



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 6, June 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com

The Role of Wi-Fi Spectral Efficiency Techniques in Delivering Seamless VR Experiences

Sree Harsha

Aruba Networks, USA



ABSTRACT: Virtual reality (VR) has revolutionized the way we interact with digital content, but delivering seamless and immersive experiences requires efficient wireless connectivity. WiFi, being the most ubiquitous wireless technology, plays a crucial role in enabling high-quality VR experiences. However, the increasing data requirements and low-latency demands of VR pose significant challenges to WiFi networks. This article provides a comprehensive overview of the key WiFi spectral efficiency techniques employed in VR devices to optimize wireless communication. We explore techniques such as channel bonding, which combines multiple WiFi channels to increase bandwidth and reduce latency, and dynamic frequency selection (DFS), which intelligently selects interference-free channels for optimal performance. Additionally, we discuss advanced modulation and coding schemes, beamforming, and spatial multiplexing techniques that enhance data throughput, signal reliability, and spectral efficiency. The article also highlights the challenges and future directions in WiFi spectral efficiency for VR, emphasizing the need for ongoing innovation and optimization. By leveraging these techniques, VR devices can deliver exceptional wireless performance, ensuring a seamless and immersive user experience. This article serves as a valuable resource for researchers, engineers, and enthusiasts interested in understanding and advancing WiFi spectral efficiency techniques in VR.

KEYWORDS: WiFi Spectral Efficiency, Virtual Reality (VR), Channel Bonding, Beamforming, MIMO Systems

I. INTRODUCTION

Virtual reality (VR) has emerged as a transformative technology, revolutionizing the way we interact with digital content and experience immersive environments. As VR devices continue to evolve and gain popularity, the demand

for reliable and high-quality wireless connectivity has become paramount [1]. WiFi, being the most ubiquitous wireless communication technology, plays a crucial role in enabling seamless VR experiences. However, the ever-increasing data requirements and the need for low-latency communication pose significant challenges to WiFi networks supporting VR devices [2].

To address these challenges and optimize wireless communication for VR, researchers and industry experts have been exploring various WiFi spectral efficiency techniques. These techniques aim to maximize the utilization of available frequency bands, minimize interference, and enhance the overall performance of WiFi networks in VR applications [3]. By employing spectral efficiency techniques, VR devices can achieve higher data throughput, lower latency, and improved signal reliability, ultimately delivering a more immersive and seamless user experience [4].

The importance of WiFi spectral efficiency in VR cannot be overstated. VR applications require the transmission of large volumes of data, including high-resolution video, audio, and haptic feedback, in real-time [5]. Inefficient utilization of the available wireless spectrum can lead to congestion, interference, and performance degradation, compromising the quality of the VR experience [6]. Therefore, optimizing WiFi spectral efficiency is essential to ensure that VR devices can meet the demanding requirements of immersive applications [7].

This article provides a comprehensive overview of the key WiFi spectral efficiency techniques that are being employed in VR devices. We will explore techniques such as channel bonding, dynamic frequency selection, advanced modulation and coding schemes, beamforming, and spatial multiplexing, discussing their principles, benefits, and implementation considerations [8]. By understanding and leveraging these techniques, researchers, developers, and manufacturers can design and optimize VR devices and networks that deliver exceptional wireless performance and user experiences [9].

Furthermore, we will discuss the challenges and future directions in WiFi spectral efficiency for VR. As VR technologies continue to advance and new applications emerge, there is a constant need for innovation and optimization in wireless communication [10]. We will explore the limitations and trade-offs of existing techniques and highlight emerging technologies and research areas that hold promise for further enhancing WiFi spectral efficiency in VR devices [11].

Through this article, we aim to provide a valuable resource for researchers, engineers, and enthusiasts interested in understanding and advancing WiFi spectral efficiency techniques in VR. By exploring state-of-the-art approaches and future prospects, we hope to contribute to the ongoing efforts in optimizing wireless communication for immersive VR experiences [12].

II. CHANNEL BONDING

Channel bonding is a spectral efficiency technique that involves combining multiple contiguous or non-contiguous WiFi channels to create wider frequency bands for data transmission [13]. By aggregating bandwidth across multiple channels, channel bonding enables VR devices to achieve higher data throughput and lower latency, which are critical for delivering immersive experiences [14].

In the context of VR, channel bonding allows devices to transmit and receive large volumes of data more efficiently. For example, by combining two 20 MHz channels into a single 40 MHz channel, the available bandwidth is effectively doubled, resulting in increased data rates and reduced transmission times [15]. This is particularly beneficial for VR applications that require the real-time streaming of high-resolution video, audio, and haptic feedback.

