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Patent Landscape and Essentiality Analysis of Beamforming Patents with Wi-Fi 6 Standard.

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1. Introduction

Wi-Fi, short for "Wireless Fidelity," is a technology that allows devices to connect to the internet or communicate wirelessly within a network using radio waves. Developed based on IEEE 802.11 standards, Wi-Fi has evolved over the years to accommodate increasing demand for **speed, reliability, and support** for numerous connected devices. Wi-Fi networks are widely used in homes, offices, and public spaces, enabling seamless internet access for various devices, from smartphones and laptops to smart appliances and IoT systems.

1.1 Wi-Fi 6

Wi-Fi 6, also known as 802.11ax, represents the sixth generation of Wi-Fi standards, offering significant improvements over the predecessor, Wi-Fi 5 (802.11ac). Released in 2019, Wi-Fi 6 is designed to operate in high-density environments and also improve performance and efficiency. Wi-Fi 6 introduces advanced technologies such as Orthogonal Frequency Division Multiple Access (OFDMA), 1024-QAM modulation, Target Wake Time (TWT), and improved Multiple-Input Multiple-Output (MIMO) support. These enhancements enable Wi-Fi 6 to deliver faster speeds, lower latency, and more reliable connections, particularly in environments with many connected devices. The adoption of Wi-Fi 6 has fueled growth in applications requiring **high throughput and responsiveness**, such as streaming, gaming, and smart home networks, as well as supporting emerging technologies like augmented reality (AR) and IoT. The IEEE published the standard for Wi-Fi 6, officially known as IEEE 802.11ax, in February 2021.

1.2 Beamforming

Beamforming is a signal processing technique used in wireless communication to focus a signal in a specific direction, rather than broadcasting it equally in all directions. This directional transmission improves signal strength, extends range, and enhances data rates, making it an **essential technology in modern wireless standards** like Wi-Fi and mobile communications. By adjusting the phase and amplitude of signals from multiple antennas, beamforming enables precise targeting of devices, reducing interference and optimizing network efficiency.

1.2.1 Beamforming in Wi-Fi 6

The focused beamforming signal improves both the strength and efficiency of the connection, reducing interference and delivering a faster, more reliable Wi-Fi experience. Beamforming is particularly helpful in dense environments where multiple devices compete for bandwidth, as it allows the router to direct its signal more precisely, enhancing coverage and reducing wasted energy.

