5G communications: development and prospects

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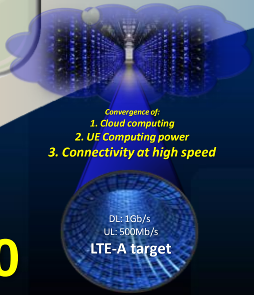
Vision

"*The advanced 5G infrastructure is expected to become the nervous system of the Digital Society and Digital Economy*"

Günther Oettinger, European Commission, MWC 2016

"*The smart phone is the extension of what we do and what we are, the mobile is the answer to pretty much everything*"

Eric Smith, Google, MWC 2010



2010

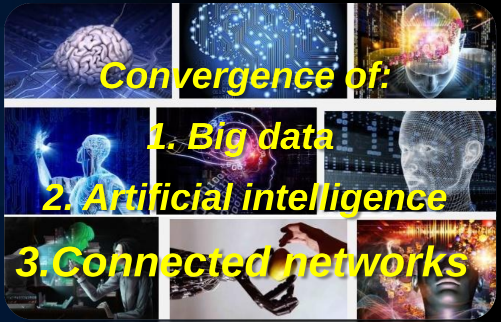
"*Client Server*"

➔ *Bit pipe and Free Communication Services*

2020

"*Multi-Tenant*"

➔ *Nervous system of the Digital Society and Economy*



Main 5G initiatives ongoing globally

http://www.3gpp.org/technologies/presentations-white-papers

EU
- 5G PPP in Horizon 2020 (€700mn)
- White Paper

UK
- 5GIC at University of Surrey
- http://www.surrey.ac.uk/5gic

US
✓4G (5G) Americas : White Paper

China
✓IMT-2020 (5G) Promotion Group
- 863 Research Program
- Future Forum : White Paper

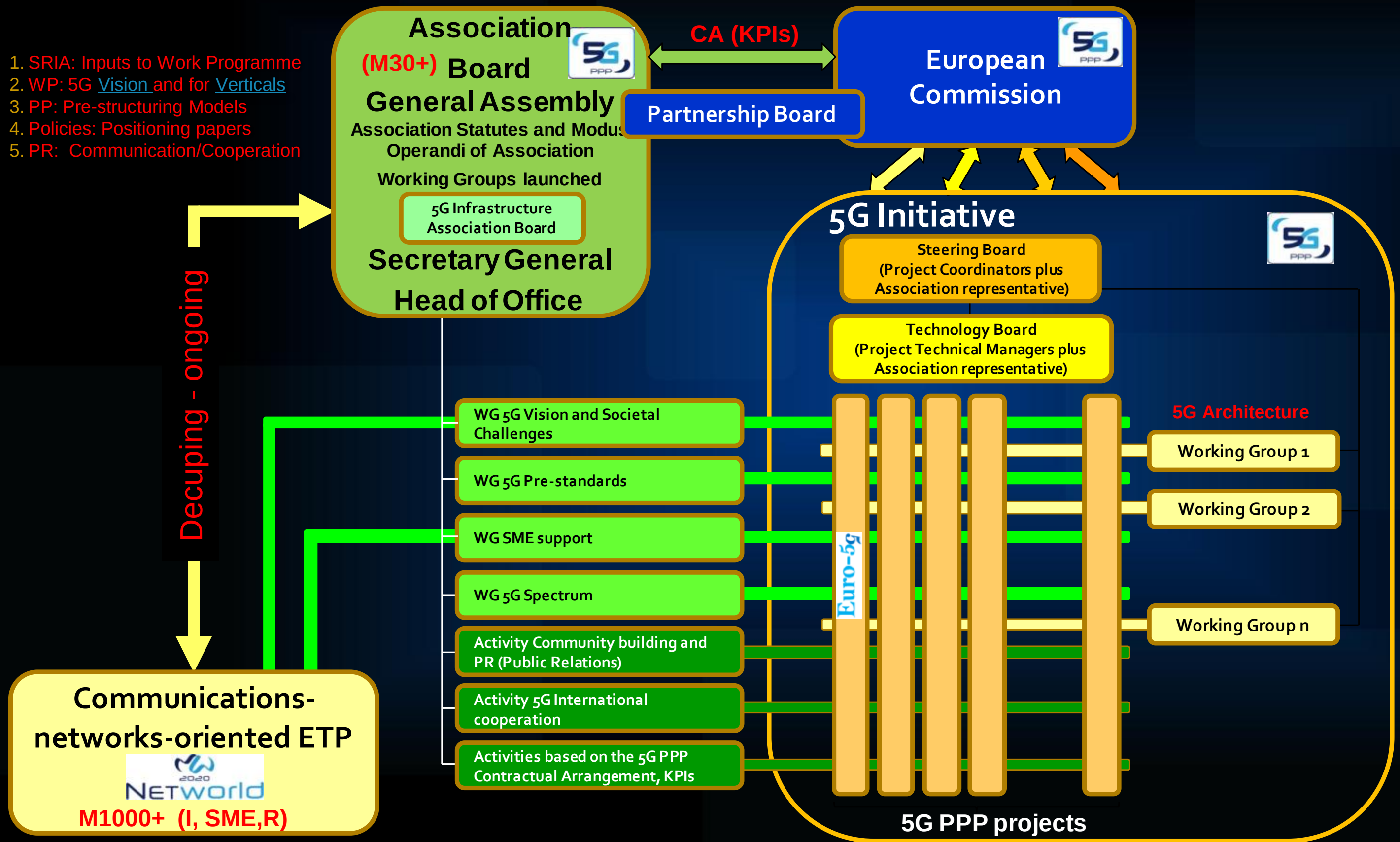
Japan
✓5G Promotion Forum (ARIB)
- White Paper

Korea
✓ 5G Forum as PPP
- White Paper

NGMN
- White paper

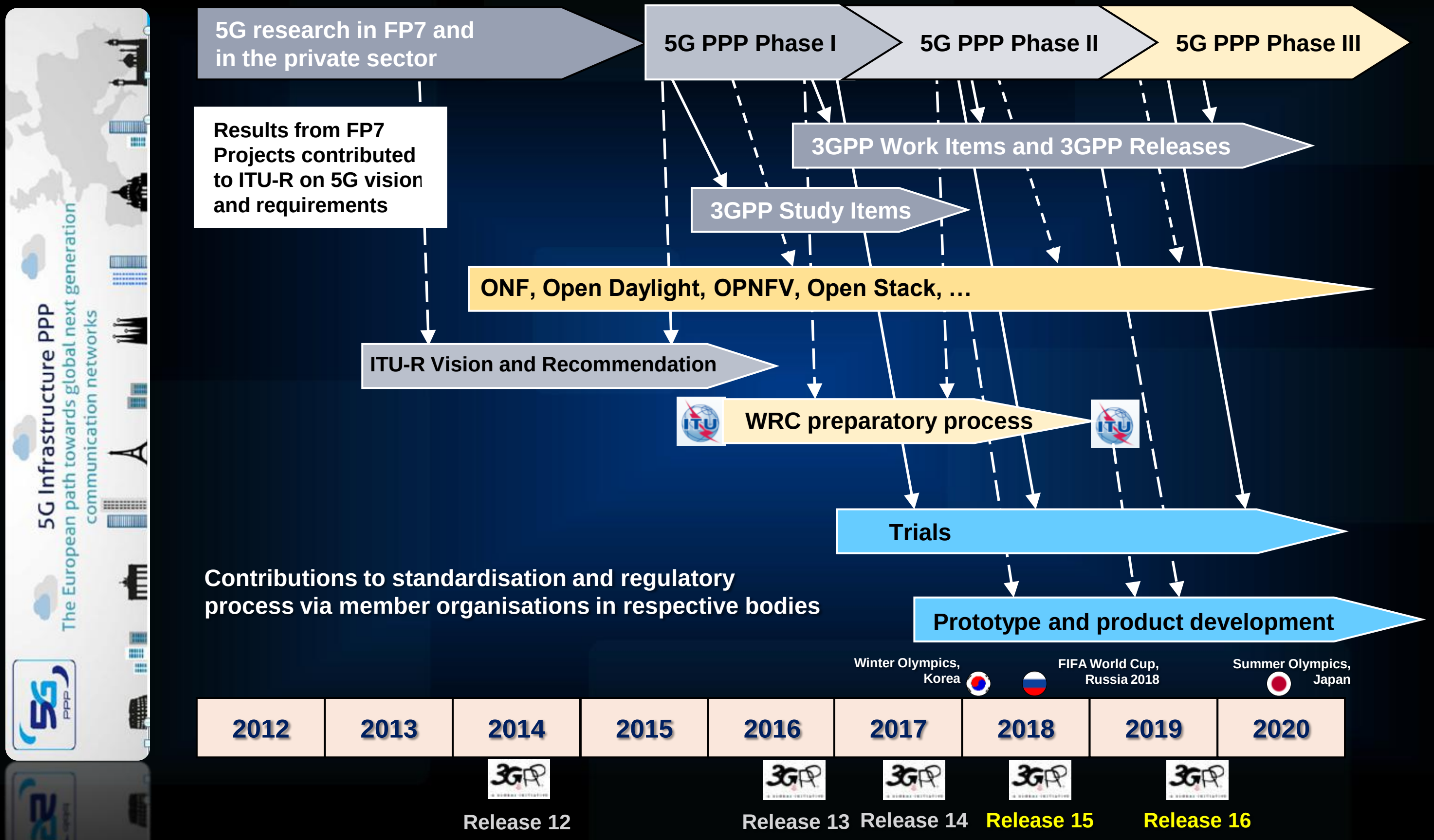
5G Public Private Partnership (PPP): €700 mn ➔ €1.4+ bn

