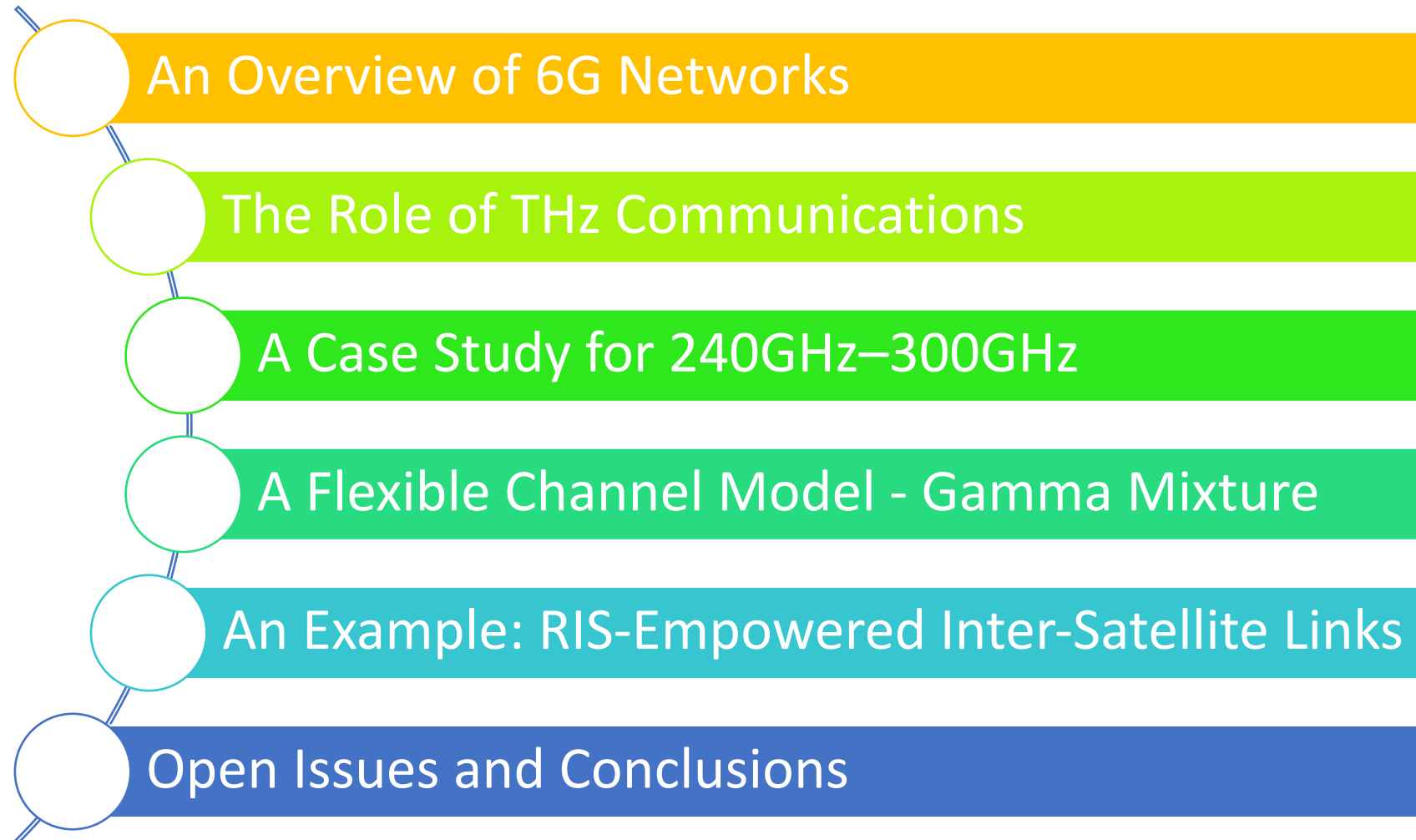


# Potential of THz Communications towards 6G

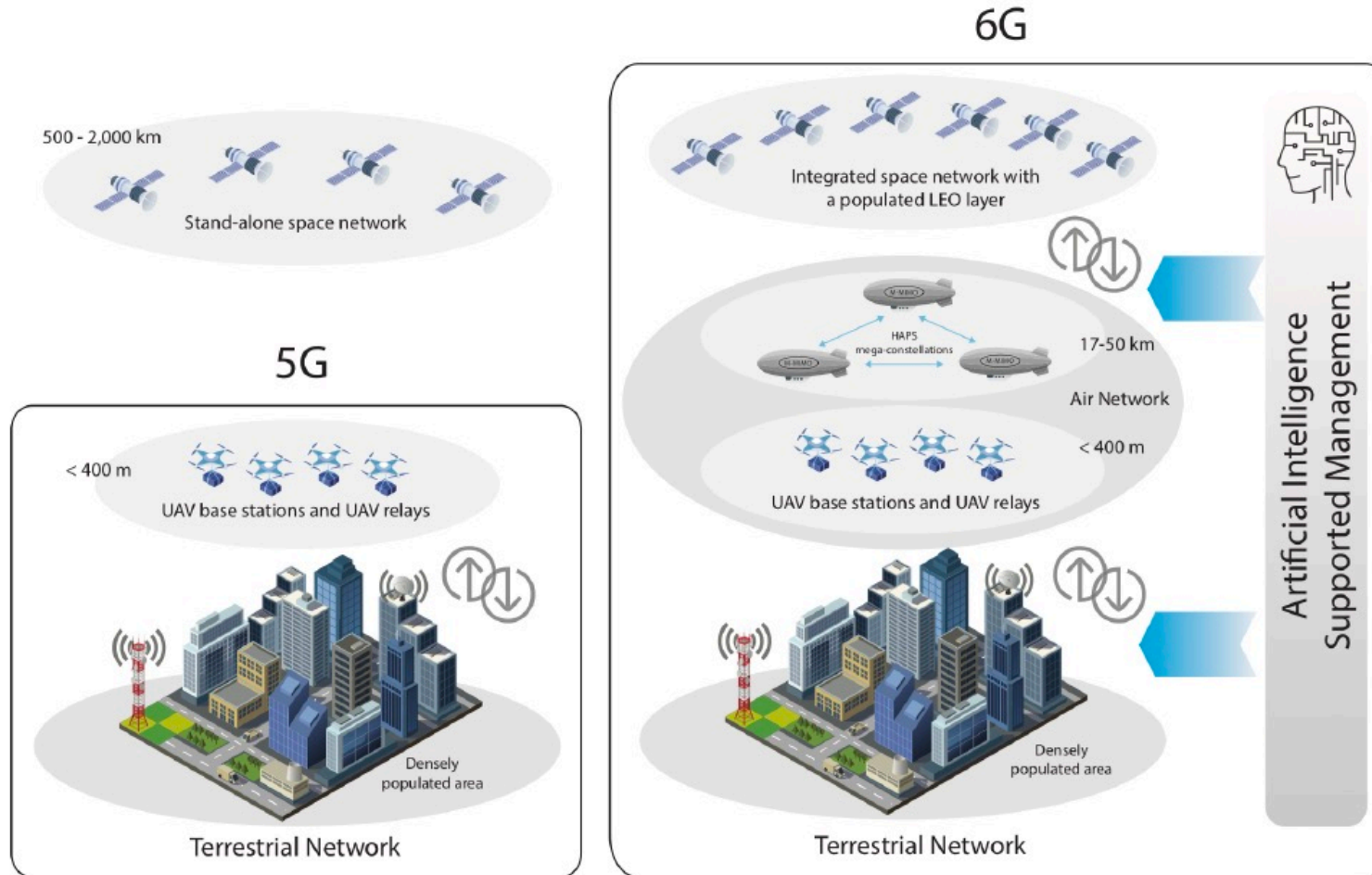
Gunes Karabulut-Kurt,  
École Polytechnique de Montréal, Canada  
[gunes.kurt@polymtl.ca](mailto:gunes.kurt@polymtl.ca)

Joint work with Kürşat TEKBIYIK (PhD Candidate at Istanbul Technical University),  
Prof. Halim YANIKOMEROGLU (Carleton), Prof. Ali Riza EKTİ (TUBITAK) and other valuable collaborators

