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Whitepaper

Wi-Fi 8:
Ultra High Reliability in the Unlicensed Bands

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Abstract

Now that the 802.11be task group has started to wrap up its standardization efforts, the IEEE 802.11 working group has turned its attention to the development of the next generation Wi-Fi standard. The recently formed Ultra High Reliability (UHR) study group will work on drafting a Project Authorization Request (PAR) of what will become the next major release of Wi-Fi, i.e., Wi-Fi 8. Compared to 802.11be (i.e., Wi-Fi 7) mainly focuses on improving the throughput (i.e., Extremely High Throughput Wi-Fi), UHR focuses on reliability. In this paper, we give an overview of the potential technologies and use cases that are currently being discussed in the UHR study group with the hope of encouraging wireless researchers to contribute to its development.

I. Introduction

As Wi-Fi applications evolve, their demand for higher data rate, lower latencies and higher reliability also continuously increases. Therefore, even before 802.11be devices start to proliferate, the IEEE 802.11 working group is already preparing the next generation 802.11 standard. The IEEE 802.11 working group voting members have agreed to form the Ultra High Reliability (UHR) Study Group (SG) during the July 2022 plenary meeting with a Yes vote of 134 and a No vote of 8 (94% approval) with the intent of creating a Project Authorization Request (PAR) and a Criteria for Standards Development (CSD) which initiate the creation of the next generation Wireless LAN (WLAN) standard. When both CSR and Par are approved, a task group for UHR will be created whose task is to develop the actual new technologies that will be included in Wi-Fi 8.

During the time this paper was written, the UHR SG has yet to approve official PAR and CSD drafts. However, according to the latest versions of two proposed PAR documents [1, 2], UHR will be able to support a maximum aggregate throughput of at least 100 Gbps and carrier frequencies that covers the millimeter wave bands. For latency sensitive applications, UHR is expected to provide improvements in terms of maximum latency and jitter at the 99 to 99.9999th percentile compared to 802.11be [1].

Due to the competition for channel access in the unlicensed bands, providing a highly reliable connection has become increasingly harder to achieve. As the standardization for UHR is still in the very early stages, it is hard to predict what technologies will be adopted to achieve UHR's goal. In this paper, we review a number of technologies that have the potential to be adopted in the UHR standardization based on the early UHR SG discussions during the November 2022 IEEE 802.11 plenary meeting and UHR SG conference calls. These technologies include multiple access point (AP) coordination and transmission (Section II), low latency mechanisms (Section III) and millimeter wave (mmWave) links (Section IV). We conclude the paper in Section V.

