Unlocking the potential of THz Communications

for Ubiquitous, Intelligent and Perceptive wireless connectivity

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Outline

- 6G Usage Scenarios
- THz wireless links unique features
- THz links for 6G and beyond system concepts:
  - Pencil BF for Ubiquitous Connectivity
  - RIS for Intelligent Connectivity
  - Near Field processing for Perceptive Connectivity
- Concluding remarks

Usage Scenarios (r)evolution

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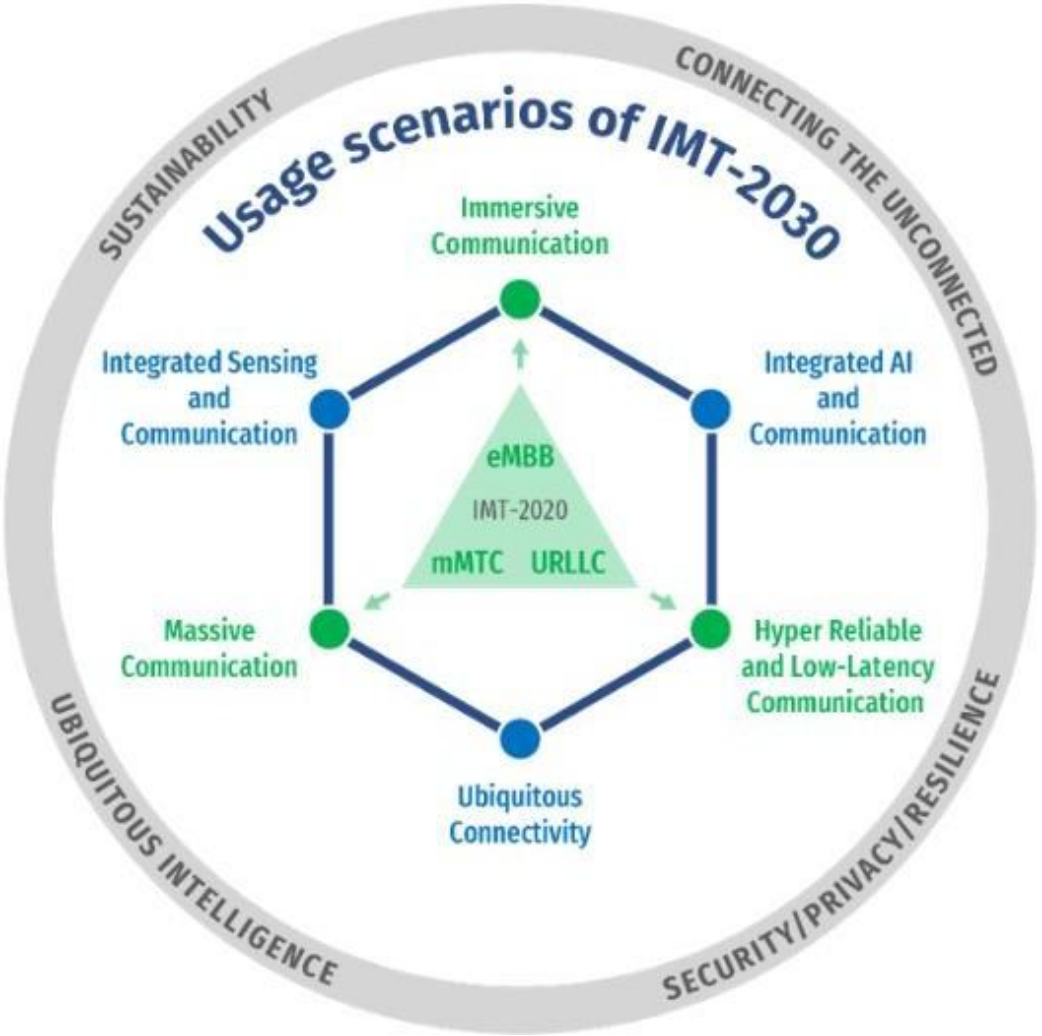
Perceptive Networks



AI

Beyond Shannon Intelligence

Beyond transmitting bits:

- Monitoring
- Detection
- Tracking
- Localization
- Shape identification
- Semantics

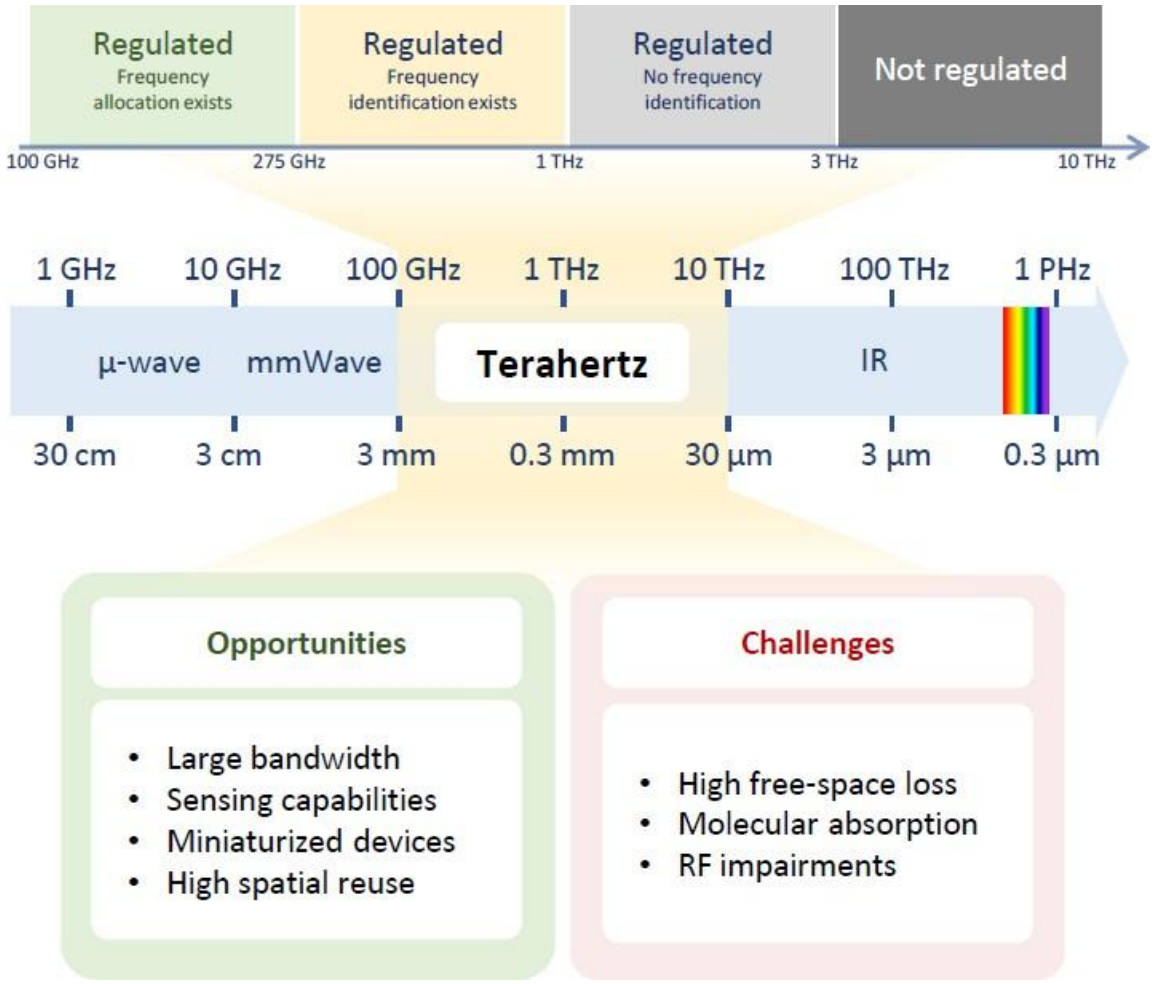
Beyond throughput/coverage:

- Reconfigurability
- Programmability/ Tunability
- Agility
- Accuracy
- Sustainability
- Resilience

‘fiber over the air’

Usage Scenarios schematic from ITU-R M.2160-0 (11/2023)

