Institute for the Wireless Internet of Things
at Northeastern University

Mentor DCN ec-21-0267-00-00EC

The Role of the Spectrum above 100 GHz

Reality Check

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Scoring the Terabit-per-second Goal

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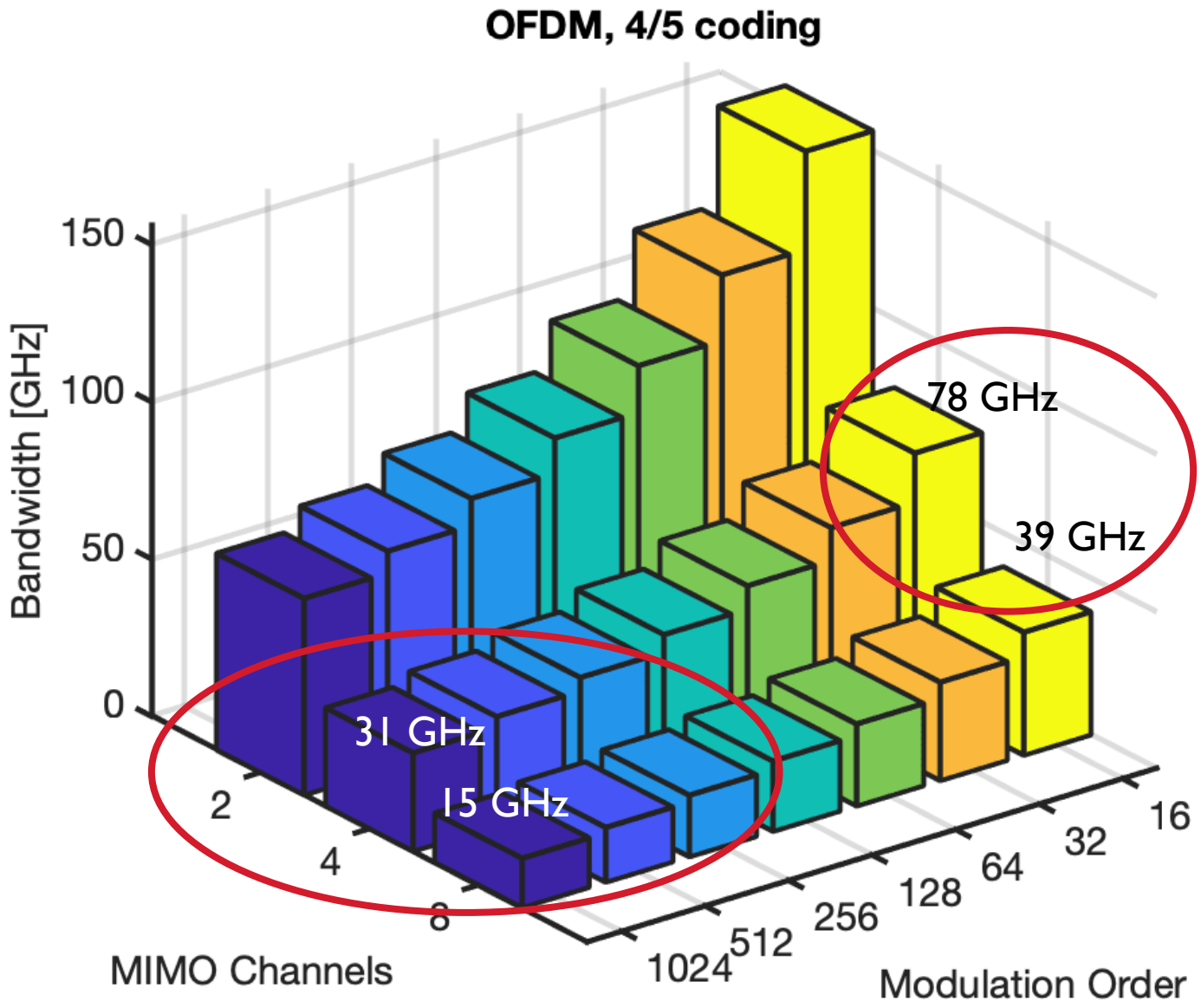
- Early discussions on 6G point to **1 Terabit-per-second (Tbps)** as the target peak bit rate
- How much bandwidth do we need to meet the demand for 1 Tbps?
- It depends on:
  - Modulation order/channel
  - Number of MIMO channels
- Can the technology support these?



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On a Quest for Resources

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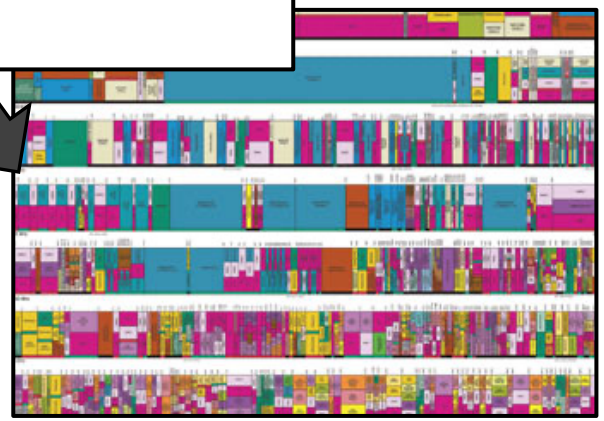
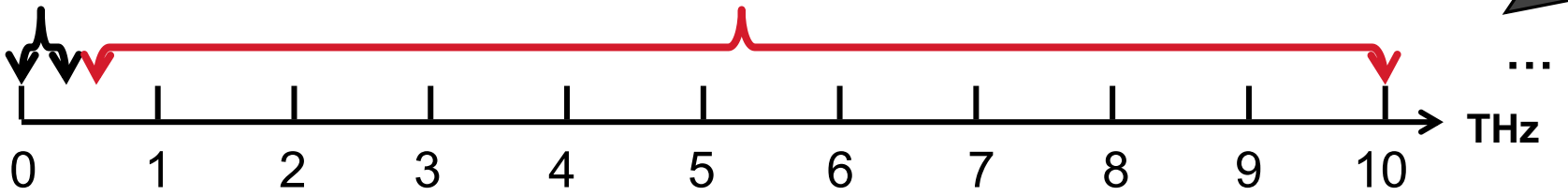
Where do we find such bandwidth?

