BROADCOM®

White Paper

IEEE 802.11ax

The Sixth Generation of Wi-Fi

Executive Summary

IEEE 802.11ax is the fastest, most versatile Wi-Fi standard ever created. While previous generations of Wi-Fi focused solely on improved raw speeds, IEEE 802.11ax is built to fully optimize the wireless ecosystem for devices we use every day. Built for capacity, IEEE 802.11ax delivers speeds up to six times as fast as the IEEE 802.11ac standard while simultaneously supporting more of the 23 billion Wi-Fi-connected devices and the people that depend on them. Thanks to new features such as 1024-QAM modulation and flexible PHY timing parameters, IEEE 802.11ax can achieve peak data rates of 1 Gb/s. While previous Wi-Fi standards were designed to maximize *peak speeds* for a limited number of devices and users, this standard improves user experience in dense environments by maximizing *average speeds* for a large number of devices while preserving the benefits of legacy Wi-Fi technologies, such as backwards compatibility and low cost.

IEEE 802.11ax achieves these advancements through six primary features:

- Orthogonal Frequency Division Multiplexing Multiple Access (OFDMA), which increases spectrum capacity by slicing channels into smaller chunks, which together host multiple devices simultaneously.
- Multi-User MIMO (MU-MIMO) technology to increase channel capacity when simultaneously servicing multiple devices using the same frequency chunks.
- Smarter access points capable of providing improved outdoor connectivity through longer guard intervals.
- Target Wake Time (TWT), which allows the Wi-Fi radio in battery-powered devices such as phones to go to sleep when not exchanging data.
- BSS Coloring, which allows overlapping Wi-Fi networks to transmit simultaneously in cases where they do not unacceptably interfere with each other, resulting in improved spectral efficiency.
- 160 MHz channels capable of outperforming today's best-in-class Wi-Fi devices and providing multi-gigabit wireless connections.

What is IEEE 802.11ax?

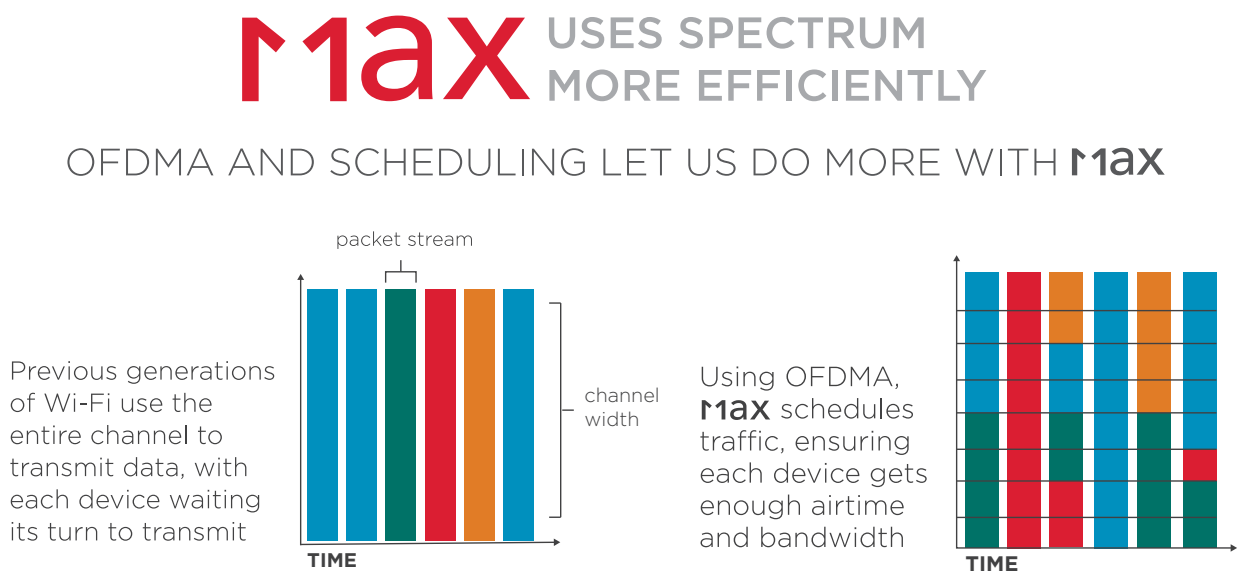
IEEE 802.11ax—implemented in Broadcom's Max WiFi family of chipsets—is the newest evolution of Wi-Fi, designed with the Wi-Fi users of today and the trends for tomorrow in mind. Broadcom Max WiFi, which is fully compliant with the IEEE 802.11ax specification and the Wi-Fi Alliance's Wi-Fi 6, delivers faster speeds than any other standard and provides greater capacity to connect more devices in more places.

