Misan Journal of Engineering Sciences ISSN: 2957-4250
Vol. 4, No. 1, June 2025 ISSN-E: 2957-4242

Hybrid Integration Strategies: Combining the Strengths of mmWave and Sub-6 GHz Technologies

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(Received 6 May, Revised 8 June, Accepted 8 June)

Abstract: It is necessary to observe that the technologies used in the field of radio transmission and wireless communications determine the features and efficiency of networks. Given the ever-increasing need for high-speed wireless communication, Millimeter-wave (mmWave) and sub-6 GHz technologies have been developed and integrated into current communication systems. This article summaries the comparison between these two different frequency bands regarding their unique advantages, disadvantages, and their uses, while emphasizing more in their advantages. We consider hybrid integration solutions capitalizing on complementary characteristics of both frequency bands in order to achieve improved performance in 5G and beyond networks. mmWave frequencies offer high data rates and large bandwidth that is required by applications requiring extremely fast connectivity. Due to the limited range and sensitivity to obstructions, sub-6 GHz frequencies are required; however, the coverage and penetration through the obstructions are higher. By combining these technologies, hybrid systems can ensure smooth communication, increase dependability, and improve the spectrum utilization. As it considers the technical challenges, possible solutions, and performance gain of hybrid mmWave and sub-6 GHz integration, this article points out the role of increasingly sophisticated antenna designs, beamforming methods and smart spectrum control array This research gives insight into the future of wireless communication by analyzing through simulation experiments and thorough analysis of the essential elements whose successful deployment is needed in order to utilize the benefits of hybrid systems.

Keywords: mmWave; Hybrid integration; Antenna; Sub-6 GHz ; Throughput; 5G Networks**.**

1. Introduction

Today, due to the advancement of wireless communication in the form of mobility devices, IoT, and broadband applications, use data traffic has significantly expanded. To address such needs, the telecom sector is exploring the use of two emerging technologies, namely mmWave and sub-6 GHz. All of them are designed for different environments and usages due to their values[1]. In the case of the building of new wireless communication systems, decisions on which transmission type to use whether it is Sub-6 GHz or mmWave becomes important especially when implementing 5G and even beyond [2].

This is the reason why sub-6 GHz crops are much less able in delivering large data rates and capacity than the

millimeter-wave technology, which works in frequencies more than 30 GHz. Specifically, when it comes to applications such as Virtual Reality[3]. Real-Time gaming, High-Definition Video Streaming that require high speed and large data throughout, then mmWave is perfect because of this. However, the effective coverage range of mmWave is relatively lower and it needs a higher small cell density to cover the large area due to higher probability of route loss and air absorption [4].

DOI: https://doi.org/10.61263/mjes.v4i1.146

On the other hand, Sub-6 GHz frequencies are frequencies lower than 6 GHz, which indeed have better coverage and ability to penetrate through the obstacles. For this reason, the Sub-6 GHz technology is therefore ideal for indoor coverage and also the wide area networks as the signal reliability is maintained through the building materials and distance. However, Sub-6 GHz has lower peak data rates than mmWave but it has some benefits mostly because of its reliability in non-line-of-sight environment, mobility, and IoT[5] [6]. Table 1 shows comparison between mm-Wave and Sub-6 GHz.

Table 1 below shows a comparison between mm-Wave and Sub-6 GHz in different aspects [7], [8].

Feature	**mmWave**	**Sub-6 GHz**
Frequency Range	Above 24 GHz (typically 24 GHz to 100 GHz)	Below 6 GHz
Bandwidth	Very high (up to several GHz)	Lower (tens to hundreds of MHz)
Data Transfer Rates	1 Gbps	100-700 Mbps
Coverage Area	Short range; typically less than a kilometer	Wider area; can cover several kilometers
Penetration & Propagation	Poor (struggles with buildings, rain, etc.)	Better (can penetrate walls and buildings)
Deployment	Urban areas, stadiums, and indoor environments	Urban, suburban, and rural areas
Capacity	Very high (supports high user density)	Moderate (lower than mmWave)
Use Cases	High-speed broadband, AR/VR	Mobile broadband, IoT, wide-area coverage
Infrastructure Requirement	Dense network of small cells	Less dense, traditional cell towers
Latency	Very low	Low (but typically higher than mmWave)
Cost	High (due to dense infrastructure needs)	Lower (due to wider coverage per cell)
Device Compatibility	Limited (not all devices support mmWave)	Widespread (most modern devices support Sub-6 GHz)
Standardization	More complex due to higher frequencies	More mature and widely adopted
Security	Potentially more vulnerable to signal interference	Generally less susceptible to interference

This helps create the groundwork for the analysis of strategic hybrid integration solutions, focus on technological challenges, creativity and potential benefits. This paper aims at providing the necessary knowledge about the future developments in wireless communication and the way towards the advancement of 5G and beyond solutions through evaluating the details of the integration of mmWave and sub-6 GHz bands.