Everything: Radio, TV, Cellular Systems, Wi-Fi, Radar, GPS, etc.



The Terahertz Band/ Submillimeter Waves

Optical Wireless Systems



I. F. Akyildiz, J. M. Jornet and C. Han, **"TeraNets: Ultra-broadband Communication Networks in the Terahertz Band,"** IEEE Wireless Communications Magazine, 2014.

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Opportunities at Terahertz Frequencies

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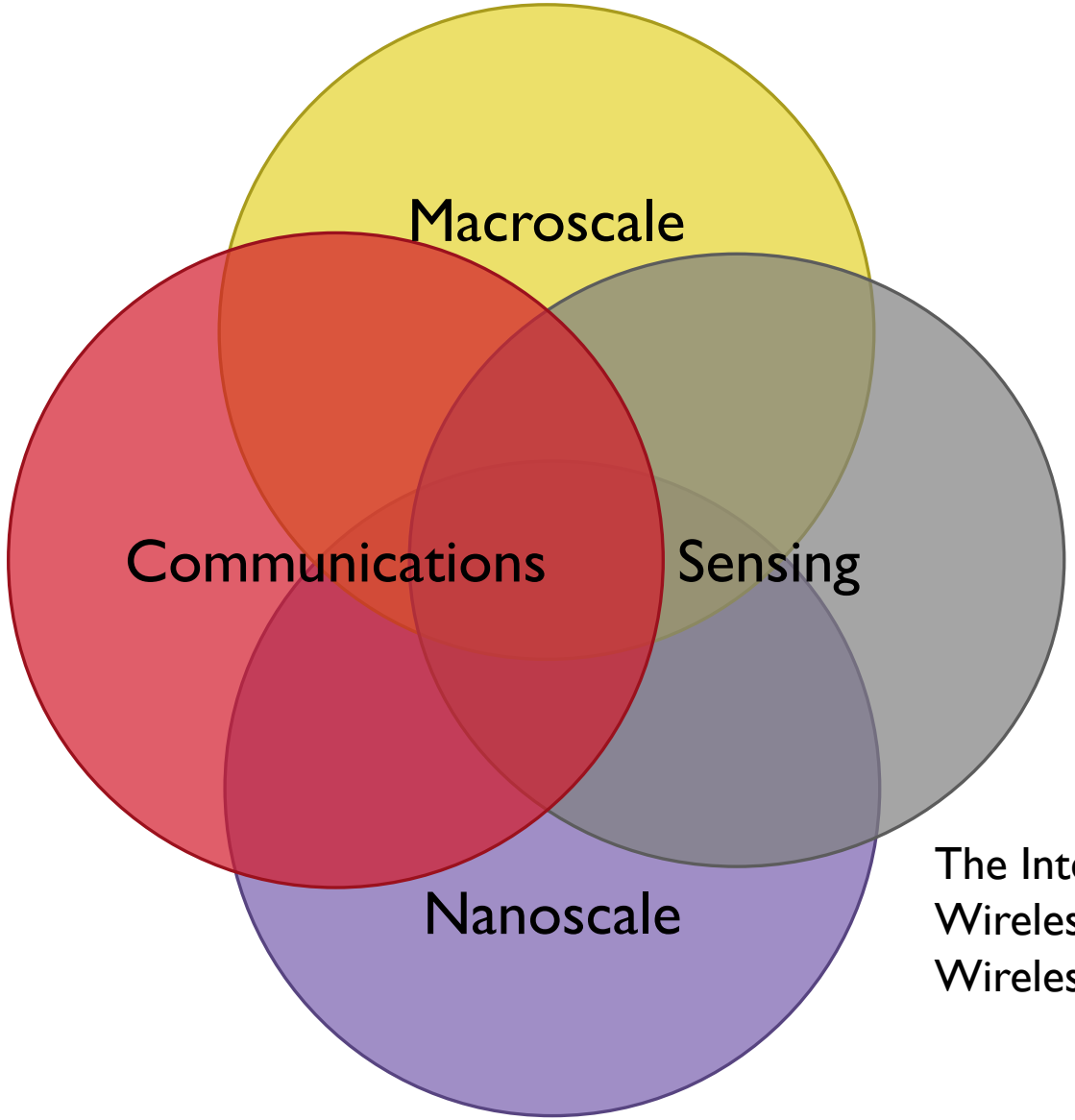

Terabit WPAN/WLAN
Terabit wireless backhaul
Inter-satellite and Space Networks
…

Bridging the Digital Divide

High resolution radar/localization
Non-damaging imaging
Spectroscopy
Earth and space exploration

The Internet of Nano-Things
Wireless Nanosensor Networks
Wireless Networks on Chip

