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MATLAB Implementation of Effects of Fifth Generation on Free Space

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Abstract: Given that there is a widespread demand for quick internet access, all of the main telecommunications providers throughout the world are working hard to improve their speed on the internet. Internet connectivity that is dependable is becoming more in demand across the whole economy, including the home market, the watch market, the mobile phone market, and the auto-mobile market. The creation of 5G technology is a response to a society that is defined by rapidly changing conditions and increasing expectations for technological advancement. Increasing capacity, improving data rates, decreasing latency, and enhancing service quality are some of the main goals that should be pursued in the future, especially in an environment that is post-4G infrastructure. In order to accomplish these goals, the architecture of 5G cellular has to undergo substantial changes. In this research, the architecture of the 5G cellular network as well as certain breakthrough technologies that have the potential to improve the design and meet the demands of users are the primary topics of discussion and how it effects in free space.

Keywords: Mobile broadband services, latency, connectivity, throughput.

تنفيذ ماتلاب لتأثيرات الجيل الخامس على الفضاء الحر

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المستخلص: نظرًا للطلب الواسع على الوصول السريع إلى الإنترنت، تعمل جميع شركات الاتصالات الرئيسية في جميع أنحاء العالم بجد لتحسين سرعتها على الإنترنت. أصبحت الاتصالات بالإنترنت الموثوقة أكثر طلبًا في جميع أنحاء الاقتصاد، بما في ذلك سوق المنازل، وسوق الساعات، وسوق الهواتف المحمولة، وسوق السيارات. إنشاء تقنية الجيل الخامس هو استجابة لمجتمع يتميز بتغيرات سريعة في الظروف وزيادة التوقعات للتقدم التكنولوجي، زيادة السعة، تحسين معدلات البيانات، تقليل الكمون، وتعزيز جودة الخدمة هي بعض الأهداف الرئيسية التي يجب السعي لتحقيقها في المستقبل، خاصة في بيئة ما بعد بنية 4Gالتحتية. من أجل تحقيق هذه الأهداف، يجب أن تخضع بنية شبكة الجيل الخامس الخلوية لتغييرات جوهرية. في هذا البحث، يتم مناقشة هيكل شبكة الجيل الخامس الخلوية وكذلك بعض التقنيات الرائدة التي لديها القدرة على تحسين التصميم وتلبية متطلبات المستخدمين، وكيفية تأثيرها في الفضاء الحر.

الكلمات المفتاحية: الاتصال، معدل نقل البيانات، التأخير، خدمات النطاق العريض المتنقل.

1. Introduction

5G, the fifth generation of wireless communication technology, represents a revolutionary leap forward in mobile networking. It builds upon the foundation of earlier generations (1G through 4G) while introducing transformational capabilities that redefine how devices, systems, and people interact. With unprecedented speed, reliability, and capacity, 5G is set to power the next wave of digital transformation across industries and everyday life [1, 2, 3].

The journey to 5G began decades ago with the evolution of mobile networks:

1. 1G (1980s): Analog voice communication, enabling the first mobile phones.
2. 2G (1990s): Digital voice and text messaging (e.g., SMS).
3. 3G (2000s): Internet access on mobile devices, laying the groundwork for smart-phones.
4. 4G LTE (2010s): High-speed mobile broadband, enabling video streaming and cloud services[4, 5, 6].

Table (1) compression between communication networks.

Feature	1G	2G	3G	4G	5G
Introduction year	1980s	1990s	2000s	2010s	2020s
technology	analog	Digital (GSM, CDMA)	WCDMA, HSPA	LTE(OFDM, MIMO)	NR(Massive MIMO, mmWave)
Data speed	-2..4 kbps	Up to 64 kbps	Up to 2Mbps	Up to 1 Gbps	Up to 10-20 Gbps
Latency	-500 ms	-300 ms	-100-150 ms	-30-50 ms	-1-10 ms
Key service	Voice call	Voice + SMS	Voice + Data	High - speed internet	Ultra-low latency. IoT
Bandwidth	Narrow band	Narrow band	wideband	broadband	Massive broadband
Mobility support	basic	Improved	High	Very high	Vary high
Spectrum usage	Analog bands	900/1800 MHZ	2100 MHZ	700/2600 MHZ	600 MHZ to mmWave(28 GHZ)
Security	minimal	Improved (encryption)	Better (stronger auh)	Advancsed (ip security)	Enhanced (end-to-end)