II. Multi-AP Transmission

Figure 1: Coordinated beamforming and joint transmission

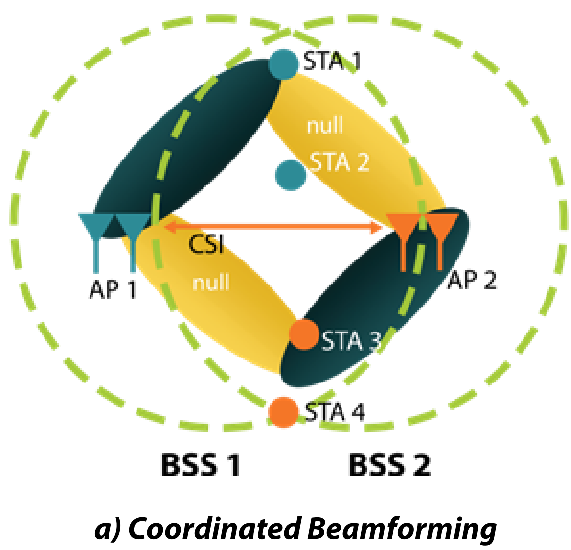
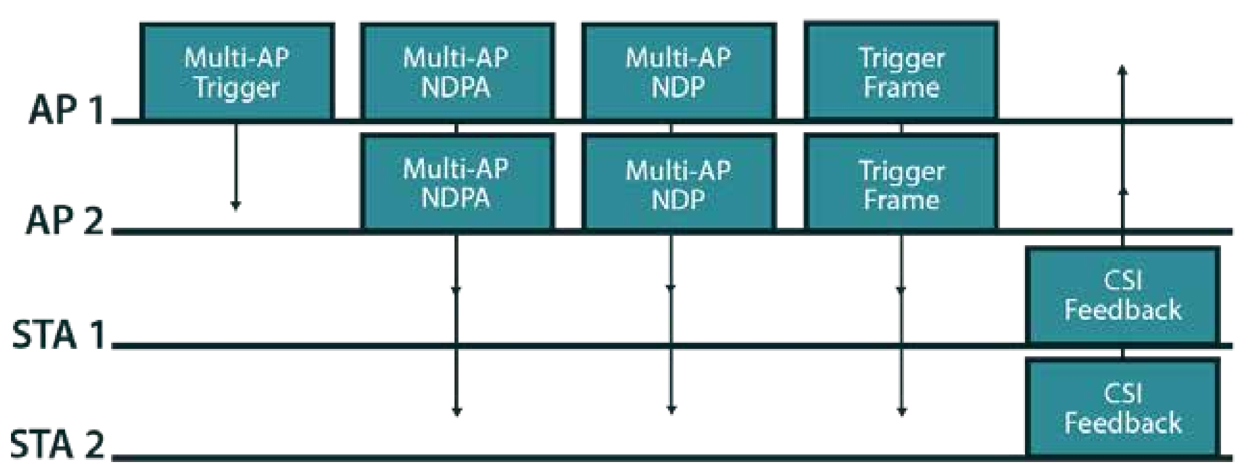


Figure 2: Joint Sounding. STAs 1 and 2 are associated with APs 1 and 2 respectively



Ultra-high reliable Wi-Fi is expected to support multiple AP (multi-AP) coordination and transmission. A typical Wi-Fi basic service set (BSS) will often co-exist with another BSS that operates in the same channel. This is especially true in a building where each room is served by a dedicated AP such as an apartment or an office. Because of this, transmissions from one BSS interfere with transmissions from another BSS resulting in system throughput degradation.

With multi-AP coordination and transmission, multiple independent APs (e.g., AP 1 and AP 2) can coordinate their transmission parameters such as operating frequency, transmit schedule, and transmit power such that the transmissions do not interfere with each other. For example, in a coordinated time domain multiple access (CTDMA) scheme, APs can schedule the transmissions in their own BSS such that they do not overlap with another BSS's transmissions (i.e., given they know the other AP's schedule). In a coordinated orthogonal frequency domain multiple access (COFDMA) technique on the other hand, transmissions from two or more BSS may overlap in time but are transmitted in distinct frequency channels/bands. In a coordinated spatial reuse (CSR), the transmissions from two or more BSSs may overlap in both time and frequency but the transmit powers are precisely controlled such that the interference experienced by a receiving station (STA) is small enough not to cause a packet reception error.

While the above techniques effectively allow multiple BSSs to share resources, each BSS's maximum throughput in every multi-AP transmission is also reduced proportional to the number of BSSs participating. A way to solve the problem is to perform advanced beamforming techniques such as coordinated beamforming (CBF) or joint transmission/reception (JTR) as shown in Fig. 1. When multiple APs can share instantaneous channel state information (CSI), it enables them to perform digital beamforming such that simultaneous transmissions can be done on the same time and frequency resources at the maximum allowed antenna transmit power.

CBF and JTR are the two most sophisticated multi-AP schemes being considered for Wi-Fi. CBF as shown in Fig. 1a allows both APs to transmit a signal to its target STA while at the same time forming a null to the target STA of the other AP. Since the transmissions can be done at the same frequency and time and at the allowed maximum antenna transmit power, no reduction of throughput occurs (i.e., aside from the overhead of the sounding procedure). JTR is a more advanced scheme compared to CBF and requires a much higher synchronization accuracy compared to CBF. As shown in Fig. 1b, JTR involves transmitting the signals destined to the two target STAs simultaneously from both APs. This requires the two APs to

have a chip level synchronization as well as a shared payload for both target STAs. The advantage of this compared to CBF case is increase of transmit diversity and antenna efficiency as the APs can use more of their transmit antennas for actual data transmission instead of transmitting nulls.