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Challenges Across the Board

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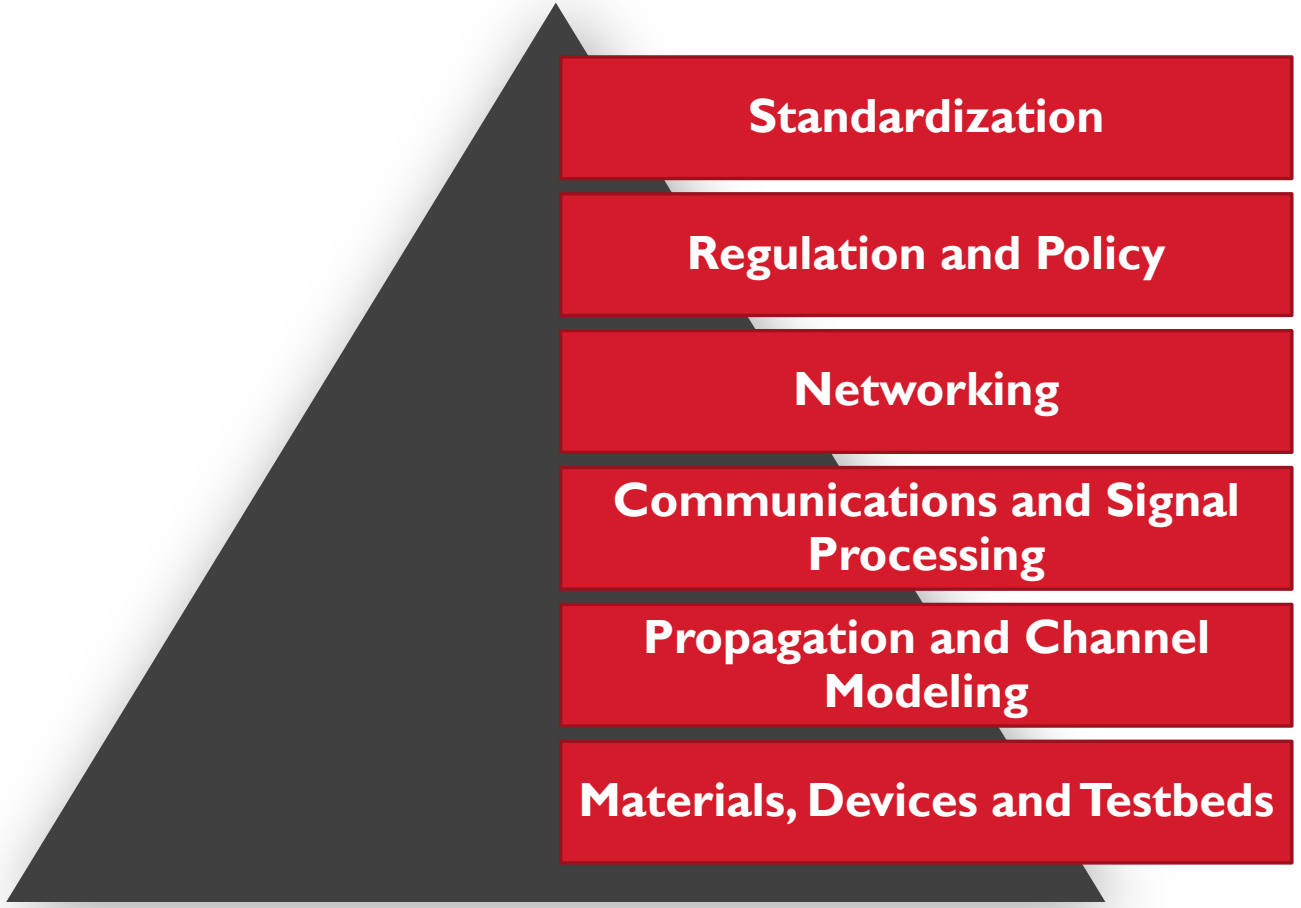

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From Materials and Devices to Communication Networks

