THz Communications
the next wireless networks frontier

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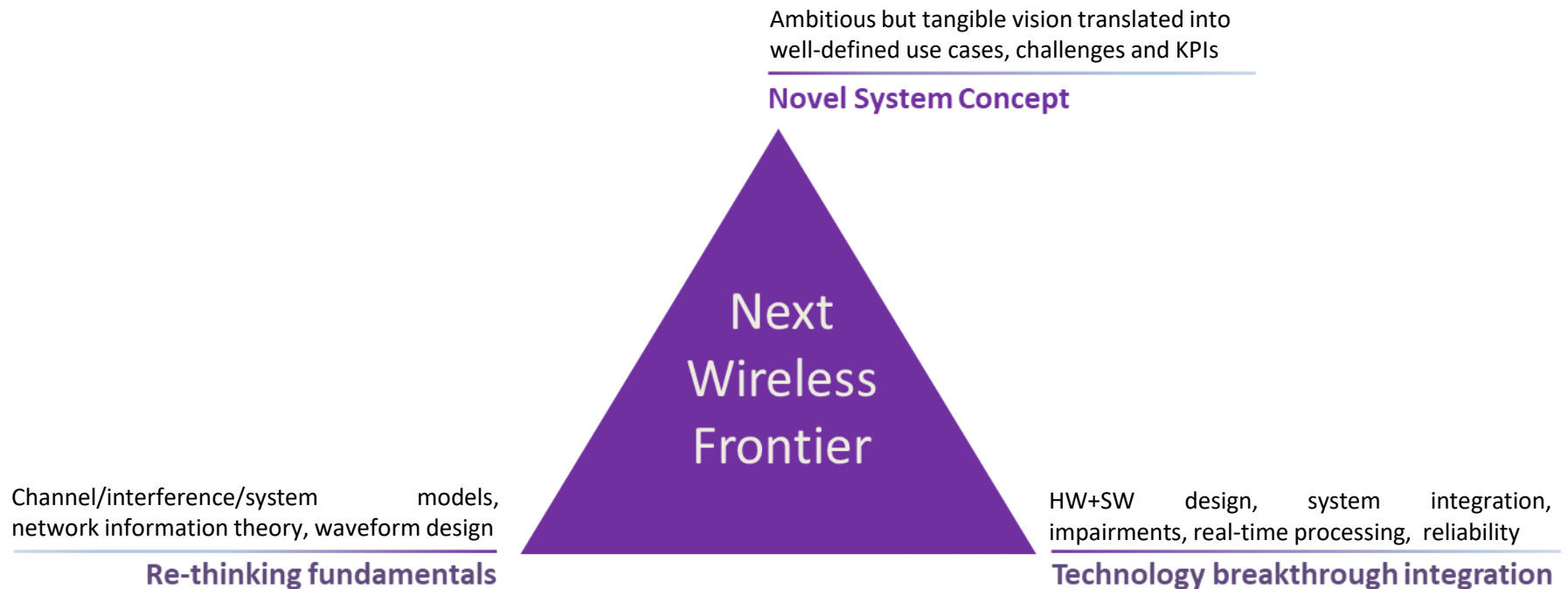
TERRANOVA PM, ARIADNE TM

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3rd Towards Terahertz Communications Workshop (3TTCW)

12 March 2021

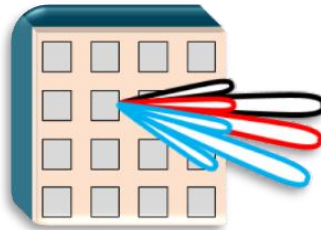# THz Communications: what does it take to be the next Wireless Frontier ?

Ambitious but tangible vision translated into well-defined use cases, challenges and KPIs

Novel System Concept

Next Wireless Frontier

Channel/interference/system models, network information theory, waveform design

Re-thinking fundamentals

HW+SW design, system integration, impairments, real-time processing, reliability

Technology breakthrough integration

THz unique challenges

Optical Fiber Interface
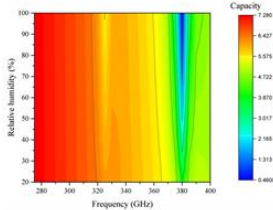
Wireless Channel & DSP
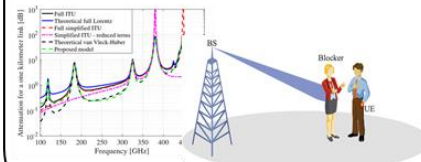
THz Hardware Technology

