Innovation Insight: Wi-Fi 7 (802.11be) Helps Address Specific Connectivity Use Cases

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Initiatives:I&O Platforms

Marketed as "Wi-Fi 7," the 802.11be standard is expected to be ratified in late 2024. Cloud and edge I&O leaders responsible for wireless networks should assess the need for the performance improvements offered by Wi-Fi 7, to find the right entry point for future wireless infrastructure upgrades.

Overview

Key Findings

- Wi-Fi 6 (802.11ax) will continue to fulfill enterprise-defined Wi-Fi infrastructure needs until at least 2027, though vertical market use cases will continue to evolve, and many of them can benefit from Wi-Fi 6E and Wi-Fi 7.
- While Wi-Fi 6E can provide some technology-future-proof justification by offering a new frequency of operation, Wi-Fi 7 is technically more advanced and will better serve many emerging applications, such as augmented reality (AR), virtual reality (VR) and 4K/8K video.
- Exploiting the full potential of Wi-Fi 7 demands endpoint devices that can operate on the 6 GHz band, and in most cases also requires switching infrastructure upgrades.
- Multilink operation, a feature of Wi-Fi 7, is still under development. The ability to distribute traffic over multiple links to boost Wi-Fi performance might take years to be effective.

Recommendations

- Do not rush to deploy early and prestandard Wi-Fi 7 products. Wi-Fi 6 products will continue to fulfill most Wi-Fi infrastructure needs.
- Prioritize Wi-Fi 7 over Wi-Fi 6E investments after approval of the 802.11be standard (especially if you have use cases driven by time-sensitive networking [TSN]), but demand aggressive discounts.
- Test Wi-Fi 7 in a pilot project to evaluate performance improvements, while considering the support of 6 GHz in the end-user devices of your environment, before deciding to scale it out enterprisewide.
- Invest or plan your budget to make appropriate wired infrastructure upgrades prior to deploying Wi-Fi 7.

Strategic Planning Assumptions

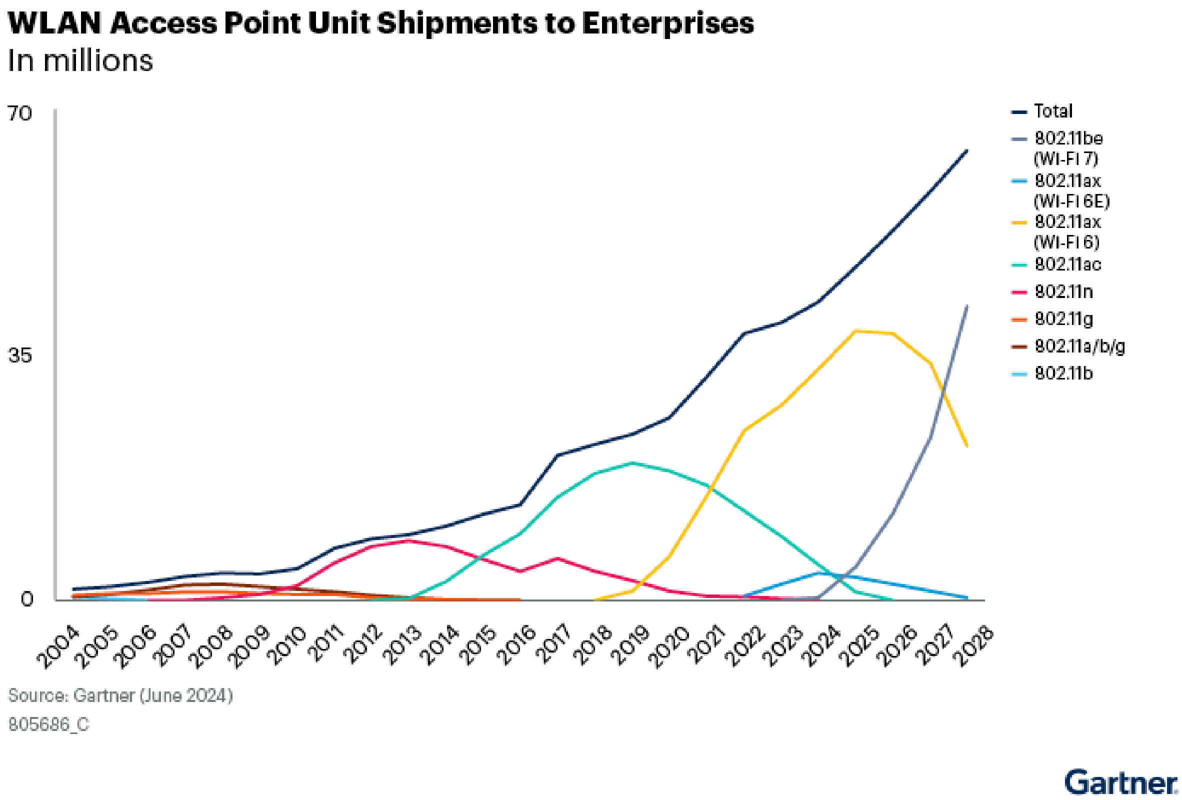
- Through at least 2026, over 70% of wireless local-area network (WLAN) deployments will lack a tangible use case for organizations to deploy Wi-Fi 7, as most business applications do not require the enhanced capabilities of the new standard.
- By 2027, 70% of enterprises refreshing and/or expanding their WLAN will upgrade to Wi-Fi 7, due to future-proofing aspirations and vendor push, combined with aggressive product marketing.