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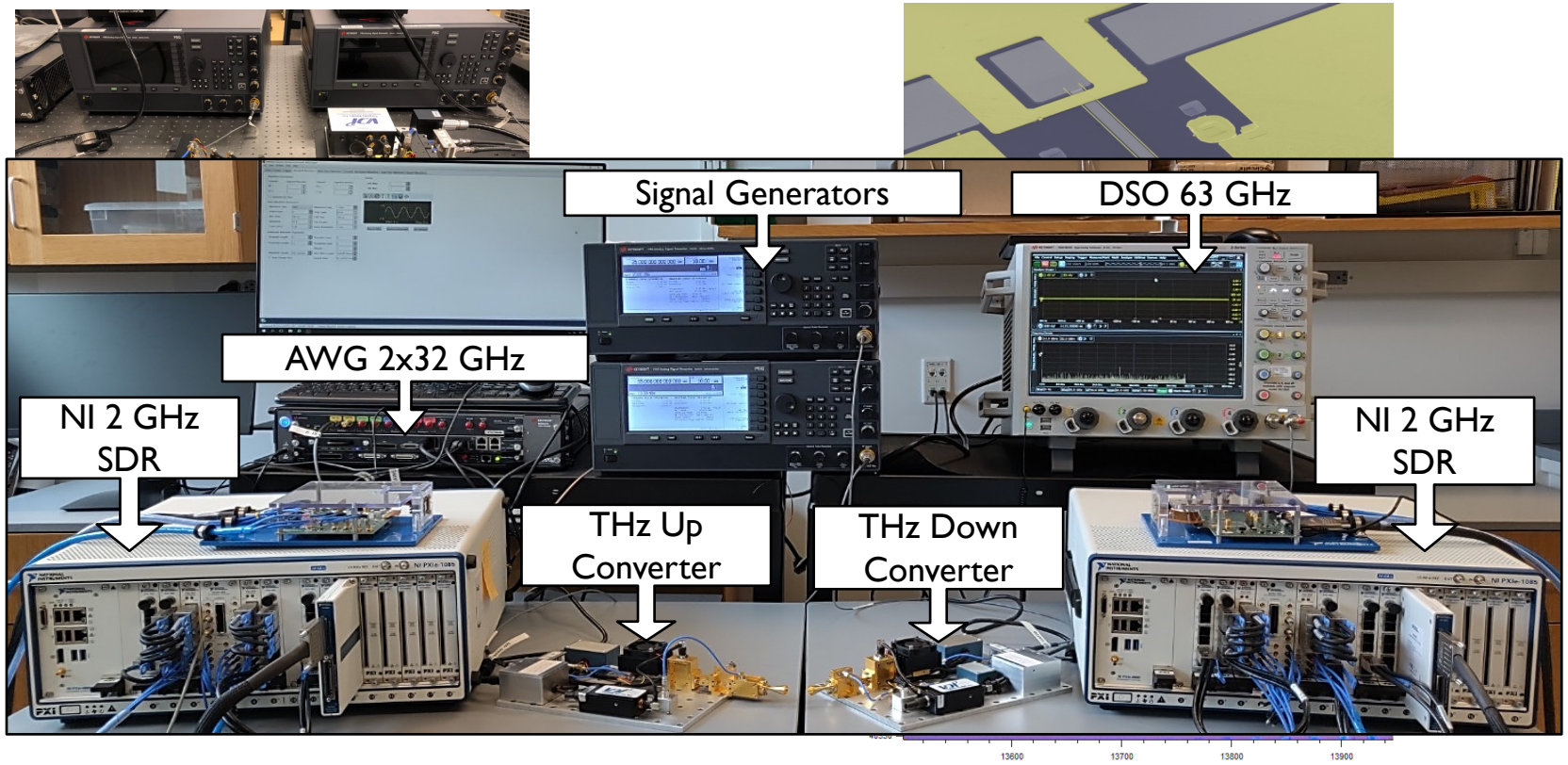
- Standardization
- Regulation and Policy
- Networking
- Communications and Signal Processing
- Propagation and Channel Modeling
- **Materials, Devices and Testbeds**



The THz technology gap is almost closed:
From electronics and photonics to graphene plasmonics

"Graphene-based Plasmonic Nano-transceiver for Terahertz Band Communication," U.S. Patent No. 9,397,758 issued on July 19, 2016.
"Graphene-based Plasmonic Nano-antennas for Terahertz Band Communication in Nanonetworks," U.S. Patent No. 9,643,841, issued on May 9, 2017.
"The TeraNova Platform: An Integrated Testbed for Ultra-broadband Wireless Communications at True Terahertz Frequencies," Computer Networks (COMNET), 2020.
"Experimental Wireless Testbed for Ultrabroad-band Terahertz Networks," Computer Networks (COMNET) 2021. Early version in Proc. of ACM WiNTECH 2020.

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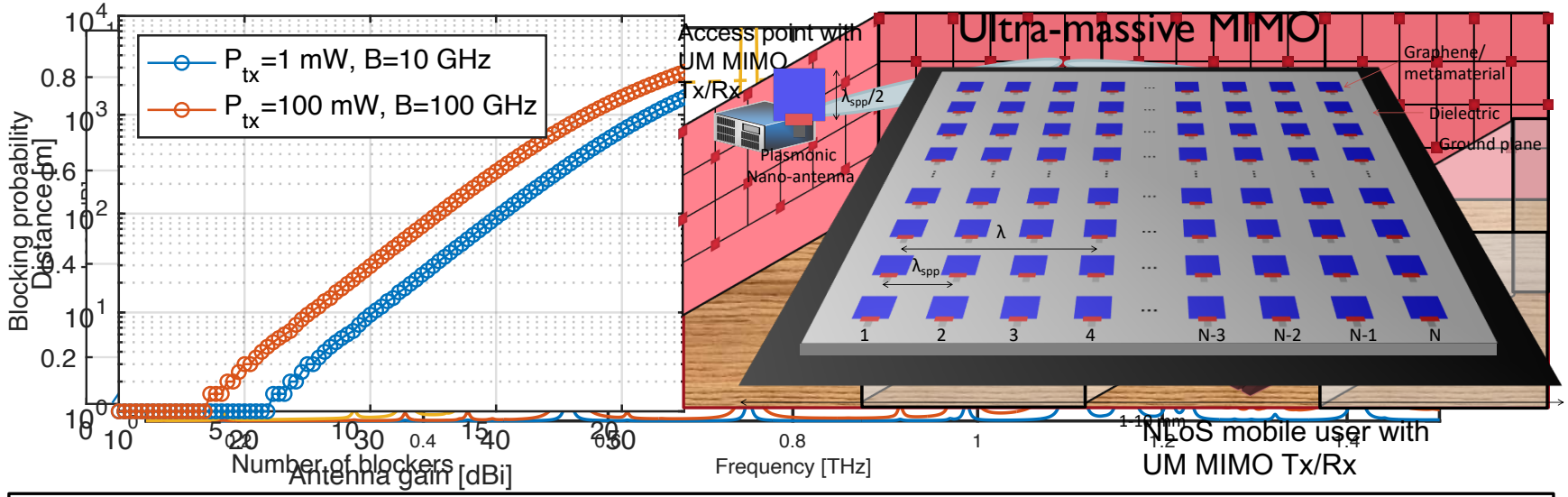
Weather conditions affect the channel (less than at optical frequencies)