OFDMA

A technology borrowed from the cellular world, Orthogonal Frequency Division Multiple Access (OFDMA) forms the backbone of Max WiFi and makes the 6th generation of Wi-Fi more efficient, reliable, and flexible than previous generations. In current and previous generations of Wi-Fi standards, clients use the entire wireless channel available to them when uploading or downloading data. If multiple clients try to connect simultaneously, they share the channel in time, which can result in delays.

OFDMA increases the capacity of these channels by segmenting them into multiple smaller subchannels stacked on top of each other with slightly different frequencies. Rather than waiting in line to transmit across the whole frequency, devices are able to share smaller sections of the channel. By allowing simultaneous parallel transmissions in a network to occur, the network becomes more efficient because devices do not have to contend against each other for a time slot.

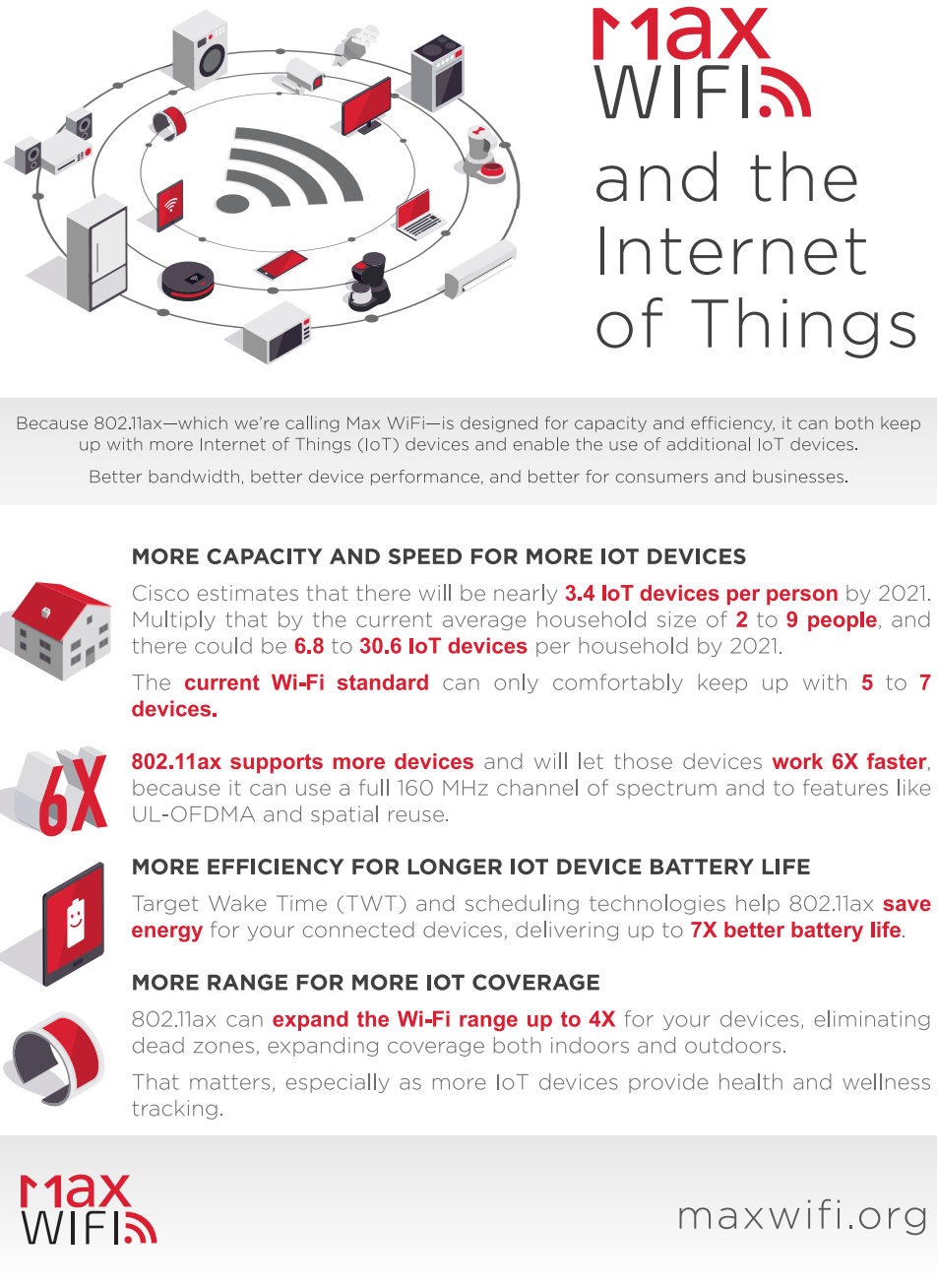
Figure 1: The Efficiency of OFDMA Transmission Scheduling