Channel state information for CBF or JTR can be obtained by performing joint sounding between two or more APs. As seen in Fig. 2, a joint sounding procedure can be initiated by one AP (AP 1) by transmitting a multi-AP trigger frame. Note that a trigger frame in 802.11 is a control frame that triggers a transmission from another STA. In this case, because the triggered STA is an AP, the trigger frame is called a multi-AP trigger frame. The multi-AP trigger frame from AP 1 triggers AP 2 to send a multi-AP null data packet announcement (NDPA) whose purpose is to inform the STAs (i.e., STA 1 and STA 2) a multi-AP Null Data Packet (NDP) is about to be transmitted. Upon reception of the multi-AP NDP, STA 1 and STA 2 will each compute their CSI from both APs using the training symbols contained in the multi-AP NDP. Both APs will then solicit this information from both STAs using another trigger frame specific for this purpose.

In summary, multi-AP coordination and transmission techniques are one of the promising technologies that UHR can support. Given the substantial discussions the 802.11be task group has already done regarding this technology, the possibility that it will be adopted in UHR is considerably high.

III. Low Latency

During the IEEE 802.11be standardization, TGbe developed new tools to support low latency traffic. These tools included multi-link operation (MLO), restricted Target Wake Time (R-TWT) and a new Stream Classification Service (SCS) based Quality of Service (QoS) signaling mechanism. In [4], the authors showed that 802.11be using both R-TWT and the new SCS based QoS signaling can achieve a bounded latency of less than 25 ms. However, this is still not enough to meet industrial applications that require latencies of less than a ms to a few ms [5]. While it is unclear if UHR can meet this latency goal, it is expected that UHR will build on top of the mechanisms developed by 802.11be to further lower the maximum latency of Wi-Fi.

Multi-link operation is the ability of an 802.11be device to operate over multiple links. By doing so, it is able to increase its throughput by mapping multiple traffic streams to multiple links instead of one link in pre-802.11be. To support the requirements of a low latency application, it can map the traffic of a low latency application to a link with a lower latency to ensure that data is transmitted without the need for retransmissions. This can be any channel in the 6 GHz band since pre-802.11ax devices (the majority of Wi-Fi devices) are currently not using the band. With UHR, talks are ongoing whether to support 71 GHz bands as potential links under MLO. When adopted, UHR devices can take advantage of the several GHz of frequency resources in these bands to support low latency applications.

802.11be devices support a new variant of the TWT mechanism called the restricted TWT. The original TWT mechanism gives STAs pre-defined service periods (SP) to transmit and receive packets for the purpose of power optimization, i.e. STAs can switch their power state to doze state except in their allocated TWT periods. During a STA's allotted TWT, it may find that the channel is busy due to another STA. This can be a STA that started transmitting just before the start of the said TWT schedule. The R-TWT mechanism is a variant of the original TWT mechanism that solves this problem. It does this by requiring STAs to end their current transmissions before the start of the R-TWT SP. As shown in Fig. 3, STA 2, which has a low latency traffic joins the R-TWT SP for it to transmit its data. STA 1, which is not a member of the R-TWT SP ensures that its transmission finishes before the R-TWT SP starts and continues transmitting any remaining frames after the R-TWT SP.

While the R-TWT mechanism provides increased determinism specially for periodic traffic, it may be ineffective in providing protection for non-periodic low latency traffic use cases. Non-periodic low latency traffic includes emergency stop packets for wirelessly controlled factory robots and sensor packets for VR and game controllers. When a STA is already transmitting a low priority frame when these high priority non-periodic frames arrive to the STA, there is currently no way for a STA to transmit them until the on-going transmission finishes.

