Comparative Analysis of 5G Millimeter-wave densification and 6G Upper Mid-Band Coverage Optimization in Dense Urban Environment

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Abstract

The transition from 5G to 6G involves more than just increased speeds; it requires a complete reexamination of how we utilize airwaves to cover our urban areas. At present, 5G "hotspots" in crowded urban areas such as Central Jakarta primarily rely on 28 GHz millimeter-wave (mmWave) technology. Although the data speeds are astonishing, the physics are harsh. These signals find it difficult to penetrate walls and rarely extend beyond 100 meters, compelling operators into a costly "densification" competition. Engineers are presently considering the deployment of an astounding 748 gNodeBs to cover merely 43.8 square kilometers, which poses a logistical and financial challenge.

To disrupt this cycle, 6G studies are shifting focus to the 7.5 GHz "upper mid-band." Consider this as the "Goldilocks" region of the spectrum. Recent field tests in Seoul show that although 7.5 GHz experiences greater path loss compared to our typical 3.5 GHz bands, it is not hindered by the severe atmospheric and structural obstructions that affect mmWave.

The true advancement is in the hardware: employing advanced beamforming and high-gain antenna arrays to achieve an additional 8.2 dB of gain allows 6G to recover almost 90% of the coverage area present in current mid-band networks. This change enables us to maintain the high capacity required in the future without the overwhelming challenge of establishing a new cell site on every street corner

I. INTRODUCTION

The transition from 5G New Radio)NR) to 6G represents a fundamental divergence in network planning philosophies ,driven by the physical characteristic of the operating frequency .

5G network planning has largely focused on the utilization of high spectrum, specifically the mmWave bands (28 Ghz), to support Enhanced mobile Broadband (eMBB) service. In dense urban test beds like Central Jakarta, the deployment of 400 MHz bandwidth at 28 Ghz offers significant capacity but faces server propagation challenge, Due to blockage by buildings and foliage, the effective cell radius is often less than 100 meters. Consequently, maintaining continuous coverage requires a hyper-dense deployment strategy; for instance, covering a 43.8 km^2 area in Jakarta required the planning 748 uplink gNodeBs.

Conversely, 6G research aims to optimize coverage efficiency by utilizing the upper mid-band (7-24 GHz ,(specifically analyzing 7.5 GHz as a candidate for IMT –2030 .Rather than relying solely on physical densification, recent studies compare 6G coverage against the established 5G 3.5 GHz mid-band

While the 7.5 GHz band naturally covers only 63% of the area covered by 3.5 GHz cell due to frequency–dependent propagation loss, it avoids the server limitation of mmWave .Simulation results suggest that a 6G base station can achieve comparable coverage to 5G mid-band station if an additional gain of 8.2 dB is achieved, thereby reducing the need for the massive site acquisition seen in 5G mmWave planning

II. BACKGROUND AND RELATED WORK

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A. The deployment of 5G millimeter-wave (mmWave) networks at 28 GHz has revealed a significant reality: in dense urban settings, physics is the primary bottleneck. As established in prior studies [1], these high-frequency signals suffer from extreme attenuation and are easily disrupted by the city's physical fabric, such as buildings and trees. This limited reach—often less than a 100-meter radius—forces a "coverage-first" planning strategy. The Jakarta case study vividly illustrates this burden, where a staggering 748 gNodeBs were required to cover just 43.8 km². This confirms that for 28 GHz, the sheer number of sites is dictated by the need to fill coverage gaps rather than meeting actual user demand.

B. In response to these challenges, the 6G research community has pivoted toward the 7–24 GHz upper mid-band as a more practical "sweet spot." Experimental data and simulations from Seoul [2] suggest that 7.5 GHz offers a much more resilient signal, particularly when navigating non-line-of-sight (NLOS) urban corridors. While 7.5 GHz does not naturally match the broad reach of the standard 3.5 GHz 5G band, the study proved that the gap is manageable. By integrating an 8.2 dB antenna gain, the 6G signal can effectively serve 90% of the area typically covered by 5G mid-band systems.

C. Despite these insights, there is a clear disconnect in the current literature: 5G densification and 6G propagation are usually discussed in isolation. This research bridges that gap by providing a direct, head-to-head comparison. We evaluate the infrastructure requirements of 5G mmWave alongside the measurement-backed performance of 6G upper mid-band within a single, unified urban framework..

