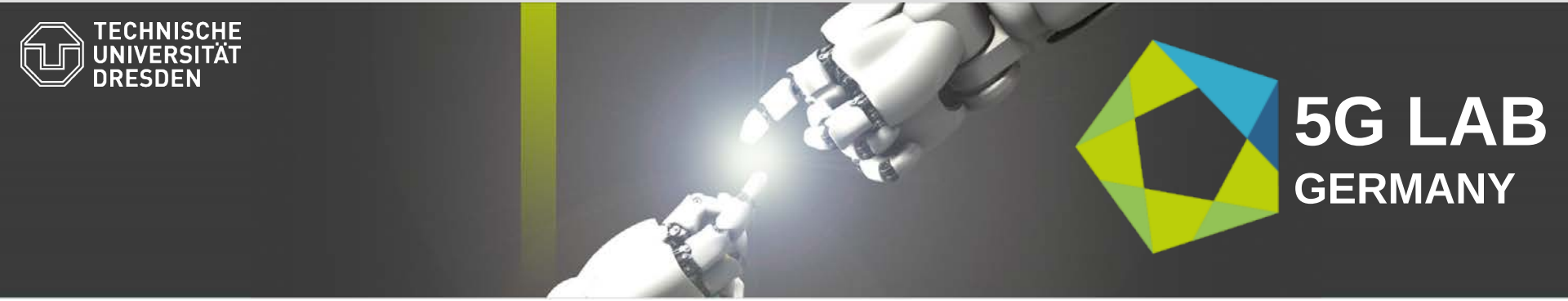

5G – the Door Opener to 6G?

Gerhard P. Fettweis Vodafone Chair Professor/TU Dresden
CEO Barkhausen Institute

IEEE Webinar 2018-November-20

vodafone chair @ TU Dresden: Key Facts & Figures

The Team

1	Professor
6	Senior scientists/lecturers
4	Post-docs
32	Ph.D. students
15+	Master students
2	Program managers
12	Start-up incubator employees
2	Secretaries
5	Lab engineers

IPP Sponsors

arm, actix, BOSCH, cadence, HUAWEI, intel, NATIONAL INSTRUMENTS, NOKIA, ROHDE&SCHWARZ, SYNOPSYS, Texas Instruments

vodafone

TECHNISCHE UNIVERSITÄT DRESDEN

Accomplishments

Scientific:

- 92 Ph.D. grads
- 279+ Ms. grads
- 1000+ publications
- 17,500+ citations
- 200+ patent appl.
- 85+ patent families

Innovation:

- 17 spin-outs
- 200 engineers

Funding:

- € 60M Chair
- € 60M VC
- € 1/2B projects

Project Partners

vodafone, NOKIA, CLAAS, NATIONAL INSTRUMENTS, SAMSUNG, Deutsches Forschungszentrum für Künstliche Intelligenz GmbH, ERICSSON, IDT, NEC, GWT forschung+innovation, Masdar Institute, HORIZON 2020, 5G PPP, Deutsche Forschungsgemeinschaft DFG, Bundesministerium für Bildung und Forschung, Europa fördert Sachsen. ESF Europäischer Sozialfonds, Freistaat Sachsen Staatsministerium für Wissenschaft und Kunst

The Vodafone Chair's Startup History

1999 OnDSP™ based WLAN chip-sets

system on chip — 2002 → NXP founded by Philips

2000 SON systems

radioplan — 2006 → amdocs

2003 Broadband Wireless HW (LTE,…)

SIGNALION — 2012 → NATIONAL INSTRUMENTS

2004 Module and reference board design

IN-CIRCUIT — 2006 → IN-CIRCUIT

2005 MPSoC semiconductor IP

DRESDEN SILICON — 2007 → SIGNALION

2007 Wireless audio

freedelity

KLETTERARENA DRESDEN

2008 Network performance measurement

RADIOOPT — 2016 → vodafone

2008 LTE Cellular Handset Chip IP

blue wonder communications — 2012 → intel

2010 Satellite Communications

INRADIOS integrated radio solutions — 2017 → ROHDE&SCHWARZ

2012 Startup incubation and growth partner

High Tech Startbahn — STARTBAHN Venture Fonds

2013 IoT solutions

exelonix

2013 Bitcoin harvesting engines

COINBAU.com

2013 Massive MIMO Cells

AIRRAYS

2014 Machine vision for manufacturing

VISINAUT

2015 Cellular IoT Chip IP

commSOLID — 2018 → GOODiX

2016 Telemetry for IoT

metirionic WIRELESS DISTANCE MEASUREMENT

Update 5G Lab Germany Members

5G LAB GERMANY

HARDWARE & WIRELESS


Frank Ellinger


Gerhard Fettweis


Karlheinz Bock


Dirk Plettemeier


Christian Mayr


Michael Schröter


Kambiz Jamshidi

NETWORK & CLOUD


Thorsten Strufe


Frank Fitzek


Wolfgang Nagel


Diana Göhringer


Hermann Härtig


Christel Baier


Christof Fetzer


Eduard Jorswieck


Jürgen Weber

TACTILE INTERNET APPLICATIONS


Uwe Aßmann


Ercan Altinsoy


Thomas Herlitzius


Jens Krzywinski


Klaus Janschek


Leon Urbas


Peter Birkholz

[Team of 600+ Researchers]

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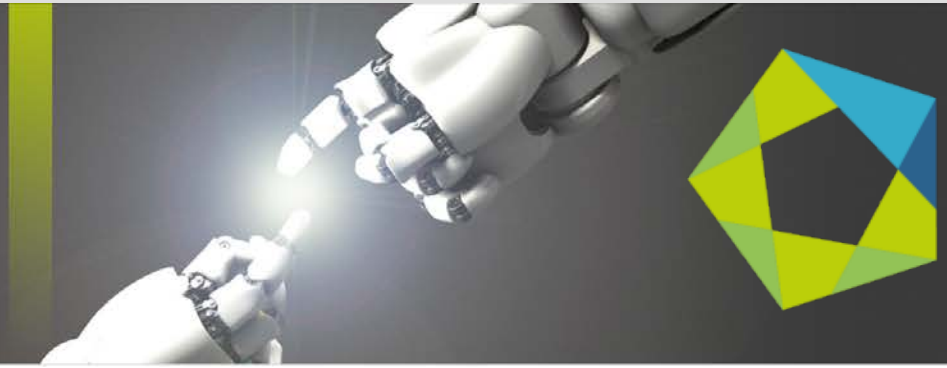