For sub-6 GHz band and mmWave band, we explore the Prof and cons of both bands and propose a sub-6 GHz integration with mmWave band. As to check the effectiveness of the provided solution, the simulations and performance analyses are also performed.

The rest of this article is as follow: Section II provide some related works' literature reviews.

2. Literature Review

Experts in the field and technocrats have considered using both the mmWave as well as the sub-6 GHz frequencies to reap the benefit of the strengths offered by the two frequency bands in the wireless communication systems. Numerous

2.1 Related Works

This strategy has been explored by various researchers looking at different aspects of the problem and coming up with suggestions on how to overcome challenges to achieve integration of the strategy. The concepts applicable to the hybrid integration solutions are rooted in the prior knowledge, starting from the works of [9].The idea this work shows by theoretical models that it is feasible to integrate Sub-6 GHz and mmWave for joint spatial multiplexing to increase the capacity of the network. To enhance the coverage and capacity inHetNet using both frequency bands, Akdeniz et al. studies hybrid beamforming method in [10]. The proposal to use Sub-6 GHz for macro-cell and mmWave for small-cell deployment was initially in a research done by Ghosh et al. in [11].

In beamforming and specifically with reference to the antenna array for operating both in mmWave and sub-6 GHz, Rappaport et al. in [9] discussed the use of mmWave frequency for 5G cellular communication. In their research, they established that the use of mmWave technology could make it possible to get high data rates while at the same time, the sub6GHz technology could be used to provide extensive coverage. In [12], Niu et al presented many methods of beamforming for millimeter-wave communication with focus on the need for advanced kinds of antenna to overcome the limit of frequency. They stressed that 6ghz below systems would benefit from the features offered by adaptive beamforming to ensure coverage and link reliability.

When writing the paper in Spectrum Management and Resource Allocation, the authors focused on sub-6 GHz and hybrid mmWave systems' spectrum sharing strategies. They proposed dynamic methods for allocating spectrum aiming to make the best out of the available frequencies to give as much spectral efficiency as possible by balancing the two bands dependent with the current status of the network [13]. Mousa et al., [14] employed cognitive radio technology for facilitating the management of radio spectrum in the hybrid networks. As the findings of their study show, cognitive radio can improve the performance and minimize interference when switching between mmWave and sub-6 GHz frequencies.

As for the Network Architecture and Deployment, Han et al. provided options for the network deployment focusing on the coexistence of mmWave and sub-6 GHz base station. They opine that for mmWave, nodes should be deployed in hotspots while sub-6 GHz should be used for coverage to enhance the overall network performance significantly [15]. Ghosh et al has also discussed the architectural specifications which are specified for mmWave and sub-6 GHz in 5G in [16]. Specifically for the mmWave communication the idea of using tiny cells and for the sub-6 GHz band the idea of macro cells were proposed which will improve the user experience of the network as well as the network capacity.

Consequently, in the case of Performance Evaluation and Simulation, Performance evaluation and simulation studies have been conducted through simulation experiments as described by Zhang et al. in [17] to determine the performance of hybrid mmWave and sub-6GHz systems. They concluded that the utilization of both mmWave and sub-6 GHz networks offer a good balance of data rate, coverage and latency that are way better compared to the results gotten when only mmWave or sub-6 GHz networks are used. This was further supported by the latency and throughput analysis presented by Wang et al. in [18] detailing the suitability of HE that called for the efficiency of handover schemes in light of different frequency bands proficiency.

2.2. Problem Statements with mm Wave and Sub-6 GHz.

In this section, we present some of main challenges in mm wave and sub-6 GHz systems:

2.2.1 Properties of Propagation

The propagation at mmWave frequencies is restricted due to increased path loss and vulnerability to obstructions, including structures and plants. Whereas, sub-6 GHz has less path loss and can pass through obstructions to provide greater coverage than mmWave, but has a smaller bandwidth [19].

2.2.2 Challenges in Deployment

Because of the shorter transmission range of mmWave, dense deployment of small cells is required for optimal coverage, requiring the use of robust beamforming and MIMO algorithms.
Sub-6 GHz less base stations are needed for coverage, although there may be restrictions on the amount of spectrum available and difficulties reaching high data speeds [20][21] .

