A Quantum Leap Revisited: **Wi-Fi 8's Year of Progress**

This paper presents a review of Wi-Fi 8’s development over the last year, focusing on technological advancements and their implications for future connectivity.

by
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Abstract

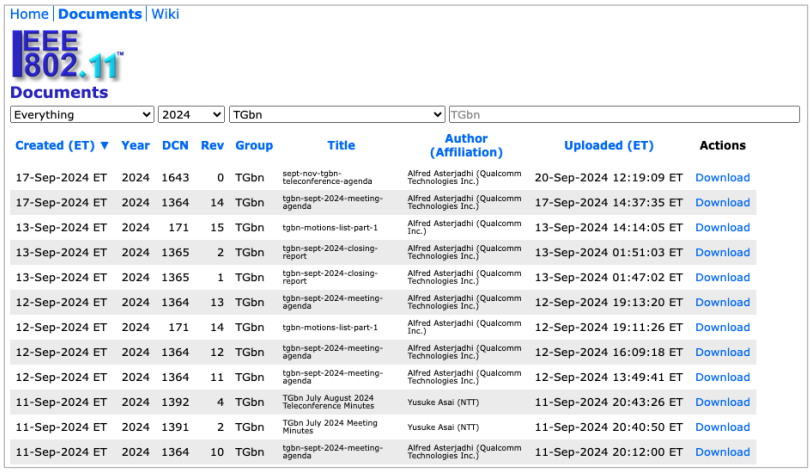
This white paper presents a comprehensive analysis of the Wi-Fi 8 (IEEE 802.11bn) standard over the past year, from September 2023 to September 2024. Our ongoing research on Wi-Fi 8 has deepened our understanding of its features, applications, and the challenges it addresses within the evolving landscape of wireless communication. This updated analysis builds on our prior work, where we discussed initial developments in Wi-Fi 8 and identified key players in the patent landscape. This paper highlights new features discussed in recent IEEE meetings, recent innovations, and emerging challenges, ultimately paving the way for future research directions.

Introduction

As the demand for faster and more reliable wireless communication intensifies, the development of new Wi-Fi standards has become paramount. Wi-Fi 8, or IEEE 802.11bn, is the latest iteration aimed at delivering ultra-high reliability (UHR) and enhanced performance across diverse applications. In our last research (available here), we explored the initial discussions within the IEEE meetings, identified pioneering companies in the patent race, and examined applications found in relevant patents. This paper aims to expand upon that foundation, providing insights into new features, applications, challenges, and the key players in the Wi-Fi 8 ecosystem.

Research Methodology

To stay updated on Wi-Fi 8 developments, we systematically explored the IEEE 802.11 website, focusing on group updates and the Task Group bn (Wi-Fi 8 task group) details. We closely followed the discussions and technical submissions presented during the task group meetings, which provided valuable insights shaping the standard.



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Created (ET) ▼	Year	DCN	Rev	Group	Title	Author (Affiliation)	Uploaded (ET)	Actions
17-Sep-2024 ET	2024	1643	0	TGbn	sept-nov-tgbn-teleconference-agenda	Alfred Asterjadhi (Qualcomm Technologies Inc.)	20-Sep-2024 12:19:09 ET	Download
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(Source: IEEE802.11 Documents)

Key Developments and IEEE Task Group Meetings

Over the past year, several significant IEEE 802.11bn task group meetings have taken place, yielding numerous technical submissions and insights into the evolving features of Wi-Fi 8:

1. **Task Group Meeting (March 2024 - Denver, Colorado, USA)**: Over **45 technical submissions** were discussed, focusing on topics such as multi-AP coordination, LDPC, coexistence strategies, and feedback mechanisms.

2. **Task Group Meeting (May 2024 - Warsaw, Poland)**: This meeting saw over **50 technical submissions** covering topics like MIMO, range extension, and power-saving techniques.

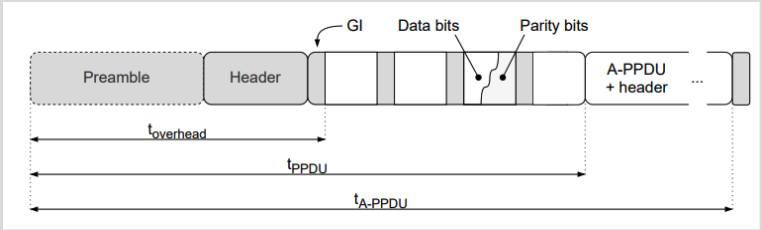
3. **Task Group Meeting (July 2024 - Montreal, Canada)**: The group examined around **80 submissions,** emphasizing advancements in UEQM (Unequal modulation), control frame design, and low latency.

