# Unleashing the Power of Wi-Fi

Enterprise-Grade Wi-Fi 6 Forecast, 2019~2023

HUAWEI

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# 1. Enterprise Wi-Fi Networks: Benefits and Challenges

## 1.1 Benefits At-A-Glance

With the advent of the mobile Internet era, wireless networks are bringing unprecedented convenience to our daily work, learning, and life. Internet access anytime and anywhere has become a basic necessity for us. Wi-Fi networks are widely recognized as infrastructure that is as equally important as water and electricity. With Wi-Fi enters its 20th year, the benefits and business values of Wi-Fi are well known for enterprise. Wi-Fi technology will continue to develop to improve the Wi-Fi user experience by enhancing performance, capacity, and coverage.

### 1.1.1 Efficiency-Prioritized Mobile Access

Wi-Fi networks are an important part of enterprises' digital transformation. With Wi-Fi networks, enterprises can achieve the movement of network resources with users, and employees can benefit from collaborative mobile offices or anytime working via mobile apps. Today, 70% of enterprises have implemented wireless offices, greatly improving their working efficiency. Through a Wi-Fi network, teachers and students can conveniently obtain online learning resources. Schools can also provide more abundant teaching contents through Virtual Reality (VR) and Augmented Reality (AR), making teaching and learning more convenient and efficient than ever.

Wi-Fi networks reduce enterprises' network construction expenses. For example, in an enterprise, one common Wi-Fi AP can support 60 stations (STAs) and an employee usually has three Internet access terminals. In this example, one Wi-Fi AP can cover 20 cubicles of employees. No matter whether they are surfing the Internet or making Internet calls, they actually are using this Wi-Fi AP. This is quite different from the traditional approach that needs to deploy two Telecommunications Outlets (TOs) for each cubicle (one TO is for the network cable and the other is for telephony), which will occupy more switch ports.Especially in a stadium or a large conference room, it is unrealistic to deploy a wired network that enables all users to access the Internet. Using Wi-Fi for full coverage, however, is an inevitable and feasible choice.

### 1.1.2 Wi-Fi Is a Natural Transmission Network for IoT

An era of Internet of Everything is fast approaching. It is predicted that the number of connected devices will reach 100 billion by 2025. Technologies such as NarrowBandIoT (NB-IoT) or Long Range (LoRa) are widely used in long-distance transmission of IoT. Typical IoT applications include remote meter reading, smart parking, smart water, and environmental monitoring. These applications are characterized by low data bandwidth, high latency, and large coverage range.

However, enterprises' IoT data usually requires secure data transmission, and low latency. Typical use cases include the delivery of production instructions from production workshops, delivery of warehousing, logistics, stocktaking, and robot control instructions, real-time monitoring over medical vital signs, and real-time surveillance of campus cameras. A Wi-Fi network naturally features high bandwidth, secure transmission in a LAN, and low latency. Therefore, it is an inevitable and feasible way to carry IoT data on a Wi-Fi network. Currently, many vendors have proposed their IoT APs that have built-in Bluetooth or ZigBee modules to transmit IoT device data.

### 1.1.3 Improves User Satisfaction and Enhances Business Competitiveness

Free Wi-Fi is available everywhere in places with frequent people movement, such as shopping malls, airports, hotels, and subways. Providing free Wi-Fi for consumers and offering location, navigation, and mobile payment services through Wi-Fi help increase customer loyalty and improve customer satisfaction.

Meanwhile, commercial free Wi-Fi can set up a new platform for communication between consumers and merchants. In accordance with security policies, merchants can use big data statistics about consumers' daily activities to assist decision marking on their operating policy planning and Online to Offline (O2O) precision marketing. By doing so, merchants can provide customized services that meet personalized needs, such as advertisement push and discount information. These efforts maximize the business value and improve the overall competitiveness of enterprises.

## 1.2 Challenges and Trends of Wi-Fi Networks

After nearly 20 years of development, enterprise Wi-Fi has achieved great success. The biggest contribution of Wi-Fi is to liberate people from traditional wired networks and to provide diverse services for individual users, enterprises, and carriers. Globally, Wi-Fi is bearing more than half of the total data traffic. However, with the emergence of innovative new products and technologies, wireless networks are facing and will continue to face new challenges in the future.

### 1.2.1 Ultimate Mobile Experience

A video conference in an enterprise may be suddenly freezing, a robot on the production line may stop working due to failure to receive instructions, and a student may encounter network interruption while he or she is communicating with foreign mentors. All these occurrences affect user experience. Therefore, higher requirements are imposed on mobile experience, including:

- **High stability**
- **Fast speed**
- **Low latency**

First of all, a wireless network must be stable enough to ensure service continuity. To this end, mobile terminals must be highly compatible with the wireless network. Meanwhile, the wireless network has a good roaming processing mechanism and a network redundancy assurance mechanism.

The growing use of AR, VR, and video requires ever-increasing wireless network bandwidth. Wi-Fi 6 with high speed and high access capacity can satisfy the challenge of user experience .

For some companies who are reluctant to abandon wired networks and shift towards wireless networks, one of their biggest concerns lies in delay and packet loss, which are usually caused by interference. In particular, when 80 MHz or even 160 MHz channel bandwidth is used in Wi-Fi 5 and Wi-Fi 6 scenarios, mutual interference is inevitable. Therefore, interference between channels must be avoided and the channel multiplexing rate must be improved. In addition, increasing Wi-Fi frequency bands is imperative. The Federal Communications Commission (FCC) has proposed to open up the 6 GHz band to Wi-Fi, which greatly improves the world's confidence in Wi-Fi.

### 1.2.2 Wi-Fi Network Security

The security of wireless networks is always the focus of attention due to their openness. In an enterprise, their wireless network needs to carry more important data. Therefore, the security of the wireless network is the biggest challenge. Wireless network security generally includes Radio Frequency (RF) security, terminal (endpoint)security, network access security, and data security.

**RF security:** Wireless RF is vulnerable to attacks because of its openness. Attackers may initiate Denial of Service (DoS) attacks to cause network unavailability. A bogus AP transmits the same Service Set Identifier (SSID) signal as that in the enterprise to induce user connections and then obtain the user account information.

**Endpoint security:** To ensure that only authorized devices can access the enterprise network, two methods are often used. Specifically, enterprise laptops get authorized by joining a domain, and mobile terminals get authorized by using Bring Your Own Device (BYOD) digital certificates. However, not all devices support either of these two modes. How to preventbogusdevices is a challenge facing enterprise wireless network security.

**Network access security:** Password authentication is often used for network access. Enterprises usually use high-security 802.1X authentication to ensure secure access. In public locations such as hotels, airports, and cafes, simple Portal authentication, simple pre-shared key (PSK) authentication, or even open authentication without passwords is used. MAC address authentication is typically used on IoT devices.

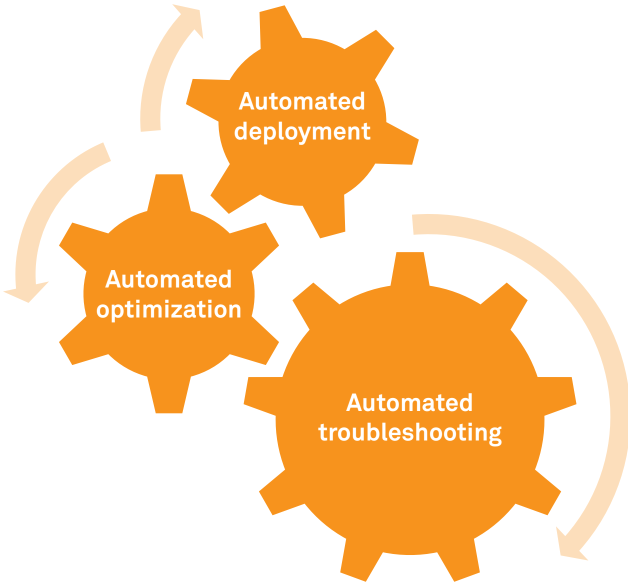
**Data security:** In most cases, encryption is used to ensure data transmission security. Encryption algorithm complexity and key confidentiality need to guarantee data security.

Wi-Fi CERTIFIED WPA3™, a  certification program from Wi-Fi Alliance addresses can solve these access security problems.

### 1.2.3 Network Automation

Future Wi-Fi market competition will no longer focus on hardware. Instead, it will gradually turn to the management platform, using machine learning technologies to predict network behaviors and automatically execute more tasks.

Automation ensures that expected goals can be achieved on devices or systems through automated detection, information processing, analysis, and control, requiring no or minimal manual intervention. Network automation refers to the automatic completion of the entire process from network implementation, to network optimization, and then to network O&M management, requiring no or minimal manual intervention.




Time costs, labor costs, and user experience are the main driving forces for network automation.

**Automated deployment:** The traditional network deployment mode has low efficiency, which severely affects the digital transformation and service expansion of enterprises. When an enterprise needs to deploy an enterprise wireless network across cities or countries, IT management personnel need to configure and deploy devices separately in branches. This leads to heavy workload and complex configurations. Automated deployment implements plug and play of network devices and unified configuration of the entire network through Software-Defined Networking (SDN) API or cloud management.

**Automated optimization:** AIOps is the trend of network O&M in the future. A key difference between a wireless network and a wired network is that a wireless network needs to be continuously optimized based on the onsite environment and user experience. In the past, IT personnel optimize tasks based on their experience or user feedback, which is difficult to achieve the desired effect. Automated network optimization uses AI and big data analytics to collect onsite network running information in real time, automatically generate optimization policies, automatically complete network optimization configuration, and even customize optimized networks based on individual network behaviors.

**Automated troubleshooting:** Traditionally, post-incident response is made after network faults occur. IT personnel know, analyze, and then rectify the network faults only after the network management system or users report the network faults. Automated network fault warning uses AI big data to analyze and monitor key network indicators, dynamically optimize baselines based on historical and real-time data, predict network exceptions, and eliminate potential network faults in advance.

