5G Overview

Mobile Technologies and the Way to 5G

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ROHDE&SCHWARZ
Mobile Network Testing

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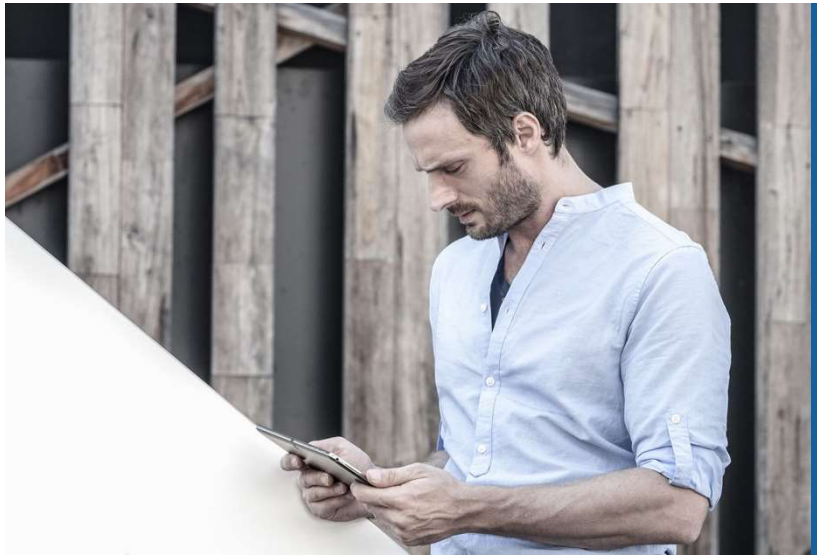
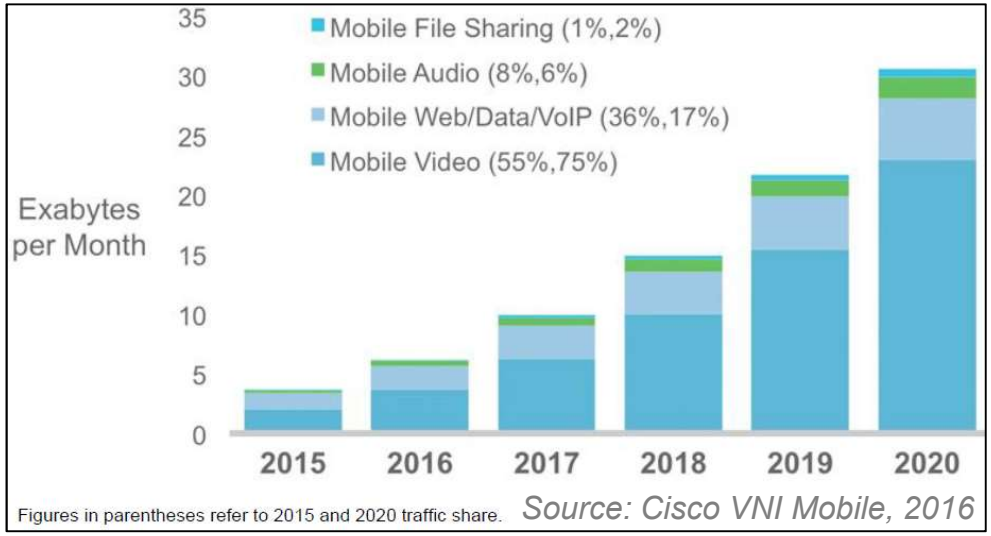
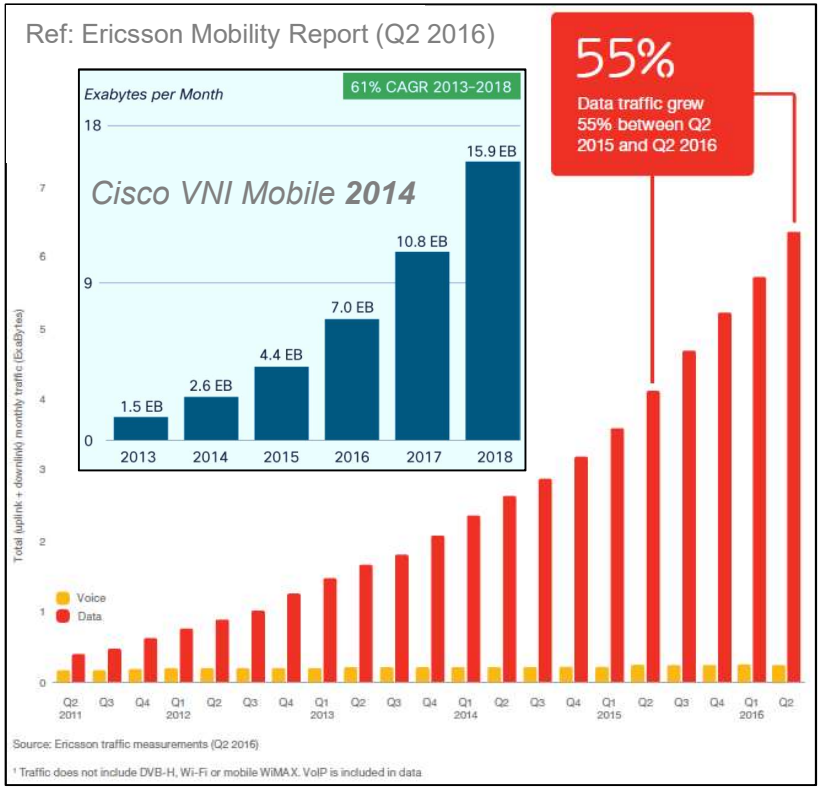


- **LTE and evolution (IOT and unlicensed)**
- 5G use cases (incl. first deployments)
- 5G challenges and test solutions
- Ultra Reliable and Low Latency Communication (URLLC)
- Conclusion

Mobile Data Traffic Growth: it is happening!

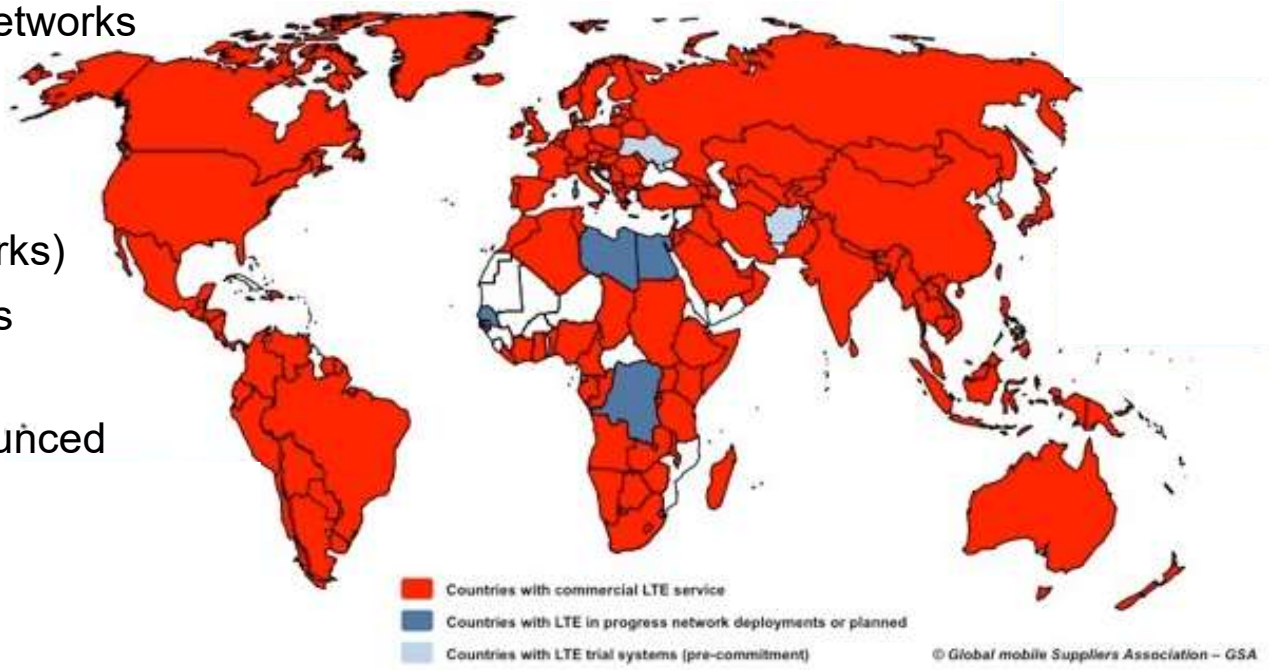




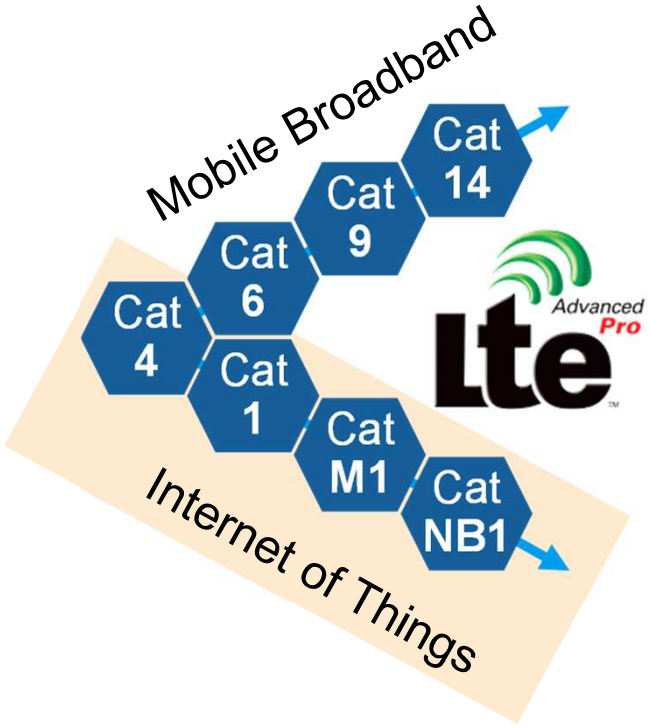
- **Mobile data traffic growth is not a myth, it is real!**
- **Operators have to invest to provide higher capacity (Where? How much? When?)**

LTE Today (Source GSA: Jan 2017)

- 581 commercially launched networks in 186 countries
- 183 LTE-Advanced systems launched in 87 countries (17 LTE-Advanced Pro networks)
- 1.683 billion LTE subscriptions globally: Q3 2016
- 7,037 LTE user devices announced (2,797 TD-LTE capable)
- LTE is the fastest developing system technology ever



3GPP Standardization targets



Targets:

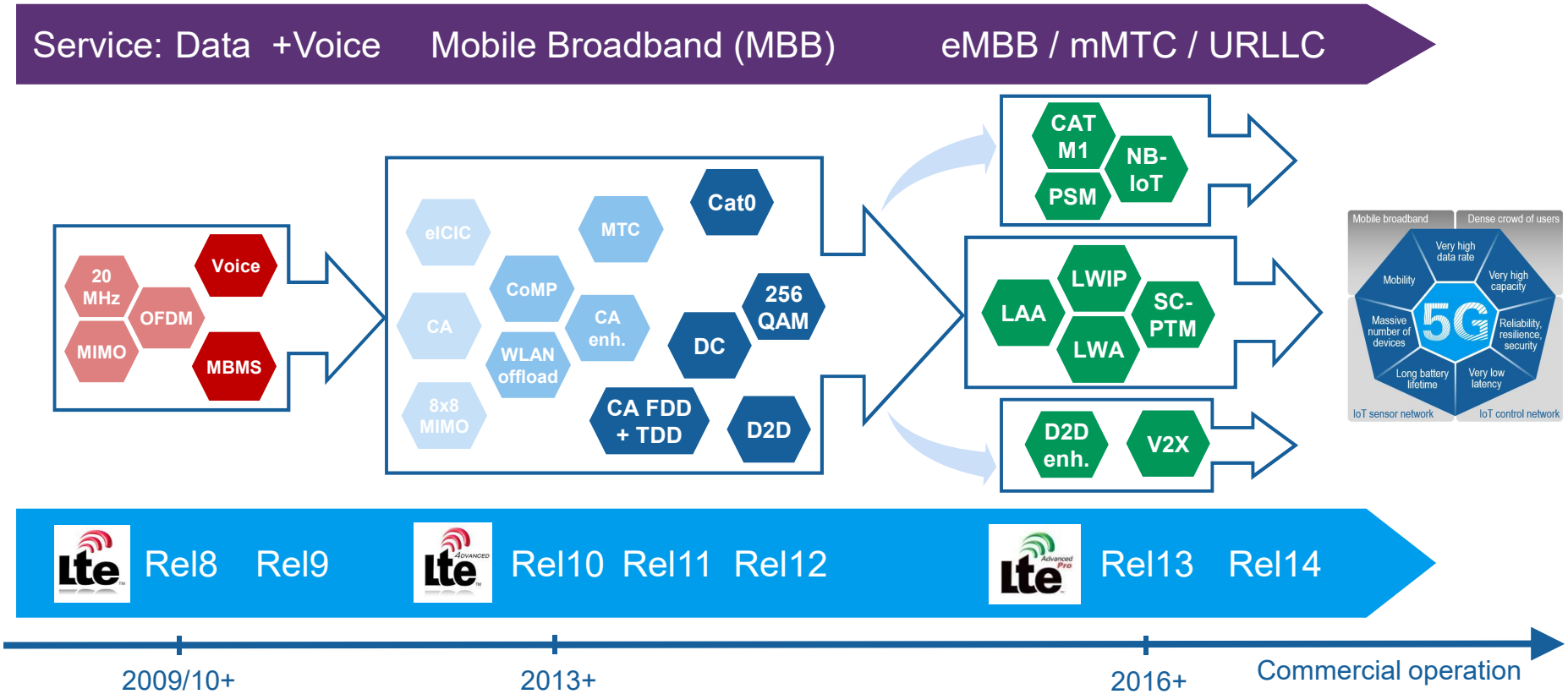
- Higher data throughput
- Wider bandwidth (Carrier Aggregation)
- Higher complexity (4x4 MIMO, interference mitigation, etc.)

→ 2 contradicting evolution paths in 3GPP

Targets:

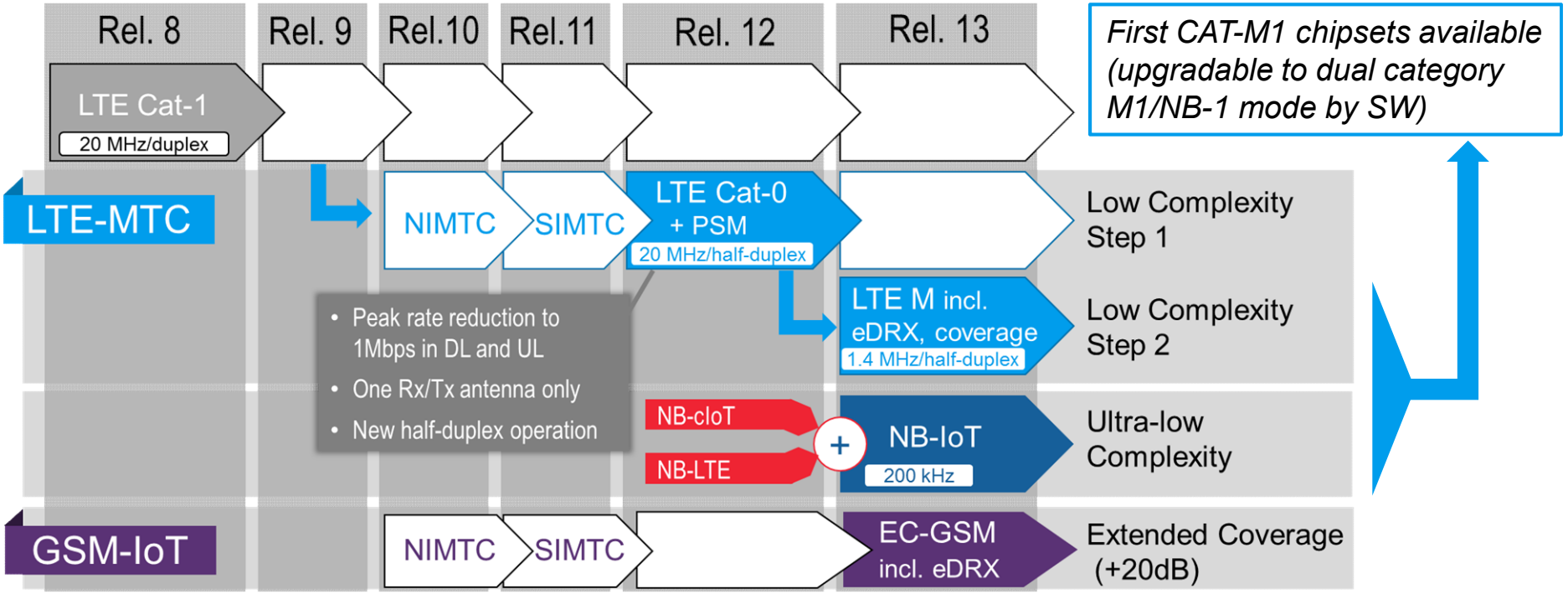
- Lower data throughput
- Less bandwidth
- Lower power consumption
- Lower complexity

LTE-Advanced Pro: Continuing the Success of LTE / LTE-A



MTC enhancements

Introduction



Introduction: LTE in unlicensed spectrum

LTE-U Forum
(own specification)

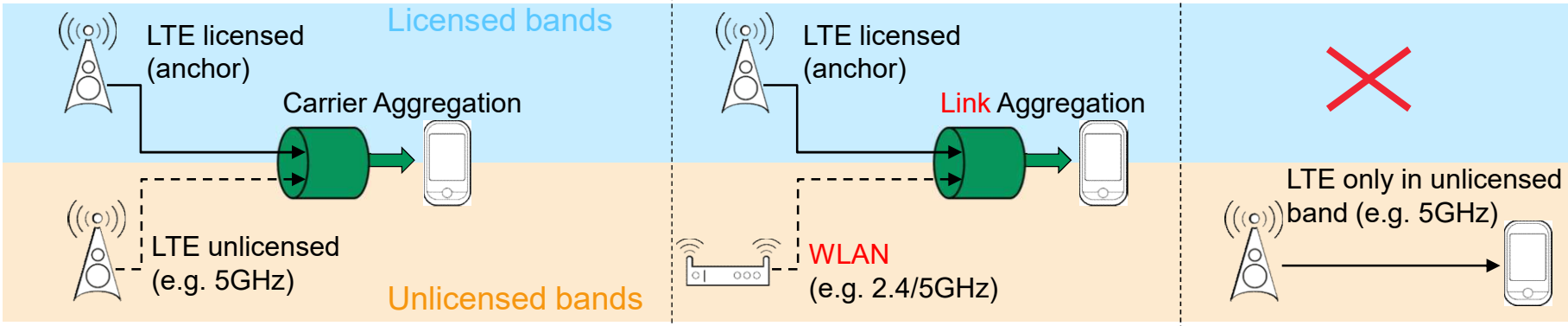
LTE-U
LTE-Unlicensed

/ LAA:
/ Licensed-Assisted Access

3GPP
A GLOBAL INITIATIVE

LWA:
LTE WiFi Link Aggregation

MULTEFIRE
(own specification)
MulteFire



LTE-U: Dynamic channel selection with CSAT (based on Rel.12)

LAA: Dynamic channel selection with LBT (3GPP Rel.13 DL)

LWA part of 3GPP Rel.13; requires an interface (Xw) between eNB and WLAN

DL based on 3GPP Rel.13
UL based on 3GPP Rel.14

CSAT: Carrier Sensing Adaptive Transmission LBT: Listen Before Talk

Benefits LTE-U / LAA / LWA / MulteFire

LTE-U Forum
(own specification)

LTE-U
LTE-Unlicensed

/ LAA:
/ Licensed-Assisted Access

LWA:
LTE WiFi Link Aggregation

(own specification)
MulteFire

- Higher data rates (CA)
- Higher capacities (wide spectrum available)
- LTE anchor → control on MNO side
- Traffic steering based on apps or reliability requirements
- Ideal for small cell deployments

- High capacities (wide spectrum available)
- Reusing (carrier-grade) WiFi infrastructure

- High capacities (wide spectrum available)
- New use cases (e.g. Enterprise)
- Alternative operators

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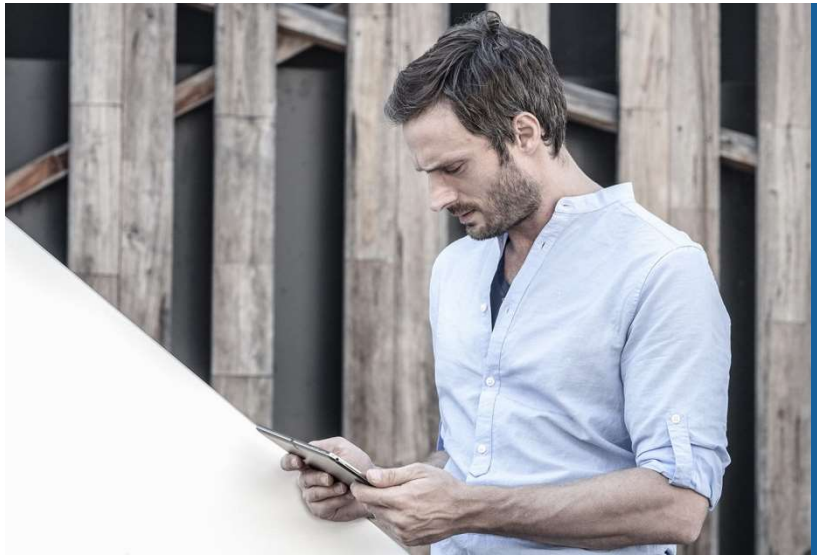


- LTE and evolution (IOT and unlicensed)
- **5G use cases (incl. first deployments)**
- 5G challenges and test solutions
- Ultra Reliable and Low Latency Communication (URLLC)
- Conclusion