The technical submissions and discussions from these IEEE 802.11bn task group meetings have not only refined the framework of Wi-Fi 8 but have also driven its distinctive technological leaps. From innovations in multi-AP coordination to breakthroughs in MIMO and low-latency performance, these developments are critical in making Wi-Fi 8 a standout advancement in wireless connectivity. As a result, Wi-Fi 8 introduces a series of specialized features aimed at meeting the specific challenges of modern, high-demand applications, from ultra-reliable low-latency communication to enhanced energy efficiency and security measures tailored for next-generation environments. In the next section, we explore these key innovations that set Wi-Fi 8 apart from its predecessors and competitors alike.

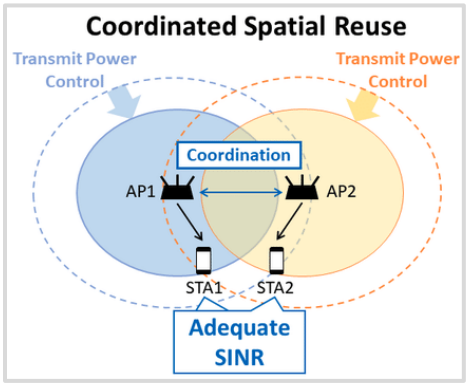
Potential Features of Wi-Fi 8

The following potential key features are critical in shaping the advancements of the next generation of wireless communication, driving improvements in performance, reliability, and efficiency:

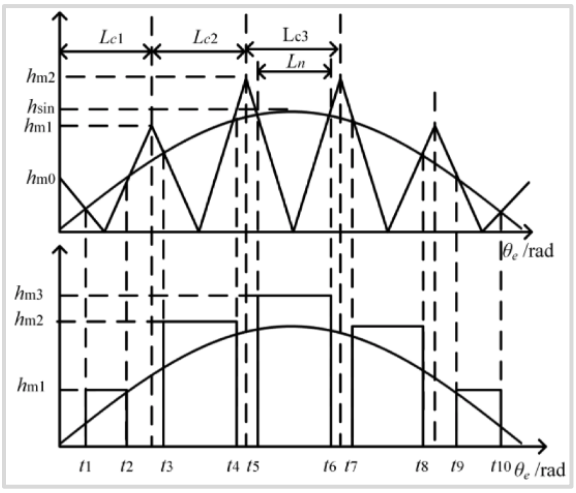
- **Aggregated PPDU (A-PPDU):** The Aggregated PPDU (Protocol Data Unit) is a key concept in modern wireless communication standards. It represents an advanced method to enhance the efficiency of data transmission by combining multiple PPDUs into a single, larger transmission unit.



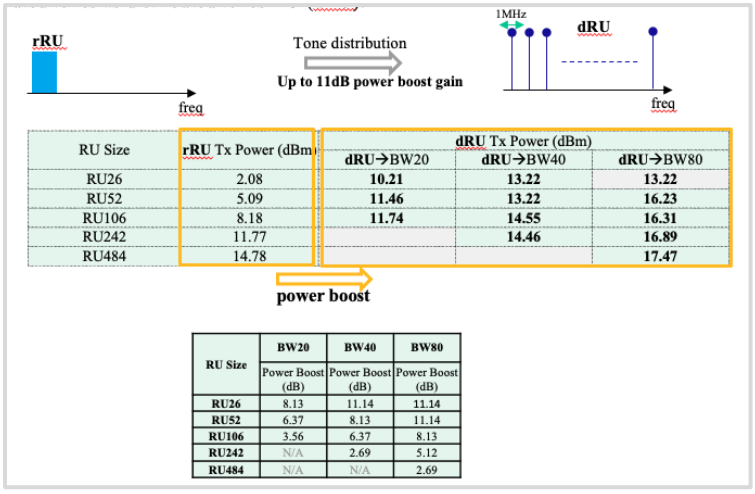
- **Coordinated spatial reuse (CSR):** Coordinated Spatial Reuse (CSR) is a cutting-edge technique in wireless communication designed to enhance the efficiency and capacity of networks by allowing multiple devices to use the same frequency spectrum simultaneously in a coordinated manner.