***EU 5G socio-economic analysis*: €56.6 bn *5G investment (EU28 Member States)* ➔ Value: €425.5 bn (7.5x), Jobs: 7.184 mn**

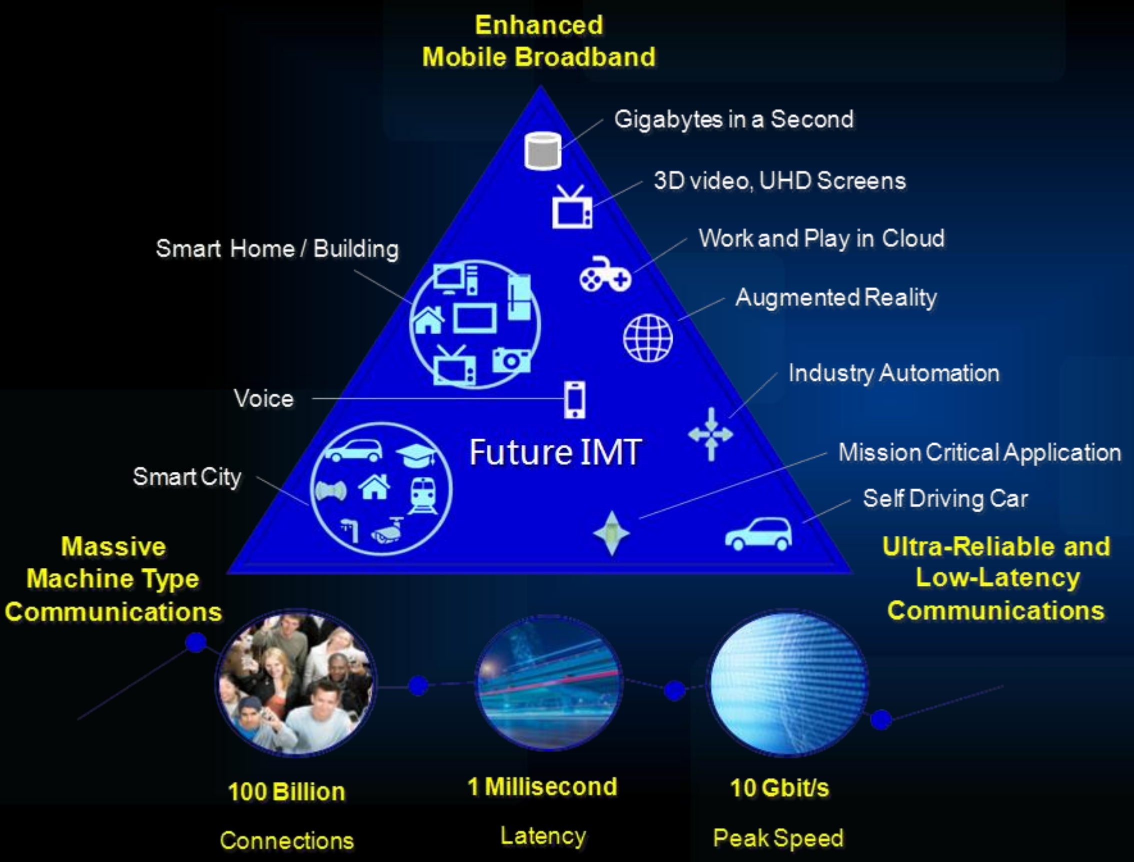


- **5G-PPP Phase III** (2018-20 EU Public funds €425mn): *Large scale trials in Europe with Verticals*
- **5G-PPP Phase II** (2017-18, EU Public funds €148mn): *Verticals, Satellites, Optical, SW networks*
- ✓ **5G-PPP Phase I** (2015-16, EU public funds €125mn): *19 retained Actions*

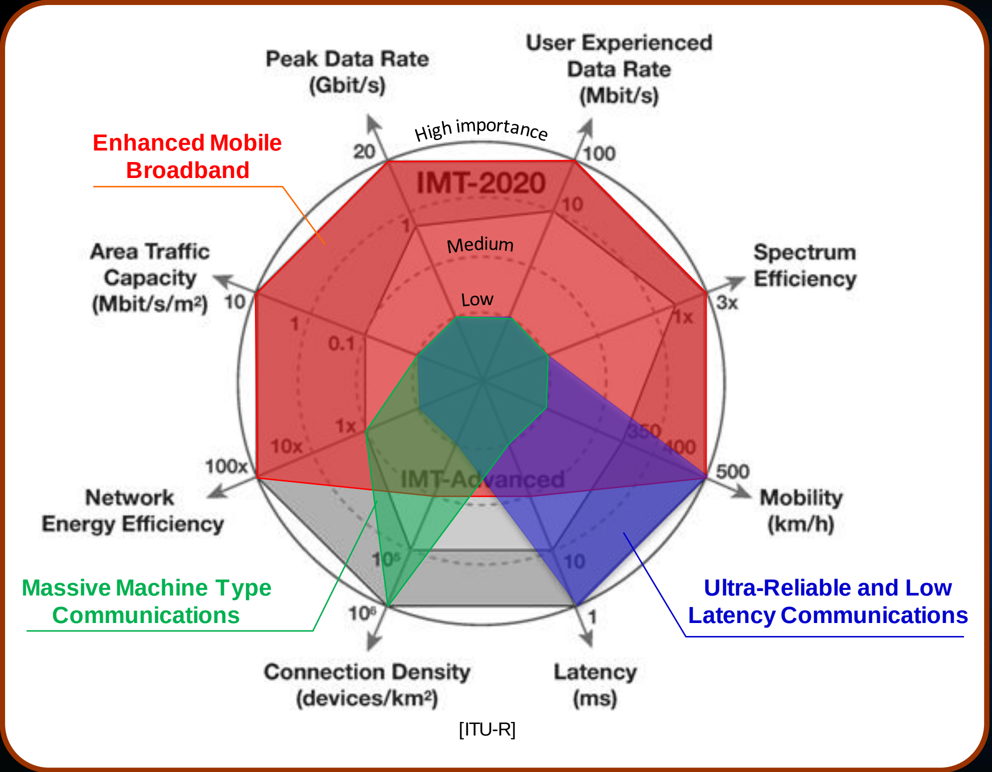
5G-PPP: Exploitation of results



Usage scenarios of IMT for 2020 and beyond (5G)