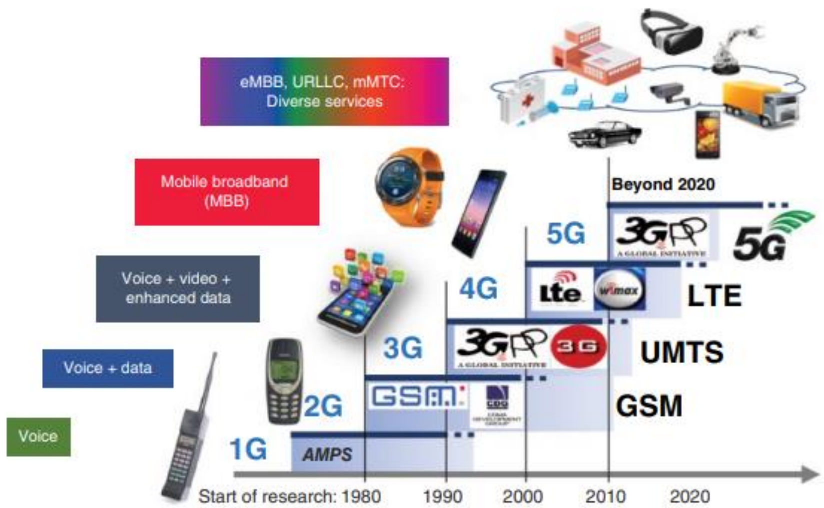


Figure (1) illustrates the principal factors influencing 5G and preceding cellular communication technologies

- While 4G revolutionized the smartphone era, the exponential growth in data demand, connected devices, and new applications has pushed the boundaries of existing networks [7, 8]. Enter 5G, designed to address these limitations and pave the way for innovations like smart cities, autonomous vehicles, and immersive virtual reality[9].

Key Features of 5G Technology:

1. Blazing Speeds: 5G delivers data speeds up to 10 Gbps, making it up to 100 times faster than 4G.This improvement supports seamless streaming of ultra-high-definition content, large file transfers, and real-time cloud computing.[10-14]
2. Ultra-Low Latency: Latency, the time it takes for data to travel between devices, is reduced to as low as 1 millisecond.This is critical for real-time applications like autonomous vehicles, remote surgeries, and virtual/augmented reality[15].
3. Massive Connectivity: 5G can connect up to 1 million devices per square kilometer, a significant improvement over 4G.This feature supports the rapid growth of the Internet of Things (IoT), enabling smart homes, cities, and industries[16, 17]..
4. Network Efficiency and Reliability: 5G uses advanced technologies like beamforming and massive MIMO to enhance signal strength and reliability.It also improves energy efficiency, extending the battery life of connected devices and reducing the environmental footprint of networks[18].
5. Spectrum Diversity: 5G operates on three frequency bands—–low, mid, and high—–each tailored for specific use cases: 1.Low-band: Wide coverage with modest speeds, ideal for rural areas.2.Mid-band: Balances speed and coverage, suitable for urban settings.3.High-band (mmWave): Delivers ultra-high speeds for dense urban areas and specialized applications[19, 20].

How 5G Works: Enabling Technologies:

5G networks are powered by a combination of innovative technologies that enhance performance:

1. Massive MIMO (Multiple Input, Multiple Output): Increases capacity and throughput by using multiple antennas to transmit and receive data.[20].
2. Beamforming: Focuses wireless signals directly toward specific devices rather than broadcasting broadly, improving efficiency and reducing interference.
3. Network Slicing: Creates virtual networks tailored to specific needs, such as low-latency slices for autonomous vehicles or high-capacity slices for entertainment [21].
4. Edge Computing: Brings computational power closer to users, reducing latency and enhancing real-time applications[22].

Applications of 5G Across Industries:

The impact of 5G extends far beyond faster mobile browsing. It is a foundational technology for the digital transformation of numerous sectors:

1. Healthcare: Enables remote surgeries, telemedicine, and real-time patient monitoring.and Supports wearable devices for continuous health tracking.
2. Transportation: Powers autonomous vehicles by enabling instant communication between cars, infrastructure, and traffic systems.also it Improves public transportation through smart scheduling and monitoring[23, 24].
3. Manufacturing and Industry: Drives Industry 4.0 with connected robots, predictive maintenance, and supply chain optimization.and Enhances automation and safety in factories.
4. Entertainment and Media: Delivers immersive experience through augmented reality (AR) and virtual reality (VR).and Supports cloud gaming and instant access to 8K video content[25, 26].
5. Smart Cities: Facilitates real-time monitoring of infrastructure, energy use, and public safety.also it Enhances urban planning with data-driven insights.
6. Agriculture: it Improves crop monitoring, irrigation, and livestock management through IoT sensors and drones[27].

