5G Air Interface for Ultra Reliable Robot Communication

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BUILDING A BETTER CONNECTED WORLD

Huawei Technologies Duesseldorf GmbH

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5G Air Interface for Ultra Reliable Robot Communication

- *HUAWEI at a Glance*
- *5G Test Bed for I4.0 Solutions*
- *Test Results on Demonstrator*
- *Potential & Challenge*
- *Way Forward on 5G*

Bildquellen:
Bosch
Phoenix Contact
Playme AR
HKSE Engineering

HUAWEI at a Glance
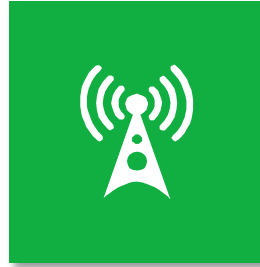
- A global company providing information and communications technology (ICT) solutions.
- Products and solutions have been deployed in over 140 countries, serving one third of the world's population.
- A privately-owned company founded in 1987, in Shenzhen, China.

Global Footprint

180,000 Employees	**80,000** R&D employees	**170+** Countries	**15** R&D institutes and centers	**No. 72** Interbrand's Top 100 Best Global Brands	**No. 129** Fortune Global 500
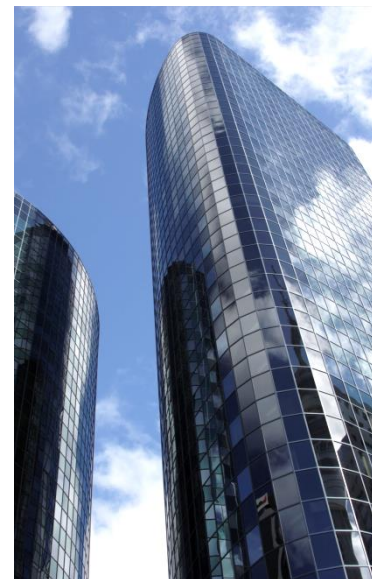
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Core Businesses

Carrier
Business Group

- Fixed Network
- Wireless Network
- IoT Platforms

Enterprise
Business Group

- Enterprise Networking
- Data center infrastructure
- Big data analytics platforms
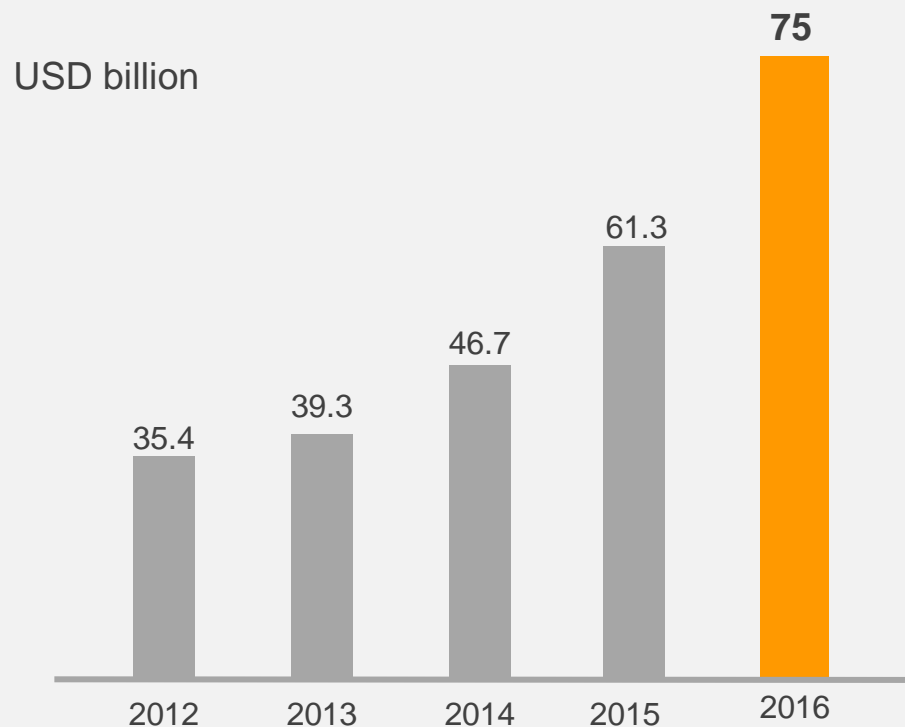- Cloud services

Consumer
Business Group

- Devices Business
- - Smart Phone
- - Home Devices
- - MBB   Devices
- Devices Chipset
- Devices Cloud