What is 5G? – It's a paradigm shift

1G ~1985

2G 1992

3G 2001

4G 2010

5G 2020

Transition from analog to digital…

1. Define use case
2. Analyze requirements
3. Define technology

1. Define technology framework
2. Find a use case

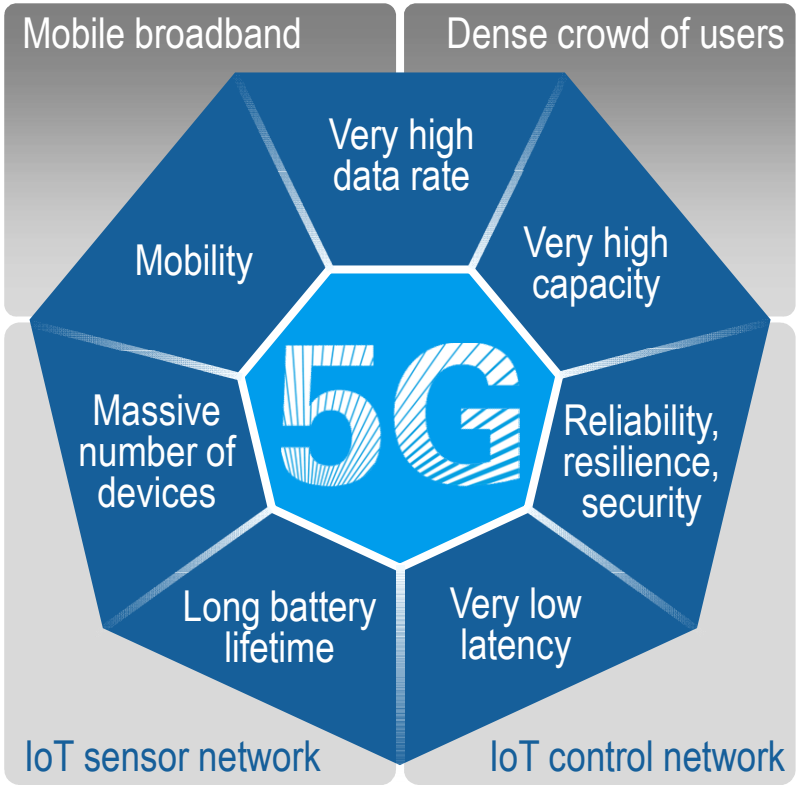
Use cases: Much more than only Mobile Broadband

Scenarios & Requirements

- **Mobile broadband / Dense crowd of users**
  Mobility, high data rates, high capacity and partly limited area.

- **Internet of Things – reliable and low latency**
  Low latency, high reliability, resilience and security; user case specific data rates/capacity.

- **Internet of Things – massive number of devices**
  The volume of devices and “things” will create new requirements.
  Battery life time expectation → years

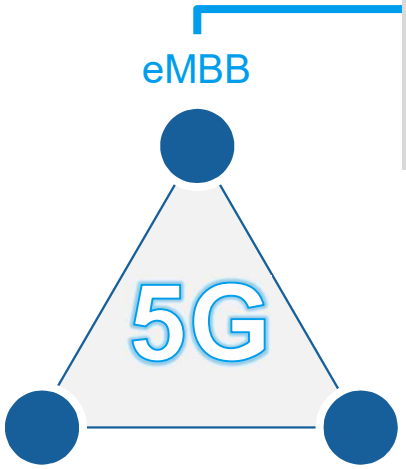


The Triangle of 5G Use Cases

eMBB remains Priority 1

Massive IoT

- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M, NB-IoT,…)
- It's all about cost efficiency and massive connectivity



eMBB – the known playground

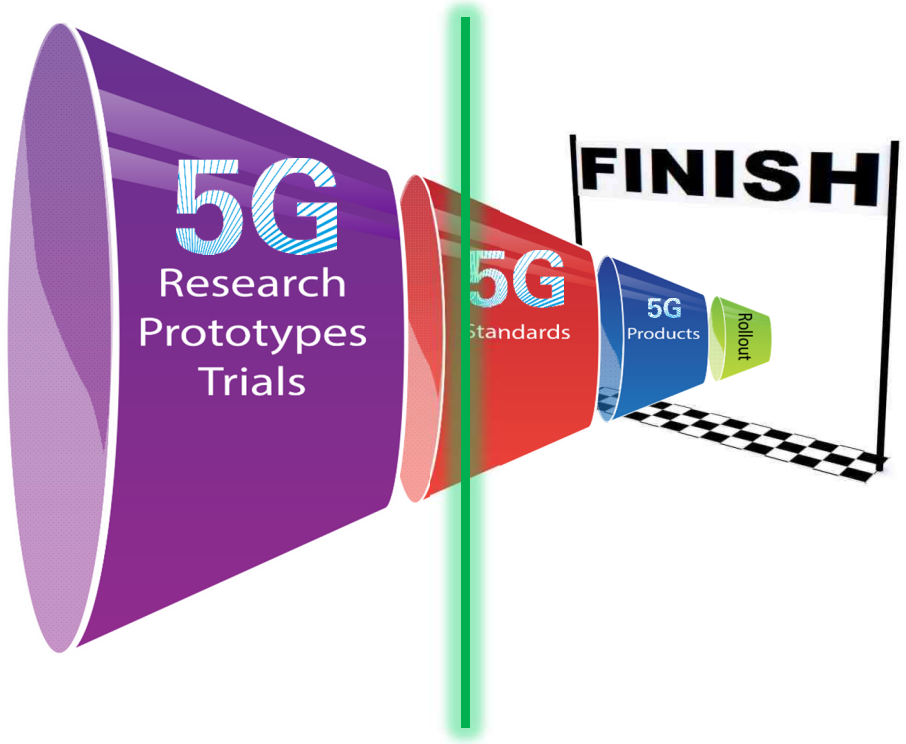
- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies (LTE-A, 802.11 ad) and revolutionary additions (cm- / mm-wave)
- It's all about data (speed and capacity)

URLLC

- A significantly enhanced and diverse ecosystem (operators (?), manufacturers, verticals, certification not existing (yet))
- Existing technologies do not provide sufficient performance
- It's all about reliability and security (data and capacity)

Where do we stand with 5G?

- Transition from pure research phase and early 5G prototype and demonstrator stage towards standardization work.
- 3GPP added first official (5G) work items in March 2016 and updated its timeline in June 2016 due to parallel industry activities outside standardization body.
- Pre-commercial field trials are anticipated mid of 2017 with proprietary standards based on agreements between network operator(s) and their vendors.



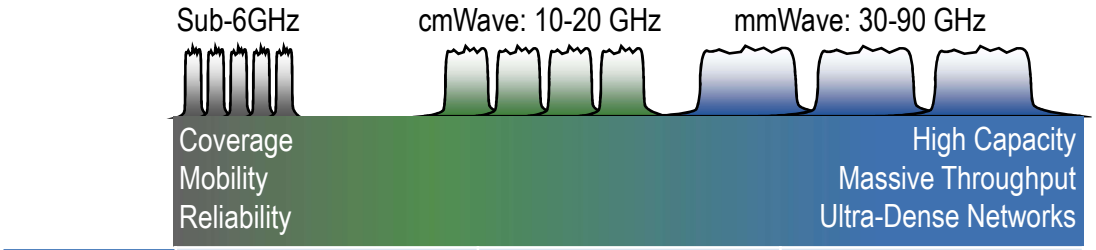
5G Spectrum Outlook

Conclusion from WRC-15

- Considered frequency ranges and bands to be studied for 5G:
  - 24.25 to 27.5 GHz
  - 31.8 to 33.4 GHz
  - 37.0 to 43.5 GHz
  - 45.4 to 50.2 GHz
  - 50.4 to 52.6 GHz
  - 66 to 76 GHz
  - 81 to 86 GHz.

  Total available bandwidth: ~30 GHz

  - 28GHz band is not fully covered, however of high interest for deployment in US and Korea.



Carrier BW	n x 20 MHz	n x 100 MHz	1-2 GHz
Cell Size	Macro	Small	Ultra-small

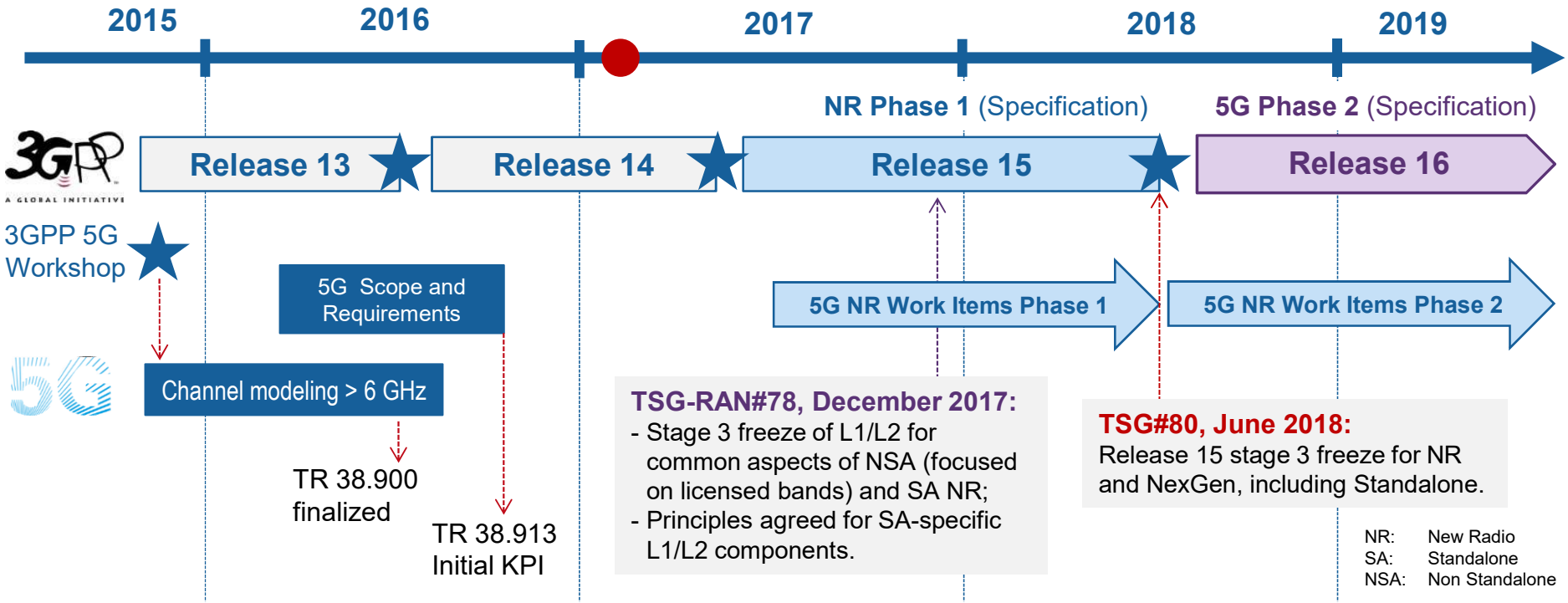
Recommended Bands < 6GHz (Europe)

Sub 700MHz 470-694 MHz	TD-LTE 2.7-2.9 GHz
L-Band 1350-1400 MHz 1427-1517 MHz	C-Band 3.4-3.8 GHz 3.8-4.2 GHz

Total available bandwidth: 1.3 GHz

3GPP Standardization

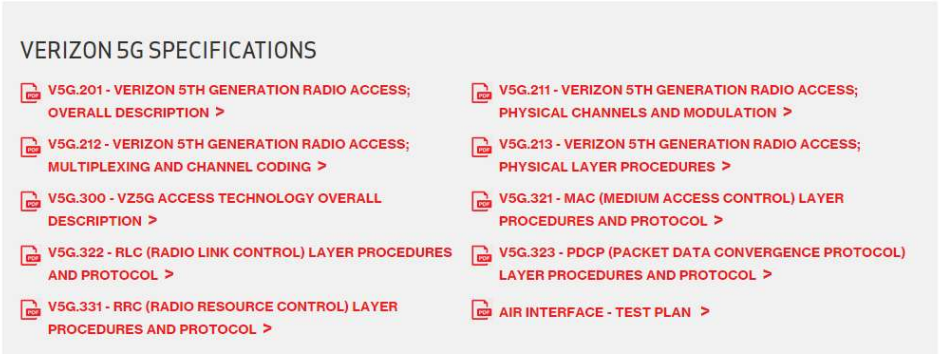
Timeline after 3GPP RAN#74 (Dec 2016)



BUT: Early 5G plans by Verizon Wireless, KT relies on same PHY/MAC

- Verizon Wireless 5G specification first version made available in July 2016: www.5gtf.org
  - KT published it's version in Nov. 2016 w/ mobility.

