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Investigating the Role of WiFi7 for Machine Type Communication

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List of Abbreviations and symbols

A-MPDU	Aggregated MAC Protocol Data Unit
A-MSDU	Aggregated MAC Service Data Unit
AC	Acknowledgement
AP	Access Point
BA	Block ACK
BFR	Beamforming Report
BSS	Basic Service Ser
CBF	Coordinated Spatial Reuse
CC	Chase Combining
CSI	Channel State Information
CSR	Coordinated Spatial Reuse
DL	Downlink
EDCA	Enhanced Distributed Channel Access
EHT	Extreme High Throughput
FD	Full Duplex
HAR	Hybrid Automatic Retransmis
HARQ	Hybrid Automatic Retransmission Control
IR	Incremental Redundancy
LDPC	low-density parity-check
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MLD	Multi-link Device
MU	Multi-user
NDP	Null Data Packet
NOMA	Non-orthogonal Multiple Access
OFDMA	Orthogonal Frequency-Division Multiple Access
PHY	Physical layer
PS	Power-saving
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency interface
RTA	Real-Time Applications
RU	Resource Unit
RX	Recive
SIC	Successive Interference Cancellation
SNR	Signal-to-Noise Ratio
SOMA	Semi-orthogonal Multiple Access

SR	Spatila Reuse
SS	Spatila Stream
TSN	Time-Sebnsitive Networking
TWT	Target Wakeuo Time
TX	Transmission
TXOP	Transmission opportunity
UL	Uplink

Abstract

The advancement of technology has revolutionized the way we communicate and connect the world around us. One significant development in this regard is the emergence of wireless communication system, 5G, 6G and wireless local-area network (WLAN). Over the years, different versions of wireless fidelity (Wi-Fi) have been introduced, each offering fasters speeds and improved connectivity. The upcoming version of WiFi is WiFi7, also known as IEEE802.11be, which is the advancement in wireless technology aiming to revolutionize machine-to-machine communication.

IEEE802.11be or WiFi7 is an updated version of IEEE 802.11ax (Wi-Fi 6). It is expected to be a game-changer for Machine Type Communication (MTC), referring to the communication between machine type devices without human intervention, such as in Internet of Things (IoT) applications. With the increasing popularity and usage of IoT, MTC has become a crucial aspect of our everyday lives, from smart phones to industrial automations. IEEE802.11be plays a play a paramount role in MTC due to its enhanced features and capabilities.

In this thesis I have done some research of WiFi 7 with articles to explored key updates from WiFi 6, like 160MHz to 320Mhz, 16 spatial streams, 4k-QAM and OFDMA. And some features of WiFi 7, like HARQ, FD, NOMA, Multi-line operation. Also explained WiFi 7 use cases and limitations at the end. Simulation is included in this thesis with result figures which is done by Matlab. As a conclusion observed from the simulation results is depending on use cases we need to choose right MCS for different use cases. in some places were throughput matters, then use higher MCS. But in the place where speed is not important but need to be robust to attenuation then lower MCS can be also option.

In this thesis I will go through all the updated features and new features of about WiFi7, how does the features work and furthermore its use cases and challenges.

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IEEE802.11be Wifi7

What is IEEE802.11be WIFI7

IEEE802.11be is also know as WiFi7. This is a family of wireless network and the latest version of the IEEE802.11 family standard, which is currently under development. It is designed to provide extremely high performance and low latency for indoor and outdoor wireless local area network (WLAN) operation in place and roaming speed 2,4,5and 6 GHz frequency bands. The goal of the new standard is integrating time-sensitive network (TSN) as one of the key components of the IEEE 802.11be to support low latency and ultra-reliability in license-exempt spectrum bands.

IEEE802.11be is expected to have several new features that enable low-latency operation, such as wider bandwidth, more spatial streams, and larger modulation size. the maximum supported modulation size in IEEE802.11be is boosted with adoption of the 4096-QAM modulation. The maximum number of spatial streams is doubled its number from 8 in IEEE 802.11ac/ax to 16 in IEEE802.11be. The inclusion of the 6 GHz band in the IEE 802.11be standard covers 320 MHz wide channels, allowing for higher transfer rates.

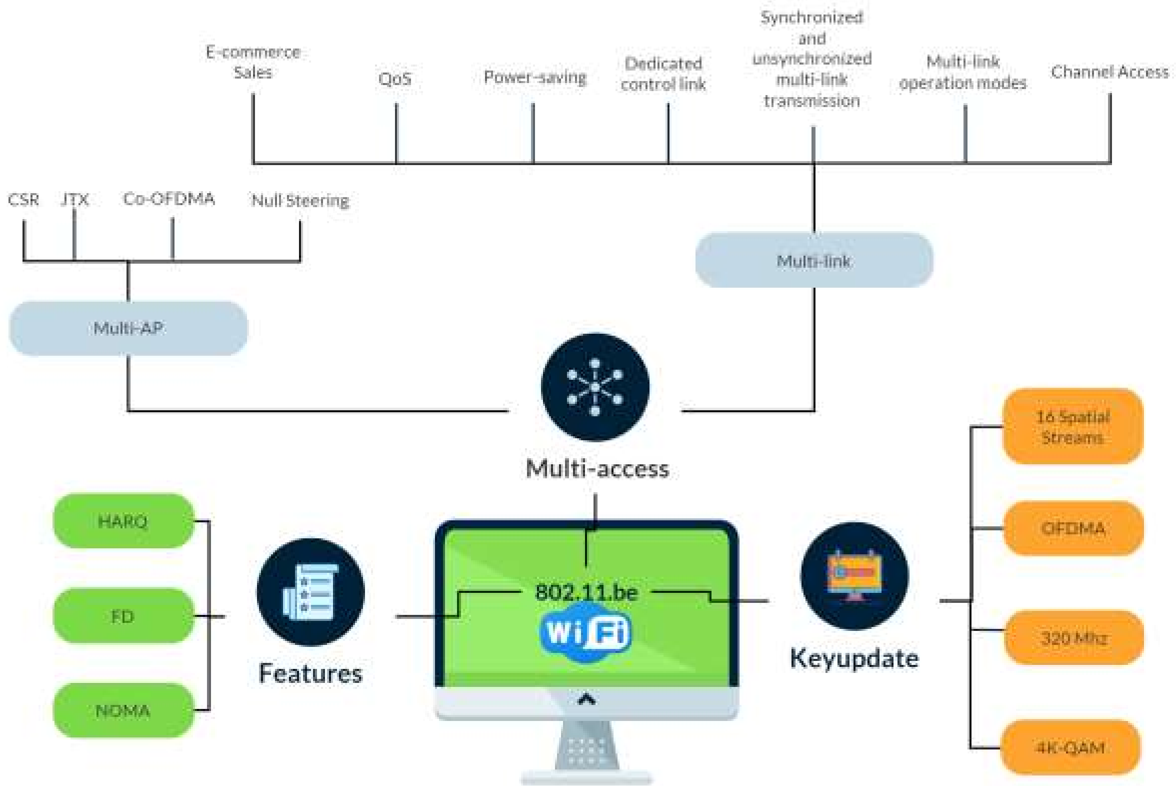

Figure 1. Overview of IEEE 802.11be updates and features.

Key updates from IEEE 802.11ax

320MHz

In 802.11be devices will operate in the 6 GHz band and the Maximum Transmission Bandwidth will increase from 160 to 320 MHz There are also new channel access rules in the 6 GHz band. Such as, removing IDCs and allowing AP to control all transmission in UL and DL [3] [6] [7].

16 Spatial Streams (PHY layer)

In 802.11be the spatial streams maximum number will be increased from 8 to 16. This could probably double the spectral efficiency vs IEEE 802.11ax. This upgrade will be very useful for indoor operations. Like rich scattering, higher angular spreads, lower correlation good propagation conditions diversity of channels and helps receiver to separate information more easily in spatial domain [3-4] [6] [7].

In a MIMO environment, the signals being transmitted by many antennas. Those antennas are multiplied by using different Spatial Streams within the same spectral channel. The multiplexing technique is Spatial Multiplexing which use many signals are being transmitted and received at the same time. In Spatial Multiplexing when different antennas transfer wireless signal at the same time, each signal will transmit through a spatial stream with the given spectral channel. This will avoid collisions [3] [6] [7].

4k-QAM

QAM is Quadrative Amplitude Modulation and combination of Amplitude and Phase Modulation. It is the common modulation which radio use to encode Amplitude, Frequency, and Phase. QAM modulation have two inputs, one input is the RF carrier signal, and the other input is digital data. Those inputs are combined in the modulator and controls the amplitude and the phase of the resulting output signal. which can encode more information onto the signal compared to any other Modulation alone. The data input length defines the QAM depth and the symbols maximum number. constellation diagrams are the call when the symbols are mapped. when QAM depth is growing, more information can be pack into the same signal and between the symbols space will be shrink. In 802.11be will be 4k-QAM which is four times versus 802.11ax [3] [6] [7].

OFDMA (MAC layer)

In OFDMA Multiple devices can schedule resource unit or RU at the same time. This can reduce the channel access delay and give flexibility to spread resources between devices with different Traffic Profiles. WiFi7 uses WiFi6's channel bonding to approach OFDMA. An access point (AP) can open a downlink (DL) multiuser (MU) transmission using OFDMA and/or a trigger-based uplink (UL) MU transmission, or MIMO. This feature is related to transferring multiple RUs to one STA. In WiFi6 networks, based on the AP-decided hierarchy of embedded channels, station (STA) devices can adaptively select the bandwidth for each transmitted frame. After successfully accessing the medium in a primary 20 MHz subchannel, a STA can expand the bandwidth by concatenating secondary channels step by step if they are idle. In the WiFi6 concept, if the secondary 20 MHz channel is busy but the secondary 40 MHz channel is idle, the STA can only transmit on the primary 20 MHz channel. This can lead to a waste of channel resources [1] [3].

