



HYPERCONNECTIVITY

Beyond 5G, Opportunities & Challenges

Simplified Approach for Directional Multipath Component Modeling for mmWaves using Ray Tracing

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Agenda

- Introduction
- Objective
- Deterministic Outdoor Channel Model
 - SISO Model
 - MIMO Model
- Results and Discussion
- Conclusions
- References

Introduction: 5G

- 5G Vision: A Unified Design [1]
 - Addressing wide range of use cases/applications
 - eMBB, mMTC, URLLC
 - Scalable to various requirements/KPIs
 - data rate, connection density, latency, energy efficiency....
 - With the scope of Non-STA and STA architectures
 - Supporting various spectrum types/bands
- Standardization activities actively initiated in ITU-R, 3GPP and others
 - Design of 5G New Radio (NR) operating at two frequency ranges
 - FR1 (< 6GHz)
 - FR2 (> 6GHz, e.g. millimeter waves)

Introduction: Millimeter Waves

mmWave spectrum: 30GHz-300 GHz [2-3]
: Unlicensed 60 GHz [4-6]

- Why ?
 - Large bandwidths (100s of MHz)
 - Inherent support for massive MIMO and network densification
- Challenges
 - High omnidirectional pathloss
 - High blockage
 - High atmospheric absorption loss
- Combating Method
 - Directional transmission
 - Beam steering towards dominant signal path

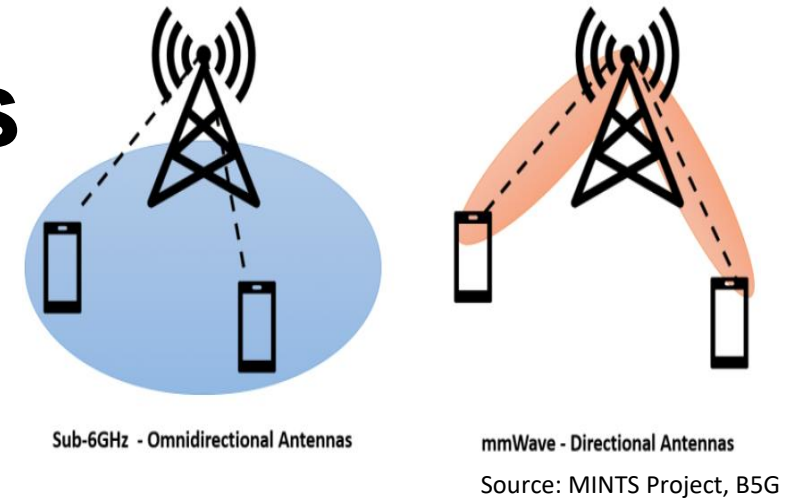


Fig. 1. Directional transmission

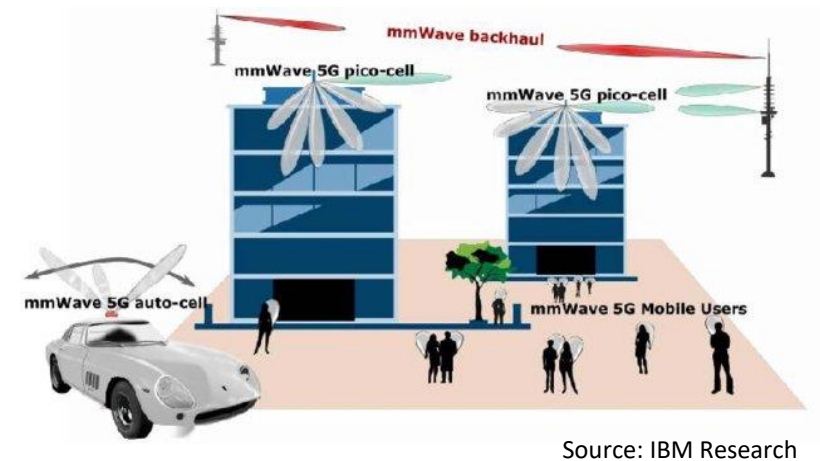


Fig. 2. Beam steering

Introduction: mmWave Channel Modeling

Purpose

- Modeling how the physical channel impacts the signals
- Important for device design and defining realistic test cases

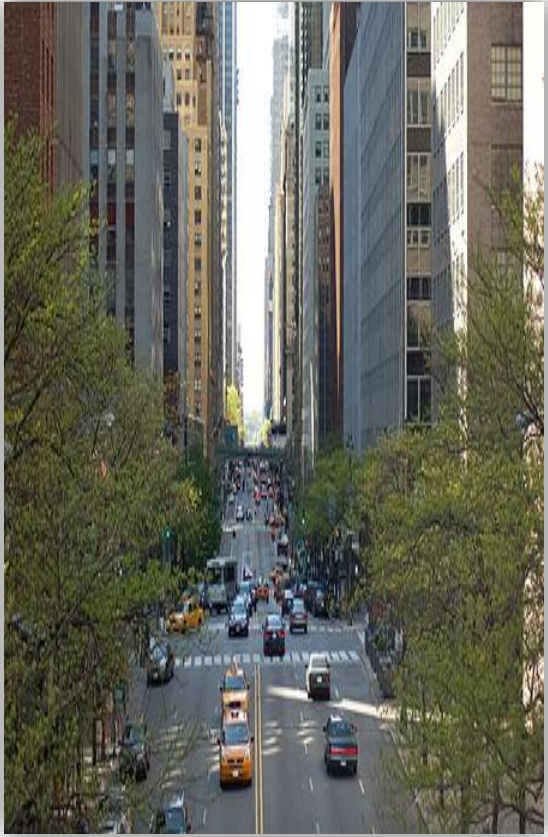
Existing Work: Strategies investigated [2][3]

