WI-FI TECHNOLOGY
FUNDAMENTALS COURSE

Module 5: Advanced Features and Standard Extensions

Session 5b:

Wi-Fi 6 NEW FEATURES- OFDMA, MU-MIMO, BSS Coloring, TWT

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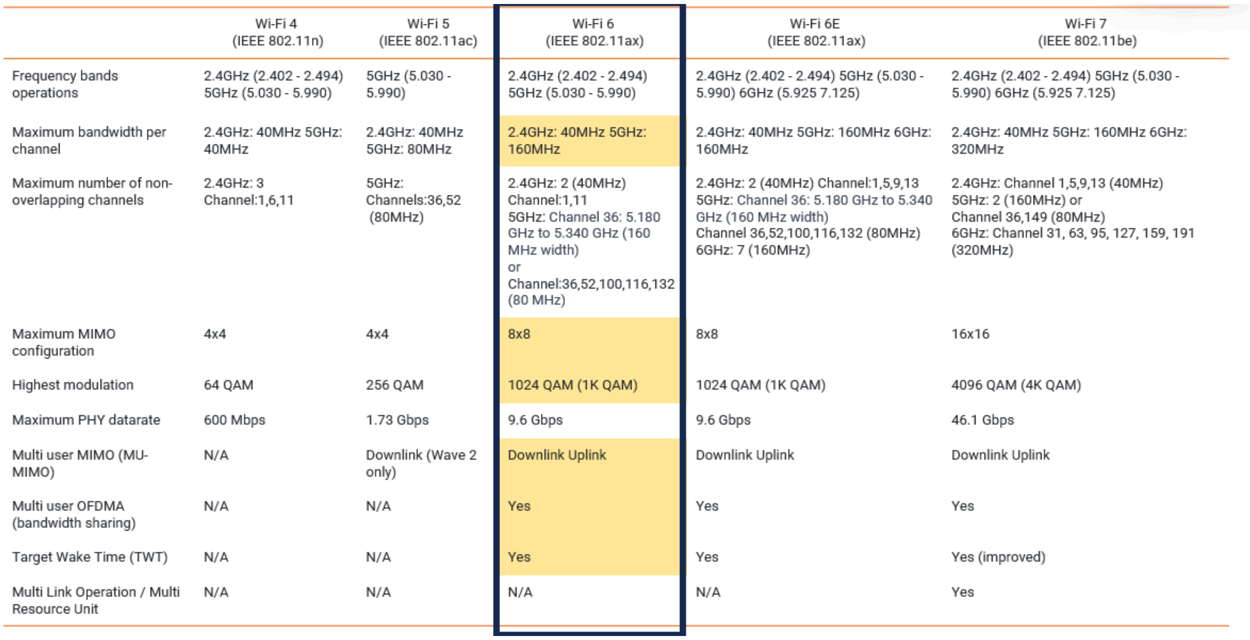
Wi-Fi Technology Generations:



	Wi-Fi 4 (IEEE 802.11n)	Wi-Fi 5 (IEEE 802.11ac)	Wi-Fi 6 (IEEE 802.11ax)	Wi-Fi 6E (IEEE 802.11ax)	Wi-Fi 7 (IEEE 802.11be)
Frequency bands operations	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990)	5GHz (5.030 - 5.990)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125)
Maximum bandwidth per channel	2.4GHz: 40MHz 5GHz: 40MHz	2.4GHz: 40MHz 5GHz: 80MHz	2.4GHz: 40MHz 5GHz: 160MHz	2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 160MHz	2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 320MHz
Maximum number of non-overlapping channels	2.4GHz: 3 Channel:1,6,11	5GHz: Channels:36,52 (80MHz)	2.4GHz: 2 (40MHz) Channel:1,11 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) or Channel:36,52,100,116,132 (80 MHz)	2.4GHz: 2 (40MHz) Channel:1,5,9,13 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) Channel 36,52,100,116,132 (80MHz) 6GHz: 7 (160MHz)	2.4GHz: Channel 1,5,9,13 (40MHz) 5GHz: 2 (160MHz) or Channel 36,149 (80MHz) 6GHz: Channel 31, 63, 95, 127, 159, 191 (320MHz)
Maximum MIMO configuration	4x4	4x4	8x8	8x8	16x16
Highest modulation	64 QAM	256 QAM	1024 QAM (1K QAM)	1024 QAM (1K QAM)	4096 QAM (4K QAM)
Maximum PHY datarate	600 Mbps	1.73 Gbps	9.6 Gbps	9.6 Gbps	46.1 Gbps
Multi user MIMO (MU-MIMO)	N/A	Downlink (Wave 2 only)	Downlink Uplink	Downlink Uplink	Downlink Uplink
Multi user OFDMA (bandwidth sharing)	N/A	N/A	Yes	Yes	Yes
Target Wake Time (TWT)	N/A	N/A	Yes	Yes	Yes (improved)
Multi Link Operation / Multi Resource Unit	N/A	N/A	N/A	N/A	Yes

Fig 1

Wi-Fi technology has evolved through several generations, each offering faster speeds and improved capabilities:

- Wi-Fi 1-3 (802.11a/b/g): Introduced in the late 1990s and early 2000s, these early generations offered limited speeds and range.
- Wi-Fi 4 (802.11n): Released in 2009c, 802.11n significantly increased speeds and introduced features like MIMO (Multiple-Input, Multiple-Output) for better performance.

- Wi-Fi 5 (802.11ac): Introduced in 2013, 802.11ac offered even higher speeds and expanded to the 5 GHz band, improving performance in congested environments.
- Wi-Fi 6 (802.11ax): Designed for efficiency in dense environments with many devices.
- Wi-Fi 6E (802.11ax): An extension of Wi-Fi 6, adding the 6 GHz band for more available spectrum.
- Wi-Fi 7 (802.11be): Offers extreme speeds and improved performance for diverse applications.

The Backward Compatibility Problem:

A major challenge in Wi-Fi evolution is backward compatibility. Each new generation must be compatible with older devices to ensure widespread adoption. While this allows older devices to connect, it can limit the full potential of newer technologies due to:

- Sharing resources: Newer devices must share the same resources (bandwidth, channels) with older devices, reducing their effective speed.
- Lowering capabilities: Newer technologies might have features (like higher modulation rates) that older devices cannot support, limiting the overall performance.

What's New with 802.11ax (Wi-Fi 6):

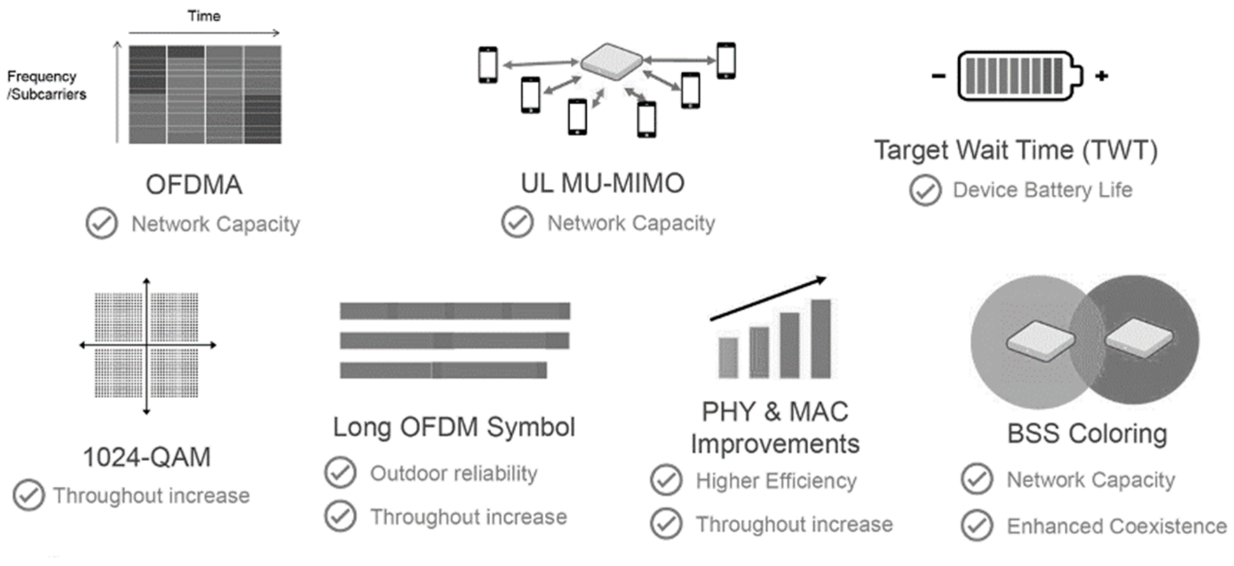


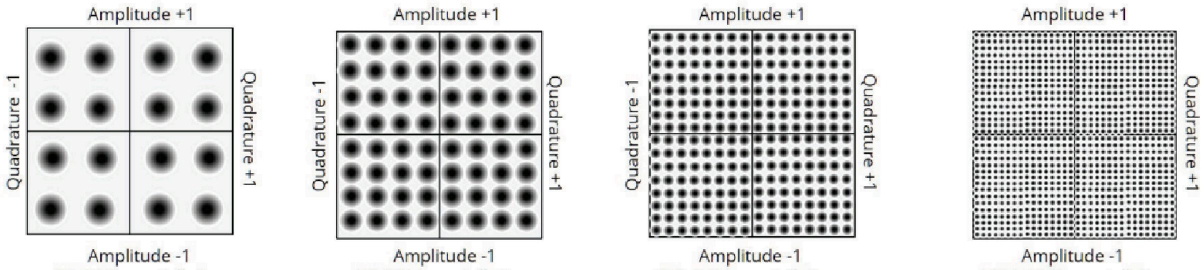
Fig 2

- Released in 2019, 802.11ax (Wi-Fi 6) addresses the limitations of previous generations, focusing on efficiency and performance in dense environments:
- OFDMA(Orthogonal Frequency Division Multiple Access): This technology enables efficient data transmission to multiple devices simultaneously by assigning them dedicated portions of the frequency spectrum, improving performance in congested networks.
- UL MU-MIMO(Uplink Multi-User, Multiple-Input, Multiple-Output.): This technology allows a Wi-Fi access point to transmit data to multiple devices simultaneously on the uplink channel, improving upload speeds and efficiency.
- Device Battery Life: Wi-Fi 6 introduces Target Wake Time (TWT) to improve battery life for battery-powered devices. TWT schedules data transmission times for these devices,

minimizing the time they need to stay awake and listen for data, reducing power consumption.

