International research collaboration – Key to a sustainable 6G road

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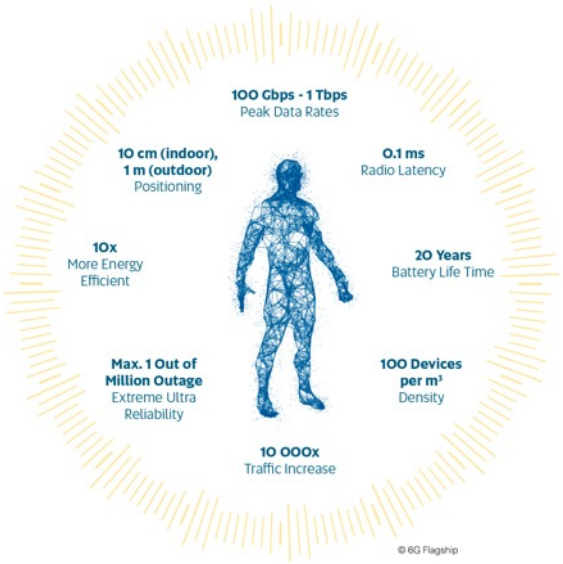
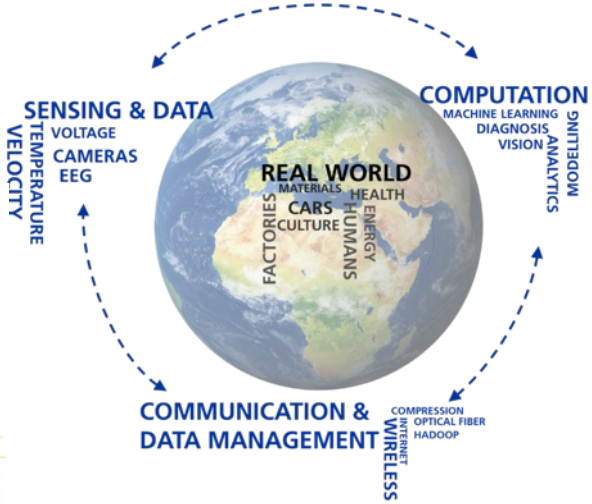
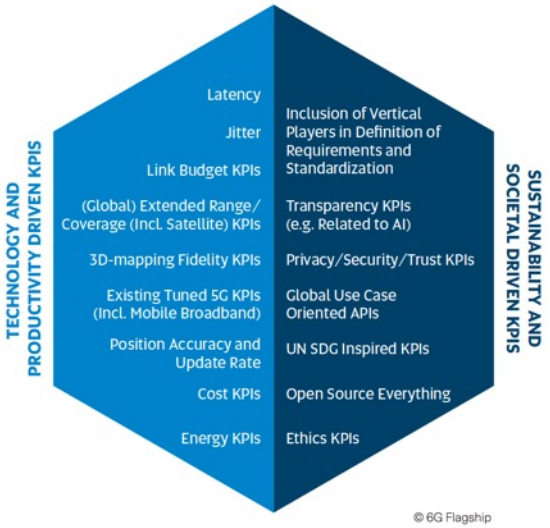
Research Topics relevant for the Future Society
The Era: 5G…5G+…6G







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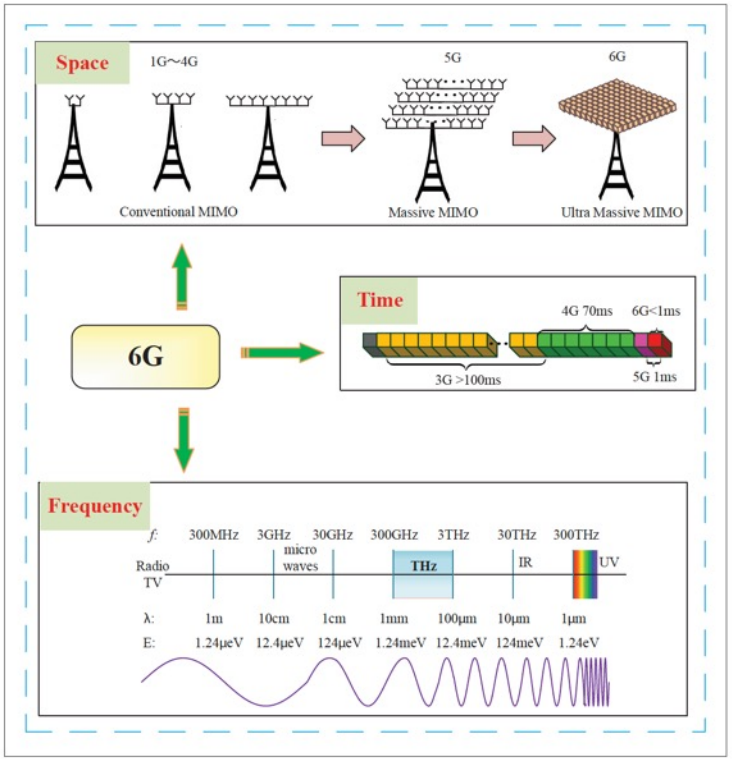
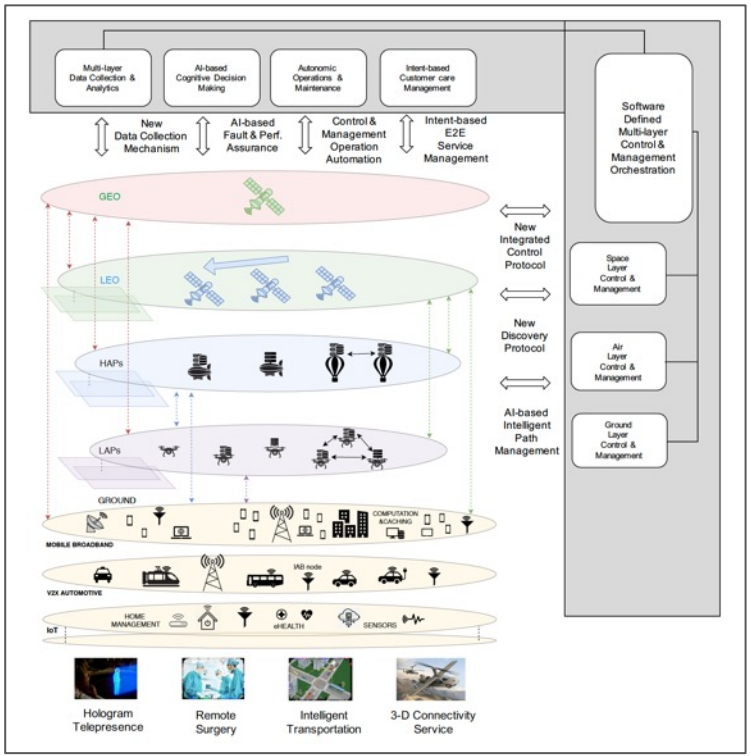
Key Drivers behind 6G