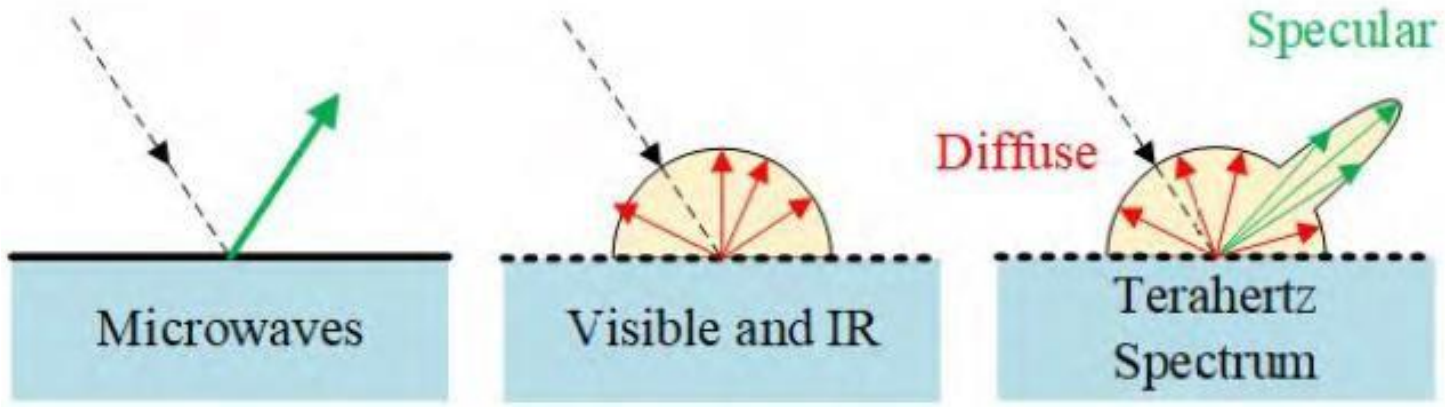
THz unique feature #1
bandwidth



Band [GHz]	Bandwidth [GHz]	Regulatory status
102 - 109.5	7.5	Allocated
141 - 148.5	7.5	Allocated
151.5 - 164	12.5	Allocated
167 - 174.8	7.8	Allocated
191.8 - 200	8.2	Allocated
209 - 226	17	Allocated
231.5 - 239.2	7.7	Allocated
252 - 275	23	Allocated
275 - 296	21	Identified
296 - 306	10	Not identified
306 - 313	7	Identified
313 - 318	5	Not identified
318 - 321	3	Identified
327 - 333	6	Identified
333 - 356	23	Not identified
356 - 368	12	Identified
391 - 433	42	Identified
452 - 520	68	Not identified
598 - 722	124	Not identified
786 - 953	167	Not identified

Zugno, Tommaso, Cristina Ciochina, Sharad Sambhwani, Patrick Svedman, Luis M. Pessoa, Ben Chen, Per Hjalmar Lehne, Mate Boban, and Thomas Kürner. "Use Cases for Terahertz Communications: An Industrial Perspective." *arXiv preprint arXiv:2501.03823* (2025).

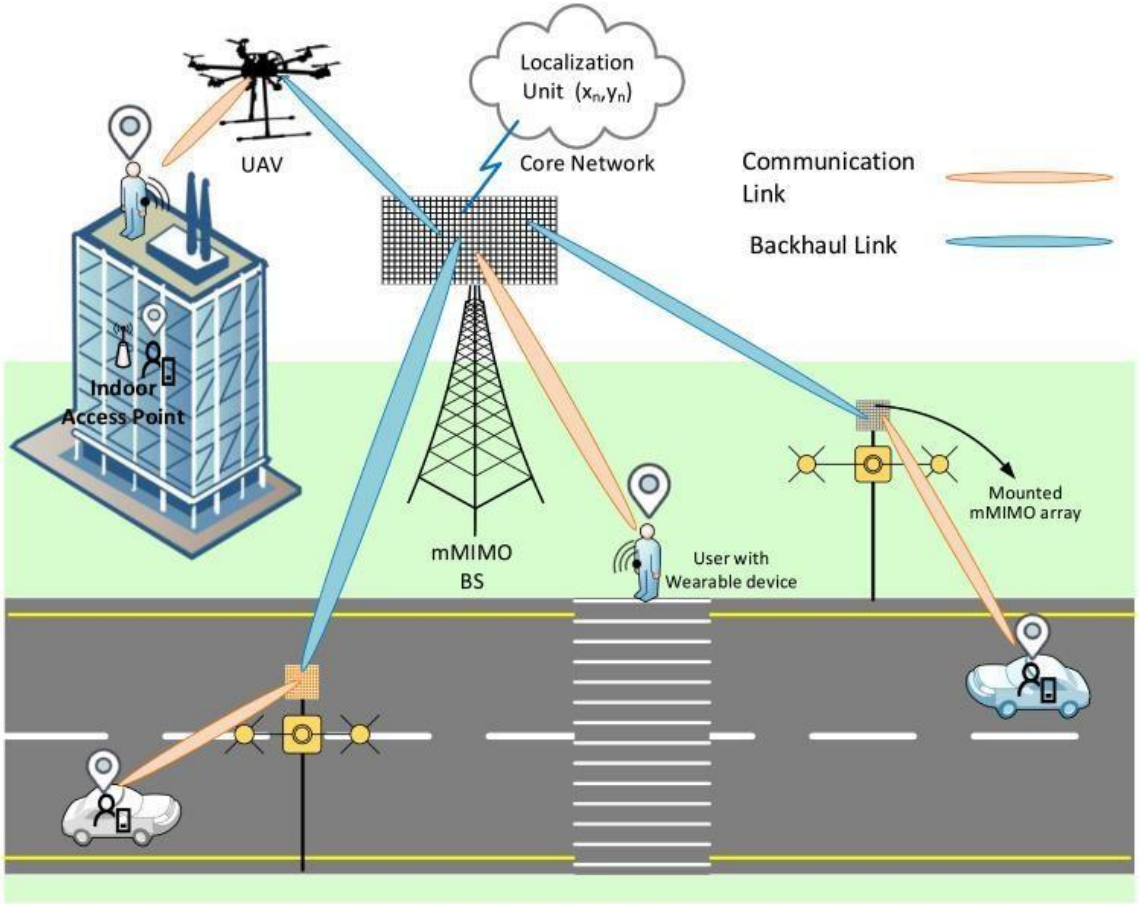
THz unique feature #2
propagation



T. S. Rappaport et al., "Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond," in IEEE Access, vol. 7, pp. 78729-78757, 2019, doi: 10.1109/ACCESS.2019.2921522.

- THz waves combine advantages of microwaves and visible light.
- THz scattering exhibits both specular and diffuse scattering from most building surfaces.
- The strong specular component turns the surfaces into ‘‘electrical mirrors’’, thus allowing imaging, while maintaining pencil beams and high spatial resolution.

THz unique feature #3
Large Aperture Antenna Arrays



- Pencil Beamforming
- Massive MIMO / XL-MIMO
- Reconfigurable Intelligent Surfaces
- Holographic MIMO

Pencil Beamforming THz wireless links for Ubiquitous Connectivity

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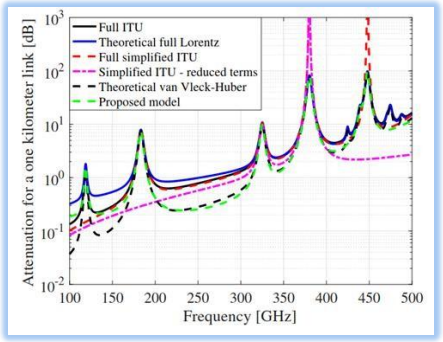
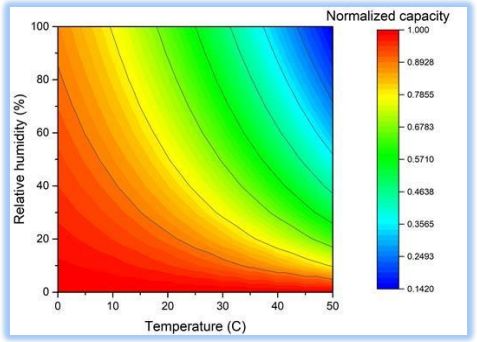
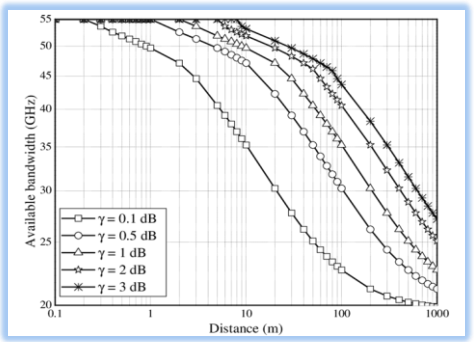
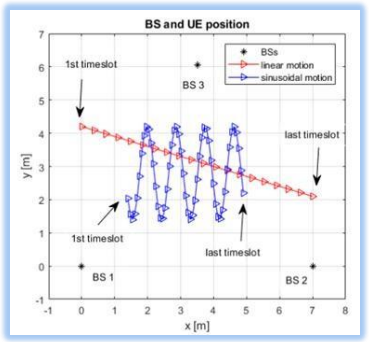
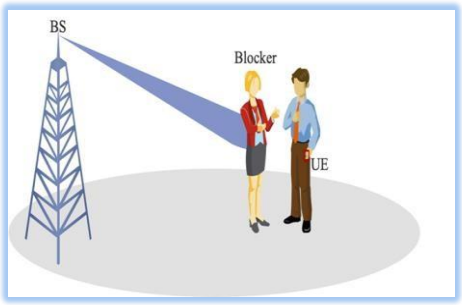


