR, Tele-education, Internet of Everything

Thank you