Analysis of mm-Wave Wireless Networks Using Cylindrical Receiver Grids in Street Canyon Urban Areas

Samad R. Shabestari
School of Computing, Queen's University,
Kingston, ON, Canada
s.r.shabestari@queensu.ca

Hossam Hassanein
School of Computing, Queen's University,
Kingston, ON, Canada
hossam@cs.queensu.ca

***Abstract*— The deployment of millimeter-wave (mm-Wave) frequencies in urban wireless networks offers a promising solution to meet escalating data demands. However, challenges such as severe signal attenuation, multipath propagation, and signal strength fluctuations complicate mm-Wave technology implementation in urban street canyons. While effective at lower frequencies, traditional planar receiver grids fail to address these issues due to limited dimensional coverage and sensitivity to urban dynamics. This analysis advocates cylindrical receiver grids as an innovative technique to enhance mm-Wave network analysis in environments. Cylindrical grids offer a three-dimensional signal capture, which is essential for understanding the complex propagation behaviors within urban canyons. The results show that cylindrical grids capture more detail on how millimeter radio waves interact with their environment and detect a broader range of path rays, indicating comprehensive signal detection in both horizontal and vertical planes.**

Keywords*— *millimeter-wave, cylindrical receiver grids, urban areas, Raytracing

I. INTRODUCTION

The increasing demand for higher bandwidth in urban communication networks has accelerated the adoption of millimeter-wave (mm-Wave) frequencies. These frequencies offer substantially greater bandwidth than traditional lower-frequency bands, making them ideal for supporting the heavy data demands of densely populated urban areas. As cities densify, mm-Wave technology emerges as a key player in enabling high-capacity wireless communication to support data-heavy applications, mitigating the congestion encountered at lower frequencies. Nonetheless, this transition introduces intricate propagation challenges in urban street canyons, where high-rise structures and mobile obstacles precipitate signal variability and loss. Addressing these issues necessitates a departure from traditional receiver grid designs.

II. WHY CYLINDRICAL RECEIVER GRIDS?

Traditional planar receiver grids are effective at lower frequencies but fall short in accurately characterizing mm-Wave propagation in urban settings, where there is greater sensitivity to spatial changes in the surrounding environment that impact channel predictions.

The cylindrical receiver grids represent a paradigm shift, offering:

1. Three-Dimensional Coverage: They capture vertical signal components alongside horizontal, pivotal for urban canyon scenarios.
2. Enhanced Multipath Analysis: Due to its encompassing geometric form, the cylindrical design enables the detection of complex multipath interactions.
3. Adaptability to Urban Dynamics: Cylindrical grids are better suited to adapt to dynamic urban environments, capturing transient characteristics of mm-Wave channels influenced by moving objects like vehicles and pedestrians.

Therefore, they allow for a more comprehensive analysis of multipath effects and adaptability to the transient urban landscape, improving network reliability.

III. DIFFERENCE IN RAY TRACING ANALYSIS

Ray tracing simulations are indispensable for wave propagation analysis in complex urban landscapes, particularly when direct field measurements are constrained by cost and logistical challenges. Recognized references, including [1] [2] [3], highlight ray tracing's accuracy in modeling interactions with urban features, substantiating its value over traditional methods. Applying cylindrical receiver grids in these simulations overcomes the limitations of rectangular grids by capturing intricate signal dynamics in urban canyons and junctions. This approach offers a realistic representation of signal behavior and streamlines network optimization and performance prediction, circumventing the need for extensive field trials.

IV. EXPERIMENTAL SETUP APPROACH

Figure 1 illustrates a proposed cylindrical receiver point grid to capture the delay-angle power profile to analyze radio propagation parameters in a street canyon of an urban intersection. This cylindrical Rx grid contains between 344 and 355 receiver points over the surface of a cylinder with a spacing of 11.5492 degrees (or 0.1 meters) from one another. Thus, they are a set of spatially correlated receiver points. The cylinder has a height of one meter and a radius of 0.5 meters. The receiver points are set on the surface of this cylinder, and each receiver point is equipped with an omnidirectional antenna.

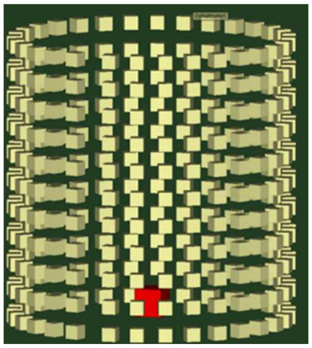

Figure 1. The proposed cylindrical receiver grid.

Using Wireless Insite [4], five cylindrical Rx grids assess mmWave propagation from a junction to an NLOS street, operating at 73 GHz with a base station power of 30 dBm. Surrounded by buildings and traffic, as shown in Figure 2, these grids better capture complex signal dynamics, including vertical paths and multipath effects, than traditional planar grids. This approach enables the capture of joint angular and delay spread power profiles, which leads to realistic urban channel models that improve network planning and optimization.

