# 5G for Industrial IoT

2020年6月22日（月）
Rohde Schwarz Japan
江森 浩司

**ROHDE&SCHWARZ**

Make ideas real

**From a two-man laboratory to a global group of companies with various fields of business**

86 years
of success

12.100
employees

300
new products

Test and Measurement

Networks and Cybersecurity

Aerospace & Defense

Security

Broadcast and Media

Make ideas real

# A story about mobile evolution over four decades



**5G**
Audio, Video, Apps, AR/VR (eMBB)
Sensors (mMTC)
Sensors/Aktuator (URLLC)

**4G** Voice, Audio, Video, Apps , …

**3G** Phone, SMS, Web

**2G** Phone, SMS

**1G** Phone

1980    1990    2000    2010    2020    2030

# 5G becomes reality



eMBB

mMTC

URLLC

Driven by the mobile ecosystem for fixed-wireless access and high data rate on the go

Essentially available today with NB-IoT and LTE-M which will coexist with 5G NR Rel.16

Strong drive by verticals to make 5G ready for industrial and automotive applications

# WHO USES 5G IN FUTURE AND HOW?

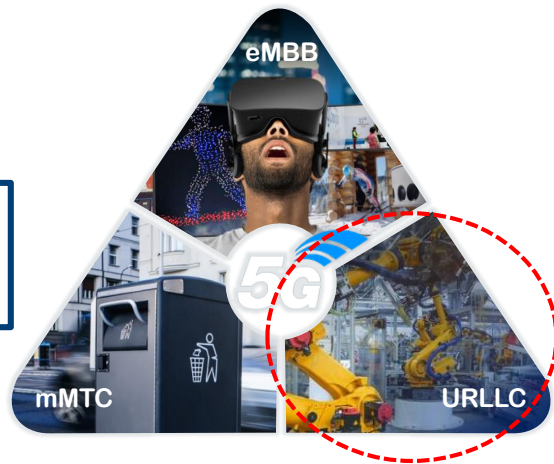▶ New **classes** of users in 5G

  – **Humans** (smartphone use case)

  

  more interactive eMBB applications

  – **Automotive** (connected, autonomous driving, Vehicle-to-X)

  – **Industry 4.0** (Smart Manufacturing, private 5G networks)

  – **IoT, mMTC** (Smart City, Connected Energy,...)

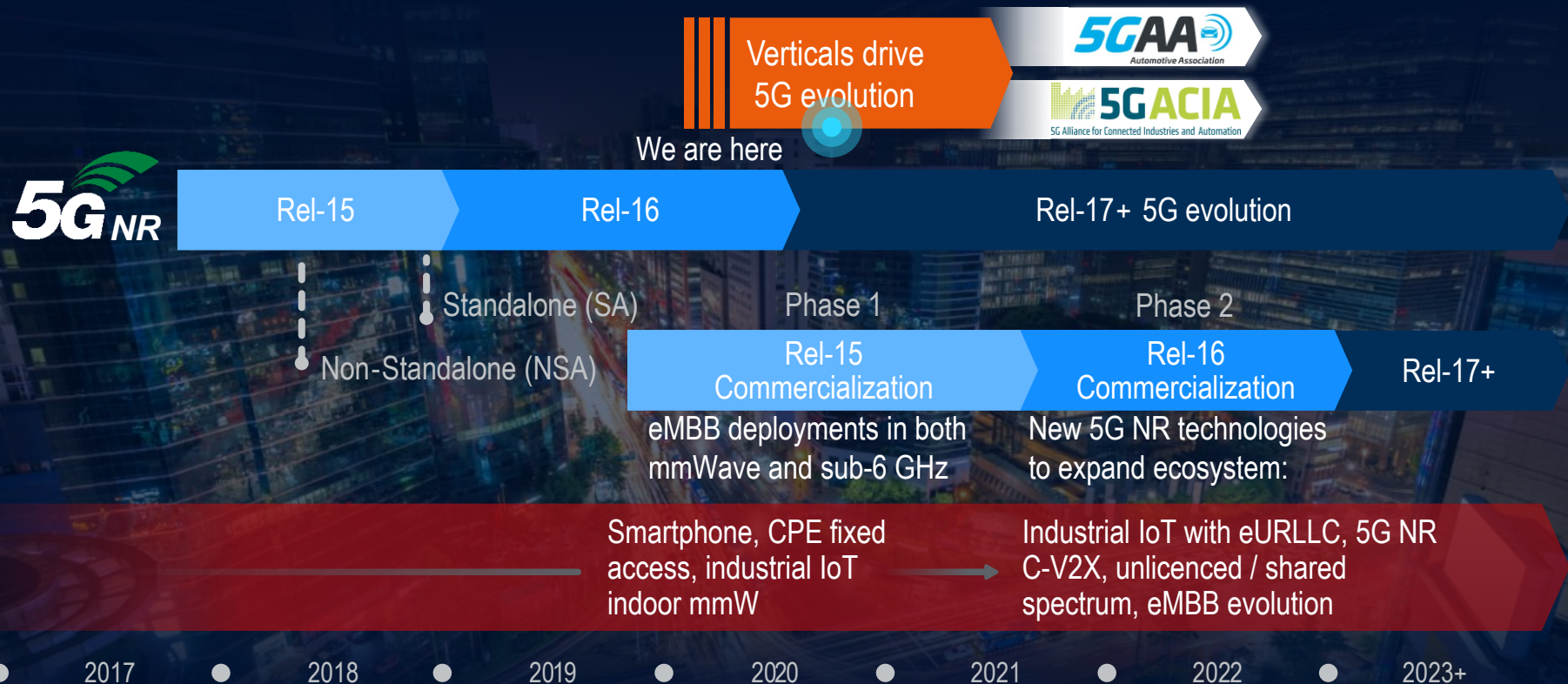  Really low latencies require standalone 5G

> ➢ **Each user class generates <u>individual traffic patterns</u> and has <u>individual network requirements</u>!**
> ➢ **A network optimized for human users may not deliver best performance for cars or industry**

# The magic triangle of communication is smart factories



**Latency**

**Reliability**

*Security*

► Security is a must!

► Reliability is essential, but on different levels

► Strongest latency requirements apply for specific applications (e.g. AGV)

# 5G roadmap and ecosystem expansion

Verticals drive 5G evolution

5G AA Automotive Association

5G ACIA 5G Alliance for Connected Industries and Automation

We are here

**5G NR**

| Rel-15 | Rel-16 | Rel-17+ 5G evolution |

Standalone (SA)

Phase 1

Phase 2

Non-Standalone (NSA)

| Rel-15 Commercialization | Rel-16 Commercialization | Rel-17+ |

eMBB deployments in both mmWave and sub-6 GHz

New 5G NR technologies to expand ecosystem:

Smartphone, CPE fixed access, industrial IoT indoor mmW

Industrial IoT with eURLLC, 5G NR C-V2X, unlicenced / shared spectrum, eMBB evolution

| 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023+ |

# 5G NR technology cornerstones to meet latency requirements of URLLC applications (Rel 16)

## Mobile edge computing
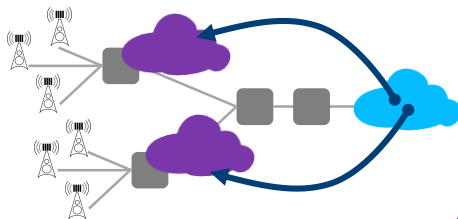


- bring cloud to edge of network
- controlled private environment in NPN (non-public networks)

## Grant free access



Code, Power, .... frequency

time
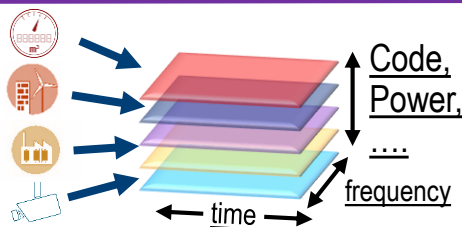
NOMA: power/code domain multiplexing

## Minislots – short symbols



14s

60 kHz    30 kHz    15 kHz

7s
4s
2s

Minislots of 7, 4 or 2 symbols

100 µs    500 µs    1 ms
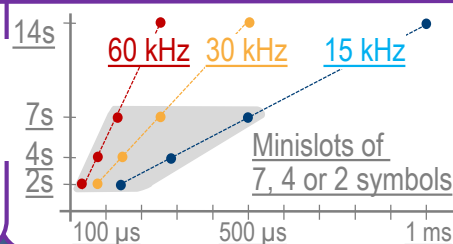
- new 5G NR numerology and TTI for lower latency
- basic URLLC in Rel 15 with TTI structures for low latency (AR/VR entertainment)
- flexible slot structure for different SCS: mini-slot 35µs

## Network Virtualization



*app specific slices*
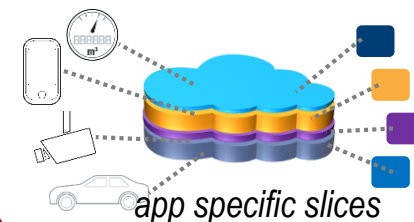
- ensure QoS
- network slicing tailored to applications

