White Paper on Building High-Quality WLANs in Typical Enterprise Scenarios

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Key Authors(in no particular order)

Zhang Lei, Zhang Haitao, Ma Nan, Huang Min, Zhang Tao, Sun Shengbai, Deng Haiyang, Xu Fangxin, Ran Jianjun, Zhao Hangbin, Zheng Qiuping, He Jingfeng, Li Guande, Yan Mingjian, Zeng Weiwei, Lin Sen, Li Haijun, Zhao Yongping, Wu Liang, Wang Lei, Yang Jie, Qiu Yuefeng, Geng Liang, Ji Chenhe, Qi Shuang, Yang Quan, Wang Hao, Wang Lei, Tang Yu, Cheng Peng, Wei Zhiwei, Ma Changchun, Fan Shaodong, Yu Fang, Wu Jun, Lei Gen, Li Yuan, Ren Hu, Yang Tao, Shi Hao, Yuan Liquan, Wang Xianqing, Shi Baiqing, Huang Jian, Wu Rihai, Lv Maosheng, Yuan Yaru, Hu Xiuming, Yuan Yunlian, Wang Yuting, Lv Changwen, Shan Lina, Liu Cheng, Gong Dafu, Fang Lijie, Jia Weidong, Wang Jun, Wu Qinggen, Wang Wei, Yang Peikun, Wang Hao, Cheng Yongchun, Li Guofeng, Lu Yao, Li Ming, Wang Zhijun, Lv Zhihua, Chen Jinhua, Jiang Wei, Peng Kai, Yang Jianrui, Huang Junhong, Fan Zhichao, Qi Shaofeng, Zhang Jinlin, Ma Di, Zhang Xi, Wang Xiaomeng, Wang Miao, E Lei, Tang Xinbin, Zhou Wangsong

Preamble

The World WLAN Application Alliance (WAA) is an international organization dedicated to the development of the wireless local area network (WLAN) industry. WAA is registered in the Ministry of Civil Affairs of China. Inspired by the vision of "Building the WLAN that delivers the best experience in the digital world", WAA works with global partners to promote the development of the WLAN industry.

WLAN applications have been widely used in various scenarios, such as home, office, education, production, and logistics. WLAN applications are critical to the national economy and people's livelihood and are the key infrastructure of the digital economy. As WLAN technologies and service scenarios evolve, the industry needs a deeper understanding of service requirements and network construction standards in different scenarios to keep up with the demand for better network quality and user experience.

This white paper analyzes the characteristics and service requirements of WLANs in various enterprise application scenarios, and the latest development trends of WLAN technologies. It serves as reference for WLAN network construction and application in enterprise scenarios.

This document is intended for WLAN users, network builders, and maintainers in enterprise application scenarios.

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1 Despite Widespread Usage of WLANs in Enterprises, the Industry Lacks Standards Regarding Performance and Experience

1.1 WLAN Carries 70% of Last-Hop Traffic, with Continuous Growth in Industry Scale and Economic Value

In the mobile Internet era, wireless networks are bringing unprecedented convenience to people's work and life. Internet access that is available anytime, anywhere has become a basic need. WLAN networks have become a daily necessity and key infrastructure, just like water and electricity. The application and commercial value of WLAN technologies are also widely recognized. According to a report from a third-party consulting firm, more than 70% of the world's last-hop traffic is implemented through WLAN technology, making WLAN the most important terminal access technology.

WLANs are the basic requirements for smart homes. In homes, the number and types of devices supporting WLAN are increasing. Terminals such as mobile phones, tablets, laptops, cameras, smart TVs, and smart home appliances need to connect to the WLAN, leading to a higher access density of the home WLAN.

WLANs are a basic facility in campuses and public locations. Places with high foot traffic such as shopping malls, airports, hotels, and subways provide free WLAN access for consumers. The consumers use WLANs for positioning, navigation, and mobile payment. This in turn increases customer loyalty and satisfaction.

WLANs are also important infrastructures for enterprises' digital transformation. With the WLAN network, employees can work and collaborate on mobile networks or use mobile apps to work at any time. Currently, more than 70% of enterprises have implemented wireless offices, greatly improving work efficiency. Digital transformation has also led to explosive growth in the number of Internet of Things (IoT) devices. It is predicted that the number of connected devices worldwide will reach 100 billion by 2025. As the first network connection point for IoT devices, WLAN will demonstrate even more value.

All these examples speak one thing: WLAN is a "small" technology but a "big" industry. Its industry scale and economic value will continue to grow. According to the analysis of a third-party consulting firm, the global WLAN market is expected to continue to grow significantly from 2019 to 2025. The annual shipments of WLAN devices will increase from 3.1 billion units in 2019 to more than 4.5 billion units in 2025, with a compound annual growth rate of more than 10%.

WLAN has become a key technology in enterprise and carrier networks and an important part of consumer products for homes and individuals. This value will continue to grow as next-generation products become popularized in the coming years.

1.2 The WLAN Industry Lacks Scenario-based Performance Experience Test Standards

In the more than 20-year development of WLAN, its application used to be basic services, such as Internet access and e-mail. Such services have low requirements for network performance. However, as the application scenarios and service types of WLAN become more diversified, demands arise for experience-critical performance, such as latency, reliability, anti-interference, and roaming handover. This has become a new challenge to the WLAN industry.

		1997	1999	2007	2009	2012	2019
Technical standard interoperability certification	IEEE WFA	802.11	802.11b/a Wi-Fi 1/2	802.11g Wi-Fi 3	802.11n Wi-Fi 4	802.11ac Wi-Fi 5	802.11ax Wi-Fi 6
Performance standard certification	BBF CCSA None			None		TR-398 Performance requirements and test methods for WLAN interfaces of home gateways	

Figure 1-1 The WLAN industry has long lacked a performance standard certification system

Currently, the test and certification of the WLAN industry focuses mainly on interoperability. There are no WLAN network construction standards, network performance, experience performance test specifications, or certification systems, and carriers do not have acceptance standards, either, resulting in poor user experience. The industry has long lacked a WLAN performance standard certification system, which has become an obvious weakness in the development of the WLAN industry and needs to be addressed imperatively.

2 Enterprise WLAN Scenarios Are Complex and Diversified, Calling for Standards for Building High-Quality WLANs

Wireless networks are widely used in fields such as education, healthcare, tourism, warehouse management, and exhibition. Different scenarios have different requirements for network experience. Mainstream scenarios are classified into the following:

2.1 Campus Office

2.1.1 Scenario Overview

As wireless network technologies become increasingly mature, more and more enterprises build wireless networks to meet daily service requirements. Wireless office scenarios include high-density office areas, low-density office areas, conference rooms, recreation areas, and canteens. The applications in these scenarios are mainly office software, e-mail, web browsing, file transfer, instant messaging (IM), and audio and video conferencing. The key demand is to ensure critical office services such as audio and video conferencing and IM. Users' top concerns are network transmission efficiency, access stability, and mobile office smoothness. Wireless deployment is required to support high-density access, high-concurrency applications, and efficient transmission with low latency.

2.1.2 Scenario-specific Service Requirements

Campus office services mainly include office software, e-mail, web browsing, file transfer, IM, and audio and video conferencing. The following table lists the bandwidth requirements of services and their proportions by bandwidth consumption.