5G LAB GERMANY

5G Lab Germany – Partners

vodafone

ROHDE&SCHWARZ

NATIONAL INSTRUMENTS

NOKIA

ERICSSON

NEC

BOSCH

IDT

Telemotive AG
a company of Magna

GLOBALFOUNDRIES

Hewlett Packard Enterprise

Racyics

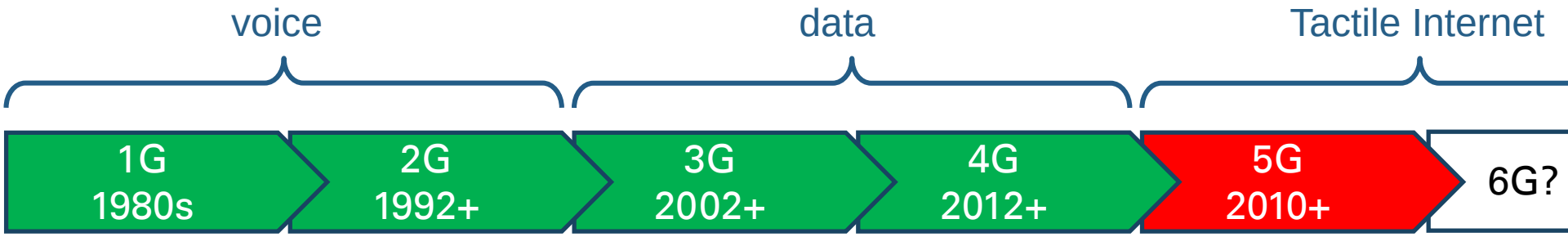
LIEBHERR

VOLKSWAGEN
AKTIENGESELLSCHAFT

SYNOPSYS

Infineon

5G Today



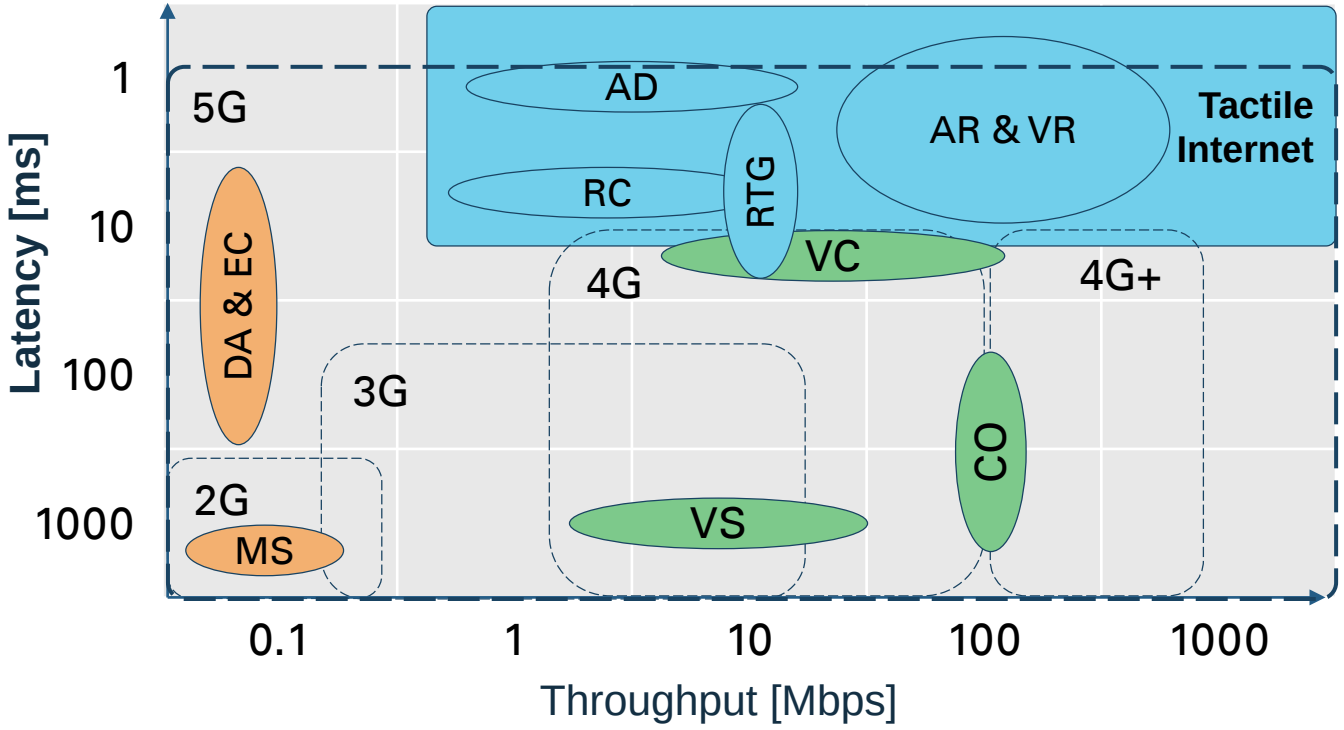
Rushed into a standard 2 years early

Not considered: many key requirements

➔ “5G New Radio”: more like LTE + massive MIMO support

5G Enabled Applications

Multiple applications with tremendously diverse TLR requirements



4G enabled – moving content

- Video Call (in “best case”)
- Video Streaming
- Cloud Office

5G enabled – Tactile Internet

- Automatic Driving
- Augmented Reality
- Virtual Reality
- Real-Time Gaming
- Remote Control

5G enabled –low rate

- Emergency Call & Disaster Alert
- Monitoring Sensor

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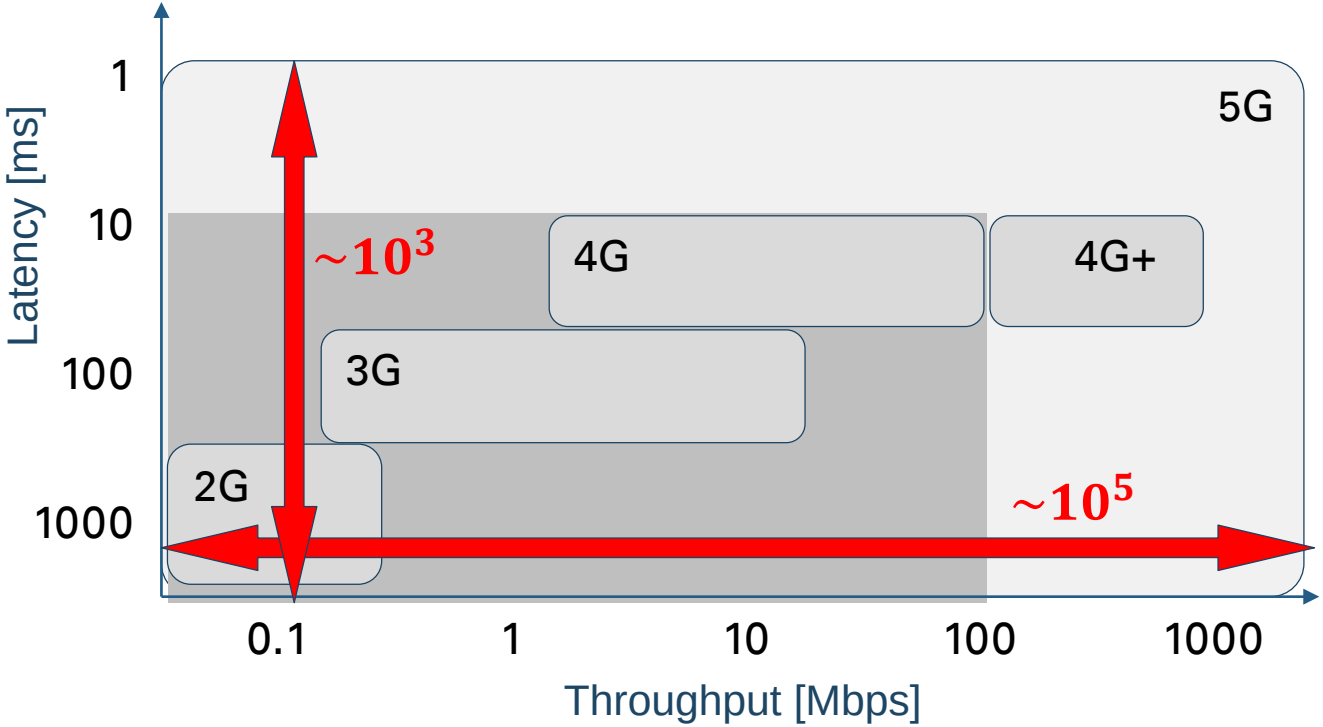
Scalability Challenge

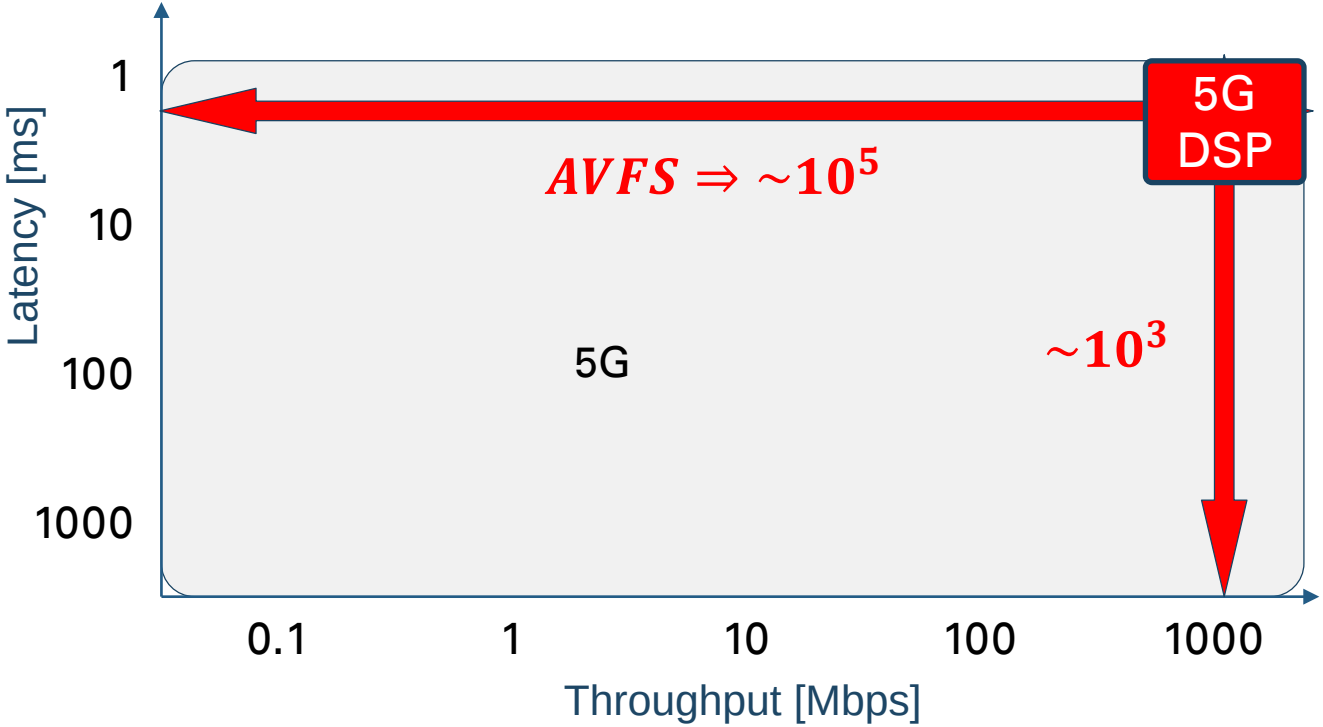
Wireless Throughput & Latency Evolution

5G Challenge: Huge throughput-latency range & diversity of apps requirements



Baseband Processing Challenge

How to Design the Processing Platform: starting from the high performance



AVFS:
Adaptive voltage & frequency scaling

Our Design Roadmap

M3, M5, Samira (Tapeout: 1997/2000/2005)

- WLAN PHY, Mobile Multimedia accelerators

Tomahawk1 – 4G (Tapeout: 2007)

- 13 heterogenous core machine

Tommy (Tapeout: 2010)

- Iterative detection-decoding, NoC Testchip

Atlas (Tapeout: 2011)