NOMA: non-orthogonal multiple access          SCS: 5G NR subcarrier spacing

# 4<sup>th</sup> industrial revolution – Industry 4.0



*mass production*

*handmade*

*Customized*

**Complexity & Efficiency**

**1<sup>st</sup> industrial revolution**

Water and steam power used for mechanical production equipment

~1790

**2<sup>nd</sup> industrial revolution**

Electrical energy used to introduce mass production lines

~1870

**3<sup>rd</sup> industrial revolution**

Use electronics and computing for further automation of production

~1970

**4<sup>th</sup> industrial revolution**

Based on Cyber-Physical systems, Internet of Things and Big Data

~2010

# Industrial Internet of Things – Smart Factories
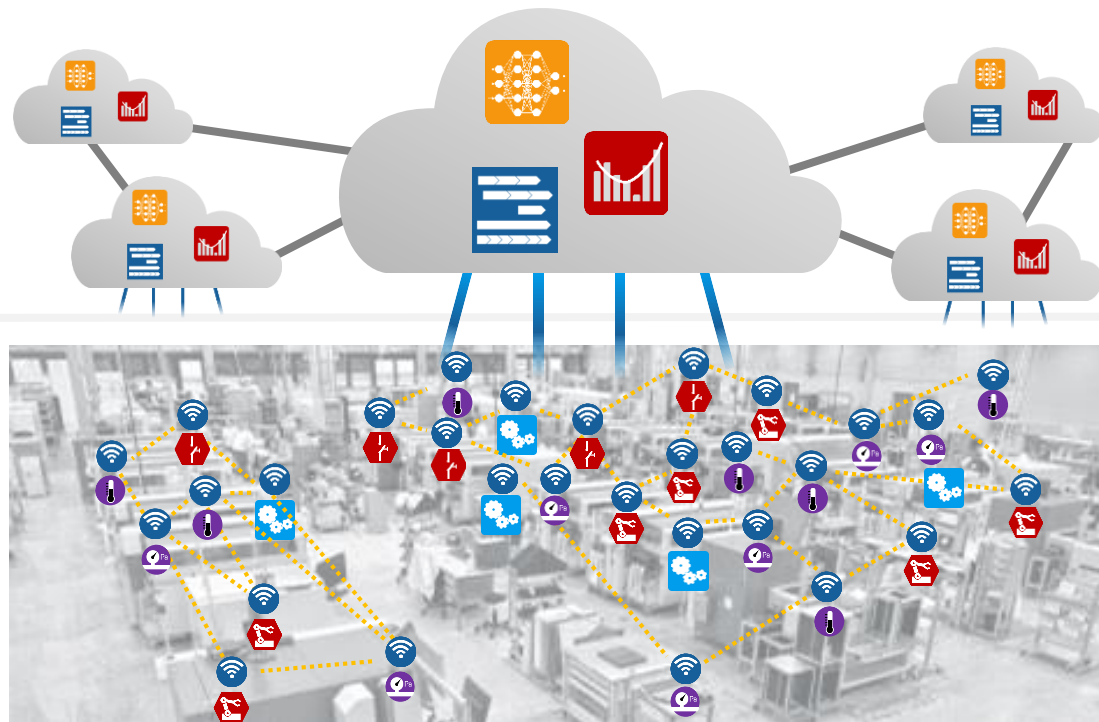


Deep Learning

Data Analytics

Process control

Real-time processing

Connectivity

Actuators

Real-Time Sensing

# High diversity of 5G applications in smart factories, ….



**mMTC**

- Sensors
- Door looks
- Screwdrivers
- ……

**eMBB**

- VR/AR human-machine i/f
- Handhelds
- Surveillance CAMs

**uRLLC**

- Robots
- Automated guided vehicles (AVG)

…. which require safe, reliable and secure operation 24/7/365

# INDUSTRY 4.0 SPECIFIC DEPLOYMENT SCENARIOS
## 5G-ACIA WP: 5G NON-PUBLIC NETWORKS (NPN) FOR INDUSTRIAL SCENARIOS
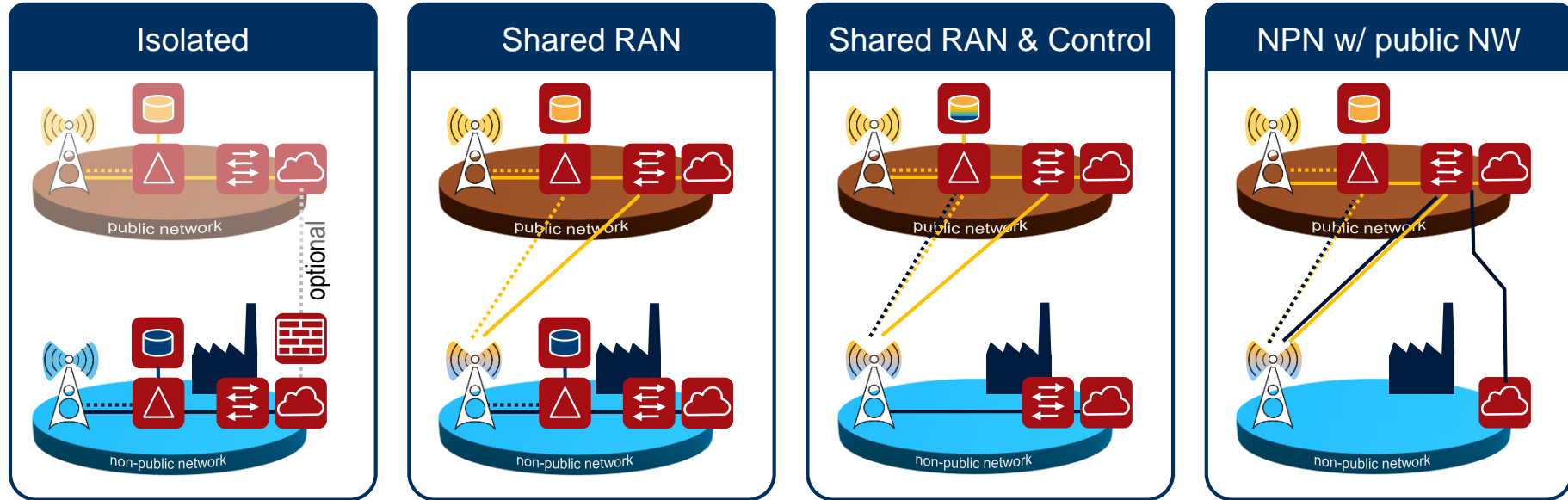


- WP provides a description of the four industrial deployment scenarios for 3GPP-defined 5G non-public networks (NPN)
- NPN provides 5G network services to a clearly defined user organization or group of organizations
- NPN deployed on the organization's defined premises, such as a campus or a factory

# R&S FACTORIES WILL DEPLOY 5G PRIVATE NETWORKS

► Big manufacturers will deploy own, private 5G networks (sometimes in dedicated spectrum)

► 5G deployed in private spectrum opens the door for high efficiency and more flexibility

► Strong need for Network Performance Testing and Security solutions
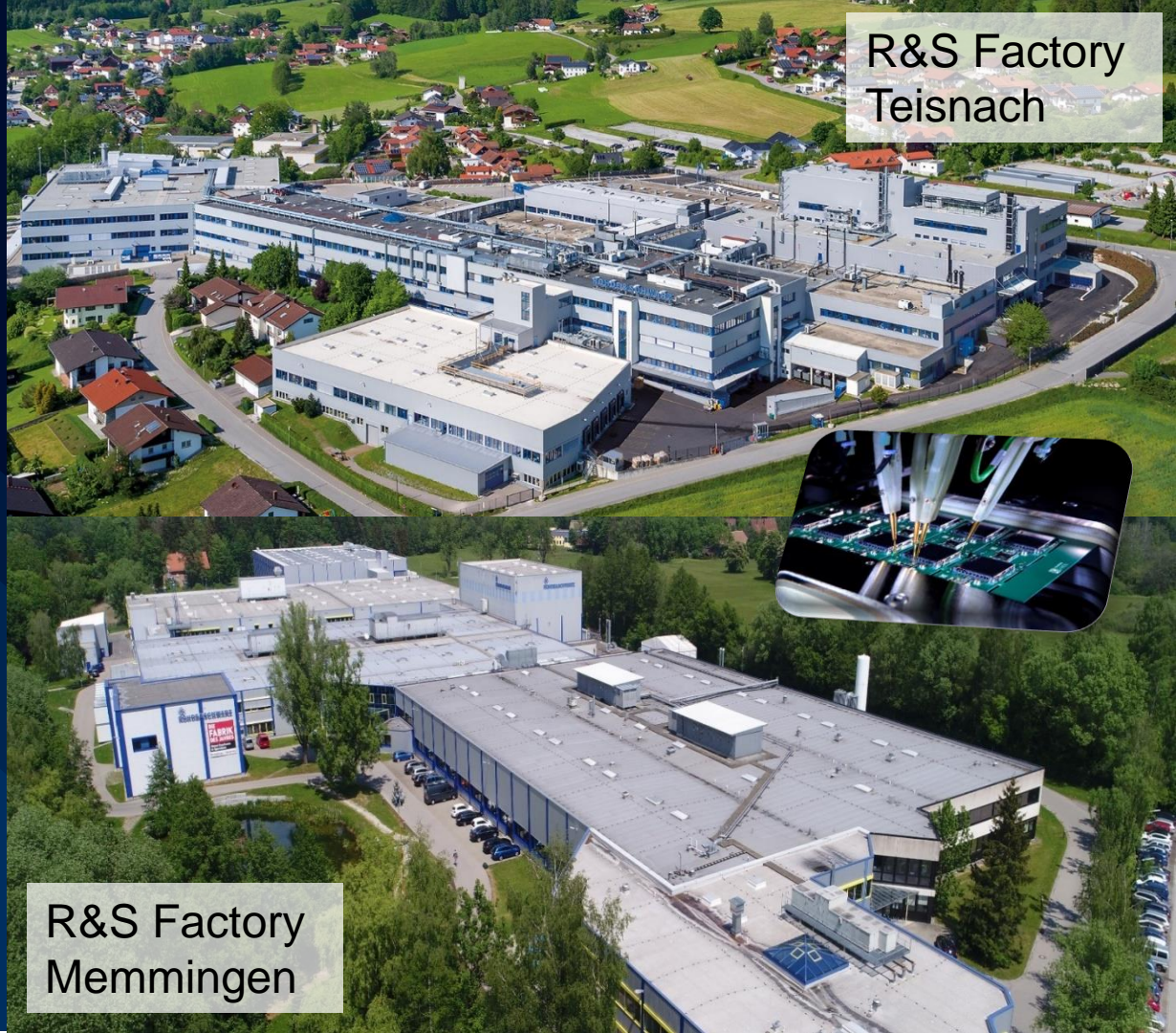