Enhancement of key capabilities from 3GPP LTE to 5G



New Radio requirements

KPI	value
Peak data rate	20Gbps DL 10Gbps UL
Peak Spectral efficiency	30bps/Hz - 15bps/Hz
Control plane latency	10ms
User plane latency	URLLC: 0.5ms UL&DL
Mobility interruption time	0 ms
Inter-system mobility	With other IMT systems
Reliability	URLLC: P=10-5 in 1ms
Coverage	mMTC 164dB
Extreme Coverage	100-400 km voice/low data
UE battery life	mMTC 15 years
Connection density	mMTC 1M device/km2
Mobility	500 km/h

Summary of the key resolutions at WRC15 pertinent to 5G

WRC15

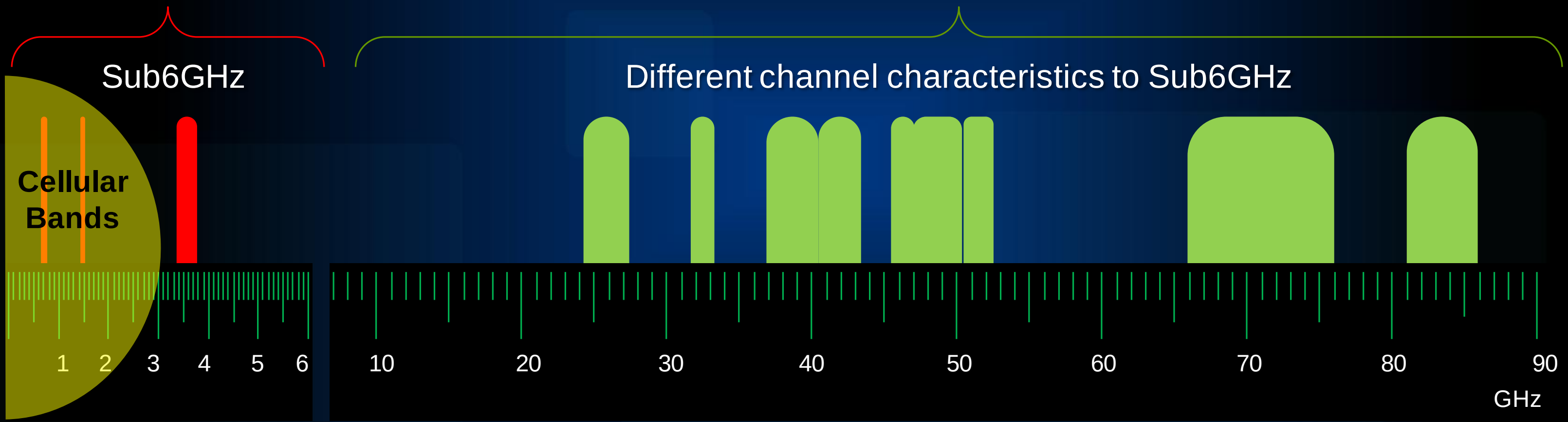
New or Harmonized bands for IMT Use

- 700MHz Band (694-790 MHz)
- L-Band (1427-1518 MHz)
- C-Band (3.4-3.8 GHz)

WRC19

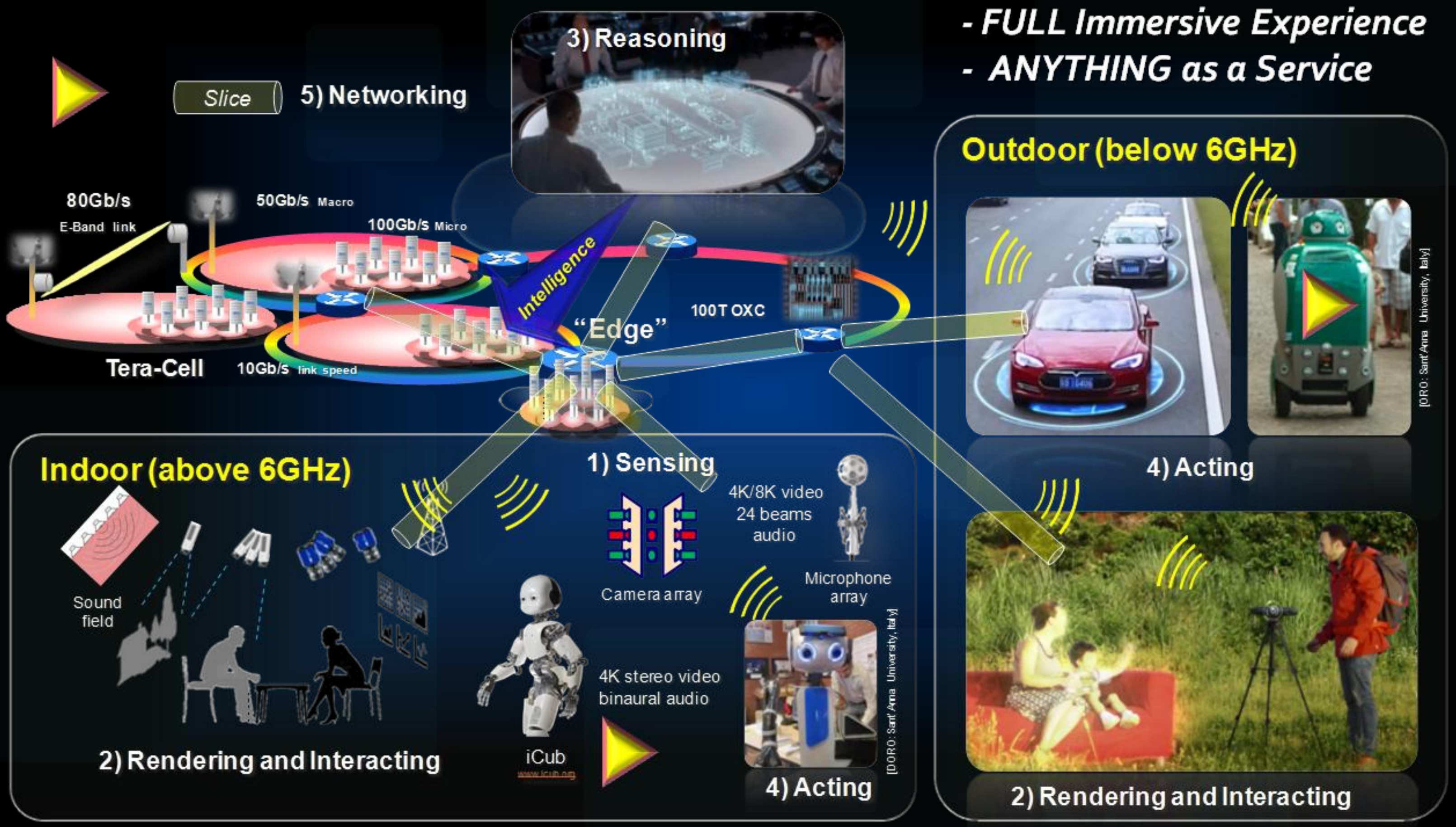
New bands agreed for discussions in 2019

- 24.25-27.5 GHz
- 31.8-33.4 GHz
- 37-40.5 GHz
- 40.5-43.5 GHz
- 45.5-47 GHz
- 47-50.2 GHz
- 50.4-52.6 GHz
- 66-76 GHz
- 81-86 GHz