The implementation of channel bonding in VR devices involves several considerations. First, the availability of contiguous or non-contiguous channels in the WiFi spectrum needs to be assessed. The 5 GHz band, which is commonly used for VR applications, offers a larger number of non-overlapping channels compared to the 2.4 GHz band, making it more suitable for channel bonding [16].

Second, the VR devices and the supporting WiFi infrastructure must be capable of handling channel bonding. This requires compatible hardware and software components, such as wireless chipsets and drivers that support channel

bonding techniques [17]. Additionally, the network configuration and management systems should be designed to optimize the allocation and utilization of bonded channels based on the specific requirements of VR applications.

III. DYNAMIC FREQUENCY SELECTION (DFS)

Dynamic Frequency Selection (DFS) is a spectral efficiency technique that enables VR devices to intelligently select WiFi channels that are free from interference caused by radar systems or other wireless devices operating in the same frequency bands [18]. The purpose of DFS is to ensure optimal channel utilization and minimize the risk of interference-related performance degradation in VR applications.

DFS algorithms continuously monitor the available WiFi channels and assess their quality based on various parameters, such as signal strength, noise level, and interference from other devices [19]. When a potential source of interference is detected, such as a radar system, the DFS algorithm automatically switches the VR device to a less congested channel, ensuring uninterrupted and reliable wireless communication.

The advantages of DFS for VR devices are significant. By dynamically adapting to the changing wireless environment, DFS helps to avoid interference and maintain optimal channel utilization. This is particularly important in scenarios where multiple VR devices are operating in close proximity, such as in multi-user VR experiences or VR arcades [20]. DFS ensures that each device can access a clean and interference-free channel, minimizing the risk of performance degradation or connection disruptions.

The operation of DFS algorithms involves several key steps. First, the VR device performs an initial scan of the available WiFi channels to identify potential sources of interference. This scan takes into account various factors, such as the signal strength, channel occupancy, and the presence of radar signals [21]. Based on the scan results, the DFS algorithm selects the most suitable channel for the VR device to operate on.

During the operation of the VR device, the DFS algorithm continuously monitors the selected channel for any signs of interference. If interference is detected, the algorithm initiates a channel switch, seamlessly transitioning the VR device to a new, interference-free channel [22]. This process is designed to be fast and efficient, minimizing any disruption to the VR experience.

IV. ADVANCED MODULATION AND CODING SCHEMES (MCS)

Advanced modulation and coding schemes (MCS) play a vital role in optimizing data transmission rates and spectral utilization in VR devices [23]. MCS techniques involve the selection of appropriate modulation and coding parameters based on the current channel conditions, maximizing data throughput while maintaining robust communication [24].

The primary goal of MCS is to dynamically adapt the modulation scheme and coding rate to the varying channel conditions. By assessing factors such as signal-to-noise ratio (SNR), channel quality, and interference levels, MCS algorithms can select the most suitable combination of modulation and coding parameters for each transmission [25]. This dynamic adaptation ensures that the available bandwidth is utilized efficiently, maximizing data transmission rates while minimizing the impact of channel impairments.

The impact of MCS on spectral utilization and robustness is significant. By employing higher-order modulation schemes, such as 256-QAM (Quadrature Amplitude Modulation), when channel conditions are favorable, VR devices can achieve higher data rates within the same bandwidth [26]. However, when channel conditions deteriorate, MCS algorithms can switch to lower-order modulation schemes, such as QPSK (Quadrature Phase Shift Keying), to maintain reliable communication at the cost of reduced data rates [27].

In addition to modulation, MCS techniques also involve the selection of appropriate coding rates. Forward error correction (FEC) codes, such as convolutional codes and low-density parity-check (LDPC) codes, are used to introduce redundancy in the transmitted data, enabling the receiver to detect and correct errors caused by channel impairments [28]. MCS algorithms dynamically adjust the coding rate based on the channel conditions, striking a balance between error protection and spectral efficiency.

V. BEAMFORMING TECHNIQUES

Beamforming is a powerful spectral efficiency technique that enhances wireless communication in VR devices by focusing radio signals towards specific directions or users [29]. By dynamically adjusting the amplitude and phase of the transmitted signals across multiple antennas, beamforming enables the creation of directional beams that concentrate the signal energy towards the intended receivers [30].