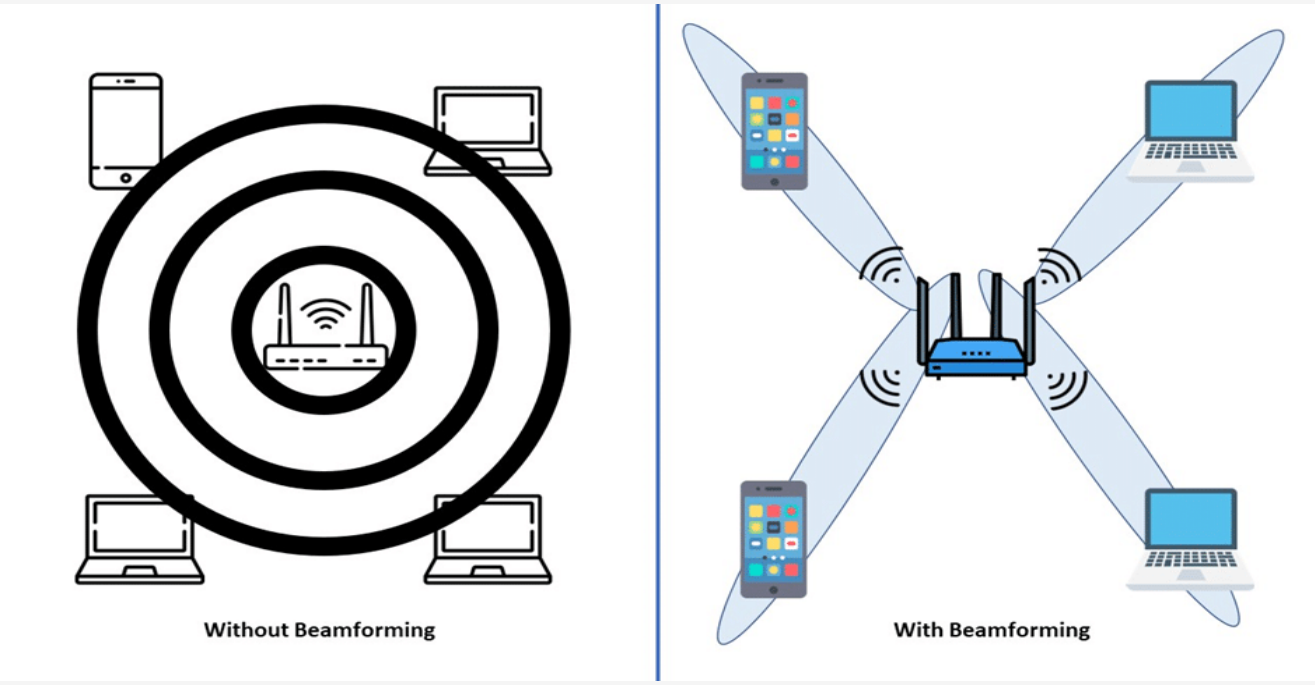

Figure 1: Comparison of Signal Transmission with and without Beamforming

Figure 1 demonstrates how beamforming optimizes signal transmission. This focused signal pathway results in stronger, more stable connections with minimal interference. Without beamforming, data transmission is spread broadly, causing signals to weaken and reducing overall efficiency. In contrast, beamforming ensures that signals are **concentrated on connected devices**, improving signal quality, and enhancing data transfer rates.

In Wi-Fi 6, beamforming is carried out through the High-Efficiency (HE) Sounding Protocol, a key process that enables the access point (the HE beamformer) to direct signals toward specific devices (STAs) with precision. For effective beamforming, the HE beamformer needs detailed information about the wireless channel conditions, which is provided through a process called channel state information (CSI) feedback. This feedback helps the beamformer adjust its signal paths to optimize connectivity.

To gather this channel information, Wi-Fi 6 uses two methods within the HE Sounding Protocol: non-trigger-based (non-TB) sounding and trigger-based (TB) sounding.

Non-Trigger-Based (Non-TB) Sounding: In this method, the HE beamformer sends a special training signal called an HE sounding null data packet (NDP) to the device (the HE beamformee). This signal allows the beamformee to analyze the channel and send back a compressed report of the channel state. The beamformer uses this feedback to form a steering matrix, which calculates the best transmission path to improve the focus and strength of the signal.

Trigger-Based (TB) Sounding: This approach is more flexible, allowing the HE beamformer to request specific types of feedback based on network needs. There are three main types of feedback:

Single-User (SU) Feedback: Used when the beamforming is directed toward a single device, with the device sending back data on the channel for the beamformer to optimize the single-user connection.

Multi-User (MU) Feedback: Supports multiple devices simultaneously, with the beamformer receiving separate channel state information for each device to optimize signals in a multi-user setting.

Channel Quality Indicator (CQI) Feedback: Provides information on overall channel quality, which helps in managing resource allocation and improving signal focus for all devices.