Table 2-1 Service bandwidth requirements in campus offices

Service Type	Baseline Rate (Mbps) per Service		Proportion of Bandwidth Consumption in Each Scenario				
	Excellent	Good	High-Density Office Area	Low-Density Office Area	Conference Room	Recreation Area	Canteen
Web browsing	8	4	20%	20%	50%	25%	25%
Streaming media (1080p)	16	12	10%	5%	5%	30%	30%
Streaming media (4K)	50	25	10%	5%	5%	20%	25%
VoIP	3	2	10%	20%	10%	0%	0%
Electronic whiteboard	32	16	5%	5%	10%	0%	0%
E-mail	32	16	3%	3%	5%	10%	10%
File transfer	32	16	2%	2%	10%	0%	0%
Desktop sharing	3	2	10%	10%	0%	0%	0%
Gaming	2	1	0%	0%	0%	10%	5%
Instant messaging	1	0.5	30%	30%	5%	5%	5%

2.1.3 High-Density and Low-Density Office Areas

2.1.3.1 Scenario Examples

Figure 2-1 High-density office area

Figure 2-2 Low-density office area

2.1.3.2 Service Description

This scenario is mainly wireless offices. Service types include office services and non-office services. Office services include video conferencing, web browsing, e-mail, and file download. Non-office services include video, gaming, and voice communication.

2.1.3.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3—5 meters, areas ranging from several square meters to several hundred square meters
- **Density:** High density: 2—3 square meters per person. Low density: 4—5 square meters per person

- **Capacity:** High density: 80 terminals per access point (AP), 40% concurrency. Low density: 40 terminals per AP, 40% concurrency
- **Coverage:** Received signal strength indicator (RSSI) ≥ –65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.1.3.4 Wireless Function Requirements

- **Wide coverage:** In open office scenarios, the area is large and there is no fixed hurdles. However, users are concentrated. Therefore, sufficient wireless signal coverage needs to be considered.
- **High concurrency:** In office scenarios, a large number of wireless connections may cause interference and congestion on the wireless network. Within the given bandwidth, the network must be properly planned and radio resources must be configured to meet the concurrency requirements of wireless users.
- **High bandwidth:** In office scenarios, a large amount of data traffic needs to be transmitted, such as in audio and video conferences and large file transfers. These applications have high requirements for network bandwidth. Resource assurance technologies need to be used to meet the bandwidth requirements of key applications or key terminals.
- **Interference resistance**: In high-density scenarios, there is strong wireless interference, including WLAN interference and non-WLAN interference. Interference on a wireless network affects network stability, data transmission speed, and network connection quality, and can even cause network interruption. Therefore, devices must be capable of resisting interference to ensure the Internet access experience of wireless users even in the case of severe interference.
- **Seamless roaming:** Mobile office requires fast and seamless handovers between different APs to ensure mobile office continuity and efficiency. In addition, the service quality and user experience of mobile offices in different locations must be ensured. Quality of service includes connection speed, data transmission speed, linking time, availability, and stability of mobile devices.
- **Assurance for key users:** In office scenarios, key users must access the network as VIP users. The bandwidth guarantee for VIP users must be all-round. Such users are marked

on the network so that they have prioritized access to the network, unlimited rate, and reserved resources. VIP users can enjoy a higher-quality wireless network experience than common users. For example, VIP users have higher wireless network priority, higher network bandwidth, and lower network latency.

2.1.4 Meeting Rooms

2.1.4.1 Scenario Examples

Figure 2-3 Meeting rooms

2.1.4.2 Service Description

Services in this scenario are mainly wireless office applications, including electronic whiteboards, web browsing, e-mail, and file download.

2.1.4.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3—5 meters
- **Density:** Small meeting rooms: 20 square meters/10 persons. Medium-sized meeting rooms: 50 square meters/20 persons. Large meeting rooms: 200 square meters/60 persons
- **Capacity:** 40 terminals per AP, 30% concurrency (Triple-radio APs are recommended in specific scenarios to reduce the number of APs to be deployed.)
- **Coverage:** RSSI ⩾ -65 dBm in 95% of the areas within a conference room
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.1.4.4 Wireless Function Requirements

- **High concurrency:** In the case of large meeting rooms, a large number of wireless connections may cause interference and congestion on the wireless network. Within the given bandwidth, the network must be properly planned and RF resources must be configured to meet the concurrency requirements of wireless users.
- **High bandwidth:** In meeting room scenarios, a large amount of data traffic needs to be transmitted, such as in audio and video conferences and large file transfers. These applications have high requirements for network bandwidth. Resource assurance technologies need to be used to meet the bandwidth requirements of key applications or key terminals.
- **Interference resistance**: In large meeting rooms, there is strong wireless interference, including WLAN interference and non-WLAN interference. Interference on a wireless network affects network stability, data transmission speed, and network connection quality, and can even cause network interruption. Therefore, devices must be capable of resisting interference to ensure the Internet access experience of wireless users even in the case of severe interference.
- **Assurance for key users:** In meeting room scenarios, key users, such as users using wireless projection, must be able to access the network as VIP users. The bandwidth guarantee for VIP users must be all-round. Such users are marked on the network so that they have prioritized access to the network, unlimited rate, and reserved resources. VIP users can enjoy a higher-quality wireless network experience than common users. For example, VIP users have higher wireless network priority, higher network bandwidth, and lower network latency.

2.1.5 Canteens

2.1.5.1 Scenario Examples

Figure 2-4 Canteen

2.1.5.2 Service Description

This scenario is mainly wireless entertainment, including web browsing, audio and video services, e-mail, and gaming.

2.1.5.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3—5 meters, areas ranging from dozens of square meters to several hundred square meters
- **Density:** 1—2 square meters per person
- **Capacity:** 60 terminals per AP, 30% concurrency
- **Coverage:** RSSI ⩾ -65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.1.5.4 Wireless Function Requirements

- **Wide coverage:** In canteen scenarios, the area is large and there is no fixed hurdles. However, users are concentrated. Therefore, sufficient wireless signal coverage needs to be considered.

- **High concurrency:** In canteen scenarios, a large number of wireless connections may cause interference and congestion on the wireless network. Within the given bandwidth, the network must be properly planned and RF resources must be configured to meet the concurrency requirements of wireless users.
- **Seamless roaming:** Mobile office requires fast and seamless handovers between different APs to ensure mobile office continuity and efficiency. In addition, the service quality and user experience of mobile offices in different locations must be ensured. Quality of service includes connection speed, data transmission speed, response time, availability, and stability of mobile devices.

2.2 Education

2.2.1 Scenario Overview

Classrooms often have a huge number of wireless users and as a result, many wireless access requests are usually made concurrently, both of which tend to increase expectations of the network experience. During a class, all electronic devices and applications — from smart blackboards and smart displays to online education applications and the teachers' laptops and tablets — require a strong and stable connection and adequate bandwidth. When students study independently in a classroom or take breaks, both students and teachers need the network to support concurrent access requests for multiple types of services.

Dormitories are another place where students intensively use the wireless network. Given that each dormitory room accommodates four to eight students, a significant number of devices connect to the network across the dormitory buildings. Peak usage hours are at lunchtime and in the evening. Major services include video, gaming, and file download, all of which rely on huge network bandwidth and high network quality.

2.2.2 Scenario-specific Service Requirements

Education services mainly include audio and video, file transfer, instant messaging, desktop sharing, and web browsing. The following table lists the bandwidth requirements of services and their proportions by bandwidth consumption.

Table 2-2 Service bandwidth requirements in education

Service Type	Baseline Rate (Mbps) per Service		Proportion of Bandwidth Consumption in Each Scenario	
	Excellent	Good	Dormitory Room	Electronic Classroom
Web browsing	8	4	10%	20%
Streaming media (1080p)	16	12	20%	30%
Streaming media (4K)	50	25	10%	20%
VoIP (Voice)	3	2	0%	0%
Electronic whiteboard	32	16	0%	0%
E-mail	32	16	5%	0%
File transfer	32	16	20%	0%
Desktop sharing	3	2	0%	20%
Gaming	2	1	30%	0%
Instant messaging	1	0.5	5%	10%

2.2.3 Dormitories

2.2.3.1 Scenario Example

Figure 2-5 Dormitory

2.2.3.2 Service Description

This scenario is mainly wireless entertainment, including web browsing, audio and video services, large file download, and gaming.