Introduction

To optimize their planning and deployment decisions, I&O leaders responsible for managing network infrastructure need to understand that most of the technological advantages that Wi-Fi 7 can offer rely on an ecosystem in an early stage of development. The “campus WLAN” ecosystem involves network infrastructure/software providers, radio frequency (RF) regulatory bodies and manufacturers of wireless endpoints/devices. The advances made on Wi-Fi 7 heavily depend on how this ecosystem will evolve and mature over the next few years.

Wi-Fi 7 is the latest iteration of 802.11 standards developed through ratification over the past 20 years. Wi-Fi 7 (802.11be) is expected to be ratified by the end of 2024, though IEEE-preratified products already exist in the market. Figure 1 illustrates this trend for the enterprise market, with each respective 802.11 standard eventually displacing its predecessor while maintaining backward compatibility. We have included access point shipments to small businesses (fewer than 100 employees) and forecast estimates through 2028.

Figure 1: WLAN Access Point Unit Shipments to Enterprises



Description

Wi-Fi 7 (802.11be) is the next amendment proposal to IEEE 802.11 for advances in WLAN. The amendment is expected to provide more efficient usage of noncontiguous spectrum, support up to 40 Gbps performance and increase the number of spatial streams from eight to 16. Moreover, it will introduce TSN for low-latency traffic and standardize 6 GHz support.

Following in the footsteps of Wi-Fi 6E, which for the first time opened the use of the 6 GHz frequency band, the new uncrowded spectrum also available for Wi-Fi 7 can more than double the usable channels of 2.4 GHz and 5 GHz channels combined. It potentially triples the unlicensed spectrum available for Wi-Fi. However, the approved regulatory support for 6 GHz remains patchy, varying by region and country.

Compared to previous Wi-Fi standards, 802.11be offers several enhancements that can provide better application performance, including for mission-critical applications that require very low latency and packet loss, and high network availability.

Table 1: Business Benefits of Wi-Fi 7

(Enlarged table in Appendix)

Technical Capabilities	Business Benefit
Higher data rates: Wi-Fi 7 allows for the use of channel widths up to 320 MHz, doubling the bandwidth of the 160 MHz channels used with 802.11ac and 802.11ax. 802.11be also supports up to 4096-QAM in the modulation scheme, which also contributes to enhanced bandwidth.	Support of **bandwidth-hungry applications**, especially those that require real-world throughput exceeding 1 Gbps.
Enhancements in spectrum reuse efficiency and interference mitigation: Multilink operation (MLO; see Note 1) is a new feature proposed by the 802.11be standard. In addition to enhancing bandwidth and roaming characteristics, MLO improves latency and network availability through better spectrum reuse efficiency, prioritizing real-time applications and adding stability to Wi-Fi in high-density environments. Another feature of Wi-Fi 7 — multiple resource units — targets interference mitigation, also contributing to reducing latency.	▪ **Enhanced application performance** from low latency. ▪ Increased **network resiliency**. ▪ **Improved support of high-density device environments and challenging RF installations.**
Time-sensitive networking support. Many 802.11be enhancements target support of key TSN components. The traffic-aware multiband admission control capabilities of MLO can, for instance, push time-sensitive traffic to exclusively use the 6 GHz band. 802.11be also includes an extension of target wake time (TWT) mechanisms, which enables a dedicated service period for low-latency traffic.	**Support of mission-critical industrial applications** (e.g., precision manufacturing) that require very low latency, packet loss and jitter, as well as zero congestion loss, while coexisting on the same network with best-effort traffic. TSN can also serve enterprise use cases, such as professional audio applications.
Emergency preparedness communication services (EPCS). 802.11be includes the certification of EPCS support as part of the standard, for the first time in Wi-Fi, to provide priority access for critical emergency communication needs.	**Priority access for critical emergency communication needs over Wi-Fi.**