Sustainable, Robust Growth

Sales Revenue

USD billion

- 2012: 35.4
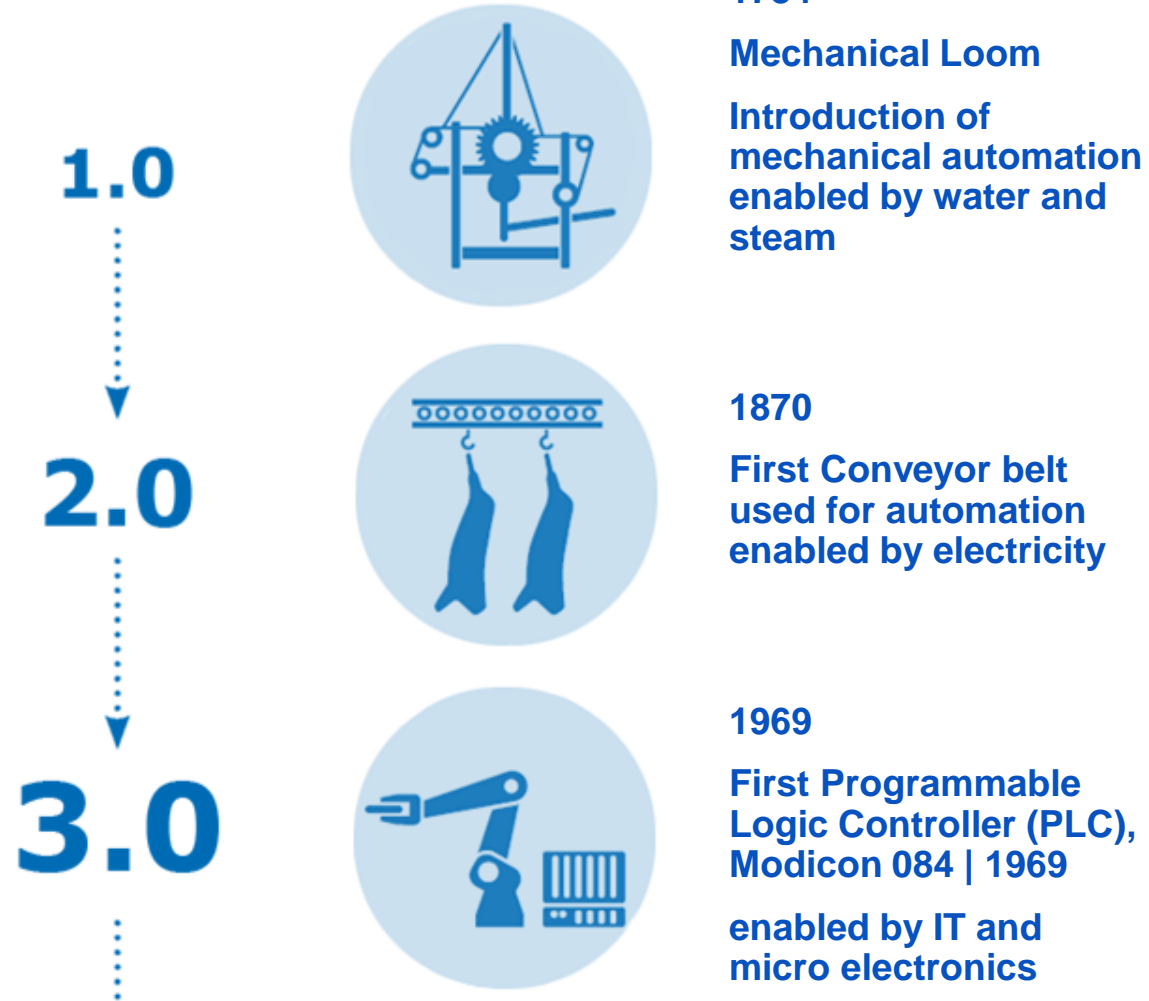- 2013: 39.3
- 2014: 46.7
- 2015: 61.3
- 2016: 75

Source: HUAWEI Annual Report 2016:
Revenue CAGR 24%, Operating Profit CAGR 23%, Cash Flow CAGR 18%

Robust growth across all business segments, thanks to balanced market presence worldwide and commitment to strategic focus

- Enterprise business: innovative solutions for digital transformation delivered together with partners; profitable and sustainable growth in key industries (e.g., smart cities, energy, finance, transportation, and manufacturing)

- Consumer business: key breakthroughs in the global high-end market, taking Huawei's brand influence to a new level

- Carrier business: stronger position in network products and services; video, cloud, and operations transformation as strategic priorities; growing the industry and moving it forward; higher working capital efficiency

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Principles of I4.0

Evolution Steps

1.0

1784

Mechanical Loom

Introduction of mechanical automation enabled by water and steam

2.0

1870

First Conveyor belt used for automation enabled by electricity

3.0

1969

First Programmable Logic Controller (PLC), Modicon 084 | 1969

enabled by IT and micro electronics

State of the art

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Principles of I4.0

Cyber Physical Systems (CPS)

4.0

Enterprise

Work
Centers

Station

Control
Device

Field
Device

Product

PLATTFORM
iNDUSTRIE 4.0

**11 Application Scenarios in
Manufacturing (WG2 „R&D")**

Connected
World

Smart
Factory

Smart
Products

Source: Platform I4.0

Traditional Automation Pyramid
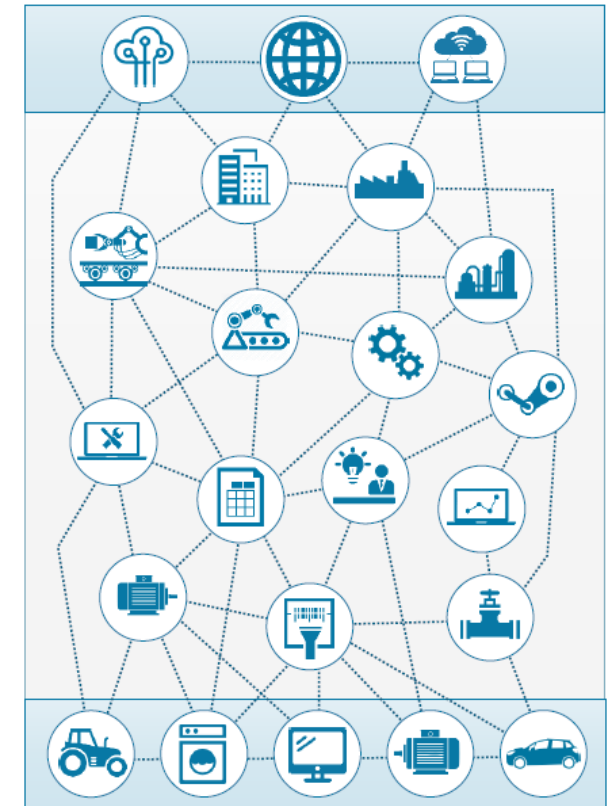
Network of I4.0 components (CPS)

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Principles of I4.0

Concept of I4.0 Components

Industry 4.0 Components consist of the object (asset) and its Administration Shell that describes its service
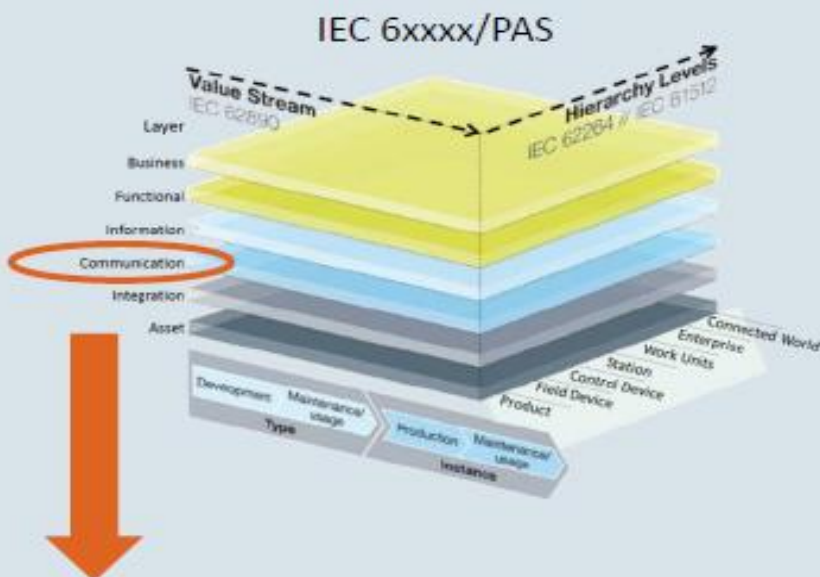
Enabling:

- **Active networking via standardized interfaces**

- **Autonomous negotiation of resources**

- **Virtual twins: product design incorporating production design**

- **Product being part of the network over the whole life cycle**

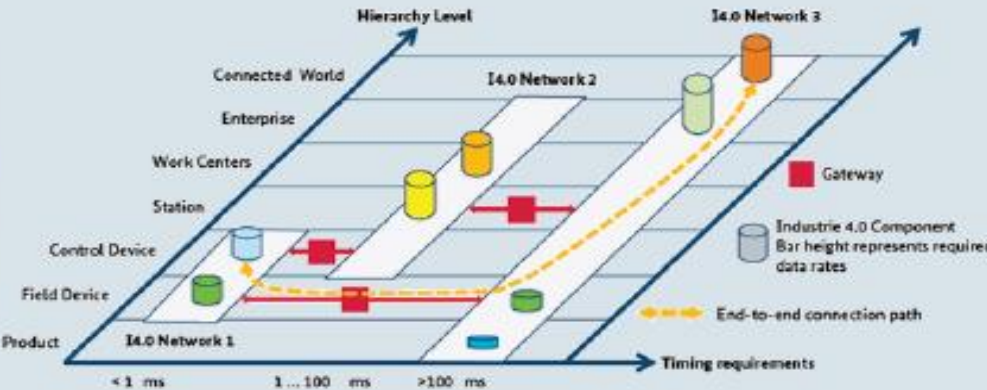➜ **An I4.0 Component maps the runtime data of the asset in the information world**

Administration Shell

Objects

Source: Platform I4.0

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Principles of I4.0

Communication Layer Structuring

Quelle: ZVEI

Quelle: Plattform I4.0

Source: Plattform I4.0, WG1- "Reference Architectures", subgroup "networks"

Quality of Service	Motion Control	Condition Monitoring	Augmented Reallity
Latency	250 µs – 1ms	100 ms	10ms
Reliability (1)	1e-8	1e-5	1e-5
Data Rate	Kbit/s-Mbit/s	Kbit/s	Mbit/s-Gbit/s

(1) – Resual Paket Error Rate
Source: Plattform Industrie 4.0 „Network based communication for Industry 4.0"

Gap:

Wireless standards do not meet: availability (interference robustness), latency, security, reliability, response time in production cells, i.e. motion control.   (current upgrade: IEC 62948)

Need:

Flexible & secure E2E communication

- **Interaction of M2M protocols, i.e. OPC UA (IEC 62541) with TSN**

- **With 5G: Network function virtualisation (NFV) & network slicing**

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5G Test Bed for I4.0 Solutions

PLC in the Cloud for Dynamic Industrial Setups
Closed Loop Synchronization of Cooperating Robots

Description

Evaluation results of a 5G air interface for ultra reliable communication of robots

- Analysis of impact of communication delay and reliability on the performance of closed loop control algorithms running in the cloud
- Virtualization of control (PLC in the Cloud)
- Real-time machine-to-machine communication

Test Design

- Balancing a ball on a tablet (HUAWEI-FESTO demonstrator)
- tracking of the ball on resistive touch sensitive surface
- closed loop control algorithm executed on external controller,
- Comparison of 4G vs. 5G based robot control.

.ııi Map of Industrie 4.0 use cases   Use cases

5G Testbed Adaptive&Connected Equipment

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Application example Manufacturing industry

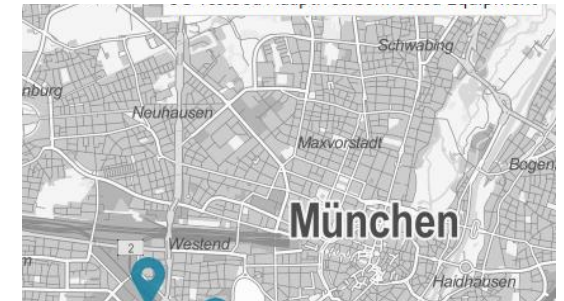**Value creation** Design & Engineering

Region Bavaria

An Industrial 4.0 test laboratory will be set up at the European Research Center of HUAWEI in Munich. The aim is to evaluate a pilot cell of scalable degrees of automation in man-robot collaboration for handling, quality assurance and testing of electronic products.
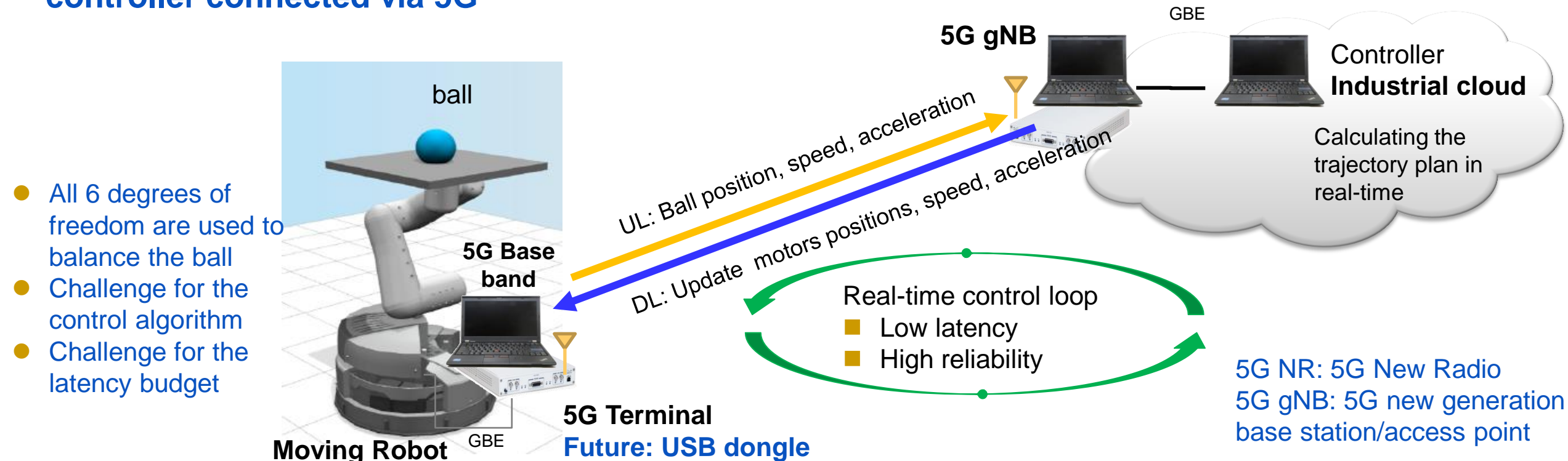
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KUKA
ABB
BOSCH