# 2. Development of Enterprise Wi-Fi

## 2.1 Overview

Internet of Everything has been a hot topic in the industry in recent years, which catalyzes both old and new short-distance transmission protocols to become popular. In addition to Wi-Fi, the following protocols and standards are commonly used in IoT:

- Bluetooth technology, started in 1994, was developed by Ericsson in Sweden. It is a radio technology that supports short-distance device communication (often within 10 m). Bluetooth allows wireless information to be exchanged between a variety of devices such as mobile phones, personal digital assistants (PDAs), wireless headsets, and laptops. The current Bluetooth standard is Bluetooth 5.0, which significantly improves the transmission distance, transmission rate, and power consumption. Wireless APs of many vendors have built-in Bluetooth modules, which can be used for Bluetooth positioning and geo-fencing and implement IoT transmission.

- ZigBee is a wireless self-organizing communication technology, characterized by low range, low power, low rate, and low cost. It resolves the defects in Bluetooth technology, including high complexity, high power, and small network scale.
  ZigBee networks have been widely used in various fields such as home automation, home security, industrial field control, environment control, medical care, and transportation. For example, ZigBee technology is applied to gateways of IoT devices in a smart home.

- Radio frequency identification (RFID) is a wireless communication technology that uses radio signals to identify a specific target, read and write related data. It does not require mechanical or optical contact between the card reader system and a specific target. An RFID reader identifies and sends the product information (passive tag) stored in a chip through induced currents. Alternatively, a tag actively sends the signal (active tag) of a certain frequency, and the reader reads and decodes the information and sends it to the central information system for data processing. RFID has been widely used in IoT scenarios such as asset management, access control, and parking lot. Its application market will grow with the development of IoT.

- Near field communications (NFC) is evolved from the integration of RFID and interconnection technologies. NFC is a short-range high-frequency radio technology with a working frequency of 13.56 MHz within a 20 cm distance. Contactless data read and exchange are performed between cards and a card reader. NFC is similar to Bluetooth technology but its transmission rate and distance are not as fast and far as Bluetooth. In addition, its power consumption and costs are low and confidentiality is ensured. These advantages make NFC a favorite of mobile payment and consumer electronics.

- Light Fidelity (Li-Fi) is a technology for wireless communication between devices using visible light (such as light from light bulbs) to transmit data. Li-Fi can transmit data by using light from light emitting diodes (LEDs) and provide lighting and wireless networking without causing electromagnetic interference. Data is transmitted in light with high security. Its main limitations include environmental interference and reverse communication between terminals and light sources. Currently, there are few Li-Fi commercial products.

- Wi-Fi HaLow™, based on the IEEE 802.11ah standard addresses low-power, long-range wireless data transmission. Wi-Fi HaLow operates in the 900 MHz frequency band, which is lower than the 2.4 GHz and 5 GHz frequency bands of today's Wi-Fi. Wi-Fi HaLow offers low power, long range of up to 1 km, and strong signal strength with less interference.

**Table 2-1: Comparison of short-distance transmission technologies**

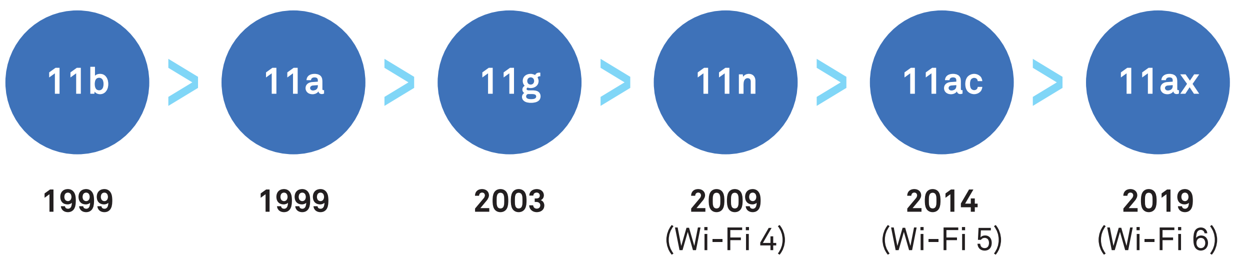
| Technology | Bluetooth | ZigBee | RFID | NFC | Li-Fi | Wi-Fi HaLow | Wi-Fi |
|---|---|---|---|---|---|---|---|
| Bandwidth | 1–24 Mbit/s | 250 kbit/s | 1 Mbit/s | 106 kbit/s 212 kbit/s 424 kbit/s | 10 Gbit/s or higher | 4 Mbit/s | < 10 Gbit/s (theoretically) |
| Transmission Distance | 50 m | 10–100 m | 10 cm–10 m | 20 cm | 10 m (based on light) | 100–1000 m | 50–200 m |
| Frequency Band | 2.4 GHz | 2.4 GHz | 125 kHz, 13.56 MHz, 433 MHz, 2.4 GHz... | 13.56 MHz | Optical transmission | 900 MHz | 2.4 GHz, 5 GHz |
| Advantage | Low power consumption, simple networking, and low cost | Low power consumption, self-organizing, and low cost | Fast read/write speed, good penetration, and large data memory | Low power consumption, fast network construction, and high security | Fast speed and high security | Low power consumption, long transmission distance, and good penetrability | High rate, simple deployment, and low cost |
| Disadvantage | Short distance, small number of devices on the network, and poor security | Low rate and poor stability | Poor security and standardization | Short transmission distance, low rate, and identity unable to be verified | The communication distance is affected by obstacles, reverse communication is limited, and the communication is susceptible to interference. | low rate, mainly used for IOT access but not Internet access. | Low penetrability in 5GHz |
| Application Scenario | Short-distance transmission of various types of data and voice of headsets, mobile phones, and other terminals | Sensors used in home automation, industrial field control, environment control, medical care, and more | Asset management, access control, parking lot, and more | Currently, this technology is mainly used in mobile payment. | Currently, this technology is mainly used in scientific research and seldom used in actual applications. | Smart home, industrial control, and more | Enterprises, campus self-built networks, and high-density scenarios |

## 2.2 Development History of Wi-Fi

The development history of Wi-Fi is actually a process of pursuing high bandwidth. As shown in Figure 2-2, Wi-Fi technical evolution occurs every four to five years. The main purpose of each evolution is to increase the bandwidth.

- **EEE 802.11a/g**, with the theoretical maximum bandwidth of 54 Mbit/s, defines the available 2.4 GHz and 5 GHz Wi-Fi channels.
- **IEEE 802.11n** introduces multiple-input/multiple-output (MIMO) for the first time in Wi-Fi technology, and supports a maximum of four antennas and four spatial streams when operating at 2.4 GHz and 5 GHz. In addition, 802.11n supports 40 MHz channel bonding to improve bandwidth. For 802.11n, the theoretical maximum bandwidth for one spatial stream operating at 40 MHz wide is 150 Mbit/s. Therefore, the maximum bandwidth for four spatial streams can achieve 600 Mbit/s.
- **IEEE 802.11ac** optimizes 5 GHz channels and supports 80 MHz channel bandwidth. The maximum bandwidth for a single spatial stream with the channel width of 80 MHz is 433 Mbit/s. Although 802.11ac supports eight spatial streams, a maximum of four are used in actual products (data rates of up to 1.733 Gbit/s when there are four spatial streams). In the 802.11ac Wave 2 phase, downlink MU-MIMO (multi-user MIMO) is supported. This feature allows APs to communicate with multiple users at a time (switching mode), rather than with only one user (hub mode). So 802.11ac Wave 2 improves network resource utilization and dramatically enhances the communication capability of wireless APs.

**Figure 2-2: Development history of Wi-Fi**




- **IEEE 802.11ax**: In October 2018, to better promote Wi-Fi technology, Wi-Fi Alliance renamed Wi-Fi standards by referring to the naming approach of communications technologies. 802.11ax becomes Wi-Fi 6, Wi-Fi 5 represents 802.11ac, and Wi-Fi 4 is 802.11n. Wi-Fi Alliance plans to introduce an industry certification program for Wi-Fi 6 products in 2019. Wi-Fi 6 improves the maximum data rate of a single spatial stream with the channel width of 80 MHz to 600 Mbit/s. In addition, Wi-Fi 6 focuses more on enhancing user experience.

## 2.3 Influence of New 802.11ax (Wi-Fi 6) Technologies

Wi-Fi 6 will become the main technology in the Wi-Fi market in the next five years, which will bring the following changes to improve user experience:

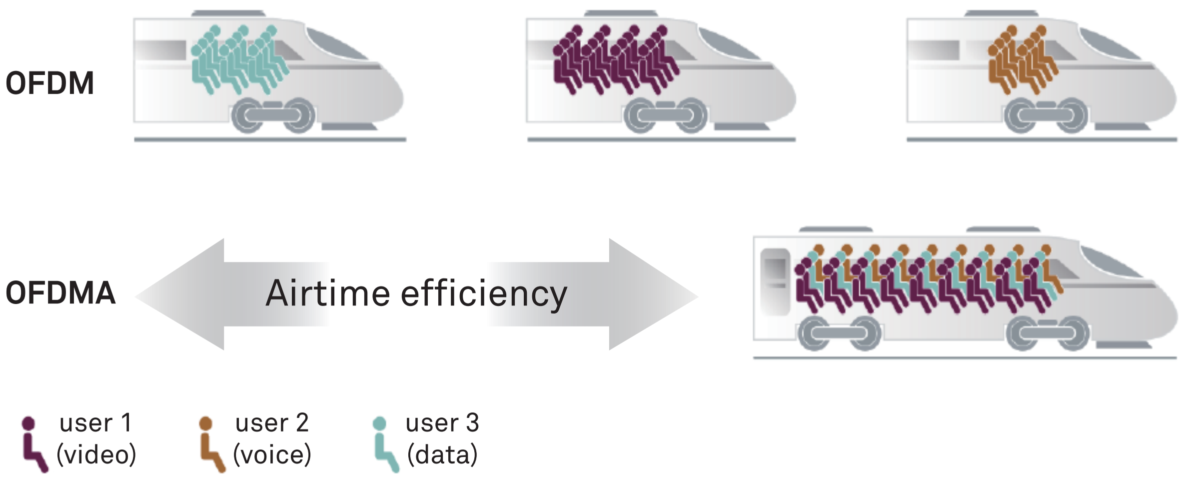
- Ultra-high bandwidth: 9.6 Gbit/s (theoretical)
- 4-times of 11ac on network access capacity, allowing for more STAs to access the network concurrently
- Power consumption of terminals reduced by more than 30%, meeting the requirement of IoT terminals for low power consumption

The IEEE 802.11ax standard involves dozens of features, including orthogonal frequency division multiple access (OFDMA), multi-user multiple-input multiple-output (MU-MIMO), target wake time (TWT), and BSS coloring.

