Optimal User Experience

White Paper of Home Wi-Fi Networks

HUAWEI

Contents

1 Introduction

With the rapid development of Internet of Things (IoT), cloud computing, Big Data, and ultra-broadband, services such as 4K, virtual reality (VR), and smart home applications are booming under the background of "Internet+". Wi-Fi gradually becomes a rigid demand for broadband users. Data demonstrates that 80% traffic of the current carrier comes from Wi-Fi and most of the traffic belongs to video services, which is mainly consumed in home scenarios. This is also a market opportunity for carriers in new business models.

However, after broadband acceleration (for example, 100 Mbit/s/1000 Mbit/s), the bandwidth of user homes increases, but the bandwidth of 100 Mbit/s is not equal to 100 Mbit/s experience. The bottleneck lies in the poor quality of home networks on the user side. In addition, HD video services and high-quality high-speed Wi-Fi connecting mobile terminals become the focuses of user complaints. The main problems are: The Wi-Fi speed is slow, the Wi-Fi coverage is narrow and is interfered, and the Wi-Fi quality is invisible to carriers. Therefore, it is difficult to locate and solve problems. As a result, the carrier's broadband brand is affected, invalid guarantee is increased, and high-value service development is restricted. For large-size houses, carriers operating video bearing and smart home can leverage their advantages in home Wi-Fi networks to build differentiated home network capabilities.

As Wi-Fi becomes the main connection mode for home networks and users pay attention to video experience, when frame freezing occurs, 1/3 users feel unbearable and immediately stop watching, and 84% users stop watching 1 minute after their experience deteriorates according to user video report released by Conviva. Also data shows that nearly 1/3 users are not satisfied with the Wi-Fi coverage and speed in their homes; 1/2 users are willing to pay for Wi-Fi service packages. Therefore, video experience through Wi-Fi is pivotal to successful home network business.

For the home Wi-Fi network coverage and quality issues that carriers and users are eager to pay attention to, the carrier-level home Wi-Fi network should be centered on dual-band Wi-Fi home gateways and fully utilize routed indoor cables or 5G Wi-Fi as Wi-Fi extension media to implement smart Wi-Fi coverage. The gateway functions as the control center to implement seamless Wi-Fi roaming and channel optimization on the entire home network. The gateway provides optimal video experience and can manage and maintain home Wi-Fi networks. In addition, home gateway-centric Wi-Fi experience measurement standards need to be provided, including key quality indicators (KQIs) and key performance indicators (KPIs). These indicators quantify user experience (such as the video streaming delay, web page loading time, and response time to online gaming). Based on such information, guidance on end-to-end best video experience improvement is posed to construct a manageable and maintainable home Wi-Fi network architecture to help carriers deploy home Wi-Fi networks in a high-quality and efficient manner, improve QoS of 4K video over Wi-Fi, sense Wi-Fi networks, and enhance cloud management and O&M. This guidance effectively solves problems such as poor home

Wi-Fi coverage, low Internet access rate, and even complaints about fault locating and troubleshooting failures.

By building a home gateway-centric home Wi-Fi network with the optimal experience, the Wi-Fi signal can be flexibly extended through the Ethernet cable, power line, wireless relay, and 5G Wi-Fi to effectively solve the Wi-Fi coverage and performance problems. The 1+N home network supports intelligent synchronization of network parameters, seamless roaming of terminals, Wi-Fi channel optimization on the entire network, and QoS of video services carried over Wi-Fi networks, achieving smart and full home Wi-Fi coverage and optimal video experience. Furthermore, self-service home Wi-Fi management is supported, facilitating easy maintenance and ease of use. Through the cloud management platform and mobile phone App, the home Wi-Fi network can be quickly installed and maintained, and managed, improving the operation efficiency for home Wi-Fi networks.

Keywords

4K, experience, network, home network, KQI, KPI, 100M, Wi-Fi, FTTH, WMM, cloud management platform

Abstract

With the increasing number of mobile terminals at homes, mobile video and ultra HD (UHD) IPTV continuously drive ultra-broadband development, and also enable Wi-Fi to become the main video bearing mode for home networks. Furthermore, carriers also transform their focus from connection to experience. Accordingly, the idea of home network construction also changes to business and experience. To provide users with good Wi-Fi coverage and optimal 4K video experience, a home Wi-Fi network centered on user experience needs to be built up. This document describes the technologies and working principles, quality standard KQIs, and deployment suggestions for home Wi-Fi networks providing superior video experience. Carriers can select the most appropriate deployment solution based on their network infrastructure and service development policies.

2 Wi-Fi Technologies and Working Principles

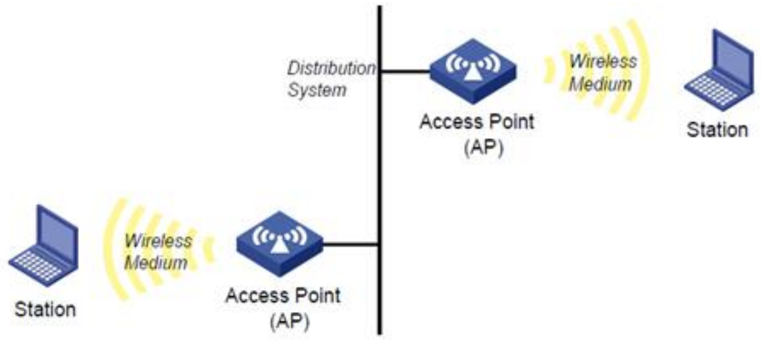
With the development of the Wi-Fi technology, 802.11ac is a new-generation Wi-Fi standard that works on the 5 GHz frequency band. The mainstream configuration is 5 GHz 2x2 MIMO, the highest air interface rate is 1166 Mbit/s, and the actual throughput reaches about 500–600 Mbit/s. Compared with the 2.4 GHz frequency band based on the IEEE 802.11n, the dual-band Wi-Fi gateway has multiple advantages, including a large number of available channels, stronger anti-interference capacity, higher rate, and shorter latency, better supporting high-speed Wi-Fi services such as HD videos.

2.1 Basic Wi-Fi Concept and Working Principle

2.1.1 Concept

Wi-Fi is a wireless local area network (Wi-Fi) technology based on the IEEEE 802.11 standard. A Wi-Fi network consists of the following components:

Figure 2-1 Components of a Wi-Fi network



- Stations (STA): a workstation refers to a laptop, tablet, or smartphone with the Wi-Fi function.
- Access point (AP): an access hotspot refers to the ONT, CPE, cable modem (CM), or router with the Wi-Fi function.
- Wireless medium: a radio medium, which uses radio frequency (RF) and antenna, and transmits signals through air.
- Distribution system: consists of STAs, APs, and wireless media.

When an AP provides the wireless access service, the service set identifier (SSID) must be configured. When an STA enables the Wi-Fi function, the scanned Wi-Fi hotspot name is the SSID.

A physical AP can be configured with multiple SSIDs, which is equivalent to multiple virtual APs (VAPs). When enabling the Wi-Fi function, an STA can scan multiple hotspots. Multiple VAPs are used to differentiate services and do not increase air interface resources.

2.1.2 How to Send Data

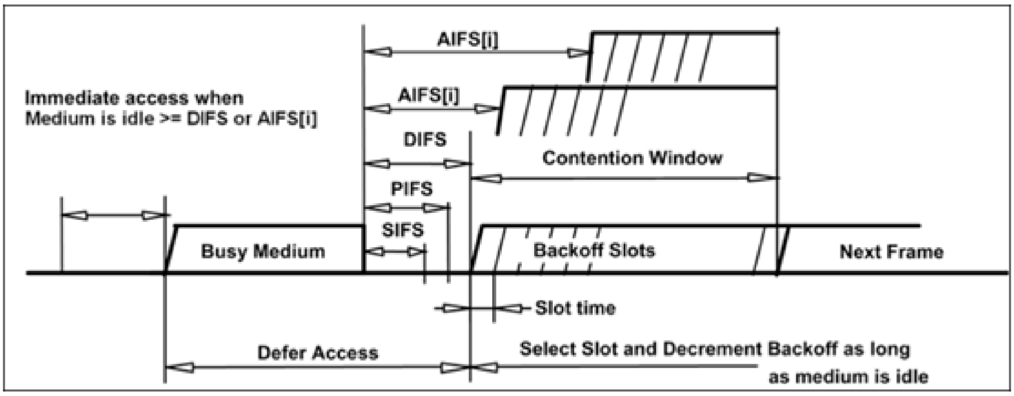
The AP and STA must send data in different time periods. Otherwise, they interfere with each other and cannot receive data. To successfully send data, Wi-Fi has 3 coordination mechanisms:

- DCF: distributed coordination function. The AP and the STA send data by using carrier sense multiple access with collision avoidance (CSMA/CA).
- PCF: point coordination function. The AP uniformly coordinates the time for each device to send data.
- HCF: hybrid coordination function. DCF and PCF are used together.

  There may be multiple APs connected to the air interface, and the PCF efficiency is low. Therefore, DCF is widely used.

  The following figure shows the process of sending data in the DCF mechanism. In this process, whether the air interface is busy is checked first. If the air interface is idle, wait for the DIFS+random time. After waiting, if the air interface is still idle, the data is sent.

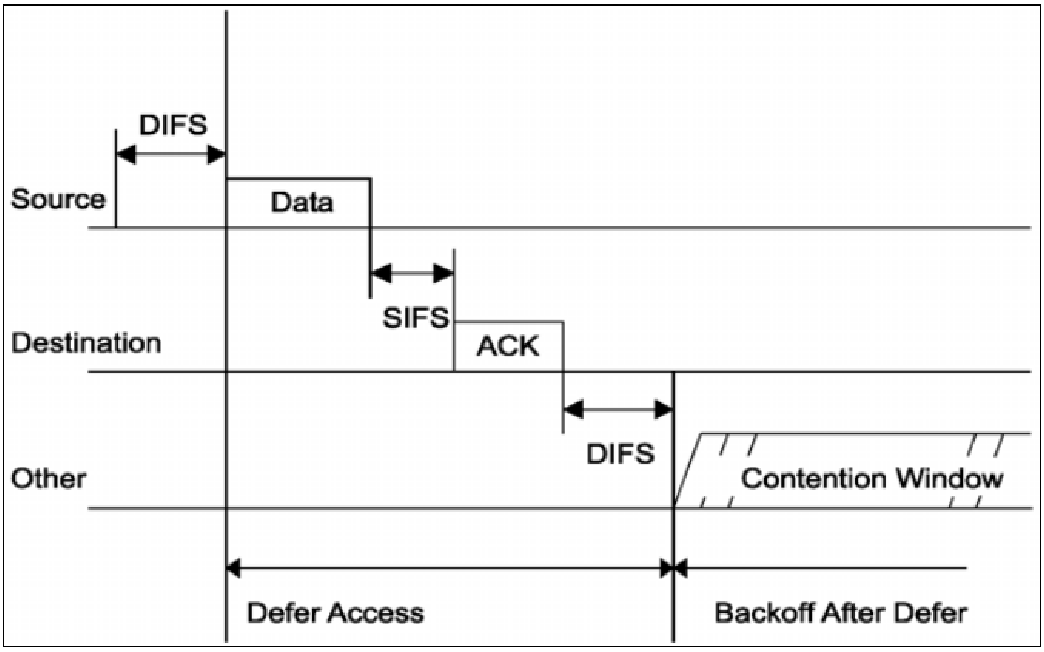
Figure 2-2 Process of sending data in the DCF mechanism on a Wi-Fi network



Short interframe space (SIFS) is a continuous process interval. PCF interframe space (PIFS) is used for PCF. DCF interframe space (DIFS) is used for DCF.