- Vector DSP, NoC and LP-DDR2 Testchip

Tomahawk2 (Tapeout: 2013)

- Energy Efficient Task Scheduling

Titan3D (Tapeout: 2014)

- Big Data search engine Testchip

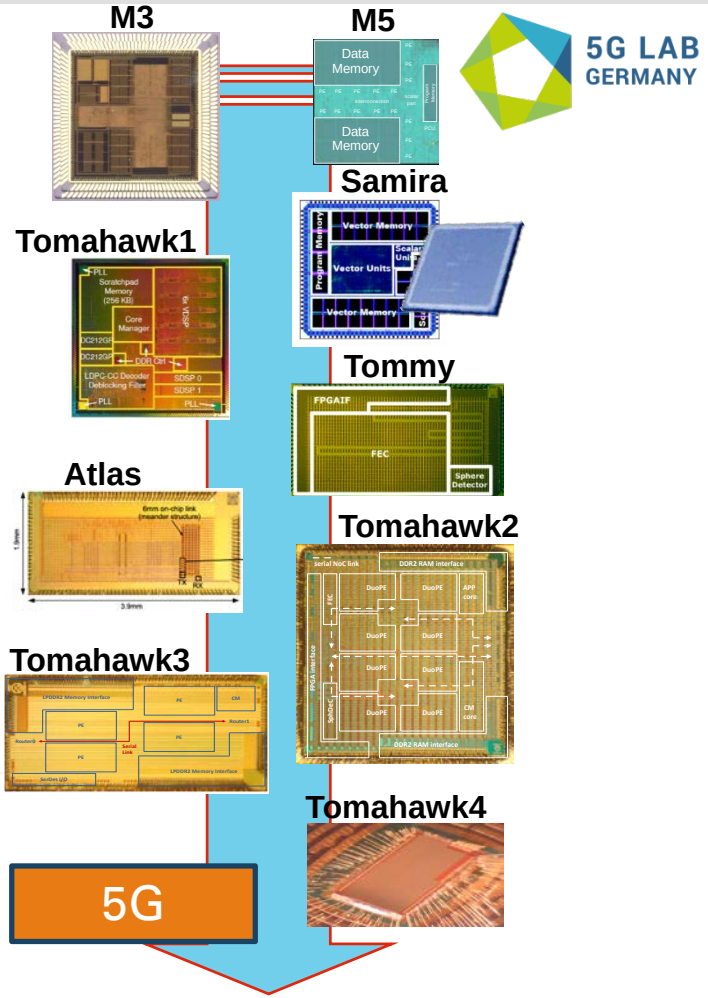
Tomahawk3 (Tapeout: October 2014)

- Big Data search engine and 28nm LP-DDR2 Test

Tomahawk4 (Tapeout: July 2015)

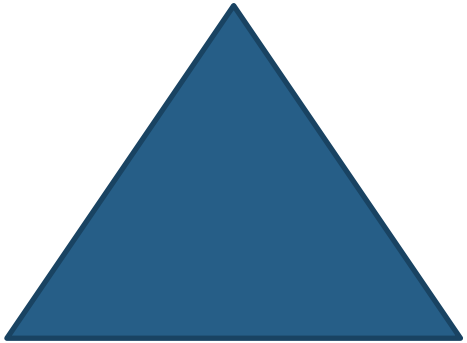
- 5G Terminal engine platform

5G (Tapeout Q1 2019)



3GPP’s View of 5G:

eMBB
Extreme
Mobile
Broadband



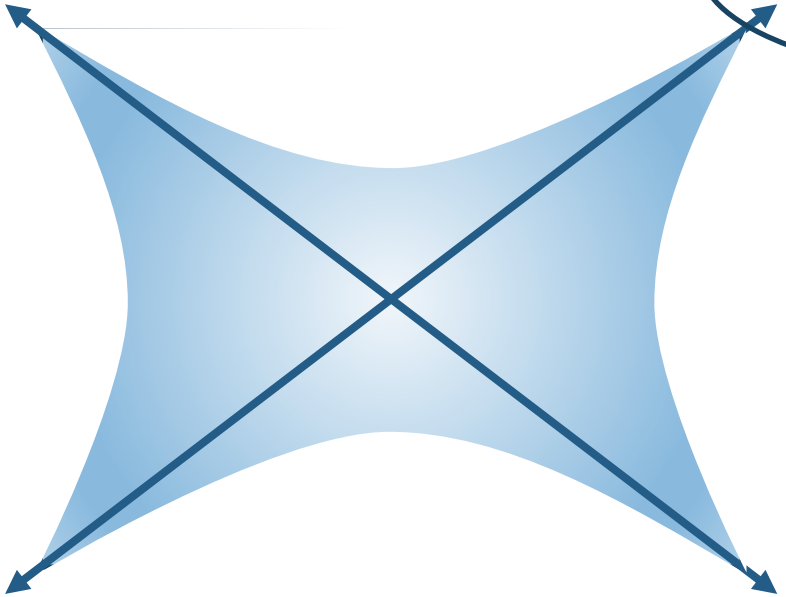
mMTC
massive
Machine-type
Communications

URLLC
Ultra reliable
Low-latency
Communications

5G Dimensions – Challenges Addressed ?

10 years from AAA battery
Massive IoT

Speed: >10 Gb/s ➔ Tb/s
Massive Content



Massive Relability
Availability Probability 1-10^{-5}

Massive Control
Response: 1-10 ms

The Wireless Roadmap >2020 Outlook

100Tb/s
10 Tb/s
1 Tb/s
100Gb/s
10Gb/s
1Gb/s
100Mb/s
10Mb/s
1Mb/s
100Kb/s
10Kb/s

1995 2000 2005 2010 2015 2020 2025 2030 2035

WLAN (10m)

killer app
for >10Gb/s?

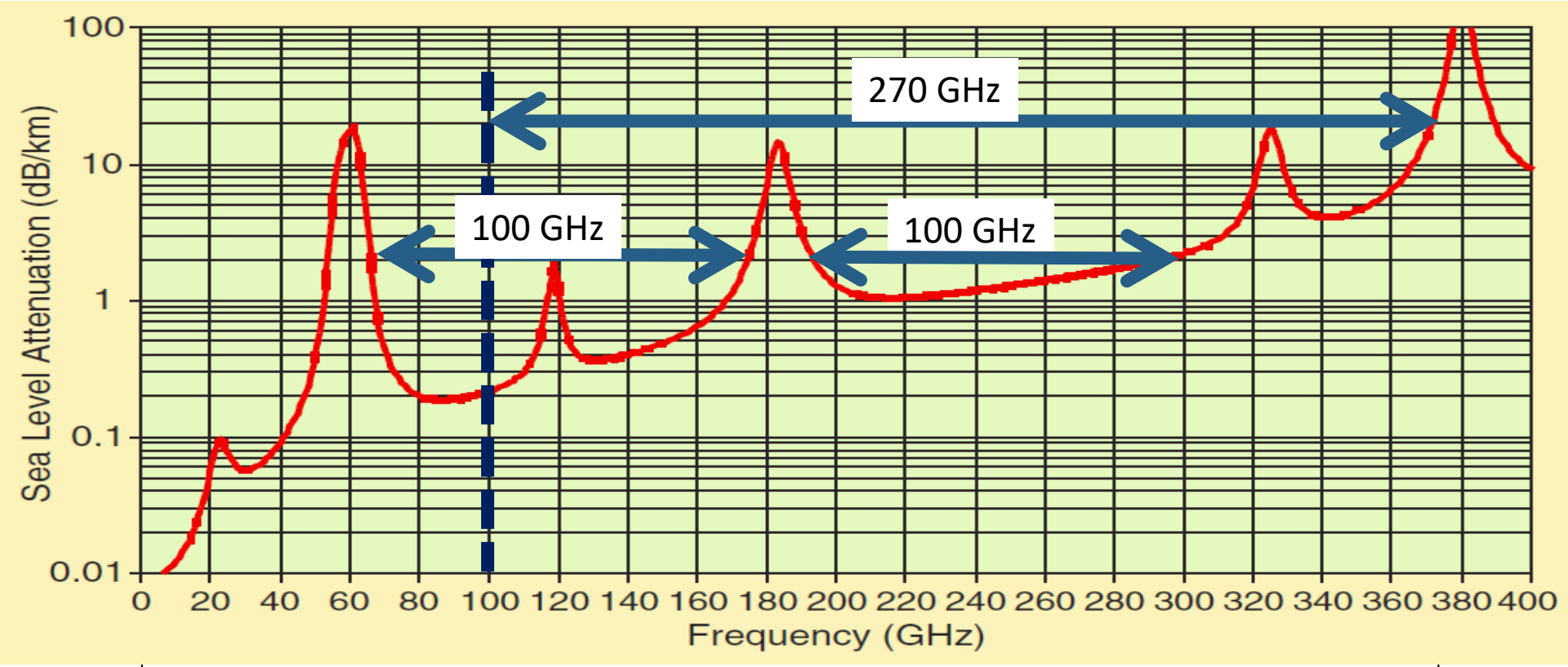
802.11
802.11b
802.11ag
802.11n
802.11ac
802.11ax
802.11ay

GSM
GPRS
3G R99 / EDGE
3G
HSPA
LTE
LTE Advanced
5G P1
5G P3

Cellular (100m)

Spectrum Challenge

Where to Find The Spectrum For 1Tb/s?