- **Unequal modulation:** Unequal modulation is an advanced communication technique that assigns different modulation schemes to different portions of a transmitted signal. This approach can enhance the efficiency and performance of wireless communication systems by optimizing the use of available bandwidth and power resources.



- **Distributed tone resource unit:** The Distributed Tone Resource Unit (DTRU) is a technique used to improve the flexibility and efficiency of spectrum allocation in OFDMA-based systems.



RU Size	rRU Tx Power (dBm)	dRU Tx Power (dBm)		
		dRU→BW20	dRU→BW40	dRU→BW80
RU26	2.08	**10.21**	**13.22**	**13.22**
RU52	5.09	**11.46**	**13.22**	**16.23**
RU106	8.18	**11.74**	**14.55**	**16.31**
RU242	11.77		**14.46**	**16.89**
RU484	14.78			**17.47**

power boost

RU Size	BW20	BW40	BW80
	Power Boost (dB)	Power Boost (dB)	Power Boost (dB)
RU26	8.13	11.14	11.14
RU52	6.37	8.13	11.14
RU106	3.56	6.37	8.13
RU242	N/A	2.69	5.12
RU484	N/A	N/A	2.69

- **Non-primary channel access (NPCA):** Non-primary channel access refers to a mechanism in wireless communication systems where devices can utilize additional channels beyond their primary operating channel to enhance performance. This concept is particularly relevant in modern Wi-Fi standards, such as Wi-Fi 6 (802.11ax) and the upcoming Wi-Fi 7 (802.11be), which aim to increase throughput, reduce latency, and improve spectrum efficiency.

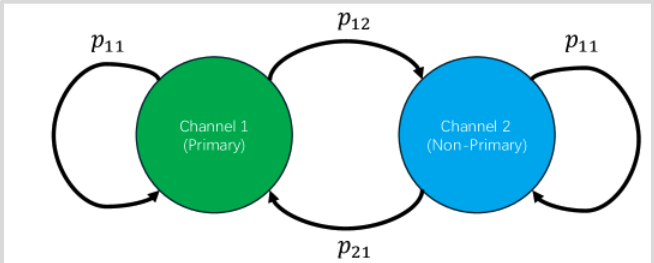
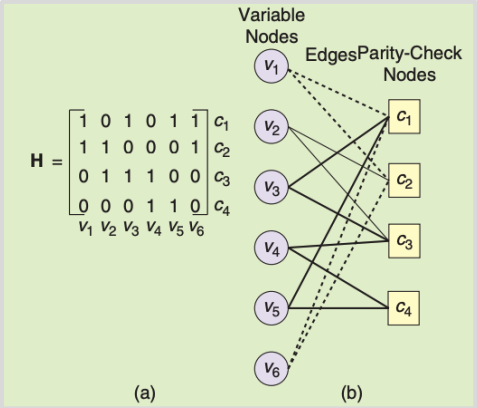


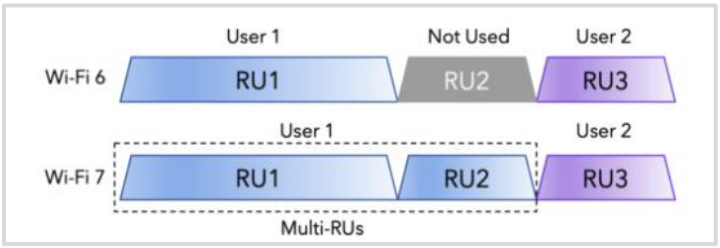
Figure 4: The State Machine Transition Probability Distribution.