- Based on 3GPP Release 12 LTE specification several changes and adaptations:
  - OFDM(A) used also in the uplink.
  - Beamforming: Beam Reference Signal (tracking & Acquisition), Beam Refinement Reference Signal.
  - Beam recovery
  - Phase Noise compensation reference signal defined for downlink and uplink.
  - PHY/L1, MAC/RLC adaptations, new physical signals and new or extended PHY channel/functionality
  - Higher layer (protocol) changes to be added.



Comparison LTE and Verizon Wireless 5G

PHY parameterization (1/2)

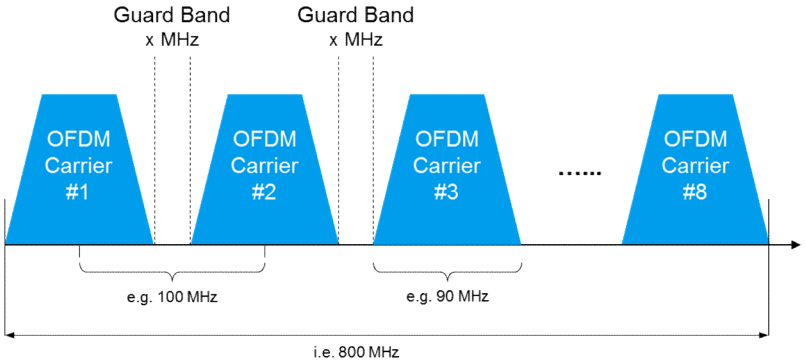
PHY parameter	LTE (Rel.8-14)	Verizon 5G
Downlink (DL)	OFDM	OFDM
Uplink (UL)	DFT-s-OFDM (SC-FDMA)	OFDM
Subframe Length	1ms	0.2ms
Subcarrier Spacing	15 kHz	75 kHz
Sampling Rate	30.72 MHz	153.6 MHz
Bandwidth	20 MHz	100 MHz
NFFT	2048	2048
OFDM symbol duration, no CP	66.67 us	13.33 us
Frame Length	10 ms	10 ms
#Subframes (#slots)	10 (20)	50 (100)
CP Type	Normal & Extended	Normal Only
Multiplexing	FDD / TDD	Dynamic TDD
Max RBs	6,15,25,50,75,100	100
DL/UL Data coding	Turbo Code	LDPC code

Not part of 3GPP 5G NR numerology (yet)!

Comparison LTE and Verizon Wireless 5G

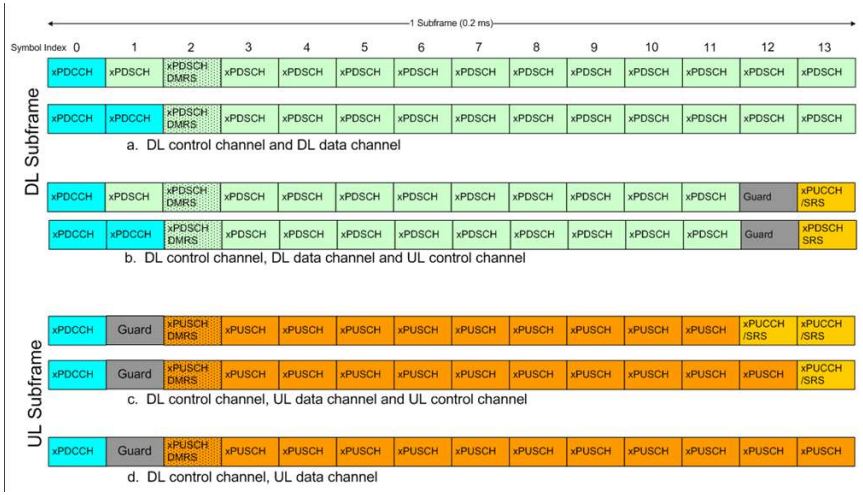
PHY parameterization (2/2)

- Aggregation of up to 8 carriers 100 MHz each.
  - LTE: 3GPP Rel.10-12: only 5 carriers 20 MHz each.
  - LTE: 3GPP Rel.13: 32 carriers up to 20 MHz each.



- New PHY signals and new or modified PHY channels, supporting additional capabilities.

- Dynamic switch on a subframe basis from downlink to uplink transmission.
  - 4 possibilities:



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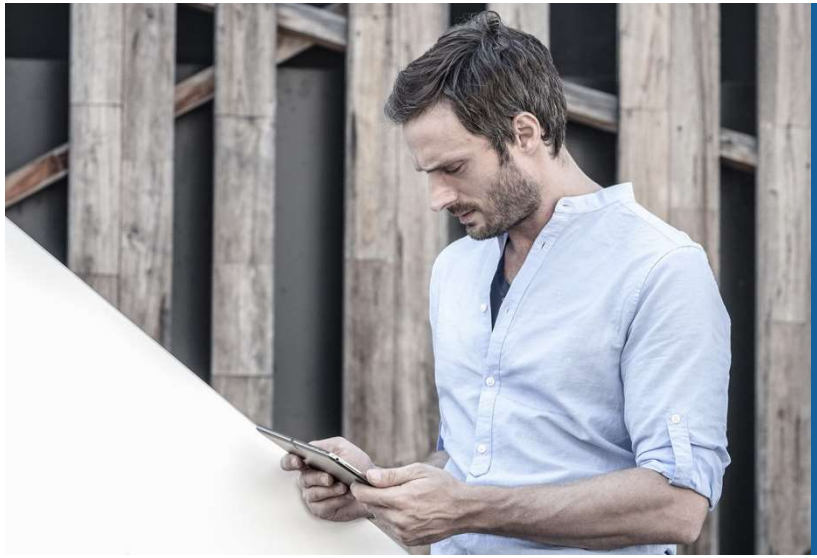

- LTE and evolution (IOT and unlicensed)
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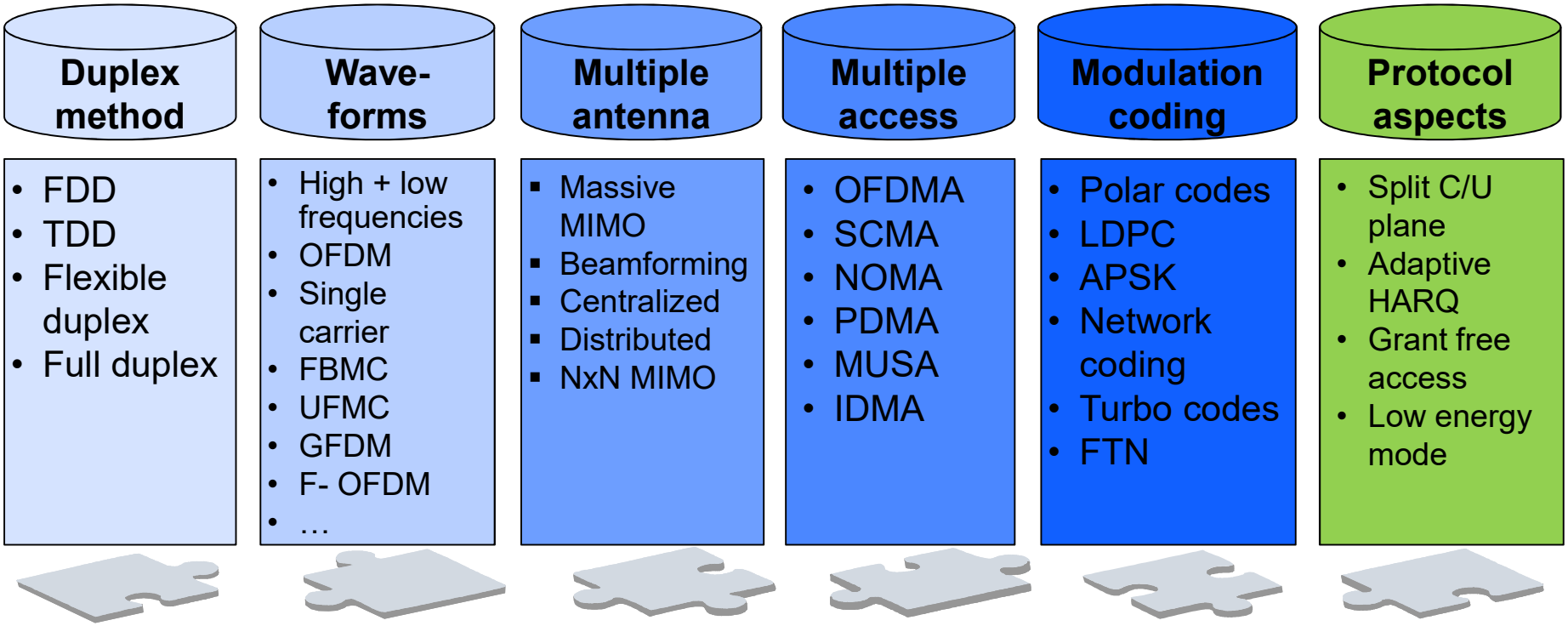
Air interface framework for 5G