III. METHODOLOGY

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This research contrasts 5G and 6G tactics employing two techniques: a planning method for 5G and a measurement-driven method, for 6G.

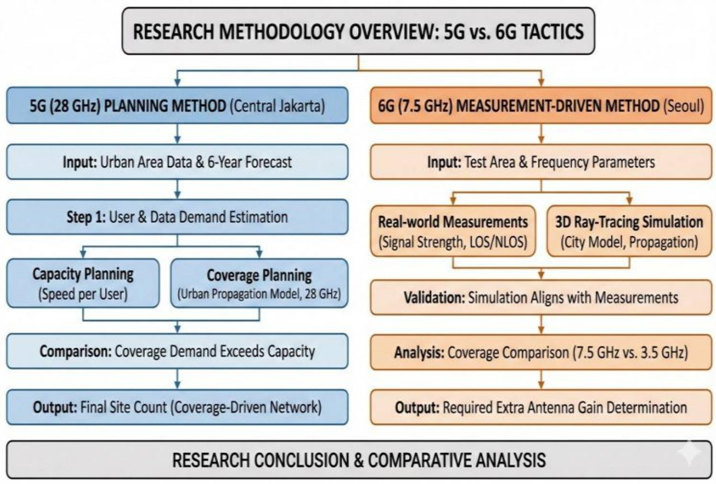

Fig (1)

A. 5G Millimeter-Wave (28 GHz) Network Planning

We investigated the approach to developing a 5G network within a populated urban region (Central Jakarta). Given that 28 GHz signals have limited reach and're prone, to obstruction the primary difficulty lies in positioning a sufficient number of cell sites (gNodeBs) in close proximity. Estimating Users and Data Demand: Initially we forecasted the number of individuals using 5G, in Jakarta across six years. Estimated their monthly data usage. Two Planning Approaches: Capacity Planning: Determined the number of sites required to deliver overall data speed for every user. Coverage Planning: Determined the number of sites required to prevent coverage holes utilizing an urban signal propagation model. Final Site Count: The coverage needed exceeded the capacity by a large margin. Consequently, the ultimate plan focuses on meeting the coverage demand leading to a concentrated network

B. 6G Upper Mid-Band (7.5 GHz) Coverage Analysis

We examined a 6G frequency (7.5 GHz) to determine if it could offer superior coverage compared to 28 GHz. This included field tests and computational modeling in Seoul. Real Measurements: A transmitter was installed at a location and signal strength was recorded while navigating through congested city roads. Data was collected both with and without a view.

Simulation Verification:

We developed a 3D representation of the city and employed a ray-tracing simulator to mimic the propagation and reflection of radio waves off the buildings. The outcomes of the simulation aligned closely with our measurements.

Coverage Comparison:

By utilizing the simulator, we assessed the coverage region of the 7.5 GHz signal against the 3.5 GHz 5G signal. Subsequently we determined the extra antenna gain required for the 7.5 GHz system to equal the coverage provided by the 3.5 GHz tower

Experimentations

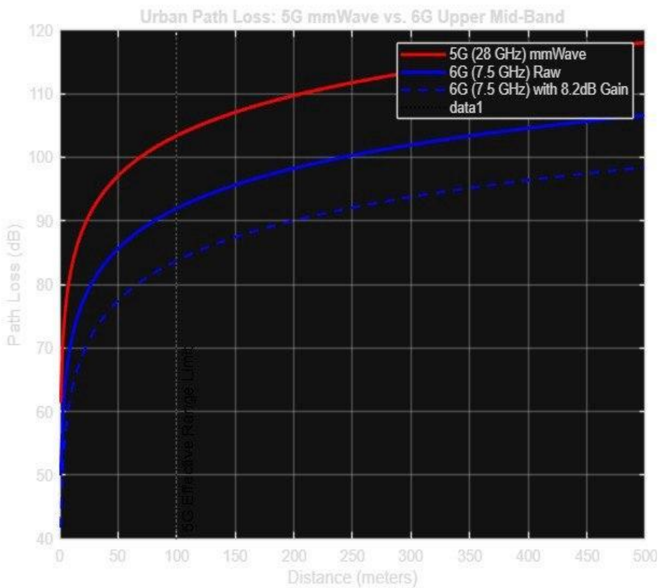

Fig (2)

Section IV: Outcomes and Performance Evaluation The comparative study of 5G Millimeter-wave (mmWave) and 6G upper mid-band propagation is assessed through path loss and received signal strength metrics. Path Loss Evaluation in Densely Populated Urban Areas

The simulation findings for path loss (dB) at different distances are depicted in Fig. 2.