- **New applications**
  - Extended reality (XR) with haptic feedback and holographic display
  - Applications based on massive/wideband sensing
- **Proliferation of Intelligence**
  - Integrated/embedded AI
  - data protection and trustworthiness
- **Societal drivers and new business opportunities**
  - UN sustainability development goals
  - Environmentally sustainable network access
  - Increased role of data, new business models driven by connected data, concerns on privacy …

6G – What's next after 5G-Advanced?

Dimensions: Space, Spectrum und 3D-Coverage





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Road to 6G

- Covid 19 Pandemic showed clearly what communication networks are capable of enabling
- 5G-Advanced research was intensified and 6G programmes were initiated worldwide
  - European programmes and National programmes in Europe (Germany, France, UK, Italy,…)
  - North America and South America
  - Asia: China, Korea, Japan, India,…
- New Associations have been formed (6G-IA (EU), Next G-Alliance (US), 6G Global (Korea), …)
- Existing associations published White and Positions Papers (NGMN, 5GAA, 5G-ACIA,…)
- 6G Standardization is to start around 2025 being rolled out around 2030
- Consensus building what 6G should deliver and which technology components it should contain is in early stage

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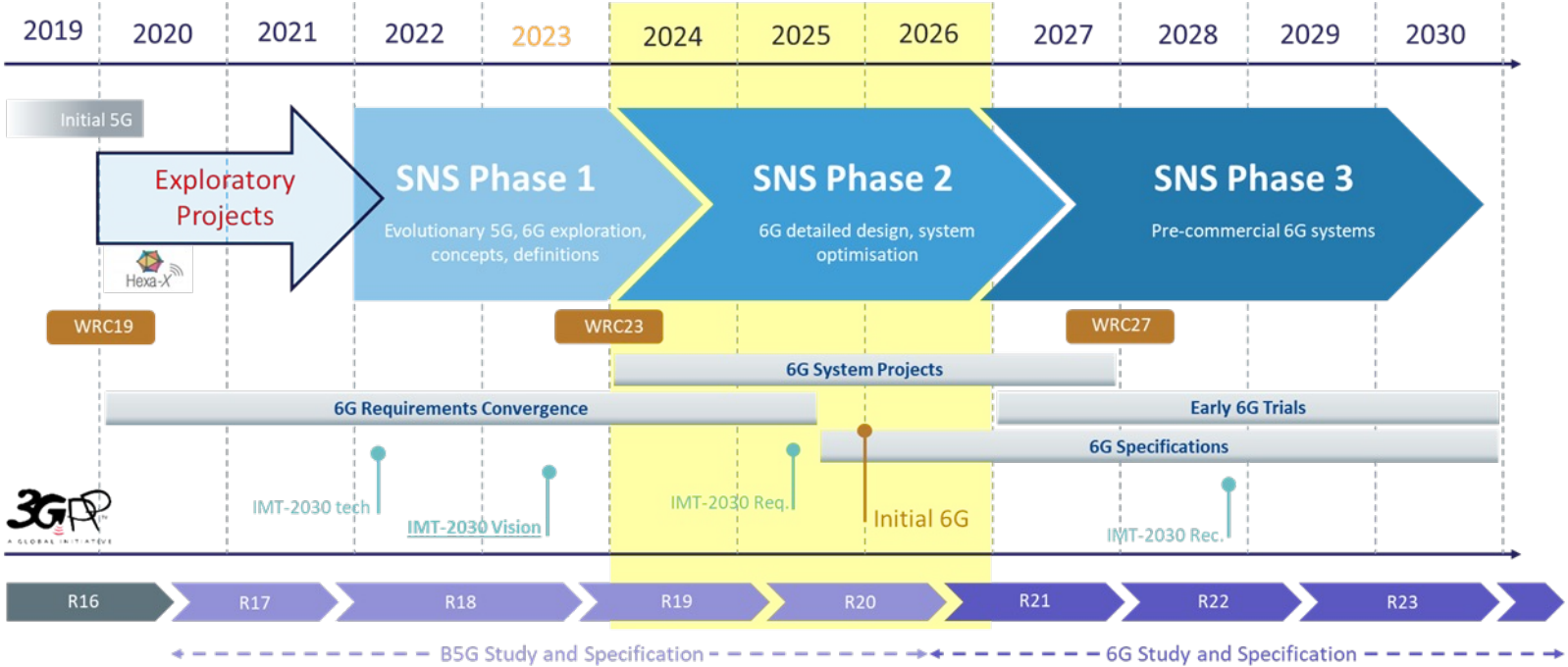
EU Research funded through SNS-JU



