Wi-Fi 6 And Wi-Fi 6E Are Building The Foundation For New Home Applications

A Technical Paper prepared for SCTE•ISBE by

Massinissa Lalam, Ph.D
Sr. Expert on Wireless Technology
Sagemcom
250 Route de l'Empereur; 92500 Rueil-Malmaison, France
+33 1 57 61 13 41
massinissa.lalam@sagemcom.com

Kamal Koshy
Sr. Director Wireless Engineering
Charter Communications
Denver, CO
kamal.koshy@charter.com

Xavier Briard
SVP Broadband Solutions
Sagemcom
Dallas, TX
xavier.briard@sagemcom.com

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1. Introduction

Years after years, Wi-Fi has become the de-facto way to access Internet at home. Based on the IEEE 802.11 standard family, the Wi-Fi technology has experienced several major PHY/MAC updates during the last 20 years, each one defining a generation on its own. Not so long ago, the general public was still not aware of those gaps and just called "Wi-Fi" any one of them. The generational naming introduced by the Wi-Fi Alliance in 2018 was seen a better way to advertise each new release instead of relying on 802.11 amendments name.

Built upon the IEEE 802.11 ax amendment, Wi-Fi technology is currently at its sixth coined "Wi-Fi 6" which operates on the unlicensed 2.4 and 5 GHz ISM band with an extension into the 6 GHz territory called Wi-Fi 6E.

Each Wi-Fi generation brought an improvement in peak throughput: from the original 11Mbps back in 1999, Wi-Fi 6/6E now offers up to 9.6 Gbps. However, Wi-Fi 6/6E main target was not peak throughput increase but improved efficiency in dense environments.

Indeed, the success of Wi-Fi, due to its low cost, ease of use and performance led to an explosion of Wi-Fi devices, exhibiting the limits of previous generations in terms of congestion and channel access in such scenarios.

Prior to Wi-Fi 6, access points (APs) and stations (STAs) were contending to access the medium with similar priority. More and more end-devices being deployed, resulting congestion has led to a degraded experience in crowded places like multi-dwelling units (MDUs).

In this paper, we will briefly present the evolution of IEEE 802.11/Wi-Fi technology and its quest for more throughput. We will then present the main features of Wi-Fi 6 and the change of paradigm it brought to the table with a more AP-centric channel access. We will then discuss how Wi-Fi has changed the residential environment and the main uses cases it needs to address. We will then present how Wi-Fi 6 can change user experience at home today and how the opening of the 6 GHz band will drastically change the user experience tomorrow. With three times more spectrum available, results achieved in clean environment could be truly representative of the end user experience even in dense environment.

2. Evolution of Wi-Fi Technology

Wi-Fi technology, which brand is owned by the Wi-Fi Alliance (WFA), is based on IEEE 802.11 standard. While IEEE 802.11 develops the technology, the WFA aims to promote it and creates as such interoperability testing and certification programs to ensure the end-users of a certain level of performance and compatibility. While independent, both organizations are tightly linked in the way Wi-Fi became so successful nowadays. General public knows the brand "Wi-Fi" but is generally not aware of the main generations it has experienced in its life, partly because Wi-Fi has always been backward compatible with its previous generations. An equipment bought in 1999 could work today with the same performance even in the most advanced Wi-Fi network. The generational naming introduced in 2018 by the WFA with numbers is a step to better differentiate the Wi-Fi technologies. Before addressing Wi-Fi 6/6E, we will recall what are the different Wi-Fi generations and their quest to always increase the throughput.

2.1. Early Wi-Fi Generations

The first commercial success of the IEEE 802.11 technology was relying on the 11b amendment back in 1999. Operating on the 2.4 GHz industrial, scientific and medical (ISM) band, this technology was based on direct sequence spread spectrum (DSSS) and complementary code keying (CCK) modulations and offered up to 11 megabits per second (Mbps) at the physical (PHY) layer on channel occupying 22 MHz. Its inclusion in laptop's CPU helped democratizing what can be considered as the first generation of Wi-Fi.

While development started at the same time as 11b, products based on 11a amendment came later. This technology was solely operating on the 5 GHz ISM band where more spectrum was available. It was relying on orthogonal frequency division multiplexing (OFDM), which divides the bandwidth in smaller subcarriers for a transmission in the frequency domain. Back in that day 11a could delivered a throughput up to 54 Mbps at PHY layer through the use of higher order modulations (64 quadature amplitude modulation (QAM)) and a channel bandwidth of 20 MHz. This can be considered as the second generation of Wi-Fi.

The will to port most of 11a innovations introduced in the 5 GHz ISM band into the 2.4 GHz ISM band gave birth to the 11g amendment in 2003. The same OFDM and modulations as 11a were introduced, while keeping backward compatibility with 11b devices. Only the 20 MHz channel bandwidth from 11a was kept As such 11g offered up to 54 Mpbs at the PHY layer with 20 MHz channel and could be considered as the third generation of Wi-Fi.

2.2. Generational Wi-Fi

In order to increase even more the throughput and as computation capability was more affordable, IEEE 802.11 worked on a new amendment which would be defined for both 2.4 and 5 GHz ISM band. With 11n, peak PHY throughput was increased by doubling the bandwidth (from 20 MHz to 40 MHz, an option viable mainly in the 5 GHz ISM band which is larger) and introducing multiple-input multiple-output (MIMO) concept which allow the use of up to four antennas. If channel conditions permit, spatial multiplexing which is a mode of MIMO transmission allow the transmission on the same channel of different parallel streams, increasing the throughput. 11n could then offer a throughput up to 600 Mbps at the PHY layer. 11n was published in 2009 by IEEE 802.11, but some years before people could buy products supporting a draft version of 11n pushed by the WFA to respond to the public demand. 11n is the fourth generation of Wi-Fi and named as Wi-Fi 4 by the WFA.