In addition, OFDMA allows routers to dynamically adjust the transmit power used for each device to improve reception for devices further away. In the uplink, the router can group transmissions from multiple devices together, like tourists on a double-decker bus, to produce speeds six times as fast as current networks. Essentially, OFDMA turns Wi-Fi from a letter carrier delivering mail house-to-house to an e-mail server capable of routing information to multiple users simultaneously.

Estimates predict the average household (a family of four) is expected to have 50 wireless connected devices by 2020. IEEE 802.11ax's increased capacity and flexibility to use spectrum will support this exploding ecosystem of smart thermostats, doorbells, refrigerators, and light bulbs. IEEE 802.11ax is the Wi-Fi industry's response to address the emergence and expected growth of the Internet of Things (IoT).

Figure 2: Max WiFi's Role in IoT

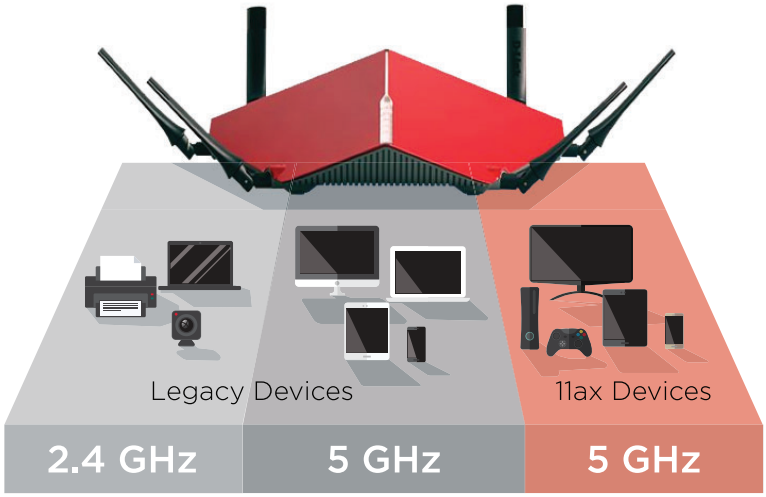


The current generation of Wi-Fi—IEEE 802.11ac—introduced consumers to gigabit speeds by adding the ability to send device traffic along wider channels—80 MHz wide. Max WiFi products are capable of using up to 160 MHz-wide channels, which doubles the bandwidth of the best-in-class Wi-Fi today. Coupled with faster modulation schemes such as 1024-QAM, Max WiFi can deliver speeds six times faster than current IEEE 802.11ac networks for more devices. Max WiFi also has protocol changes that pack signals closer together in longer OFDM symbols. This results in a reduction of guard interval overhead, enabling higher efficiency in indoor environments, and increased robustness to multipath in outdoor environments while maintaining high efficiency.