Various combinations of above methods to fulfill multiple scenarios

5G Test & Measurement Challenges

High Frequency / high bandwidth: Generation + Analysis

High Frequency: Channel Characterization

High Frequency: PA / components

Antenna Arrays / massive MIMO, beamforming

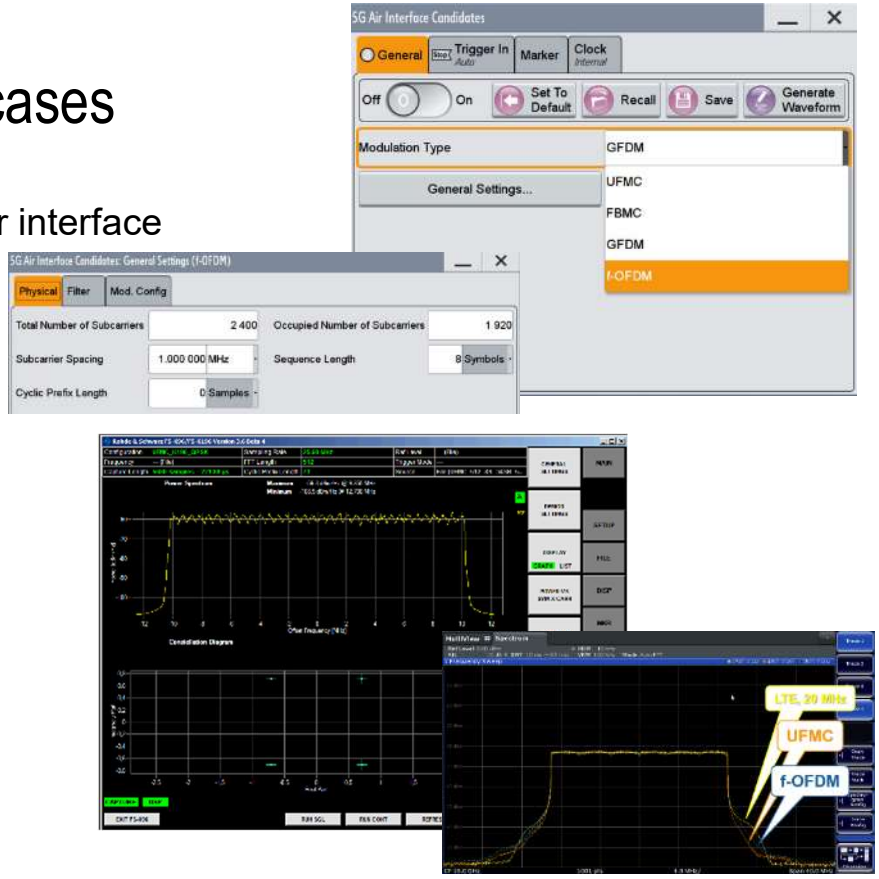
Air Interface Candidates

Pre-5G trial support

5G Challenges

LTE air interface will not support all use cases

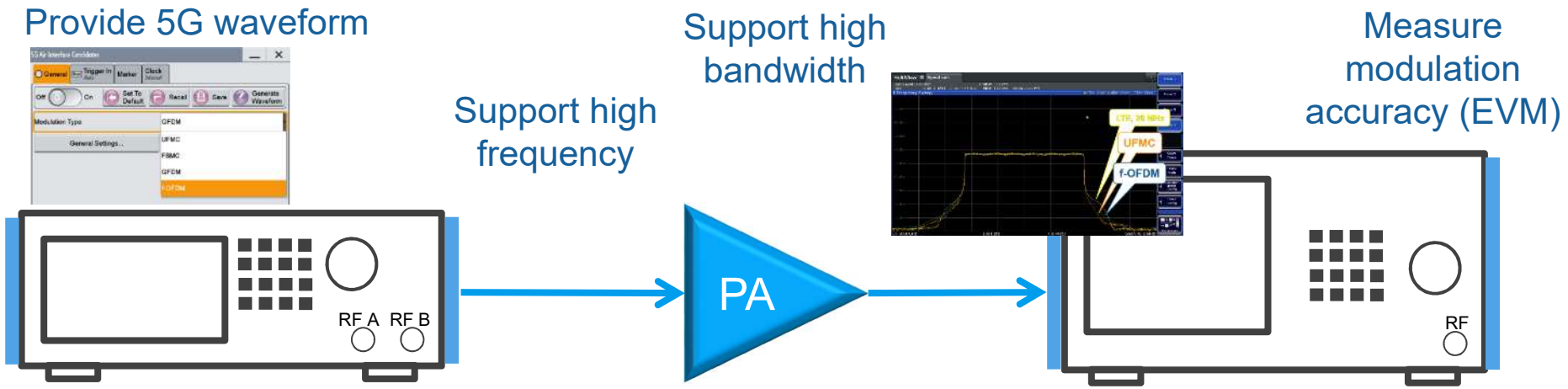
- In particular low latency requirements require redesign
- Many different use cases suggest more than a single air interface
- Discussed candidates comprise:
  - **UFMC**: Universal Filtered Multi-Carrier
  - **FBMC**: Filter-Bank Multi-Carrier
  - **GFDM**: Generalized Frequency Division Multiplexing
  - **f-OFDM**: Filtered-OFDM
- Discussed multiple access schemes
  - **SCMA**: Sparse Code Multiple Access
  - **NOMA**: Non-Orthogonal Multiple Access
- Common advantages at the cost of higher complexity:
  - Better robustness against imperfect synchronism
  - Reduced out-of-band emission
- Common key parameters:
  - FFT size, number of active subcarriers, subcarrier spacing
  - Number of symbols per subcarrier, symbol source



5G Challenges

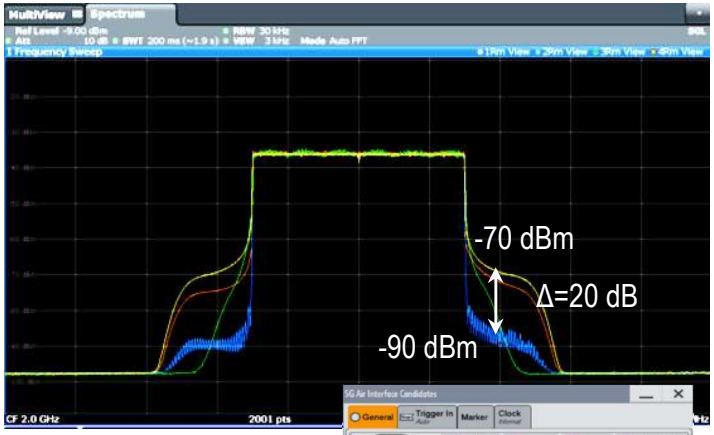
PA Implementation Challenge - Very High Data Rate (= High Bandwidth)

- Existing power amplifier designs need to be adapted
  - changed frequency and bandwidth requirements below 6 GHz
  - new design for broadband support at cm-/mm-wave frequencies (e.g. 28 GHz)
- Demanding requirements for T&M instruments (f, BW, EVM, flatness, …)



5G Challenges: Waveform Gains - From Theory to Reality

From: Waveform theory and simulation



OFDM
FBMC
UFMC
GFDM

R&S®SMW200

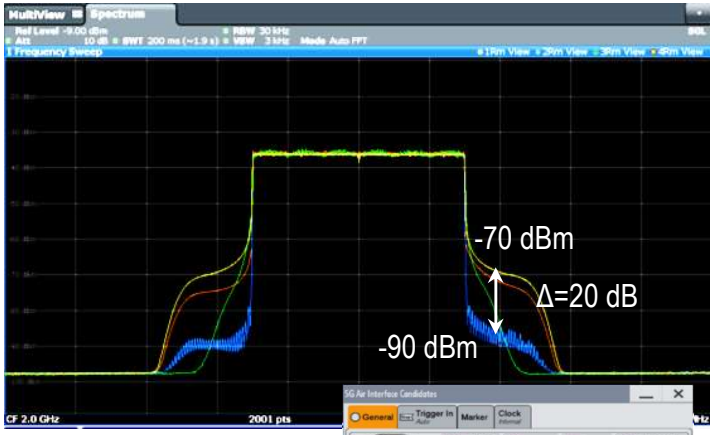
R&S®FSW85

ARB
Waveform Files

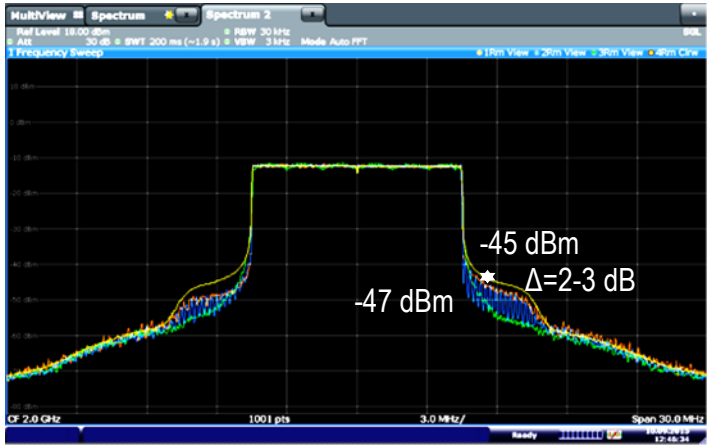
5G Challenges: Waveform Gains - From Theory to Reality

From: Waveform theory and simulation

To: Real devices with non-linear elements



OFDM
FBMC
UFMC
GFDM



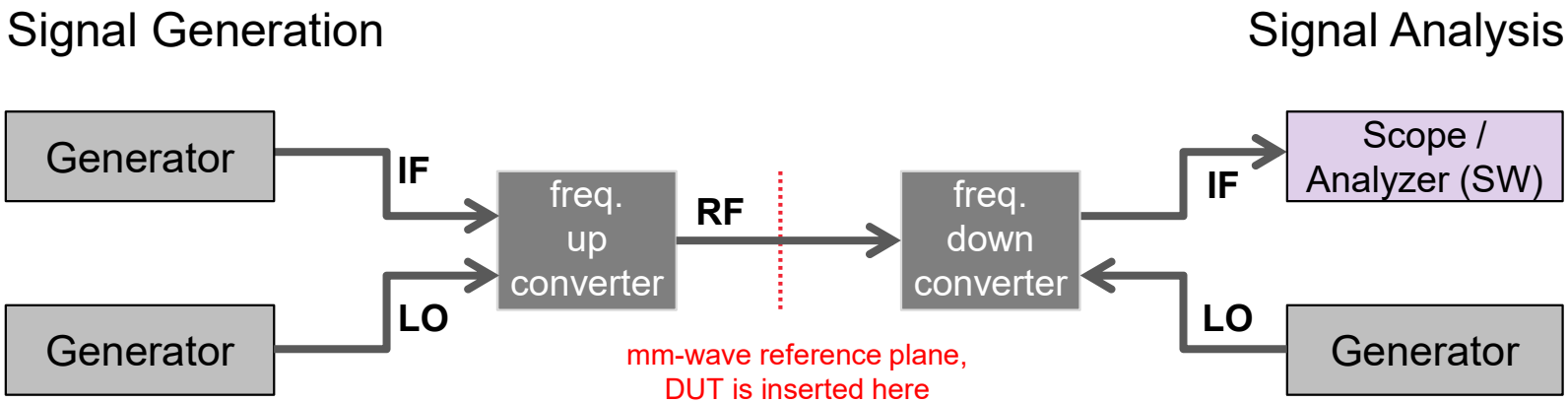
R&S®SMW200

R&S®FSW85

ARB
Waveform Files

DUT: Power Amplifier

General considerations and challenges of high frequency test setups

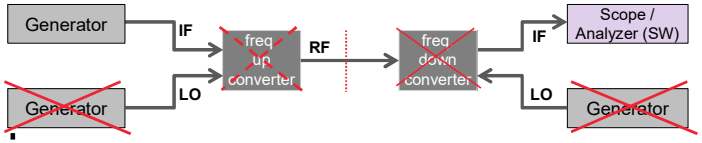


- Complexity of the test setup is very high (many instruments, up- and down-conversion, etc.)
- Be careful with signal quality and the performance of used test instruments!
- Be careful with increasing sensitivity of mm-wave test setups (touching cables, handling waveguides, etc.) – repeatability should be key!