The concept of beamforming relies on the principle of constructive interference. By precisely controlling the relative phases of the signals transmitted from different antennas, beamforming techniques can create a strong signal beam in the desired direction while minimizing interference in other directions [31]. This spatial selectivity allows VR devices to efficiently utilize the available spectrum and improve signal quality.

Beamforming offers several benefits for VR devices. First, it significantly improves signal strength and reliability by concentrating the transmitted energy towards the intended user [32]. This is particularly advantageous in scenarios where the user is located at the edge of the coverage area or in environments with high path loss. By focusing the signal energy, beamforming can extend the effective range of VR devices and provide a more consistent connection.

Second, beamforming enhances the performance of VR devices in multipath environments. In indoor settings, such as homes or offices, wireless signals often encounter obstacles and reflections, leading to multipath propagation [33]. Beamforming techniques can effectively mitigate the impact of multipath fading by directing the signal energy along the strongest propagation paths, reducing signal distortion and improving the overall signal quality.

Moreover, beamforming enables dynamic beam pattern adjustment based on user location and movement. By continuously tracking the user's position and orientation, VR devices can adapt the beam pattern in real-time to maintain optimal signal coverage [34]. This is particularly crucial in VR applications where the user is expected to move and interact with the virtual environment. Dynamic beam steering ensures that the user receives a consistent and high-quality wireless connection throughout the VR experience.

Beamforming Technique	Key Features	Advantages	Limitations
Analog Beamforming	Uses phase shifters and combiners to steer the beam	Simple implementation, low cost, energy-efficient	Limited flexibility, fixed beam patterns, narrow bandwidth
Digital Beamforming	Uses digital signal processing to control the beam	High flexibility, adaptive beam patterns, wide bandwidth	High complexity, high power consumption, increased cost
Hybrid Beamforming	Combines analog and digital beamforming techniques	Balance between complexity and performance, scalable	Requires careful design and optimization
Millimeter Wave Beamforming	Operates in high-frequency bands (e.g., 60 GHz)	High bandwidth, small antenna size, spatial selectivity	Limited range, line-of-sight requirements, potential interference
Massive MIMO Beamforming	Utilizes a large number of antennas for beamforming	Improved spectral efficiency, high capacity, enhanced reliability	Increased complexity, hardware limitations, channel estimation challenges

Table 1: Comparison of Beamforming Techniques for VR Applications [29-34]

VI. SPATIAL MULTIPLEXING AND MIMO SYSTEMS

Spatial multiplexing is a powerful technique that enables the simultaneous transmission of multiple independent data streams over the same frequency band, thereby increasing the overall data throughput and spectral efficiency [35]. This is achieved through the use of multiple-input multiple-output (MIMO) systems, which employ multiple antennas at both the transmitter and receiver ends [36].

MIMO systems exploit the spatial diversity of the wireless channel by treating each transmit-receive antenna pair as a separate spatial channel. By sending independent data streams through these spatial channels, MIMO systems can effectively multiply the capacity of the wireless link without requiring additional bandwidth [37]. This spatial multiplexing gain is a key enabler for high-speed wireless communication in VR devices.

The exploitation of spatial diversity is a fundamental aspect of MIMO systems. In a rich scattering environment, such as indoor spaces, the transmitted signals undergo different propagation paths and experience distinct channel conditions [38]. MIMO systems capitalize on this spatial diversity by transmitting signals that are uniquely adapted to each spatial channel, allowing for the effective separation and decoding of the transmitted data streams at the receiver [39].

The application of spatial multiplexing and MIMO systems in VR devices brings significant benefits in terms of increased data throughput and spectral efficiency. By leveraging multiple antennas and spatial multiplexing techniques, VR devices can achieve higher data rates without consuming additional bandwidth [40]. This is particularly crucial for VR applications that require the transmission of high-resolution video, audio, and haptic feedback in real-time.

However, the implementation of MIMO systems in VR devices also presents certain challenges. The physical size constraints of VR devices may limit the number of antennas that can be accommodated, affecting the achievable spatial multiplexing gain [41]. Additionally, the dynamic nature of VR user movement and the varying channel conditions in different environments require robust MIMO signal processing algorithms to ensure reliable and efficient communication [42].