Proof of Concept - Design of Experiment 5G New Radio (5GNR)

- **Proof of concept of Robot as a Service (RaaS) using 5G technology**
- **Proof of low latency wireless communications for real time control loops**

Use case: balancing a ball on a tablet – with control functions running on an external (cloud) controller connected via 5G

- All 6 degrees of freedom are used to balance the ball
- Challenge for the control algorithm
- Challenge for the latency budget

ball

5G gNB

GBE

Controller **Industrial cloud**

Calculating the trajectory plan in real-time

UL: Ball position, speed, acceleration

DL: Update motors positions, speed, acceleration

5G Base band

Real-time control loop
- Low latency
- High reliability

5G NR: 5G New Radio
5G gNB: 5G new generation base station/access point

5G Terminal
Future: USB dongle

Moving Robot

GBE

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Proof of Concept - PLC in the Cloud by 5G New Radio (5GNR)
Robot control in the cloud connected by 5G

DL: Update motors positions, speed, acceleration

UL: Ball position, speed, acceleration

Position processing

Position sensor

Balancing control algorithm

Interface

GBE

GBE Interface

6 degree arm

Moving control

Engine ctrl RT ROS

Movement engine

Gigabit Ethernet

5G Radio

eMBB mode	URLLC mode

Gigabit Ethernet

5G Radio

eMBB mode	URLLC mode

High data volumes & rates : i.e., for cameras

eMBB: 10 Gbit/s

Ultra Low Latency

GBE = Gigabit Ethernet
MBB = mobile broadband
URLLC = Ultra Reliable Low Latency Communication
gNM = new generation base station

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System Setup - Closed loop PID control (6DoF)
Use Case: Balancing a ball during robot motion

Robot motion superimposed by game controller 3DoF

Balance Controller

Inverse Kinematics
3-5ms

Axis$_{1...5}$ Controller
1ms

Base Controller
1ms

Robot

Ball

Motor Sensors

Res. 0.0018 deg. per step

Touch-screen
150 Hz
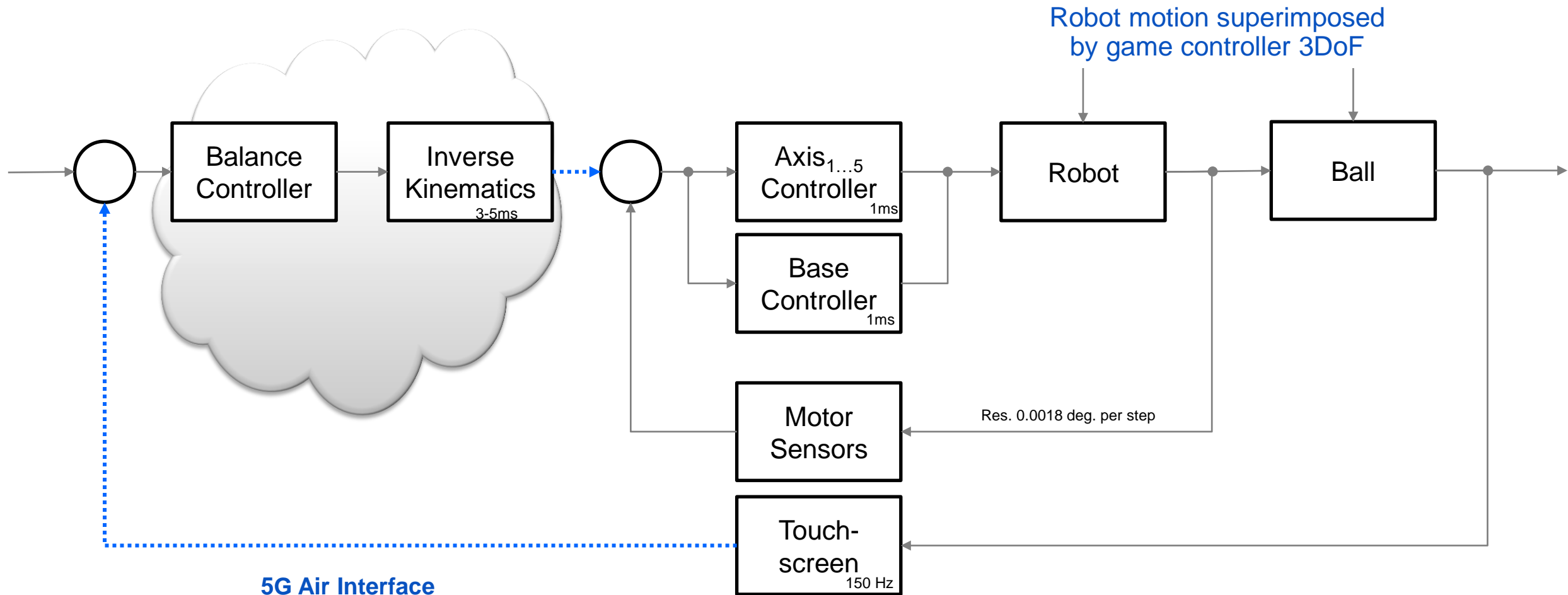
5G Air Interface

Systemic (physical) latency of not optimized demonstrator system ~ 6ms

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System Setup - PLC in the Cloud by 5G New Radio (5GNR)
Use Case: Balancing a ball during robot motion