If multiple devices have the same random time, a conflict occurs. In this case, data needs to be reset at an appropriate time. To ensure that the peer end can receive data, the peer end needs to confirm the data. Frame and ACK involve a continuous process. The air interface does not need to be checked when the ACK packet is sent.

Figure 2-3 Data transmission mechanism on a Wi-Fi network

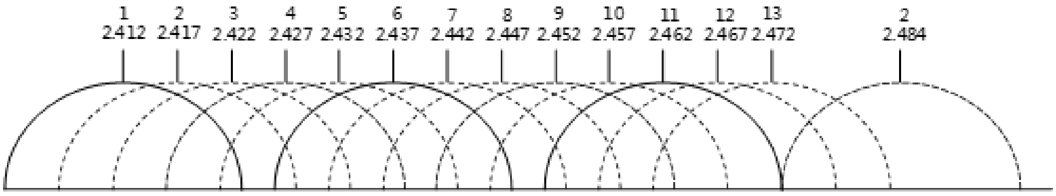


2.1.3 Working Channel and Frequency Bandwidth

When a Wi-Fi device transmits data through radio waves, it needs to work in a certain frequency range. This frequency range is called a channel. The AP selects a working channel, and the STA follows the working channel of the AP. Wi-Fi devices working on different channels can send data at the same time. Wi-Fi devices working on the same channel cannot send data at the same time. The working Wi-Fi frequency range can be different, which is called working bandwidth, including 20 MHz, 40 MHz, 80 MHz, and 160 MHz.

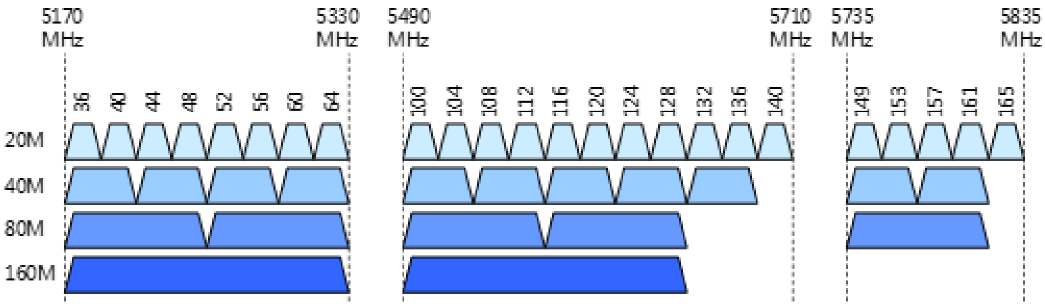
In the 2.4 GHz frequency band, channels 1–13 are opened in mainland China. These channels overlap. The bandwidth of 11bg is 22 MHz, and only channels 1, 6, and 11 do not overlap. When the 40 MHz bandwidth is used, there is only one channel that does not overlap.

Figure 2-4 Channels on the Wi-Fi 2.4 GHz frequency band



In the 5 GHz frequency band, channels 36–64 channel and 149–165 are opened in mainland China. Among which, channels 52–64 need to support DFS/TPC for radar detection and power control. Different from 2.4 GHz, channels of bandwidth 40 MHz, 80 MHz, and 160 MHz are defined by the standard and cannot be combined randomly.

Figure 2-5 Channels on the Wi-Fi 5 GHz frequency band



2.2 Physical Rate of an Air Interface

IEEE 802.11 defines multiple physical layer standards. Different standards support different physical rates of an air interface.

2.2.1 802.11b

802.11b works at the 2.4 GHz frequency band and supports physical rates 1 Mbit/s, 2 Mbit/s, 5.5 Mbit/s, and 11 Mbit/s.

2.2.2 802.11g and 802.11a

802.11g works at the 2.4 GHz frequency band and 802.11a works at the 5 GHz frequency band. The supported physical rates are as follows:

Table 2-1 Physical rates supported by 802.11g and 802.11a

Modulation Mode	Coding Rate	Physical Rate (Mbit/s)
BPSK	1/2	6.0
BPSK	3/4	9.0
QPSK	1/2	12.0
QPSK	3/4	18.0
16-QAM	1/2	24.0
16-QAM	3/4	36.0
64-QAM	2/3	48.0
64-QAM	3/4	54.0

Wi-Fi devices need to dynamically adjust modulation modes and coding rates based on the air interface status to work at different physical rates.

2.2.3 802.11n

802.11n works at the 2.4 GHz or 5 GHz frequency band. It supports MIMO. The physical rate of multiple spatial streams is multiplied by the number of spatial streams based on the physical rate of a single spatial stream. Also, it supports 40 MHz frequency bandwidth. The following table lists the supported physical rates.

Table 2-2 Physical rates supported by 802.11n

MCS Index	Number of Spatial Streams (MIMO)	Modulation Mode	Bit Rate	Air Interface Rate in 20 MHz (Mbit/s)	Air Interface Rate in 40 MHz (Mbit/s)
0	1	BPSK	1/2	7.2	15.0
1	1	QPSK	1/2	14.4	30.0
2	1	QPSK	3/4	21.7	45.0
3	1	16-QAM	1/2	28.9	60.0
4	1	16-QAM	3/4	43.3	90.0
5	1	64-QAM	2/3	57.8	120.0
6	1	64-QAM	3/4	65.0	135.0
7	1	64-QAM	5/6	72.2	150.0
...					
15	2	64-QAM	5/6	**144.4**	300.0
...					

MCS Index	Number of Spatial Streams (MIMO)	Modulation Mode	Bit Rate	Air Interface Rate in 20 MHz (Mbit/s)	Air Interface Rate in 40 MHz (Mbit/s)
23	3	64-QAM	5/6	216.7	450.0
…					
31	4	64-QAM	5/6	288.9	600.0

The number of spatial streams depends on the shared capabilities of the AP and STA. If the number of spatial streams supported by the STA is small, the STA cannot reach a higher rate. There are lees 2.4 GHz channels and usually they cannot work in the 40 MHz bandwidth. Generally, 802.11n devices support 2 spatial streams, and reach physical rate 144.4 Mbit/s in 20 Mbit/s bandwidth.

2.2.4 802.11ac

802.11ac works at the 2.4 GHz or 5 GHz frequency band. On the basis of 802.11n, 802.11ac modulation modes are improved, supporting more spatial streams and higher bandwidth. The following table lists the supported physical rates.

Table 2-3 Physical rates supported by 802.11ac

MCS Index	Number of Spatial Streams (MIMO)	Modulati on Mode	Bit Rate	Air Interface Rate in 20MHz (Mbit/s)	Air Interface Rate in 40 MHz (Mbit/s)	Air Interface Rate in 80 MHz (Mbit/s)	Air Interface Rate in 160 MHz (Mbit/s)
0	1	BPSK	1/2	7.2	15.0	32.5	65.0
…							
7	1	64-QAM	5/6	72.2	150.0	325.0	650.0
8	1	256-QAM	3/4	86.7	180.0	390.0	780.0
9	1	256-QAM	5/6	/	200.0	433.3	866.7
…							
9	2	256-QAM	5/6	/	400.0	**866.7**	1733.3
…							
9	3	256-QAM	5/6	/	600.0	**1300.0**	2600.0
…							
9	4	256-QAM	5/6	/	800.0	**1733.3**	3466.7
…							
9	8	256-QAM	5/6	/	1600.0	3466.7	6933.4

802.11ac devices support 80 MHz bandwidth. 2 spatial streams can reach physical rate 866.7 Mbit/s, 3 can reach 1300 Mbit/s, and 4 can reach 1733.3 Mbit/s.

2.2.5 802.11ax

802.11ax works at the 2.4 GHz or 5 GHz frequency band. The standard is not finalized yet. On the basis of 802.11ac, 802.11ax modulation modes are improved, optimizing coding mode. The following table lists the supported physical rates.

Table 2-4 Physical rates supported by 802.11ax

MCS Index	Number of Spatial Streams (MIMO)	Modulation Mode	Bit Rate	Air Interface Rate in 20MHz (Mbit/s)	Air Interface Rate in 40 MHz (Mbit/s)	Air Interface Rate in 80 MHz (Mbit/s)	Air Interface Rate in 160 MHz (Mbit/s)
0	1	BPSK	1/2	8.6	17.2	36.0	72.1
…							
9	1	256-QAM	5/6	114.7	229.4	480.4	960.8
10	1	1024-QAM	3/4	129.0	258.1	540.4	1080.9
11	1	1024-QAM	5/6	143.4	286.8	600.5	1201.0
…							
11	2	1024-QAM	5/6	286.8	573.5	1201.0	2401.9
…							
11	3	1024-QAM	5/6	430.1	860.3	1801.5	3602.9
…							
11	4	1024-QAM	5/6	573.5	1147.1	**2401.9**	**4803.9**
…							
11	8	1024-QAM	5/6	1147.1	2294.2	**4803.9**	9607.8

The mainstream 11ax chip supports 4 spatial streams, 80 MHz bandwidth, and physical rate of 2401.9 Mbit/s. If 4 spatial streams with 160 MHz bandwidth, or 8 spatial streams with 80 MHz bandwidth are supported, the physical rate can reach 4803.9 Mbit/s.

2.3 Bearing Rate of an Air Interface

The rate at which Ethernet packets are transmitted over the air interface is different from the physical rate of the air interface. The causes are as follows:

- The overhead of the 802.11 frame header is great. Time is consumed by conflict avoidance mechanism adopted by the air interface, ACK frames, and management frames.