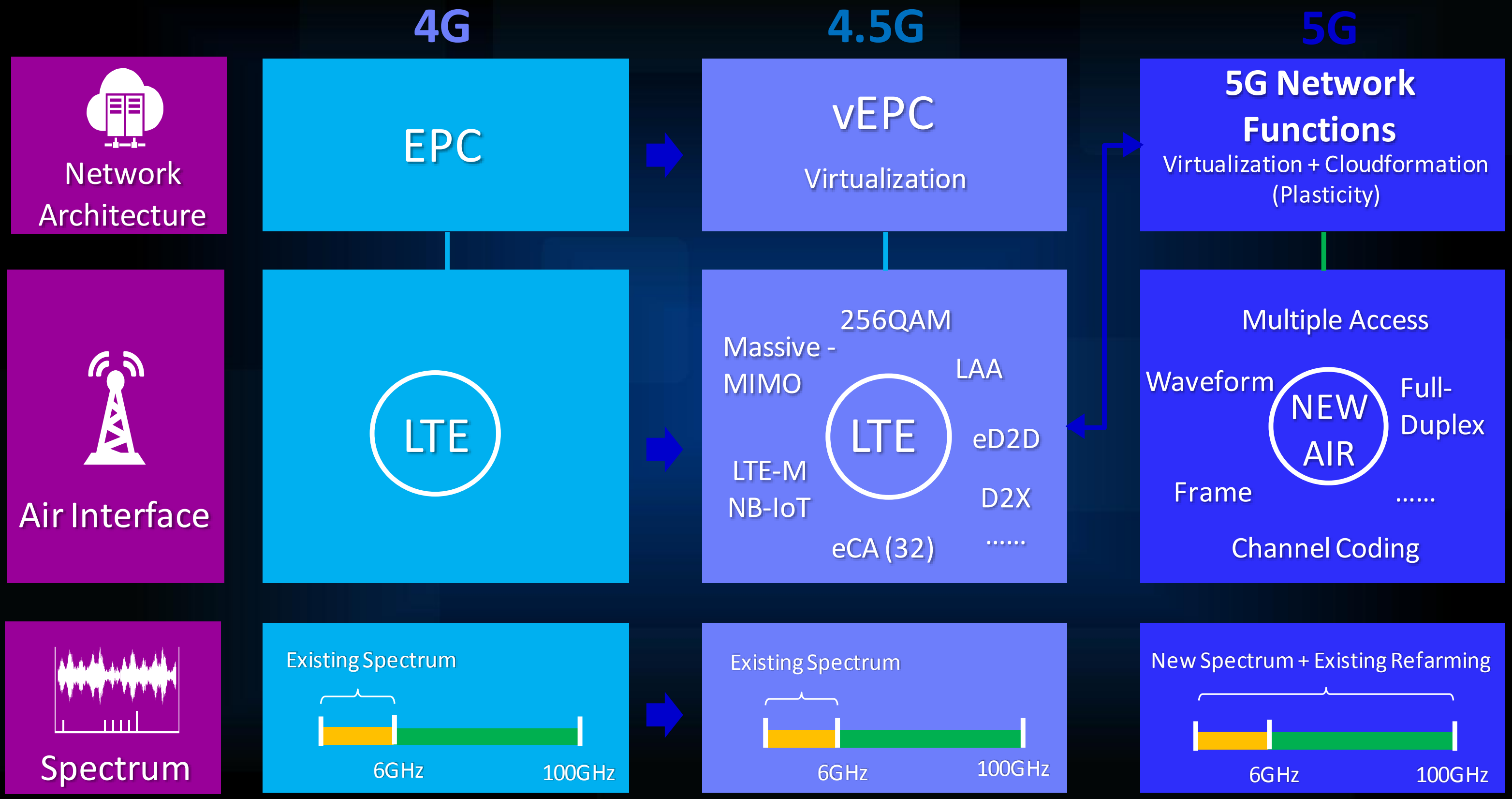


Attributes	Values or assumptions
Carrier Frequency	around 30 GHz or around 70 GHz or Around 4 GHz
Aggregated system bandwidth	Around 30GHz or Around 70GHz: Up to 1GHz (DL+UL) Around 4GHz: Up to 200MHz (DL+UL)

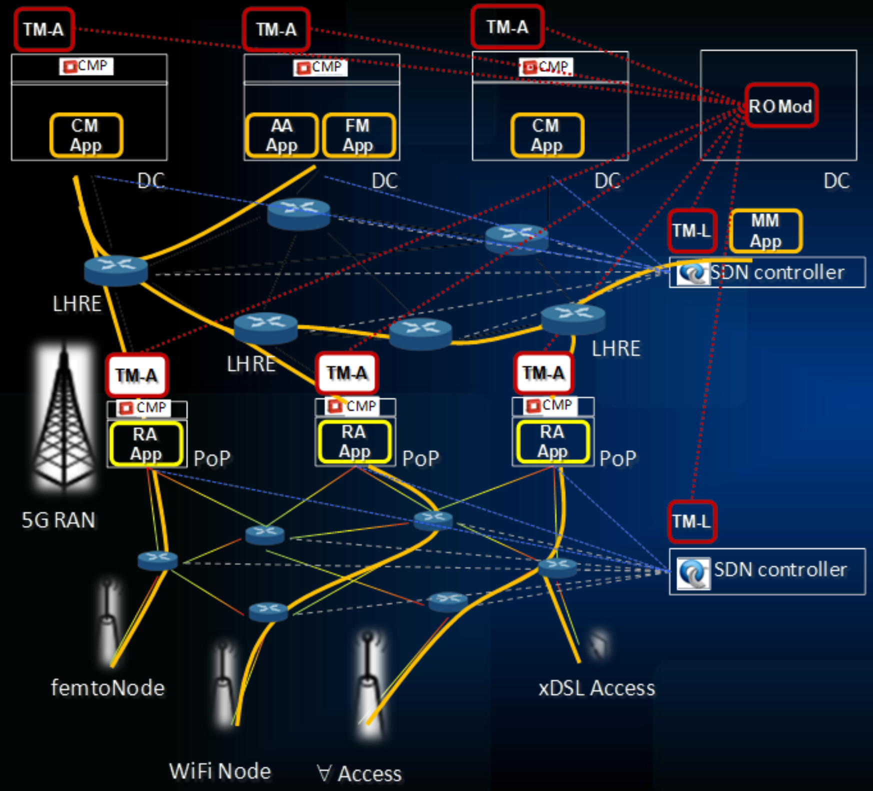
5G multi-tenant network and services vision



Network, air interface and spectrum usage evolution from 4G to 4.5G and 5G



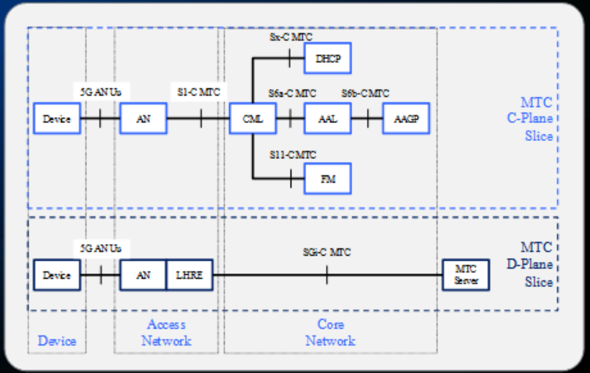
5G plastic architecture and example application to static machines type of traffic



= **Orchestration**
RO: Apps and Links *Control Plane (C-Plane)*
TM-A: Apps Enforcement /Maintenance
TM-L: Links Enforcement /Maintenance

= **Control plane**
FM App: Links *Data Plane (D-Plane)*

5G C-Plane (Slice)
Orchestration interfaces
SDN Controller interface
5G App – SDN Controller interface