Blockage plays a key role



Intelligent Environments

Ultra-massive MIMO

THz signals propagate better than what many people think (for the good and for the bad)

"Channel Modeling and Capacity Analysis of EM Wireless Nanonetworks in the Terahertz Band," IEEE Trans. on Wireless Communications, 2011.
"Realizing Ultra-Massive MIMO communication in the Terahertz band," Nano Communication Networks, 2016. US Patent No. 9,825,712, 2017.
"Interference and SINR in Terahertz Communication Systems with Blocking and Directional Antennas," IEEE Trans. on Wireless Communications, March 2017.
"Intelligent Environments Based on Ultra-massive MIMO Platforms for Wireless Communication in Millimeter Wave and Terahertz Bands," ICASSP 2019.

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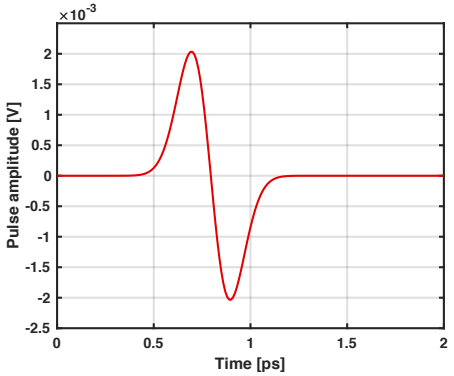
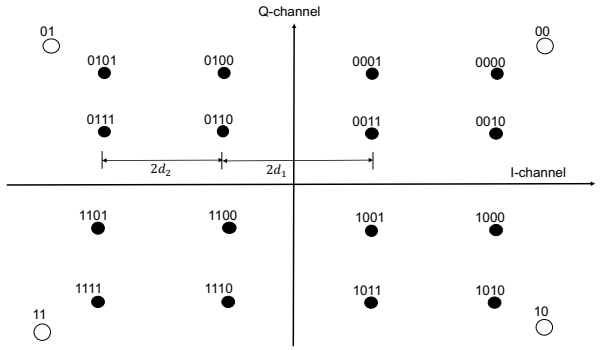
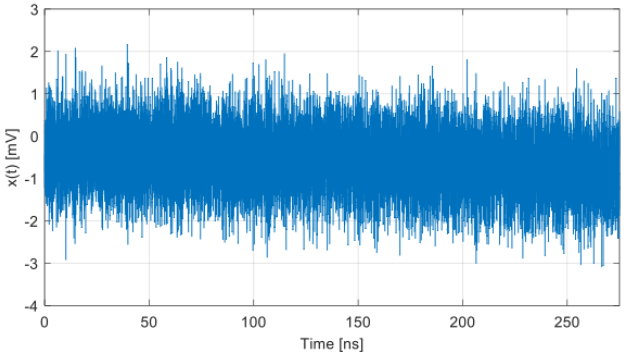
Femtosecond-long Pulses



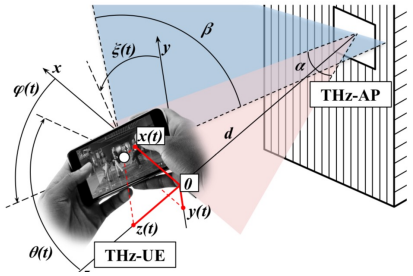
Hierarchical Bandwidth Modulations



Ultra-broadband Spread Spectrum



Making the most out of the (huge) available bandwidth is a challenge
(and we can do much better than with traditional modulation, synchronization, …)



Challenging spatial, time, frequency and phase synchronization

"Femtosecond-long Pulse-based Modulation for Terahertz Band Communication in Nanonetworks," IEEE Transactions on Communications, May 2014.
"Hierarchical Bandwidth Modulation for Ultra-broadband Terahertz Communication," in Proc. of IEEE ICC, 2019.
"Ultra-broadband Chirp Spread Spectrum Communication in the Terahertz Band," in Proc. Of the SPIE Defense and Security Conference, 2020.
"Capacity and Outage of Terahertz Communications with User Micro-mobility and Beam Misalignment," IEEE Transactions on Vehicular Technology, May 2020.

