Seminario

5G: standardizzazione, aspetti di sicurezza e la strada verso il 6G

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5G:standardizzazione ed evoluzione

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3GPP e sua organizzazione

3GPP e sua organizzazione

- **Cosa è il 3GPP ?**
- 3GPP, **3rd Generation Partnership Project** è una collaborazione industriale che gestisce gli standard per i sistemi di comunicazioni mobili attuali e futuri.
  - Inizialmente incentrato sulla tecnologia 3G UMTS
  - Sin dal momento della sua nascita il 3GPP si è anche occupato del GSM cosi come del 4G LTE, e ora del 5G.
- **Obiettivo del 3GPP**
  - Il 3GPP, gestisce una varietà di standard ed essenzialmente si occupa degli standard emersi da GSM e UMTS. Questi includono:
    - GSM e tecnologie 2G / 2.5G inclusi GPRS e EDGE.
    - UMTS e gli standard 3G incluso lo HSPA
    - LTE e tutti gli standard 4G
    - L'evoluzione del IP Multimedia Subsystem (IMS) sviluppato in modo indipendente dalla rete di accesso
    - 5G standard
- **3GPP location**
  - 3GPP è la ''somma'' di un gran numero di organizzazioni, ha una sede centrale e uno staff permanente.
  - Il team di supporto 3GPP, noto come Mobile Competence Center, si trova presso gli uffici dell'European Telecommunications Standards Institute, ETSI, a Sophia-Antipolis, vicino a Nizza, nel sud della Francia.

- All'inizio, 3GPP era incentrato sull'Europa, ma nel corso degli anni 3GPP è cresciuto anche a livello internazionale ed è ora riconosciuto come l'ente principale per lo sviluppo di ulteriori standard di telecomunicazioni mobili, come dimostrato dal fatto che è responsabile dello Standard 5G.

Partner dell'organizzazione 3GPP

- Sono istituzioni operanti a livello regionale e provenienti da tutto il mondo.
- **Obiettivi:**
  - definire la politica e la strategia generale del 3GPP, nonché intraprendere una serie di altri compiti specifici.
- Lista dei partner del 3GPP

3GPP Organizational Partners		
Organization	**Originating region**	
ARIB	Association of Radio Industries and Businesses	Japan
ATIS	Alliance for Telecommunications Industry Solutions	USA
CCSA	China Communications Standards Association	China
ETSI	European Telecommunications Standards Institute	Europe
TSDI	Telecommunications Standards Development Society India	India
TTA	Telecommunications Technology Association	Korea
TTC	Telecommunication Technology Committee	Japan

Rappresentanti del mercato all’interno del 3GPP

- Nel 3GPP sono inclusi partner che rappresentano il mercato; essi possono essere invitati dai partner organizzativi e prendere parte alle attività 3GPP.
- **Obiettivi:** forniscono un prezioso supporto su numerose tematiche tra cui l’orientamento del mercato sui requisiti per gli attuali e per i nuovi sistemi radiomobili
  - **La valutazione dei requisiti** è importante per lo sviluppo di un nuovo standard come il 5G; tenere conto delle richieste del mercato è importante per la funzione del 3GPP.
- I partner in rappresentanza del mercato **non hanno la capacità ne l'autorità** per definire o pubblicare standard nell'ambito del 3GPP.
- L’elenco dei **Market Representation Partners** nel 3GPP è indicato a lato

3GPP Market Representation Partners
Organization
IMS Forum
TD-Forum
GSA
GSM Association
IPV6 Forum
UMTS Forum
4G Americas
TD SCDMA Industry Alliance
InfoCommunication Union
Small Cell Forum (formerly Femto Forum)
CDMA Development Group
Cellular Operators Association of India (COAI)
Next Generation Mobile Networks (NGMN)
TETRA and Critical Communications Association (TCCA)

Inoltre per rappresentare gli interessi dell'industria e di tutti coloro che sviluppano gli standard di comunicazione mobile, il 3GPP ha collegamenti con molte manifatturiere operanti nel settore delle telecomunicazioni. In generale, il 3GPP opera ascoltando anche le principali organizzazioni del settore, nonché le principali aziende che sviluppano la tecnologia e, non da ultimi, associazioni che rappresentano gli utenti.

Modalità di lavoro del 3GPP

- The work carried out by 3GPP is undertaken in various Technical Specifications Groups, (TSGs) and **Working Groups**, (WGs) inside the TSGs.
- **Objectives:** **the work undertaken by 3GPP in updating and maintaining the standards for existing technologies as well as introducing new technologies is undertaken by Technical Specifications Groups, TSGs and under these are Working Groups, WGs.**
- In total there are **four** 3GPP Technical Specifications Groups, or TSGs, each of which consists of **multiple Working Groups, WGs**.
- Each 3GPP Technical Specification Group is structured with a hierarchy to enable it to function in an organised fashion.

3GPP Technical Specification Groups and Working Groups

Project Co-ordination Group (PCG)

TSG GERAN ** GSM EDGE Radio Access Network	**TSG RAN** Radio Access Network	**TSG SA** Service & Systems Aspects	**TSG CT** Core Network & Terminals
GERAN WG1 ** Radio Aspects	RAN WG1 Radio Layer 1	SA WG1 Services	CT WG1 MM/CC/SM (Iu)
GERAN WG2 ** Protocol Aspects	RAN WG2 Radio Layer 2 spec Radio Layer 3 RR spec	SA WG2 Architecture	CT WG3 Interworking with external networks
GERAN WG3 ** Terminal testing	RAN WG3 Iu spec, Iub spec, Iur spec, UTRAN O&M requirements	SA WG3 Security	CT WG4 MAP/GTP/BCH/SS
	RAN WG4 Radio performance, protocol aspects	SA WG4 Codec	CT WG6 Smart card application elements
	RAN WG5 Mobile terminal conformance testing	SA WG5 Telecom management	
	RAN WG6 Legacy RAN radio and protocol / GSM EDGE Radio Access Network	SA WG6 Mission critical applications	

3GPP: gruppi di lavoro per la definizione delle specifiche tecniche (TSG)

- **Project Co-ordination Group, PCG**
  - The 3GPP Project Coordination Group is the body that oversees the work of the 3GPP Technical Specifications Groups and the Working Groups.
  - The **Project Coordination Group** meets formally every six months. In these meetings it undertakes a number of functions including:
    - **final adoption of 3GPP Technical Specification Group work items**,
    - ratification of election results;
    - ratification of the 3GPP resources.
  - The PCG manages the various Specifications Group areas.
- **Technical Specification Groups**
  - **TSG RAN**
    - The RAN or Radio Access Network specifications groups are known as TSG RAN. This is split into **six working groups**: RAN WG1 to RAN WG6 (shortened to just **RAN1 to RAN6**)
    - The TSG RAN is **responsible for the definition of the functions, requirements and interfaces associated with the radio access network**, i.e. UTRA / E-UTRA in both FDD and TDD modes.
    - TSG RAN **encompasses both user equipment and base station functionality** addressing areas **including radio performance, physical layer, layer 2 and layer 3 RR specification in UTRAN/E-UTRAN**; specification of the access network interfaces (Iu, Iub, Iur, S1 and X2); definition of the O&M requirements in UTRAN/E-UTRAN.
    - TSG RAN **also addresses the conformance testing** of both the UE and the Base Stations to ensure complete interoperability regardless of the manufacturer / designer of the equipment.

3GPP: i gruppi di lavoro per le specifiche tecniche (TSG) (cont.)

- **TSG SA**
  - The **Service and System Aspects** Working Group is known as TSG SA.TSG SA is responsible for the **overall architecture and service capabilities of systems based on 3GPP specifications and, as such, has a responsibility for cross TSG coordination**.
  - There are **six working groups** known as SA WG1 to SA WG6. Again these are often referred to as just **SA1 to SA6**.
  - Each working group is responsible for a different area of the services and systems: SA1 - Services; SA2 - Architecture; SA3 - Security; SA4 - Codec; SA5 - Telecom management; and SA6 - Mission critical applications.
- **TSG CT**
  - The TSG CT is the working group that addresses the **Core Network and Terminals**.
  - In this **role it is responsible for specifying terminal interfaces** (logical and physical), **terminal capabilities** (such as execution environments) and the **Core network part** of 3GPP systems.
- **TSG GERAN**
  - The TSG GERAN assesses the legacy requirements for the GSM / EDGE networks that are still active. As GSM has been particularly successful since its introduction in the early 1990s, it has been necessary to retain the TSG GERAN.
  - TSG GERAN is responsible for the **specification of the Radio Access part of GSM/EDGE**

- **Since 3GPP has an organised set of TSGs and WGs with defined roles, it is possible for the different areas to work separately and undertake the work without fear of overlap.**
- **Needless to say there is a lot of cooperation and coordination still required between the different TSGs and WGs.**

Documenti 3GPP: tipo e numerazione

- All 3GPP specifications have a specification number consisting of 4 or 5 digits. (e.g. 09.02 or 29.002).
- The first two digits define the series, followed by 2 further digits for the 01 to 13 series or 3 further digits for the 21 to 55 series. The full title, specification number and latest version number for every specification can be found in the current status list.
- Si distingue in **"Type" indicates Technical Specification (TS) or Technical Report (TR).**
- Technical Reports are of two classes:
  - Those intended to be transposed and issued by the Organizational Partners as their own publications;
  - Those not intended for publication but which are simply 3GPP internal working documents
- The first category have numbers of the form: **xx.9xx**, the second category have numbers of the form: xx.8xx (feasibility study reports, etc) or, more rarely, 30.xxx / 50.xxx (planning and scheduling)
  - For some spec series, the stock of xx.8xx TRs has been exhausted, and in these cases, further internal TRs are allocated xx.7xx numbers.
- The 3GPP Specifications are stored on the file server as zipped MS-Word files. The filenames have the following structure:

SM[-P[-Q]]-V.zip

- The character fields have the following significance
  - S = series number - 2 characters (see the table)
  - M = mantissa (the part of the spec number after the series number) - 2 or 3 characters (see above)
  - P = optional part number - 1 or 2 digits if present
  - Q = optional sub-part number - 1 or 2 digits if present
  - V = version number, without separating dots - 3 digits (6 digits when any component of the three-digit range has been exhausted)
- So for example:
  - 21900-320.zip is 3GPP TR 21.900 version 3.2.0
  - 0408-6g0.zip is 3GPP TS 04.08 version 6.16.0
  - 32111-4-410 is 3GPP TS 32.111 part 4 version 4.1.0
  - 29998-04-1-100 is 3GPP TS 29.998 part 4 sub-part 1 version 1.0.0
  - 29898-133601 is 3GPP TR 29.898 version 13.36.1

Subject of specification series	3G and beyond / GSM (R99 and later)	GSM only (Rel-4 and later)	GSM only (before Rel-4)
General information (long defunct)			00 series
Requirements	21 series	41 series	01 series
Service aspects ("stage 1")	22 series	42 series	02 series
Technical realization ("stage 2")	23 series	43 series	03 series
Signalling protocols ("stage 3") - user equipment to network	24 series	44 series	04 series
Radio aspects	25 series	45 series	05 series
CODECs	26 series	46 series	06 series
Data	27 series	47 series (none exists)	07 series
Signalling protocols ("stage 3") -(RSS-CN) and OAM&P and Charging (overflow from 32.- range)	28 series	48 series	08 series
Signalling protocols ("stage 3") - intra-fixed-network	29 series	49 series	09 series
Programme management	30 series	50 series	10 series
Subscriber Identity Module (SIM / USIM), IC Cards. Test specs.	31 series	51 series	11 series
OAM&P and Charging	32 series	52 series	12 series
Access requirements and test specifications		13 series (1)	13 series (1)
Security aspects	33 series	(2)	(2)
UE and (U)SIM test specifications	34 series	(2)	11 series
Security algorithms (3)	35 series	55 series	(4)
LTE (Evolved UTRA), LTE-Advanced, LTE-Advanced Pro radio technology	36 series	-	-
Multiple radio access technology aspects	37 series	-	-
Radio technology beyond LTE	38 series	-	-

Specifiche rilasciate dal 3GPP: le release

- The 3GPP standards undergo continuous change. **To ensure that there is an organised release of new functionality, new releases of the standards occur at planned times.**
- For the new 3GPP releases, there is a **schedule of releases** which contained set introductions of new functionality and **this represents the work of the various Technical Specifications Groups and Working Groups.**
- The first 3GPP releases were termed Phase 1 and Phase 2. After this the releases were given the year of the anticipated releases, but after Release 99, they reverted to specific release numbers. Release 4 was also known as 3GPP Release 2000.
- **3GPP Release topics**
  - 3GPP Phase 1 reflected the first introduction of GSM. Work on GSM was the main focus through until Release 98.
  - 3GPP Release 99 was the first release of the UMTS / WCDMA standard, and work on this proceeded with the introduction of HSDPA, the HSUPA to form HSPA.
  - 3GPP Release 8 saw the first introduction of LTE and this was steadily updated with enhancements of LTE with LTE-A and improvements to many areas.
  - Moving on, 3GPP Release 14, Release 15, and Release 16 will include the 5G technologies. Initially 3GPP Release 14 will include elements that build towards 5G, the next two including the actual specifications for it.
- **3GPP Release schedule and summary**
  - The table gives the approximate dates and some of the salient features of the different 3GPP Releases for their standards.

Note: each release updates all the 3GPP standards - even the GSM standards are being updated in the various 3GPP Releases. The 3GPP standards and specifications cover all aspects of the cellular / mobile communications systems from the radio access network to the network, billing, authentication and much more.

3GPP Releases		
3GPP Release	**Release date**	**Details**
Phase 1	1992	Basic GSM
Phase 2	1995	GSM features including EFR Codec
Release 96	Q1 1997	GSM Updates, 14.4 kbps user data
Release 97	Q1 1998	GSM additional features, GPRS
Release 98	Q1 1999	GSM additional features, GPRS for PCS 1900, AMR, EDGE
Release 99	Q1 2000	3G UMTS incorporating WCDMA radio access
Release 4	Q2 2001	UMTS all-IP Core Network
Release 5	Q1 2002	IMS and HSDPA
Release 6	Q4 2004	HSUPA, MBMS, IMS enhancements, Push to Talk over Cellular, operation with WLAN
Release 7	Q4 2007	Improvements in QoS & latency, VoIP, HSPA+, NFC integration, EDGE Evolution
Release 8	Q4 2008	Introduction of LTE, SAE, OFDMA, MIMO, Dual Cell HSDPA
Release 9	Q4 2009	WiMAX / LTE / UMTS interoperability, Dual Cell HSDPA with MIMO, Dual Cell HSUPA, LTE HeNB
Release 10	Q1 2011	LTE-Advanced, Backwards compatibility with Release 8 (LTE), Multi-Cell HSDPA
Release 11	Q3 2012	Heterogeneous networks (HetNet), Coordinated Multipoint (CoMP), In device Coexistence (IDC), Advanced IP interconnection of Services,
Release 12	March 2015	Enhanced Small Cells operation, Carrier Aggregation (2 uplink carriers, 3 downlink carriers, FDD/TDD carrier aggregation), MIMO (3D channel modelling, elevation beamforming, massive MIMO), MTC - UE Cat 0 introduced, D2D communication, eMBMS enhancements.
Release 13	Q1 2016	LTE-U / LTE-LAA, LTE-M, Elevation beamforming / Full Dimension MIMO, Indoor positioning, LTE-M Cat 1.4MHz & Cat 200kHz introduced
Release 14	Mid 2017	Elements on road to 5G
Release 15	End 2018	5G Phase 1 specification
Release 16	2020	5G Phase 2 specification
Release 17	~Sept 2021	

5G

Percorso di standardizzazione del 5G

Requisiti e caratteristiche del 5G

5G: percorso di standardizzazione nel 3GPP

- **Release 14:**
  - Elementi sulla strada del 5G -> inizia la standardizzazione della interfaccia radio 5G NR; attività conclusa a dicembre 2017 e ripresa nella Release 15
- **Release 15** (conclusa a fine 2018):
  - **Specifiche del 5G: fase 1**
- **Release 16** (conclusione a dicembre 2020 causa shift temporale di 3 mesi):
  - **Specifiche del 5G: fase 2**
- **Release 17** (Termine settembre 2021):
  - Rilasciato il piano delle attività per la release 17; le attività sul 5G proseguono secondo un percorso evolutivo

Requisiti del 5G: dalla specifica ITU IMT2020

- Outline requirements were set in place by the ITU as part of IMT2020. Even now with 5G as an active mobile communications system, it is useful to refer to these requirements.
- Specifiche di prestazione recepite dal 3GPP

Suggested 5G Wireless Performance	
Parameter	**Suggested Performance**
Peak data rate	At least 20Gbps downlink and 10Gbps uplink per mobile base station. This represents a 20 fold increase on the downlink over LTE.
5G connection density	At least 1 million connected devices per square kilometre (to enable IoT support).
5G mobility	0km/h to "500km/h high speed vehicular" access.
5G energy efficiency	The 5G spec calls for radio interfaces that are energy efficient when under load, but also drop into a low energy mode quickly when not in use.
5G spectral efficiency	30bits/Hz downlink and 15 bits/Hz uplink. This assumes 8x4 MIMO (8 spatial layers down, 4 spatial layers up).
5G real-world data rate	The spec "only" calls for a per-user download speed of 100Mbps and upload speed of 50Mbps.
5G latency	Under ideal circumstances, 5G networks should offer users a maximum latency of just 4ms (compared to 20ms for LTE).