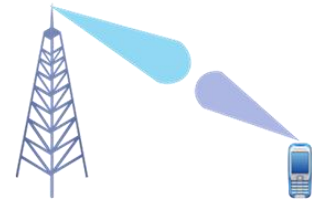**Technology and Signal Processing**

Network Management
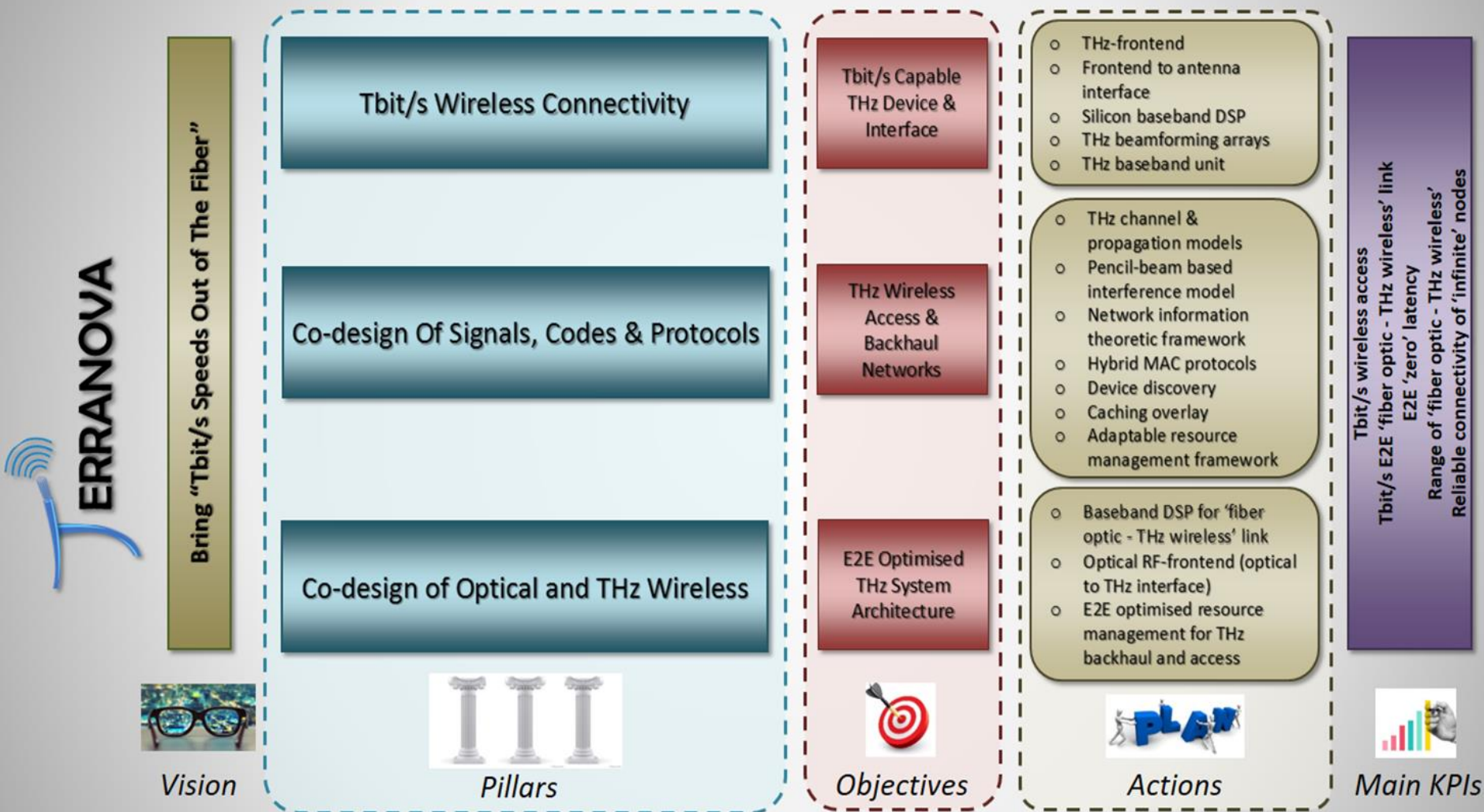
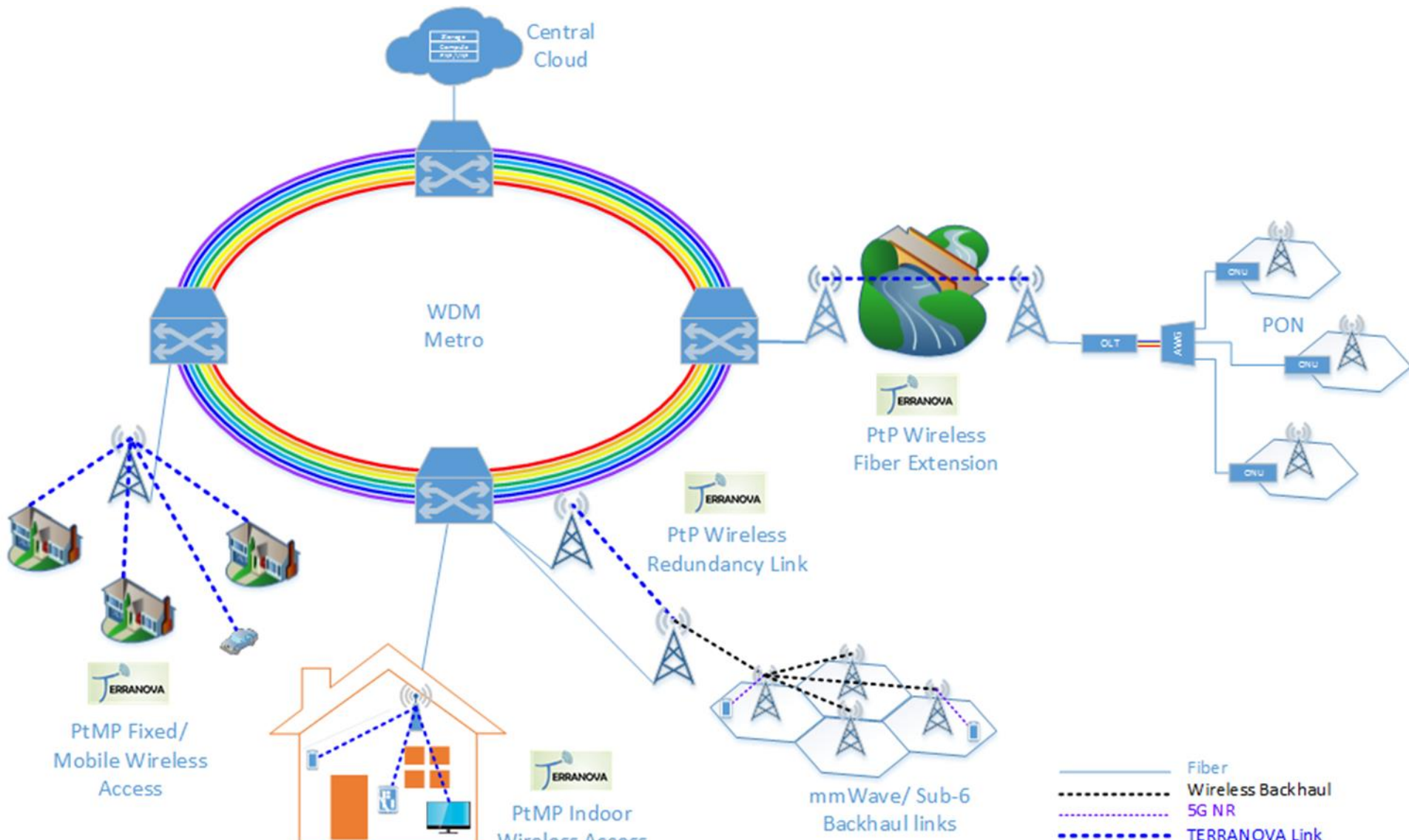THz network information theory and fundamentals

THz propagation and impairements

MAC/Initial Access/Relaying

TERRANOVA: a THz system concept based on co-design

Vision
Bring "Tbit/s Speeds Out of The Fiber"

Pillars
- Tbit/s Wireless Connectivity
- Co-design Of Signals, Codes & Protocols
- Co-design of Optical and THz Wireless

Objectives
- Tbit/s Capable THz Device & Interface
- THz Wireless Access & Backhaul Networks
- E2E Optimised THz System Architecture

Actions
- THz-frontend
- Frontend to antenna interface
- Silicon baseband DSP
- THz beamforming arrays
- THz baseband unit

- THz channel & propagation models
- Pencil-beam based interference model
- Network information theoretic framework
- Hybrid MAC protocols
- Device discovery
- Caching overlay
- Adaptable resource management framework

- Baseband DSP for 'fiber optic - THz wireless' link
- Optical RF-frontend (optical to THz interface)
- E2E optimised resource management for THz backhaul and access