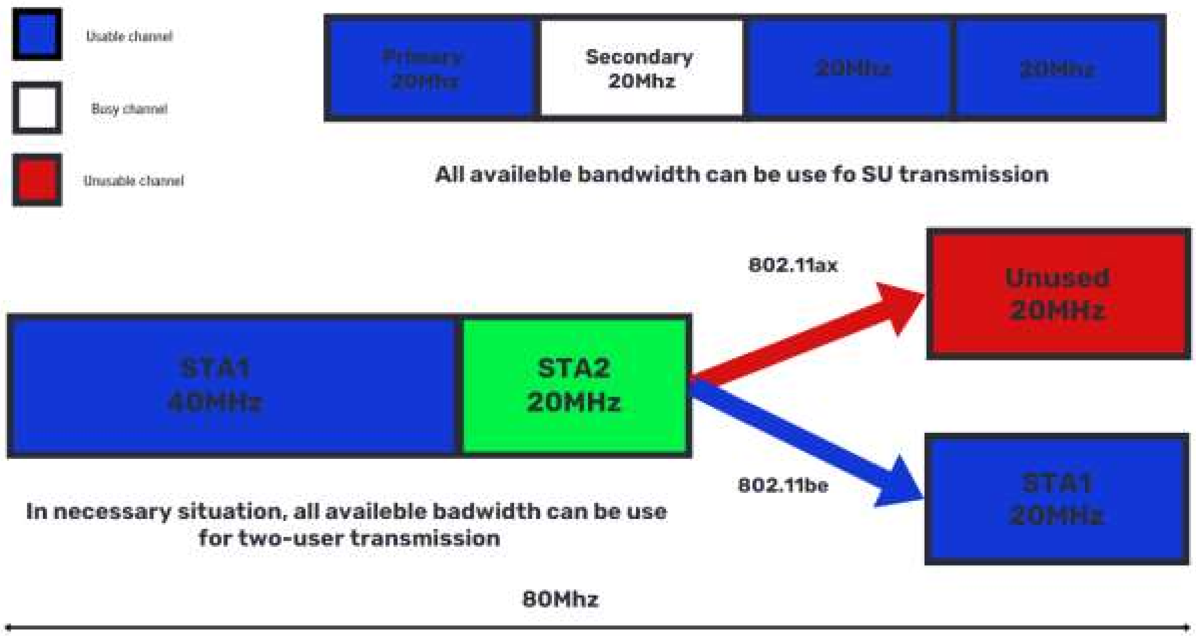

Figure 2.In this figure we can see how OFDMA is working on MU RU per STA.

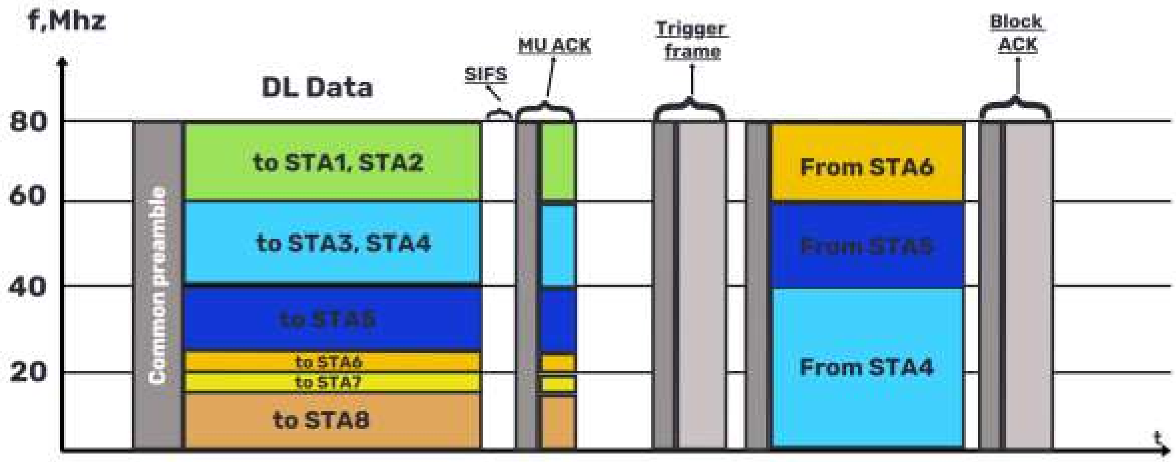

Figure 3. OFDMA and MIMO transmission

preamble puncturing can be used to avoid this problem. During multi-user (MU) transmission in a channel of 80 MHz or wider, some busy subchannels of 20 MHz or wider can be punctured. This means that the frame preamble is not transmitted, and Resource Units (RUs) are not reserved for those subchannels. WiFi 6 has multiple models of puncturing. In 80 MHz transmission, only one 20 MHz and primary subchannels can be punctured. In 80+80 or 160 MHz transmission, only primary (80 MHz) and one 40 MHz can be punctured. With WiFi7, puncturing can be 320 MHz, and puncturing is just for a single user (SU) frame [1] [3].

In situation when 80 MHz and two STA situation is available. In this case second STA only needs 20 MHz but first STA wants as much as possible. 802.11ax couldn't assign the 20 MHz channel because first STA can only use one resource unit but in MURU 802.11be it can fully use available bandwidth. WiFi7 supports multiple RU per STA, whereas WiFi6 doesn't. The biggest problem is how to describe the set of RUs most simply. For example, small RU combinations shall not cross the 20 MHz subchannel limitation. RUs can be grouped only within one 160 MHz subchannel in OFDMA transmission 320/160 + 160 MHz [1] [3].

With OFDMA direct links between the STAs, the neighboring STAs can transmit the data directly to each other. AP allocates dedicated RUs for direct links to help avoid crushes between two peers communicating STAs and a nearby BSS. Having received a data frame in RU through a direct link, the STA sent an acknowledgement (ACK) to the same RU. (likely sent with the same transmission parameters as the data frame). OFDMA can increase the number of RTA STAs in a network by 50% [1].

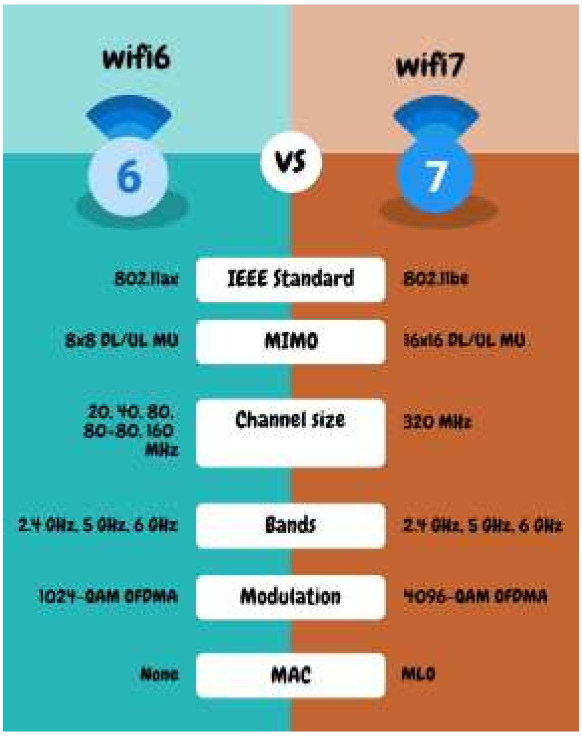

Figure .4 802.11ax vs 802.11be

EDCA features of IEEE 802.11be

HARQ

Compared to the old retransmission process Automatic Repeat Request (ARQ), which abandon failed transmitted MPDU and don't information from the previous tries.[3] HARQ uses the information from the previous tries and reuse failed transmitted MPDU. The receiver chains the signals from several transmission attempts, which improve spectrum efficiency, increases the chance that receiver decodes the packet correctly and better SNR [1] [3] [6] [7].

HARQ is more robust to the errors in the estimation of the SNR at the receiver. It allows the transmitter to select a higher Modulation and Coding Scheme (MCS) opportunistically. Either the transmission is fast with the good channel, or the receiver extracts some information anyway with the poor channel and decodes the packet with a transmission retry. Moreover, HARQ avoids reducing MCS for such retries [1] [3] [6] [7].

HARQ have three methods, first one is Chase Combining (CC). In CC it is quite easy to combine the signals and to achieve gains in the SNR, because in every retry contains there is same information as the original transmission. CC is worth HARQ methods to performance because it's not so complicated versus other method. Second is Punctured CC, which reduces HARQ-induced overhead a lot. This because the transmitter repeats only the part of the coded bits that have low SNR. Third we have Incremental Redundancy (IR), this is most complex but efficient one. HARQ can prove more reliable error estimation of the SNR. transmitter select a higher MCS with either the transmission is fast in the good channel, or the receiver gets decodes the packet with a retransmission in the poor channel. Additionally, HARQ evades reducing MCS for such retries [1] [3] [6] [7].

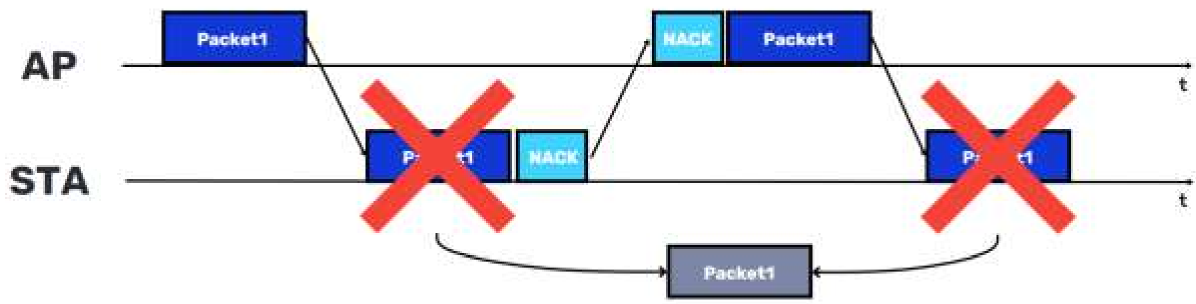

Figure 5. HARQ working method

FD

In Band Full Duplex (FD) allows UL and DL on the same spectrum at same time. This maximizes the use of available spectrum and reduce latency, high scalability, increased throughput and interference cancellation. collision reduction is FD's additional features. Basically, DL signal-protect UL by prevent potential hidden nodes transmitting during. FD can also fix relay-based networks problems by transmit multiple relays at the same times [1].