- Time is consumed by other wireless devices.
- Due to obstacles, spatial attenuation is generated. Therefore, the highest physical rate cannot be fulfilled.
- The STA supports less spatial streams, or does not support the latest technical standard, or does not work on the maximum bandwidth.

When evaluating the bearing rate of an air interface, the current technical standard, bandwidth, number of spatial streams, signal strength, and interference need to be checked and confirmed. The following lists reachable bearing rates without considering the mentioned factors.

Table 2-5 Actual rates of air interfaces of different types

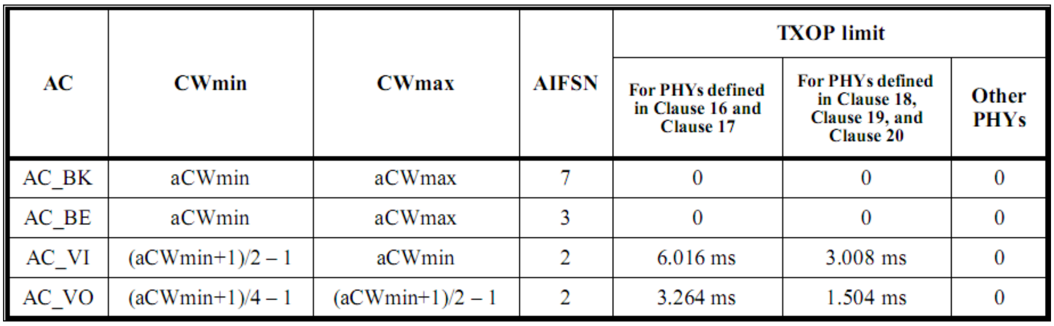
Air Interface Type	Working Frequency Bandwidth	Physical Rate of an Air Interface	Ideal Test Rate	Actual Rate
2*2 11n	20M	144M	80–95M	60–75M
3*3 11n	20M	216M	110–130M	80–100M
2*2 11ac	80M	866M	500–530M	370–420M
3*3 11ac	80M	1300M	650–750M	580–650M

2.4 Technologies Improving the Air Interface Efficiency

2.4.1 WMM

When video and voice services are carried over Wi-Fi, the Wi-Fi multimedia (WMM) mechanism can be used to prevent data services from affecting the quality of video and voice services. As mentioned in the preceding content, "DIFS+random time" requires and then data can be sent out. After WMM is supported, DIFS is changed to AIFS. WMM defines 4 service types: VO (voice), VI (video), BE (best effort), and BK (background). Different service types have different AIFS values and different random time windows. The difference between the AIFS and random window ensures that data of the voice and video services is more likely to be sent.

Figure 2-6 WMM working principle



AC	CWmin	CWmax	AIFSN	TXOP limit		
				For PHYs defined in Clause 16 and Clause 17	For PHYs defined in Clause 18, Clause 19, and Clause 20	Other PHYs
AC_BK	aCWmin	aCWmax	7	0	0	0
AC_BE	aCWmin	aCWmax	3	0	0	0
AC_VI	(aCWmin+1)/2 – 1	aCWmin	2	6.016 ms	3.008 ms	0
AC_VO	(aCWmin+1)/4 – 1	(aCWmin+1)/2 – 1	2	3.264 ms	1.504 ms	0

For voice and video packets, correct priority must be set in the IP header or VLAN tag to ensure that the packets can be mapped to the VO or VI queue. VLAN tag priority is taken as an example: priorities 6 and 7 correspond to VO, 4 and 5 correspond to VI, 3 and 0 correspond to BE, and 2 and 1 correspond to BK.

2.5 Wi-Fi Application Prospect

Wi-Fi bears over 42% mobile data traffic and 90% tablet data traffic worldwide. It has become the foundation in the mobile Internet era. In the future, more devices will be connected through Wi-Fi in various industries, increasing social automation, productivity, and comfort.

With popularization of the 4G/5G concept, mobile users' requirements are increasing. Assuming that an LTE network provides user experience and persons born approximately the same as those provided by a Wi-Fi network. In this case, sites need to be deployed densely. As a result, costs on site lease and equipment maintenance increase sharply. In contrast, Wi-Fi has thousand times lower than LTE in terms of power consumption, maintainability, hardware cost, and facilities. The future mobile network needs Wi-Fi, and now VoWi-Fi has emerged.

In the smart home field, as more and more Wi-Fi Internet of Things (IoT) devices are deployed, Wi-Fi is expected to be one of the protocols for smart home connection. Its advantages lie in fast transmission rate, low product cost, and most popular in daily's life. For users, smart home based on Wi-Fi is the most cost-effective, and they only need to purchase devices for network connection. For example, video surveillance based on Wi-Fi can avoid complex cabling and dramatically reduce the deployment time.

In a word, home Wi-Fi can meet the requirements of home mobile devices, video bearing, and VR/AR. In the future, mobile communications and smart home applications will also unleash its unlimited potential.

3 Challenges to Home Wi-Fi Networks

Statistics show that in a China's household, an average of 6 terminals are connected through Wi-Fi and more than 80% users enjoy video on demands through Wi-Fi. However, the actual Wi-Fi rate does not match the bandwidth package rate, which severely affects user experience. As a result, user complaints increase. In addition, there is no efficient method of locating and resolving Wi-Fi performance issues. As a result, user complaints cannot be addressed in time.

3.1 Hard OAM

High professional skills are required for home Wi-Fi network planning and engineering. If a user DIYs a Wi-Fi network, many potential quality problems may occur:

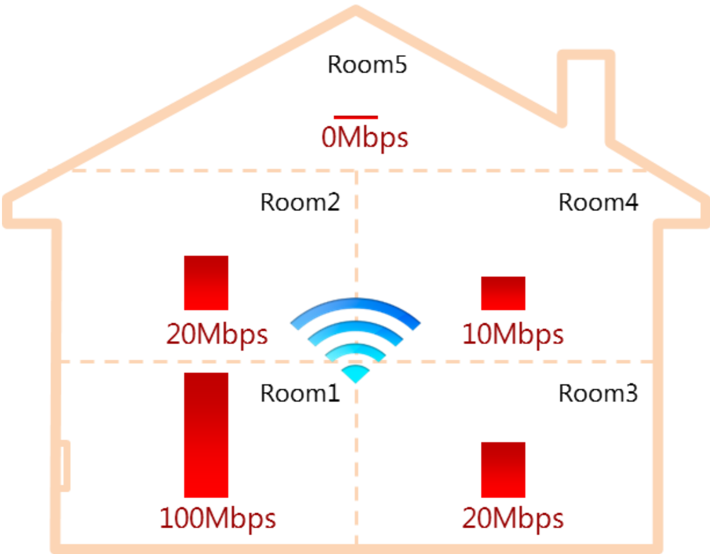
1. Network planning is incorrect. It is difficult for users to answer questions, for example, what kind of home gateways are needed for the house, how many distributed APs are needed, and where can these home gateways and distributed APs be placed.
2. It is hard to ensure compatibility of self-purchased home gateways or distributed APs, leading to poor network performance.
3. The gateway or AP is incorrectly configured.
4. Engineering errors occur, such as cable connection and installation.

Regardless of whether carriers provide home Wi-Fi services, users often regard the home Wi-Fi network as a part of broadband services. Once a problem occurs, users report faults to carriers. According to statistics, 30% to 50% problems in home networks are caused by Wi-Fi. However, home Wi-Fi now is hardly managed. On one hand, carriers' management system does not collect the running Wi-Fi data. On the other hand, there is no effective OAM tool on CPEs deployed on boundaries of carriers' networks. In this case, if a fault occurs, remote maintenance personnel cannot quickly determine whether the fault is caused by home Wi-Fi or broadband network. Instead, the fault can only be handled at users' homes by the installation and maintenance personnel.

3.2 Deteriorated Wi-Fi Performance

Inappropriate location and antenna direction of home gateways in users' homes affect Wi-Fi coverage performance. For example, a home gateway is placed in an information box, in a closed storage room, or on the ground in the corner; antennas are placed against the wall, or the omnidirectional antennas are not erected or form a certain angle.

Figure 3-1 Deteriorated Wi-Fi performance



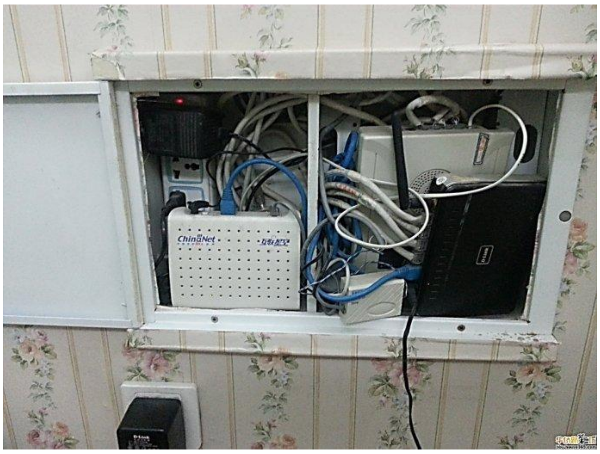
Complex home environment attenuates Wi-Fi signals greatly. The following table lists Wi-Fi signal attenuation caused by common home obstacles. For example, the bearing wall attenuates Wi-Fi signals from 1% (20 db) to 0.01% (40 db).

Table 3-1 Wi-Fi signal attenuation caused by common home obstacles

Obstacle	Attenuation	Obstacle	Attenuation
Bearing wall	20–40 db	Concrete wall	10–18 db
Floor	30 db	Hollow brick wall	4–6 db
Plasterboard wall	3–5 db	Glass door and window	2–4 db
Wooden door	3–5 db	Reflective glass door and window	12–15 db
Wooden furniture	2–10 db	Wood partition wall	5–8 db
Metal object	Full reflection	Water	Full absorption

Note that Wi-Fi signals cannot penetrate metal objects. However, many information boxes housing home gateways have metal plates. As a result, Wi-Fi signals are of poor quality.

