6 GHz Spectrum Needs for Wi-Fi 7

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Introduction

There is insufficient license-exempt spectrum in 2.4 GHz and the 5 GHz bands to accommodate the growth in demand with the expected quality of service (QoS) of the current applications (video streaming, gaming, voice, etc.) and, at the same time, to enable new innovative services and usage scenarios that make use of the Wi-Fi network. Therefore, user experience is compromised due to channel congestion. Allocation of the 1200 MHz of contiguous spectrum in the 6 GHz band to license-exempt operation provides sufficient bandwidth such that Wi-Fi 6E and the next generation of Wi-Fi, namely Wi-Fi 7, can benefit from the cleaner, non-overlapping larger channel bandwidths of up to 320 MHz.

This column discusses the expected performance and underlines significant importance of availability of three non-overlapping 320 MHz channels for the development and future deployment of Wi-Fi 7 by analyzing the behavior of a fast-emerging time-sensitive application, namely augmented/virtual reality (AR/VR), which has been moving away from mere entertainment and finding its place in many emerging enterprise and industrial applications.

Wi-Fi 7 Applications and Deployment Scenarios

Building on the success of Wi-Fi 6 (based on IEEE 802.11ax [7]), Wi-Fi 7 (based on IEEE 802.11be [3]) will boast physical layer throughput speeds up to 23 Gb/s through the use of 320-MHz-wide channels, higher-order modulations (4096-QAM, quadrature amplitude modulation), and eight spatial streams, and will operate in license-exempt frequencies up to 7.125 GHz. Wi-Fi 7 will reduce transmission latency and jitter and increase transmission reliability to meet QoS requirements of time-sensitive applications such as AR/VR.

More specifically, video traffic will continue to be the dominant traffic in many Wi-Fi deployments. Emergence of 4k and 8k video (uncompressed rate of 20 Gbps) has underlined these applications' ever- increasing throughput and bandwidth requirements.

Demand for new high-throughput, low-latency applications, such as AR/VR, remote office, cloud computing, and electronic gaming and e-sport, is rapidly increasing. These applications, which are envisaged to be used in a variety of environments, including homes, enterprise, and industrial plants, require enhanced throughput and reliability, reduced latency (e.g., latency lower than 5 ms for real-time gaming) and jitter, and improved power efficiency in Wi-Fi networks [1]. Advanced AR/VR applications require 4k–8k video, minimum throughput of 400–2350 Mb/s, and a maximum streaming/ interactive latency on the order of 10 ms [2, Appendix 3].

Wi-Fi 7 will also define mechanisms that can enable deterministic operation by introducing features that provide predictable latency and jitter. Improved integration with time-sensitive networks (TSNs) to support applications over heterogeneous Ethernet and wireless LANs is targeted in Wi-Fi 7. IEEE 802.11be [3] aims at further improvement of aggregate throughput and latency over these networks in the coming years [4]. Wi-Fi 7 also provides enhanced support for existing indoor/outdoor residential and enterprise deployments while enabling vertical and industrial IoT applications that require an advanced level of determinism and reliability performance.

Analysis of Key Performance Indicators

A key performance indicator (KPI) refers to a system parameter heavily influenced by, and important for, the design of the system. KPI values are indicative of how well the system performs at several levels and are often used in comparison with similar technologies or previous generations of the same technology.

While a variety of KPI categories are important to support various use cases and applications, some of them have direct implications on spectrum requirements (e.g., channel sizes and number of contiguous channels) of Wi-Fi 7. Among those, peak data rate, spectrum efficiency, and low, bounded latency are the most important KPIs in enabling new applications.

The trade-off between throughput and latency/determinism requirements can impact spectrum needs. Emerging applications need lower latency with determinism/reliability as well as high throughput. To provide strict latency guarantees, there is a need to reserve resources for some applications, which may lead to inefficiencies and fewer resources available for other applications. The competition for resources between applications and neighboring networks is a major cause of variable and typically high worst case latencies in current Wi-Fi deployments. Future applications will need both high throughput and latency guarantees, which would be very hard to meet under resource limitation constraints.

Spectrum Needs

Latency, reliability, and determinism have been improved considerably in Wi-Fi 7, along with throughput, to enable time-sensitive applications such as AR/VR, Industrial Internet of Things (IIoT), and high-end electronic gaming.