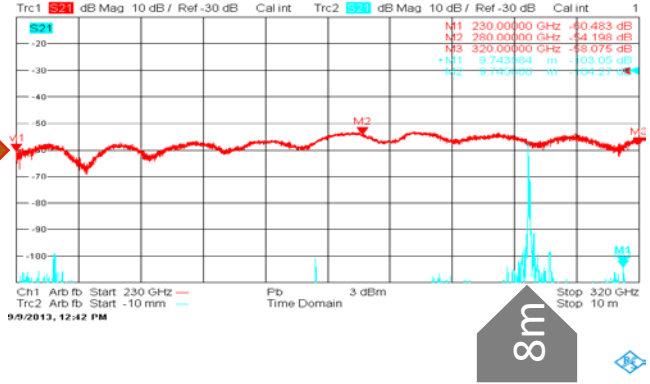
Jonathan Well, „ Faster Than Fiber: The Future of Multi-Gb/s Wireless," IEEE Mirrowave Magazine, May 2009, pp. 104-112

Channel Measurement @230-320GHz

by Prof. Dirk Plettemeier and team

Simple bounce off wood – roundtrip distance 8m

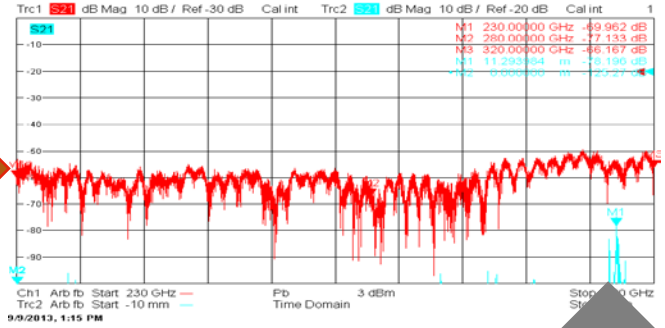
-60dB



8m

Corner bounce off brick/wood – roundtrip distance 10m

-60dB



11m

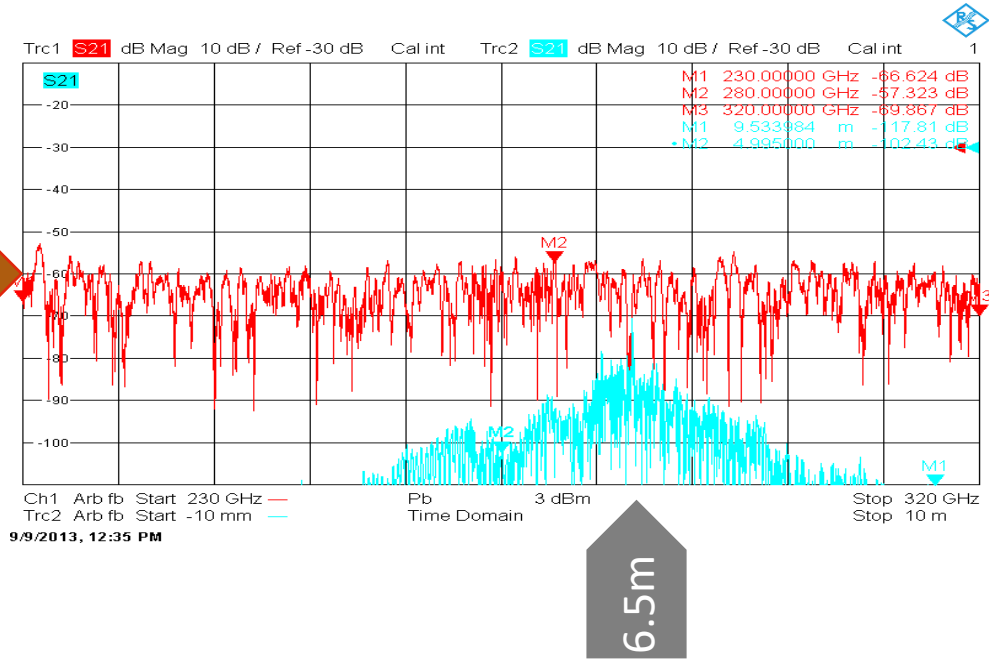
Channel Measurement @230-320GHz

by Prof. Dirk Plettemeier and team

5G LAB GERMANY

Curtain bounce – roundtrip distance 6m

-60dB



6.5m

Signaling and Sampling at Very High Rates

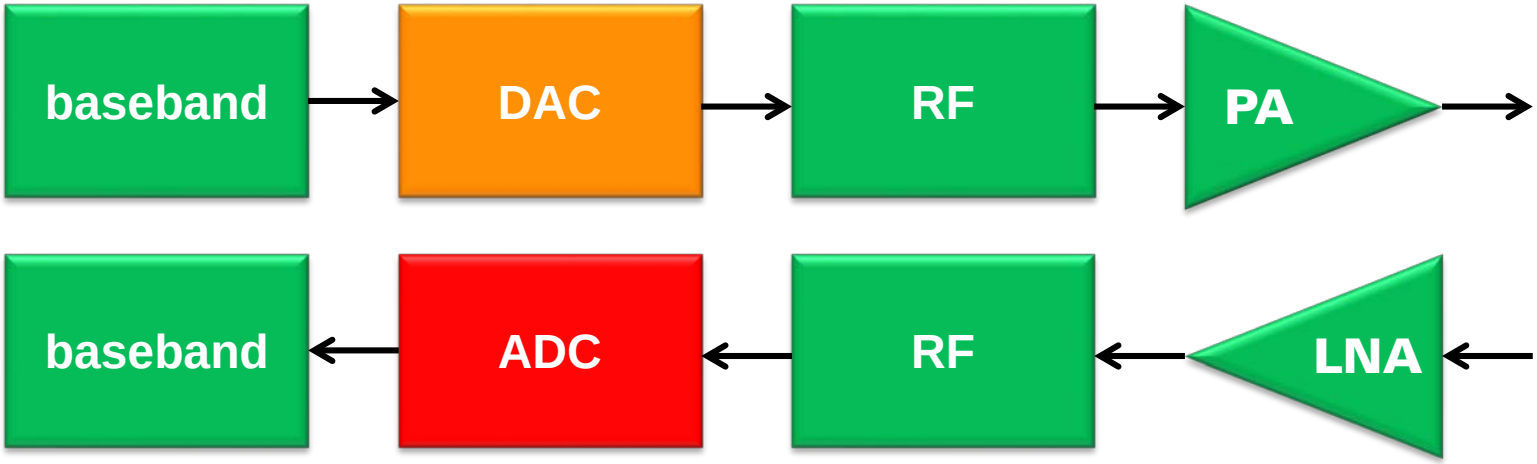
Recognizing my (former) team members



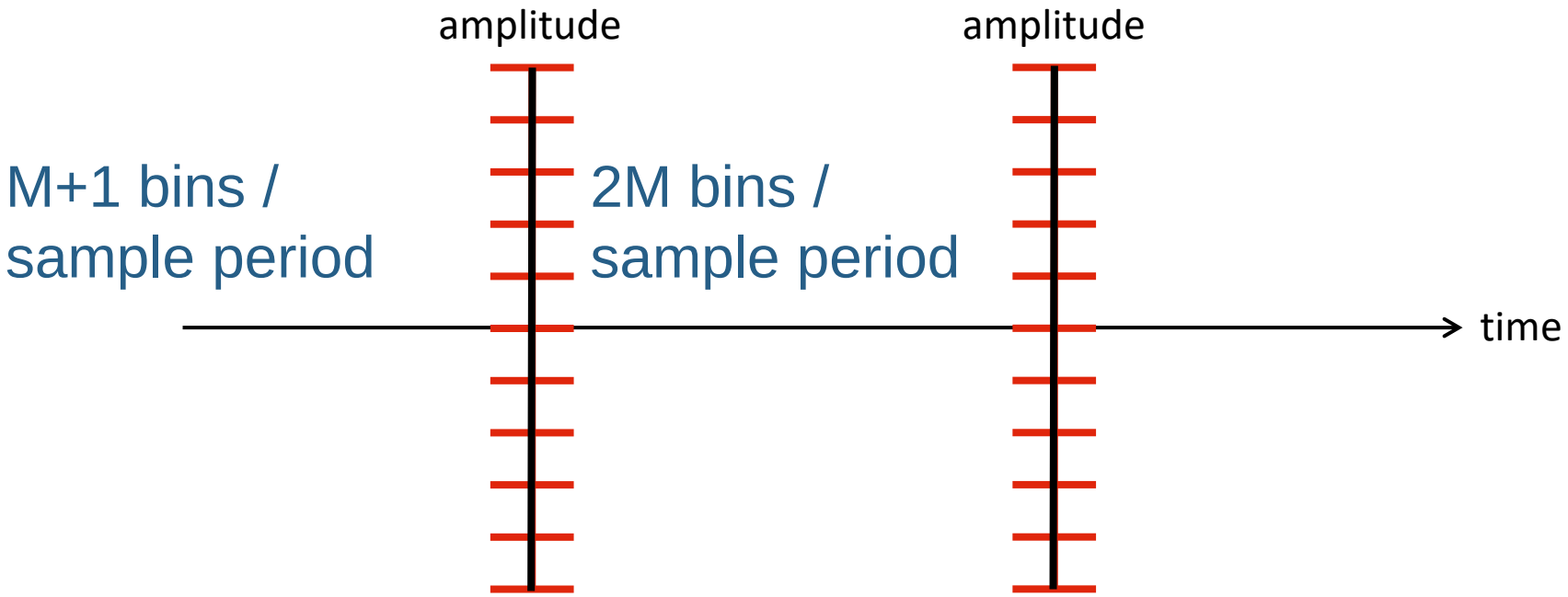
L. Landau **S. Bender** **M. Dörpinghaus**