Figure 3-2 Information boxes housing home gateways have metal plates

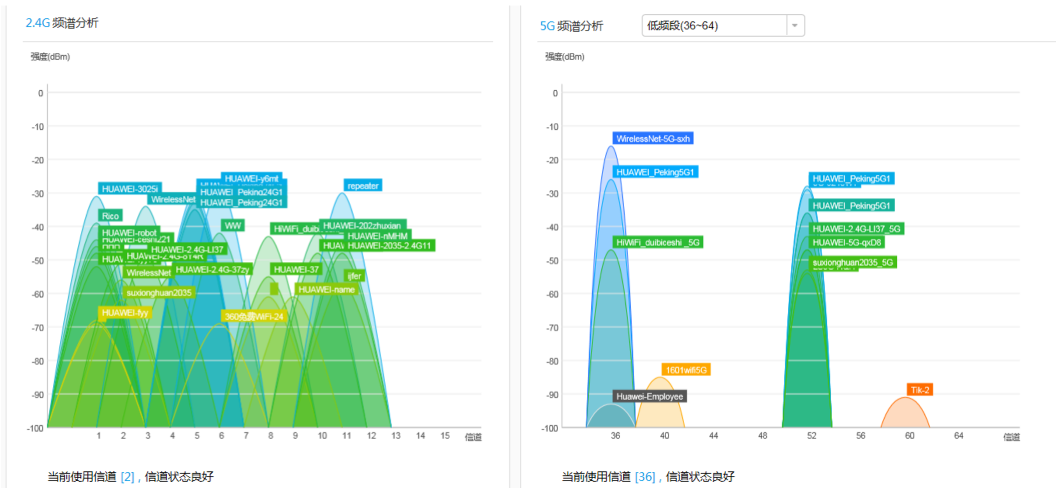


In a multi-room house, indoor partition walls block Wi-Fi signals obviously, but no distributed APs are deployed to enhance the Wi-Fi coverage. Even so, many users only purchase costly high-performance Wi-Fi home gateways, and they do not know how important that distributed APs brought to large-house Wi-Fi coverage.

Interference also hinders Wi-Fi performance:

- Co-channel or adjacent-channel interference
  - Co-channel interference: mutual interference between Wi-Fi devices working on the same channel. Air interfaces are public transmission media of all devices. The 2 APs back off each other according to the CSMA/CA, which greatly reduces the performance. The 2.4 GHz frequency band has only 3 non-overlapping channels. Therefore, it is difficult to find a channel that does not overlap with other channels in communities.
  - Adjacent-channel interference: mutual interference between Wi-Fi devices working on different channels. If the Tx bandwidth of Wi-Fi devices with different center frequencies overlap, mutual interference may be generated.

Figure 3-3 Wi-Fi interference



- Non-Wi-Fi interference source

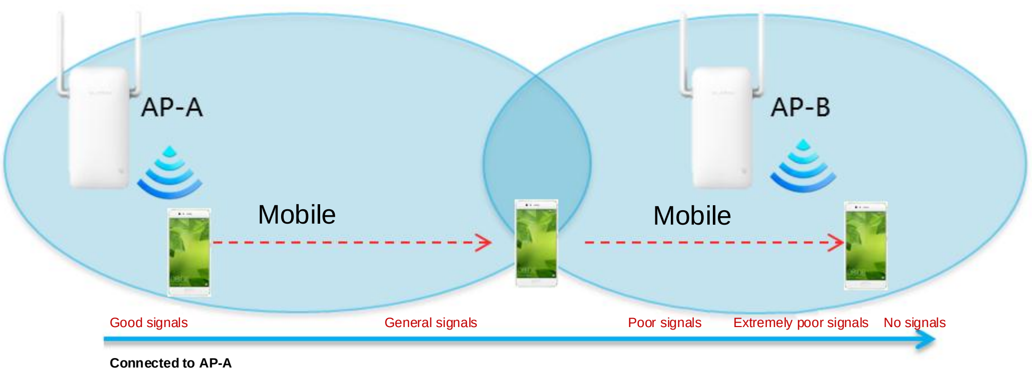
Table 3-2 Wi-Fi interference brought by common home devices

Interference Source	Frequency	Power	Interference Evaluation
Microwave oven	Band S (2.4–2.5G)	> 800 W	Severe interference (rate decreases obviously when the distance is < 4 m; network is disconnected occasionally when the distance is < 2 m)
Cordless phone	2.4G, 5G	3 W	Severe interference (rate decreases when the distance is < 1 m; network is disconnected when the distance is < 0.5 m)
Wireless camera	2.4G	0.5–1 W	Relative slight interference, but long distance required
Bluetooth device	2.4G	1 mW	Slight interference
Radar	5G	kW–MW	Severe interference brought by great radar power despite long distances

Wi-Fi performance deteriorates due to:

1. The Wi-Fi bandwidth is insufficient and mobile performance is poor.
2. Lots of home gateways are not upgraded to 11ac dual-band ones, or gateways are new 11ac dual-band ones, but terminals such as PCs and STBs use 11b/n/g. As a result, the overall performance lags.
3. When a mobile phone or tablet is used to access the Internet or watch videos, signals cannot be switched to an AP releasing stronger signals because the home gateway or terminal does not support band-steering (supported by 11k and 11v). As a result, services are suspended for a long time.
4. Some users configure different SSIDs for the distributed AP and the home gateway respectively. As a result, connected terminals cannot be automatically switched.

Figure 3-4 Wi-Fi quality impact brought by terminal moving



3.3 Poor Video Experience

Many users use Wi-Fi to connect STBs for convenience or beauty. However, the actual experience is poor. This is because that the Wi-Fi network quality of many households cannot meet requirements on high-quality videos. The following table lists the end-to-end quality requirements on IPTV videos. According to the data listed, live TV is based on UDP, which has no high requirements on delay and jitter but is sensitive to packet loss rate (PLR). Unlike live TV, TCP-based VoD or over the top (OTT) videos are sensitive to delay. In addition, the network must meet the bandwidth requirements of 1.3 times or even 1.5 times to the bit rate.

The following table lists video quality KPIs defined by Huawei.

Table 3-3 Video quality KPIs defined by Huawei

IPTV Video	Bit Rate	Bandwidth	Delay	Jitter	PLR
HD live TV	**CBR 15M**	> 19.5M	< 200 ms (single-directional)	< 50 ms	< 0.0011%
4K live TV	**CBR 30M**	> 39M	< 200 ms (single-directional)	< 50 ms	< 0.001%
4K TCP VoD /OTT video	**VBR–25M, peak 40M**	> 37.5M	< 55 ms (bi-directional)	< 20 ms	< 0.01%

The following table lists typical quality parameters of a Wi-Fi network. According to the data listed, 2.4G frequency bands interfered severely hard to meet high quality requirements on HD videos.

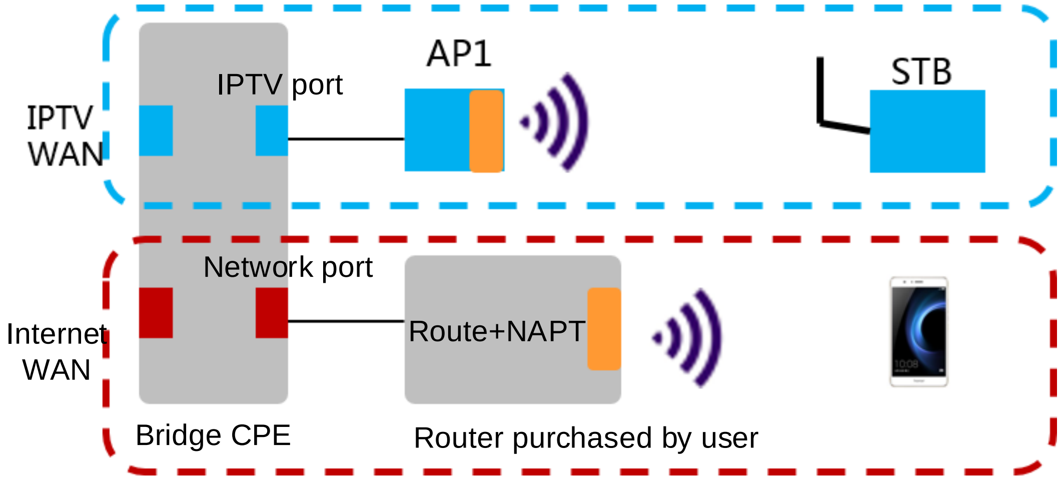
Table 3-4 Typical quality parameters of a Wi-Fi network

Single STB	Bandwidth at 5 m Without Obstacles	Average Bi-directional Delay	Jitter	PLR
2.4G 2*2 MIMO weak interference	Down: 65 Mbit/s Up: 63 Mbit/s	5 ms	116 ms	0.1%
2.4G 2*2 MIMO strong interference	Down: 19 Mbit/s Up: 17.5 Mbit/s	12 ms	138 ms	0.6%
5G 2*2 MIMO weak interference	Down: 420 Mbit/s Up: 280 Mbit/s	4 ms	10 ms	0%

In the future, home video consumption will evolve to multi-channel 4K or even 8K, which will have higher requirements on Wi-Fi networks.

3.4 Failed IPTV and Internet Access Integration

Figure 3-5 Failed IPTV and Internet access integration



Many carriers use the LAN-WAN binding technology to separate the IPTV service from the Internet access service so as to allocate separate bandwidth and service channels to the IPTV service. In this case, the STB needs to connect to a fixed port of the CPE, which brings the following problems:

1. If Ethernet connection is used, only 1 STB can be connected.
2. If the user connects an STB using Wi-Fi, the user cannot use Wi-Fi connection of the self-purchased home gateway. (Wi-Fi of the home gateway provides only the Internet access service.)
3. If an STB is connected using Wi-Fi, many purchased APs cannot support multicast and IGMP. Even if a user purchases a pair of bridging APs to connect to the CPE IPTV port and STB, the user cannot watch live programs.
4. This harms integration of multiple services on terminals. In the future, terminals must support multiple services, that is, users can use STBs and smartphones to watch IPTV programs provided by carriers, watch OTT videos, and access the Internet.
5. Users cannot use smartphones or tablets to watch IPTV videos.

4 KQI of Home Wi-Fi Networks

How to measure the quality of home networks, especially Wi-Fi quality, is a problem that carriers and users willing to resolve. Therefore, it is critical to define KQIs and KPIs for Wi-Fi experience measurement. These indicators quantify user experience (such as the video streaming delay, web page loading time, and response time to online gaming). Based on such information, guidance on end-to-end best video experience is posed to construct a manageable and maintainable home Wi-Fi network architecture to help carriers deploy home Wi-Fi networks in a high-quality and efficient manner, improve QoS of 4K video over Wi-Fi, sense Wi-Fi networks, and enhance cloud management and O&M.

4.1 Quality Standards of Home Wi-Fi Networks

QoE: quality of experience sensed by users.

QoS: quality of service.

MOS: mean opinion score, which can be subjective MOS or objective MOS. According to ITU-T P.800 and P.830 proposals, different persons compare their feelings on services under different network conditions, obtain the MOS, and finally calculate the average value.

Experience KQI: objective service quality parameters that are determined based on service feature analysis and are used to determine the service quality.