Challenges in Deploying 5G:

Despite its promise, 5G faces several challenges:

1. Infrastructure Requirements: 5G requires a dense network of small cells, antennas, and base stations, leading to high deployment costs.
2. Spectrum Allocation: Governments and regulators must allocate sufficient and appropriate frequency bands[28].
3. Interference and Range Limitations: High-frequency bands (mmWave) have limited range and are easily obstructed by buildings and weather conditions.
4. Security Concerns: The increased connectivity of devices introduces potential vulnerabilities and cybersecurity risks[2].

5. Global Inequality: The rollout of 5G is uneven, with rural and low-income areas lagging behind urban centers in access and infrastructure [29, 30].

Future of 5G: Unlocking the Next Wave of Innovation:

The evolution of 5G is far from over. As adoption grows, it will lay the groundwork for emerging technologies:

- 6G: The sixth generation is expected to integrate AI and quantum computing for even faster and smarter communication networks.
- AI Integration: 5G will enhance machine learning and AI applications by providing the necessary bandwidth and computational power.[31, 32, 33].
- Space Communication: 5G satellites will extend connectivity to remote areas and contribute to global communication systems.

The Importance of 5G Services in Today's World:

Although it is possible to deduce, to a certain extent, the qualitative needs of the three core categories of 5G services based on their definitions, it is still necessary to describe these requirements in numeric terms. As a consequence of this, the ITUR has identified the following metrics as basic abilities for the IMT2020 [14]:

The maximum bit-per-second data rate that can be achieved by any user or device under ideal circumstances is referred to as the peak data rate. Uplink (UL) peak data rates for 5G must be at least 10 gigabits per second (Gbps), and downlink (DL) peak data rates must be at least 20 Gbps.

Peak spectral efficiency is the greatest data rate that can be achieved under perfect conditions, and it is quantified in bits per second per Hertz (bps/Hz). The channel bandwidth is used to normalize the peak spectral efficiency measurements. The International Telecommunication Union (ITU-R) has published specifications for downlink (DL) at 30 bps/Hz and uplink (UL) at 15 bps/Hz. For the purpose of satisfying the criteria that have been established, the incorporation of this key performance indicator (KPI) with the peak data rate demand that was previously indicated is required to have 23GHz of spectrum[35].

The cumulative distribution function of user throughput, normalized by channel capacity in bits per second, is the user spectral efficiency that corresponds to the fifth percentile.

The average data throughput per unit of spectrum resource and per cell is the definition of average spectral efficiency, which is often referred to as spectrum efficiency. This data throughput is measured in bits per second per Hz per cell[36].