R&S Factory Teisnach

R&S Factory Memmingen

# DIFFERENT PHASES OF TEST
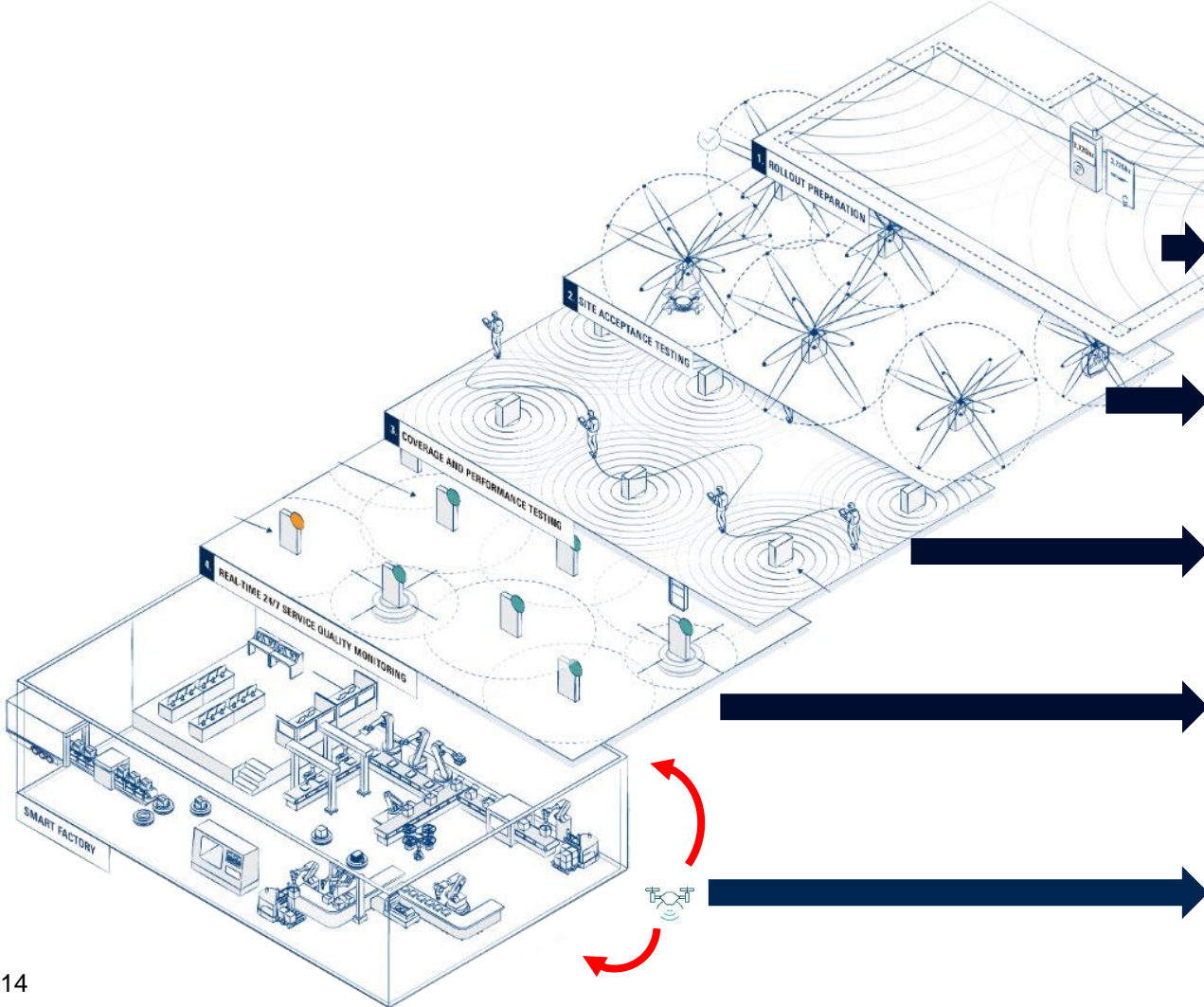
1) Rollout preparation / spectrum clearance

2) gNb installation / site acceptance testing (redundant coverage, CoMP)

3) Coverage and performance testing   (once / regularly / continuously)

4) Service Quality Monitoring / Service Level Agreement verification

5) Regulatory obligations: spurious emissions from campus network

# TEST PHASES

# RELIABLE CAMPUS NETWORKS REQUIRE:

1) Rollout preparation / spectrum clearance

- ► Before deployment: Is the spectrum free?
- ► Low noise floor?
- ► If not: Interference hunting inside / outside the factory!

2) gNb installation / site acceptance testing (redundant coverage, CoMP)

- ► Functional test + Site Testing incl. demodulation
- ► Sufficient coverage / number of gNb signals everywhere for CoMP?

3) Coverage and performance testing (once / regularly / continuously) incl. interference hunting

- ► Sufficient coverage (RSRP) and signal quality (SINR)?
- ► QoE: Application / throughput / interactivity tests
- ► Trouble shooting in case of non-optimal performance

4) Service Quality Monitoring / SLA verification

- ► Measure the campus network quality and performance
  - ► Manual tests regularly
  - ► Automatic tests continuously (fixed RF/QoE probes)
- ► Analytics + Machine Learning: identify risks pro-actively

5) Regulatory obligations: spurious emissions from campus network

- ► Check signal leakage outside campus area
- ► Walk test or "fly" test (drones) around campus

# TEST SOLUTION OPTIONS

1) Rollout preparation / spectrum clearance

2) gNb installation / site acceptance testing (redundant coverage, CoMP)

3) Coverage and performance testing (once / regularly / continuously) incl. interference hunting

4) Service Quality Monitoring / SLA verification

5) Regulatory obligations: spurious emissions from campus network



Scanner: TSMA6   Spectrum Analyzer

QualiPoc Android   5G Site Testing Solution

Spec. Analyzer FPH

? RF probes

QualiPoc Probe   RF probes

SmartMonitor/Analytics ML ?
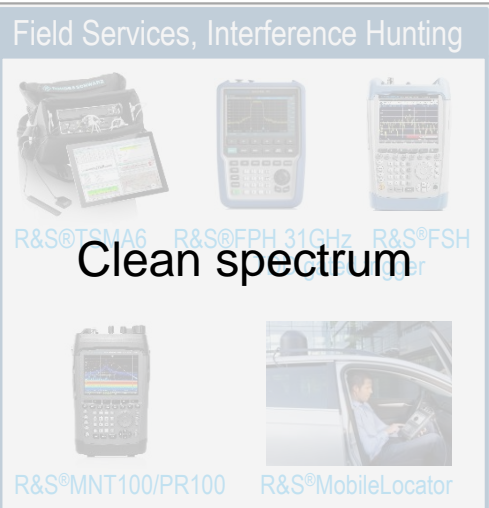
TSMA6

# R&S TEST SOLUTIONS TO DEPLOY MOBILE NETWORKS
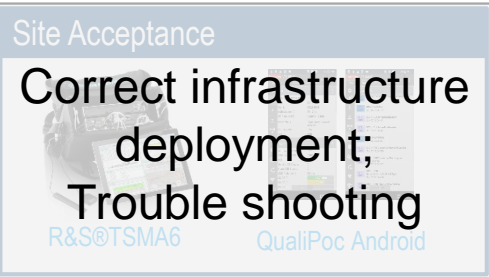
## Field Services, Interference Hunting

R&S®TSMA6    R&S®FPH 31GHz    R&S®FSH

R&S®MNT100/PR100    R&S®MobileLocator

**Clean spectrum**

## Site Acceptance

R&S®TSMA6    QualiPoc Android
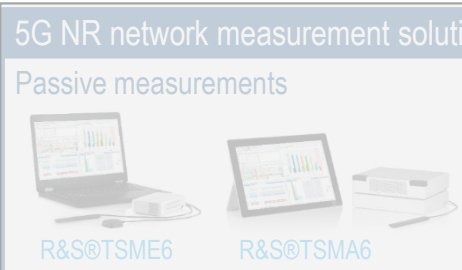
**Correct infrastructure deployment; Trouble shooting**

## 5G NR network measurement solution

### Passive measurements

R&S®TSME6    R&S®TSMA6
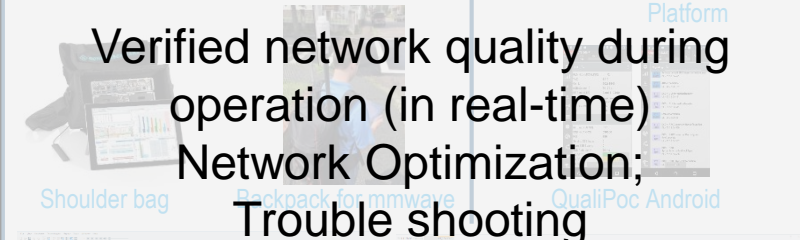
Shoulder bag    Backpack for mmwave

### Active measurements

Smartphones    Mobile Test Platform

QualiPoc Android

**Verified network quality during operation (in real-time) Network Optimization; Trouble shooting**

R&S®ROMES4: 5G NR Software for network engineering, analysis and optimization

## Data Analytics

SmartAnalytics Scene

SmartAnalytics Scene - NPS

**Verified network quality post processing to get deep insights; Quality Benchmarking; Network Monitoring**

# IIOT CONNECTIVITY LANDSCAPE TODAY



**≈ 50%**

**Industrial Ethernet**

**≈ 40%**

**Fieldbus**

**< 10%**

**Wireless**

Dominated by industrial Ethernet connection supporting also TSN for industry automation

# 5G as a Key Technology for Industry 4.0
# The Factories of the Past & the Future (Bosch)

## Factory of the Past

Image: Bosch

**Rather static and highly optimized for one particular product**

## Factory of the Future

**rexroth**
A Bosch Company
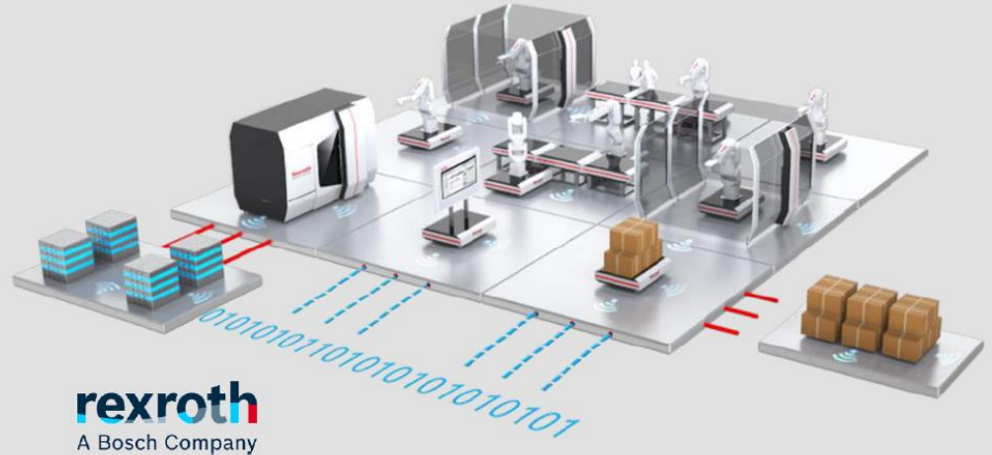
**Highly flexible and support of high degree of customization**
→ walls, roof and factory floor as only fixed components
→ ubiquitous wireless connectivity for plug-and-play + mobility

# Time-Sensitive Networks: Deterministic communication with a common sense of time implemented on Layer 2

## IEEE standardization for TSN

| **Time Synchronization** IEEE 802.1AS | **Ultra Reliability** IEEE 802.1CB /Qci /Qca |
| --- | --- |
| **Bounded Low Latency** IEEE 802.1Qav /Qbv /Qbu /Qch /Qcr | **Resource Management** IEEE 802.1Qcc /Qcp / Qcw / CBcv |

Central User control (configuration)

Central network control (scheduler)

TSN bridge

TSN bridge

TSN talker

TSN flow

TSN listener

TSN bridge

TSN bridge

# SMART FACTORIES GOING WIRELESS!

ABI Research: Global Digital Factory Connections, 2016 to 2030
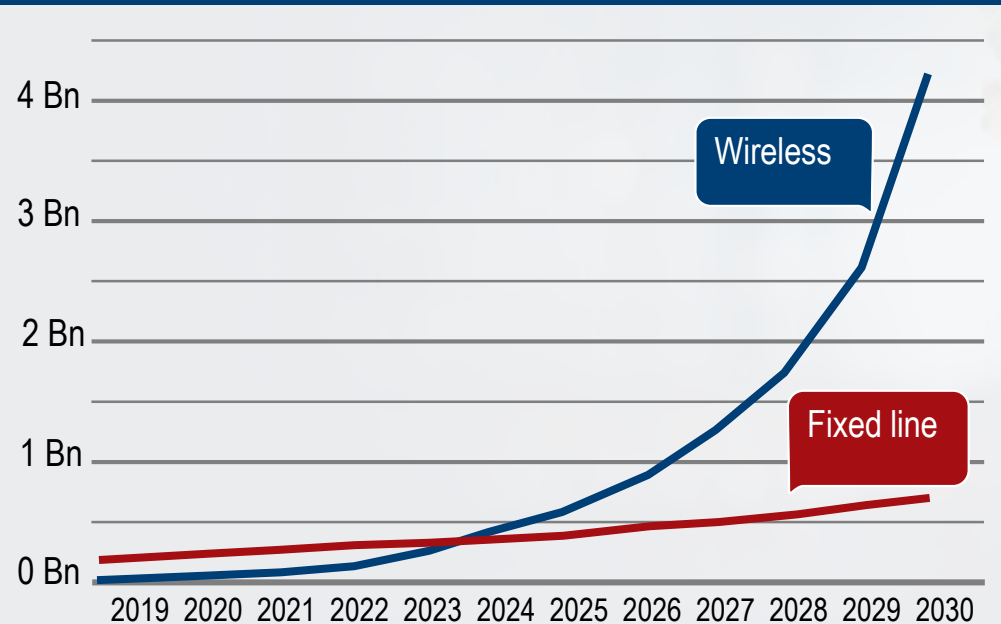


ABI Research forecasts that the smart manufacturing market will grow to US$1 trillion with **4.3 billion** wireless connections by 2030.
Majority (3.8 Bn) will be for asset tracking using LPWAN (NB-IoT/LTE-M)

# Wireless technologies IN SMART factories



Bluetooth
UWB — looks

NB-IoT
LoRaWAN — sensors

Bluetooth
Wi-Fi — tools

RFID
UWB — assets

Wi-Fi
LTE — glasses

Wi-Fi
LTE — handhelds

???? — AGV

Robots
????

