5G Technology Introduction, Market Status Overview and Worldwide Trials

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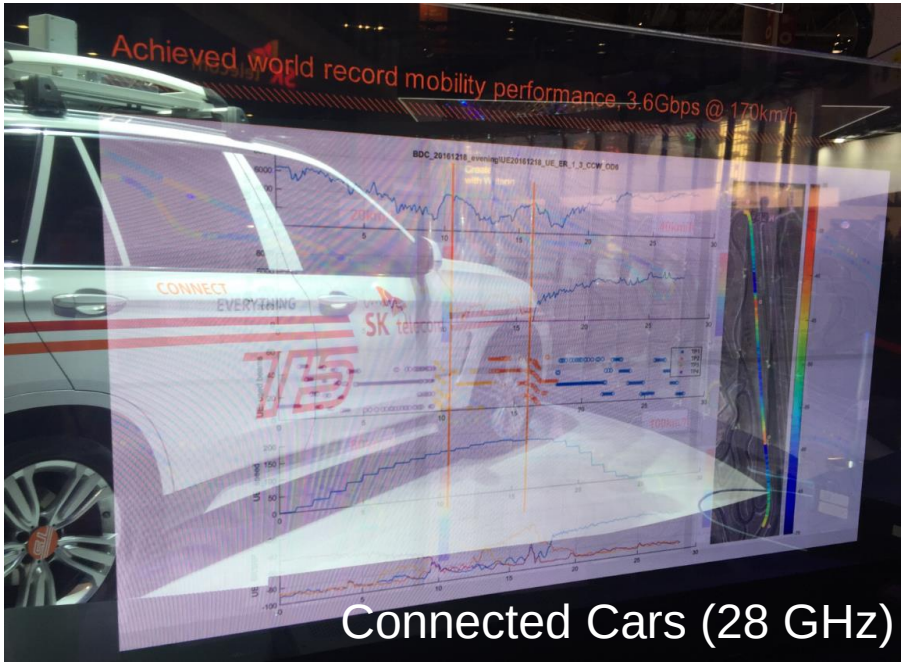
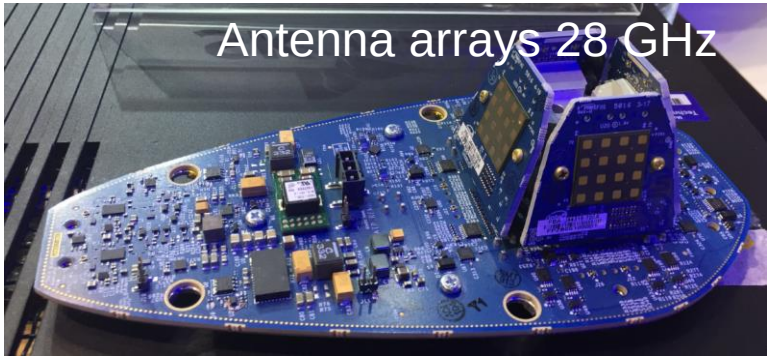
ROHDE&SCHWARZ

TÉCNICO LISBOA

Mobile World Congress 2017 Barcelona (It'not Smartphones anymore)

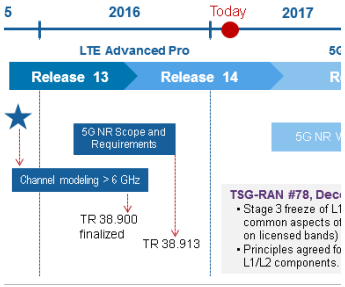


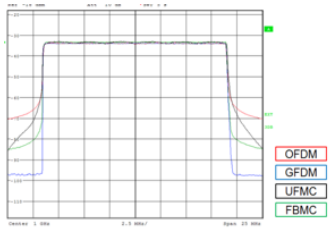


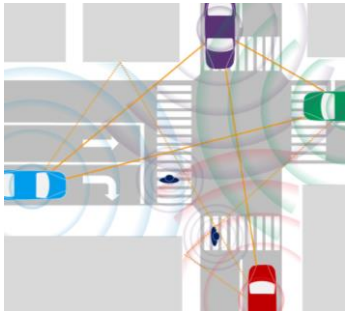
5GAA Automotive Association

Outline

Introduction	Standardization	Trials	Physical Layer	Vehicle-to-X
• What is 5G ?	• Timeline	Verizon SKT KT NTT DOCOMO Etc.	Considerations	- LTE-V2X - 5G V2X (URLLC) - IEEE 802.11p







What is 5G? – It's a paradigm shift

1G 1980s

2G 1990s

3G 2000s

4G 2010s

5G 2020s

Transition from analog to digital…

- Define use case
- Analyze requirements
- Define technology

- *Define technology framework*
- *Find a use case*

What is 5G?

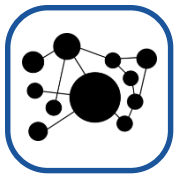
Ultra-Dense Networks

Broadband Access

Broadcast Services

Mobility

Lifeline communications



Sensor Networks

Tactile Internet

E-Health

Evolutionary Wide Area Networks < 6GHz

Revolutionary mmWave Data Networks

Energy Savings	System Capacity	Data Rates	Low Latency	Device Capacity
10-200X	100X	10-100X	< 1 ms	100X

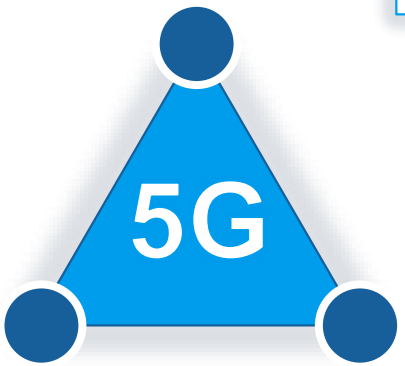
The Triangle of 5G Use Cases

eMBB remains Priority 1

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)

enhanced Mobile Broadband (eMBB)



Massive IoT

- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M1, NB-IoT,…)
- It's all about cost efficiency and massive connectivity