GBE

5G gNB
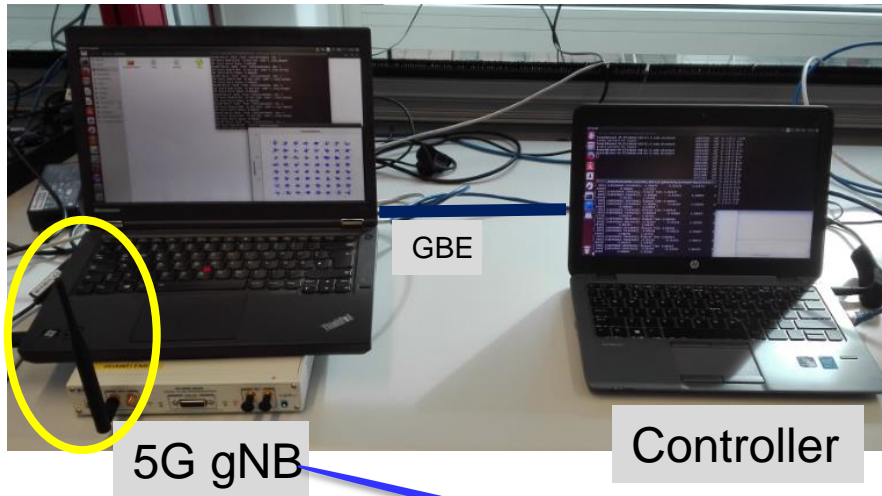
Controller

2.6 GHz
Test license BW: 20 MHz
future BW: 40-100 MHz

5G terminal

Mobile
Service Robot

Target: performance of 5G allows cloud based processing of closed control loops

- Very Low Latency (Ping < 1ms)
- Usage of higher frequency bands (candidates: 3.5GHz, 30 GHz)
- High data rates (10GBit/s)
- Low energy consumption (battery: 6V, 12AH, 20 HR)

Example: Robot / AGV - can be any mobile device, i.e. drone

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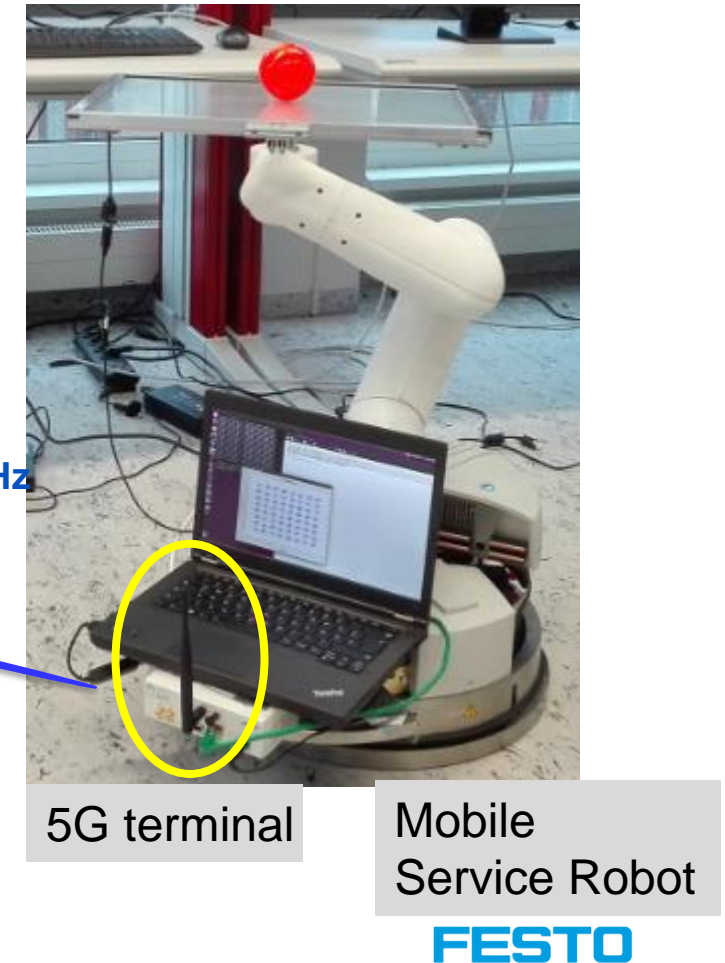
Test Result - Robot / Controller message trace
Balancing a ball during robot motion

Message type							Message size in Byte	Rate	delay/ms	Bandwitdh in kByte/s	kbit/s	
cmd_vel							51	100	10	5.10	40.8	
joint_states							360	100	10	36.00	288	
move_group	/ goal						1074	200	5	214.80	1718.4	
move_group							153	200	5	30.60		
move_group							2388	200	5	477.60		
move_group							138	200	5	27.60		
odom							710	200	5	142.00		
											0	
robotino							1	20	50	0.02	0.16	
robotino							48	20	50	0.96	7.68	
robotino							130	30	33.3333333	3.90	31.2	
											0	
robotino_arm	/ arm	/ joint states					2030	200	5	406.00	3248	
robotino_arm	/ arm	/ joint_trajectory_controller	/ follow_joint_trajectory	/ status			124	200	5	24.80	198.4	
robotino_arm	/ arm	/ joint_trajectory_controller	/ follow_joint_trajectory	/ result			76	200	5	15.20	121.6	
robotino_arm	/ arm	/ joint_trajectory_controller	/ follow_joint_trajectory	/ goal			1598	200	5	319.60	2556.8	
robotino_arm	/ arm	/ joint_trajectory_controller	/ state				420	200	5	84.00	672	
											0	
robotino_arm								200	5	13.60	108.8	
robotino_arm								200	5	24.80	198.4	
robotino_arm								200	5	15.20	121.6	
robotino_arm								200	5	120.00	960	
											0	
tf								200	5	50.00	400	
										2011.78	16094.24	data rate
										0.02	0.00	min data rate
										477.60	3820.80	max data rate

Observation:
Packet size is big > 2000 byte

Delay/latency (one way) < 5ms

Maximum data rate: 3.8 Mbps

Rate per second 200 → 5ms

Packet size of >2000 Byte

Conclusion:
- Short latency in combination with quite big packet sizes
- LTE has latency > 10 msec, can not reach requirement
- **Required Latency of 5ms can only be reached with 5G**