Service KPIs: technical indicators that are not directly perceived by users but affect user experience.

Network KPI: key network performance indicators.

Home Wi-Fi network service experience indicators are divided into: experience KQIs, service KPIs, and network KPIs.

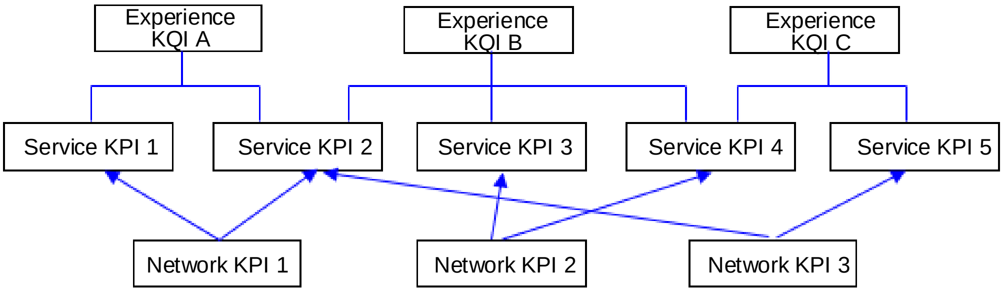
Experience KQIs are decomposed and quantified from users' perspectives. Such KQIs can be divided into multiple service KPIs.

Service KPIs analyze technical factors that affect user experience from O&M technical personnel's perspectives.

Network KPIs directly reflect key performance indicators of network operations. Such KPIs directly affect service KPIs and indirectly affect experience KQIs.

The relationship between these indicators is shown in the following figure.

Figure 4-1 Relationship between these indicators



4.1.1 Experience KQI of Home Wi-Fi Networks

4.1.1.1 Web Browsing

This KQI refers to the experience KQI for the mobile terminal to browse web pages through Wi-Fi.

KQIs of web browsing experience perceived by users are: page response time, above-the-fold time, and full loading time.

Page response time: defined for the user access page (DNS resolution process is required). It refers to the time period from when the user initiates an access instruction on the terminal (enters a URL address in the browser's address bar and touches or presses **Enter**) to the time when the user views the first content on the page. For the browser (Windows OS), the first content is represented by the displayed title of the browser; for the browser (smartphone App), the first content is represented by the first displayed element.

Above-the-fold time: time used for fully displaying the upper screen (assume that the terminal resolution is 1920*1080) on the browser. It refers to the time from when the user initiates an access instruction (enters a URL address in the browser's address bar and touches or presses **Enter**), and the browser sends out a request to obtain the target website data, to the time when needed data is returned and the terminal screen is fully displayed.

Full loading time: defined for the user access page (DNS resolution process is required). It refers to the time period from when a user initiates an access instruction on a terminal (enters a URL address in the browser's address bar and touches or presses **Enter**) to the time when the entire page is completely loaded on the browser.

Table 4-1 Web browsing service experience KQI

User Experience Level	MOS	Indicator		
		Page Response Time (Unit: s)	Above-the-Fold Time (Unit: s)	Full Loading Time (Unit: s)
Very good	4.5–5	< 0.6	< 1.5	< 8
Good	3.5–4.5	0.6–1.5	1.5–3	8–18
Average	2.5–3.5	1.5–2	3–5	18–30
Poor	1.5–2.5	2–2.5	5–7	30–48
Very poor	0–1.5	> 2.5	> 7	> 48

4.1.1.2 Broadband Speedtest

This KQI refers to the experience KQI for the mobile terminal to test broadband speed through Wi-Fi.

KQIs of broadband speedtest experience perceived by users are: ratio of the download rate and ratio of the upload rate.

Ratio of the download rate: ratio of the highest download rate obtained from the specified server to the average downstream user bandwidth in peak hours (obtained from the wireless planning department) by using the speed test software recommended (see the tool requirements).

Ratio of the upload rate: ratio of the highest upload rate obtained from the specified server to the average upstream user bandwidth in peak hours (obtained from the wireless planning department) by using the speed test software recommended (see the tool requirements).

Table 4-2 Broadband service experience KQI

User Experience Level	MOS	Indicator	
		Ratio of the Download Rate	Ratio of the Upload Rate
Very good	5.0	≥ 100%	≥ 100%
Good	3.5–4.9	≥ 90%	≥ 90%
Average	2.5–3.5	≥ 70%	≥ 70%
Poor	1.5–2.5	≥ 50%	≥ 50%
Very poor	0–1.5	< 50%	< 50%

4.1.1.3 Video Streaming

This KQI refers to the experience KQI for the mobile terminal to order online videos through Wi-Fi.

KQIs of video streaming experience perceived by users are: initial buffering time, number of frame freezing times, and frame freezing ratio.

Initial buffering time: time elapsed from when a terminal sends OTT program requests until the OTT cloud platform returns data large enough for the terminal to display the first video image. An OTT program request can be triggered when a user initiates a VoD request or fast forwards or rewinds during the video playback.

Number of frame freezing times: number of times when the image freezes because the downloaded data amount is less than that required for the decoding and playing of a video within a specified watching time (for example, 5 minutes). The pauses actively performed by a user and the pauses that occur when the terminal CPU runs under heavy load are not counted.

Frame freezing ratio: ratio of the buffering time to the watching time when the image freezes because the downloaded data amount is less than that required for the decoding and playing of a video within a specified watching time (for example, 5 minutes). The pauses actively performed by a user and the pauses that occur when the terminal CPU runs under heavy load are not counted.

Table 4-3 Video streaming service experience KQI

User Experience Level	MOS	Indicator		
		Initial Buffering Time (Unit: ms)	Number of Frame Freezing Times*	Frame Freezing Ratio*
Very good	5	≤ 100	0	0%
Good	4	1000	1	0.1%
Average	3	2000	3	1%
Poor	2	5000	6	5%
Very poor	1	8000	> 10	10%

* The statistical period is 45 minutes. (Generally, an episode has 45 minutes.)

4.1.1.4 Online Gaming

This KQI refers to the experience KQI for the mobile terminal to play games online through Wi-Fi.

KQIs of online gaming experience perceived by users are: operation response time and operation freezing ratio.

Operation response time: average time (unit: ms) difference between the time when a user clicks the mouse or keyboard to the time when the gaming client starts to respond to user operation during repeated operations (1000 times recommended).

Operation freezing ratio: ratio (unit: %) of the number of gaming suspension times to the total number of operations (not considering the terminal performance bottleneck) during the repeated operation test (1000 times recommended).

Table 4-4 Online gaming service experience KQI

User Experience Level	MOS	Indicator*	
		Operation Response Time (Unit: ms)	Operation Freezing Rate (Unit: %)
Very good	4.5–5	< 0.4	0%
Good	3.5–4.5	0.4–0.7	< 3%
Average	2.5–3.5	0.7–0.9	3%–7%
Poor	1.5–2.5	0.9–1.2	7%–10%
Very poor	0–1.5	> 1.2	> 10%

* MMORPG online gaming is used as an example.

4.1.1.5 High-speed Download

This KQI refers to the experience KQI for the mobile terminal to perform high-speed download through Wi-Fi.

The KQIs of high-speed download experience perceived by users are: transmission request response delay, transmission rate stability, and average transmission rate.

Transmission request response delay: delay from the time when a user initiates a request to the time when the file transfer connection is successfully set up, including DNS resolution (optional), TCP connection setup, and first connection request.

Transmission rate stability: ratio of the time when the real-time transmission rate falls within the average rate 80%–120% to the total transmission time, which reflects rate fluctuation.

Average transmission rate: average rate during data transmission, which reflects the network transmission capability.

Table 4-5 High-speed download service experience KQI

User Experience Level	MOS	Indicator		
		Transmission Request Response Delay (Unit: s)	Transmission Rate Stability (Unit: %)	Average Transmission Rate (Unit: Mbit/s)
Very good	4.5–5	0.1–0.14	65%–70%	4–5 Mbit/s
Good	3.5–4.5	0.14–0.22	55%–65%	2–4 Mbit/s
Average	2.5–3.5	0.22–0.3	45%–55%	0.8–2 Mbit/s
Poor	1.5–2.5	0.3–0.38	35%–45%	0.5–0.8 Mbit/s
Very poor	0–1.5	0.38–0.5	20%–35%	0–0.5 Mbit/s

4.1.2 Network KPI of Home Wi-Fi Networks

Network KPIs determine the actual end-to-end throughput between user terminals and Internet content, affecting the time of transmitting Internet content to user terminals and further affecting user experience KQIs.

Home Wi-Fi network KPIs include service experience, connection capability, coverage, throughput, and anti-interference. Network KPIs affecting Internet user experience include two-way delay and PLR. These indicators are related to the cloud features of Internet services and device features of client applications.

4.1.2.1 Service Experience

1. **Web browsing**

   Two-way delay: two-way delay between the client (device) and web page object (cloud). This indicator applies to both fixed broadband Internet users and mobile Internet users.

   PLR: rate of packet loss between the client (device) and web page object (cloud). This indicator applies to both fixed broadband Internet users and mobile Internet users.

2. **Broadband speed test**

   Two-way delay: two-way delay between the client (device) and speed test server (cloud). This indicator applies to both fixed broadband Internet users and mobile Internet users.

   PLR: rate of packet loss between the client (device) and speed test server (cloud).

3. **Video streaming**

Two-way delay: two-way delay between the client (device) and server (cloud) on which the video fragmentation file played locates. This indicator applies to both fixed broadband Internet users and mobile Internet users.

PLR: rate of packet loss between the client (device) and server (cloud) on which the video fragmentation file played locates. This indicator applies to both fixed broadband Internet users and mobile Internet users.

4.1.2.2 Connection Capability

Indicators measuring Wi-Fi connection stability include signal stability, abnormal disconnection rate, balance between Tx and Rx capabilities, multi-STA hybrid service, and multi-AP roaming performance.

Signal stability refers to signal fluctuation in extreme scenarios. In the same area, signal strength of an STA cannot fluctuate greater than 1 signal bar.

Abnormal disconnection rate refers to the proportion of abnormal STA disconnections when the Wi-Fi network is interfered or the device is abnormal.

Balance between Tx and Rx capabilities refers to the budget balance between uplinks and downlinks between the Wi-Fi AP and STA. This indicator prevents Internet access failures though there are signals.

Multi-STA hybrid service includes 2 indicators: performance, delay, and PLR of the Wi-Fi network when multiple STAs are running different services, and mutual impact (hybrid service) of the STAs at different distances.

Multi-AP roaming performance refers to the comprehensive impact on service experience when an STA roams between 2 APs.

