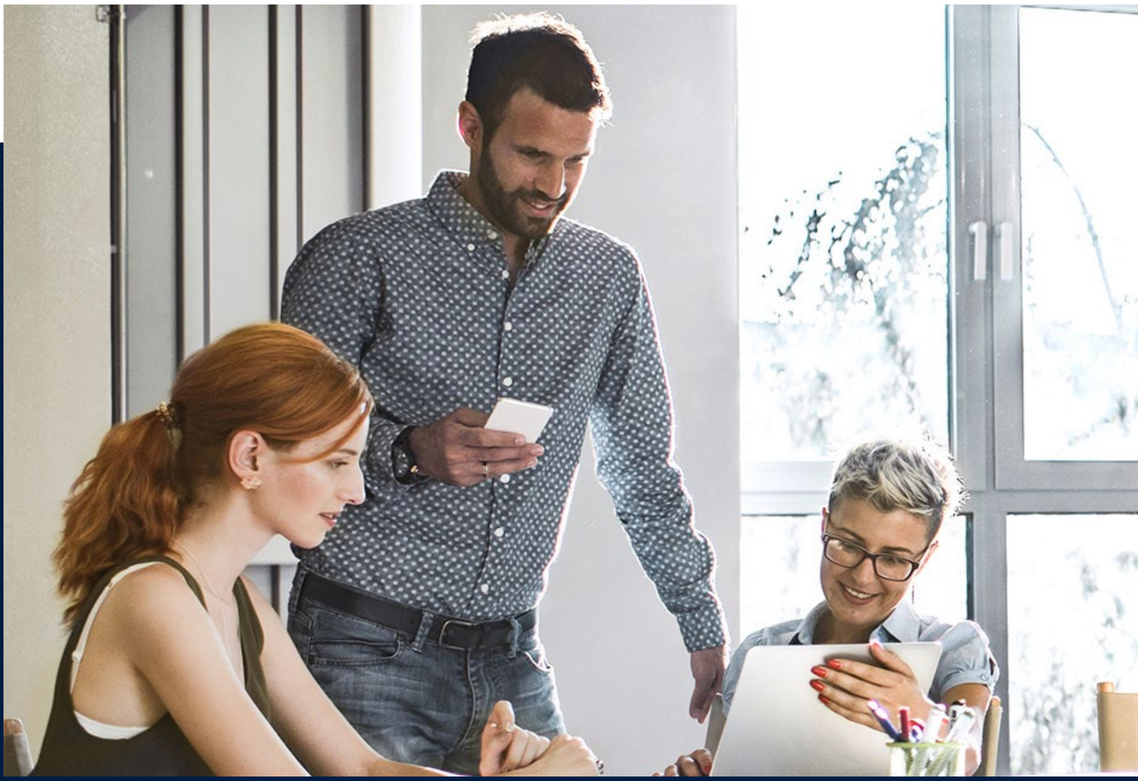
White Paper

The Wi-Fi standard Wi-Fi 6



The Wi-Fi standard Wi-Fi 6*—also called IEEE 802.11ax or High Efficiency Wireless (HEW)—offers high-throughput possibilities for operating in so-called "high-density environments". In areas with large numbers of Wi-Fi clients, with numbers set to grow even further with the increasing popularity of IoT devices, this technology will reduce the number of collisions that occur when many clients operate simultaneously and increase the overall throughput. By making more efficient use of the available bandwidths and channels, Wi-Fi 6 brings more stability and reliability to intensively used wireless LANs compared to Wi-Fi 5. The advantage of Wi-Fi 6 over former standards is a reduction in latency time for each Wi-Fi client. The available bandwidths are allocated to each client much more efficiently. All the technologies presented in this white paper also form the basis for the next evolutionary stage in WLAN called "Wi-Fi 6E".

It used to be quite simple: a new Wi-Fi standard primarily brought more speed to the data highways. Today, the world is much more complex. This is how technologies emerge that bring progress—but sometimes only in clearly defined areas. The old credo of "Higher, faster, further" therefore only applies to Wi-Fi standards to a limited extent. The leap from the fifth to the sixth generation is no longer just about more speed, but about increasing the average throughput per Wi-Fi client—and especially where it is needed, namely in high-density environments.