# We see a high diversity of attractive 5G factory applications

**mMTC**

- Sensors
- Door locks
- Screwdrivers
- ……

**eMBB**

- VR/AR human-machine i/f
- Handhelds
- Surveillance CAMs

**uRLLC**

- Robots
- Automated guided vehicles (AGV)

…. which require safe, reliable and secure operation 24/7/365

# The magic triangle of communication in smart factories
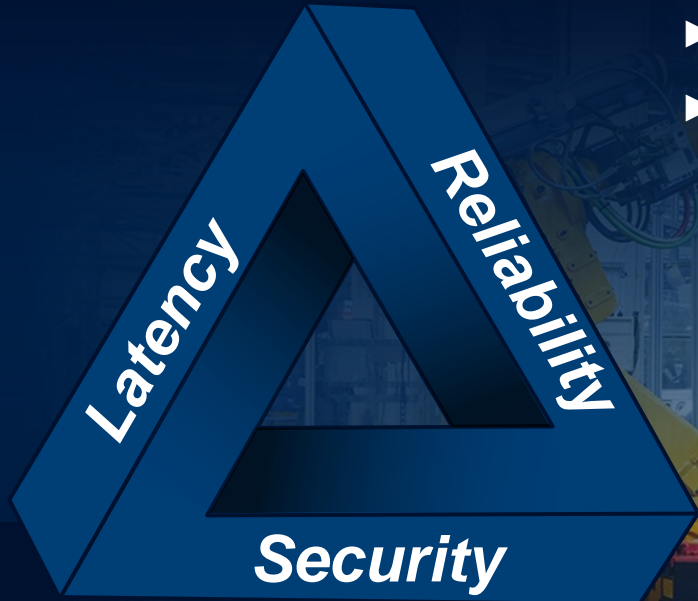


Latency

Reliability

*Security*

► Security is a must!

► Reliability is essential, but on different levels

► Strongest latency requirements apply for specific applications (e.g. AGV)

# LATENCY
## MOTION CONTROL IS THE MOST DEMANDING USE CASE

► Schematic of a motion control system
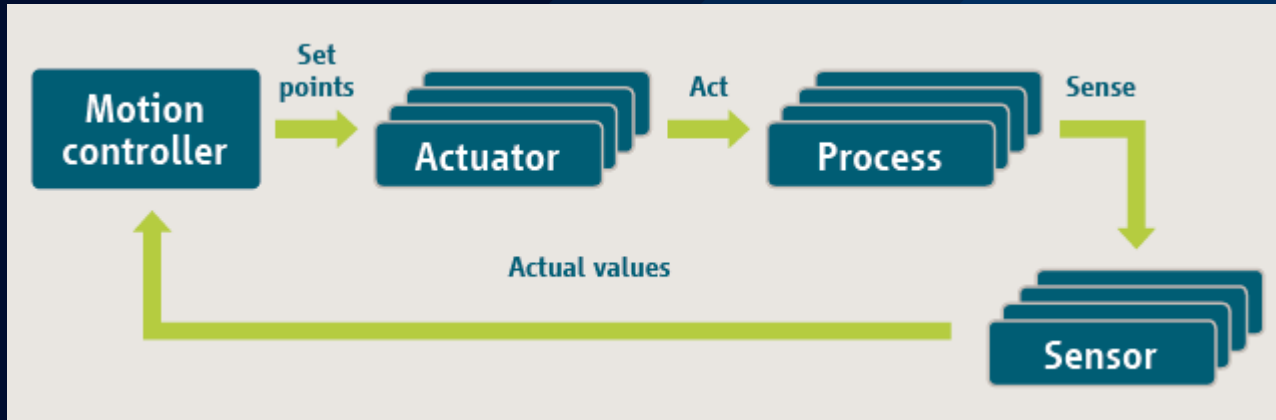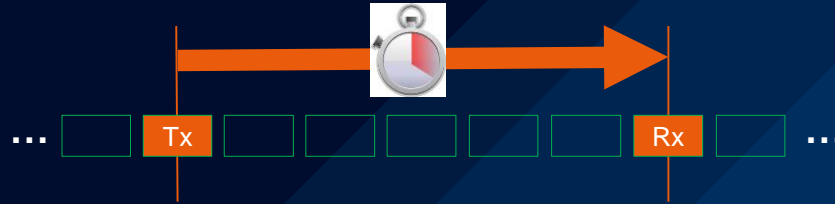
# Need for accurate one-way latency measurement



QualiPoc Android:
5G NR performance measurements on commercially released smartphones

Prototype to measure and analyze one-way latency using GPS based time measurements

IP packet [time stamp]

IP packet [time stamp]

IP packet [time stamp]

GPS receiver

GPS receiver

MEDIAN   = 15.76 ms
AVERAGE = 16.82 ms
STD.DEV = 2.09 ms

Time synchronization via GPS-locked PPS

PPS

PPS
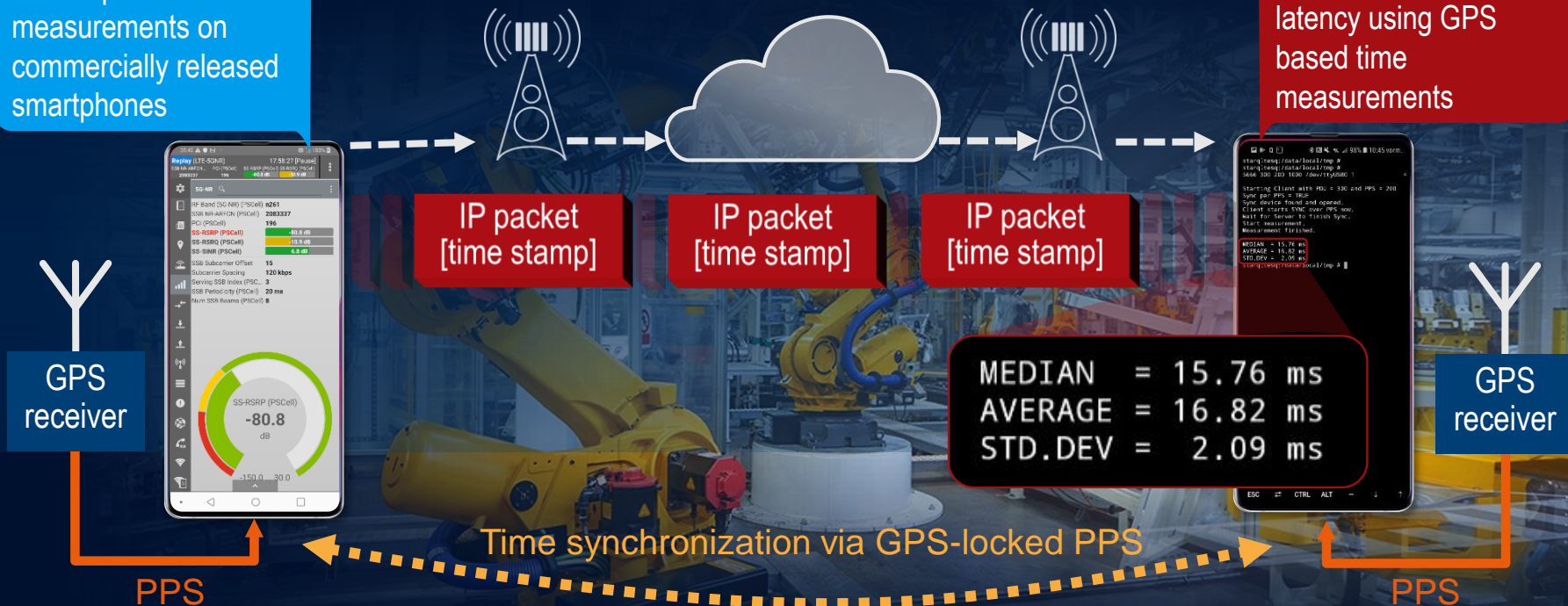
# Demand for testing the complete communication stack: TUM FTM research project: Tele-operated driving



Internet

Server

video/data

control
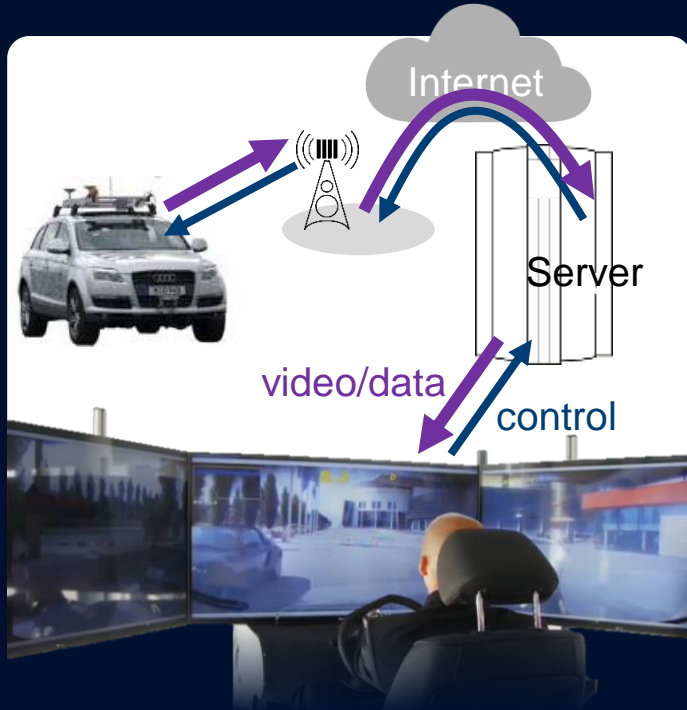


Lehrstuhl für Fahrzeugtechnik
Fakultät für Maschinenwesen
Technische Universität München

http://www.ftm.mw.tum.de/forschungsfelder/fahrerassistenz-und-sicherheit/teleoperiertes-fahren/