Interrupting an ongoing transmission to transmit a higher priority frame is currently not supported in Wi-Fi. An example is shown in Fig. 4. In this figure, the STA is already transmitting a low priority data frame when another high priority packet frame arrived. In order to transmit the higher priority frame, the STA terminates the transmission of the lower priority frame and start transmitting the higher priority frame. If an AP receiving the high priority data frame receives it correctly, it sends an acknowledgement frame (ACK) back to the STA. A more difficult problem is when the on-going low priority transmission is done by another peer STA or worse, if the on-going low priority transmission is done by the target receiver of the high priority frame.

Finally, Artificial Intelligence (AI) or Machine Learning (ML) algorithms can reduce low latency of non-periodic traffic by learning the latency profile of the channel and optimize it such that low latency traffic can be transmitted with minimal latency and/or jitter. The recently formed AIML topic interest group in the IEEE 802.11 WG is actively discussing other AI/ML methods that can be potentially adopted by UHR [6].

Figure 3: Restricted Target Wake Time

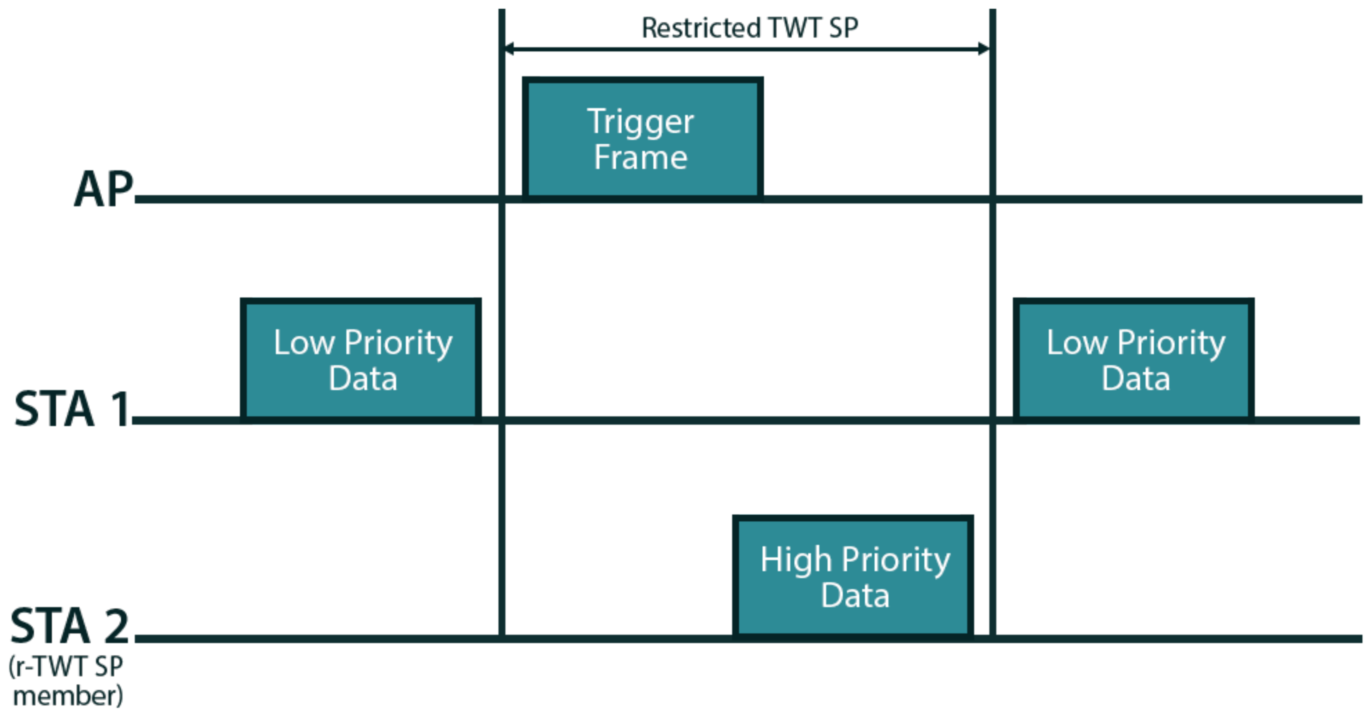


Figure 4: Interruption of Low Priority Transmissions

IV. Millimeter Wave Links

	2.4 GHz	5 GHz	6 GHz	mmWave
Max bandwidth	40 MHz	160 MHz	320 MHz	1280 MHz
Max data rate (1 spatial stream)	286.8 Mbps	1.441 Gbps	2.882 Gbps	11 Gbps
Max PHY throughput (8 spatial streams)	2.3 Gbps	11.5 Gbps	23.1 Gbps	88 Gbps
Relative Expected Range (Free space)	100 m	50 m	40 m	4 m
Antenna Directionality	Omnidirectional	Omnidirectional	Omnidirectional	Directional/ Quasi-omni
Incumbent Systems	802.11b/g/n/ax/be Bluetooth, Zigbee	802.11a/n/ac/ax/be LTE LAA, 5G NR-U	802.11ax/be/5G NR-U	802.11ad/ay, 5G NR-U

Table 1: Potential UHR mmWave Link Support

