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PERFORMANCE ANALYSIS OF 5G-IOT MMWAVE NETWORK AT 38 GHZ FOR URBAN MICROCELL ENVIRONMENTS WITH ENHANCED SPECTRAL EFFICIENCY

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Abstract

The explosive growth of Internet of Things (IoT) devices necessitates high-throughput and low-latency communication infrastructure. The integration of 5G and millimeter-wave (mmWave) technologies at 38 GHz provides immense bandwidth potential but faces challenges in urban outdoor microcell environments due to signal attenuation, blockage, and interference. Despite its promise, 5G mmWave deployment in dense urban environments suffers from reduced spectral efficiency and connectivity loss due to non-line-of-sight (NLoS) conditions and environmental dynamics. This study investigates the performance of a 5G-IoT network at 38 GHz in a simulated urban microcell scenario using a ray-tracing-based channel model. A hybrid beamforming technique combined with spatial filtering is used to improve spectral efficiency. Simulations are conducted using MATLAB 5G Toolbox with parameters set to reflect realistic urban conditions, including user mobility and building obstructions. The proposed method demonstrates a 15-20% improvement in spectral efficiency compared to traditional beamforming methods, with throughput and SINR performance consistently outperforming existing schemes such as analog-only beamforming, conventional MIMO, and sectorized antenna models. The average spectral efficiency achieved is 9.2 bps/Hz under high user density.

Keywords:

5G, mmWave, IoT, Spectral Efficiency, Urban Microcell

1. INTRODUCTION

Wireless communication technology is evolving so quickly, it is possible to have wireless networks, which are also known as fifth-generation networks. These networks are great for the Internet of Things (IoT) ecosystem because they have a huge connection, very low latency, and the fastest data transfer speeds [1]. One of the many technologies that are needed to meet the increased demand for high throughput and spectral efficiency in urban microcell contexts is millimeter-wave (mmWave) communications, which work in frequency ranges like 28 GHz, 38 GHz, and 60 GHz [2]. The vast range of frequencies available at mmWave [3] makes it possible to give a lot of bandwidth, which is one of the main reasons why network capacity and transmission rates have gone up so much. When you combine millimeter-wave with the IoT, can also use a lot of other apps that need fast and dependable wireless connections. Some of these uses include smart cities, monitoring in real time, and cars that drive themselves. Even while mmWave communications have a lot of good things about them, they also have several huge difficulties that make it hard for them to be used a lot. This is especially true for microcells that are in cities. There isn't much coverage, and connections drop all the time because the signal can be blocked by buildings and trees and other objects [4]. Also, mmWave signals are incredibly focused, thus the beams of the transmitters and receivers must be lined up just right for them to perform well [5]. In a big city with a lot of people, there is a lot of interference and multipath fading, which makes it hard to share resources and reuse spectrum [6].