- Statistical models based on CI and ABG models
 - ✓ Defined for limited fixed input specifications
 - ✓ Inclination towards omnidirectional formulations
- Ray tracing models [8-11]
 - ✓ Modeling fixed number of contributing paths

Requirement

- Attributing to the spatial filtering of directional antennas
- Supporting antenna directionality in horizontal and vertical planes
- Modeling effective antenna gains and analysing their impact on the channel multipath statistics
- Defining mmWave channel characteristics for any input spec

Objective



Investigate the deterministic directional mmWave channel model in 3D UMi SC scenario; custom ray tracing based model with

- Directional antenna geometry in 3D plane
- Frequency dependent specific attenuation
- Foliage losses

Contributions

- Examined the role of antenna directionality in spatial filtering
- Assessed the impact of directionality on street canyon (SC) outdoor deployments
- Investigated antenna diversity for combating deep fades

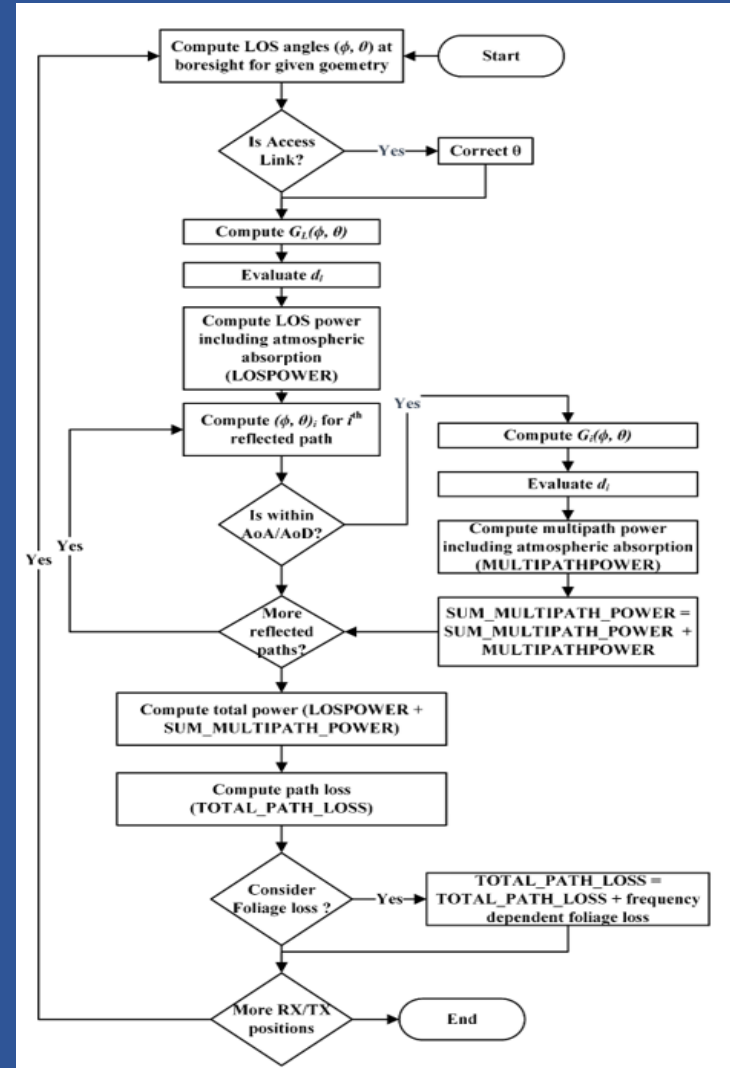
Deterministic Outdoor Channel Modeling

MiDDCM –

Millimeter Wave Directional Deterministic Channel Model

- For SISO : directional antennas will aggregate the multipaths between Tx and Rx if and only if their AoA/AoD fall within the directional antenna beam area
- For MIMO : multipaths between every Tx and Rx pair are checked for this condition

$$|\phi_{LOS,g}| \leq HPBW_A \text{ and } |\theta_{LOS,g}| \leq HPBW_E$$



Channel Modeling: MiDDCM

- For the SISO case

$$h(f, d, \phi, \theta) = \sqrt{G_{LOS}(\phi, \theta)} H_{LOS} + \sqrt{G_g(\phi, \theta)} H_g + \sum_i \sqrt{G_i(\phi, \theta)} H_i \quad (1)$$

$$H_{LOS} = \left[\frac{\lambda}{4\pi d_{LOS}} e^{(-K_a d_{LOS}/2)} \right] e^{(-j\frac{2\pi}{\lambda} d_{LOS})} \quad (2)$$

$$H_g = \left[\Gamma_g \frac{\lambda}{4\pi d_g} e^{(-K_a d_g/2)} \right] e^{(-j\frac{2\pi}{\lambda} d_g)} \quad (3)$$

$$H_i = \left[\Gamma_i \frac{\lambda}{4\pi d_i} e^{(-K_a d_i/2)} \right] e^{(-j\frac{2\pi}{\lambda} d_i)} \quad (4)$$