Further details to be found under https://smart-networks.europa.eu/

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EU Research funded through SNS-JU

Stream A:_Smart Communication Components, Systems And Networks For 5G Mid-Term Evolution Systems

BeGREEN, 5G-STARDUST, SEASON, 6Green, VERGE, NANCY, ACROSS follow an evolutionary path towards 6G. Research topics covered include energy efficient radio networks, adaptive Open RAN, integrated 5G-Non-Terestrial Networks (NTN), AI-based edge platforms, and intelligent resource management ensuring security, privacy & trustworthiness.

Stream B:_ Research For Revolutionary Technology Advancement Towards 6G

The focus is on novel technologies that are expected to be adopted in commercial networks in a mid and/or long-term time period. Research topics of **ADROIT6G, DETERMINISTIC6G, DESIRE6G, PREDICT-6G, TERA6G, TERRAMETA, 6GTandem, CENTRIC, TIMES, FLEX-SCALE, ETHER, 6G-NTN, SUPERIOT, CONFIDENTIAL6G, RIGOUROUS, HORSE, PRIVATEER, Hexa-X-II, 6G-SHINE** include, inter alia, novel 6G system architectures, advanced wireless and optical communication technologies, advances in Non Terrestrial Networks, secure development of ultra-reliable, and low-latency communications (URLLC) applications.

Stream C:_ SNS Experimental Infrastructures

6G-SANDBOX, 6G-BRICKS, 6G-XR aim at developing EU-wide experimentation platforms that can incorporate promising technical 6G enablers for their further validation. Accessibility and openness with well-defined and clearly-documented technological and business interfaces are also considered key assets of the infrastructures to be developed.

Stream D:_ Large-Scale SNS Trials And Pilots

TARGET-X, TrialsNet, FIDAL, IMAGINE-B5G are implementing large-scale SNS trials and pilots with specific verticals of high economic and societal importance. The aim is to explore and demonstrate 5G/6G technologies, advanced applications and services in vertical sectors such as energy, construction, automotive, manufacturing, eHealth, culture, and media.

Further details to be found under https://smart-networks.europa.eu/

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6G Platform Germany

The German Platform for Future Communication Technologies and 6G

Enabling digital sovereignity for the citizens in a hyperconnected world

6G Research-Hub "6G-RIC"

Coordinator: Prof. Dr. Slawomir Stanczak,
Fraunhofer HHI Berlin
Obtain more information at www.6g-ric.de

6G Research-Hub "6GEM"

Coordinator: Prof. Dr. Haris Gačanin,
RWTH Aachen University
Obtain more information at www.6gem.de

6G Research-Hub "6G-life"

Coordinator: Prof. Dr. Frank Fitzek,
Technical University Dresden
Coordinator: Prof. Dr. Holger Boche,
Technical University München
Obtain more information at www.6g-life.de

6G Research-Hub "Open6GHub"

Coordinator: Prof. Dr. Hans D. Schotten,
DFKI GmbH
Obtain more information at www.open6ghub.de

Source: https://www.6g-platform.com/

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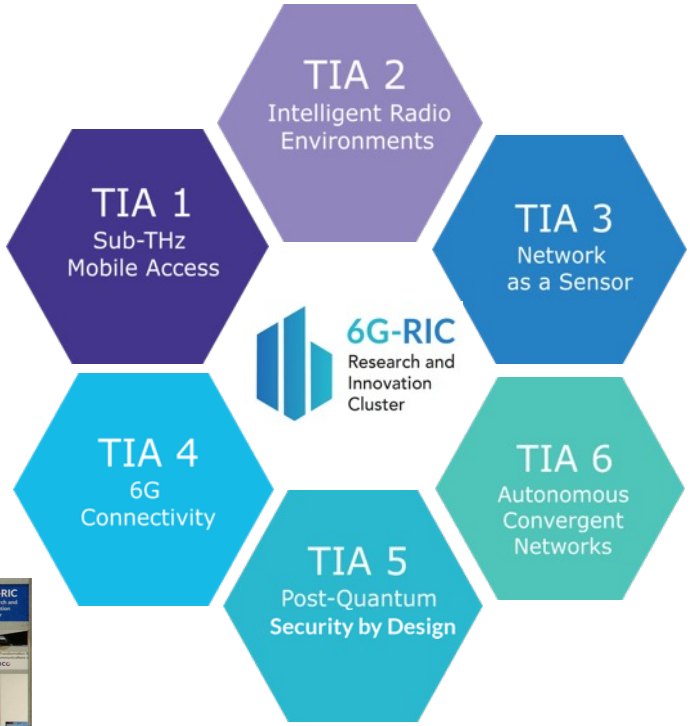
6G Key Technologies

6G-RIC Technical Innovation Areas (TIA)



48	70	20	60
Months Project Duration	Million € Funding	Universities and Research Institutions	Associate Partners