NOMA

Non orthogonal multiple access (NOMA) is designed to increase peak throughput and improve efficiency. NOMA basic idea is that an AP can serve multiple STAs in the same baseband same time, by share part of the total transmission power for each STA. The AP can perform NOMA transmissions with the superposition coding. (=superposition of multiple signal components with different factor subject to a power limitation) [1].

that's why the component reception is more reliable when the power is bigger. If there is two STA, the high-power component is set to a far STA with worse channel conditions, and the low-power component is sent to a near STA. The receives the composite signal as it is and as noise far STA detecting interference from low-power component. The near STA is using SIC to separates the signal components [1].

NOMA is complementary technique to MIMO. NOMA works better with the STAs that have diffrent attenuation and correlated channels and MU-MIMO works better if the STAs have not different attenuation but orthogonal MIMO channels. The AP can make several spatial beams to STA groups by MU-MIMO, and in those beam, STA groupe carries NOMA signal [1].

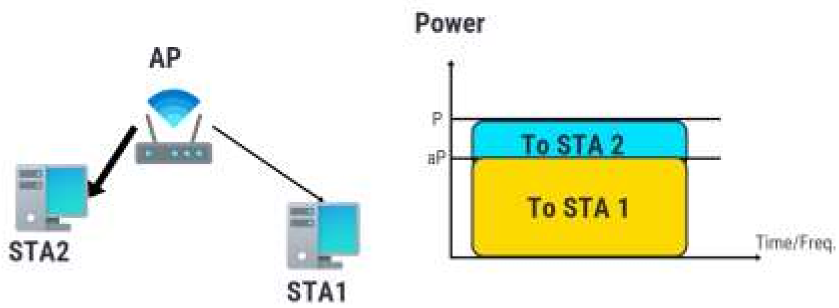

Figure 6. figure shows how NOMA is working.

Multi-link operation (MAC layer)

IEEE 802.11be Multi-Link Operation has numerous benefits. The first benefit is that coordinated operations across multiple links enhance efficiency and achieve additive throughput for data flows split over links. The second benefit is the parallel use of multiple links, which significantly reduces latency, which is critical for applications requiring real-time responsiveness. The third benefit is that multi-link operation enhance reliable transmission of critical data by transmitting same frame but multiple copies via separated link. Finally, the ability to assign data flows to specific links based on application needs allows for traffic separation and differentiation [1-3] [6-8].

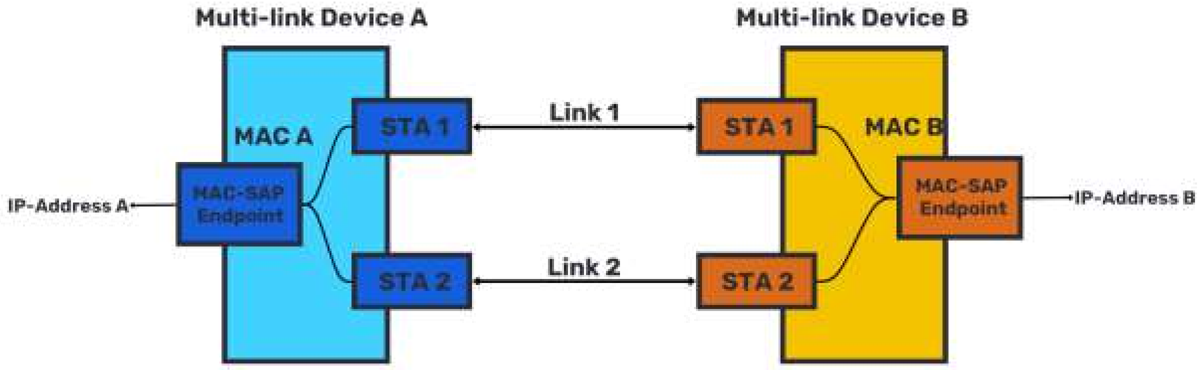

Figure 7. Working of MLO

To implement multi-link operation, 11be uses the concept of a multi-link device (MLD), which consists of multiple linked Wi-Fi devices or more than one linked STA device. Each device has its own PHY interface to the wireless media, with a single interface to the logical link control (LLC) layer. This means the upper-layer protocols treat the MLD as a single device, even though it has multiple physical radio interfaces. The MLD has only one MAC address, and the sequence numbers are created uniquely from the same sequence number space. This action helps simplify fragment and packet reassembly, duplication detection, and dynamic link switching. It allows packet retransmission on any link, regardless of the link of the origin transmission of the packet [1] [2] [6-8].

Featuring a single MAC data service access point (SAP) to logical link control (LLC), this framework sets apart AP MLDs, where linked STAs are access points, and non-AP MLDs, where affiliated STAs are non-AP STAs. Multi-Link Discovery is the process through which a non-AP MLD discovers an AP MLD and decides whether to associate with it. Traditional discovery methods involve passive and active scanning. IEEE 802.11be simplifies this by introducing mechanisms like reduced neighbour reports and ML probe requests, reducing scanning overhead[1] [6-8].

After discovering an AP MLD, the next step involves association and verification. The multi-link setup executed over one link, enables capability exchange and setup procedures for multiple links. Security measures, including the four-way handshake, are extended to multi-link device scenarios. Channel access rules are defined for multi-link operation, ensuring independent access to each link.

Different rules apply for different operations, such as Enhanced Multi-Link Station Receive (EMLSR), Non-Stationary Traffic (NSTR), and Enhanced Multi-Link Station Transmit (EMLMR) [1] [2] [6-8].

Channel access

There is two types of categories of multi-link channel access, channel access based on primary channel and channel access based on multiple access. In one primary channel based multi-link channel access the STA simultaneously accesses 2.4/5 GHz and 6 GHz bands. In the primary channel there is contention-based access which could causing scanning and decrease scanning latency and energy consumption for 6 GHz operations. However, to obtaining 6 GHz TXOP not only depends on the primary channel at 2.4/5 GHz but also on the activity of the secondary channels at 6 GHz [1] [4] [6-8].

This method has less flexibility in channel selection and usage for multi-link in dense deployment process. This can decrease significantly the multi-link Wi-Fi system's performance because of increase collisions and reduce of primary channel access opportunities. For this reason, preamble puncturing schemes may be perfect option [1] [4] [6-8].

In channel access based on multiple access when the primary channel is unavailable temporary primary channel (T-PCH) can be set on the secondary channels to increase the channel use opportunities. the STA can use the T-PCH as well as the primary channel. T-PCH obtains TXOP on the if the T-PCH is idle and when the primary channel is busy. After the T-PCH becomes busy and primary channel becomes idle STA can immediately return from the T-PCH to the primary channel. this increase STA to obtain more TXOP on the more idle channels, but such channel access also limits the use of the idle channels because presence of T-PCH depends on the status of the primary channel [1] [4] [6-8].

Multi-link operation modes

There are two modes of multi-link operation: restricted mode and dynamic link switch mode. In restricted mode, data frames and ACKs are tied to one link. Management exchanges transferred over one link, such as those related to block ACK (BA) negotiation, power save mode, security key negotiation, etc. This is a simple concept of multiple independent links with aggregation enabled.

In dynamic link switch mode, multiple links can transmit the same flow. The management information and negotiations link can apply to other links. This mode balances load and avoids congestion. This mode also increases peak throughput and reduces latency overhead and power utilization [1] [4] [6-8].

An important benefit of multi-link operation (versus a single extra-wide channel) is the MLD's access to perform channels and transmit data through multiple links asynchronously. MLD can do synchronized transmission and reception (TRX) in the 2.4/5/6 GHz bands. The power leak between the bands is minimal because the spectral distances are high. But there may be interference if links are in the same band, like MLD-affiliated devices that share the same antennas or antennas that are in the same neighbourhood as each other [1] [6-8] .

The spectrum mask of a Wi-Fi signal is not perfect because the signal strength on the transmitter is much higher than that on the receiver. Even if affiliated devices are using different channels, the interference between them can be significant. The closer affiliated devices' channels of an MLD are, the stronger the power leak from a transmitting affiliated device to the others. Such interference makes problems for real-time transmission and reception capabilities [2] [6-8].

Synchronous multi-link operation and synchronous transmissions are one solution to this problem, reducing throughput caused by more rare channel access. A second potential solution is forbidden transmission during the transmission of the intended receiver. For example, if an MLD transfers is on one link, it cannot receive any frames on another link. The MLD should stop transmission in neighbouring bands to receive the BA successfully [2] [6-8].

Synchronized and unsynchronized multi-link transmission

In unsynchronized multi-link transmission, a device can transmit frames with unaligned transmission starting time and end time on multiple links. Each link has own primary channel, EDCA parameters and independent channel access. In unsynchronized multi-link transmission with simultaneous TX and RX capability transmitting on one link may be supported [1] [4] [6-8].