Source: Gartner

Benefits and Uses

Gartner inquiries show that it is rare to find an I&O leader with a specific business or technical use case for deploying Wi-Fi 6E or Wi-Fi 7. Wi-Fi 6 (802.11ax) will continue to fulfill most Wi-Fi infrastructure needs until at least 2027, though use cases will continue to evolve and some vertical requirements can strongly benefit from Wi-Fi 7.

Looking at the benefits of Wi-Fi 7, we divided our analysis by broad use case, namely employee and line of business connectivity, public venue connectivity, and industrial networks.

Employee and Line of Business Connectivity Benefits

Better 4K and 8K Video Communication

Improved video communication is a benefit of Wi-Fi 7. As a real-time application, video conferencing is a common source of complaints when Wi-Fi connectivity degrades performance. TSN can prioritize latency traffic and bandwidth stability to the endpoint by implementing a minimum throughput SLA. While 4K video streaming can today be served by Wi-Fi 6/6E, 8K significantly raises the network requirements (at least 25 Mbps to 100 Mbps download speed, depending on the video codec, and less than 40 ms in latency). The use of 4K and especially 8K video communication is today limited due to costs of services, and HD displays, but adoption is slowly picking up.

Reduced Latency for Augmented Reality

Augmented reality (AR) head-mounted displays (HMDs; see Note 2) are overwhelmingly wireless, and Wi-Fi 7 integration can reduce latency for high-resolution video, for a greater sense of reality and dimension. However, general-purpose AR HMDs are not ready for mainstream adoption, as devices remain expensive. Our research shows that adopters are primarily pursuing AR HMDs for training use cases, followed by workflow and quality optimization, and product design. Our recommendation for organizations considering upgrading to Wi-Fi 7 in view of supporting AR applications is to have clear ROI plans. AR HMD implementations should demonstrate strong, measurable ROI to justify their purchase. Currently, training and education use cases are most capable of clearly demonstrating ROI across multiple verticals, with impact being measured in terms of knowledge retention, process improvement, and cost and time savings.

Improved Virtual Reality

Unlike AR HMDs, VR HMDs are today more dependent on wired connectivity, since some popular VR headsets are tethered to a computer, hence there is an opportunity for wireless to be more widely deployed over time. VR is another demanding application on networks that can benefit from Wi-Fi 7, with requirements ranging from 25 Mbps to 100 Mbps in bandwidth and 30 ms to 40 ms in maximum latency. Future VR use cases will potentially call for 400 Mbps to over 2 Gbps of throughput, such as for interactive VR, and 10 ms to 20 ms in latency. Adoption of VR is increasing, driven by rising awareness of the technology and the development of new use cases for various sectors and segments. Gartner expects adoption of VR HMDs (see Note 3) to double from 2023 to 2026. Training for high-risk and high-cost scenarios is where VR HMDs are currently delivering the most value. Adoption for collaboration, medical and educational use cases is increasing, providing value in the form of operational effectiveness and cost savings.

Reduced Congestion for Emerging Healthcare Applications

Healthcare delivery organizations are congested already when it comes to wireless access for devices. Not only are there clinical devices contending for bandwidth, but also patient entertainment systems, cameras and microphones used for virtual care, physical security, and devices for training. In addition, hospitals are becoming smart campuses that include building automation, real-time location systems (RTLSs) and intelligent lighting. Bandwidth congestion must be answered by connectivity technology advancement, or it will become a limiting factor for innovation; this is where Wi-Fi 7 can help. The lower latency offered by MLO enables faster frequency shifting, which relieves congestion — much needed in the healthcare delivery space. The extremely high throughput offered by Wi-Fi 7 opens up the possibilities for reliable wireless telemetry, next-generation nurse call solutions, and future medical and Internet of Things (IoT) technology innovations.

