A First Look at 160 MHz WiFi 6/6E in Action: Performance and Interference Characterization

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***Abstract*—This paper presents the first experimental evaluation of WiFi 6 (in the 5 GHz band) and WiFi 6e (in the 6 GHz band) with 160 MHz channels using commercial hardware. Our results show that 160 MHz channels offer significant throughput gains compared to 80 MHz channels. However, the gains are limited to short ranges and line of sight (LOS) conditions, while the performance degrades sharply in longer ranges or NLOS environments, especially in the 6 GHz band. We also perform the first extensive interference characterization of WiFi 6/6e. Our experiments with links using homogeneous channel widths show the existence of strong interference due to power leakage in adjacent channels and even non-adjacent channels, in both frequency bands. Our experiments with links in overlapping channels using heterogeneous channel widths and different primary channels reveal a variety of interference patterns, which have not been observed in previous studies with 802.11n or 802.11ac links.**

I. Introduction

An emerging class of mobile applications, such as Ultra-HD video streaming, Augmented Reality (AR), Mixed Reality (XR), and the Metaverse, demand ultra high bandwidth from the underlying wireless network. In addition, dense deployments and an increasing number of overlapping networks possibly characterized by different channel configurations require fair and efficient utilization of spectrum resources. 802.11ax or the 6th generation WiFi (WiFi 6) [5], officially released in 2019 with the High-Efficiency Wireless (HEW) amendment and updated in 2020 to support the new 6 GHz band (WiFi 6e) has the potential to provide very high data rates to multiple users in dense user environments and satisfy the requirements of the aforementioned bandwidth-hungry applications.

While 802.11ax introduces new channel access mechanisms (OFDMA, TWT, and BSS coloring) to improve efficiency in dense, multi-user, multi-AP environments, it improves the throughput of an individual user compared to its predecessor 802.11ac via higher-order modulation (1024-QAM vs. 256-QAM in 802.11ac), support for more MIMO spatial streams (8 vs. 4 in 802.11ac), and wider channels (160 MHz vs. 80 MHz in 802.11ac). However, 1024-QAM increases the PHY data rate only by 25% compared to 256-QAM and commercial 802.11ax devices on the market typically support only 2 or 3 spatial streams, making 160 MHz channels the primary factor contributing to a throughput improvement for individual users. Note that 160 MHz channels were already introduced in the 802.11ac standard, but they were not supported by the first generation of WiFi 6 devices known as "Wave 1" and by many of the "Wave 2" clients that came later.

Despite having a myriad of WiFi 6 enabled routers and smartphones commercially available today, the performance of WiFi 6 networks in the real world, especially when using 160 MHz channels, remains largely unknown. Aggarwal et al. [2] studied the performance and power consumption of the first-generation of WiFi 6 smartphones supporting only 80 MHz channels. Liu et al. [6] recently studied the impact of OFDMA and TWT on performance and power consumption, but, similar to [2], they also used 80 MHz channels in their study. Additionally, these studies only considered the 5 GHz frequency band.

Our work, to the best of our knowledge, conducts the first performance and interference characterization of 802.11ax links using 160 MHz channels using commercial-off-the-shelf (COTS) devices. Additionally, we evaluate for first time the performance and interference patterns of 802.11ax in the 6 GHz frequency band (WiFi 6e) and compare them against the performance and interference patterns in the legacy 5 GHz band (WiFi 6).

Our performance evaluation shows that WiFi 6/6e using 160 MHz channels can achieve Gbps data rates, 78-84% higher than using 80 MHz channels, at short ranges and LOS conditions. However, the throughput of 160 MHz channels drops fast at longer AP-client distances or in environments with multiple walls, especially in the 6 GHz band. Our interference characterization study using links with homogeneous channel widths shows strong interference due to power leakage in adjacent channels, in both frequency bands. In the uplink direction with 80 MHz and 160 MHz channels, interference is also observed in non-adjacent channels more than 400 MHz apart. Further, our experiments using links tuned to overlapping channels with heterogeneous channel widths and different primary channels reveal a variety of interference patterns, which were not observed in previous studies with 802.11n or 802.11ac links. We believe that the findings presented in this work will help in understanding the potential and pitfalls of using wide channels in today's and future dense WiFi AP deployments.

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TABLE I: Baseline throughput (Mbps) for different channel widths.

	WiFi 6		WiFi 6e	
	Downlink	Uplink	Downlink	Uplink
160 MHz	1628	1685	1641	1657
80 MHz	931	918	923	928
40 MHz	470	459	468	460
20 MHz	243	231	241	232

II. Experimental Methodology

We use Samsung Galaxy S21 Ultra smartphones and Netgear Nighthawk RAXE500 WiFi routers for all the experiments. Both devices support all the 802.11ax MCSs (0-11) and channel widths of 20/40/80/160 MHz. The phone supports two spatial streams, yielding peak PHY data rates up to 2.4 Gbps. The router supports 4 spatial streams, yielding peak PHY data rates up to 4.8 Gbps.