- BSS Coloring: This feature helps differentiate between neighboring Wi-Fi networks operating on the same channel, reducing interference and improving performance in dense deployments.
- 1024-QAM: This modulation scheme allows more data to be packed into each symbol, improving overall throughput and efficiency.
- Long OFDM Symbol: Wi-Fi 6 introduces longer Orthogonal Frequency Division Multiplexing (OFDM) symbols compared to previous generations. This allows for more efficient use of the transmission time and potentially increases range, especially in outdoor environments.
- PHY & MAC Improvements: Wi-Fi 6 incorporates various physical layer (PHY) and medium access control (MAC) layer improvements that contribute to its overall performance and efficiency.

1024 QAM



16-QAM constellation 64-QAM constellation 256-QAM constellation 1024-QAM constellation

Fig 3.1

- The first new thing in Wi-Fi 6 is higher order modulation rate.
- Every time we go to a newer standard, we just want to pack more and more bits per symbol and we're using higher and higher modulation rates.
- Compared to Wi-Fi 5 (802.11ac) with a 256 QAM modulation rate, Wi-Fi 6 (802.11ax) boasts a modulation rate that is four times higher, reaching up to 1024 QAM.
- There is always a trade-off that the higher order modulation rate gives you more bits per symbol, it gives you higher spectral efficiency which means it gives you much higher throughput but the tradeoff is that the communication is not reliable and you need a much better signal quality and much better signal to noise ratio(SNR) to maintain communication at that higher order modulation rates.
- What that means is, if you have a 802.11ax access point and if you're transmitting in 1024 QAM maybe within like 2 meters or 3 meters or 5 meters and if you have line of sight then you should be able to successfully communicate. Then the signal to noise ratio is high, there is no Co-Channel interference then you should be able to make the full use of the higher order modulation rate and get the full throughput.

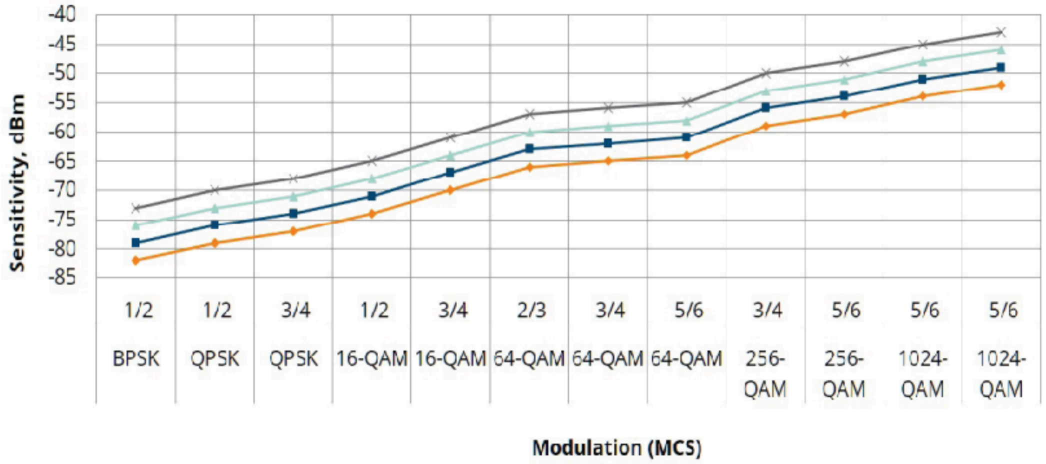


Fig 3.2

- The chart above shows that the receiver sensitivity needs to be much higher for 1024 QAM i.e, about -45 dBm.
- While with BPSK, you go all the way up to -85 to -90dBm.
- So basically your signal to noise ratio and the quality of the received signal needs to be really good to be able to use these high data rates.
- Even though the box(here we're referring to the labels on the AP) says you can achieve like 9.6 Gbps throughput, there are lots of caveats and lots of conditions under which you can achieve that.

MCS	Modulation & Rate	20 MHz 1x SS	20 MHz 2x SS	20 MHz 4x SS	20 MHz 8x SS	40 MHz 1x SS	40 MHz 2x SS	40 MHz 4x SS	40 MHz 8x SS	80 MHz 1x SS	80 MHz 2x SS	80 MHz 4x SS	80 MHz 8x SS
0	BPSK 1/2	8.6	17.2	34.4	68.8	17.2	34.4	68.8	137.6	36.0	72.1	144.1	288.2
1	QPSK 1/2	17.2	34.4	68.8	137.6	34.4	68.8	137.6	275.3	72.1	144.1	288.2	576.5
2	QPSK 3/4	25.8	51.6	103.2	206.5	51.6	103.2	206.5	412.9	108.1	216.2	432.4	864.7
3	16-QAM 1/2	34.4	68.8	137.6	275.3	68.8	137.6	275.3	550.6	144.1	288.2	576.5	1,152.9
4	16-QAM 3/4	51.6	103.2	206.5	412.9	103.2	206.5	412.9	825.9	216.2	432.4	864.7	1,729.4
5	64-QAM 1/2	68.8	137.6	275.3	550.6	137.6	275.3	550.6	1,101.2	288.2	576.5	1,152.9	2,305.9
6	64-QAM 3/4	77.4	154.9	309.7	619.4	154.9	309.7	619.4	1,238.8	324.3	648.5	1,297.1	2,594.1
7	64 QAM 5/6	86.0	172.1	344.1	688.2	172.1	344.1	688.2	1,376.5	360.3	720.6	1,441.2	2,882.4
8	256-QAM 3/4	103.2	206.5	412.9	825.9	206.5	412.9	825.9	1,651.8	432.4	864.7	1,729.4	3,458.8
9	256-QAM 5/6	114.7	229.4	458.8	917.6	229.4	458.8	917.6	1,835.3	480.4	960.8	1,921.6	3,843.1
10	1024-QAM 3/4	129.0	258.1	516.2	1,032.4	258.1	516.2	1,032.4	2,064.7	540.4	1,080.9	2,161.8	4,323.5
11	1024-QAM 5/6	143.4	286.8	573.5	1,147.1	286.8	573.5	1,147.1	2,294.1	600.5	1,201.0	2,402.0	4,803.9

Fig 3.3

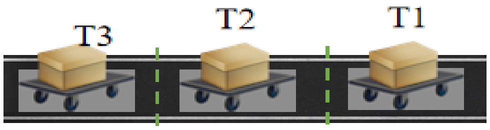
- 802.11ax introduces two new MCS rates.
- We have up to MCS 9 that goes to 256QAM with 802.11ac.
- 802.11 ax added MCS 10 & MCS 11 that is 1024 QAM at 3/4 coding rate & 5/6 coding rate. This allows you to basically achieve even more throughput.
- So 1024 QAM is purely about speed and better throughput.

OFDMA

- 802.11ax is also about higher efficiency and also increasing the capacity of the number of users that can simultaneously use an access point.
- In 802.11ac, usually, in an enterprise environment, you might have around 20-30 devices connected to one access point. But with 802.11ax, the aim is to support many more

devices, possibly up to 1000, by using technologies like OFDMA. This lets the access point serve multiple clients at the same time, even at lower bandwidths.

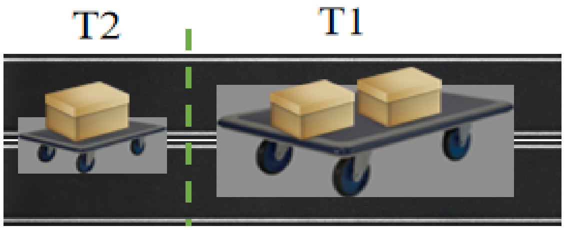
- Let's understand OFDMA concept in WiFi 6 with a simple example:



40MHz Channels - OFDM

Fig 4.1

- As shown in the figure 1.1, Let's imagine you have a 40MHz channel, and you're utilizing it for OFDM transmission. In this analogy, think of the channel as a road.
- Now, at time instant T1, consider a vehicle of a certain size (smaller than the road width) that needs to carry a payload. At time instant T2, perhaps another payload from a different vehicle can be transported, and at time instant T3, yet another payload can be carried on another vehicle.



80MHz Channels - OFDM

Fig 4.2

- Consider figure 1.2, If the road is wider(assume 80MHz channels), it's like having a broader path. A bigger vehicle (representing data) can use the entire path, allowing twice the information from a single user at a specific moment (T1).
- However, as we make the road faster, we're making the AP faster and the connected devices need more bandwidth.
- For example, streaming high-definition 4K or 8K video requires a lot of bandwidth. Yet, devices like IoT devices, printers or scanners need not require that much space. So, at a different moment (time instant T2), some parts of the road may be unused.

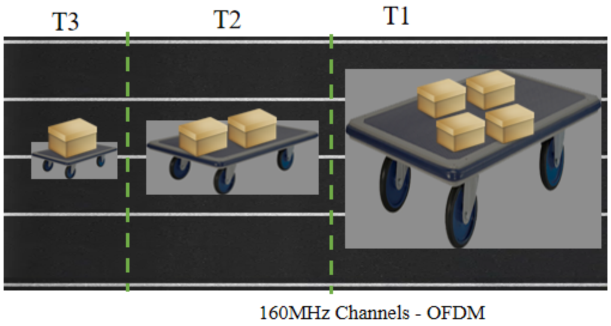


Fig 4.3

- As shown in Figure 1.3, wider channels result in faster speeds, allowing for the transmission of larger volumes of data and accommodating larger vehicles.
- For instance, with an 8K video stream requiring 200 Mbps data rate, you can utilize a bigger vehicle for transmission. However, the problem arises when other devices, not

requiring such high bandwidth, occupy the entire spectrum, leading to spectrum wastage.

- It's more efficient to split the spectrum into separate channels. For example, modern access points often use 80 MHz or 160 MHz channels. If your transmission only needs a small amount of data, using a 160 MHz channel wastes a significant portion of the spectrum.
- This is how normal OFDM works.