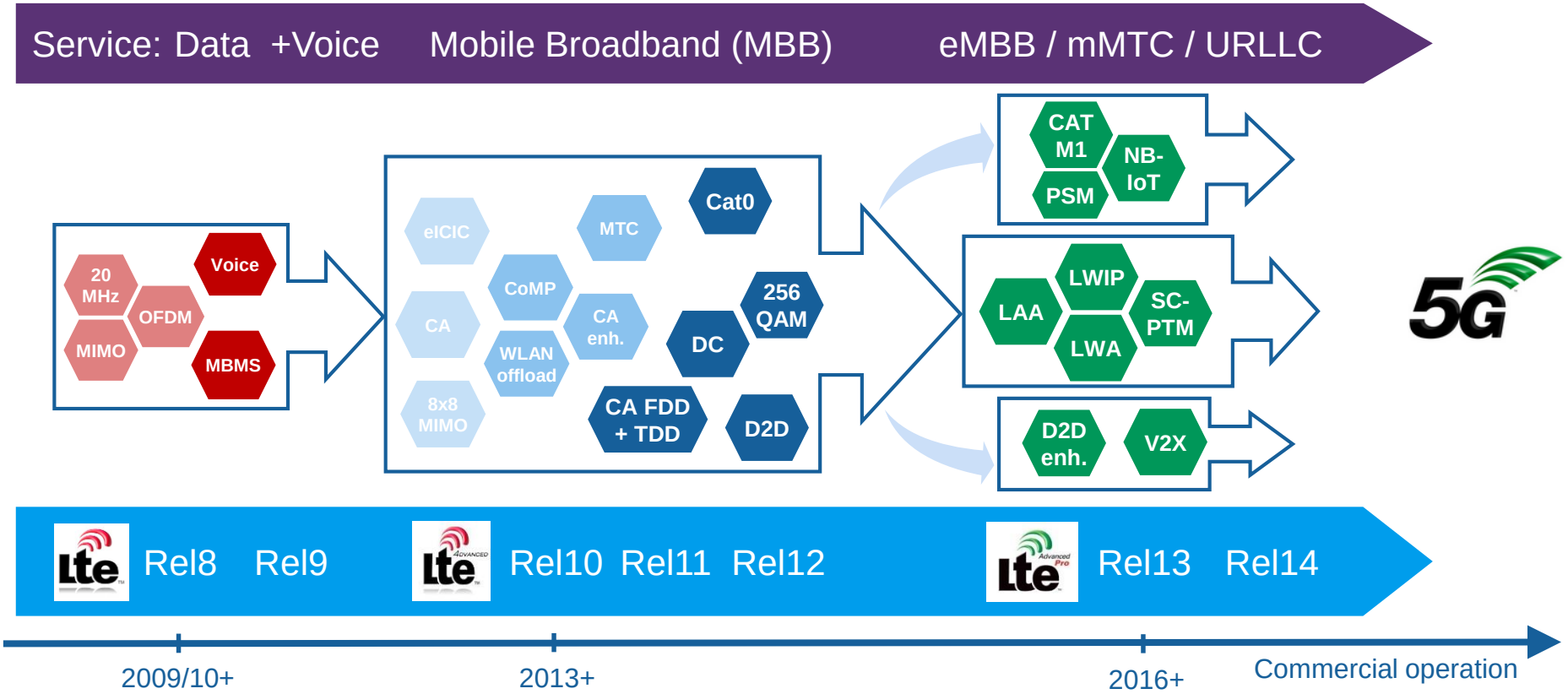
massive Machine Type Communication (mMTC)

Ultra reliable & low Latency communication (URLLC)

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)

5G - Continuing the Success of LTE Evolution



How to increase spectral efficiency ?

Increased Capacity, Increased OPEX

Capacity (bits/second)

Number of Channels

$$C = W\,N\,log_2(1+SNR)$$

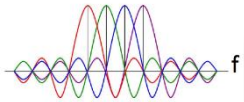
Signal BW (Hz)

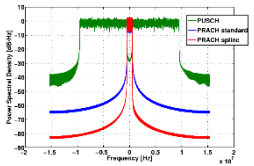
Signal to Noise Ratio *(S/N)*

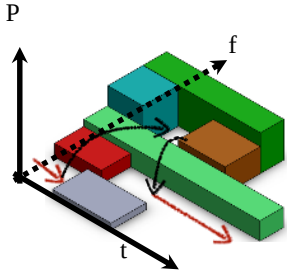
Solutions: mmWave & Massive MIMO

- Use additional frequency bands in **mmWave** spectrum (24 to 110 GHz) for increased **signal bandwidth** up to 2 GHz
- Increase **SNR** of 5G **waveforms** and multiple access
- Implement **Massive MIMO** with multiple **channels** and beamforming to improve SNR

5G: Required Radio Technologies







Waveforms

mmWave Radio

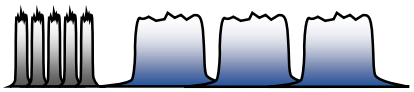
IoT

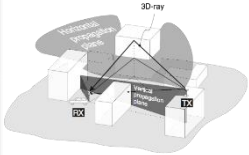
5G Radio Access Network

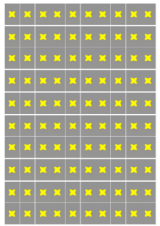
Multiple Access

Massive MIMO

Fiber Interconnect

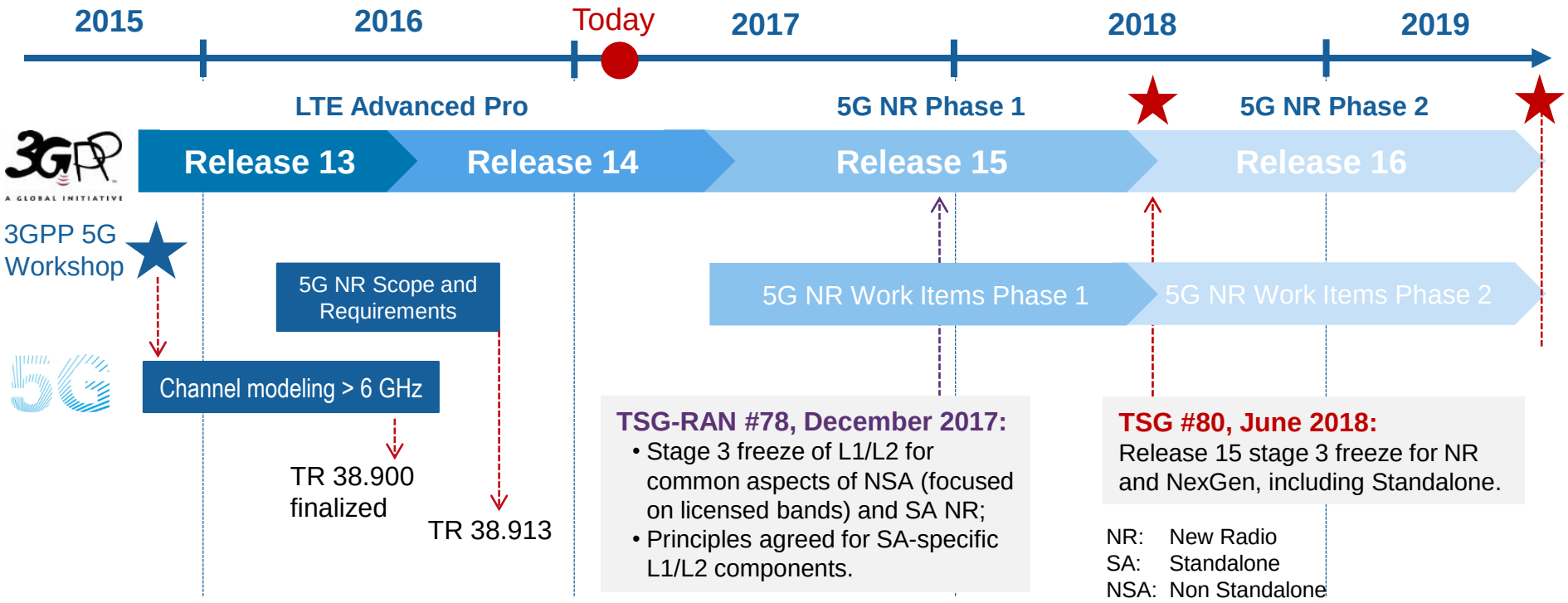






3GPP 5G Standardization Update

Timeline after RAN #74 (Dec 2016)