We use iperf3 to generate backlogged TCP traffic, with the default congestion control algorithm, CUBIC, and log throughput every 100 ms. In the baseline/range experiments (§III-A, §III-B), we collect one 60 s trace and present the mean and standard deviation (error bars) of all the 100 ms samples. In all other experiments, we collect 3-6 traces of 20 s each and present their average and standard deviation. We set up a WiFi 6/6e capable laptop in monitor mode and captured MAC headers from which we extract the selected MCS, number of spatial streams, and channel width. All the experiments are performed at night in a university campus to avoid interference from other networks in the campus. In all our experiments, we use the channels on the lower end of each frequency band, i.e., channel number 36 and 33 for WiFi 6 and WiFi 6e, respectively, unless otherwise stated.

III. Performance Characterization

A. Baseline experiments

We begin by comparing the peak performance achieved by the two technologies (WiFi 6 and WiFi 6e) operating at both 160 MHz and 80 MHz in the downlink (router to phone) and uplink (phone to router) direction. The phone is kept 5 ft away from and facing the AP with no obstruction in between, establishing a LOS link.

Table I shows that *both WiFi technologies with 160 MHz channels achieve Gbps throughput* (∼1.6 Gbps) in both directions. However, the throughput gain of 160 MHz channels over 80 MHz channels (78-84%) is lower than the gain of 80 MHz over 40 MHz channels or 40 MHz over 20 MHz channels (93-102%). The performance is symmetric in both directions. This observation is different from the one reported in [2], where with WiFi 6 at 80 MHz, the uplink performance was always lower then the downlink performance by ∼300 Mbps. This disparity probably stems from our usage of upgraded devices – Samsung S21 and Netgear RAXE500 in contrast to Samsung S10, Xiaomi Mi 10, and Asus RT-AX88U, which were the state-of-the-art devices when the work in [2] was conducted.

B. Range

In this section, we evaluate the impact of channel width (160 MHz vs. 80 MHz) and frequency band (5 GHz vs. 6 GHz) on the communication range. We perform measurements in a long, narrow corridor, approximately 6 ft wide. We measure uplink and downlink throughput while varying the AP-client distance from 5 ft to 85 ft.

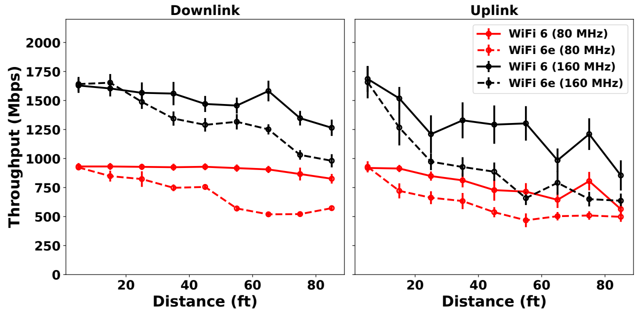


Fig. 1: WiFi 6/6e throughput over distance.

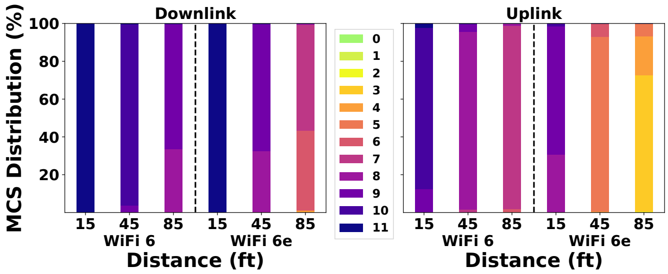


Fig. 2: MCS distribution at 160 MHz for range experiments.

Fig. 1 shows that *the throughput with 160 MHz channels drops fast with distance for both technologies and in both traffic directions*. At 85 ft, the WiFi 6 (WiFi 6e) downlink/uplink throughput drops down to 78%/51% (60%/38%) of the baseline value. Importantly, *the throughput drop is more pronounced in case of WiFi 6e*. Further, *the gap between the two technologies is more pronounced in the uplink direction*, possibly due to lower transmit power on the smartphone compared to the router and/or due to the small form-factor of the smartphone antennas. While in the downlink direction both technologies sustain Gbps throughput with 160 MHz channels even at a distance of 85 ft from the AP, in the uplink direction, the WiFi 6e throughput drops below 1 Gbps at distances longer than 25 ft. In fact, at distances longer than 45 ft from the AP, the WiFi 6e uplink throughput at 160 MHz becomes comparable to the WiFi 6 throughput at 80 MHz.