Ch2	Occupied	Occupied	Idle	Idle
Ch1	Occupied	Idle	Occupied	Idle
Prob	$p_1 p_2$	$(1-p_1)p_2$	$p_1(1-p_2)$	$(1-p_1)(1-p_2)$

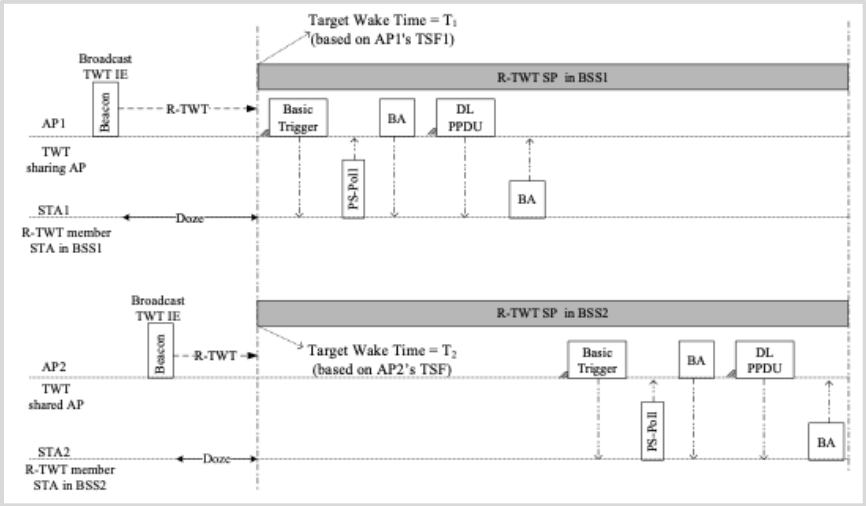
- **Low density parity check (LDPC):** Low-Density Parity-Check (LDPC) codes are a class of linear error-correcting codes that are widely used in modern communication systems. They are particularly effective in correcting errors in data transmission.



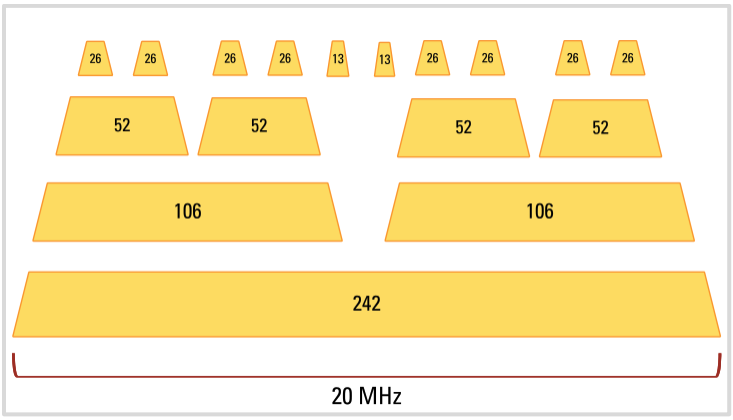
- **Multi-Resource unit (MRU):** A Multi-Resource Unit (MRU) is a flexible resource allocation mechanism that enables the simultaneous use of multiple resources—such as frequency channels, time slots, and spatial streams—by a single user or a group of users.



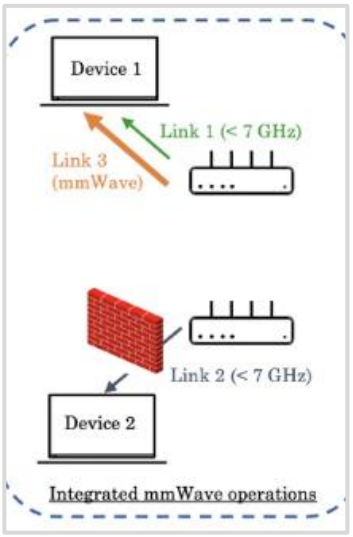
- **Coordinated restricted target wake time (CR-TWT):** Coordinated Restricted Target Wake Time (CR-TWT or C-TWT) is an advanced feature that addresses these needs by allowing devices to wake up and communicate in a coordinated manner, reducing power consumption and improving overall network performance.



- **Regular resource unit (RRU):** These are the standard sizes of RUs defined in Wi-Fi 6. They are typically used in regular operating conditions and are designed to provide a balance between performance and complexity.



- **Integrated mm-Wave Operations:** Integrated mmWave operation in Wi-Fi 8 refers to the seamless combination of millimeter-wave frequencies with lower frequency bands to optimize performance, enabling high-speed, low-latency communication while dynamically adjusting to varying network conditions.