2.2.3.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3 meters, areas ranging from ten-plus square meters to several dozen square meters
- **Density:** 4—8 people per room
- **Capacity:** 8—16 terminals per AP, 50% concurrency
- **Coverage:** RSSI ⩾ –65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.2.3.4 Wireless Function Requirements

- **High bandwidth:** In the dormitory scenario, a large amount of data traffic needs to be transmitted, such as in audio and video services and large file transfers. These applications have high requirements for network bandwidth. Resource assurance technologies need to be used to meet the bandwidth requirements of key applications or key terminals.
- **Interference resistance**: In the dormitory scenario, there is strong wireless interference, including WLAN interference and non-WLAN interference. Interference on a wireless network affects network stability, data transmission speed, and network connection quality, and can even cause network interruption. Therefore, devices must be capable of resisting interference to ensure the Internet access experience of wireless users even in the case of severe interference.

2.2.4 Classrooms

2.2.4.1 Scenario Example

Figure 2-6 E-classroom

2.2.4.2 Service Description

This scenario is mainly wireless education, including electronic whiteboards and multi-tablet audio and video services.

2.2.4.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3—5 meters, areas ranging from several dozen square meters to several hundred square meters
- **Density:** 1 square meter per seat
- **Capacity:** 100 terminals per AP, 30% concurrency
- **Coverage:** RSSI ⩾ -65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.2.4.4 Wireless Function Requirements

- **Wide coverage:** In the classroom scenario, the area is large and there is no fixed hurdles. However, users are concentrated. Therefore, sufficient wireless signal coverage needs to be considered.
- **High concurrency:** In the classroom scenario, a large number of wireless connections may cause interference and congestion on the wireless network. Within the given bandwidth,

the network must be properly planned and RF resources must be configured to meet the concurrency requirements of wireless users.

- **High bandwidth:** In the classroom scenario, a large amount of data traffic needs to be transmitted, such as in audio and video, large file transfer, and electronic whiteboards. These applications have high requirements on network bandwidth. Resource assurance technologies need to be used to meet the bandwidth requirements of key applications or key terminals.
- **Interference resistance**: In high-density scenarios, there is strong wireless interference, including WLAN interference and non-WLAN interference. Interference on a wireless network affects network stability, data transmission speed, and network connection quality, and can even cause network interruption. Therefore, devices must be capable of resisting interference to ensure the Internet access experience of wireless users even in the case of severe interference.

2.3 Smart Manufacturing

2.3.1 Scenario Overview

As industries continue to transform and upgrade, the trend of automating previously manual work is gaining momentum. Automated guided vehicles (AGVs) are increasingly being used in sectors such as warehousing, logistics, and electricity. An AGV in operation is always on the move, and this requires a stable wireless connection.

The AGV-based warehousing scenario, otherwise known as automated warehouses, is one of the major application scenarios of enterprise WLANs. In this scenario, services (such as AGVs) require low latency and frequent roaming, and are highly sensitive to packet loss. Warehouses are usually tall buildings, and some are even more than 10 meters tall. Inside a warehouse, there are often spots where the wireless signal is weak or even unavailable, and this is often due to shelving and the storage of goods.

2.3.2 Scenario-specific Service Requirements

Smart manufacturing services mainly include barcode scanners and AGVs. The following table lists the bandwidth requirements of services and their proportions by bandwidth consumption.

Table 2-3 Service bandwidth requirements in smart manufacturing

Service Type	Baseline Rate (Mbps) per Service		Proportion of Bandwidth Consumption in Each Scenario	
	Excellent	Good	Shelf	AGV
Barcode scanner	128	64	80%	0%
AGV	256	128	0%	90%
Other	300	128	20%	10%

2.3.3 AGVs and Shelves

2.3.3.1 Scenario Examples

Figure 2-7 Shelves and AGVs

2.3.3.2 Service Description

This scenario mainly involves AGVs and barcode scanners, which have high requirements on roaming and latency and low requirements on bandwidth.

2.3.3.3 Environment Setting and Performance Requirements

- **Capacity:** 50 or fewer terminals per AP, 30% concurrency
- **Coverage:** RSSI ≥ -65 dBm in 95% of the coverage areas
- **Roaming:** Roaming success rate > 99%; high requirements on average latency and packet loss rate

2.3.3.4 Wireless Function Requirements

- **Wide coverage:** In the warehousing and AGV scenarios, the area is large and there are no fixed hurdles. Therefore, sufficient wireless signal coverage needs to be considered.
- **Seamless roaming:** AGVs require fast and seamless handovers between different APs to ensure their continuity and efficiency. The packet loss rate and latency during roaming must be as low as possible. Technologies such as network-terminal synergy can help reduce the packet loss rate and latency during roaming and improve network reliability.

2.4 Healthcare

2.4.1 Scenario Overview

More and more hospitals are deploying powerful medical information management systems, such as hospital information systems (HISs) and picture archiving and communication systems (PACSs). Medical workers can use these systems when inspecting wards, monitoring patients, prescribing and dispensing medicine, managing and monitoring medical equipment in real-time, managing medical inventories, or querying patient files and cases. Unlike fixed networks, wireless networks support portable terminals and provide flexible and easy access. As a result, more hospitals are using wireless networks in areas such as outpatient centers, offices, wards, inpatient buildings, and operating rooms. With wireless networks, managers, doctors, and nurses can work more efficiently, tasks can be more easily coordinated between departments and inpatients' needs for wireless connectivity can be met. Wireless services are in huge demand in both outpatient centers and inpatient buildings.

2.4.2 Scenario-specific Service Requirements

Healthcare services mainly include medical personal digital assistants (PDAs) and mobile diagnosis and treatment vehicles. The following table lists the bandwidth requirements of services and their proportions by bandwidth consumption.

Table 2-4 Service bandwidth requirements in healthcare

Service Type	Baseline Rate (Mbps) per Service		Proportion of Bandwidth Consumption in Each Scenario	
	Excellent	Good	Outpatient Center	Inpatient Building
Medical PDA	10	5	0%	40%
Mobile diagnosis and treatment vehicle	500	300	0%	30%
Web browsing	8	4	30%	10%
Streaming media (1080p)	16	12	20%	5%
Streaming media (4K)	50	25	10%	5%
Instant messaging	1	0.5	40%	10%

2.4.3 Outpatient Centers

2.4.3.1 Scenario Example

Figure 2-8 Outpatient center

2.4.3.2 Service Description

This scenario mainly involves web browsing and audio and video services.

2.4.3.3 Environment Setting and Performance Requirements

- **Space:** Floor height 3—5 meters, areas covering several hundred square meters
- **Density:** 1—2 square meters per person
- **Capacity:** 100 terminals per AP, 30% concurrency
- **Coverage:** RSSI ⩾ -65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.4.3.4 Wireless Function Requirements

- **Wide coverage:** In the outpatient center scenario, the area is large and there is no fixed hurdles. However, users are concentrated. Therefore, sufficient wireless signal coverage needs to be considered.
- **High concurrency:** In the outpatient center scenario, a large number of wireless connections may cause interference and congestion on the wireless network. Within the given bandwidth, the network must be properly planned and RF resources must be configured to meet the concurrency requirements of wireless users.
- **High bandwidth:** In the outpatient center scenario, a large amount of data traffic needs to be transmitted, such as in audio and video services. These applications have high requirements on network bandwidth. Resource assurance technologies need to be used to meet the bandwidth requirements of key applications or key terminals.
- **Interference resistance:** In high-density scenarios, there is strong wireless interference, including WLAN interference and non-WLAN interference. Interference on a wireless network affects network stability, data transmission speed, and network connection quality, and can even cause network interruption. Therefore, devices must be capable of resisting interference to ensure the Internet access experience of wireless users even in the case of severe interference.
- **Seamless roaming:** Services in outpatient centers require fast and seamless handovers between different APs to ensure mobile service continuity and efficiency. In addition, the service quality and user experience of outpatient centers in different locations must be

ensured. Quality of service includes connection speed, data transmission speed, response time, availability, and stability of mobile devices.