Now PUC Rio

Power Bottleneck: Conversion



Time Versus Amplitude Processing



Receiver Design: Sequence vs. Symbol based

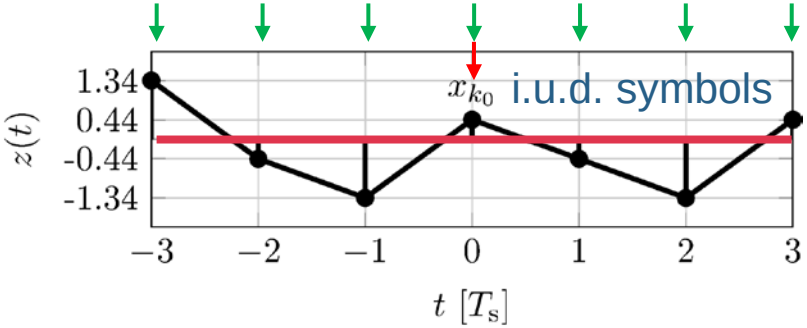
5G LAB GERMANY

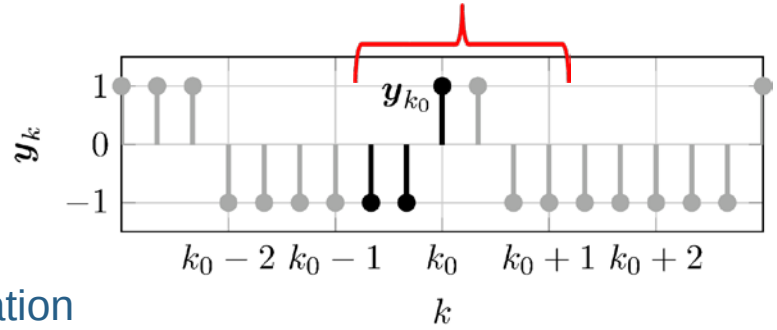
Sequence based

Detection based on entire sequence

- $\lim_{n\to\infty} \frac{1}{n} I(X^n; \boldsymbol{Y}^n)$

Simulation based computation of the rate [Arn06]





Symbol based

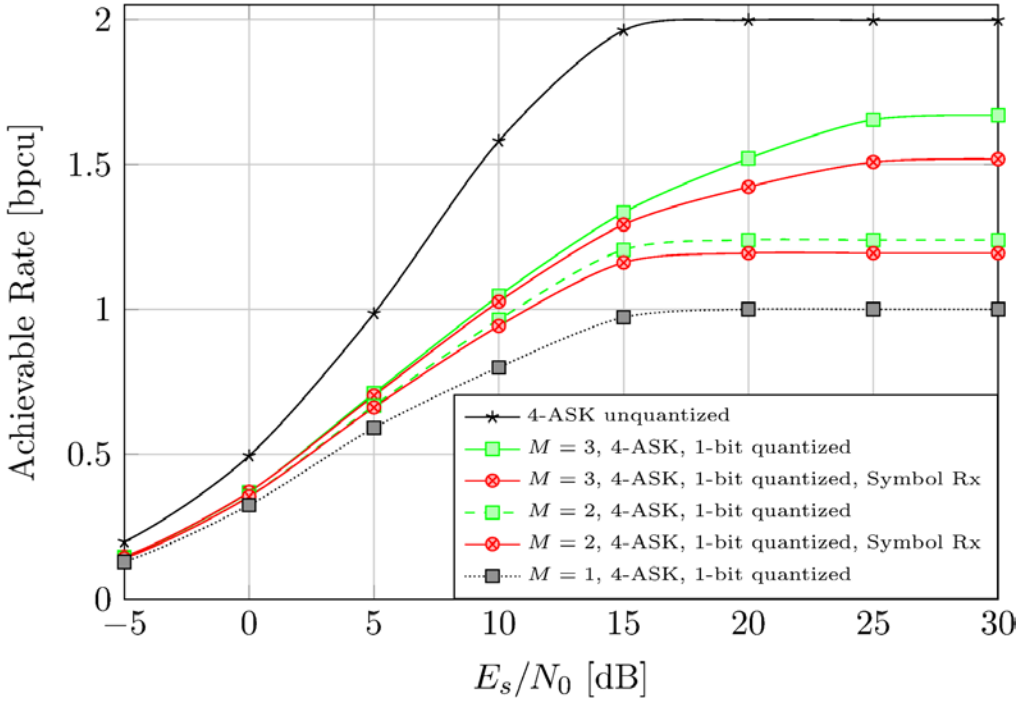
Detection based on observation window

- $I(X_k; \boldsymbol{Y}_k^{k+1})$

Lower bound on the rate (i.u.d. symbols)

[Arn06] D. M. Arnold et al., Simulation-Based Computation of Information Rates for Channels With Memory, *IEEE Trans. Inf. Theory*

Achievable Rate: ASK



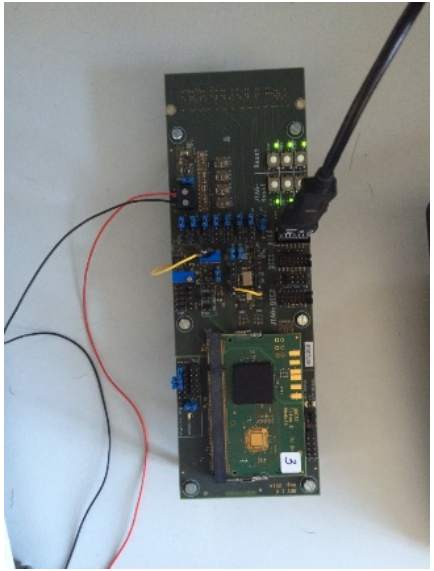
$$h(t) = g(t) = \frac{1}{\sqrt{T_s}} \mathrm{rect}\left(\frac{t}{T_s}\right)$$

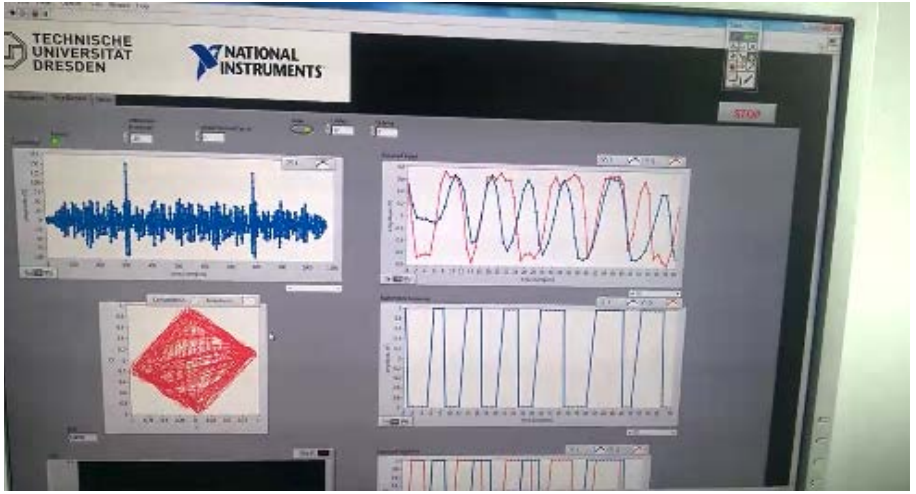
- Significant benefit from oversampling in terms of achievable rate
- Significant loss of information, when considering only symbol based detection.

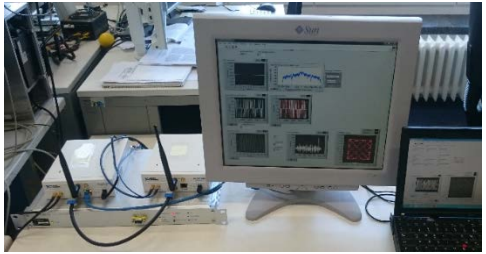
[La14a]L. Landau, G. Fettweis, Information Rates employing 1-bit Quantization and Oversampling at the Receiver, *SPAWC*

Lab Demos (e.g. @300GHz)

5G LAB GERMANY





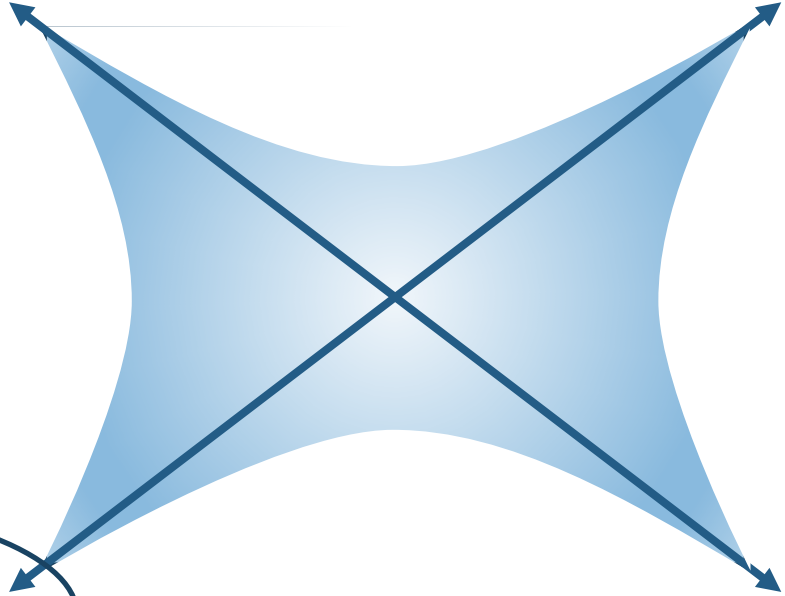


Special thanks to NATIONAL INSTRUMENTS vodafone

5G Dimensions – Challenges Addressed ?