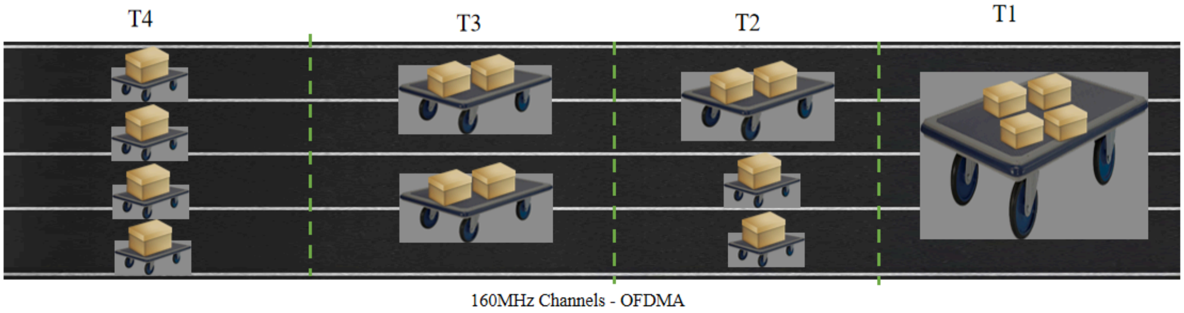
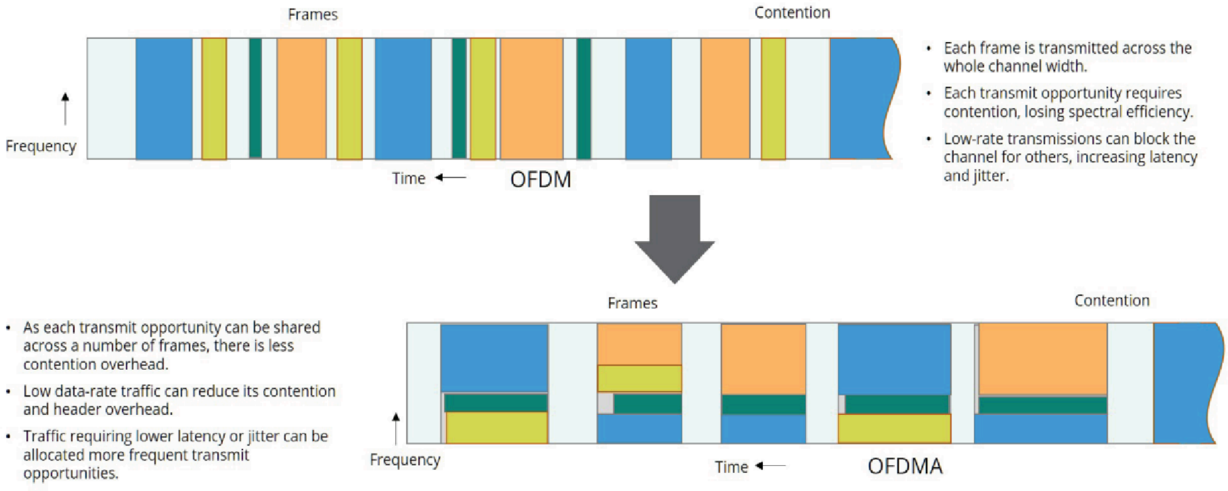


Fig 4.4

- OFDMA works in an interesting way. It operates by dynamically allocating bandwidth to multiple devices.
- Consider figure 1.4, thinking of it like a highway: initially, when one device requires a lot of data, it's like a large vehicle occupying the entire road. But as other devices with lighter data loads join, the highway is divided into smaller lanes, each serving as a separate channel.
- Now, devices with varying bandwidth needs can utilize different lanes simultaneously, enabling multiple transmissions without slowing down overall throughput.

- This simultaneous access reduces wait times and latency, improving communication speed.

How does OFDMA increase spectral efficiency?



- Each frame is transmitted across the whole channel width.
- Each transmit opportunity requires contention, losing spectral efficiency.
- Low-rate transmissions can block the channel for others, increasing latency and jitter.

- As each transmit opportunity can be shared across a number of frames, there is less contention overhead.
- Low data-rate traffic can reduce its contention and header overhead.
- Traffic requiring lower latency or jitter can be allocated more frequent transmit opportunities.

Fig 5.1

- If you examine how OFDMA operates conceptually, the first diagram illustrates OFDM, while the bottom one depicts OFDMA. The x-axis represents time, and the y-axis represents frequency.
- Over time, the lighter sections indicate when the medium isn't being used, including contention and management frames.
- Each transmission occurs sequentially, with one device using the entire frequency band at a time, much like the earlier road analogy.
- In contrast, OFDMA allows for simultaneous transmission.
- At the first time interval, device1 can transmit in the blue frequency slot, device2 in the green, and device three in the yellow, all simultaneously.
- Subsequently, in the next transmission opportunity, a different set of devices may transmit with varying channel bandwidths, demonstrating the flexibility of OFDMA at a conceptual level.

Orthogonal Frequency Division Multiplexing (OFDM):

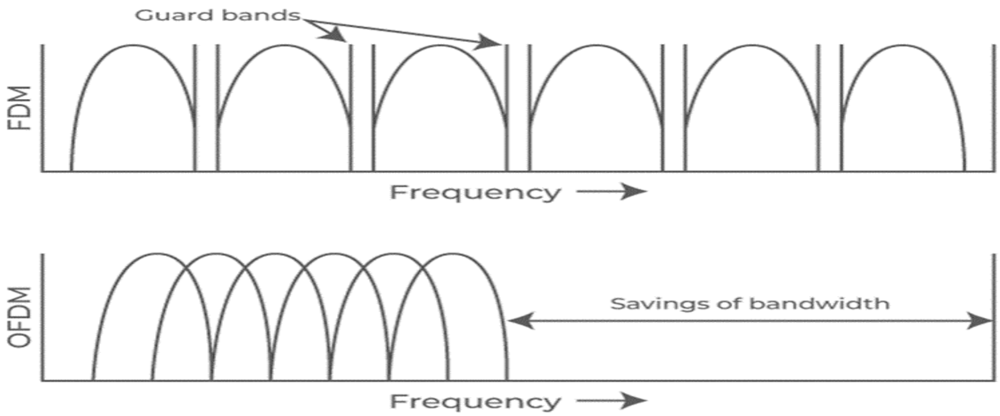
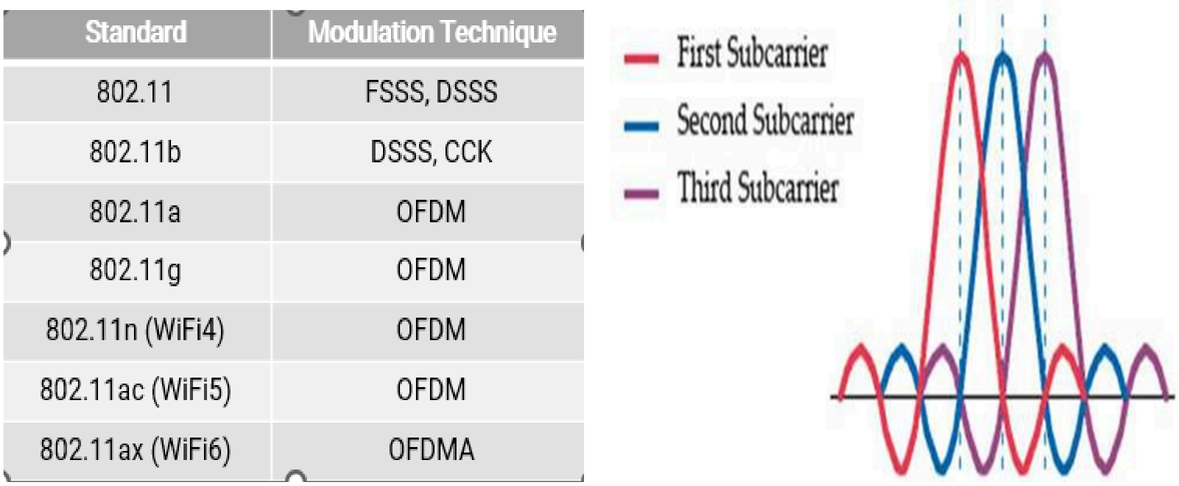


Fig 5.2

Let's know about how Wi-Fi technology works, specifically at the OFDM (OrthogonalFrequency Division Multiplexing) level. First, we need to understand a bit about Frequency Division Multiplexing (FDM), where information is sent on different frequencies at the same time. Now, onto OFDM:

- In OFDM,several bits can be sent in parallel, or at the same time, in separate sub stream channels.
- OFDM lets us send information in smaller chunks, making better use of frequencies.
- It works like a puzzle, with subcarriers (small chunks of data) overlapping in an octagonal pattern.
- This clever overlapping avoids problems, like interference, making it work well.

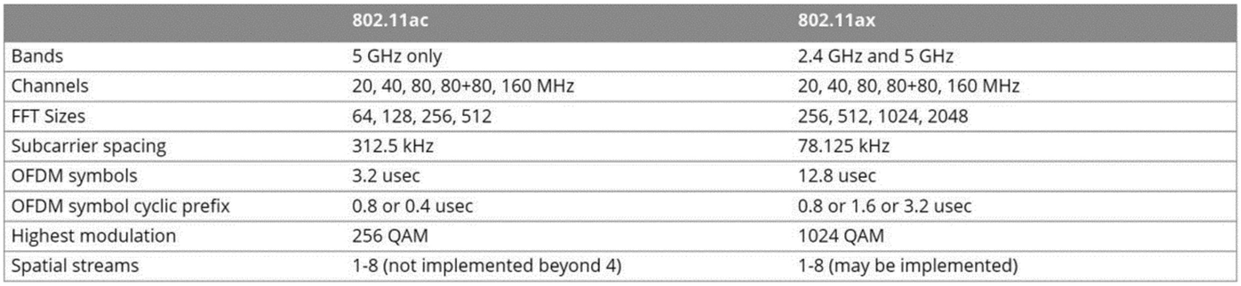
This maximizes how much data we can send in a given space.This helps Wi-Fi work more efficiently.