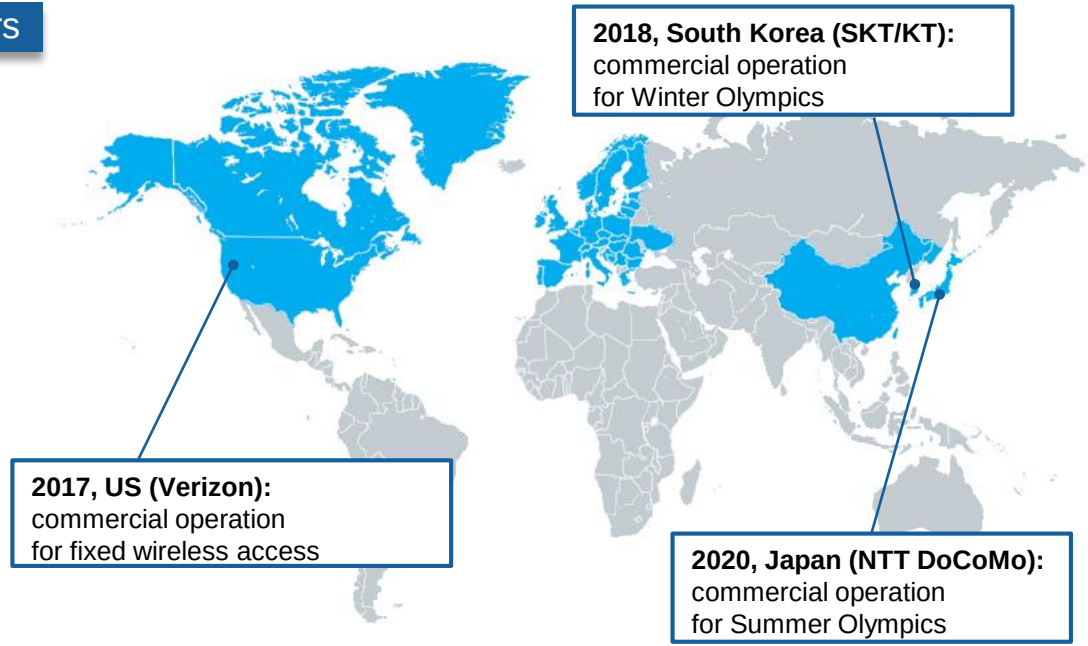


Global 5G Trial Activities

5G Open Trial Specification Alliance

Network Operators

- Verizon
- SK Telecom
- Korea Telecom
- NTT DoCoMo
- AT&T
- TeliaSonera
- Optus
- China Mobile
- Vodafone
- Dt. Telekom
- TIM
- Orange
- Telefonica
- …



OEMs

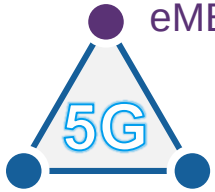
- Ericsson
- Intel
- Nokia
- Samsung
- Cicso
- Qualcomm
- Huawei
- Samsung
- ZTE
- NEC
- Fujitsu
- …

Harmonization of 5G specification is driven by the four operators Verizon, SKT, KT and NTT DoCoMo

5G Trials and Network Deployments

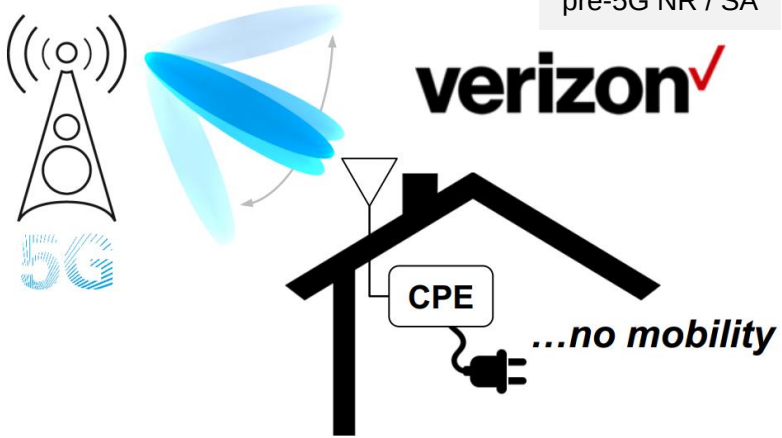
Use Cases

Focus of 5G trials and early network deployments is on enhanced Mobile Broadband



Fixed Wireless Access (FWA)