As the most efficient way to increase throughput is to use more spectrum, the next IEEE 802.11 amendment was only operating at the 5 GHz ISM band where more than two 20-MHz channels could be aggregated. 11ac amendment use all possible dimensions available to increase its peak throughput: higher bandwidth (up to 160 MHz), higher modulation order (up to 256 QAM), higher MIMO (up to 8 antennas). A full feature 11ac could offer up to 6.9 gigabits per second (Gbps) at the PHY layer, while the vast majority of gateways were shipped with up to 4 antennas. 11ac was published in 2013 by IEEE 802.11. The WFA used only a subset of 11ac features for its wave 1 certification based on a stable 11ac draft, later completed with additional ones for its wave 2 program. The use of larger channel was possible because spectrum was made available in the 5 Ghz band. However, all 160 MHz channels available in this band overlap with incumbents (e.g. radar) which have primary access. The constraint made on the devices to detect those signature and move away in case of positive detection (process often called dynamic frequency selection (DFS)) is such that in practice only 80 MHz channels are really used in residential deployments. 11ac is the fifth generation of Wi-Fi and named as Wi-Fi 5 by the WFA.

After the completion of 11ac, IEEE 802.11 group was trying to address a problem which was more and more visible as Wi-Fi technology was more and more successful. Originally thought as a cable replacement, the issue of density of devices and congestion associated to it was not really part of the design. With the 11ax amendment, IEEE was targeting to improve efficiency in dense deployment scenarios, with a throughput increase measured this time not at PHY layer but above the medium control access (MAC) layer, i.e., at the application layer, directly related to the user experience in such deployment. Since no work have been carried out on the 2.4 GHz ISM band since 2009, it was decided from the beginning to define 11ax for both the 2.4 and 5 GHz band, with a later extension to the 6 GHz band. 11ax brings a lot of changes which we will detail in a later section, but it also increases the throughput by using four times more subcarriers within the same spectrum (guard band can be reduced while guard interval (typical of OFDM modulation) is proportionally smaller) and up to 1024 QAM modulation. Therefore, a full 11ax solution can deliver up to 9.6 Gbps. 11ax amendment is expected to be published in 2021 by IEEE 802.11, but products are already available. WFA release 1 certification is ready since mid-2019 based on a subset of 11ax features from a stable draft. This certification only covers the 2.4 and 5 GHz band and it is expected that the 6 GHz band will be covered soon. 11ax is the sixth generation of Wi-Fi called Wi-Fi 6, while Wi-Fi 6E is used to indicate support of the 6 GHz band.

2.3. Peak Throughput Evolution

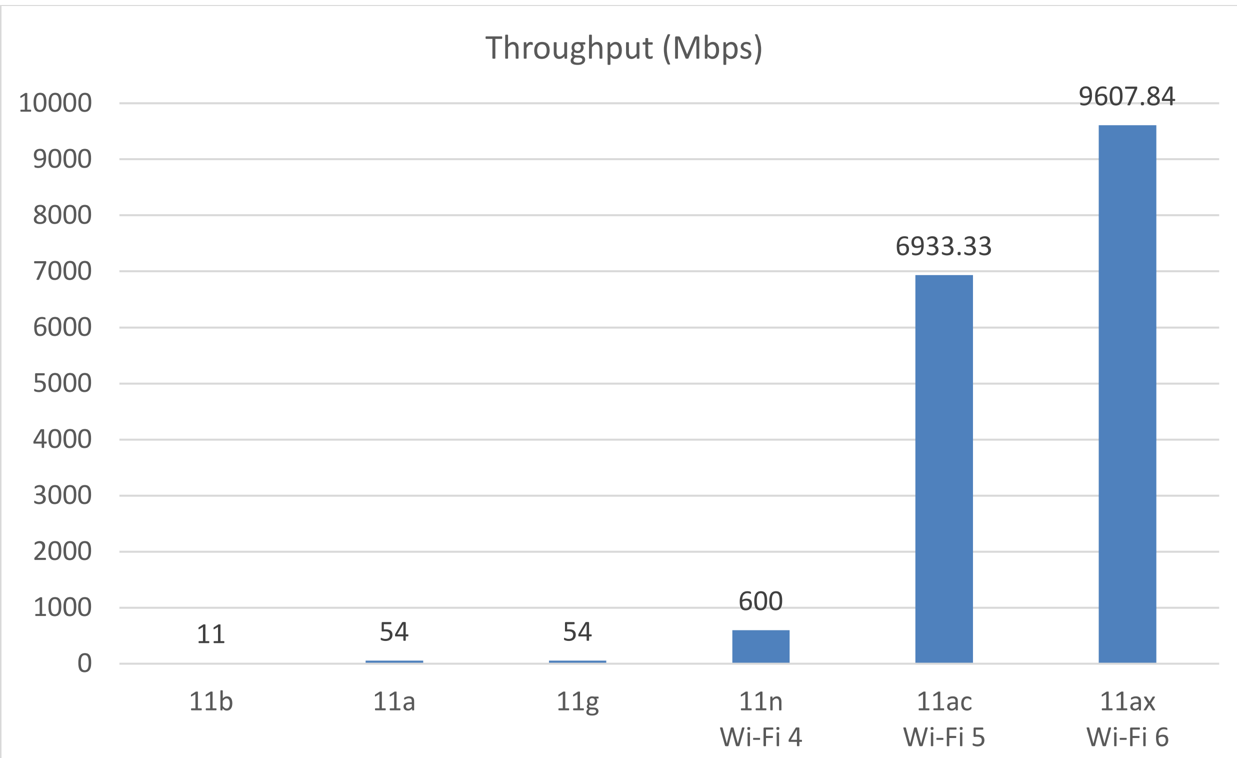

Figure 1 - Throughput increase over the Wi-Fi generation

As shown from Figure 1, Wi-Fi technology, like any successful wireless technology, has always known peak throughput increase though its various generations. Wi-Fi 6/6E is particular in the sense that this metric was not its primary objective. Wi-Fi 6/6E was developed to improve efficiency in dense environment like MDUs or stadium, where the limit come from too much devices trying to access a limited spectrum available at the same time.