Main KPIs
- Tbit/s wireless access
- Tbit/s E2E 'fiber optic - THz wireless' link
- E2E 'zero' latency
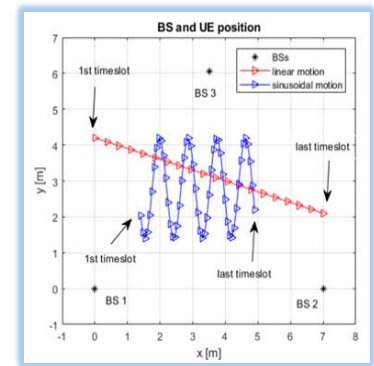- Range of 'fiber optic - THz wireless'
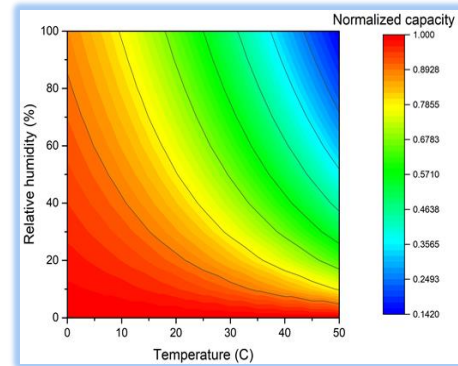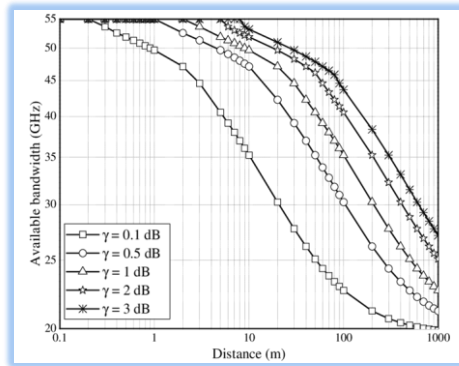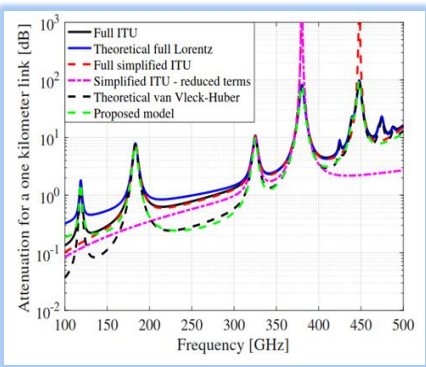- Reliable connectivity of 'infinite' nodes

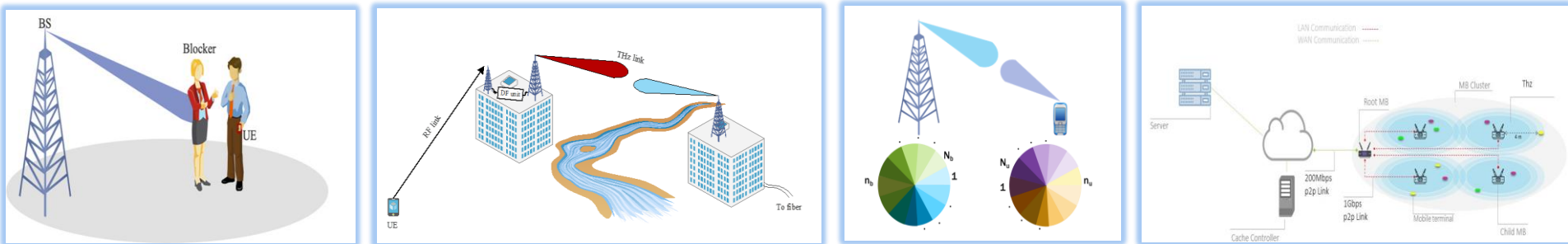# THz communications network use cases and architecture

Re-thinking wireless fundamentals

- ❑ Path loss in THz regime
- ❑ Extreme bandwidth
- ❑ Distance-dependent bandwidth
- ❑ Environment/weather impact
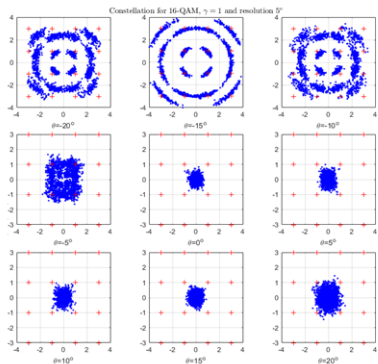- ❑ Pencil-beam wireless access
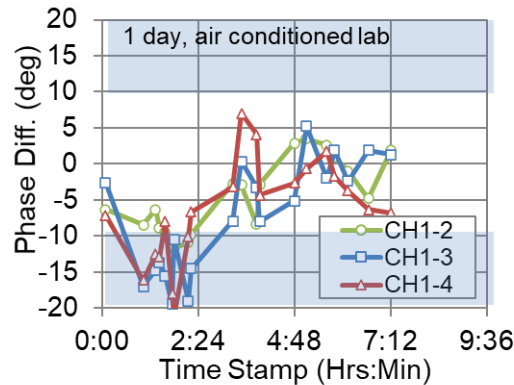
Re-thinking wireless design

- ❑ Misalignment and blockage-aware wireless access
- ❑ Pencil beam based Initial Access, MAC, multiple access
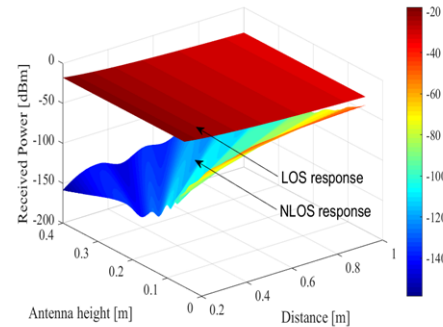- ❑ Caching for latency and load balancing improvements
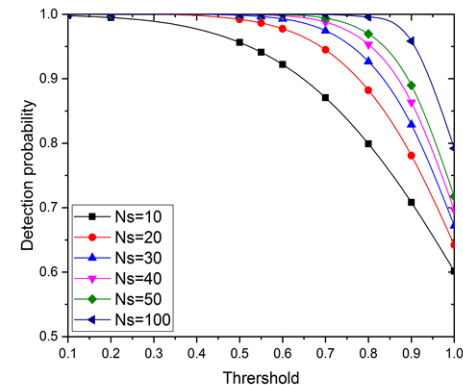
Real-time THz Beamforming

Codebook Design	Hardware Optimization	Channel Modelling	MAC Initial Access

Codebook Design
- ❑ *Codebook resolution*
- ❑ *Codebook extraction*
- ❑ *Impairment Mitigation*
- ❑ *Real-time implementation*

Array Scaling

Hardware Optimization
- ❑ *Short / Long-term LO stability*
- ❑ *Multi-channel carrier estimation*
- ❑ *LO distribution architectures*

THz Hybrid Beamforming Feasibility

Channel Modelling
- ❑ *Iterative schemes*
- ❑ *FPGA real-estate analysis*
- ❑ *Setup optimization*
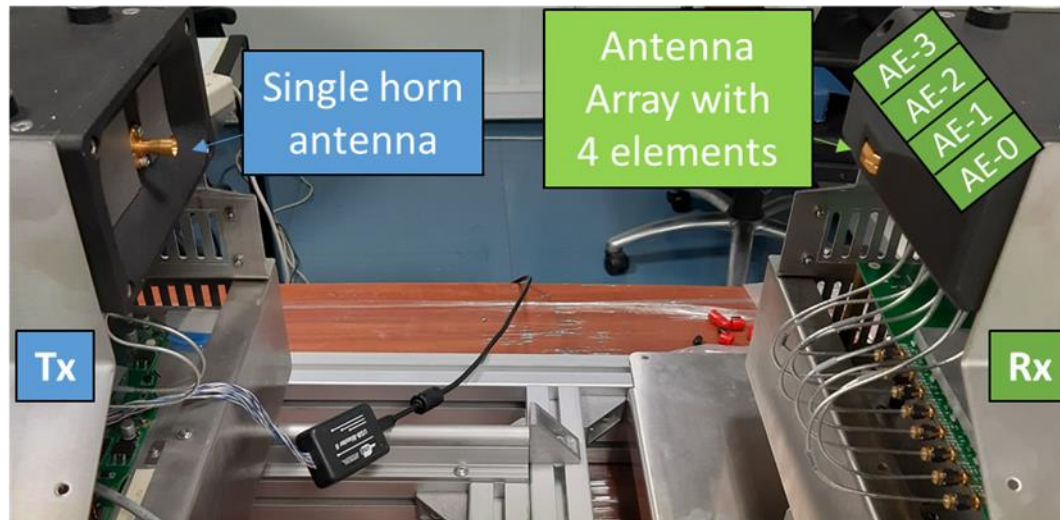- ❑ *Simulation models*