Key applications that require fast and reliable connections include life support systems, remote surgery/patient monitoring and next-generation interactive patient care (IPC) digital platforms. Wi-Fi 7 can also boost the performance of WLAN-based RTLSs and start interacting with virtual reality devices and wearables for remote rehabilitation services. However, next-generation IPC platforms require significant investments in high-definition “smart” TVs or table devices, and remote surgery remains very niche, due to the risks of surgical interventions performed remotely.

Public Venue Connectivity Benefits

This encompasses Wi-Fi deployments in shopping malls, airports, train stations, sports stadiums, municipalities and so forth. Like Wi-Fi 6E, Wi-Fi 7 supports mesh networking at 6 GHz, allowing extended coverage for public venue owners, since the use of 6 GHz to backhaul mesh can provide an immediate benefit in access point deployment and flexibility. Additional mesh nodes can be deployed for specific events, or relocated in response to changing conditions, and utility will increase as automatic frequency control (AFC) permits outdoor use at higher power. Additionally, Wi-Fi 7's higher capacity and enhancements in spectrum reuse efficiency enables:

- **Increased endpoint density.** Wi-Fi 7 provides additional bandwidth through spectrum reuse with multiuser multiple input/multiple output (MIMO). Signal reflections can be used to deliver directed bandwidth, while the same frequency can directly deliver service to another user, significantly increasing endpoint density.

- **EPCS priority access.** Wi-Fi 7 enables prioritization of emergency personnel communications over other users, which is essential when the network is highly congested.

Benefits for Industrial Networks

Historically, organizations have had little room to move away from industrial protocols, due to the limitations of traditional "nondeterministic" 802.3 Ethernet in assuring adequate network latency and low jitter for critical industrial applications. Ethernet operates on a best-effort basis to deliver network packets. Latency can be in the range of several seconds, and jitter can be very high when a packet transfer is repeated over the internet. Wi-Fi 7, for the first time in wireless, will include TSN capabilities (see Note 4), enabling it to address the low-latency and jitter requirements of operational technology (OT)/IoT applications, while maintaining connection stability. The use cases/applications include industrial production monitoring, robotics (including autonomous mobile robots), autonomous guided vehicles, industrial safety control applications, real-time energy monitoring, predictive maintenance and so forth.

Interoperability for Industrial Protocols

Wi-Fi 7, and Ethernet in general, provides broad market interoperability missing in proprietary industrial protocols. While many key industrial protocols are based on conventional Ethernet, they modify or provide additional mechanisms to address latency limitations, and provide deterministic and real-time control. For instance, this includes using the IP protocol at the networking layer, coupled with a proprietary application layer protocol, and modifying the media access control (MAC) layer. Broader interoperability would imply leveraging TCP/IP as the standard communication protocol. However, the TCP/IP overhead increases latency, which would make these protocols unsuitable for time-sensitive applications, hence creating market fragmentation.

Minimized Latency and Guaranteed Bandwidth

The support of TSN with Wi-Fi 7 creates a path to “real-time Ethernet”; hence, for organizations, it represents an opportunity to start moving away from proprietary industrial protocols. TSN can address the requirements of demanding industrial applications by assuring that a minimum of latency and guaranteed bandwidth are met. This is critical for real-time automation processes, for instance, in which transmission latency is often required to be around 1 ms.

Enhanced Network Stability and Roaming Capabilities

Wi-Fi 7 will add more stability to connections and lower the bar for adoption. Penetration of Wi-Fi in industrial networks is currently relatively low, but the enhancements of Wi-Fi 7, particularly with distributed multilink operation and TSN, will contribute to higher adoption. This will be particularly helpful in environments that want cellular-protocol-type performance, since it also means higher-speed roaming and better stability/assurance of packet delivery.

Reduced Costs via Wireless

Cabling is still prevalent today in industrial environments and Wi-Fi 7 provides the opportunity to reduce costs. Cabling changes are major expenses when a manufacturing line needs to be reconfigured to implement product line modifications.