- λ = Wavelength of mmWave
- K_a = Oxygen absorption coefficient
- d_{LOS} = Path length for LOS
- i = No. of wall reflections
- (ϕ, θ) = Azimuth, elevation angles
- $G(\phi, \theta)$ = Tx-Rx antenna power pattern product
- Γ_i = Reflection coefficient for i^{th} path
- Γ_g = Ground reflection coefficient
- d_i = Path length of i^{th} reflected path
- d_g = Path length of ground reflected path

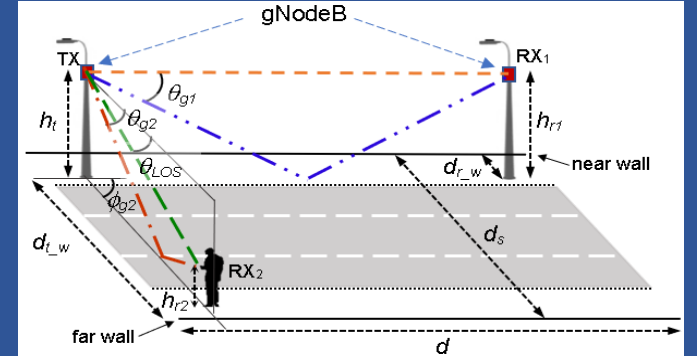


Fig. 3. mmWave UMi SC scenario illustrating direct LOS and ground reflection

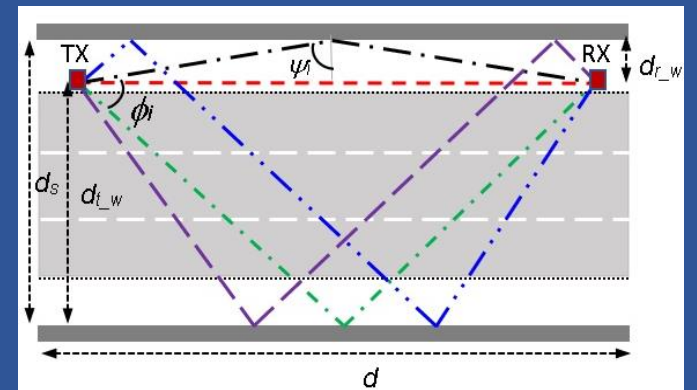


Fig. 4. Top-down view illustrating direct LOS and up to 2nd order wall reflections

Channel Modeling: MiDDCM

- For the SISO case

$$h = \sqrt{G_{LOS}(\phi, \theta)} H_{LOS} + \sqrt{G_g(\phi, \theta)} H_g = 1 + \alpha_g e^{-j\beta_g} \quad (5)$$

$$\alpha_g = \Gamma_g \frac{d_{LOS}}{d_g} \sqrt{\frac{G_g(\phi, \theta)}{G_{LOS}(\phi, \theta)}} e^{-\left(\frac{K_a \Delta d_g}{2}\right)} \quad (6)$$

- For the MIMO case

$$h^r_{mn} = 1 + \alpha_{gmn} e^{-j(\beta_{gmn})} \quad (7)$$

$$\alpha_{gmn} = \Gamma_g \frac{d_{LOSmn}}{d_{gmn}} \sqrt{\frac{G_{gmn}(\phi, \theta)}{G_{LOSmn}(\phi, \theta)}} e^{-\left(\frac{K_a \Delta d_{gmn}}{2}\right)} \quad (8)$$

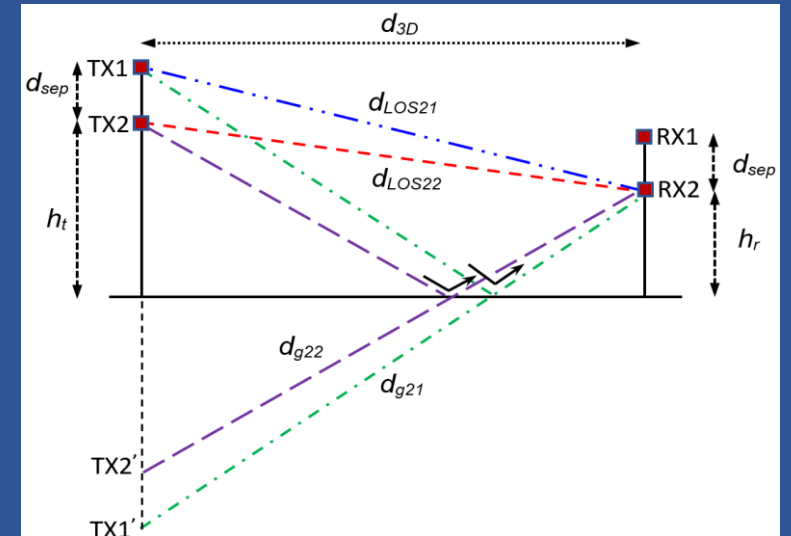


Fig. 5. 2 × 2 MIMO geometry illustrating transmit diversity with LOS paths and ground reflected rays