2.2.3 Proposed Method

Our proposed approach involves the following steps:

a. Create a network model that includes overlapping coverage areas for mmWave and sub-6 GHz base stations (BS).

a. Provide mechanisms for devices to connect sub-6 GHz BS and mmWave, dynamically switching according to network conditions and signal quality.

b. Use algorithms to distribute traffic across the two bands as effectively as possible.

c. Create methods to reduce interference between bands.

By combining mmWave and Sub-6 GHz technology, the hybrid integration approach seeks to maximize network performance by utilizing the advantages of both frequency bands.

Let C_{mm} represents the capacity of mm Wave link and C_{Sub} represents the capacity of Sub-6 GHz link. Also, C_T represents the total capacity, it can be expressed as:

$$C_T = \alpha C_{mm} + (1-\alpha) C_{Sub}$$

Where α is a weighted factor based on current network conditions. The problem is optimized as in the following formula:

$$Max_{\alpha}\, C_T \quad 0 \le \alpha \le 1$$

$$\sum_{i=1}^{N} R_i \le C_T$$

Where, N is the number of users, and R is the data rate requirements.
In the targeted area, mmWave and sub-6 GHz base stations are first deployed to initiate the system. Then, the devices connect to the BS and measure the quality of the signal. Based on a predetermined signal-to-noise ratio (SNR) threshold, devices switch between sub-6 GHz and mmWave as equation below:

$$User\ Assignment_{\,i} = \begin{cases} 1 & \text{if SNRi} > \text{SNRthreshold (assigned to mmWave)} \\ 0 & \text{otherwise (assigned to Sub} - \text{6 GHz)} \end{cases}$$

Finally, optimize network performance by balancing load and interference management algorithm. Algorithm 1 presents our proposed approach and Figure 1 shows the proposed flowchart.

Algorithm. 1: Hybrid Integration Algorithm
1. Initialize System
Deploy mmWave and sub-6 GHz BS. User devices initiated.
2. User Association
For each user device: Measure SNR for mmWave and sub-6 GHz. If $SNR_{mm\ Wave} > SNR_{threshold}$, connect to mmWave. Otherwise, connect to sub-6 GHz.
3. Switching Dynamically
For connected devices, check SNR periodically If SNR conditions change, switch connection.
4. Load Balancing
Determine the amount of traffic on each BS. Rearrange traffic to balance the load.
5. Management interference
Interference sources identification. To minimize interference, adjust transmission parameters.