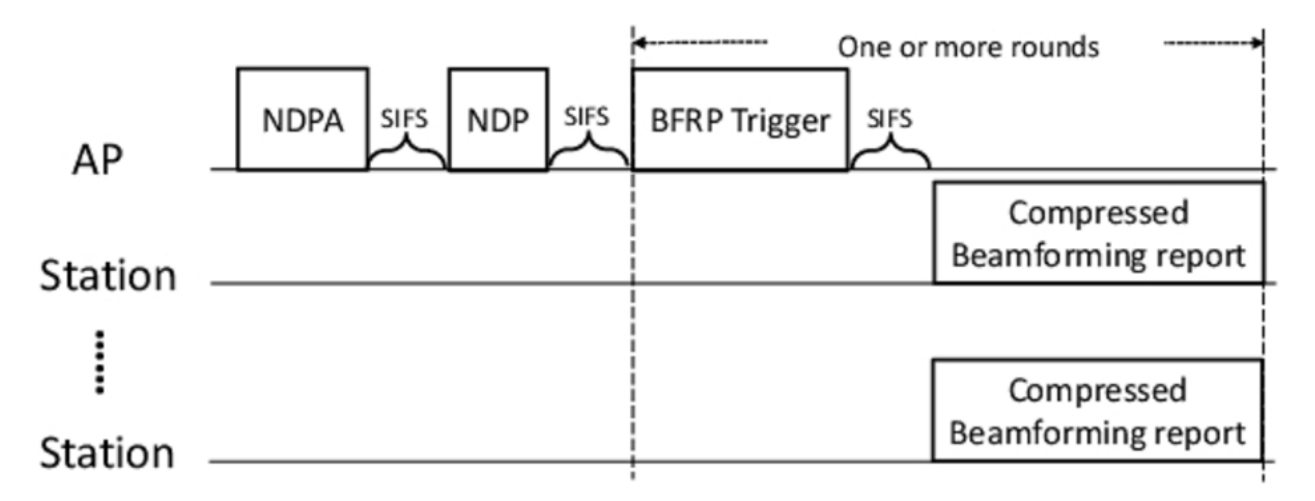

Figure 2:Channel sounding in MU-case

An example of an HE TB sounding sequence with more than one HE beamformee is shown in Figure 2.

The HE beamformer initiates the sounding process by sending an HE NDP Announcement frame to connected devices, followed by an HE Sounding NDP signal after a Short Inter-frame Space (SIFS) interval. Devices (beamformees) then measure the channel state and return a compressed feedback report to the beamformer. This feedback enables the beamformer to calculate a steering matrix, directing signals precisely to each device and enhancing connection strength and efficiency across the network.

In Wi-Fi 6, SU-MIMO and DL MU-MIMO beamforming enhances signal delivery by directing signals more precisely, based on channel information. SU-MIMO beamforming targets a single device, while DL MU-MIMO divides the transmission into subsets for different devices within a resource unit (RU) with at least 106 tones.

For both types, the received signal is modeled using channel, steering, and noise matrices, adapting based on beamforming feedback. This feedback is provided as a compressed matrix of angles from each device (beamformee) and helps calculate the steering matrix, which guides future transmissions. Feedback also includes CQI (Channel Quality Indicator) values derived from SNR to optimize RU selection and assignment for efficient multi-user communication. The steering matrix computation is specific to the implementation but is aimed at minimizing interference across users.

1.2.2 Commonalities between 5G and Wi-Fi 6 w.r.t. beamforming

Beamforming in Wi-Fi 6 and 5G networks shares the core concept of focusing a wireless signal towards a specific device or user to improve data rates, coverage, and overall connection quality. Both 5G and Wi-Fi 6 use phased array antennas to electronically control signal direction, achieving targeted coverage in crowded areas. A critical component of this process is CSI, which provides real-time feedback on channel conditions. CSI enables dynamic adjustments to beam patterns, refining signal quality and network reliability. In 5G, CSI is continuously collected from user equipment to optimize beamforming for changing conditions, such as user movement or obstacles. This includes various feedback types, such as CQI and Precoding Matrix Indicators (PMI), which tune transmissions to maintain high data rates, reliable coverage, and low latency in dense environments. Wi-Fi 6 also uses CSI to fine-tune beamforming, allowing routers to deliver focused, interference-minimized signals to connected devices. This is especially effective in crowded indoor spaces, where CSI enables better resource allocation and performance for multiple active users or devices.

There are significant differences between the beamforming used in Wi-Fi 6 and 5G, particularly in terms of frequency bands, beamforming types, precision, and more. The first major difference lies in the frequency band of operation. Wi-Fi 6 primarily operates in the 2.4 GHz, 5 GHz, and newly added 6 GHz bands (for Wi-Fi 6E). These frequencies are relatively lower and are better suited for shorter-range communication within indoor environments. In contrast, 5G spans a much broader frequency range, including low-band (sub-1 GHz), mid-band (1 GHz to 6 GHz), and high-band frequencies (millimeter-wave) above 24 GHz. The high-frequency bands in 5G, especially millimeter waves, present unique challenges, requiring advanced beamforming techniques to maintain strong and reliable connections over long distances.