3. Wi-Fi 6 Technology Overview

Wi-Fi 6 introduced many features to address the high density problem. In the following, we will detail the most important one when facing a residential unmanaged deployment.

3.1. Geared For Multi-User Transmissions

When too many stations are doing traffic at the same time, one solution to reduce congestion is to group them to either send them data (downlink) or receive data from them (uplink).

Wi-Fi 5 AP could already send data up to 4 STAs at the same time with a method relying on spatial separation called DL MU-MIMO. This technique is useful to exploit the asymmetry in antenna configurations between an AP (equipped generally with 4 antennas) and the STA (usually no more than 2 antennas) to send more streams to different STAs. However, this approach is heavily dependent on the radio conditions, topology and signal processing at the STA side.

To cope with this, Wi-Fi 6 introduced OFDMA as a way to group several STAs together in the frequency domain. Supported in both DL and UL directions, this method allocates group of (contiguous) subcarriers to different STAs.

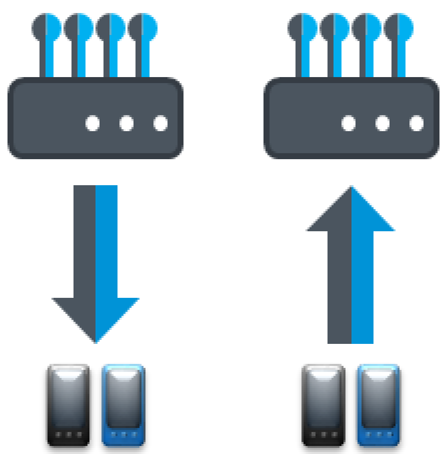

Figure 2 - DL/UL OFDMA

This technique is particularly efficient when packets to transmit are small, reducing the air time needed to send them.

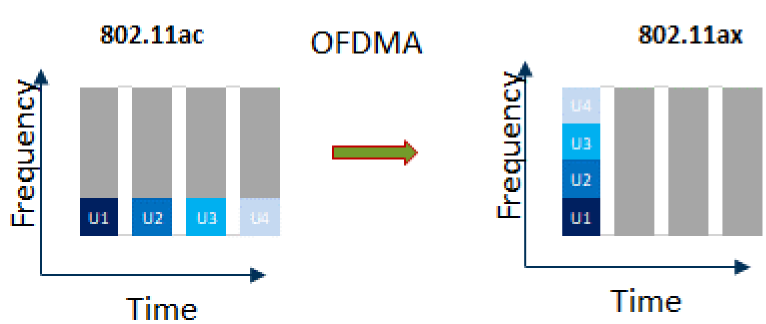

Figure 3 - DL/UL OFDMA efficiency for small packets delivery

If traffic is heavy with larger packet size, OFDMA could be less efficient due to the fact that the bandwidth is divided among the users. But Wi-Fi 6 can still use DL MU-MIMO transmissions to deal with such use case. Later Wi-Fi 6 products are also expected to be able to use this technique in the reverse direction as well with UL MU-MIMO.

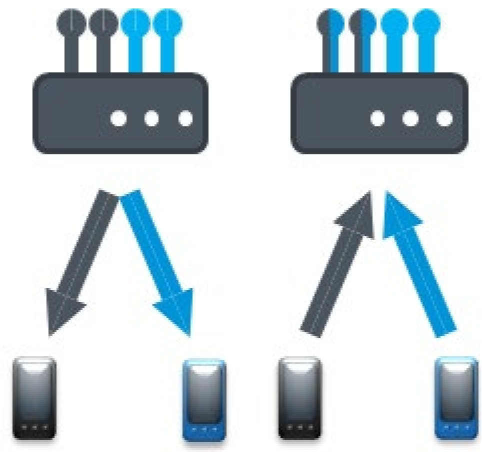

Figure 4 - DL/UL MU-MIMO

In Wi-Fi 6, scheduling at the AP side takes an even more important role as the AP is now in charge of DL and UL transmission. To make the STAs transmit in the uplink when the AP wants to, a new trigger mechanism is introduced which allow a more AP-centric medium access as we will discuss below.

3.2. Toward an AP-centric Channel Access

Before explaining how the trigger principle works and how it can improve efficiency at the network level, it is worth recalling how channel access used to work prior to Wi-Fi 6.

3.2.1. Classical Channel Access Mechanim

During the history of Wi-Fi products, the channel access mechanism has been mainly updated from the distribued coordination function (DCF) access originally defined in the first IEEE802.11 standard from 1997[1]. Based on carrier sense multiple access with collision avoidance (CSMA/CA), each device wanting to transmit shall listen first to the medium to detect any energy above a given threshold. If none is detected, then it can transmit. Such principle is also known as the listen before talk (LBT) principle, terminology often used in regulation. Of course some refinements were added to this simple principle to avoid systematic collision between two devices such as the use of a backoff counter and an exponential contention window.

A device, being it a STA or an AP, shall pick a random value between 0 and the actual contention window size and store it in a counter. After sensing the medium for a fixed duration (DIFS), if the medium is idle (i.e. no energy detected above the threshold), then the device can decrement the counter by one for each time slot (lasting 16µs or 9µs) it senses the medium idle. When the counter reaches zero, the device can transmit. If energy is detected while the counter was not zero, then the device should stop until no more energy is detected and resume the decount after the fixed duration sensing (DIFS). If the frame sent is not acknowledged, then the device shall pick a new value but this time it shall double the

[1] Another mechanism based on polling, called point coordinated function (PCF), was also introduced but never encountered success through commercial products.

contention window size to reduce the probability of collision. Figure 5 shows an example of two STAs contending for the medium.