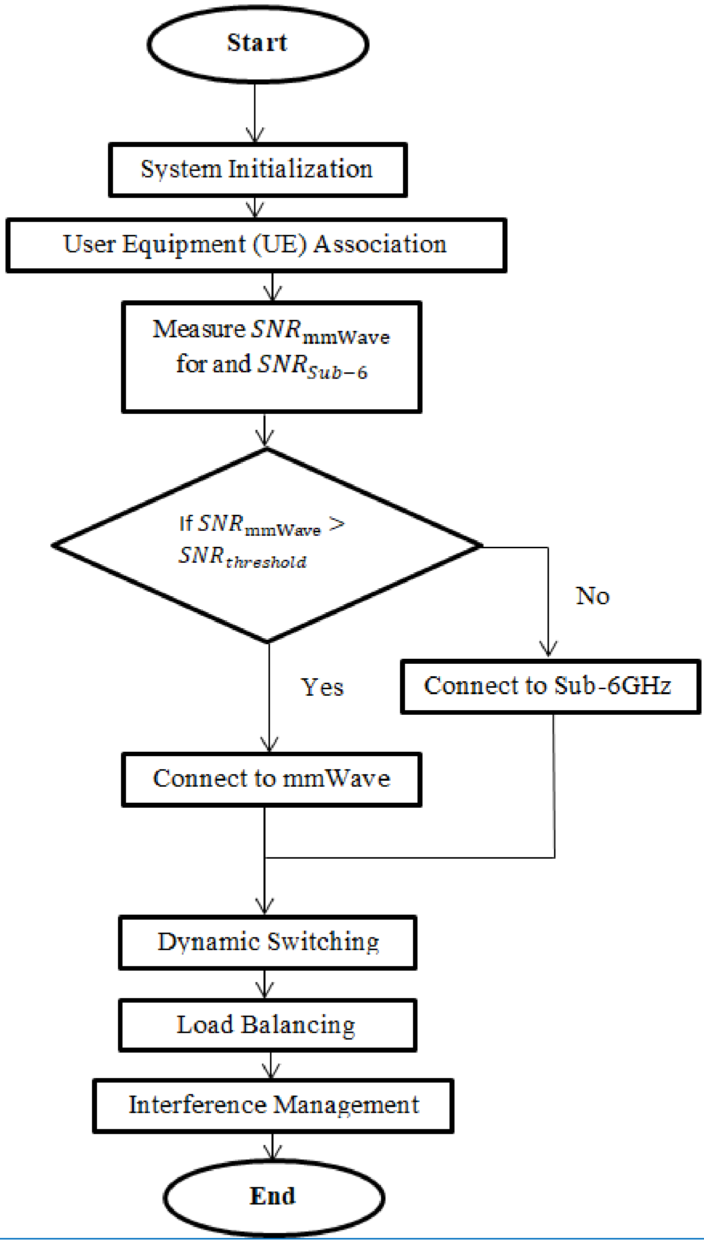

Fig. 1 Hybrid Integration Flow Chart

4. Performance Analysis and Simulation Results

Key performance indicators like throughput, latency, and coverage are used to evaluate the effectiveness of the proposed hybrid integration approach. The investigation compares the sub-6 GHz and mmWave systems with the hybrid approach. We use Matlab code to implement our proposed.

4.1Throughput

The throughput of our proposed system is calculated as in the following formula:

$$\text{Throughput}_{\text{hybrid}} = \alpha\left(\frac{\text{Number of mmWave users}}{\text{Total users}} \,.\, C_{mm}\right) + (1+\alpha)\left(\frac{Number\ of\ Sub-6GHz\ users}{Total\ users} . C_{sub}\right)$$

Figure 2 below shows the throughput result for our Hybrid model in a comparison with mmWave and Sub-6 GHz.

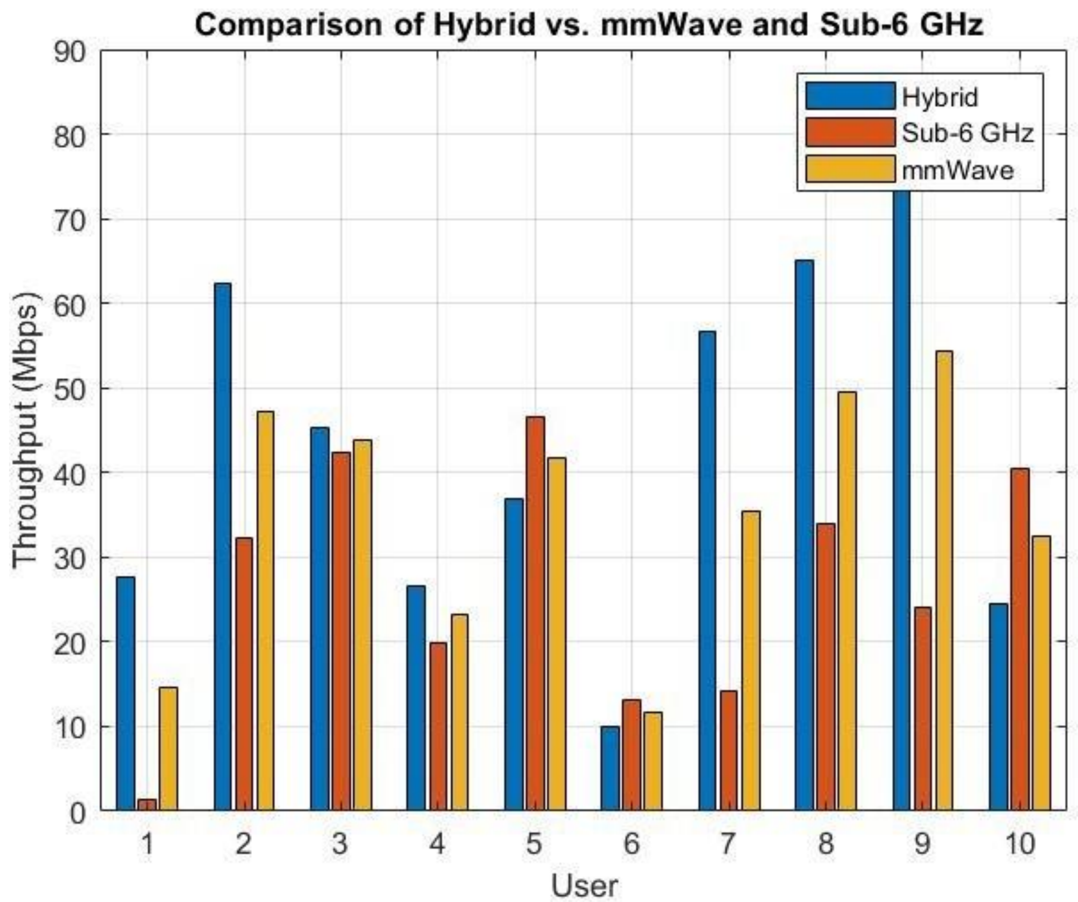

Fig. 2 Throughput Results.