pre-5G NR / SA



Verizon's Shammo: 5G pilot in 2017 is all about fixed wireless, not mobility

April 21, 2016 | By Monica Alleven

Mobile Networks

pre-5G NR SA

5G NR NSA

PyeongChang 2018

TOKYO 2020 CANDIDATE CITY

...mobility required

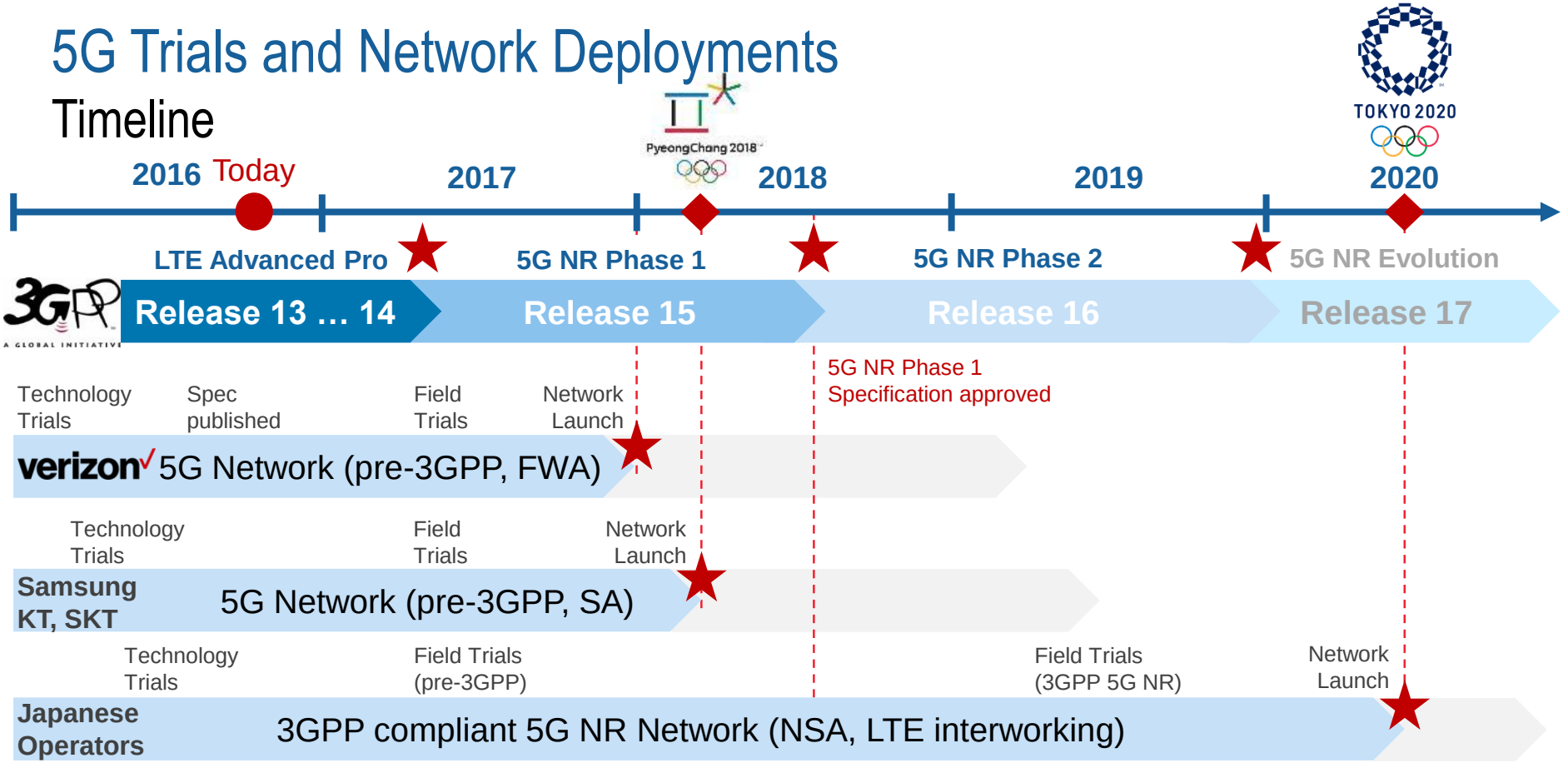
SK telecom

kt

NTT docomo

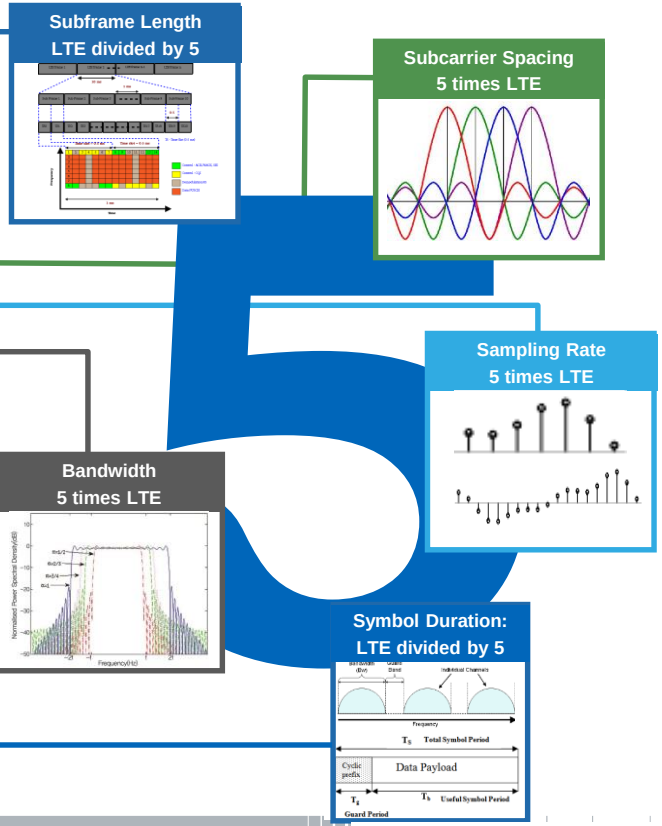
5G Trials and Network Deployments

Timeline



From 4G LTE to Verizon 5G PHY Comparison

PHY parameter	LTE (Rel.8-14)	Verizon 5G
Downlink (DL)	OFDM	OFDM
Uplink (UL)	DFT-s-OFDM	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

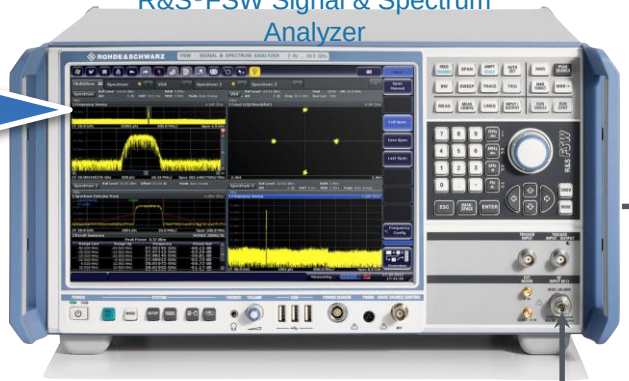


Fixed Wireless: V5G@28 & 39 GHz

R&S®SMW200A Vector Signal Generator

» Up to 40 GHz with up to 2 GHz modulation bandwidth
» Automatic correction of frequency response independent of frequency, power level, and bandwidth

R&S®FSW Signal & Spectrum Analyzer



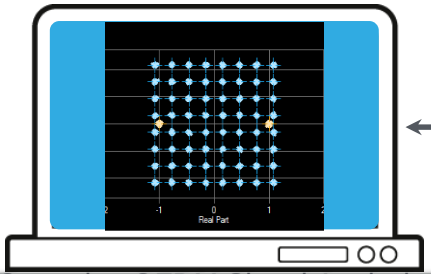
» Up to 43.5 GHz with 1200 MHz internal bandwidth
» EVM < 1% across 10 dB sweep at 28 GHz

- Generate Downlink at 28 & 39 GHz
- Used as REF for DL signal

- Analyze Uplink at 28 & 39 GHz
- Used as REF for UL signal

verizon

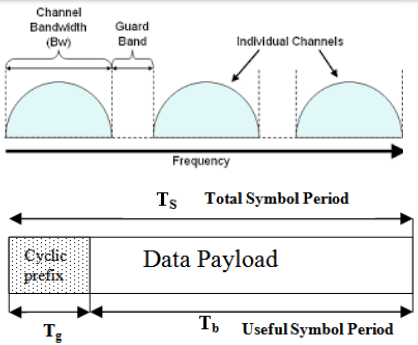
CPE



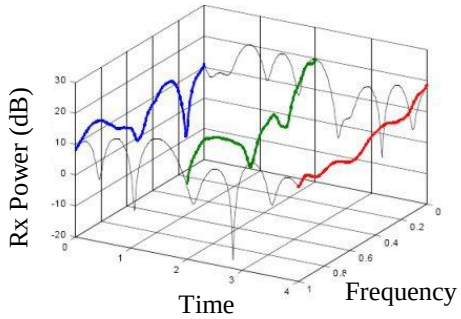
PC running OFDM Signal Analysis Software