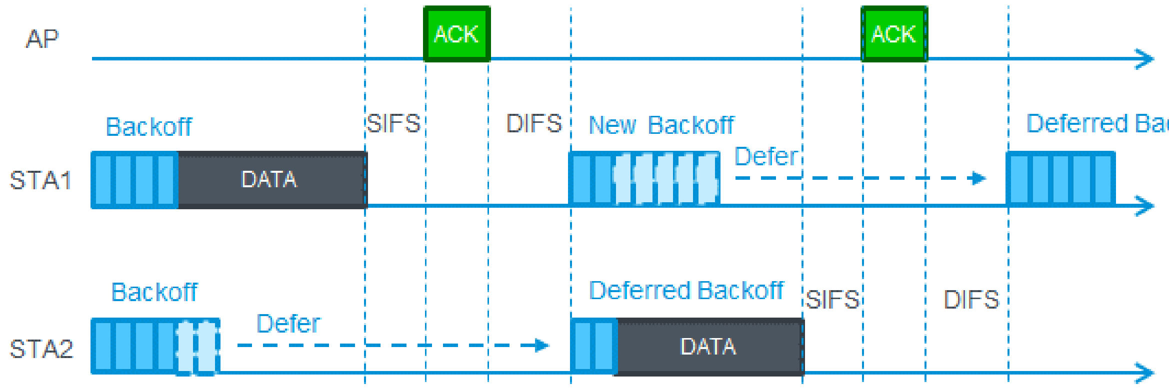

Figure 5 - Channel access example (pre-11ax)

Additionally to this energy detection mechanism, Wi-Fi relies also on a preamble detection PHY mechanism. Preamble is a part of each Wi-Fi frame which indicates the duration of the given frame. By successfully decoding it, the sensing device knows when it can resume its sensing if it wanted to transmit. This process is further refined by the fact that if the sensing device decodes the complete frame, then the MAC header contains information on the duration on the ongoing exchange (though the network allocation vector (NAV) field), i.e.; including duration of the next frames to be sent which helps the sensing device even more.

Modifications have been added to this channel access mechanism, in particular through the 802.11e amendment from IEEE 802.11 and the wireless multimedia (WMM) certification from WFA, like aggregation of MAC and service packets (AMPDU, AMSDU respectively) to increase the throughput of the support of quality of service (QoS). Qos is achieved by having different parameters for the contention window size minimum and maximum values and the fixed duration used for sensing (AIFS) leding to an enhanced distributed channel access (EDCA).

More details can be found in the relevant standards and specifications, but the main principle pre-11ax was that all devices should operate using this principle. This means that within in a Wi-Fi network, or basic service set (BSS), the AP and all its associated STAs contend equally for the medium. Note that when QoS is engaged, the AP may a slight advantage in terms of access with default parameters for:

- best effort category: with a maximum contention windows size lower than the one to be used by the STAs,
- voice/video categories: with a lower fixed duration used for sensing.

With more and more devices being deployed at home, AP is competing with more and more STAs increasing collision over the air and congestion. This become a greater problem when other Wi-Fi networks are deployed in the vicinity on the same channel. The networks, called overlapping BSSs (OBSS) have APs but also STAs connected to them. One can easily understand that such crowed environment could lead to bad user experience: all devices fighting for the medium with (almost) the same priority.

3.2.2. 11ax Trigger Frame Channel Access

To mitigate this effect, Wi-Fi 6 decided to shift the paradigm of the channel access to make it more AP-centric instead of device-centric for the uplink direction. Instead of having all STAs contending for the medium, only their AP will do so. For example, if we have 2 BSSs with *N* STAs associated to each one, instead of having 2*N*+2 devices trying to access the medium, only the 2 APs will contend for both downlink (DL) and uplink (UL) transmissions.

To coordinate multi-user transmissions in uplink the trigger frame (TF) was introduced. This frame, sent by the AP, schedules the next UL transmissions of all addressed STAs. Figure 6 shows an UL-OFDMA transmission on a 80 MHz BSS where STA1 is allocated the first 20 MHz, STA2 is allocated the second 20 MHz nd STA3 is allocated the remaining 40 MHz. The AP can acknowledge the reception of all uplink transmission with a single ACK frame (called M-BA). In this case instead of three stations contending for the medium, only the AP will to send its trigger frame

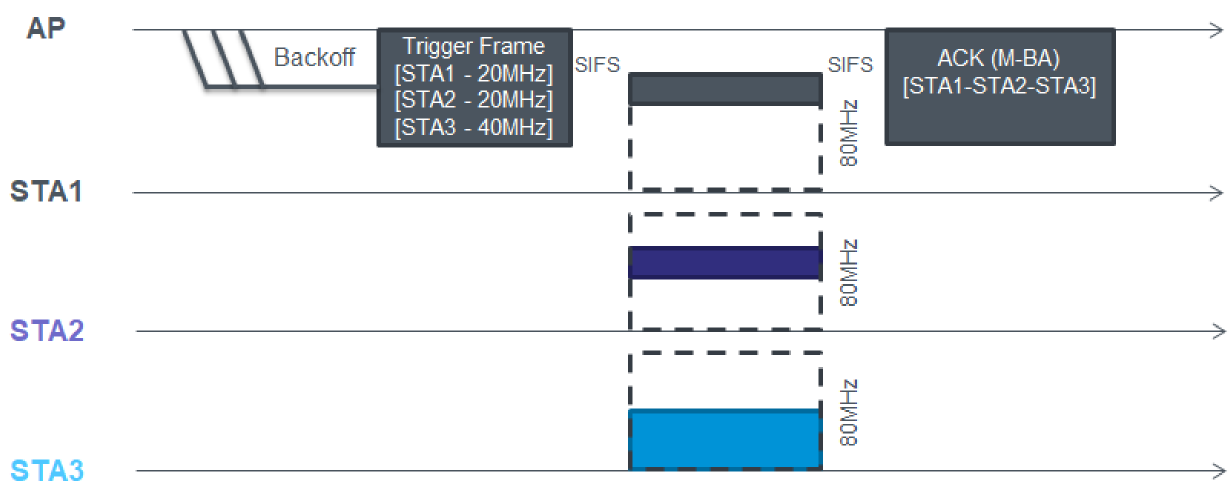

Figure 6 - Example of a Trigger Frame exchange for UL-OFDMA transmission

Once engaged at least once in such uplink procedure, the STAs will refrain to access the channel autonomously leaving only their AP in charge of gaining access to the medium for them.