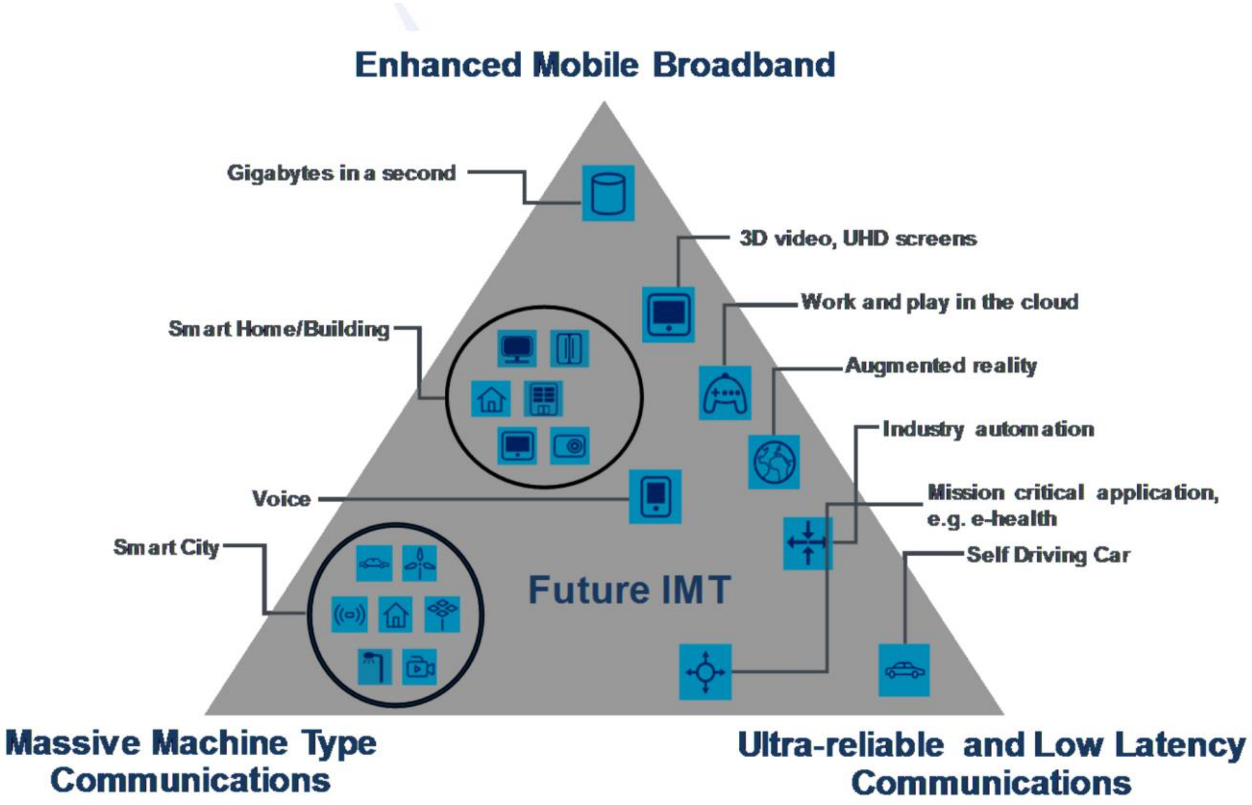
Classificazione dei servizi per la rete 5G (ITU)

- eMBB (enhanced Mobile Broadband)
- URLLC (Ultra Reliable Low Latency Communications)
- mMTC (massive Machine Type Communications)

Requirements for the network for 5G are very different and contrasting.

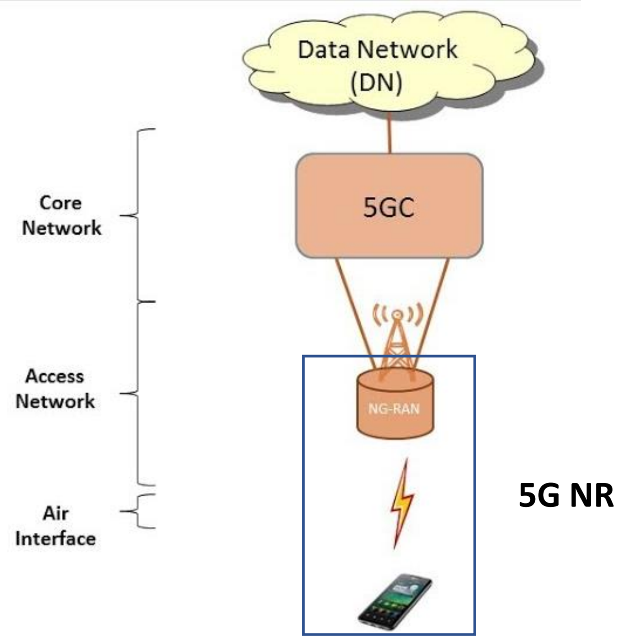
- ***Very high bandwidth communications*** are needed,
- in other applications there is a need for ***exceedingly low latency***, and
- there are also ***requirements for low data rate communications*** for machine to machine and IoT applications.

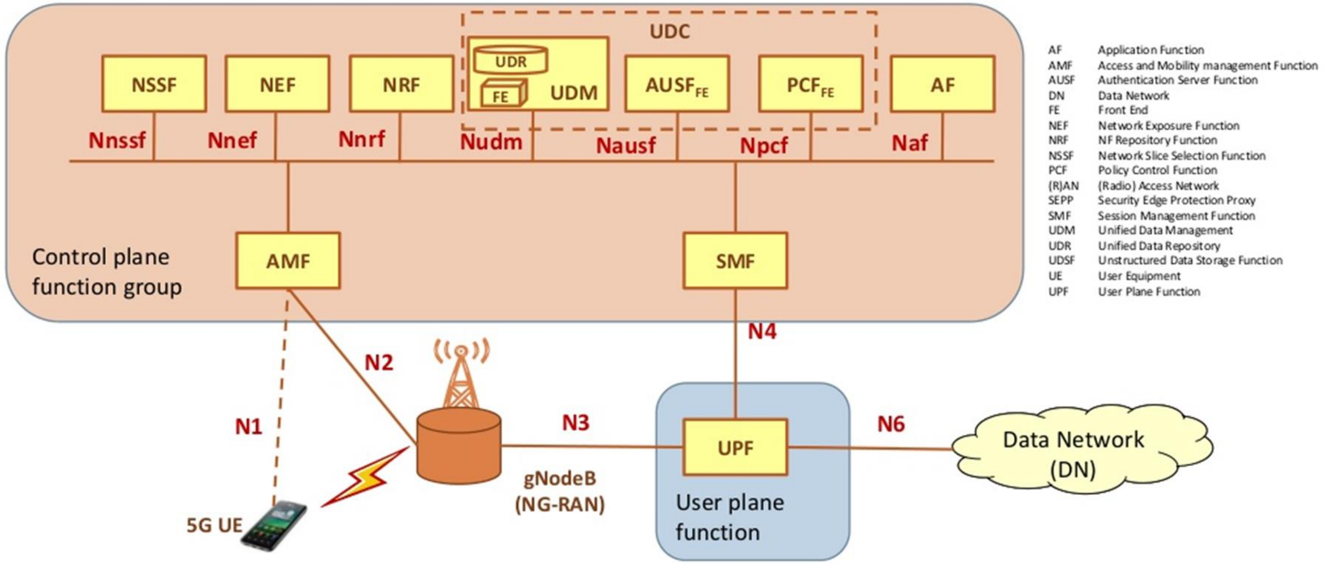
In amongst this there will be **normal voice** communications, **Internet surfing and all the other applications that we have used and become accustomed to using**.



Elementi del sistema 5G

- Main innovations in the 5G mobile cellular communications are:
- ***5G New Radio, 5G NR:***
    - 5G new radio is the new name for the **5G radio access network and radio interface**.
    - It consists of the different elements needed for the new radio access network (gNB).
    - It is able to respond to the different and changing needs of mobile users whether they be a small IoT node, or a high data user, stationary or mobile.
- ***5G NextGen Core Network (5GC):***
    - Initial deployments of 5G utilizes the core network of LTE or possibly even 3G networks (NSA),
    - The 5G core network moves to a much flexible structure to provide the **data capability** and **low latency** needed (SA).





5G-NR: nuove tecnologie supportate sulla rete di accesso

- 5G incorporates many technologies, many of which are new, to enable the it to provide the very high levels of performance required of it.
- Some technologies for 5G mobile communications include:
  - ***Waveforms & modulation:***
    - One of the major discussions when 5G was being developed was based around the type of waveform to be used.
    - In the end the scheme was based around OFDM: Scalable OFDM with numerology for both uplink and downlink transmissions
  - ***Millimetre-Wave communications:***
    - Millimetre wave mobile communications was not implemented for the initial deployments of the 5g mobile communications system as the technology for cost effective millimetre wave communications had not been sufficiently developed.
    - The use of mmWave for 5G mobile communications will require a large number of base stations to give the required coverage.
  - ***Massive MIMO with beam-steering (especially for mmWave):***
    - The antenna technologies for 5G have provided significant opportunities for enhancement of the performance over 4G. Although MIMO was used with 4G LTE, the technology has been taken further.
    - Beam-steering technology has also been adopted to enable the transmitter and receiver antenna beams to be focussed towards the mobiles with which they are communicating. Each mobile can have its own beam, using advanced antenna technology, and this focussed the transmitted power where it is required and reduces interference between mobiles. This gives a significant improvement in performance.
  - ***Dense networks:***
    - Reducing the size of cells provides a much more overall effective use of the available spectrum. Whilst the large macro cells will be retained for general communications, many more small cells will be deployed **to ensure that the data capacity can be provided**.
    - The use of smaller cells gives **much greater frequency re-use** and as a result the overall network can **provide a significantly increased level of data capacity**. As data usage is increasing rapidly, this is a clear and pressing requirement.