### 2.3.1 OFDMA

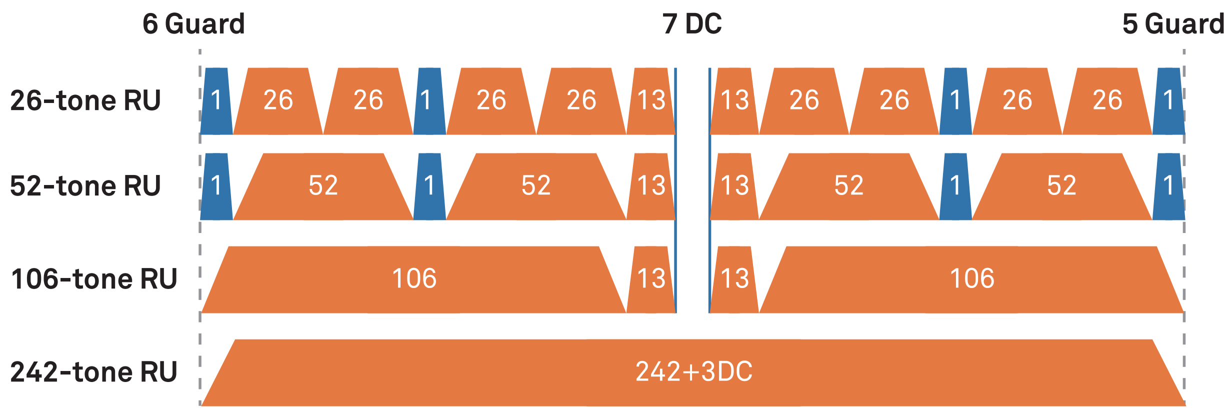
OFDMA is evolved from orthogonal frequency division multiplexing (OFDM) and was first applied to communication technologies. OFDMA technology is adopted in the Wi-Fi 6 standard to improve the spectrum utilization. In the traditional manner, when each STA sends data (regardless of the size of the data packet), the entire channel is occupied by a large number of small-sized management frames and control frames. This is like a big bus carrying only one passenger. OFDMA technology divides a radio channel into multiple subchannels (subcarriers) in the frequency domain to form resource units (RUs). User data is carried on the RUs and does not occupy the entire channel, thereby implementing simultaneous transmission of data from multiple STAs during each time segment. STAs no longer need to wait in queues or compete with each other, which improves the efficiency and reduces the queuing delay.

**Figure 2-3: Wi-Fi 6 OFDMA (source: Wi-Fi Alliance)**




OFDMA divides the bandwidth of a bus (20 MHz) into 256 small seats (subcarriers). Each seat (bandwidth) is fixed at 78.125 kHz. However, a small seat (subcarrier) is too narrow for even a kid (basic packet). Therefore, 26 small seats (subcarriers) are bound together to form a minimum RU. One RU provides 2 MHz bandwidth (also called 26-tone RU). The bus (20 MHz) can carry a maximum of nine passengers (nine concurrent users) at the same time. The remaining space is used for segregation of seats. The following figure shows the RU division at 20 MHz frequency bandwidth.

**Figure 2-4:** 20 MHz OFDMA RU division




A maximum of nine RUs with the same size are supported. That is, nine users can concurrently transmit data. If the content outputs of the users have different sizes or priorities, other combinations may be used or more RUs may be occupied, for example, four 52-RU and one 26-RU are used to concurrently transmit data. When the frequency bandwidth is 20, 40, 80, or 160 MHz, seven types of RUs are supported: 26-RU, 52-RU, 106-RU, 242-RU, 484-RU, 996-RU, and 2x996-RU.

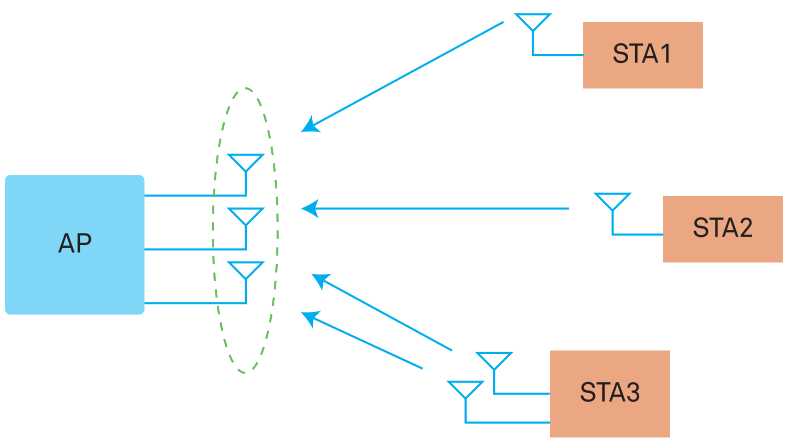
Wi-Fi 6 supports OFDMA in both downlink and uplink directions. In downlink OFDMA, an AP determines the allocation of RUs based on the downlink packets and priorities of users. In uplink OFDMA, an AP notifies STAs of the resources that can be allocated through trigger frames, and the STAs negotiate with the AP about RU allocation and STA preamble frame synchronization.

### 2.3.2 MU-MIMO

One of the biggest highlights of 802.11ac Wave 2 is downlink MU-MIMO. APs can send data packets to multiple STAs that support MU-MIMO at the same time, while in the past, APs can communicate with only one STA at a time.

Wi-Fi 6 inherits this technology and is able to send data to eight STAs at the same time. Additionally, Wi-Fi 6 supports uplink MU-MIMO and allows for concurrent uplink transmission of a maximum of eight 1x1 STAs.

**Figure 2-5:** Uplink MU-MIMO



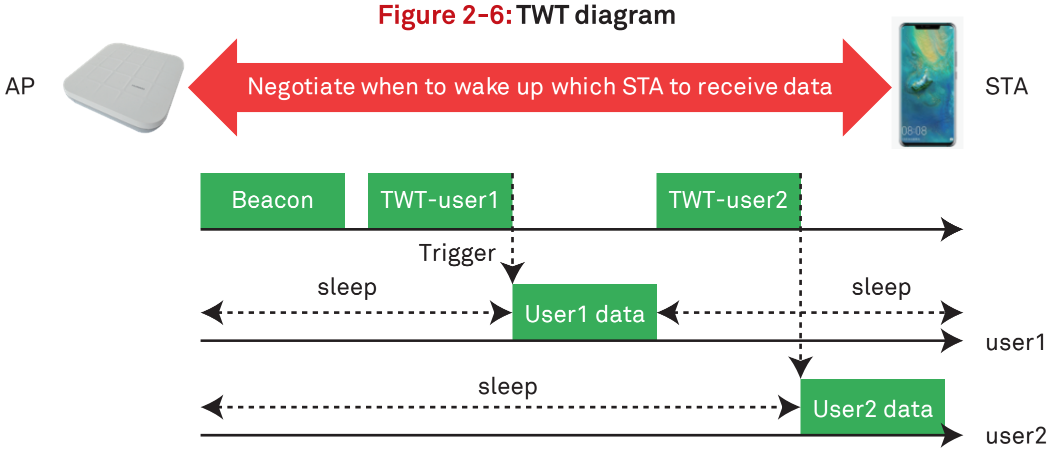
OFDMA and MU-MIMO are key technologies of Wi-Fi 6. They allow for multiple concurrent transmission in the frequency space and physical space, respectively. These cutting-edge advantages greatly improve the overall network performance and speed, and optimize user experience.

### 2.3.3 TWT

Target Wake Time (TWT) is another important resource scheduling function supported by Wi-Fi 6. This technology allows a device to negotiate when and how long it will wake up to send or receive data. APs can group STAs into different TWT periods. In this way, a smaller number of devices will compete for wireless medium at the same time after wakeup. The TWT function also increases the sleep time of devices, greatly prolonging the battery life.

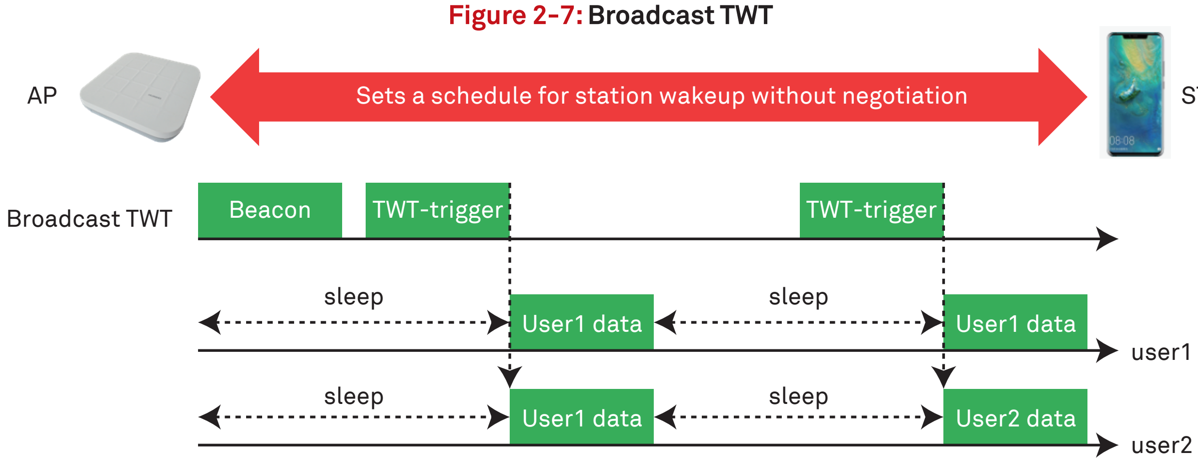
For example, if multiple smart home devices are connected to the Wi-Fi network in your home, the AP can establish a wake-up protocol with each device separately. In this manner, the devices enter the working state only after receiving the wakeup messages, and stay in sleep state during other time.