By using mmWave's large capacity and ensuring steady communication with sub-6 GHz, the hybrid approach significantly increases throughput. So, our hybrid approach achieves higher throughput compared with mmWave and Sub-6 GHz systems, with increasing the number of users. Throughput combines the dependable coverage of Sub-6 GHz with the high capacity of mmWave.

4.2 Latency

The propagation delay and the latency of each technology have an impact on our model's latency. It is calculated as:

$$\text{Latency}_{Hybrid} = \alpha \cdot (\text{Latency of mmWave} + \text{P}_{Delay}) + (1-\alpha) \cdot (\text{Latency of sub6GHz} + \text{P}_{Delay})$$

$$P_{\boldsymbol{Delay}} = \frac{Distance}{Light\ Speed}$$

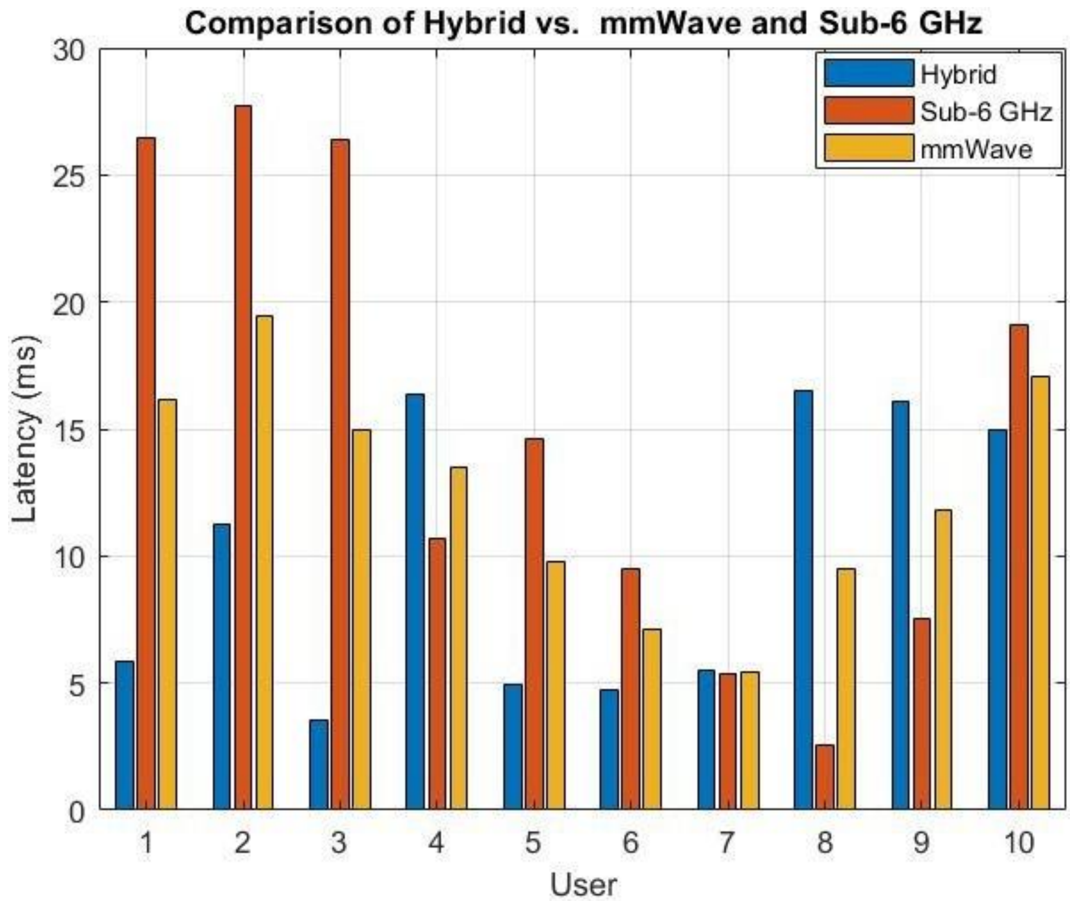

Fig. 3 Latency Results

Load balancing and dynamic switching minimize delay by avoiding traffic and allocating resources as efficiently as possible, also guaranteeing a more seamless user experience. So, our Hybrid model achieves less latency in a comparison with the two standard systems.