Using monitor traces, we found that both WiFi technologies never drop their channel bandwidth and use 2 spatial streams 99% of the time. Fig. 2 shows the MCS distribution at 3 representative AP-client distances: 15 ft (near), 45 ft (middle), and 85 ft (far). For both technologies, the drop in MCS is much faster in case of uplink as the AP-client distance increases. This explains the high throughput disparity between downlink and uplink at longer distances (>45 ft) for a particular technology. In addition, for a given distance, WiFi 6 always has a higher MCS compared to WiFi 6e.

In contrast to 160 MHz, the throughput at 80 MHz for WiFi 6 is trivially affected by the distance in the downlink direction, whereas for WiFi 6e, there is a significant drop, especially as the AP-client distance becomes more than 45 ft. On the other hand, for uplink, there is performance degradation for both

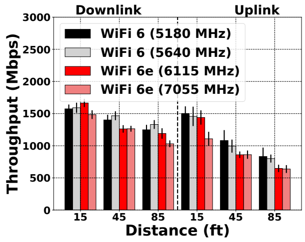


Fig. 3: Performance comparison at different frequencies.

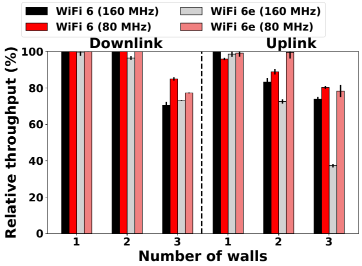


Fig. 4: Performance comparison under blockage.

technologies as the AP-client distance increases, however, the degradation is again more pronounced for WiFi 6e.

C. Performance at different frequencies

The results in the previous section illustrate a significant difference in the throughput of WiFi 6 vs. WiFi 6e, especially at longer AP-client distances, indicating that higher operating frequencies have a large impact on performance. In this section, we further explore the impact of the operating frequency on performance. In our baseline and range experiments, we chose a channel that corresponds to the bottom of the frequency spectrum for each technology – 5180 MHz for WiFi 6 and 6115 MHz for WiFi 6e. In this section, we compare the performance at the lower and upper end of each frequency band. Fig. 3 shows the results for three different distances.

Fig. 3 shows that *the operating frequency has a minimal impact on the performance of WiFi 6*. In fact, in the downlink direction, the throughput at the upper end of the spectrum (5640 MHz) is slightly higher than at the lower end of the spectrum (5180 MHz). On the other hand, *the impact is more pronounced in the case of WiFi 6e*, as the frequencies are higher and the gap between the lower and upper end of the spectrum is larger.

D. Performance under blockage

To assess the performance under blockage, we kept the AP in a room inside an office building and placed the phone in nearby rooms separated by one, two, and three walls from the room in which the AP was kept. The distance between the AP and the phone in the three cases were 10 ft, 20 ft, and 30 ft, respectively. We also repeated the experiments at the same three distances in LOS conditions to establish the baseline performance. Fig. 4 shows the performance under blockage relative to the baseline performance.

We observe that *blockage has a higher impact on wider channels* for both technologies. The throughput gap between 80 MHz and 160 MHz channels is small for WiFi 6 in both traffic directions and for WiFi 6e in the downlink direction, but increases significantly in the uplink direction for the latter. With two walls between the AP and the client, the WiFi 6e throughput at 160 MHz drops to 73% of the baseline while the throughput at 80 MHz remains unaffected. Similarly, with three walls between the AP and the client, the WiFi 6e throughput at 160 MHz drops to 38% of the baseline while the throughput at 80 MHz only drops to 78%. Using monitor traces, we found that, similar to the range experiments, the AP and the phone only drop the MCS to combat signal attenuation while always keeping the channel width and number of spatial streams fixed. We found that WiFi 6e uses MCS 2 and 3 more than 95% of the time in the uplink direction with three walls, which explains its large throughput drop in Fig. 4.

Overall, the results in §III-A-§III-D show that, *160 MHz channels offer significant throughput gains compared to 80 MHz channels at short ranges and LOS conditions, but they experience faster performance degradation with the AP-client distance and are more susceptible to blockage, especially in the uplink direction. Additionally, the degradation is much more pronounced in WiFi 6e as its higher operating frequency suffers higher attenuation. While the new 6 GHz band opens up more spectrum creating ample opportunities for interference-free operation across multiple non-overlapping 160 MHz channels, the benefits of 160 MHz channels diminish at longer distances or in environments with multiple walls, where their throughput often becomes comparable to or lower than the throughput of 80 MHz channels.*