Comprehensive Enterprise Wireless Strategy

Wi-Fi 7 advancements enable its deployment in OT scenarios, allowing enterprises to deploy more use cases without interference or performance reduction. The coexistence of Wi-Fi 7 and private 5G in industrial spaces enables enterprises to adopt a comprehensive wireless coverage strategy, leveraging both technologies to meet the diverse needs of their operations. This combination ensures high reliability, advanced roaming capabilities, and the ability to match endpoint capabilities with required data rates and determinism for industrial applications.

Lower Energy Cost and Increased Sustainability

As a result of better energy management in power-sensitive apps, Wi-Fi 7 extends the target wake time (TWT) mechanisms of .11ax, for longer battery life (e.g., of IoT sensors). TWT lets Wi-Fi APs schedule the wake time for each client, based on the individual device requirements and expected traffic activity. However, this feature is offset by the increased power needs of Wi-Fi 7 APs; hence, energy savings will depend on IoT endpoint density and other variables.

Risks

Automated frequency coordination and regional restrictions on the use of the 6 GHz band is a key inhibitor for Wi-Fi 7, as not all countries allow for the available spectrum of 6 GHz. Hence, the improved performance of Wi-Fi 7 will not be geographically consistent, with limits on frequency varying between countries and regions.

Another risk that broadly applies to all use cases is the unavailability of some Wi-Fi 7 features. The key one is MLO, which is still under development. With MLO, APs can transmit and receive data from the same traffic flow over multiple radio interferences. However, the ability to distribute traffic over multiple links to boost Wi-Fi performance might take years to become effective.

The key drawbacks, risks, pitfalls and/or nonoptimal implementations of Wi-Fi 7 are summarized below.

Employee and Line of Business Connectivity Risks

Lack of Investment Justification

As previously noted, Wi-Fi 6 (802.11ax) will continue to fulfill most Wi-Fi infrastructure needs until at least 2027. A risk for buyers with Wi-Fi 7 is overspending, as the technology will have a price premium for a number of years. AR, VR or specific vertical applications, which demand the low latency and high bandwidth/network resiliency that Wi-Fi 7 can deliver, are not widely deployed. As noted, adoption of VR will grow, but other applications will remain relatively niche in the next five years.

Very Small Installed Base of End-User Devices Supporting 6 GHz

All Wi-Fi 7 APs offer backward compatibility through support of “legacy” 2.4 GHz and 5 GHz radios, since .11a/b/g/n/ac devices cannot operate on the 6 GHz band. In other words, there are no benefits from deploying Wi-Fi 7 unless the devices also support the 6 GHz spectrum. Endpoints that support the new spectrum are starting to come to the market (such as the iPhone 15 Pro, the iPad Pro 11 or the Samsung Galaxy S24 Ultra). However, it will be 2027 before the majority of new devices shipping support 6 GHz, and longer before the majority of the installed base migrates into the band.

Required Upgrades to Switching Infrastructure

In most cases, deploying Wi-Fi 7 will require this change, based on the premise that the 802.11be standard delivers theoretical speeds of up to 40 Gbps. I&O leaders should consider the following:

A standard 24 or 48-gigabit port access layer switch (with 10 Gbps uplinks) diminishes the value proposition of upgrading to Wi-Fi 7. This is because the theoretical bandwidth of wireless is far greater than the wired connection in the switch, causing a theoretical bottleneck. While there are plenty of Wi-Fi 6 installations today based on this setting (often because switches and Wi-Fi are on different replacement cycles), this network design flaw becomes far too incoherent with Wi-Fi 7. Hence, organizations need access layer switches that support multigigabit (mGig) switching that can deliver 2.5/5/10 Gbps over copper cabling to the APs. These switches have a price premium of at least 30% to 50%, and in some cases higher.

The purchasing decision then becomes how much mGig density is required, which is important for “all-wireless-office” deployments. Some switches support mGig on a portion of the ports, and others on all ports (except uplinks). As the density grows, so do the uplink requirements, including cabling. As an example, the uplink options on a 24-port switch with 8 mGig ports can be four 10-Gbps copper links, as opposed to a 24-port mGig switch that requires two to four 25-Gbps fiber connections.