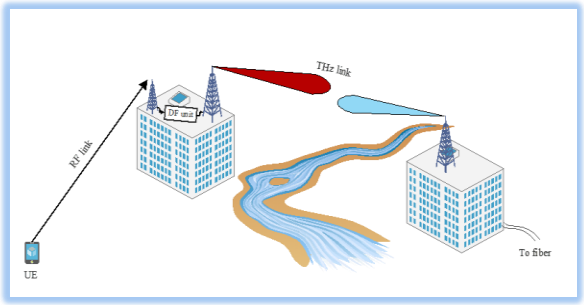


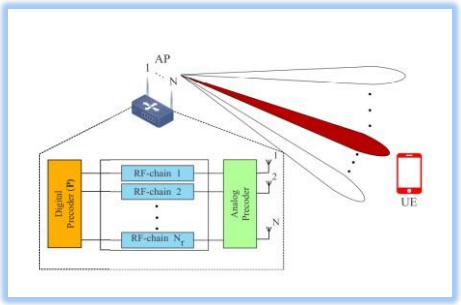


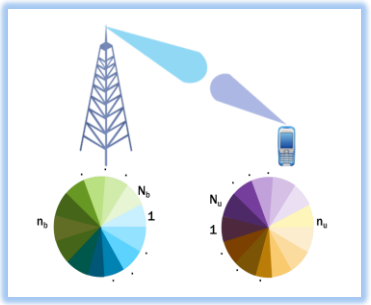


- Path loss, channel modelling
- Environmental parameters
- Distance-dependent BW
- Pencil Beamforming





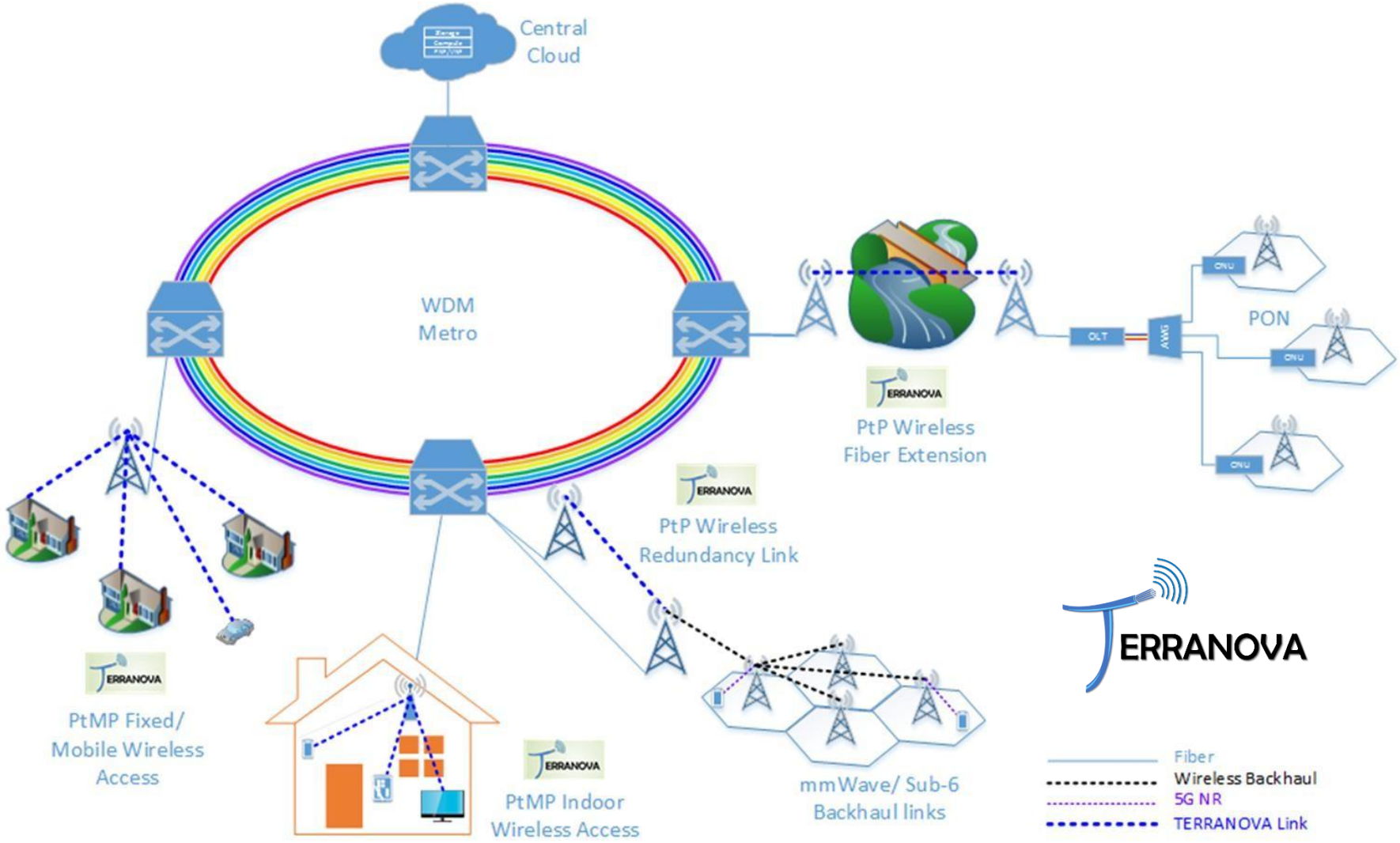




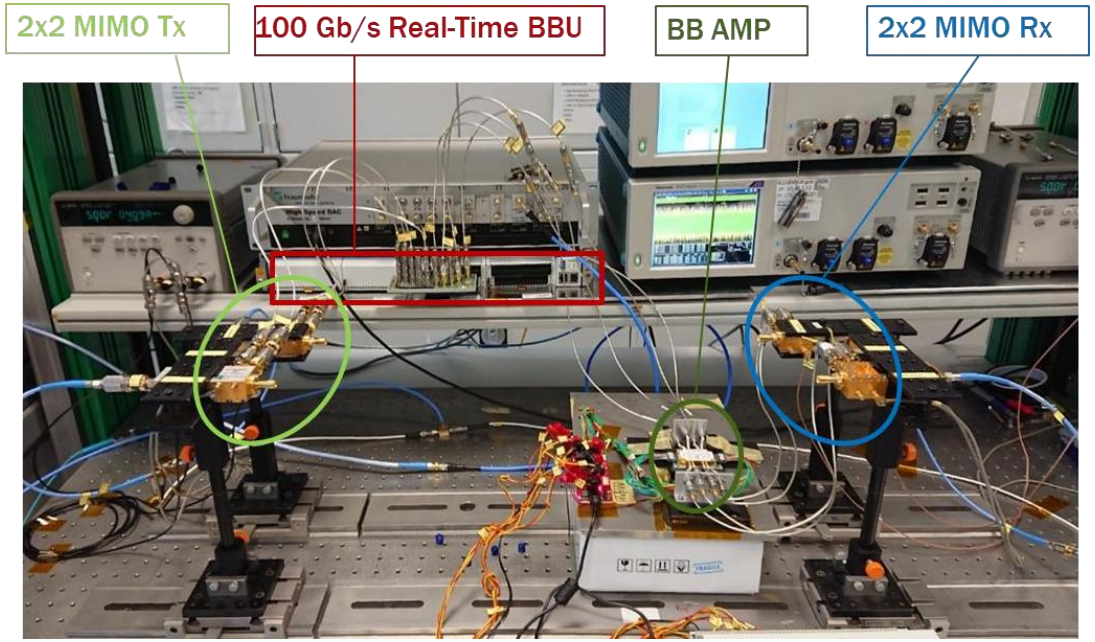
- Blockage
- Misalignment
- BF Tracking
- Pencil-beam PHY, MAC

‘Fiber over the air’