Another notable difference lies in the beamforming techniques each technology uses. Wi-Fi 6 relies on *SU-MIMO* and *MU-MIMO* to improve network efficiency by directing signals to specific devices. MU-MIMO in Wi-Fi 6 supports up to eight users simultaneously, reducing interference and enhancing data flow. In contrast, 5G employs *Massive MIMO*, which is a more complex, large-scale approach to beamforming. This method uses hundreds of antennas to steer beams toward multiple users at once, an essential capability for handling high-capacity, low-latency demands, particularly in the millimeter-wave bands.

As Wi-Fi 6 operates on lower frequency bands, where precise beamforming is less critical, it uses *explicit beamforming*, where feedback from the receiving device helps optimize signal direction. On the other hand, 5G's higher-frequency bands, especially in mm Wave, require highly accurate beamforming techniques. Advanced methods such as *Angle-of-Arrival (AoA)* and *Angle-of-Departure (AoD)* are used to fine-tune beam direction, maintaining strong connections even in high-mobility conditions.

The distinct differences in beamforming technologies between 5G and Wi-Fi 6 make it impractical to apply 5G beamforming methods directly to Wi-Fi 6 networks, or vice-versa. Each technology operates on unique frequency bands and serves different connectivity needs, requiring **optimized beamforming techniques suited to their specific use cases**. This contrast in design and application highlights the need to carefully differentiate and evaluate patent claims associated with each technology. Thus, separating beamforming patents for Wi-Fi 6 and 5G is crucial, as each system depends on innovations that address unique operational requirements.

2. Beamforming patent analysis

2.1 Methodology on finding beamforming related patents

This report contains information on the patent landscape relating to beamforming. To identify beamforming-related patents, searches were conducted across multiple patent databases, including PATSEER and Espacenet, utilizing a range of search strings, IPC/CPC classifications, and beamforming-specific keywords. Since the Wi-Fi 6 standard was launched in 2021, the upper priority date was set to February 2021.

A total of 363 beamforming-related unique families were identified. The 363 families are held by companies such as Origin Wireless Inc., Qualcomm Inc., Intel Corp., LG, Huawei, NXP Semiconductors Netherlands, Samsung Group, MediaTek Inc., InterDigital Inc., and Atlas Global Technology LLC.

2.2 Shortlisting of Wi-Fi 6 related patents

To identify the patents specifically related to Wi-Fi 6, an in-depth review of each patent from the initial set of 363 families was undertaken. By examining the claims, abstracts, and descriptions in detail, patents relevant to Wi-Fi 6 were accurately identified. This thorough approach narrowed the selection to 135 unique families highlighting key advancements and innovations that directly align with the Wi-Fi 6 standard. Figure 3 shows the distribution of patents related to Wi-Fi 6 by respective assignees.