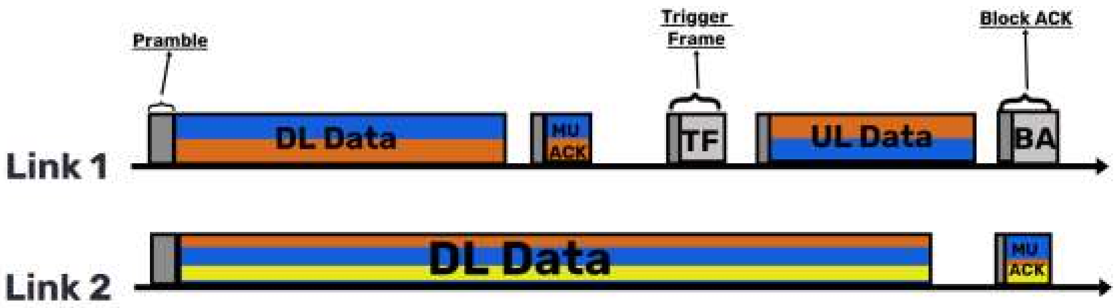

Figure 8. unsynchronized multi-link transmission

Using different channel conditions, Independent PPDU length and regulatory power limits for different links can achieve optimal throughput with high spectrum utilization and individual MCS per link. QoS point of view, non-sequential packet due to differences in transmission timing and frame length across links. Reception can fail if signals leak to an adjacent channel. This leads to unnecessary retransmissions because of varying channel quality between links[1] [4] [6-8].

The synchronized multi-link transmission means that a device shall transmit frames on multiple links with aligned transmission starting time and ending time. every links has dependent channel access and complex rule for channel access without simultaneous TX and RX capability. Also synchronized multi-link transmission have low spectrum utilization and dependent PPDU, bandwidth and MCS. In synchronized multi-link, it may need schemes to hold the idle channel, because while waiting Clear Channel Assessment (CCA) idle status, there will be time wasted on all links before the transmission[1] [4] [6-8].

In QoS point of view unnecessary retransmission is because of channels quality differences between links. The synchronized multi-link transmission means that a device shall transmit frames on multiple links with aligned transmission starting time and ending time. every links has dependents channel access and complex rule for channel access[1] [4] [6-8].

Also synchronized multi-link transmission have low spectrum utilization and dependent PPDU, bandwidth and MCS. In synchronized multi-link, it may need schemes to hold the idle channel, because while waiting Clear Channel Assessment (CCA) idle status, there will be time wasted on all links before the transmission. Also, In QoS point of view unnecessary retransmission is because of difference of channel quality between links in synchronized multilink transmission the non-simultaneously transmitting and receiving on one or more links are permitted[1] [4] [6-8].

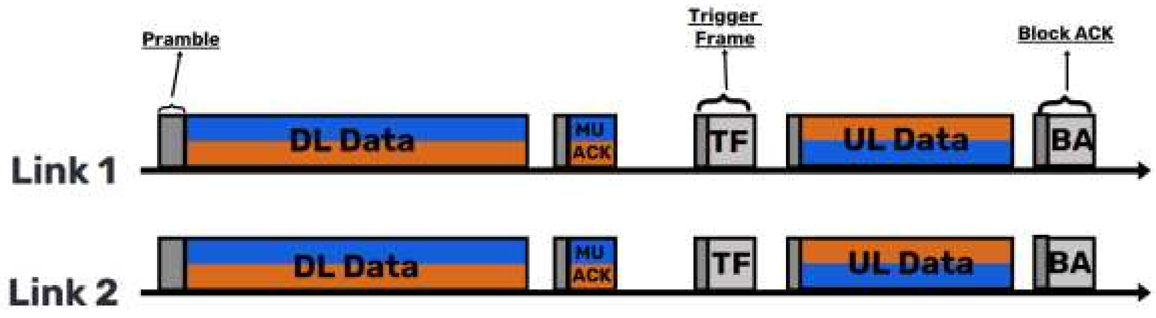

Figure 9. synchronized multi-link transmission

Fast switching transmission

Usually when the transmission bandwidth is wider, there is higher the appearance probability for co-channel and nearby channel interference on neighboring nodes.This will degrate the spectrum efficiency. For this problem fast link switching maybe the solution, whch is a critical technology designed to reduce the strong interference from neighboring nodes. Fast switching between multiple links improves efficiently of channels select in different links to gain high spectrum utilization. Seamless switching between different links can provide efficient retransmission, load balancing and coexistence constraints[1] [4] [6-8].

For example, in link 1 the DL frame failed, retransmission can happen via available link 2 for reducing the waiting latency and the channel diversity can take care of link fluctuations.
Based on different load balancing methods, STAs can switch all traffic or some traffic from one busy link to another not so busy link to improve QoS. For example, depends on types of traffic, the STA can decide to transmit high-throughput and low-latency services on 5/6 GHz link and transmit delay-insensitive services via another 2.4 GHz link[1] [4] [6-8].

Dedicated control link

To improve spectrum utilization and decrease transmission delay, data and control planes can be decoupled over different links. this also helps update regular control/management frames on one of the links, at the same time leave the other links primarily for data exchange. The control link can organize every communication over different data channels, this needs a method that the receiver can know exactly which channels to receive the data via negotiation or intelligent algorithms. Dedicated control link can also transfer control frames, MAC/PHY header and other control information and provide the exchange of control information can get more efficient resource allocation in out-of-link. The perfect decoupling of the data and control should divide data packets into two parts. One is the data part, and another is the control part transmitted over multiple links. Since data is sent across various links, and the reception is non-sequential due to disparities in transmission timing[1] [4] [6-8].

Power-saving

The basic power management mechanisms for a Wi-Fi device are active and power-saving mode (PS). In active mode, the device stays awake all the time and can transmit and receive frames. In PS, the radio can be in the doze state from time to time; it can't transmit or receive. In theory, STA should notify the AP before changing the operation mode (active or power-saving mode). The AP protects all frames destined for this STA if the STA is in PS mode. To notify PS STAs about the protected packets, the AP enters in each beacon a Traffic Indication Map (TIM) that shows the packets destined for each STA. After that, every PS STA periodically wakes up to receive beacons[1][2] [6-8].

The STA returns to the doze state immediately after the beacon. If the beacon says that no protected packets are destined for the STA, Then, the STA sends a PS-Poll frame, and as a response to the PS-Poll, the AP sends buffered frames. TWT allows an STA to negotiate with the AP moments when the STA wakes up for TWT service periods and exchange frames with
the AP. STA can always stay dozed, except for the negotiated service periods, and does not need to wake up for beacons anymore. This reduces energy consumption significantly. [2] [6-8]

Depending on the channel loads, traffic, and interference at different links, the AP communicates with STAs, and links will be switched off and data will not transfer. This is the so-called anchor link for management and the groupcast link. This means other links can be deactivated if there is not intensive traffic, and when it is needed, the multi-link AP may use the anchor links to wake up others to them. Many multi-link STAs may use different channels for anchor links to connect with a multi-link AP[1] [3] [6-8].

Multi-link operation modes for RTA

There are two multi-link operation modes for RTA: duplicate and joint mode. In Duplicate Mode, the transmitter (TX) sends copies over multiple links of each frame. Once the receiver (RX) gets a frame, it drops all its copies that are received after. There is also conditional packet duplication mode, where an MLD primarily tries to deliver a frame only through one link. If the actions fail, it replicates the packet and tries to deliver it through other links with the highest priority. This also drops all the copies that are received after. Duplicated mode increases the probability of successful transmissions. In the joint mode, the transmitter produces no copies but spreads frames over available links, decreasing transmission latency [1] [2] [6-8].

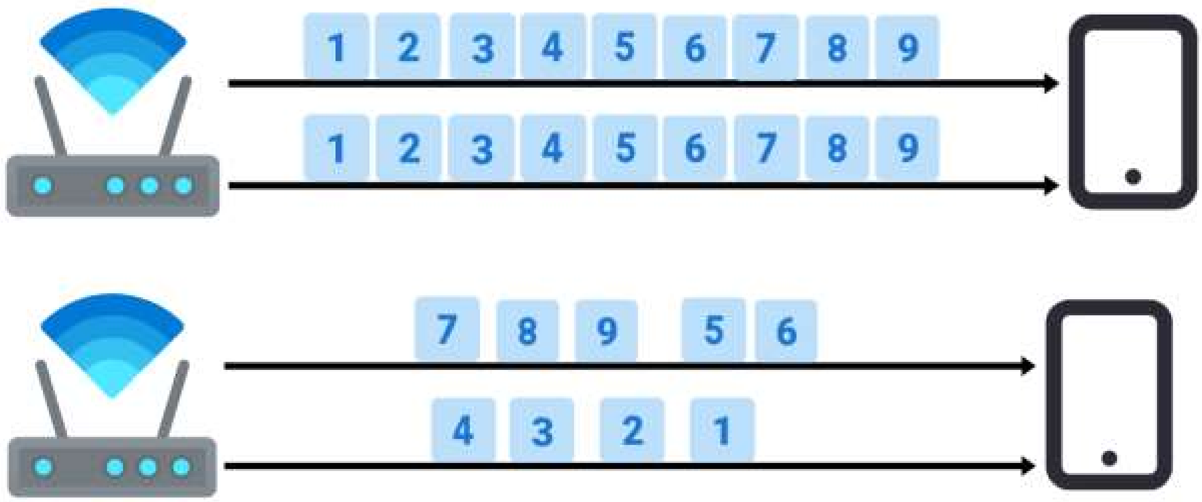

Figure 20. Duplicate and joint mode. Above is example of how duplicate mode work. below is joint mode.

QoS

IEEE 802.11be has also enhanced quality of service (QoS) management. QoS manages some use scenarios like real-time applications (RTA), industrial IoT, AR/VR, and emergency services, which demand more stringent QoS requirements. QoS provisioning in Wi-Fi 7 builds on the existing Stream Classification Service (SCS) protocol. Non-AP EHT STA transmits SCS Request frames, facilitating the creation of corresponding scheduling services at the Multi-Link Device level. Also, the QoS provisioning model features a dedicated, deterministic, low-latency, and reliable access category. This model serves as a robust identifier for QoS traffic, ensuring a tailored and responsive approach to the unique requirements of critical applications[2] [6-8].

multi-AP

Coordinated Spatial Reuse (CSR)

There are two types of multi-AP systems. Coordinated system is first one. which send and receive each portion of data by a single AP. Second one is Joint systems, it sends and receives data by multiple APs. Coordinated Spatial Reuse (CSR) is the simplest coordinated multi-AP system, which is an evolution from spatial reuse (SR) system (used in WiFi6). At all the STAs, the APs decrease interference by controlling it's TX power for enough SNR . CSR needs only few inter-AP feedback, it is more robust to interference versus with uncoordinated SR from 11ax[1] [6] [7].