# Outline



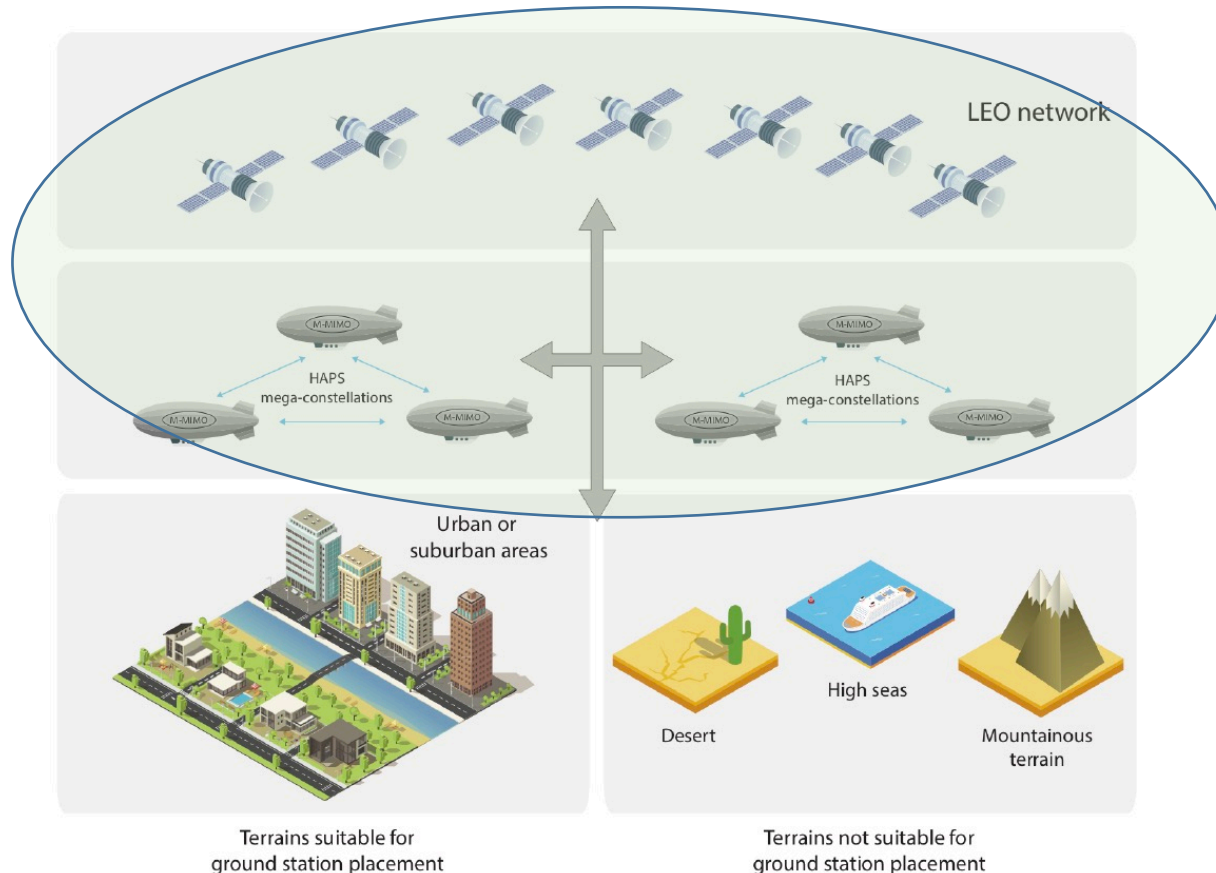
# An Overview of 6G Networks



A fully integrated Vertical Heterogeneous Network (VHetNet)

G. Karabulut Kurt, M. G. Khoshkholgh, S. Alfattani, A. Ibrahim, T. S. J. Darwish, Md S. Alam, H. Yanikomeroğlu, and A. Yongacoglu, "A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future," accepted for publication in *IEEE Communications Surveys and Tutorials* (2021) <https://arxiv.org/abs/2007.15088>

# A Closer Look



A big change is expected in space/air networks !

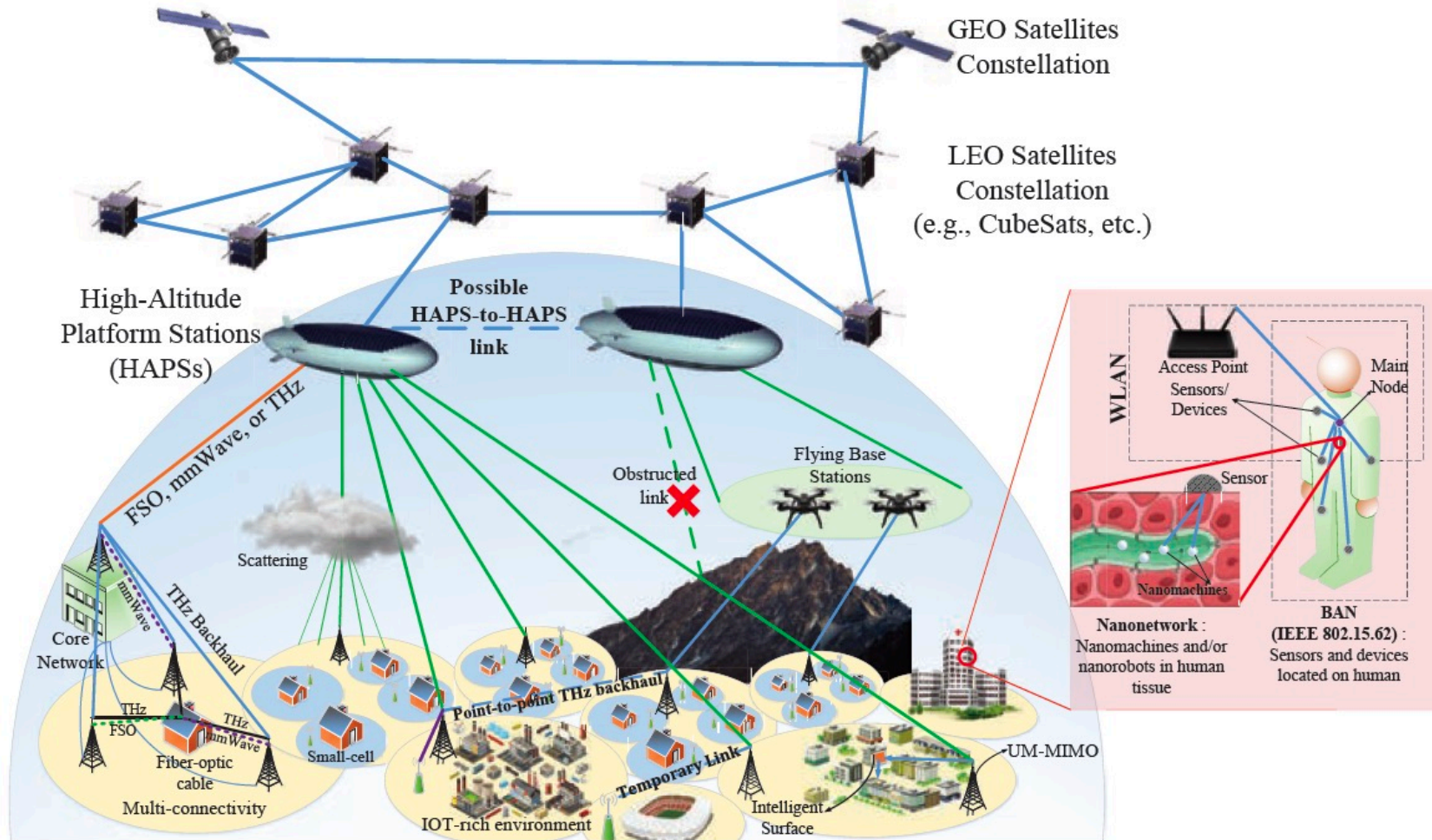
There is a need to push the carrier frequency beyond the mmWave band to overcome the spectrum scarcity below 100 GHz.

Requirements

1. High bandwidth (i.e. high data rate)
2. Controllable interference management in congested deployments

G. Karabulut Kurt, M. G. Khoshkholgh, S. Alfattani, A. Ibrahim, T. S. J. Darwish, Md S. Alam, H. Yanikomeroğlu, and A. Yongacoglu, "A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future," accepted for publication in *IEEE Communications Surveys and Tutorials* (2021) <https://arxiv.org/abs/2007.15088>

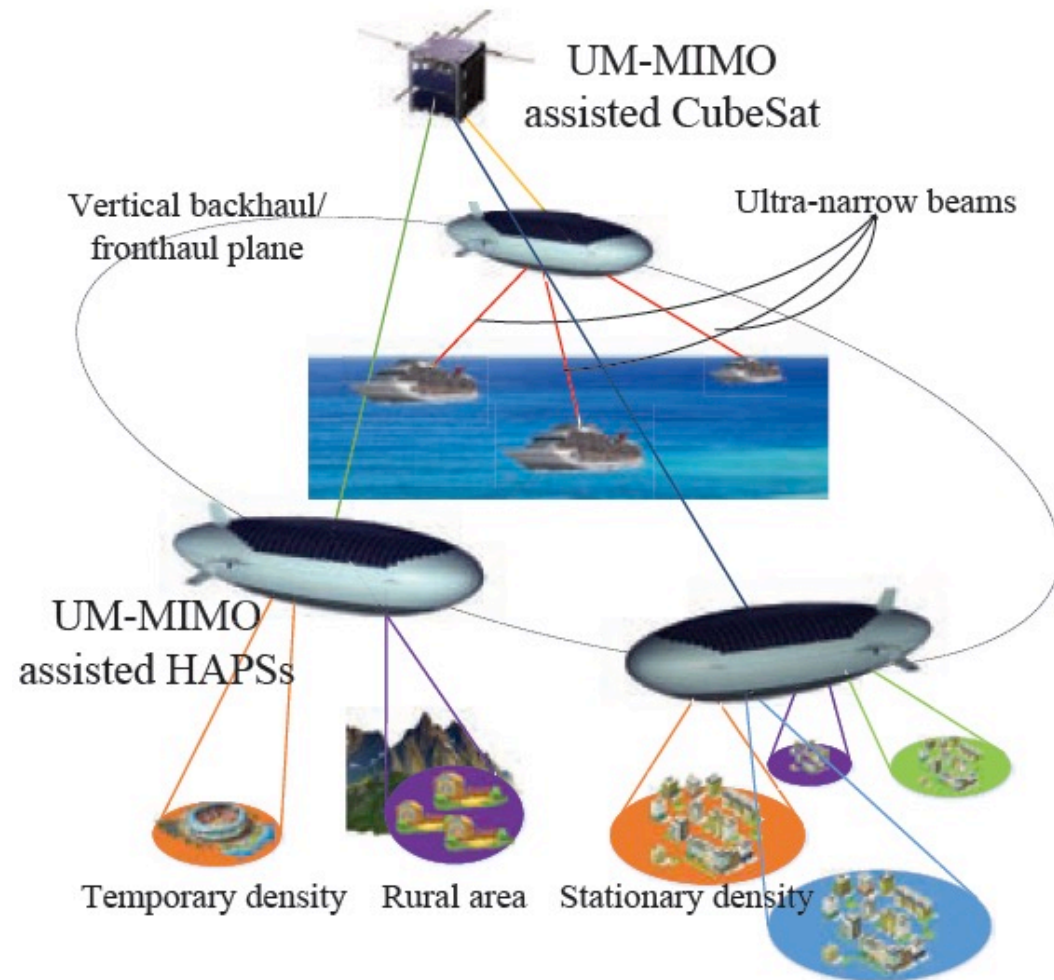
# The Role of THz Communications



Varying network scales  
 (from body area networks to inter-planetary communications)