Range di frequenze per il 5G e caratteristiche dei segnali 5G

- Two different frequency ranges are available for the 5G technology and the different ranges have been designated
    - **FR1 - frequency range 1**
    - **FR2 - frequency range 2.**
- The bands in frequency range 1, FR1 are envisaged to carry much of the traditional cellular mobile communications traffic.
- The higher frequency bands in range FR2 are aimed at providing short range very high data rate capability for the 5G radio.
    - With 5G wireless technology anticipated to carry much higher speed data, the additional bandwidth of these higher frequency bands will be needed.
- Signal parameters for FR1 and FR2 are indicated in the second Table

Frequency Ranges, FR1 & FR2 for 5G NR	
Frequency range designation	**Frequency Range (MHz)**
FR1	410 - 7 125
FR2	24 250 - 52 600

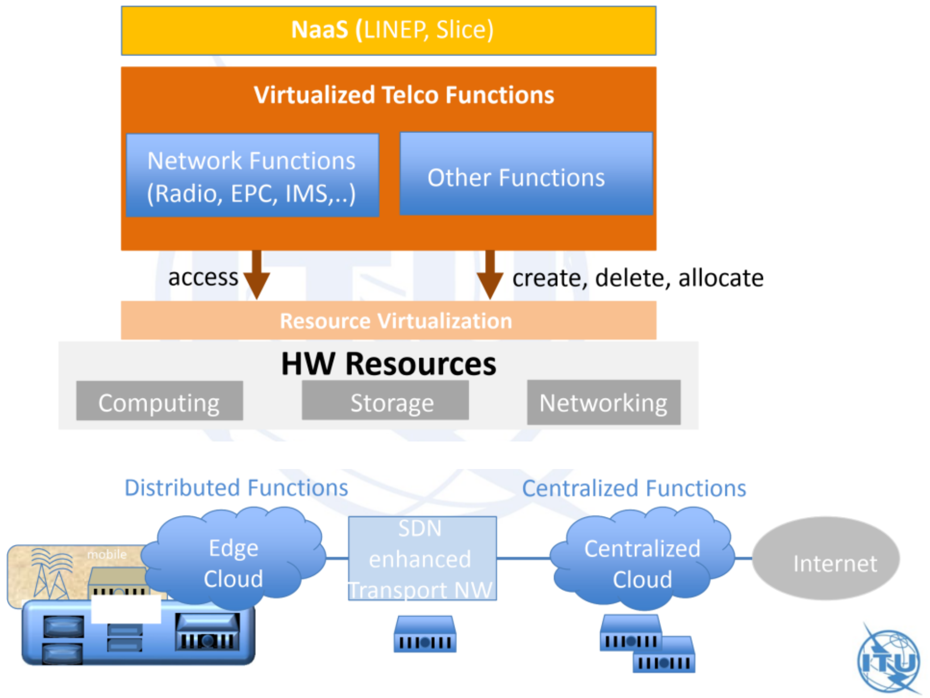
SC-OFDM

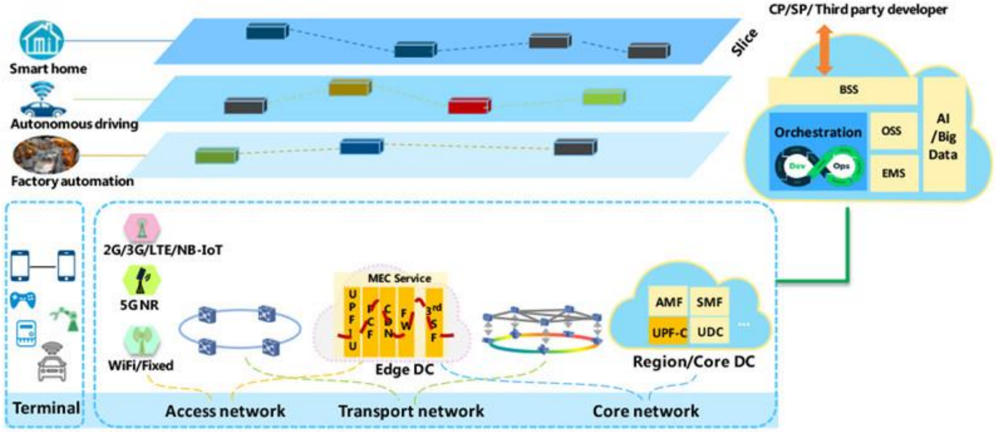
5G NR Parameters for Different Frequency Bands		
5G NR Parameter	**FR1**	**FR2**
Bandwidth options per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 kHz
Maximum number of subcarriers	3300 (FFT 4096)	
Carrier Aggregation	Up to 16 carriers	
Moodulation schemes	QPSK, 16QAM, 64QAM, 256QAM,	
Radio frame length	10ms	
Subframe duration	1ms	
Duplex mode	FDD, TDD	TDD
Multiple access scheme	Downlink: SC-OFDM Uplink: SC-OFDM	
MIMO scheme	maximum of 2 codewords mapped to maximum of 8 layers in downlink and to a maximum of 4 in uplink.	

5G: il nucleo di rete 5GC di nuova generazione

- **5G NextGen NG core network basics**
- The 5G NextGen network will need to accommodate a huge diversity in types of traffic and it will need to be able to accommodate each one with great efficiency and effectiveness.
- To achieve the requirements for the 5G network (IMT2020) a number of techniques are being employed so to render the 5G network considerably more scalable, flexible and efficient.
  - ***Software defined networking, SDN:*** Using software defined networks, it is possible to run the network using software rather than hardware. This provides significant improvements in terms of flexibility and efficiency
  - ***Network functions virtualisation, NFV :*** When using software defined networks it is possible to run the different network function purely using software. This means that generic hardware can be reconfigured to provide the different functions and it can be deployed as required on the network.
  - ***Network slicing:*** As 5G will require very different types of network for the different applications, a scheme known as network slicing has been devices.
    - Using SDN and NFV it will be possible to configure the type of network that an individual user will require for his application. In this way the same hardware using different software can provide a low latency level for one user, whilst providing voice communications for another using different software and other users may want other types of network performance and each one can have a slice of the network with the performance needed.

ITU - IMT2020





5G: fase 1

- Release 15

Release 15

- NR
- The 5G System – Phase 1
- Massive MTC and Internet of Things (IoT)
- Vehicle-to-Everything Communications (V2x) Phase 2
- Mission Critical (MC) interworking with legacy systems
- WLAN and unlicensed spectrum use
- Slicing – logical end-2-end networks
- API Exposure – 3rd party access to 5G services
- Service Based Architecture (SBA)
- Further LTE improvements
- Mobile Communication System for Railways (FRMCS)

After initial delivery in late 2017 of 'Non-Stand-Alone' **(NSA) NR new radio** specifications for 5G, much effort focused in 2018 on timely completion of 3GPP Release 15 – the first full set of 5G standards – and on work to pass the first milestones for the 3GPP submission towards IMT-2020.

Initial specifications enabled non-standalone (NSA) 5G radio systems integrated in previous-generation LTE networks.

- The scope of Release 15 has been to expand 5G so to cover 'standalone' 5G **(SA), with a new radio system complemented by a next-generation core network**.

It also embraces enhancements to LTE and, implicitly, the Evolved Packet Core (EPC).

- This crucial way-point enables vendors to progress rapidly with chip design and
- initial network implementation during 2019.

5G NR nella release 15

- **Actual status of 5G NR in accordance with release 15**
  - Release 15 has introduced innovations (**revolutionary**) defining 5G-NR,
  - **In the following releases we will assist to the 5G evolution**
  - A main characteristic of NR is the substantial expansion in terms of the range of spectrum in which the radio-access technology can be deployed, **with operation from below 1 GHz up to more than 40 GHz**
  - This spectrum flexibility is enabled by a scalable OFDM numerology and inherent support for massive beamforming.
  - Further reduced latency (compared to, for example, LTE), enabled by:
    - **Shorter slots:** possibility for transmission over part of a slot, sometimes referred to as "mini-slot" transmission
    - **Faster Hybrid ARQ retransmissions**
    - **Possibility for tight interworking with LTE including LTE/NR dual-connectivity** (simultaneous connectivity via LTE and NR) as well as spectrum co-existence (the possibility to deploy NR on top of LTE in the same spectrum).
      - The latter is enabled by the OFDM-based transmission scheme with an LTE-compatible (15 kHz-based) numerology
  - **MIMO to increase spectral efficiency**
    - Support of beam-based operation, which is required for mmWaves
    - Scalable and flexible CSI codebook with up to 32 ports and an RS design including CSI-RS, DMRS and SRS.
      - CSI type I codebook providing basic closed-loop MIMO support
      - CSI type II (high resolution) codebook which brings significant gain (at least 30%) over LTE and fits Multi-User-MIMO (MU-MIMO) operation.

5G: fase 2

- Release 16

Release 16

- **The 5G System – Phase 2**
- **V2x Phase 3:** Platooning, extended sensors, automated driving, remote driving
- **Industrial IoT**
- **Ultra-Reliable and Low Latency Communication (URLLC) enh.**
- **NR-based access to unlicensed spectrum (NR-U)**
- **5G Efficiency:** Interference Mitigation, SON, eMIMO, Location and positioning, Power Consumption, eDual Connectivity, Device capabilities exchange, Mobility enhancements
- **Integrated Access and Backhaul (IAB)**
- **Enh. Common API Framework for 3GPP Northbound APIs (eCAPIF)**
- **Satellite Access in 5G**
- **Mobile Communication System for Railways (FRMCS Phase 2)**

In addition to that formal process, work has progressed on Release 16 studies, on a variety of topics such as:

- *Multimedia Priority Service,*
- *Vehicle-to-everything (V2X) application layer services,*
- *5G satellite access (continua nella release 17),*
- *Local Area Network support in 5G,*
- *wireless and wireline convergence for 5G,*
- *terminal positioning and location,*
- *communications in vertical domains and*
- *network automation and novel radio techniques.*

Further items being studied include security, codecs and streaming services, Local Area Network interworking, network slicing and the IoT.

5G: e la release 17

- Release 17 (Contenuti preliminari)

Release 17

- NR MIMO
- NR Sidelink enh.
- 52.6 - 71 GHz with existing waveform
- Dynamic Spectrum Sharing (DSS) enh.
- Industrial IoT / URLLC enh.
- Study - IoT over Non Terrestrial Networks (NTN)
- NR over Non Terrestrial Networks (NTN)
- NR Positioning enh.
- Low complexity NR devices
- Power saving
- NR Coverage enh.
- Study - NR eXtended Reality (XR)
- NB-IoT and LTE-MTC enh.
- 5G Multicast broadcast
- Multi-Radio DCCA enh.
- Multi SIM
- Integrated Access and Backhaul (IAB) enh.