UHR may support data rates of up to 100 Gbps for high data rate and low latency applications such as Augmented Reality (AR)/ Virtual Reality (VR)/ Mixed Reality (MR). With mmWave links, this is easily achieved in theory due to the several GHz of available bandwidth in these bands. The challenge however is in providing the needed reliability for each application at a reasonable complexity and transmit power.

As discussed in Section II, MLO was adopted in 802.11be allowing Wi-Fi 7 devices access to multiple links at the same time. Each link is associated with a distinct AP/STA inside the AP/non-AP multi-link device (MLD) as shown Fig. 5. One STA or AP within the MLD can be tuned to a 2.4 GHz link while the other can be tuned to a 5 GHz link and so on as shown Fig. 5. While Wi-Fi 7 devices can only operate links below 7GHz, many companies in the UHR SG support the addition of unlicensed mmWave links.

Unlicensed mmWave bands are frequency bands in the 45 GHz and 60 GHz spectrum and are currently home to 802.11ad/ay devices. These carrier frequencies, while subject to severe attenuations with respect to distance or obstacles (e.g., walls, roof), can offer several GHz of bandwidth to UHR just as it is currently providing to 802.11ad/ay devices. One big difference however is that UHR being an evolution from 802.11be has access to the lower frequency bands (e.g., 2.4 GHz, 5 GHz, 6 GHz). This means that management and control of mmWave transmissions can be done more efficiently by transmitting them in the lower bands as lower band transmissions are more robust and a generally much more mature technology.

Table 1 shows the potential bands that may be supported by UHR. The first three links namely 2.4 GHz, 5 GHz, and 6 GHz link are the same links that 802.11be supports. As shown in the table, the 6 GHz band has the best throughput and least potential of interfering with an incumbent system. The 6 GHz link offers up to 2.882 Gbps of