Sparse Channel Estimation

MAC Initial Access
- ❑ *Energy-based user detection*
- ❑ *Efficient scanning schemes*
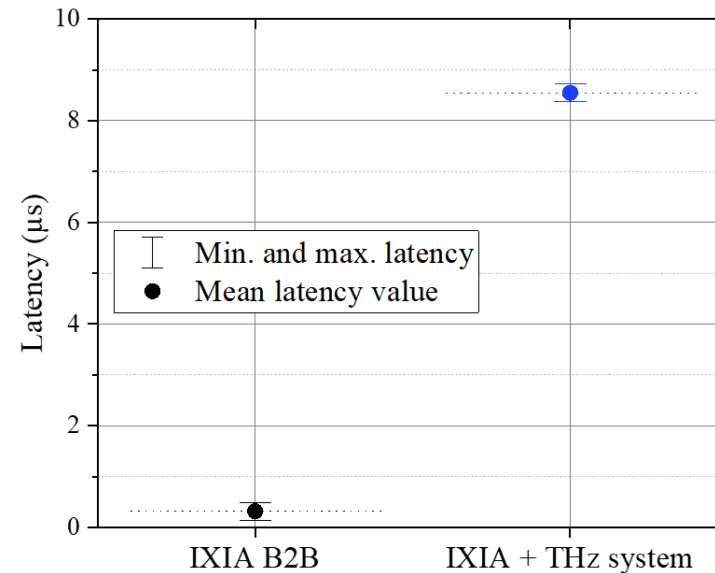- ❑ *False-alarm prevention*
- ❑ *Latency reduction*

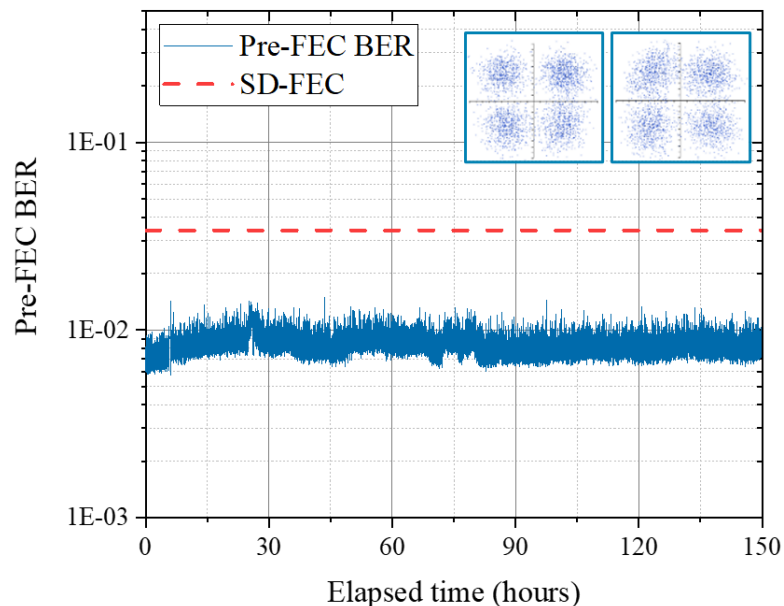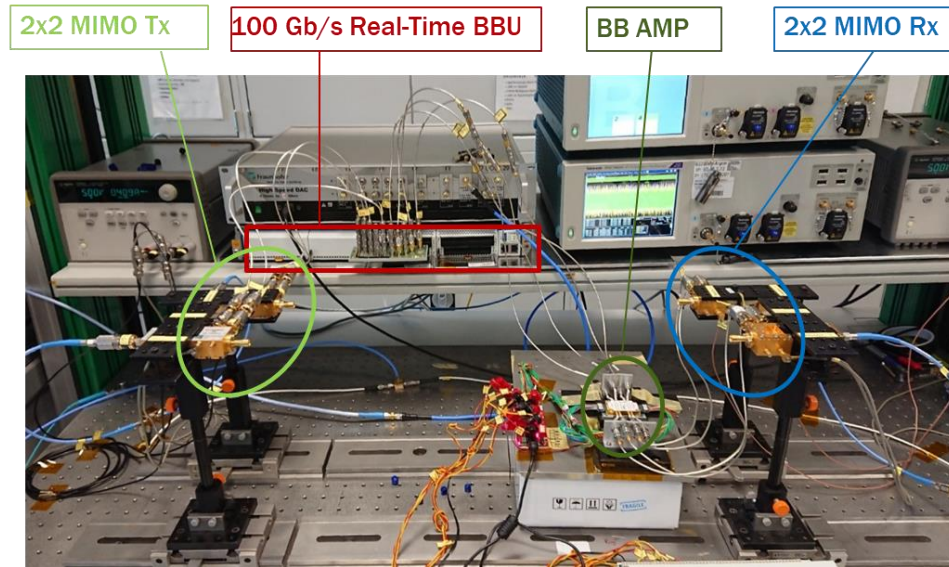**Sensitivity of Cell Search**
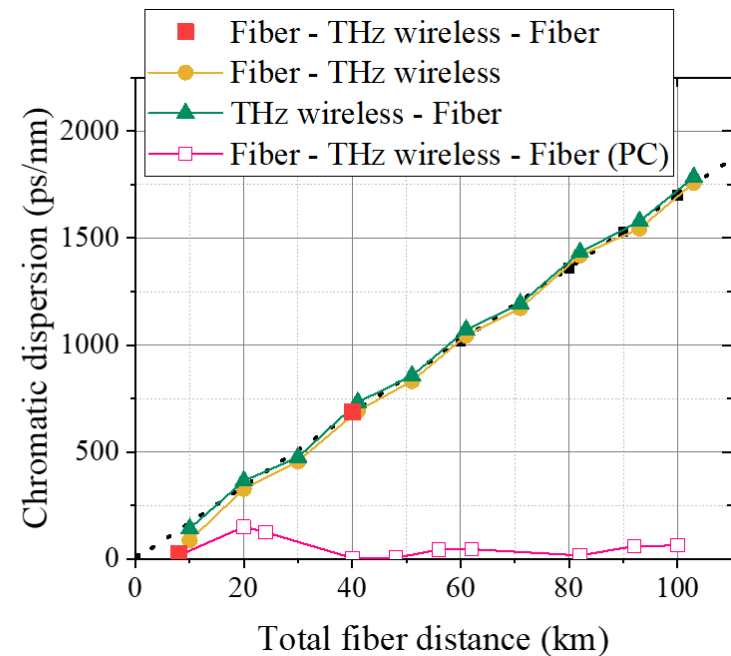
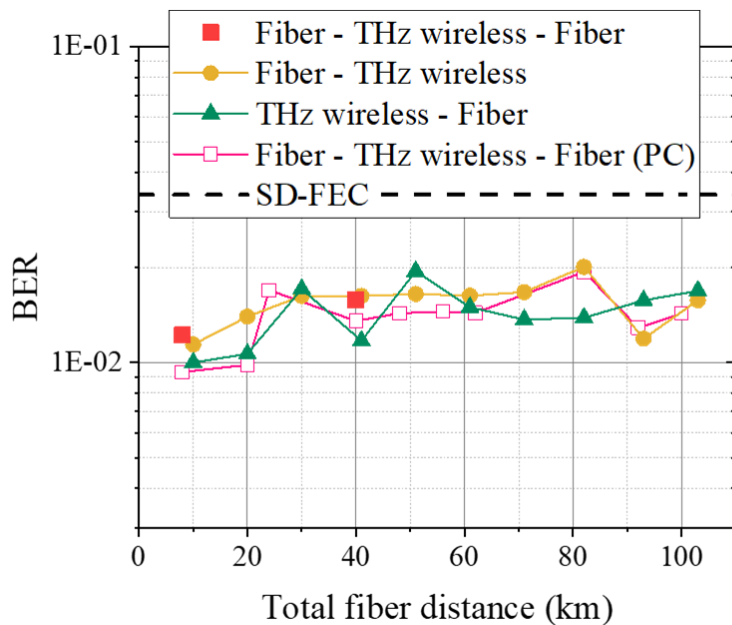# Real-time THz Beamforming Demo

