NOKIA

Go Allwhere.

Ensure Network Quality of Private Campus Networks

Private Campus Networks | Test Phases | Quality Verification | Latency | Learnings

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AGENDA

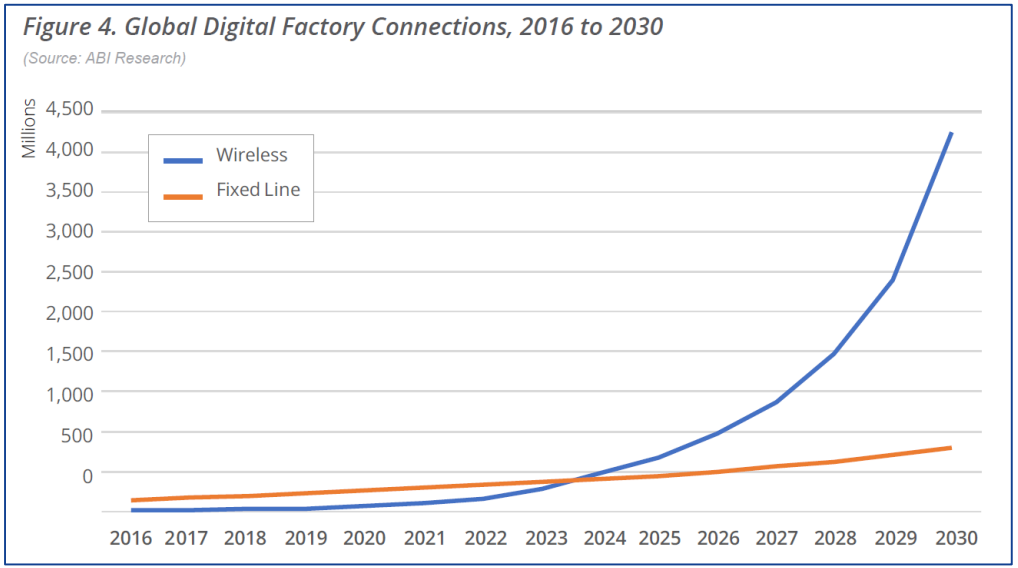
- **Campus Network Trends & Architecture**
- **Campus Network Deployment Options**
- 5G network test phases: From spectrum clearance to deployment, optimization and operation
- How to verify Campus Network quality, in particular latency (round-trip vs. one way)
- Learnings for successful Smart Factory operation

Market potential for Campus Networks

Fixed line connections will stay yet outpaced by number of wireless ones

Figure 4. Global Digital Factory Connections, 2016 to 2030

(Source: ABI Research)



(Source: ABI Research; Oct 2019)

Smart manufacturing connection revenue:

2020:
USD 5 bln, thereof **wireless: USD 0.5 bln (10%)**

2030:
USD 35 bln; thereof **wireless: USD 25 bln (72%)**

x50

Private wireless technology selection – 4G/LTE or 5G – based on use case scenarios and needed reliability, availability, security and performance

	Business driven communication with WiFi	Business critical communication with 4G/LTE	Industrial-grade communication with 5G
	Day2day business and office communication for non-business-critical applications	**Reliable, secure communication for operational & business-critical applications**	**Industrial-grade communication for mission-critical applications with safety features**
	Capacity: ~30-100 connections/AP	**Capacity:** up to 400 connections/AP	**Capacity:** up to 400 connections/AP
	Coverage: 50-100m AP radius	**Coverage:** 50m-30km AP radius	**Coverage:** 50m-30km AP radius
	QoS: best effort, lack of prioritization	**QoS:** managed, with prioritization	**QoS:** managed, prioritized, NW slicing
	Performance: high peak rates	**Performance:** predictable, 3-4x “9’s”	**Performance:** predictable, 4-5x “9’s”
	Mobility: 15s connect. loss @ handover	**Mobility:** up to 350 km/h	**Mobility:** up to 350 km/h
	Latency: 1ms-2sec, fluctuating	**Latency:** 8-20ms, stable	**Latency:** 1-5ms, stable
	Security: Key/password-based	**Security:** APN/SIM authentication	**Security:** APN/SIM authentication

Industrial Private Wireless Technologies

Increasing levels of guaranteed reliability, availability, security and performance

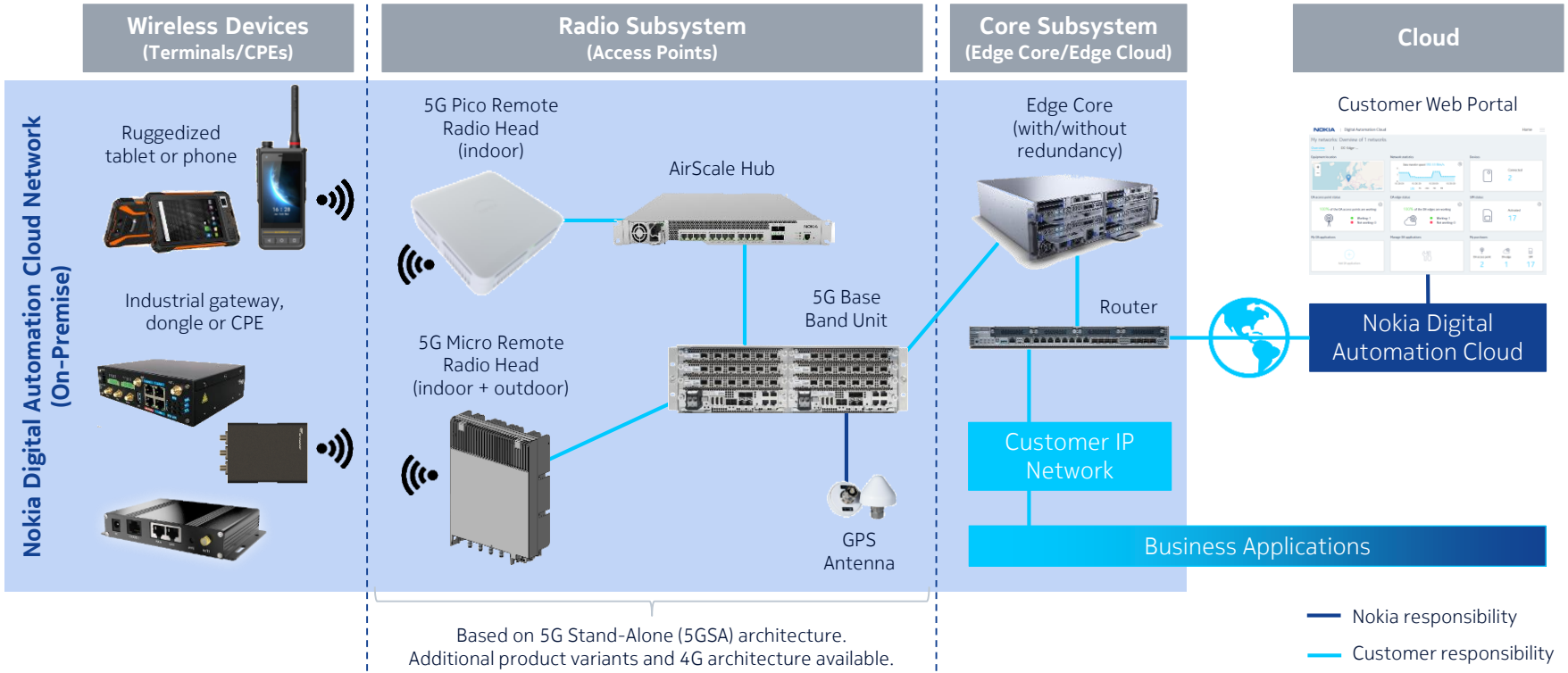
Trends to enable Private Campus Networks