More information @ https://6g-ric.de/ and demos @ all major 6G conferences

6G-RIC Research and Innovation Cluster

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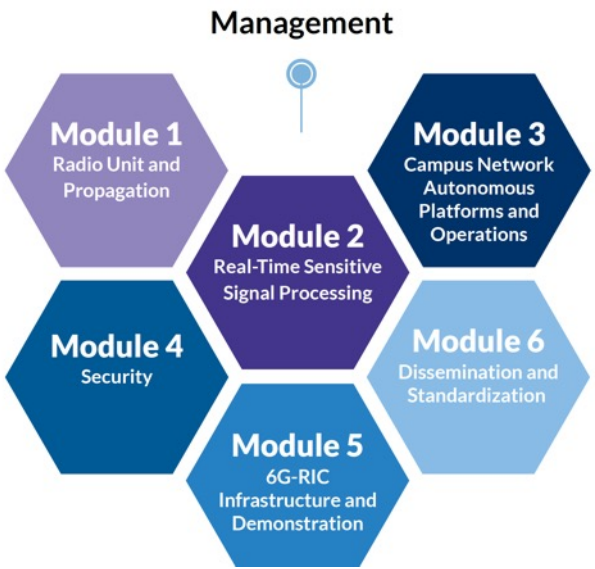
6G-RIC

Structure

Associated Industry Partners

+32

Advisory Board



Standardization and Memberships

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More information @ https://6g-ric.de/ and demos @ all major 6G conferences

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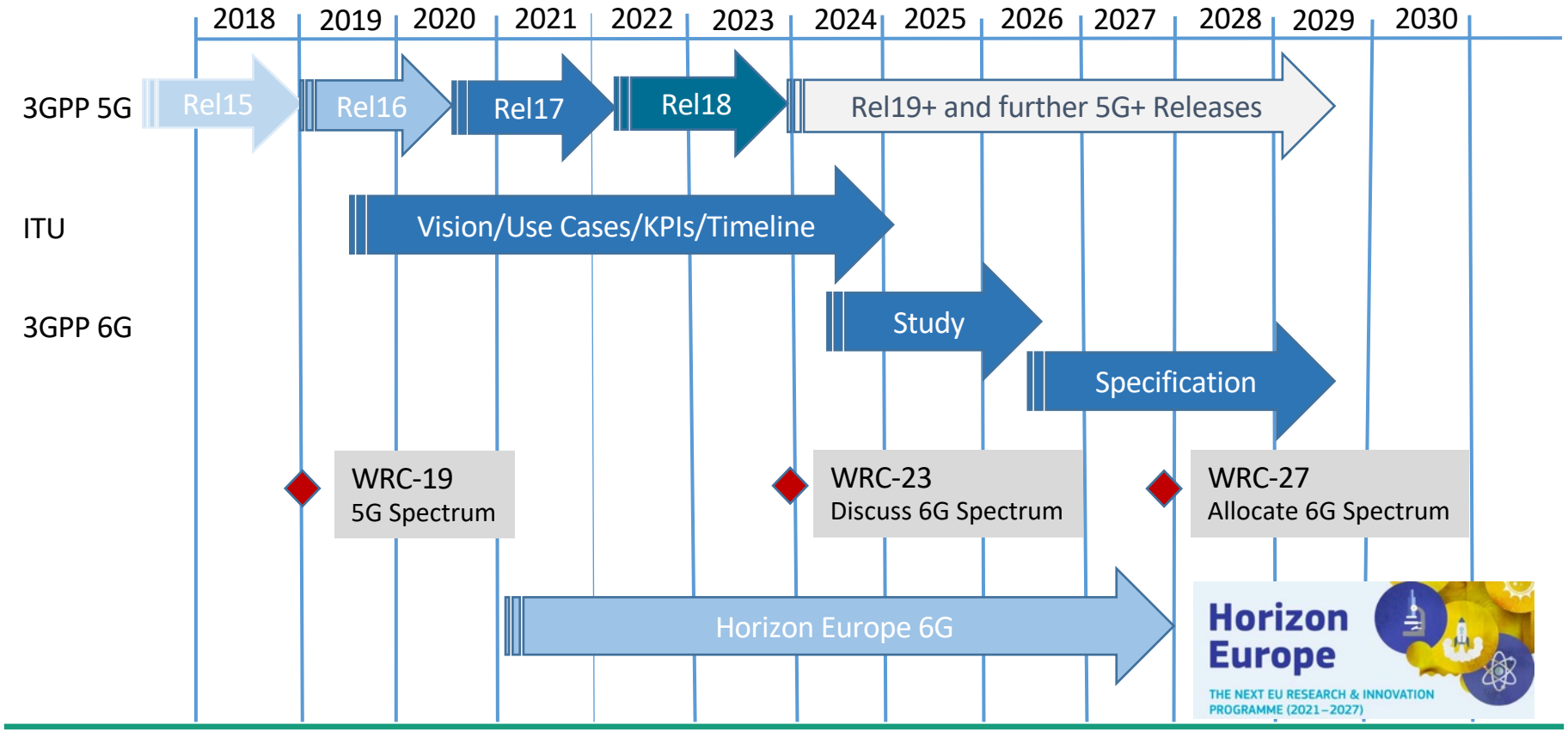
5G+ and 6G Timeline