K. Tekbiyik, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and H. Yanikomeroğlu, "A Holistic Investigation on Terahertz Propagation and Channel Modeling Toward Vertical Heterogeneous Networks," IEEE Communications Magazine, vol. 58, no. 11, Nov. 2020. <https://ieeexplore.ieee.org/document/9269928>

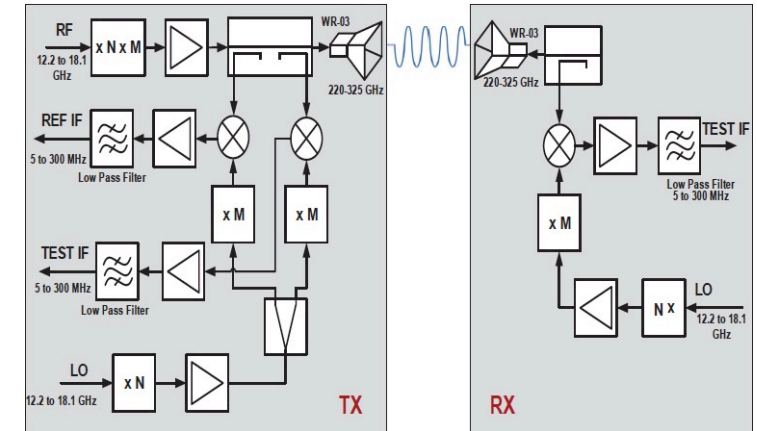
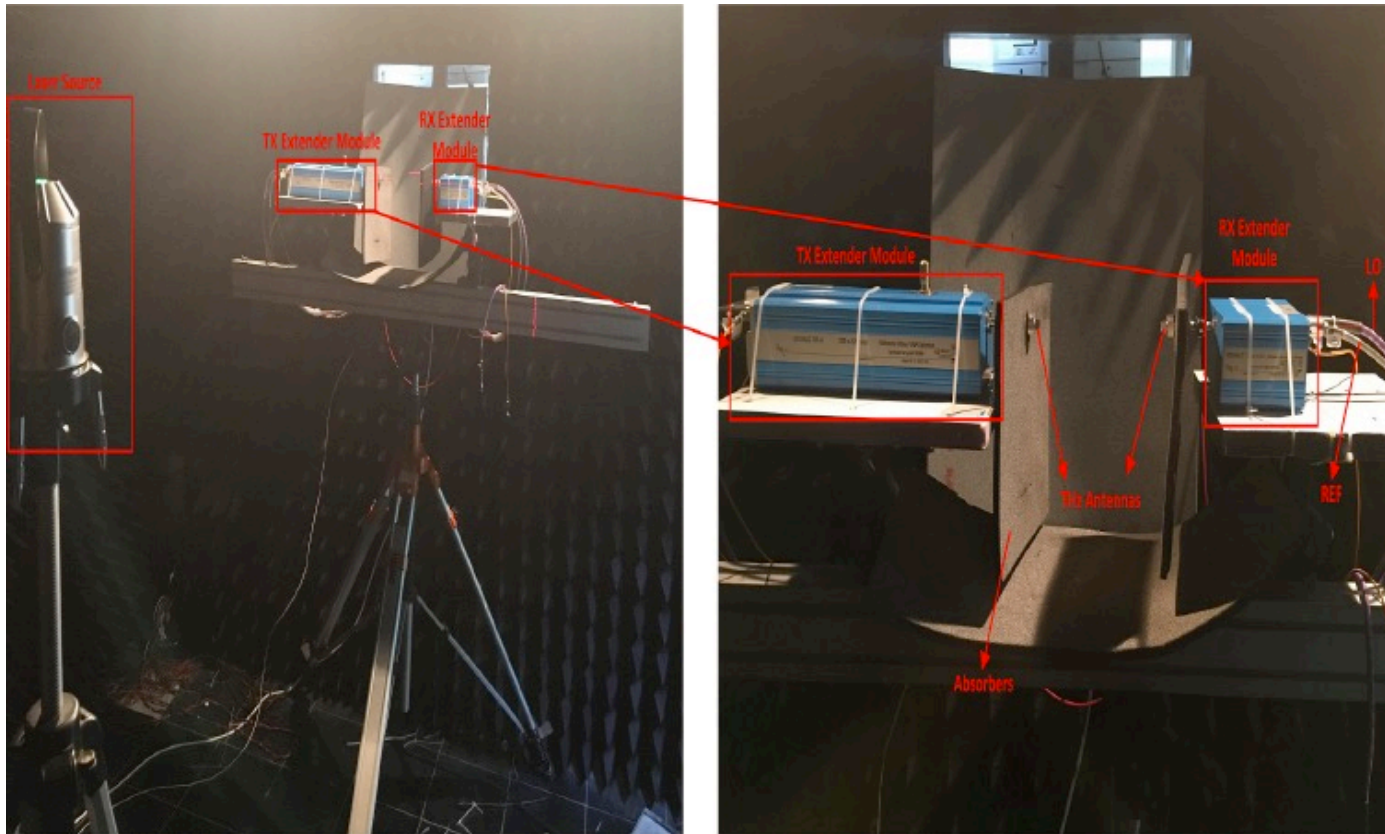
# The Hidden Potential



- THz networks can employ ultra-massive antenna arrays → possible to cover a 1 mm<sup>2</sup> area with four antennas at 300 GHz
- This form factor it can be turned into an advantage by dynamically adjustable beam pattern and multiple spot flexibility.
- **Accurate channel models are needed to quantify the benefits fully!**

K. Tekbiyik, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and H. Yanikomeroğlu, "A Holistic Investigation on Terahertz Propagation and Channel Modeling Toward Vertical Heterogeneous Networks," *IEEE Communications Magazine*, vol. 58, no. 11, Nov. 2020. <https://ieeexplore.ieee.org/document/9269928>

# A Case Study for 240GHz–300GHz (1/4)



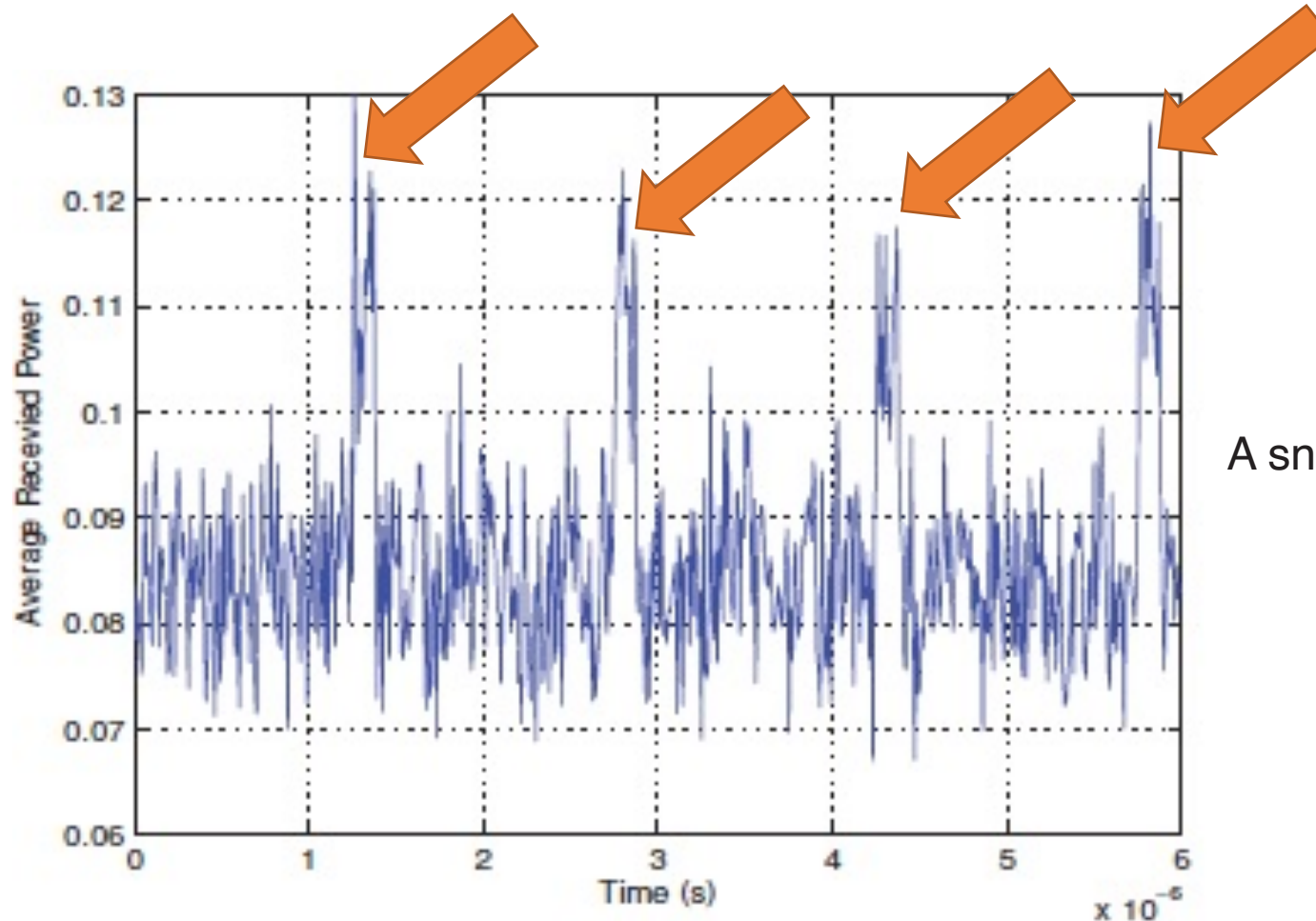
Measurement setup is prepared in the anechoic chamber to suppress possible reflections and guarantee LOS conditions. Laser source is used to eliminate any misalignment.