Technologies | Business Need | Mobile Cellular Technology | Spectrum

Emerging technologies enable new industrial use cases	There is a need for robust, reliable, on campus mobile connectivity	Mobile Cellular Technology developed further	Spectrum options
Video capture, processing and analytics	There is need for further efficiency gains	5G caters for mMTC & uRLLC	New dedicated spectrum options for local or industry specific users
Big data analytics	Industry 4.0: Digitalization, Data Analytics, AI	Software-defined network functions allow for VNFs	New shared spectrum options (like CBRS)
Affordable sensing	Flexible work-places and manufacturing processes	Compute performance allows for dense, small-size network elements	New technology options for shared spectrum use (like MuLTEfire)
Machine Learning		Small Cells & MEC as genuine building blocks for campus networks	
Artificial Intelligence			

Industrial private wireless network based on Nokia's Digital Automation Cloud

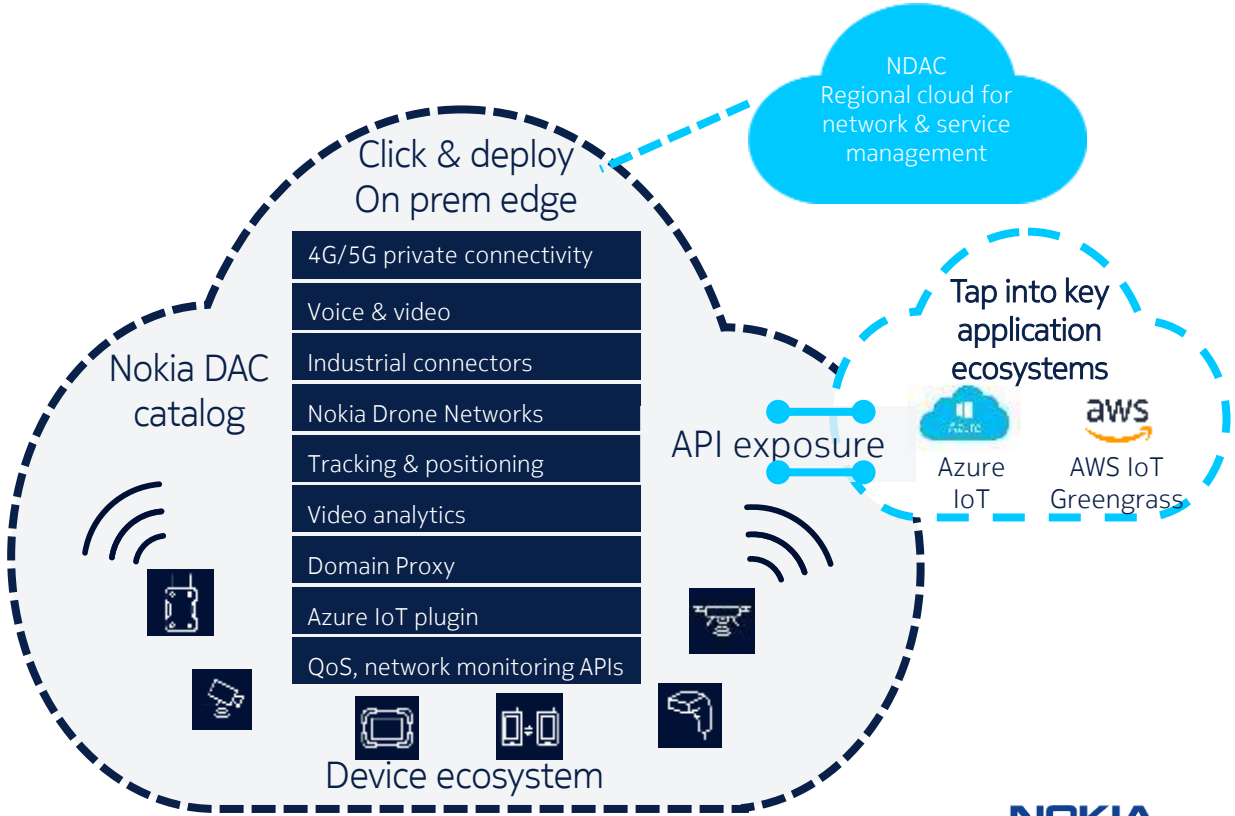
On-premise radio & core Subsystem with cloud-based network management



Nokia Digital Automation Cloud – value beyond connectivity

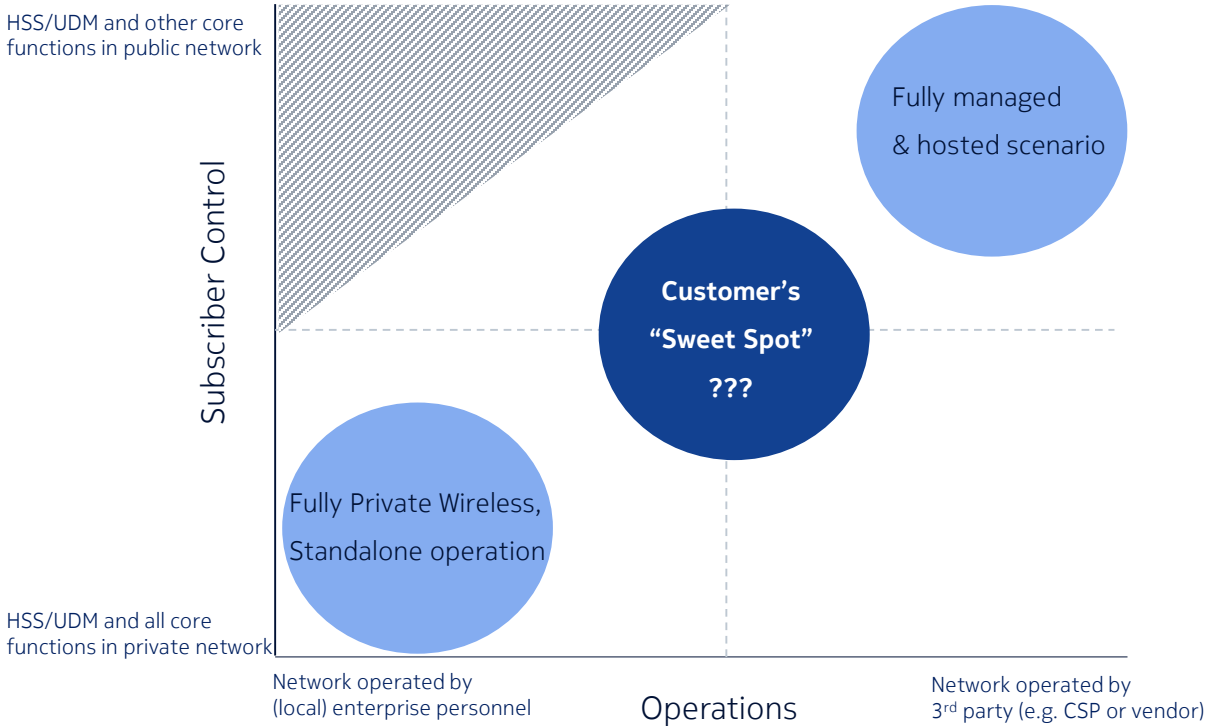
End-to-end platform for digitalization

1. Best out of cloud and edge with telco grade reliability at optimized cost
2. Key digitalization enablers through one platform
3. Automated application management, operations & maintenance with Application framework
4. Fast adoption of new applications