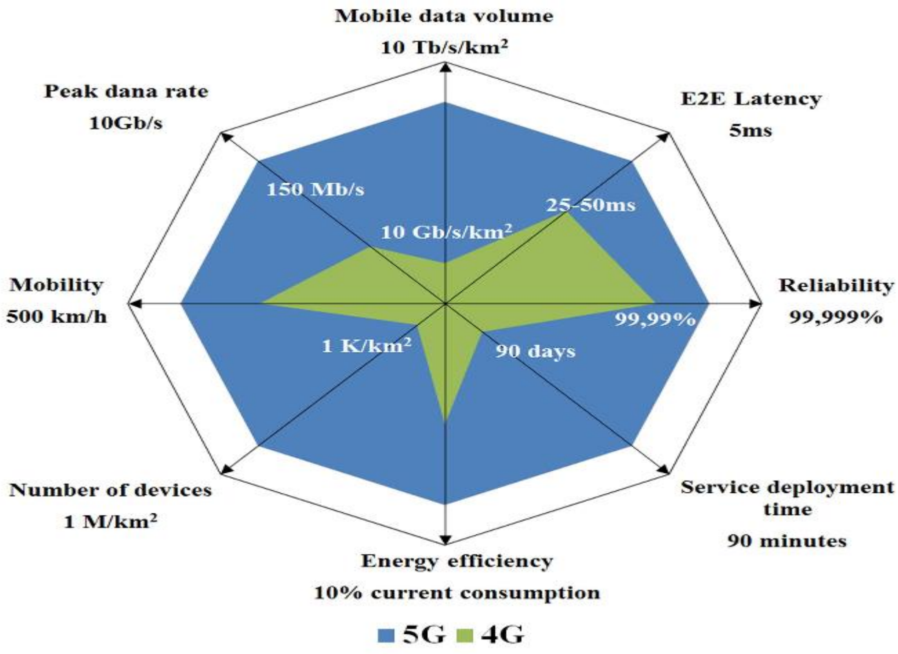


Figure (2) Benefits of 5G valued

Energy efficiency can be defined as the number of bits per joule of information that are transmitted or received by users in comparison to the amount of energy that is consumed by the radio access network (RAN) on the network side, as well as the number of bits per joule of information that is transmitted or received in comparison to the amount of energy that is consumed by the communication module on the device side [10].

- **Effects of 5G in Free Space:** High power antennas, dense networks, and various forms of wireless networks will all expand and fully meet this massive need. The cost of all of this infrastructure is borne by the environment in the form of carbon emissions[37]

Future predictions for the Information and Communication Technology (ICT) business suggest that the carbon dioxide equivalent footprint will increase by around 4% each year. [3]

It is expected to increase by 70% by 2020, reaching a total of 1000 million tonnes [2]. This accounts for 9% of the total CO2 predicted worldwide in 2020.[5]

High data needs will entail increased power usage. As a result, the environment will need more energy. Given that CO2 is a harmful gas, environmental safeguards should be applied with prudence.[21]

It is critical to use and create energy-efficient devices that can function on batteries. Since most current gadgets require non-replaceable batteries, the number of electronic devices is increasing[20]. The everyday growth in mobile usage requires a large amount of battery energy [21].

2-Related Works.

Here are some related works on the effects of 5G in free space with credible sources:

- In[39] the authors focuses on developing compact laser communication terminals for Beyond-5G (B5G) applications, integrating advanced technologies such as beam-divergence control and Tbit/s-class modem prototypes. It addresses the role of FSO in scenarios like High-Altitude Platform Stations (HAPSs) and CubeSats for enhanced connectivity.
- In[40] the authors explores FSO systems as essential components of Beyond-5G and 6G networks, highlighting their benefits such as low latency, high data rates, and security. It includes topics like hybrid FSO/RF systems, satellite-ground links, and integration with terahertz technologies for robust backhaul and fronthaul frameworks[40].
- In[1] the authors reviews the challenges and advantages of integrating free space optical (FSO) communication with 5G networks, focusing on attenuation in open-air environments.
- In[7]the authors Examines millimeter-wave propagation of 5G in free space, highlighting interference and energy efficiency optimization.

3-Methodology:

1- Analytical and statistical analysis:

Firstly the analytical analysis, the mathematical expressions were discessed:

1. Calculate free-space path loss (FSPL):

FSPL(db)= 20. log 10 (distance) + 20.log 10 (frequency) - 147.55

- The term (20. log 10 (distance)) indicates that path loss increases logarithmically with distance.And (20.log 10 (frequency)) reflects the fact that higher frequencies (such as those used in 5G) experience more path loss than lower frequencies. And -147.55 is a constant that adjusts the units, assuming frequency in Hz and distance in meters.so 5G uses high-frequency bands (e.g., 28 GHz or 39 GHz), where path loss is more severe in free space. Therefore, FSPL is a critical factor in determining the range and coverage of 5G networks, often requiring more base stations in high-frequency deployments[2].

2. Received Power (Pr):

Pr (dBm)= Transmit power (dBm) - FSPL (db)

- This equation accounts for how much power is left at the receiver after signal loss due to distance (FSPL).The result is in dBm, a common unit in wireless communications that allows easy calculation of link budgets. For 5G, higher frequencies mean higher

FSPL, reducing received power significantly at large distances. Hence, this equation shows why 5G cells are typically smaller, as power at high frequencies diminishes quickly over distance[4]

3. Noise Power:

Noise power (dBm) = -174 +10. log 10 (bandwidth) +Noise

- dBm/Hz is the thermal noise floor, representing the minimum noise in a perfect system at room temperature. 2.adjusts the noise floor based on the signal bandwidth (in Hz). Larger bandwidths increase noise power, impacting SNR. 3.The Noise Figure (in dB) reflects additional noise introduced by the receiver itself, which is critical in 5G where high-quality components are necessary to reduce signal degradation.5G requires wider bandwidths (e.g., 100 MHz) for high data rates, which increases noise power. Low-noise components are essential for preserving SNR and achieving the high speeds expected from 5G[5].