4.3 Packet Loss Ratio

Packet loss rate can be affected by many factors including interference, signal to noise ratio and environmental conditions. Figure 4 below shows the results of packet loss rate of our Hybrid system in a comparison with the mmWave and Sub-6GHz.

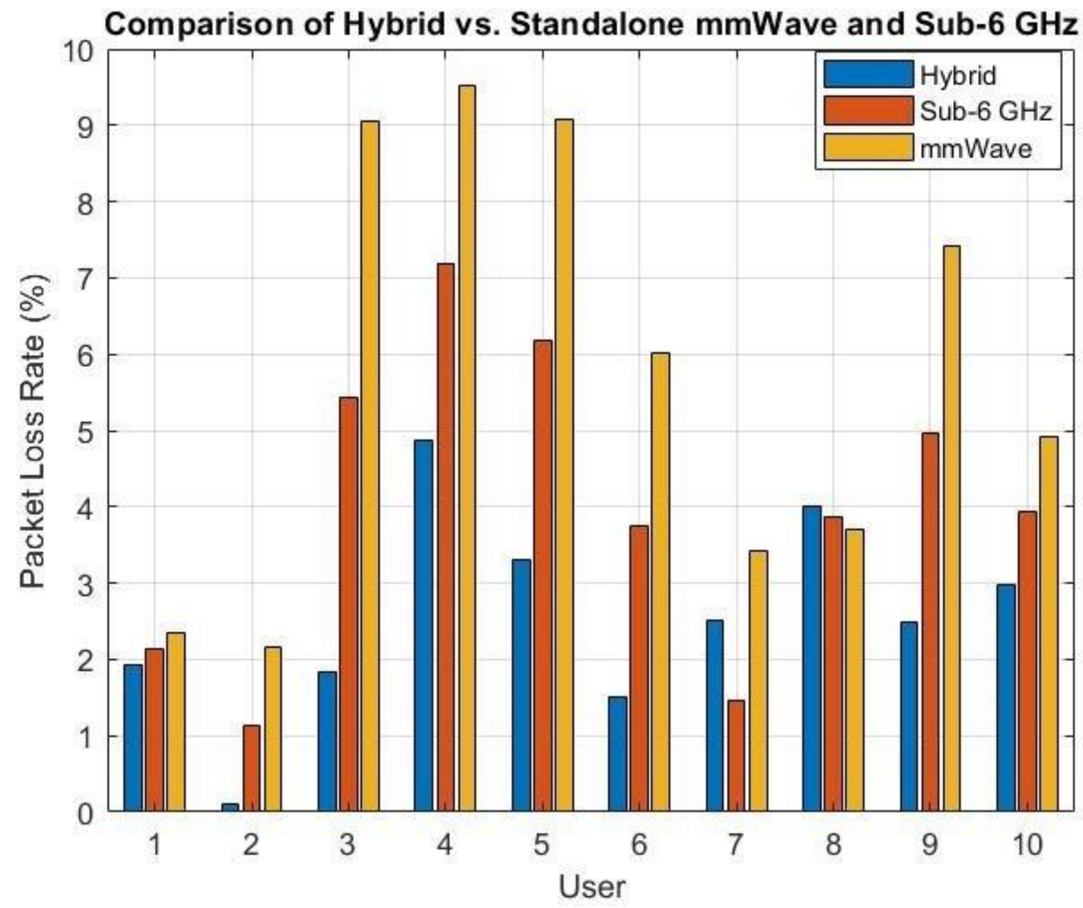

Fig. 4 Packet Loss Rate Results

We can see that our Hybrid model achieves the lowest loss in packets, so this improves the overall network efficiency compared with mmWave and Sub-6GHz.

4.4 Round Trip Time (RTT):

It is the amount of time, measured in milliseconds (ms), that a network request takes to go from its beginning point to its destination and back. Figure 5 below shows the RTT results for our proposed. Propagation delay, queuing delay, and base latency—all of which rise with user count—can affect RTT.