Of course this mechanism can only be applied by Wi-Fi 6 STAs. But as more of them are entering the market right now, legacy devices will also see some benefits: the newer STAs will not contend for the medium but only their APs will. In fact, by choosing to address dense deployment, Wi-Fi 6 true potential will only be achieved if enough Wi-Fi 6 capable device are in the market. So while the trend is in favor of it, we have to remember that the vast majority of the devices at home are still Wi-Fi 4/5-only capable.

4. Wi-Fi Challenges at Home

Wi-Fi as a technology has become synonymous to internet both in residential and enterprise environments. From its inception in the late 1990s, Wi-Fi performance has improved by orders of magnitude as shown previously. The use cases supported by Wi-Fi has also significantly changed over the years. In a typical residential environment, Wi-Fi may support an average of 15 devices (2020), and up to 50 devices in a tech centric residence. The use cases supported by now includes internet access, gaming devices, IoT devices, mobile devices with varied used cases. The following sections detail some of the key use cases that Wi-Fi as a technology needs to address

4.1. Entertainment

With streaming services that are available, home entertainment has moved to wireless from the earlier fixed media devices like DVD, CD etc. Supporting robust streaming services require dedicated bandwidth to media consumption devices including TVs, Roku, media players and mobile devices used as media consumption devices. Simultaneous media consumption with multiple devices also needs to be supported by Wi-Fi technology. Additional support for newer use devices that support augmented reality(AR) and virtual reality (VR) is also a requirement for Wi-Fi technology.

4.2. Smart Home

Smart Home include variety of devices including video devices (video doorbell, cameras) and IoT sensors (Wi-Fi and other technologies). Smart video devices require sufficient bandwidth to support video upload/download. IoT sensors based on Wi-Fi require technology support for long battery life and reliable communication at the edges of the residence.

4.3. Internet access

The requirements of internet access to homes has gone up significantly over the years. As mentioned earlier, the number of devices in many US homes is 15 and in many cases approach 50 devices. The increase in devices places significant burden on the network to provide great connectivity to devices. In addition, due to the shared nature of the access medium in Wi-Fi, additional technologies have to be developed to support the increase in number of devices. Multi-dwelling units present additional challenges since the number of devices that are in proximity can be significantly higher than in standalone residences. New technologies and best practices have to be developed to support internet access in multi-dwelling units.

The recent introduction of Wi-Fi 6 should help addressing the previous use cases while the opening of the 6 GHz band should alleviate the most critical issue in MDUs which is congestion due to lack of spectrum.

5. How Wi-Fi 6E Will Change Experience in Dense Residential Areas

5.1. Experience in Legacy Band

Where Wi-Fi 6 really shines, to the point of improving the user experience by a factor 4, is really in the heavy congested environments with lots of users sending small packets. The trigger frames sent by the AP to schedule uplink transmissions of its associated STAs dramatically reduces the congestion otherwise observed with the classical EDCA mechanism where all STAs contend for the medium.

However, you do not need a dense deployment to see the benefit of Wi-Fi 6 which may be not throughput related. To demonstrate it, we set ourselves in a clean environment (i.e. no neighboring networks). We set up an 11ax 4x4 Wi-Fi 6AP configured on a 80 MHz channel, similar to what is available in the 5 GHz band without having to rely on an DFS mechanism. We associated to it :

- two 2x2 160 MHz-capable Wi-Fi 6 laptops, and
- one 4x4 Wi-Fi 6 160 MHz-capable router set as a station (think of it as an extender for instance).

The devices are close to the AP with equivalent received power. Figure 7 shows our setup which is an interference free one.

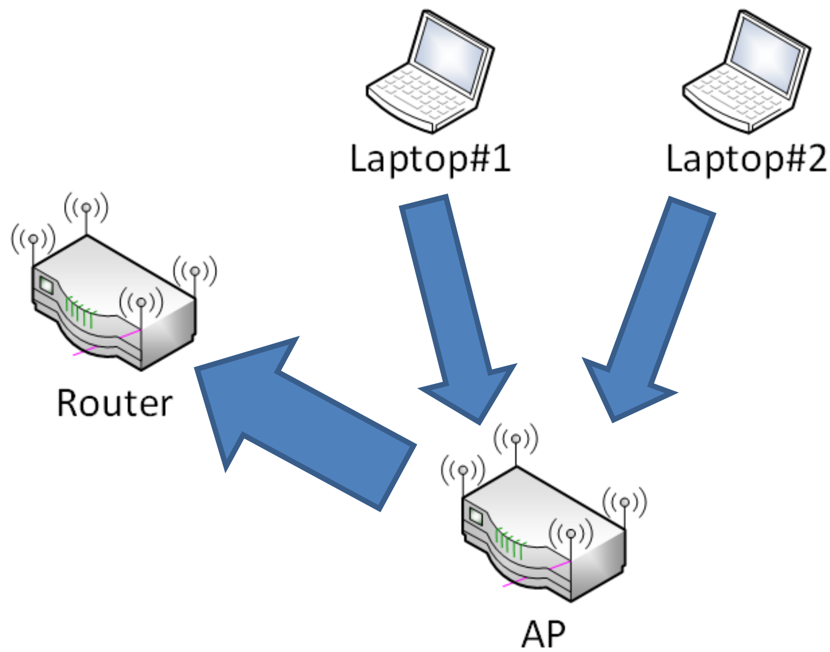

Figure 7 - Interference Free Setup

To evaluate any benefit of Wi-Fi 6 in such scenario, we run throughput tests (using IxChariot) when setting the AP first in Wi-Fi 5 mode then in Wi-Fi 6 mode. For both runs, we use the following traffic profiles at the same time:

- a UDP uplink transmission with a throughput target of 250 Mbps for each laptop,
- a UDP downlink transmission with a throughput target of 500 Mbps for the router.