- Real-time estimation of the inserted phase shifts w.r.t. reference (AE-0)
- Continuous operation with almost identical communication quality (SNR) irrespective of the Rx rotation
- Best paper award in EuCNC 2020

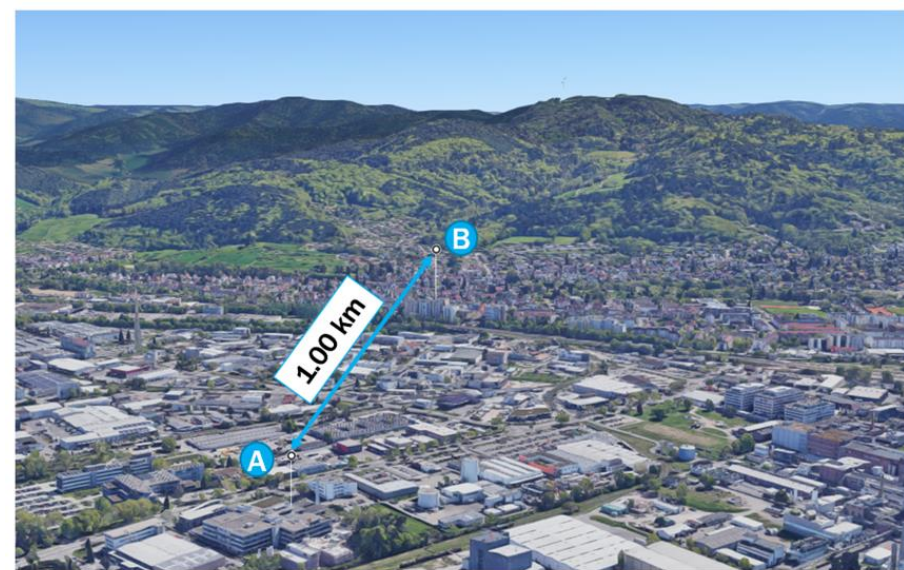# 100 Gb/s Real-Time THz Wireless Demo

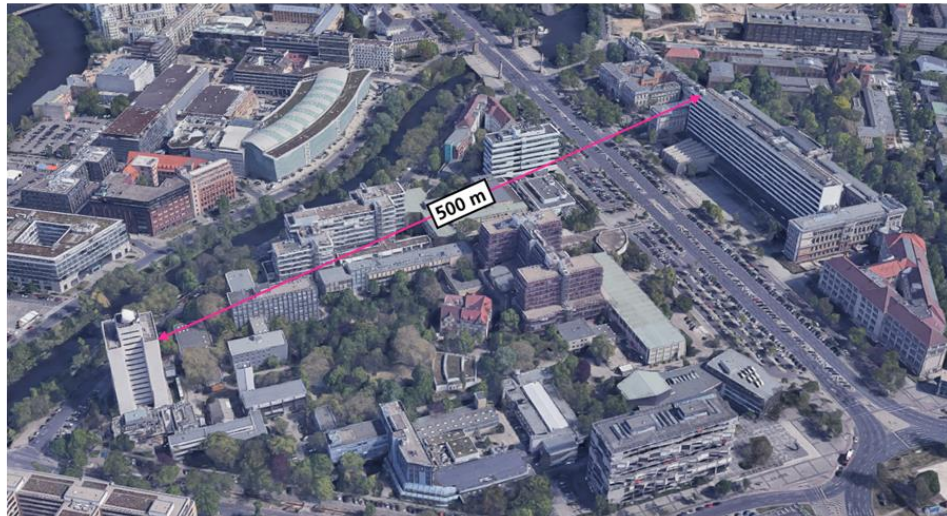# 100 Gb/s Real-Time Fiber-Optic / THz-Wireless Demo

Long-Range THz Wireless Transmission Demo

Test site in Freiburg / Germany over 1 km
(August 2019)

Test site in Berlin / Germany over 500 m
(March 2020)

Are we there yet?
Major THz challenges tackled?

✓ Distance and frequency dependent performance/ design

✓ Range and coverage in the THz regime

✓ Co-design of signals and protocols

✓ Co-design of optical and wireless

✓ Analytical, algorithmic and experimental proof-of-concept for THz

? Blockage, misalignment, mobility, agility, reconfigurability, reliability
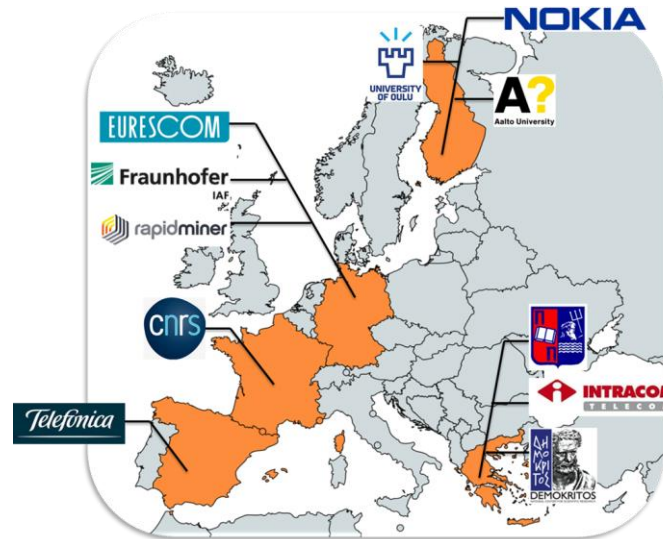
TERRANOVA

Terabit/s Wireless Connectivity by THz innovative technologies to deliver Optical Network Quality of Experience in Systems B5G

ict-terranova.eu

ARtificial Intelligence Aided D-band Network for 5G long term Evolution

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ict-ARIADNE

ARIADNE Pillars and Objectives

| Pillars	Objectives	Actions	Demos	Main KPIs
D-band for 100 Gbit/s reliable wireless connectivity	100 Gbit/s capable, energy and spectral-efficient D-Band wireless B5G networks	• D-band front-end • Baseband DSP • Adaptive spatial SP • High gain D-band antennas • Channel modelling	P2P D-band LOS outdoor demo	100 Gbps throughput / 100m range / Massive number of devices / Zero latency / Ultra-high reliability
Communications beyond the Shannon paradigm	Ultra-reliable D-band connectivity and reconfigurability in all usage environments	• Reconfigurable adaptive metasurface design • Beamforming for LOS and NLOS links • MAC design	Metasurface-based D-band demo	
Artificial Intelligence-based wireless system concept	Transform networks B5G into intelligent connectivity/computing platforms	• ML for channel modelling • ML-based resource allocation and energy efficiency ML for network deployment optimization	Intelligent D-band Network Demo	