# Verification of low-latency communication in dynamic environments requires one-way latency measurement (us precision)
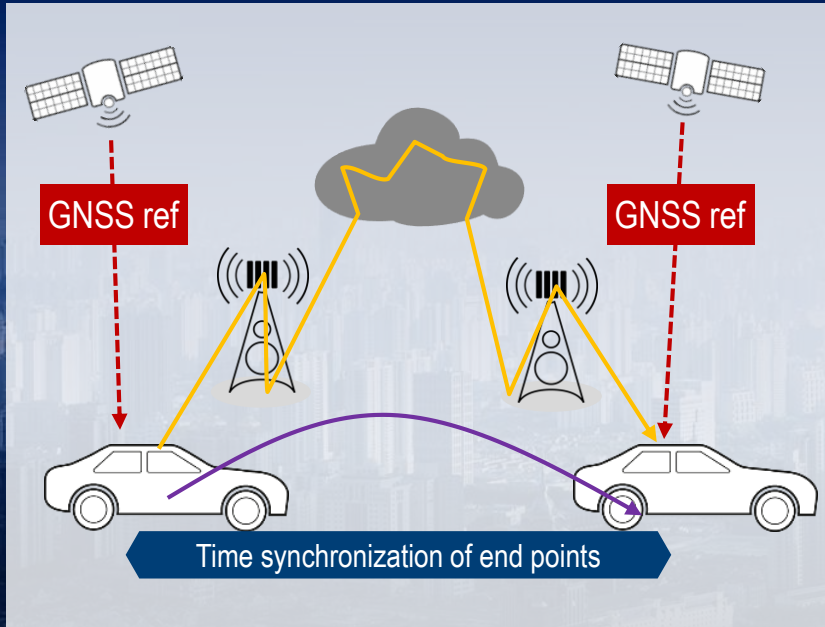


Designed for less than 1 ms latency, but implementation shows some issues

GNSS ref

GNSS ref

Time synchronization of end points

CDF

60%
50%
40%
30%
20%
10%
0%

0 ms    1 ms    2 ms    3 ms    4 ms    5 ms
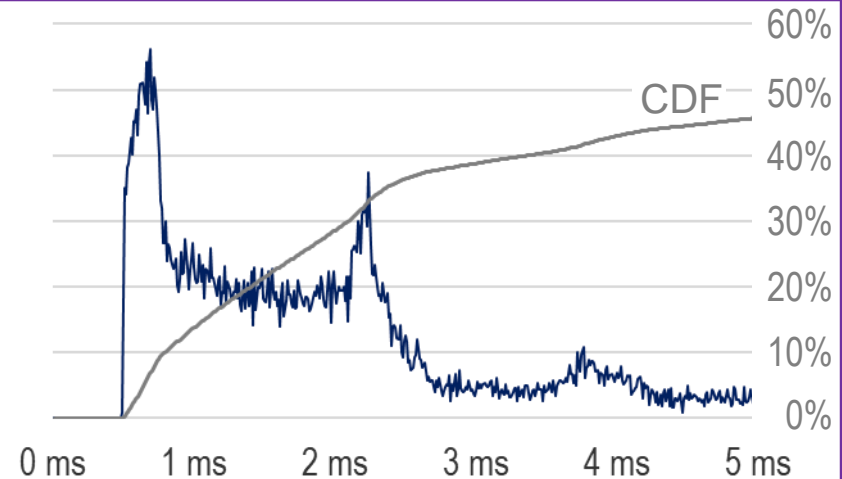
# Providentia
# Digitalization of roads and highways

► Providentia sets focus on future digital highways

► Investigates specific senor infrastructure to extend view of automotive onboard sensors

► 5G mobile communications network to transmit object data provided by a digital twin

► R&S supports partners to

  – Establish 5G infrastructure

  – Investigate deployed 2G, 3G and 4G networks for new automotive use cases

  – Verify whole system performance
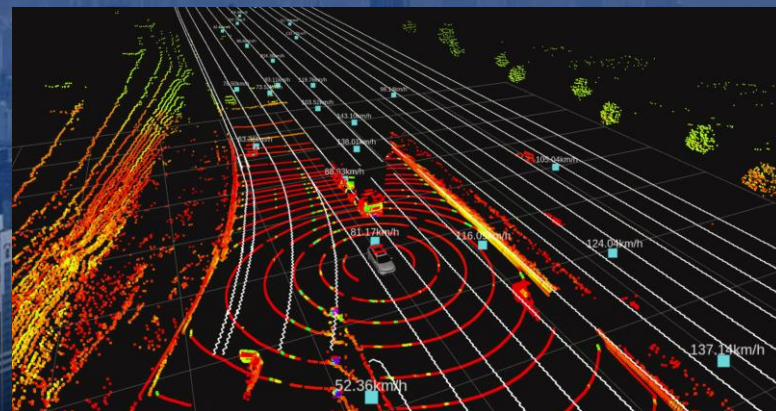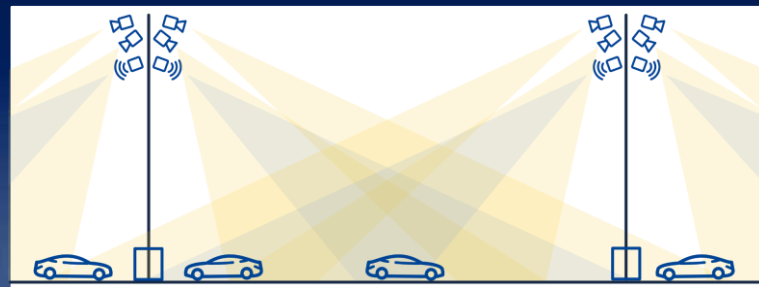
# Providentia: Setup of infrastructure

# Providentia: 5G NR V2X latency measurements (July 2019) distance up to 1km from BTS



5G Delay – Downlink Measurements
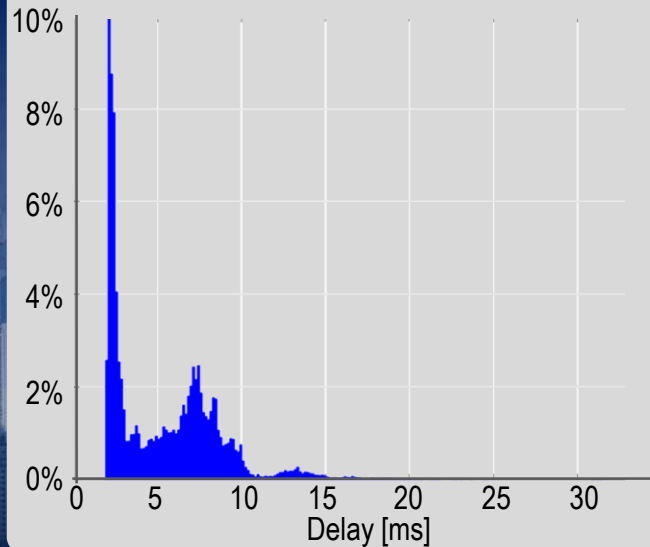


5G Delay – Uplink Measurements
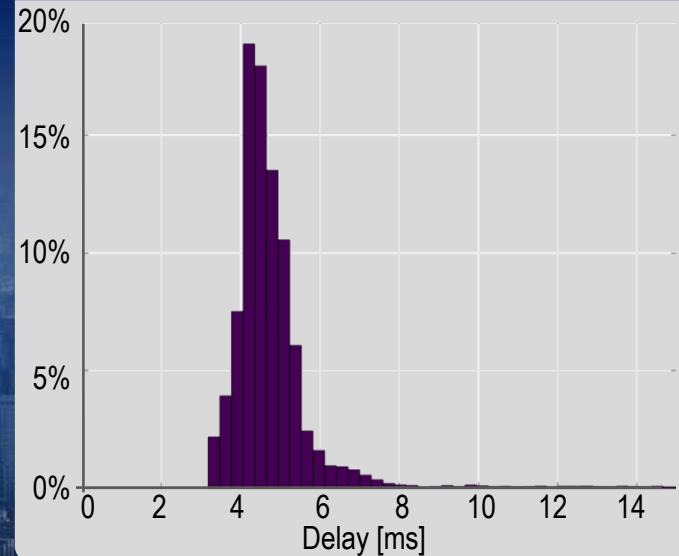
# Delay measurement in V2X scenario (LTE, UMTS, GSM) from English garden via providentia test track to R&S HQ



Test Track

DOWNLINK

Δ 12ms

~13 ms

~35 ms

~15 ms

~11 ms

~35 ms

~23 ms

UPLINK

# 5G in R&S factories

Vimperk
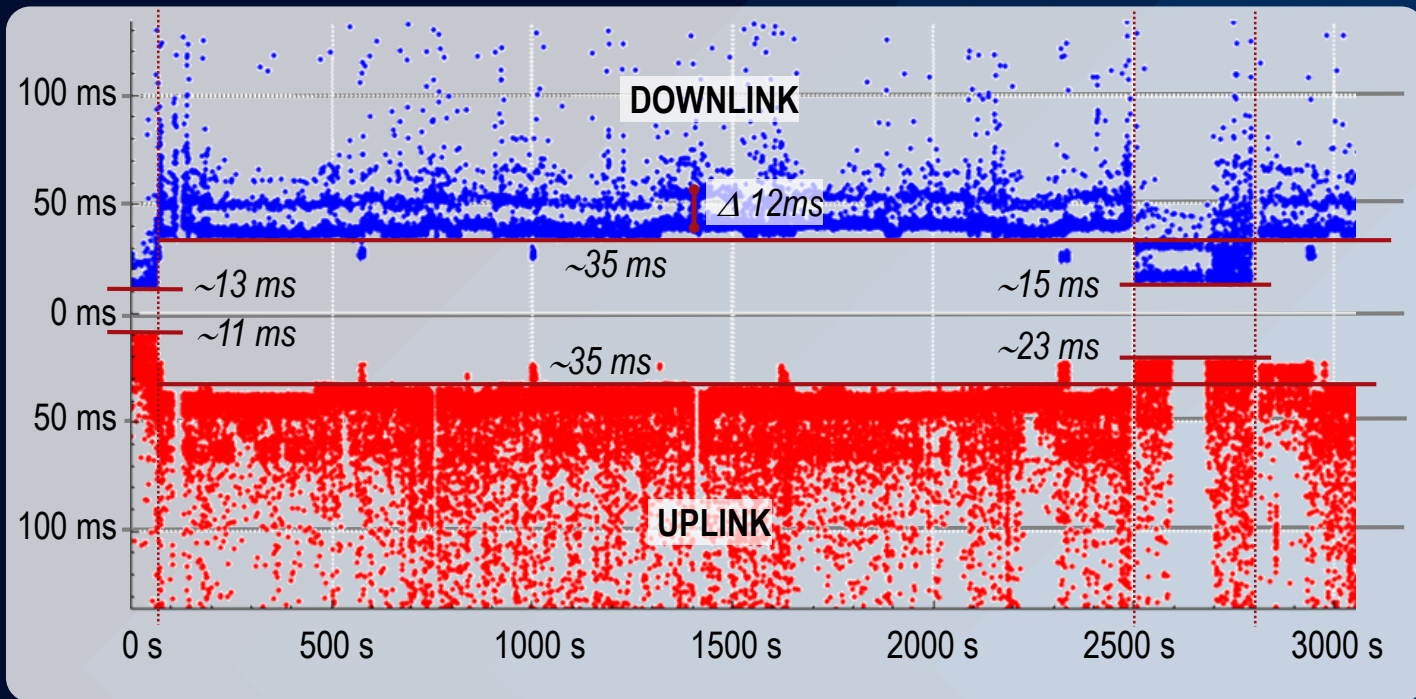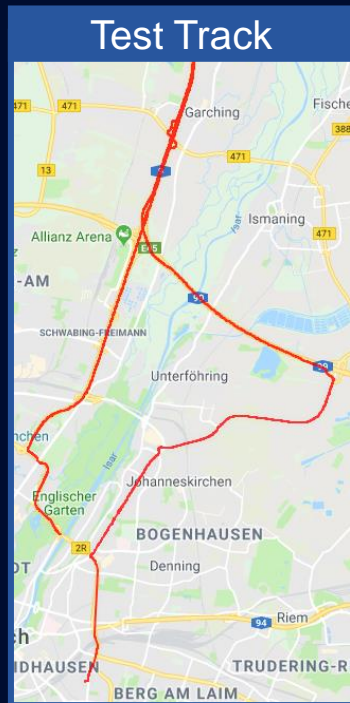
Memmingen