**Figure 2-6: TWT diagram**




The TWT function can also work with OFDMA technology to carry out a "Broadcast TWT" operation. An AP can set an orchestration agenda and provide the TWT value to multiple STAs. In this way, no individual TWT protocol is required between the two ends. Multiple devices can be woken up at the same time to implement concurrent connections for multiple services, such as video, voice, and data services. The traffic proportion and priority are adjusted for different services, thereby improving user experience.

**Figure 2-7: Broadcast TWT**



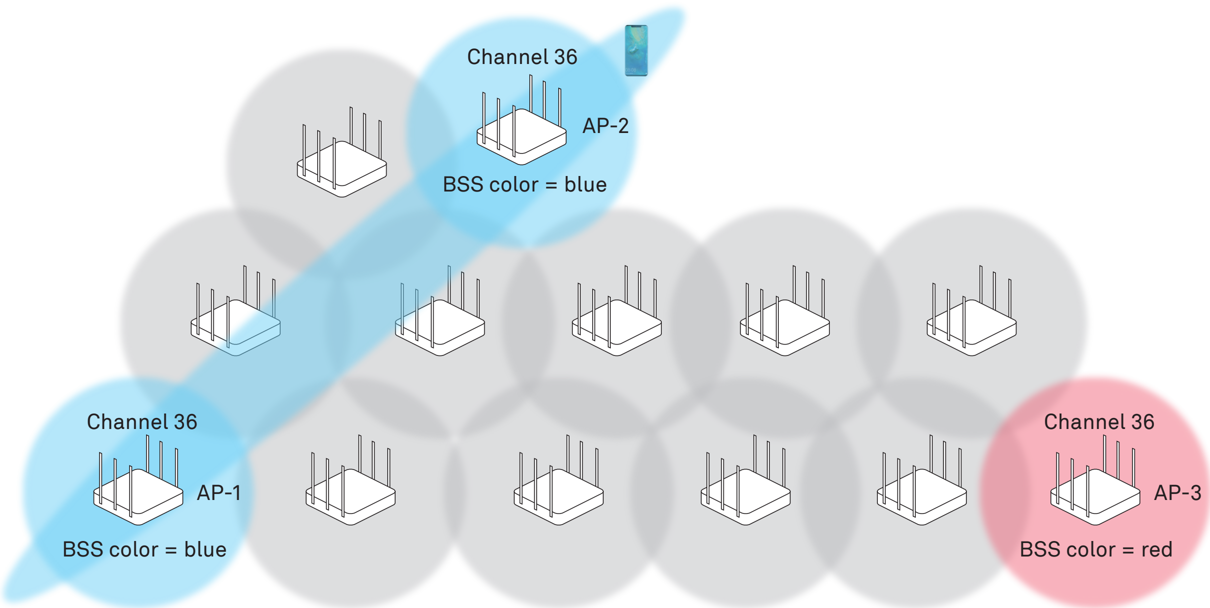
The TWT function fully reflects the determination of Wi-Fi 6 to embrace the IoT. The TWT function can save more than 30% power for battery-powered IoT devices.

### 2.3.4 Spatial Reuse (BSS Coloring)

The shortage of frequency resources has been a challenge to Wi-Fi deployment, especially in closed high-density stadiums. When multiple APs are deployed, they can detect the frames of all other APs on the same channel. Even the most powerful frequency modulation algorithm cannot solve the co-channel interference issue.

To improve overall system performance and utilization of spectrum resources in a dense deployment environment, Wi-Fi 6 proposes a spatial reuse technique, that is, BSS coloring. This technique adds a 6-bit identifier to a frame to distinguish the BSS of different APs on the same channel. As shown in the following figure, AP-1, AP-2, and AP-3 work on channel 36 and transmit data in the same BSS. The BSS coloring mechanism ensures that STAs connected to AP-3 are not interfered by AP-1 or AP-2, and can transmit and receive data on the same channel as AP-1 or AP-2. When finding that the BSS color of AP-2 is the same as that of itself, AP-1 can negotiate with AP-2 and modify the color accordingly to avoid conflicts.

**Figure 2-8: BSS coloring**



# 3. Status Quo and Development Trend of Wi-Fi Related Industries

Wi-Fi Alliance is expected to start certification of Wi-Fi CERTIFIED 6 products in 2019. Chip vendors such as Qualcomm, Broadcom, and Marvell have launched Wi-Fi 6 chips. Mainstream AP vendors such as Huawei, Aruba, Ruckus, and H3C have launched Wi-Fi 6 wireless AP products. Wi-Fi 6 chips for terminals have begun commercial deployments, and terminals that support Wi-Fi 6 will also emerge in the early 2019. The innovation of Wi-Fi technology is driving the development of the entire technology industry.

## 3.1 Status Quo and Development of the Wi-Fi Chip Industry

With the popularity of IoT, Wi-Fi chips are installed on TVs, cameras, vending machines, and more and more devices. According to statistics, shipments of Wi-Fi chips exceed 4billion pieces per year and is on the increase. Among them, the chips used by smartphones account for almost half of the shipment of Wi-Fi chipsets. Typically, smartphones use 802.11ac chips with 1x1 MIMO antenna, and laptops use 802.11ac chips with 2x2 MIMO antennas. Almost all terminals support both 2.4 GHz and 5 GHz Wi-Fi. Enterprise Wi-Fi mainly use 2x2 MIMO and 4x4 MIMO chips. 3x3 MIMO chips are gradually replaced by 4x4 MIMO chips in the 802.11ac Wave 2 phase. In addition, enterprise-class chips that support 802.11n are expected to completely exit the market in 2019.

In the second half of 2018, chip vendors had conducted publicity activities for Wi-Fi 6 chips and claimed to launch a full series of such chips. Most of these chips can support the main functions of Wi-Fi 6, and are supposed to pass WFA Wi-Fi 6 certification.. Wi-Fi 6 chips support the following antenna modes: 1x1, 2x2, 4x4, and 8x8; wireless APs support 2x2, 4x4, and 8x8 antenna modes (5 GHz); and mobile terminals, laptops, and IoT devices support 1x1 and 2x2 antenna modes (2.4 GHz and 5 GHz).

In our opinion, the shipment of Wi-Fi 6 chips will account for more than 10% of the total shipment of chips in 2019. By 2023, the shipment of Wi-Fi 6 chips will be up to 90% of total shipment. Migration to Wi-Fi 6 offers another golden opportunity for chip vendors that focus on technology innovation to increase their revenue and market share.

## 3.2 Status Quo and Development of the Mobile Terminal Industry

Since 2000, more than 20 billion Wi-Fi-enabled terminals have been delivered worldwide. Currently, the attach rate of Wi-Fi on smartphones and laptops is close to 100%, and Wi-Fi is rapidly expanding to innovative consumer electronic devices, IoT devices, and vehicles. Many users prefer to access available Wi-Fi networks, even if they have sufficient mobile traffic volume. Therefore, almost all electronic devices come with the Wi-Fi function.

The explosive growth of smartphones and tablets has cooled down, while the growth of relevant markets is still stable. The main driving forces include:

- (1) Feature phones still have an installed base and have not been completely replaced by smartphones. So the following years will see an incremental demand for smartphones, and the penetration rate of smartphones in developing countries is still considerable.
- (2) Technical upgrade improves the product iteration speed and shortens the upgrade cycle of smartphones. It is now very common for consumers to replace their old phones with new ones within two or three years. Continuous product upgrade requirements promote the continuous development of the smartphone market.
- (3) Driven by technologies such as IoT, various types of terminal emerge one after another. In the emerging smart mobile terminal field, wearable devices, smart household products, smart cars, and VR devices are very likely to spawn a huge potential market.

With consumers' pursuit for fashion and personality, continuous innovation becomes the driving force behind development of smart terminals. In 2019, Wi-Fi 6 compliant terminals will be gradually launched onto the market. It is expected that the number of such terminals will increase exponentially.

## 3.3 Status Quo and Development of the Wireless Network Device Industry

Wireless network devices mainly involve access controllers (ACs) and APs.

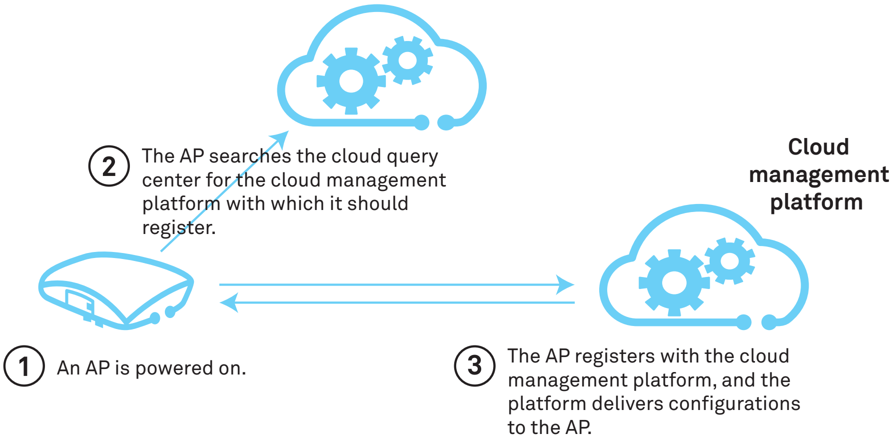
### 3.3.1 Cloud-based Development of Wireless Network Management

After a round of performance and capacity expansion of ACs, an AC can manage a maximum of 2K to 10K APs currently, and the port bandwidth can reach 40 Gbit/s or 100 Gbit/s. As VXLAN moves from data center networks to campus networks, the overlay architecture for one network for multiple purposes becomes a new trend. In addition, wired and wireless networks are fully converged, and campus networks become bearer networks for multiple services and are isolated from each other. The tunnel forwarding mode between APs and ACs is gradually replaced by VXLAN-based forwarding. ACs will be mainly responsible for AP management and configuration, but not for user data forwarding.