2.4.4 Inpatient Buildings

2.4.4.1 Scenario Examples

Figure 2-9 Inpatient buildings

2.4.4.2 Service Description

This scenario mainly involves medical PDAs and mobile diagnosis and treatment vehicles.

2.4.4.3 Environment Setting and Performance Requirements

- **Space:** Floor height: about 3 meters; area: over 10 square meters
- **Density:** About 5 square meters per person
- **Capacity:** 10 terminals per AP, 30% concurrency
- **Coverage:** RSSI ≥ -65 dBm in 95% of the coverage areas
- In addition, the planning needs to take into account factors such as the AP deployment mode, distance between APs, and bandwidth, based on the actual scenario.

2.4.4.4 Wireless Function Requirements

- **Wide coverage:** In inpatient buildings, wards are relatively small and have fixed partitions. Terminals such as PDAs and mobile diagnosis and treatment vehicles have high requirements on mobility. Therefore, sufficient wireless signal coverage needs to be considered.

- **High bandwidth:** With the development of medical technologies, the required bandwidth of medical images has changed from megabyte level to gigabyte level, or even over 10 gigabytes. For example, the PACS used by inpatient departments displays images in seconds, which requires APs to provide high bandwidth.
- **Seamless roaming:** PDAs and other services require fast and seamless handovers between APs. Customers expect to have uninterrupted networks to ensure the continuity and efficiency of PDAs and other services.

2.5 Summary

The preceding analyses show that enterprises have different requirements on WLAN coverage, concurrency, roaming, interference, latency, bandwidth, and security based on scenarios. Continuous technical development and evolution are essential to achieving high-quality wireless coverage in different scenarios.

3 Key Technologies of High-Quality Enterprise WLAN: —Status Quo and Development Trends

3.1 Coverage Optimization Technologies

3.1.1 Background

WLAN technology originates from small-scale application scenarios such as homes. In residential environments, the channel, power, and anti-interference capabilities of only a single AP need to be considered. When a WLAN is deployed for an enterprise campus, however, network access anytime, anywhere is needed. To achieve this, the WLAN needs to ensure network coverage without coverage holes at all network access positions of users. Additionally, the air interface resources of a WLAN are shared. As such, the WLAN needs to minimize signal interference between APs to improve network-wide performance and user experience. The following lists typical factors to be considered during enterprise WLAN construction:

- Signal coverage
- Channel, power, and frequency bandwidth for better network-wide performance
- On-demand dynamic network resource adjustment for adapting to user and traffic changes
- Dynamic adjustment when a device is faulty or interference suddenly occurs, reducing the impact of abnormal events on the network
- Anti-interference and better coverage capabilities in complex environments

WLAN device vendors are doing research on coverage optimization technologies, aiming at meeting the coverage requirements raised during enterprise WLAN construction.

3.1.2 Radio Resource Optimization Technologies

Radio Resource Management (RRM) is a radio resource optimization solution. It uses systematic real-time intelligent radio management to enable a WLAN to quickly adapt to changes in the environment and maintain the optimal radio resource status. RRM technology involves three key factors: channel adjustment, power adjustment, and frequency bandwidth adjustment. RRM technology can be classified as local RRM or cloud RRM based on data sources and the carriers for analysis and computing.

- Local RRM uses local data stored on wireless devices for analysis and computing.
- Cloud RRM uses rich data on the cloud platform and big data analysis to perform multi-dimensional computing.

When both local RRM and cloud RRM are enabled, cloud RRM is used for unified scheduling and adjustment to provide better wireless services.

3.1.2.1 Local RRM

The spectrum resources of WLAN frequency bands are limited. Each radio operates on a limited number of channels. If neighboring APs operate on the same channel, interference is generated. In addition, interference from radar signals and microwave ovens may exist in the surrounding environment. Automatic channel adjustment allocates optimal channels to radios. This prevents APs from operating on channels with severe interference, thereby ensuring reliable transmission.

Conventional power control methods only pursue the maximum signal coverage range and therefore set the transmit power of the radio to the maximum value. This ensures the signal coverage range; however, interference is caused to other wireless devices. In addition, such methods may hinder STAs from roaming, causing STA stickiness and degrading the wireless network experience. In comparison, automatic power adjustment reduces interference between APs while ensuring radio signal coverage for a better roaming experience of STAs and allocates proper transmit power to radios.

Typically, the frequency bandwidth of radios can be set to the maximum value to achieve the maximum rate and throughput. This can increase the negotiated rates between APs and STAs and also increase the theoretical throughput of them can be improved theoretically. However, severe interference may occur when neighboring APs use the same channel because the number of available channels is limited. As a result, the overall capacity of the system is reduced, failing to meet the high throughput requirements of users. Therefore, when selecting the frequency bandwidth, you need to consider the deployment density of APs, the number and traffic of STAs, and interference for better network-wide throughput while ensuring the quality of wireless services.

3.1.2.2 Cloud RRM

Cloud RRM collects historical network statistics and performs RRM analysis and prediction based on AP statistics, neighbor information, STA statistics, and time. Such technology is applicable to different scenarios and supports more accurate solution adjustment. For example, it can accurately distinguish off-peak hours from peak hours based on the traffic model and optimize AP channels in advance to better meet service requirements according to actual network conditions. Besides, it can modify radio parameters in the early morning to reduce the impact on STAs and improve user experience.

According to long-term historical data, APs are densely deployed in open places with obvious tidal crowds, such as canteens. During peak hours, the crowd flow, number of STAs, and service traffic increase significantly. As such, the interference between APs is severe, and the WLAN service cannot work properly. In this case, cloud RRM can lower the frequency bandwidth to increase the number of available AP channel combinations and limit inter-AP interference within an acceptable range for improved user experience. After peak hours, the number of users and that of STAs decrease rapidly, and so does the service traffic volume. In this case, cloud RRM can increase the frequency bandwidth and adjust channels to increase the STA rates for improved user experience.

3.1.3 Coverage Enhancement Technologies

The traffic model of a wireless network is dynamic in real time because STAs continuously access, go offline, move, and roam. As such, it has become a hot topic that how to ensure good user experience at different locations, especially at the coverage edge. According to the Shannon formula, the signal-to-noise ratio (SNR) plays a key role in further improving the transmission rate and user experience with the spatial stream and frequency bandwidth remaining unchanged. In scenarios where the locations of APs and STAs are fixed, the received SNR can be improved by increasing the transmit power through receive enhancement technology, precoding technology, and smart antennas.

3.1.3.1 Receive Signal Enhancement

When the number of spatial streams supported by receive antennas is greater than the number of data streams, the receive end can perform antenna selection (ASEL) to select an antenna with optimal signal quality or leverage maximum ratio combining (MRC) to combine data from multiple antennas for a higher received signal to noise indicator (RSNI).

3.1.3.2 Precoding

Precoding technology is widely used together with multiple-input multiple-output (MIMO) technology. The transmit end obtains channel state information (CSI) through the reciprocity between uplink and downlink channels or direct feedback of STA protocol packets. The precoding system adjusts the amplitude and phase of signals from the transmit antenna according to the obtained CSI, and properly allocates the limited transmit power. In this way, STAs can receive the optimal signal.