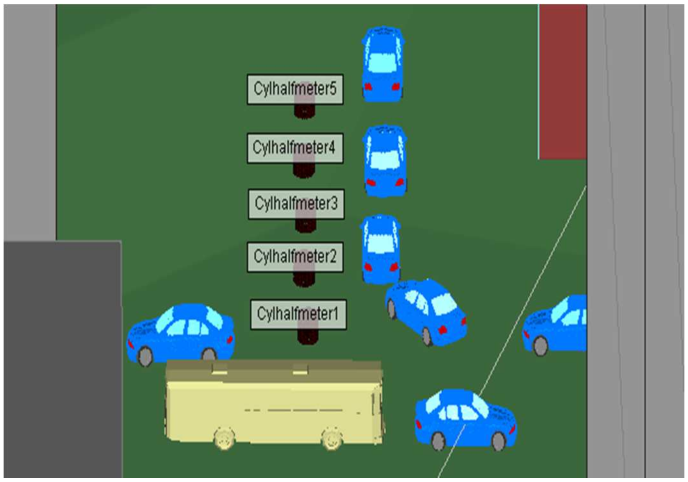

Figure 2. Deployment of five cylindrical receiver grids in WI raytracing.

V. RESULTS

Figure 3 and Figure 4 exhibit the power variation in cylindrical and planar receiver grids at an urban junction. The cylindrical grid captures a wider range of power fluctuations, indicative of its comprehensive signal detection in both horizontal and vertical planes.

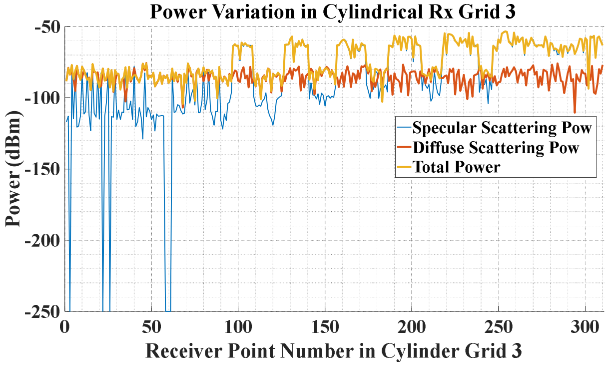

Figure 3. Power variation measurement by the cylindrical Rx grids.

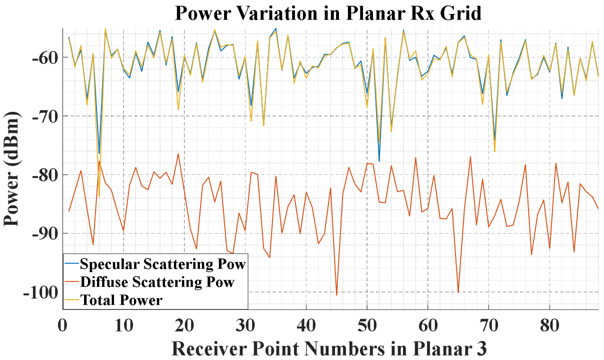

Figure 4. Power variation measurement by the planar Rx grid.

Specular scattering showed significant variability, reflecting its sensitivity to direct paths and angular dependencies. In contrast, the planar grid displayed smoother power variations, suggesting a restricted capture of vertical multipath components. These findings underscore the cylindrical grid's enhanced accuracy in characterizing the complex mm-Wave propagation environment, proving its superiority over planar grids for urban wireless network analysis.

VI. CONCLUSION

The study confirms the cylindrical receiver grid's pivotal role in mm-Wave networks for 5G and beyond. It distinctly outperforms planar grids by detailing signal behaviors in 3D space, which is crucial for accurate urban propagation modeling. Enhanced channel insights from the cylindrical grid translate into robust network performance, addressing mm-Wave challenges in urban canyons. The cylindrical grid's deployment is essential for the future of adaptive, high-capacity wireless communications. Planar grids show the limited influence of diffuse scattering power on total power fluctuation, reflecting their horizontal signal capture. However, cylindrical grids reveal a more significant influence of diffuse scattering power on total power variation due to their 3D signal capture across multiple propagation paths. This data highlights cylindrical grids' superiority in detailed mm-Wave signal analysis, which is essential for urban canyon environments.

VII. REFERENCES

[1] A. F. Molisch, A. Karttunen, S. Hur, J. Park and J. Zhang, "Spatially consistent pathloss modeling for millimeter-wave channels in urban environments," 10th EuCAP, pp. 1-5, 2016.

[2] G. Reus-Muns, J. Du, D. Chizhik, R. Valenzuela and K. R. Chowdhury, "Machine Learning-based mmWave Path Loss Prediction for Urban/Suburban Macro Sites," GLOBECOM Communications Conference, pp. 1429-1434, 2022.

[3] M. Al-samman et al., "A survey of millimeter wave (mm-Wave) communications for 5G: Channel measurement below and above 6 GHz," in Proceedings of the 3rd International Conference of Reliable Information and Communication Technology (IRICT 2018), 2019.

[4] Remcom Inc., "Wireless InSite," Version 3.4.4.13, 2023.