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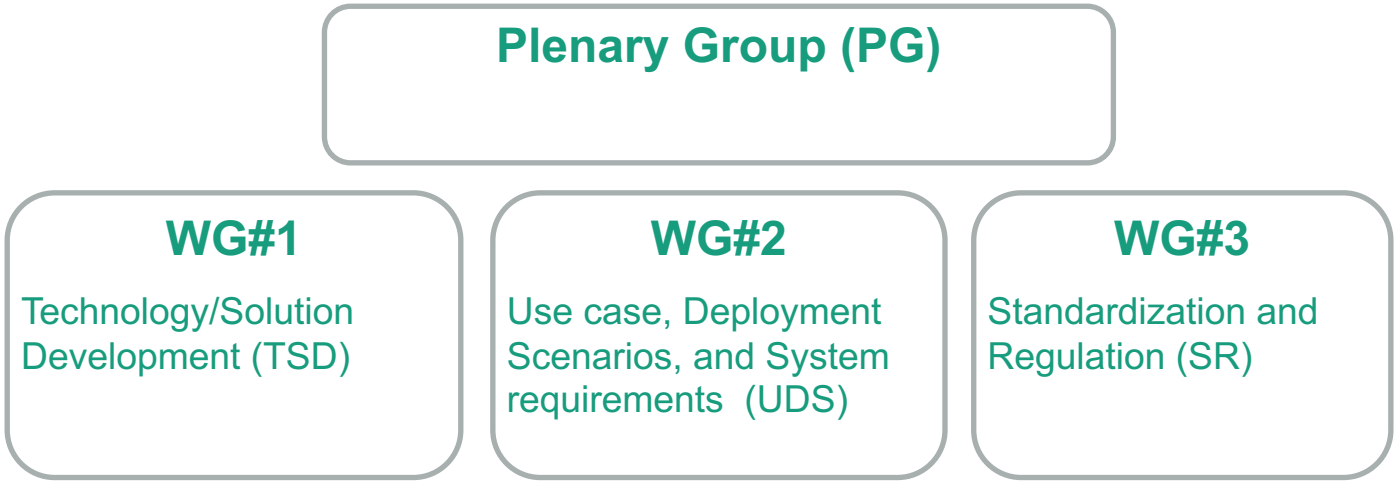
Full-Duplex Radios Interest Group (FDR-IG)

Structure and Members



Members
LG Electronics
Huawei
Fraunhofer
Korea Telecom
IITM
IITH
CEWiT
Reliance Jio
ETRI

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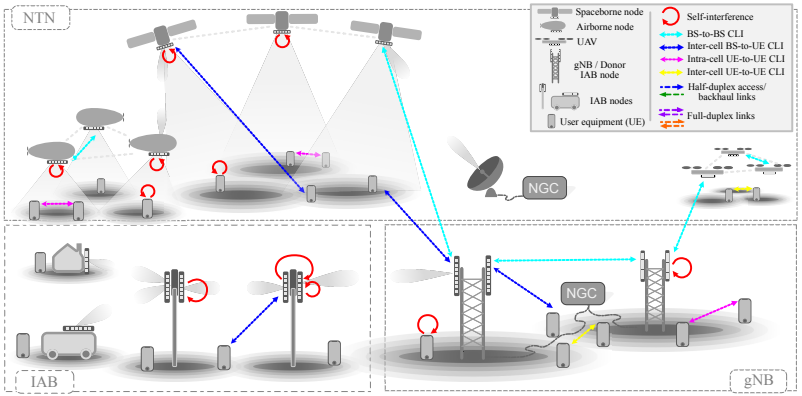
Full-Duplex Radios Interest Group (FDR-IG)

Scientific Promotion Activities & Standard Contributions

- IEEE PIMRC 2019 Workshop on Full Duplex Technologies for Next Generation Wireless Communications
- IEEE PIMRC 2019 Industry Panel “Full duplex: technologies, standards and roadmap ”
- IEEE WCNC 2020 Workshop on Full Duplex Radio (FDR) Technologies for Next Generation Wireless Communications
- IEEE WCNC 2021 Industry Panel “Full duplex: Technologies, standards and roadmap”
- IEEE ICC 2022 Workshop and Industry Panels
- Publications: e.g. R. Askar, J. Chung, Z. Guo, H. Ko, W. Keusgen and T. Haustein, "Interference Handling Challenges toward Full Duplex Evolution in 5G and Beyond Cellular Networks," in IEEE Wireless Communications, vol. 28, no. 1, pp. 51-59, February 2021, doi: 10.1109/MWC.001.2000228.
- 3GPP Contributions to advocate the need for SIDs for FDR



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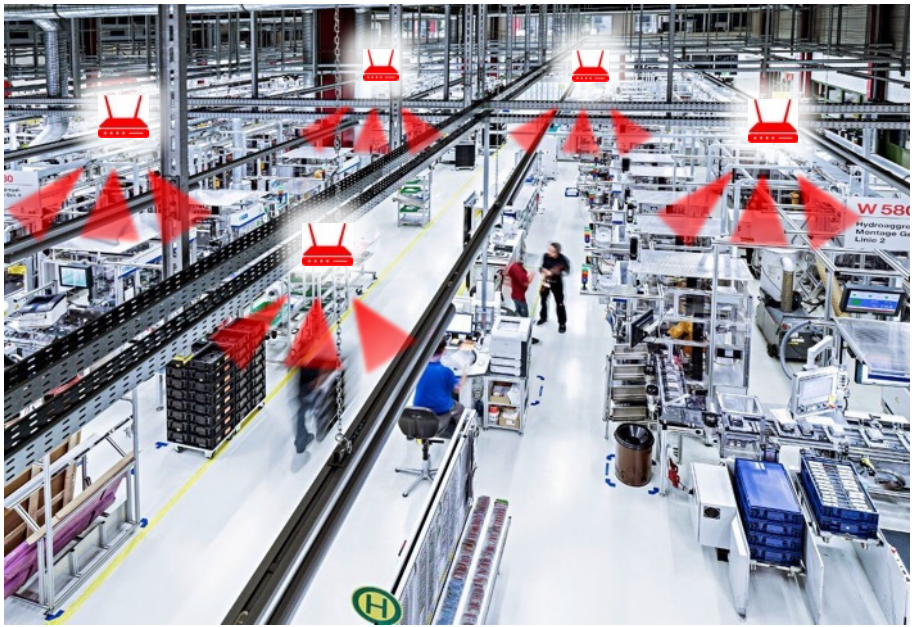
mmW und THz Radio for Industrial Communication