Teisnach

Development of private campus networks with high IT security in the plants

Worker guidance & robotics as pilot use cases in Teisnach and Memmingen

Use of private test licenses 3.7-3.8 GHz possible since Sep 2019

5G

Elaboration & Evaluation of Pilot use cases

Planning & Decision on Infrastructure

Implementation of Infrastructure & Pilot use cases

# R&S USER PERSPECTIVE

► Digitalization enables significant potential for process optimization

► 5G deployed in private spectrum opens the door for high efficiency and more flexibility

► Smooth integration into existing deployments is a key requirement

# Basic Setup for Channel measurements
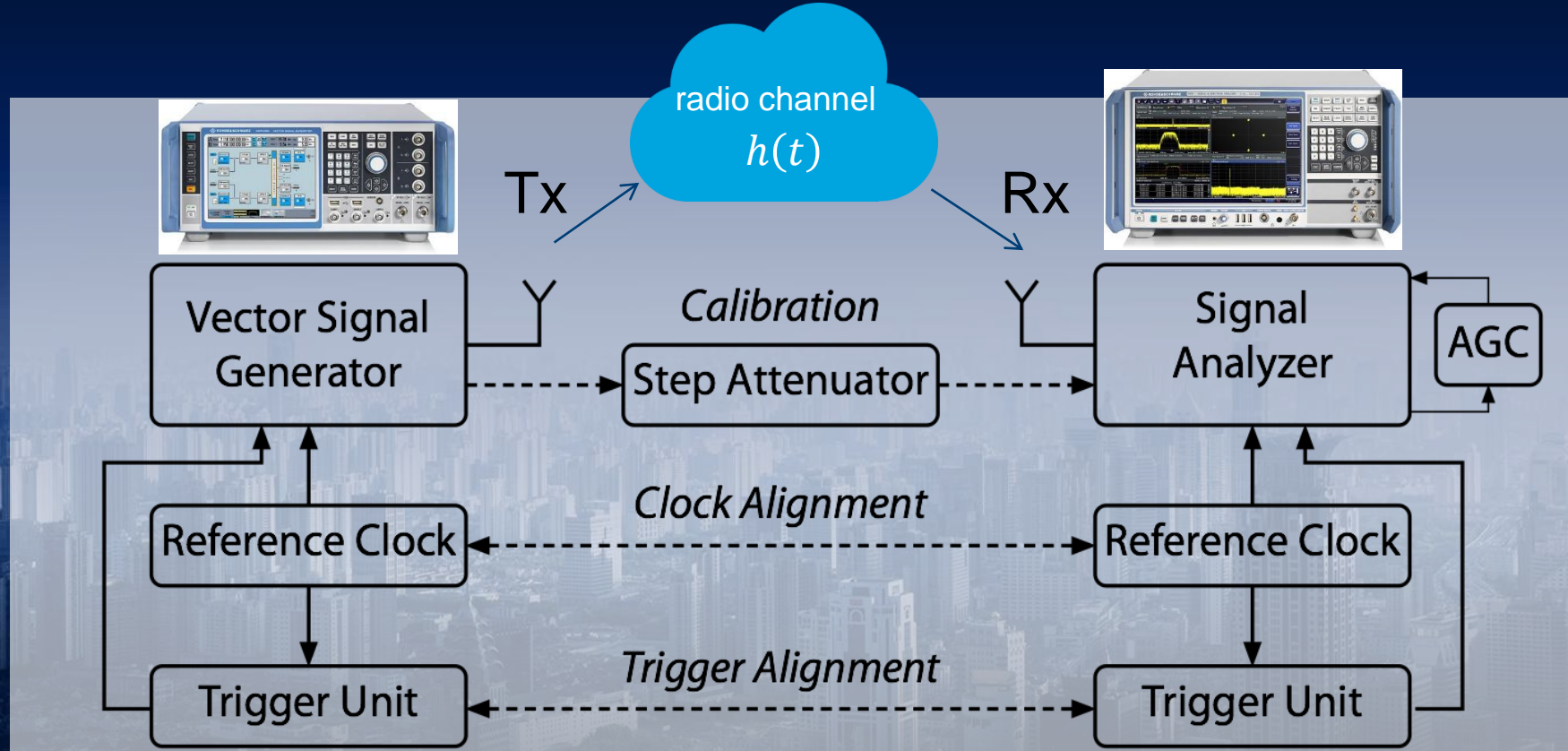
# Measurement campaigns at 28 GHz (3.7 GHz, 67 GHz) in our factories in Memmingen and Teisnach performed together with NTT DOCOMO and Fraunhofer HHI

► Measurement Campaign at 3.7 GHz, 28 GHz and 67 GHz

Power Delay Profile
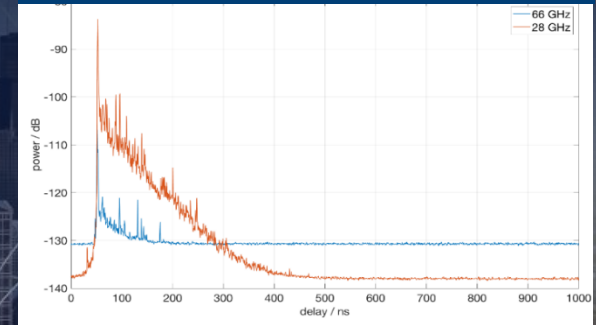


Contribution to the 3GPP study item (Rel.16: FS_IIIOT_CM )
on channel modeling for indoor industrial scenarios up to 100 GHz, EuCAP 2020 paper