4.1.2.3 Coverage

Indicators that measure the Wi-Fi coverage performance include the basic RF performance indicators, Tx power, and receiver sensitivity of a Wi-Fi AP, and distance coverage performance and 360 °angle coverage performance that can comprehensively measure coverage capabilities.

Tx power refers to the equivalent isotropic radiated power (EIRP) of a Wi-Fi transmitter in a shielded environment, which can be seen as the strength of signals transmitted. Receiver sensitivity refers to the minimum Rx power at which the Wi-Fi receiver can correctly extract useful signals in the shielded environment.

Theoretically, the larger the Tx power, the better the coverage in the Tx direction, the lower the receiver sensitivity, the better the performance in the Rx direction. However, the coverage performance is related to the Tx power and receiver sensitivity of an STA. Optimal coverage can be achieved only when signals are balanced in the Tx and Rx directions. If signals in the Tx direction are weak, STA signals are weak. If signals in the Rx direction are weak, the STA may have signals but cannot connect to the network.

Distance coverage performance refers to throughputs at different distances in an open area without obstacles and without interference.

360 °angle coverage performance refers to the throughput measured at a fixed angle by rotating the Wi-Fi AP or STA located at a fixed distance. Generally, 12 points are tested every 30 °. This indicator measures the omnidirectional coverage capability of Wi-Fi AP antennas. Compared with the distance coverage performance, the 360 °angle coverage performance is more suitable for measuring the comprehensive coverage performance in the home scenario.

4.1.2.4 Throughput

Indicators that measure the throughput of a home Wi-Fi network include extreme throughput, home environment throughput, multi-user throughput, and RvR performance.

Extreme throughput refers to the maximum Wi-Fi throughput between a Wi-Fi AP and STA in a shielded environment.

Home environment throughput refers to the 360 °angle performance after signals are transmitted over different positions or attenuated in the actual home environment with interference. Generally, 4 positions are selected: short distance, medium distance, long distance, and extreme distance (that is, extreme coverage point). 360 °angle performance is recorded at every position.

Multi-user throughput refers to the maximum total Wi-Fi throughput of multiple STAs in short, medium, and long-distance concurrent services in the actual home environment with interference.

RvR performance refers to the curve of the maximum throughput and attenuation obtained after the Wi-Fi AP is connected to the STA through the coaxial cable and different attenuation values are increased. This curve intuitively shows the ultimate performance of a Wi-Fi AP under different distances.

4.1.2.5 Anti-interference

Indicators that measure the anti-interference performance of a home Wi-Fi network include co-channel/adjacent-channel/overlapping interference, and strong/medium/weak interference.

Co-channel/adjacent-channel/overlapping interference refers to the performance of a single user and multiple users in terms of throughput, delay, and PLR in the case of co-channel, adjacent-channel, or overlapping interference.

Strong/medium/weak interference refers to the performance of a single user or multiple users in terms of throughput, delay, and PLR in a specified interference model (severe interference, moderate interference, or weak interference).

4.1.2.6 Maintenance and Management

Carriers' home Wi-Fi networks must be operable and manageable to bring benefits to carriers. Maintenance and management include fault diagnosis and fault demarcation.

Fault diagnosis refers to the capability of remotely collecting fault information and analyzing and locating faults based on the collected fault information when a home Wi-Fi network is abnormal.

Fault demarcation refers to the capability of locating a specific fault position, such as upstream port, Wi-Fi AP, or Wi-Fi line, based on the collected fault information when a home Wi-Fi network is abnormal. In this way, the fault scope can be narrowed down to quickly recover the network.

4.2 Target of Next-Generation Home Wi-Fi Networks: 100M@Anywhere

The 100M@Anywhere home network must meet the requirements of at least 2-channel 4K TV (30P) services and 100 Mbit/s mesh coverage.

Table 4-6 Home Wi-Fi bandwidth, delay, and PLR requirements of 4K TV (30P) services

	1080p	Pseudo 4K	Basic 4K	Real 4K	Ultra 4K
Resolution	1920*1080	3840*2160	**3840*2160**	3840*2160	3840*2160
Frame rate	23P	23P	**30P**	50/60P	100/120P
Sample bits	8	8	**8**	10	12
Compression	H.264	H.264/H.265	**H.265**	H.265	H.265
Bandwidth	5–8 Mbit/s	8–15 Mbit/s	**20–30 Mbit/s**	30–50 Mbit/s	50–100 Mbit/s
Delay	12–20 ms	7–12 ms	**6–11 ms**	6–11 ms	6–11 ms
PLR	$5*10^{-4}$	$5*10^{-4}$	$\mathbf{1*10^{-4}}$	$5*10^{-5}$	$5*10^{-5}$

To achieve 100 Mbit/s mesh coverage in the next-generation home network, Wi-Fi throughput of the main Internet access location in the typical home environment must reach about 100 Mbit/s. In STAs roaming between different APs, the bandwidth, delay, and PLR must meet the 4K TV (30P) service experience requirements.

5 Wi-Fi Coverage Solutions and Key Features

When building home networks that bring premium experience, operators need to focus on home gateways and extend Wi-Fi signals through multi-medium such as Ethernet cables, power lines, Wi-Fi relays, and 5 GHz Wi-Fi to effectively solve the issues related to home Wi-Fi coverage and performance. "1+N" home networks are being built to support intelligent synchronization of network parameters, seamless roaming and switching of terminals, network-wide Wi-Fi channel optimization, Wi-Fi video bearing QoS, and other key features, realizing intelligent and full home Wi-Fi coverage and delivering premium video experience.

5.1 Specification Requirements of Home Gateways and APs

Hardware configurations and specifications of gateways and APs are important for home network performance and quality. For example, specifications of CPUs, memories, flashes, and Wi-Fi have great impacts on forwarding and Wi-Fi throughput, and surge protection and power saving features are important for network security and stability. Smart gateways can support smart home services in the future. Specification requirements of home gateways and APs are as follows:

Table 5-1 Specification requirements of home gateways and APs

Items	Specification Requirements of Home Gateways	Specification Requirements of APs
Memory	Above 256 MB	Above 128 MB
Flash	Above 256 MB	Above 128 MB
Wi-Fi specification	Above 2 x 2 11ac + 2 x 2 11n	Above 2 x 2 11ac + 2 x 2 11n
NNI	GPON/XG-PON/10G EPON/1GE	1GE/5 GHz Wi-Fi/PLC

Items	Specification Requirements of Home Gateways	Specification Requirements of APs
UNI	2–4 GE + 2.4 GHz Wi-Fi + 5 GHz Wi-Fi	1GE + 2.4 GHz Wi-Fi + 5 GHz Wi-Fi
Antenna gain	Above 2 dBi	Above 2 dBi
Wi-Fi channel optimization	Automatic channel optimization	Automatic channel optimization and smart gateway-controlled channel optimization
Proactive Wi-Fi roaming	STA roaming and switching through the IEEE 802.11k or IEEE 802.11v Roaming and switching decision-making center	STA roaming and switching through the IEEE 802.11k or IEEE 802.11v
Video bearing	Video packet priority marking and WMM	WMM
Band steering	Preferential configuration of 5 GHz and 2.4 GHz	Preferential configuration of 5 GHz and 2.4 GHz
Beamforming	Beamforming; directional sending	Beamforming; directional sending
Service provisioning	Inheriting existing provisioning modes	Zero configuration; PnP
Intelligent operating system (OS)	Open OSGi-based system	----
Remote management and maintenance	Plug-in-based home network management	Management through smart gateways
Power saving	Wi-Fi power-saving mode	Wi-Fi power-saving mode
Surge protection	4 kV	4 kV
CE certification	Needs to be supported	Needs to be supported
Wi-Fi Alliance authentication	Needs to be supported	Needs to be supported

5.2 Performance Enhancements for Home Wi-Fi Networks

5.2.1 Intelligent Channel Management

The 2.4 GHz band provides only 3 non-repeated channels. Each AP selects one channel from them and needs to have a different channel from its adjacent AP. The 5 GHz band provides many channels, but users also need to take good care of relationships between adjacent APs regarding channels and power. Without ideal functions, users have to configure channels and power for APs one by one, which is complex. While surrounding environments dynamically change, configured AP channel and power may fail to meet usage requirements. To simplify AP configuration, these users are urgently demanding for comprehensive and intelligent channel and power adjustment.