What's changed since the previous Wi-Fi 5 standard

The progress from Wi-Fi 5 to Wi-Fi 6 is due to a close interaction of the following already known but also new features:

- → Multi-User MIMO (MU-MIMO) brings more efficiency with large data packages, not only in the download, but now also in the upload. Perfect for 4K video conferencing.
- → OFDMA can process several small data packets in parallel in just one stream. The available radio channels are used very efficiently by up to 2 MHz narrow sub-carriers, thus relieving the already overcrowded spectrum in the air.
- → QAM-1024 with Wi-Fi 6 provides 25 percent more data throughput compared to the older QAM-256 with Wi-Fi 5 due to a high modulation density per data packet.
- → TWT (Target Wake Time) uses intelligent "wake-up mechanisms" to extend battery life for Wi-Fi 6 clients.
- → Basic Service Set (BSS) Coloring maximizes network performance through trouble-free coexistence at high client density.

* Wi-Fi 5 and Wi-Fi 6 are synonymous with IEEE 802.11ac and IEEE 802.11ax. For simplicity's sake, we are now using the consecutive numbering of the Wi-Fi standards as introduced with IEEE 802.11n (Wi-Fi 4), which is the new nomenclature of the Wi-Fi Alliance.

Still investing in Wi-Fi 5 or investing in Wi-Fi 6 or higher?

To be able to make an investment decision in favour of one of the two standards, it is worth taking a close look to find out which technology has the desired added value at all. So the question is not “What is the newest, fastest Wi-Fi standard on the market?”, but “Which current or future standard best meets my needs?

The standard for high client density

The Wi-Fi 5 Wave 2 standard is particularly suitable for high-performance Wi-Fi networks. As the second evolutionary stage of Wi-Fi 5, it already offers data transmission at a rapid speed. In addition, Wi-Fi 6 allows a large number of end devices to be connected, making it ideal for so-called “high-density environments”, i.e. areas with a high number of WLAN devices. Typical areas of application for Wi-Fi 6 are open-plan offices, sports stadiums, concert halls, universities, large school buildings, and shopping centres or environments with high IoT device density such as smart cities.

More than just a new access point

Wi-Fi 6 is not just about the faster speed like its predecessor, but rather the more efficient way to transfer data to multiple clients, so if you simply want more speed for your enterprise WLAN, you should take a closer look at the advantages and speeds of the current Wi-Fi 5 standard.

In addition, users of Wi-Fi 5 infrastructures must bear in mind when switching to Wi-Fi 6 that, in addition to new access points, more powerful switches with higher transmission rates may also become necessary, since some infrastructures do not have switches with fast 2.5 or 5 Gbps ports (IEEE 802.3bz or 2.5GBASE-T or 5GBASE-T).

Powering Wi-Fi 6 access points with eight antennas may require switches that support the new IEEE 802.3bt PoE standard with up to 60 watts of power output. Older network cabling may need to be replaced with more advanced multi-Gigabit Ethernet cables and, of course, on the client side, new investments will need to be made to take full advantage of the Wi-Fi 6 infrastructure.

Let's take a look at the technologies that are new or have been improved with Wi-Fi 6.

Broader bands for greater bandwidth

The wider the channels, the higher the speed. In the 5 GHz wireless band, Wi-Fi can realize 6 channels with bandwidths of 20, 40, 80, and 160 MHz, in the 2.4 GHz band it is 20 or 40 MHz.

80 and 160 MHz channels can be used for high-resolution 4K or 8K video streaming, high-quality video conferencing, or large data backups. However, the top speed of an access point offering a 160 MHz bandwidth can only be achieved if the client connected to it is also capable of a 160 MHz bandwidth.