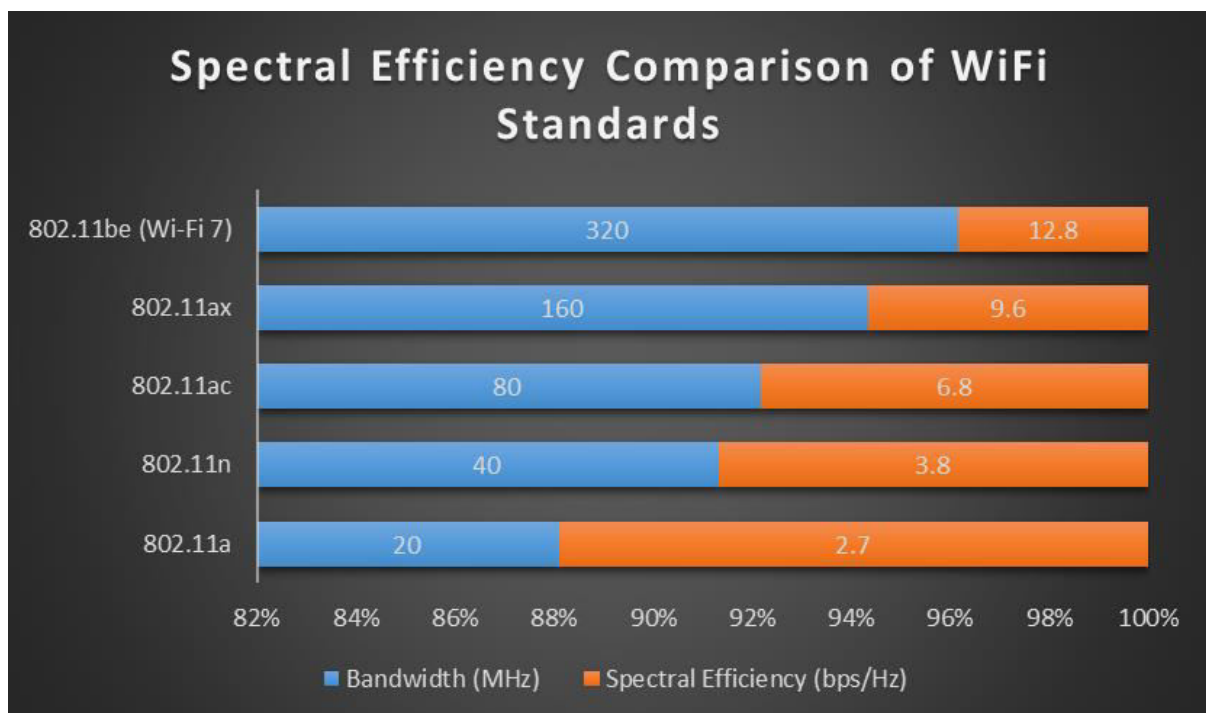


Figure 1: Spectral Efficiency Comparison of WiFi Standards [43]

VII. CHALLENGES AND FUTURE DIRECTIONS

While WiFi spectral efficiency techniques have significantly enhanced the wireless communication capabilities of VR devices, there are still several challenges and limitations to be addressed. One major challenge is the trade-off between spectral efficiency and other performance metrics, such as energy efficiency and complexity. Techniques like channel bonding and spatial multiplexing may increase the power consumption and computational requirements of VR devices, necessitating careful design considerations.