Source: Bosch

- Potential solution for production cells or distributed industrial plants
- Point to multi-point networking with directional transmission
- large bandwidth, low latency
- low interference to neighbouring systems
- Higher immunity to jamming and eavesdropping

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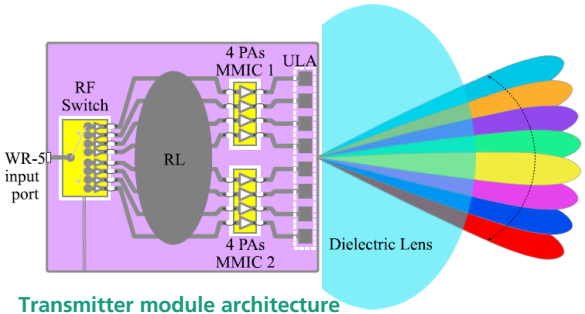
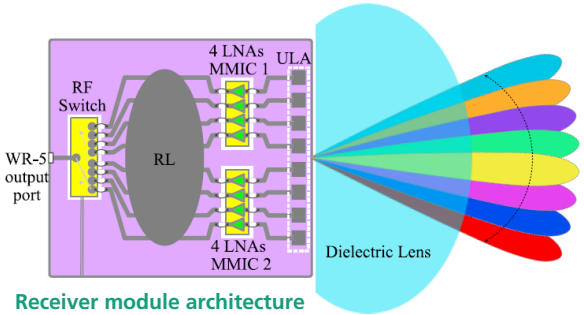
D-Band Integrated Analog Beamforming Front-End Development and Trials

Architecture and parameters

- Design and fabrication of D-band TX and RX front-end modules for sub-THz wireless communication in the frequency range 150-170 GHz
- Rotman lens as passive beamforming network to generate 8 beams
- 8 parallel power amplifiers (PAs) / low-noise amplifiers (LNAs)
- Switches and amplifiers fabricated on indium gallium arsenide (InGaAs) mHEMT technology
- All components integrated on resistive silicon substrate
- Dielectric lens to increase gain by focusing in the elevation plane



Transmitter module architecture



Receiver module architecture

Parameter	Value
Transmitter and receiver module	
Operation frequency range	150 GHz to 170 GHz
Operation bandwidth	20 GHz
Number of RF beams	8
Antenna parameters – transmitter and receiver	
Single antenna element gain	7.5 dBi @ 155 GHz
Number of antenna elements	8
Antenna array configuration	1×8 ULA
Azimuth beam scan angle	8 × 6° = 48°
Transmitter RF specification	
Single PA measured power output	14 dBm
Number of PAs	8 (dual 4-channel MMIC chips)
Measured EIRP	37 dBm
Receiver RF specification	
Single LNA gain	>20dB*
Single LNA noise figure	<3dB
Number of LNAs	8 (dual 4-channel MMIC chips)

*Within 145 GHz to 175 GHz frequency range

[JML+23] Multi-Channel PA, LNA, and Switch MMICs for Beam-Switching Applications at 160 GHz, Based on an InGaAs mHEMT Technology," in *IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)*, 2023.

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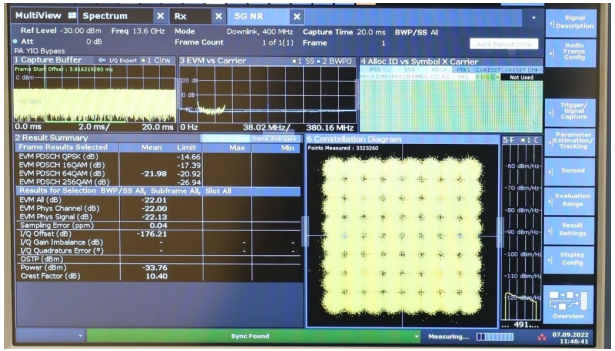
D-Band Integrated Beamforming TX/RX Development and Demonstration

Indoor trials with 5G NR FR2 waveforms at 160 GHz



Indoor transmission experiments validating features and performance

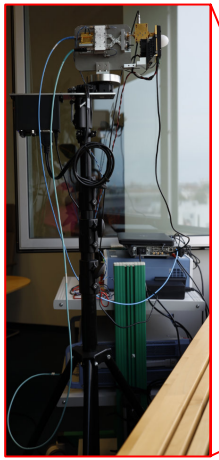
- High signal quality supporting complex waveforms (5G NR)
- Successful test of dynamic beamforming
  - Waveform design and beam management concepts of 5G NR
  - 10 ms radio frame containing 8 SS/PBCH blocks, one corresponding to each transmit beam
  - On each SS/PBCH block, VSG triggered the front-end module to switch to the next beam
  - Continuous switching through 8 receive beams at RX side and capturing of signal period