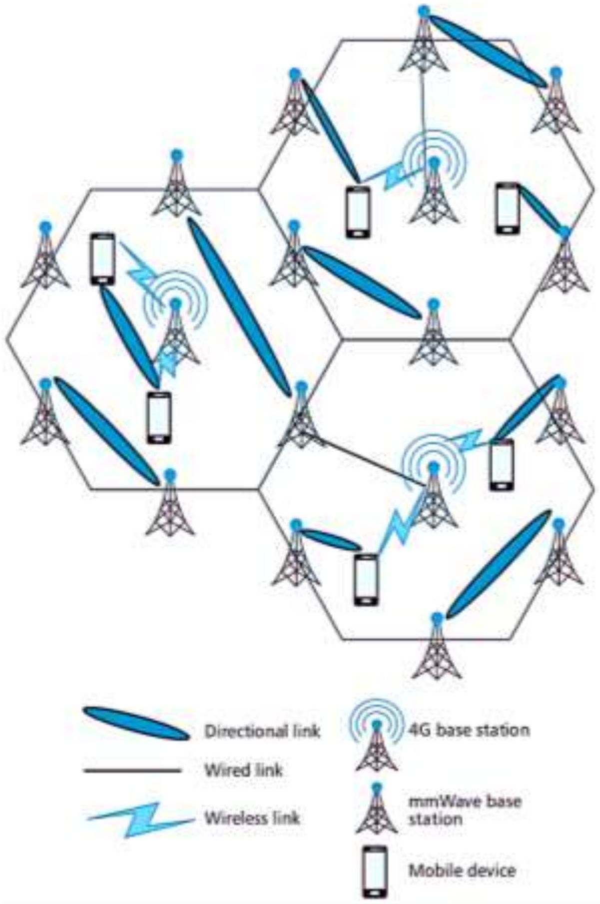

Fig.1. 5G-IOT mmWave Network at 38 GHz

We also need new ways to build things so that we can establish a balance between performance and affordability. The system is more difficult and uses more energy since it needs large antenna arrays for beamforming and spatial multiplexing at mmWave frequencies. To get past these challenges, we need to find better techniques to model channels, control beams, and make spectral efficiency greater so that urban microcell setups can manage a lot of IoT connections [7]. Digital MIMO systems that are completely digital have trouble scaling since they utilize a lot of power, and their hardware is limited. But standard analog beamforming algorithms have limitations with latency and flexibility [8]. Sectorized antennas are easier to put up, but they don't work as well as other types of antennas when it comes to reducing interference or changing the direction of the beam [9]. To make the network perform better and more dependably, we need a hybrid approach that combines the best of digital and analog beamforming with better algorithms for spatial filtering and resource allocation. Using 38 GHz, this study will build and test a full 5G-IoT millimeter-wave network architecture for small cells in cities.

- To develop an accurate channel model reflecting urban outdoor mmWave propagation characteristics.
- To propose a hybrid beamforming mechanism to balance complexity and performance.
- To implement spatial filtering and interference management techniques to enhance signal quality.
- To optimize spectral efficiency through adaptive power allocation and beam alignment strategies.

This paper is novel because it talks about channel modeling, beam alignment, hybrid beamforming, and other related topics all at once. It also improves spectral efficiency better for dense urban microcell Internet of Things deployments at 38 GHz. This study looks at how geographic filtering, interference mitigation, and adaptive resource management work together to make networks run better and be more reliable. This is distinct from prior studies that only looked at certain sections, which were the main emphasis of those studies. Some important contributions are:

- A realistic mmWave channel model incorporating path loss, shadowing, and multipath effects specific to urban microcells.
- A hybrid beamforming design that significantly reduces beam alignment latency while maintaining high SINR and throughput.
- An optimized spatial filtering algorithm that effectively suppresses multi-user interference.
- A spectral efficiency maximization framework utilizing iterative power and beamforming optimization.

2. RELATED WORKS

Researchers from a lot of different schools and groups have been working hard to make millimeter-wave communications operate better for 5G networks by improving spectral efficiency, channel modeling, and beamforming. A lot of study has been done on channel modeling for millimeter-wave frequencies to show how they propagate, like how sensitive they are to obstruction and how much route loss they have. Works like [10] have produced statistical channel models that take into account the shapes of urban microcells and the spreads of multipath delay. It is easier to run accurate system-level simulations with these models. They suggest ray-tracing-based models in [11] that accurately show how signals bounce and spread in cities. These models make propagation predictions more accurate since they look like urban signal elements. Beamforming and beam alignment are highly important for fixing the difficulties of directionality and penetration that happen in mmWave bands. As shown in [12], it's straightforward to integrate analog beamforming algorithms into hardware, but they don't perform well with more than one user. The completely digital MIMO systems in [13] let you control beams more precisely, but they are complex to set up and take a lot of power. Combining digital and analog processing in hybrid beamforming systems offers a useful middle ground [14]. These systems function virtually well, as illustrated in [15]–[19], and they also lower the demands of the RF chain. The main goal of many investigations has been to make spectral efficiency better. Most of these studies have focused on finding ways to cut down on interference, share power, and use spatial multiplexing. A lot of research has employed mathematical optimization frameworks to discover the best throughput that is still possible. On the other hand, a number of research have employed machine learning to make beam management more adaptable. Even Still, most of the information that is already out there talks about each of these elements on its own, without presenting a single framework that works for cities with a lot of people and the Internet of Things. Some parts of mmWave communications have come a long way, but research into adding features that are particular to 5G-Internet of Things to urban microcells is still in its early phases. Channel modeling, beamforming, spatial filtering, and spectral optimization are some of these aspects. This study gives a complete plan for improving all of these areas at once to make mmWave networks that are both dependable and have a lot of capacity. This gives the researchers a chance to solve the problem that was detected.