MillimeterWave and Terahertz Technologies Research Laboratories (MITAL) at the Scientific and Technological Research Council of Turkey (TUBITAK) in Gebze, Turkey

Tekbiyık K, Ekti AR, Kurt GK, et al.. THz Wireless Channel Measurements in between 240GHz and 300GHz

Available: <https://iee-dataport.org/open-access/thz-wireless-channel-measurements-between-240ghz-and-300ghz>

# A Case Study for 240GHz–300GHz (2/4)



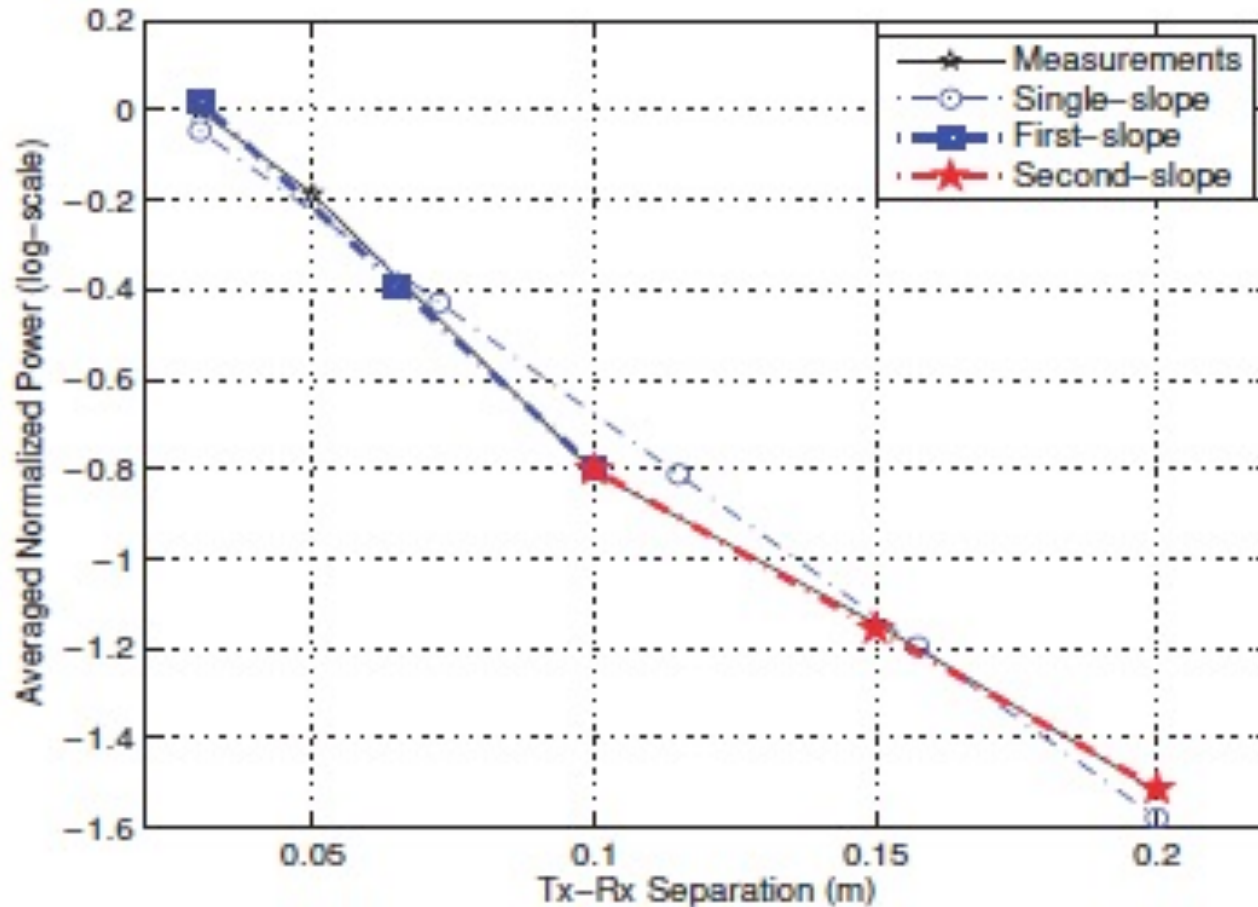
A snapshot of pulse train measurement.

K. Tekbiyik, E. Ulusoy, A.R. Ekti, S. Yarkan, T. Baykas, A. Gorcin, and G. Karabulut Kurt, “Statistical channel modeling for short range line-of-sight terahertz communication,” in IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Istanbul, Turkey, 08-11 September, 2019

<https://ieeexplore.ieee.org/abstract/document/8904237>



# A Case Study for 240GHz–300GHz (3/4)



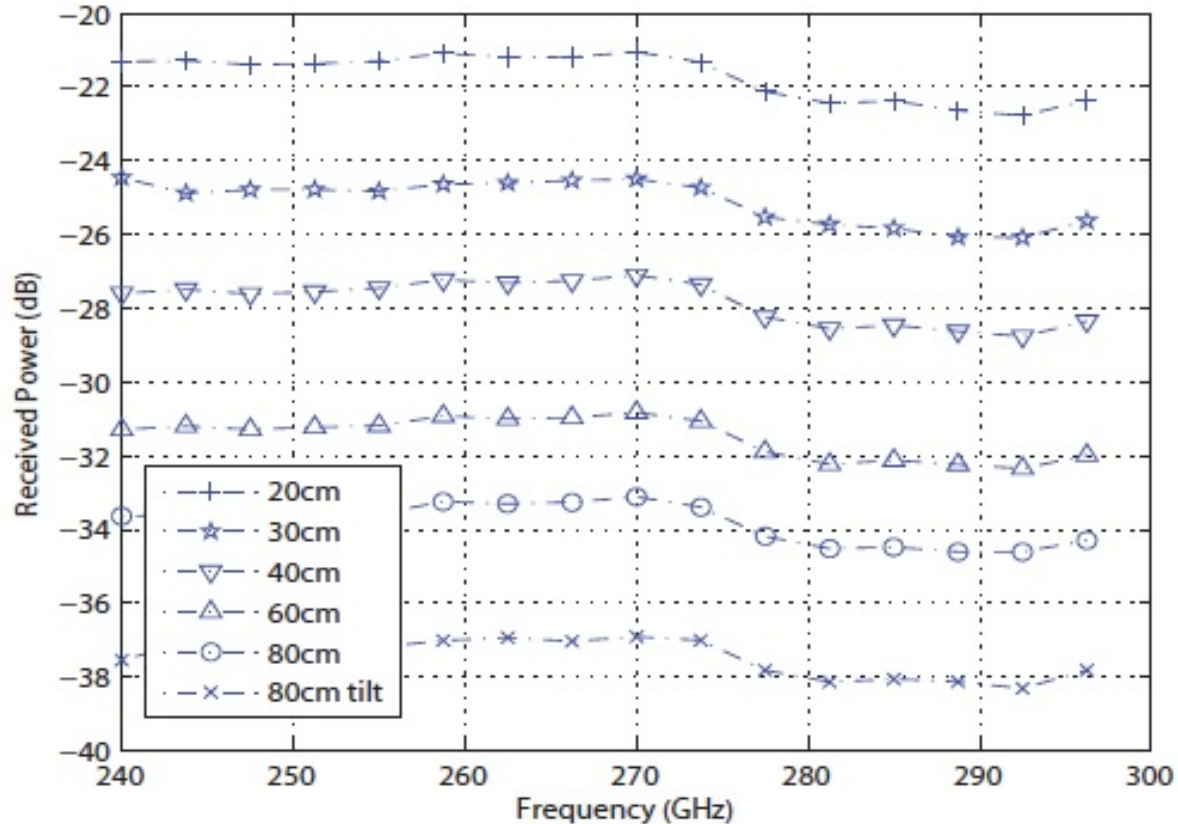
Normalized received power averaged over frequencies with respect to transmitter–receiver separations.

$$PL = \begin{cases} 0.37 - 11.7d & , d \in (0, 0.1)\text{m} \\ -0.09 - 7.11d & , d \in [0.1, 0.2)\text{m} \end{cases}$$