5G NR FR2 measurement results with R&S T&M equipment (SMW and FSW) @ 320 m (FSPL = 95.31 dB @ 160 GHz)

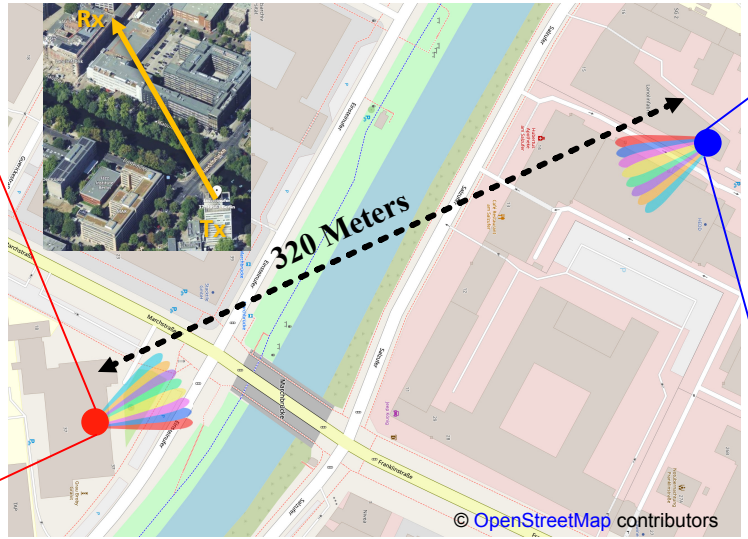
Num of RB (Bandwidth)	Modulation	EVM
264 (380.16 MHz)	64 QAM	-21.98 dB

D-Band Integrated Analog Beamforming Front-End Development and Trials

Outdoor trials with 5G NR FR2 waveforms at 160 GHz



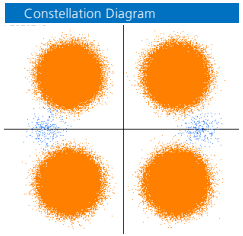
Transmitter setup

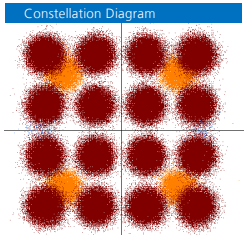


Receiver setup

5G NR FR2 measurement results with R&S T&M equipment (SMW and FSW) @ 320 m (FSPL =126.6dB @ 160 GHz)

Num of RB (BW)	Modulation order	EVM
120 (172.8 MHz)	QPSK	-14.7 dB
45 (64.8 MHz)	16QAM	-17.47 dB





World's first integrated analog beamforming TX/RX front-ends for long-range communication in the D-band!

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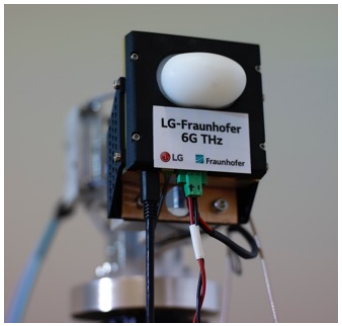
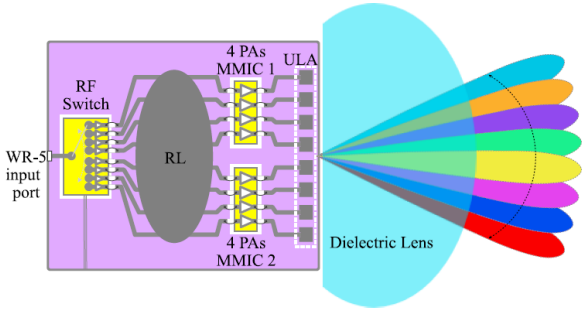
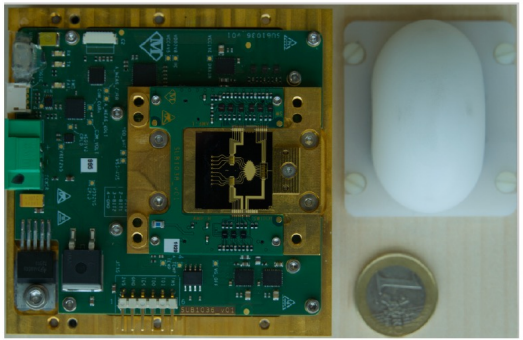
D-Band Integrated Analog Beamforming Front-End Development

Prototyping natural extensions for high spatial degrees of freedom





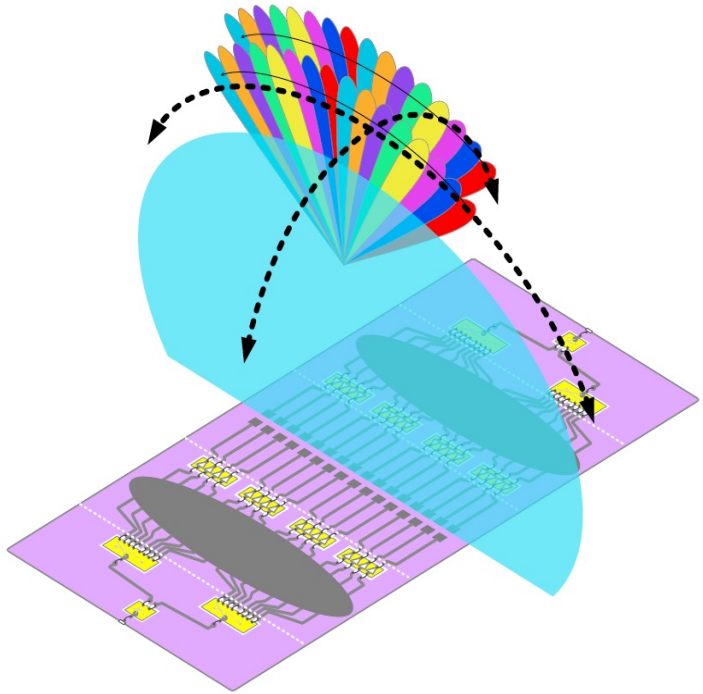


(a) Dismanteled module – on the left side is the module with its peripheral DC biasing and control PCBs, and on the right is the dismantled dielectric lens