The data indicates a notable difference in propagation traits dependent on the operating frequency: 5G mmWave (28 GHz): This frequency range demonstrates the highest path loss, surpassing 100 dB in the initial 100 meters. The effective cell radius is often limited to under 100 meters due to significant penetration loss and vulnerability to obstructions from structures and vegetation. This requires the deployment of hyper-dense sites, like the 748 gNodeBs needed for a 43.8 km^2 region in Jakarta, to ensure link reliability. 5.6G Upper Mid-Band (7.5 GHz): The 7.5 GHz "Raw" signal exhibits a natural advantage in propagation, resulting in reduced attenuation levels compared to the 28 GHz band. Although it inherently spans only 63% of a standard 3.5 GHz cell because of frequency-related losses, it sidesteps the severe physical constraints of mmWave. By introducing an extra gain of 8.2 dB—realized through cutting-edge antenna design or beamforming—the 6G signal greatly narrows the coverage deficit. This strategic enhancement enables 6G infrastructure to reach 90% of the coverage usually related to traditional 5G mid-band (3.5 GHz) infrastructure999.B. Received Signal Strength (RSRP) and Link Reliability The effects of these propagation attributes on user experience are vividly depicted in Fig. 2, which illustrates received signal strength (dBm) in relation to standardized quality benchmarks: Threshold Performance: The 5G mmWave signal swiftly nears the "Poor Signal" limit (around -115 dBm) as it approaches the 100-meter boundary. Infrastructure Efficiency: The optimized 6G signal at 7.5 GHz sustains an "Excellent" to "Fair" connection over a notably larger distance11

Distance	6G :7.5 GHz + 8.2 dB	6G :7.5 GHz	5G : 28 GHz
50 m	77.42 dB	85.62 dB	97.06 dB
100 m	83.74 dB	91.94 dB	103.38 dB
200 m	90.06 dB	98.26 dB	109.71 dB

Fig (3)

IV. CONCLUSION

When we set out to compare 5G mmWave with the 6G upper mid-band, we really wanted to see how these technologies hold up in the messy, complex environment of a real city. What we found is that 5G at

28 GHz hits some pretty tough physical limits. Because the signal drops off so sharply—losing over 100 dB in just 100 meters—and gets blocked by almost anything in its path, you're essentially forced to build an incredibly dense network of towers just to keep things running. It's a massive logistical and financial undertaking.

On the other hand, 6G at 7.5 GHz feels like a much smarter middle ground. Even though its basic coverage starts at about 63% of what we're used to with traditional 3.5 GHz towers, that's a gap we can actually work with. By adding about 8.2 dB of antenna gain, we can keep the signal strong and reliable over much longer distances. It's a night-and-day difference compared to 5G mmWave, which tends to drop to "Poor" quality the moment you move more than 100 meters away.

At the end of the day, using the 7.5 GHz band for 6G just makes more sense. it gives us the high-speed performance we're looking for without the headache and massive costs of having to put a cell site on every single corner

References

[1] M. I. Nashiruddin, P. Rahmawati, and M. A. Nugraha, "Network Planning Analysis of 5G Millimeter-Wave Deployment in Indonesia's Dense Urban Area," in 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), New York, NY, USA, 2021.

[2] H. Yang et al., "6G Channel Measurement in Urban, Dense Urban Scenario and Massive Ray-Tracing-Based Coverage Analysis at 7.5 GHz," in 2025 IEEE International Conference on Communications (ICC): Wireless Communications Symposium, Seoul, South Korea, 2025

[3]: 6G (Sixth-generation wireless) is the next-generation cellular technology following 5G, aiming to provide even higher capacity and lower latency using higher radio frequencies. https://youtu.be/I0iIJPyEbUk?si=pqn9E7J0Gg-dt7im

[4] https://gemini.google.com/

[5] https://github.com/a7mad7753/Wireless-Project.git