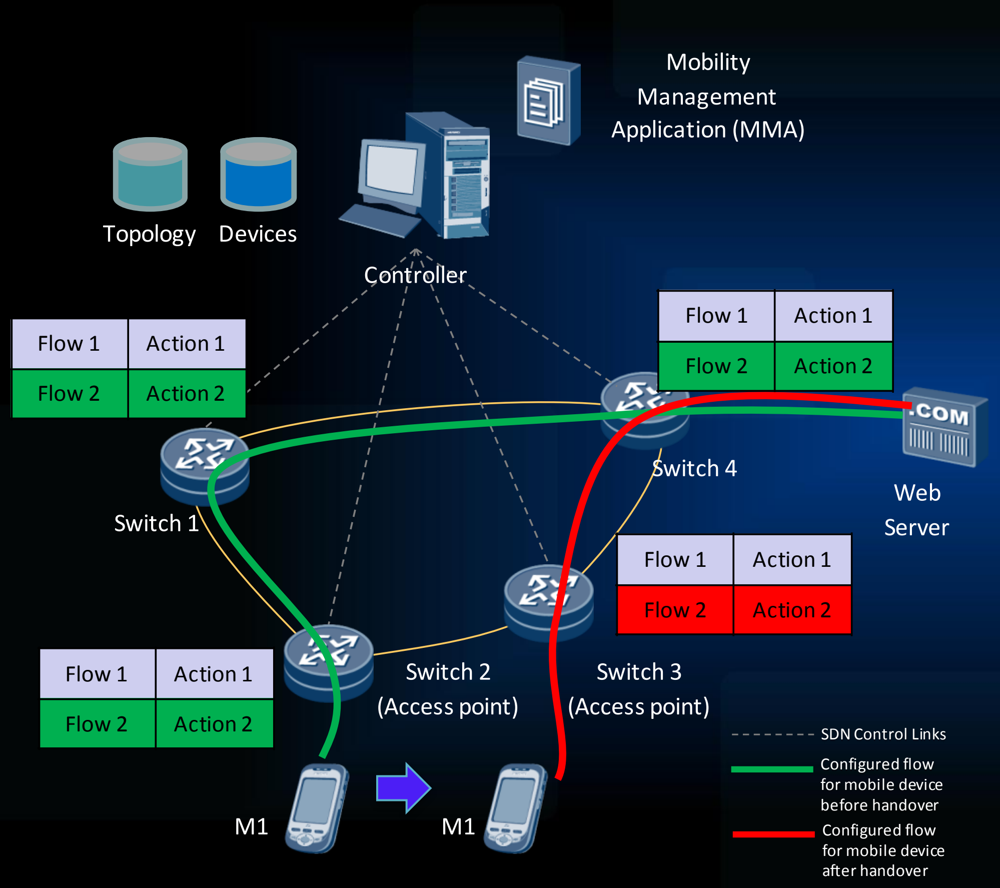


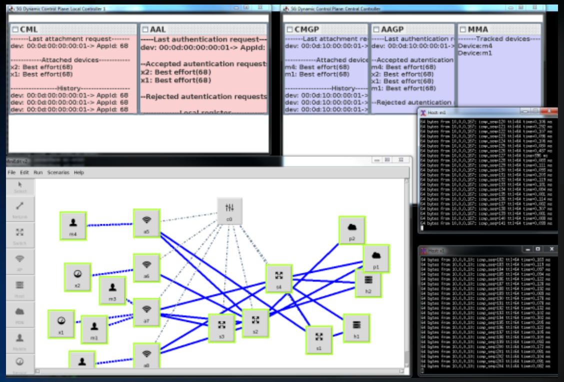
Example application to static machines type of traffic

PoP = Point of Presence (e.g. small Data Center); DC= Data Center; CMP = Cloud Management Platform (e.g. OpenStack)
SDN Platform = Open Flow based Control Platform (e.g. Floodlight); LHRE = Last Hop Routing Element

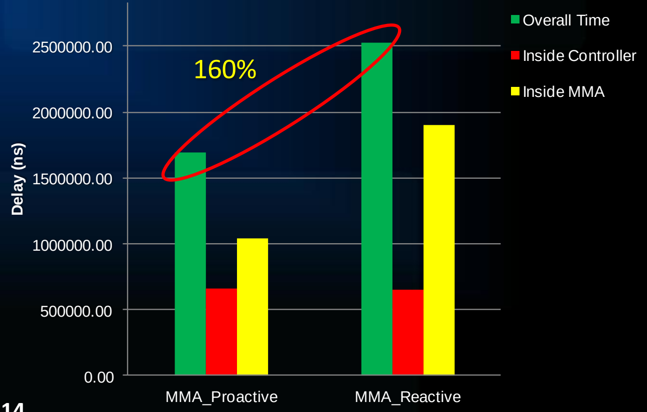
AN = generic Access Network element; CML = Connectivity Management Local function
FM = Flow Management; AAL = Authentication and Authorization (AA) Local; GP = General Purpose
DHCP = Dynamic Host Configuration Protocol function, e.g. Addresses; Sxx, Uu = 3GPP Interfaces

Mobility Management Application (MMA) for SDN: case study

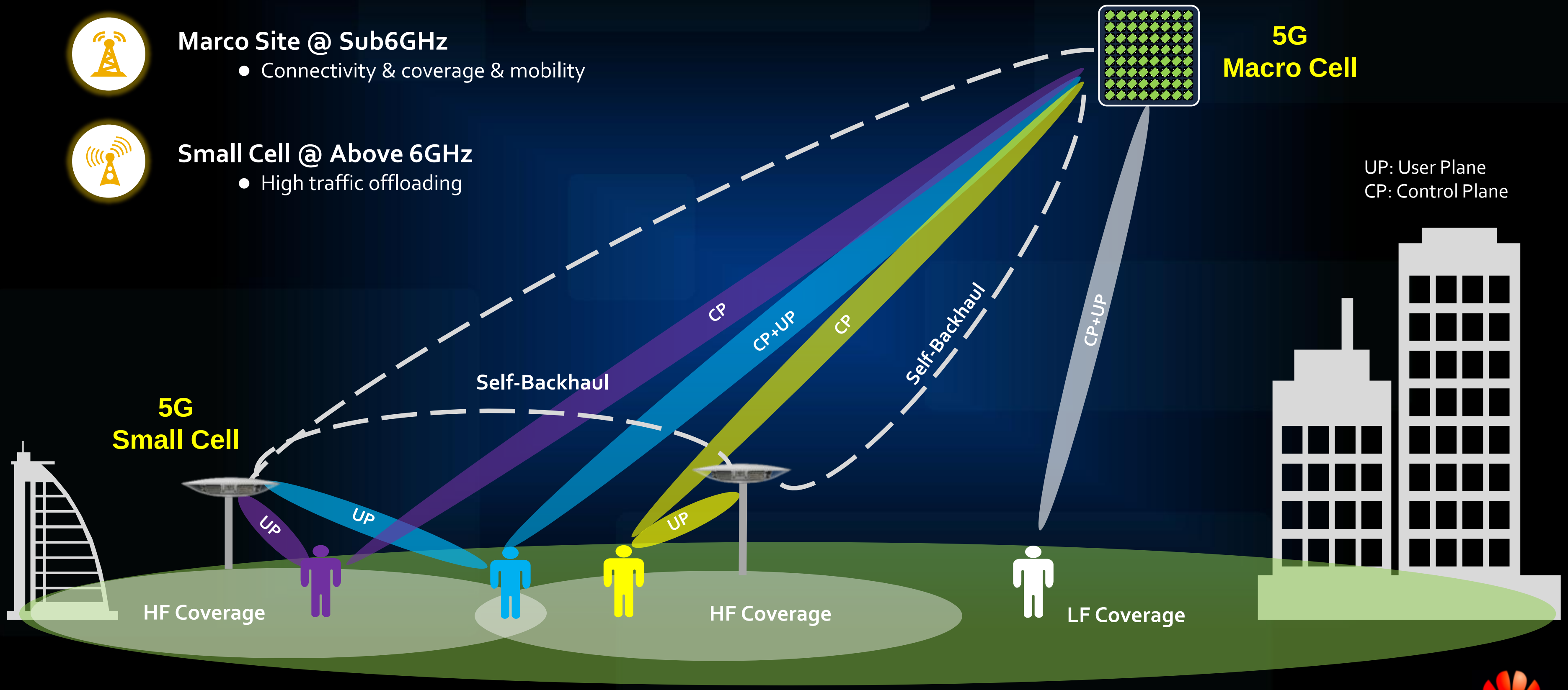




- Topology: 10 Access Points, 200 active mobiles
- 10 Handovers/s **with ran**dom mobility



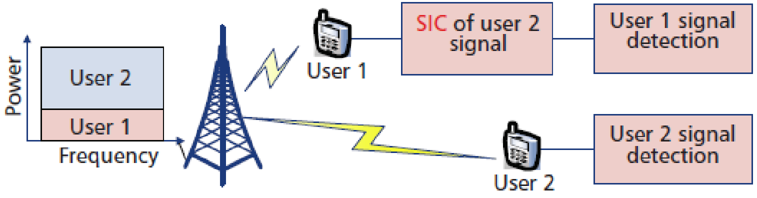
High band non-standalone assisted by low band