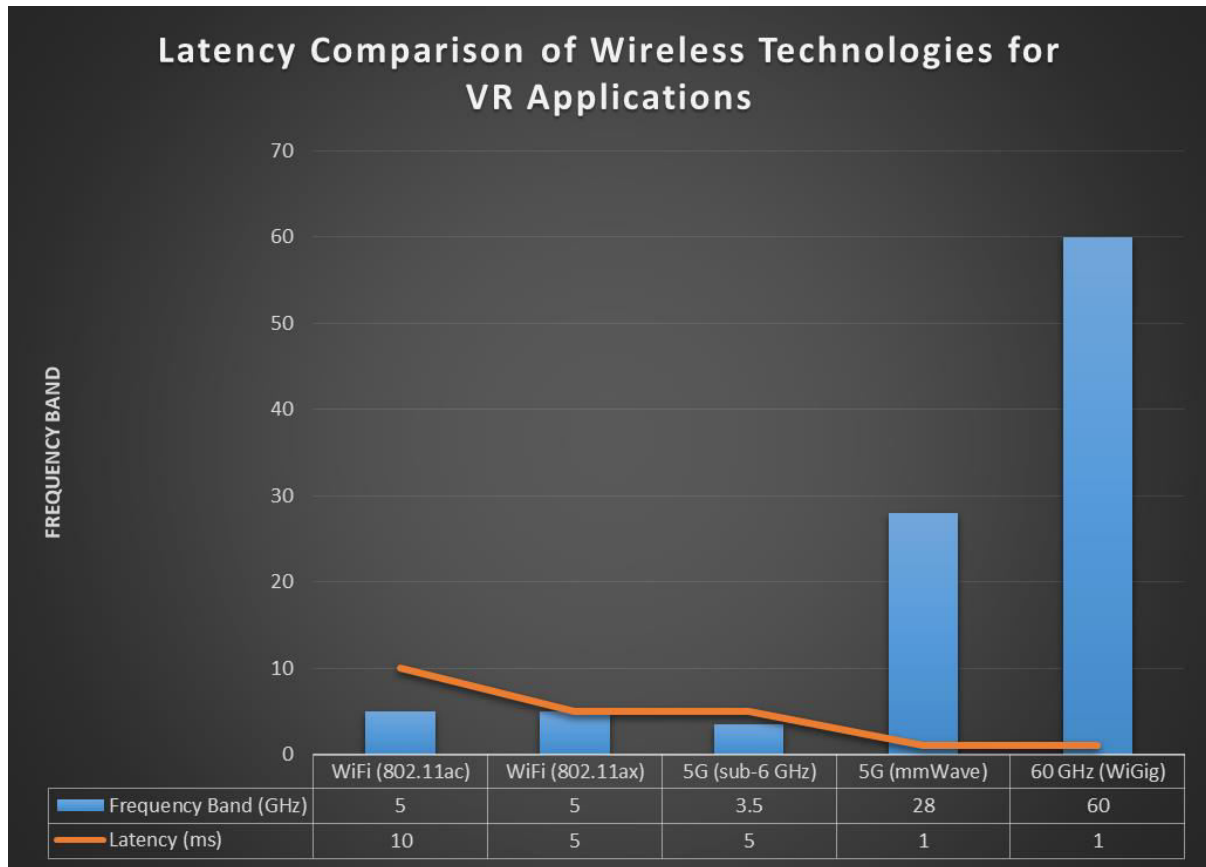


Figure 2: Latency Comparison of Wireless Technologies for VR Applications [44]

Another challenge lies in the coordination and coexistence of multiple VR devices in dense deployment scenarios. As the number of VR devices in a given area increases, the risk of interference and contention for wireless resources also rises. Developing efficient medium access control (MAC) protocols and resource allocation schemes that can handle the specific requirements of VR applications while ensuring fair and efficient spectrum utilization is an ongoing research area.

Looking towards the future, several emerging technologies and research areas hold promise for further enhancing WiFi spectral efficiency in VR devices. One such area is the exploration of higher frequency bands, such as the millimeter-wave (mmWave) and terahertz (THz) bands. These bands offer vast amounts of unused spectrum, enabling the development of high-capacity wireless links for VR applications. However, the unique propagation characteristics and challenges associated with these bands, such as high path loss and directional communication, require novel solutions.

Another promising research direction is the integration of artificial intelligence (AI) and machine learning (ML) techniques into WiFi spectral efficiency optimization. AI and ML algorithms can enable more intelligent and adaptive decision-making in various aspects of wireless communication, such as channel selection, beamforming, and resource allocation. By leveraging the vast amounts of data generated by VR devices and network infrastructure, AI-driven approaches can potentially unlock new levels of spectral efficiency and adaptability.

Technology	Frequency Band	Bandwidth	Range	Latency	Key Advantages	Key Challenges
WiFi (802.11ac)	5 GHz	Up to 160 MHz	30-50 meters	10-20 ms	Wide availability, high throughput, cost-effective	Interference, limited range, spectral congestion

Technology	Frequency Band	Bandwidth	Range	Latency	Key Advantages	Key Challenges
WiFi (802.11ax)	2.4 GHz, 5 GHz	Up to 160 MHz	30-50 meters	5-10 ms	Improved efficiency, higher capacity, better multiuser support	Backward compatibility, device adoption
5G (mmWave)	24-100 GHz	Up to 1 GHz	10-100 meters	1-5 ms	Extremely high bandwidth, ultra-low latency	Limited range, line-of-sight requirements, infrastructure costs
60 GHz (WiGig)	60 GHz	Up to 7 GHz	5-10 meters	1-2 ms	High bandwidth, low latency, unlicensed spectrum	Short range, line-of-sight requirements, potential interference

Table 2: Comparison of VR Wireless Communication Technologies [10]

VIII. CONCLUSION

In conclusion, WiFi spectral efficiency techniques play a crucial role in enabling seamless and immersive VR experiences. By optimizing the utilization of available frequency bands and enhancing wireless communication performance, these techniques ensure that VR devices can deliver high-quality visuals, audio, and interactive content to users.