UDP is used to show to see Wi-Fi 6 benefits at MAC/PHY layer without any recovering protocol from upper layers. We use the same quality of service for all traffics (Best Effort).

5.1.1. Inteference free setup

Table 1 shows the average throughput obtained after 1 minute of traffic.

Table 1 - Wi-Fi 5 vs Wi-Fi 6 Average Throughput (Interference Free Setup)

Device	Traffic Direction	Throughput Target (Mbps)	Wi-Fi 5 (Mbps)	Wi-Fi 6 (Mbps)
Laptop #1	Uplink	250	238	209
Laptop #2	Uplink	250	156	217
Router	Downlink	500	491	494

We see that in both mode downlink traffic is almost the same, the 500 Mbps target is almost honored for Wi-Fi 5 and Wi-Fi 6. However, the uplink results show a different story. In Wi-Fi 5 mod, one laptop is getting significantly more throughput (238 Mbps) than the other (156 Mbps). The radio conditions being the same, this demonstrates that some STA implementations could be more aggressive than others in their channel access mechanism (with use of frame bursting for instance). In Wi-Fi 6 however, both STAs have equivalent uplink throughput (209 Mbps vs 217 Mbps) which is controlled by the AP. Both do not reach the target throughput (250 Mbps) though.

The full story is shown by the throughput curves during the time which are given in Figure 8 and Figure 9 for Wi-Fi 5 and Wi-Fi 6, respectively.

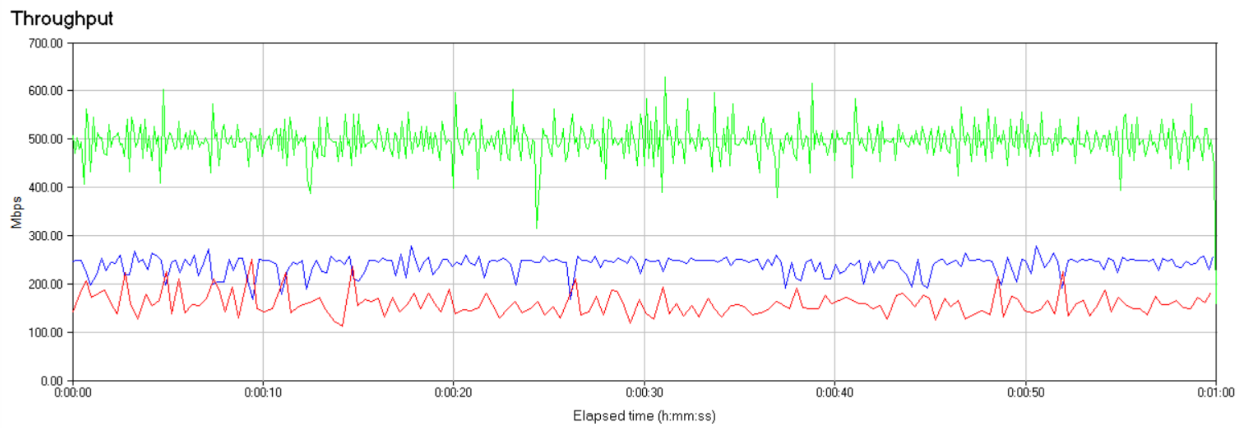

Figure 8 - Wi-Fi 5 Throughput Evolution (Interference Free Setup)

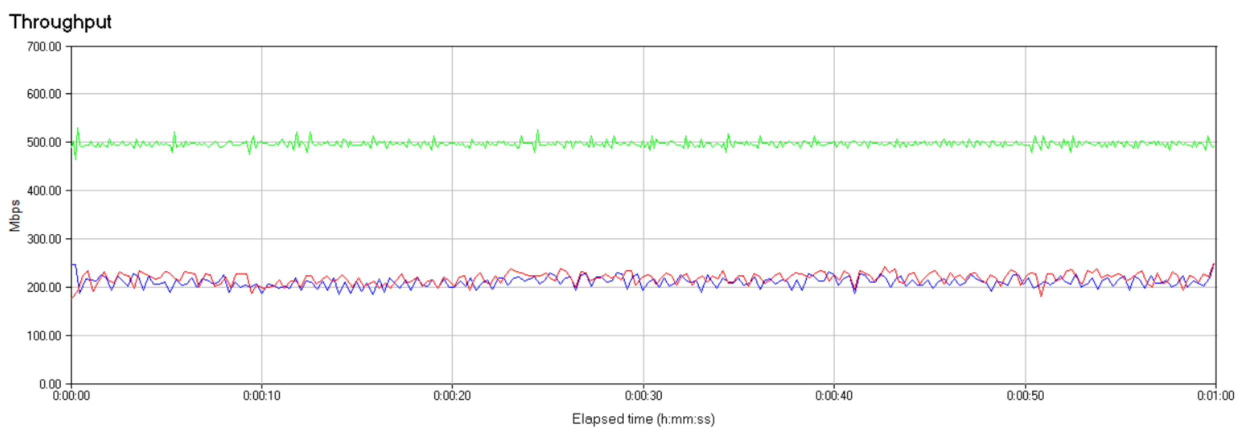

Figure 9 - Wi-Fi 6 Throughput Evolution (Interference Free Setup)

All Wi-Fi 5 curves are more impacted by the lack of coordination between the three sources of traffic which all contend to access the medium. Wi-Fi 6 curves are less prone of such variation since only the AP controls the traffic by triggering the two laptops and instructing them to use UL OFDMA transmissions while it serves also the third device in downlink. One can see that both STA curves (blue and red) are almost the same leading to a better fairness. Ultimately, this will also result in better latency for all three devices with a service delivery more stable thanks to Wi-Fi 6.

5.1.2. OBSS Setup

In an MDU type of deployment however, you are usually not alone on an 80 MHz channel. To see the effect, we introduced an interfering network on the same channel as our setup (OBSS) but at a reasonable distance from it. In the lab, we reduced the transmit power of such interferer to simulate distance. On this setup we run a continuous TCP full-buffer traffic (iperf) to create a Wi-Fi noise to which our setup has to defer (mainly due to preamble detection).