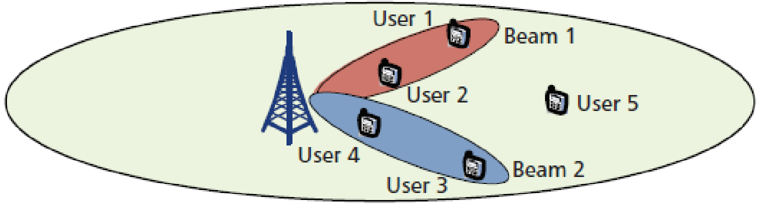
Multiple access techniques

Non-orthogonal multiple access **(NOMA): time and frequency resources sharing in the same spatial layer via *power* or *code domain multiplexing*, e.g. SCMA, MUSA, LDS-OFDM, etc.**

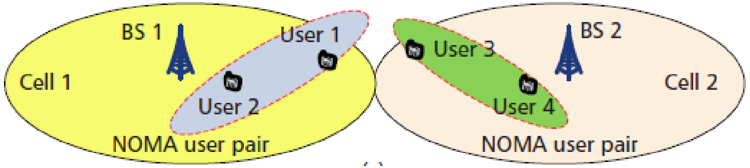
SIC = Successive Interference Cancellation



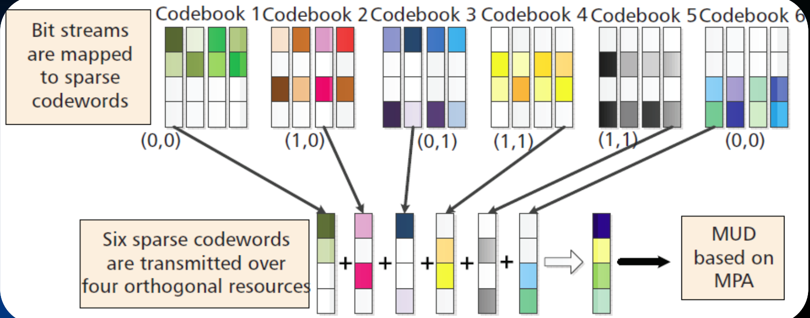
Basic NOMA: SIC receiver



Spatial Filtering NOMA: Using 3D-BF, AAS, M-MIMO



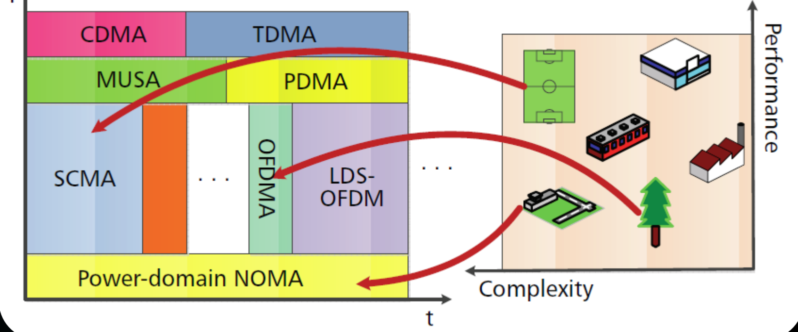
Network NOMA: multi-user precoding



MPA = Message Passing Algorithm (MPA)

Ex: 6 Users, two bits mapped to a complex codeword, which are then multiplexed over four shared orthogonal resources (e.g. OFDM subcarriers)

SoDeMA = Software Defined Multiple Access

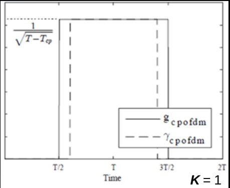


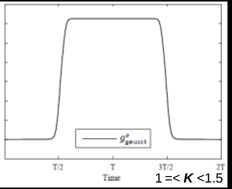
[Source CMCC]

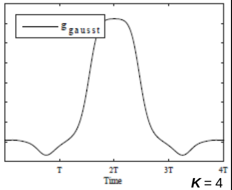
Advanced waveforms

- ***Per-subcarrier pulse shaping*****: using prototype filter with steep power roll-off for shaping subcarrier signals in both frequency and time domain**
- ***Sub-band filtering*****: applying filters to a group of subcarriers after OFDM modulation**

Pulse shape design parameters			Waveform Name	
Pulse length	**Pulse shapes**	**Localization**		
***K*=1**	Rectangular	Time	**CP-OFDM**	**F- OFDM (*)**
***K*=1 (N_{FFT} long)**	Rectangular	Time	ZP-OFDM	UF-OFDM (*)
1<= ***K***<1.5	Various	Time + Frequency	W-OFDM	
***K*=4**	Long pulse	Time + Frequency	FBMC/QAM	
Arbitrary ***K***	Various	Flexible	**P-OFDM**	
(*) Additional band pass filter needed				

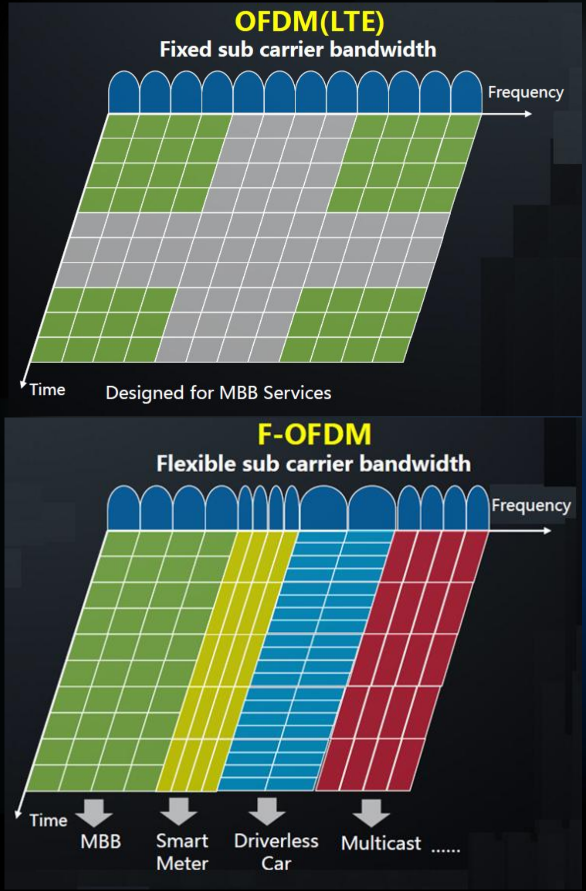






The choice of either one of the two variants depends on the required degree of spectral and temporal confinement

Filtered-OFDM (F-OFDM)



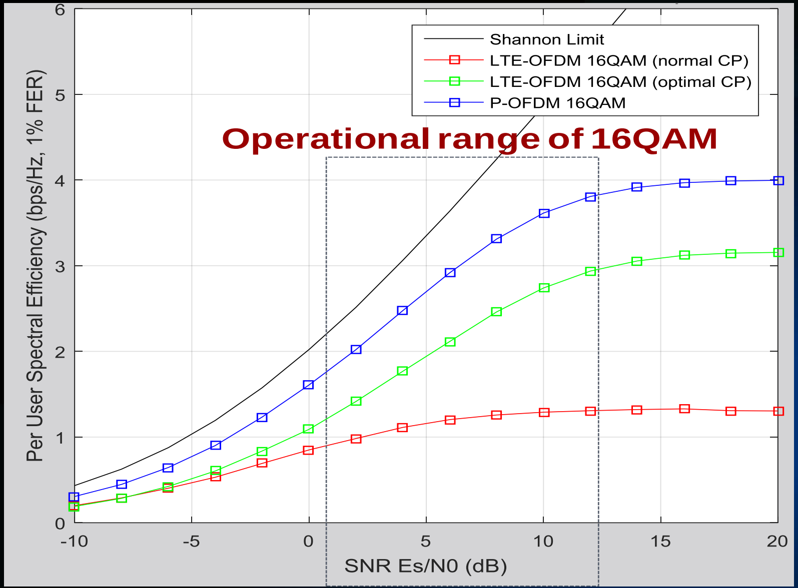
Pros

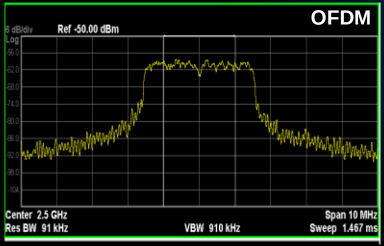
- ✓ Multi-service with different time and frequency numerology (e.g. CP, sub-carrier spacing (symbol duration), TTI at different carrier frequencies)
- ✓ Low out-of-band emission (OOBE)
- ✓ Flexible frequency multiplexing
- ✓ Simple channel equalization
- ✓ Multi-antenna transmission
- ✓ Efficient spectrum utilization
- ✓ Affordable computational complexity
- ✓ Possibility to incorporate other waveforms
- ✓ Backward and forward compatibility