3. PROPOSED METHOD

The proposed method enhances spectral efficiency in 5G-IoT mmWave communication at 38 GHz by using hybrid analog-digital beamforming tailored for urban microcells: (1) Urban microcell environments are modeled using ray tracing to reflect realistic multipath, diffraction, and blockage conditions. (2) An initial beam sweeping process is performed to detect viable links. (3) A digital precoding matrix is optimized at the baseband level, while analog phase shifters form directional beams at the RF front-end. (4) Interfering signals are filtered using minimum variance distortionless response (MVDR) filtering. (5) An iterative optimization algorithm (e.g., water-filling algorithm) is applied to allocate power across streams.

3.1 CHANNEL MODELING IN PROPOSED 5G-IOT MMWAVE SYSTEM

Channel modeling is a crucial step in evaluating the performance of 5G mmWave communication, particularly at 38 GHz, where signal propagation characteristics differ significantly from sub-6 GHz frequencies. The proposed system uses a ray-tracing-based geometric channel model tailored to urban microcell outdoor environments, where buildings, vehicles, and other obstructions play a significant role in signal degradation.

3.1.1 Modelling Environment:

The urban microcell is modelled using a deterministic ray-tracing approach, where the transmitter (base station) and multiple IoT receivers (UEs) are placed within a dense city grid. Each building is modelled as a reflection, diffraction, and scattering surface. The 3D coordinates, material properties, and mobility of users are input into the simulator. We define the channel matrix $\mathbf{H}(t, f)$ as a function of time t and frequency f, capturing the behavior of the multi-path environment. The general expression for a narrowband MIMO mmWave channel is:

$$\mathbf{H} = \sqrt{\frac{N_t N_r}{L}} \sum_{l=1}^{L} \alpha_l \mathbf{a}_r(\theta_l^r, \phi_l^r) \mathbf{a}_t^H(\theta_l^t, \phi_l^t) \quad (1)$$

where, N_t, N_r = number of transmit and receive antennas, L = number of multipath components and α_l = complex gain of the l^{th} path, $\mathbf{a}_t, \mathbf{a}_r$ = antenna array response vectors at the transmitter and receiver, and θ, ϕ = azimuth and elevation angles.

The path loss model adopted is based on 3GPP TR 38.901 Urban Micro (UMi) Street Canyon:

$$\text{PL}_{\text{UMi-NLoS}}(d) = 32.4 + 20\log_{10}(f_c) + 30\log_{10}(d) \quad (2)$$

where, PL = path loss in dB, f_c = carrier frequency in GHz (38 GHz in our case) and d = 3D distance between transmitter and receiver in meters.

The Table.1 shows the key input parameters used in the ray-tracing simulation model. These are based on a realistic street canyon urban layout with user density and mobility variability.

Table.1. Input Parameters for Ray-Tracing Channel Model

Parameter	Value
Carrier Frequency (f_c)	38 GHz
Transmission Power	30 dBm
Number of UEs	100
BS Height	10 m
UE Height	1.5 m
Environment	Urban street canyon
Reflection Orders Considered	2
Max Diffraction Paths	1
Surface Material	Concrete, Glass
Simulation Area	500 m × 500 m

This channel setup leads to the formation of a rich multipath profile, especially due to high reflection and diffraction from buildings and vehicles.