Emerging applications such as AR/VR, Industry 4.0, and mobile and collaborative robotics require ultra-reliable low-latency communications. Leading to the IEEE 802.11be project kickoff, the IEEE 802.11 Working Group published a study of real-time applications (RTAs) and their requirements [6]. The IEEE 802.11 RTA report described time-sensitive applications that need lower latency with determinism or very high-reliability guarantees, and in some cases also have extremely high throughput requirements. For instance, according to the report, AR/VR applications generally require end-to-end latencies of under 10 ms with 99.9 percent reliability and single-stream throughput of around 100 Mb/s. Such time-sensitive requirements mean that the Wi-Fi 7 induced latency must be as low as possible, stable, and preferably bounded with very high probability. (See [2, Appendix 3] for details).

Provisioning resources with exclusivity is the fundamental tool to guarantee deterministic latency and reliability in any network shared by a range of applications, which are the expected scenarios for Wi-Fi 7 networks. Competition for resources between networks and applications is a major issue that causes variable and typically high worst case latencies observed in existing Wi-Fi deployments. Future applications in Wi-Fi 7 networks will need to address the trade-off between extremely high throughput and deterministic low latency guarantees, which would be very hard to meet simultaneously if there are constraints in spectrum resources. Some of the limitations of the existing spectrum resource models are illustrated in the next section.

Simulation Setup

Simulations are performed for various deployment scenarios with one to three access points (APs) and several client devices communicating with the APs, supporting a mix of traffic, including typical Wi-Fi connectivity and AR/VR streams.

Figure 1 depicts the deployment scenarios being analyzed.

The four scenarios in Fig. 1 are chosen to evaluate the impact of:

1. The number of 320 MHz channels
2. The overlap among 320 MHz channels on the performance of the Wi-Fi 7 system in support of the expected latency as the target KPI

Figure 2 shows the 6 GHz channelization based on IEEE 802.11ax [7] and 802.11be [3] global operating classes. Channelization configurations analyzed in the simulations are depicted in Fig. 3.

In Configuration 1, there is only a single 320 MHz channel available due to limited spectrum availability. This single channel is simulated to be used by a single basic service set (BSS) or shared between two or three BSSs. The 160 MHz channel option is also implemented with this configuration for comparison.

In Configuration 2, there are two 320 MHz channels, used by BSS1 and BSS2, overlapping by 50 percent due to the limited amount of spectrum, for example, as is the case in current Conference of European Post and Telecommunications (CEPT) regulations with a total 480 MHz of spectrum designated as license-exempt.

Configuration 3 represents the case where three 320 MHz channels are used in an overlapping manner within the same amount of spectrum (480 MHz). In this configuration, BSS2 has 75 percent overlap with BSS1 and BSS3; BSS1 and BSS3 have 75 percent overlap with BSS2 and 50 percent overlap with each other.

Configuration 4 depicts the situation where there is 0 percent overlap between three 320 MHz channels. This configuration would only be possible if there is at least 960 MHz of spectrum available, as is the case in the United States, Korea, Canada, Brazil, Saudi Arabia, and other countries. The 160 MHz channel option is also implemented with this configuration for comparative analysis.

To assess the impact of the size of allocated spectrum on end-to-end latency of downlink AR/VR streams, various deployment scenarios and channel configurations were analyzed. For each deployment scenario/channel configuration pair, delay statistics for each stream were derived from simulations. For comparison purposes, 160 MHz channels are also simulated in two cases to represent scenarios with smaller available spectrum (480 MHz instead of 1200 MHz). In simulations related to Configurations 2 and 3, the primary channel of at least one AP is overlapping with another AP's channel. Furthermore, in all configurations, each BSS is assumed to serve eight randomly dropped clients (STAs), each with a different TCP-based application stream with a mix of uplink and downlink traffic, including web browsing, email, video, and voice, generating a stream of 30 Mb/s (MCS10) for each STA. In addition, up to 20 AR/VR stations downloading content from the APs are being dropped. AR/VR is modeled as a video stream with 16 ms inter-arrival time and 208 kB frame size at the application level, resulting in 100 Mb/s data streams. A full list of other simulation assumptions is contained in [2, Appendix 1].

It should be noted that in a managed network (e.g., enterprise), a network design with non-overlapping primary channels among APs may be implemented to avoid excess performance impact in non-collocated APs. However, there are no guarantees for an interference-free primary channel in an unmanaged network, such as an apartment complex.