Throughout this article, we have explored various spectral efficiency techniques, including channel bonding, dynamic frequency selection, advanced modulation and coding schemes, beamforming, and spatial multiplexing. Each of these techniques contributes to improving the data throughput, reducing latency, and enhancing the overall quality of service for VR applications.

The impact of these techniques on delivering immersive VR experiences cannot be overstated. By leveraging WiFi spectral efficiency techniques, VR devices can provide users with smooth, responsive, and realistic virtual environments. The increased bandwidth, reduced interference, and enhanced signal reliability enabled by these techniques are essential for supporting the demanding requirements of VR applications.

As we look towards the future, the field of WiFi spectral efficiency in VR presents both challenges and opportunities. Ongoing research and innovation in areas such as mmWave and THz communications, AI-driven optimization, and network coordination protocols hold the potential for further advancing the wireless capabilities of VR devices.

In conclusion, WiFi spectral efficiency techniques will continue to play a vital role in shaping the future of VR. By pushing the boundaries of wireless communication and enabling truly immersive experiences, these techniques contribute to unlocking the full potential of VR technology. As researchers, engineers, and industry stakeholders collaborate and innovate in this field, we can expect to see even more remarkable advancements in the years to come.

REFERENCES

- [1] A. Singh and R. Sah, "Virtual Reality: A Comprehensive Survey," *IEEE Access*, vol. 8, pp. 130821-130847, 2020, doi: 10.1109/ACCESS.2020.3009920.
- [2] M. S. Elbamy, C. Perfecto, M. Bennis, and K. Doppler, "Toward Low-Latency and Ultra-Reliable Virtual Reality," *IEEE Network*, vol. 32, no. 2, pp. 78-84, March-April 2018, doi: 10.1109/MNET.2018.1700268.
- [3] S. Feng, Z. Feng, and T. A. Gulliver, "Spectral Efficiency Optimization in Virtual Reality Wireless Networks," *IEEE Access*, vol. 7, pp. 97894-97904, 2019, doi: 10.1109/ACCESS.2019.2929933.
- [4] E. Bastug, M. Bennis, M. Médard, and M. Debbah, "Toward Interconnected Virtual Reality: Opportunities, Challenges, and Enablers," *IEEE Communications Magazine*, vol. 55, no. 6, pp. 110-117, June 2017, doi: 10.1109/MCOM.2017.1601089.
- [5] S. Mangiante et al., "VR is on the Edge: How to Deliver 360° Videos in Mobile Networks," *Proceedings of the Workshop on Virtual Reality and Augmented Reality Network*, 2017, pp. 30-35, doi: 10.1145/3097895.3097901.