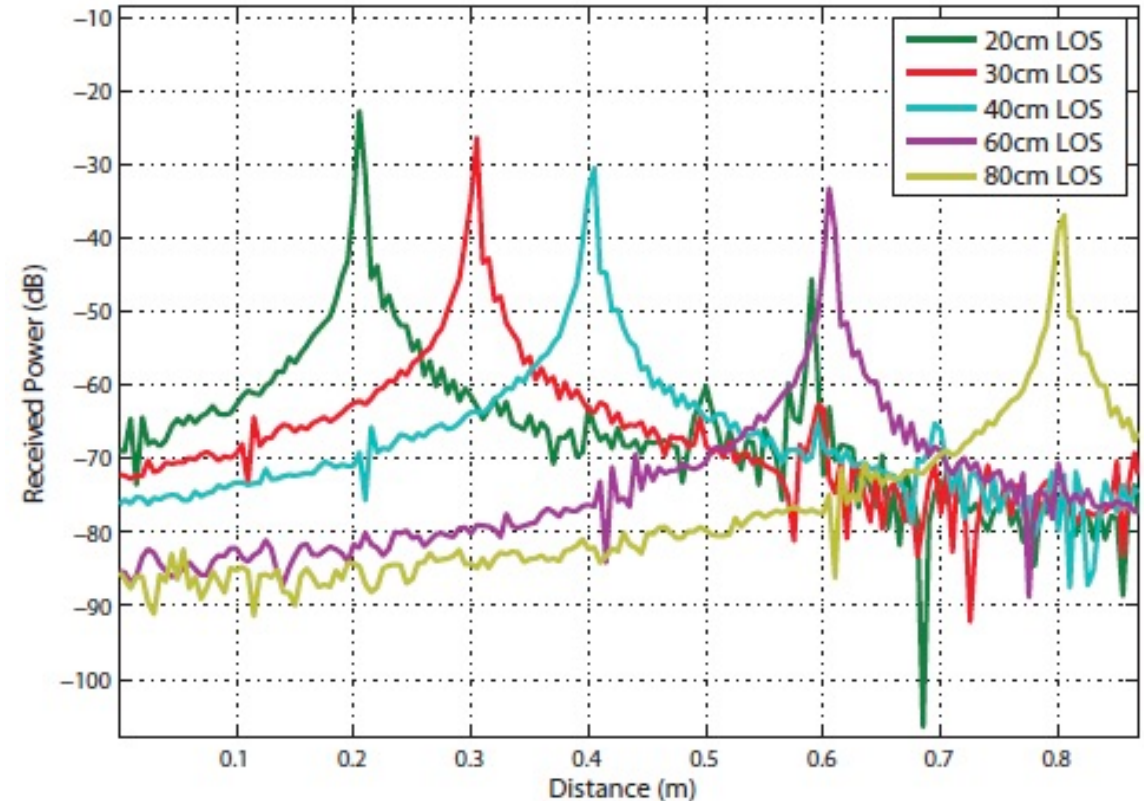
K. Tekbiyik, E. Ulusoy, A.R. Ekti, S. Yarkan, T. Baykas, A. Gorcin, and G. Karabulut Kurt, “Statistical channel modeling for short range line-of-sight terahertz communication,” in IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Istanbul, Turkey, 08-11 September, 2019

<https://ieeexplore.ieee.org/abstract/document/8904237>

# A Case Study for 240GHz–300GHz (4/4)

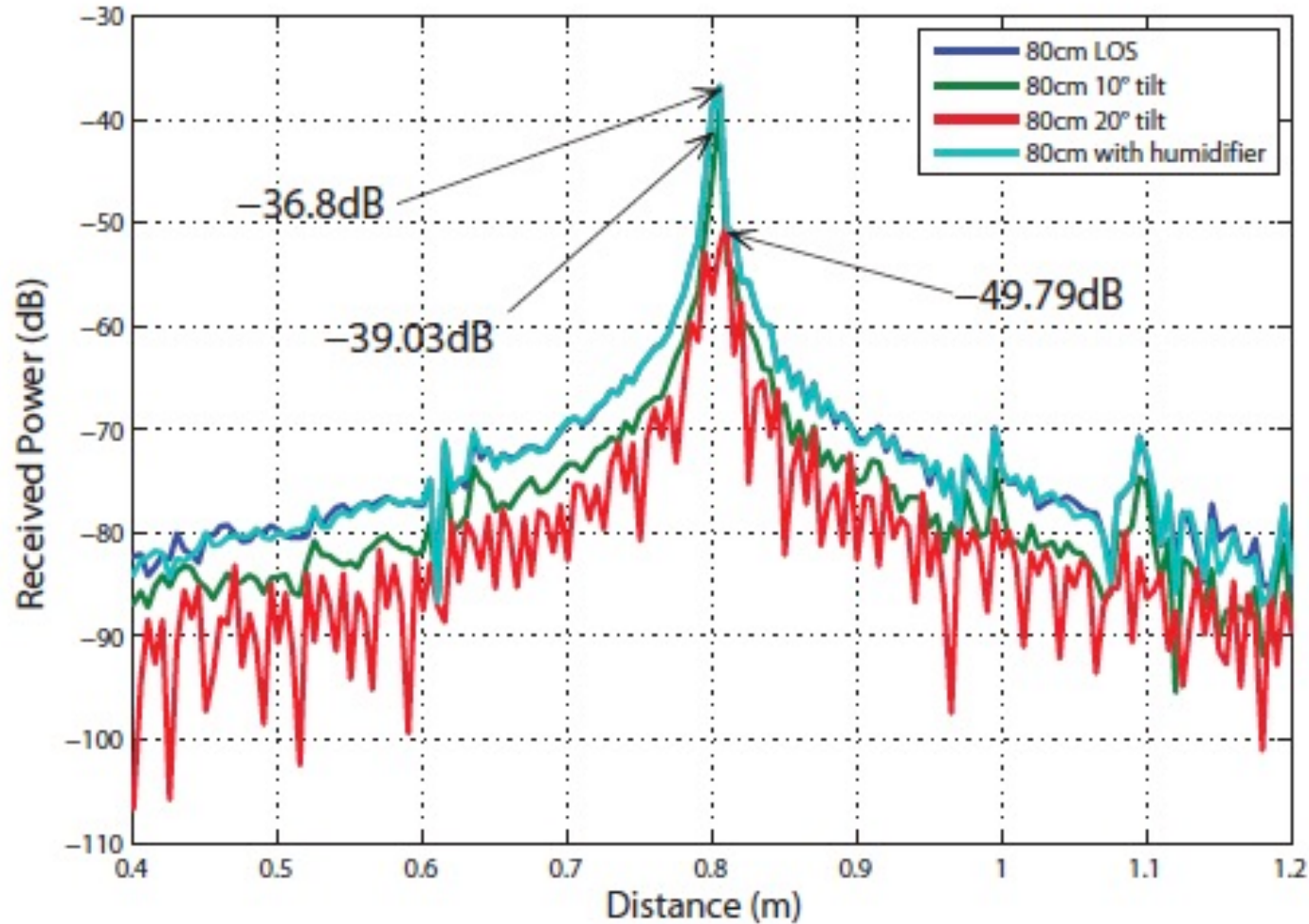


Averaged channel frequency responses in logarithmic scale for various LOS scenarios including the impact of antenna misalignment via antenna tilt.



First arriving paths in temporal domain for different transmitter–receiver separations under LOS. The horizontal axis is given in terms of transmitter–separation.

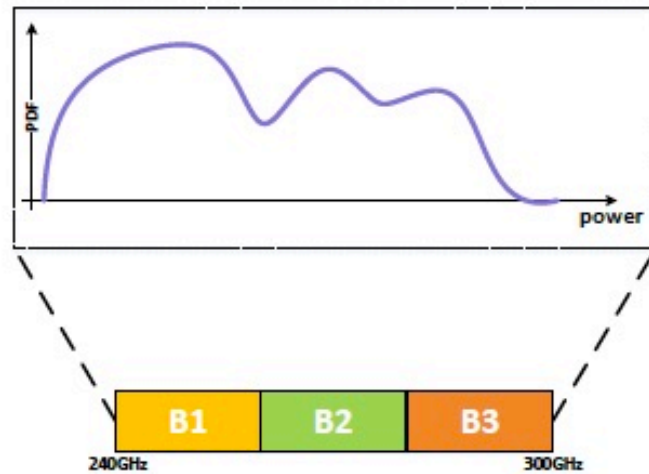
# The Impact of Environmental Conditions



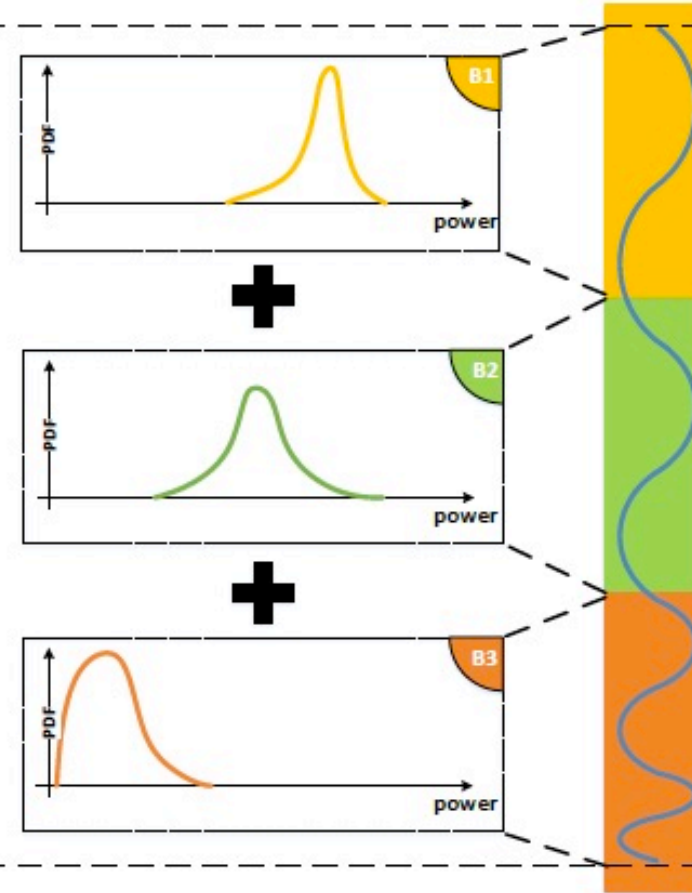
Measured channel impulse responses at 80cm in logarithmic scale with several antenna tilts along with a separate measurement in the presence of dense humidity.