Private Wireless Campus Network deployment scenarios

Today's technology allows for flexible scenarios according to needs and preferences



Mobile Network Testing

ENSURE NETWORK QUALITY OF PRIVATE CAMPUS NETWORKS

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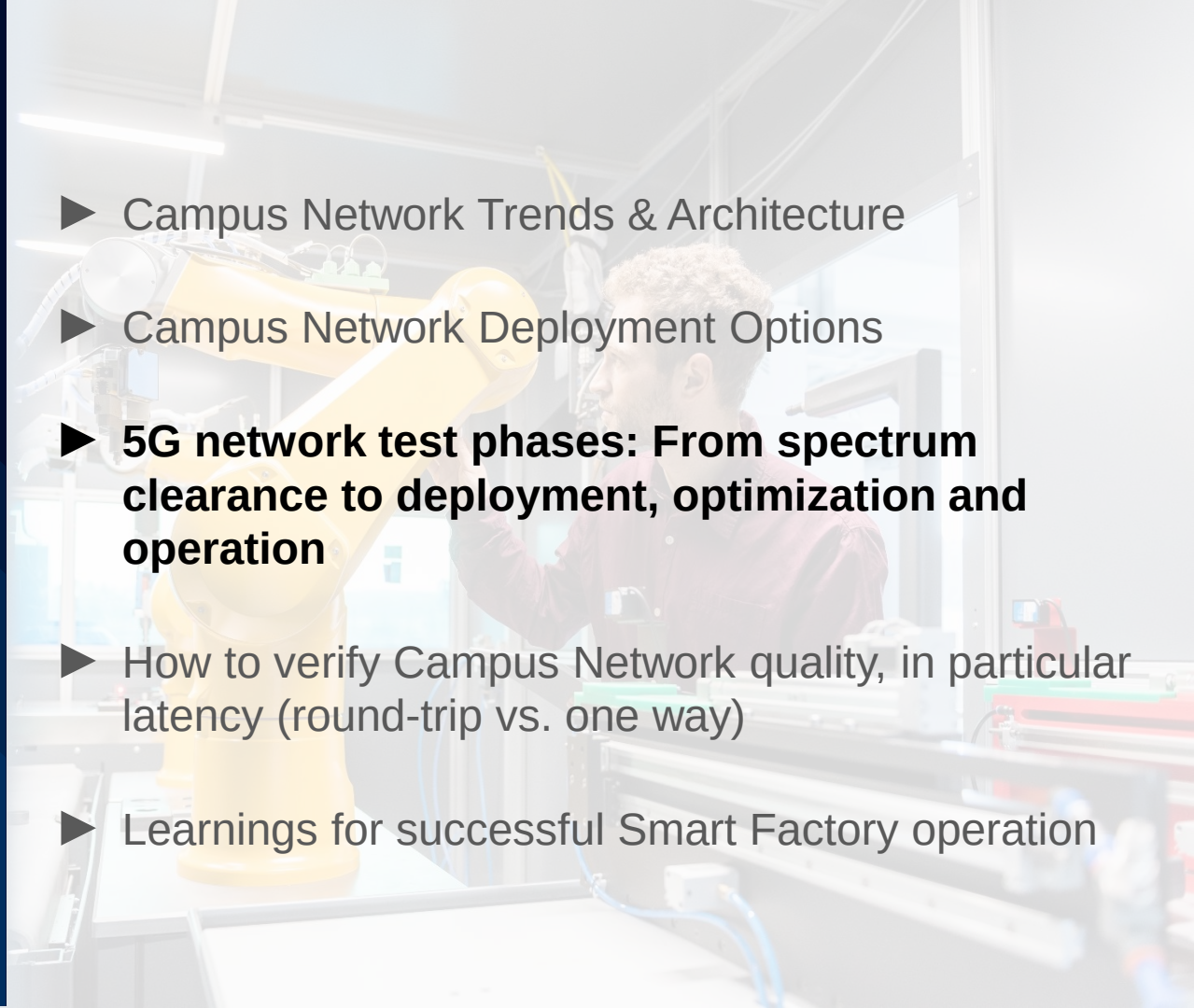
Make ideas real

AGENDA



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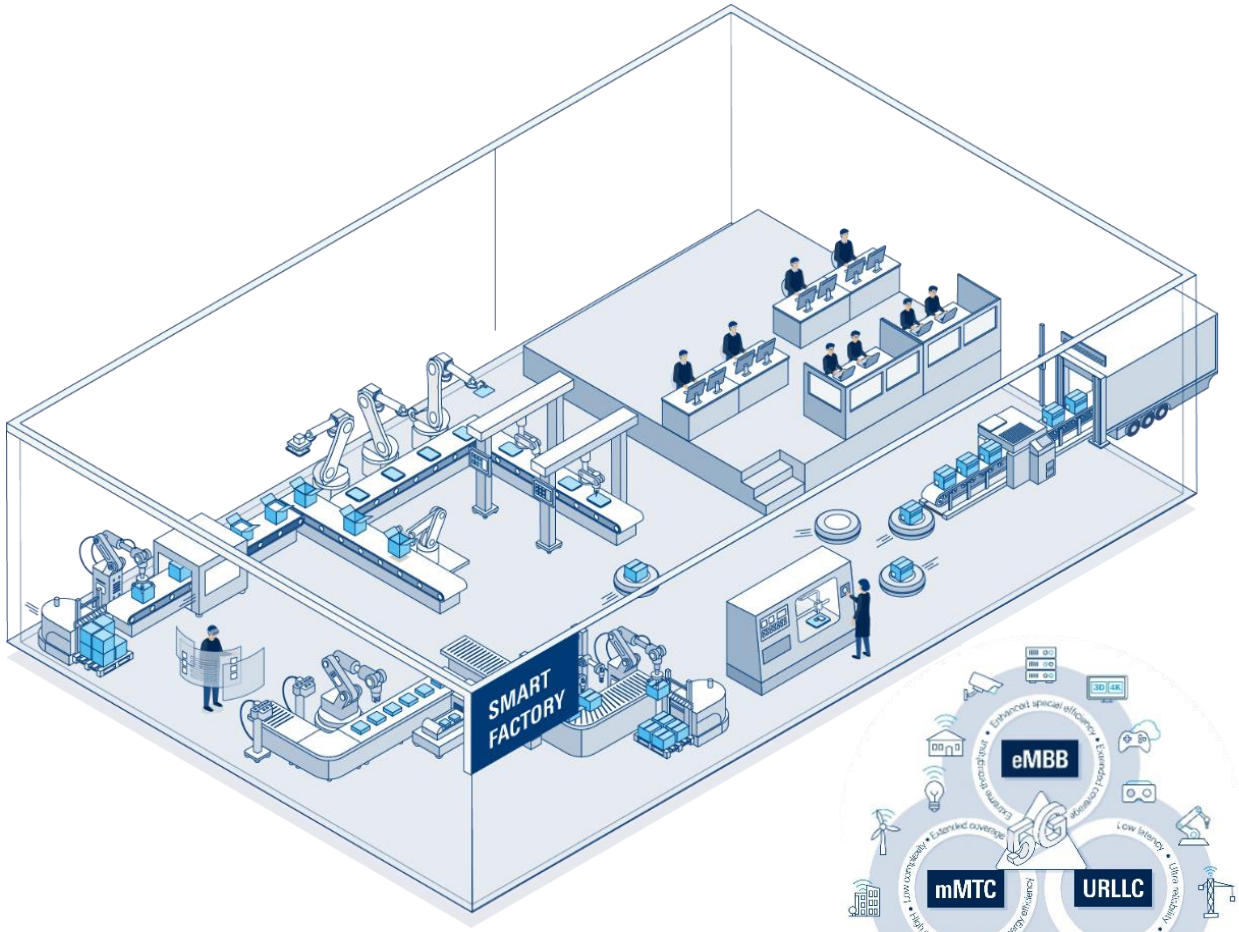