Standard	Modulation Technique
802.11	FSSS, DSSS
802.11b	DSSS, CCK
802.11a	OFDM
802.11g	OFDM
802.11n (WiFi4)	OFDM
802.11ac (WiFi5)	OFDM
802.11ax (WiFi6)	OFDMA

Fig 5.3

802.11ax OFDM PHY Changes



	802.11ac	802.11ax
Bands	5 GHz only	2.4 GHz and 5 GHz
Channels	20, 40, 80, 80+80, 160 MHz	20, 40, 80, 80+80, 160 MHz
FFT Sizes	64, 128, 256, 512	256, 512, 1024, 2048
Subcarrier spacing	312.5 kHz	78.125 kHz
OFDM symbols	3.2 usec	12.8 usec
OFDM symbol cyclic prefix	0.8 or 0.4 usec	0.8 or 1.6 or 3.2 usec
Highest modulation	256 QAM	1024 QAM
Spatial streams	1-8 (not implemented beyond 4)	1-8 (may be implemented)

Fig 6

Wi-Fi 11ax brings significant improvements by optimizing subcarrier spacing, symbol duration, and guard intervals, ensuring better efficiency and increased data transmission capacity within the given frequency spectrum.

Changes in 11ax OFDM:

- 11ac OFDM divided a 20 MHz channel into 64 subcarriers with a spacing of 312.50 kHz.
- In 11ax, subcarrier spacing is reduced to 78, making subcarriers even closer.
- This allows packing more data into the same 20 MHz spectrum.
- 11ax can handle 256 subcarriers within the same channel, compared to 64 in 11ac.

Symbol Duration:

- Symbol duration, the time a symbol is transmitted, has increased from 3.2 microseconds in 11ac to a new value in 11ax.

Guard Interval:

- Guard interval is the interval between subcarriers, influencing interference.
- Longer guard intervals are introduced in 11ax (0.8, 1.6, and 3.2 microseconds).
- Longer guard intervals are useful for long-range communication and scenarios with multipath interference.

Efficiency Consideration:

- Despite increased guard intervals, overall efficiency is maintained.

- Symbol time increase and reduced inter-symbol gap compensate for the potential efficiency loss.

Longer Guard Interval for better Range

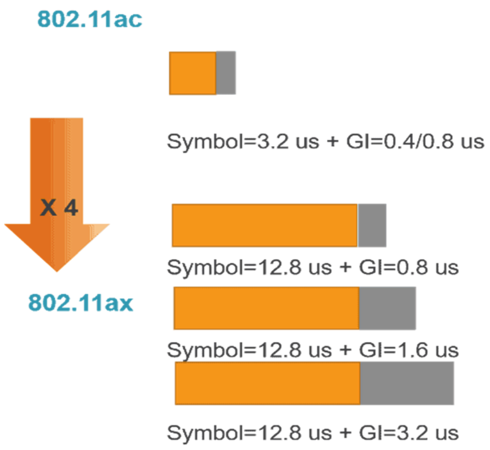


Fig 7

Wi-Fi 11ax gives us more options for guard intervals.Longer guard intervals are like extra safety time for better performance in tricky places.

Why Longer Intervals?

- They help avoid mix-ups between signals, especially outside.

- This makes Wi-Fi work better in wider areas.

Comparison with Older Wi-Fi:

- Before, we had two choices for guard intervals in 802.11ac:
  - A longer one (0.8 μs).
  - A shorter one (0.4 μs).
- Now, with 802.11ax, we get three choices:
  - A regular one (0.8 μs).
  - A double-sized one (1.6 μs).
  - A four-times bigger one (3.2 μs).

Keeping Things Efficient:

- Wi-Fi 11ax is still efficient.
- Even with the longest guard interval, it doesn't slow things down because the main signal time is longer.

Resource Units

- A Resource Unit (RU) is a group of sub carriers (tones) that can be assigned to a single User.
- Each RU or group of RUs can be allocated to different users to achieve OFDM –Multiple Access, also referred to as OFDMA
- The 20MHz channel can be subdivided into as small as 2MHz channels. Each 2MHz corresponds to 26 tones.

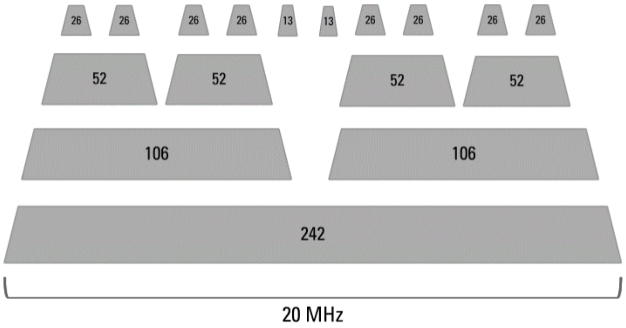


Fig 8.1

- Imagine we have a Wi-Fi channel, like a road with different lanes. In the traditional setup, the entire road is used by just one device to send data. But with OFDMA (Orthogonal Frequency Division Multiple Access), we can do things differently.
- Normally, in a 20 MHz Wi-Fi channel, only one device can send data at a time. It's like one car using the entire road. But with OFDMA, we can split this road into smaller parts called "resource units."
- Each resource unit can be used by a device to send data. So, instead of one device hogging the whole road, we can have multiple devices using different parts of it simultaneously. It's like having separate lanes on a highway for different cars.

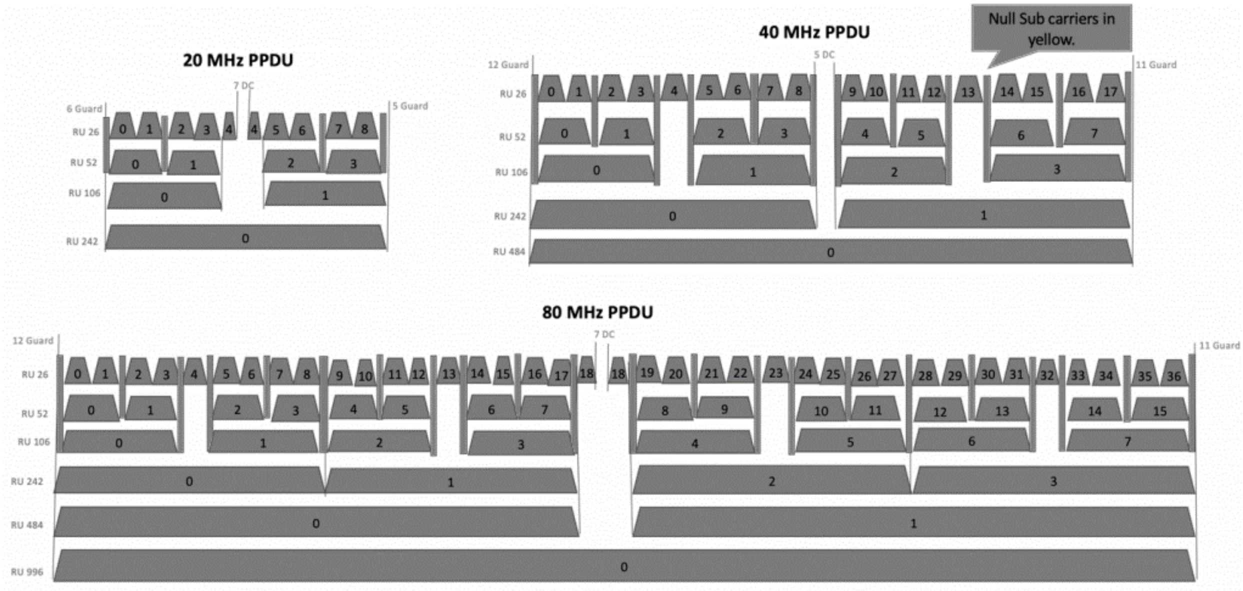


Fig 8.2

- Now, let's say we have a 20 MHz channel, and normally one device would use all of it. With OFDMA, we can divide it into two resource units, each covering 160 tones (think of tones as small parts of the road). This means two devices can now send data at the same time using these two units.
- We can go further and split it into four resource units, each with 52 tones, allowing four devices to communicate simultaneously. We have the flexibility to adjust the size of

these units based on the needs of different devices.

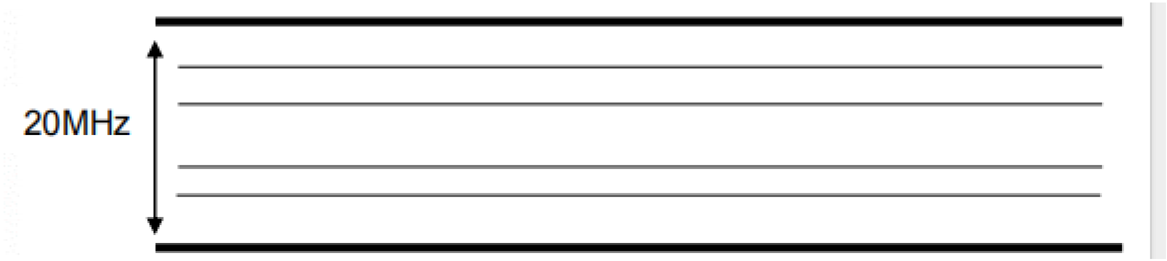


Fig 8.3

- For instance, a high-quality 8K TV might use the entire 20 MHz band for its data transmission, while simpler devices like doorbells or wireless cameras might use smaller parts. This flexibility allows various devices to communicate efficiently based on their data requirements.
- So, the key takeaway is that OFDMA allows us to efficiently use Wi-Fi channels by dividing them into smaller units, enabling multiple devices to communicate at the same time, similar to having different lanes on a road. This flexibility is a cool feature, even though implementing the maximum number of simultaneous users might be challenging in practice.