Range

Max WiFi increases the range of Wi-Fi connections by mitigating asymmetry in existing connections between access points and mobile devices. Simply put, access points (APs) have more range than mobile devices. This is due to the fact that APs are usually plugged into a power source, and hence, battery life is of no concern. In addition, most APs have more antennae—typically four to eight—which increases their range.

Figure 3: Max WiFi Range



Meanwhile, mobile phones and other wireless devices must optimize battery life. As a result, they transmit less power than their infrastructure counterparts and have a limited number of antennae—typically two. This limits the range of a Wi-Fi user because even though the AP can reach the phone, the phone cannot reach the AP. With Max WiFi, the phone can concentrate its energy in channels as narrow as 2 MHz and reach the access point by boosting the power spectral density of the signal transmitted. This feature solves the asymmetry in legacy Wi-Fi standards while significantly increasing range.

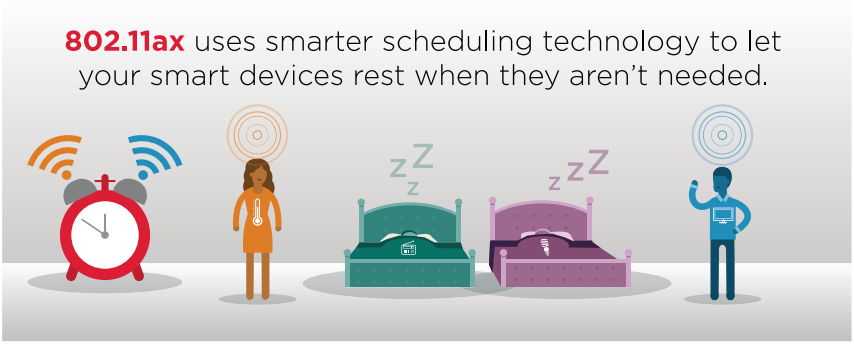
Additionally, Max WiFi provides support for an extended range mode that increases range in downlink, too. Extended coverage has a host of benefits, but one in particular is worth mentioning. Cities all over the world have massive Smart City projects planned (and underway, currently) which will improve services and livability for residents. From traffic management to road-weather information systems to environmental sensing and waste management, improved Wi-Fi range will reduce costs and improve the performance of these technologies for cities.

Target Wake Time

Max WiFi implements a feature called Target Wake Time (TWT), which allows the Wi-Fi radio in battery-powered devices, including phones, to sleep when not exchanging data. As a result, Max WiFi-equipped devices can stay connected for a longer period of time and experience up to seven times less battery drain. With TWT, Max WiFi-capable routers and mobile devices can negotiate their sleep cycles according to data traffic, so that they only wake up when it is their turn to communicate, allowing them to preserve their battery.

For example, if your home has four smart home devices, rather than sharing an alarm to *wake them up* and start working, TWT gives each device its own alarm that tells it to start working. This allows your other devices to rest when they are not needed. On top of that, each individual device can negotiate multiple separate wake-up agreements with the access point—spanning several different types of application traffic.

Figure 4: IEEE 802.11ax Scheduling Technology



With TWT, devices can also be programmed to wake up at the same time to take advantage of OFDMA so that they can communicate at the same time and share the channel, resulting in increased network capacity. This helps form a well-synchronized data flow that allows all devices to connect simultaneously based on their needs. This improves the user experience as video, voice, data and IoT traffic are proportioned and prioritized effectively.

BSS Coloring

Max WiFi reduces interference and uses spectrum more efficiently than previous generations with a scheme called BSS Coloring. With BSS Coloring, Max WiFi lets multiple access points operate on the same channel and intelligently decides when they can transmit at the same time. This spatial reuse technique operates by each access point assuming a unique identifier, or a *color*.