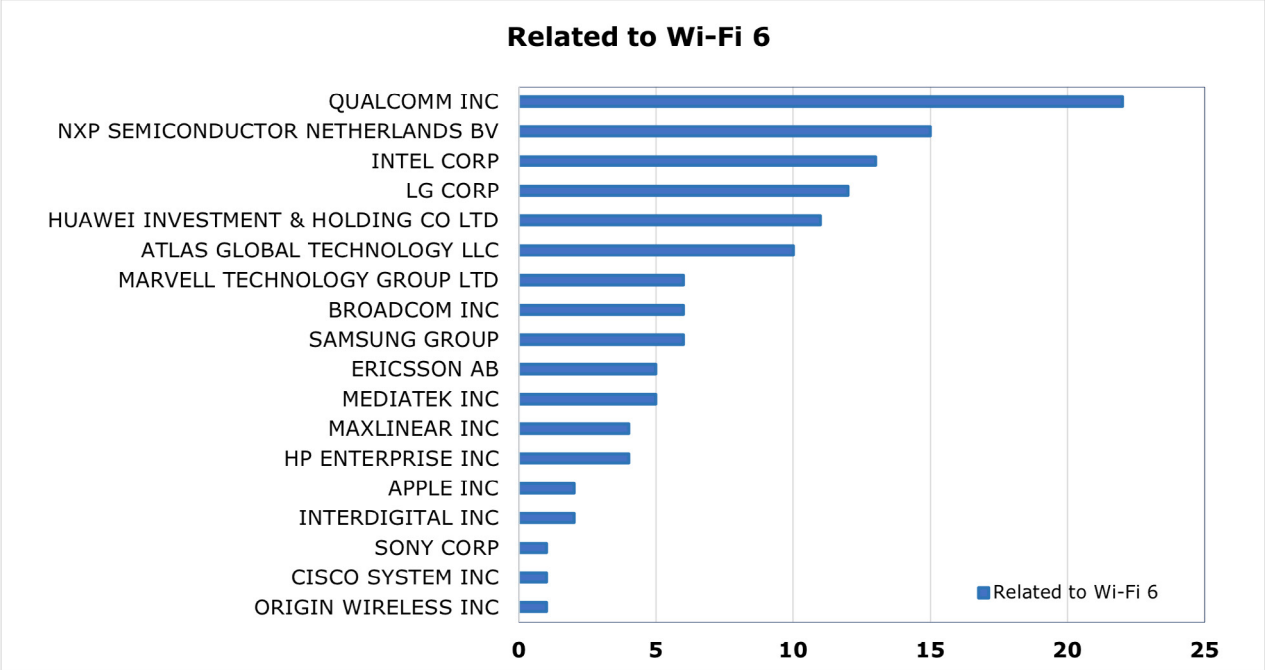

Figure 3: Distribution of Wi-Fi 6 related patents across various assignees

2.3 Filing trend of Wi-Fi 6 beamforming patents

The patent filing trend for Wi-Fi 6 beamforming technology demonstrates a noticeable rise in activity, with a **peak in 2016** when the highest number of filings occurred. This surge reflects heightened interest and innovation in beamforming technology. The consistent number of filings in the years 2016 -2020 show the significance of beamforming in Wi-Fi 6 advancements over the years.

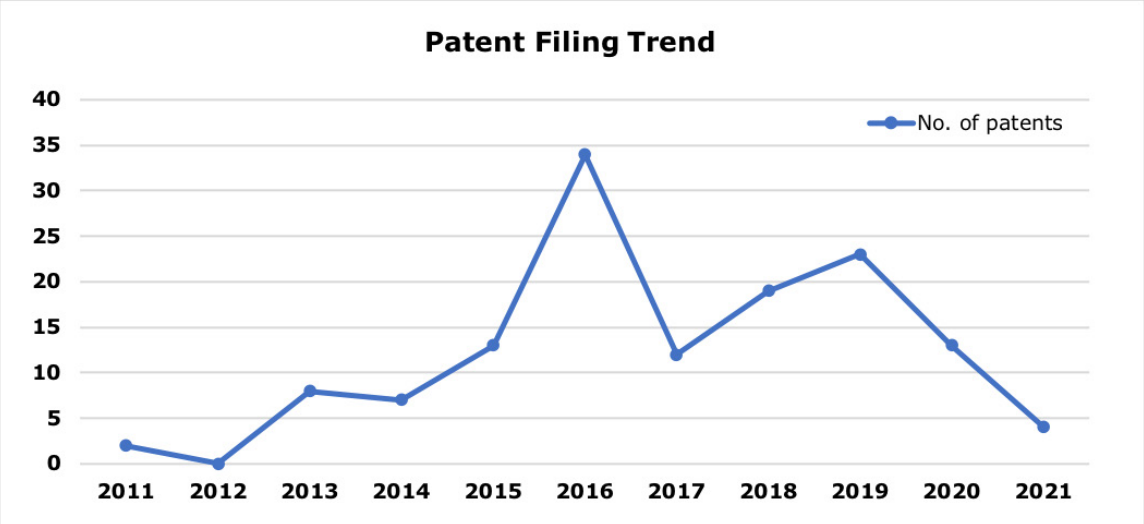

Figure 4: Filing trend of Wi-Fi 6 beamforming patents

2.4 Essentiality Analysis

An essentiality analysis of 135 Wi-Fi 6 related families suggests that there is a probability of approximately 21% (29) being essential, while 79% (106) are likely non-essential as shown in Figure 5.