RU type	20 MHz BW	40 MHz BW	80 MHz BW	80+80/160 MHz BW
26-tone RU	9	18	37	74
52-tone RU	4	8	16	32
106-tone RU	2	4	8	16
242-tone RU	1	2	4	8
484-tone RU	N/A	1	2	4
996-tone RU	N/A	N/A	1	2
2x996-tone RU	N/A	N/A	N/A	1

Fig 8.4

Downlink OFDMA Frame Exchange Process

- The AP sends a multi user request-to-send (MU-RTS) frame to associated client STAs.
  - The MU-RTS frame contains a list of RU assignments for each 802.11ax client and helps coordinate the multiuser frame exchange.
  - The MU-RTS frame also contains a timer (network allocation vector (NAV)) to notify clients how long the exchange will take
  - This frame is transmitted using OFDM across the entire channel so legacy clients know to remain silent through the OFDMA frame exchange
- The 802.11ax clients send clear-to-send (CTS) responses in parallel using their assigned RUs.
- The AP transmits each client's data in parallel using the assigned RUs.
- The AP sends a block acknowledgement request (BAR) to confirm if each client received the transmission successfully.
- If the data frames were received successfully, the clients respond with a block acknowledgement (ACK) in parallel.

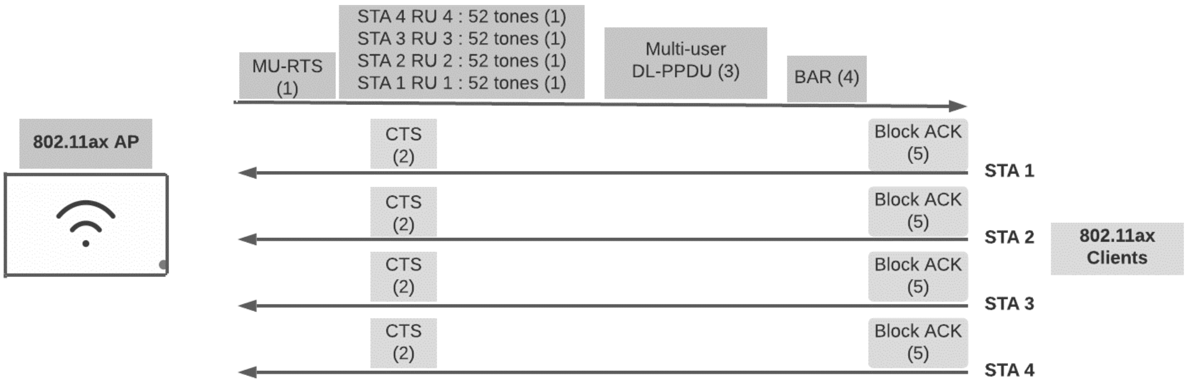


Fig 9

Now, let's see how the process of sending data from the Wi-Fi access point (AP) to multiple devices works using OFDMA.

- Picture this: you have an AP, and there are four devices nearby that want to receive data from it. It's important to note that both the AP and these devices must support OFDMA for this to happen. If a device doesn't support OFDMA, it will have to wait for its turn to transmit data.
- Now, the AP has some data that it needs to send to these four devices. Each device has a different amount of data to receive – one has a little, another has a lot, and so on. The AP knows this information.
- To kick off the OFDMA process, the AP sends out a special broadcast message called a "multi-user RTS frame" or a "request to send frame." This message tells all devices which part of the Wi-Fi spectrum (like different lanes on a road) they can use for transmission.

- The AP allocates specific "tones" (think of them as segments of the road) to each device based on how much data they have. For example, it might assign more tones to a device with a lot of data and fewer tones to a device with less data.
- All the devices that can participate in OFDMA listen to this message and confirm their readiness by sending a "clear to send" frame. Importantly, they send this frame only in the allocated tones specified by the AP. This is like cars claiming their designated lanes on the road.
- Now, with everyone in place, all four devices can transmit data simultaneously in their assigned tones. It's like having different cars in their lanes on the road, all moving at the same time.
- After this simultaneous transmission, the AP sends a "multiuser download PDU" – essentially, it sends data to all four devices at the same time in their designated frequency portions.
- Finally, the AP requests acknowledgment from the devices using a "block act request." Each device responds with a "block acknowledgment" in their allocated tones to confirm that they received the data.
- This entire process is one transmission opportunity. After this, another opportunity may be given to devices that don't support OFDMA, and then the OFDMA process repeats for the next transmission opportunity.
- So, in simpler terms, the AP assigns specific parts of the Wi-Fi spectrum to devices based on their data needs, and then they all transmit and receive data simultaneously, making the communication more efficient.

Uplink OFDMA Frame Exchange Process

- The 802.11ax AP sends a buffer status report poll (BSRP) to check how much buffered data the clients are ready to send.

- Clients respond with a buffer status report (BSR). This helps the AP plan RU size and quantity.
- The AP sends a multi user request-to-send (MU-RTS) frame to all clients.
    - ➔ The MU-RTS frame contains a list of RU assignments for each 802.11ax client and helps coordinate the multiuser frame exchange
    - ➔ The MU-RTS frame also contains a timer to notify clients how long the exchange will take
    - ➔ This frame is transmitted using OFDM across the entire channel so legacy clients know to remain silent through the OFDMA frame exchange
- The 802.11ax clients send clear-to-send (CTS) responses in parallel using their assigned RUs.
- The AP sends one last trigger frame to coordinate each client's transmission.
- The clients transmit their data frames to the AP in parallel.
- If the data frames were received successfully, the AP responds with a block acknowledgement (ACK).

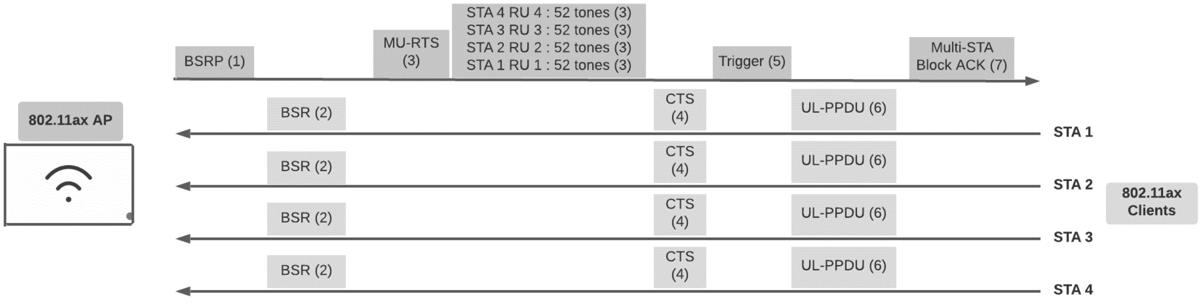


Fig 10

- Now, when our device is sending information to the Wi-Fi access point (AP). This process, called the uplink, is a bit similar to the downlink we discussed earlier, but there's a small difference.
- When the AP is sending data to our device, it already knows how much data each device needs because it has it all stored. But when our device wants to send data to the AP, the AP doesn't know how much data each device has to share.
- To solve this, the AP sends out a special message called a "buffer status report poll frame". This is like the AP asking all devices, "Hey, how much data do you have to send?"
- Each device responds with its own "buffer status report," letting the AP know how much data they want to send. Once the AP gets this information, it figures out how to split the Wi-Fi spectrum into different parts for each device.
- Then, just like in the downlink process, the AP sends a "multi-user RTS frame," and devices acknowledge it with a "CPS frame." But in the uplink, there's an extra step. The AP sends a "trigger frame" to instruct the devices to start sending their data.
- Now, all the devices can send their data simultaneously to the AP, each using their assigned part of the Wi-Fi spectrum. After this simultaneous transmission, there's a block acknowledgment process to confirm that the data was received.
- It's important to note that this process adds some complexity with status reports, RTS frames, and trigger frames being sent across the entire Wi-Fi spectrum. This complexity might be a bit much, but it becomes more efficient when you have lots of devices with smaller amounts of data to send.
- So, in simpler terms, when our device wants to talk to the Wi-Fi, the AP first checks how much data our device has to send, assigns a space for it, and then tells our device to start talking. This way, multiple devices can talk at the same time, making things more efficient.

Multi User – MIMO Basics

- Basic concept of Mu-MIMO is to improve spectral efficiency using spatial diversity

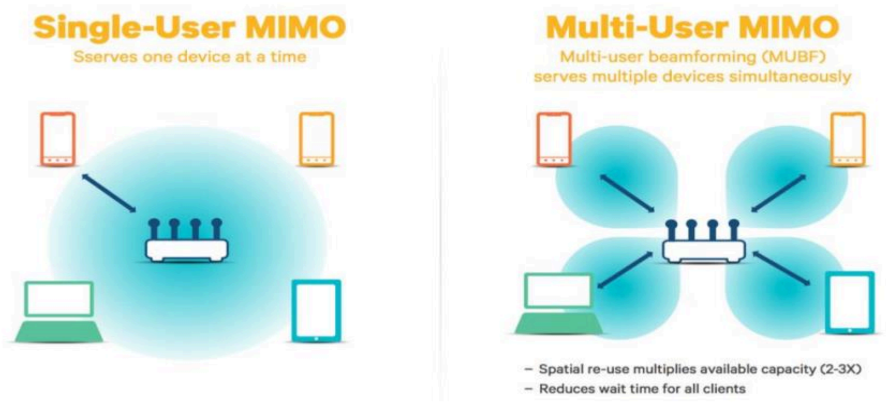


Fig 11.1

- Imagine you have a Wi-Fi router in your home. Usually, it sends out signals in all directions, like a light bulb illuminating a room. This is how traditional routers work. But what if the router could focus its signal like a flashlight towards different devices in different directions?
- That's the basic idea behind multi-user MIMO. Instead of broadcasting signals everywhere, it directs them more precisely towards specific devices. So, if you have

multiple devices spread around the router, it can send signals to each one directly without them interfering with each other.

Here's a simple breakdown of how it works:

- **Spatial Diversity:** Instead of broadcasting signals in all directions, multi-user MIMO allows the router to send signals to different devices in different directions.
- **Simultaneous Communication:** With multi-user MIMO, the router can talk to multiple devices at the same time, each in their own direction. This means that several devices can be active and communicate with the router simultaneously without causing interference.
- **Improved Efficiency:** By directing signals more precisely, multi-user MIMO makes better use of the available wireless spectrum. This means that even though each device might be getting a smaller portion of the router's attention, overall, more devices can be served efficiently.
- **Maximizing Capacity:** While the total capacity of the router's connection doesn't increase, multi-user MIMO allows for better utilization of that capacity by serving multiple devices simultaneously. So, even though each device might get a smaller slice of the pie, more devices can be served at once.