With the increase in wireless network deployment scale and the number of network nodes, the traditional AC-based management mode cannot meet the management requirements. To meet management requirements, cloud-based management comes into being. Cloud managed networks support device plug-and-play, are easy to manage, have high openness, and can provide value-added services, such as customer flow analysis and advertisement pushing. Therefore, cloud-based management has been gradually accepted by customers. Currently, mainstream device vendors (such as Cisco, Aruba, and Huawei) are focusing on the cloud-based management mode, and expect to occupy the multi-branch enterprise market and small- or medium-sized enterprise market. In addition to the cloud management platform operated by each vendor, leasing of Wi-Fi as Service from MSPs is also a major feature of cloud-based management.

In cloud-based management ode, a cloud AP obtains an IP address that can access the public network after being powered on and then searches the cloud query center for the cloud management platform with which it should register based on the default initial configuration. (Vendors usually have multiple cloud management platforms around the world.) After the cloud management platform delivers configurations to the cloud AP, the AP can works properly.

**Figure 3-1: Cloud-based management process**




Cloud-based Wi-Fi network will become more popular in the next 5 years. Most vendors provide only the public cloud deployment mode, but some enterprises would like to use private cloud mode for privacy and security purposes.

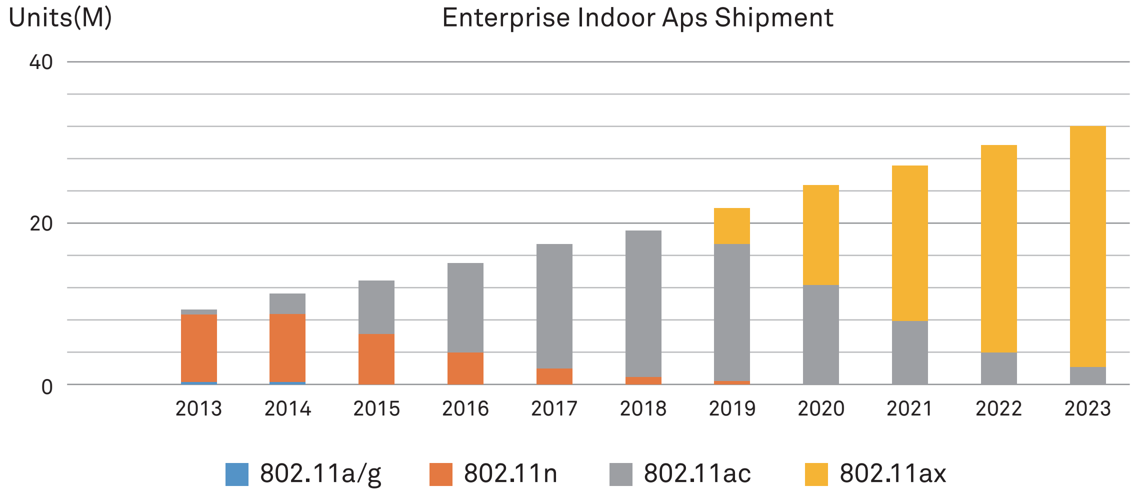
### 3.3.2 Status Quo and Development of Enterprise Wireless APs

As front-end devices of wireless networks, wireless APs are mainly responsible for radio transmission and interaction with terminals. Therefore, wireless APs differ mainly in hardware and supported protocols. The development of wireless APs has the following trends:

- (1) Currently, mainstream APs in the market support dual bands, that is, 2.4 GHz and 5 GHz bands. Single-band APs that support only the 2.4 GHz or 5 GHz band are nearly unavailable in the market.
- (2) To meet the requirements of different application scenarios, most vendors launch scenario-specific APs, such as dual-5G APs that meet high-density coverage requirements of stadiums and tripe-radio APs (one 2.4 GHz radio and two 5G radios).
- (3) To meet the transmission requirements of IoT scenarios, device vendors design IoT APs with built-in Bluetooth modules and built-in or external IoT slots for expanding IoT modules.
- (4) To meet the high bandwidth requirements of 802.11ac and 802.11ax, high-rate APs are usually designed with 2.5GE or 5GE ports.
- (5) Although high-performance APs can have MU-MIMO antennas such as 8x8 MIMO and 4x4 MIMO antennas, these APs have high prices. Currently, the most cost-effective APs with 2x2 MIMO antennas are the mainstream in the market.

In terms of market development, most wireless APs in the enterprise market comply with 802.11ac, and there is only a small installed base of 802.11n APs. Global markets have great confidence and interest in 802.11ax. According to the prediction of Dell'Oro Group, as the Wi-Fi 6 standard has been launched, the shipment of enterprise indoor 802.11ax-compliant APs will exceed 4 million units in 2019, which is estimated to exceed 10% of the global shipment of indoor APs. Customers use 802.11ax-compliant APs mainly to build new Wi-Fi networks or replace existing 802.11n APs. 802.11n APs will gradually quit the market. Starting from 2020, the market share of 802.11ax APs will grow significantly. With the maturity of Wi-Fi 6 chips and the popularization of Wi-Fi 6 terminals, Wi-Fi 6 will become the mainstream in the market. By 2023, the shipment of enterprise-class indoor APs that comply with 802.11ax will reach 30 million units, accounting for more than 90% of the global shipment of enterprise-class indoor APs. In other words, there will be more than 90% enterprises select Wi-Fi 6 to build their Wi-Fi network.

**Figure 3-2: Estimated shipment of enterprise-class indoor APs (source: Dell'Oro)**




## 3.4 Status Quo and Development of Emerging Applications

The following table describes the bandwidth requirements of several emerging wireless applications in different sectors. As shown in the table, AR/VR and 4K applications have high requirements on bandwidth, and are widely used in the education, enterprise, and healthcare sectors.

**Table 3-3: Bandwidth requirements of applications**

| Scenario | Application | Bandwidth | Delay |
|---|---|---|---|
| Office | Video conferencing | 30Mbit/s | 100ms |
| | 4K wireless display | 50 Mbit/s (peak value) | 50ms |
| | VoIP | 512kbit/s | 20ms |
| | 360° VR live broadcasting | 50 Mbit/s | 10–20ms |
| | Conference live broadcasting | 30 Mbit/s | 50ms |
| Education | Mobile gaming | 3 Mbit/s | 80ms |
| | Interactive gaming | 200 Mbit/s (full interaction) | 10–20ms |
| | VR distance education | 60 Mbit/s | 10–20ms |
| Healthcare | AR | 60 Mbit/s | 20ms |

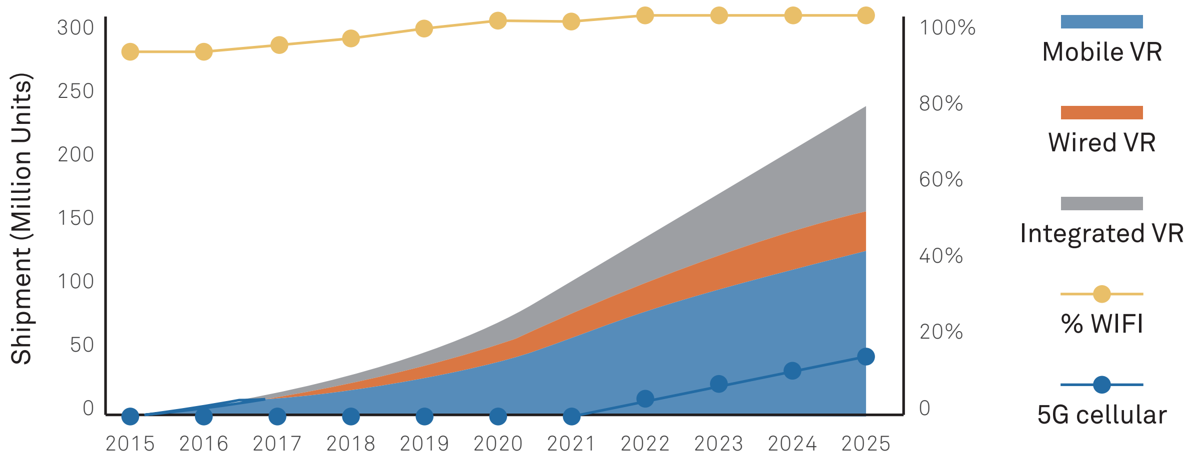
The following will describe the status quo and development of these applications.

### 3.4.1 VR/AR Industry

AR/VR shields users' real sight and brings their senses into a virtual space, providing users with a more in-depth and realisticexperience. AR can supplement or enhance the real world of users. VR/AR extends a flattened video experience to a three-dimensional immersive experience, and changes the way people live. Traditional VR/AR helmets are heavy and difficult to wear for a long time, and easily cause dizziness due to unclear video images, delivering a poor user experience. With the popularization of 5G and Wi-Fi 6, increase of the transmission rate, and reduction of delay, the VR/AR experience will be greatly improved. It is an inevitable trend to provide superior AR/VR experience based on 5G and Wi-Fi 6 anytime and anywhere as well as cloud content publishing and rendering with lower requirements for terminals and helmets. Additionally, Wi-Fi technologies in 60 GHz, Wi-Fi CERTIFIED WiGig™ also offer VR/AR use cases.

According to the market forecast in the following figure, the shipment of VR/AR devices around the world is about 10 million in 2018. It is predicted that the global shipment of VR/AR devices will increase to 250 million by 2025, and almost all devices support Wi-Fi connections. According to the forecast made by Huawei Wireless X Labs and ABI Research, the AR/VR market will create values of US$292 billion by 2025 (US$151 billion by the AR market US$141 billion by the VR market).

**Figure 3-4: Estimated shipment of VR/AR devices in the global market and connection types (source: Wireless X Labs and ABI Research)**




### 3.4.2 Status Quo and Development of the 4K/8K Industry

4K indicates the 4K resolution, and 8K indicates the 8K resolution. The 4K resolution is 3840 x 2160 pixels, while the 8K resolution is 7680 x 4320 pixels, which is four times of the 4K resolution and 16 times of 1080p. The expressiveness of videos can be improved to provide users with a visual feast brought by quality images. The 4K/8K industry involves the upstream and downstream vendors including playback device vendors and content vendors as well as network providers. High-quality videos require high bandwidth. The traffic cost for serving one 4K TV user is equivalent to that for serving nine PC or tablet users. Currently, 4K has not been completely popularized, and 8K is being developed. The 8K resolution not only brings a wide field of view and high-definition image effects to users, but also creates unique layered images and stereoscopic vision. The stereoscopic sense of human eyes is derived from the visual perception of objects and a way eyes sense objects near and far. 8K high-definition images can reproduce these natural differences and display the dimensionality and spatiality of the objects.