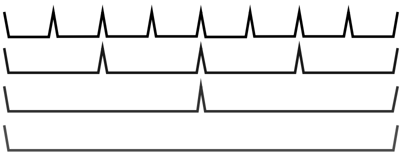


Figure 1:
Possible channel bandwidths with Wi-Fi 6

MIMO

MIMO (multiple input multiple output) uses different transmitters and receivers to realize several parallel data streams, known as spatial streams. Until Wi-Fi 5 Wave 1, access points supported single-user MIMO technology only, where just one client after the other could transfer data in sequence. The wireless standard Wi-Fi 5 Wave 2 saw the arrival of the MU-MIMO principle. MU means “Multi-User” and allows the various spatial streams to be distributed to several different clients at the same time, rather than serving them one after the other as before.

Spatial Streams

With MIMO technology, the access point transmits a number of independent data streams. Each data stream is called a spatial stream because it uses different paths through space and transports the same or different data packets to the receiver or Wi-Fi client. Depending on the Wi-Fi concept, a transmitter such as an access point can simultaneously transmit two, four, or even eight spatial streams. In Wave 2 of the Wi-Fi 5 standard, this allowed for up to 4 simultaneous data streams to a receiver in single-user MIMO mode (SU-MIMO). Wi-Fi 6 is also capable of SU-MIMO, although now up to eight streams can be bundled for a single Wi-Fi client.

Up to eight fast lanes thanks to 8 × 8 MIMO

With the introduction of Wave 2 in the Wi-Fi 5 standard, MIMO became available for the first time with 4 streams, so enabling download speeds of up to 1,733.3 Mbps (gross):

Table 1:
Possible download speeds for different transmitter-receiver pairings with Wi-Fi 5 (channel width 80 MHz, QAM-256)

Wi-Fi 5, 80 MHz, QAM-256 with up to 4×4 MIMO			
1×1	2×2	3×3	4×4
433.3 Mbps	866.7 Mbps	1,300 Mbps	1,733.3 Mbps

With Wi-Fi 6 offering up to eight parallel streams and QAM-1024, gross data rates of up to a theoretical 4,800 Mbps are possible:

Table 2:
Possible download speeds for different transmitter-receiver pairings with Wi-Fi 6 (channel width 80 MHz, QAM-1024)

Wi-Fi 6, 80 MHz, QAM-1024 with up to 4×4 MIMO				
1×1	2×2	3×3	4×4	8×8
600 Mbps	1.2 Gbps	1.8 Gbps	2.4 Gbps	4.8 Gbps

MU-MIMO – up and down

Not only does MU-MIMO share the different spatial streams of an access point between several clients, it can provide them all at the same time. Wave 2 in the Wi-Fi 5 standard saw the arrival of MU-MIMO, but only for the downlink. With Wi-Fi 6, MU-MIMO can be used not only for the downlink but for the uplink as well.

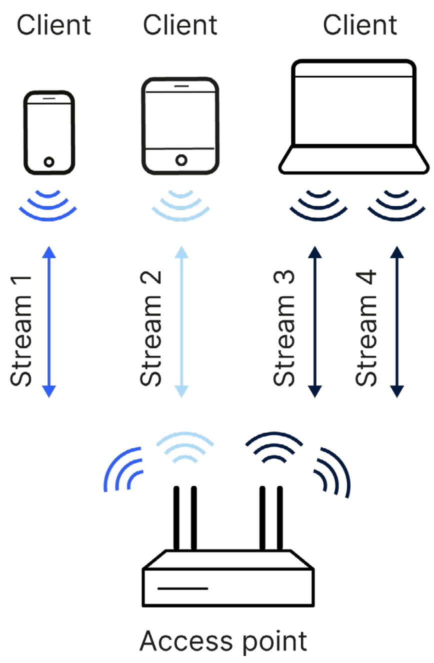


Figure 2:
Multi-User MIMO for down- and uplink

This support of MU-MIMO in the uplink direction further improves latency and throughput, which are vital for bandwidth-hungry real-time applications such as virtual and augmented reality.