We ran the same experiment in both Wi-Fi 5 and Wi-Fi 6 to check the effect of OBSS in way which is closer to what people are experiencing. Results are given Table 2, Figure 10 and Figure 11.

Table 2 - Wi-Fi 5 vs Wi-Fi 6 Average Throughput (OBSS Setup)

Device	Traffic Direction	Throughput Target (Mbps)	Wi-Fi 5 (Mbps)	Wi-Fi 6 (Mbps)
Laptop #1	Uplink	250	132	168
Laptop #2	Uplink	250	68	176
Router	Downlink	500	479	486

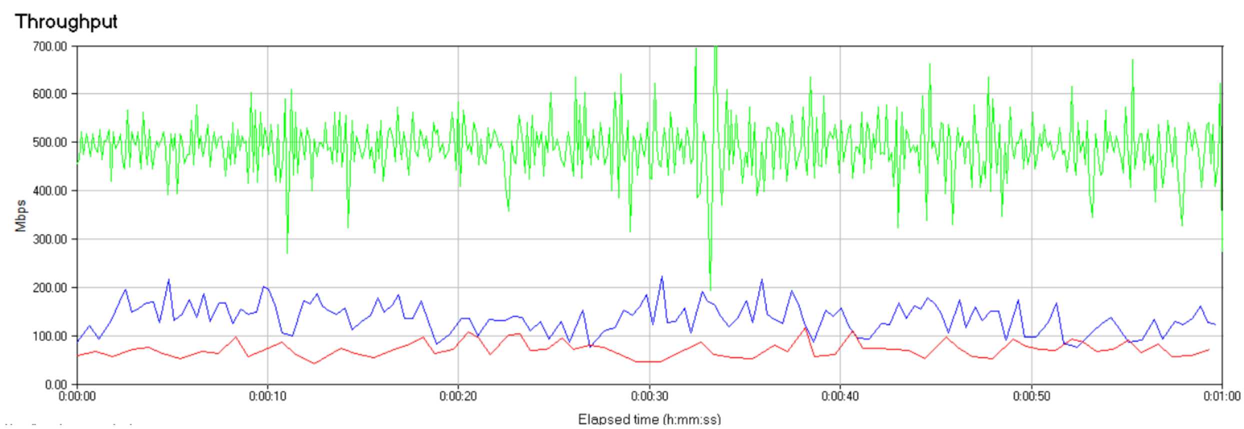

Figure 10 - Wi-Fi 5 Throughput Evolution (OBSS Setup)

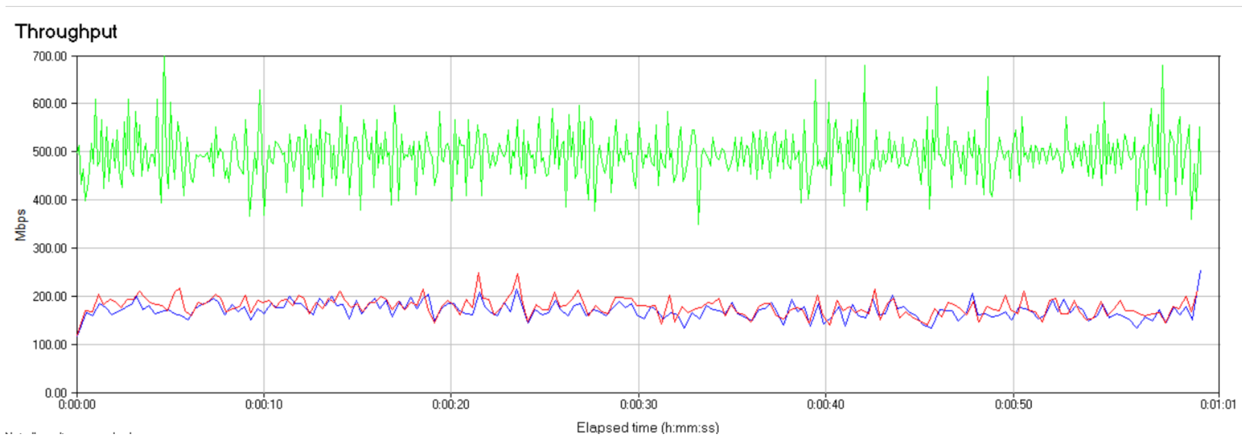

Figure 11 - Wi-Fi 6 Throughput Evolution (OBSS Setup)

As one can see, both setups are affected by the OBSS and none could reach the throughput target, but the Wi-Fi 6 one offers more stability to both uplink transmissions with fair access of the spectrum to both of them.

5.2. The 6 GHz Experience

With the recent FCC decision to open the 6 GHz band to wireless devices, more than 1.2 GHz band will be made available for Wi-Fi 6E I nthe US. It is envisaged that residential AP deployment may choose to use low-power indoor model to avoid the access to a geolocation database for automatic frequency selection (AFC). Under such conditions, the whole 6 GHz band is available without any constraints à-la DFS. To put it simply, seven 160 MHz channels will be available for a Wi-Fi 6E AP to choose from, greatly reducing the risk of OBSS really affecting the performance.