In simpler terms, multi-user MIMO is like a smart flashlight that can shine its light on multiple objects at once, making sure each one gets the attention it needs without wasting any energy.

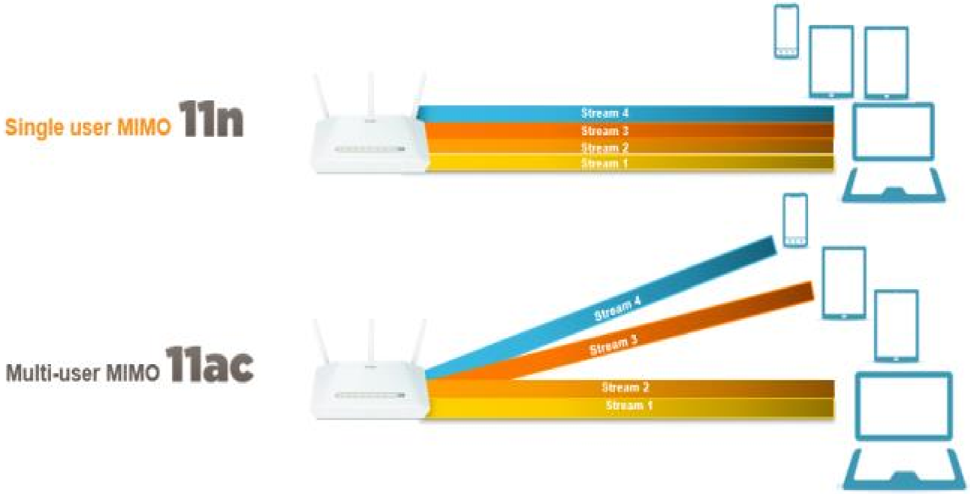


Fig 11.2

- **Directing Signals:**Imagine an access point transmitting signals towards one device, while another device is positioned in a different direction. If the access point can direct its signal towards each device individually, without interfering, it can communicate with multiple devices simultaneously.

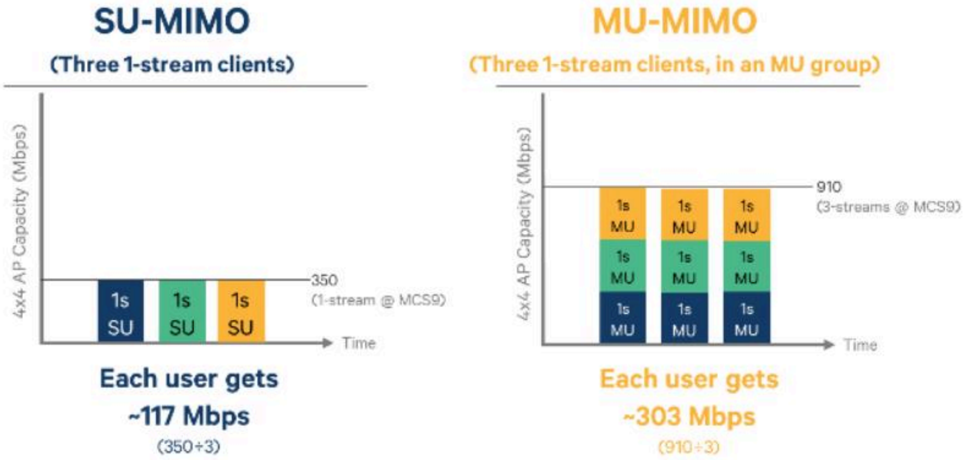


Fig 11.3

- **Frame Exchange in Multi-user MIMO:**In multi-user MIMO, the exchange of frames (data packets) between the access point and multiple devices is orchestrated to enable simultaneous communication without interference. Each device receives its data stream without being affected by transmissions to other devices, thanks to spatial diversity and careful signal direction.

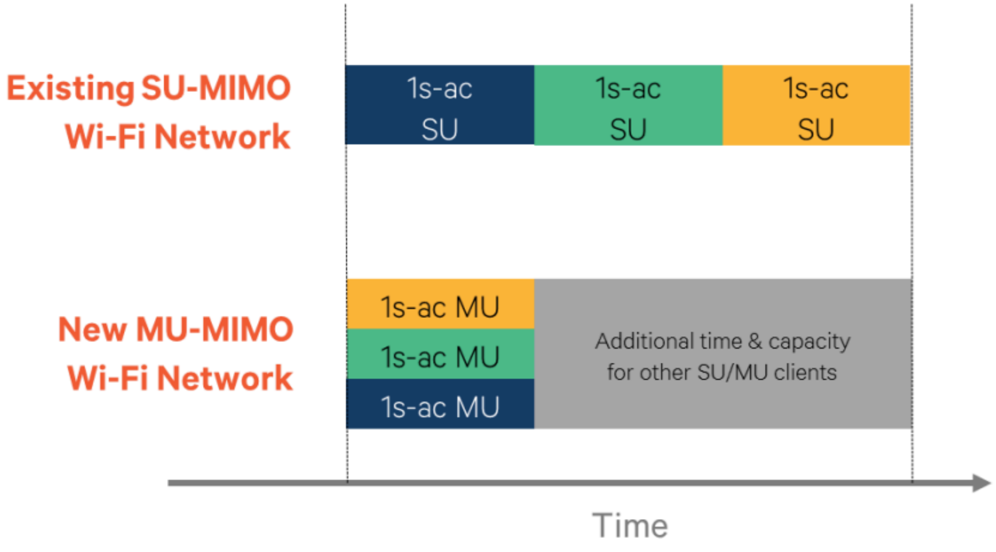


Fig 11.4

In essence, multi-user MIMO optimizes wireless communication by focusing signals towards specific devices, allowing for simultaneous transmission to multiple users without causing interference, thus improving overall network performance.

Downlink MU-MIMO in 802.11 ac:

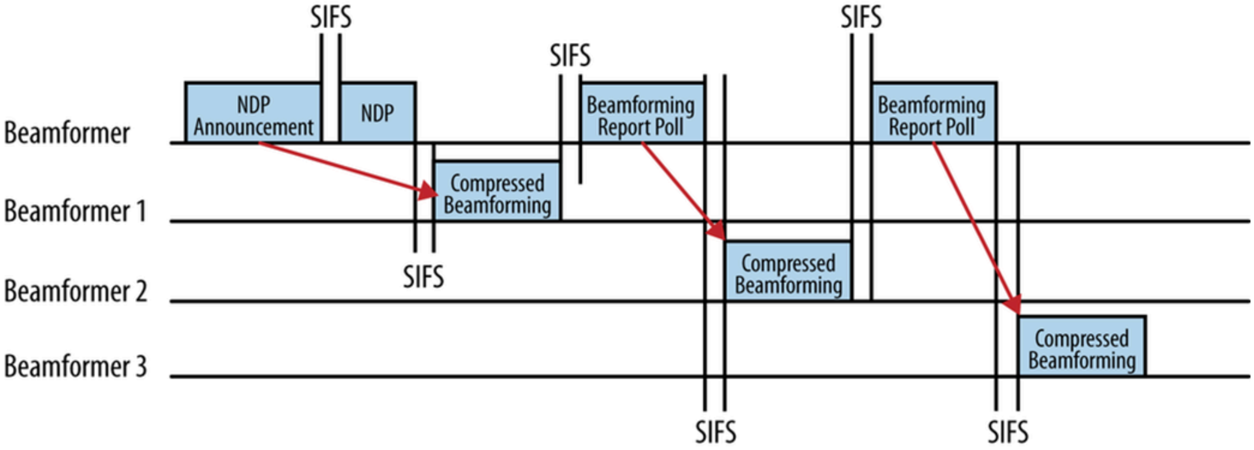


Fig 12.1

- In multi-user downlink transmission, the access point (AP) sends an NDP announcement followed by a null data packet which is a broadcast frame.
- Stations willing to participate in multi-user downlink listen to the NDP frame and send compressed channel state information.
- AP then Polls each station to receive the beamforming report.
- Based on this data the AP can then decide how to do the beamforming to multiple stations.
- The AP collects channel state information from all devices, computes relative channel orthogonality, and decides which stations to simultaneously transmit to.
- Explicit beamforming enables the AP to make transmission decisions based on feedback from stations.

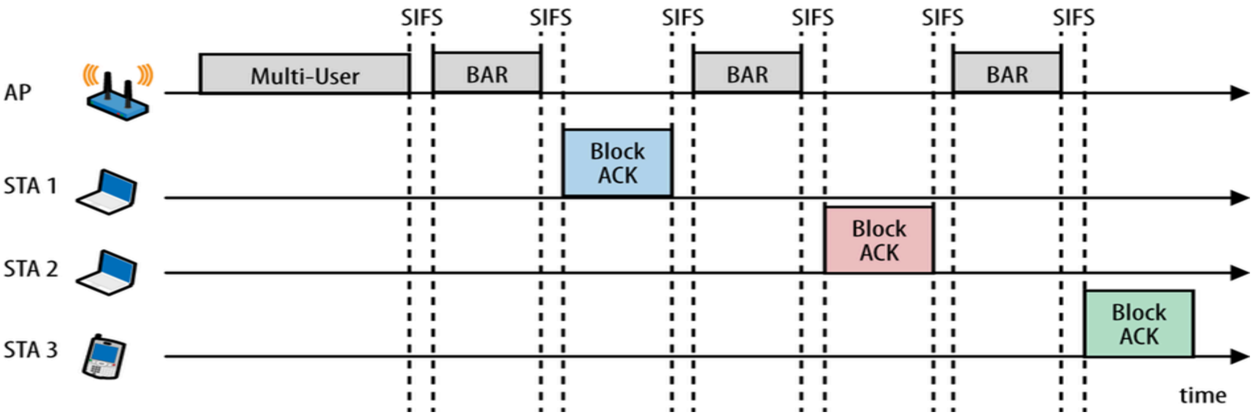

SIFS
SIFS
SIFS
SIFS
SIFS
SIFS
AP
Multi-User
BAR
BAR
BAR
STA 1
Block ACK
STA 2
Block ACK
STA 3
Block ACK
time