- TXBF technology: Transmit beamforming (TXBF) technology is mainly used for single-user systems, that is, point-to-point transmission is performed between an AP and a single STA. The transmit end weights transmitted signals based on the CSI to increase the SNR at the receive end, thereby increasing the communication throughput and reducing the packet loss rate.
- MU-MIMO technology: Multi-user MIMO (MU-MIMO) technology upgrades the single-STA beamforming to joint beamforming for multiple STAs. This not only ensures that each STA can receive good signals, but also minimizes the interference between different STAs, thereby improving the capability of concurrently transmitting data streams.

In addition to precoding technologies such as point-to-point beamforming (TXBF) and point-to-multipoint beamforming (MU-MIMO), research have been conducted on multipoint-to-multipoint joint precoding technologies, which will further improve the transmission performance and edge throughput of STAs.

3.1.3.3 Smart Antenna

Smart antenna technology can be referred to as adaptive beam switching technology. It uses an antenna array that has multiple hardware antennas and intelligently selects multiple antenna elements to transmit and receive radio signals. Combining different antennas can form different signal transmission directions, allowing STAs at different locations to use the optimal transmit or receive antenna for signal transmission, improving received signal quality and system throughput.

Smart antenna technology mainly includes the smart antenna array (antenna array hardware design) and the smart antenna beam selection algorithm (how to select an antenna in the antenna array).

- Smart antenna array

  An antenna array is made up of a series of small antennas. Each small antenna can be an omnidirectional antenna or a directional antenna. The antenna arrangement depends on the gain, polarization mode, and radiation pattern of small antennas. The number of small antennas determines the number of beams that are finally formed. In addition, the more the elements on the small antennas are, the more the antenna combinations will be, and the more accurate the directivity of beam transmission will be. This makes signals more concentrated, thereby improving the received signal quality and the system throughput.

- Smart antenna beam selection

  The basic principle of the smart antenna selection algorithm is to select the most appropriate antenna configuration for the current user based on the packet error rate (PER) and received signal strength indicator (RSSI) fed back by the antenna layer by sending training packets under the current antenna configuration. The antenna configuration mainly includes the antenna combination and transmit rate.

  The smart antenna selection algorithm is an important feature of small antennas. By sending data packets to STAs, STA locations can be determined. The smart antenna selection algorithm can then select appropriate antenna combinations from an antenna array to improve network performance. Directional beams are used to replace original omnidirectional beams to concentrate the energy, improving received signal quality and system throughput.

3.2 Resource Scheduling Assurance

3.2.1 Background

In networking scenarios such as office and education, new preferences and traffic models emerge accompanying the popularization of fully wireless networks. For example, users have more than one terminal, and application types are becoming diversified, including data, audio, and video services. Additionally, the amount of concurrent data increases significantly.

As the data traffic increases greatly and different services are sensitive to parameters such as delay, packet loss, and jitter, wireless devices must properly allocate and schedule air interface resources to ensure differentiated services.

3.2.2 Resource Assurance Technology

In a WLAN quality of service (QoS) policy, Wi-Fi Multimedia (WMM) is used to guarantee priority services. However, in multi-user and multi-service scenarios, the random backoff mechanism adopted in WMM can no longer meet the requirements of new scenarios. As such, resource assurance is raised in the aspects of VIP user assurance, intelligent bandwidth allocation, service identification, and differentiated scheduling.

- VIP user assurance: Bandwidth needs to be guaranteed for high-priority users on the network. These users are VIP users, who are identified by user attributes but not by service types. The traffic of the VIP users needs to be preferentially guaranteed and scheduled.
- Intelligent bandwidth allocation: The main purpose of bandwidth allocation and resource assurance is to achieve a good user experience. As radio resources are limited, an available resource threshold evaluated by a device can reduce air interface waste caused by resource contention between multiple devices. Additionally, this ensures that STAs connected to the device are allocated proper resources and enjoy a good network experience. Bandwidth allocation involves the resource evaluation algorithm, bandwidth allocation algorithm, and STA scheduling algorithm.
  - Resource evaluation algorithm: roughly evaluates the available network bandwidth by detecting network running parameters, such as the noise floor, channel utilization, and number of STAs. The network bandwidth is dynamically updated in real time based on the network running status and is used for subsequent bandwidth allocation.
  - Bandwidth allocation algorithm: evaluates the STA attributes by detecting the traffic volume and type of each STA in a multi-STA scenario. This algorithm traces the collected data and allocates a proper bandwidth usage threshold to the STAs. The bandwidth for a STA cannot exceed the threshold while services are guaranteed. If there is idle bandwidth, STAs with heavy traffic are allowed to preempt the idle bandwidth. In this way, resources can be properly allocated, achieving differentiated scheduling for multiple STAs.
  - STA scheduling algorithm: works with application identification technology and tags packets with priority. High-priority packets can be preferentially forwarded and scheduled. The effective bandwidth threshold obtained by multiple STAs is fixed. When high-priority packets are scheduled, services are preferentially processed. The

bandwidth of multiple clients is determined, in addition, the resources of multiple clients are guaranteed.

- Application identification and scheduling assurance: APs or ACs use technologies such as Deep Packet Inspection (DPI) and Deep Flow Inspection (DFI) to accurately categorize applications of end users. Different policies can be configured to mark different types of applications, allowing for preferential scheduling and assurance for key services. For example, audio and video conferences are important services in office scenarios. Application identification technologies can be used to identify, preferentially schedule, and guarantee service traffic of audio and video conferences, improving user experience.
- Dynamic rate adjustment: On a WLAN, multiple types of STAs, such as Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6, may use the WLAN service simultaneously. The maximum transmission rates supported by different types of terminals are fixed based on standard protocols. If interference exists on the network or the RSSI is low, the retransmission rate and packet loss rate are high. In this case, the transmission rate is reduced. To prevent this, the system can detect the air interface environment, collect statistics on rate selection information, and adjust the selectable STA rates in a range. Such adjustment helps reduce the packet loss rate, retransmission rate, and finally, the contention over the air interface, improving air interface efficiency.
- Link optimization based on orthogonal frequency division multiple access (OFDMA): OFDMA technology improves multi-user communication efficiency by allocating subcarriers of a frequency band to different STAs for concurrent communication. This technology divides resource units (RUs) based on STA requirements and flexibly allocates RUs to multiple STAs, providing efficient experience rates.
- Enhanced MU-MIMO: In multi-STA scenarios, service packets of different STAs arrive at an AP at different times, and the number of packets is different. As a result, the AP cannot meet MU pairing requirements when forwarding service packets. Enhanced MU-MIMO enables the AP to preprocess packets, increasing the MU pairing success rate. MU-MIMO is used to send service packets of multiple STAs at the same time. This reduces the frequency of sending service packets over the air interface, improves the use efficiency of air interface resources, and increases network-wide bandwidth.
- Joint resource scheduling on the air interface: The proportion of TCP-based data traffic on the current network is more than 90%. When multiple STAs coexist, there is a high probability that uplinks TCP ACK packets conflict with downlink MU-PPDUs, which may cause error packets. PPDU is short for physical layer convergence procedure Protocol

Data Unit. In this scenario, air interface resources can be jointly scheduled, and uplink service packets of multiple STAs can be sent at the same time. This reduces the probability of uplink and downlink transmission collisions on the air interface and improves the concurrent capability of multiple STAs.

3.3 Seamless Roaming

3.3.1 Background

On a conventional WLAN, roaming is initiated proactively by STAs, and the roaming time is controlled by the STAs. During this process, STAs do not coordinate with APs about roaming detection and roaming decision-making, which cannot ensure a satisfactory roaming effect. Common issues that may occur include roaming stickiness, delayed roaming, repeated roaming, and O&M issues. Therefore, roaming coordination is needed among the STAs, wireless devices, and cloud O&M platform to form a roaming system to ensure that user services are not affected by the roaming process.