10 years from AAA battery
Massive IoT

Speed: >10 Gb/s ➔ Tb/s
Massive Content



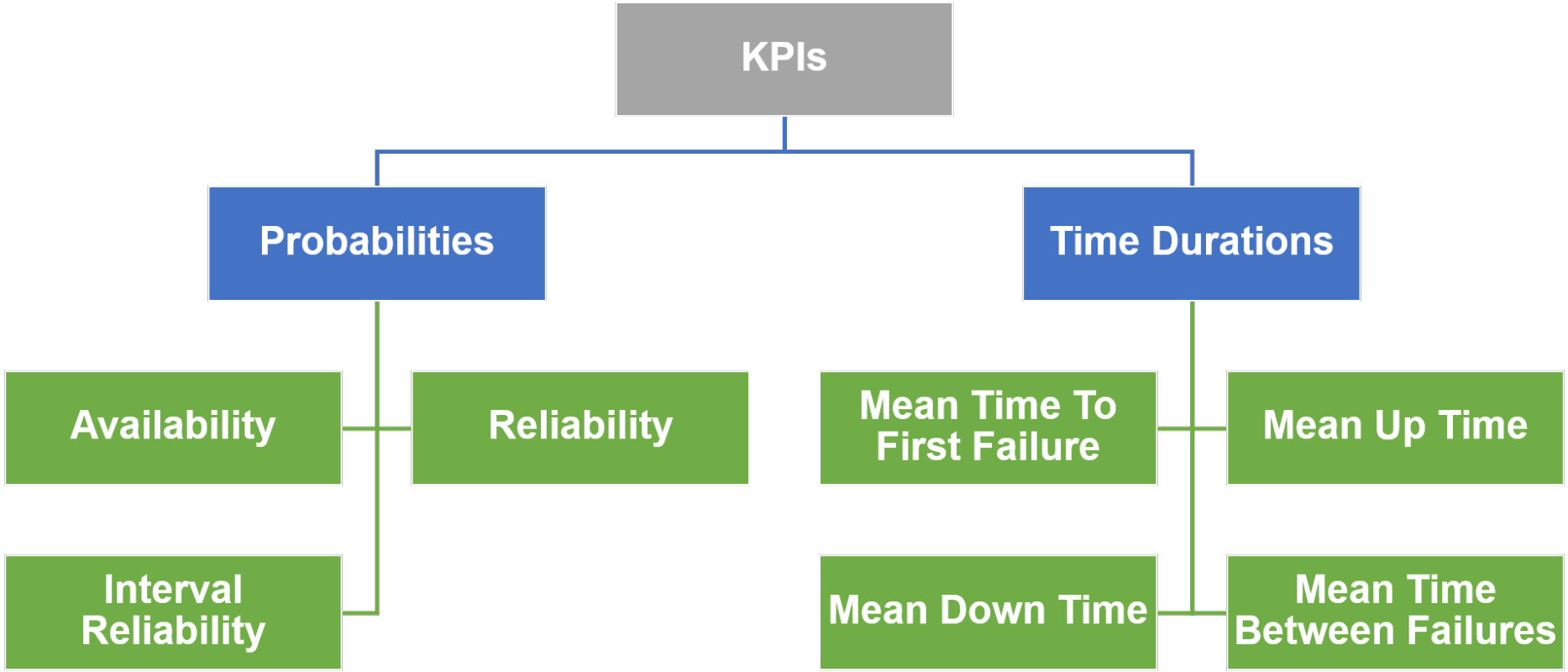
Massive Reliability
Availability Probability 1-10^{-5}

Massive Control
Response: 1-10 ms

WHAT IS RELIABILITY?

T. Hößler, L. Scheuvens, N. Franchi, M. Simsek and G. P. Fettweis,
"Applying reliability theory for future wireless communication networks,"
2017 IEEE 28th PIMRC, Montreal, QC, 2017, pp. 1-7.

Reliability Theory Vocabulary



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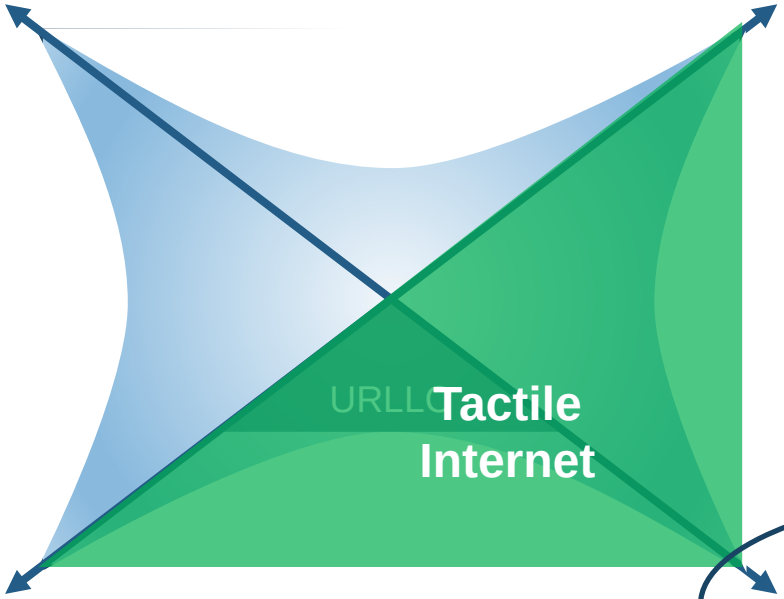


Massive Reliability
Availability Probability 1-10^{-5}

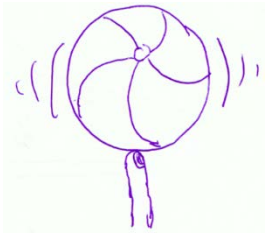
Massive Control
Response: 1-10 ms

Physiology und Psychology

Today's networks:
100ms latency

tactile interaction

1ms
(1/1000 s)




5G Ready
5G Link
Ultra-Responsive
1 Millisekunde Latenz
5G Ready
vodafone
vodafone
vodafone
thyssenkrup
5G Lab
GERMANY