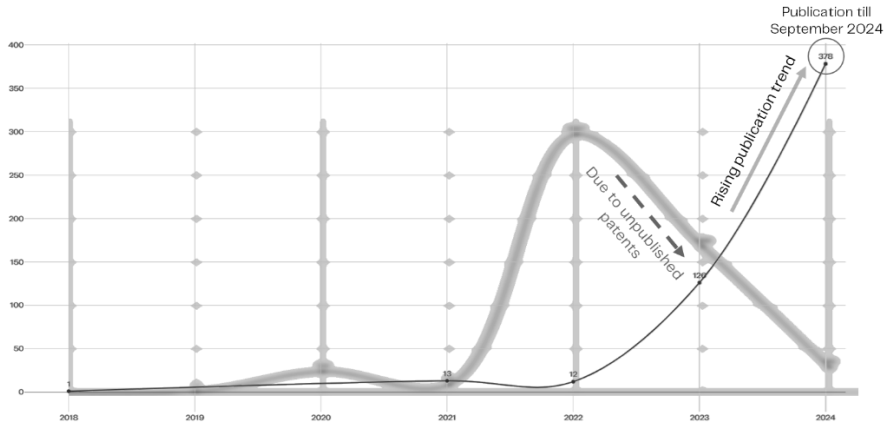


The technical advancements in Wi-Fi 8, such as Aggregated PPDU, Unequal Modulation, and Coordinated Spatial Reuse, have not only transformed wireless communication capabilities but have also spurred a wave of innovation reflected in recent patent filings. Companies and research institutions across the globe are actively seeking to protect their IP related to these cutting-edge features and their applications. In the next section, we observe the patent landscape surrounding Wi-Fi 8, analyzing the patents filed for specific technologies, addressing real-world challenges, and exploring the leading companies driving this innovation.

Our analysis delves into the patent activity across key areas, highlighting trends in applications like low-latency communication, energy efficiency, and enhanced security protocols. We also address the challenges identified through these filings, such as signaling overhead, hidden node problem, and large bandwidth requirements, and how patented solutions aim to tackle these issues.

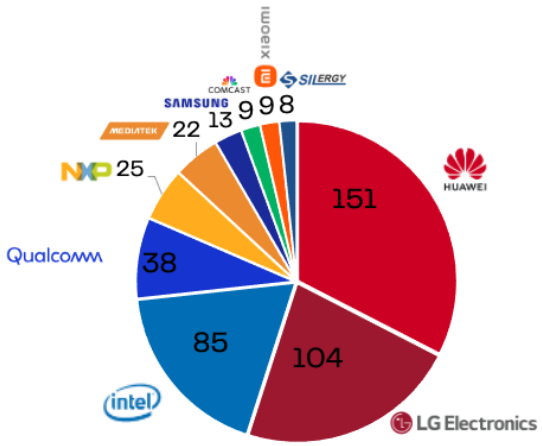
Evolving Patent Activity in Wi-Fi 8

Since our last analysis of Wi-Fi 8 in October 2023, around 476 new patent families have been published, raising the total to 530. This surge in filings aligns with the establishment of the TGbn (Wi-Fi 8 Task Group) in November 2023, indicating the growing innovation and increased focus on securing intellectual property as the standard continues to evolve.



(Chart: Patent filing and publication trends)

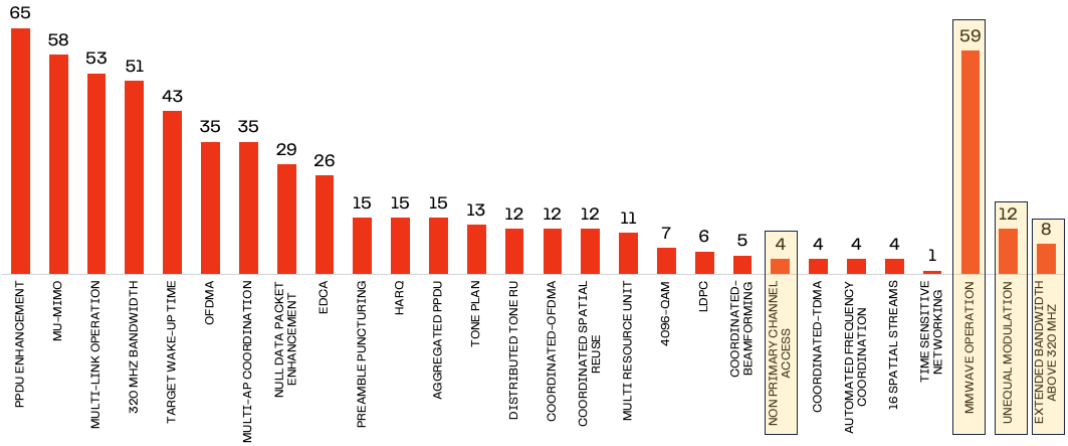
In our earlier analysis, Intel was emerged as the dominant player in the Wi-Fi 8 patent landscape, holding the highest number of patents. MediaTek and Huawei followed, though their patent portfolios were significantly smaller in comparison. However, the latest analysis reveals a notable shift in this landscape. Huawei has now surpassed Intel, emerging as the top player in Wi-Fi 8 patent filings, while Intel has dropped to third. Additionally, LG Electronics has risen as a key player. This evolution reflects the dynamic and competitive nature of the industry, where continuous innovation and strategic efforts are essential for maintaining leadership.