SMART FACTORY CRITERIA

- 5G connectivity allows flexible and adaptable production facilities
- Connected robots and AGV (Automated Guided Vehicles) – self driving
  → URLLC
- AR/VR support for operations
  → eMBB
- Numerous sensors, inventory control, supply chain management
  → mMTC

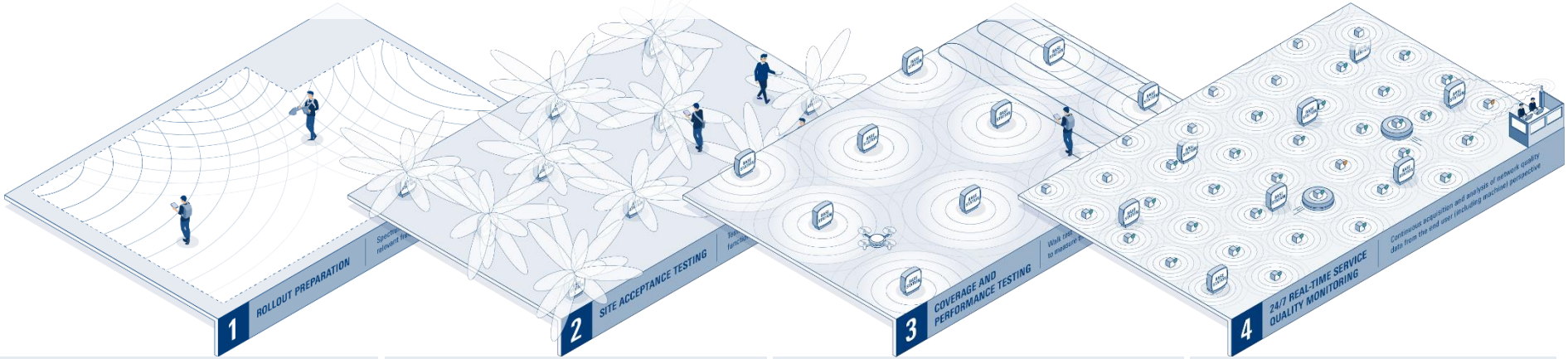
AVAILABILITY AND LATENCY REQUIREMENTS FOR SPECIFIC INDUSTRIAL USE CASES

(Data source: WP 5G-ACIA, ZVEI, ABI Research)

Use Case	Latency	Typical payload size	Availability
AR (next gen 360° video, mixed reality, multi-sensory remote tactile control)	< 10 ms; 0.5 ms for remote tactile control	> 50 Mbps data rate	99.9999% for remote tactile control
Collaborative robots (Cobots)	1 ms	40 to 250 Bytes	99.9999%
Video-operated remote-control robots with haptic feedback	< 20 ms	15 to 150 kBytes	99.999%
Handheld terminal	< 10 ms	varies	99.9%
Motion control	< 0.5 to 2 ms	20 to 50 Bytes	99.9999%

99.9999% means 31 seconds downtime per year!
1 out of 1,000,000 connection requests / messages lost!

HOW TO ENSURE NETWORK PERFORMANCE



Spectrum Clearance

Identify interferers

Measure relevant frequency bands

Functional testing

Measure download, upload and RTT performance from end user perspective.

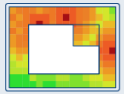
Coverage and performance analysis

Test 5G connectivity incl. sufficient redundancy (portable HW platform); analyze with data analytics SW in control room

Continuous data collection

Multiple RF probes evenly distributed inside the factory and on AGVs to test network connectivity

Interference Hunting



Locate interferers

Locate source of interfering signal

OTA RF signal verification

Visualize the transmitted signal to verify correct 5G transmission, incl. SSBs

Network optimization

Optimization by modifying the network configuration, e.g. base station position, power- or beam-specific parameters.

Real-time QoE monitoring

Deviations from required QoE are visualized in network performance dashboard

Signal decoding

Verify PCI, SSB and SIB for 5G and LTE. Troubleshoot parameters (e.g. SINR).