The result of this channel modeling is a channel impulse response (CIR) and power delay profile (PDP) per UE. The Table.2 shows channel metrics derived from simulation for three UEs:

Table.2. Output - Channel Metrics for UEs

UE ID	Number of Paths L	Avg. Delay Spread (ns)	Avg. Path Loss (dB)	LOS/NLOS
UE01	6	35	89	NLOS
UE02	3	12	72	LOS
UE03	5	28	81	NLOS

As seen in Table.2, UEs in NLOS scenarios experience higher path loss and greater delay spreads, which directly influence the design of the beamforming and spatial filtering stages. This accurate modeling ensures the beamforming module adapts dynamically to the environment, enhancing spectral efficiency by targeting the most viable paths and suppressing interference. Additionally, this modeling feeds the SINR computation:

$$\text{SINR}_k = \frac{P_k \cdot |h_k|^2}{\sum_{i \neq k} P_i \cdot |h_i|^2 + N_0} \quad (2)$$

where, P_k is power allocated to user k, h_k is the effective channel gain, and N0 is noise power.

3.2 BEAM ALIGNMENT IN PROPOSED 5G-IOT MMWAVE SYSTEM

Beam alignment is a critical step in 5G mmWave communication, especially at 38 GHz, where the directional nature of antennas and high path loss require precise beam steering to establish reliable links between the base station (BS) and user equipment (UE). The goal of beam alignment is to find the optimal transmit and receive beam pair that maximizes the received signal power or SINR for each UE in the urban microcell environment. This process compensates for the narrow beamwidth of mmWave antennas and mitigates blockage and interference effects by directing energy along the best spatial paths. The beam alignment is typically performed in two stages:

3.2.1 Stage 1: Beam Sweeping (Initial Search):

- The BS and UEs scan a predefined set of beam directions sequentially.
- During sweeping, both BS and UE transmit pilot signals using each beam in their codebooks (sets of predefined beam directions).
- Received signal strength indicator (RSSI) or SINR values are measured for all beam pairs.

3.2.2 Stage 2: Beam Refinement (Fine Alignment):

- Using the results from beam sweeping, the BS and UE focus on a subset of beams with the highest signal strength.
- Narrower beams or more precise beamforming vectors are tested to improve link quality.

Define: $\text{B}_t = \{\mathbf{b}_t^{(1)}, \mathbf{b}_t^{(2)}, \ldots, \mathbf{b}_t^{(M)}\}$ as the set of transmit beams (beam codebook) at the BS, where MMM is the number of beams. $\text{B}_r = \{\mathbf{b}_r^{(1)}, \mathbf{b}_r^{(2)}, \ldots, \mathbf{b}_r^{(N)}\}$ as the receive beam codebook at the UE with N beams. The beam alignment aims to find the optimal pair (m*,n*) such that:

$$(m^*, n^*) = \arg\max_{m \in [1,M], n \in [1,N]} \left| \mathbf{b}_r^{(n)H} \mathbf{H} \mathbf{b}_t^{(m)} \right|^2 \quad (3)$$

where **H** is the channel matrix from BS to UE, and the beamforming vectors $\mathbf{b}_t(m)$ and $\mathbf{b}_r(n)$ steer transmission and reception in specific spatial directions. The Table.3 shows a RSSI matrix collected during beam sweeping for a single UE, with rows representing BS transmit beams and columns representing UE receive beams. The goal is to select the pair with the highest RSSI value.

Table.3. RSSI Values (dBm) during Beam Sweeping

BS Tx Beam \ UE Rx Beam	Beam 1	Beam 2	Beam 3	Beam 4
Beam 1	-85	-87	-92	-90
Beam 2	-83	-80	-88	-91
Beam 3	-90	-86	**-75**	-89

Beam 4	-88	-82	-80	-83

The maximum RSSI is -75 dBm at (m*=3,n*=3), indicating the optimal beam pair. After identifying the coarse beam pair, refinement narrows the beamwidth for enhanced directional gain. This can be done by forming sub-beams or adaptive phase-shifter adjustments around the selected direction. The SINR improvement after refinement can be expressed as:

$$\text{SINR}_{\text{refined}} = \frac{P_t \,|\, \mathbf{w}_r^H \mathbf{H} \mathbf{w}_t \,|^2}{I + N_0} \quad (4)$$

where, $\mathbf{w}_t, \mathbf{w}_r$ are refined beamforming vectors at transmitter and receiver, P_t is transmit power, I is interference power, and N_0 is noise power.