Fig 12.2

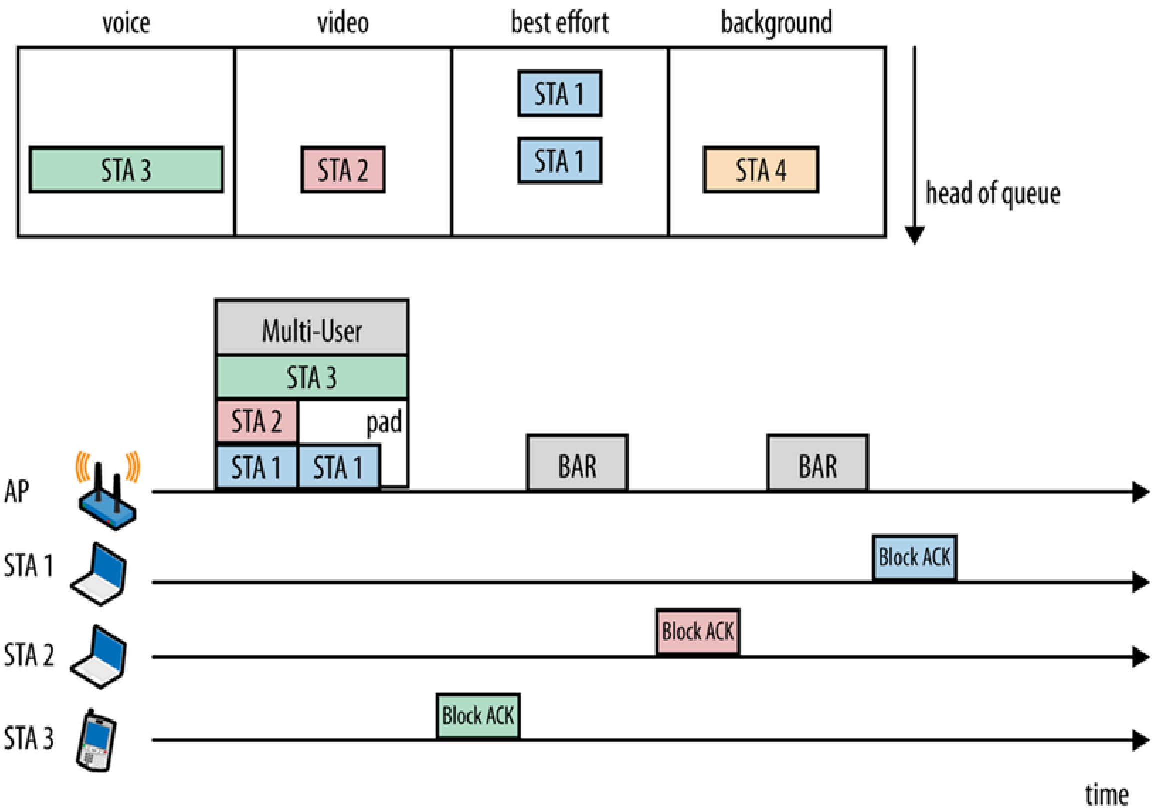


Fig 12.3

- The AP can transmit data to multiple stations simultaneously if they are orthogonal to each other.
- After transmission, block acknowledgement requests are sent serially to each station.
- Multi-user transmission can suffer from high overhead, especially if channel conditions change frequently or clients move frequently.
- In Wi-Fi 6, uplink multi-user MIMO (MU-MIMO) addresses the problem of serial uplink transmissions, improving overall TCP throughput.

- There is no Uplink Mu-MIMO which means that for TCP the ACKs should still be transmitted serially in the Uplink.

Downlink/Uplink Mu-MIMO in 802.11 ax:

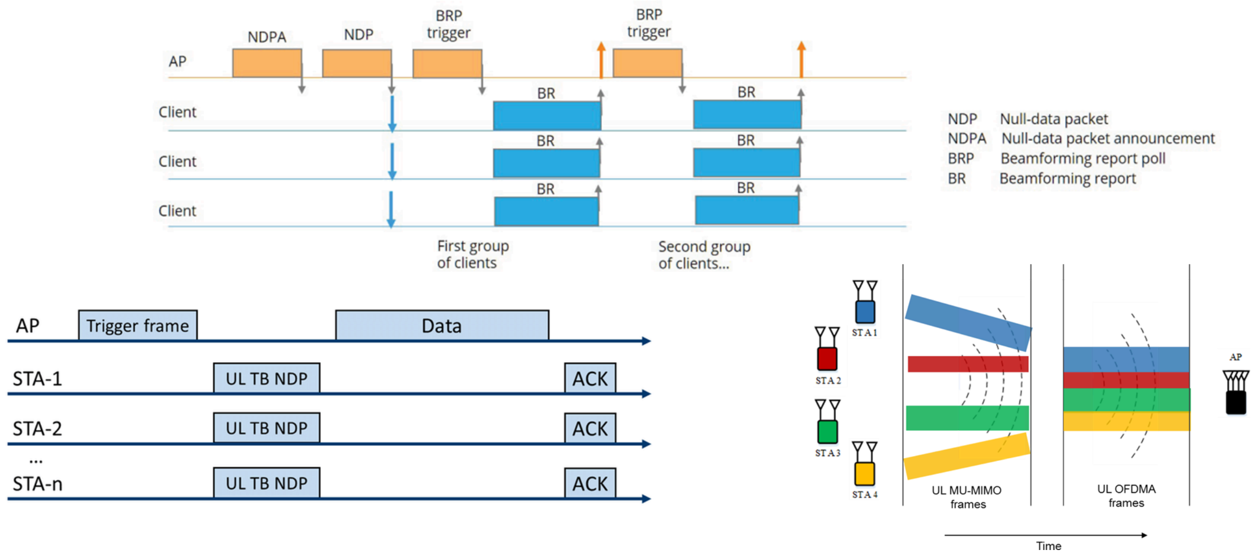


Fig 13

- In 802.11ax Mu-MIMO is supported both in Uplink and Downlink.
- When AP sends a beamforming report poll, all the STAs can send a Beamforming report at the same time using UL-OFDMA or UL-MIMO for efficient transmission.
- After sending the data simultaneously to all the users, the blocks ACKs can also be received simultaneously in the uplink and this reduces the inefficiencies from DL-Only Mu-MIMO.

- Multi-user transmissions occur in the downlink, while block acknowledgements utilize OFDMA in the uplink.
- This allows for simultaneous uplink and downlink transmissions using a combination of MU-MIMO and OFDMA.
- All Uplink and Downlink transmissions are controlled and scheduled by the AP using Trigger frames.
- APs can use a combination of MU-OFDMA and MU-MIMO to achieve the most optimal use of the spectrum.

BSS Coloring:

- BSS Coloring is a smart technique used in busy wireless environments to improve efficiency by reducing interference between overlapping access points (APs).
- In places like large enterprises, stadiums, or universities, where hundreds of users connect to Wi-Fi, APs are often installed close to each other. This proximity causes interference due to limited frequency channels.
- If we consider the 2.4GHz band, there are only three non overlapping channels. So, there will be some channel overlapping.

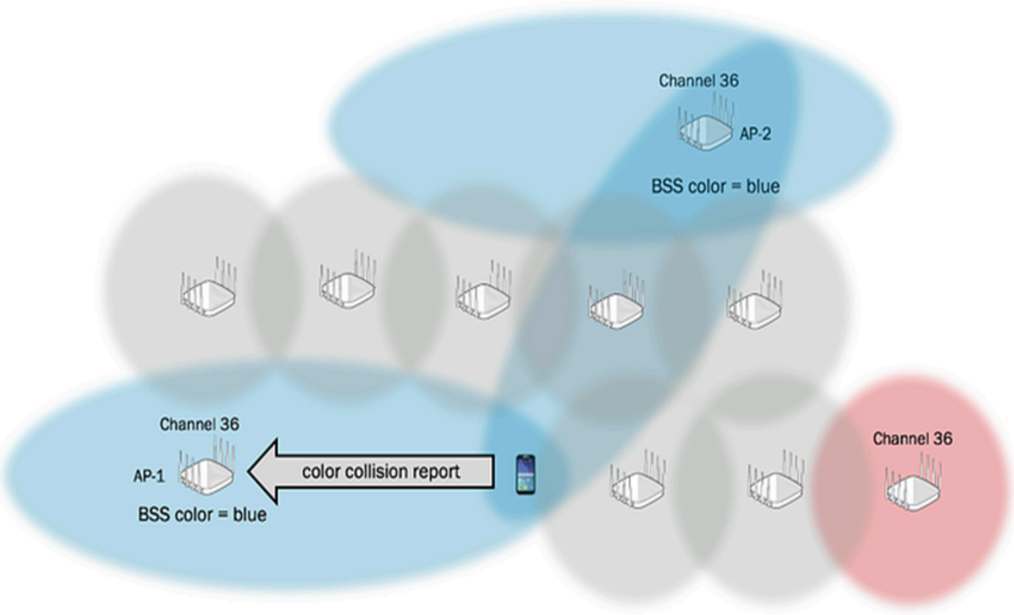
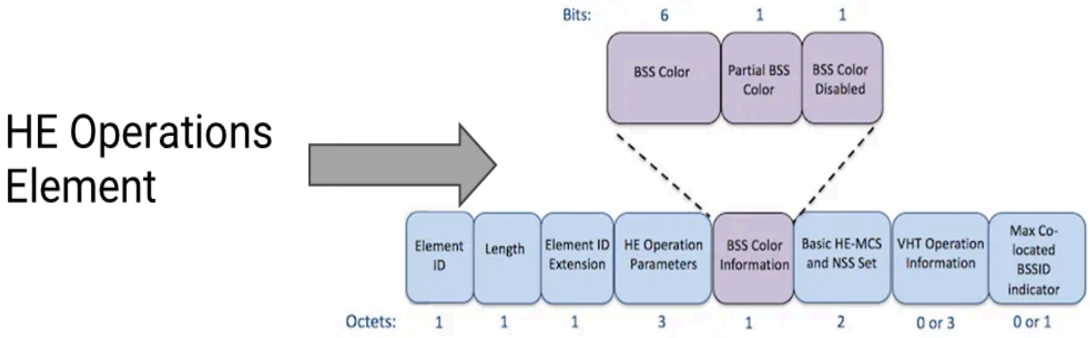


Fig 14.1

- It assigns a unique "color" (essentially a number) to each wireless LAN cell.
- APs on the same channel can have the same color if they're close together, assuming they share the same contention domain.
- Distant APs on the same channel may have different colors.
- For example, imagine classrooms as wireless LAN cells:
    - Classroom 1 has a teacher and students, and Classroom 2 has another teacher and students.
    - Both teachers are giving lectures, and students are listening.
    - If a student in Classroom 1 hears noise from Classroom 2, they ignore it since it's not relevant to their lesson.