The notation "transmitter x receiver" indicates the number of the transmitting and receiving antennas. 8×8 MIMO thus describes eight transmitting and eight receiving antennas, although this number of antennas is usually only found on the side of the access points. With 8×8 MU-MIMO, there is no need for all eight streams to be spread between eight different clients. Generally speaking, MU-MIMO-enabled end devices such as notebooks or tablets have two antennas at most. This means that two streams can be bundled to provide the device with a higher data rate. Smartphones usually have just one antenna, because having more would increase their power consumption. Due to the different number of antennas of the clients, simultaneous MU-MIMO transmissions are possible to up to eight smartphones, or to four tablets or notebooks with two antennas each. This is especially noticeable in environments where several Wi-Fi users need to receive and send data in parallel.

Table 3:
Assignment of streams between transmitter(s) and receiver(s)

Transmitter x receiver = number of transmit x receive antennas	
8 × 8 MIMO = 8 transmit and 8 receive antennas	
8 streams	8 1×1 smartphones
8 streams	4 2×2 tablets or 2×2 notebooks
8 streams	4 1×1 smartphones + 1 2×2 tablet + 1 2×2 notebook

Orthogonal Frequency Division Multiple Access (OFDMA)

The biggest benefactors of 4×4 or even 8×8 MU-MIMO are transmissions of large data packets such as those for HD video streams. Furthermore, Wi-Fi 6 supports a technology referred to as OFDMA. This is of most benefit where smaller data packets are involved, such as those sent by IoT devices.

Up to and including the Wi-Fi 5 standard used Orthogonal Frequency Division Multiplexing (OFDM) for channel management: During data transmission, the entire frequency range of a Wi-Fi channel is occupied per unit of time. Wi-Fi 6 introduces the much more complex technology known as Orthogonal Frequency Division Multiple Access (OFDMA). This technology is already in use with LTE/4G mobile technologies. OFDMA divides the frequency range of a Wi-Fi channel into a number of frequency blocks per unit of time, which results in sub carriers or resource units (RU). These sub carriers can be just 2 MHz wide, so they do not block the entire channel width of 20, 40, or even 80 MHz width for the small amounts of data they transmit. On the other hand, the Wi-Fi 6 access point is able to bundle and transport multiple RUs.

OFDMA gives Wi-Fi 6 access points a whole new level of performance that was simply not available with the Wi-Fi 5 standard. Since Wi-Fi channels are already a scarce commodity, we should use the ones we have to maximum effect. In one way, this technology can be viewed as a bit like car sharing. Rather than many cars each with just one occupant clogging the roads, OFDMA clears the streets so that fewer, multi-occupant cars can travel faster. This applies equally in the upstream and downstream directions.