ARIADNE System Concept and Use Cases

Use Case 1: Outdoor backhaul/fronthaul
Use Case 2: Advanced NLOS connectivity based on RISs
Use Case 3: Adhoc connectivity in moving network topology
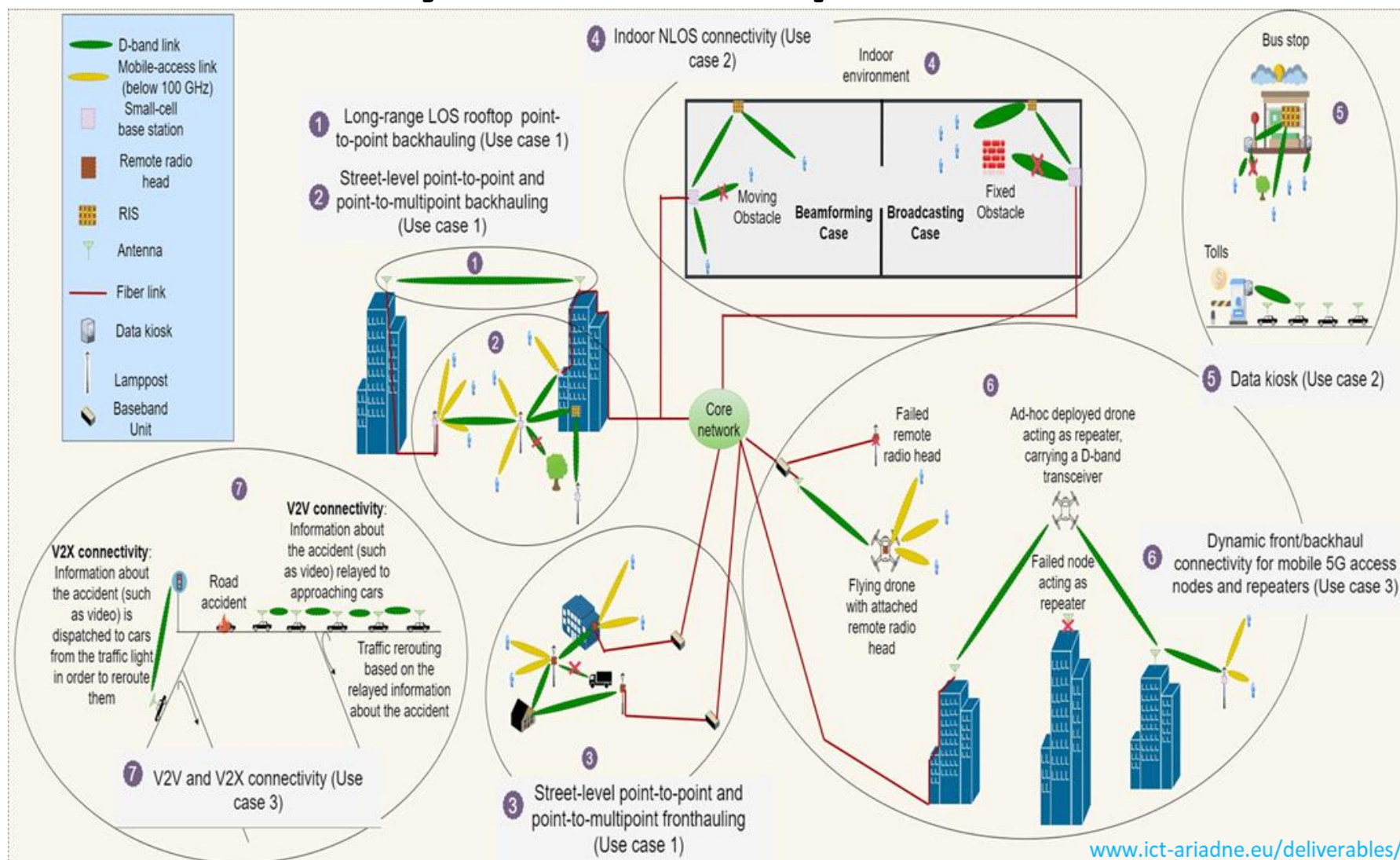
www.ict-ariadne.eu/deliverables/

Beyond Shannon Communication System Architecture
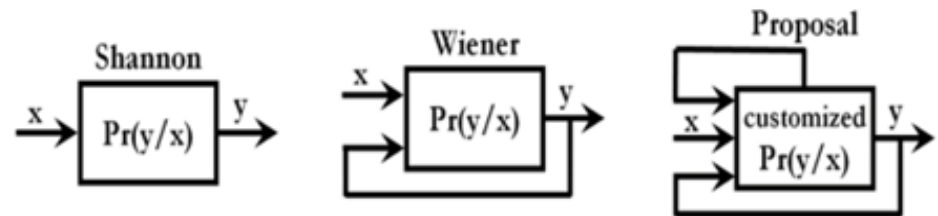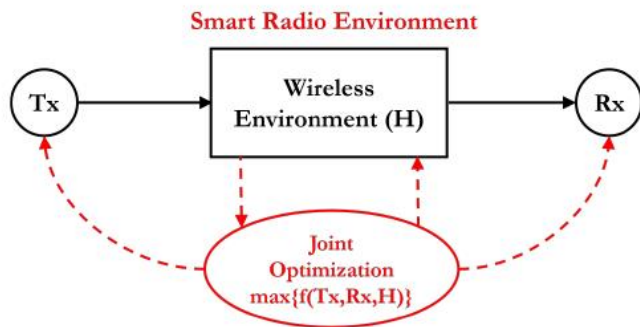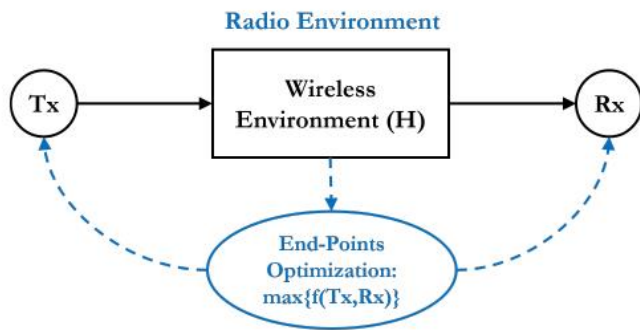
By jointly optimizing the transmitter, the receiver, and the environment, the channel capacity of a point-to-point wireless communication system can be further improved.

Source: M. Di Renzo et al., "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2450-2525, Nov. 2020, doi: 10.1109/JSAC.2020.3007211.