Channel Modeling: MiDDCM

- For the MIMO case
 - Various path lengths can be analytically deduced from the deployment geometry
 - As $d_{sep} \ll d_{3D}$, the path length differences between LOS paths amongst antenna pairs are small => allows to make approximations
 - i.e., ray tracing computations are further simplified
 - As $d_{sep} \ll h_t, h_r \ll d_{3D}$, the additional phase difference can be further simplified as:

$$\gamma_g = \left(\frac{2\pi}{\lambda} \right) \left(\frac{(h_t + h_r)d_{sep}}{d_{3D}} \right) \quad (9)$$

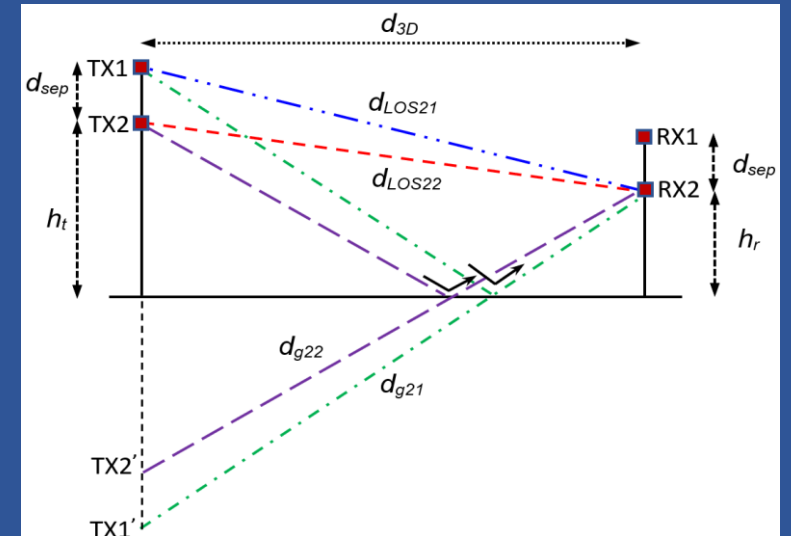
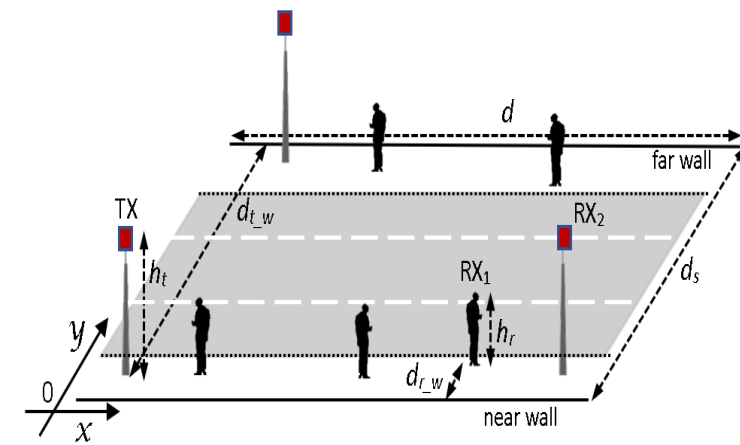


Fig. 5. 2×2 MIMO geometry illustrating transmit diversity with LOS paths and ground reflected rays

Results and Discussion

Link Budget

Link Budget Parameter	Value
Antenna gain	21.6 dBi
Max P_t	13.4 dBm
Max EIRP	35 dBm
Channel bandwidth	1.5 GHz
Oxygen absorption loss	16 dB/km
Link margin	5 dB
Bit rate	2 Gbps
Min E_b/N_o	12 dB
Receiver sensitivity	-66 dBm



Deployment Geometry

Simulation Parameter	Value
Link range (d)	200 m
Width of the street (d_s)	20 m
Tx to wall distance (d_{t_w})	16 m
Rx to wall distance (d_{r_w})	4 m

Results and Discussion: SISO

- Large signal fluctuations relative to FSPL due to strong dominant paths
- Significant fades at several Rx locations
- Large variations of the signal strength distributions for small changes in the deployment geometry