(Chart: Patent filing and publication trends)

From Broad Insights to Specific Innovations: A Closer Look at Wi-Fi 8's Key Feature focused in the Patents

With the notable changes in the patent landscape, it becomes essential to take a closer look at the specific technological areas propelling these advancements. This section delves into the patents linked to Wi-Fi 8's standout features, addressing the key challenges and practical applications they target. By exploring these emerging technologies, we gain valuable insights into Wi-Fi 8's future direction and the shifting dynamics of competition within the industry.



(Chart: Major focused features of Wi-Fi 8)

In this analysis, several key features of Wi-Fi 8 are emerging. Earlier evaluations highlighted unique advancements such as mmWave operations and the expansion of bandwidth beyond 320 MHz. Features such as MU-MIMO (Multi-User Multiple Input Multiple Output), 320 MHz bandwidth, and an optimized tone plan were frequently patented, each representing significant improvements over prior Wi-Fi standards.

In the latest analysis, additional features such as unequal modulation and non-primary channel access have gained prominence alongside previously noted technologies like mmWave operations and extended bandwidth. The most frequently patented features now include advancements in MU-MIMO, PPDU (Physical Protocol Data Unit) enhancements, and multi-link operation, all of which represent continued innovation to boost Wi-Fi performance, efficiency, and capacity compared to earlier standards.

Patent holders of Wi-Fi 8’s unique features

Continuing from our analysis of Wi-Fi 8’s key advancements, this section will spotlight the unique features of the Wi-Fi 8 standard and the companies that hold patents on these innovations. By examining the patent ownership of these breakthroughs, we can gain a clearer understanding of the technological developments propelling Wi-Fi 8 forward and the leading players at the forefront of its evolution.

Unequal modulation:

5 patent families	3 patent families	1 patent family	1 patent family

MM wave operation:

26 patent families

8 patent families

5 patent families

4 patent families

Extended bandwidth above 320 MHz:

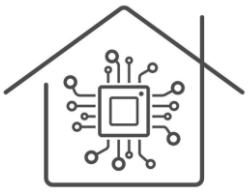
4 patent families

2 patents families

Applications and Use Cases of Wi-Fi 8

Building on our exploration of the unique features and key patent holders of Wi-Fi 8, this section will delve into how these advancements are being utilized across various industries, showcasing the transformative impact of Wi-Fi 8 on communication, connectivity, and overall user experience.

- **Intelligent / Smart home:** Improved performance for smart home systems, including security systems, smart appliances, and home automation.



- **Intelligent / Smart cities:** Better management of public services with connected infrastructure and improved traffic management, public safety systems, and environmental monitoring.

- **Gaming:** Ultra-low latency and high-speed connections for cloud gaming and eSports, enhanced VR/AR gaming experiences.

- **Smart office:** Smart offices can take advantage of higher speeds, lower latency, and better connectivity to enhance various aspects of office operations.

- **Remote surgery:** Wi-Fi 8, with its superior speed, low latency, and enhanced reliability, can significantly advance the capabilities and safety of remote surgery.

- **Connected vehicle:** Connected vehicles, which utilize advanced communication technologies to exchange data with other vehicles, infrastructure,

and the cloud, stand to benefit significantly from the enhancements offered by Wi-Fi 8. This next-generation Wi-Fi technology can support a variety of applications that improve safety, efficiency, and convenience on the road.