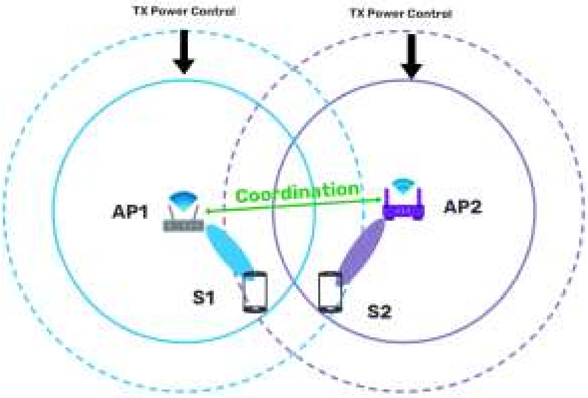

Figure 31. overview of CSR

Joint Transmission and Reception(JTX)

Joint system is second one. Joint Transmission and Reception allows APs to serve multiple STA by creating a dynamic distributed MU-MIMO system. This system runs jointly on multiple APs. In DL, the profit of joint transmission and reception is experimentally proven to be the highest compared with the coordinated multi-AP systems. To increase frame reception probability, Spatial diversity can be used. However, this method is too complicated and has severe requirements, such as high-speed backhaul and accurate synchronization across the APs[1] [4] [6] [7].

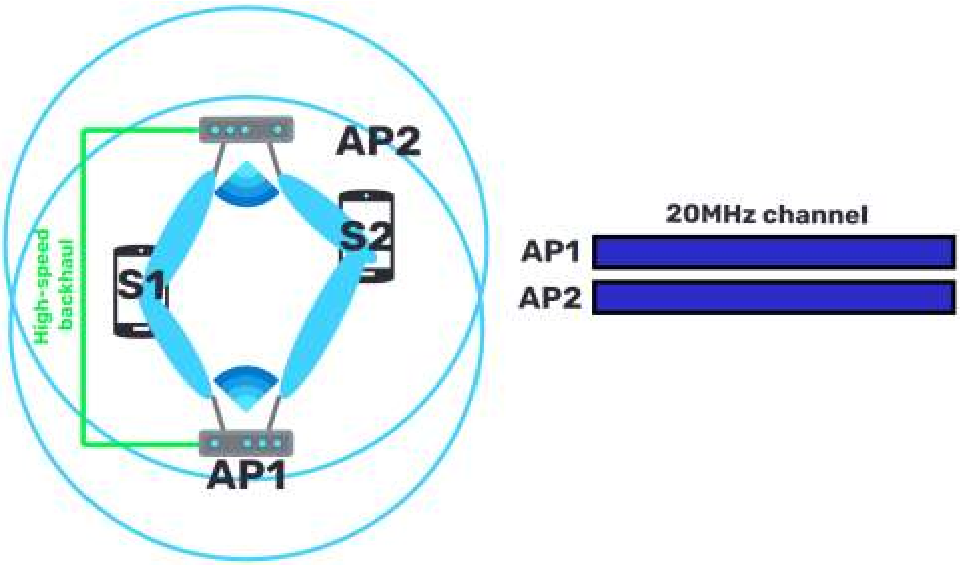

Figure 42. overview of JTX

Co-OFDMA

The Co-OFDMA multi-AP system allows the APs to coordinate their schedules in time and frequencies and optimize the efficiency. With Co-OFDMA, the nearby APs can assign the same RUs for some STAs if such transmission does not interfere, or they can assign different RUs to avoid interference. Co-OFDMA is effective for medium or large AP density, because multi-AP system let the APs to coordinate their schedules in time and frequencies. moreover, if transmission does not cause interfere, the nearby APs can transfer the same RUs for some STAs. To avoid interference APs can also transfer different RUs [1] [4] [6] [7].

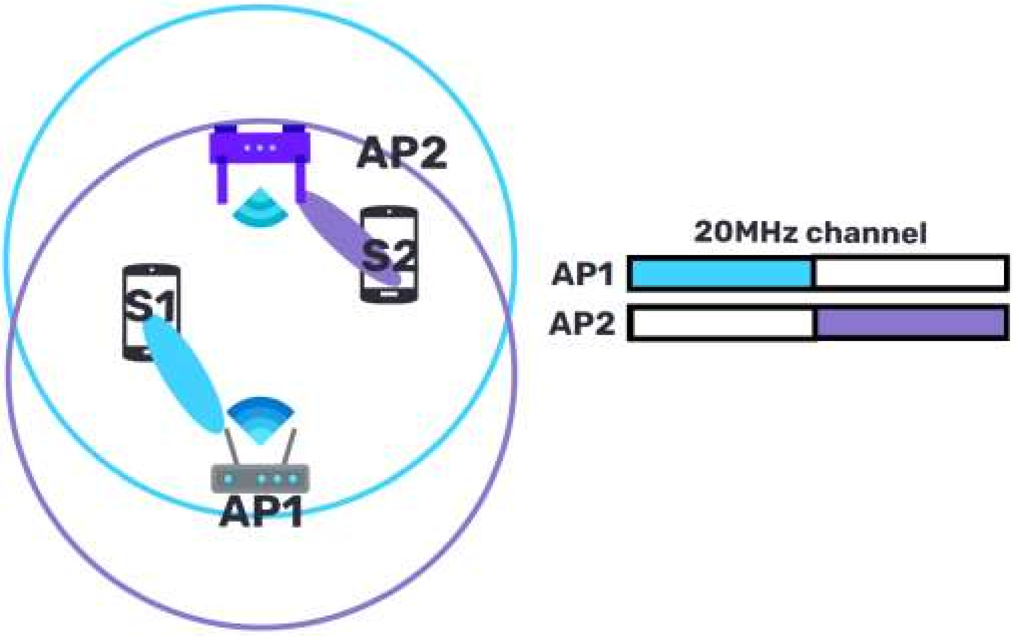

Figure 53. overview of Co-OFDMA

Null Steering

Null Steering know as coordinated beamforming (CBF), is for DL transmission. basic idea is that when beams is forming to their STAs, an AP also targets to another STAs and spatial radiation null its interference to it. This avoids interference between nearby traffic. Null steering method for UL transmission is called Per-AP Interference Cancellation. In this method basic idea is each AP collects information about the channel to all the nearby STAs, before UL frame reception. After that AP ignore interference from the other STAs and configures its receiver to get a frame from its connected STA. This doesn't need exchange data across APs and it allows same time transmission by different STAs to the matching Aps [1] [3] [6] [7].

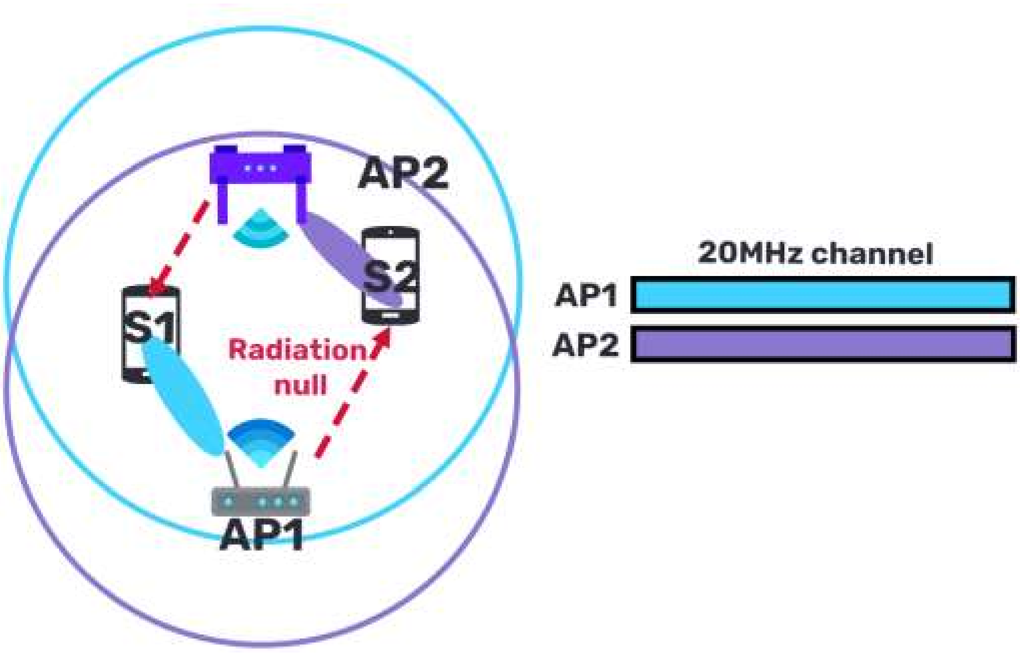

Figure 64. overview of null steering

Use cases

Wi-Fi can be everywhere, Indoors and outdoors. Indoors with low latency WiFi7 can be use in Mobile Devices Multimedia Applications, home office, enable time-sensitive services like 4/8k audio or video streaming, VR/AR, Gaming and Interactive Applications. Moreover WiFi 7 can be use in Training and Educational purposes. Health care and medical point of view WiFi7 will assist Artificial Intelligence (AI) with telediagnosis, telesurgery, telemonitoring and robotic arms. Also Monitor and managing in real-time will be easier, accurate and reliable. In the industrial point of view WiFi7 will bring concept of Industry 4.0. RTA in machines and other appliances.4K-QAM will bring hight throughput and improve bandwidth efficiency. Multi-link increase reliability and support hybrid data traffic. Multi-AP Make seamless connectivity for robots possible and enhance coverage in factory floor. Wider bandwidths provide massive machine and sensor monitoring. WiFi sensing provide more reliable inventory tracking and real-time machine monitoring [3-5].

