5G – the Door Opener to 6G?

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CEO Barkhausen Institute

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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

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

IPP Sponsors

Project Partners

arm
actix
BOSCH
cadence®
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NATIONAL INSTRUMENTS
NOKIA
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ESF
Europa fördert Sachsen
Freistaat Sachsen
Staatsministerium für Wissenschaft und Künste

vodafone chair @ TU Dresden: Key Facts & Figures
The Vodafone Chair’s Startup History

1999 OnDSP™ based WLAN chip-sets
2000 SON systems
2003 Broadband Wireless HW (LTE, …)
2004 Module and reference board design
2005 MPSoC semiconductor IP
2007 Wireless audio
2008 Network performance measurement
2008 LTE Cellular Handset Chip IP
2010 Satellite Communications
2012 Startup incubation and growth partner
2013 IoT solutions
2013 Bitcoin harvesting engines
2013 Massive MIMO Cells
2014 Machine vision for manufacturing
2015 Cellular IoT Chip IP
2016 Telemetry for IoT
Update 5G Lab Germany Members

HARDWARE & WIRELESS

Frank Ellinger
Gerhard Fettweis
Karlheinz Bock
Dirk Plettremeier
Christian Mayr
Michael Schröter
Kambiz Jamshidi

NETWORK & CLOUD

Thorsten Strufe
Frank Fitzek
Hermann Härtig
Diana Göhringer
Christel Baier
Christof Fetzer
Eduard Jorswieck

TACTILE INTERNET APPLICATIONS

Uwe Åßmann
Ercan Altinsoy
Thomas Herlitzius
Jens Krzywinski
Klaus Janschek
Leon Urbas
Jürgen Weber
Peter Birkholz

[Team of 600+ Researchers]
5G Lab Germany – Partners

vodafone
ROHDE & SCHWARZ
NATIONAL INSTRUMENTS
NOKIA
ERICSSON
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BOSCH
IDT
Telemotive AG
GLOBALFOUNDRIES
Hewlett Packard Enterprise
Racyics
BMW
LIEBHERR
VOLKSWAGEN
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
Scalability Challenge
Wireless Throughput & Latency Evolution

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

Latency [ms] vs Throughput [Mbps]

- 2G: ~10^3
- 3G
- 4G
- 4G+
- 5G: ~10^5

Throughput [Mbps] vs Latency [ms]
Baseband Processing Challenge
How to Design the Processing Platform: starting from the high performance

AVFS: Adaptive voltage & frequency scaling

Latency [ms] vs. Throughput [Mbps]

AVFS $\Rightarrow \sim 10^5$

$\sim 10^3$
Our Design Roadmap

- WLAN PHY, Mobile Multimedia accelerators

Tomahawk1 – 4G (Tapeout: 2007)
- 13 heterogeneous 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?

- Speed: >10 Gb/s → Tb/s
- Massive Content
- 10 years from AAA battery
- Massive IoT
- Massive Reliability
- Availability Probability 1-10^-5
- Massive Control
- Response: 1-10 ms
The Wireless Roadmap >2020 Outlook

killer app for >10Gb/s?
Spectrum Challenge
Where to Find The Spectrum For 1Tb/s?

Channel Measurement @230-320GHz
by Prof. Dirk Plettemeier and team

Simple bounce off wood – roundtrip distance 8m

Corner bounce off brick/wood – roundtrip distance 10m

-60dB

8m

-60dB

11m
Channel Measurement @230-320GHz
by Prof. Dirk Plettemeier and team

Curtain bounce – roundtrip distance 6m
Signaling and Sampling at Very High Rates

Recognizing my (former) team members

L. Landau  S. Bender  M. Dörpinghaus

Now PUC Rio
Power Bottleneck: Conversion

- DAC
- LNA
- RF
- PA

baseband → DAC → RF → PA → LNA → RF → baseband
Time Versus Amplitude Processing

M+1 bins / sample period

2M bins / sample period

amplitude

amplitude

time
Receiver Design: Sequence vs. Symbol based

Sequence based
Detection based on entire sequence

\[ \lim_{n \to \infty} \frac{1}{n} I(X^n; Y^n) \]

Symbol based
Detection based on observation window

\[ I(X_k; Y_{k+1}^k) \]

Simulation based computation of the rate [Arn06]

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

Achievable Rate: ASK

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

\[ h(t) = g(t) = \frac{1}{\sqrt{T_s}} \text{rect} \left( \frac{t}{T_s} \right) \]
Lab Demos (e.g. @300GHz)

Special thanks to

NATIONAL INSTRUMENTS

vodafone
5G Dimensions – Challenges Addressed?

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- Massive Content
- Massive IoT
- 10 years from AAA battery
- Massive Reliability
  Availability Probability 1-10^{-5}
- Massive Control
  Response: 1-10 ms
WHAT IS RELIABILITY?

Reliability Theory Vocabulary

KPIs

Probabilities
- Availability
- Interval Reliability

- Reliability

Time Durations
- Mean Time To First Failure
- Mean Up Time
- Mean Down Time
- Mean Time Between Failures
5G Dimensions – Challenges Addressed?

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

10 years from AAA battery
Massive IoT

Massive Reliability
Availability Probability 1-10⁻⁵

Massive Control
Response: 1-10 ms

URLLC
Tactile Internet
Physiology und Psychology

Today’s networks: 100ms latency

1ms
(1/1000 s)
tactile interaction
Wireless Premises Network
Up to – 1.000m

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

Drone can also act as a relay station.
Digitized Agriculture

- Farm Management System
- (Edge) Cloud Computing Resources
- Farm

- WPN
- Wireless Premises Network

- M2S
- Machine-to-Satellite

- M2N
- Machine-to-Network

- H2N
- Human-to-Network

- Core Network, Internet

- Cellular Network Infrastructure

- Field(s)

- I2P
- Infrastructure-to-WPN

- Neighboring City

- Sensors

- 5G LAB GERMANY
Wireless Premises Networks

3 Examples of Unsolved Challenges

- Challenge 1: WPN-B
- Challenge 2
- Challenge 3
5G → Security → 6G ?
Security & Privacy

MEC: Mobile Edge Cloud
Security & Privacy
Barrier Skin

Terminal

Edge Cloud

Cloud
Security & Realtime & Reliable

Terminal

Cloud

Edge Cloud

Reliable & Latency

HW/SW Secure Realtime

HW/SW Secure Realtime
Conclusions
5G – Only The Beginning: “The Carl Benz Automobile” for the Tactile Internet
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?
Thank you Vodafone for 24 years of continued support!

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