In general, Wi-Fi devices listen for interference before sending data and back off if data is sensed in the band; this is called carrier-sense multiple access (CSMA). This means that when multiple access points operate networks on the same channel, the capacity of each network is reduced since they have to share the channel. With Max WiFi, when a router or a device listens and hears another transmission it checks the signal strength of that other transmission, and its BSS Color, to determine if the signal is from the same access point's network and, if not, determine if the device can also transmit at the same time without causing significant interference. This allows the router or device to find additional opportunities to communicate while limiting the impact on neighboring networks.

The IEEE 802.11ax standard provides two different operating modes—one optimized for dense managed networks such as stadiums and enterprises where the siting of access points is carefully planned to allow operators to adjust CSMA detection thresholds, and the other optimized for scenarios like a busy city block where routers and devices are less uniformly distributed. This allows denser deployment of access points to deliver increased Wi-Fi capacity for more users, while keeping interference between different networks under control.

Figure 5: Max WiFi Home Coverage

Guard Interval

For outdoor devices, Max WiFi allows data to be sent using a longer guard interval with only minimal impact on efficiency, providing extra protection against inter-symbol interference caused by multipath delay spread as the data moves longer distances. This can improve outdoor Wi-Fi throughput for these devices by 50%.

Spectrum and 160 MHz Channel Width

Demand for Wi-Fi is large and growing. According to the Wi-Fi Alliance, three billion Wi-Fi devices are expected to ship this year, bringing the global total of installed devices to over 10 billion. IEEE anticipates that there will be 50 billion connected wireless devices by 2022. In addition, Cisco reports over 60% of all mobile data traffic is offloaded from cellular networks onto Wi-Fi.

Regulators around the world are looking to give Wi-Fi a boost by expanding the amount of available unlicensed spectrum. Wi-Fi is valuable, not only because it helps us work and connect with our loved ones, but also because it adds value to the economy. In fact, a study commissioned by WifiForward says Wi-Fi and unlicensed technologies will contribute $834.48 billion to the U.S. economy by 2020.

If Max WiFi is a highly efficient new race car, you can think about spectrum as the number of lanes on a highway. Upgrading to an incredible vehicle is great, but it is even better when there are sufficient high-speed lanes for all of us to drive on. We need more fast lanes—more spectrum—to make the best use of Wi-Fi technologies like Max WiFi, which can operate on channels up to 160 MHz. As it stands now, there are not enough contiguous 160 MHz channels to take advantage of IEEE 802.11ax devices' ability to dramatically improve speed.

A broad range of technology companies—from major semiconductor companies to mobile operating system vendors to content providers to enterprise Wi-Fi vendors—support unlicensed spectrum. Regulators have also stepped up and are looking at opening up the 6 GHz mid-band spectrum for use of unlicensed services such as Wi-Fi, while taking adequate steps to protect incumbent users in those frequency bands. Opening bands like 6 GHz for unlicensed use will give users access to faster Wi-Fi and will give users the opportunity to take full advantage of all that Max WiFi has to offer.

How Does IEEE 802.11ax Affect Me?

Max WiFi combines increased bandwidth, data efficiency, range, and coverage to help consumers, businesses, and services providers get the most out of their Internet. Max WiFi is optimized to facilitate faster video streaming as well as data-intensive, cloud-based tools. Max WiFi is faster and also safer, all thanks to next-generation WPA3 security. Max WiFi will also play an integral role in helping cellular 5G networks offload surplus traffic.