3.3.2 Coordinated Roaming Technology System

In this coordinated roaming technology system, APs and STAs detect the network from multiple dimensions, and an access controller (AC) performs comprehensive computing and negotiates with STAs to implement precise roaming, improving user experience.

An AP uses the 802.11k protocol to provide STAs with the channels and wireless service information about neighboring APs. In this manner, STAs are free of scanning channels one by one and require shorter service discovery times.

APs monitor link quality in real time and perform precise roaming. By monitoring link quality, an AP selects a proper time to trigger roaming to a target AP. The target AP is selected based on the historical access path, neighboring APs discovered by 802.11k measurement STAs, and STA roaming characteristics. Then the local AP steers STAs to the target AP at a proper time based on the 802.11v protocol. This ensures that the link quality jitter is small and services are not affected.

802.11r can be deployed on the network for fast roaming.

The AC continues to monitor and calibrate the link quality after a STA roams. If the link quality deteriorates significantly, the AC calibrates roaming and steers the STA to a proper AP to ensure that the link quality is within the expected range.

The cloud O&M platform analyzes STA roaming behavior data and optimizes the STA roaming profile library.

3.3.3 Link Quality Detection Enhancement Technology

APs monitor link quality changes of STAs in real time, including uplink signal changes, uplink and downlink rate changes, sleep changes, and traffic usage. For 802.11k-capable STAs, 802.11k measurement is used to obtain downlink signal changes of STAs. Auxiliary radios can obtain signal changes of surrounding APs. Based on the changes of various factors, an AP can determine the possible behaviors of a STA, such as stationary, stationary signal jitter, fast movement, and slow movement. Based on different behaviors, the AP gets prepared for roaming to the target APs at different times and performs roaming handovers accordingly at different times.

3.3.4 Roaming Calibration Technology

Due to factors such as AP layout, configured thresholds, and STA positions, some STAs cannot achieve the expected roaming handover effect. In this case, the AC needs to automatically identify multiple roaming events and rectify the calibration so that the STAs can go online on the optimal service and stop roaming.

3.3.5 Assisted Roaming-Assisted STA Profile Library

The STA profile library changes the "one profile for all" to "personalized STA profiles", generates the roaming parameter settings for each type of STAs, and minimizes the adverse impact of protocol compatibility and STA implementation differences.

Huawei analyzes the roaming steering behavior of different STAs based on a large number of roaming data samples, trains a large number of parameters, and finally learns roaming profiles suitable for different STAs. The roaming profile content in the STA profile library is categorized as follows:

- Static characteristics: include capabilities supported by STAs or the STA behavior, including the steering protocol capability, measurement protocol capability, and frequency band capability.

- Dynamic characteristics: include service characteristics of STAs under specific network coverage, such as the roaming signal threshold and source/target signal strengths.

Based on the preceding STA roaming parameters, coordinated measurement steering technology is used to continuously detect signals of STAs, determine the movement trend of STAs (close to or far away from associated APs), and proactively steer STAs to the AP with the optimal quality at the most appropriate location and time. In this way, STAs can roam in a timely manner and the roaming success rate is higher.

3.4 Interference Mitigation

3.4.1 Background

With the popularization and application of WLAN technologies, especially the large-scale use of WLANs in enterprise campuses, WLAN interference becomes increasingly prominent, which affects network stability, data transmission speed, and network connection quality, and even causes network interruption.

WLAN interference may be caused by conflicts between WLAN signals and electromagnetic wave signals generated by devices such as microwave ovens, radio frequency identification (RFID) devices, or Bluetooth devices. Besides, WLAN interference may also be caused by overlapping or closed channels of two WLANs.

3.4.2 3D Radio Calibration

Traditional radio calibration forms a two-dimensional (2D) topology of neighbor relationships between APs based on the signal strength measured by APs. The basic calibration principle is to prevent adjacent APs from being allocated the same channel and lower the allocated power to minimize mutual interference and ensure timely roaming. However, due to complex AP installation environments, and the 2D network topology cannot fully reflect the accurate relationships between APs. Therefore, the traditional radio calibration result is unsatisfactory for APs at complex positions. Typical scenarios include:

- Blocking between APs: APs are blocked from each other and can hardly or cannot detect each other. In this case, no neighbor relationship or weak neighbor relationship is displayed on the logical network topology. As a result, APs are allocated the same channel, causing strong co-channel interference on the STA side.

- AP installation at high positions: APs detect strong signals between each other and lower the transmit power. However, the signal strength of APs detected by STAs is weak, degrading user experience.

3D radio calibration leverages downlink measurement on STAs to form a 3D topology, which reflects the actual propagation of radio signals in the space and the impact of signals on STAs and APs. Radio calibration based on the 3D topology can better adapt to the complex and variable space environment and improve the environment generalization of the algorithm.

3.4.3 Multi-AP Coordination

- Basic service set (BSS) coloring technology is proposed in the Wi-Fi 6 standard to address BSS overlapping on the same frequency, improve the spatial reuse rate, and reduce the air interface contention overhead caused by BSS overlapping. BSS color information is added to both the PHY and MAC layers of WLAN packets. During contention, the device allocates contention behavior at the MAC layer based on the BSS color field in the PHY header. The contention behavior is classified as intra-BSS or inter-BSS (also known as OBSS: overlapping BSS). The adaptive clear channel assessment (CCA) mechanism is introduced to increase the OBSS signal detection (SD) threshold and keep the intra-BSS SD threshold low to reduce contention and improve the efficiency at the MAC layer.

- Transmit power coordination among multiple APs is supported. In high-density office scenarios, APs are densely deployed, causing co-channel interference. When an AP sends data, surrounding co-channel APs are affected. Through coordination between APs, the transmit power of the AP is controlled to eliminate interference to neighboring co-channel APs. In this manner, neighboring co-channel APs can send data at the same time, improving the capacity of the entire network.

3.4.4 Dynamic EDCA

When the network is in use, the number of STAs and the service volume both change dynamically. The enhanced distributed channel access (EDCA) parameters can be dynamically adjusted based on the number of STAs and the service volume of the entire system. When the number of STAs is small and services are simple, the EDCA window size is decreased to reduce unnecessary backoff and improve air interface efficiency. When the number of STAs is large and services are diversified, EDCA parameters are adjusted for services with different priorities to guarantee air interface quality for high-priority services and to reduce collisions over the air interface.

3.4.5 Dynamic CCA

The 802.11 protocol defines the CCA mechanism to monitor the idle/busy status of channels. A WLAN device starts to preempt a channel only when the channel is idle. By using the CCA mechanism, signals are not sent when interference exists on a channel, thereby avoiding conflicts on the channel and reducing the impact of interference on WLAN performance.

The CCA mechanism can monitor the idle/busy status of a channel, and send a packet only when the channel is idle. This reduces conflicts caused by sending packets at an unknown channel state. CCA threshold—based detection can accurately determine whether a channel is idle or busy. In this manner, data packets can be sent when the channel is idle, effectively reducing air interface conflicts and improving transmission efficiency.

However, when the same default CCA threshold is used in different scenarios, actual effects vary. As such, the dynamic CCA mechanism is introduced to dynamically adjust the CCA threshold of APs based on scenarios to reduce the conflict probability and increase the AP concurrency rate, improving user experience on the entire network.

3.5 Network-Terminal Synergy

3.5.1 Background

WLAN technology originates from the local area network (LAN). Compared with the 3rd Generation Partnership Project (3GPP) network, WLAN technology has disadvantages in mobility management and QoS control, such as untimely roaming and unstable links.