# A Flexible Channel Model (1/3)

$$f_G(x) = \sum_{l=1}^m \rho_l f_l(x; \alpha_l, \beta_l), \quad l = 1, 2, \dots, m, \quad x > 0, \quad \rho_l > 0$$



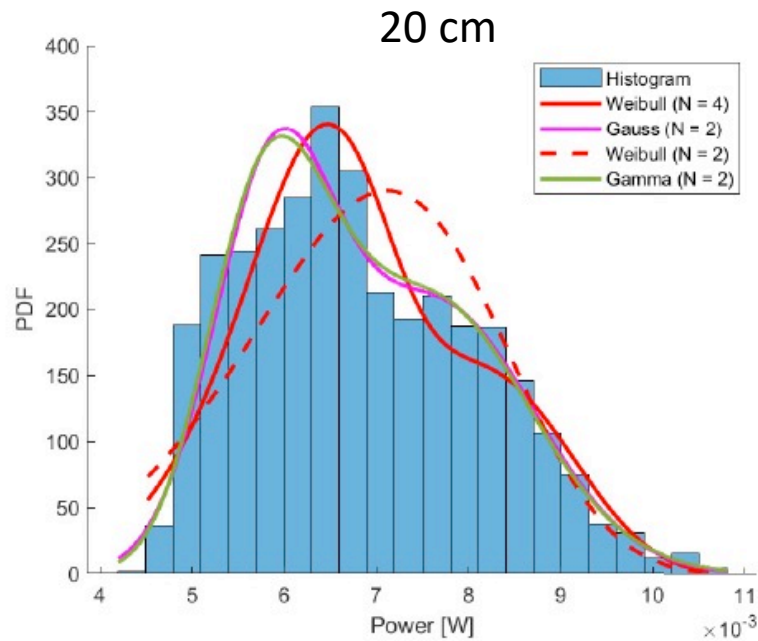
=



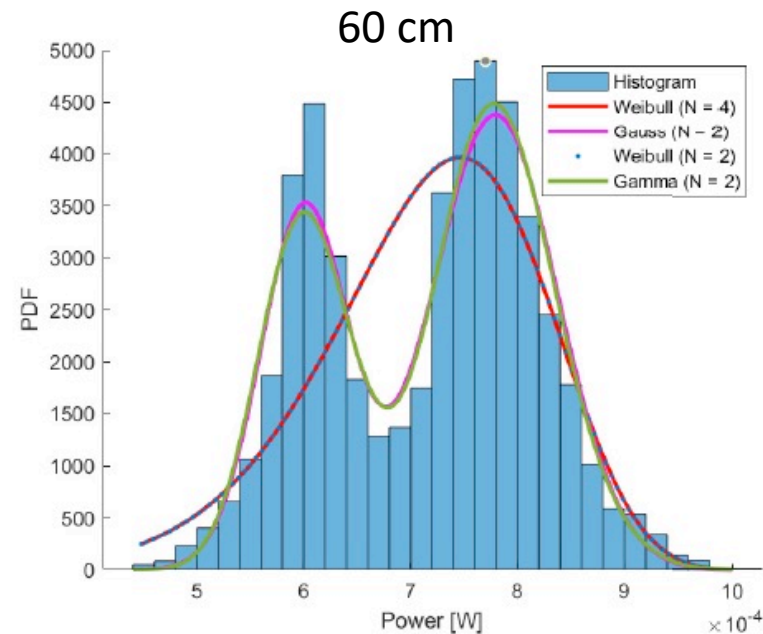
Instead of using a single distribution to model the received power characteristics, the mixture model is able to give information about each sub-band characteristics.

K. Tekbiyik, O. Akbunar, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and S. Yarkan, "Modeling and Analysis of Short Distance Sub-Terahertz Communication Channel via Mixture of Gamma Distribution," accepted for publication in IEEE Transactions on Vehicular Technology 2021, <https://ieeexplore.ieee.org/document/9368251>

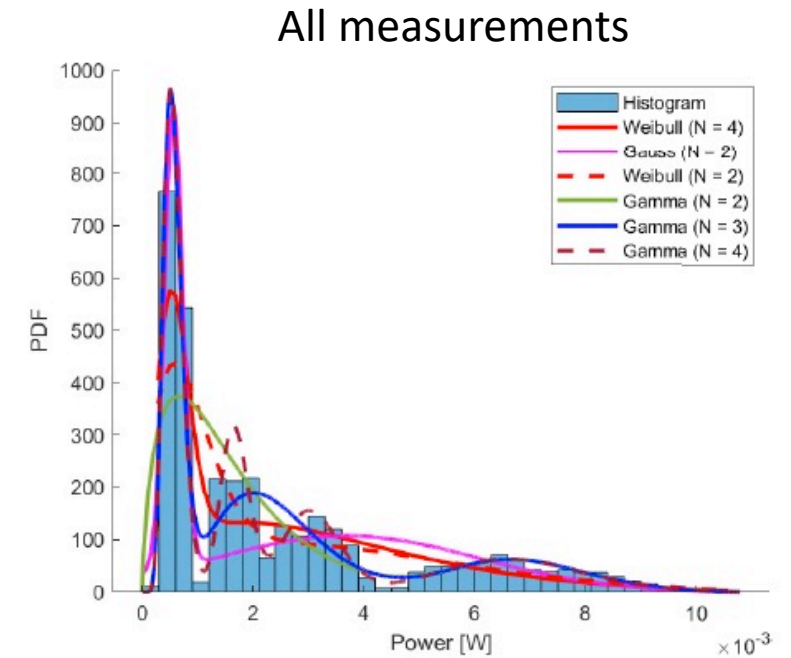
# A Flexible Channel Model (2/3)



(a)



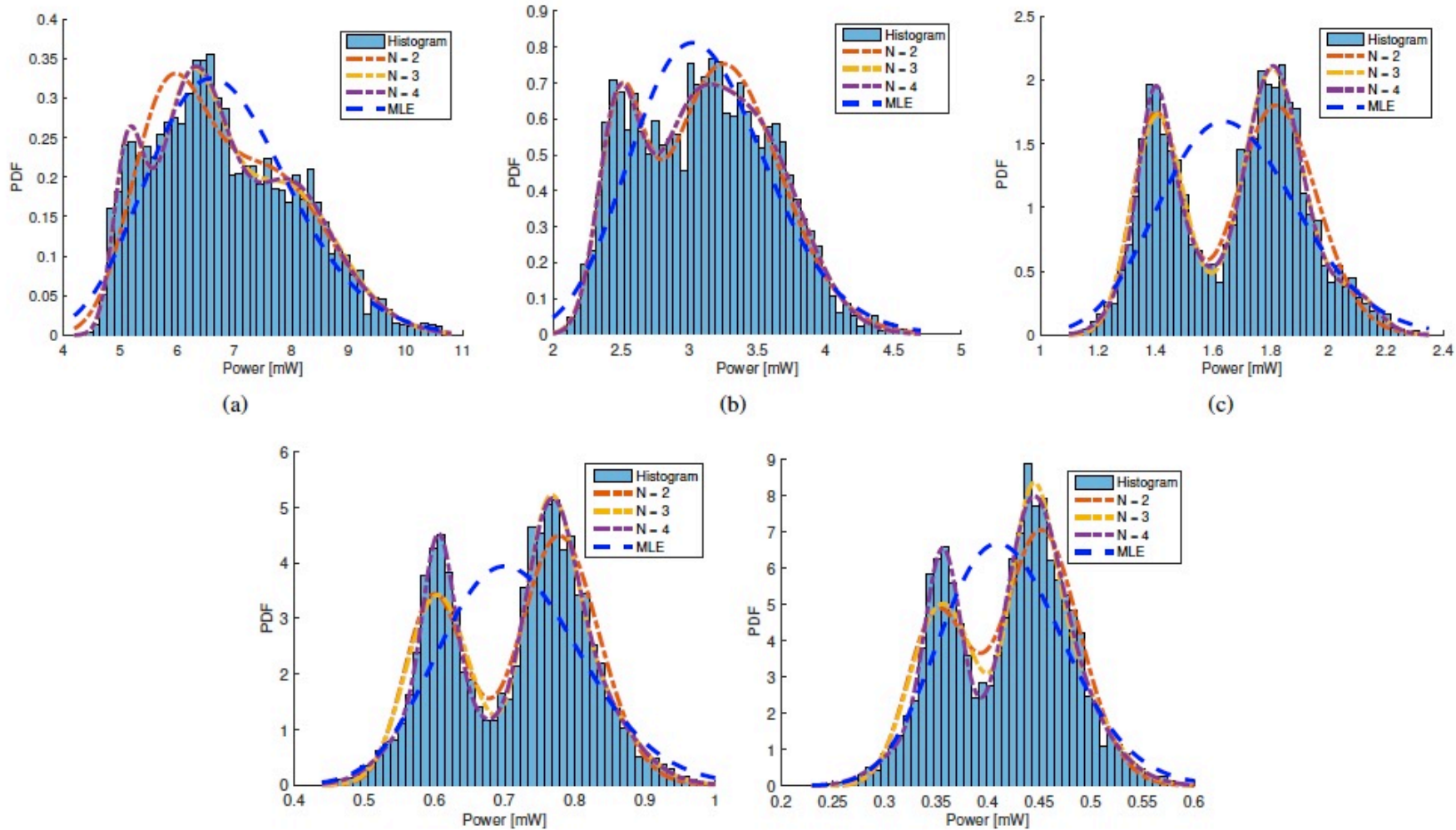
(b)



(c)