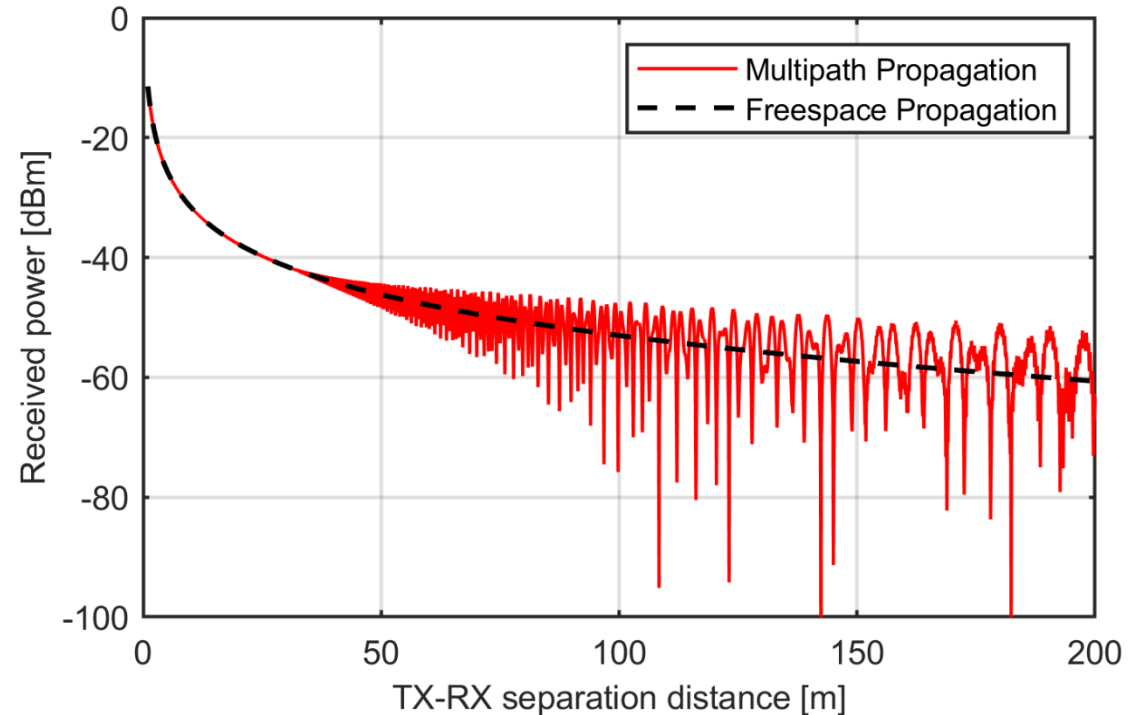


Fig. 6. Backhaul received signal strength variations at 60GHz mmWave transmission