► After every factory modification

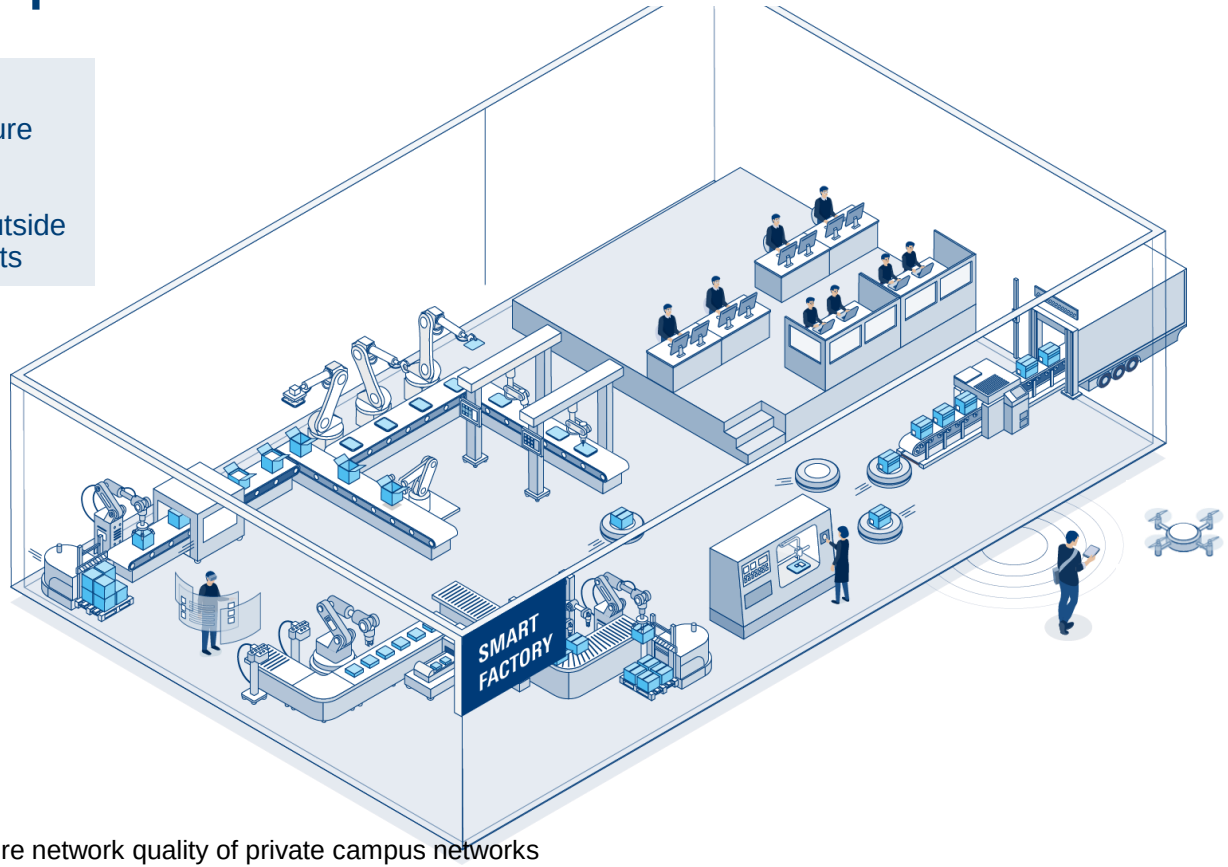
Data analytics

Machine learning algorithms are used to identify trends and detect anomalies.

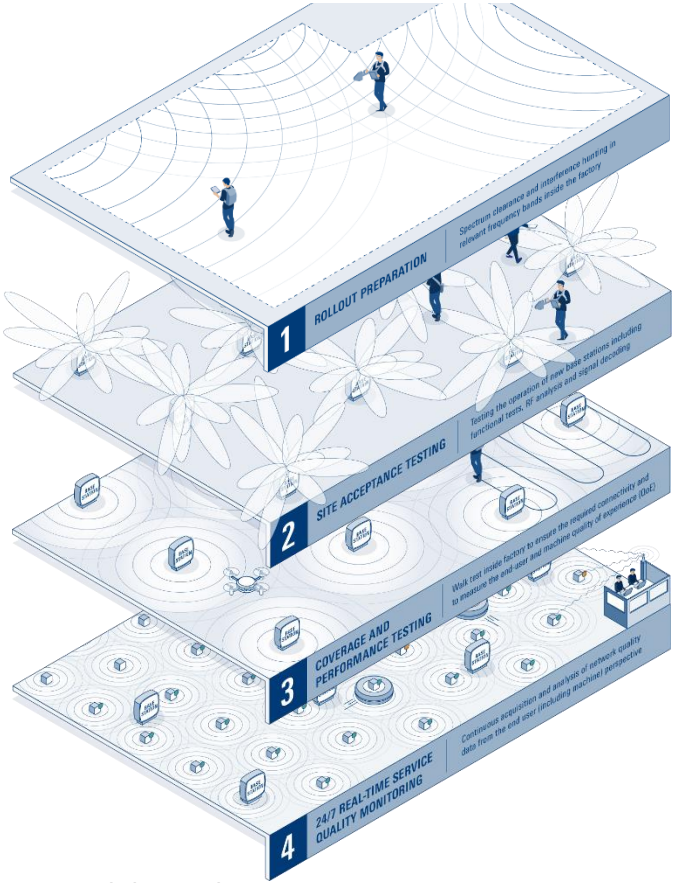
TEST PHASE 5: REGULATORY COMPLIANCE
Network compliant to private network license terms

Periodic spectrum clearance
Measure RF environment to ensure compliance with private network license terms, e.g. to keep transmission of leaked signals outside of the factory within specified limits

Walk test solutions or network test solutions mounted to a drone



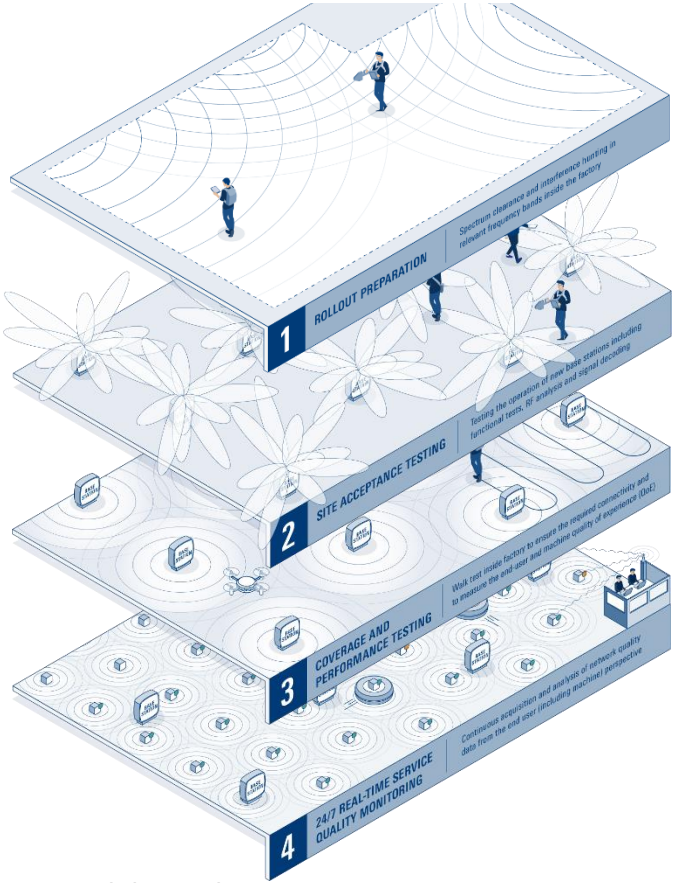
HOW TO MEASURE



 R&S®TSMx6 scanning receiver	 R&S®FPH spectrum analyzer	 R&S®MNT100 handheld receiver
 QualiPoc Android smartphone	 R&S®FPH spectrum analyzer	 R&S®5G STS Site Testing Solution
 R&S®TSMx6 scanning receiver	 QualiPoc Android smartphone	 R&S®SmartONE optimization SW
 → 5G/LTE modules QualiPoc Android probe smartphone	 SmartMonitor network monitoring SW	 SmartAnalytics software (ML)

- Most network measurement solutions available already
- 24/7 Service Quality Monitoring requires tailored RF modules