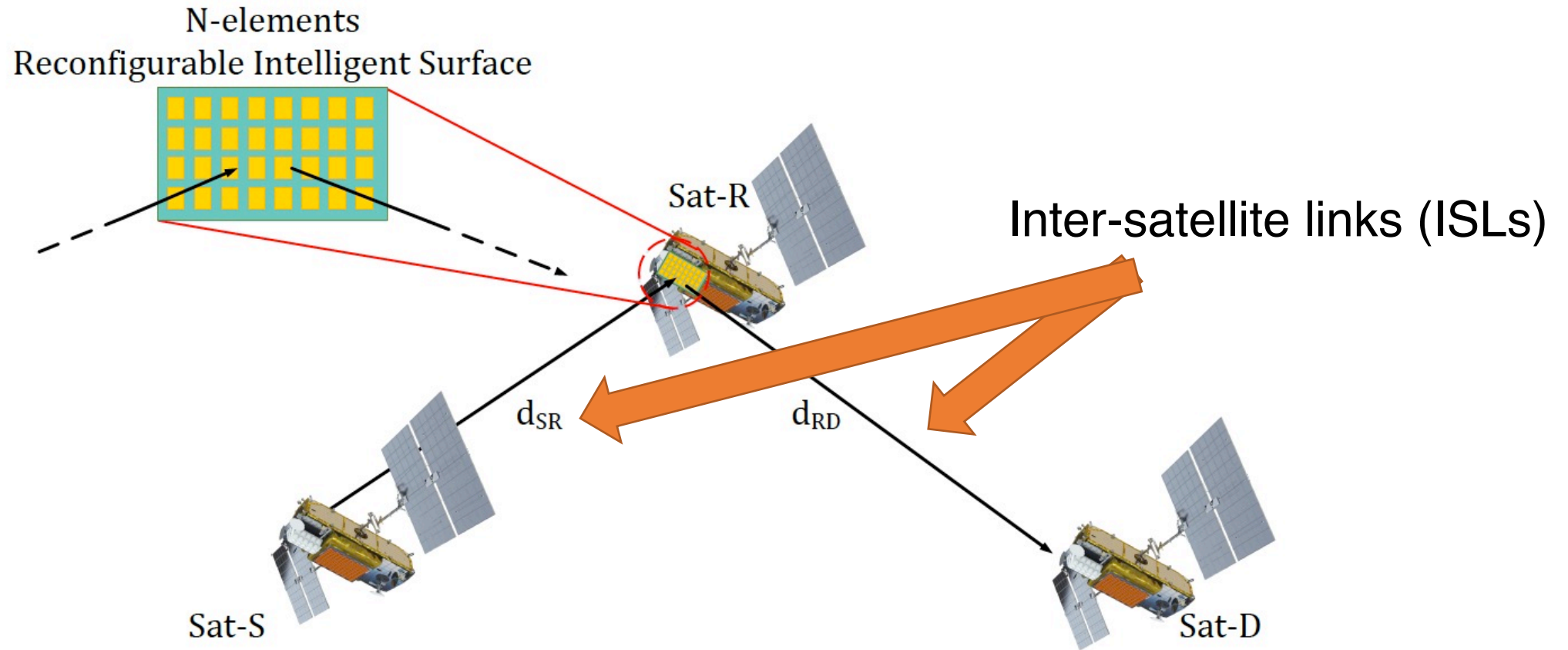
K. Tekbiyik, O. Akbunar, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and S. Yarkan, "Modeling and Analysis of Short Distance Sub-Terahertz Communication Channel via Mixture of Gamma Distribution," accepted for publication in IEEE Transactions on Vehicular Technology 2021, <https://ieeexplore.ieee.org/document/9368251>

# A Flexible Channel Model (3/3)



K. Tekbiyik, O. Akbunar, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and S. Yarkan, "Modeling and Analysis of Short Distance Sub-Terahertz Communication Channel via Mixture of Gamma Distribution," accepted for publication in IEEE Transactions on Vehicular Technology 2021, <https://ieeexplore.ieee.org/document/9368251>

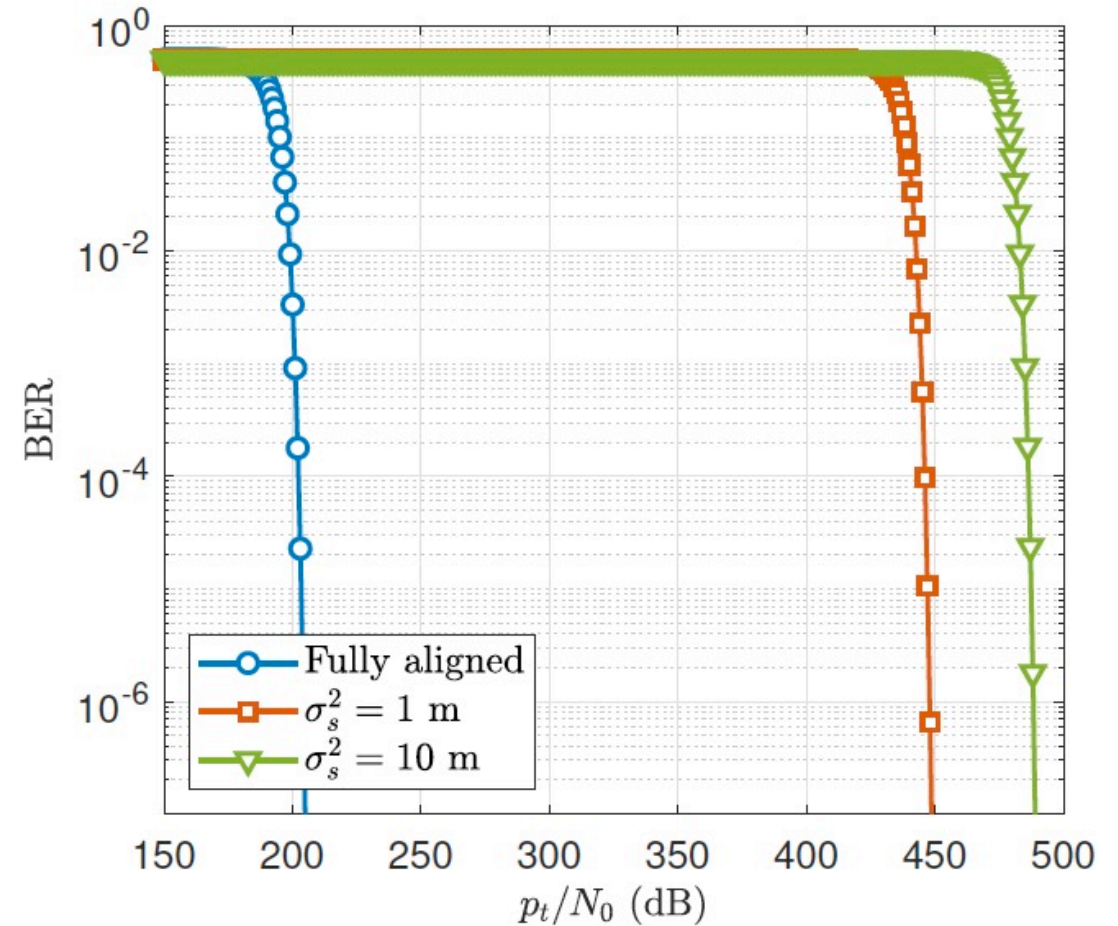
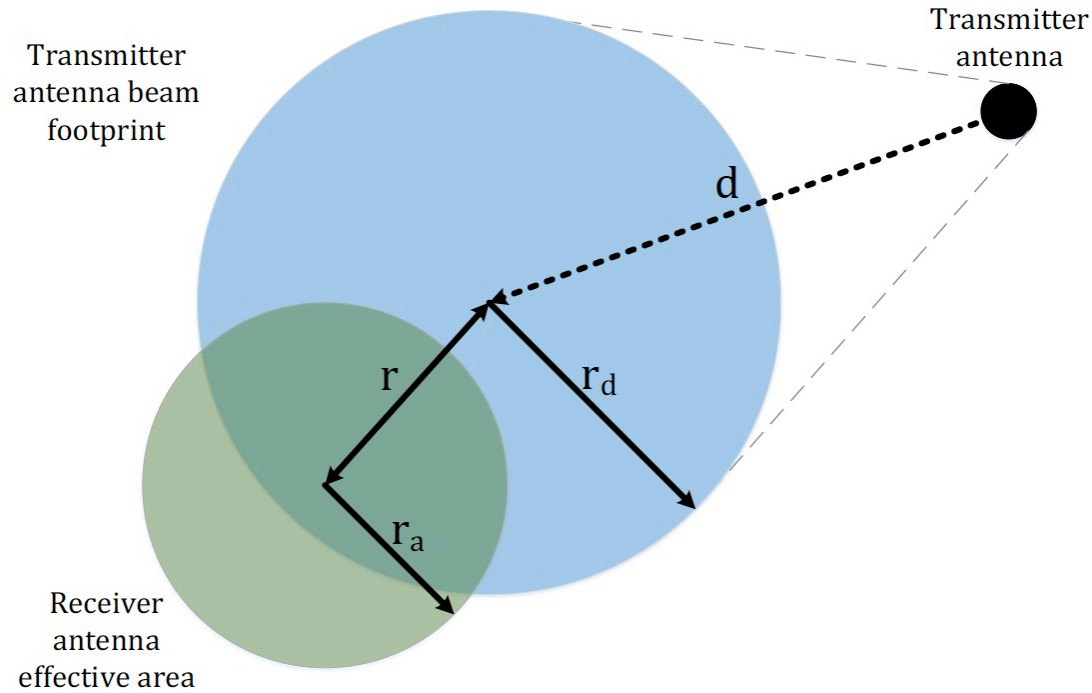
# An Example: RIS-Empowered ISLs (1/3)



K. Tekbiyik, G. Karabulut Kurt, A.R. Ekti, A. R., Görçin, A., and H. Yanikomeroglu, "Reconfigurable intelligent surface empowered terahertz communication for LEO satellite networks", under review (preprint arXiv:2007.04281), <https://arxiv.org/abs/2007.04281>