Outdoor will use WiFi7 technology in transport sector in air, road and water and real-time traffic information telecommunications. Like automated vehicles, public transport and cargo transport without human intervetion. tranport sector will be more automated, sustainbility and safe. in real-time traffic information telecomcations point of view, informations will be more real-time, reabile and accurate [3] [4].

Figure 75. overview of WiFi 7's use cases

5G

Flexible Numerology for radio resource allocation. 3GPP 5G NR use two main frequency ranges: frequency range 1 (FR1) and frequency range 2 (FR2). FR1 is sub6 GHz band, and FR2 is millimetre wave (mmWave) band. The space between OFDM subcarriers and the maximum channel bandwidth depends on the use of specific frequency range. In sub-carrier spaces and the length of OFDM symbols, flexible numerology allows for variations, and this will affect the available data rate and transmission latency [5].

This will benefits radio access parameters to match industrial applications unique demands. For example, low latency for real-time control and high throughput for data-intensive tasks. numerology allows also different applications with varying requirements to operate together in the same

frequency band and manage to optimal spectrum usage. This can enhanced efficiency, productivity and improved automation and quality control in manufacturing processes [5].
mmWave's spectrum allocation bring much more bandwidth than sub-6GHz, provide more applications possibility for Industry 4.0. like advanced smart industrial functions: vision-guided robots, remote visual monitoring and testing with ultra-HD video and imaging, smart safety systems and environment, intelligent automated logistics, and so on. mmWaves enables high throughput communication and sensing. for equipment or machines, this can bring smooth and adaptive behaviour to detect environments objects and react to nearby movement by adjusting their operating rate or even stop actions [5].

Antenna beamforming use group multiple antennas to generate a direct beam. Beamforming's benefit is reducing interference in sub-6-GHz bands which bring higher throughput in direct transmission. Beamforming also makes machine simultaneous communication easier in a smart industrial environment. mmWave frequencies enhances channel gain and use beamforming for provides reliable communication. Beamforming, for example, facilitate concurrent communication collaborate robots [5].

Massive MIMO utilizes spatial stream to support multiple devices simultaneously communication, which saves time and frequency sources. because of signals and interferences reflections, full metallic surfaces industrial environments are challenging for wireless communication. Massive MIMO's c can solve this problem. channel hardening effect is robust to fast fading and provide more deterministic communications. This is important for many industrial applications with harsh QoS requirements [5].

Network slicing can help Next-generation factories deal with handle diverse traffic flows and provide performance, reliability, and security. With Network slicing all this and more specific services can happen on single physical 5G substrate. But for now, in industry most of automation system are based wired local area network (LAN), which let devices across the LAN to discover their services and communicate directly with each other's. The 5G LAN-type is design based on LAN concept but make 5G device's communication easier in industrial automation environments, which are more peer-to-peer oriented and depends on switching and routing in the 5G core network [5].

Problems, limitations, and open issues

HARQ

In 11be HARQ are using low-density parity-check (LDPC) coding. Supporting HARQ with binary convolutional coding seems to be too much, and it doesn't get any gain. Cellular systems use HARQ, even though HARQ in Wi-Fi raises many issues. One of the most important issues is the HARQ data unit (the piece of information that the transmitter will repeat if transmission failed). Every MPDU has a control sum, in failure case HARQ can repeat the whole MAC protocol data unit (MPDU). However, this cost many problems [7].

The first problem is the retransmission and original transmission carries different information because of different retry bit cannot be combined directly, examples ciphertext, CRC bits, scramblers. and if the lost MPDU sums up in an A-MPDU, the LDPC codewords will not be aligned to MPDUs within A-MPDU and in a new A-MPDU, the MPDUs are mapped to codewords differently. To fix issues, we could repeat and repeat without doing any changes. But, repeating the whole A-MPDU costs too much [7].

A solution could be repeating only the damaged codewords. But Codewords have only LDPC Parity Check and checksum of MPDUs. so, PHY can ask the codewords link with the failed MPDUs. executing codeword retransmissions need tight MAC-PHY communication, which may cause execution issues. HARQ block can be negotiated or predefined if codewords be grouped several that carries one or several MPDUs with padding bits in an HARQ block [7].

HARQ Blocks' acknowledgment can use again The BA mechanism and HARQ Blocks are larger than codewords, so they cost less feedback overhead. However, System cost more overhead in the form of MAC padding. and retransmission may contain already delivered MPDUs if several small MPDUs are lined within an HARQ Block. In HARQ Blocks could have multiple MPDUs and their fragments but if fragmented MPDU fails the retransmission overhead will be large [7].

To implement the HARQ protocol, changing the BA mechanism can be good option and it suits best for MPDU and HARQ Block units. Feedback overhead is small, but retransmission overhead can be huge. Reusing BA for codeword-level HARQ is challenging because need of additional MAC-PHY connections. Codeword-level HARQ can dodge MAC communication by communicating only between transmitter and receiver (TRX) in PHY levels. there is definition need to be done to the corresponding communication protocol If this scheme is approved [1] [7].

An HARQ retransmission can appear in a new TXOP with minimal changes from standard, or in the same TXOP. If the HARQ retransmission happens in a new TXOP, the AP can receive HARQ frames from multiple STAs and the AP needs to support many HARQ processes. If HARQ use same TXOP as the original transmission, retries speeds up and this will use more less memory than the first approach. But TXOP limit will be the limit of HARQ retransmissions. besides, the sender needs to choose such a TXOP period that is enough for original transmission and retries. this may lead to an unfinished HARQ process or resource waste[1] [7].

one way to improve HARQ performance benefiting the frequency diversity and to make additional transmission tries at different frequencies or even through different links. Another way to enhance HARQ is by multi-layer HARQ. This method utilizes the fact that in a high-order modulation, many bits have different reliability, like the codewords are transmitted with different reliability, if these bits belong to different codewords. multi-layer HARQ can improve transmission reliability in the low-SNR area by suitable mapping of the codewords to the modulated bits. this way no need immediately SNR information and may get much better performance[1] [7].

There is problematic with Punctured CC and IR because is hard to deciding type of codes shall be use with HARQ and how to puncture codewords. Another issue is the amount of information to be sent in situation when transmission fails. The optimal percentage of transmitted information is opposite to the SNR in terms of overall throughput. Anyways, additional retry counter for HARQ retransmission attempts may be used but the amount of the attempt is under discuss [1] [7].

MAC processing needs to be faster in codeword-based HARQ. The receiver has to process an entire A-MPDU during this short time and feedback with ACK even there is only a few codewords fail, this may limit HARQ gains. The performance of HARQ in Wi-Fi is still an open issue. For example, HARQ best gain only if SNR is low and beamforming increases SNR, which reduces HARQ performance. moreover, in dense deployments the HARQ performance where the packets are lost by random collisions is not well studied [1] [7].

Applying HARQ in cheap Wi-Fi devices costs memory consumption and required computational speed issues. HARQ needs receiver saves log-likelihood ratios (LLRs) for received bits. This memory-hungry technique makes HARQ more than complex. There are some size estimates for first-order memories, but standpoints are different. We need to gain a more errorless and more objective assessment of the needed memory and its expected performance [1] [3] [7].

FD

Adopt FD to leverage its advantages in Wi-Fi is hard because of the quick adaptation' requirement and well scaled antenna system designing in fast channel variations and MIMO.

When FD is been used in the Wi-Fi technology there is still many open issues unsolved like how to modify the transmission protocol? which STAs can be involved in FD? how to combine FD and MIMO/OFDMA? how to keep backward compatibility? etc. Another important open issue is when to apply FD [1] [7].

Multi-AP

SIC can makes transmission and reception happening in same time yet it is the most complex problem to solve. By two parts of SIC, internal reflections, non-linear components, and multipath will be reduced. First part is analog SIC, it reduces the strongest components. Second is digital SIC that reduces the interference below the noise floor. SIC can work perfectly only if the STA knows the amount of its internal reflections and non-linearity. To get this, the STA needs a powerful calibration with minimum system-level overhead [1] [7].

In null steering one of the most major challenges is that the APs need to use to other APs to get CSI from non-served STAs. multi-AP cooperation raises many open issues with topics its implementation and provided gains. Centralized and distributed clusterization is a part of mmWave Wi-Fi and Multi-AP cooperation needs tight synchronization between APs that can be done by wireless or backbones links. It is typically assumed that in Wi-Fi networks the neighbors APs may have different owners and be produced by different vendors. Thus, choosing any decisions to a concurrent APs is a problematic strategy [1] [7].

There are some innovation ideas that in a corporation network, single owner may have the majority of APs. Thus, any centralized decisions could be productive. However, issue is, unsure how efficient this idea effects alien STAs that are not under control. Multi-AP operation needs advanced scheduling techniques which will be higher than standard. the APs need to exchange information about channel resource requires, even in Co-OFDMA. Anyhow centralized or distributed Multi-AP scheduling methods raise the fairness problem [1] [7].

There are also many open issues related to joint transmission and reception. One of the topics is APs time, frequency, and phase synchronization. Synchronization can be affected by many things. For example, time shifts between NDP and Data frame, independent carrier frequency offsets, propagation delay between the APs to the STA and carrier frequency drifts at APs between the NDP and Data frames. Another topic is joint transmission and reception backhaul requirements. backhaul can provide data for all APs of all participating STAs. In theory, the backhaul can be deployed on the same channel as the fronthaul or another wireless/wired channel. In practice, backhaul have a huge capacity to exceeding the growing throughput of all the STAs in the network. The usage of it is questionable [1] [7].