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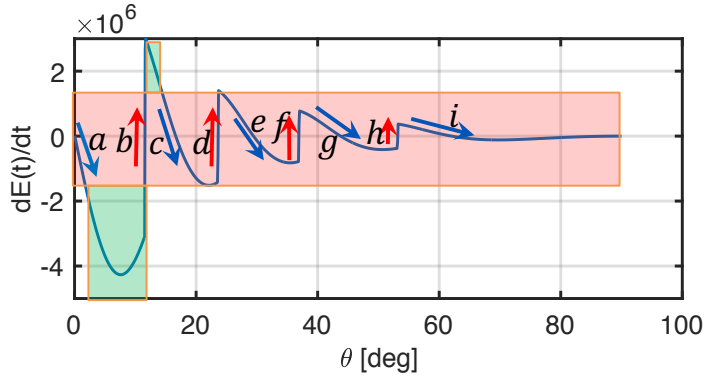
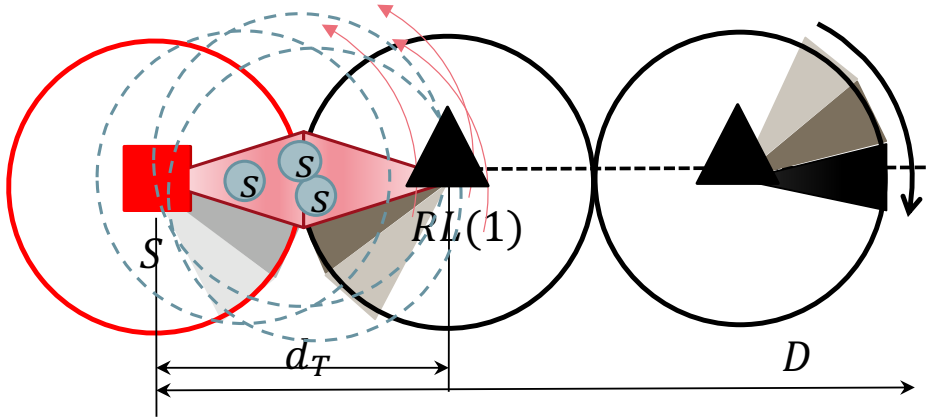
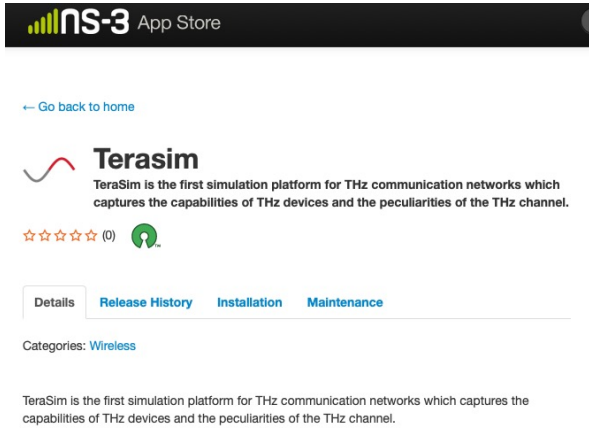




Bandwidth is no longer a constraint, but everything else is (neighbor discovery, MAC, relaying, …)



"A Link-layer Synchronization and Medium Access Control Protocol for Terahertz-band Communication Networks," IEEE Trans. on Mobile Computing, 2019.
"Leveraging Antenna Side-lobe Information for Expedited Neighbor Discovery in Directional THz Networks," IEEE Trans. on Vehicular Technology, 2019.
"Routing Protocol Design for Directional and Buffer-limited Terahertz Communication Networks," in Proc. of ICC, June 2020.

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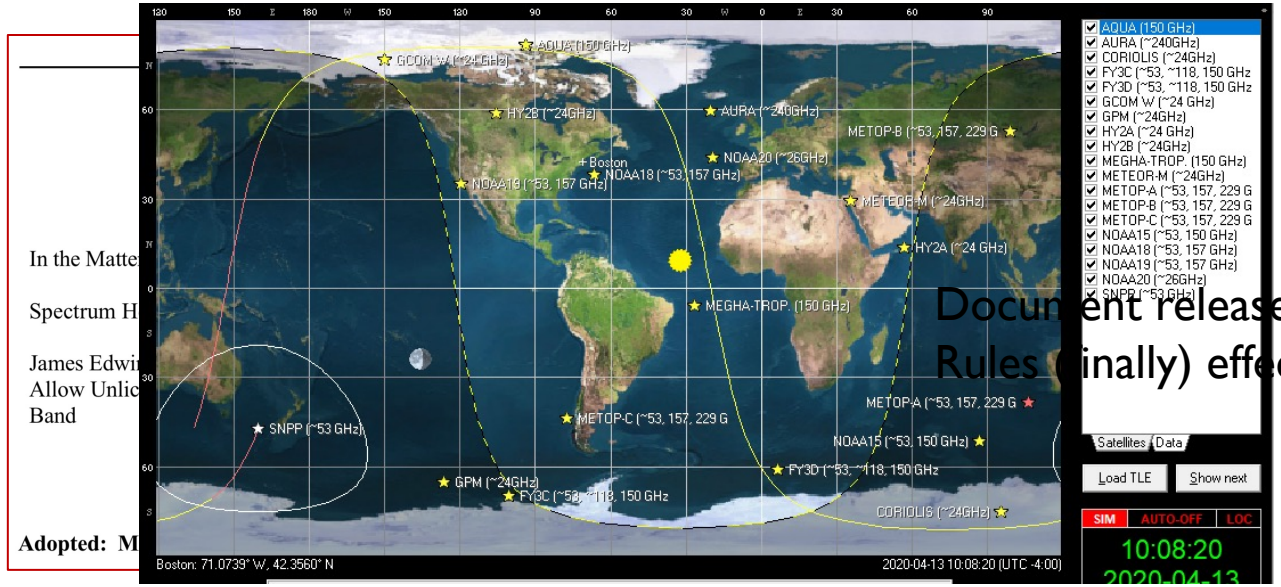
We are not the only ones who like the THz band:
The scientific community was here first: need to enable efficient coexistence



Document released 03/15/2019
Rules (finally) effective on 08/24/2020

"Proposed addition to Chairman's Report WP1A for new bands under AI 1.15," ITU-R WP1A, 2018.
"Information on antenna patterns greater than 100 GHz related to work on the revision of Recommendation ITU-R F.699-8," ITU-R WP 5C, July 2018.