4. Signal-to-Noise Ratio (SNR)

SNR (dB) = Received Power (dBm) - Noise Power (dBm)

- SNR is the ratio of received signal power to noise power, expressed in dB. It is a direct measure of signal quality.A higher SNR indicates a clearer signal, which supports faster data rates and lower error rates in data transmission. High-frequency signals in 5G are more susceptible to noise, so maintaining a good SNR is challenging, especially over long distances. Lower SNR leads to reduced data rates and degraded service quality. This need for high SNR is why 5G often requires small cells and beamforming technologies to focus the signal and reduce noise interference[1].

➢ These equations work together in link budget analysis, a critical process in wireless network planning to ensure reliable communication. The following aspects are essential in understanding the implications[8].

1. Frequency and Path Loss: Higher frequencies, common in 5G, have shorter ranges due to increased path loss.
2. Cell Density: To maintain adequate received power and SNR, 5G networks use smaller cells compared to previous generations, necessitating more base stations.
3. Noise Management: With wider bandwidths, noise management is crucial. Low-noise amplifiers and high-quality receivers are essential to maintaining good SNR[9].

2- The flow chart for simulation:

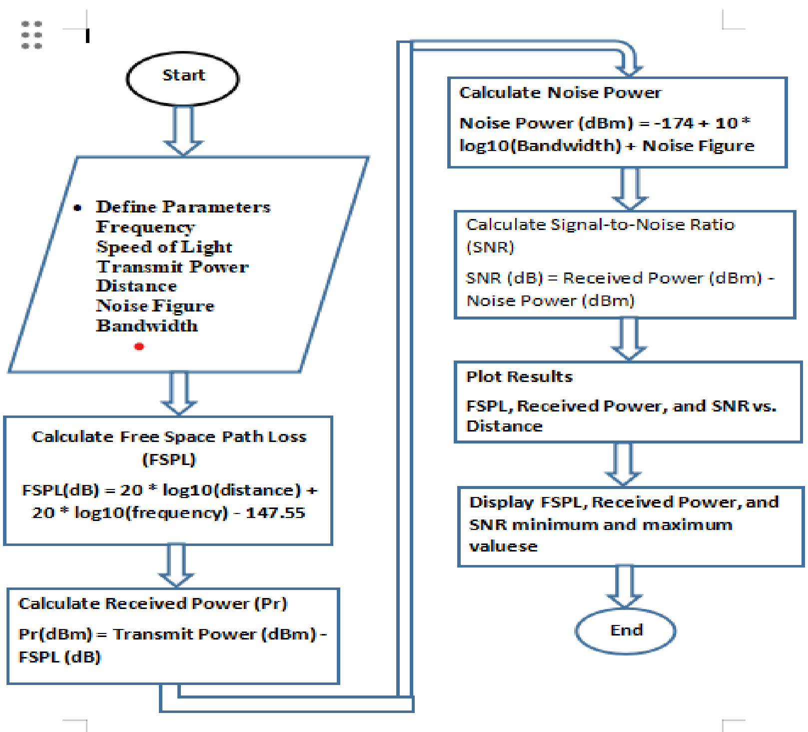


Figure (3) the simulation's flow chart

Simulaiton analysis:

Each of these parameters is used to calculate free-space path loss (FSPL), received power, noise power, and SNR over the specified distances for the 5G signal in free space.

Table (2) simulation parameters values.

Parameter	Value	Unit	Description
Frecuncy	28e9	Hz	Frecuncy of the signal (e.g, 28 GHZ)
Speed_of_light	3e8	m/s	Speed of light in a vacum
Distance	Linspace (1, 1000, 1000)	Meters	Array representing distances from 1 to 1000 meters l
Bandwidth	100e6	Hz	Bandwidth of the signal (e, g., 100 Hz
Noise_ figure	10	db	Noise figure representing receiver noise level

4-Simulation results and discussion

The provided plots analyze the free-space path loss (FSPL) for 5G frequencies, demonstrating how signal attenuation varies with distance and frequency. Here's a detailed discussion for each plot:

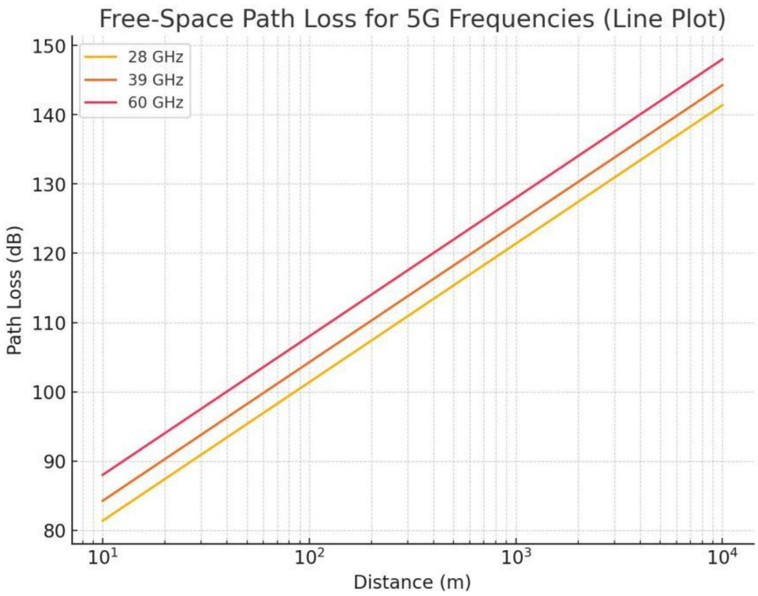


Figure (4) the free- space path loss for 5G frequencies (line plot)

- ✧ Line Plot: Path loss increases logarithmically with distance for all frequencies. Higher frequencies (e.g., 60 GHz) experience significantly higher path loss compared to lower frequencies (e.g., 28 GHz).Higher frequencies have shorter wavelengths, resulting in greater attenuation over the same distance due to their inability to diffract effectively around obstacles. This demonstrates the need for small cells or repeaters in 5G networks operating at high frequencies to maintain coverage and signal strength[38, 5].

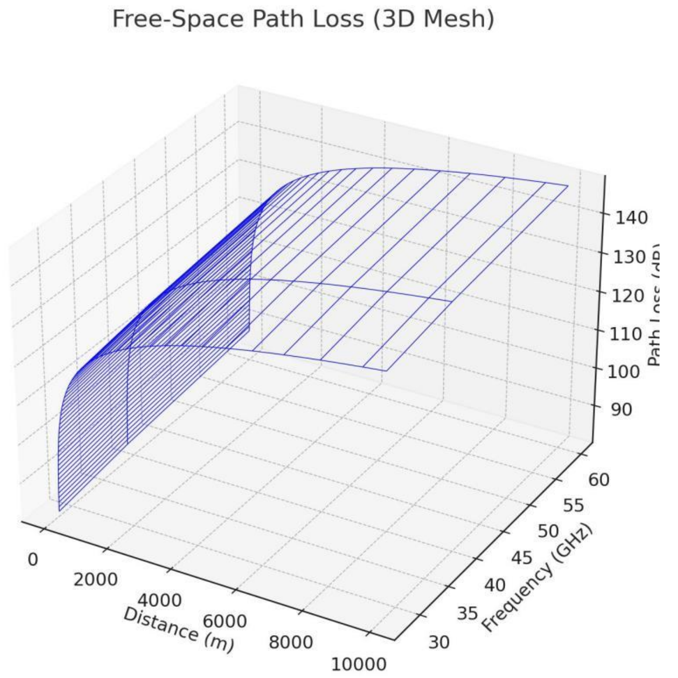


Figure (5) the free- space path loss for 5G frequencies (3D mesh)

- 3D Mesh Plot: The plot shows a clear correlation between frequency, distance, and path loss. The higher the frequency or the farther the distance, the greater the path loss.As distance increases, signal strength weakens following the inverse square law. At higher frequencies, the shorter wavelength leads to increased sensitivity to environmental factors like absorption and scattering.Network designs must account for both distance and frequency, emphasizing beamforming and advanced antenna techniques for high-frequency 5G bands[5].