Simulations

Packet Error Rate Simulation

A The simulation can be found in 802.11be mathlab simulation examples. In this simulation we are using 160 and 320 MHz channel bandwidth, an APEP length of 10 000 bytes, four transmit antennas (4 TRX), four space-time streams, MCS value from 0 to 13 and 4096-QAM. PHY and transmission parameters for an SU packet format configuration can be done by using matlab wlanEHTMUConfig object. In Channel configuration point of view, the example uses TGax NLOS indoor channel model with delay profile Model-B. This means that gap between TX and RX is greater or equal to 5 meters with NLOS considered. In this simulation I choose transmit and receive distance value to 5 meters [9].

In Simulation parameters point of view, need to set snrRange and steps to get SNR point. Then mathlab simulation creates the specified number of packets and set the packets through a channel after that demodulates the received signal to determine the packet error rate.

In mathlab, we have maxNumErrors and maxNumPackets objects parameters to control the number of packets tested for each SNR point. maxNumErrors is controlling the maximum number of packet errors simulated for each SNR point. The simulation is complete in this SNR point when number of packet erros reaches the limt. Object maxNumPackets is controlling the maximum number of packets in simulation and for each SNR point. if the simulation does not reach the packet error limit, the leght of simulation will be limitated [9].

For processing SNR points, first we should create a PSDU and encode it, because we need to generate a single -packet waveform and using different channel realization for each packt by passing the waveform through an indoor TGax channel model [9].

To create the desired average SNR per subcarrier after OFDM demodulation we must add AWGN to the received waveform.The system configuration takes into account the channel normalization within by the quantity of receiving antennas and the energy of the noise in the
unused subcarriers. During the process of OFDM demodulation, these unused subcarriers are eliminated. This simulation eliminates the unused subcarriers during OFDM demodulation.
After this, system detect packet and do estimation, also correction for bad CFO. Little bit after that using L-STF, L-LTF and L-SIG samples to perform fine timing synchronization. Also good looking CFO will be estimated and corrected for plotting [9].

Next step uses the synchronized received waveform to get EHT-LTF and OFDM will demodulate it and run channel estimation. Also, from the synchronized received waveform, we can get data field and run OFDM demodulation. After this system will run common phase error pilot tracking to verify CFO. After this, demodulated data field pilots and single-stream channel estimation at pilot subcarriers noise will estimate the noise. In the end channel estimation equalize symbols, by demodulating and decoding quealized symbols, PSDU will be recovered [9].

Results

For 160MHz 4TRX

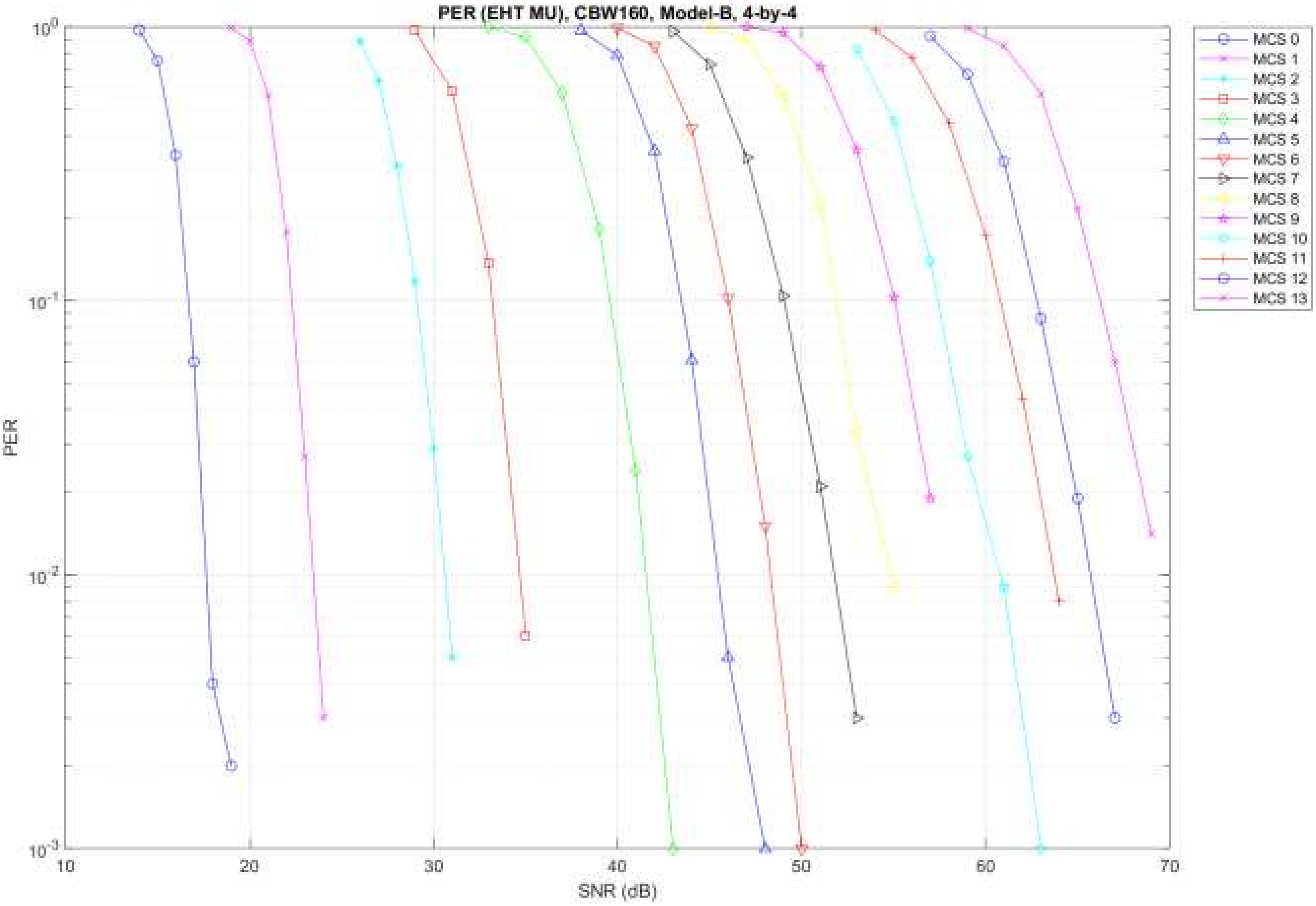

Figure 86. plot of simulation results with channel band 160MHz and 4 TRX.

For 320MHz 4TRX

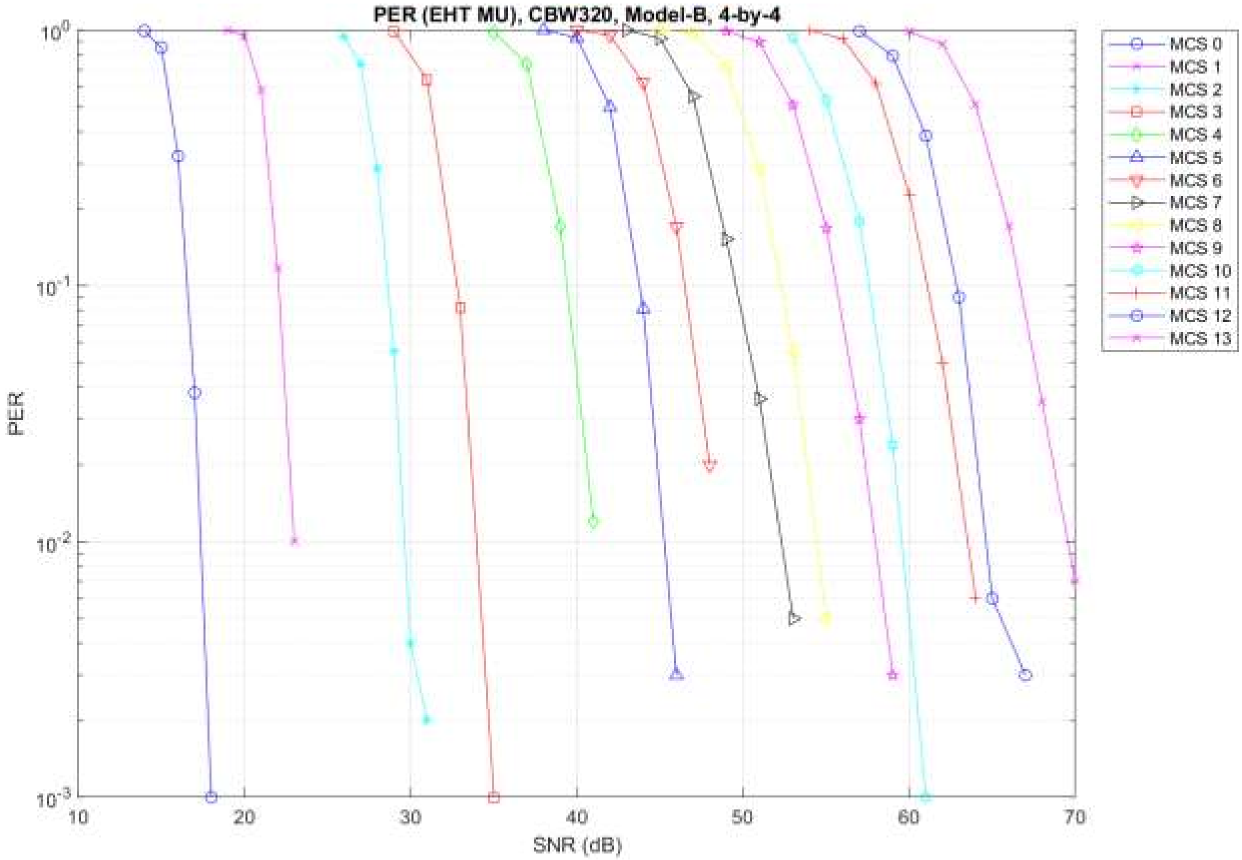

Figure 97. plot of simulation results with channel band 320MHz and 4 TRX.