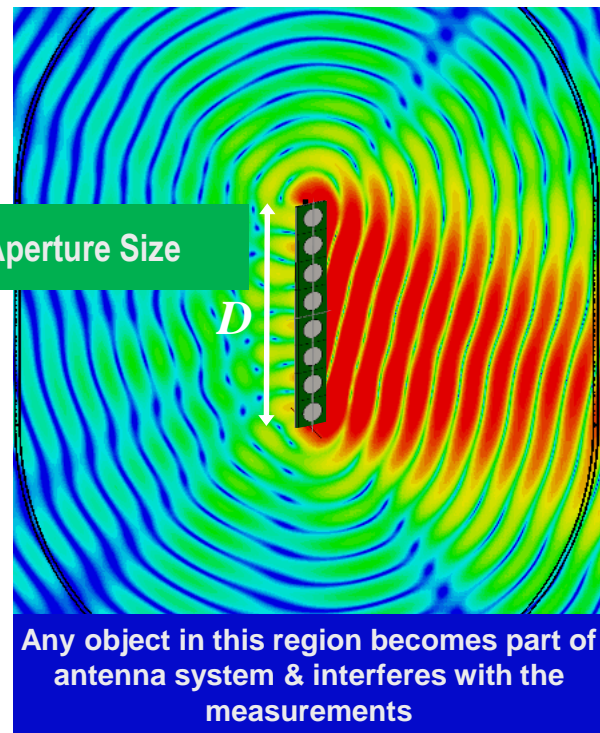# Averaged Power Delay Profile (28 GHz Line-of-Sight)
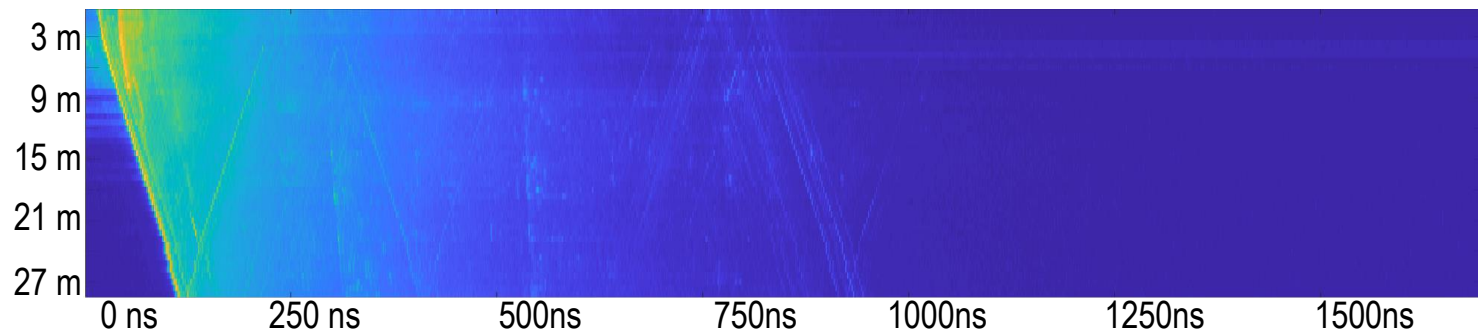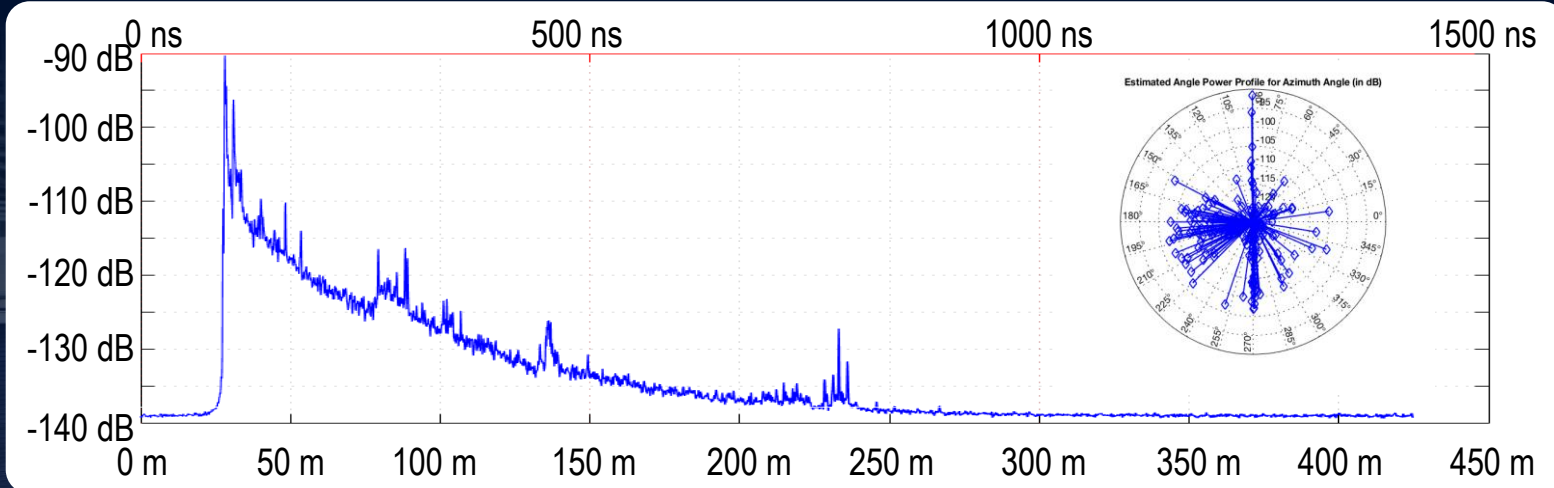
# EVM SIMULATION FOR ARRAY ANTENNAS
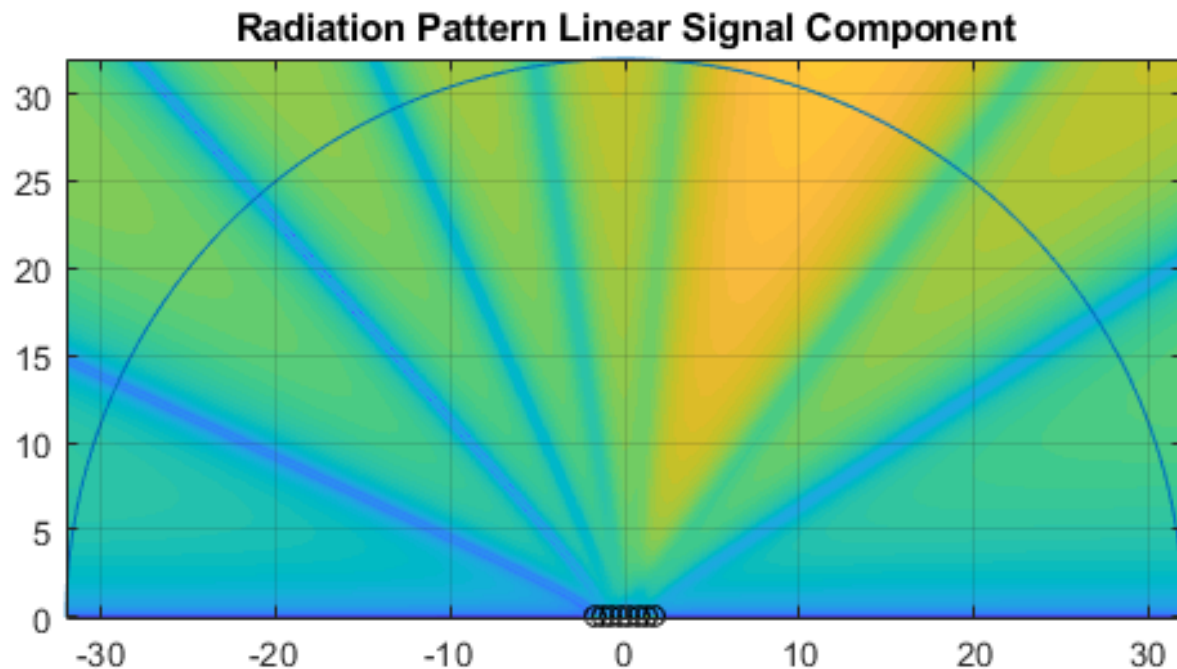
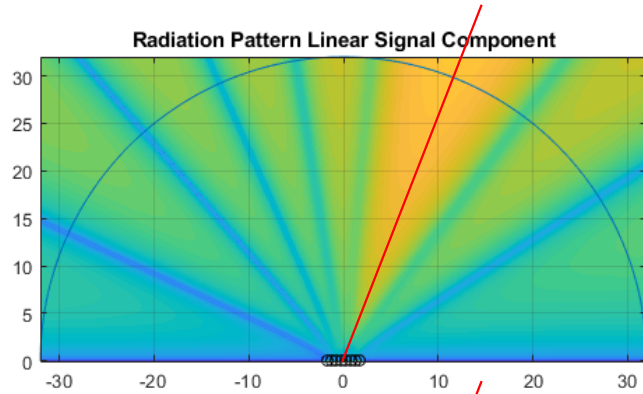# ELECTROMAGNETIC FIELDS: WHERE IS THE FAR-FIELD?

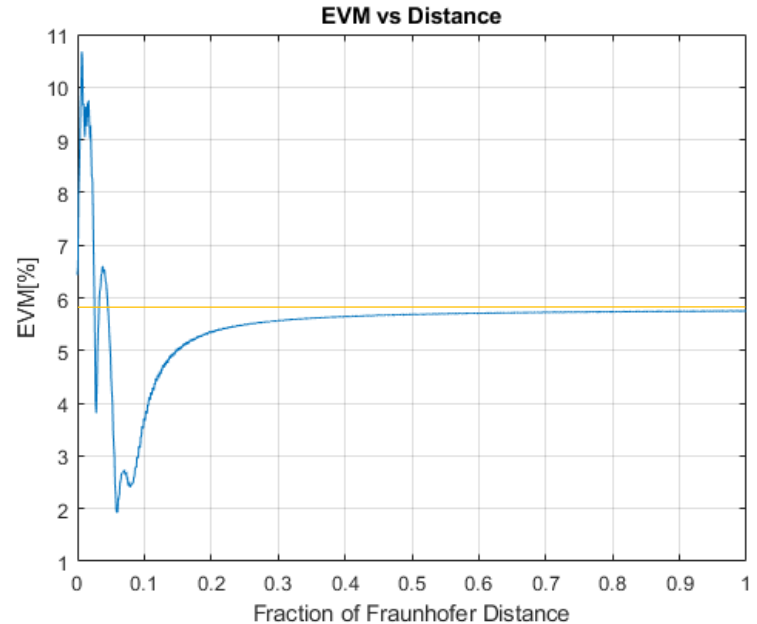$$\frac{2D^2}{\lambda} = 16.0m$$



**Antenna Array (30cm) at 28 GHz**

**Reactive Near Field Region**

D = Radiating Aperture Size
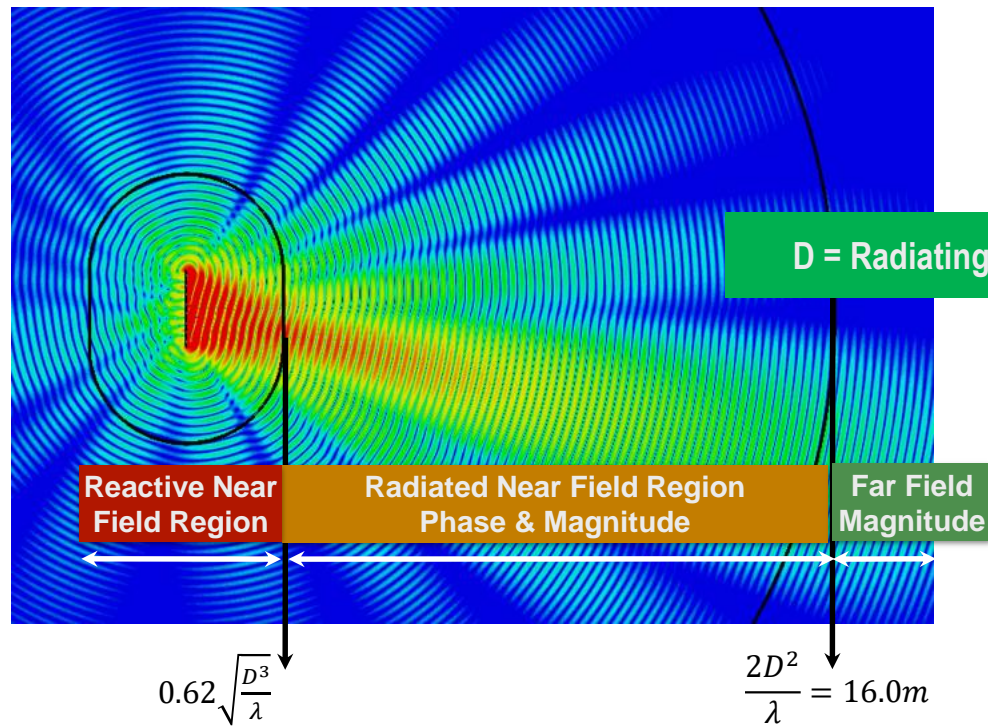
**Reactive Near Field Region**

**Radiated Near Field Region Phase & Magnitude**

**Far Field Magnitude**

$$0.62\sqrt{\frac{D^3}{\lambda}}$$

$$\frac{2D^2}{\lambda} = 16.0m$$

**Any object in this region becomes part of antenna system & interferes with the measurements**

# RADIATION PATTERNS & EVM

### Radiation Pattern Linear Signal Component

### Radiation Pattern IM3 Signal Component

Fraunhofer Distance

### EVM vs Distance

EVM[%]
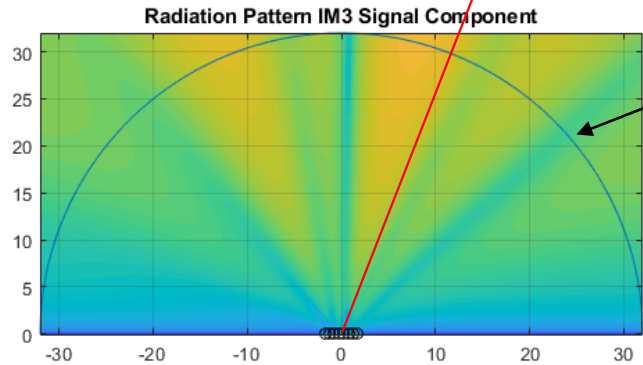
Fraction of Fraunhofer Distance

Farfield EVM

# Positioning technologies: 3GPP Rel-16 5G NR positioning and sensor fusion (GNSS, motion sensors, barometer for vertical)
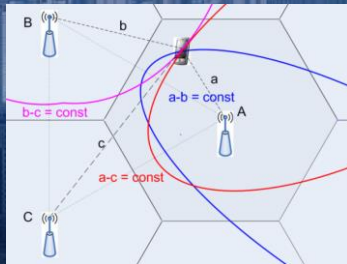
## Outdoor