Results and Discussion: SISO

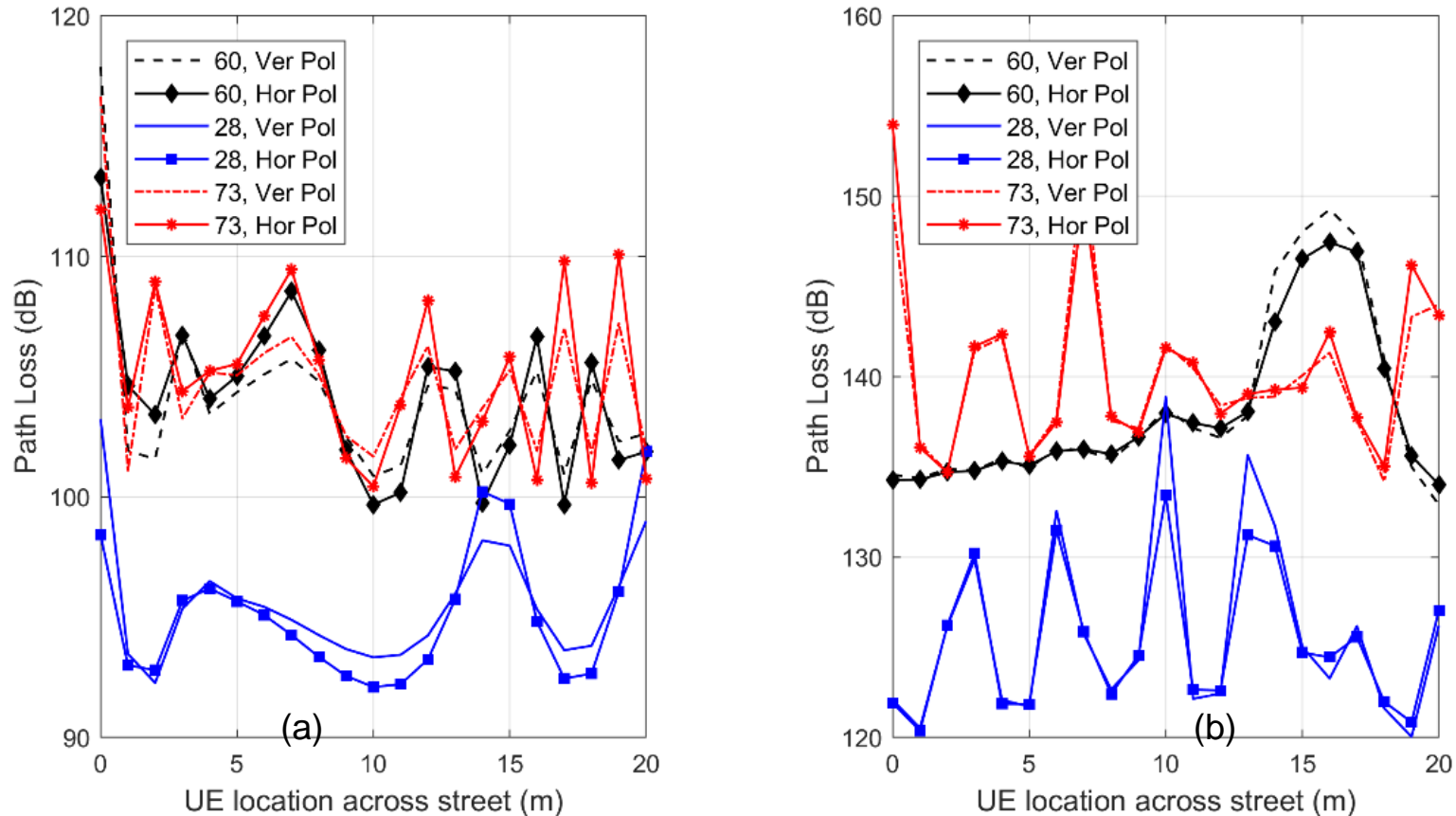


Fig. 7. Path loss for varying mmWave frequencies and polarizations at different UE locations along the street width (a) LOS and (b) NLOS [8]

Results and Discussion: MIMO

- Exploit spatial diversity – to minimize variations
- MISO received signal strength at varying antenna separation distances d_{sep}

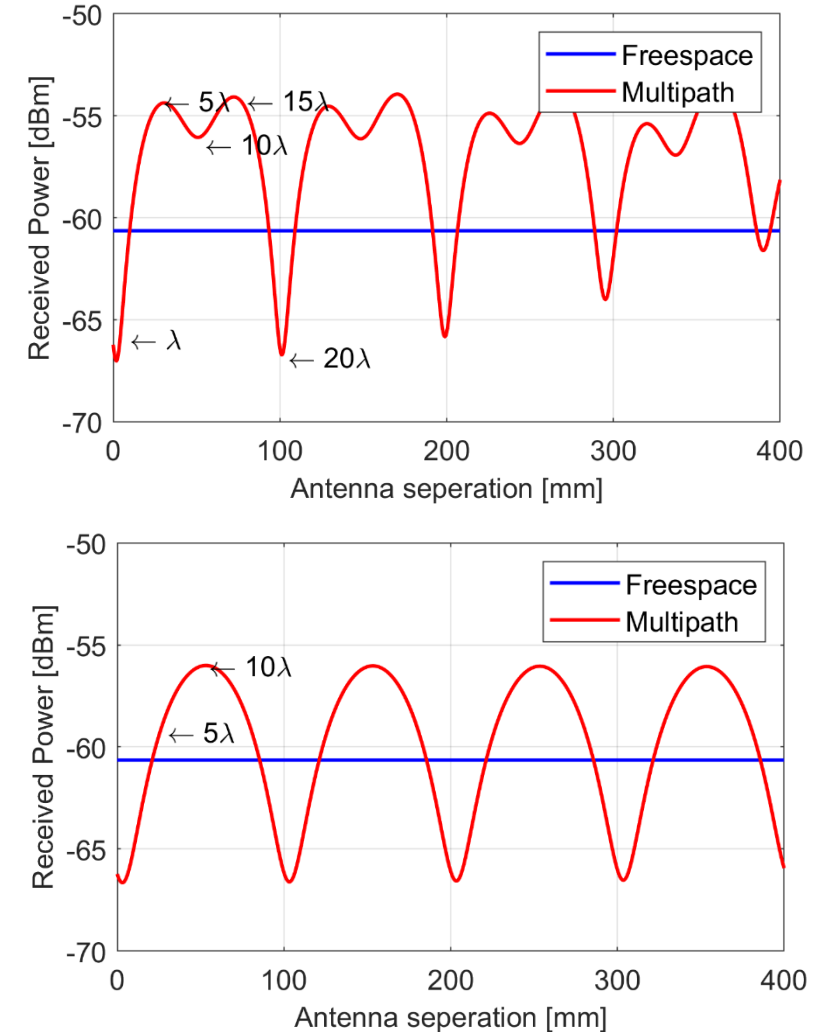


Fig. 8. Signal variations introduced with spatial diversity for antenna separation varying at (a) RX1 (b) RX2

Results and Discussion: Comparison

- CDF: Link range is varied between 30 m and 200 m
- SISO channel shows comparable significant fades below the receiver sensitivity of -60.64 dBm almost 10% of the time
- MISO demonstrates a higher signal power with a reduced fading probability and the signal is always larger than the free space value
- MISO fading probability was higher for the access case, 6% of the time