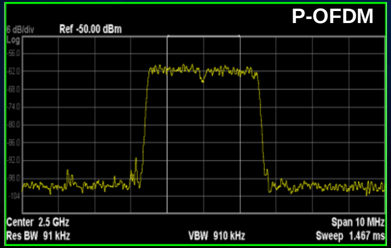
Cons

- × Non-orthogonal in time and quasi-orthogonal in frequency
- × Slightly more prone to delay-spread channels

Pulse shaped OFDM (P-OFDM)







Pros

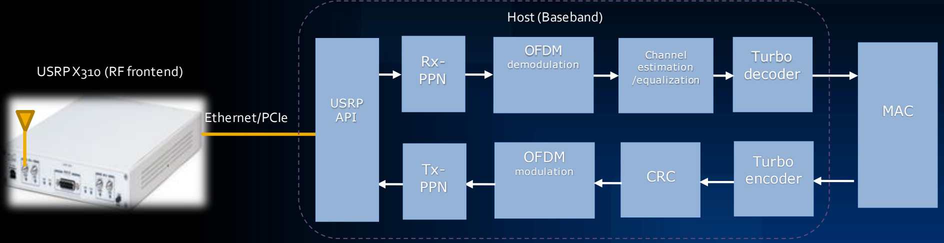
- ✓ Excellent OOB interference control and efficient utilization of narrow frequency bands
- ✓ Partitioning of spectrum into independent bands with excellent capabilities for coexistence of services in the same frequency band and spectrum sharing
- ✓ Any modulation order and MIMO capability
- ✓ Excellent robustness against synchronization errors
- ✓ Flexible frame structure with large subcarrier spacing for high Doppler in Vehicle to Anything (V2X) applications
- ✓ Short TTI length for low latency scenarios and one way ping delay < 0.5 ms

Cons

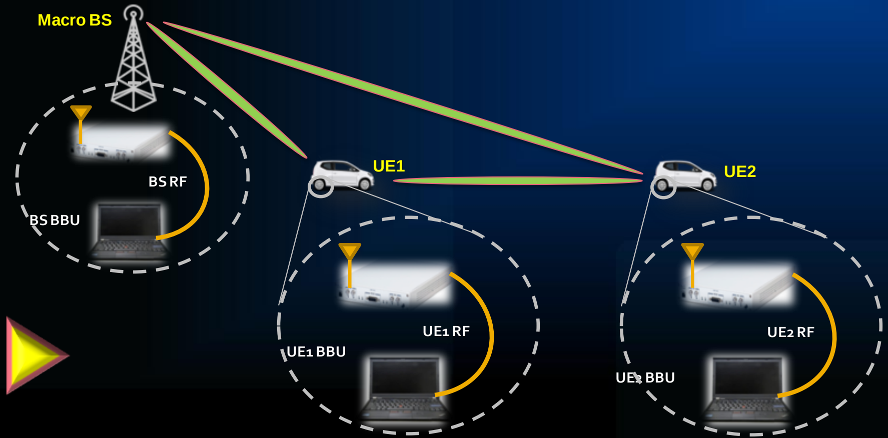
- ✗ Filter length may be limited by delay constrains

V2X P-OFDM Based Low Latency Real-Time (Demonstration)

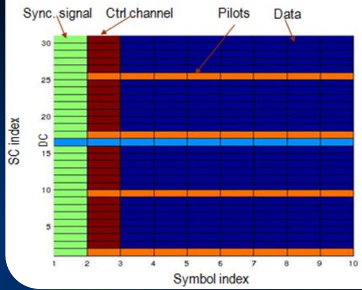
Optimized baseband processing running on Intel platform x86_64
USRP SDR as RF frontend



Enabling D2D and cellular assisted D2D access

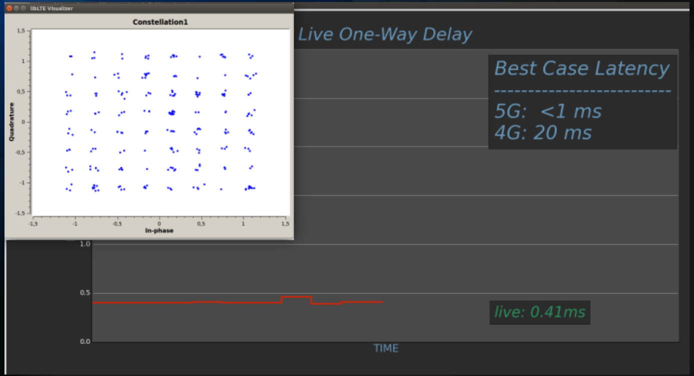


Flexible Frame structure:
Large subcarrier spacing for high Doppler in V2X applications
Short TTI length for low latency scenarios



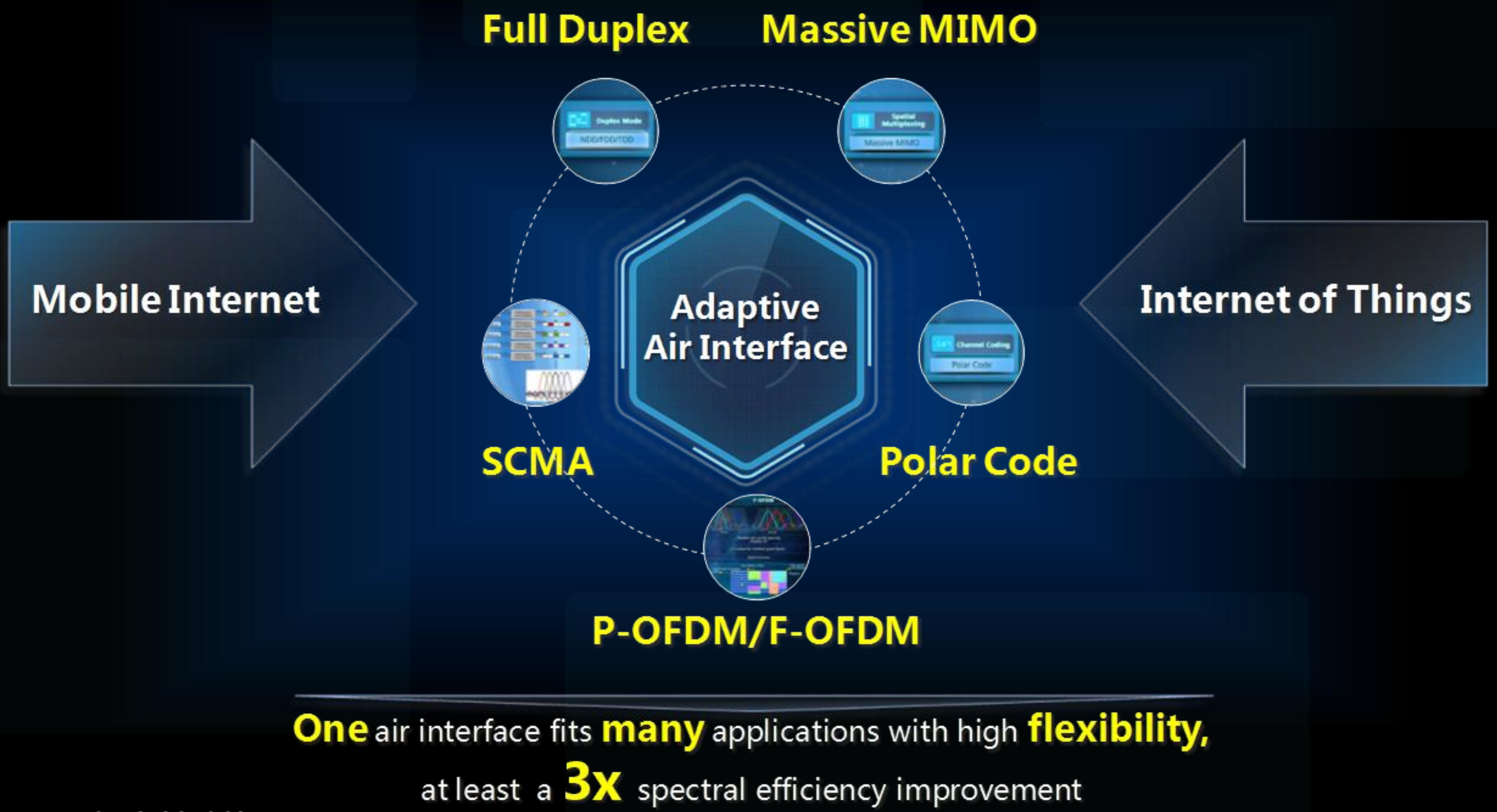
Parameter	Initial Value
Sampling rate:	12.5MHz
FFT size:	128
Over sampling	5/4
Symbol length	160
Subcarrier spacing:	97.656kHz
Effective SC	Adjustable, 30 here for example
Bandwidth	Adjustable, 3 MHz here for example
Number of symbol per TTI	Adjustable, 10 here for example
TTI length:	Adjustable, 0.17 ms here for example
Sync. signal	1 PN
Pilot distribution	Distance of 8 RE in freq. 1 RE in time, flexible depending on the channel
Modulation:	BPSK, QPSK, 16QAM, 64QAM
Coding:	1/3 (LTE Turbo)