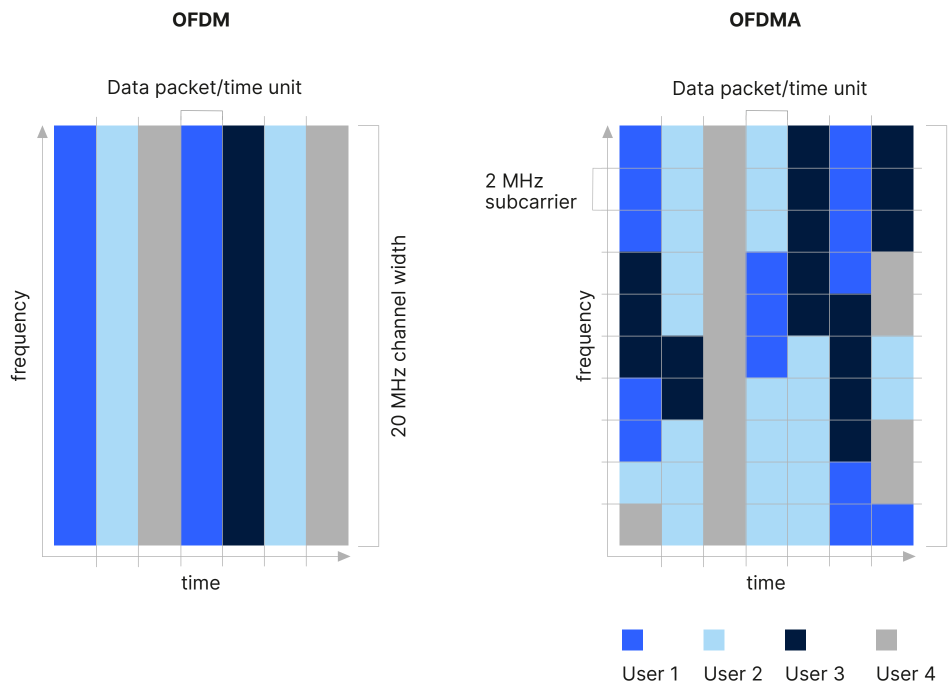


Figure 3:
Comparing OFDM (Wi-Fi 5) vs. OFDMA (Wi-Fi 6) technologies

Quadrature Amplitude Modulation (QAM)

This method increases the data throughput. The difference between Wi-Fi 5 with QAM-256 and Wi-Fi 6 with QAM-1024 is 25 percent more data throughput, from 8 to 10 bits per symbol. The method combines two amplitude-modulated signals into a single channel, thereby doubling the effective bandwidth. A QAM signal contains two carriers of the same frequency. The two carriers have a phase offset of 90 degrees, i.e. a quarter of a cycle (360°). Mathematically, these two signals can be represented as a sine curve and a cosine curve (90° shift).

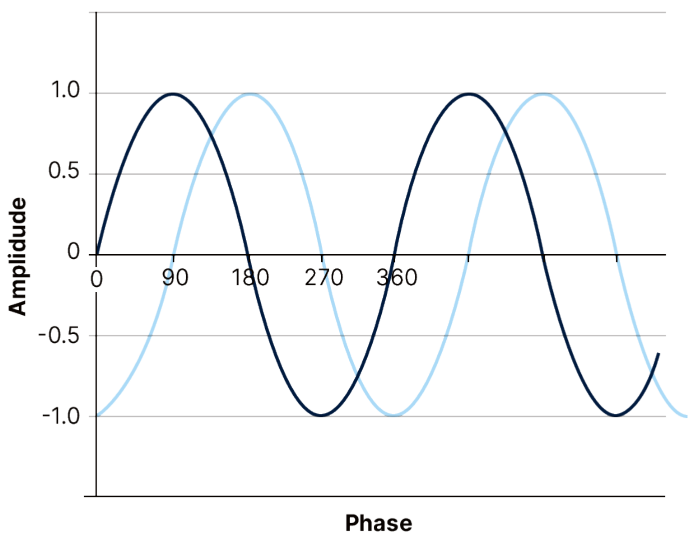


Figure 4:
Both carriers of the QAM signal, same frequency, phase shifted by 90°

If the phase and amplitude of the sine waves are modulated, they produce signals that can transmit an ever increasing amount of information per signal, i.e. a higher rate of simultaneously transmitted data. Put simply, a higher QAM level provides a higher data throughput for the Wi-Fi devices. If the amplitude and the phase of the signal vary, access points can generate signals in the following constellation.