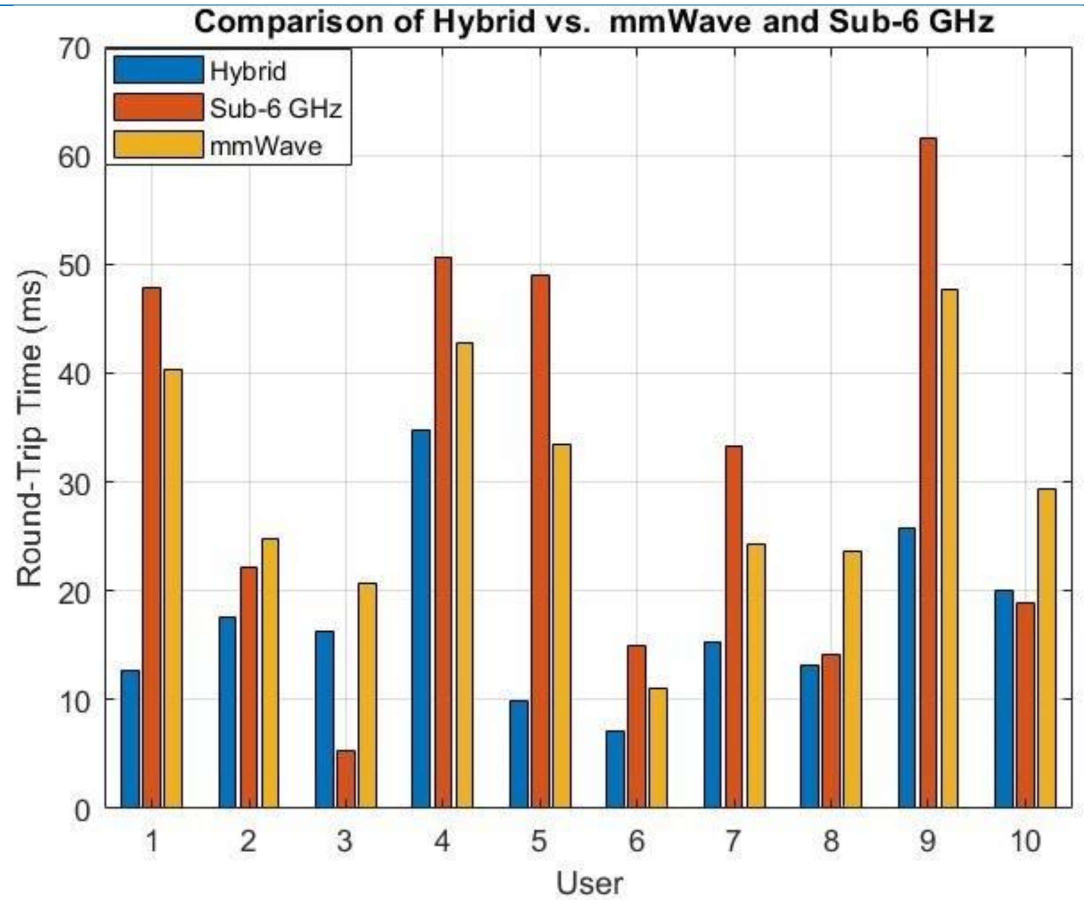

Fig. 5 RTT Results

Because of the queuing delay, the RTT for mmWave technology rises as the number of users increases. Also, the reason for the increased total RTT of Sub-6 GHz technology is the higher base latency. Figure 5 shows how the Hybrid strategy helps to reduce the RTT in a comparison with mmWave and Sub-6GHz. So, the Hybrid technology optimizes the RTT across varying users' loads.

5.Conclusion

Due to the growing demand for high-speed wireless communication, mmWave and sub-6 GHz technologies have been developed and integrated into modern communication systems. Each of these technologies has distinct characteristics—mmWave offers extremely high data rates and large bandwidth but suffers from limited coverage and poor penetration; on the other hand, sub-6 GHz offers wider coverage and better obstacle penetration but with relatively lower data rates.

In order to overcome the shortcomings of both technologies, a hybrid integration technique has been suggested. The proposed hybrid model integrates both frequency bands in a dynamic and adaptive framework. Devices are able to connect to either mmWave or sub-6 GHz base stations depending on SNR measurements and traffic conditions. A load-balancing mechanism and interference management algorithm were also incorporated to further improve overall system performance.

Through comprehensive MATLAB-based simulations, we demonstrated that the hybrid model consistently outperforms systems that rely solely on either mmWave or sub-6 GHz. The hybrid strategy improves overall network performance by utilizing load balancing, dynamic switching, and advanced optimization techniques to provide higher throughput, reduced Packet loss rate, Round trip time, and latency. Also, the Hybrid approach improves the coverage. These improvements confirm that the hybrid approach provides a robust and scalable solution for modern wireless networks.

In future works, we will focus on real-world implementation. Also, 5G and other future wireless communication standards evolve; we will modify the hybrid technique to fit their need.

Author Contributions: The authors contributed to all parts of the current study.
Funding: This study received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.

References

[1] M. Xiao *et al.*, “Millimeter wave communications for future mobile networks,” *IEEE J. Sel. Areas Commun.*, vol. 35, no. 9, pp. 1909–1935, 2017.