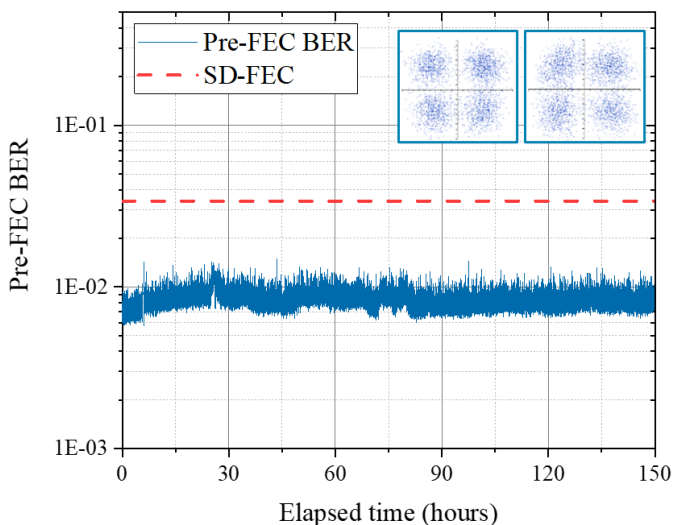
An integrated architecture for Ubiquitous Connectivity based on Pencil Beamforming sub-THz links

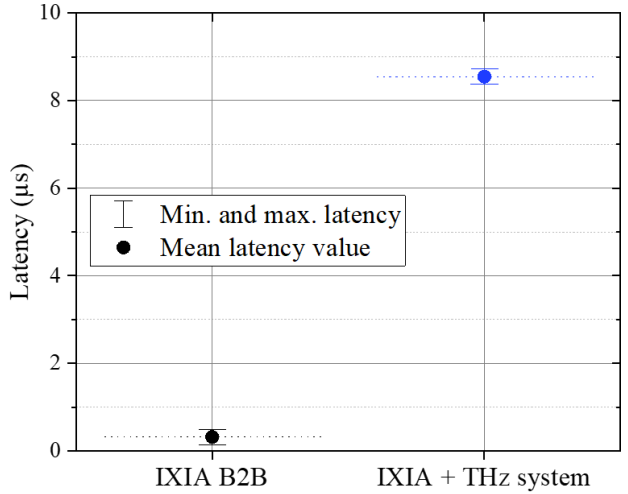


High-Capacity THz Wireless Demo



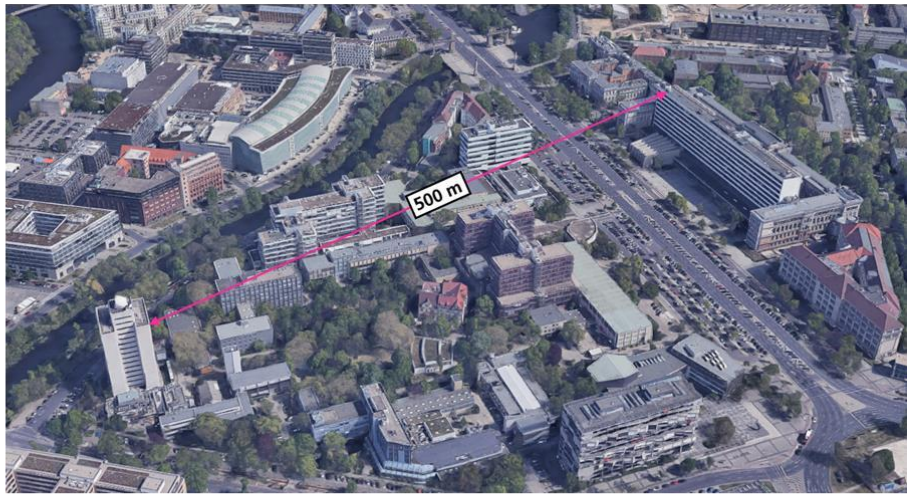
Demo developed by TERRANOVA project partner Fraunhofer HHI





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)

Demo developed by TERRANOVA project partners Fraunhofer HHI and Fraunhofer IAF

RIS-aided THz wireless links for Programmability Intelligence

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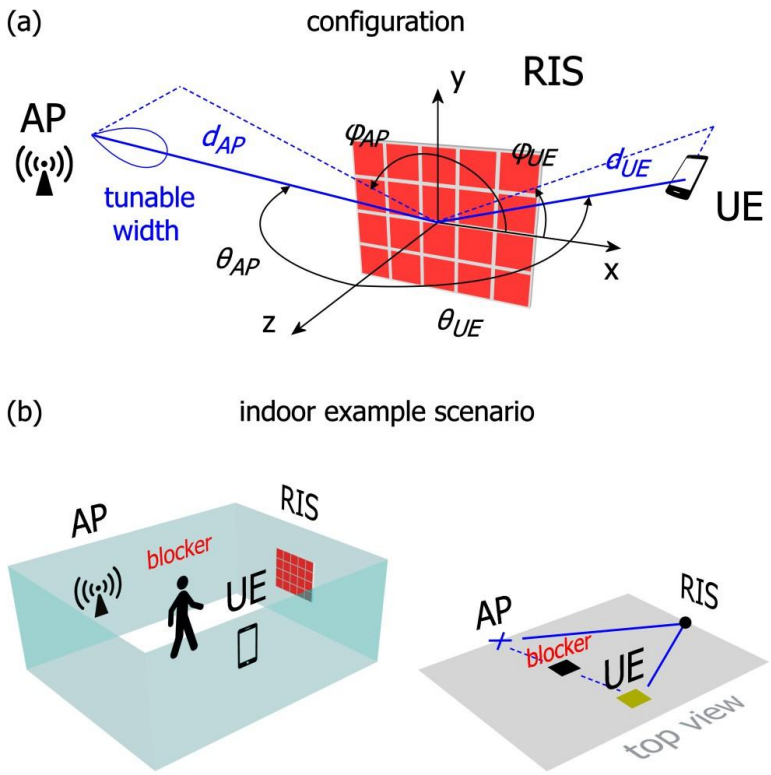
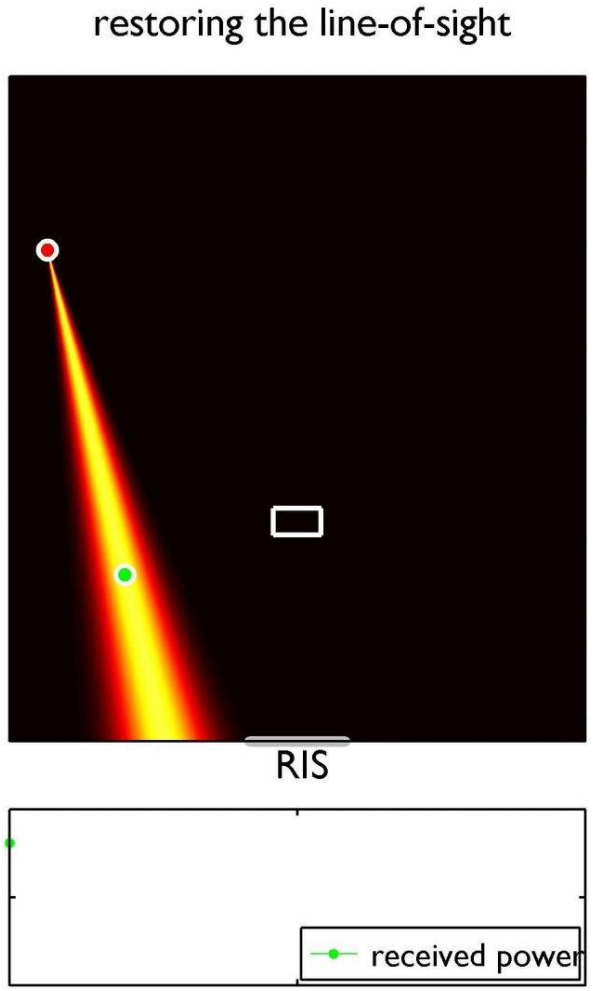
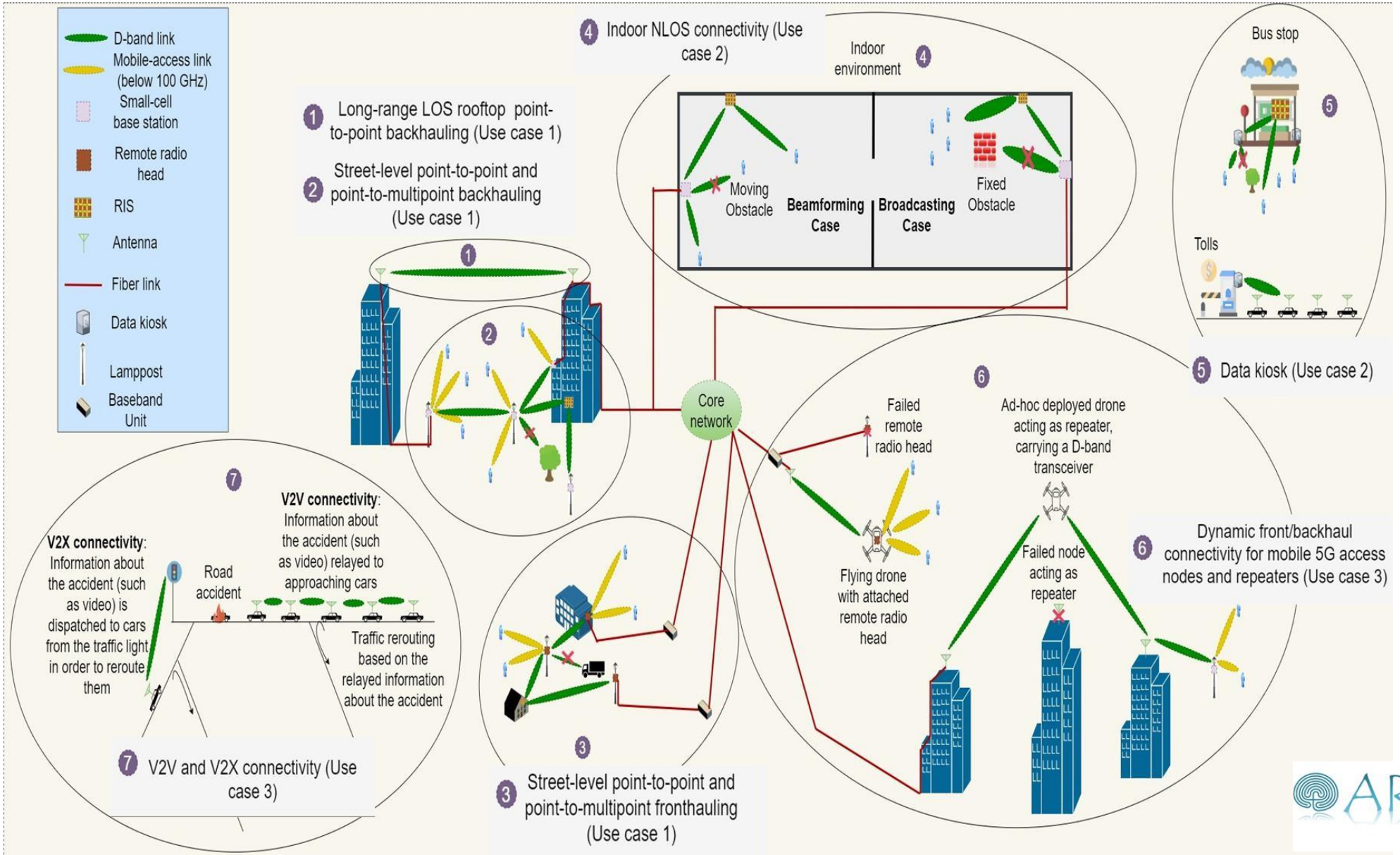