        - They only pay attention to their teacher's voice.
        - Similarly, they speak when it's their turn, ignoring any interference from neighboring classrooms.
- Similarly, in the above image AP1, AP2 and AP3 are in the 36 channel. But, AP1 and AP2 are close to each other which are indicated with blue color. There exists interference between the connected clients of these APs.
- But, there will be no interference from the AP3 as it is much far from these APs.



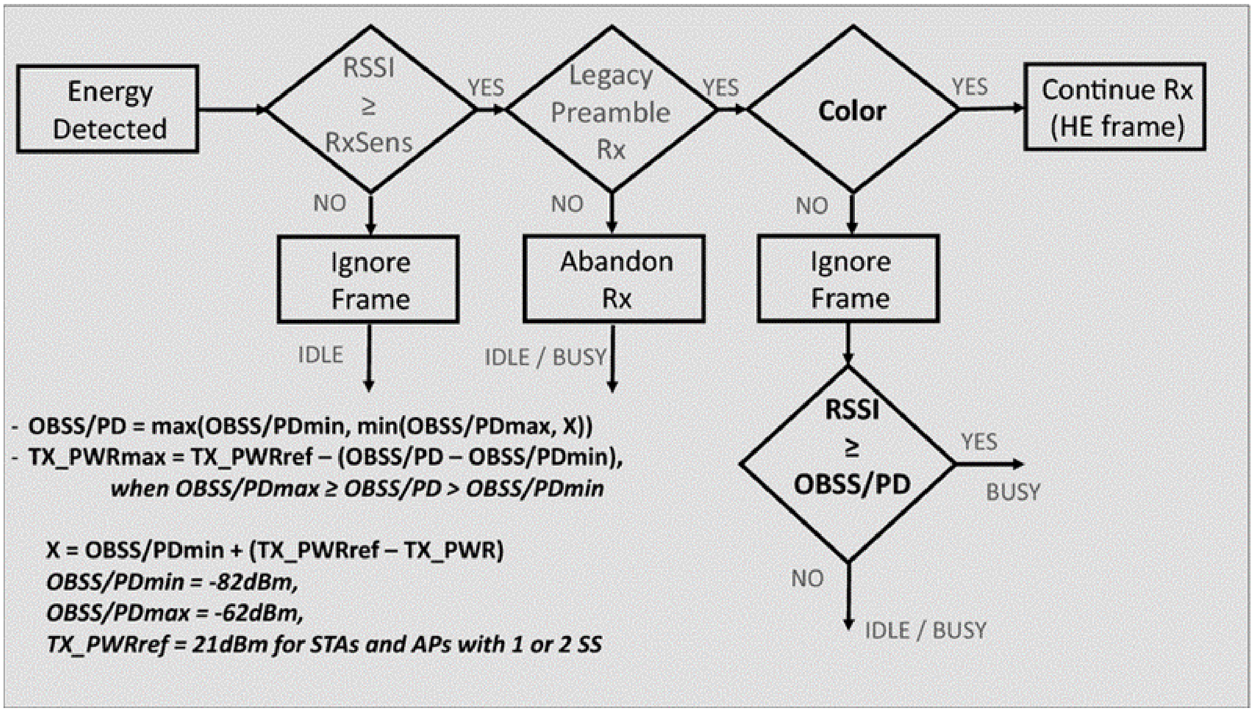


Fig 14.2

- When a station wants to communicate, it checks the BSS color information in the signal header.
- When a Wi-Fi 6 radio is listening to the medium and hears the PHY header of an 802.11ax frame sent by another Wi-Fi 6 radio, the listening radio will check the BSS color of the transmitting radio. Channel access is dependent on the color detected.
- If the color is the same, then the frame is considered an intra-BSS transmission and the listening radio will defer. In other words, the transmitting radio belongs to the same BSS as the receiver; therefore, the listening radio will defer. It is indicating interference, the station backs off.

- If the color is different, then the frame is considered an inter-BSS transmission from an OBSS, and deferral may not be necessary for the listening radio. The station assumes it's from a neighbor but transmits if the signal strength is low.

BSS Color Configuration: Custom ①
BSS Color Status: ● ②
BSS Color: 1 ③

BSS Color setting on AP

Fig 14.3

- In the 11AX APs, we can configure the BSS coloring based on the frequency reuse.
- In configuration, BSS Coloring allows assigning different colors based on frequency reuse management in the wireless LAN cell.
- This enables the creation of multiple access points (APs) using the same channels while maintaining independent contention domains.
- BSS Coloring optimizes wireless network performance in high-density deployments by minimizing interference and maximizing spectrum utilization.

Target Wake Time:

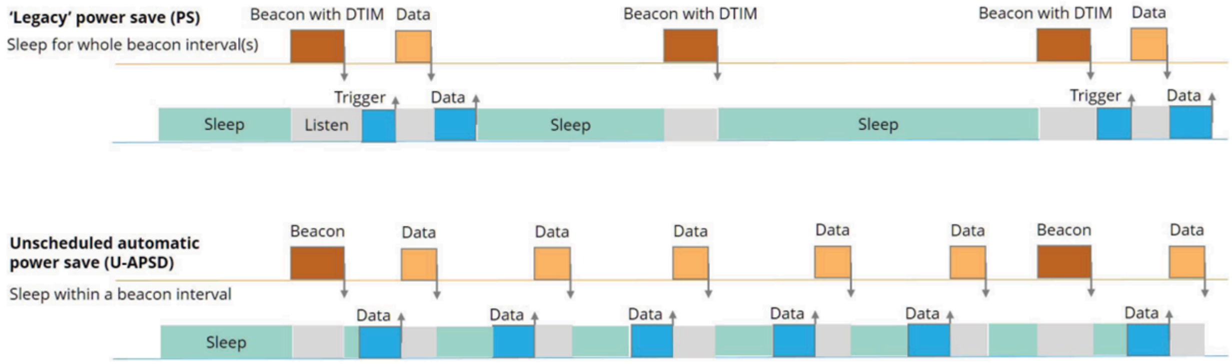


Fig 15.1

- Target Wake Time (TWT) is a new feature that allows an Access Point (AP) and stations to "wake up" at negotiated times.
- In legacy systems, power-saving decisions were controlled by the access point. If the AP had data to send, it would keep the station awake.
- APs transmits periodic beacons to announce network presence. Beacons indicate buffered data availability to stations. Stations wake up at specified intervals to check for data in beacons.
- Wi-Fi 6 introduces TWT, allowing stations and APs to negotiate sleep times. Stations can inform the AP when they want to sleep.
- TWT allows devices to negotiate sleep times with the AP. It improves battery life by allowing devices to sleep longer.

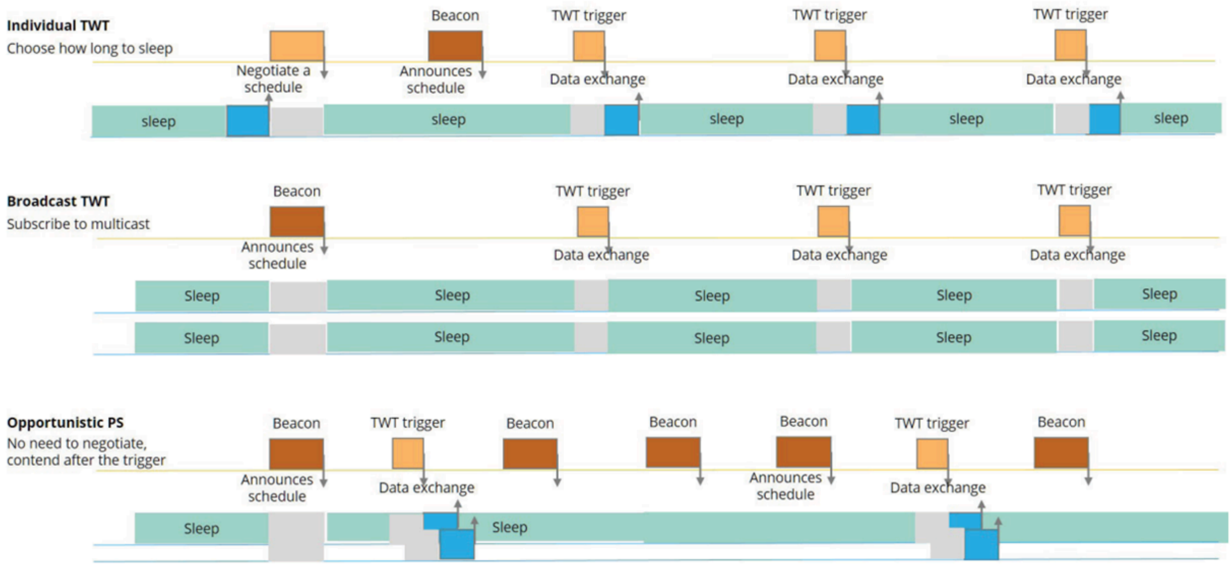


Fig 15.2

- The stations and AP reach a TWT agreement that defines when a station is awake to receive and send data.
- Without TWT, the AP will broadcast a beacon frame to alert some stations to possible data transmissions.
- When multiple clients have data to receive they all have to stay awake even though only one client can receive at a time.
- TWT allows each station to negotiate their periods with the AP to transmit and receive data packets before the beacon period.
- Stations only wake up at TWT sessions and remain in sleep mode for the rest of the time.

Module5: Advanced Features and Standard Extensions
Session 5b: Wi-Fi 6 New Features