- GNSS (time delay, TOF)
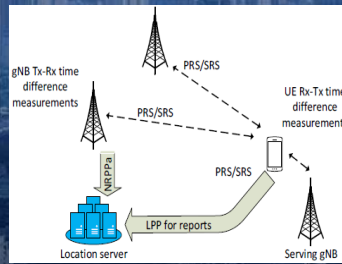- GNSS enhancement for ultra-precise positioning (phase): RTK

- OTDOA observed time difference of arrival

5G NR positioning:
- new positioning reference signals







TOF: time-of-flight
RTK: real-time kinetic

## Indoor

- Bluetooth LE
- WiFi (Beacons RSSI, AoA)

- ultra-wideband UWB (TOF relative to at least 3 anchor positions, precision 10-30cm)
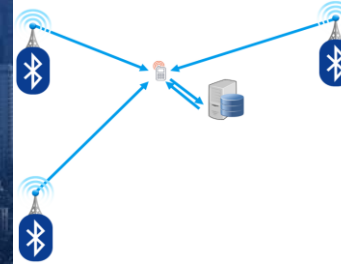




RSSI: Received signal strength indicator
AoA: Angle-of-Arrival
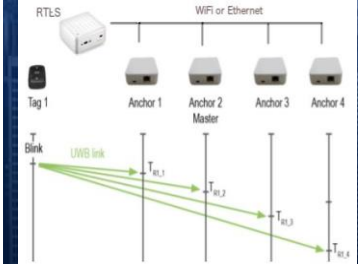
# Correlation for time delay measurement (RTK)

**Analogy to GPS (each satellite distinctive PRN "song")**

**Velocity = Distance / Time**



Rohde & Schwarz
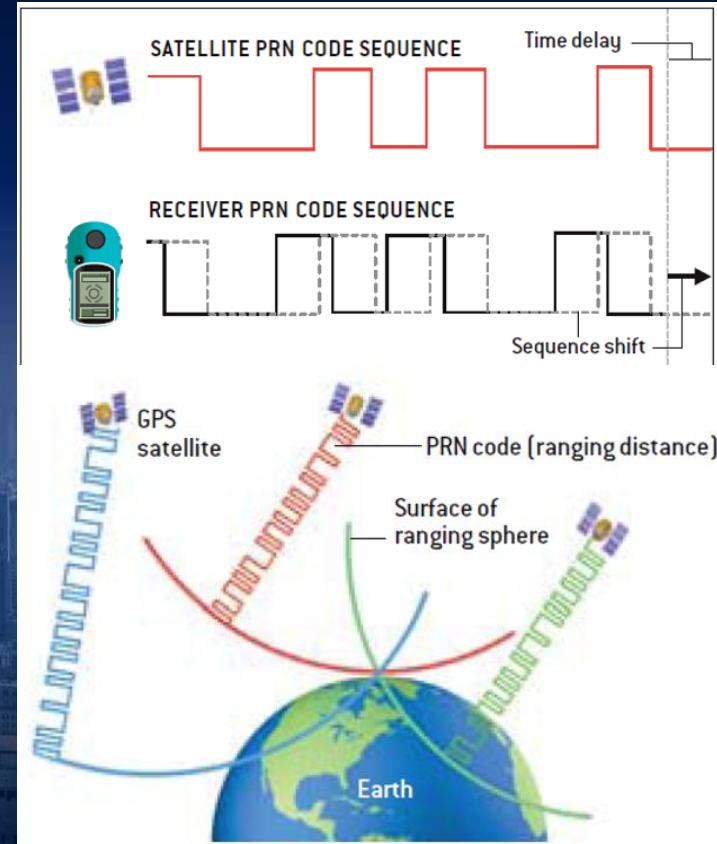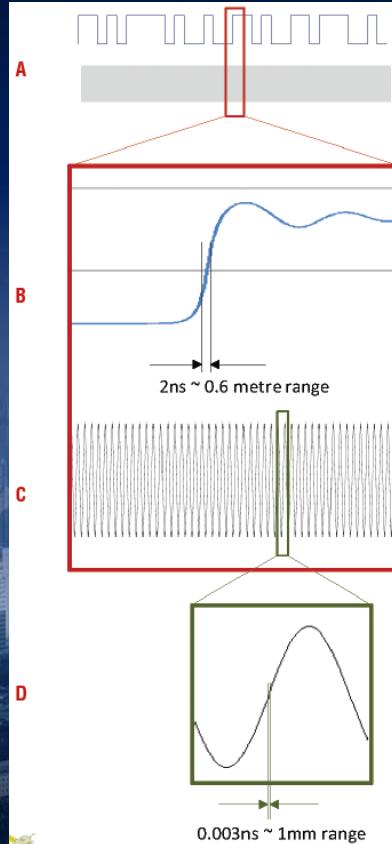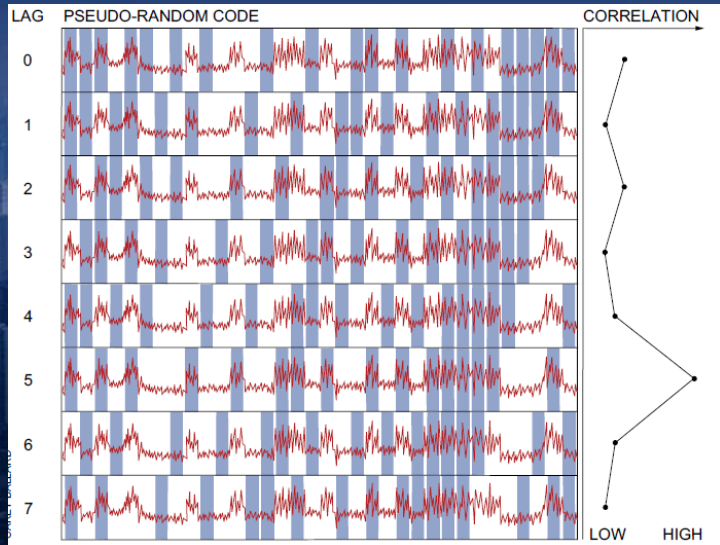
# AMMCOA: Autonomous Mobile Machine Communication for Off-Road Applications (mmWave positioning)

Objective: development of PLMN-embeddable infrastructure-less wireless 5G networking solution for agricultural and construction vehicles for supporting novel cooperative autonomous driving functions

► Communication & autonomization solution for vehicle-centric applications in agriculture and road construction

► Partner: Fraunhofer HHI, Infineon, John Deere, TU Kaiserslautern, Robot Makers GmbH, etc., T&M equipment: R&S

► Meshed mmW point-to-point communication links

► mmW-based point-to-point positioning

► Cellular / Sub GHz / long range air interface
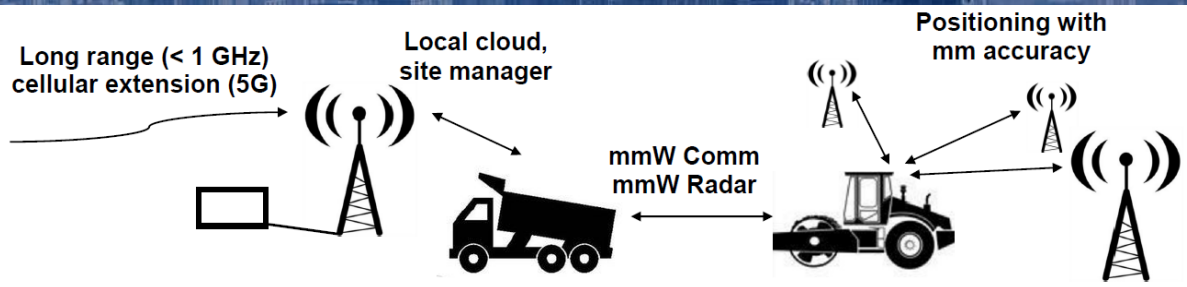
# AMMCOA: Measurement setup
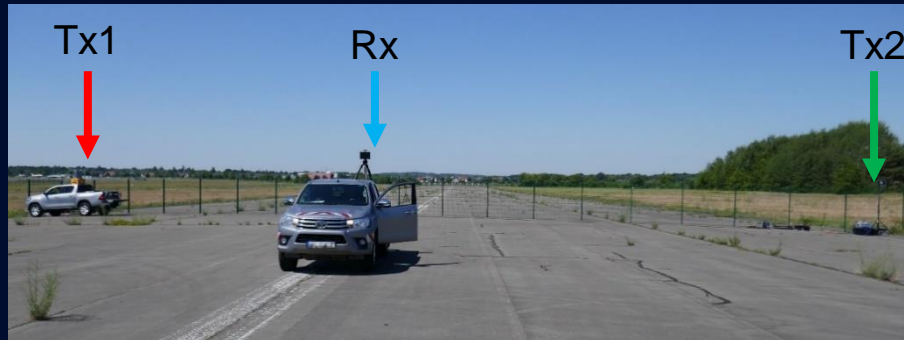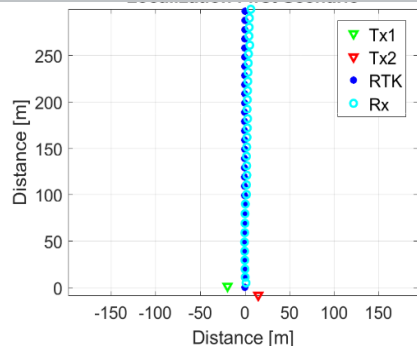

Transmitter Tx1


Transmitter Tx2


Receiver Rx

- The used measurement setup consists of two transmitters (fixed reference points) and one receiver with the aim of performing a spatially resolved simultaneous multi-transmitter channel measurement that allows a receiver localization based on angle of arrival (AoA) and time of arrival (ToA) information
- The measurement has been performed at a carrier frequency of 28.5GHz with a used bandwidth of 2GHz
- For verification of the calculated receiver positions a RTK GPS reference has been used
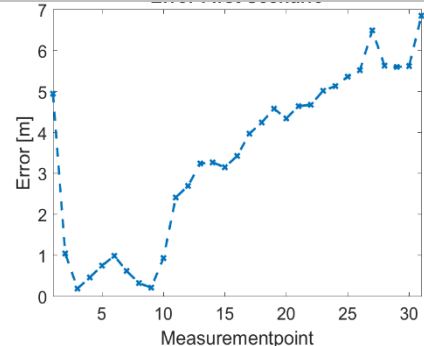
# AMMCOA: Measurement results (Berlin, Gatow, former airport)







Localization (1st scenario)



Error (1st scenario)



- ▶ A total # of 31 measurement points have been recorded
- ▶ Every 10 m a measurement has been performed (distance over 300 m)
- ▶ The transmitters distance is approx. 40m
- ▶ The determined receiver positions have been calculated from ToA and AoA information that originate from a fully synchronized measurement setup  and the Fraunhofer HHI VUCA (Virtual Uniform Circular Array)
- ▶ Overall an accuracy of 18cm to 7m has been achieved