Wireless Premises Network

Up to – 1.000m

5G LAB GERMANY

Drone can also act as a **relay station**

Single- or Multi-hop communication

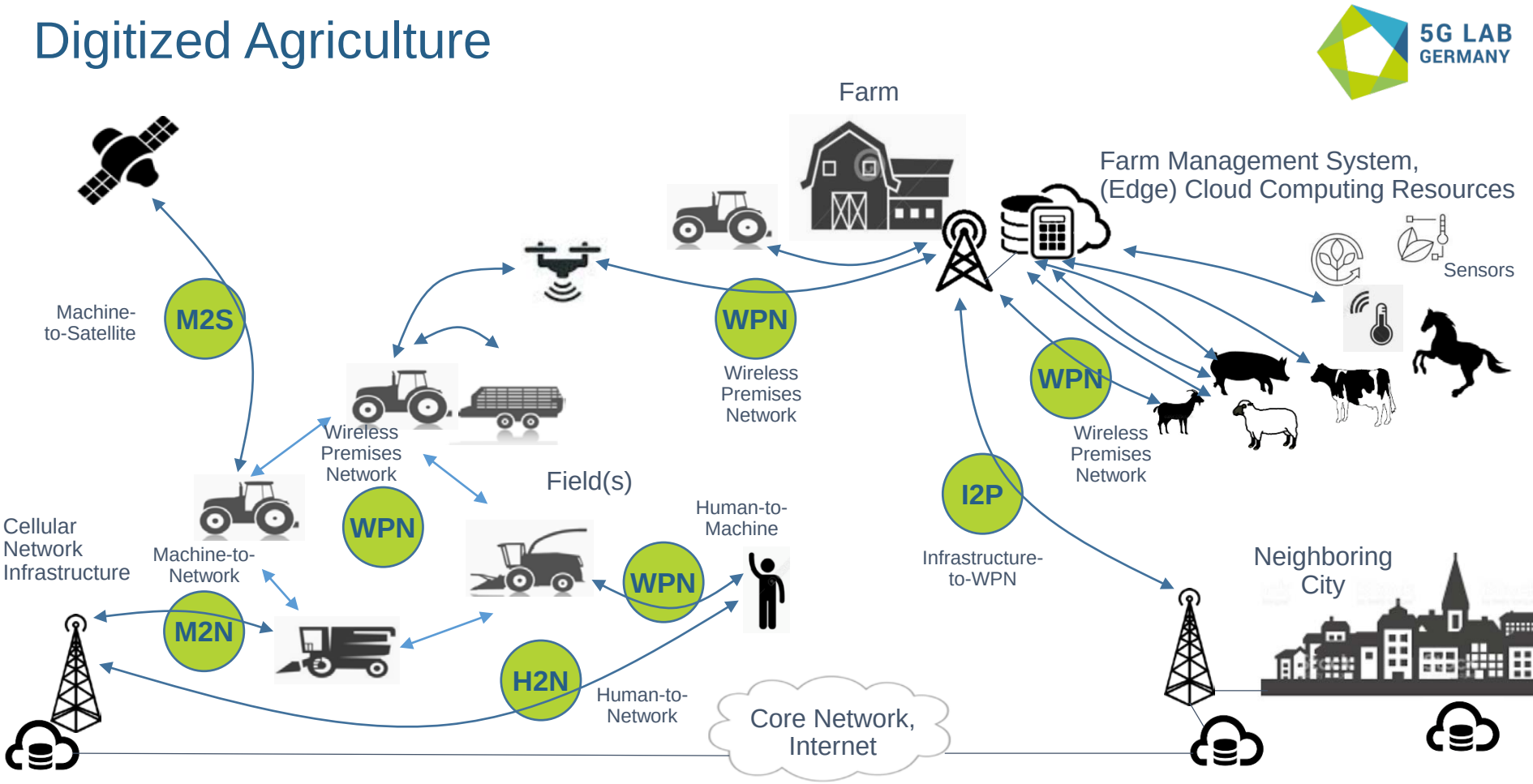
Camera

Radar

Detecting obstacles

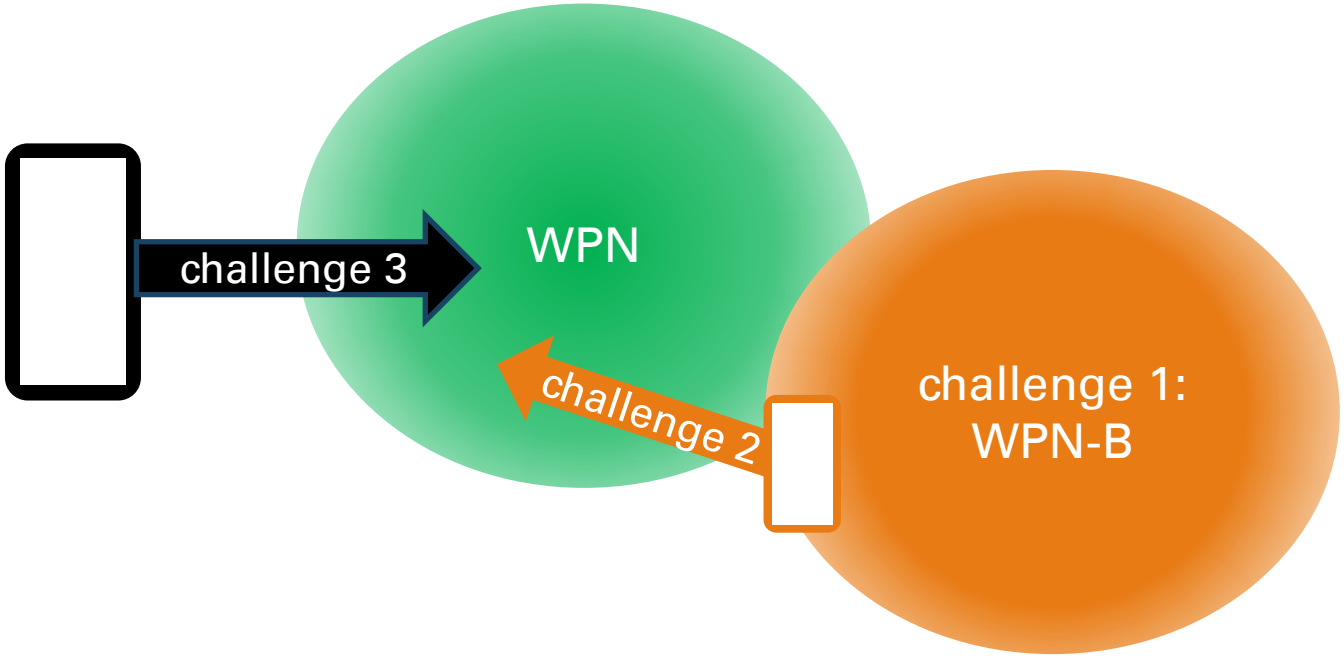
Cooperative machines, monitoring of process data,
remote control, connecting drones to machines and process automation