➔ Try to simplify the setup as much as possible (avoid up- and down-conversion)

R&S Test Solution

5G wideband signal generation and signal analysis



Signal and spectrum analysis

Remote controlled

R&S®RTO1044

R&S®FSW

Analysis up to 85 GHz and built-in demodulation up to 2GHz bandwidth

RF

Device under test

Signal generation

R&S®SMW200

RF up to 40 GHz

2 RF outputs (up to 20GHz each) or 1RF output (up to 40GHz) with up to 2GHz bandwidth

Optional:
1RF output (58 GHz to 65 GHz); up to 2GHz bandwidth

Signal Analysis:

- FSW up to 85 GHz and 2 GHz analysis bandwidth
- Signal Analysis > 85 GHz with FSW using external mixer
- FSW internal support for 512 MHz analysis bandwidth (FSW-B512)

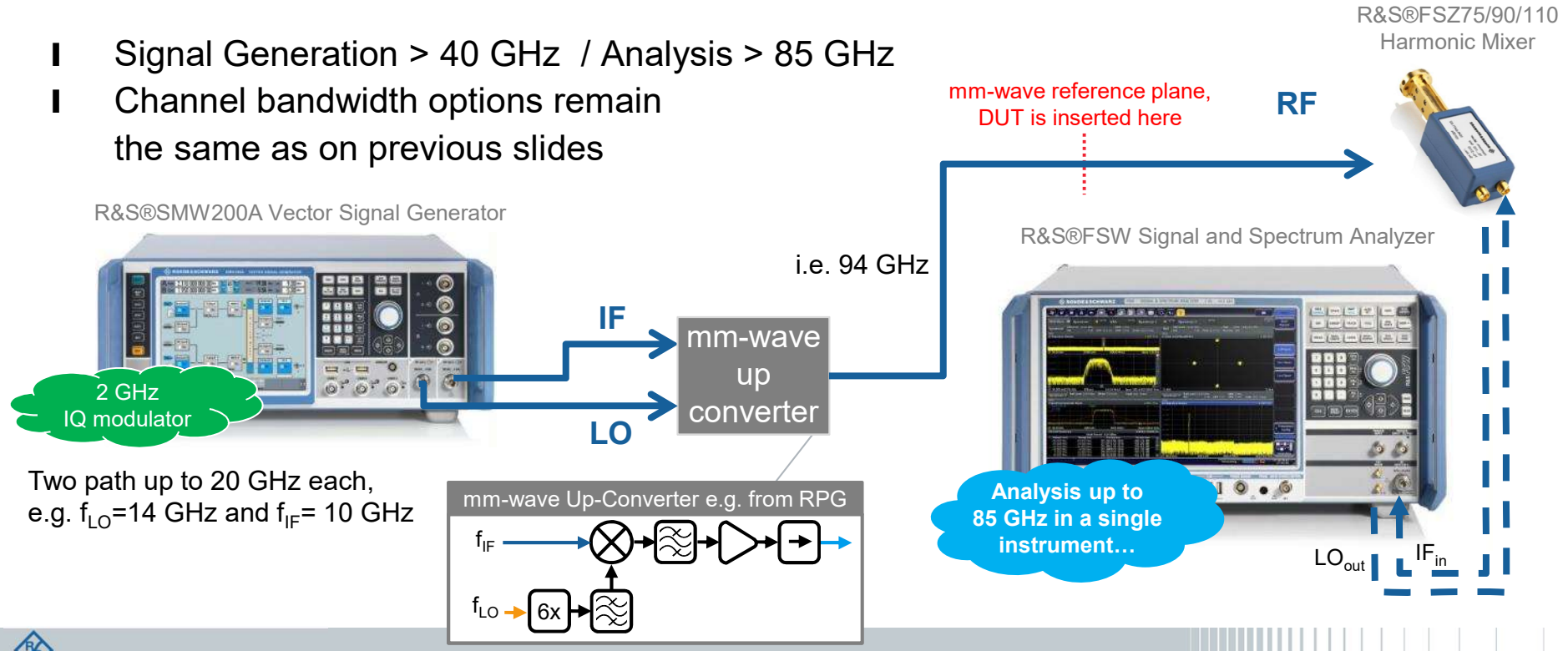
Signal Generation:

- SMW: up to 40GHz without up-conversion (best signal quality)
- Bandwidth up to 2GHz
- Optional V-Band Upconverter

R&S Test Solution

Signal Generation / Signal Analysis for very high frequencies

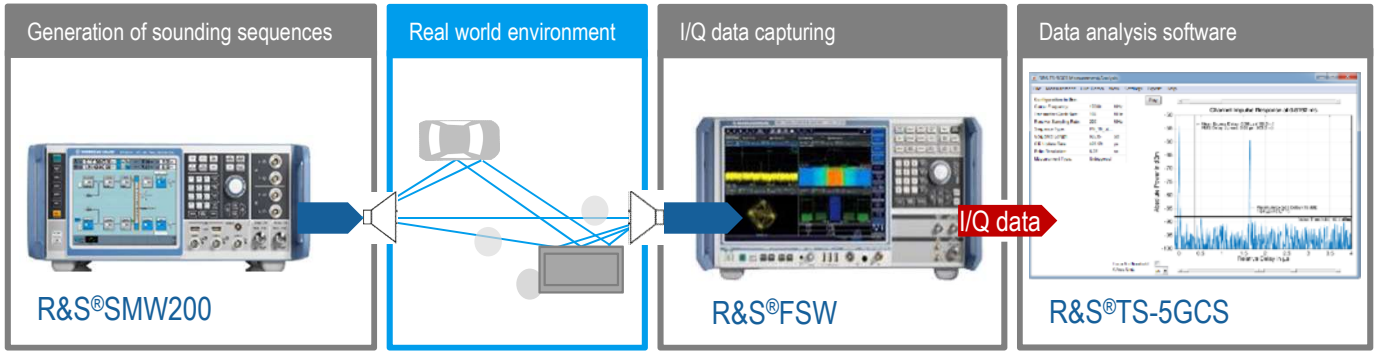
- Signal Generation > 40 GHz / Analysis > 85 GHz
- Channel bandwidth options remain the same as on previous slides



Channel sounding for 5G

R&S Test Solution with TS-5GCS

Channel sounding = characterization of the radio channel by decomposing the radio propagation path into its individual multipath components (due to reflections, etc.).
Essential for developing robust modulation schemes to transmit data over the channel.

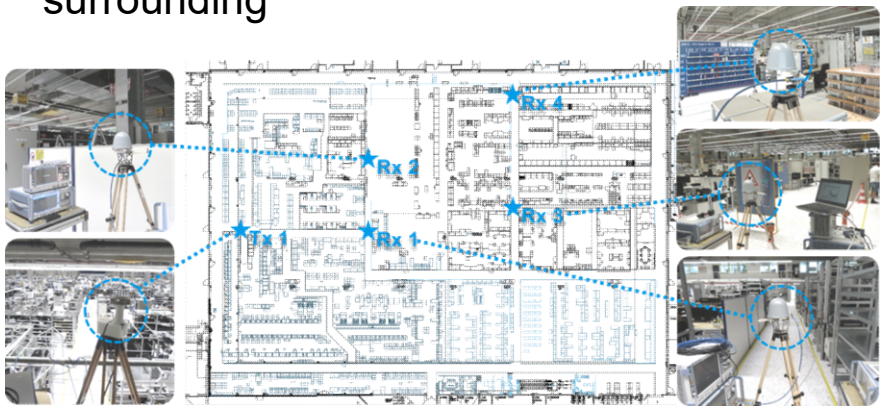


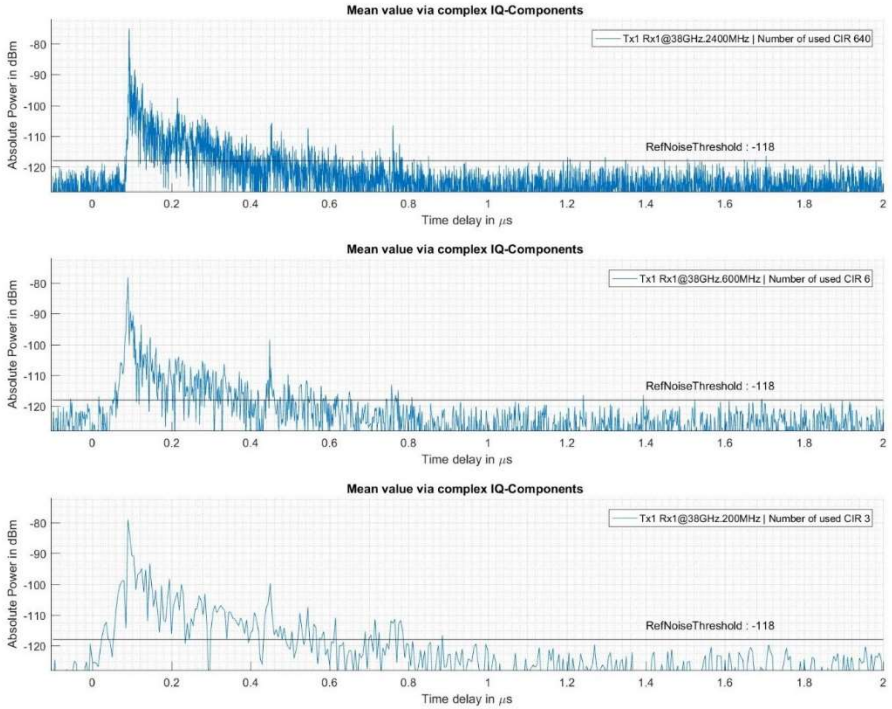
- The R&S solution enables direct measurement of the **channel impulse response (CIR) in the time domain**.
  - Benefits of high quality T&M instruments, like traceability, repeatability and flexibility
  - Unique dynamic range due to the R&S®FSW high receiver sensitivity and built-in low-noise power amplifier
  - Various sounding signals (e.g. m-sequences or ZC sequences) with flexible bandwidth independent of the frequency

Channel Sounding Example

Based on off-the-shelf T&M equipment

- Industry 4.0: R&S conducted own channel sounding campaigns in industrial surrounding





Power delay profile measurements in the factory
Frequencies: 38GHz with 160MHz, 500MHz and 2GHz bandwidth (path resolution)