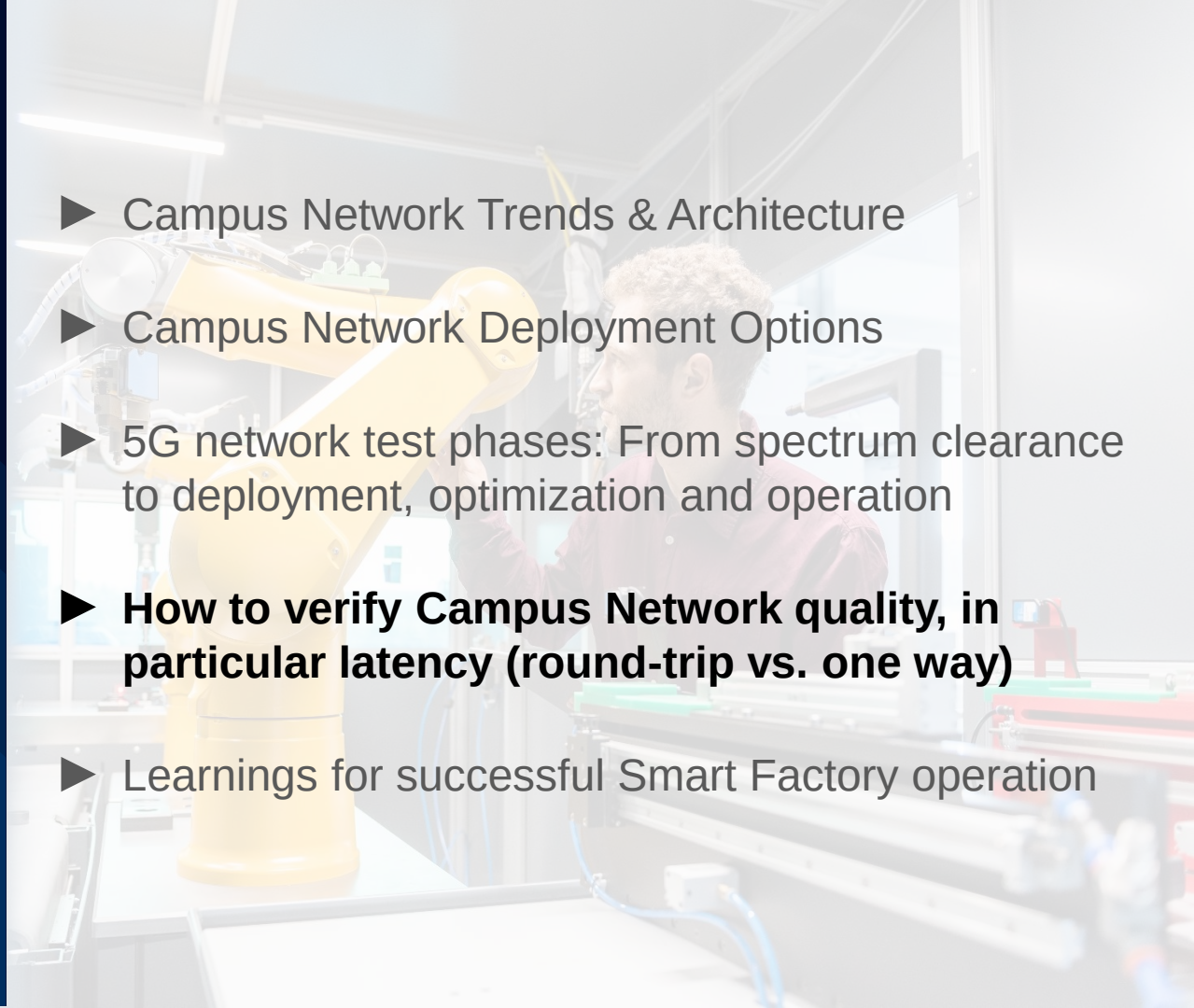
RECOMMENDED TEST SOLUTION PORTFOLIO



STS R&S®TSMx6 scanning receiver	R&S®FPH spectrum analyzer	0x R&S®MNT100 handheld receiver
QualiPoc Android smartphone	1x R&S®FPH spectrum analyzer	1x R&S®5G STS Site Testing Solution
STS R&S®TSMx6 scanning receiver	3x QualiPoc Android smartphone	1x R&S®SmartONE optimization SW
5G/LTE modules? 400 … 1200x QualiPoc Android probe smartphone	1x SmartMonitor network monitoring SW	1x SmartAnalytics software (ML)

For a typical smart factory (10.000 … 30.000 sqm)

AGENDA



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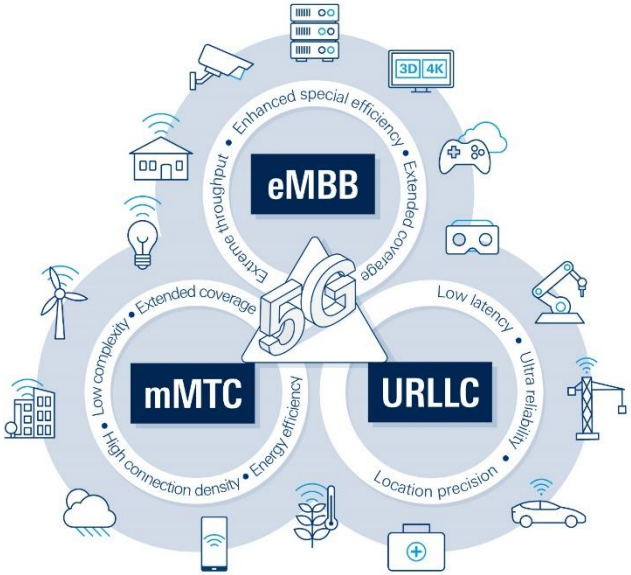


- ❑ Round-trip latency
- ❑ One way latency
- ❑ Redundancy

Key performance Indicators for operating a Smart Factory

eMBB: Augmented Reality (AR / VR)

- ► Interactive / round-trip latency is key → Interactivity test!

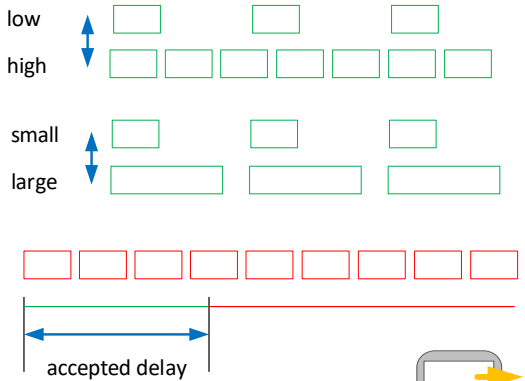
URLLC:

- ► Often one-way latency is important (e.g. robot control, automated guided vehicles, remote controlled trolley, etc.)

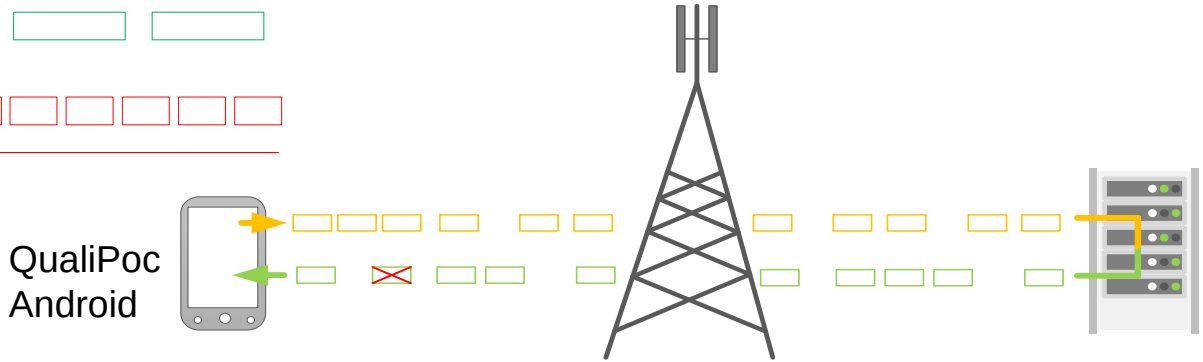
THE NEW INTERACTIVITY TEST – eMBB IS ROUND-TRIP