- NR Sidelink relay
- RAN Slicing
- Enh. for small data
- SON / Minimization of drive tests (MDT) enh.
- NR Quality of Experience
- eNB architecture evolution, LTE C-plane / U-plane split
- Satellite components in the 5G architecture
- Non-Public Networks enh.
- Network Automation for 5G - phase 2
- Edge Computing in 5GC
- Proximity based Services in 5GS
- Network Slicing Phase 2
- Enh. V2x Services
- Advanced Interactive Services
- Access Traffic Steering, Switch and Splitting support in the 5G system architecture

- Unmanned Aerial Systems
- 5GC LoCation Services
- Multimedia Priority Service (MPS)
- 5G Wireless and Wireline Convergence
- 5G LAN-type services
- User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)

These are some of the Rel-17 headline features, prioritized during the December 2019 Plenaries (TSG#86)

Start of work: January 2020

Full details of the content of Rel-17 are in the Work Plan: www.3gpp.org/specifications/work-plan

Alcuni aspetti **evolutivi** del sistema 5G

Nella release 16

Evoluzione 5G NR nella release 16

- Release 16 is an evolutionary development targeting new verticals by improving the capacity and operation of existing features.
- The features being developed for NR Release 16 can be roughly divided into two groups, as seen in Table
  - Features **that expand NR to new verticals** such as the transport industry, industrial IoT, manufacturing, enterprise, automobile, etc.
  - Features **that enhance capacity and improve the operation efficiency of the wireless networks**

Vertical Expansion		Capacity and Operational Efficiency Enhancement	
• IIoT (Industrial IoT) • URLLC • 2-Step RACH	• NR Positioning • NR Unlicensed • V2X	• MIMO Enhancements • MR-DC • Integrated Access and Backhaul (IAB)	• Mobility Enhancements • cross link interference (CLI)/remote interference management (RIM) • UE Power Savings

MR-DC: multi RAT dual connectivity

Estensioni 5G NR: MIMO and Multiple Transmission-Reception (TRP)

- Enhancements to CSI type II codebook for MU-MIMO pre-coding support
  - Overhead reduction by compressing the CSI report in the frequency domain.
  - Extending the CSI type II codebook to rank larger than two.
- **Multi-beam operation enhancements** primarily targeting FR2 (*mmWaves*). This includes:
  - Reduced latency and overhead, by avoiding beam tracking via RRC
  - Beam failure recovery for Scell
  - Measurement and reporting of L1-SINR
- Multi-TRP transmission enhancements for different backhaul assumption (**ideal and non-ideal**) and for both inter-cell and intra-cell multi-TRP transmission.
- This includes:
  - Downlink control signaling for non-coherent joint transmission. Two designs are considered;
  - single PDCCH from one TRP scheduling PDSCH transmissions from multiple TRPs, and
  - multiple PDCCH with each TRP having one PDCCH transmission scheduling the corresponding PDSCH transmission, see Figure A
  - Uplink control signaling for supporting non-coherent joint transmission.
- Multi-TRP for URLLC. Figure B shows an example of how multiple TRPs can enhance reliability by replicating transmissions,
  - **if one TRP is blocked the signal can still be received from the other TRP**.
  - At most two TRPs can be used for simultaneous multi-TRP reception in Release 16

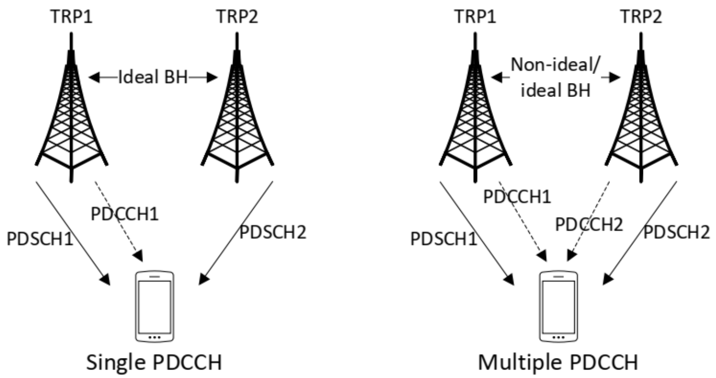


Figure A Support of single PDCCH and multiple PDCCH for Multi-TRP transmission.

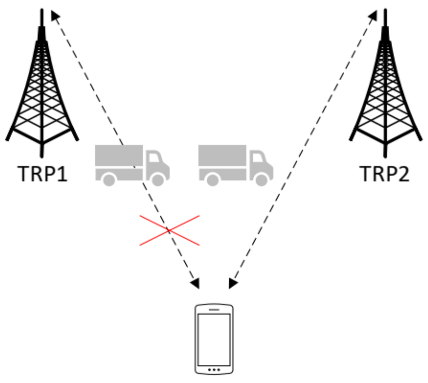
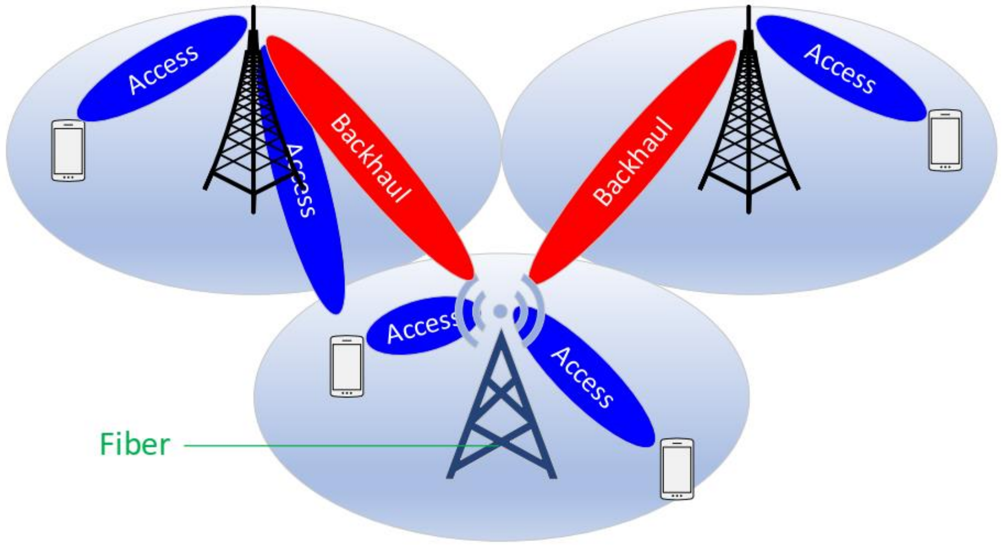
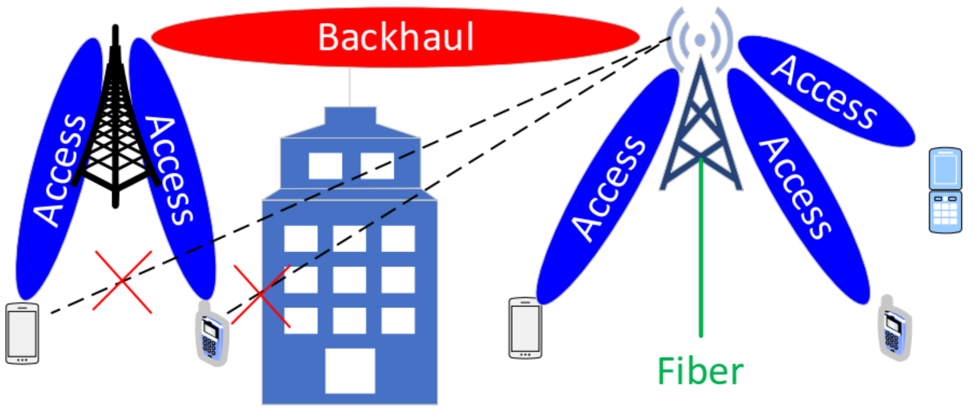


Figure B Multi-TRP for enhancing URLLC operation.

Integrated access backhaul (IAB) – Release 16

- Integrated Access and Backhaul supports wireless backhaul and relay links in-band or out-of-band with access links, as shown in Figure.
- **NR bandwidth can be split between access and backhaul links**, especially in mmWaves.
- The primary goals of IAB are:
  - **Improve capacity** by supporting networks with a higher density of access points in areas with only sparse fiber availability.
  - **Improve coverage** by extending the range of the wireless network and by providing coverage for isolated coverage gaps.
    - For example, if the UE is behind a building (as shown in Figure B), an access point can provide coverage to that UE with the access point being connected wirelessly to the donor cell.
  - **To bridge indoor to outdoor coverage**, for example, with an IAB access point on top of a building that serves users within the building.