Content is a big challenge to the popularization of 4K terminals, as well as 8K terminals. As the content, 5G, and Wi-Fi 6 networks and technologies are becoming more mature, 4K and 8K panels will develop quickly and people will enter a new 4K and 8K era. Statistics show that 8K panels have 1% share in the market of 60-inch or larger panels in 2018, and the figure will reach 9% by 2020 and as high as 50% by 2022.

## 3.5 Intelligent O&M — Improving the Quality of Enterprise Wi-Fi Networks

Currently, high-quality network services have become an indispensable part of enterprise operations. From mobile office and HD video conference to guest reception, network experience is closely related to employee efficiency and customer satisfaction. However, as the enterprise scale expands, more and more enterprise applications are carried on the wireless network, making the network environment that is difficult to measure more complex than ever. Traditional O&M methods cannot proactively detect problems, resulting in low troubleshooting efficiency and bringing heavy burden to IT personnel.

An increasing number of device vendors launch their own Artificial Intelligence for IT Operations (AIOps) products. These AIOps products can automatically learn network behaviors and identify fault modes through algorithms such as big data analytics and machine learning, helping O&M personnel discover potential network problems and delivering an excellent network service experience. AIOps products have the following features:

- **Visualized user experience and automatic optimization**
  Network data is collected from multiple dimensions to display the network profile of each user in real time and visualize the network experience (including who, when, which AP, and experience status). Network monitoring is no longer centered on devices, but is changed to user experience-centric. The historical status of users at each moment can be played back to accurately identify problems that affect user experience.

  The wireless network environment is complex and changeable, which is difficult to be optimized manually in real time. The intelligent O&M system provides network optimization suggestions based on historical experience of wireless users and automatically delivers optimization parameters to the network within a specified range.

- **Automatic identification and proactive prediction of potential network problems**
  There are many KPIs related to the network state. Are these KPIs associated with each other? Does a KPI at different moments affect the network in the future? If network O&M is still analyzed in the traditional resource monitoring mode (single-node analysis), the timeliness and changeable locations of wireless access and mobile users on Wi-Fi make user experience problems difficult to be identified in real time. The intelligent O&M system correlates and analyzes data of various indicators through big data analytics and AI technologies, greatly improving the rate of potential problems identified. In addition, the intelligent O&M system can analyze a large amount of historical data and generate dynamic baselines through machine learning, and then compare and analyze the baselines with real-time data to predict potential faults. It also uses data-driven insight to proactively identify and solve problems before user and enterprise services are affected, improving the network performance.

- **Intelligent analysis and automatic rectification of network faults**
  The process from user access to application access seems to be simple, but many nodes on the network are involved in this process. Each node could be a failure point or affect user experience. IT personnel sometimes know that a fault occurs but cannot quickly locate the faulty node. This is because they check nodes one by one based on problem symptoms and related logs. This O&M method requires a large amount of IT resources, which is obviously inefficient for large-scale wireless enterprise networks. Enterprises can use the intelligent O&M system and machine learning capability to enable machines to manage devices and intelligently identify fault modes. They can also use the big data analytics platform to automatically analyze possible causes, provide recovery suggestions, and even automatically rectify the faults.

  The ultimate goal of intelligent O&M is to reduce dependency on people, gradually trust machines, and realize self-judgment and self-determination of machines. However, intelligent O&M technologies are not implemented overnight. It is a gradual process of value popularization. There is still a long way to go for the development of intelligent O&M.

## 3.6 Development of Other Technology Industries Driven by Wi-Fi 6

### 3.6.1 802.3bt PoE Switch

To facilitate deployment, wireless APs generally use PoE power supply. As technologies of APs develop, they consume more power. For example, in the 802.11n era or earlier, APs comply with 802.3af. In the 802.11n era, APs equipped with modules such as USB and BLE comply with 802.3at and can even function as the PSE to supply power to IoT device. Because Wi-Fi 6 APs consume more power, 802.3at (30 W) cannot meet requirements in all application scenarios.

The 802.3bt standard has been approved in 2018. 802.3bt enables a power supply capability (90 W) of the PSE three times 802.3at, and increases the power supplied to powered devices (PDs) to 71 W, facilitating large-scale deployment of Wi-Fi 6 APs. Enterprises should consider the power supply requirements in the next few years when purchasing PoE switches.

### 3.6.2 802.3bz 2.5G/5G Ethernet Switch

IEEE 802.3bz (approved on September 22, 2016) is compatible with mainstream Cat5e and Cat6 cables, so existing cables do not need to be replaced. Additionally, 802.3bz increases the rate to 2.5 Gbit/s (2.5GBASE-T) and 5 Gbit/s (5GBASE-T). In the 802.11ac era, some APs are equipment with Ethernet ports that support 802.3bz, preventing the APs' uplink interfaces from becoming a bottleneck of network bandwidth. However, the actual throughput of APs cannot reach over 1000 Mbit/s, so customers are not willing to replace the APs with 802.3bz switches.

Wi-Fi 6 greatly improves network performance. 802.3bz-capable Ethernet interfaces will be the standard configuration of a high-performance AP. Therefore, consider deploying 802.3bz switches when building a Wi-Fi 6 wireless network.

The popularization of Wi-Fi 6 will drive the market development of 802.3bt and 802.3bz switches.

# The Economic Value of Wi-Fi

Wi-Fi is one of the greatest success stories of the technology era, and its societal benefitshave long been known. Wi-Fi has connected and entertained people, andhas assisted in the creation of new technologies, industries, and careers the world over.There are now nearly13 billion Wi-Fi devices in use , and individuals, families, governments, and global organizations depend on Wi-Fi every day.

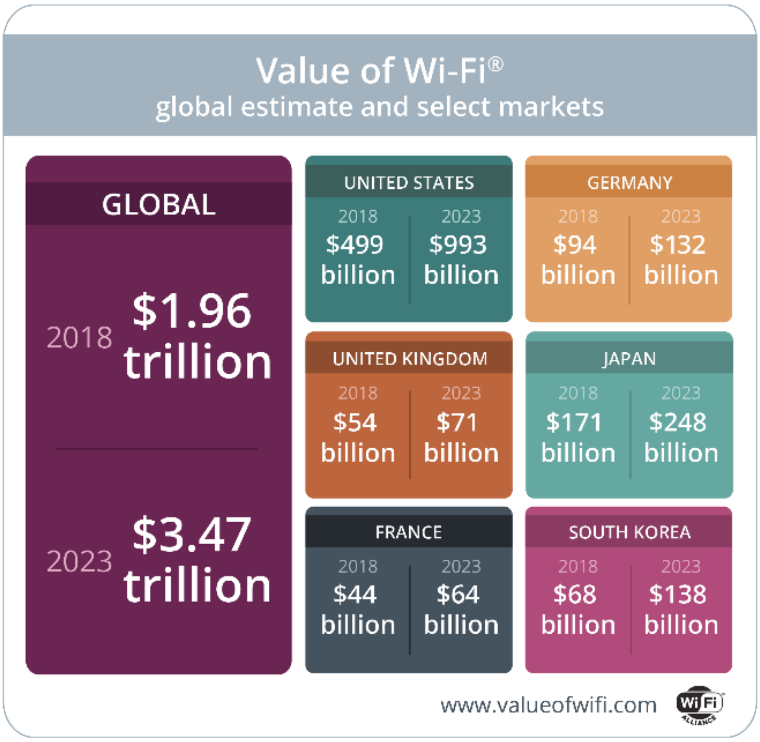
## Defining economic value

In 2018 Wi-Fi Alliance commissioned a study into the global economic value of Wi-Fi. The study concluded that Wi-Fi brings the greatest impact to the economy in four key categories: developing alternative technologies to expand consumer choice, creating innovative business models to deliver unique services, expanding access to communications services for fixed and mobile networks, and complementing wireline and cellular technologies to enhance their effectiveness.

The study reviewed the tangible, economic gains that Wi-Fi provides consumers and producers, and then adds the net contribution to Gross Domestic Product (GDP).Economic gains are termed as economic surplus, which includes consumer and producer surplus.The value of the consumer and producersurplus,as well as GDP contribution, is defined by multiple inputs, including the impact that Wi-Fi contributes to the economy in public, residential, and enterprise networks, device manufacturing, cellular network offload and carrier revenue, among other factors.

## Key findings

The study concluded that in 2018 Wi-Fi provided a global value of $1.96 trillion USD. By 2023, the study estimates a global value of $3.47 trillion USD.




The principal sources of economic value include Wi-Fi used by consumers in their homes and enterprise Wi-Fi networks. Economic value was also found in the producer segment through device manufacturing, cellular carrier traffic offload to Wi-Fi, and growing use of Wi-Fi hotspots in locations such as shopping malls, stadiums, and transportation hubs.In addition, Wi-Fi generates economic value and opportunity as a key solution for bringing broadband to rural areas and isolated geographies where coverage is scarce, while also providing an important platform for free internet access.