One way ping delay < 0.5 ms



New air interface

Service Oriented Radio (SOR): choosing different air interface components for different applications

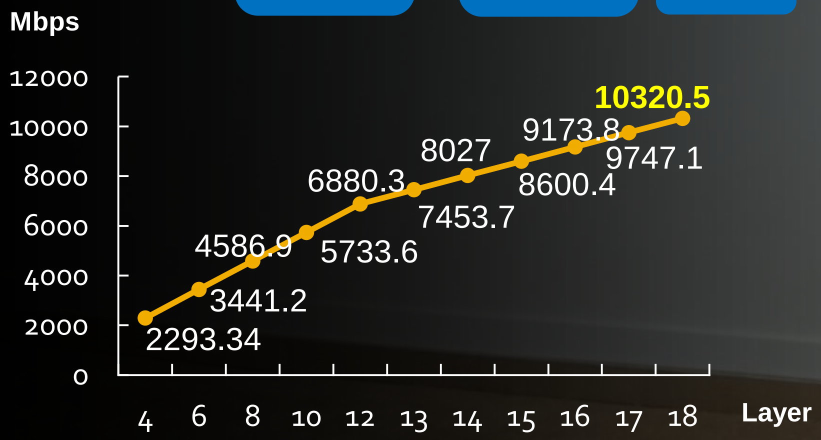


Technology Innovations

Huawei 5G Low Band Test Bed

World's Highest Throughput @ Sub6G

10 . 32 Gbps



51.6 bps/Hz

200MHz BW	18 Layers

F-OFDM + SCMA + Polar Code + M-MIMO

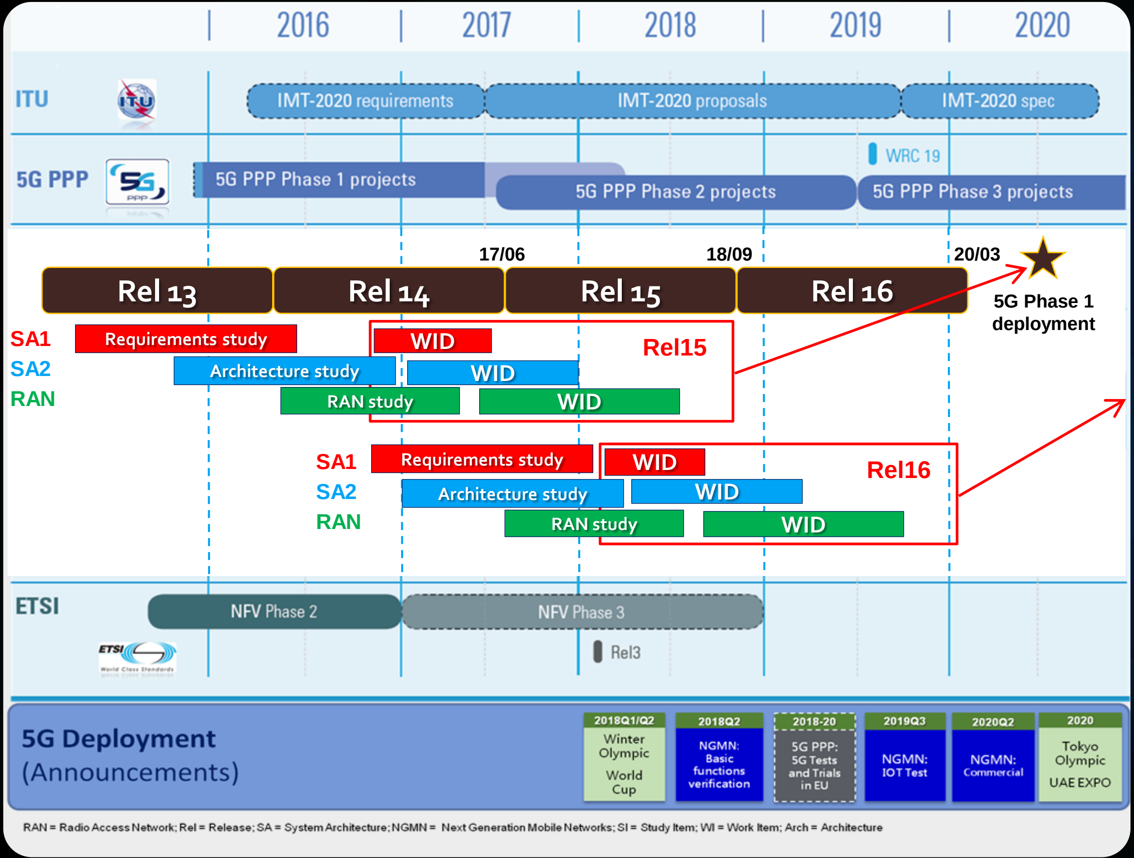
Huawei 5G High Band Test Bed

World's Highest Throughput @ E-Band

115 **Gbps**

9.6GHz BW

5G timeline

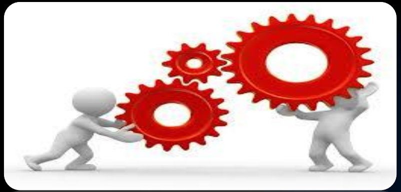


3GPP timeline

- ***Phase 1*** *by Sep 2018/**Rel-15** for more urgent commercial needs (to be agreed)*
  ➔ Deployment 2H2020
- ***Phase 2*** *by Mar 2020/**Rel-16** for all identified use cases/ requirements:*
  ➔ Deployment 2H2021

*NB: **New Radio** (NR) design **forward compatible** so that features can be added in optimal way in later releases*

Conclusions



5G tests and trials with Verticals essential step towards effective standardization

3GPP primary organization and others – such as, e.g., ONF and IETF – complementary

Public party crucial role in early consensus (e.g. 5GPPP), policies, regulatory processes

IP Rights shall not hinder 5G technologies adoption and market uptake

Thank you

References

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