The concept of dual-cables from two switches to a single AP can be another variable, either for performance (link aggregation) or resiliency (a switch fails or reboots for a software upgrade) reasons.

Wi-Fi 7 increases Power over Ethernet (PoE) requirements, with APs generally expected to require more than the 25.5 watts of power that 802.3at (PoE+) can deliver, namely 802.3bt (PoE++) or a proprietary equivalent, for at least 50 watts of power. This offsets the TWT feature of Wi-Fi 7 that generates energy savings from IoT devices going into sleep mode.

Long-term, the use of 25 Gbps links in access layer switches might be an option for endpoint connectivity, including Wi-Fi 7 APs, which today are unavailable and limited to uplink ports. Our recommendation for organizations is to make sure that the access to distribution or access to core links meet an oversubscription ratio that does not exceed 4:1.

Public Venue Connectivity Risks

The replacement cycle of consumer equipment will delay propagation of the Wi-Fi 7 standard into endpoints for several years. Early deployment will not lead to rapid improvement in the end-user experience, making it harder to justify the additional cost of Wi-Fi 7.

Industrial Network Risks

Competition With Mature Industrial Protocols

Wi-Fi 7, and generally Ethernet, competes with many mature industrial protocols, some of them heavily adopted. Compared to other industries, Ethernet adoption has been relatively slow in industrial and building automation spaces, primarily due to latency and jitter limitations. Key industrial protocols, such as CC-Link IE EtherNet/IP, EtherCAT, Modbus, Profinet and POWERLINK address a wide range of use cases, guaranteeing bandwidth and low latency for critical industrial applications (see Note 5).

Fragmented TSN

TSN services are only capable when endpoints, application servers and all devices, such as switches, adhere to TSN service requirements, which may require replacement of existing switches or deployment of an overlay.

Low Penetration of Wi-Fi in Industrial Networks

A historical issue with Wi-Fi is that the quality of the connection can make it challenging to support critical business processes in manufacturing and warehousing. High-voltage machinery and materials (metals and liquids) are common sources of radio frequency interference issues, and AP placement can be challenging in buildings with very high ceilings.

Adoption Rate

Historically, future-proofing has been a key driver for organizations to adopt a new standard. Wireless performance varies based on multiple factors and details related to antenna and spectrum technology lack real-world applicability for I&O infrastructure and operations (I&O) leaders. We expect much of this trend to continue with Wi-Fi 7, with shipments growing to 65% of overall APs shipped by 2028.

While very small today, the installed base of end-user devices that support 6 GHz will grow over time, and as it does, organizations will increasingly be able to reap the benefits of the new spectrum. However, as highlighted, some of this differentiation relies on features (such as MLO) that will not be available or mature when the standard is ratified by the Wi-Fi Alliance. We see product availability (and demand) unfolding as follows:

- **Short-term investments (next six months):** The 802.11be standard is expected to be approved at the end of 2024. Organizations with WLAN upgrade/expansion projects and strongly interested in the potential of the 6 GHz spectrum have the choice of investing in Wi-Fi 6E or preratified Wi-Fi 7 (though availability of Wi-Fi 7 products is still lagging).

- **Midterm investments (2025):** Organizations with WLAN projects will have the choice of Wi-Fi 7 ratified products, including “entry-level” APs by some vendors. By the end of 2025, virtually all vendors will have Wi-Fi 7 products in the market. We expect to see a price premium of 7 over 6E, of approximately 40% on average.

- **Long-term investments (2026 and beyond):** We expect vendors will start devesting in 6E products, which, combined with declining Wi-Fi 7 semiconductor component costs, will start to slowly erode Wi-Fi 7 price premiums. Organizations will no longer have a reason to invest in 6E and adoption of 7 will start to accelerate.

Alternatives

As noted, today Wi-Fi 6E and predominantly Wi-Fi 6 compete with Wi-Fi 7. Wi-Fi also often competes with 4G/5G cellular connectivity, as well as with other technologies. These include Wi-Fi HaLow (based on the use of sub-1 GHz bands), Zigbee, long-range (LoRa) and Bluetooth low energy (BLE), all of which are better than Wi-Fi for long battery life use cases.