5G waveform candidates – some design aspects

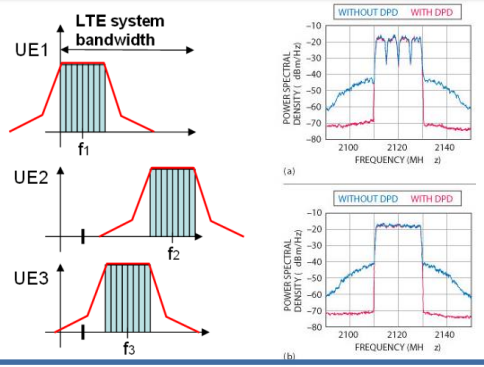
Overhead



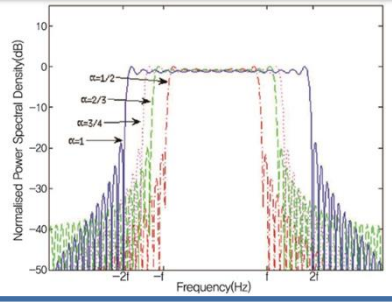
Resistance to Interference



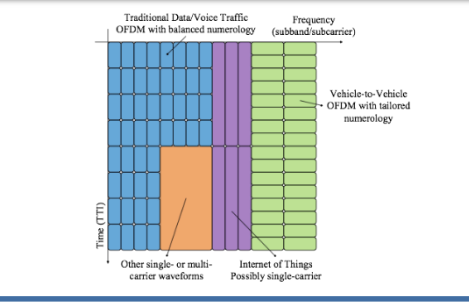
Out of Band Emissions



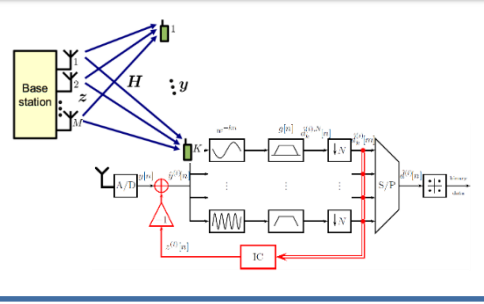
Spectral Efficiency



Flexibility



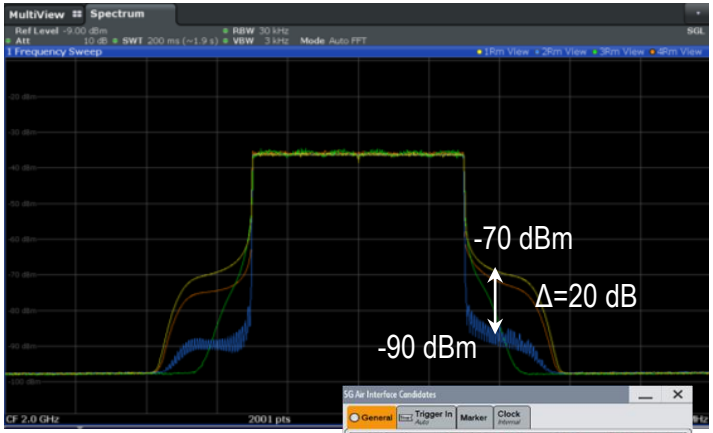
Receiver/MIMO Complexity



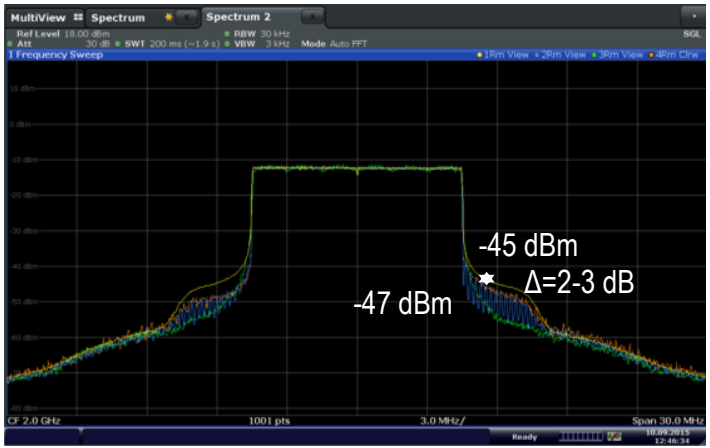
Waveform Gains: From Theory to Reality

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

5G New Radio (NR) numerology: 3GPP vs. Pre-5G

m =	-2	0	1	2	3	4	5	…
Subcarrier Spacing [kHz]	3.75	15	30	60	120	240	480	
Symbol Length [µs]	266.67	66.67	33.33	16.67	8.33	4.17	2.08	…
Component Carrier BW [MHz]	20 MHz per CC <6 GHz | 80+ MHz per CC <70 GHz | 640 MHz ≥70GHz							
Cyclic Prefix Length [µs]	FFS							
Subframe Length [ms] (= $1/2^m$)	4	1	0.5	0.25	0.125	0.0625	0.03125	
Radio Frame Length [ms]	FFS							

No 75 kHz

3GPP A GLOBAL INITIATIVE

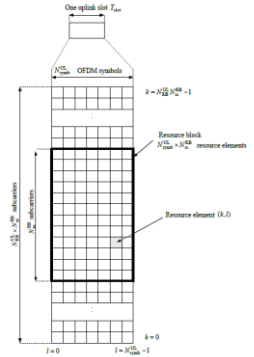
PHY parameter	LTE (Rel.8-14)	Verizon 5G
Downlink (DL)	OFDM	OFDM
Uplink (UL)	DFT-s-OFDM (SC-FDMA)	OFDM
Subframe Length	1ms	0.2ms
Subcarrier Spacing	15 kHz	75 kHz
Sampling Rate	30.72 MHz	153.6 MHz
Bandwidth	20 MHz	100 MHz
NFFT	2048	2048
OFDM symbol duration, no CP	66.67 us	13.33 us
Frame Length	10 ms	10 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

first 5G concept based on „modified“ OFDM:
-> discrepancy between 3GPP and Pre-5G
-> still many aspects unclear