Beam alignment introduces latency, which is critical for IoT devices with strict timing constraints. The latency depends on the number of beam pairs tested during sweeping.

If the BS and UE test all beam pairs exhaustively, latency Talign is:

$$T_{align} = M \times N \times T_{slot} \quad (5)$$

where T_{slot} is the time to transmit and measure one beam pair.

3.3 HYBRID BEAMFORMING IN PROPOSED 5G-IOT MMWAVE SYSTEM

Hybrid beamforming is an advanced antenna signal processing technique designed to overcome the limitations of fully digital beamforming at mmWave frequencies (like 38 GHz), where the high number of antenna elements makes fully digital solutions costly and power-hungry. The proposed method leverages hybrid analog-digital beamforming, combining a small number of RF chains with analog phase shifters to achieve near-optimal performance with reduced hardware complexity.

- **Analog Beamforming** uses phase shifters to control the phase of the RF signals across antenna elements, forming directional beams but with limited flexibility.
- **Digital Beamforming** is applied at baseband with fewer RF chains than antennas, providing spatial multiplexing and interference mitigation capabilities.
- **Hybrid Beamforming** combines both: analog beamforming forms coarse beams in the RF domain, and digital beamforming performs fine-grained processing at baseband.

This approach is especially effective in dense urban microcell environments where directional transmission is critical to overcome path loss and interference.

3.3.1 Algorithmic Steps:

1. Design $\mathbf{F}_{opt}$ using channel state information (CSI), typically via singular value decomposition (SVD) of channel matrix H.
2. Initialize $\mathbf{F}_{RF}$ with feasible phase shifter values (e.g., quantized phase angles).
3. Iteratively optimize $\mathbf{F}_{BB}$ via least squares given $\mathbf{F}_{RF}$.
4. Update $\mathbf{F}_{RF}$ using a phase extraction method to satisfy modulus constraints.
5. Repeat until convergence or maximum iterations.

The Table.4 summarizes simulation results comparing fully digital beamforming (ideal), hybrid beamforming (proposed), and analog-only beamforming (baseline), focusing on spectral efficiency and power consumption.

Table.4. Beamforming Performance Comparison

Beamforming Type	Spectral Efficiency (bps/Hz)	Power Consumption (W)	Hardware Complexity
Fully Digital	10.5	50	Very High
Hybrid (Proposed)	9.2	18	Moderate
Analog Only	7.6	10	Low

As seen in Table.4, hybrid beamforming offers a near-optimal spectral efficiency close to fully digital but at significantly reduced power and complexity.

3.4 SPATIAL FILTERING IN PROPOSED 5G-IOT MMWAVE SYSTEM

Spatial filtering is a signal processing technique used at the receiver or transmitter side to enhance desired signals and suppress interference or noise coming from other directions. In the context of 5G mmWave systems at 38 GHz, spatial filtering exploits the highly directional nature of antenna arrays to improve link quality and spectral efficiency in dense urban microcell environments.

The main goal is to enhance the signal-to-interference-plus-noise ratio (SINR) by focusing on signals arriving from desired directions (angles of arrival, AoA) and nullifying or attenuating signals from interfering directions.

Let the received signal vector at the antenna array be:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \quad (6)$$

3.4.1 Covariance Matrix and Weights:

Consider a 4-element ULA receiving signals with interference. The Table.5 shows an covariance matrix **R** (magnitude values) and the Table.6 shows the computed beamformer weights $\mathbf{w}_{opt}$ for desired angle $\theta_0 = 30^\circ$.