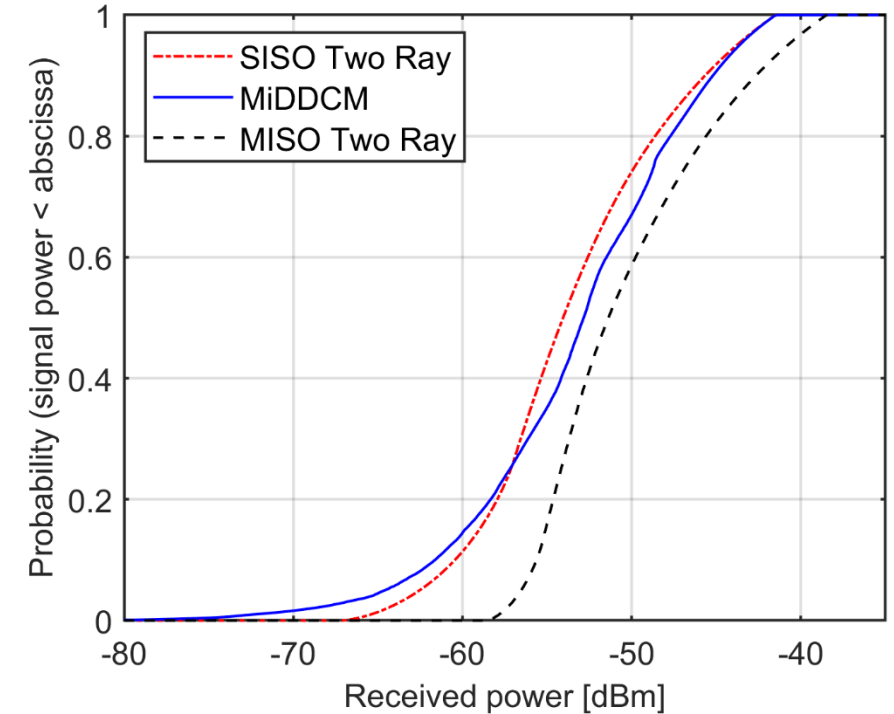


Fig. 9. Comparison of received power for SISO and MISO mmWave link with $h_t = h_r = 7\text{m}$

Results and Discussion: Comparison..

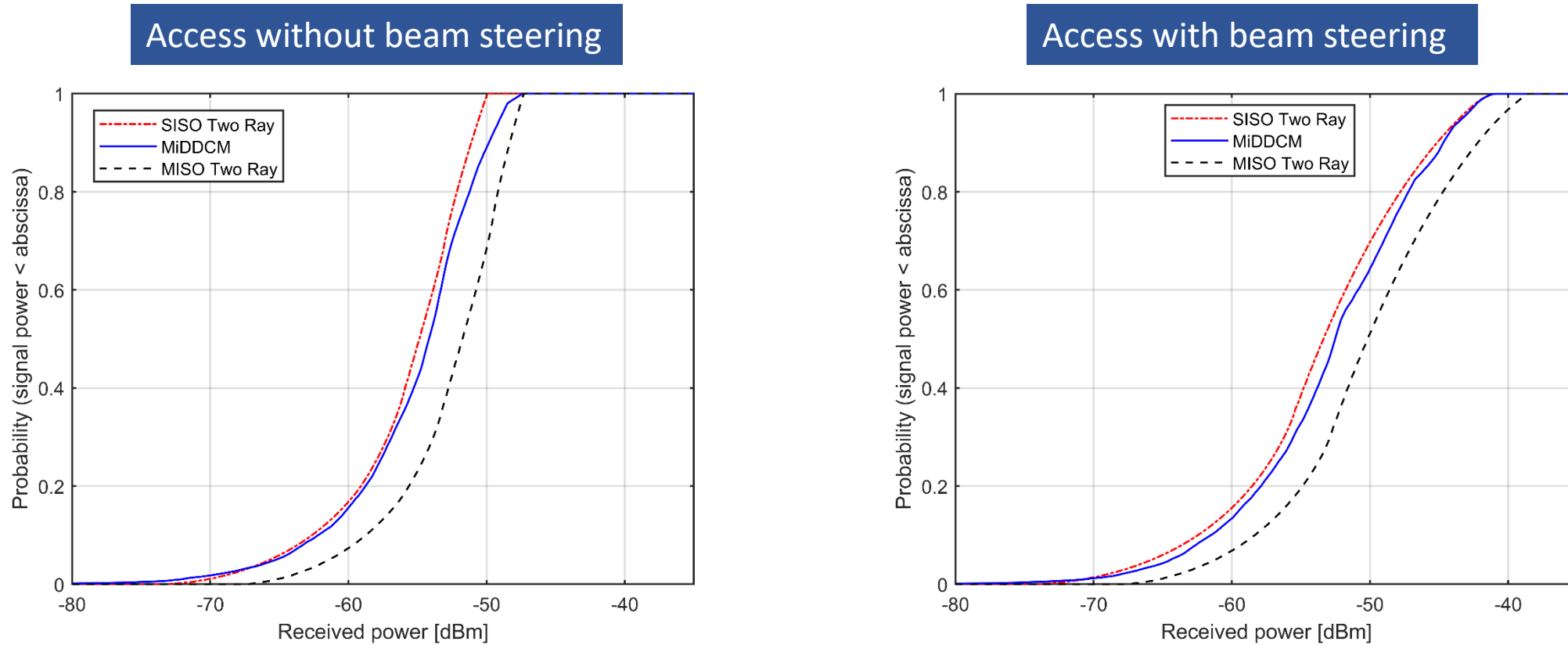


Fig. 10. Comparison of received power for SISO and MISO mmWave link with $h_t = 7\text{m}$, $h_r = 1.5\text{m}$

Results and Discussion: Channel Capacity

- MIMO maximizes the channel capacity
- SISO channel capacity is lesser than the free space benchmark of 4.84 b/s/Hz
- Eigen value analysis:
 - Large eigen value spread => high spatial correlation
 - Eigen value spread reduced for access channels