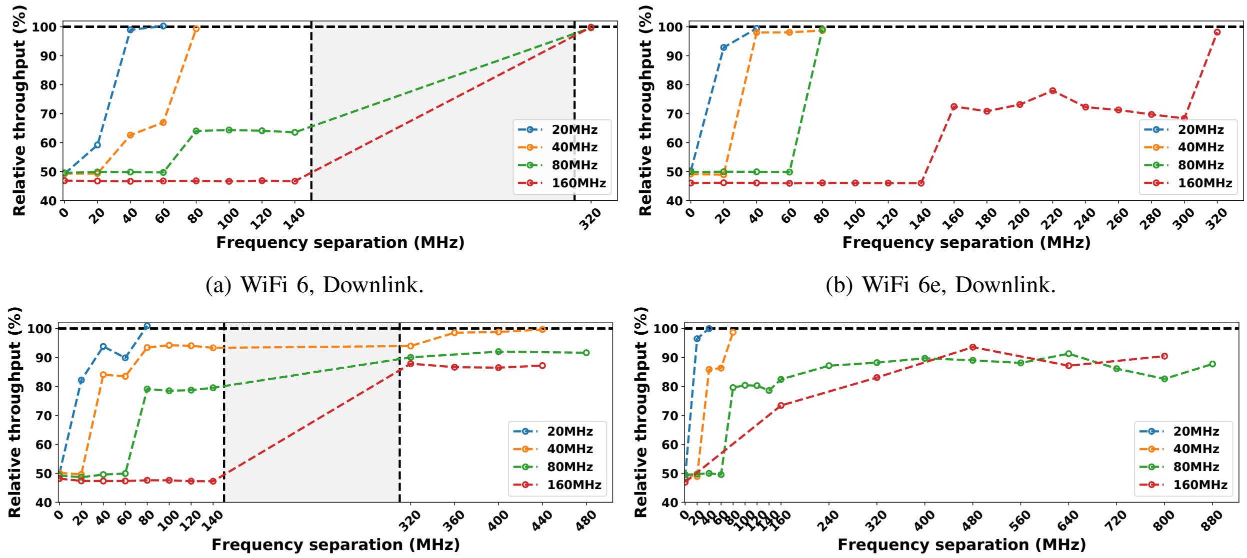
IV. Interference Characterization

In this section, we perform the first detailed interference characterization study of 160 MHz WiFi channels in both frequency bands. We divide our study in two parts. We study interference between links with homogeneous channel widths in §IV-A and with heterogeneous channel widths in §IV-B. In both sections, our set up involves two router-phone links, 3 ft apart form each other, unless otherwise mentioned. The router-phone distance is set to 5 ft.

A. Homogeneous channel widths

In this case, both links use the same channel width. 802.11ax APs, irrespective of the channel width, always utilize a 20 MHz *primary channel* inside the specific channel width as a control channel to send beacons and management frames. Similar to its predecessors, 802.11ax allows the selection of any 20 MHz channel within a specific channel width as the primary channel. Hence, we perform experiments with multiple *overlapping*, *adjacent*, and *non-adjacent* 40/80/160 MHz channels.

We tune the two links to the same primary channel (the one at the lower end of each frequency band) for a given channel width and record the performance when the two links are individually and then simultaneously active. Then, we keep changing link 2's primary channel at a step of 20 MHz until the sum throughput of the two links when they are active simultaneously becomes equal to the sum throughput of two links in isolation. Fig. 5 shows the normalized throughput of the two links with respect to the baseline (sum throughput of individual links) as a function of the frequency separation between their primary channels. Note that in the 5 GHz band, the frequency chunk between 5330 MHz and 5490 MHz is unused. This corresponds to the gray area in Figs. 5a and 5c. Ideally, the relative throughput in Figs. 5a-5d should be equal to 50% of the baseline in the case of overlapping channels, where nodes compete for access to the medium using CSMA, and



(a) WiFi 6, Downlink.

(b) WiFi 6e, Downlink.

(c) WiFi 6, Uplink.

(d) WiFi 6e, Uplink.

Fig. 5: Relative sum throughput of two links transmitting simultaneously with respect to the sum throughput of the two links transmitting individually, as a function of the frequency separation between their primary channels.

100% of the baseline in the case of non-overlapping (adjacent and non-adjacent) channels.

Figs. 5a-5d confirm that, across all cases, when the two links are on overlapping channels, their sum throughput is close to 50% of the baseline, irrespective of their primary channel. This suggests that the links achieve fair sharing as expected. However, when link 2 is tuned to non-overlapping channels, the performance is different across the technologies and traffic directions. The sum throughput of the two links is lower than the baseline in most cases when the links are tuned in adjacent channels and often even when they are tuned in non-adjacent channels, indicating interference between the two links due to channel leakage between theoretically orthogonal channels. We discuss our observations separately for each traffic direction.