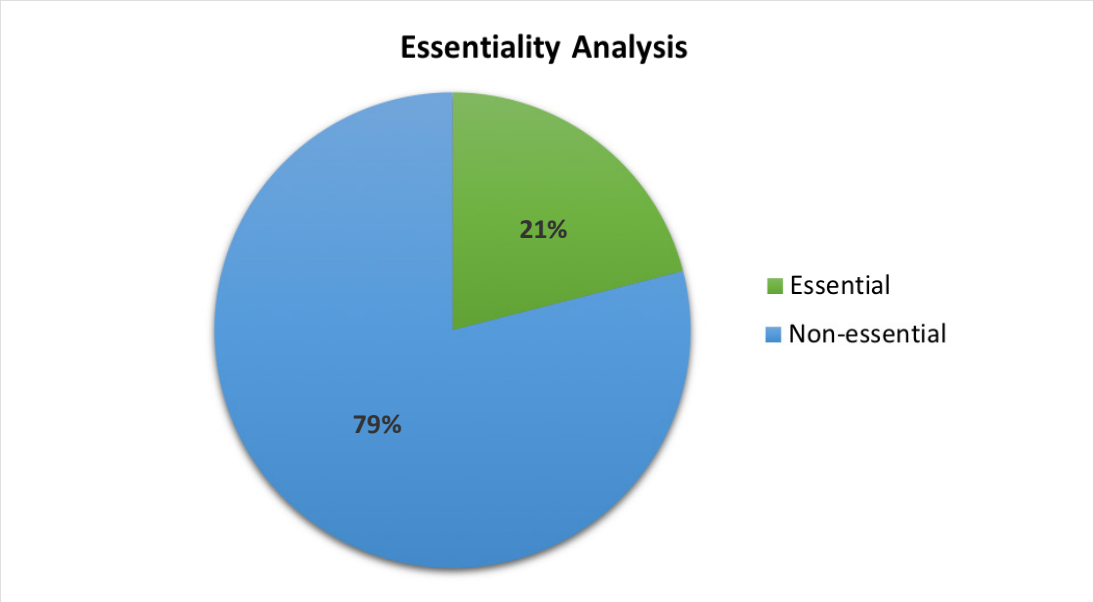

Figure 5: Percentage-wise essentiality analysis of Wi-Fi 6 related beamforming patents

The distribution of essential patents by company is shown in Figure 6. LG Corp holds the highest number of essential patents closely followed by Atlas Global Technology LLC.