from fan-beamforming to

2D-beamforming

to enable MIMO, MU-MIMO,
electronic elevation BF



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Internation Collaborations are Key for a 6G Success

Globally and across domains

- Urgent need to align ongoing 6G research activities regionally and globally through:
  - Use case analysis through industry platforms
  - Technology exploration between academia and industry research
    - e.g. 6G PPP, industry funded research, ETSI ISGs (THz, RIS, ISAC,…)
  - PoC demonstration of feasibility of new technology components e.g. ISAC, positioning, NTN, full-duplex, sub-THz, AI assisted comms,…
  - Tighter interaction with vertical players (many seem disappointed what 5G delivered so far)
- Consider a more enabling standardization process
  - Forward enabling technology components to be standardized, e.g. AI, ISAC, Duplex, cell-free concepts, enablers for massive IoT
  - Support a wider range of use case scenarios and business models

Research with Impact

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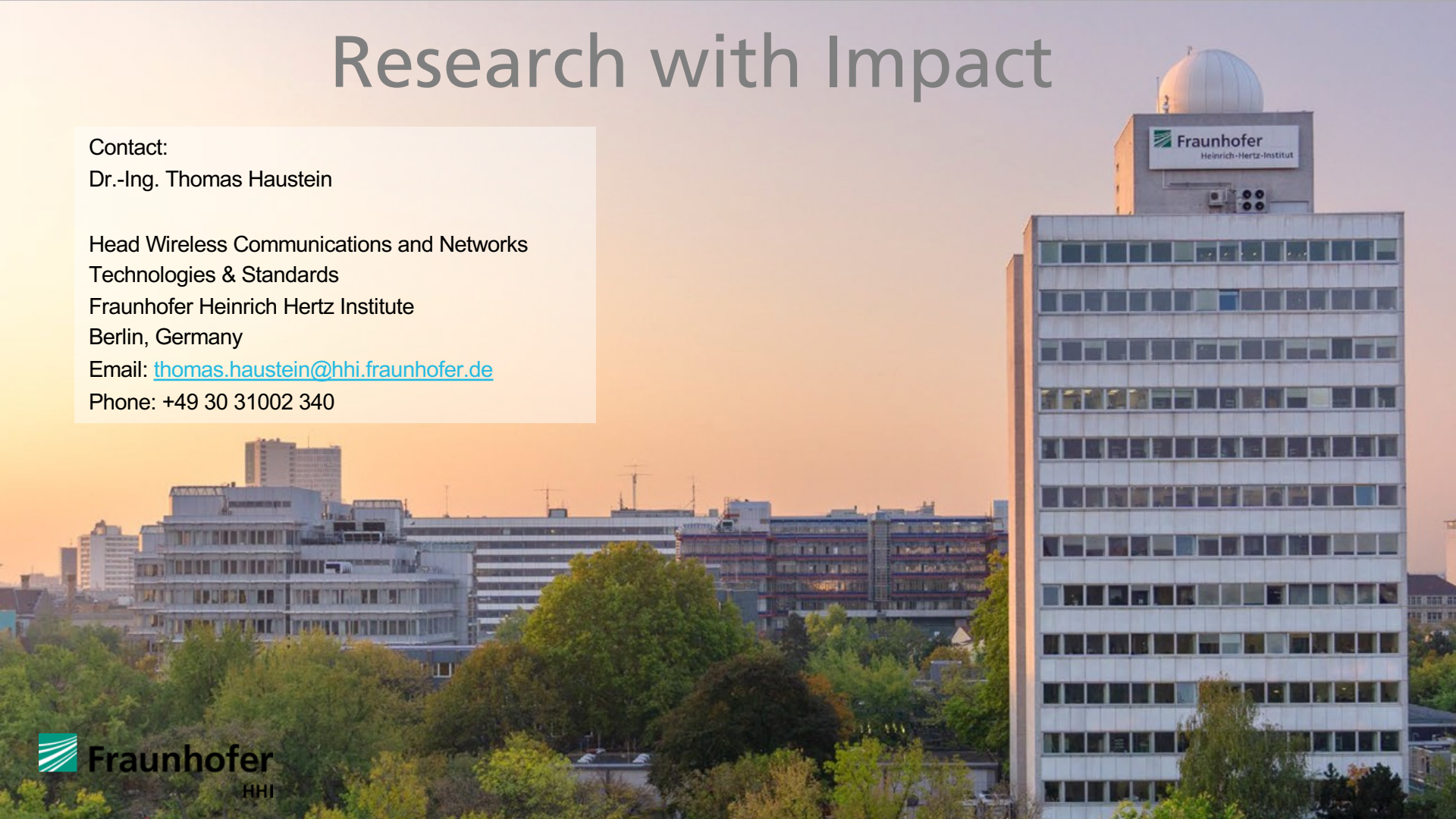

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