Feature comparison 3GPP 5G vs. Pre-5G

Pre-5G

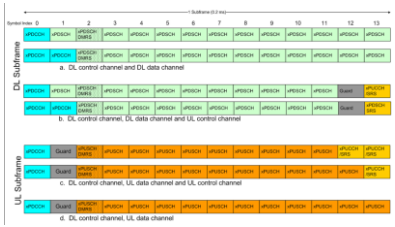
Ressource grid:



constant ressource grid: Δf = 75kHz, #SC per RB = 12
#OFDM symbols per slot = 7

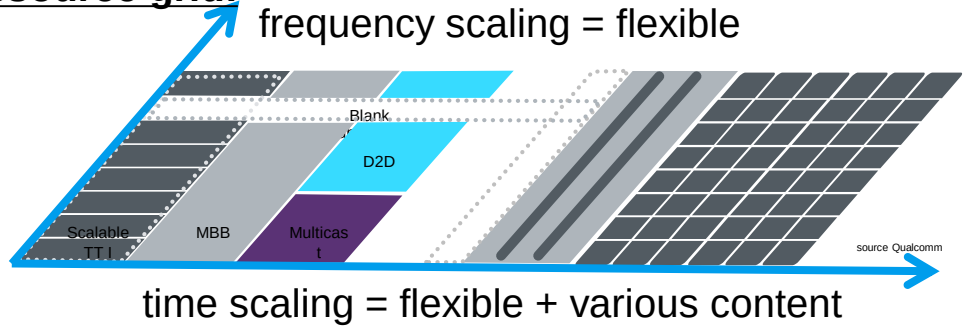
Duplex scheme:

TDD: flexible TDD with
4 configurations



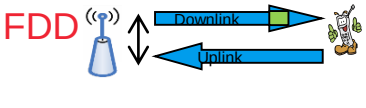
3GPP 5G + vision

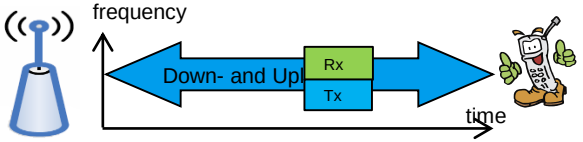
Ressource grid:



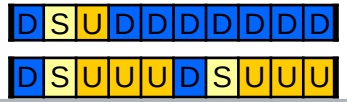
Flexible framework: scalable TTI and subcarrier spacing + fixed allocated ressources, service oriented

Duplex scheme:





flexible TDD

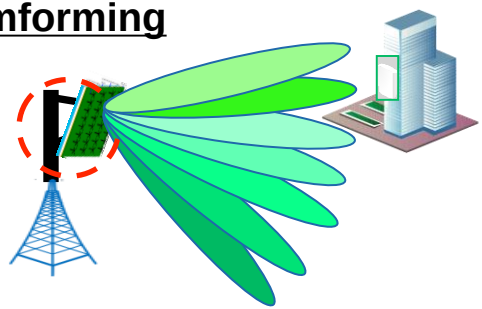


full duplex

Feature comparison 3GPP 5G vs. Pre-5G

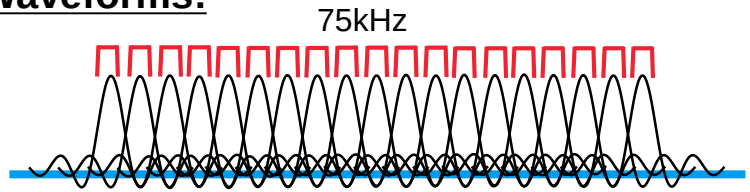
Pre-5G

Beamforming



Concept based on beamforming. static beams, closed loop reporting, beam switching

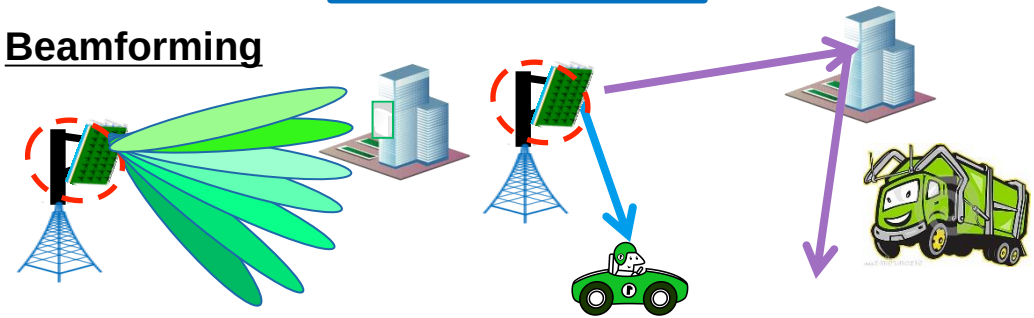
Waveforms:



f-OFDMA: constant subcarrier spacing and TTI length

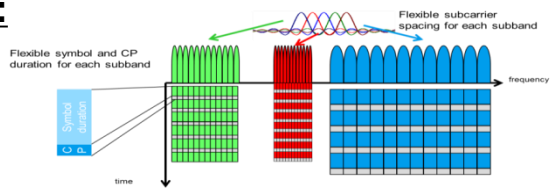
3GPP 5G + vision

Beamforming



Same as Pre-5G but enhancements possible: beam tracking, beam recovery, beam steering etc.

Waveforms:



Rel. 15: f-OFDM with pseudo-dynamic parameterization: TTI dynamic and subcarrier spacing

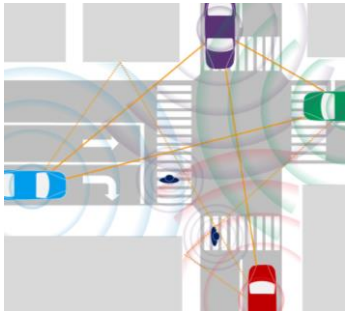
Rel. 16: Ongoing discussion with other waveforms: FBMC, single-carrier, UFMC, GFDM, etc.

Outline

Vehicle-to-X

- LTE-V2X
- 5G V2X (URLLC)