Downlink. *In the case of WiFi 6, irrespective of the channel width, the primary channels of the two links need a frequency separation at least twice the size of the operating channel bandwidth, to achieve a performance similar to the baseline*, as shown in Fig. 5a. In other words, we observe strong interference between adjacent channels only. We found from sniffer traces that when the two links are tuned in adjacent channels, the number of MAC retries is very low (<5%) and the highest MCS is used more than 90% of the time, suggesting power leakage mainly between the two transmitters, which results in carrier sensing and deferred transmissions. Similar observations were made in [3] for 802.11n WiFi links operating at 20 and 40 MHz channel widths.

On the other hand, for WiFi 6e (Fig. 5b), we observe two different patterns. *For 20 and 160 MHz channels, the results are similar to WiFi 6, where a separation of frequency separation at least twice the size of the operating channel bandwidth is required for interference-free transmissions*. However, for 40 MHz and 80 MHz channels, the sum throughput is 98% of the baseline when link 2 is set to an adjacent channel. In other words, *there is no interference between adjacent channels when their channel width is 40 MHz or 80 MHz*. Sniffer traces for adjacent 40 MHz and 80 MHz channels show that the number of MAC retries is negligible (<1%) and MCS 11 is used >98% of the time, while for 20 MHz and 160 MHz channels, the number of MAC retries is slightly higher (3-5%), and MCS 11 is used less often (80-90% of the time). However, a 20 MHz channel bandwidth results in much better performance in adjacent channels compared to 160 MHz bandwidth (93% vs. 70% of the baseline), as shown in Fig. 5b.

Uplink. In contrast to the downlink direction, Figs. 5c and 5d do not reveal any distinct interference pattern in the uplink direction. WiFi 6e links operating at 20 MHz and 40 MHz channel widths achieve a performance similar to the baseline when their primary channels are separated by a distance at least twice the size of the operating channel width, similar to the behavior observed for the WiFi 6 downlink links (Fig. 5a), although the performance of 20 MHz links tuned in adjacent channels is also very close (93%) to the baseline. On the other hand, WiFi 6 links operating at 20 MHz and 40 MHz channel widths need a much large frequency separation of their primary channels for interference free transmissions – 80 MHz and 360 MHz, respectively. Even more surprisingly, *80 MHz and 160 MHz links in both frequency bands always interfere even when there is a frequency separation of more than 400 MHz and 800 MHz for WiFi 6 and WiFi 6e, respectively!* Figs. 5c and 5d shows that their sum throughput never exceeds 90% of the baseline.

Sniffer traces reveal that, when link 2 is tuned to an adjacent channel, there is a significantly higher number of MAC retries compared to the downlink case, often exceeding 10%, as well as high MCS fluctuation. In the case of 20 MHz and 40 MHz channels, as the link 2 is tuned to non-adjacent channels, the number of MAC retries and the MCS fluctuation start

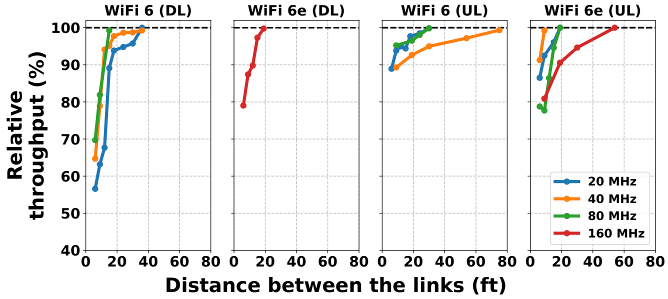


Fig. 6: Impact of link distance on mutual interference.

reducing, finally allowing the links to be completely free from interference when the frequency separation becomes 80 MHz (WiFi 6 at 20 MHz), 360 MHz (WiFi 6 at 40 MHz), or 40/80 MHz (WiFi 6e at 20/40 MHz), as we saw in Figs. 5c and 5d. On the other hand, for 80 MHz and 160 MHz channels, we observe that MCS fluctuations in non-adjacent channels continue even at a separation of 400+ MHz (WiFi 6) or 800+ MHz (WiFi 6e).

The larger number of MAC retries and MCS fluctuations in adjacent channels in the uplink case, compared to the downlink case, suggests more collisions due to power leakage on the receiver (AP) side, when the two clients transmit without sensing each other's transmissions. This is different from the downlink case, where we concluded that the main reason for low performance in adjacent channels is carrier sensing on the transmitter side. By comparing Fig. 5a against Fig. 5c for WiFi 6, we observe that the relative throughput when the two links operate in adjacent channels is much higher in the uplink case compared to the downlink case (80% vs. 60-70% of the baseline), which further strengthens our conjecture; carrier sensing due to leakage on the transmitter side in the downlink results in higher throughput drop compared to the drop caused by 10% MAC retries due to collisions in the uplink.

Overall, our analysis of the root causes of performance degradation – carrier sensing on the transmitter side in the downlink direction, collisions on the receiver side in the uplink direction – suggest that in both cases, power leakage is caused mainly by imperfect analog filters on the AP side rather than the phone side. This might be an artifact of the devices we use in our study. Our client devices, S21 Ultra phones, are flagship smartphones; on the other hand, our WiFi routers are consumer-grade routers (albeit high-end models), which may have imperfections compared to enterprise-grade models.