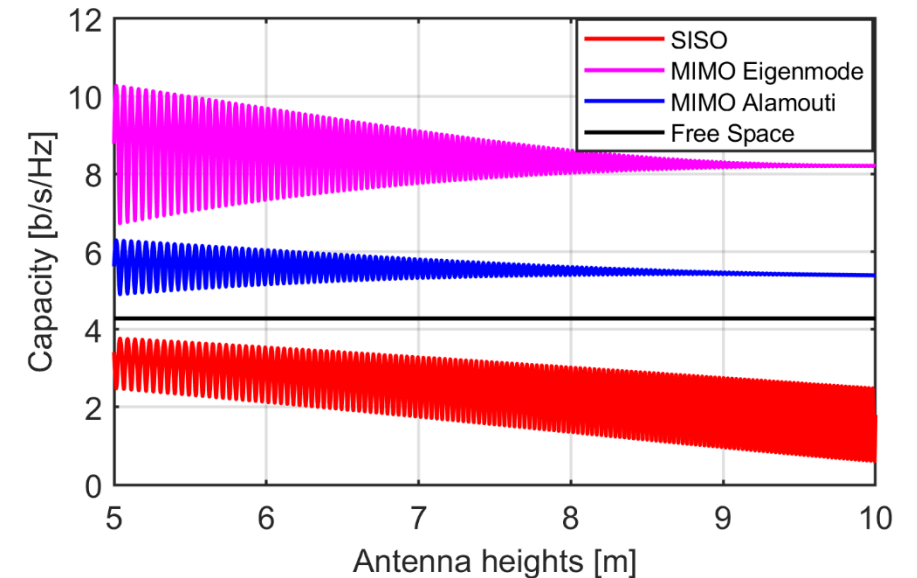


Fig. 11. Backhaul channel capacity variations with the antenna height

Conclusions and Future Scope

- Proposed and analyzed MiDDCM - Directional mmWave model for UMi SC to emphasize the significance of integrating antenna effect in channel modelling
- Stabilized the signal strength variations with a simple 2 x 2 MIMO architecture for diversity
- Examined the effect of antenna separation for vertically separated antennas
 - unlike a rich scattering channel omnidirectional channel, directional MIMO channel requires a minimum antenna separation of multiples of λ
- Observed large eigen value spread indicating high spatial correlation in directional mmWave sparse channels
- Future scope: To extend the model for varying input specifications and layout geometries

References

- [1] Ericsson, "Ericsson Mobility Report," 2020. [Online]. Available: <https://www.ericsson.com/49da93/assets/local/mobility-report/documents/2020/june2020-ericsson-mobility-report.pdf>
- [2] A. N. Uwaechia and N. M. Mahyuddin, "A comprehensive survey on millimeter wave communications for fifth-generation wireless networks: Feasibility and challenges, " IEEE Access, vol. 8, pp. 62367–62414, 2020.
- [3] I. A. Hemadeh, K. Satyanarayana, M. El-Hajjar, and L. Hanzo, "Millimeter-Wave Communications: Physical Channel Models, Design Considerations, Antenna Constructions, and Link-Budget," IEEE Commun. Surv. Tutorials, vol. 20, no. 2, pp. 870–913, 2018.
- [4] D. M. Matic, H. Harada, and R. Prasad, "Indoor and outdoor frequency measurements for mm waves in the range of 60 GHz," in IEEE Vehicular Technology Conference 1998, VTC 98, Vol. 1, pp. 567–571, 1998.
- [5] H. Singh, R. Prasad, and B. Bonev, "The Studies of Millimeter Waves at 60 GHz in Outdoor Environments for IMT Applications: A State of Art," Wireless Pers Communications, 463–474, 2018.
- [6] J. Purwaha, A. Mank, D. M. Matic, K. Witrisal, and R. Prasad, "Wide-Band Channel Measurements at 60GHz in Indoor Environments," Proc. IEEE Benelux 6th Symp. Veh. Technol. Commun, 1998.
- [7] R. Prasad, and L. Vandendorpe "An overview of millimeter wave indoor wireless communication systems," Proceedings of 2nd IEEE International Conference on Universal Personal Communications 2, 885-889, 1993.
- [8] Sheeba Kumari M., N. Kumar, "Channel Model for Simultaneous Backhaul and Access for mmWave 5G Outdoor Street Canyon Channel," Springer Wireless Networks, July 2020.
- [9] M. Sheeba Kumari, N. Kumar and R. Prasad, "Performance of mmWave Ray Tracing Outdoor Channel Model Exploiting Antenna Directionality," 2020 IEEE 3rd 5G World Forum (5GWF), Bangalore, India, pp. 607-612, 2020.
- [10] Sheeba Kumari M., S. A. Rao, and N. Kumar, "Modeling and Link Budget Estimation of Directional mmWave Outdoor Environment for 5G," in 2019 European Conference on Networks and Communications, EuCNC 2019, pp. 106–111, June 2019.
- [11] M. Lecci et al., "Simplified Ray Tracing for the Millimeter Wave Channel: A Performance Evaluation," in Information Theory and Applications Workshop (ITA), San Diego, US, February 2020.
- [12] 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.

Thank You