Analysis and Results

The distribution of delay for AR/VR streams running on one, two, or three APs in deployment scenarios a, b, c, and d, and configurations relevant to each deployment scenario are analyzed. More specifically, the impact of the number of overlapping 320 MHz channels corresponding to the amount of available spectrum is analyzed.

The statistics of delay measured in the downlink direction at each AR/VR client associated with its AP is created to extract the maximum number of AR/VR streams that could be supported while maintaining end-to-end delay for AR/VR streams below 10 ms for 99.9 percent of the time. CDF plots of delay for all the analyzed cases are included in [2, Appendix 2], and results are summarized in Table 1.

The deployment scenario and channel configuration from Table 1 represent the two current regulatory situations in the 6 GHz band in countries/regions where license-exempt services are allowed, namely:

1. Availability of 500 MHz in the lower part of the band (5925–6425 MHz)
2. Availability of the entire 1200 MHz (5925–7125 MHz)

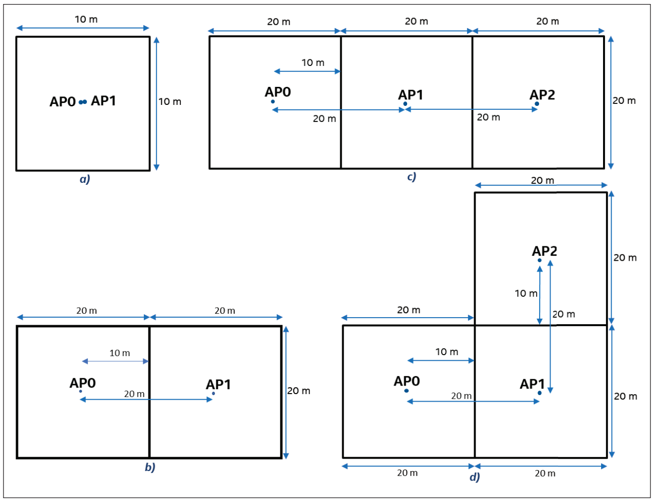

Figure 1. Wi-Fi 7 deployment scenarios a) single room with one or two APs; b) two APs in two adjacent rooms; c) three APs in three colinear adjacent rooms; d) three APs in three L-shaped adjacent rooms.

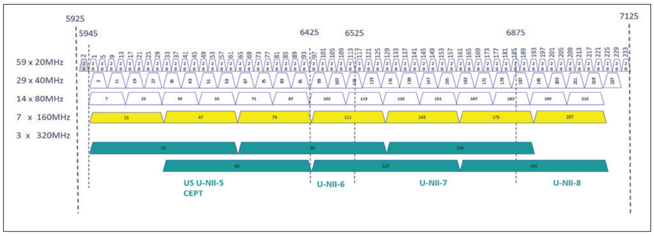

Figure 2. Global 6 GHz band channelization from IEEE 802.11ax and 802.11be (Wi-Fi 7).

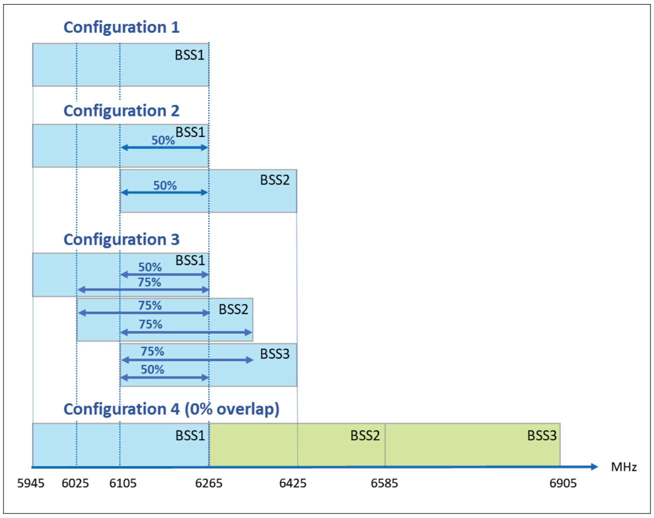

Figure 3. Various configurations of the 320 MHz channels considered in the simulations.