Currently, network vendors and terminal vendors are trying to solve or optimize these issues, for example, by improving scanning efficiency, applying the 802.11k/v/r protocol, adjusting roaming sensitivity, and mapping between wired and wireless QoS. However, no unified policy is formed on the terminal side and the network side, compatibility issues are common in some detailed logic, and some stability issues are still difficult to solve. These severely affect the continuity of user experience in audio and HD video services and the rapid expansion of WLAN technologies to emerging fields such as the industrial Internet.

To cope with the poor WLAN user experience stability, the WAA defines supplementary protocols related to coordinated control between WLAN network-side devices and terminal-side devices to address existing problems. This feature enables more terminals to provide a better user experience on more networks, meets customers' increasing service requirements, and supports the healthy development of the WLAN industry.

3.5.2 Technical Direction of Network-Terminal Synergy

1. The service discovery mechanism is optimized on the network side and terminals to ensure that services can be quickly discovered during terminal movement, ensuring the access speed of terminals.
2. The network side and terminals can jointly determine when to initiate roaming or handover and select the optimal roaming or handover target. This ensures service continuity and stability during terminal movement.
3. The network side and terminals can jointly determine the network delay and take specific measures. For example, the network side preferentially allocates network resources to terminals that are performing key operations to reduce the delay and packet loss of key services.
4. By jointly tracking network resource usage, the network side and terminals can coordinate to complete network resource allocation and scheduling, thereby maximizing network capacity and improving user experience.
5. When detecting network changes or issues, the network side and terminals notify each other of the changes or issues. In this way, the network side and terminals can cooperate with each other to quickly solve network exceptions.
6. Two air interface links are established between the network side and a terminal to enhance link reliability.

3.6 Ultra-Large Capacity

3.6.1 Background

With the development of WLAN technologies, homes, and enterprises increasingly rely on WLANs as the main means of mobile access. In recent years, new applications, such as 4K and 8K videos, VR/AR, games, remote offices, online video conferencing, and cloud computing, have higher requirements on throughput. Wi-Fi 6, in spite of its focus on user experience in high-density scenarios, cannot fully meet the preceding higher throughput requirements. As such, the 802.11be standard (Wi-Fi 7) being formulated by IEEE leverages various technologies to improve network capacity and device throughput.

3.6.2 Wi-Fi 7

Wi-Fi 7 is designed to increase the WLAN throughput to at least 30 Gbps and provide low-latency access assurance. To meet this goal, this new standard involves changes in both the PHY and MAC layers. Compared with Wi-Fi 6, Wi-Fi 7 brings the following technical changes:

1. Higher speed

   Wi-Fi 7 provides faster network speeds. With Wi-Fi 7, wireless devices can operate in a wider spectrum range, providing higher peak speeds. This allows users to download files and play videos or games much faster.

2. Higher capacity

   Wi-Fi 7 supports a higher capacity. By using a larger spectrum range and higher-order quadrature amplitude modulation (QAM), Wi-Fi 7 allows more terminals to connect to the same wireless device at the same time without causing network congestion or frame freezing.

3. Faster response time

   By using multiple technologies such as multi-link operation (MLO) and OFDMA enhancement, Wi-Fi 7 can provide faster response time.

3.7 Trend Prospect

According to a report of Ovum, the number of smart terminals in enterprises will multiply in the next two years, audio and video traffic will increase by 30% every year, and 80% of applications will be migrated to the cloud by 2025. Enterprise campus networks are developing towards ultra-broadband, simplified, high-quality experience, and intelligent O&M. With the commercialization of Wi-Fi 7, we can embrace the era of high-quality 10 Gbps campus.

4 WAA Promotes the Construction of Networks that Offers High-Quality Experience in Enterprise Scenarios Through Standards and Certifications

4.1 WAA: An International Standards and Industry Platform for High-Quality WLAN

The WLAN industry is large in scale. The Development of diverse applications is in urgent need of WLAN performance standards, which no industry organization is currently working on. This is a gap that must be filled to promote industry development. In this context, it is necessary to promptly establish and improve a WLAN performance standards certification system.

WAA is a non-profit social organization composed of enterprises, social organizations, higher education institutions, and scientific research institutes related to the WLAN industry on the basis of voluntary participation, mutual benefit, and cooperation. The goal of WAA is to establish and improve the WLAN performance standard system and conduct WLAN performance tests and certifications.

WAA is positioned as both an industry platform and an international standards platform. That means it is an industry platform for driving the implementation of industry requirements, industry planning, and industry collaboration, and also a platform for developing standards for new services and new technologies. To this end, WAA will work on the following aspects:

- Analyzing requirements of WLAN application scenarios, incubating innovative WLAN solutions, and conducting early-stage research on WLAN standards and specifications to promote standardization and internationalization of related technologies, experience, and performance.
- Organizing the communication of test cases related to WLAN network performance experience, formulating test and certification specifications, and conducting tests and certifications for external parties. This is to promote the large-scale commercial deployment and application innovation of new technologies and standards, ensure application experience, and promote the maturity and development of WLAN applications.
- Carrying out marketing and promotion for the WLAN industry, and promoting in-depth communication and cooperation on WLAN standards and application innovation across

the industry to maintain industry vitality, make the industry ecosystem thrive, and promote industry development.

- Developing industry insights and analyses on WLAN standards, technologies, applications, and markets to formulate WLAN industry development reports, and providing training for Alliance members and industry partners.
- Conducting international exchanges and cooperation on WLAN, and promoting industry cooperation between WAA and relevant organizations and institutions outside China.

4.2 WAA Keeps Promoting Standards for Constructing High-Quality WLAN in Enterprise Scenarios

WAA has been implementing two projects based on typical enterprise scenarios. One is the Campus Office Scenario Test and Certification Project, and the other is the Industrial WLAN Communications Promotion Group.

The Campus Office Scenario Test and Certification Project has fully analyzed the service and scenario characteristics of office scenarios, identified the KQI system and PI system for these scenarios (as shown in the following figure), and provided specific performance indicators and test methods based on the scenarios. The Office Campus Scenario Test and Certification Standards have been formulated to provide network construction standards for customers in office scenarios.