- **Interactivity** is the combination of **Bitrate + Latency + Continuity**!
- The device sends a UDP stream of unique packets to an (active) server that reflects it
- TWAMP: **T**wo-**W**ay **A**ctive **M**easurement **P**rotocol – specified by IETF (RFC 5357)
  (Traffic can be emulated; TWAMP defined for latency SLA verifications)

- Control parameters (on technical level) are:
  - Packet rate
  - Packet size
  - Delay budget



- Results:
  - Round-trip latency
  - Packet delay variation
  - Packet Error Rate

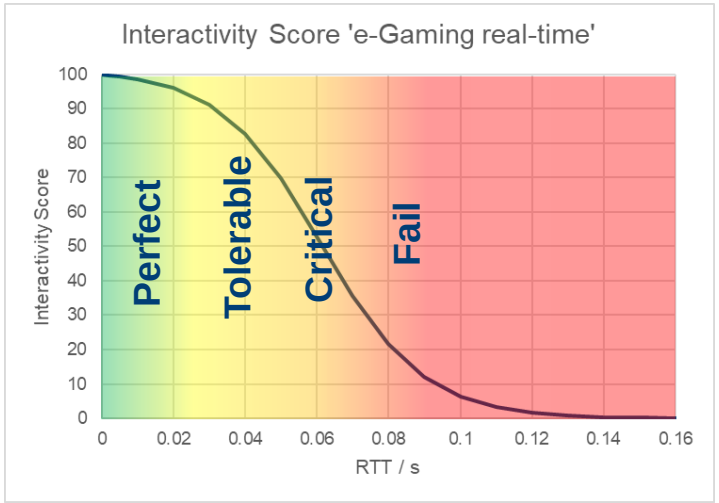


INTERACTIVITY SCORE – THE QOE MODEL

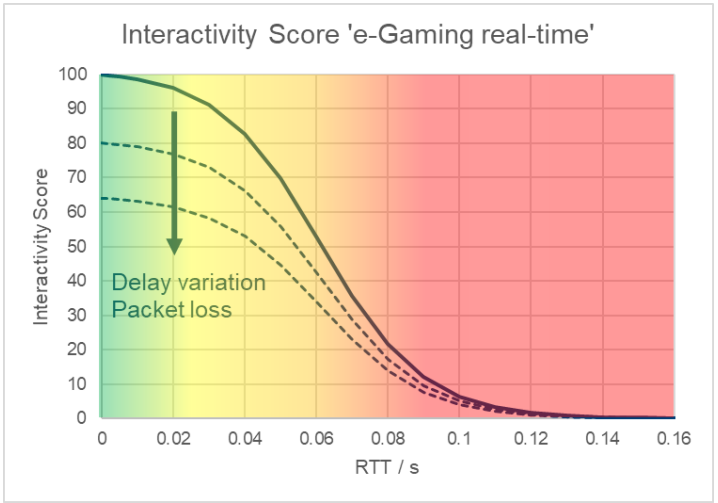
- For emulating ‘real’ applications we will apply a generic QoE model
- The QoE model produces a ‘synthetic’ MOS (Mean Opinion Score) based on QoS and techn. KPIs

- **Interactivity Score**

Interactivity Score = f_1 (latency, time)



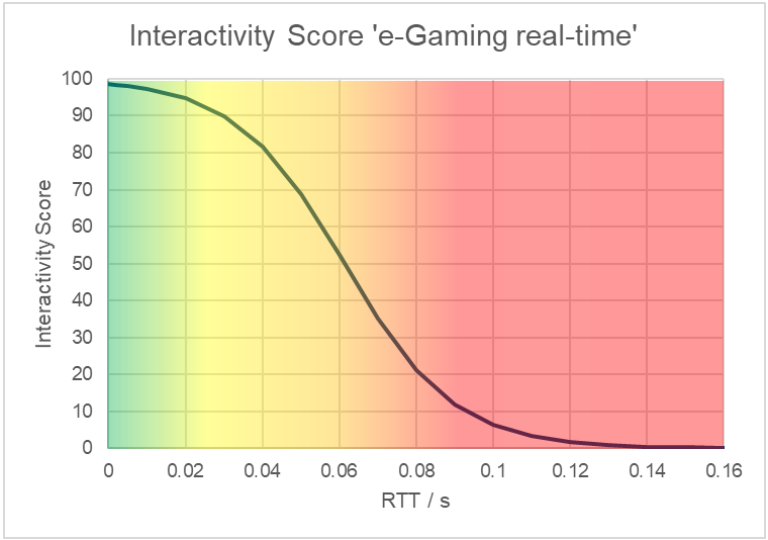
** f_2 (delay variation) * f_3 (packet loss)*



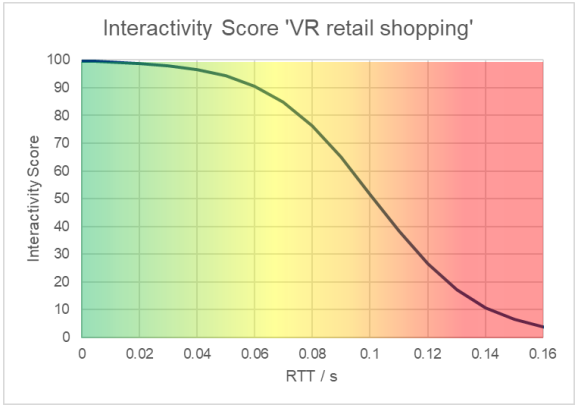
- Interactivity Score combines latency, delay variation and packet loss into one single score

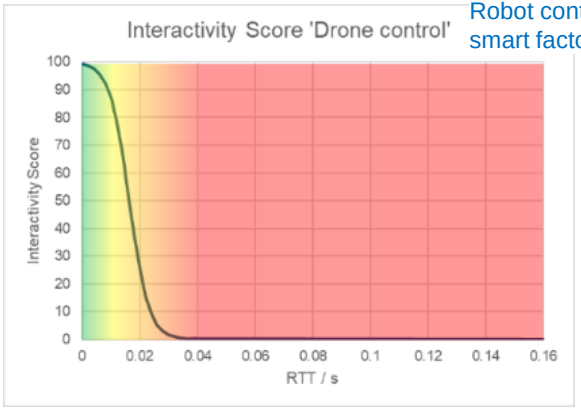
INTERACTIVITY TEST – a scalable concept for round-trip latency measurements

- This sort of generic QoE model is fully scalable



scalable

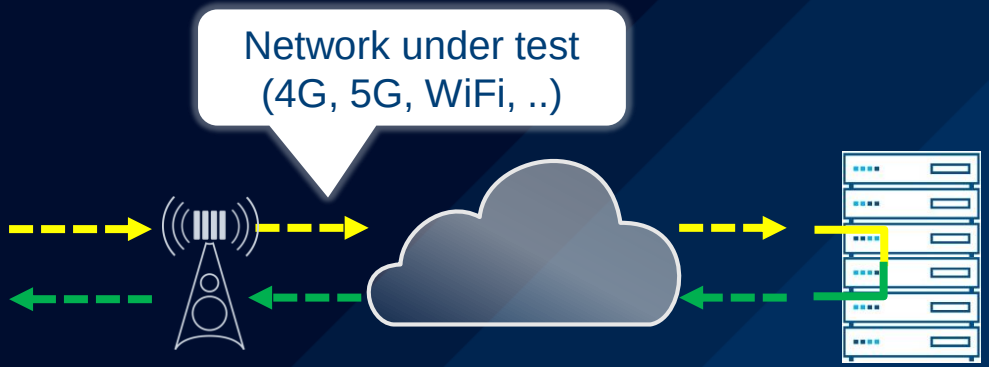




Robot control in the smart factory?