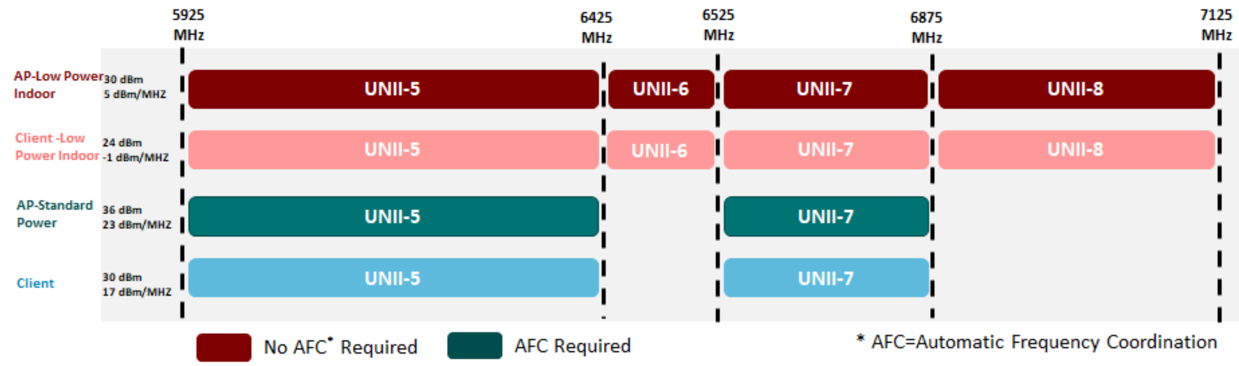

Figure 12 - 6 GHz Spectrum (US)

In dense residential deployment, most of the congestion/collision will then come from inside the BSS itself. Higher frequency means more wall attenuation and with 7 channels to choose, overlapping should not be experienced in the near future on this band. With no legacy devices present, STAs will most likely choose to be controlled by the AP for a better user experience.

It is envisaged to have 160 MHz channel bandwidth as the norm in 6 GHz band. If we take our previous interference free setup to make it operate in a 6 GHz-like environment, then we can setup our AP with a 160 MHz channel bandwidth and repeat our measurements. Table 3 shows that in this 6 GHz-like environment targets are reached on average for the three devices (less than 2% deviation) while Figure 13 shows the throughput evolution and its stability

Table 3 - Wi-Fi 6 Average Throughput (6 GHz-like Setup)

Device	Traffic Direction	Throughput Target (Mbps)	Wi-Fi 6E (Mbps)
Laptop #1	Uplink	250	168
Laptop #2	Uplink	250	176
Router	Downlink	500	486

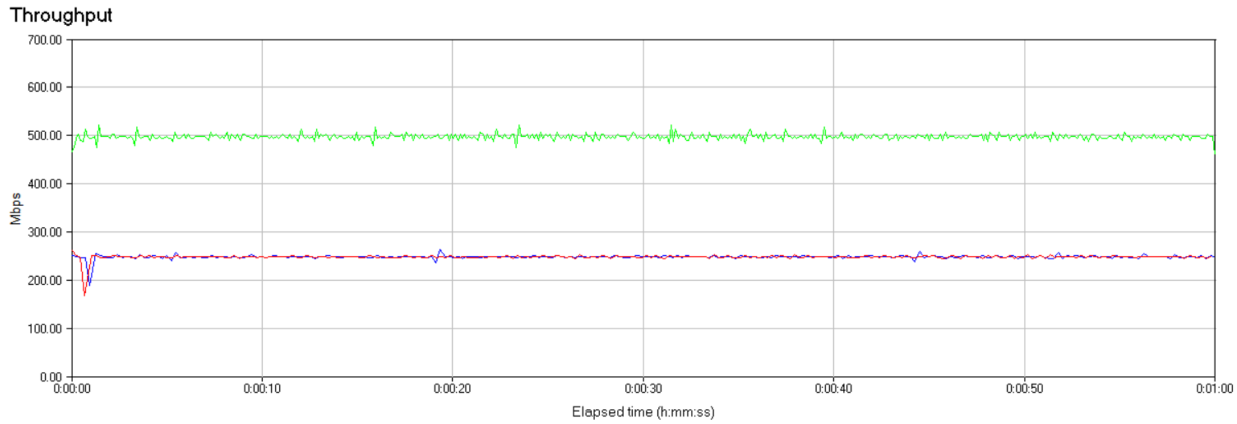

Figure 13 - Wi-Fi 6 Throughput Evolution (6 GHz-like Setup)

6 GHz opening is also considered in Europe, but on the lower 500 MHz band first. Recent decision from Ofcom UK to open it by end of this year provides three 160 MHz channel to Wi-Fi 6E devices for operation. While this is less than what the US are opening right now, the key advantage of Wi-Fi 6 are still there to improve experience at home.

6. Conclusion

In this paper we reviewed the evolution of Wi-Fi technologies over the years and the challenge it should address in dense residential scenarios. If the introduction of Wi-Fi 6 technology certainly helps in providing unique features to improve user experience in dense deployment, the wireless systems are still bounded by the spectrum available to them. Fortunately, the recent opening of the 6 GHz band in the US, paving the way to others countries (Europe, South Korea, …), allows Wi-Fi 6E to really be able to change user experience at home, even in dense areas since Wi-Fi 6 key features are more effective in Wi-Fi 6 only ecosystem. Indeed, IEEE 802.11 operation on 6Ghz band is restricted to Wi-Fi 6E devices only (i.e. no Wi-Fi 4/5 or even 11b legacy to take into considerations).

Abbreviations

AFC	automatic frequency selection
AP	access point
A-MPDU	aggregated MPDU
A-MSDU	aggregated MSDU
BSS	basic service set
CCK	complementary code keying
CSMA/CA	carrier sense multiple access with collision avoidance
DCF	distributed coordinated function
DFS	dynamic frequency selection
DL	downlink
DSSS	Direct sequence spread spectrum
EDCA	enhanced distributed channel access
Gbps	gigabits per second
GHz	giga hertz
IEEE	Institute of Electrical and Electronics Engineers
IFS	inter-frame spacing
ISM	industrial, scientific and medical
LBT	listen before talk
MAC	medium access control
Mbps	megabits per second
MDU	multi-dwelling unit
MIMO	multiple input multiple output
MPDU	MAC protocol data unit
MSDU	MAC service data unit
MU	multi-user
OBSS	overlapping basic service set
OFDM	orthogonal frequency-division multiplexing
OFDMA	orthogonal frequency-division multiplexing access
PCF	point distributed function
QAM	quadrature amplitude modulation
QoS	quality of service
STA	station
TCP	transmission control protocol
TF	trigger frame
UDP	user datagram protocol
UL	uplink
WFA	Wi-Fi Alliance

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