5G

Delivering the kinds of speeds, low latency, and coverage the ITU has defined for 5G will require an *umbrella* of technologies, deployers, and operators. The next generation of Wi-Fi will be a massive part of meeting 5G performance requirements in public, residential, and enterprise spaces while keeping the costs of the rollout of 5G services in control. International benchmarks for 5G cellular technology are driven by three factors laid out by IMT-2020:

- Enhanced Mobile Broadband (eMBB)
- Massive Machine Type Communications (mMTC)
- Ultra Reliable and Low Latency Connections (URLLC)

eMBB aims to increase the data rate for the average user; mMTC aims to provide scalable network services to serve the anticipated IoT market; and URLLC aims to serve mission-critical services by providing low latency connection for applications such as self-driving cars, remote surgery, and so on. All of these require network densification (that is, packing a lot of infrastructure equipment in a dense manner so that a lot of users can be served with the metrics imposed by eMBB, mMTC, and URLLC). However, this is very expensive. Each of these network nodes must be connected to power and a fiber connection, often leading to complex work projects involving digging of streets that make the rollout expensive, even if worthwhile. This is where Max WiFi comes to the rescue. Wi-Fi is ubiquitous and offers the lowest cost of wireless connection when measured on a cost-per-bit basis.

Cellular service providers already use Wi-Fi today to offload cellular traffic onto Wi-Fi networks to keep the overall performance and cost of their network affordable to end users. In fact, the Ericsson Mobility Report estimates that mobile users currently offload 65% to 95% of their mobile traffic to Wi-Fi when available. This strategy has enabled the rollout of 4G services across the world in a cost-effective manner. When more users are on Wi-Fi networks, cellular networks are less stressed, leading to lower Capital Expenditure and downstream savings for users. This same trend is likely to be repeated during the installation of 5G networks in the future: Max WiFi will augment the capacity needs in a low-cost manner to profit both service providers and their customers.

Augmented and Virtual Reality

Max WiFi will bring a myriad of benefits to consumers, service providers (for example, telecommunication companies and multiple service operators), and business owners alike. These benefits include better network performance; up to six times faster average speeds in a dense Wi-Fi network deployment; the ability to reliably connect more devices; and a better user experience where one can more easily share videos, photos, or memories without friction.

Max WiFi is the first Wi-Fi generation to be especially optimized for live streaming applications and emerging virtual and augmented reality activities that generate high volumes of upload traffic, particularly when that traffic is created simultaneously. MU-MIMO (Multi-user, multiple-input, multiple-output) technology brings further gains in capacity by allowing multiple devices to transmit simultaneously over the entire channel.

Using smart antennas to separate and receive the signals, MU-MIMO enables higher quality video streaming and faster uploads. OFDMA and MU-MIMO complement each other to make Max WiFi highly efficient, allowing the latest generation of Wi-Fi to optimize networks with a very large number of devices, as well as networks where the highest per-user throughput is most important.

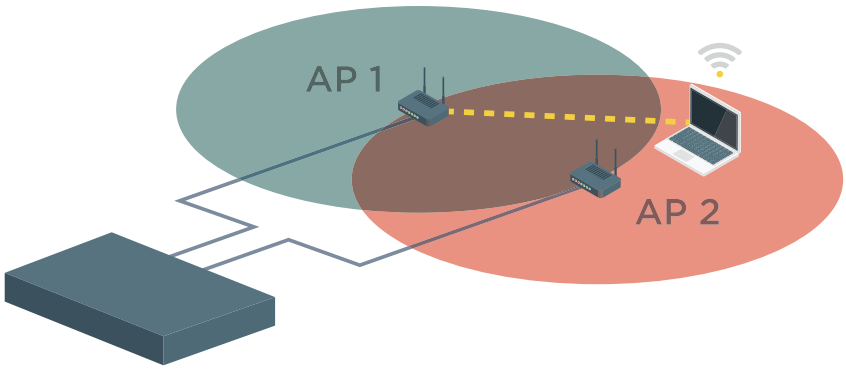
Enterprise Optimization

The high performance of Max WiFi is also important in the modern enterprise, where collaboration often occurs among large, distributed teams with real-time applications like Skype, Facetime, or WebEx. Enterprises are also increasingly using data-intensive, cloud-based tools for file sharing, backup, and enterprise resource management. Max WiFi is the first Wi-Fi designed with these uses in mind. With Max WiFi, enterprises see an upgraded network with multiple features to improve the range, robustness, and reliability of Wi-Fi connections.