A RIS-based Wireless Architecture
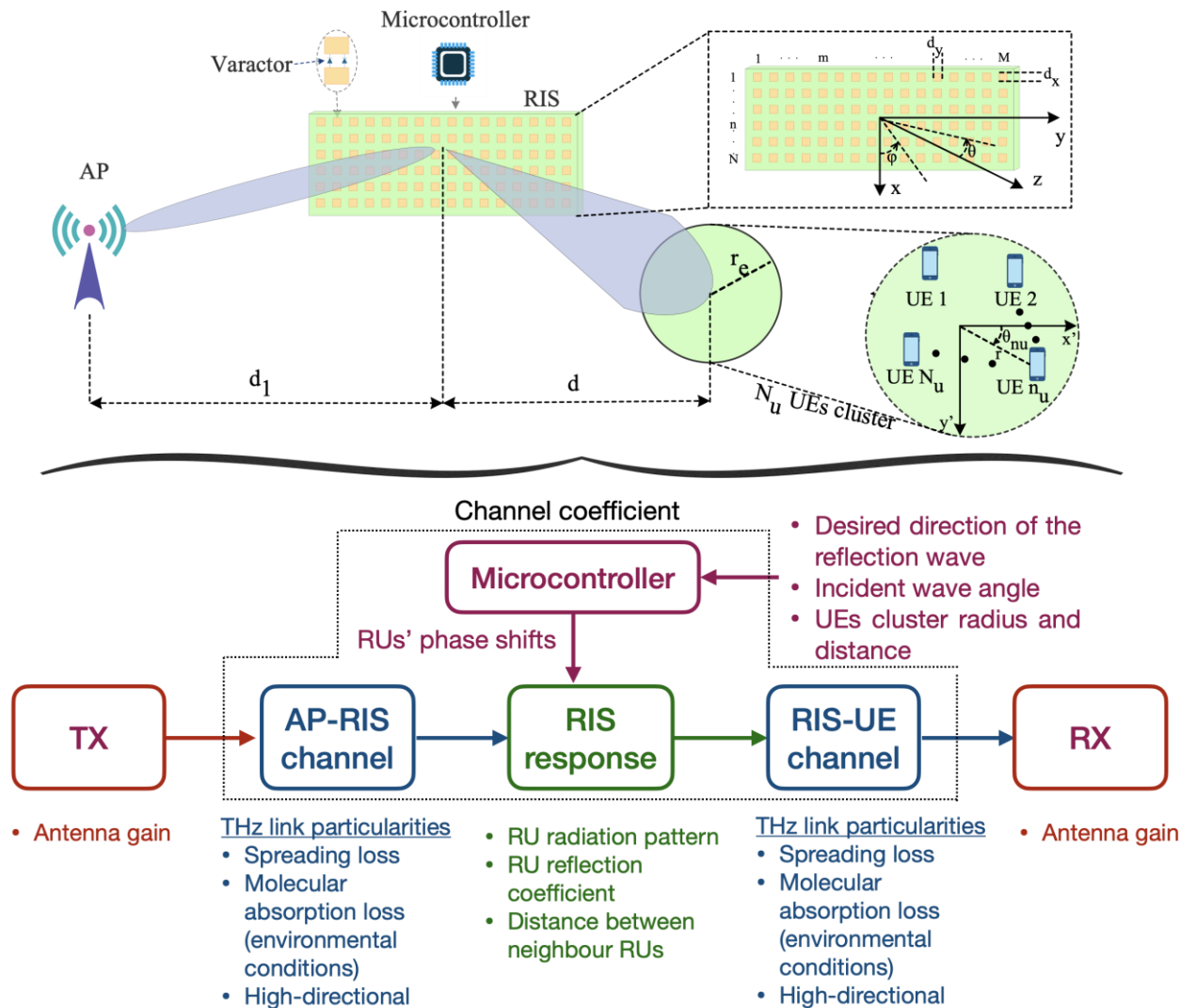
A RIS-based Beyond Shannon Communication System Architecture

Source: M. Di Renzo et al., "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 11, pp. 2450-2525, Nov. 2020
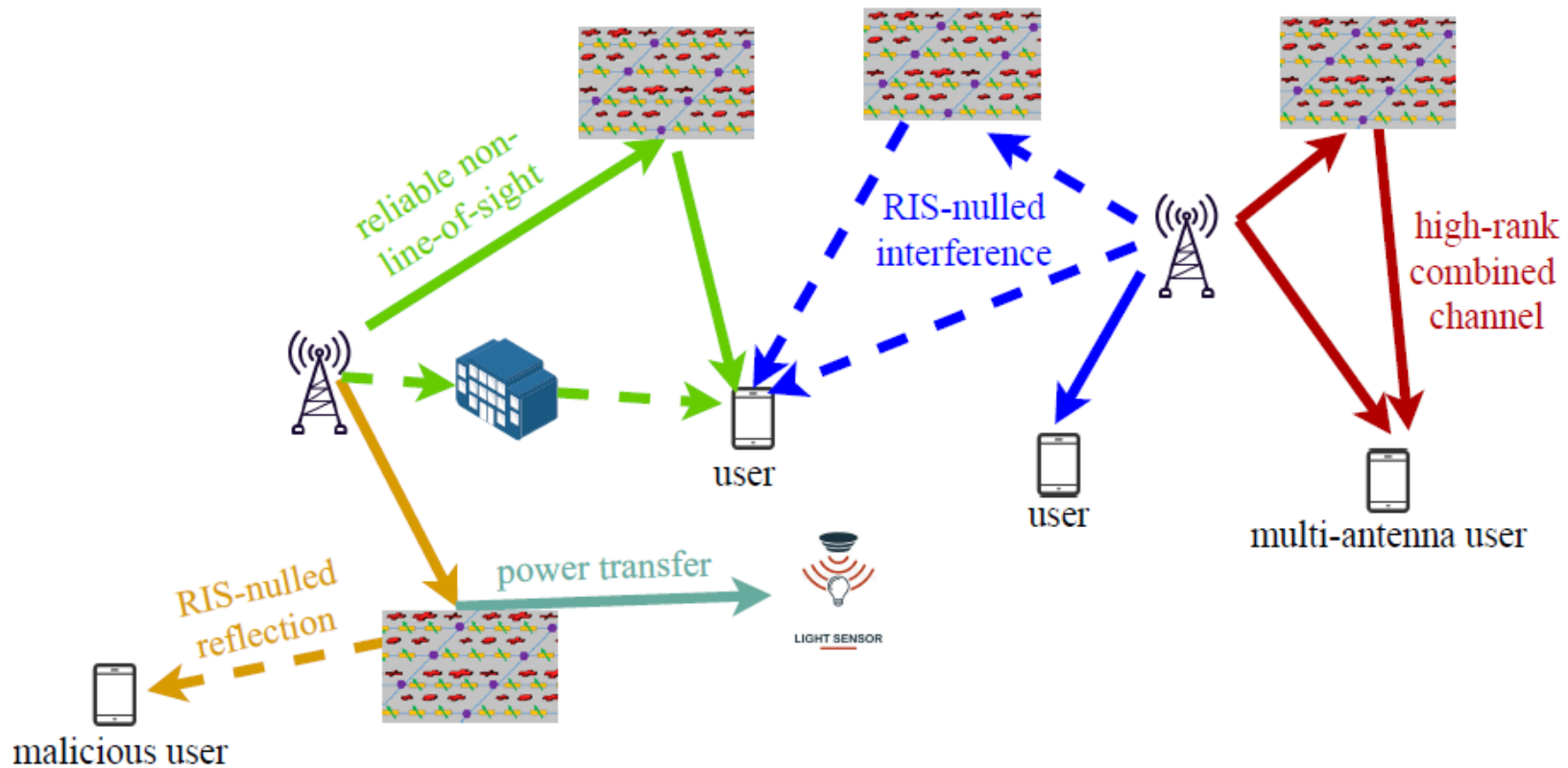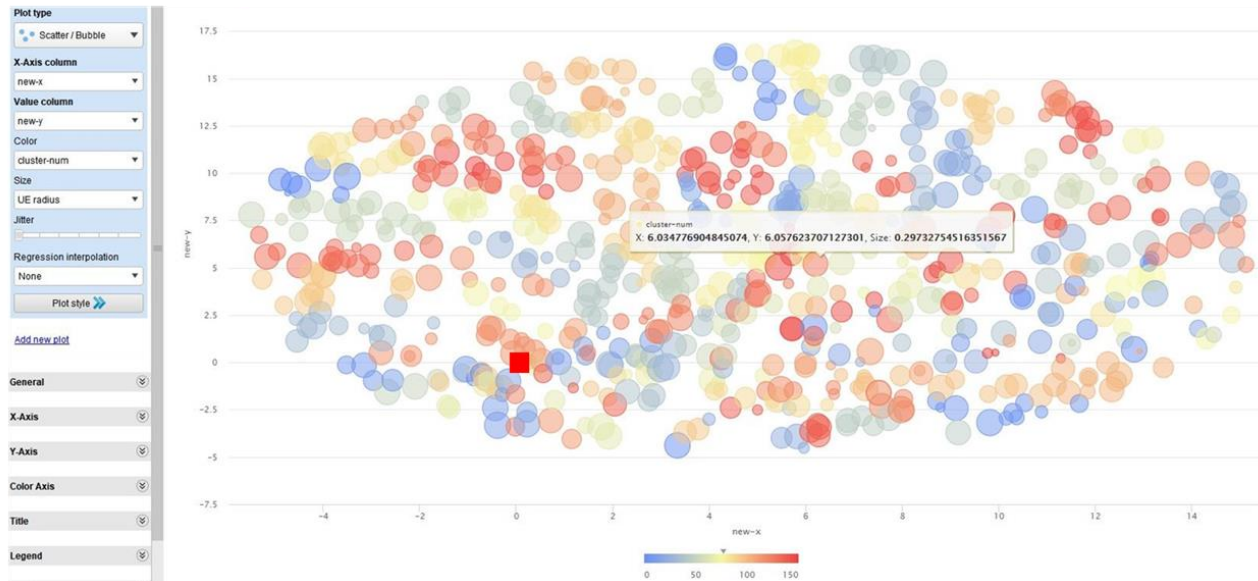
AI/ML-powered Network Architecture