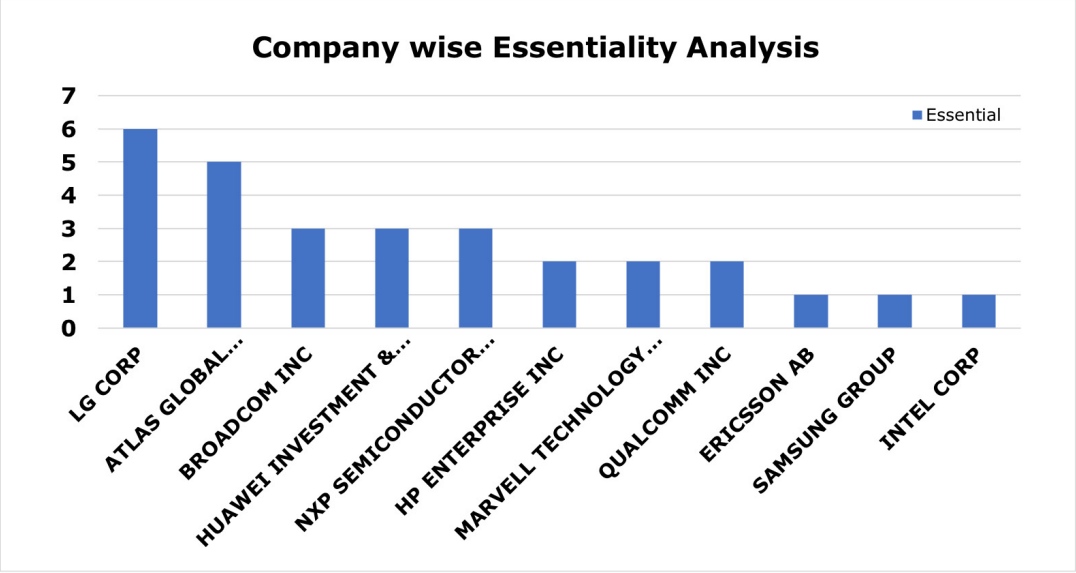

Figure 6: Essentiality analysis of Wi-Fi 6 related beamforming patents across various assignees

3. Wi-Fi 7 Patent Landscape Overview

3.1 Methodology on finding Wi-Fi 7 related patent families

The identification of Wi-Fi 7 related patent families involved a comprehensive search across multiple patent databases using various search strings. Keywords relevant to Wi-Fi 7, such as multi-channel aggregation, 320 MHz channels, multi-band aggregation, 4096 QAM, 4K QAM, multi-link operation, and multi-access point coordination, were applied. A priority date range from 2009 to the present was set to capture the most recent patents.

The analysis identified patent families related to Wi-Fi 7, with major contributions from organizations such as Huawei and MediaTek. Figure 7 illustrates the percentage-based distribution of Wi-Fi 7 patents among these top assignees.

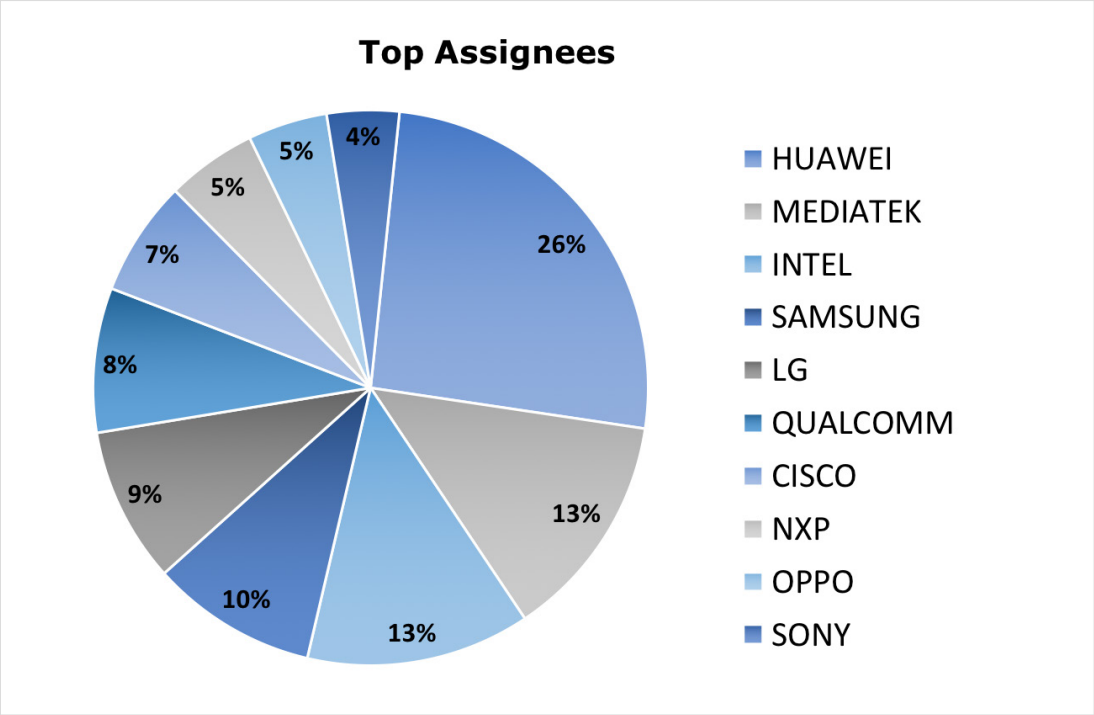

Figure 7: Distribution of Wi-Fi 7 related patents among various assignees

3.2 Filing trend of Wi-Fi 7 patents

Wi-Fi 7 related patent filings have grown significantly in the last five years. Prior to 2010, activity was minimal, but filings have gradually increased with a sharp rise 2021 – 2023. In 2024, filings account for 11.52% so far. The trend reflects the accelerating pace of Wi-Fi 7 research and development as the technology evolves.