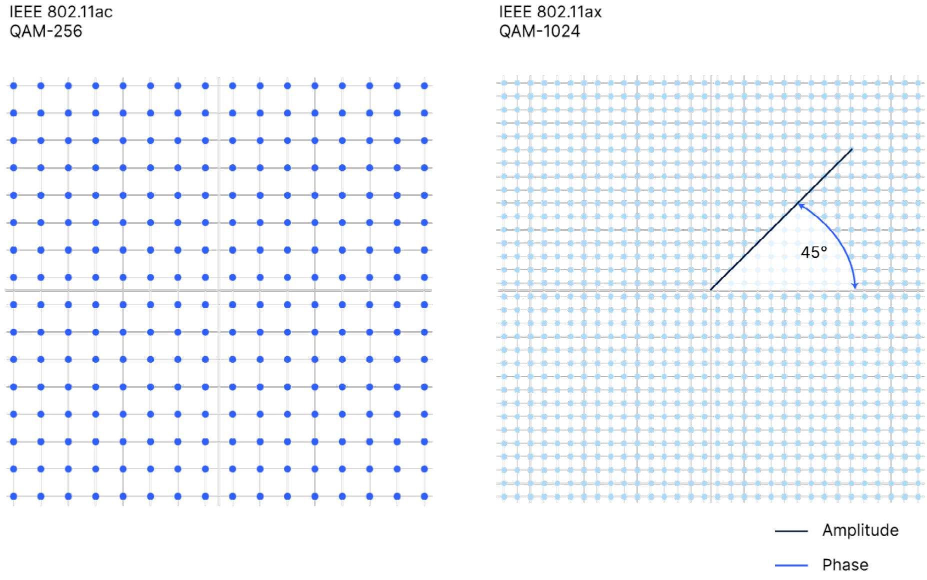


Figure 5:
QAM-256 vs. QAM-1024

QAM provides yet another speed boost in Wi-Fi evolution: The 11a standard brought QAM-64; with Wi-Fi 5 the value increased to QAM-256, and Wi-Fi 6 sees the arrival of QAM-1024. With each step, more bits per symbol could be transmitted.

Table 4:
Transmitted bits per symbol at different QAM levels

Modulation	Bits per symbol	Symbol rate
QAM-16	4	4 bit/rate
QAM-32	5	5 bit/rate
QAM-64	6	6 bit/rate
QAM-256	8	8 bit/rate
QAM-1024	10	10 bit/rate

Intelligent modulation produces higher speeds without requiring additional antennas. It should be mentioned that QAM only works under optimal conditions, i.e. over short distances, at an optimal signal level, and with only minor levels of interference.

Longer battery life thanks to TWT

With previous wireless standards up to and including Wi-Fi 5, smartphones, tablets, and notebooks had to be ready to receive so as not to miss their data packets. This of course has a significant impact on battery life. Wi-Fi 6 sees the arrival of a technology that puts an end to wasted battery charge for the clients. Target Wake Time, TWT for short, is designed to reduce consumption by allowing the access point and the client to negotiate exactly when the receiver should wake up to hear the sender's call. For many smartphones, this will mean less time tied to the charger.

Figure 6:
Longer battery life due to
Target Wake Time

Benefits for the growing number of IoT devices

Many IoT devices do not transmit permanently but send their measurements or other data to the access point every few seconds, minutes, or even less frequently. The arrival of TWT not only saves smartphone batteries, it is just in time for the boom of the Internet of Things. For the networked sensors and actuators, too, longer periods on standby mean less frequent transmissions and thus less power consumption, which saves energy and also reduces interference on the densely populated radio frequencies. Also, an advantage of the OFDMA technology that we mentioned earlier is that IoT devices occupy only a 2 MHz sub carrier, so they do not have to block the entire 20, 40 or 80 MHz band to send just one tiny measurement—a significant increase in efficiency for Wi-Fi.

BSS Coloring with Spatial Re-Use

BSS Coloring with Spatial Re-Use is a mechanism that maximizes network performance by reducing the interference between Wi-Fi devices and helping them to make more efficient use of the available spectrum where the density of access points and clients is high.

Wireless networks only have a limited number of channels available to an access point. If closely neighboring access points and their clients (basic service sets, BSS) occupy the same channel, they will inevitably interfere with one another. For older wireless infrastructures, this means that just one Wi-Fi device can transmit and the others have to wait for the channel to be free. This quickly results in the Wi-Fi becoming overloaded and the data transmission slowed.

This changes with Wi-Fi 6. To reduce interference within the same basic service set, BSS Coloring assigns a “color” label to an SSID and increases the threshold for interference from other “colors”. The coloring method identifies a basic service set and thus differentiates it from any other BSS using the same radio channel.

Wi-Fi 6-enabled devices can distinguish this BSS tag and detect when "different colored" radios are transmitting on the same channel. As a result, differently colored BSSs interfere less with one another. This greatly improves network performance by allowing Wi-Fi devices belonging to different BSSs to share the same channel but, as long as they are far enough apart and have different color coding, they can still transmit simultaneously.