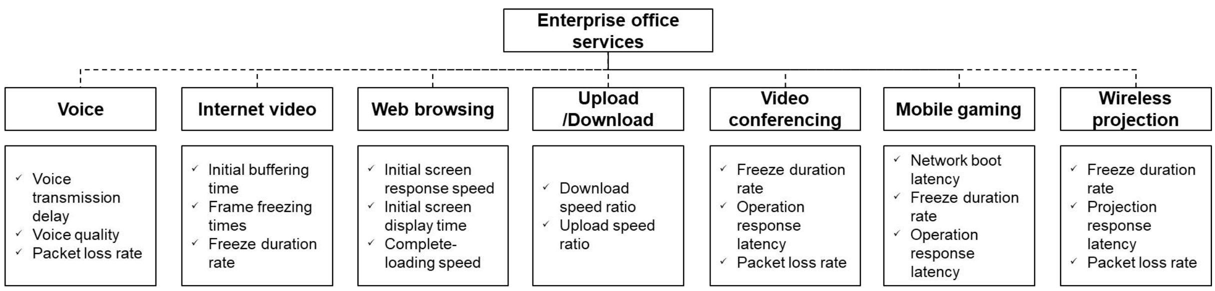

Figure 4-1 Service KQI system for campuses

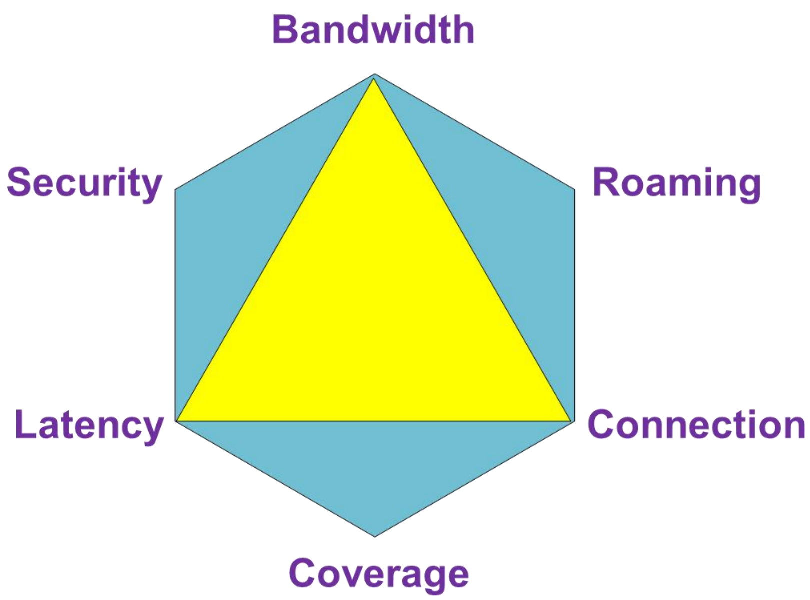

Figure 4-2 WLAN PIs for single devices on campuses

WAA has set up an Industrial WLAN Communications Promotion Group to define service requirements and scenario characteristics of smart manufacturing, and will develop related test and certification standards soon.

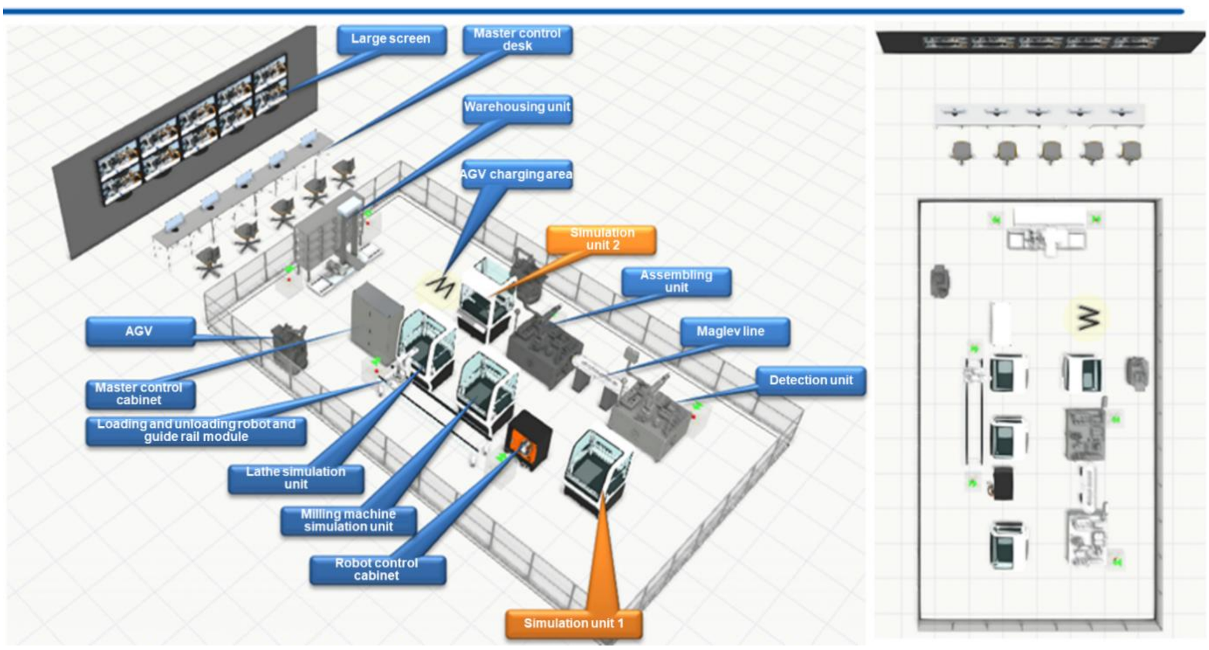

Figure 4-3 Typical scenarios and service requirements of smart manufacturing

To improve user experience with technologies, WAA is currently working on the Network-Terminal Synergy Technology Standards Project. This project aims to improve user experience by enhancing collaboration between network-side devices and terminal-side devices from the following two perspectives:

- Roaming optimization: When a device moves between multiple APs, conflicts might occur due to different roaming decision-making logics. This will result in slow roaming handovers or sticky clients.
- QoS assurance: Services carried out by Wi-Fi protocols are becoming more diversified and complex, including latency-sensitive services like interactive gaming, XR, and VR. Whether the latency meets service requirements directly affects user experience. However, APs and STAs do not have a unified negotiation mechanism. When global network information on the terminal side is missing, users may experience problems such as frame freezing and disconnection.

Based on the preceding discussion, the Network-Terminal Synergy Technology Standards Project aims to use protocols to promote collaboration between APs and STAs to improve user experience and achieve cellular-like air interface performance.

In addition to the preceding ongoing projects and workgroup, WAA plans to develop a wide range of test and certification projects for typical enterprise scenarios such as education and healthcare. These projects will provide a standard basis for network construction and device selection. WAA will keep driving high-quality WLAN technology standard projects and leading the development of the WLAN industry.

4.3 WAA Continuously Supports the Development of the WLAN Industry

WAA is committed to unifying WLAN performance standards, building a certification platform, and stimulating enterprise innovation and R&D investment by bridging gaps and cultivating strengths.

WAA works hard to build a public service platform for the industry to improve the industry standard system, drive the industry to expand and grow, and accelerate the development of a modern industry system. Specifically, as there is basically no WLAN performance and experience standard, WAA is ready to fill this gap by building unified performance standards and a certified industry public service platform alongside other industry players with the aim to support industry development and technological progress.

WAA supports the R&D of basic technologies and strengthens the cultivation of basic capabilities in the industry. WLAN technologies are widely used in fields such as intelligent transportation, smart logistics, smart energy, smart healthcare, and smart agriculture. WAA serves as a platform where industry players work together to identify key requirements and technical solutions in these fields. WAA also supports innovation resulting from collaboration between industry leaders and universities, scientific research institutes, and upstream and downstream enterprises, aiming to improve the application and user experience of WLAN, a key universally-used technology.

WAA works on establishing and improving the talent cultivation mechanism for the WLAN industry to build a high-level talent team. WAA also organizes training, technical seminars, and industry summits to consolidate talent's technical capabilities and stimulate innovation. In a nutshell, WAA cultivates industry talent in an all-round way to stimulate innovation, so as to give full play to the role of talent as the key resource to enable the industry.

WAA also helps accelerate digital industrialization and industry digital transformation. WAA focuses on stimulating the research on new scenarios throughout the industry value chain, innovating technology, and promoting the application of WLAN technologies across industries. In this way, both the WLAN technologies and cellular technologies will advance to even more critical areas of application in digital transformation. WAA promotes the building of a communications infrastructure system with extensive coverage and efficient operations. This will create new industries, business forms, and models, which will become new advantages of the digital economy.

In addition, WAA supports China's efforts in streamlining the internal cycle, building a digital China, and accelerating the formation of a new dual circulation development pattern. With the help of WAA, based on the strong market in China, the R&D, application, production, distribution, circulation, and consumption across the industry will be integrated to form a higher-level dynamic balance where demand leads supply and supply creates demand. This will promote a virtuous circle of the national economy, and accelerate China's digital development. WAA will work with international WLAN partners to promote the in-depth integration of the domestic and international industry value chains and innovation chains, and accelerate the formation of the new dual circulation development pattern.