- A RIS is a reflective surface composed of subwavelength scatterers.
- RISs tailor the wavefront of incident beams, with the aim to make wireless links programmable.

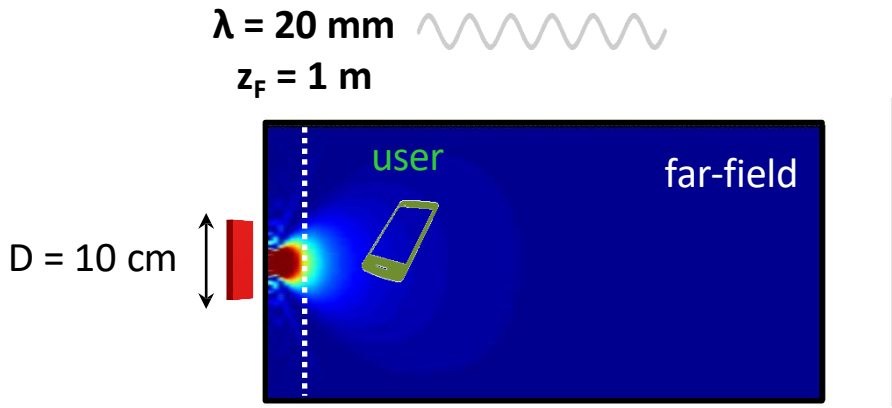
G. Stratidakis, S. Droulias and A. Alexiou, "Understanding the RIS efficiency: from partial to full illumination", IEEE 23rd International Workshop on Signal Processing Advances in Wireless Communication, Oulu, Finland (2022).
Stratidakis G, Droulias S and Alexiou A (2022) A beam-tracking framework for THz networks. Front. Comms. Net 3:965336. doi: 10.3389/frcmn.2022.965336

‘Beyond Shannon’ Intelligence
Tunability/ Programmability with RIS



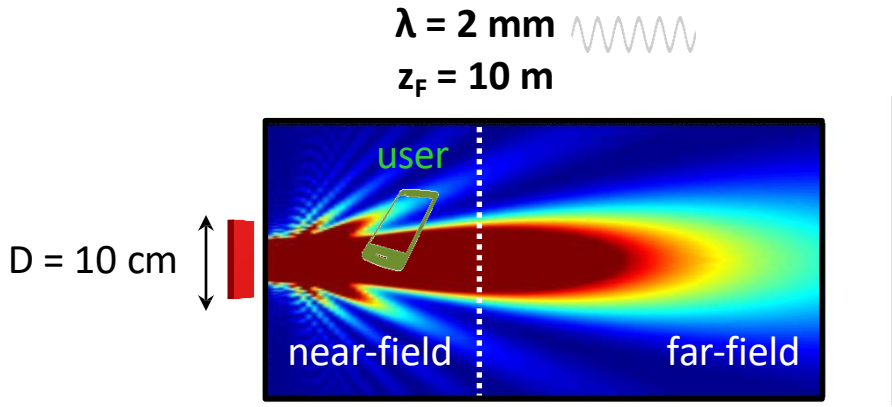
Near-Field Communications and Wavefront engineering

- **Wavefront engineering** provides control of the received power density as well as **beam trajectory control.**



Near-Field Comms merits:

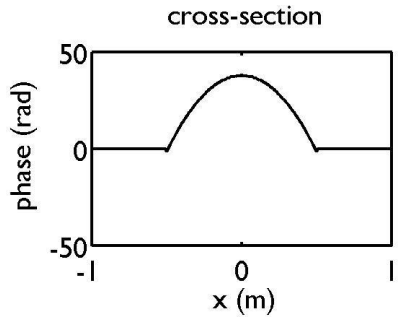
- Energy focus/efficiency/control
- Static/dynamic blockage avoidance
- Beam resilience
- Beam trajectory control
- Localization/tracking (angular, radial)