The advantages of this technology can be compared, figuratively speaking, with the situation in a restaurant with different groups sitting at different tables. The group at table A is not interested in the conversations of the adjacent table B, so that the people at the next table can talk at a certain volume without the table group A feeling disturbed. Only when a certain threshold/volume is exceeded do the two tables have to discuss their compliance with this threshold; otherwise, one of the groups would have to move to another room. This has the advantage that the capacity of a BSS increases and the latency is reduced, because neighboring networks are ignored and cannot interfere so much.

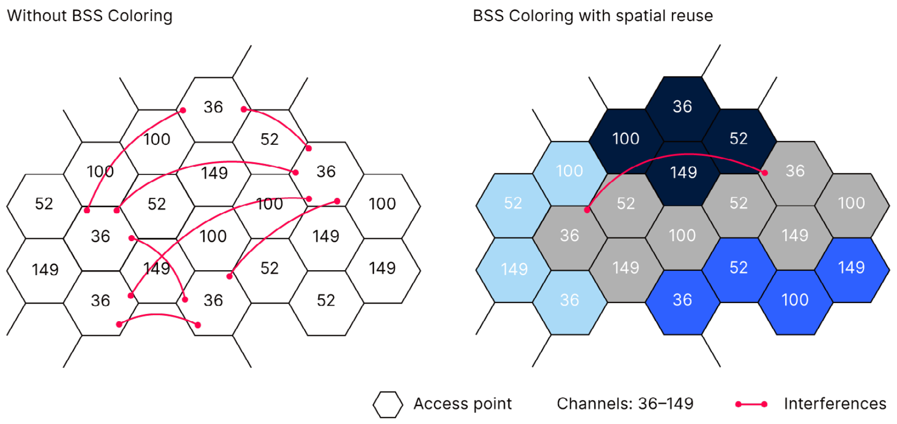


Figure 7:
High interference
without BSS Coloring
and
low interference with BSS
Coloring and Spatial Re-Use

Frequency bands: Wi-Fi at 2.4 and 5 GHz

Important for many of the technologies listed above is the available frequency space, so that 80 or even 160 MHz wide channels can be used. Wi-Fi 4 and its predecessors share the 83.5 MHz wide range at 2.4 GHz. In contrast, Wi-Fi 5 operated in three possible ranges in the 5 GHz band with widths of two times 100 MHz and once 255 MHz, but left out the 2.4 GHz band. However, Wi-Fi is not the only user of the 5 GHz band as it shares many of these frequencies with primary users, such as radar. When necessary, devices have to switch to a different frequency.

Wi-Fi 6 also uses channels from the 2.4 GHz band in addition to those available in the 5 GHz band.

Wi-Fi 6E: 6 GHz for exclusive WLAN use

In the US, 1,200 MHz of spectrum has been approved for Wi-Fi 6 in the 6 GHz band. Since July 2021, the 6 GHz frequency band has also been officially released for WLAN use in Germany, opening up an exclusive radio field free of interference. With Wi Fi 6E, the frequency range between 5.925 and 6.425 SGHz becomes usable for Europe. 6 GHz WLAN is supported for the first time by the Wi-Fi 6E standard, but not by the predecessor standards Wi-Fi 5 and Wi-Fi 4—like a VIP area in the wireless LAN. Wi-Fi 6E thus transfers the existing Wi-Fi 6 features to the 6 GHz band. More information about Wi-Fi 6E is available in the white paper.

Conclusion

Wi-Fi is ubiquitous today and its applications are diverse. On the other hand, there is a wide range of technical solutions with which the best result can be achieved.

As Wi-Fi 5 evolves into Wi-Fi 6, the techniques that have been added to it are no longer all about more speed, but more about efficiently delivering available bandwidth per Wi-Fi client.

The benchmark for corporate IT should therefore not be how "hip" it is, but how strongly it supports its own requirements for Wi-Fi operation. It is therefore worth taking a close look at Wi-Fi standards and making your decision in favour of Wi-Fi 6 or higher if your business case is characterised by a high number of clients transmitting in parallel (high-density environment).

To learn more about the interference-free Wi-Fi 6E for high-density environments, visit our technology page or read the Wi-Fi 6E whitepaper.

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