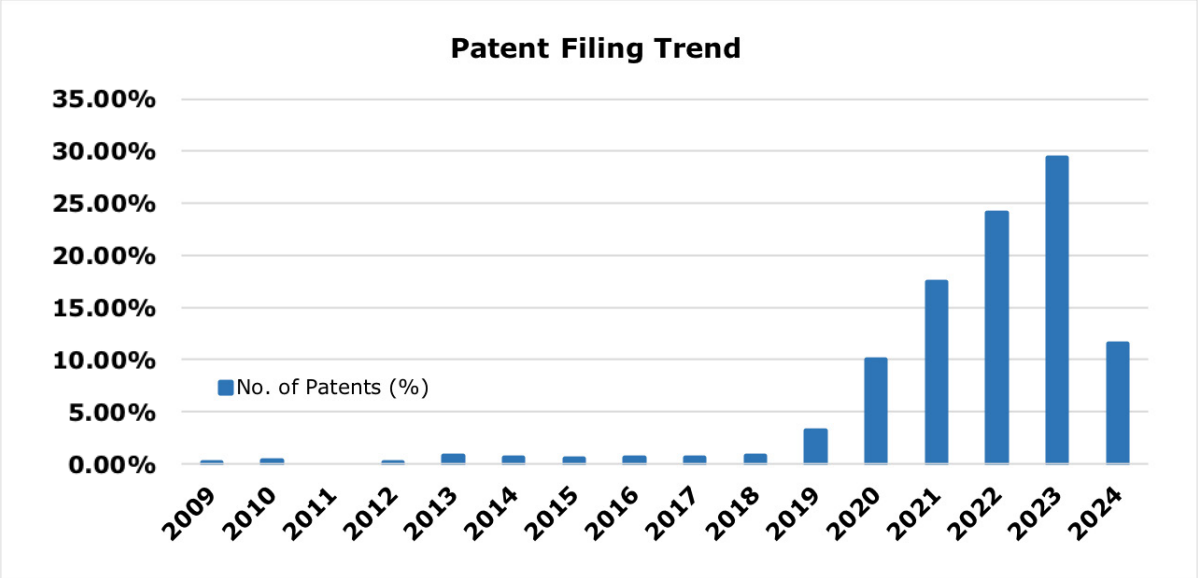

Figure 8: Patent filing trends related to Wi-Fi 7 technology

4. Conclusion

This report provides key insights into the landscape of beamforming-related patents. An extensive search of patent databases identified 363 patents, with 135 deemed directly relevant to Wi-Fi 6. The patent filing trend of beamforming patents in Wi-Fi 6 reveals a peak in activity in 2016, reflecting a **surge of innovation** in beamforming technologies leading up to the standardization of Wi-Fi 6.

Essentiality analysis of 135 Wi-Fi 6 related patents indicates that around 21% of these patents are likely essential to the standard, while the remaining 79% are non-essential.

The distribution of essential patents among leading technology companies highlights the **competitive and targeted nature** of Wi-Fi 6 beamforming.

The future of beamforming, and the patents connected to the technology, are largely correlated to the evolution of the Wi-Fi service. Beamforming efficacy has improved during the Wi-Fi 6 generation, and there is an interdependent relationship insofar as Wi-Fi 6 has increased the number of MU-MIMO users, and this was also made possible by the use of beamforming. One of the main drivers for the overall growth in the Wi-Fi market has been the **rising adoption of the Internet of Things**. As this market continues to expand across the globe and the Wi-Fi standard evolves toward Wi-Fi 7 it can be expected that beamforming will also evolve, most likely toward a **coordinated beamforming technology**, and that the patent landscape will reflect this evolution.

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