Figure 5-1 Working principle of periodical and automatic Wi-Fi optimization

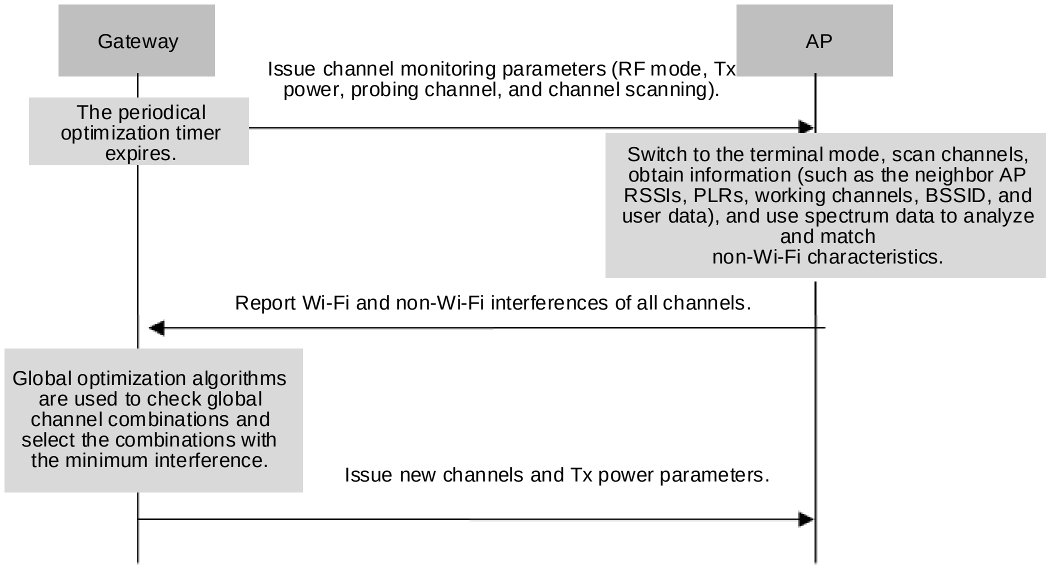
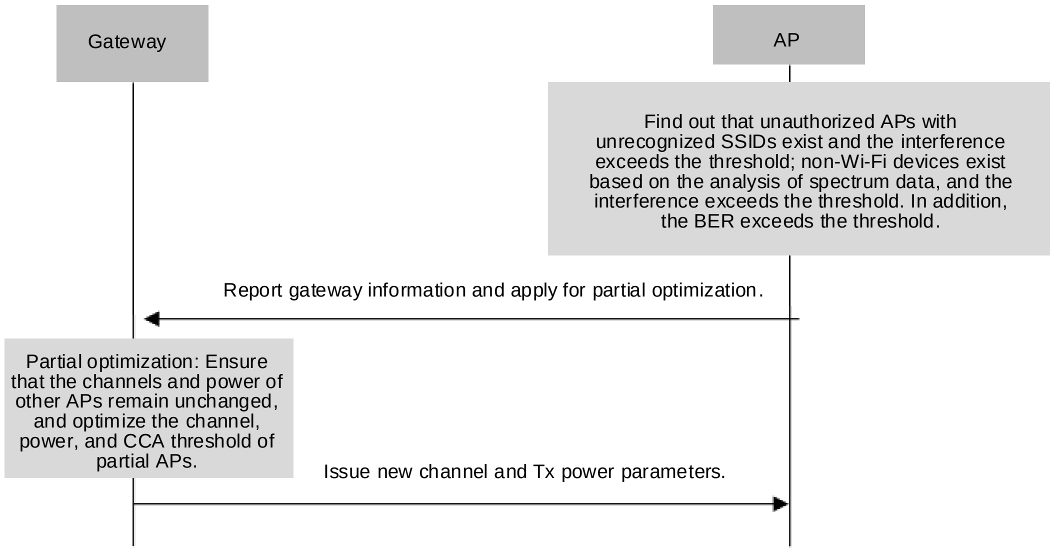
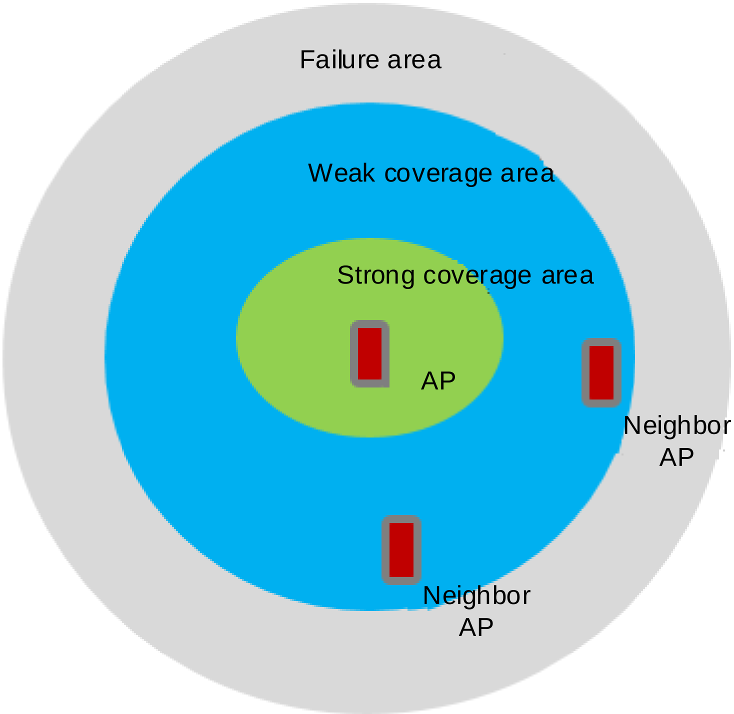


Figure 5-2 Working principle of event-triggered Wi-Fi optimization



Intelligent power management aims to balance the maximal Wi-Fi coverage and the minimum external interferences. As shown in the following figure, a strong coverage area and a weak coverage area are defined based on room layouts and service demands. For example, when the 2.4 GHz band is used, the area with signal strength greater than –70 dBm is the strong coverage area while the area with single strength between –90 dBm and –70 dBm is the weak coverage area. The strong coverage area must cover the terminals served by a specific AP. If its neighbor AP is in the failure area, Wi-Fi coverage may be insufficient. Try to place as many neighbor APs as possible in the weak coverage area to provide certain overlapped coverage. Also, prevent neighbor APs from the strong coverage area. Otherwise, conflicts occur and channels are hard to allocate. In addition, adjust the Tx power of APs to extend or narrow down the coverage area based on the preceding principles.

Figure 5-3 Intelligent power management



When a new distributed AP is added, reduce the Tx power of the gateway and the AP to eliminate external interferences. When a distributed AP is faulty, increase the Tx power of the gateway and the other APs to enhance coverage.

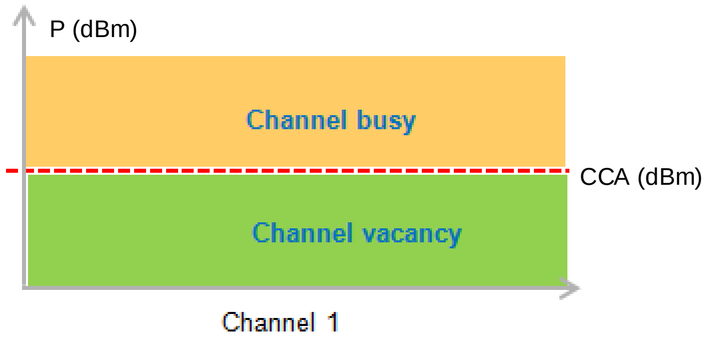
When data traffic and Tx power increase, external interferences increase accordingly. Under the conditions that performance meets requirements, traffic is small, and BER is low, reduce the Tx power. If data traffic increases or BER is high, increase the Tx power.

Gateways and APs can control their power for packets one by one. They check the signal strength of all terminals in real time. For a terminal close to an AP, if the signal strength of this terminal is greater than the target value, the AP automatically reduces the Tx power when sending data packets to it. For a terminal far away from an AP, if the signal strength of this terminal is small than the target value, the AP increases the Tx power when sending data packets to it.

5.2.2 Dynamic Anti-Interference

In dense and high-rise residential areas, users are hard to find clear channels. When APs share a congested channel, clear channel assessment (CCA) can be used to improve systems' capabilities to tolerate interferences. APs or terminals determine whether channels are idle by check their power.

Figure 5-4 Working principle of CCA



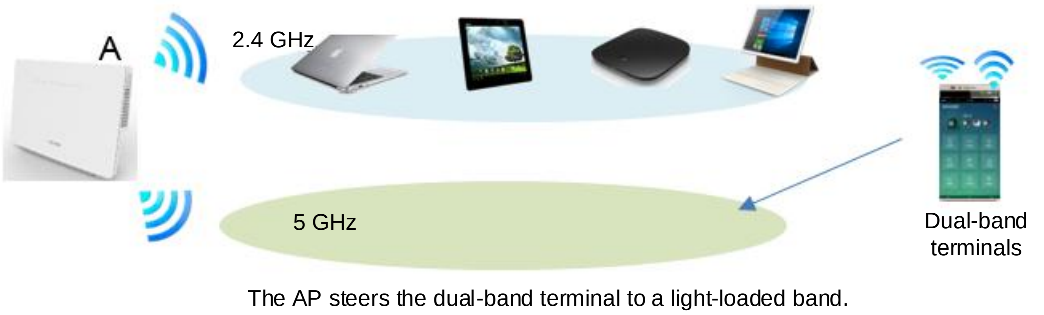
- When the power of a channel is great than or equal to the CCA threshold, the channel is considered busy and packets are not sent over this channel.
- When the power of a channel is smaller than the CCA threshold, the channel is considered idle and packets are sent over this channel.

In dense and high-rise residential areas, there are many APs and terminals close to each other, resulting in stronger signal strength than that in common scenarios. The power of channels is often greater than the CCA threshold and therefore, APs and terminals cannot send data over these channels. With the CCA optimization feature, the CCA threshold can be dynamically adjusted based on Wi-Fi channel interference conditions, BERs, and service demands. When a terminal meets BER requirements and has a high priority, the CCA threshold can be increased for it so that it receives more chances to transmit data.

5.2.3 Intelligent Band Steering

For band steering, when terminals support dual-band, gateways or APs steer the terminals to suitable bands based on the congestion conditions of the 2.4 GHz and 5 GHz bands, service features of the terminals, and received signal strength indicators (RSSIs) of bands.

Figure 5-5 Working principle of band steering



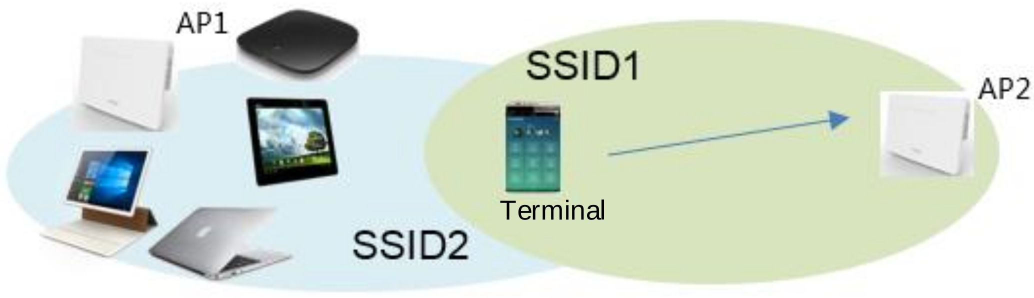
For SSID steering, when terminals can join multiple SSIDs, gateways or APs enable the terminals to join the most suitable SSID based on SSID congestion conditions and load balancing requirements.

Figure 5-6 Working principle of SSID steering

The AP steers the terminal to the light-loaded SSID.

AP steering: APs periodically scan channel information, find out overlapped neighbor APs, and record probing messages sent by all terminals. APs also need to record the current user density (RSSI) and air interface usage of each user, and periodically report the information to home gateways. These gateways then determine which AP of 2 adjacent APs is traffic or user overloaded, find out the terminals in the overlapped coverage area of the 2 adjacent APs, and switch the terminals connected to the overloaded AP to the light-loaded AP.