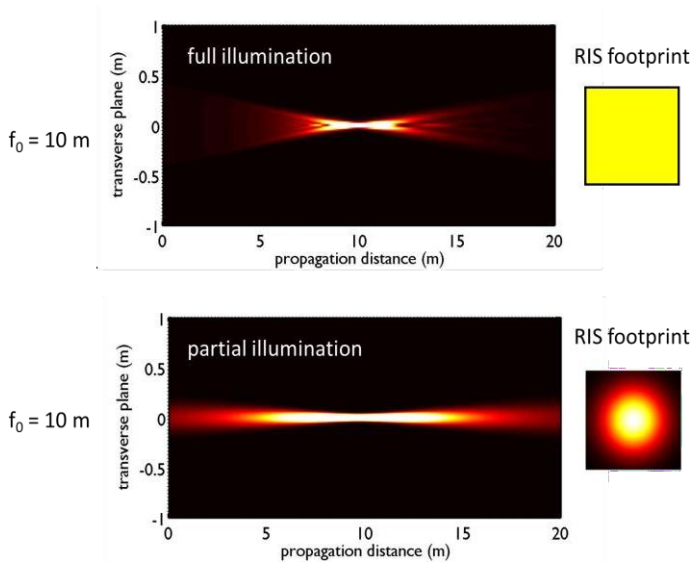


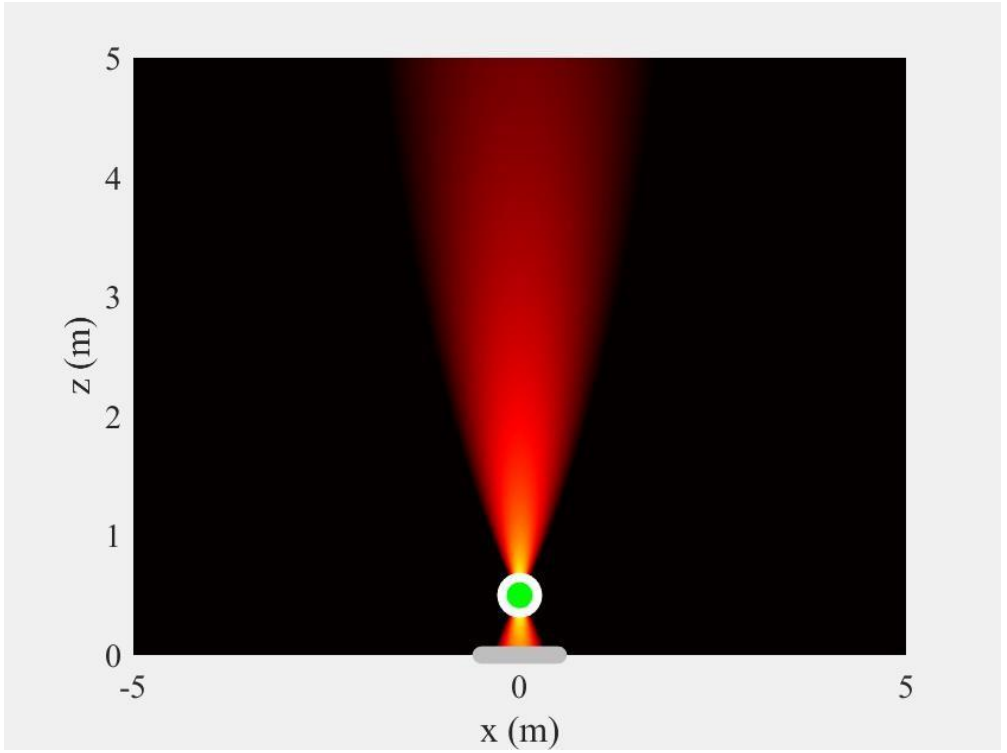
User in the ‘spotlight’ with Beam Focusing

parabolic phase

$\phi(r) = - i k r^2/2f_0$





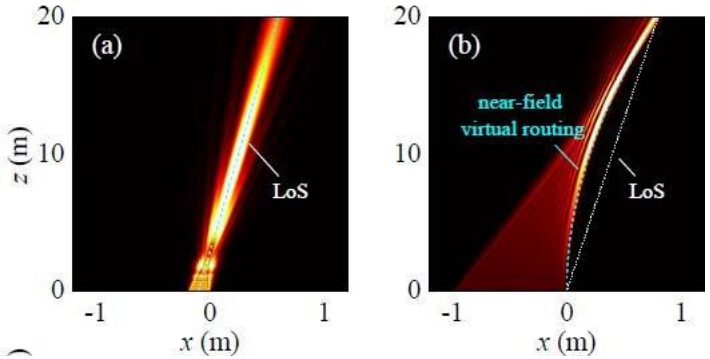


S. Droulias, G. Stratidakis and A. Alexiou, "Near-Field Engineering in RIS-Aided Links: Beamfocusing Analytical Performance Assessment," IEEE Access, vol. 12, pp. 29536-29546, 2024, doi: 10.1109/ACCESS.2024.3368397.

Wavefront engineering

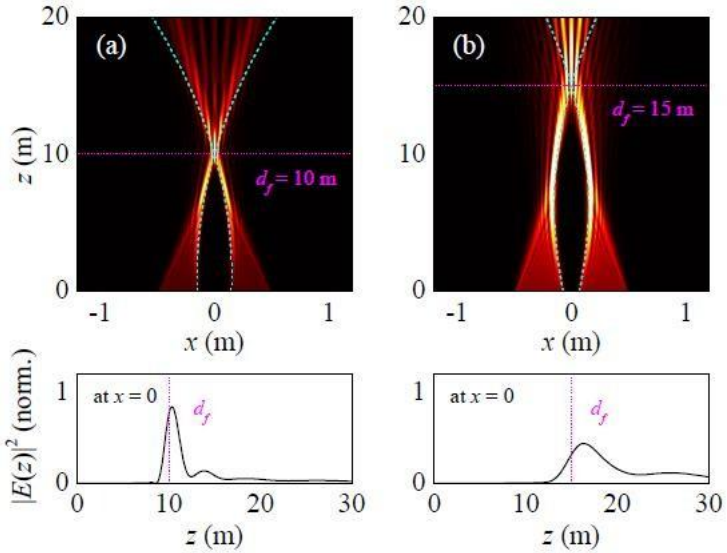
Bending Beams can be synthesized to follow an arbitrary convex trajectory

User on trajectory and near-field virtual routing

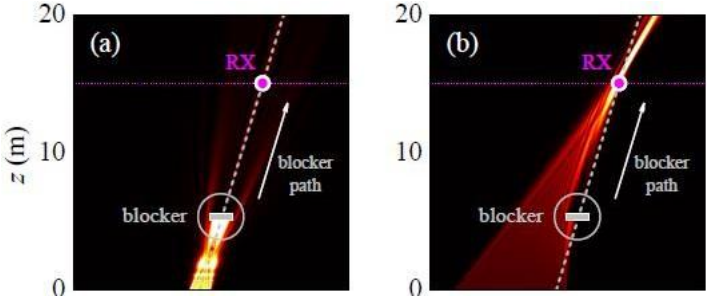


Interference management

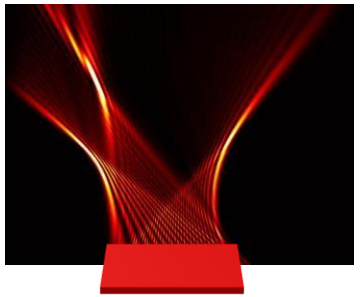
Wireless power transfer and energy efficient connectivity