Do We Really Have Huge Bandwidth?

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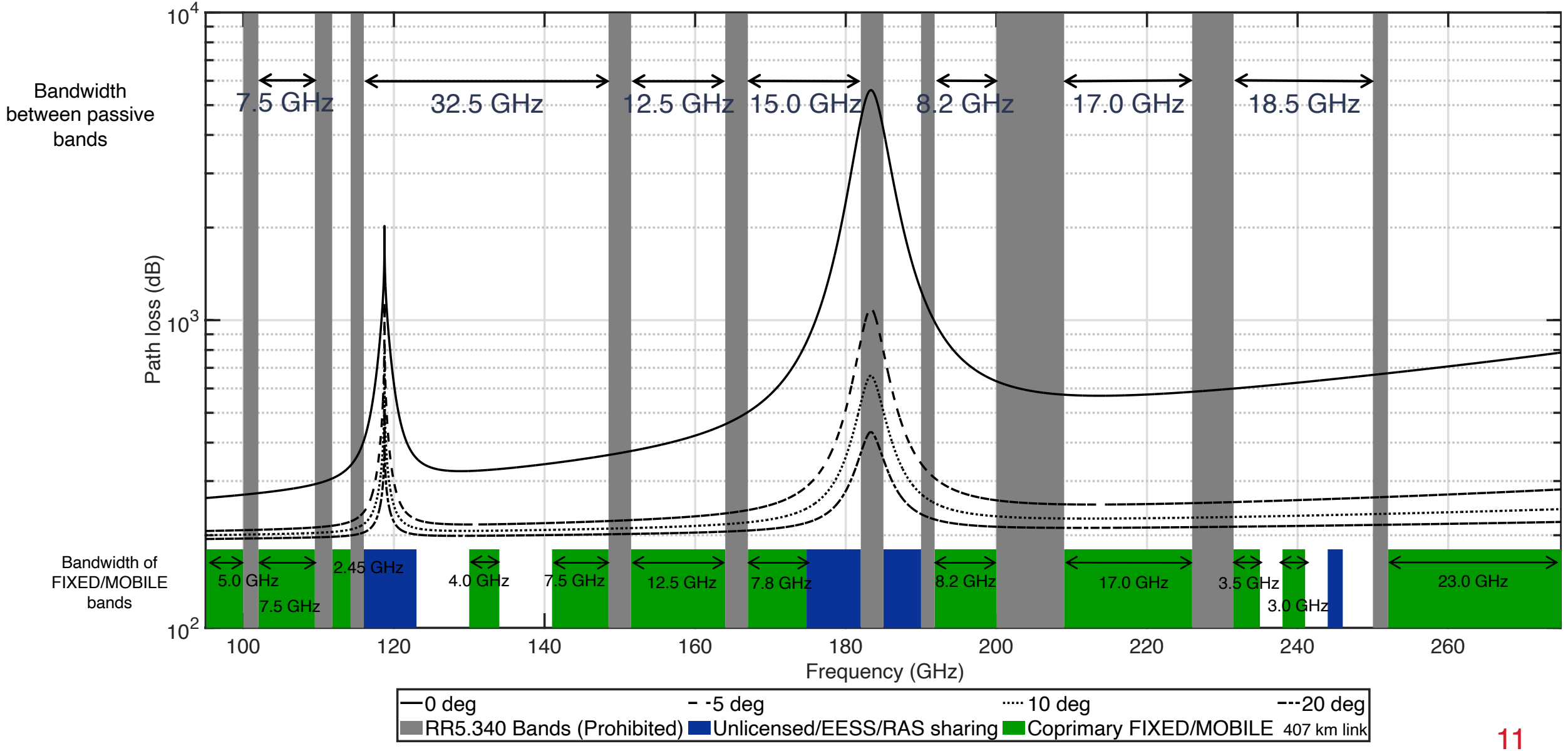

How About Unlicensed Bands above 100 GHz?

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- FCC Spectrum Horizons defines 21.2 GHz of unlicensed bandwidth above 100 GHz:
  - From 116 to 123 GHz → 7 GHz
  - From 174.8 to 182 GHz → 7.2 GHz
  - From 185 to 190 GHz → 5 GHz
  - From 244 to 246 GHz → 2 GHz
- Is this enough? Not really… so what can we do?
  - **Option 1:** Let's look for frequencies where there are no frequency allocations (yet)
    - > 275 GHz!
  - **Option 2:** Let's better share the spectrum between 100-275 GHz

M. Polese, X. Cantos-Roman, A. Singh, M. Marcus, T. Maccarone, T. Melodia and J. M. Jornet, **"Coexistence and Spectrum Sharing above 100 GHz"**, **submitted for journal publication,** October 2021.