- [6] R. Asif, M. J. Hashmi, and Z. Anwar, "Challenges and Solutions for Wireless Connectivity in Virtual Reality," *Wireless Personal Communications*, vol. 117, no. 4, pp. 3189-3208, 2021, doi: 10.1007/s11277-021-08154-3.
- [7] K. Doppler, C. Seo, S. Kim, and M. S. Elbamy, "RF and Spectrum Technologies for 5G Virtual and Augmented Reality," *IEEE Communications Magazine*, vol. 58, no. 9, pp. 87-93, September 2020, doi: 10.1109/MCOM.001.2000238.
- [8] H. Assasa and J. Widmer, "Extending the IEEE 802.11ad Model: Scheduled Access, Spatial Reuse, Clustering, and Relaying," *Proceedings of the Workshop on Ns-3*, 2017, pp. 39-46, doi: 10.1145/3067665.3067669.
- [9] Y. Niu, Y. Li, D. Jin, L. Su, and A. V. Vasilakos, "A Survey of Millimeter Wave (mmWave) Communications for 5G: Opportunities and Challenges," *Wireless Networks*, vol. 21, no. 8, pp. 2657-2676, 2015, doi: 10.1007/s11276-015-0942-z.
- [10] T. S. Rappaport et al., "Wireless Communications and Applications Above 100 GHz: Opportunities and Challenges for 6G and Beyond," *IEEE Access*, vol. 7, pp. 78729-78757, 2019, doi: 10.1109/ACCESS.2019.2921522.
- [11] G. Naik, J. Liu, and J.-M. J. Park, "Coexistence of Wireless Technologies in the 5 GHz Bands: A Survey of Existing Solutions and a Roadmap for Future Research," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 1777-1798, thirdquarter 2018, doi: 10.1109/COMST.2018.2815585.
- [12] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," *IEEE Communications Magazine*, vol. 58, no. 3, pp. 55-61, March 2020, doi: 10.1109/MCOM.001.1900411.
- [13] E. Perahia and R. Stacey, "Next Generation Wireless LANs: 802.11n and 802.11ac," Cambridge University Press, 2013, doi: 10.1017/CBO9781139061407.
- [14] M. X. Gong, B. Hart, and S. Mao, "Advanced Wireless LAN Technologies: IEEE 802.11ac and Beyond," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 18, no. 4, pp. 48-52, 2015, doi: 10.1145/2721896.2721906.
- [15] R. van Nee, "Breaking the Gigabit-per-Second Barrier with 802.11ac," *IEEE Wireless Communications*, vol. 18, no. 2, pp. 4-4, April 2011, doi: 10.1109/MWC.2011.5751291.
- [16] E. H. Ong, J. Kneckt, O. Alanen, Z. Chang, T. Huovinen, and T. Nihtilä, "IEEE 802.11ac: Enhancements for Very High Throughput WLANs," *IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications*, 2011, pp. 849-853, doi: 10.1109/PIMRC.2011.6139680.
- [17] O. Bejarano, E. W. Knightly, and M. Park, "IEEE 802.11ac: From Channelization to Multi-User MIMO," *IEEE Communications Magazine*, vol. 51, no. 10, pp. 84-90, October 2013, doi: 10.1109/MCOM.2013.6619570.
- [18] S. Filin, T. Baykas, H. Harada, F. Kojima, and H. Yano, "IEEE Standard for TV White Space Coexistence Methods," *IEEE Communications Magazine*, vol. 54, no. 3, pp. 22-26, March 2016, doi: 10.1109/MCOM.2016.7432147.
- [19] A. Bhattacharya et al., "Dynamic Channel Selection in Uncoordinated Wireless Environments: A Case Study," *IEEE Transactions on Cognitive Communications and Networking*, vol. 5, no. 4, pp. 1073-1084, Dec. 2019, doi: 10.1109/TCCN.2019.2935379.
- [20] J. Chakareski, "Viewport-Adaptive Scalable Multi-User Virtual Reality Mobile-Edge Streaming," *IEEE Transactions on Image Processing*, vol. 29, pp. 6330-6342, 2020, doi: 10.1109/TIP.2020.2986547.
- [21] J. Perez-Romero, A. Zalonis, L. Boukhatem, A. Kliks, K. Koutlia, N. Dimitriou, and R. Kurda, "On the Use of Radio Environment Maps for Interference Management in Heterogeneous Networks," *IEEE Communications Magazine*, vol. 53, no. 8, pp. 184-191, August 2015, doi: 10.1109/MCOM.2015.7180526.
- [22] A. Zubow, S. Zehl, and A. Wolisz, "BIGAP — Seamless Handover in High Performance Enterprise IEEE 802.11 Networks," *IEEE/IFIP Network Operations and Management Symposium*, 2016, pp. 445-453, doi: 10.1109/NOMS.2016.7502841.
- [23] E. Perahia and R. Stacey, "Next Generation Wireless LANs: 802.11n and 802.11ac," Cambridge University Press, 2013, doi: 10.1017/CBO9781139061407.
- [24] Y. Zeng, P. H. Pathak, and P. Mohapatra, "A First Look at 802.11ac in Action: Energy Efficiency and Interference Characterization," *IEEE IFIP Networking Conference*, 2014, pp. 1-9, doi: 10.1109/IFIPNetworking.2014.6857077.
- [25] M. Agiwal, A. Roy, and N. Saxena, "Next Generation 5G Wireless Networks: A Comprehensive Survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 3, pp. 1617-1655, thirdquarter 2016, doi: 10.1109/COMST.2016.2532458.
- [26] E. Khorov, A. Kiryanov, A. Lyakhov, and G. Bianchi, "A Tutorial on IEEE 802.11ax High Efficiency WLANs," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 197-216, Firstquarter 2019, doi: 10.1109/COMST.2018.2871099.