Static/Dynamic blockage avoidance and beam resilience

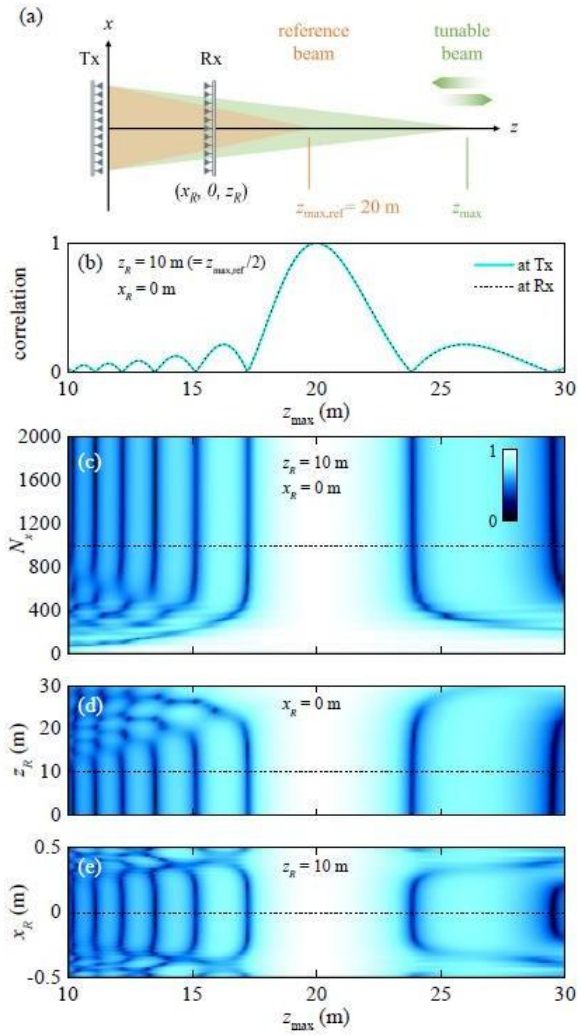


Multi-beam operation

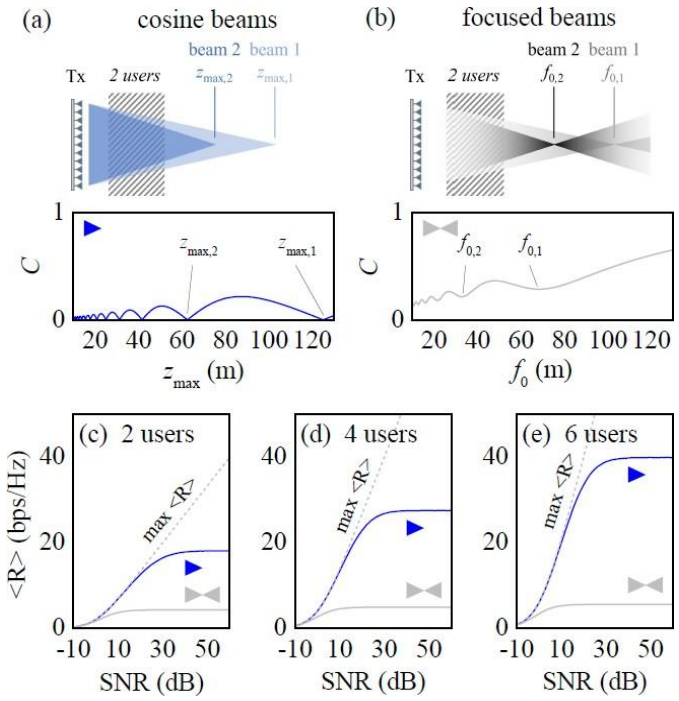


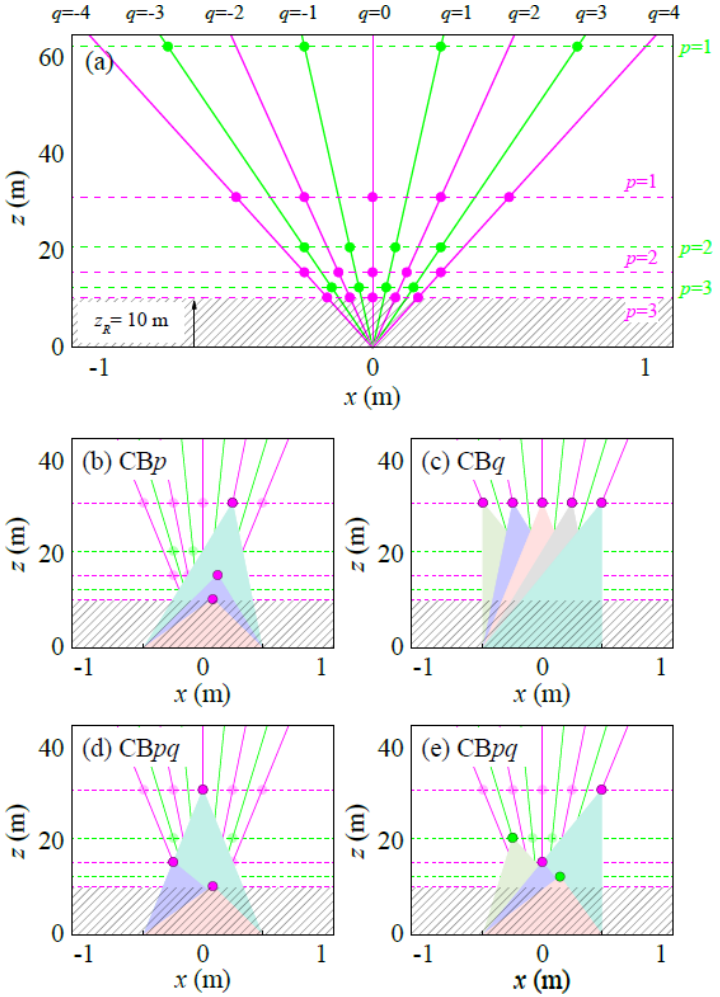
S. Droulias, G. Stratidakis and A. Alexiou, "Bending Beams for 6G Near-Field Communications," n IEEE Transactions on Wireless Communications, vol. 24, no. 2, pp. 1467-1480, Feb. 2025, doi: 10.1109/TWC.2024.3509548.

Near-field SDMA with orthogonal beams



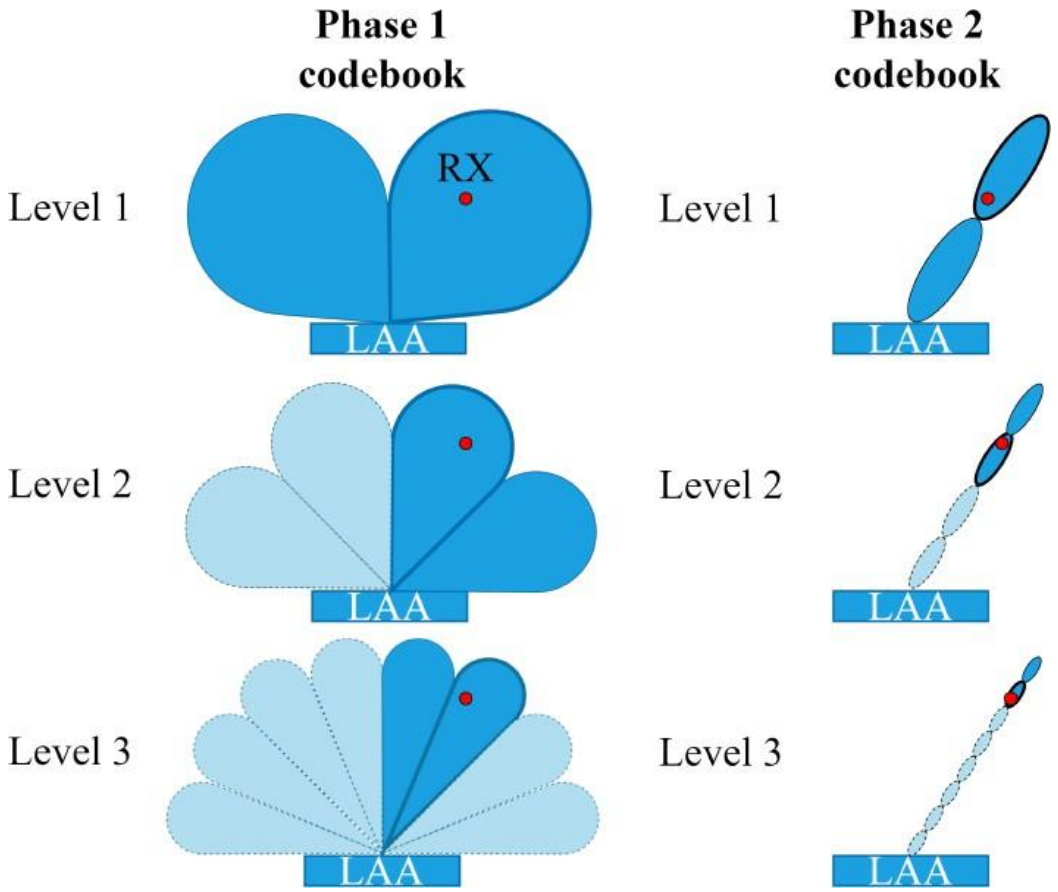
NF-SDMA offers beam orthogonality from the near- up to the far-field w.r.t. the beam direction and range.

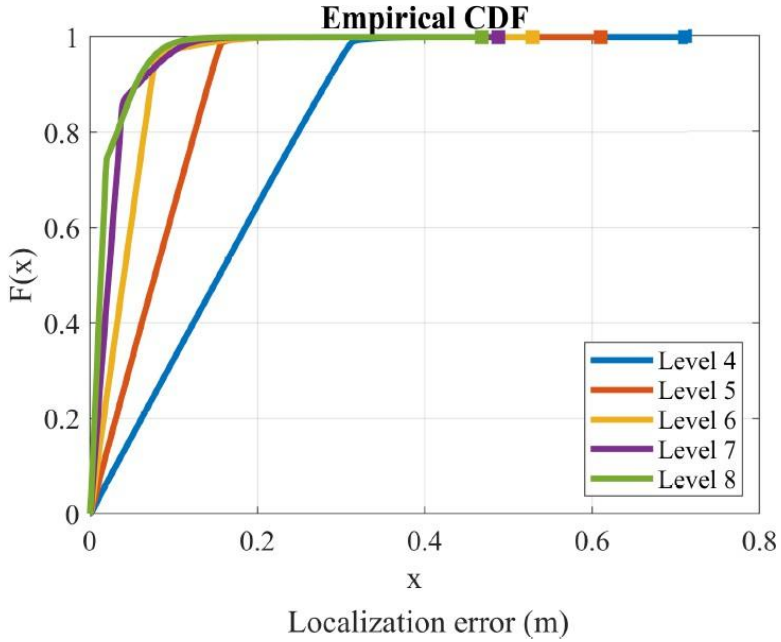




S. Droulias, G. Stratidakis and A. Alexiou, "Orthogonal beams and codebook design for near-field space division multiple access in 6G systems," in IEEE Transactions on Antennas and Propagation, doi: 10.1109/TAP.2025.3569394.