Further, our results suggest *less interference due to power leakage between adjacent channels in the 6 GHz band compared to the 5 GHz band*. We conjecture that 802.11ax routers embed newer and better analog filters in the 6 GHz band, reducing power leakage and leading to better performance.

Impact of link distance. To further understand the interference range in adjacent channels, we repeat the experiments with the two links tuned in adjacent channels for those cases where the relative sum throughput is less than 90% of the baseline in Fig. 5, while we gradually increase the distance between the two links.[1] Fig. 6 shows that the mutual interference between the two links gradually decreases as the distance between the two links increases, across all channel widths. In the downlink scenario, for WiFi 6, the interference reduces faster for larger channel widths; the interference-free distance is 15 ft for 80 MHz channels, 24 ft for 40 MHz channels, and 40 ft for 80 MHz channels. Similarly for WiFi 6e, the interference-free distance for 160 MHz channels is 18 ft. This is intuitive, as, for the same total Tx power, the Tx power per subcarrier is higher for narrower channels. However, our observations are completely different for the uplink scenario. For WiFi 6, 20 MHz and 80 MHz links recover from interference when they are 30 ft apart, while 40 MHz links require a distance of 75 ft. On the other hand, for WiFi 6e, the interference-free range is the shortest for 40 MHz links, while 160 MHz links require a distance of at least 55 ft.

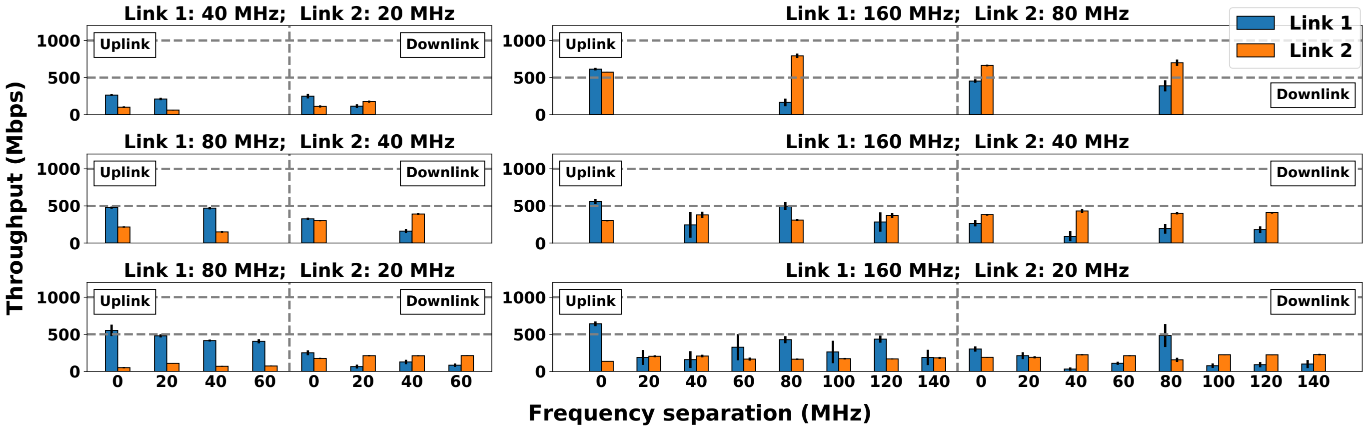
Overall, our results in this section show that *there is strong interference due to power leakage from transmissions in adjacent and even non-adjacent channels across both frequency bands, all channel widths, and both traffic directions (with the exception of WiFi 6e downlink at 40 MHz and 80 MHz). In the downlink direction, for both technologies, links typically recover from interference at a frequency separation twice the channel width but in the uplink direction, WiFi 6/6e links using wide channels interfere even when their channels are 400/800 MHz apart. Increasing the distance between the links helps to mitigate the mutual interference, however in the uplink direction, interference exists even at distances of 60-80 ft.*