Digitized Agriculture



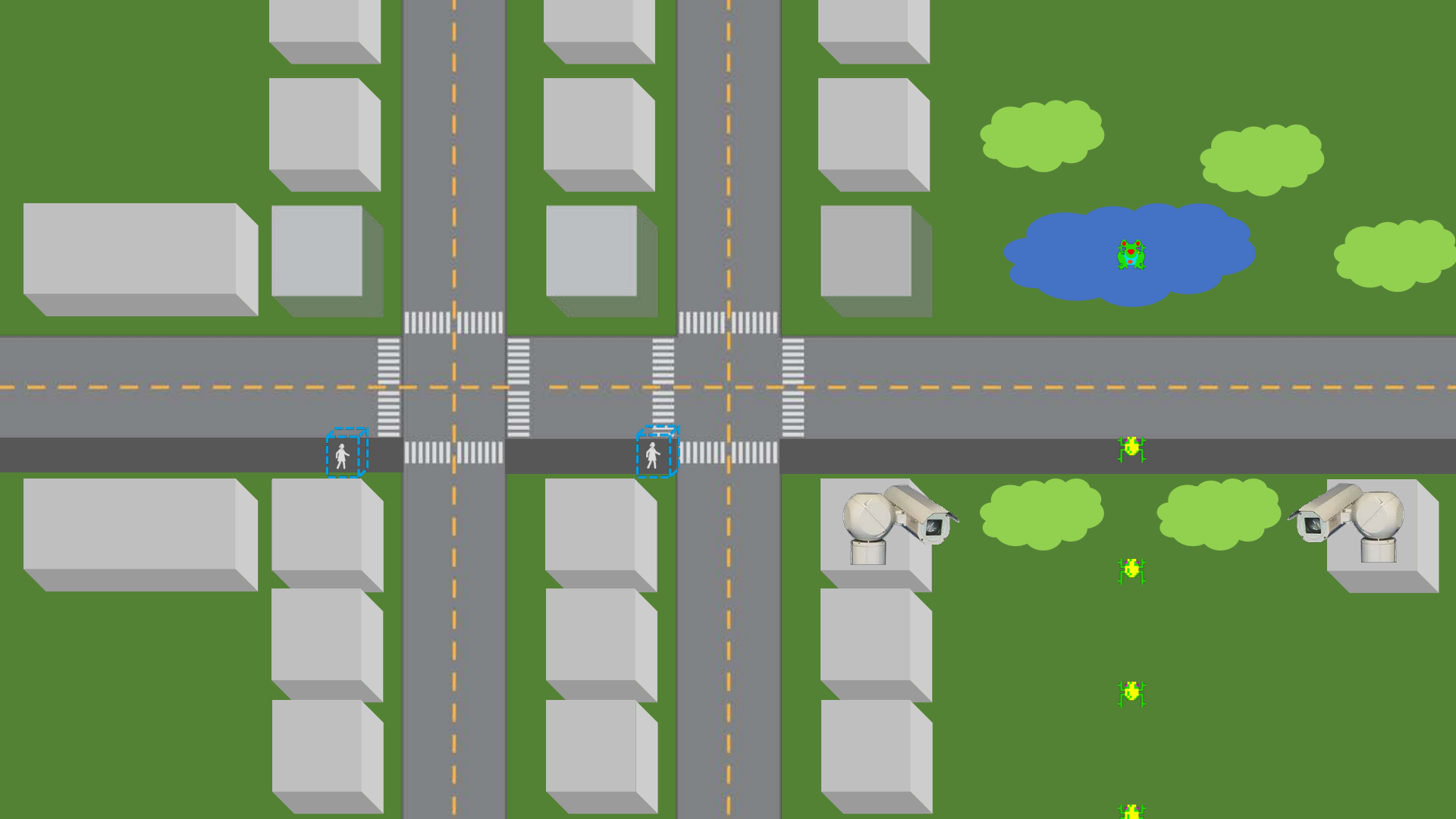
Wireless Premises Networks

3 Examples of Unsolved Challenges

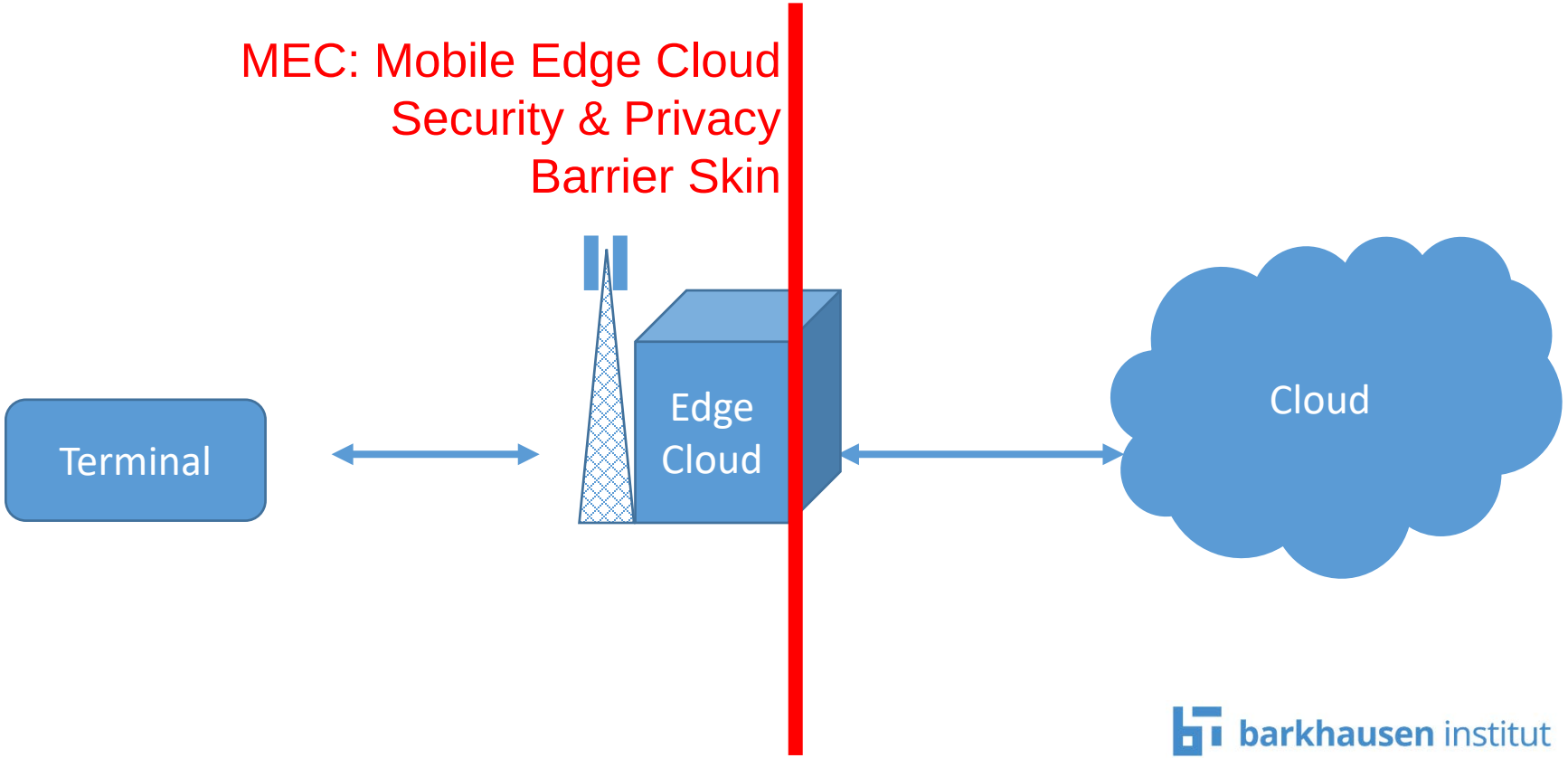


5G LAB GERMANY

5G → Security → 6G ?

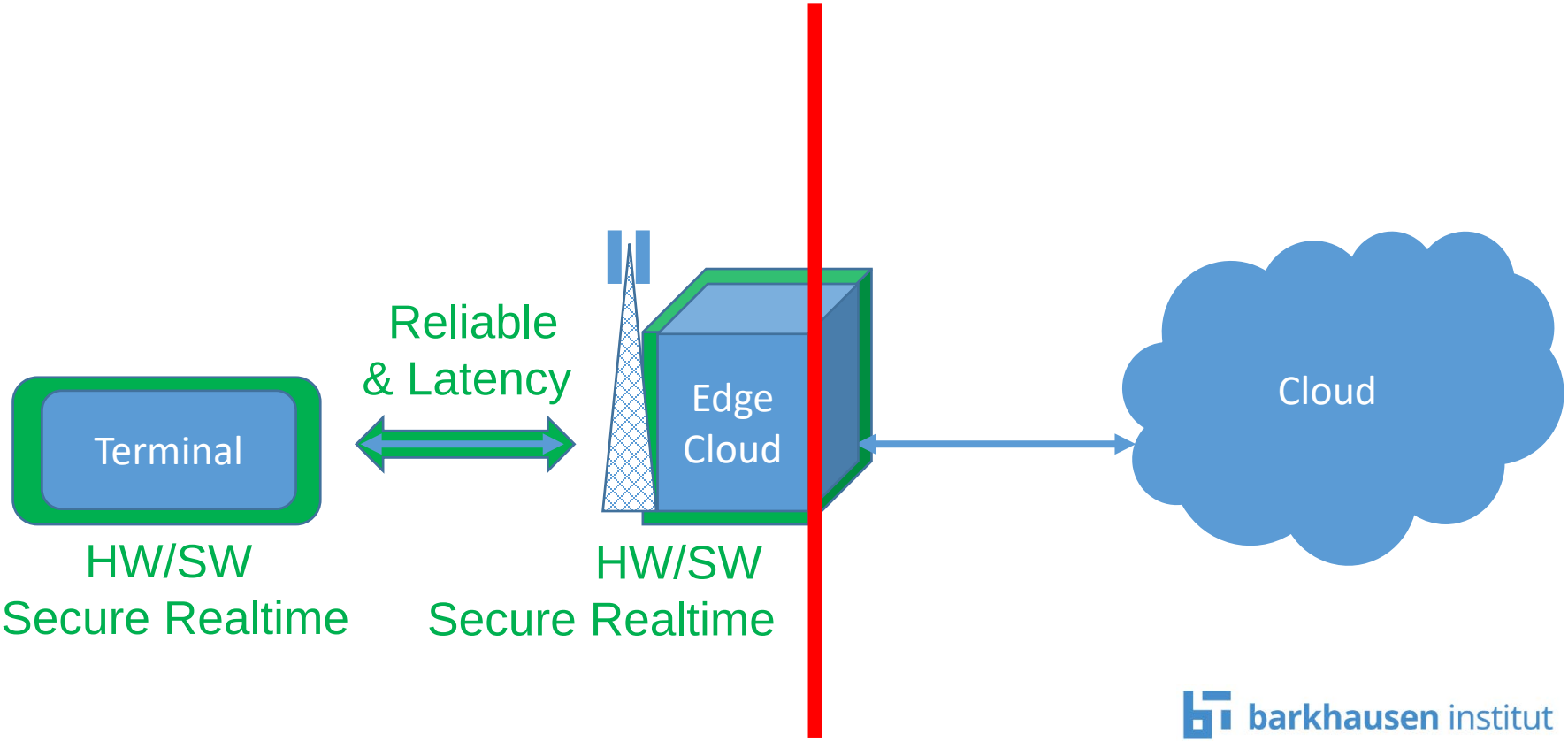


Security & Privacy



barkhausen institut

Security & Realtime & Reliable



barkhausen institut

barkhausen institut

The German Secure IoT Platform Institute

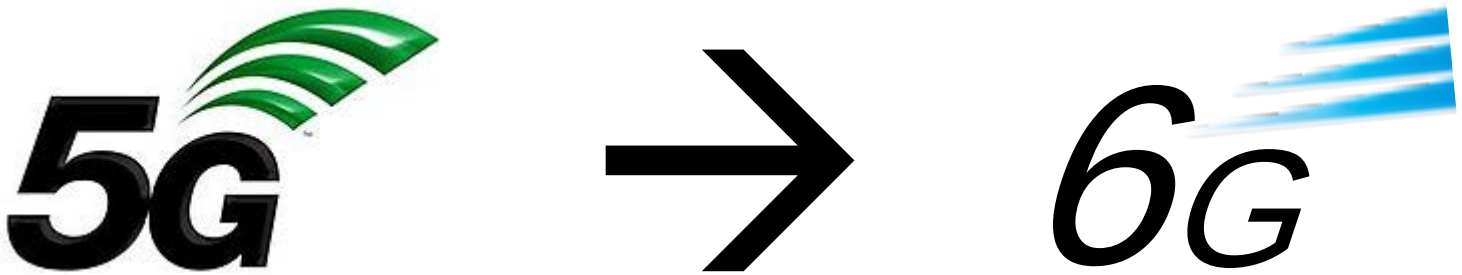
founded 2018

5G LAB GERMANY

Conclusions

5G – Only The Beginning:

“The Carl Benz Automobile” for the Tactile Internet


5G
6G

Open Challenges not Addressed by 5G (1)

True network architecture for distributed/hierarchical

- Security, Privacy: e2e
- AAA (authentication, authorization, accounting)
- Storage, Computing, Control (MEC and more)
- Learning
- Resilience

New PHY reaching towards 100Gb/s to 1Tb/s

- New modulation (OFDM “dead” for these rates?!)
- Frequencies: <1GHz, 6-10GHz, >100GHz
- Massive MIMO 2.0
    - Machine learning (antenna coupling, SON, ICIC, PA,…)
    - Beam acquisition & tracking for 1000 antennas and more

Secure IoT Platform

Open Challenges not Addressed by 5G (2)

Tactile Internet 2.0

- True e2e 1ms latency
- True network slicing 2.0: addressing plenty of “niche” markets!

  Mobile Industry 4.0, Mobile Farming 4.0, Mobile Building 4.0,…

Resilience

- Availability, Reliability, Recoverability – within which intervals!

Premises

- Wireless Premises Networks (WPN)
- Cognitive & automated

Connecting the planet:

- ER cells with 100km range
- Satcom?

TECHNISCHE UNIVERSITÄT DRESDEN

Thank you Vodafone for 24 years of continued support *!*

www.vodafone-chair.com

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