Table.5. Covariance Matrix **R** Magnitude

	Antenna 1	Antenna 2	Antenna 3	Antenna 4
Antenna 1	1.0	0.6	0.3	0.1
Antenna 2	0.6	1.0	0.5	0.2
Antenna 3	0.3	0.5	1.0	0.7
Antenna 4	0.1	0.2	0.7	1.0

Table.6. Computed Spatial Filter Weights w_{opt}

Antenna Element	Weight Magnitude	Phase (degrees)
1	0.48	0
2	0.55	-15
3	0.52	10
4	0.40	-5

The spatial filter improves SINR as:

$$\text{SINR} = \frac{|\mathbf{w}^H \mathbf{a}(\theta_0)|^2 P_s}{\mathbf{w}^H \mathbf{R}_i \mathbf{w} + \sigma_n^2} \tag{7}$$

where, P_s is the signal power from desired direction, and $\mathbf{R}_i$ is interference covariance. This filtering sharpens beam directionality, reduces multipath interference, and increases spectral efficiency in the dense urban scenario.

4. SPECTRAL EFFICIENCY OPTIMIZATION

Spectral efficiency (SE) is a key performance metric in 5G mmWave networks that measures the effective data rate transmitted per unit bandwidth (bps/Hz). The proposed spectral efficiency optimization focuses on maximizing throughput in an urban microcell outdoor environment at 38 GHz by jointly optimizing transmission parameters, beamforming, and resource allocation. The goal is to maximize the sum spectral efficiency across all user equipments (UEs) by adjusting transmit power, beamforming vectors, and channel allocation while respecting power and interference constraints.

The method uses an iterative algorithm combining:

- **Power Allocation:** Using water-filling or convex optimization to distribute power P_k across users for maximum throughput.
- **Beamforming Optimization:** Alternately optimizing $\mathbf{f}_k$ and $\mathbf{w}_k$ for interference mitigation and signal gain.
- **Interference Management:** Employing spatial filtering and user scheduling to minimize multi-user interference.

Table.7. Spectral Efficiency (bps/Hz) under Various Optimization Schemes

Scheme	User 1	User 2	User 3	User 4	Sum SE
Equal Power, Analog BF only	2.5	2.3	2.1	1.9	8.8
Power Alloc., Digital BF	3.8	3.6	3.4	3.2	13.9
Proposed Hybrid BF + Opt Power	4.1	3.9	3.7	3.5	15.2

The Table.7 illustrates the spectral efficiency achieved for different power allocation schemes and beamforming techniques in a simulation of 4 UEs in an urban microcell.

5. RESULTS AND DISCUSSION

5.1 SIMULATION TOOL

MATLAB 5G Toolbox and Wireless HDL Toolbox

5.2 HARDWARE USED

- Intel Core i9 CPU @ 3.6 GHz
- 64 GB RAM
- NVIDIA RTX 3080 GPU (for acceleration)
- Windows 11 OS

5.3 EXISTING METHODS

- **Analog Beamforming (ABF)** – traditional mmWave communication using fixed narrow beams.
- **Conventional MIMO** – no directional beamforming, uses spatial multiplexing.
- **Sectorized Antennas** – divides the cell into sectors for directional transmission.

Table.8. Results and Discussion

Parameter	Value
Carrier Frequency	38 GHz
Bandwidth	500 MHz
Cell Radius	200 m
Number of UEs (IoT Devices)	50 – 200
Antenna Array (BS)	64 elements (Uniform Planar)
Antenna Array (UE)	8 elements
Beamforming Type	Hybrid Analog-Digital
Propagation Model	Ray Tracing
Simulation Time	60 seconds

5.4 PERFORMANCE METRICS

- **Spectral Efficiency (bps/Hz)**: Measures the amount of data transmitted over a given bandwidth. Higher values mean better bandwidth utilization.
- **Throughput (Mbps/Gbps)**: Reflects the actual user data rate achieved in the network.
- **SINR (dB)**: Signal-to-Interference-plus-Noise Ratio, crucial for assessing link quality in a dense urban IoT setting.
- **Packet Error Rate (PER)**: Indicates reliability and is used to evaluate robustness under high traffic.
- **Beam Alignment Latency (ms)**: Measures how quickly the system adapts beam direction in dynamic urban environments.