Form the results, we can notice that higher MCS needs higher SNR. This means that whenever MCS increases data rate also increases coding which provides more reliability, that's why PER decreases and SNR increases. Also, the bandwidth increase (160MHz to 320MHz) improve performance and decreases PER. For example, if we take look at MCS 0 MCS 4 and MCS 13. In 160MHz plot when the SNR is 18 dB PER is still 0.004 but in 320MH plot when the SNR is 18 PER is down to 0.001. Also, in 160MHz plot MCS 4 line, when the SNR is 41dB, PER value is 0.024. Thus, 320MHz plot, same value at MCS 4, PER is 0.012 (half less). Finally, if we take look at MCS 13, SNR in 160MHz plot is 0.014 and in 320MHz plot is also half less (0.007). This shows that 320Mhz band with 4TRX bring more SNR and less data loss.

Downlink throughput MU-MIMO and OFDMA

In this simulation four STAs is simultaneously getting downlink EHT MU transmission from AP. EHT MU format can be configurated for MU-MIMO or OFDMA transmission. This brings flexibility to EHT MU transmission. In this MU-MIMO TRX simulation all four STAs share full band and for OFDMA TRX simulation, two STAs use large-size MRU and two STA RU. All transmission is BF in this simulation, for getting CSI, the channel sounding between AP and each STAs must be perfectly [9].

In the simulation there is repeats for diffracts pathlosses and AP throughput is calculated by packets number of successfully transmitted to all STAs. STA demodulates and decodes the data intended for the burst of 10 packets witch AP transmits. Also, AWGN between AP and each STAs is modeled by using TGax indroor MIMO channel [9].

Transmission configuration for cfgMIMO is an 320MHz MU-MIMO with single 996-tone RU with four users and each users has one space-time stream. For cfgOFDMA is also 320MHz but two users with 484+282-tone MRU, on user with a 106-tone RU and another one user with 106+26-tone RU In this case each user has two space-time streams. Channel model configuration is same as previous simulation. Delay profile is using model B, NLOS distance is 5 meter, and this is 4RXand 8TX. for simulate each path loss, the amount of packet is 1000 and –dB is used. AP transmit power is selected 45dBm and STA noise floor is -90dBm. Idle time between packets is kept to 20 microseconds and also APEP length in bytes is 1000 [9].

In both MU-MIMO and OFDMA TX BF Is depends on knowledge of the channel state between TX and RX at beamformer. To set up channel for BF, each STA use channel sounding to provides per-subcarrier channel state feedback. Each STA use null data packet witch the AP transmit to determine the channel state after that AP get feedback about channel state [9].

Results

Result point of view I have pick MCS 5 and MCS 13 to compare the results. Path loss to simulate for both MU-MIMO and OFDMA are form 80 dB to 120 dB with two step. Let’s check first MU-MIMO simulation.

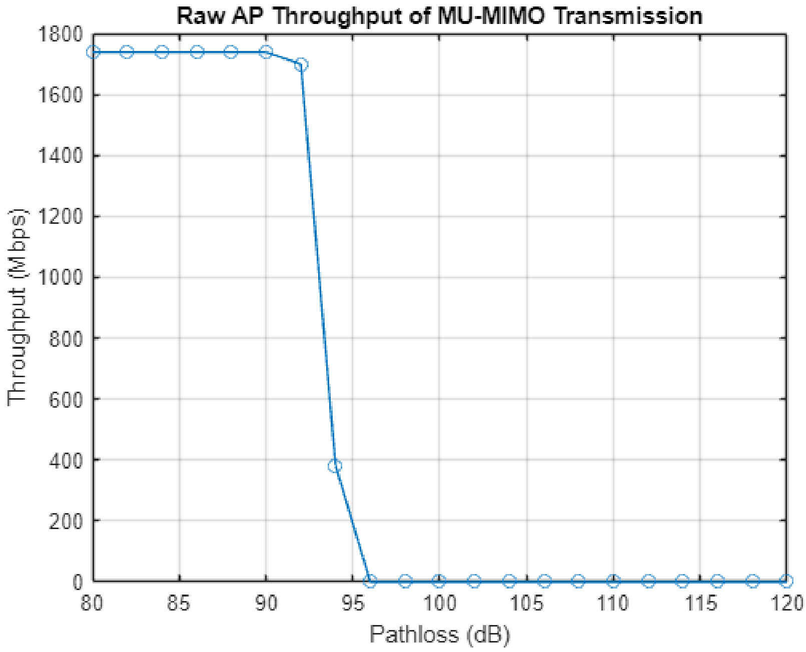

Figure 20. MCS 13 MU-MIMO

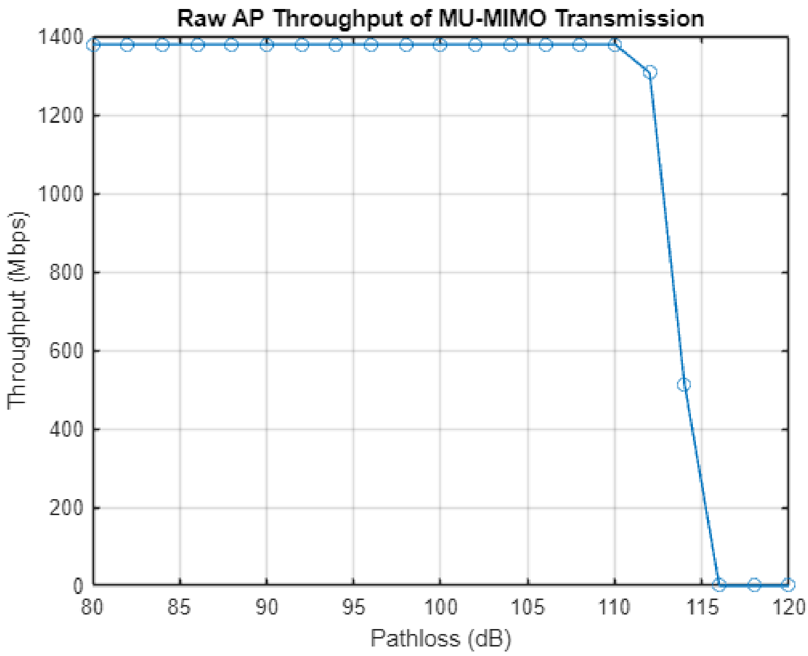

Figure 21. MCS 5 MU-MIMO

Compare these two figures we can notice that when the MCS is higher the path loss is low, and SNR is high. This provided more throughput. Also, when the SNR is low, the throughput drops very fast. In MCS 13 AP throughput drop to 0.0 Mbps at pathloss 96.0 dB, thus in MCS 5 AP throughput drop to 0.0 Mbps till pathloss 116.0 dB. But in max throughput point of view MCS 13 got 1739.1 Mbps but MCS 5 has only 1379.3 Mbps.

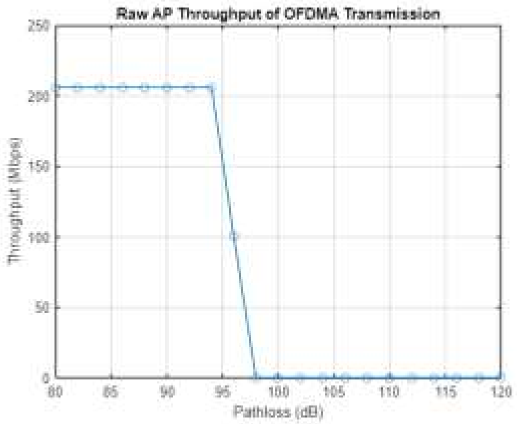

Figure 22. MCS 13 OFDMA

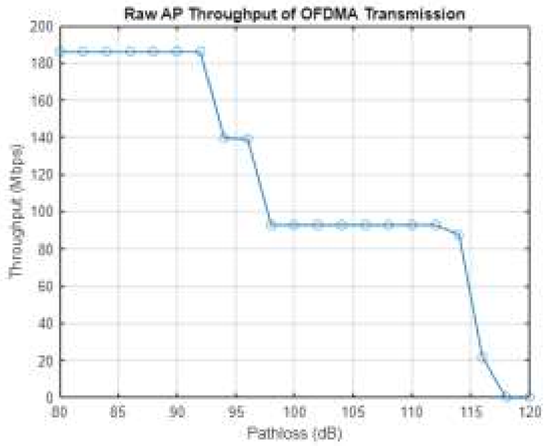

Figure 23. MCS 5 OFDMA

As we can see on the results when the path loss increases and SNR decrease, packets starts fails to be decoded and the throughput drops. with MCS 13 we have again higher throughput but MCS 5 throughput drop is more slower than MCS 13. Based on this simulation result we can see, depending on use cases we need to choose right MCS for different use cases. For example in the city, we can use high for critical things, then MCS 13 is better choice. But in the place where speed is not important but need to be robust to attenuation then MCS 5 is better choice.

Summary

IEEE 802.11be have a lot of improvement form IEEE 802.11ax. Like 320Mhz, 16 TRX, 4K-QAM and OFDMA. Also have lot new features like HARQ, FD, NOMA, MLO and MU-AP. Those have potential to bring high throughput, low latency, and multiple use for multiple stations. But most of them are still in theoretical level and have a lot of problem and limitations in the real world. Soon

IEEE 802.11be as known as Wi-Fi 7 will meet the market, let’s see how it survives. Or will the WiFi 8 be the key for all those solutions.

With articles I have learn a lot about theory part like, what is WiFi and function about features of WiFi 7, also differences between WiFi6 and WiFi7. Of course, also use cases and limitations of it. Like WiFi mainstream is used inside (manufactory, hospital or airport) than outside. With MATLAB simulations the theory part got confirm when you really got dig into the code and structure.

From the Packet Error Rate simulation, I have learned that higher MCS needs higher SNR and whenever MCS increases data rate also increases coding which provides more reliability and that follow PER decreases and SNR increases. Form the Downlink throughput simulation I learn that depending on use cases we need to choose right MCS for different use cases. in some places were throughput matters, then use higher MCS. But in the place where speed is not important but need to be robust to attenuation then lower MCS can be also option.

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