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Test Result - Data rate and packet statistics

Balancing a ball during robot motion

Wireshark · Packet Lengths · xtcp

Topic / Item	Count	Average	Min val	Max val	Rate (ms)	Percent
▲ Packet Lengths	162739	102.71	66	1514	0.6861	100%
0-19	0	-	-	-	0.0000	0.00%
20-39	0	-	-	-	0.0000	0.00%
40-79	81372	66.01	66	78	0.3431	50.00%
80-159	60254	105.70	94	154	0.2540	37.02%
160-319	20935	230.64	194	304	0.0883	12.86%
320-639	94	472.14	322	626	0.0004	0.06%
640-1279	35	786.97	642	1255	0.0001	0.02%
1280-2559	49	1506.92	1386	1514	0.0002	0.03%
2560-5119	0	-	-	-	0.0000	0.00%
5120 and greater	0	-	-	-	0.0000	0.00%

Histogram of Packet Length

Wireshark · IO Graphs · xtcp

Wireshark IO Graphs: xtcp
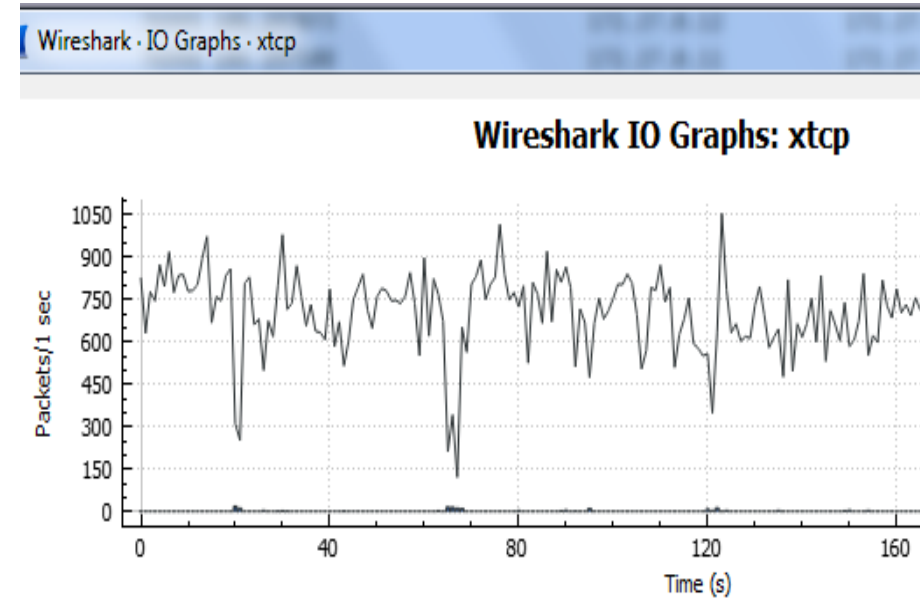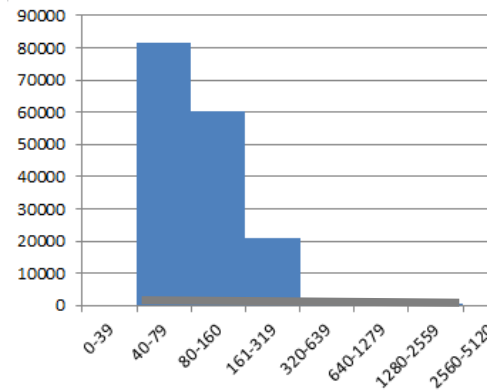
Different packet sizes up to 2500 byte, ⭐ , peak 40-160 byte

5G URLLC as defined in Rel15 (3GPP) cannot support this ➔ Requires update of URLLC standard

Packets per seconds

600 – 700 packets are exchanged per seconds in average
Frame Structure: Short TTI of 250 μs, robust numerology