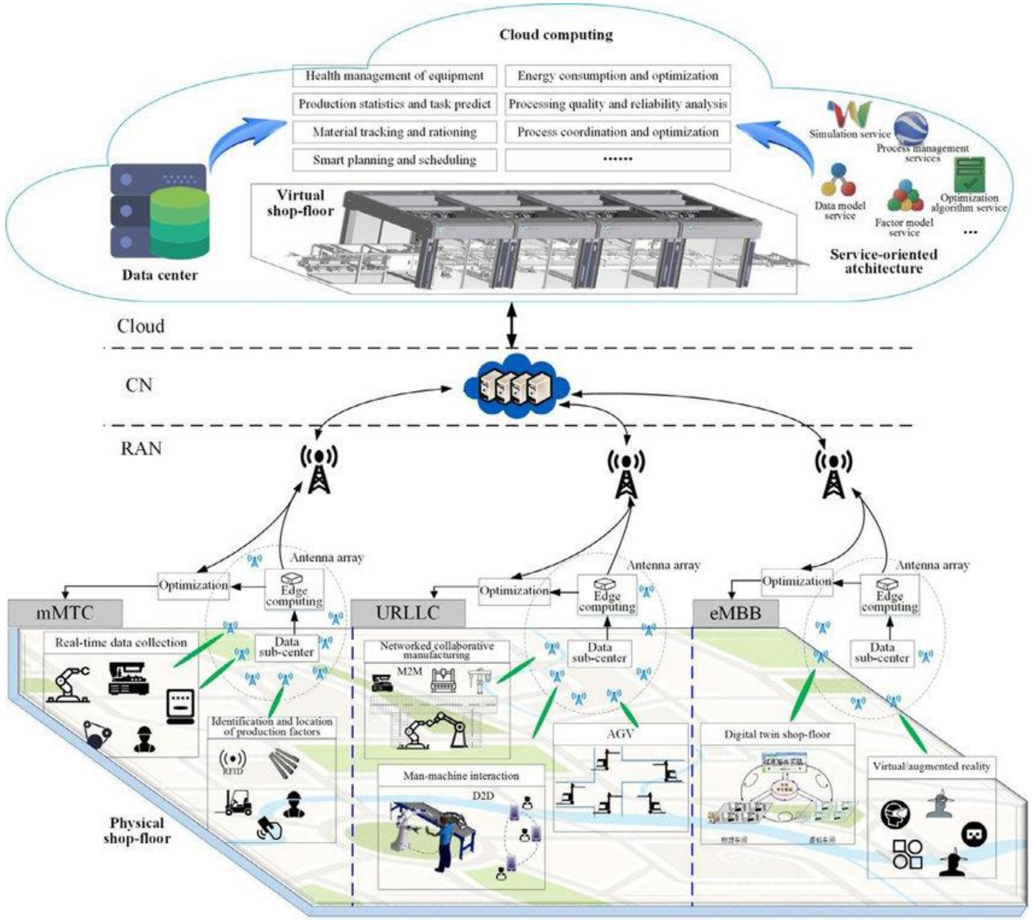




Note: a solution more like IAB was studied for LTE in 3GPP release 10 in 2011, also known as LTE relaying, but it never gained any **commercial interest**.

5G NR for the support of Industrial IoT – Release 16

- Industrial IoT has special communication requirements,
  - *high reliability*, *low latency*, *flexibility*, and (very important) *security*.
  - These are naturally provided by the 5G mobile technology, making it a successful candidate for supporting Industrial IoT (IIoT) scenarios.
- The motivation for the Release-16 work item Support of NR Industrial Internet of Things is to extend the applicability of NR to various verticals,
- This is achieved by increasing **the reliability of the Uu interface**, increasing *resource efficiency with duplication*, *better handling of high-priority traffic multiplexed with low-priority traffic in the same UE*, and *more efficient support of Time Sensitive Communications*.
  - To this purpose several mechanisms in the 5G-NR are updated in Release 16
  - The achievable latency and reliability performance of NR are keys to support use cases having tighter requirements.
- New Release 16 use cases with higher requirements to support:
  - Factory automation
  - Transport Industry (Ports, Airports)
  - Electrical Power Distribution



From ''Industrial IoT in 5G environment towards smart manufacturing'', J. Cheng, W. Chena, F. Taoa, C. Linb, Journal of Industrial Information Integration 10 (2018) 10–19

Someone ha developed solutions for 5G IIoT ?

- **Nokia announces first commercial 5G standalone (SA) private wireless networking solutions for enterprise customers (21-July 2020)**
  - Builds on foundation of more than 180 private wireless network customers worldwide
  - Provides 'direct to 5G' entry point for high-spec industrial use case validation and ecosystem development
- **And what about the connection with public networks ?**
  - A private 4.9 (LTE)/5G wireless network provides the pervasive connectivity you need to support critical applications within your industrial sites and field area networks.
  - If you need regional, nationwide or global coverage, **you can combine your private network with shared public network slices.**
  - **Nokia solution interacts seamlessly with public networks, which makes it easy to get the right network mix for your business.**

Aeroporti

Manifatturiere

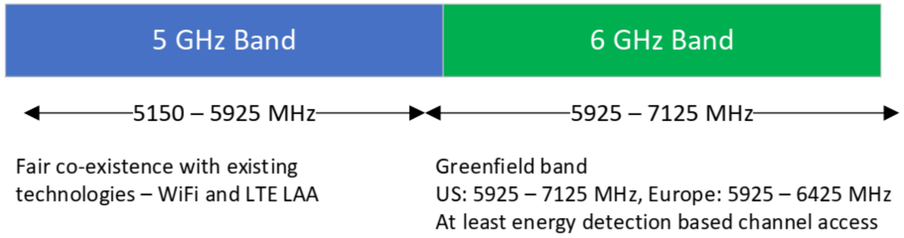
Utilities

Make smart grids genius, maintenance predictive and savings light up, while simplifying it all.

Porti

5G NR unlicensed (NR-U)

- Licensed spectrum may be the cornerstone of wireless mobile service to meet the service requirements for coverage, spectral efficiency, and reliability but unlicensed spectrum plays an important role in:
  - complementing licensed spectrum by boosting capacity and
  - improving data connectivity.
- Operation of a 3GPP-based system in unlicensed spectrum was first introduced in Release 13 in the form of license assisted access (LAA).
- The NR Unlicensed (NR-U) study and work items in Release 16 introduce NR to unlicensed frequency bands in the 5GHz and 6GHz frequency ranges of FR1
- The 5 GHz band is used by existing technologies such as Wi-Fi and LTE-based LAA.
  - In this band, the impact of NR-U on WiFi should not exceed that of an additional Wi-Fi network of the same generation on the same carrier.
- The 6GHz band is a greenfield band but lack regulatory requirements.
  - In the US, the 6 GHz band extends between 5925 – 7125 MHz,
  - in Europe, it extends between 5925 – 6425 MHz.
- In the 6 GHz band, the channel-access mechanism for NR-U will use energy detection for coexistence with other RATs sharing the same band, regulations permitting.



The NR-U can operate in one of two modes:

- **Standalone unlicensed access**, where NR operates in an unlicensed band with no assistance from a carrier in a licensed band,
- **License assisted access (LAA),** where the operation of NR in the unlicensed band makes use of a carrier in the licensed band for assistance, e.g. for control signaling.

The NR-U work item supports the following scenarios:

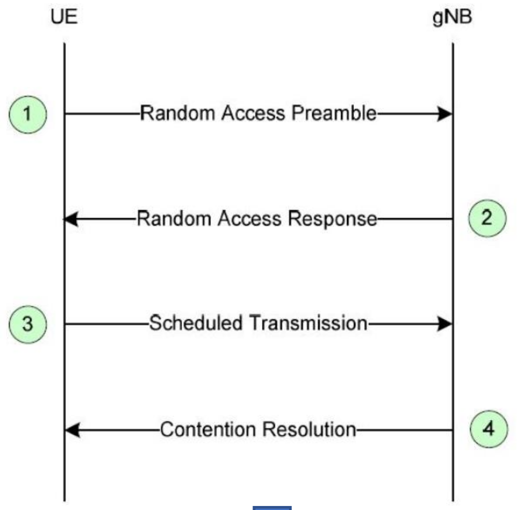
- **Scenario A:** Carrier aggregation in NR between licensed band (Pcell) and NR-U (Scell). The NR-U Scell may have both DL and UL or just DL. The NR Pcell is connected to 5GC.
  - This scenario improves NR capacity by adding more spectrum to NR.
- **Scenario B:** Dual connectivity between LTE in licensed band (Pcell) and NR-U (PSCell).
  - This scenario improves the capacity of LTE deployments.
- **Scenario C:** Standalone-NR-U connected to 5GC.
  - This scenario targets standalone deployments such as non-public networks.
- **Scenario D:** Standalone cell in unlicensed band connected to 5GC and UL in licensed band.
- **Scenario E:** Dual connectivity between NR in licensed band and NR-U, with the Pcell connected to 5G-CN.
  - This scenario improves NR capacity by adding more spectrum to NR.

Pcell: primary cell, Scell: secondary cell

5G: modifica procedura RACH: 2-steps RACH

- **RACH stands for Random Access Channel**, which is the first message from UE to eNB when it is powered on.
    - In terms of Radio Access Network implementation, handling RACH design can be one of the most important / critical portions.
- The contention-based random-access procedure from Release 15 is a four-step procedure, as shown in Figure A.
    - The UE transmits a contention-based PRACH preamble, also known as Msg1.
    - After detecting the preamble, the gNB responds with a random-access response (RAR), also known as Msg2.
    - The RAR includes the detected preamble ID, a time-advance command, a temporary C-RNTI (TC-RNTI), and an uplink grant for scheduling a PUSCH transmission from the UE known as Msg3. The UE transmits Msg3 in response to the RAR including an ID for contention resolution.
    - Upon receiving Msg3, the network transmits the contention resolution message, also known as Msg4, with the contention resolution ID. The UE receives Msg4, and if it finds its contention-resolution ID it sends an acknowledgement on a PUCCH, which completes the 4-step random access procedure.
- Modified 2-step RACH procedure
    - The motivation of two-step RACH is to reduce latency and control-signaling overhead by **having a single round trip cycle** between the UE and the base station.
    - This is achieved by combining the preamble (Msg1) and the scheduled PUSCH transmission (Msg3) into a single message (MsgA) from the UE, known as MsgA.
    - Then by combining the random-access respond (Msg2) and the contention resolution message (Msg4) into a single message (MsgB) from the gNB to UE
    - **Furthermore, for unlicensed spectrum, reducing the number of messages transmitted from the UE and the gNB, reduces the number of Listen Before Talk (LBT) attempt**