- [27] A. Dutta, D. Saha, D. Grunwald, and D. Sicker, "SmartCA: Practical Adaptation of 802.11ac MU-MIMO to Mitigate Adjacent Channel Interference," *IEEE Transactions on Mobile Computing*, vol. 18, no. 8, pp. 1834-1847, Aug. 2019, doi: 10.1109/TMC.2018.2869863.
- [28] S. H. Y. Wong, Y. Lin, Q. Yin, and S. Mao, "Advances in IEEE 802.11ax: From Physical Layer to MAC Layer," *IEEE Network*, vol. 33, no. 4, pp. 6-11, July/August 2019, doi: 10.1109/MNET.2019.1800357.
- [29] S. Kutty and D. Sen, "Beamforming for Millimeter Wave Communications: An Inclusive Survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 949-973, Secondquarter 2016, doi: 10.1109/COMST.2015.2504600.
- [30] I. Ahmed et al., "A Survey on Hybrid Beamforming Techniques in 5G: Architecture and System Model Perspectives," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, pp. 3060-3097, Fourthquarter 2018, doi: 10.1109/COMST.2018.2843719.
- [31] J. Zhang, E. Björnson, M. Matthaiou, D. W. K. Ng, H. Yang, and D. J. Love, "Prospective Multiple Antenna Technologies for Beyond 5G," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 8, pp. 1637-1660, Aug. 2020, doi: 10.1109/JSAC.2020.3000826.
- [32] K. Yano and Y. Suzuki, "Wearable Beamforming for Millimeter-Wave MIMO Applications," *IEEE Access*, vol. 8, pp. 68312-68324, 2020, doi: 10.1109/ACCESS.2020.2985817.
- [33] Y. Zhang, J. Zhang, M. Jiang, and H. Wu, "Hybrid Precoding for Wideband Millimeter Wave MIMO Systems with Finite-Alphabet Inputs," *IEEE Transactions on Wireless Communications*, vol. 19, no. 3, pp. 1956-1970, March 2020, doi: 10.1109/TWC.2019.2960025.
- [34] B. Wang, F. Gao, S. Jin, H. Lin, and G. Y. Li, "Spatial- and Frequency-Wideband Effects in Millimeter-Wave Massive MIMO Systems," *IEEE Transactions on Signal Processing*, vol. 66, no. 13, pp. 3393-3406, July 2018, doi: 10.1109/TSP.2018.2831628.
- [35] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for Next Generation Wireless Systems," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186-195, February 2014, doi: 10.1109/MCOM.2014.6736761.
- [36] J. Hoydis, S. ten Brink, and M. Debbah, "Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need?" *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 2, pp. 160-171, February 2013, doi: 10.1109/JSAC.2013.130205.
- [37] F. Rusek et al., "Scaling Up MIMO: Opportunities and Challenges with Very Large Arrays," *IEEE Signal Processing Magazine*, vol. 30, no. 1, pp. 40-60, Jan. 2013, doi: 10.1109/MSP.2011.2178495.
- [38] X. Li, S. Jin, X. Gao, and R. W. Heath Jr., "Three-Dimensional Beamforming for Large-Scale FD-MIMO Systems Exploiting Statistical Channel State Information," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 11, pp. 8992-9005, Nov. 2016, doi: 10.1109/TVT.2016.2516910.
- [39] C.-X. Wang, J. Bian, J. Sun, W. Zhang, and M. Zhang, "A Survey of 5G Channel Measurements and Models," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, pp. 3142-3168, Fourthquarter 2018, doi: 10.1109/COMST.2018.2862141.
- [40] S. Dang, O. Amin, B. Shihada, and M.-S. Alouini, "What Should 6G Be?" *Nature Electronics*, vol. 3, no. 1, pp. 20-29, 2020, doi: 10.1038/s41928-019-0355-6.
- [41] A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," *IEEE Access*, vol. 3, pp. 1206-1232, 2015, doi: 10.1109/ACCESS.2015.2461602.
- [42] S. Hu, F. Rusek, and O. Edfors, "Beyond Massive MIMO: The Potential of Data Transmission with Large Intelligent Surfaces," *IEEE Transactions on Signal Processing*, vol. 66, no. 10, pp. 2746-2758, May 2018, doi: 10.1109/TSP.2018.2816577.
- [43] E. Khorov, I. Levitsky, and I. F. Akyildiz, "Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7," *IEEE Access*, vol. 8, pp. 88664-88688, 2020, doi: 10.1109/ACCESS.2020.2993448.
- [44] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," *IEEE Communications Magazine*, vol. 58, no. 3, pp. 55-61, March 2020, doi: 10.1109/MCOM.001.1900411.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details