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Dynamic Spectrum Sharing above 100 GHz

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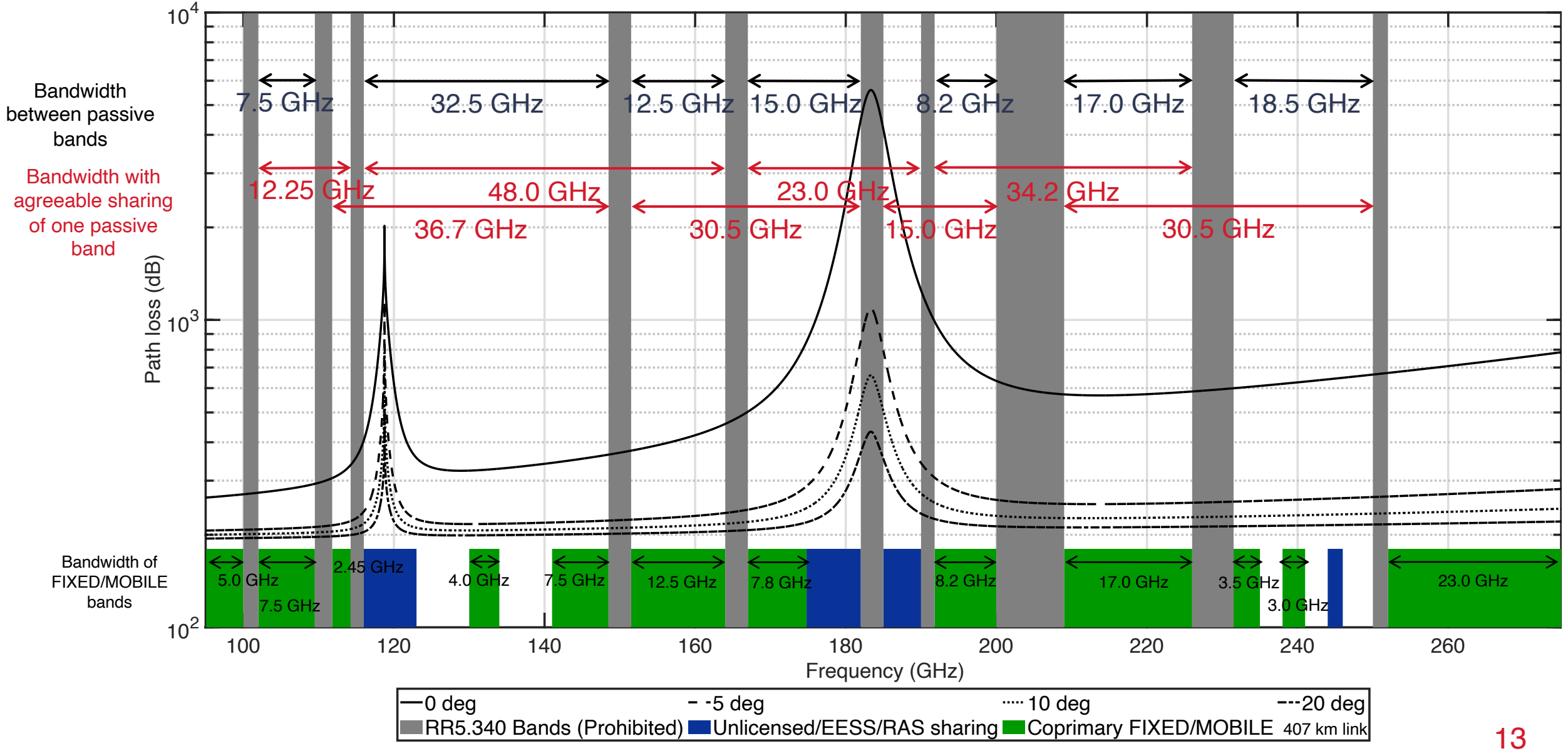

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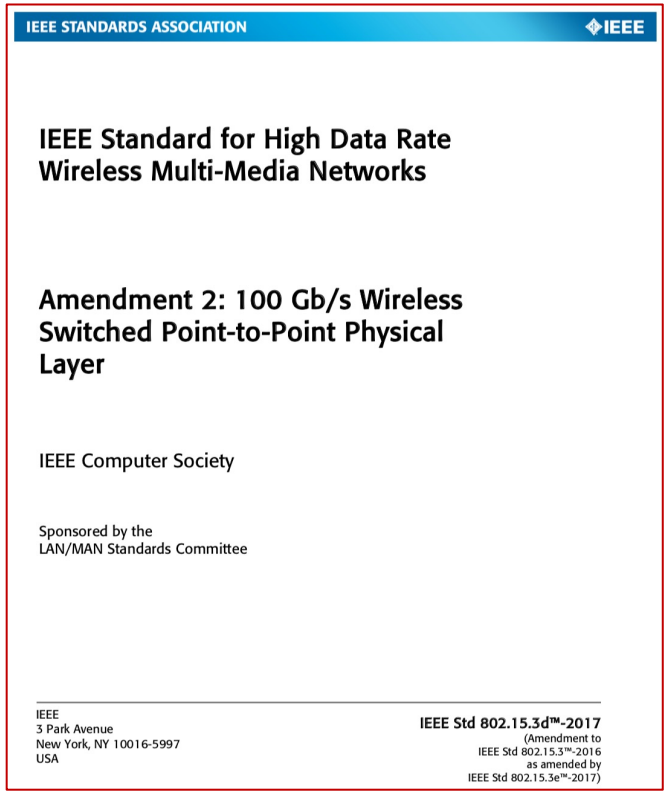
Yes, there is a standard already for point-to-point links. What is next?



IEEE STANDARDS ASSOCIATION IEEE

IEEE Standard for High Data Rate Wireless Multi-Media Networks

Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer

IEEE Computer Society

Sponsored by the LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.15.3d™-2017
(Amendment to IEEE Std 802.15.3™-2016 as amended by IEEE Std 802.15.3e™-2017)

802.15.3d
Point to point links
252-325 GHz

Should we ignore the spectrum and available technology between 100 GHz and 275 GHz?
NO

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Thank you!

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