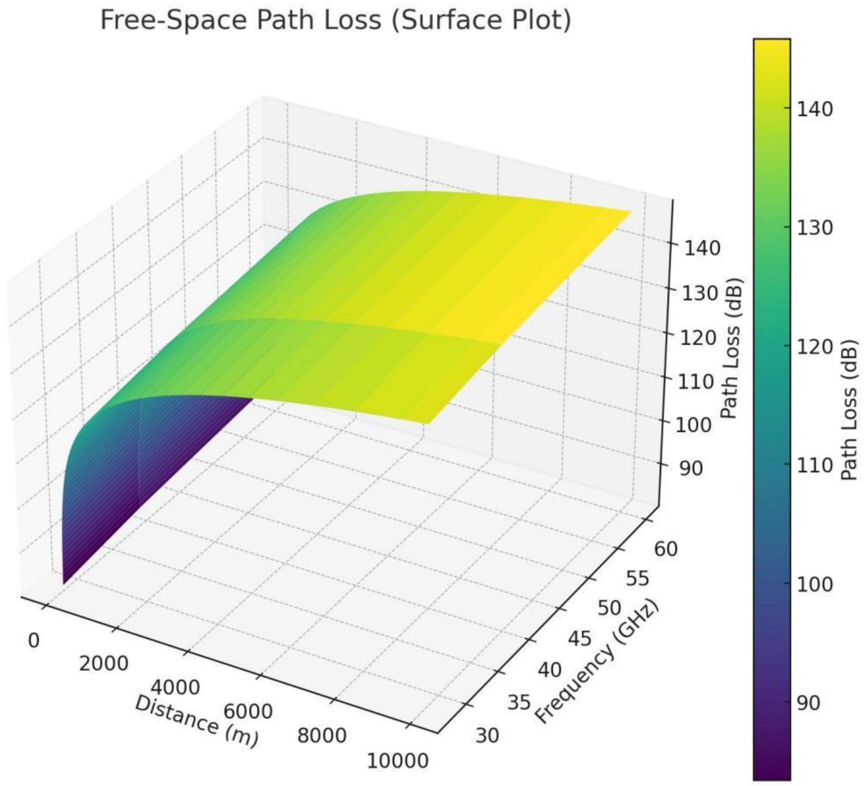
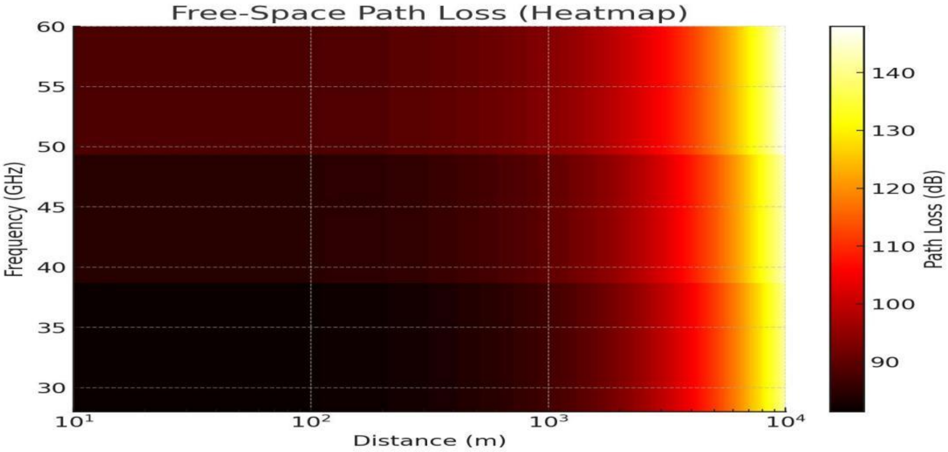


Figure (6) the free- space path loss for 5G frequencies (surface plot)

- Surface Plot: The surface plot provides a more intuitive understanding of how both parameters—distance and frequency—interact. It confirms that high-frequency bands are limited to shorter ranges.At frequencies like 60 GHz, the path loss gradient is steeper, especially beyond a few hundred meters. This plot justifies the focus on millimeter-wave technology for short-range, high-capacity environments, such as urban areas or indoor scenarios[7]



`Figure (7) free- space loss (Heat map)

✧ Heatmap: The heatmap highlights areas of high path loss as darker regions, showing a rapid increase in attenuation with both distance and frequency. At high frequencies, free-space loss dominates due to the dependency on . Additionally, increased distance further amplifies loss due to spreading.This plot visualizes the coverage challenges faced by high-frequency 5G bands, supporting the need for dense base station deployment[13]