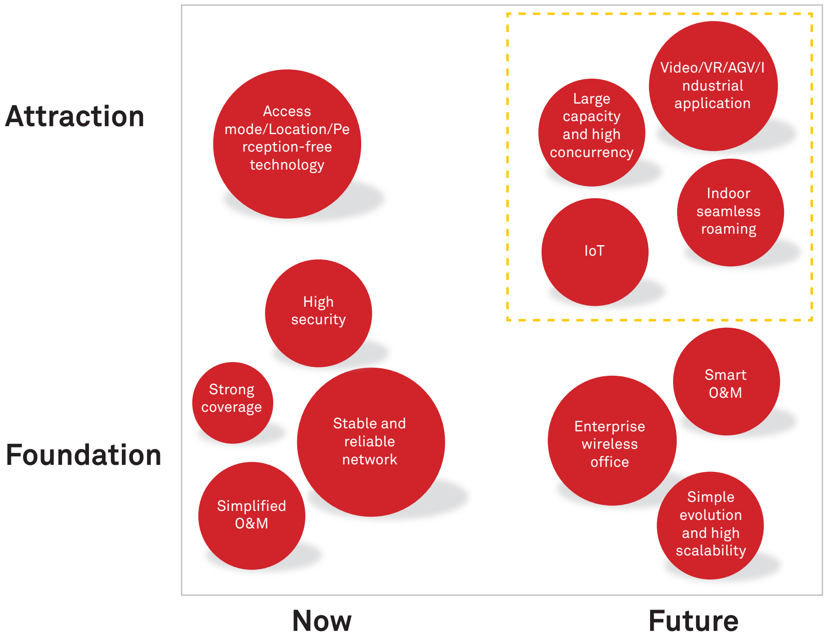
**For more details visit www.valueofwifi.com.**

***Source: Wi-Fi Alliance***

# 4. How to Build Wi-Fi Networks for Emerging Industry Applications

Currently, wireless networks are widely used by more and more enterprises because of their easy deployment, low construction cost, and wide applicability. Enterprise users can upload and share data generated during working and production through enterprise wireless networks, greatly improving the office and production efficiency. Today, wireless networks are used by more applications in more industries, even the industry communication. Enterprise wireless networks no longer just emit wireless signals and provide quick and safe wireless access. Especially, wireless applications that require higher bandwidth and lower latency, such as VR, 4K HD videos, and automated guided vehicle (AGV), are developing rapidly. Against this background, enterprise wireless networks must be designed to meet requirements of future industry applications and IoT scenarios in industry production, achieving interconnection of everything.

**Figure 4-1: Enterprise users' requirements for WLAN networks**




New technologies help enterprises improve the office and production efficiency. The latest-generation Wi-Fi 6 products make it possible to construct enterprise wireless networks oriented to large-scale future industry applications such as VR, 4K HD videos, and AGV. Wi-Fi 6 products can greatly enhance the bandwidth and capacity and shorten the latency of wireless networks. With a proper wireless network planning and design, an enterprise can construct the most cost-effective and efficient wireless network that can meet application requirements in the next five years.

## 4.1 4K over Wi-Fi Network Deployment Guide

4K brings not only higher video resolution but also better video quality with four distinct optimizations: clearer images, smoother videos, and more vivid and nature colors. Generally, the bit rate of 4K video streams is four times higher than that of full-HD (FHD) video streams with the same frame rate and the same compression and coding mode. Therefore, it requires much higher network bandwidth.

### 4.1.1 4K Video Requirements for Bandwidth

| Commercial Use Phases for 4K | | 2014-2016 | 2015-2016 | 2017-2019 | 2020- |
|---|---|---|---|---|---|
| | | **Entry-level 4K 4k@30p 8bit** | **Carrier-grade 4K 4k@60p 10bit** | **Ultra 4K 4k@120p 12bit** | **8K 8k@120p 12bit** |
| Bit Rate | Live broadcast | 25 Mbit/s to 30 Mbit/s | 25 Mbit/s to 35 Mbit/s | 25 Mbit/s to 40 Mbit/s | 50 Mbit/s to 80 Mbit/s@ H.266 |
| | Video on demand | 12 Mbit/s to 16 Mbit/s | 20 Mbit/s to 30 Mbit/s | 18 Mbit/s to 30 Mbit/s | 35 Mbit/s to 60 Mbit/s@ H.266 |
| Bandwidth | | > 30 Mbit/s | > 50 Mbit/s | > 50 Mbit/s | > 100 Mbit/s |

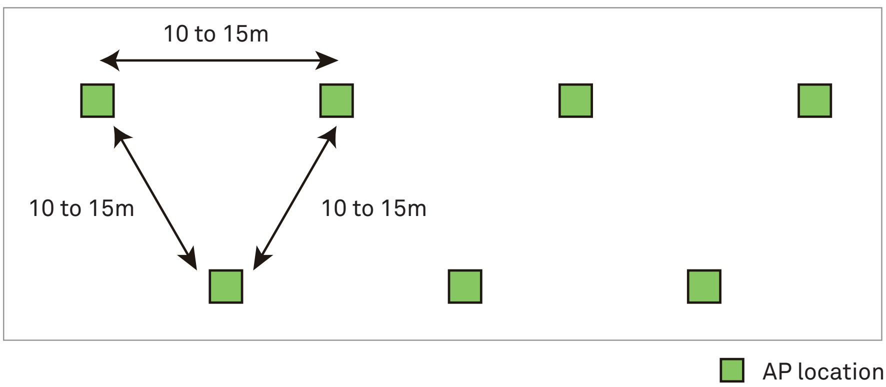
*Source: Huawei iLab*

According to the above table, the single-terminal bandwidth for 4K over Wi-Fi must be at least 50 Mbit/s, and in the future a single-terminal bandwidth of 100 Mbit/s is required.

### 4.1.2 Network Planning

In the enterprise office scenario, there are two major factors affecting the wireless network bandwidth: Wi-Fi signal quality and access scale. In the future enterprise office scenario, mobile terminals (laptops) support 2*2 MIMO. To reach the bandwidth of 50 Mbit/s@everywhere, it is recommended that the wireless network be planned with each AP supporting concurrent 12 STAs. Therefore, the recommended number of STAs supported by each AP is 12/30% (concurrent rate) = 40. Assume that the terminal density is 0.5 per square meter. The recommended coverage area of each AP is calculated as follows: 40/0.5 = 80 square meters. The recommended coverage radius is 6 m. Continuous coverage is required to ensure the roaming effect. Therefore, the coverage radius in areas with higher terminal density can be smaller. The following figure shows the recommended AP location planning for continuous semi-open area.

**Figure 4-2: AP location planning in the enterprise office scenario**




### 4.1.3 AP Selection

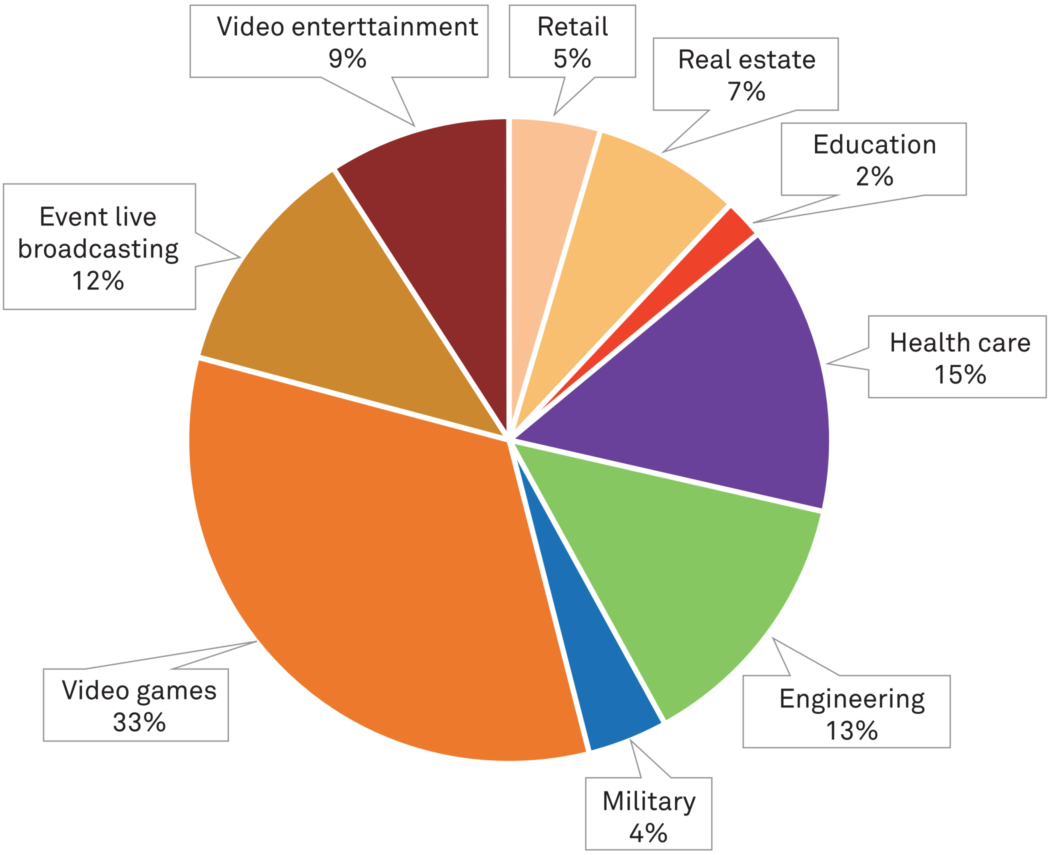
APs are selected according to both service performance and cost-effectiveness. In the enterprise office scenario, the following points should be considered when selecting APs for the area where large-scale 4K video services are provided:

| AP Hardware | AP Software |
|---|---|
| 802.11ax chip (Wi-Fi 6) | Smart radio calibration |
| Better than dual-band and four spatial streams | Dynamic anti-interference |
| Smart antenna | Smart roaming |
| IoT expansion (optional) | Application identification and acceleration |

## 4.2 VR/AR over Wi-Fi Network Deployment Guide

Currently, mainstream VR/AR applications fall into two types: panoramic video technology-based online videos on demand (VoD) and live broadcast, and computer graphics-based VR/AR standalone games, VR/AR online games, and VR/AR simulation environment, etc. Goldman Sachs predicted that in 2025, VR/AR will be widely used in nine industries, including gaming, live broadcasting, health care, real estate, retail, and education.

**Figure 4-3: Estimated application scale of VR/AR in nine industries**




*Source: Goldman Sachs Global Investment Research*

VR/AR applications in any industry require real-time connection and flow of massive information, which brings great challenges to network bandwidth and latency.