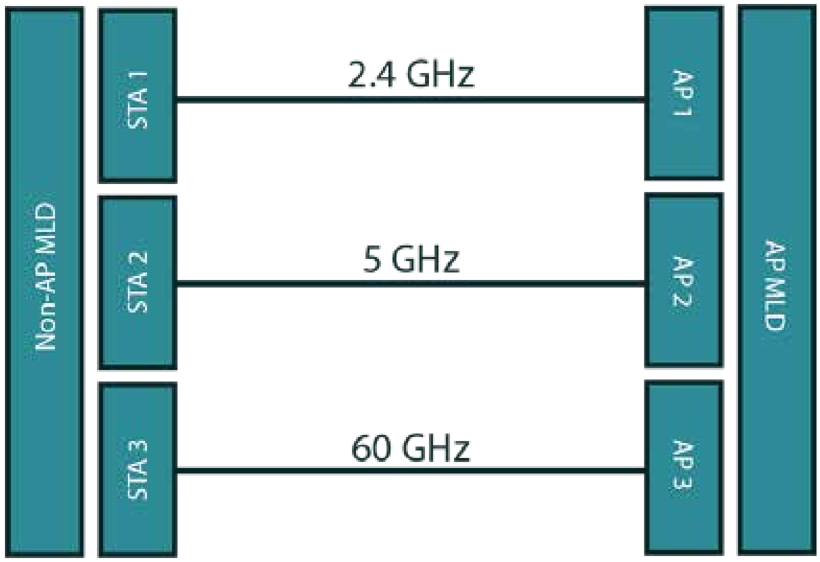


Figure 5: Multi-link Operation with a 60 GHz link

of throughput per spatial stream due to the maximum bandwidth of 320 MHz. For the mmWave links it is expected that a maximum bandwidth of 1.28 GHz will be supported for UHR. This will result in a maximum data rate of 11 Gbps assuming the same Modulation and Coding Set (MCS) of 802.11be.

Assuming a UHR device that supports 8 spatial streams per link, the mmWave link will be able to provide up to 88 Gbps of raw throughput. The rest of the 2.4 GHz, 5 GHz, and 6 GHz can provide a combined throughput of 36.9 Gbps for a total of 124.9 Gbps of throughput to support the proposed 100 Gbps requirement.

V. Conclusion

In this paper, we gave an overview of the current state of the UHR standardization in terms of potential technologies that may be supported. As we have discussed in this paper, while UHR's main goal is improvement of reliability, the draft PARs and technical contributions in UHR also address the importance of boosting the throughput to up to 100 Gbps and reduction of latency to a few ms. To meet these goals, current high level technical contributions in UHR include technologies such as multi-AP coordination and transmission, interruptible transmissions, and mmWave links. All these techniques can boost the effective throughput and/or reliability either directly or indirectly and hence are all good candidates as new UHR features.

Note that although outside the scope of this paper, UHR may also support technologies that are already proven effective in other wireless systems but were not adopted in the 802.11 standard either due to high complexity or not gaining enough support. Examples of these include 16 spatial streams (agreed to be supported but later dropped in 802.11be) and hybrid automatic repeat request (discussed in 11be but did not have enough support).

References

[1] M. Gan, et. al. 802.11 UHR SG Proposed PAR. [Online]. Available: https://mentor.ieee.org/802.11/dcn/22/11-22-1518-01-0uhr-802-11-uhr-sg-proposed-par.docx

[2] T. Baykas, et. al. Project Authorization Request Proposal for 802.11 UHR SG. [Online]. Available: https://mentor.ieee.org/802.11/dcn/22/11-22-1750-00-0uhr-project-authorization-request-proposal-for-802-11-uhr-sg.docx

[3] E. Khorov, et. al., "Current Status and Directions of IEEE 802.11be, the Future Wi-Fi 7," in IEEE Access, vol. 8, pp. 88664-88688, 2020,

[4] D. Cavalcanti, et. al. 802.11be enhancements for TSN time-aware scheduling and network management considerations. [Online]. Available: https://mentor.ieee.org/802.11/dcn/22/11-22-0634-02-00be-802-11be-enhancements-for-tsn-time-aware-scheduling-and-network-management-considerations.pptx

[5] K. Meng, et. al. IEEE 802.11 Real Time Applications TIG Report. [Online] Available: https://mentor.ieee.org/802.11/dcn/18/11-18-2009-06-0rta-rta-report-draft.docx

[6] X. Wang Status of IEEE 802.11 Artifical Intelligence Machine Learning (AIML) TIG. [Online]. Available: https://www.ieee802.org/11/Reports/aiml_update.htm

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Leonardo works as a Senior Technical Staff focusing on IEEE wireless LAN standards related technologies. His research interests include network analysis and optimization both in Physical and Medium Access Layers. He has authored several journals and conference papers on technologies such as Multi-user Beamforming, Multiple Input Multiple Output Schemes and Random access improvements for IEEE 802.11ac, IEEE 802.11ax, and IEEE 802.11be based WLAN.

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