TTI: Transmission Time Interval
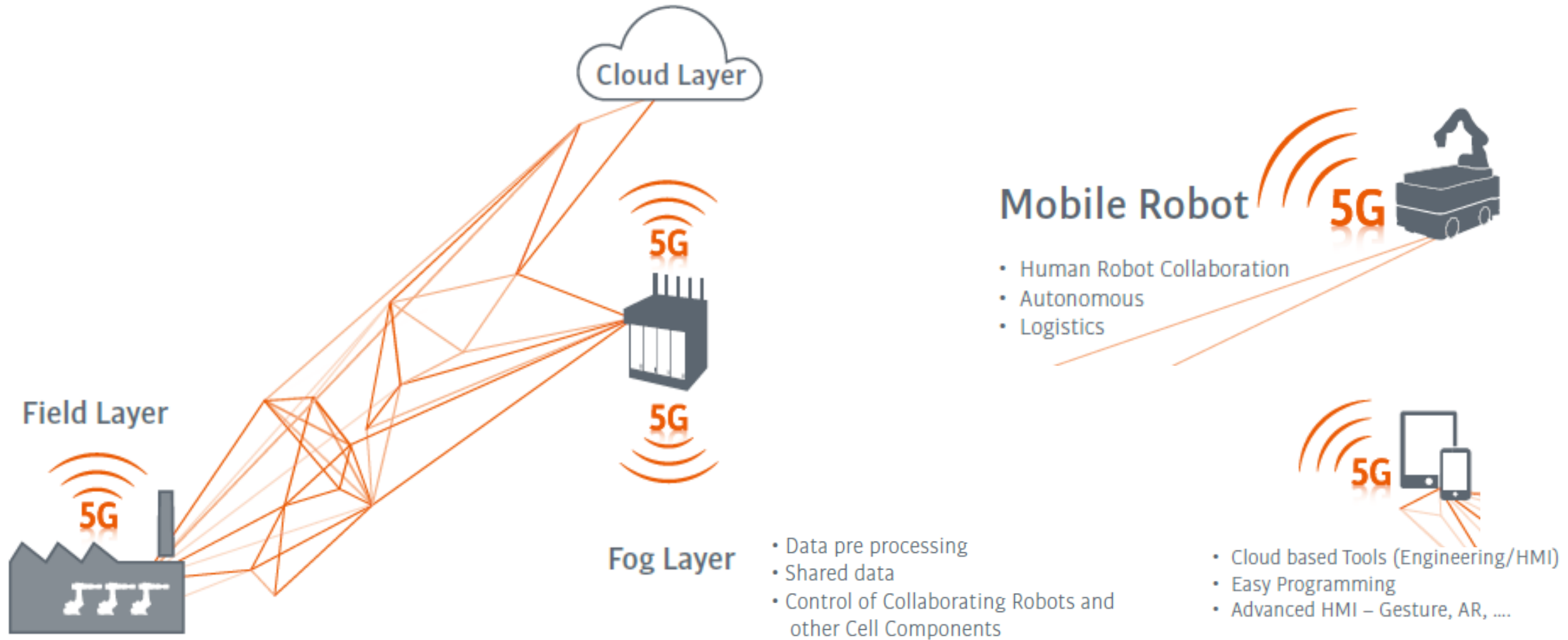
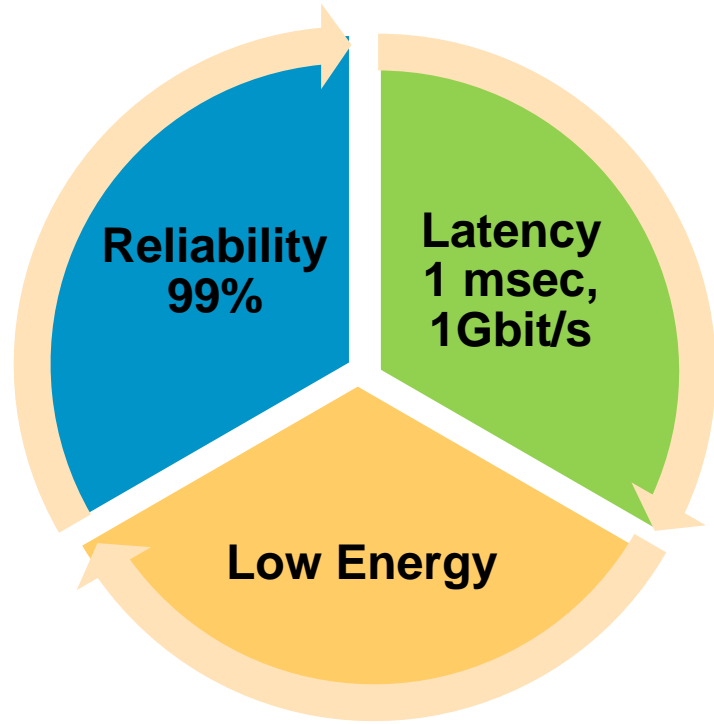URLLC: Ultra Reliable Low Latency Communication

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Cooperating Robots

KUKA-HUAWEI demo MWC 2017

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Fog / Edge Layer

Closing the Gap between Field & Cloud Layer

Cloud Layer

5G

Field Layer

5G

5G

Fog Layer
- Data pre processing
- Shared data
- Control of Collaborating Robots and other Cell Components

Mobile Robot 5G

- Human Robot Collaboration
- Autonomous
- Logistics

5G

- Cloud based Tools (Engineering/HMI)
- Easy Programming
- Advanced HMI – Gesture, AR, ….

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5G Potential & Challenge New Business Cases: Mfg, Adaptive Logistics

Reliability 99%

Latency 1 msec, 1Gbit/s

Low Energy

https://www.youtube.com/watch?v=sqCbYd8O8MU   Source: AUDI

Cloud based control of AGV & drones
Monitoring of unstructured data –as from video streams- for scene analysis and control of a multitude of cooperating robots or for fleet management of AGVs in fast changing environments

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Open Challenges - Usage of Spectrum for Automation

Wireless Solutions in Automation
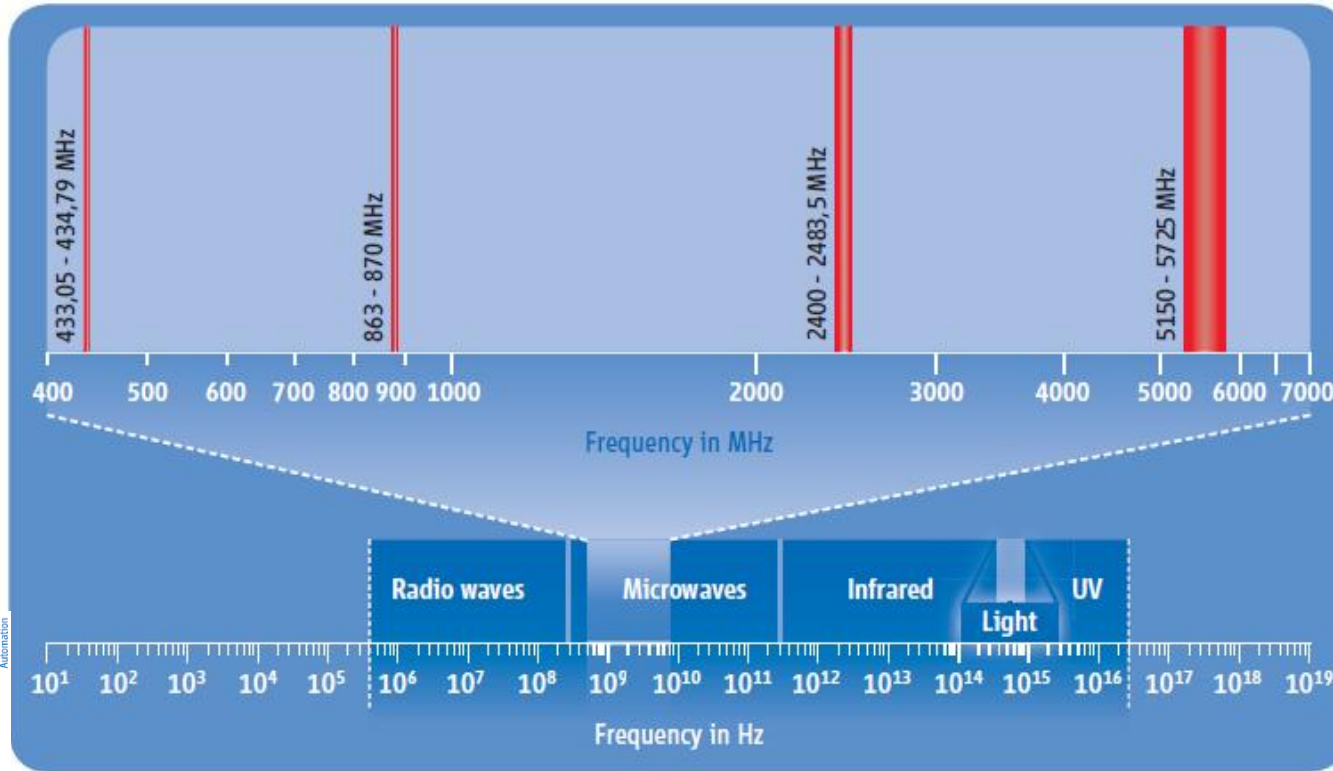
License free band
Europe: 433 MHz, 863 MHz, 2.4 GHz, 5.7 GHz
World wide: 2400 – 2483.5 MHz