R&S Test Solution

Using Vector Network Analyzers to Characterize e.g. Antenna Arrays

- The R&S®ZNB analyzer features high measurement speed, outstanding precision and exceptional ease of operation
  - Frequency range from 9 kHz to 40 GHz
- The R&S®ZVT8/R&S®ZVT20 is the first true eight-port/six-port vector network analyzer with a frequency range from 300 kHz to 8 GHz / 10 MHz to 20 GHz
- For two or four-port R&S®ZNB with ZN-Z84/Z85, configuration of up to 48 test ports possible
  - Frequency range from 9 kHz to 20 GHz
- Four-port R&S®ZNBT8 base unit (upgradeable to 8, 12, 16, 20 or 24 ports) with a frequency range from 9 kHz to 8.5 GHz
- Eight-port R&S®ZNBT20 base unit (upgradeable to 12 or 16 ports) with a frequency range from 100 kHz to 20 GHz

Multi-port VNA

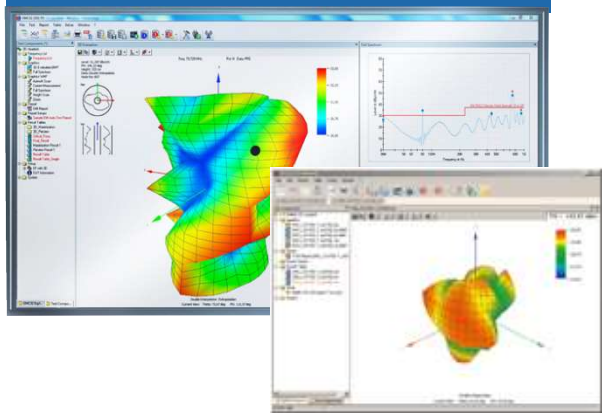
Antenna connectors will disappear (antenna arrays)

R&S: One-Stop Shop for OTA

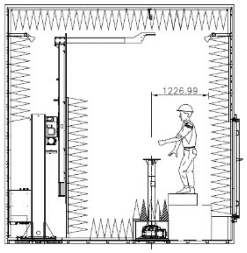
Completely Integrated & Customized OTA Solution

Measurement Equipment

AMS/EMS32 Software



Wide Range of Chambers



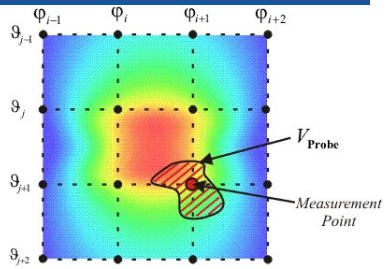
Customized EMC and OTA Chambers

Turn-key Desktop Systems

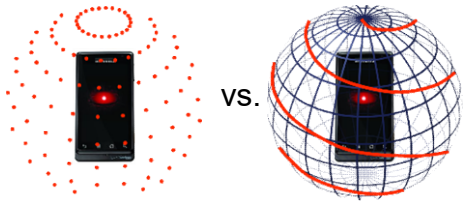
R&S Test Solutions: Nearfield to Farfield Transformation – FIAFTA

Features

Equivalent Sources



Probe Compensation

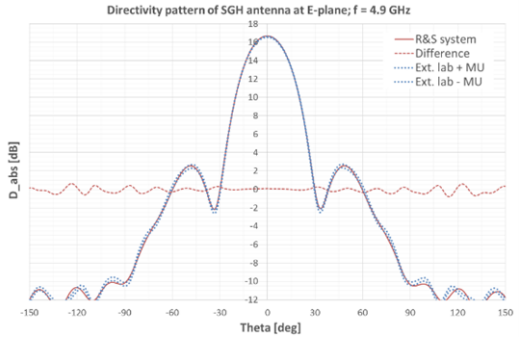


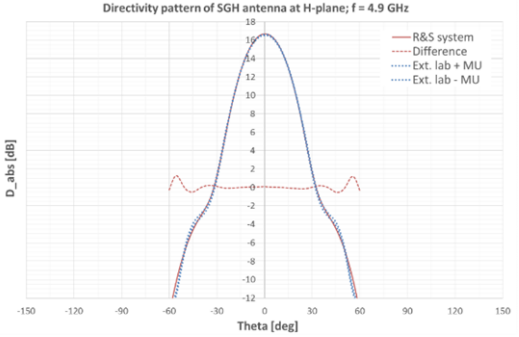
220 minutes

6 minutes

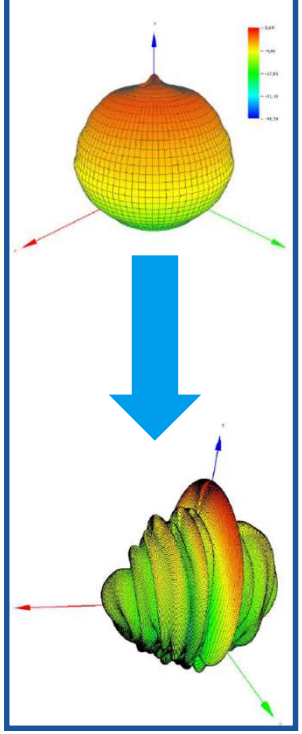
Arbitrary Grids

Performance Comparison





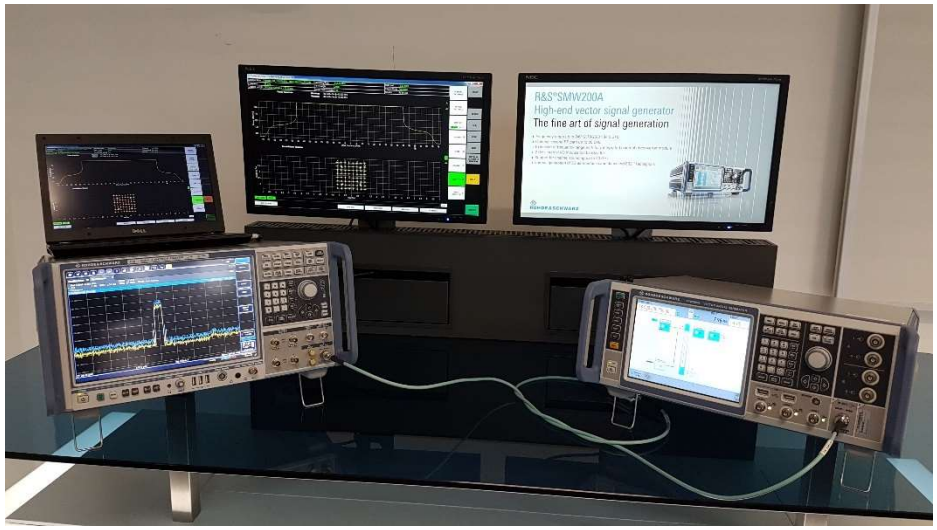
Transformation



R&S Test Solution

Support for Verizon 5G Trial Specifications

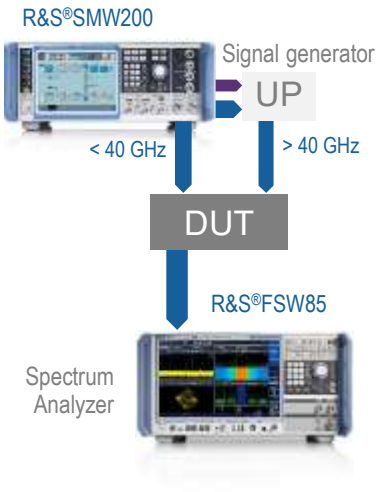
- Based on the 5G trial specifications provided on www.5gtf.org
- Rohde & Schwarz signal generation and analysis instruments already support the basic characteristic of the specified 5G Verizon signal (due to their built-in flexibility)
- R&S®SMW200A Signal Generator connected to R&S®FSW signal analyzer provides an EVM of < 1% for such a 5G signal at 28 GHz (across a 10 dB power sweep)



Rohde & Schwarz supports 5G signal generation and analysis based on Verizon 5G open trial specifications

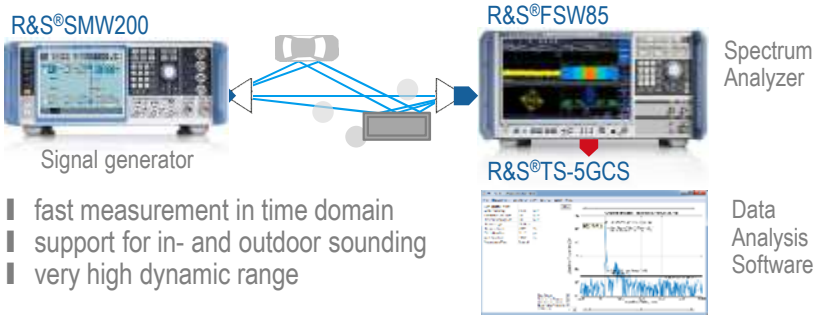
R&S test solutions to investigate, develop and standardize 5G

Wideband Signal Testing



- 40 GHz signal generation
- 85 GHz signal analysis
- 2 GHz bandwidth support

Channel Sounding Solution

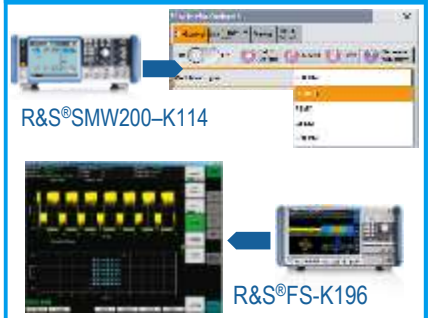


- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range

Massive MIMO - Beamforming

- Phase-coherent RF generation
- Multi-port VNA

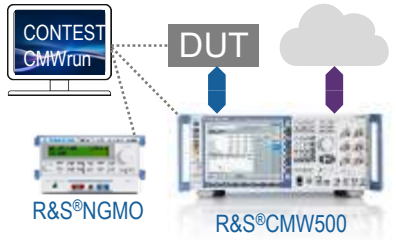
New 5G PHY Candidates



Component Characterization

Direct measurements up to 110 GHz

E2e Application Testing



Analyze application behavior like signaling load, delay, power etc.