- **Smart automotive:** The concept of "smart automotive" refers to vehicles that are equipped with advanced technologies to enhance safety, efficiency, and the overall driving experience. Wi-Fi 8, with its improved speed, low latency, and high reliability, can play a crucial role in enabling various smart automotive applications.

- **Remote controlled devices:** Remote-controlled devices encompass a wide range of applications, from industrial machinery and home automation to drones and medical equipment. Wi-Fi 8, with its advanced capabilities, can significantly enhance the performance and functionality of these devices.

- **Industrial IOT (IIOT):** WiFi 8's advancements in speed, capacity, security, and coverage make it a powerful enabler for Industrial IoT applications. It allows industries to harness the full potential of IIoT, driving efficiency and productivity.

Addressing Key Challenges

Following our exploration of Wi-Fi 8 applications and use cases, it is essential to consider the specific challenges that these patents aim to resolve. This section will highlight the critical issues identified in the Wi-Fi 8 ecosystem and how the patented innovations are designed to overcome them. By understanding the problems addressed by these patents, we can gain a clearer picture of the technology's potential to enhance connectivity and performance in various scenarios.

- **Signaling overhead:** Signaling overhead is a necessary but often problematic aspect of network communication. By consuming bandwidth, increasing latency, causing congestion, draining energy, complicating management, and potentially exposing security vulnerabilities, it can significantly impact network performance and efficiency.
- **Hidden node problem:** Hidden node problem (or hidden terminal problem) is a phenomenon in wireless communication where a node is unable to detect a potential collision because it is "hidden" from another node with which it shares a common receiver. This problem typically occurs in environments where multiple wireless nodes are communicating with a single access point or within an ad-hoc network.

- **Large bandwidth requirement:** WiFi-8 addresses large bandwidth requirement problem through wider channel bandwidths, use of higher frequency bands, efficient spectrum utilization, advanced modulation and coding schemes, and technologies like beamforming and MU-MIMO.
- **Data loss:** The data loss problem in WiFi-8 is addressed through a combination of advanced technologies and techniques designed to enhance the reliability and efficiency of wireless communication.
- **High power consumption:** WiFi-8 introduces several advanced features and capabilities that, while enhancing network efficiency and performance, can also lead to higher power consumption.
- **Signal Collision:** Signal collisions present a significant challenge for Wi-Fi 8, it occurs when two or more devices attempt to transmit data over the same frequency channel simultaneously. In the context of Wi-Fi networks, this can lead to data packets interfering with each other, causing loss of information, retransmissions, and overall reduced network performance.

Conclusion

This paper provides a detailed exploration of the Wi-Fi 8 (IEEE 802.11bn) standard, emphasizing its innovative features, evolving patent landscape, and its wide-ranging applications. Over the past year, significant strides have been made in understanding Wi-Fi 8's key technological advancements, including mmWave Operations, Coordinated Spatial Reuse, Unequal Modulation, and more. These features are poised to address critical challenges in modern wireless communication by offering unprecedented levels of performance, efficiency, and reliability.

This is just the starting point, and not even Draft 0.1 is out yet, but already a significant number of patents have been filed on this standard. The rapid evolution of its key features—driven by technical submissions in IEEE Task Group meetings—demonstrates the need for continuous research. Patent activity has surged as companies race to secure intellectual property in this competitive domain, indicating the high stakes of the Wi-Fi 8 ecosystem.

Looking ahead, Wi-Fi 8 presents immense potential to tackle critical challenges, particularly in enhancing reliability across diverse network environments. Addressing this aspect is essential for achieving consistent, low-latency communication, energy efficiency, and robust security measures. However, these developments are merely the starting point. As we approach the anticipated finalization of the Wi-Fi 8 standard in 2028, future research must delve deeper into resolving persistent technical issues, including signaling overhead, the hidden node problem, and the substantial bandwidth requirements—while continuing to push the boundaries of reliability across various applications.

In summary, this paper lays the foundation for grasping the current state and future trajectory of Wi-Fi 8. The journey has only just begun, with vast opportunities for exploration ahead. Our ongoing research seeks to enhance our understanding of this technology and monitor its evolving innovations. **Stay tuned for thrilling updates on Wi-Fi 8—who knows what groundbreaking advancements are just around the corner?**

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