Private 5G is today the most prevalent alternative to Wi-Fi. Support of large-scale deployments remains the biggest issue for Wi-Fi, due to the requirement to install a large number of APs, which provides opportunities for 5G. The network “slicing” characteristics of 5G can allow for a much wider range of services with different permutations of performance, latency, security and so on.

Recommendations

- Do not rush to deploy early and prestandard Wi-Fi 7 products. Wi-Fi 6 products will continue to fulfill most Wi-Fi infrastructure needs. Short term, organizations purchasing Wi-Fi 7 prior to approval of the 802.11be standard should demand aggressive discounts. The provider should also offer a full warranty that ensures, once the standard is ratified, APs will be fully upgradable (e.g., via a firmware upgrade). The warranty should include hardware replacement if necessary.

- Prioritize Wi-Fi 7 over Wi-Fi 6E investments after approval of the 802.11be standard, should you be strongly interested in the potential of the 6 GHz spectrum (and especially if you have use cases driven by TSN). Wi-Fi 7 offers technical differentiation over 6E, including higher bandwidth, less interference and lower latency. However, technology assessment should come from a business and/or application value, rather than about technical features.

- Test Wi-Fi 7 in a pilot project to evaluate performance improvements, while considering the support of 6 GHz in the end-user devices of your environment, before deciding to scale it out enterprisewide.

- Invest or plan your budget to make appropriate wired infrastructure upgrades prior to deploying Wi-Fi 7. In most cases, deploying Wi-Fi 7 will require upgrades to switching infrastructure.

Evidence

IEEE 802.11be Multi-Link Operation: When the Best Could Be to Use Only a Single Interface, IEEE.

Contributors

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Note 1: Multilink Operation

Multilink operation (MLO) enables simultaneous data transmission and reception in multiple channels across the 2.4 GHz, 5 GHz and 6 GHz bands. Multiple link transmission allows more efficient load balancing of data packets between bands/channels.

Note 2: Augmented Reality HMDs — Technology Description

HMDs are small displays or projection technology integrated into head-worn devices. They are worn, or mounted, on or near the face, allowing the wearer to see the optics at a viewing distance ideal for either complete immersion or information at a glance.

AR HMDs are partially immersive HMDs with either an optical display, a video see-through display or a glanceable/head-up display. AR HMDs provide real-time use of contextual information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects to deliver relevant information in real time.

Note 3: Virtual Reality HMDs — Technology Description

VR HMDs are devices that create a fully immersive and realistic experience for the user by blocking out the external environment and projecting a computer-generated 3D environment onto the user’s eyes. The devices typically have a wide field of view, high resolution, low latency and accurate head-tracking to provide a convincing sense of presence and motion in the virtual world.

Note 4: Time-Sensitive Networking (TSN)

TSN is a suite of enhancements to the IEEE 802.1Q protocol; they are extensions that address data transmission with very low latency and high availability. TSN aims at transporting latency-sensitive data regardless of any best-effort traffic carried on the same network, being designed to carry diverse types of traffic. With TSN, you can tailor both the guaranteed bandwidth and the latency to the application requirements. TSN can serve data rates ranging from 10 Mbps to 10 Gbps.

Note 5: Characteristics of Key Named Industrial Protocols

- **CC-Link IE:** Offers up to 1 Gbps of throughput. Latency below 1 ms can theoretically be achieved, as well as a cycle time of 31.25 µs (0.031 ms) or less with TSN support.
- **EtherNet/IP:** Provides up to 100 Mbps of throughput and latency in the range of 1 ms to 10 ms.
- **EtherCAT:** Can scale beyond 100 Mbps, to 1 Gbps and 10 Gbps. Latency of 100 µs (0.1 ms) cycle can be achieved, and even less than 31.25 µs (0.031 ms) in extreme cases. TCP/IP traffic can only be transported in small portions over EtherCAT.
- **Modbus:** Highly adopted in the process control and automation industry. Can support at least 100 Mbps of throughput. Latency is generally above 10 ms, making it predominantly suitable for small control applications where a small amount of data needs to be transferred between two points.
- **POWERLINK:** Provides up to 1 Gbps of throughput, and cycle times down to 250 µs (0.25 ms) with very low jitter are achievable.
- **Profinet:** Delivers up to 100 Mbps of throughput, and latency as low as 250 µs (0.25 ms) can be achieved.

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