From Link Efficiency to System Efficiency

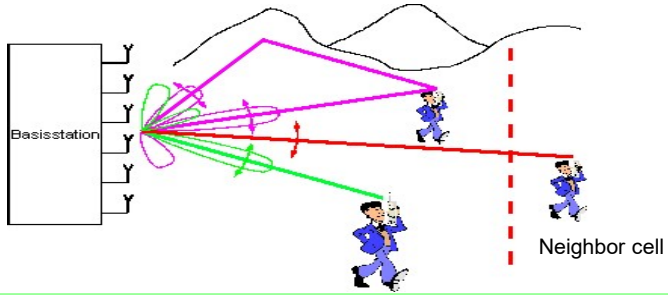
Legacy focus

Link Efficiency

One RAT: link adaptation with coding + modulation to send as much data as possible

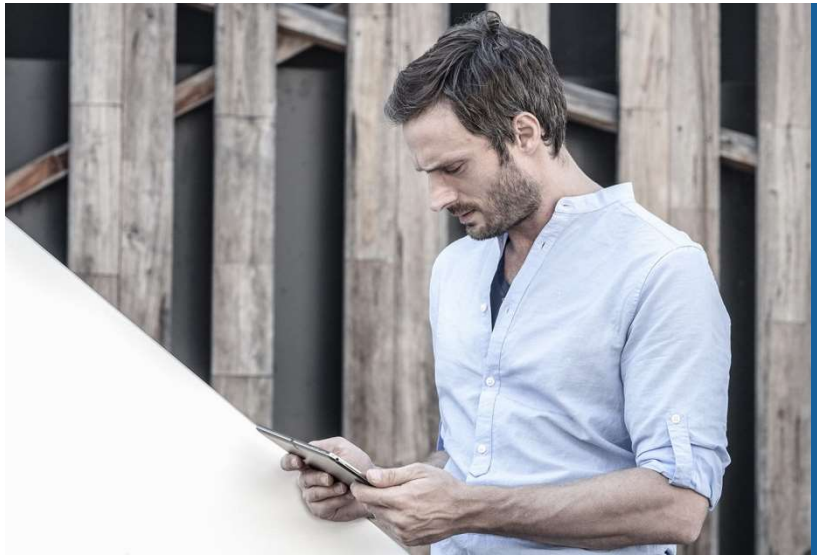
Future focus

System Efficiency



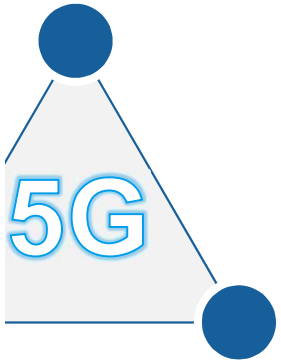
System adaptation, to select the RAT that offers the best data transmission according to the requested quality of service for each service

Contents



- LTE and evolution (IOT and unlicensed)
- 5G use cases (incl. first deployments)
- 5G challenges and test solutions
- **Ultra Reliable and Low Latency Communication (URLLC)**
- **Conclusion**

Characteristics of URLLC and how to achieve …



Ultra reliable & low latency communication

URLLC	How
▪ Low user plane latency	▪ Air Interface structure (TTI) - PHY ▪ Improved HARQ procedures, duplex schemes (FDD, TDD) ▪ Specific channel coding
▪ (Ultra) high reliability (related to latency)	▪ Architecture: redundant links ▪ Reliable links ▪ Improved PHY / HARQ procedures

TTI: Transmit Time Interval
HARQ: Hybrid Automatic Repeat Request

Air Interface structure (TTI) – PHY

Subcarrier Spacing → Symbol length → TTI → Subframe

5G New Radio (NR) numerology: subcarrier scaling is based on $f_0 * 2^m$ with f_0 = 15 kHz

m =	-2	0	1	2	3	4	5	…
Subcarrier Spacing [kHz]	**3.75**	**15**	**30**	**60**	**120**	**240**	**480**	**…**
Symbol Length [µs]	266.7	66.7	33.3	16.7	8.33	4.17	2.08	…
Subframe Length [ms]	4	1	0.5	0.25	0.125	0.0625	0.03125	

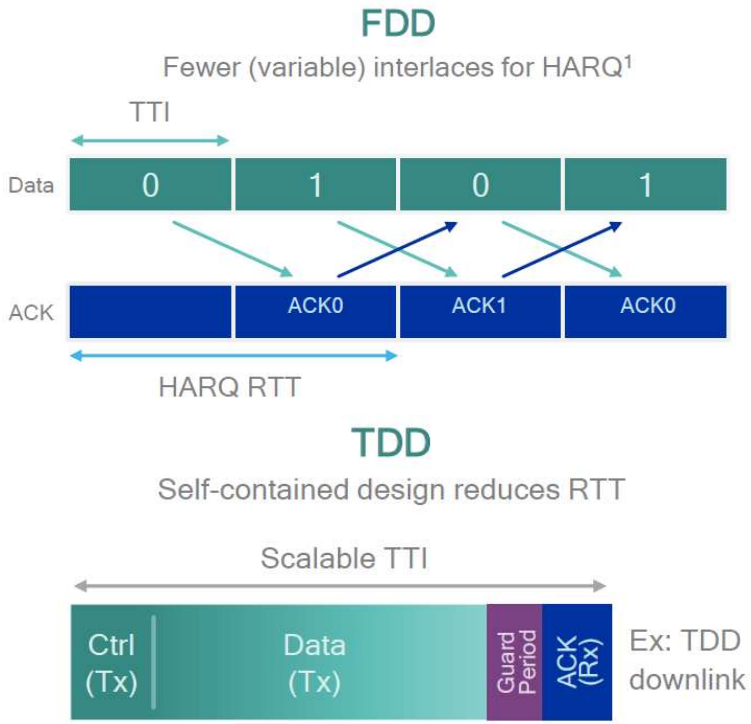
But TTI length depends on the number of symbols:
(# of symbols should not always be 14 like in the table)

TTI = # of symbols * symbol length

Short TTI:

- low # of symbols per TTI (can also be 2 or 8, etc.)
- short symbol length (high subcarrier spacing)

FDD / TDD duplex schemes - improved HARQ procedures



FDD: Retransmission possible after 2 TTI

Flexible TDD switching (betw. DL and UL)

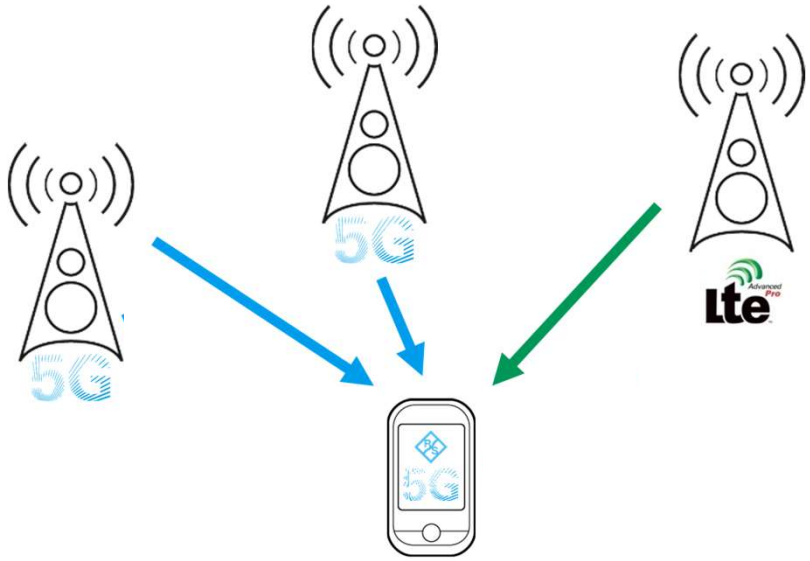
TDD: Data and ACK in the same TTI

Source: Qualcomm

RTT: Round Trip Time

How to achieve Ultra High Reliability?

Definition:
Reliability: Success probability of transmitting a certain amount of data within a certain time



Network Architecture topics:

- Simultaneous redundant links (to infrastructure – also multiple technologies)
- Reliable device-2-device links

5G NR topics:

- Improved PHY / HARQ procedures
  → lower BLER required (impact on capacity)

BLER: Block Error Rate

3GPP TR 38.913 V14.0.0 (2016-10)

Study Item on Scenarios and Requirements for Next Generation Access Technologies

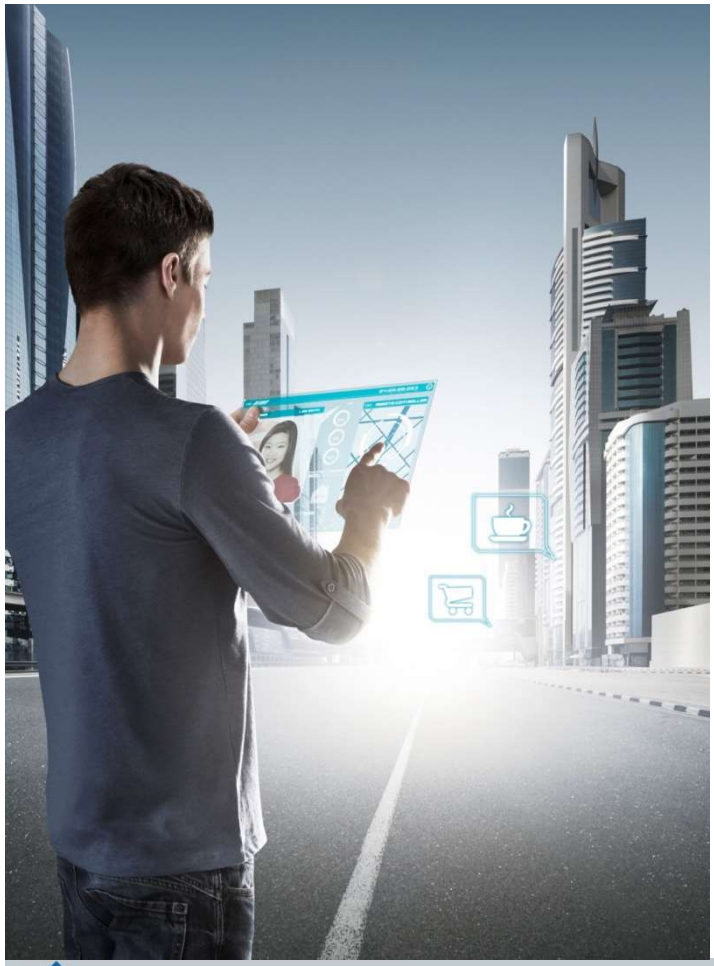
Chapter	Topic	Requirement
Deployment scenarios	Urban grid for connected car	highly densely deployed vehicles in urban area (high network load and high UE density)
KPI	User plan latency	URLLC: 0.5ms in DL and 0.5ms in UL (no DRX restrictions)
	Reliability (success probability)	URLLC: 99.999% ($1-10^{-5}$) for 32bytes with 1ms user plane latency eV2X: 99.999% ($1-10^{-5}$) for 300bytes with relaxed user plane latency
	Mobility interruption time	0ms for user plan between UE and any BS (for all intra-NR mobility)
Supplementary-Service related requirements	V2X communication	V2X communication via infrastructure and sidelink (road side unit)
Operational requirements	V2X communication	NR V2X shall complement and interwork with LTE V2X
	High Availability	Availability of a BS = X% of the time. URLLC services shall not be compromised by energy efficiency functions, system reconfigs, SW updates!

NR: New Radio
DRX: Discontinuous reception

Conclusion

- **LTE is evolving towards unlicensed spectrum and IOT use cases**
- **Is 5G just the next generation? No: It is a paradigm shift!**
  - 5G approach in industry: 1: define use cases, 2: requirements, 3: elaborate technologies / solutions
  - From cell-centric (2G - 4G) to user-centric / application-centric in 5G (beamforming)
  - From link efficiency (2G - 4G) to system efficiency in 5G (RAT defined per app)
  - From antenna connectors (2G - 4G) to Over-the-Air testing in 5G (antenna arrays, beamforming)
- **Increasing demand for security / high reliability in 5G and on high layers (mission- and safety-critical use cases)**

Rohde & Schwarz offers all essential capabilities to support the wireless communications industry with solutions needed to investigate, standardize, develop and rollout 5G



Thank you.
Questions?

"If you want to go fast, go alone.
If you want to go far, go together!"

African proverb