[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] Q. Liang, H. Aliakbari, and B. K. Lau, “Co-designed millimeter-wave and sub-6 GHz antenna for 5G smartphones,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 21, no. 10, pp. 1995–1999, 2022.

[4] N. Chukhno *et al.*, “Models, methods, and solutions for multicasting in 5G/6G mmWave and sub-THz systems,” *IEEE Commun. Surv. Tutorials*, 2023.

[5] G. Yao, M. Hashemi, and N. B. Shroff, “Integrating sub-6 GHz and millimeter wave to combat blockage: Delay-optimal scheduling,” in *2019 International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT)*, 2019, pp. 1–8.

[6] F. Pasic *et al.*, “Comparison of sub 6 GHz and mmWave wireless channel measurements at high speeds,” in *2022 16th European Conference on Antennas and Propagation (EuCAP)*, 2022, pp. 1–5.

[7] M. Haghshenas, F. Linsalata, L. Barbieri, M. Brambilla, M. Nicoli, and M. Magarini, “Analysis of spatial scheduling in downlink vehicular communications: sub-6 GHz vs mmWave,” *ITU J Futur Evol Technol*, vol. 3, pp. 523–534, 2022.

[8] A. Sufyan, K. B. Khan, O. A. Khashan, T. Mir, and U. Mir, “From 5G to beyond 5G: A comprehensive survey of wireless network evolution, challenges, and promising technologies,” *Electronics*, vol. 12, no. 10, p. 2200, 2023.

[9] T. S. Rappaport *et al.*, “Millimeter wave mobile communications for 5G cellular: It will work!,” *IEEE access*, vol. 1, pp. 335–349, 2013.

[10] M. R. Akdeniz *et al.*, “Millimeter wave channel modeling and cellular capacity evaluation,” *IEEE J. Sel. areas Commun.*, vol. 32, no. 6, pp. 1164–1179, 2014.

[11] A. Ghosh *et al.*, “Millimeter-wave enhanced local area systems: A high-data-rate approach for future wireless networks,” *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1152–1163, 2014.

[12] Y. Niu, Y. Li, D. Jin, L. Su, and A. V Vasilakos, “A survey of millimeter wave

communications (mmWave) for 5G: opportunities and challenges," *Wirel. networks*, vol 21, pp. 2657–2676, 2015.

[13] J. Shi, P. Xiao, J. Kelly, and J. Si, "Resource allocation and interference management in hybrid millimeter wave networks," in *2017 IEEE/CIC International Conference on Communications in China (ICCC)*, 2017, pp. 1–6.

[14] S. H. Mousa, M. Ismail, R. Nordin, and N. F. Abdullah, "Effective Wide Spectrum Sharing Techniques Relying on CR Technology toward 5G: A Survey.," *J. Commun.*, vol. 15, no. 2, pp. 122–147, 2020.

[15] S. Sekander, H. Tabassum, and E. Hossain, "Multi-tier drone architecture for 5G/B5G cellular networks: Challenges, trends, and prospects," *IEEE Commun. Mag.*, vol. 56, no. 3, pp. 96–103, 2018.

[16] A. Ghosh, R. Ratasuk, B. Mondal, N. Mangalvedhe, and T. Thomas, "LTE-advanced: next-generation wireless broadband technology," *IEEE Wirel. Commun.*, vol. 17, no. 3, pp. 10–22, 2010.

[17] J. Zhang, X. Ge, Q. Li, M. Guizani, and Y. Zhang, "5G millimeter-wave antenna array: Design and challenges," *IEEE Wirel. Commun.*, vol. 24, no. 2, pp. 106–112, 2016.

[18] Y. Wang, "Wang," *Jia Z, Yi Q, Song L. Var. components implied Divers. toll-like Recept. Signal. pathways mollusk Chlamys farreri. Fish Sellfish Immunol*, vol. 74, pp. 205–212, 2018.

[19] O. Semiari, W. Saad, M. Bennis, and M. Debbah, "Integrated millimeter wave and sub-6 GHz wireless networks: A roadmap for joint mobile broadband and ultra-reliable low- latency communications," *IEEE Wirel. Commun.*, vol. 26, no. 2, pp. 109–115, 2019.

[20] S. Zhang, G. Wang, and I. Chih-Lin, "Is mmWave ready for cellular deployment?," *IEEE Access*, vol. 5, pp. 14369–14379, 2017.

[21] M. K. Jabbar and T. A. Kareem, "CCOA-DC: ANovel Optimization with NMF DataCompression in WSN Data Aggregation.," Int.J. Intell. Eng. Syst., Vol. 17, No. 3, 2024