To assess the impact of available spectrum on major system KPIs, end-to-end latency in the downlink for AR/VR streams to clients was analyzed in various deployment scenarios and channel configurations. For each deployment scenario/channel configuration pair, delay statistics for each stream were derived from simulations. Table 1 provides a summary of the findings.

For each scenario, Table 1 reports:

- Maximum number of traffic streams per AP supporting 99.9-percentile delay below 10 ms

Delay (ms) for worst AR/VR stream per AP for the configuration with maximum number of supported streams over AR/VR frames														
Scenario	Channel configuration	Max AR/VR streams per AP	AP0				AP1				AP2			
			Max	98%	99%	99.9%	Max	98%	99%	99.9%	Max	98%	99%	99.9%
a	1, 1 AP	7	13.5	4.1	4.6	6.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	1, 2 AP	1/1	13.4	5.9	6.7	8.6	14.2	5.7	6.4	9.6	n/a	n/a	n/a	n/a
	1, 3 AP	0/0/0	18.5	8.6	10.3	17.6	22.4	10.0	11.6	17.8	18.4	12.8	14.0	17.8
a (160 MHz)	1, 1 AP	3	13.9	4.7	5.1	7.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	1, 2 AP	0/0	17.4	8.2	9.1	13.8	19.3	8.1	9.6	13.2	n/a	n/a	n/a	n/a
	1, 3 AP	0/0/0	38.9	13.6	18.4	26.4	38.4	14.8	18.8	27.9	32.7	15.0	16.8	26.4
a	2	0/0	22.8	8.9	10.6	16.4	25.3	10.8	12.5	19.7	n/a	n/a	n/a	n/a
b	2	1/0	14.5	5.9	7.0	9.9	59.2	24.9	29.3	43.4	n/a	n/a	n/a	n/a
c	3	1/0/0	18.6	4.7	5.2	7.3	61.2	33.1	37.9	55.5	51.1	24.5	28.2	43.0
	4	7/7/7	12.8	5.3	6.5	8.7	16.7	5.3	5.9	8.2	12.5	5.0	5.9	9.3
c (160 MHz)	4	3/3/3	17.3	3.9	4.3	5.8	6.4	3.9	4.2	5.4	12.7	4.1	4.5	6.5
d	3	0/0/0	17.0	7.0	8.0	12.3	95.8	40.2	49.5	76.9	99.5	69.9	79.5	95.2

Table 1. Summary results.

- End-to-end delay statistics for the worst AR/VR stream in the form of maximum, 98-percentile, 99-percentile, and 99.9-percentile values

This data shows that baseline case a1 can support up to 7 AR/VR streams with 99.9-percentile delay below 10 ms. However, in any other configuration involving more than one AP, the end-to-end delay is significantly impacted by the addition of clients/APs except for c4.

Availability of three non-overlapping 320 MHz channels in c4 brings the performance for all clients/APs back to a level similar to the baseline case per room. Using 160 MHz channels in a1 and c4 reduces the number of supported streams with delays below 10 ms to 3 and 3/3/3, respectively.

Conclusions

Network performance for emerging delay-sensitive residential, enterprise, and industrial applications of Wi-Fi 7, such as AR/VR and Industrial IoT, is impacted by the amount of available spectrum. In isolated and lightly loaded scenarios with a single 320 MHz channel, the end-to-end delay of AR/VR packets can stay below the target level of 10 ms for 99.9 percent of the time. However, in environments characterized with moderate to high traffic load (e.g., enterprises, dense residential complexes, hotspots), it is demonstrated that a single 320 MHz channel would not be able to maintain the end-to-end delay and reliability requirements of AR/VR applications. Only the availability of three non-overlapping 320 MHz channels would be able to cope with the increase in demand and keep the performance at acceptable levels for highly loaded scenarios.

This study indicates that if regulators only authorize the lower 500 MHz of the band (5925–6425 MHz), meaning that only a single 320 MHz or three 160 MHz channels is made available, a significant number of moderate to demanding future applications will not function as intended, and hence residential, enterprise, government and Industrial IoT users would not adequately benefit from these applications. Wi-Fi 7 will need access to three non-overlapping 320 MHz channels to meet the demand of emerging applications. As shown here, this goal can only be achieved if the entire 6 GHz band (5925–7125 MHz) is made available for license-exempt operation.

References

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Additional Resource

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