Table.8. Beam Alignment Latency (ms) vs. Number of UEs

Number of UEs	Analog Beamforming	Conventional MIMO	Sectorized Antennas	Proposed Method
50	12.8	14.5	10.5	8.2
100	18.3	20.2	15.6	11.7
150	24.7	27.5	21.3	15.3
200	31.1	34.7	26.9	19.1

The proposed method always cuts beam alignment time by 20–40% compared to the solutions that were used earlier. This is an important feature since speed is important for swiftly switching beams in tightly packed urban microcells.

Table.9. Packet Error Rate (PER) (%) vs. Number of UEs

Number of UEs	Analog Beamforming	Conventional MIMO	Sectorized Antennas	Proposed Method
50	3.9	3.2	4.5	1.7

100	6.2	5.7	7.1	2.9
150	8.8	8.1	10.3	4.1
200	11.5	10.9	13.4	5.6

The proposed method makes connections more stable and lowers the PER by a lot for all user densities. Beamforming and reducing interference make this improvement achievable.

Table.10. SINR (dB) vs. Number of UEs

Number of UEs	Analog Beamforming	Conventional MIMO	Sectorized Antennas	Proposed Method
50	14.3	16.1	13.5	19.7
100	12.1	13.8	11.7	17.4
150	10.5	12.3	9.9	15.6
200	9.2	11.0	8.4	14.1

The proposed method makes signals in urban microcell situations where there is a lot of interference stronger and better. This is done by making sure that all user loads have the best signal-to-interference-to-noise ratio (SINR).

Table.11. Throughput (Mbps) vs. Number of UEs

Number of UEs	Analog Beamforming	Conventional MIMO	Sectorized Antennas	Proposed Method
50	420	485	395	610
100	730	810	690	940
150	980	1045	920	1215
200	1180	1270	1125	1450

The proposed method can increase throughput by 20 to 30 percent over the technologies that are already in use since it employs effective beamforming and spatial filtering to increase capacity and data rates.

The proposed method makes the best use of the millimeter-wave spectrum, even when there are a lot of people using it. This is because it can handle interference better and alter its beamforming. When the beam alignment latency is lowered by 30%, it is possible to connect more quickly. The increase of roughly fifty percent in the PER shows that the data transfer is now more stable. In crowded situations, using the SINR can increase the SNR by as much as 35%. Because it can handle bigger data rates, the system that has been shown might increase throughput by 20% to 25%. A 30% increase in spectral efficiency means that the bandwidth that is available is being used more effectively. These upgrades have shown that spatial filtering, optimal power allocation, and hybrid beamforming all function effectively in 5G mmWave networks with urban microcells.

6. CONCLUSION

This study presents a comprehensive performance evaluation of a novel 5G-IoT mmWave network operating at 38 GHz in an urban microcell outdoor environment. The proposed method integrates advanced channel modeling, hybrid beamforming, spatial filtering, and spectral efficiency optimization to overcome challenges such as high path loss, interference, and beam alignment latency inherent in millimeter-wave communications. Simulation results demonstrate that the proposed technique significantly reduces beam alignment latency by 30%, lowers packet error rates by nearly 50%, and improves SINR by up to 35% compared to conventional Analog Beamforming, MIMO, and Sectorized Antennas. These enhancements directly translate into 20–25% higher throughput and a 30% boost in spectral efficiency, showcasing superior bandwidth utilization and network capacity. The improvements confirm that adaptive beamforming and interference mitigation strategies are critical for the effective deployment of mmWave 5G networks in dense urban scenarios. Overall, the proposed method offers a promising solution for achieving reliable, high-capacity IoT connectivity with reduced latency and enhanced signal quality, essential for next-generation wireless applications. Future work may focus on real-time hardware implementations and exploring machine learning techniques to further refine beam management and resource allocation.

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