Attuale



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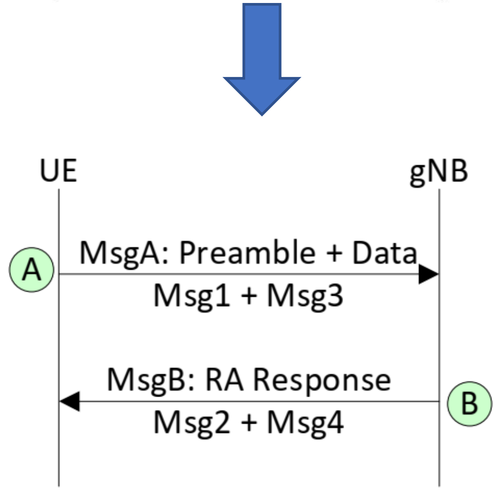


B

Problematiche legate al dispiegamento della rete 5G

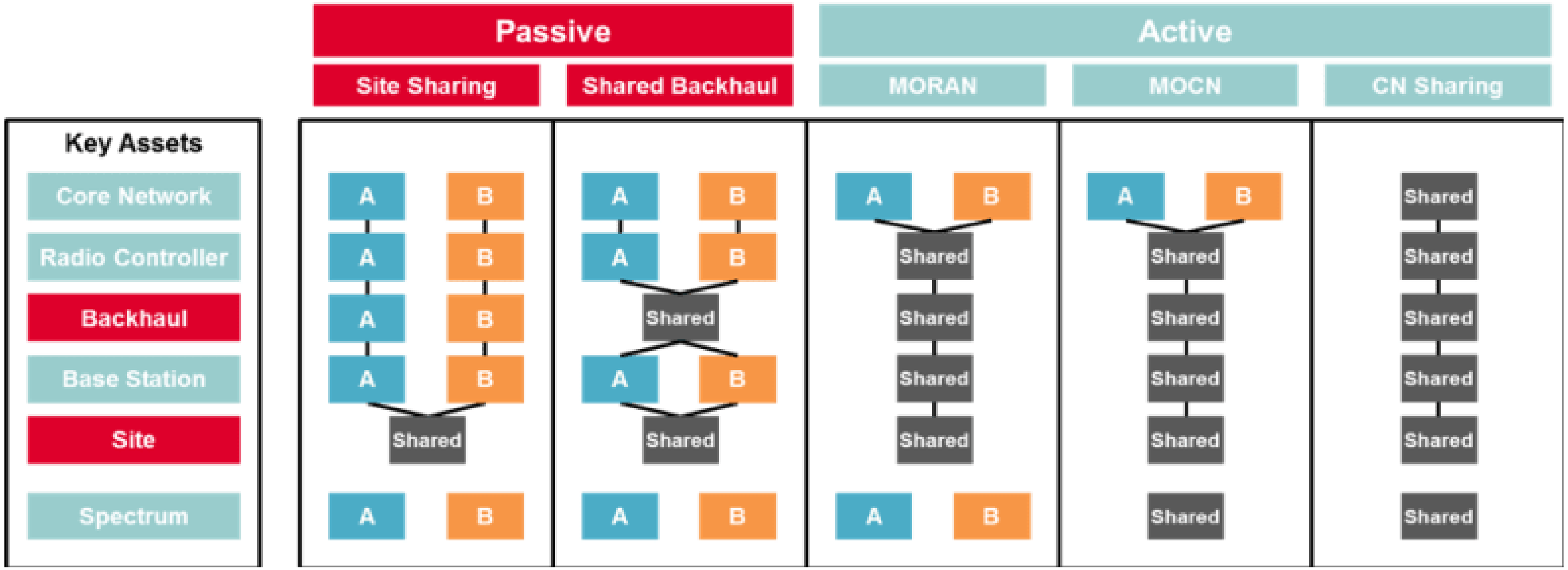
Condivisione della infrastruttura

Infrastructure sharing: main motivations

- **Difficulties in acquiring sites for access network (for a Telco but not for rail manager)**
  - Network densification to address coverage demands in indoor environments has led to increasing difficulties in acquiring sites for radio access network (namely, base stations).
- **Costs of 5G Deployments to meet throughput demand**
  - 5G networks are expected to incur a higher cost of deployment to meet throughput requirement and demand.
  - Radio access networks are the larger costs in network deployment and operation.
  - To meet mobile broadband demand, 5G is likely to be offered on higher frequency radio spectrum above 6GHz and mmWaves. **This means that cell offers smaller radius of coverage and so achieving widespread coverage may be challenging.**
- **Diverting investment to other innovation**
  - Although network infrastructure has been a key major asset, the introduction of smart devices has altered the mobile industry landscape and competition has been shifting from **infrastructure competitiveness** to **service competitiveness** (i.e. *rather than the performance of the network, it is more important for subscribers to use various services*).
  - Infrastructure sharing enables operators to focus on the competition in the service layer regardless of the extent of the sharing.
  - Operators can share whole or strategically unimportant parts of its infrastructure to share infrastructure costs while providing acceptable performance. Furthermore, these savings can facilitate mobile operators' migration to next-generation technologies and provide its customers with the latest technology available.
- **Cost effective means to address capacity demand growth**
  - Mobile operators are also under pressure to extend the capacity of the network due to the significant growth of traffic that is being handled by mobile networks, traffic that is expected to grow even further in the future. This means that the cost to handle traffic will increase and worsen the profitability of operators.
  - In this context, mobile operators need to employ cost-effective methods such that accommodation of the increased traffic does not require similar magnitude of growth in infrastructure cost. Traditional infrastructure deployment scheme can only bring limited cost reduction even under tight cost reduction pressure, but infrastructure sharing enable significant cost reduction for mobile network infrastructure deployment.
- **Social benefits**
  - Some regulators are encouraging infrastructure sharing of mobile operators because they believe that there are regulatory/social benefits that society can reap. Major social benefits come directly from the economic benefit, **where mobile operators can direct saved cost to the customer in pricing.** In addition, **infrastructure sharing can help reduce energy consumption and radio emissions of networks**.

Infrastructure sharing: technological view

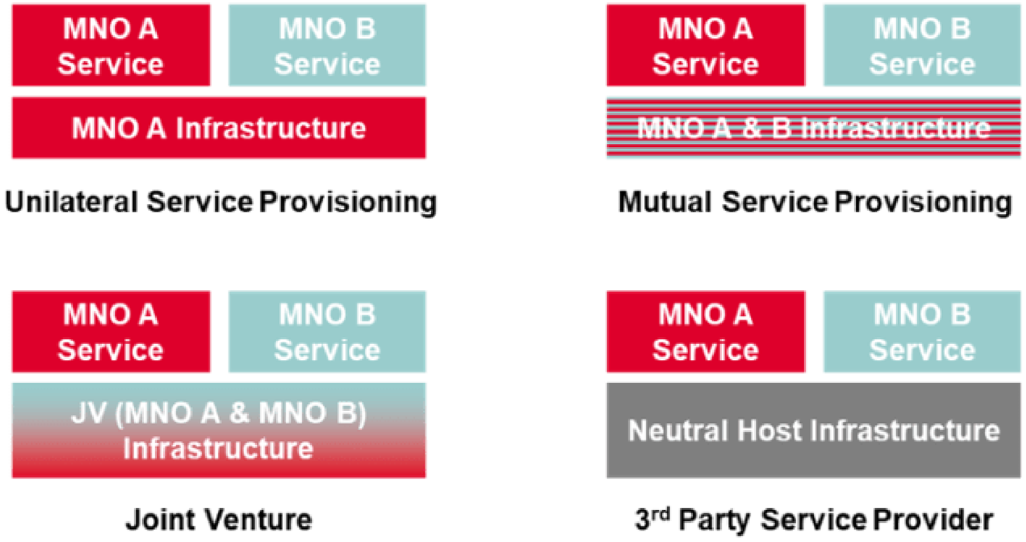
- The sharing deals can be classified depending on the **technological entity shared**, **business/ownership** assumed and **geographical distribution**.
- Most prevalent classification criterion for network sharing is **technology**.
- Options:



Legend:
- **MORAN** (Multi-Operator Radio Access Network)
- **MOCN** (Multi-Operator Core Network)

Infrastructure sharing: business/ownership view

- A different perspective of business/ownership can also classify infrastructure sharing agreements to four types.



Sharing form	Pros	Cons
Service provisioning (unilateral/mutual)	• Reduction in OPEX: removal of depreciation costs • Simpler to implement • Ownership still with operator	• Coordination of operation • Challenges in differentiation • Regulatory risks
Joint venture	• Reduced risk: fixed CAPEX is transferred to variable OPEX • Reduction in OPEX: reduced O&M costs • Cut down CAPEX cost for new deployment • Control over diverting cost savings to operators	• Coordination of operation and network deployment plans • Challenges in differentiation • Loss of strategic control and flexibility • Difficult to exit • Regulatory risks • Transformational effort (e.g., setting up new organization)
3rd party service provider	• Reduced risk: fixed CAPEX is transferred to variable OPEX • Reduction in OPEX: reduced O&M costs • Cut down CAPEX cost for new deployment • Can objectively arbitrate disputes/issues	• Loss of strategic control and flexibility • Long lock-in and reliance on 3rd party • Lack of equity participation

GSMA: Infrastructure sharing document

Achievable cost savings due to infrastructure sharing (technological view)

- **Existing reports and researches on mobile network sharing confirm that infrastructure sharing can bring in significant cost reduction.**
  - Ericsson (2012) predicted that asset savings from infrastructure sharing can reach up to 40% and cash-flow improvement up to 31% depending on the type of sharing.
  - Booz & Company (2012) stated that infrastructure sharing can enable operators to save as much as 30 to 40 percent of the network costs.
  - Coleago (2010) calculated that savings in roll-out CAPEX and savings in network operations and maintenance can reach up to 65% each with network sharing.
- **The breakdown of CAPEX and OPEX by Analysys Mason provides a hint on why infrastructure sharing can potentially reduce costs so extensively.**
  - For CAPEX, building, rigging, materials and power (i.e. building access to electrical networks to connect base stations to power) consists of more than 50% of CAPEX for both developed and emerging markets. Sharing these costs can significantly reduce required costs and some operators have experienced 35~40% reduction of TCO (Total Cost of Ownership) from sharing passive infrastructure.
  - For OPEX, Land rent, power and backhaul consist of more than half of OPEX in developed markets and almost half of OPEX in emerging markets. Again, sharing these components can significantly reduce the cost.