RIS/LAA-as-a-sensor: User tracking and localization





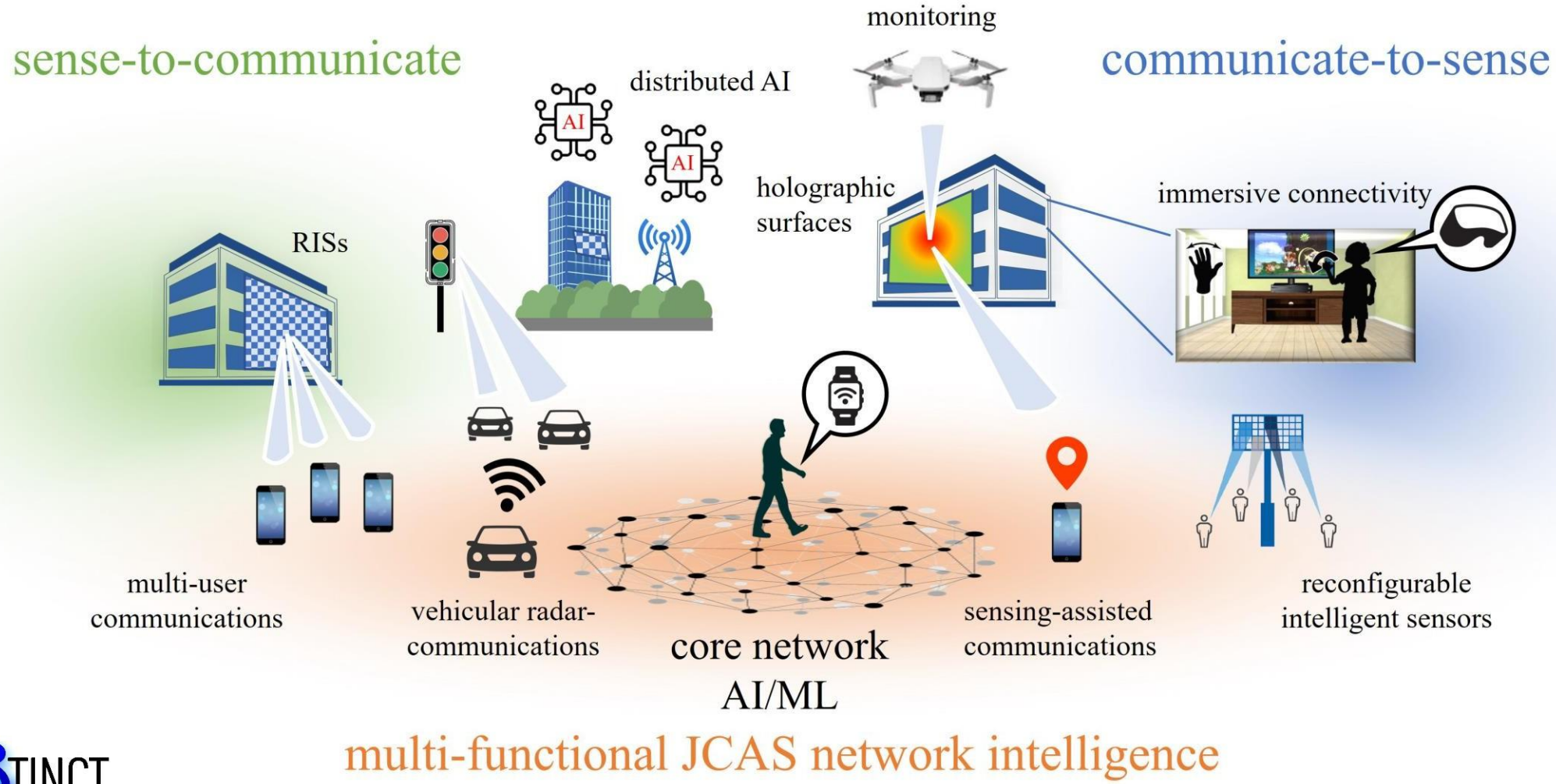
Major radius of each beam-focusing codebook level

codebook level	r_{max} $d_0 = 5$ m	r_{max} $d_0 = 10$ m
1	1.5 m	3 m
2	0.75 m	1.5 m
3	0.375 m	0.75 m
4	0.187 m	0.375 m
5	0.093 m	0.187 m
6	0.046 m	0.093 m
7	0.023 m	0.046 m
8	0.011 m	0.023 m

G. Stratidakis, S. Droulias and A. Alexiou, "Near-Field Hierarchical Localization for Integrated Sensing and Communication," in IEEE Access, doi: 10.1109/ACCESS.2025.3528857.

Perceptive Networks

Environmental mapping, situational awareness, localization/tracking, Internet of Senses



Concluding remarks

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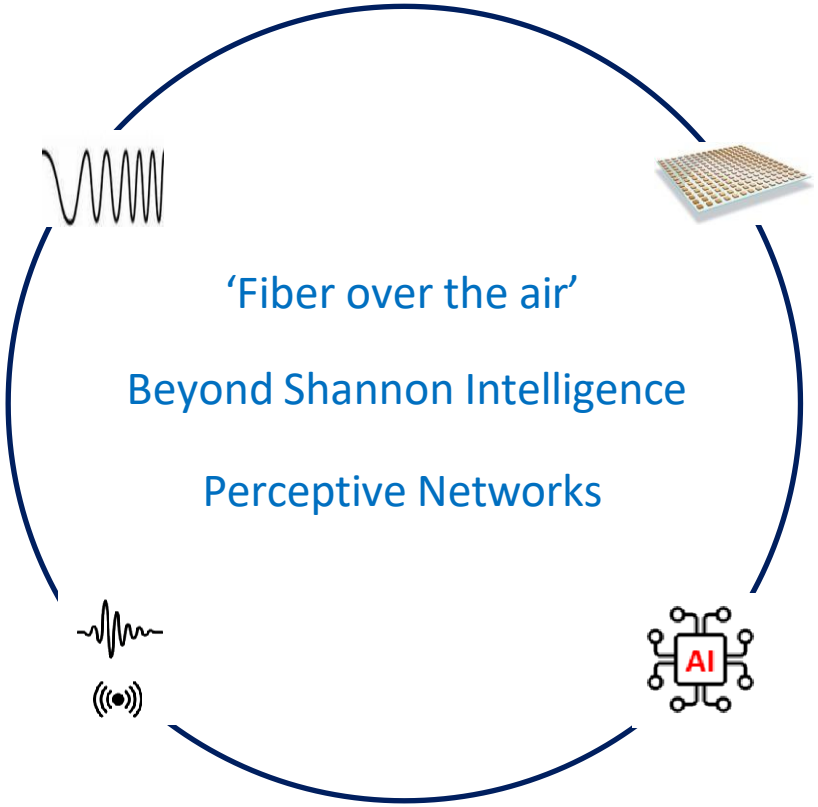
Directional THz wireless connectivity for 6G and beyond:

Ubiquitous + **Intelligent** + **Perceptive**



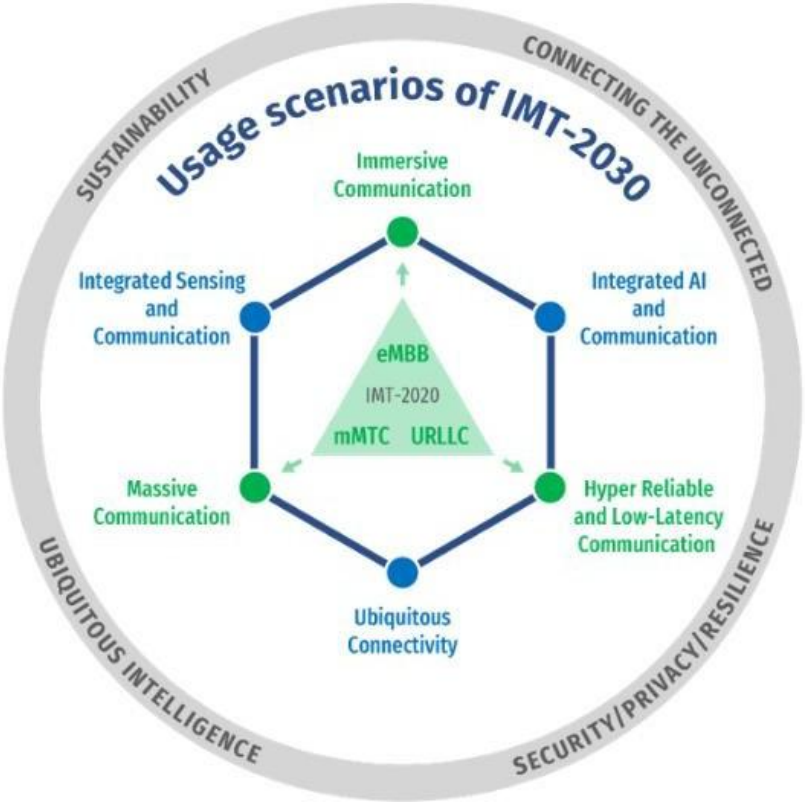
'Fiber over the air'

Beyond Shannon Intelligence

Perceptive Networks

THz Comms can *accelerate* the evolution of advanced 6G enablers: RIS, LAA/XL-MIMO, AI/ML, ISAC.

Consideration of (sub)THz bands in 6G+ may be *motivated* by radio technology developments and usage scenarios TPRs.



Thank you

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Artificial Intelligence Aided D-band Network for 5G Long Term Evolution