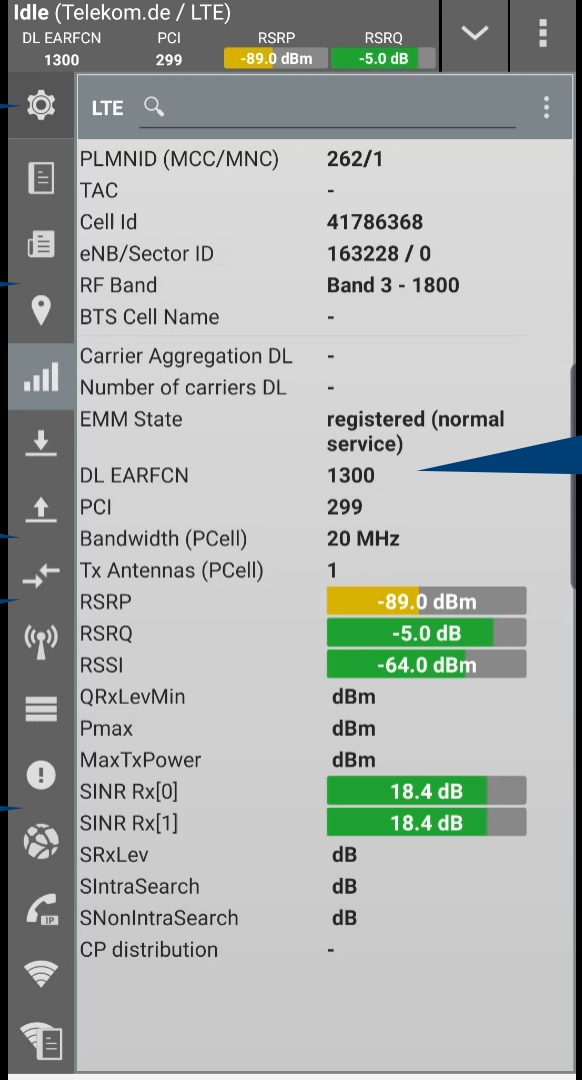
- The parametrization of the Interactivity Test and Score is individual for each application class
- e.g. AR / VR Remote Support in Smart Factory

DEMO: INTERACTIVITY TEST
ROUND-TRIP LATENCY MEASUREMENT



Measure and analyze round-trip latency on QualiPoc Android using TWAMP reflector (any TWAMP capable Internet node)

- Interactivity Test is commercially available in our QualiPoc Android solution offering



Technology (RAT)

Frequency band

Bandwidth

Good coverage

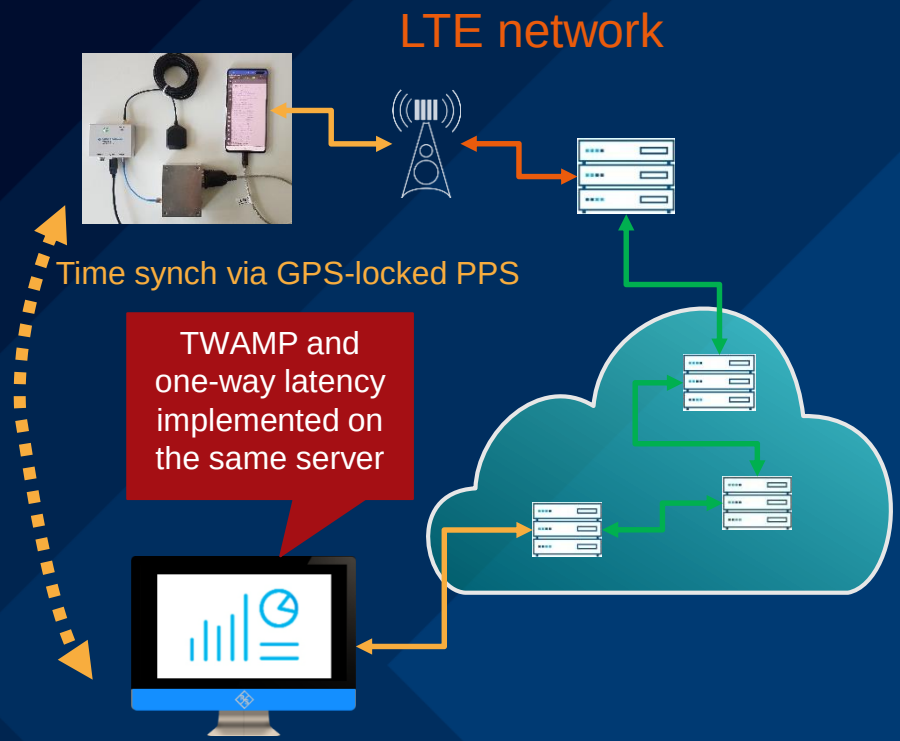
Good signal quality (SINR)

QualiPoc Android
Smartphone-based RF and QoE testing

- Interactivity Score for e-gaming application
- Not sufficient for e.g. collaborative robots!

PROTOTYPE SOLUTION: ONE-WAY LATENCY MEASUREMENT
Example results for our specific scenario (Munich)

- DL direction: server to client (includes LTE DL)
- UL direction: client to server (includes LTE UL)
- Example measurement: 6ms (DL) and 18ms (UL) for a medium data rate connection (1Mbps)
- Generally increased latency with increased data rates
- More investigations planned, in particular in real 5G based industrial deployments



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ROHDE&SCHWARZ

Make ideas real

- Despite the fact that architecture and the setup of a campus network appears to be simple, attention to detail is required for excellent performance
- 5 phases of 5G (LTE) network testing in Smart Factories require a complete portfolio of network testing solutions
- Service Quality Monitoring (24/7) in combination with Machine Learning recommended to pro-actively ensure high reliability
- Interactivity Test combines testing round-trip latency, packet delay variation and packet error rate in a single test and a single score
- Prototype test solution for one-way latency measurements based on QualiPoc Android: one-way latency ≠ round-trip latency / 2

► **Rohde & Schwarz is the one-stop shop for network testing solutions required in Smart Factories**

www.rohde-schwarz.com/mnt/smart-factory

R&S USER PERSPECTIVE

- Smooth and cost-efficient integration into existing deployments is key
- Industrial grade performance, reliability and security required
- Target: deploy 5G in private spectrum for high efficiency and flexibility
- Use Cases: Machine control, quality control using AR/VR, AGVs, flexible and efficient data distribution and collection…