Summary of cost savings: technology view

	Key benefits	Potential Cost savings
Passive sharing	• Capex and opex cost reduction • Focus on sales / marketing – move away from tower management • Speed to market	~30% Opex, ~65% Capex
Spectrum Sharing	• Reduces requirement for additional spectrum • Lower spectrum charges	*Depends on the market situation in terms of availability of additional spectrum and spectrum charges levied*
Active sharing	• Capex and opex savings (in case of new roll out) • Speed to roll out • Focus on core business	BTS/ Node B sharing: ~30-40% Opex, ~10-15 Capex RAN sharing: ~35-40% Opex, ~30-40% Capex
Transmission Sharing	• Capex savings • Time to build network • Immediate connectivity to sites	*Cost savings vary depending on level and scale of backhaul leased*
O&M Sharing	• Cost savings • Better use of capital and resources • Faster time to market	~20-25% % Cost saving in network opex *Assuming network opex accounts for two thirds of total network opex*

Additional benefits

Conclusions

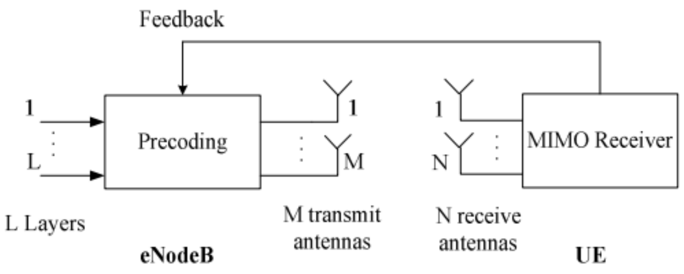
- Release 15 has been **revolutionary** introducing 5G system
- Release 16 and release 17 focus on the **evolution** of 5G
  - 5G-NR -> to adapt its usage in other contexts such as IIoT (solutions on the market are available)
  - 5G Core network performance improvement
  - Integration of terrestrial 5G networks with non-terrestrial networks is another important aspect that will be explored in Release 17
  - Evolution of MIMO, MEC and IAB and their evolution in release 17 are other important features
- In current operating scenarios, deployment of full 5G infrastructure could lead Telcos to significant expenditures with uncertainty on the return on investments
  - Infrastructure sharing can be a viable solution to reduce costs -> competitions among operators moves towards service aspects

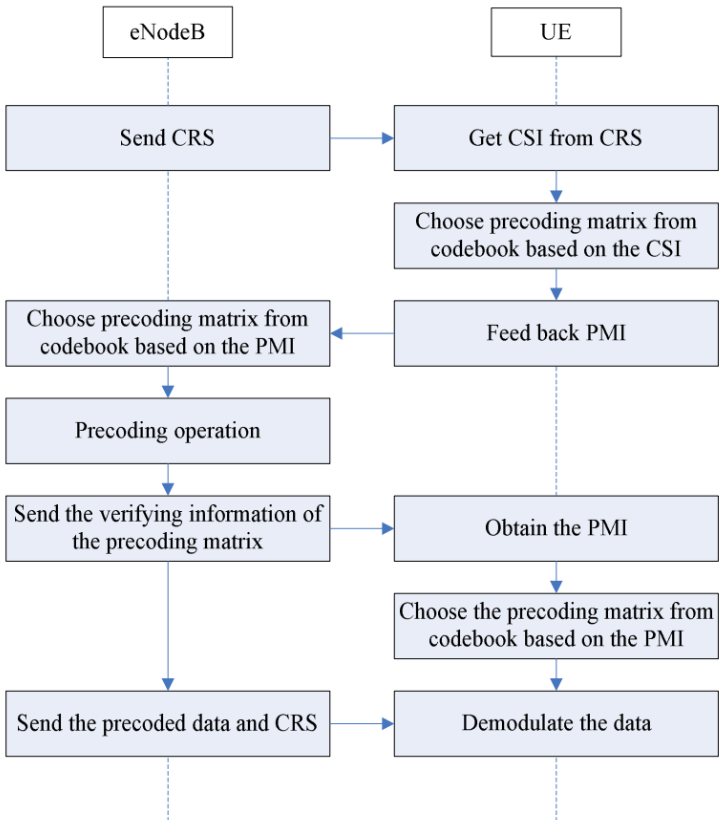
Backup

Nota sul MIMO

- The close-loop MIMO technology, typically with the feedback of the channel state information (CSI) from the User End (UE), can greatly improve the performance of MIMO systems.
- According to CSI, downlink data can be precoded before transmitted in order to get better SNR at the receiver side and a larger system capacity.
- Although perfect CSI is desirable, practical systems are usually built only on estimating the CSI at the receiver, and possibly feeding back the CSI to the transmitter through a feedback link with a very limited capacity[2]

Scenario





Under the codebook based precoding mode, as shown in Figure 1, UE gets the channel state information (CSI) from the common reference signal (CRS) sent by the eNodeB and feeds back a precoding matrix index (PMI). Then the eNodeB applies the spatial domain precoding on the transmitted signal taking into account the PMI so that the transmitted signal matches with the channel experienced by the UE. Note that the PMI may be changed by the eNodeB according to the instantaneous state and then will be sent back to UE. After the precoding operation, the UE receives the information from the eNodeB on what precoding matrix is used, which is utilized by the UE for demodulating the data.

Ideal and non-ideal backhaul

- What is "non-ideal backhaul"
- The simplest of explanation can be seen from the picture above that is extracted from 3GPP TR 36.932.

  An ideal backhaul is defined as latency less than 2.5 microseconds and a throughput of upto 10Gbps. All other types of backhaul is non-ideal.

  Another way of putting this is: If you look at the Release 12 study and technical report on Small Cell Enhancements, it is regarded as a backhaul that cannot carry a RRH to eNodeB link, which in turn has been interpreted as not meeting CPRI round trip and bandwidth requirements (via Kit Kilgour)

Release 12 3GPP TR 36.932 V12.1.0 (2013-03)

Table 6.1-1: Categorization of non-ideal backhaul

Backhaul Technology	Latency (One way)	Throughput	Priority (1 is the highest)
Fiber Access 1	10-30ms	10M-10Gbps	1
Fiber Access 2	5-10ms	100-1000Mbps	2
Fiber Access 3	2-5ms	50M-10Gbps	1
DSL Access	15-60ms	10-100 Mbps	1
Cable	25-35ms	10-100 Mbps	2
Wireless Backhaul	5-35ms	10Mbps – 100Mbps typical, maybe up to Gbps range	1

Table 6.1-2: Categorization of ideal backhaul

Backhaul Technology	Latency (One way)	Throughput	Priority (1 is the highest)
Fiber Access 4 (NOTE 1)	less than 2.5 us (NOTE2)	Up to 10Gbps	1

Via: 3G4G Small Cells Blog - smallcells.3g4g.co.uk

Pros and cons of Infrastructure sharing: technology

- From GSMA: infrastructure sharing document in network economics series

Sharing form	Pros	Cons
Passive infrastructure sharing	• Significant CAPEX/OPEX savings • Lowered risk of site acquisition • Full differentiation and complete control of spectrum • Control over sites to be shared • No/little regulatory obstacles • Easy migration to other sharing forms. • Environmental benefits	• Availability of free space in existing sites (if existing sites are to be shared) • Similar cell planning may be required
MORAN, MOCN	• Limited marginal CAPEX savings compared to Site Sharing • Substantial marginal OPEX savings compared to passive infrastructure sharing • Control over base stations to be shared • Reduction of network footprint by sharing operators	• Regulatory approval necessary • Complexity of operation • Requires long term commitment between operators • Difficult to exit from sharing agreement
Core Network sharing	• Further CAPEX/OPEX savings compared to MORAN/MOCN • Significant investment can be diverted to services • Maximum sharing for operators sharing existing infrastructure	• Regulatory approval necessary • Complexity of operation and tight integration • Challenging to differentiate quality of service
National Roaming	• Significant CAPEX/OPEX savings • Clear ownership of equipment • Differentiation based on service layer • Low risk solution for both incumbent and new entrant	• Regulatory approval necessary • Interconnection required • Reduced control over the network (e.g., outage of visited network can affect home network service) • End to end inter-PLMN QoS and inter-PLMN handover very challenging

One remark

- According to technological criterion, MVNO can also be perceived as a type of infrastructure sharing agreement
  - MVNO leases almost all of the necessary network infrastructure. However, this is not included in infrastructure sharing (IS) because IS mainly focuses on efficient deployment & operations of physical networks rather than creating virtual operators on top of physical networks.
- Instead, **spectrum sharing or use of unlicensed spectrum (see after) which is another aspect of technology sharing** depends on the regulatory landscape which can be diverse depending on the regional/national context.