B. *Heterogeneous channel widths*

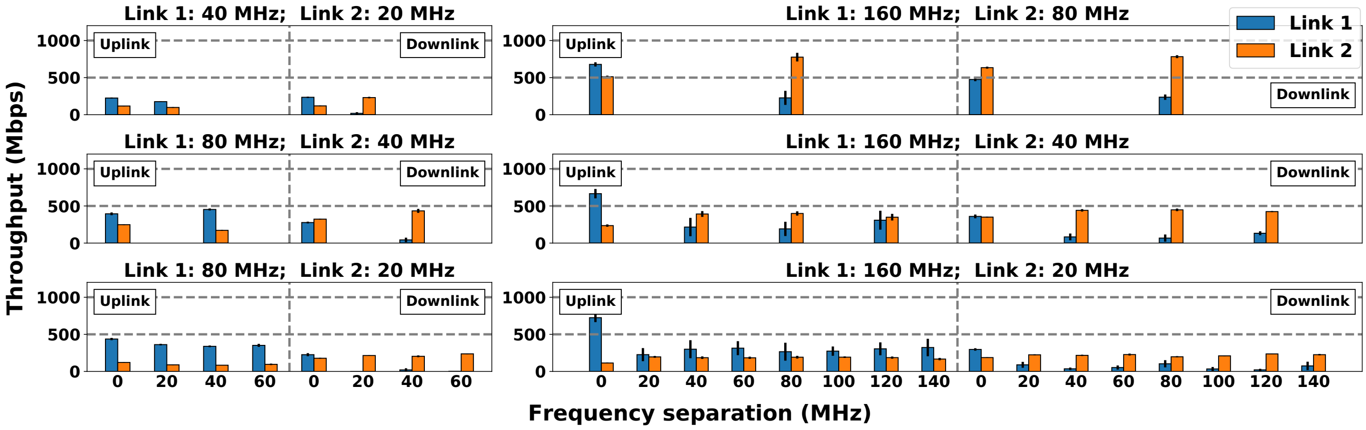
We now consider links with *overlapping* channels but heterogeneous channel widths. We consider two scenarios: 1) Both links are tuned to the same primary channel, and b) the two links are tuned to different primary channels. We consider all possible combinations of heterogeneous channel widths – 40/20 MHz, 80/20 MHz and 80/40 MHz, 160/20 MHz, 160/40 MHz, and 160/80 MHz. For each channel width combination, link 1 always uses the wide channel and link 2 uses the narrow channel. Link 1's primary channel is always the one at the lower end of each frequency band and we repeat the experiments tuning link 2 to different channels overlapping with link 1's channel for a given channel width. Fig. 7 shows the performance for the two scenarios. We make the following observations:

Scenario 1. When the two links operate on the same primary channel, there is a throughput drop for both links compared to the baseline case when they transmit individually, shown in Table I. Since both links use the same primary channel, they can sense each other and they time-share their transmissions. The throughput drop is more or less proportional to the channel width in most cases, and, as expected, the wide channel achieves higher throughput compared to the narrow channel. The same observation was reported in [7] for 802.11ac with 20/40/80 MHz channels.

[1] We skip this experiment for WiFi 6 using 160 MHz as we are not allowed to tune link 2 to the adjacent channel spanning 5330-5490 MHz.

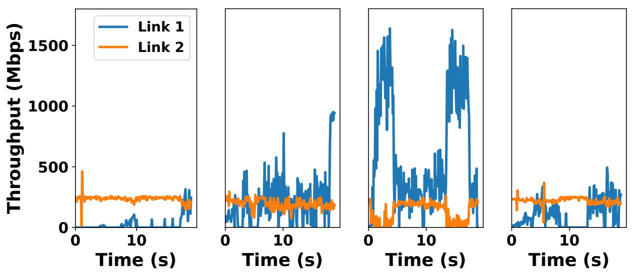


(a) WiFi 6.



(b) WiFi 6e.

Fig. 7: Link 1 and link 2 throughput as a function of the frequency separation of the two primary channels when the links are operating on overlapping channels using different channel widths.



(a) Pattern 1. (b) Pattern 2. (c) Pattern 3. (d) Pattern 4.

Fig. 8: Timelines showing different throughput patterns in experiments with heterogeneous channel widths (160 MHz for link 1, 20 MHz for link 2) when the two links are tuned to different primary channels.

Scenario 2. When the narrow link is tuned to a different primary channel, we observe a variety of behaviors. There are cases where the wide channel (link 1) starves, e.g., for WiFi 6e in the downlink direction with channel width combinations 80/40 MHz, 80/20 MHz, and most of the cases with 160/20 MHz in Fig. 7b, cases when the narrow channel (link 2) obtains higher throughput but without completely starving the wide channel, e.g., for WiFi 6 in the downlink direction with channel width combinations 80/40 MHz, 160/80 MHz, and 160/40 MHz in Fig. 7a, and cases where the wide channel obtains higher throughput than the narrow channel, similar to Scenario 1, e.g., in the uplink direction for WiFi 6 with 80/20 MHz in Fig. 7a and for WiFi 6e with 80/20 MHz and 160/20 MHz in Fig. 7b. We even observe cases where, for a given technology, direction, and channel width combination, the performance changes as link 2 is tuned to different primary channels. For example, for WiFi 6 in the downlink directions with 160/20 MHz in Fig. 7a, link 1 outperforms link 2 when link 2 uses channel 5, the two links achieve similar throughput when link 2 uses channel 2, but link 2 outperforms link 1 when it is tuned in channels 3, 4, 6, 7, or 8.