- IEEE 802.11p



On the way to a future of autonomous driving and more …

More Safety

93% of all car accidents are caused by human errors

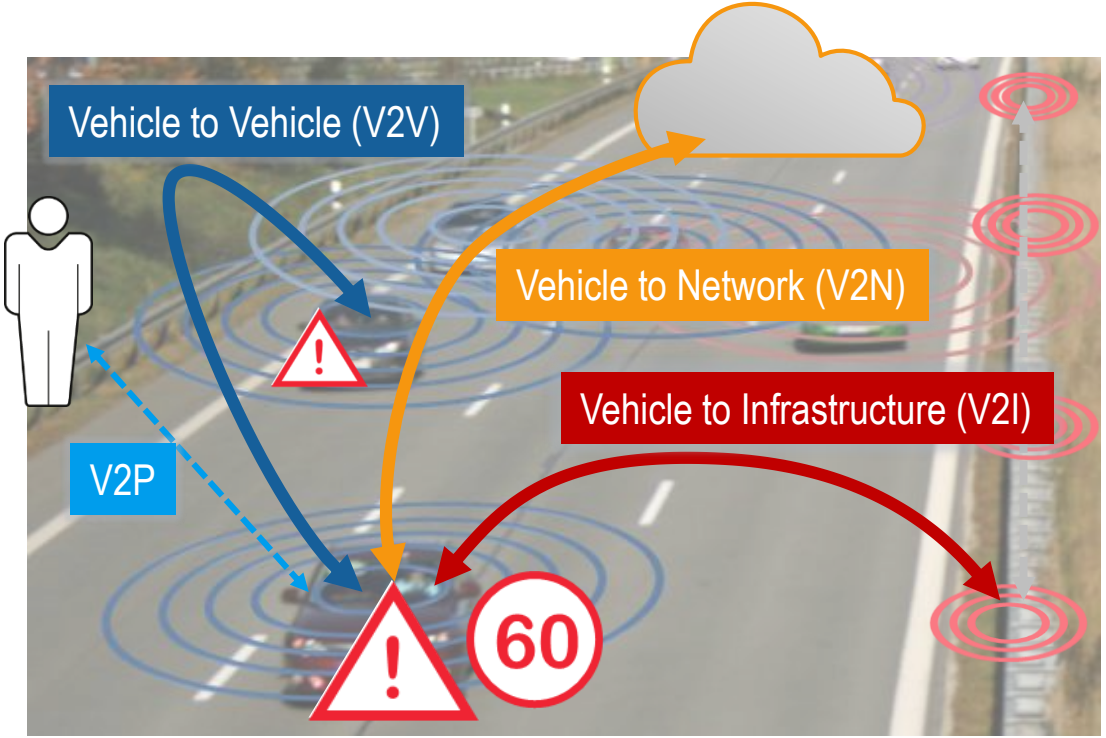
More Efficient

People spending more than 4 years of life in cars

More Comfort

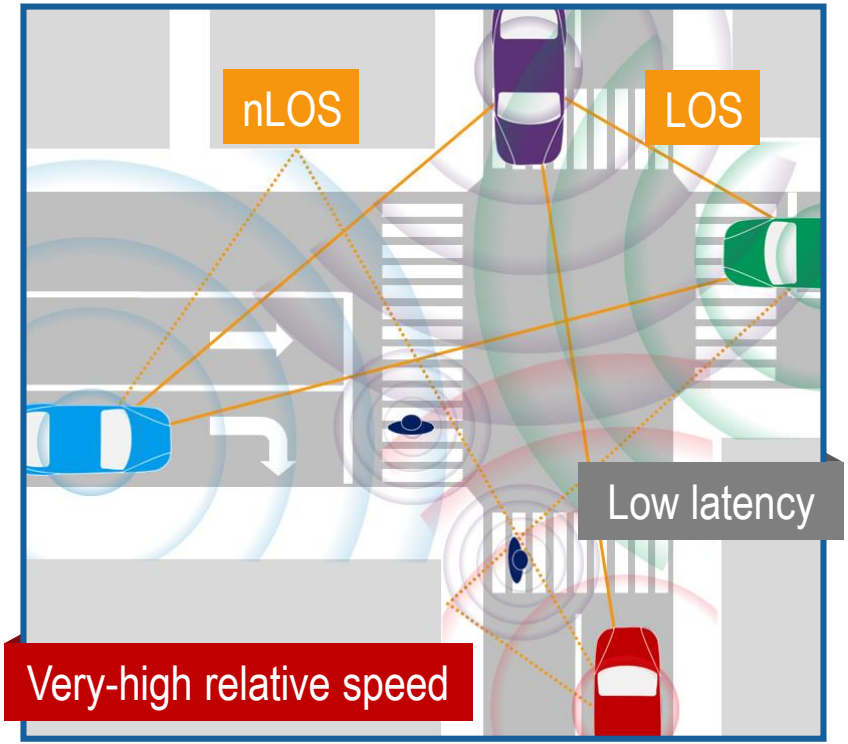
People like to text, surf or just enjoy time on cars

V2x Communication to inform the driver about a potential danger that the driver or car-sensors can not see...



- ⚠ Electronic brake light (V2V)
- ⚠ Obstacle warning (V2I)
- ⚠ Black ice warning (V2I)
- ⚠ Curve Speed Warning (V2I)
- ⚠ Emergency car (V2V)
- ⚠ Road works warning (V2I)
- (60) Traffic control (V2N)

Vehicle to Vehicle based on IEEE 802.11p



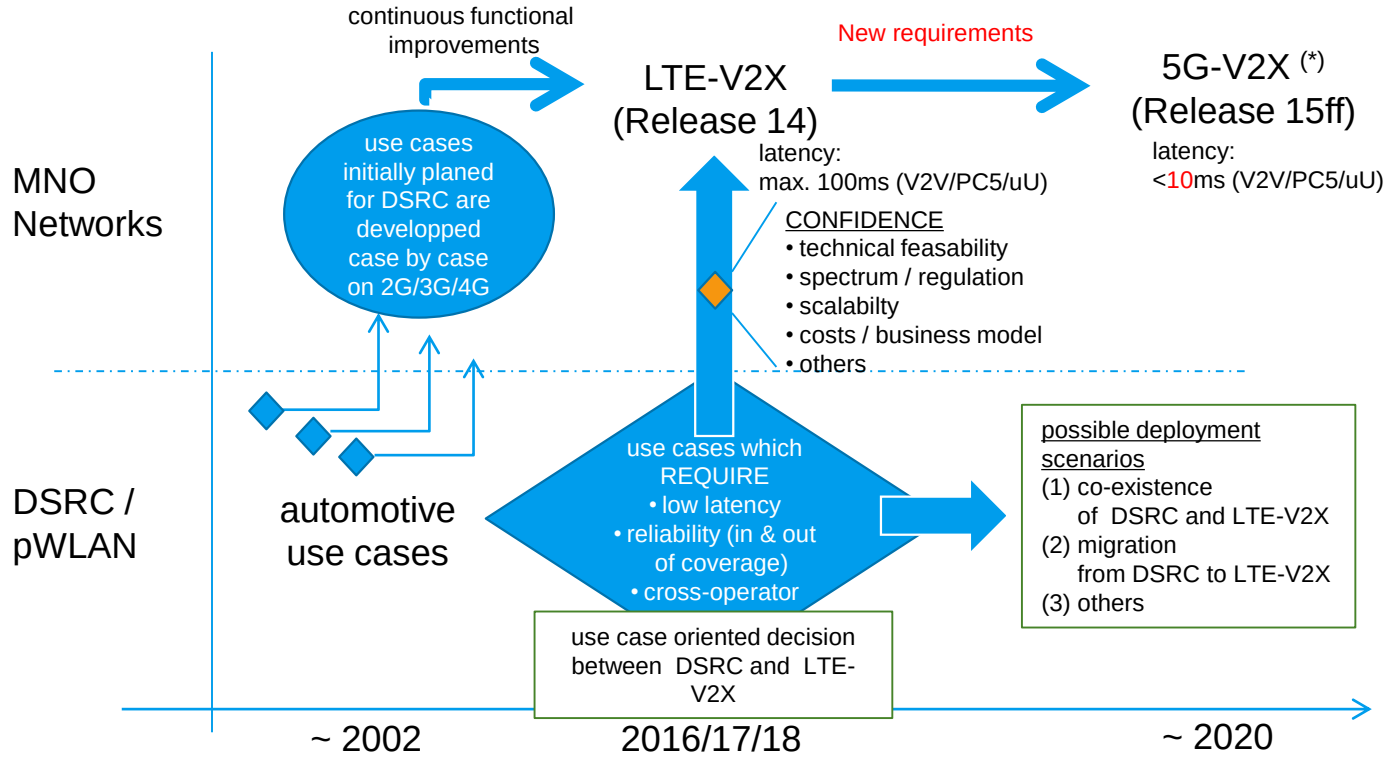
802.11a signal with reduced rate:

- 10 MHz bandwidth for robustness
- Carrier spacing reduced by ½
- Symbol length is doubled, making the signal more robust against fading.
- Operates in the 5.8 GHz and 5.9 GHz frequency bands depending on regional regulations.
- 802.11p is essentially based on the OFDM PHY

Wave mode:

- direct data exchange between vehicles using a wildcard BSSID

NGMN V2X Task Force: Automotive View on V2X



(*): except new 5G radio interface

Cross-Industry Collaboration: 5G Automotive Association

Automotive Industry

Vehicle Platform, Hardware and Software Solutions

Telecommunications

Connectivity and Networking Systems, Devices and Technologies

End to End Solutions for Intelligent Transportation, Mobility Systems and Smart Cities

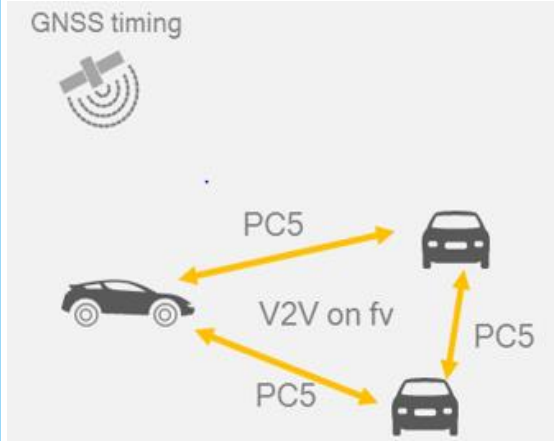
Connect telecom industry and vehicle manufacturers; work closely together to develop end-to-end solutions for future mobility and transportation services, impact regulation and standardization

Audi BMW DAIMLER ERICSSON HUAWEI intel NOKIA QUALCOMM

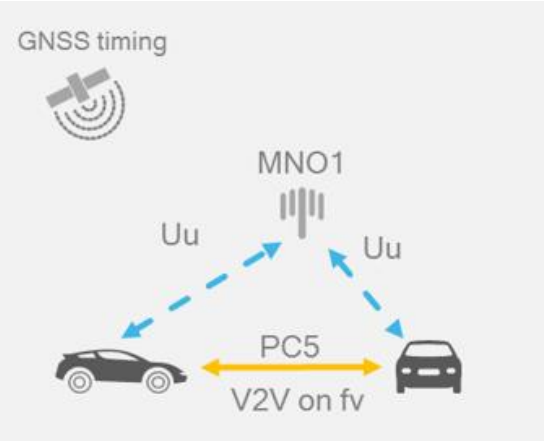
Support for V2V Services in 3GPP based on LTE Sidelink

Source: RP-161788

Configuration 1: D2D Sidelink (PC5), dedicated carrier, distributed scheduling TM4



Configuration 2: Dedicated carrier, eNB scheduling, TM3



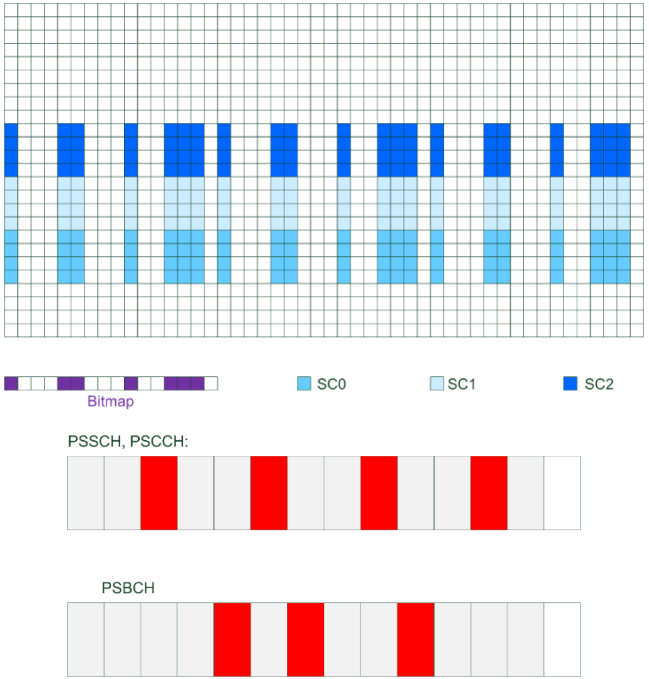
- Enhancing the D2D (PC5) interface
  - In coverage and out-of-coverage
- New transmission modes:
  - TM3: eNB schedules resources
    - Scheduled by DCI format 5A, scrambled with SL-D-RNTI
  - TM4: UE autonomous resource selection
- V2V PC5 uses a dedicated carrier which is only used for V2V communication
  - TR 36.785: (Band 47: 5.9 GHz, not yet in spec)

E-UTRA V2X band /V2X channel bandwidth						
E-UTRA V2X Band	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
47				Yes		Yes

  - Time Synchronization via GNSS possible

With & without LTE coverage | Dedicated V2X carrier with single / multiple operators | Shared V2X/ LTE on licensed LTE carriers

3GPP Rel. 14 V2X Enhancements: examples



Demodulation reference signal (DMRS) extension

to cope with higher Doppler shift up to 500 km/h

New arrangement of resources into resource pools (RPs)

RP redesign, control and data packets (channels) are in the same subframe

- New subframe (SF) structure Reducing latency (40ms separated before, now combined in 1 SF, i.e. 1TTI=1ms)

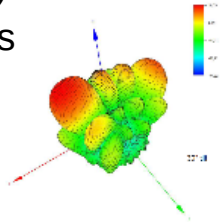
URLLC

LTE latency enhancements: TTI of 2 symbols (2 x 67us) => moved from Rel15 to Rel14 (fix expected summer 2017

Summary

Is 5G just the next generation? No: It is a paradigm shift!

- **Approach in industry:**
  - 3G (3GPP: UTRA): 1: define a technology for data transmission, 2: “what is the killer app?”
  - 4G (3GPP: E-UTRA): define a better technology than 3G based on use case (mobile data)
  - 5G (3GPP: NR): 1: define use cases, 2: requirements, 3: elaborate technologies / solutions



- From cell-centric (2G - 4G) to user-centric / application-centric in 5G
- 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 (up to mission- and safety-critical use cases)

Rohde & Schwarz is committed to supporting the industry with the T&M solutions needed to investigate, standardize, develop and implement 5G products


Thank you for your attention !