# An Example: RIS-Empowered ISLs (2/3)

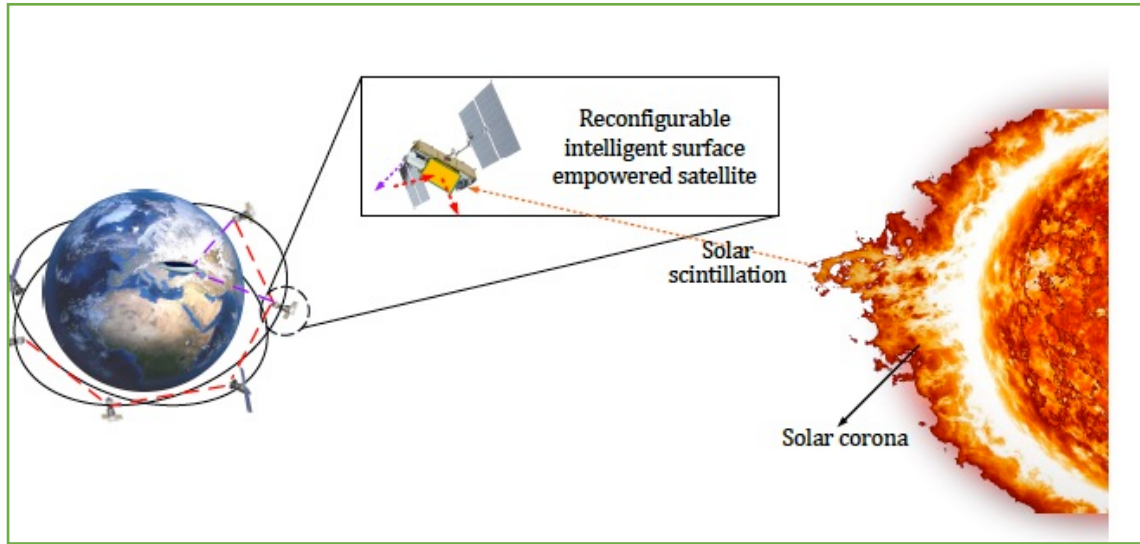
## Beam misalignment



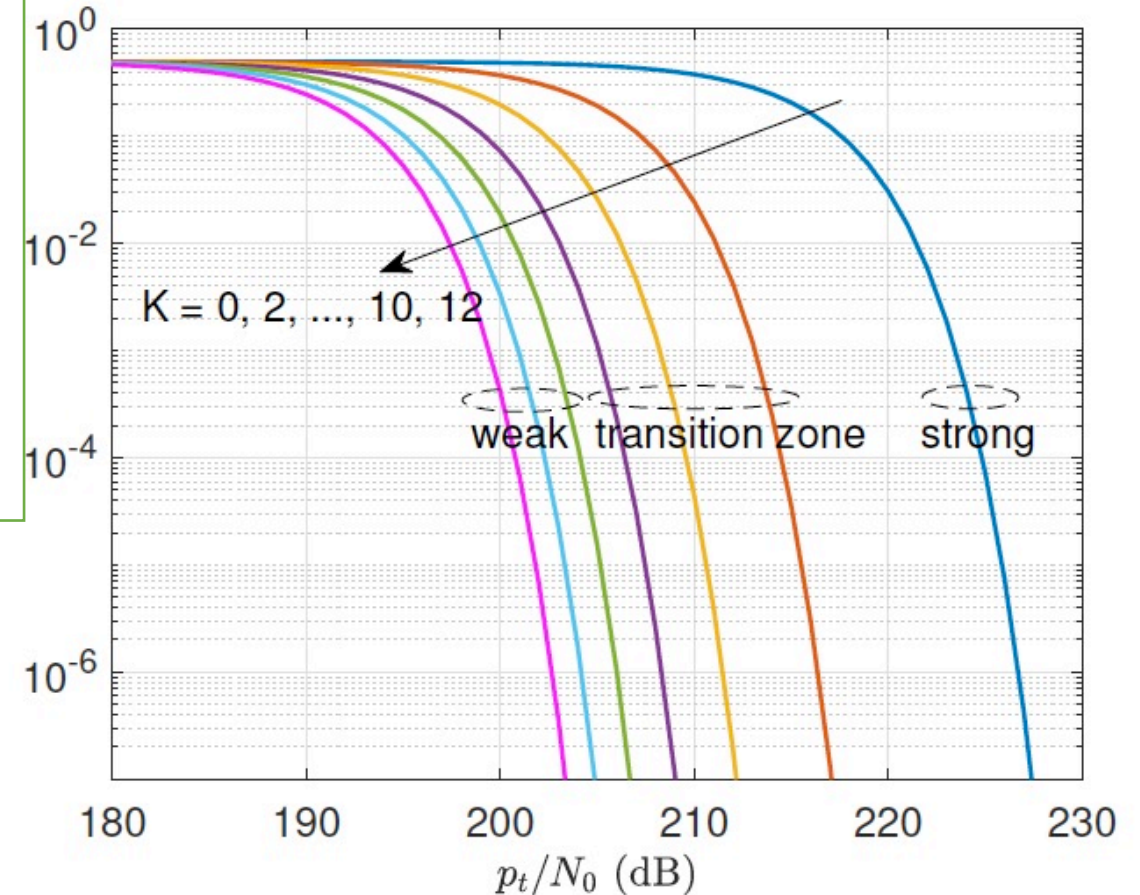
K. Tekbiyik, G. Karabulut Kurt, A.R. Ekti, A. R., Görçin, A., and H. Yanikomeroğlu, “Reconfigurable intelligent surface empowered terahertz communication for LEO satellite networks”, under review (preprint arXiv:2007.04281), <https://arxiv.org/abs/2007.04281>



# An Example: RIS-Empowered ISLs (3/3)



Solar scintillations (a phenomenon caused by changes in plasma density in solar winds ejected from the Sun)



K. Tekbiyik, G. Karabulut Kurt, A.R. Ekti, A. R., Görçin, A., and H. Yanikomeroğlu, “Reconfigurable intelligent surface empowered terahertz communication for LEO satellite networks”, under review (preprint arXiv:2007.04281), <https://arxiv.org/abs/2007.04281>

# Conclusions and Future Directions

- THz has the potential to address the high data rate demands (certainly worth more research)
- Numerous Open Issues:
  - Cell-Free Networking
  - Software-Defined and Self-Organizing Networks
  - Channel Modeling and Estimation
  - Multiple Access Techniques including on-orthogonal multiple access (NOMA),
  - Beam Alignment/Pencil Beams
- Poly-Grames Research Center: <https://www.grames.polymtl.ca>

Prof. Ke Wu, Prof. Christian Cardinal, Prof. Julien Cohen-Adad, Prof. Jean-François Frigon, Prof. Raman Kashyap, Prof. Jean-Jacques Laurin, Prof. Chahé Nerguizian, Prof. Mohammad S. Sharawi...

**European funding opportunities with Canada through Horizon Europe and EUREKA Network programs**

**Canada is an Associated Country**

# Related Publications

## Journal Papers

- K. Tekbiyik, G. Karabulut Kurt, A.R. Ekti, A. R., Görçin, A., and H. Yanikomeroglu, “Reconfigurable intelligent surface empowered terahertz communication for LEO satellite networks”, under review (preprint arXiv:2007.04281), <https://arxiv.org/abs/2007.04281>
- K. Tekbiyik, O. Akbunar, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and S. Yarkan, “Modeling and Analysis of Short Distance Sub-Terahertz Communication Channel via Mixture of Gamma Distribution,” accepted for publication in IEEE Transactions on Vehicular Technology 2021, <https://ieeexplore.ieee.org/document/9368251>
- K. Tekbiyik, A.R. Ekti, G. Karabulut Kurt, A. Gorcin, and H. Yanikomeroglu, “A Holistic Investigation on Terahertz Propagation and Channel Modeling Toward Vertical Heterogeneous Networks,” IEEE Communications Magazine, vol. 58, no. 11, Nov. 2020. <https://ieeexplore.ieee.org/document/9269928>
- K. Tekbiyik, A. R. Ekti, G. Karabulut Kurt, and A. Gorcin, “Terahertz Band Communication Systems: Challenges, Novelty and Standardization Efforts,” Physical Communication, vol.35, August 2019 <https://www.sciencedirect.com/science/article/abs/pii/S1874490718307766>

## Book Chapter

- K. Tekbiyik, A.R. Ekti, A. Gorcin, and G. Karabulut Kurt, On the Advances of Terahertz Communication for 5G and Beyond Wireless Networks, in Flexible and Cognitive Radio Access Technologies for 5G and Beyond, The Institution of Engineering and Technology, 2020. [https://digital-library.theiet.org/content/books/10.1049/pbte092e\\_ch12](https://digital-library.theiet.org/content/books/10.1049/pbte092e_ch12)

## Conference Papers

- K. Tekbiyik, E. Ulusoy, A.R. Ekti, S. Yarkan, T. Baykas, A. Gorcin, and G. Karabulut Kurt, “Statistical channel modeling for short range line-of-sight terahertz communication,” in IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Istanbul, Turkey, 08-11 September, 2019 <https://ieeexplore.ieee.org/abstract/document/8904237>
- K. Tekbiyik, G. Kirman, A.R. Ekti, S. Yarkan, and G. Karabulut Kurt, “Measurement Based LOS/NLOS Signal Detection for Terahertz Communication: Energy Detector Approach,” in 28th Signal Processing and Communications Applications Conference (SIU), 20-22 April 2020. (in Turkish) <https://ieeexplore.ieee.org/document/9302417>

## Dataset

- THz Wireless Channel Measurements in between 240GHz and 300GHz;. Available:<https://ieee-dataport.org/open-access/thz-wireless-channel-measurements-between-240ghz-and-300ghz>

# Thank you for your attention

Questions?  
[gunes.kurt@polymtl.ca](mailto:gunes.kurt@polymtl.ca)