Fig. 8 shows example timelines of link 1 and link 2's throughput patterns with link 1 using a 160 MHz channel and link 2 using a 20 MHz channel. Pattern 1 (Fig. 8a) is an example where the narrow channel completely starves the wide channel and Pattern 2 (Fig. 8b) an example where the two links achieve similar throughput, although the throughput of the wide channel exhibits large fluctuations (this is also evident from the larger standard deviations for link 1's throughput compared to link 2's throughput in Fig. 7). We also observe cases (Pattern 3) where the wide channel almost starves the narrow channel for intervals lasting several seconds, interleaved with intervals where the two links share the capacity, as seen in Fig. 8c. In the final pattern (Fig. 8d), the wide channel starves completely for a few seconds and then recovers. Upon checking the sniffer traces, we found absolutely no frames (control or data) present during those few seconds when link 1 starves, and, in most of the cases, when the throughput recovered, the bandwidth dropped from 160 MHz to 80 MHz.

Note that our observations in scenario 2 are very different from the ones in [7] for 802.11ac in the same scenario. The authors in [7] observed consistently that the narrow channel starves the wide channel for all channel width combinations. An important consideration to keep in mind is that the authors in [7] conducted their experiments with *static channel width access* and found that a node aborts when it senses any of its secondary channels busy instead of freezing the backoff counter, which explains the starvation of the wide channel. However, the routers we use in this work support only *dynamic channel width access*, i.e., they allow setting a maximum channel width but they can drop the channel width dynamically when they sense some of the secondary channels busy. Consequently, we cannot directly compare our results with those in [7]. We also repeated our experiments with different AP and client devices (Lenovo Legion laptop, Asus RT-AX88U router, Asus RT-AX89X router, Asus ROG Rapture GT-AXE11000 router), as well as with UDP traffic, and we observed the same patterns, in particular pattern 4 in Fig. 8d in all cases.

Overall, our experiments in this section show that *when links with different channel widths are tuned to overlapping channels but with different primary channels, they exhibit a variety of interference patterns. In most cases, the wide channel achieves higher throughput than the narrow channel in the uplink direction, but lower throughput in the downlink direction, although there are exceptions. We also observed several instances where the throughput of the link tuned to a wide channel drops to 0 for an interval of a few seconds, but then recovers after the AP switches to a lower channel width.* We plan to further investigate these patterns as part of our future work.

V. Related Work

There is only a handful of experimental studies of 802.11ax using real-world devices [1], [2], [4], [6]. As mentioned in §I, the works in [1], [2], [6] conduct experiments only with 80 MHz channels in the 5 GHz band. Dogan-Tusha et al. [4] conduct a measurement study in a WiFi 6e campus network supporting 160 MHz channels but focus on evaluating the interference caused by WiFi 6e routers on incumbents using the same frequency band, which is orthogonal to our study.

In terms of interference characterization, the two works most closely related to ours are the ones in [3], [7]. Deek et al. [3] study the impact of channel bonding as well as the effects of both co-channel and adjacent channel interference on network performance in 802.11n networks that support only 20 MHz and 40 MHz channels. Zeng et al. [7] study the interference among links with heterogeneous channel bandwidths tuned in overlapping channels in 802.11ac networks supporting 20, 40, and 80 MHz channels. While some of their observations are confirmed by our study for 160 MHz channels, many of our findings are different from those reported in [3], [7].

VI. Conclusion

We presented the first experimental performance and interference characterization of WiFi 6 and WiFi 6e with 160 MHz channels using APs and smartphones. Our performance study shows that 160 MHz channels offer significant throughput gains and are more energy efficient than 80 MHz channels at short ranges and LOS conditions, but they experience faster performance degradation with the AP-client distance and are more susceptible to blockage, especially in the 6 GHz band. We also perform the first extensive interference characterization of WiFi 6/6e. Our interference study reveals strong interference due to power leakage between among adjacent channels with homogeneous channel widths, which, in the case of uplink transmissions and 80/160 MHz channels, extend to non-adjacent channels more than 400 MHz apart. We also observe a variety of interference patterns between links in overlapping channels using heterogeneous channel widths and different primary channels, which have not been observed in previous studies with 802.11n or 802.11ac links. Given that the new 802.11be standard introduces support for even wider channels, our results show the need for carefully designed interference management schemes in dense WLAN deployments.

Acknowledgments

This work was partially supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on "Telecommunications of the Future" (PE00000001 - program "RESTART"), as well as the project RISC-6G (TSI-063000-2021-63) by the Spanish Ministry of Economic Affairs and Digital Transformation and the European Union-NextGenerationEU through the UNICO-5G R&D Program of the Spanish Recovery, Transformation and Resilience Plan.

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