Solving the Sticky Client Problem

Max WiFi also addresses a problem with today's Wi-Fi that has plagued engineers and consumers alike: the *sticky client problem*. A given Wi-Fi device *sticks* to a certain AP even as it moves out of range and closer to another AP. This impacts Wi-Fi speed and quality for that device and for other devices trying to use a now-overcrowded AP.

Figure 6: The Sticky Client Problem Illustrated



Leveraging its greater bandwidth access and capacity to distribute data traffic more efficiently along and across spectrum bands and other devices, Max WiFi APs communicate network congestion metrics such as channel utilization and estimated airtime fraction on the user's device. This information helps mobile devices select the right access point, band, and channel when initially joining or while roaming across networks. Max WiFi-enabled access points have more capacity in general and can send a clearer picture to devices on the network of their expected performance in the moment. These attributes help a multitude of wireless devices to determine where to connect and to experience better performance when connected.

There has been a push at the Wi-Fi Alliance to optimize Wi-Fi for service providers such as telecom companies, cable companies, and so on. As a result, various aspects of Wi-Fi network management and optimization, which have not historically been addressed, have now received the needed attention and upgrades. The Wi-Fi Alliance designed a program called Vantage that is a grouping of several certification programs such as MBO, OCE, and Passpoint.

- MBO, or Wi-Fi Certified Agile Multiband, allows the network to steer your device to a channel or band that is less cluttered, resulting in a better internet experience.
- OCE, or Wi-Fi Certified Optimized Connectivity, ensures that airtime is not consumed by excessive signaling (such as probe requests/responses) in dense networks, and enables devices to accurately assess link quality in order to intelligently switch to another access point, network, or even to a cellular connection to ensure uninterrupted services.
- Passpoint aims to reduce the friction of authentication by using pre-installed credentials such as SIM cards, or a streamlined experience with an online signup portal, to deliver seamless and transparent connections.

Increased Protection Under WPA3

Wi-Fi Alliance has also mandated that WPA3 security be a prerequisite for a device to be IEEE 802.11ax-certified. WPA3 is an improvement over WPA2 with new features such as:

- Simultaneous Authentication of Equals (SAE)
- CNSA-aligned 192-bit security suite (optional)

SAE strengthens the encryption of data between a device and access point when a password is used to authenticate to the network. This ensures that even weak passwords are less likely to succumb to brute force *dictionary* attacks launched by hackers. The 192-bit security suite is an optional capability for enterprise (RADIUS server) authentication, geared toward institutions handling particularly sensitive information. To ensure that enterprise networks meet this level of cryptographic consistency, WPA3 draws on 256-bit Galois/Counter Mode Protocol (GCMP) encryption and 384-bit Hashed Message Authentication Mode. These upgrades ensure that Wi-Fi's security protocols are up-to-date with user's needs and expectations while further strengthening how consumers and business connect to the Internet every day.

Summary

What separates Max WiFi from previous generations of Wi-Fi is its focus on delivering ultra-fast, reliable output where Wi-Fi gets strained the most: highly crowded environments. It makes better use of the available spectrum by hosting more devices on a single AP. This increased capacity is optimized to support the ecosystem of the Wi-Fi-enabled devices we depend on every day through IoT. Coverage is extended to ensure robust connectivity throughout the home and enterprise, and thanks to 1024 QAM modulation and flexible PHY timing parameters, IEEE 802.11ax can achieve multi-Gb/s peak data rates.

Max WiFi is a generational upgrade that will have an immediate impact in classrooms, airports, stadiums, and homes across the globe. With over 50 billion wireless devices set to be online by 2020, it is a necessary to redefine how we share with the world. Driven by increased bandwidth, data efficiency, range, and coverage, Max WiFi is designed for the consumers, businesses, and service providers of today as well as the trends of tomorrow.