● **Challenge**
-Load increases excessively with new applications
- Interferences if many stations are operated nearby
-Coexistence of networks
- Data and network security

●**Needs**
- Dynamic Network planning,
- Lobby for Spectrum,   new operator business models
- Demand dynamic Network Slicing

To be discussed and negotiated for Manufacturing Industry:

License Shared Access (LSA) Models for manufacturing enterprises to operate on unused frequency bands:
i.e. 3.6 -4.26 GHz
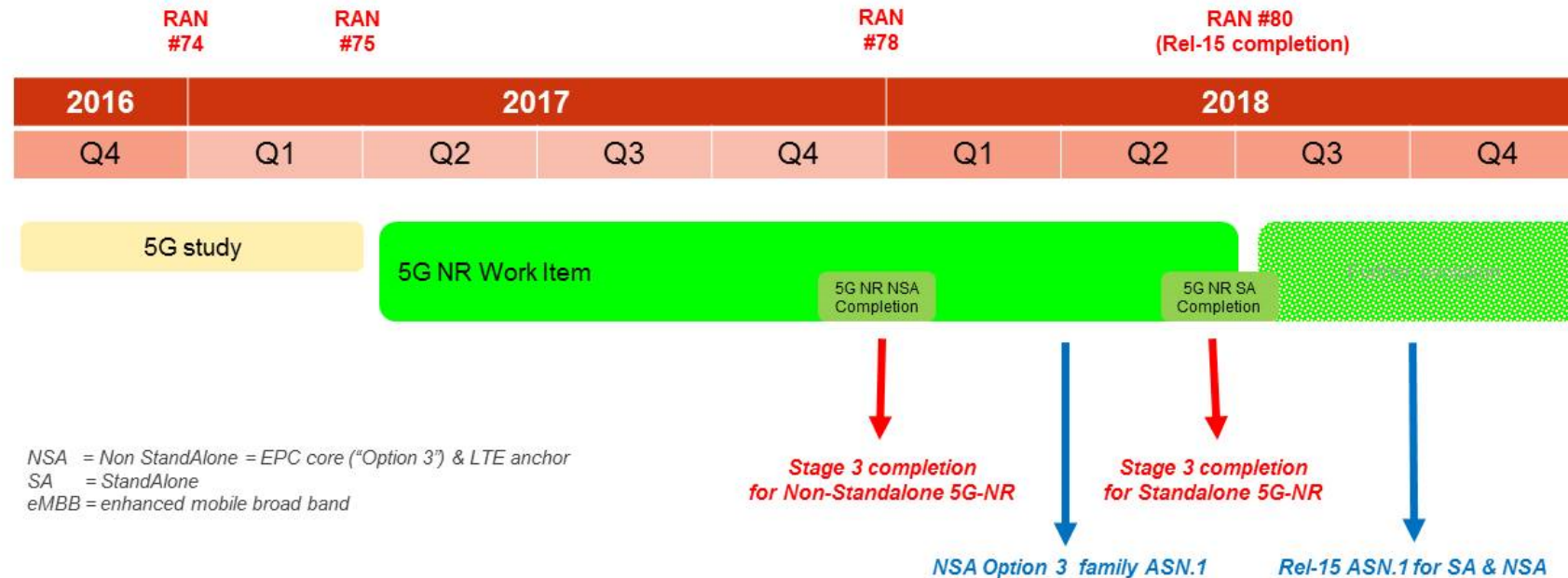
Way Forward on 5G Workplan

Proposal (cont.)

RP-170741

Way Forward
on the overall 5G-NR eMBB workplan

3GPP RAN #75
Dubrovnik, March 2017

Alcatel-Lucent Shanghai-Bell, Alibaba, Apple, AT&T, British Telecom, Broadcom, CATT, China Telecom, China Unicom, Cisco, CMCC, Convida Wireless, Deutsche Telekom, DOCOMO, Ericsson, Etisalat, Fujitsu, Huawei, Intel, Interdigital, KDDI, KT, LG Electronics, LGU+, MediaTek, NEC, Nokia, Ooredoo, OPPO, Qualcomm, Samsung, Sierra Wireless, SK Telecom, Sony, Sprint, Swisscom, TCL, Telecom Italia, Telefonica, TeliaSonera, Telstra, Tmobile USA, Verizon, vivo, Vodafone, Xiaomi, ZTE

First commercial use anticipated for 2020

NSA = Non StandAlone = EPC core ("Option 3") & LTE anchor
SA = StandAlone
eMBB = enhanced mobile broad band

From the present point of view 5G will have following features
- Wide range of licensed & unlicensed frequency bands from 300 MHz to 300 GHz (mm wave)
- Integration with Industrial Ethernet (deterministic behaviour with a latency of about 1 ms)
- Support for Cloud/ Edge computing and big data analytics via core network
- Innovations: Dynamic Network planning - Software defined networks (SDN), Network function virtualisation (NFV)

5G Addressing Vertical Industries – Smart Manufacturing

www.5GAA.org   **5G Automotive Association**

Contact us, if you want to join creating a 5G Digital Factories Association

- Lobby for spectrum   - Requirements & Use Cases   - New Business Models

JOIN US IN
BUILDING A BETTER CONNECTED WORLD

THANK YOU

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