### 4.2.1 VR/AR Application Requirements for Bandwidth

| Phase | | Entry-level phase | Comfortable-experience phase | Ideal-experience phase |
|---|---|---|---|---|
| Cloud VR Video | Bandwidth | > 60 Mbit/s | > 75 Mbit/s | > 230 Mbit/s (12K) |
| | Latency (RTT) | < 20 ms | < 20 ms | < 20 ms |
| | Packet loss rate | $9 \times 10^{-5}$ | $1.7 \times 10^{-5}$ | $1.7 \times 10^{-6}$ |
| Strong-Interaction | Bandwidth | > 80 Mbit/s | > 260 Mbit/s | > 1 Gbit/s (12K) |
| Cloud VR service | Latency (RTT) | < 20 ms | < 15 ms | < 8 ms |
| | Packet loss rate | $1 \times 10^{-5}$ | $1 \times 10^{-5}$ | $1 \times 10^{-6}$ |

*Source: Huawei iLab*

As shown in the preceding table, Cloud VR services have different requirements on network bandwidth and latency in each phase. VR cloudification will further lower requirements for network latency and bandwidth. To offer comfortable experience in VR video services, the Wi-Fi network latency must be within 20 ms and the single-terminal bandwidth must be greater than 75 Mbit/s. For strong-interaction VR services, the Wi-Fi network latency must be within 15 ms and the single-terminal bandwidth must reach 260 Mbit/s.

### 4.2.2 Network Planning

VR/AR is mainly applied in the gaming, retail, education, and health care industries. The interactive VR/AR is mainly used in the gaming industry, and VR/AR videos are mainly used in the retail, education, and health care industries. Comfortable-experience requirements for VR/AR videos are similar to the network requirements of 4K videos. For details, see section 4.1.2"Network Planning." VR/AR games require a single-terminal bandwidth of higher than 260 Mbit/s. Therefore, wireless bandwidth requirements of other services such as the web page browsing and email service can be ignored. In addition, the coverage range is not the key point. It is recommended that the wireless network be planned with each AP supporting 4 concurrent VR/AR terminals. The VR/AR terminals should be as close to the AP as possible. You are advised to enable AP application identification and application acceleration functions, and strictly control the access scale to ensure the service experience of each user.

### 4.2.3 AP Selection

Currently, the VR/AR application scenario is an independent coverage scenario that is similar to the primary and secondary school classrooms. APs are required to ensure the bandwidth and service latency of each user as much as possible.

| AP Hardware | AP Software |
|---|---|
| 802.11ax chip (Wi-Fi 6) | Smart radio calibration |
| Triple-band | Dynamic anti-interference |
| Eight spatial streams | Application identification and acceleration |

# 4.3 AGV Over Wi-Fi Network Deployment Guide

Unmanned services are the trend of smart factories in the future. Robots that replace manual labor to complete goods transportation and sorting are undoubtedly important facilities for smart factories. For instance, more and more goods are transported through AGVs. Since AGVs work in the industrial environment, communication reliability must be ensured for them. Additionally, AGVs need to travel between different working areas to load and unload goods, and there are various obstacles in different places. This requires pervasive Wi-Fi coverage and lossless roaming of AGVs between APs to ensure normal interaction with the background.

## 4.3.1 Bandwidth Requirements for AGVs

In an AGV smart warehousing scenario, AGVs require a low bandwidth, which is typically 512 kbit/s for each AGV. However, the big challenge for the Wi-Fi network is the data transmission latency and roaming reliability of AGVs that move fast in a large area. Generally, AGVs require that the latency and roaming performance be less than 50 ms. This is easy to implement for a single operating AGV. However, when 50 or even 100 AGVs work at the same time in a 1000 $m^2$ area, the latency within 50 ms or even 10 ms demands a well planned Wi-Fi network and a good compatibility with wireless network adapters of AGVs.

## 4.3.2 Network Planning

The Wi-Fi network deployment is complex in an AGV smart warehousing scenario. In a shelf area with a top roof (8-12 meters high) and many obstacles, you are advised to deploy APs with directional antennas on both sides of the aisle to bypass the obstacles. In an open transportation area, you are advised to mount APs with directional antennas to the ceiling. If the distance between the roof and ground is less than 8 meters, you can also use APs with omnidirectional antennas. A maximum of 100 AGVs are allowed in each 1000 $m^2$ area. The AGVs have a low access density and require a low bandwidth (512 kbit/s for each AGV). Therefore, pay attention to whether the Wi-Fi coverage area meets the requirements. Generally, it is recommended that the distance between APs be about 15 meters.

## 4.3.3 AP Selection

As mentioned above, AGVs have a low requirement on bandwidth and their access density is not high. Therefore, you can select cost-effective APs that provide low access specifications and bandwidth, while ensuring fast and reliable roaming of AGVs on the Wi-Fi network.

| AP Hardware | Software |
|---|---|
| 802.11ax (Wi-Fi 6) | Intelligent radio calibration |
| Dual-band | Dynamic anti-interference |
| Smart antenna and directional antenna | Lossless roaming |
| (Optional) IoT module | Application identification and acceleration |

# 5. Conclusions

Driven by the rapid iteration of standards and the explosive growth of requirement scenarios, an enterprise-class Wi-Fi has evolved from the initial "expansion of a fixed network" to a complete network solution that includes ACs, Agile Controller, NMS, and authentication system. The services carried on a Wi-Fi network are no longer simply to meet the consumer demand for "access to the mobile Internet". EnterpriseWi-Fi have become an infrastructure that supports digital transformation and improves production and work efficiency of various industries. A well designed Wi-Fi network can greatly improve enterprise operation efficiency and employee satisfaction, and support more digital and intelligent services of enterprises. Therefore, if you have not deployed a Wi-Fi or your Wi-Fi cannot meet the requirements of your digital service development, you are advised to deploy or upgrade to the latest Wi-Fi as soon as possible, with the following factors considered:

- **Trends of wireless networks in the future**

  There are three typical trends in the development and evolution of full wireless networks in the future:

  (1)Users' requirements on wireless networks are shifted from coverage-based connections to high-perception broadband experience (highly reliable signals, video-class capacity, and millisecond-level latency).

  (2) Multiple IoT applications and Wi-Fi networks are deployed together, sites on different networks are converged, capacities are collaboratively planned, and interference between networks is avoided.

  (3) More complex services will be carried on the network, covering from large-bandwidth video services to low-latency VoIP services, and even reliable connection services of some special devices. Accurate and appropriate Quality of Service (QoS) policies should be deployed to ensure differentiated experience of diversified services.

- **User access and data security**

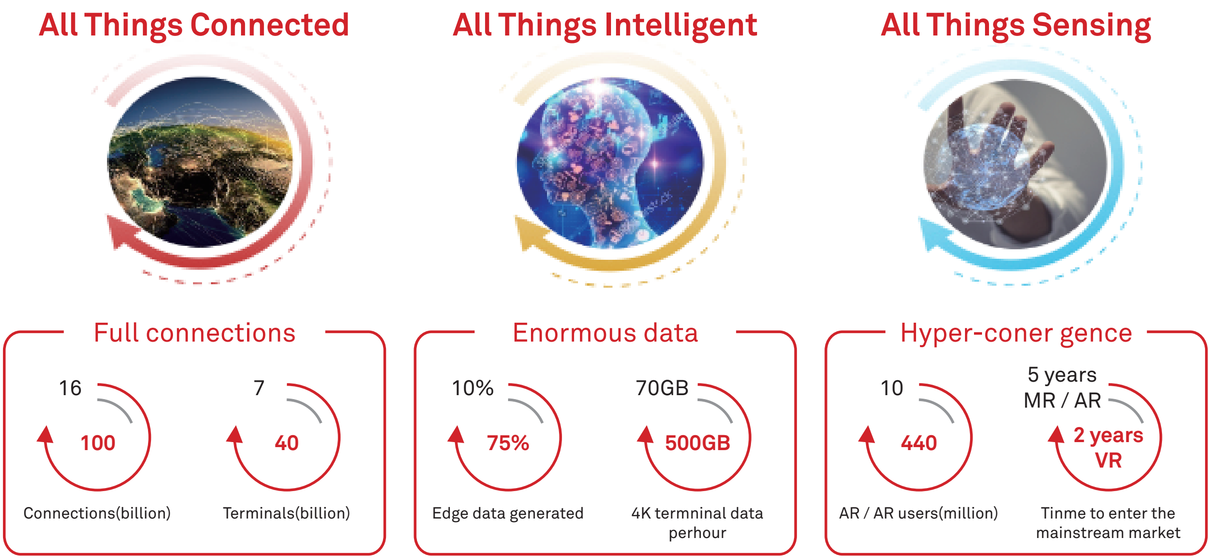
  Traditional enterprise Wi-Fi security technologies focus on wireless security, including data transmission security, attack defense, and anti-spoofing for air interfaces, as well as STA access authentication. Future enterprise Wi-Fi security needs to be further integrated with network security technologies, including flexible control of user permission and enterprise data resources, and integration of wireless and wired security policies. ACs need to work with the firewalls, virus detection system, and online behavior analysis system to enable authorized users to access authorized networks, force abnormal users to log out, and prevent unauthorized access to enterprise networks and data.

- **Wireless networks applicable to new technologies and new industries**

  Wireless networks are closely related to the development of new technologies and new industries. A large number of IoT devices are used in the intelligent transformation process of enterprises. It is not easy to smoothly introduce the IoT while further strengthening service applications. Wi-Fi 6 has been fully prepared for the IoT in terms of security, access, capacity, latency, and power saving. In addition,

Wi-Fi, as an important data entry, provides various data sources for big data analytics. With the support of IoT devices, big data analytics is further enhanced in accuracy and content.
New technologies such as machine learning and AI are also driving intelligence of Wi-Fi networks. Dynamic radio calibration based on machine learning and admission control of historical behaviors also empower Wi-Fi networks, making the Wi-Fi networks play an increasingly important role in the development of enterprises.

**Figure 5-1: Forecast on Wi-Fi network development (red: 2023; gray: 2018)**




With interconnections of tens of billions of mobile terminals, generation, computing, and transmission of enormous data, and advent of more hyper-converged applications, we are entering the era of intelligent connectivity of everything. In this era, enterprise Wi-Fi network with fast/stable/security/smart features will help enterprise success in digital transformation..

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