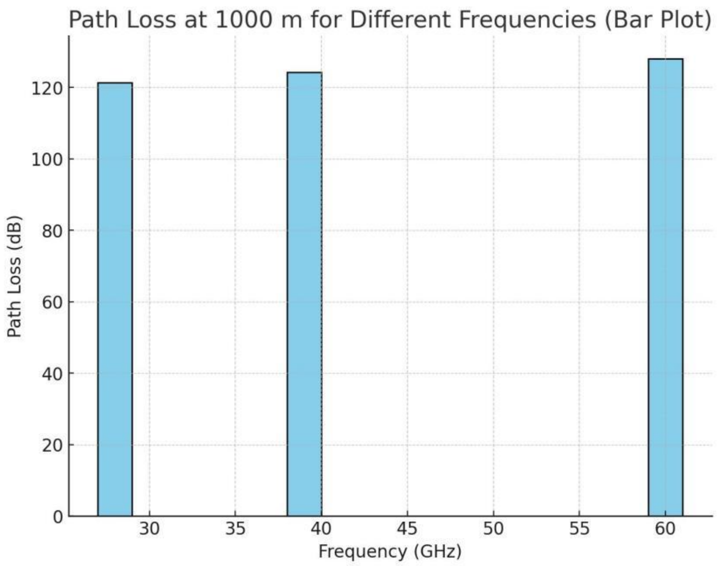


Figure (8) the free- space path loss for 5G frequencies (Bar plot)

✧ Bar Plot: At a fixed distance (1000 m), higher frequencies exhibit significantly greater path loss. For example, 60 GHz shows much higher attenuation compared to 28 GHz.The relationship between frequency and attenuation highlights the dependency of path loss on wavelength.So that while higher frequencies support greater bandwidth, their range limitations restrict their practical use to targeted, high-density deployments like city centers.

➢ While higher frequencies support greater bandwidth, their range limitations restrict their practical use to targeted, high-density deployments like stadiums or city centers.so that there are Challenges of 5G High-Frequency Bands becouse of High path loss limits the range and penetration of millimeter-wave frequencies, requiring advanced technologies such as beamforming, massive MIMO, and network densification. And the **Advantages of Low-Frequency Bands are:** Lower frequencies (e.g., sub-6 GHz) provide broader coverage and better penetration but offer limited bandwidth compared to mmWave. So that **Optimal Network Design**: A hybrid approach combining high-frequency small cells in urban areas and lower-frequency macro cells in rural areas ensures balanced coverage and performance.

5-Conclusion.

The process of building 5G will be far more complicated. The 5G network is extremely fast and stable. Fourth-generation technology supports the fifth generation. analyzing 5G network effects in free space provides crucial insights into the behavior of high-frequency signals used in modern telecommunications. The study of Free Space Path Loss (FSPL), Received Power, and Signal-to-Noise Ratio (SNR) reveals how signal quality diminishes with distance, emphasizing the unique challenges faced by 5G, such as high path loss at millimeter-wave frequencies and increased sensitivity to environmental factors. This foundational understanding aids in network planning, helping engineers optimize cell placement, manage interference, and utilize advanced technologies like beamforming and MIMO to maintain reliable, high-quality connectivity.

Looking ahead, further exploration into non-line-of-sight (NLOS) conditions, complex urban environments, and emerging technologies like 6G will be essential in enhancing network efficiency and coverage. As 5G continues to evolve, combining rigorous theoretical analysis with real-world modeling will pave the way for robust, scalable communication networks that meet the growing demands of our connected world.

6-Recommendations.

The recommendations were written in bullet points, mentioning the issues and the recommended solutions:

1. Incorporate Non-Line-of-Sight (NLOS) Conditions: Extend the current free-space model to account for urban environments with obstacles, like buildings and vegetation, which cause NLOS conditions, reflection, diffraction, and scattering. This will provide a more realistic model that better represents urban and suburban 5G deployments, helping network engineers better estimate coverage and signal quality.
2. Evaluate Path Loss Models Beyond Free Space: Use advanced path loss models like the ITU-R, COST-231, and 3GPP models, which consider factors like clutter, building density, and terrain elevation.These models can simulate real-world conditions, making them more applicable to various environments, especially for 5G, which is heavily deployed in densely populated areas.
3. Integrate Beamforming and MIMO Technology: Model the effects of advanced antenna technologies, such as beamforming and massive MIMO (Multiple Input Multiple Output), which are widely used in 5G to enhance signal quality and capacity.Simulating these technologies can provide insights into improving SNR and coverage, especially in challenging environments with interference or high user density.
4. Incorporate Interference Analysis: Expand the model to include interference from neighboring cells and devices, especially for high-frequency bands like mmWave.Interference is a significant factor in urban areas, where 5G base stations are densely packed. Analyzing interference can help in spectrum allocation and reduce network congestion.
5. Energy Efficiency and Power Consumption Modeling: Analyze power consumption and energy efficiency of 5G base stations and user devices, especially considering high-frequency bands which consume more power for Reducing energy consumption is crucial for sustainable network deployment. Understanding these factors can help design power-efficient 5G networks and devices.

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