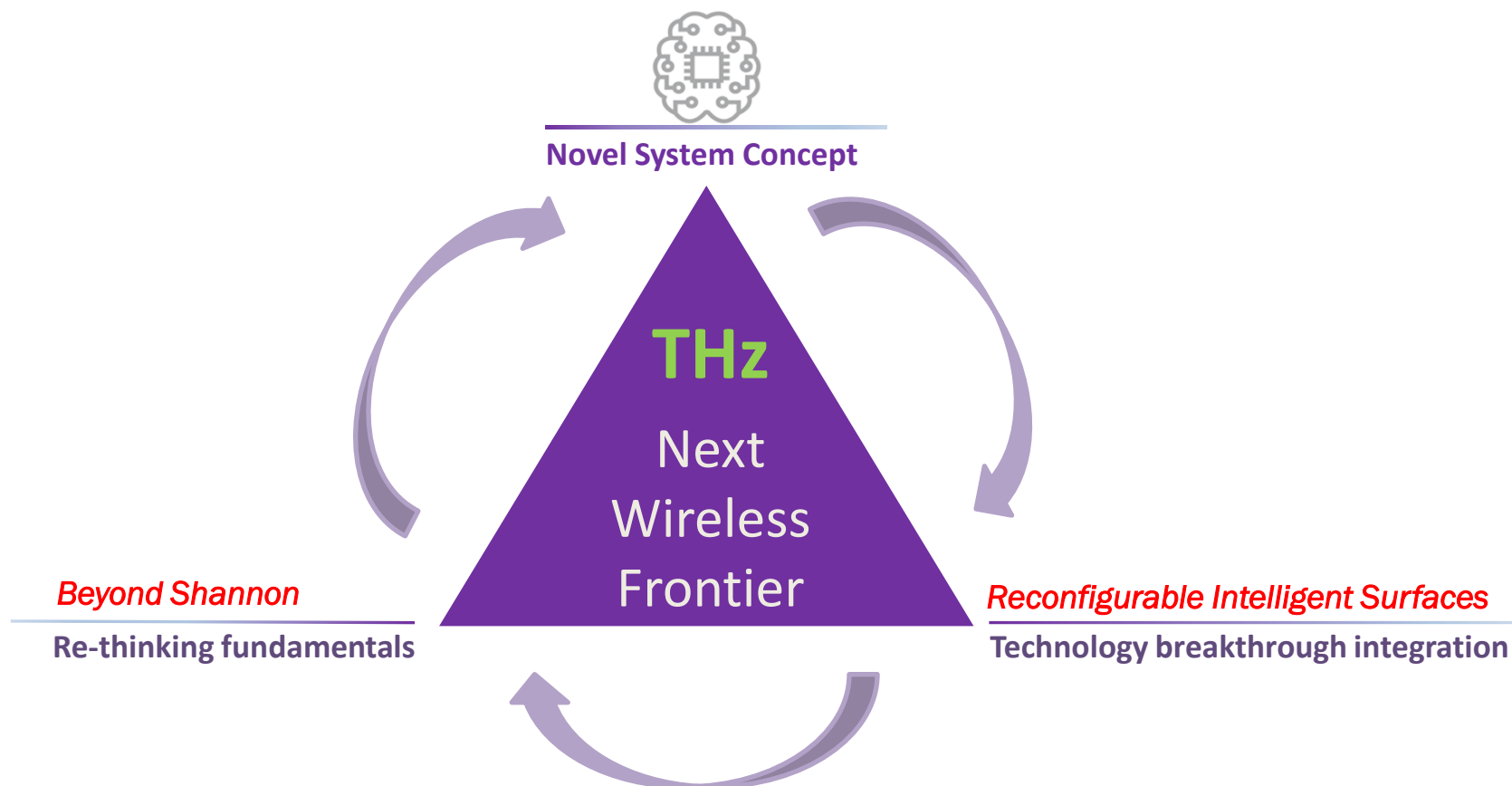- Potential blockers are clustered
  - Size of point = UE radius

Example - Blockage prediction

Other examples include:

- Channel modelling
- Beamforming and tracking algorithms
- RIS behaviour modelling, design/optimization
- Resource allocation or route finding/scheduling
- Blockage, misalignment impairments mitigation
- Wireless nodes and RISs placement and association

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A roadmap to 6G

Novel System Concept

THz Next Wireless Frontier

Beyond Shannon
Re-thinking fundamentals

Reconfigurable Intelligent Surfaces
Technology breakthrough integration

Thank You!

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