Figure 5-7 Working principle of AP steering

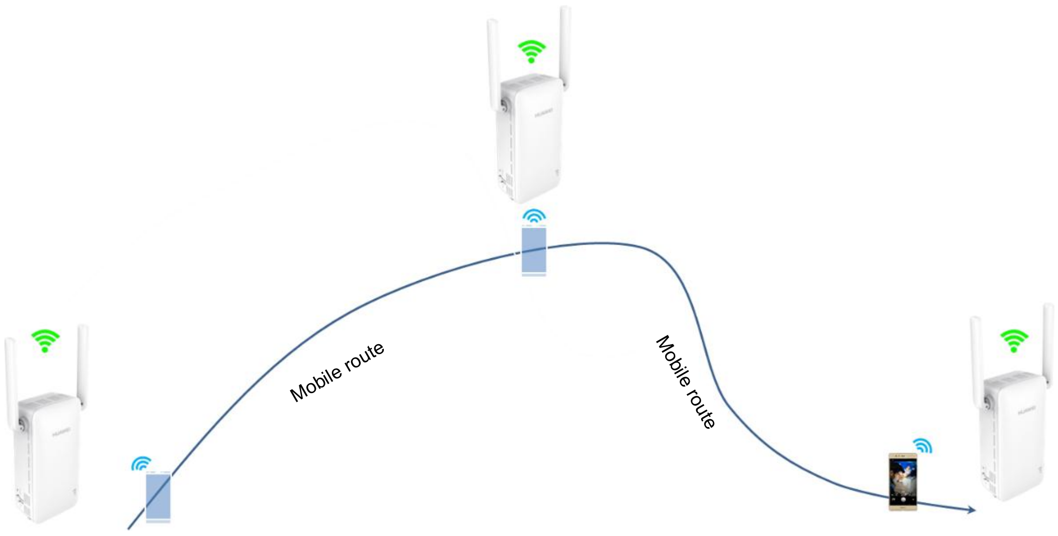


The AP steers the terminal to the light-loaded AP.

5.2.4 Intelligent Seamless Roaming

Seamless roaming technologies include the IEEE 802.11K, IEEE 802.11V, and IEEE 802.11R technologies. Through the IEEE 802.11K, STAs can measure the signal strength of APs and implement roaming based on measured results. Through the IEEE 802.11V, STAs can roam to specified channels and basic service set identifiers (BSSIDs). Through the IEEE 802.11R, STAs do not need to re-negotiate keys during roaming, saving roaming time.

Figure 5-8 Intelligent seamless roaming



Intelligent seamless roaming technologies IEEE 802.11K and IEEE 802.11V are supported by most terminals. However, many terminals do not switch to the AP with the strongest signal when they move. Gateways or APs are required to trigger proactive roaming to improve network performance. When an AP detects that indicators such as the RSSI, transmission success rate, and and rate of a terminal are lower than thresholds, this terminal is being away from the AP. In this case, the AP notifies the terminal to trigger roaming, and provides the terminal with information about the optimal target AP based on RSSI, cascading level, backhaul path, and load. Then, the terminal switches to the optimal target AP accordingly.

For the terminal that does not the IEEE 802.11K, when an AP detects that there is another AP which can provide better signal coverage for the terminal, the current AP forces the terminal to go offline; instead, the new AP connects to this terminal.

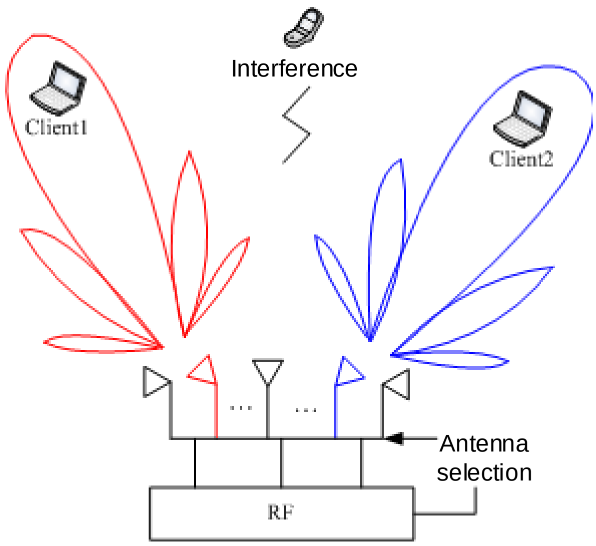
5.2.5 Baseband Beamforming

Figure 5-9 Working principle of baseband beamforming

Beamforming is a part of the IEEE 802.11n and IEEE 802.11ac protocols. It is referred to as "Tx beamforming" in these protocols. Through protocol-based interaction, APs obtain the basic channel information about terminals. Based on this information, baseband chips calculate the phase differences between spatial streams of different antennas and terminals. Multiple antennas are used to transmit the same data symbol, but the data symbol of each antenna uses a unique phase amplitude. In this way, the phases of multiple antenna signals are superposed in different directions and present different strengths, and the signal power of a specific Rx direction can be maximized. Because different antennas transmit the same data symbol, diversity gains are mainly obtained.

5.2.6 Intelligent Antenna Selection

Figure 5-10 Working principle of intelligent antenna selection



Similar to baseband beamforming, the intelligent antenna technology uses different hardware antennas to achieve different energy directivities for terminals.

1. Different omnidirectional antennas on an antenna array have some position differences. The length of the paths for transmitting signals to a terminal varies depending on omnidirectional antennas, resulting in different reaching time points (different phases). When the Tx phases are the same, some antennas have good impacts on the received signals of the terminal while the other antennas have bad impacts. For different terminals, an antenna combination needs to be selected to ensure the strongest signal superposition.
2. Directional antennas support much greater gains for signals in certain directions compared with omnidirectional antennas. Some antennas on the antenna array are designed with different directivities. For terminals in different directions, the optimal antenna combination can be selected to greatly improve the EIRP of specific terminals.

Each gateway or AP has a historical database, which records historical antenna combinations for all home terminals. When a terminal goes online, the optimal antenna combination is selected for the terminal based on historical information.

Data about the optimal antenna combination is sent to corresponding terminals.

Gateways or APs periodically send detection signals to terminals through antennas, analyze the antennas' impacts on these terminals, select the optimal antennas, and update historical databases accordingly.

When terminals move and RSSIs decrease, the process of reselecting the optimal antenna is triggered.

Unlike baseband beamforming, intelligent antenna selection does not obtain wireless channel parameters through protocol packet exchanges. In low-speed scenarios, diversity gains of antennas can be obtained. In high-speed scenarios where multiple spatial streams exist, multiplexed gains of antennas can be obtained.

5.2.7 Airtime Fairness Scheduling

For airtime fairness scheduling, the wireless channel occupation time of a certain type of service on each terminal is scheduled under the same RF to ensure that each terminal fairly occupies wireless channels when bearing the same type of service. Traditional APs implement first in first out (FIFO) queue scheduling on air interfaces and are confronted with problems as follows:

1. One terminal uses excessive downstream bandwidth resources, which is unfair for other terminals.
2. Some old (802.11b/g) low-speed terminals occupy excessive air interface resources. As a result, the overall throughput of the air interface decreases.

   For certain service queues, airtime fair scheduling makes the following improvements compared with FIFO queue scheduling:

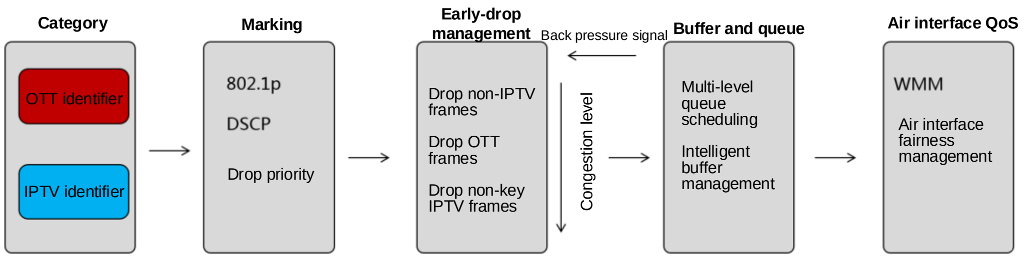
3. The scheduler periodically sends the same number of airtime tokens to all terminals. For to-be-sent packets, the scheduler estimates the airtime the packets requires and reduces corresponding airtime tokens of the destination terminal.
4. When the scheduler sends packets to the air interface, terminals are ranked based on the remaining time tokens from top to bottom. The packets of the terminal occupying the least airtime (that is, the terminal with the largest number of time tokens) are preferentially sent.
5. The scheduler periodically allocates time tokens to ensure statistics fairness in a long period.

5.3 Key Features of Video Bearing of Home Wi-Fi Networks

Home Wi-Fi networks need to be the networks that ensure video quality awareness and provide optimal video experience. As described in the preceding, video services have extremely high requirements on PLR and latency. To improve video bearing over Wi-Fi, operators need to focus on providing clear and exclusive channels and QoS scheduling preferentially for IPTV, and using re-transmission technologies if possible.

5.3.1 QoS Scheduling Preferentially for Video Services

Figure 5-11 QoS scheduling preferentially for video services



In the overall QoS architecture of a home gateway shown in the preceding figure, when this home gateway is directly connected through a Wi-Fi band to the STB with built-in Wi-Fi, the air interface channel in the downstream direction is a bottleneck for video services. If video services cannot exclusively occupy the downstream wireless channel, use the QoS scheduling mechanism to ensure that video packets are sent with high priorities.

The identifier identifies multi-channel IPTV video streams, OTT video streams, and key video frames while the marker marks 802.1p or DSCP values based on rules, and also marks the non-key frames for dropping.

The early-drop management module initiates an early drop based on back-end congestion levels. As the congestion deteriorates, this module drops the packets on queue tails based on service, terminal, and SSID priorities.

The queue and buffer management module sets the queue length, scheduling priority, weight, and rate limitation for all types of services on all terminals. The queue length of the UDP-based IPTV service must be as long as possible, while the queue length of the TCP-based OTT video service must be equal to bi-directional latency of mainstream OTT operators. Currently, the latency of 50 ms is generally designed.

The IEEE 802.11e is a Wi-Fi QoS standard and mainly defines the WMM mechanism. In this mechanism, there are 4 access categories (ACs): voice, video, best-effort, and back-ground queues in the descending order of priority. This mechanism ensures that the high-priority packets preferentially occupy wireless channels for transmission.

The WMM mechanism also defines enhanced distributed channel access (EDCA) parameters for channel competition between services.

1. Arbitration interframe spacing number (AIFSN): determines the channel idle time. A greater AIFSN value indicates longer channel idle time. When the channel idle time is short, there are more chances to obtain channels.
2. Exponent form of Cwmin (ECWmin) and exponent form of Cwmax (ECWmax): determine the average backoff time. A greater value indicates longer average backoff time.
3. Transmission opportunity (TXOP): determines the maximum duration in which a service can occupy a channel after it succeeds in a channel competition.

For video services, configure small AIFSN, ECWmin, and ECWmax values, and configure a large TXOP value to ensure that video services are preferentially transmitted on air interfaces.

In the IEEE 802.11ac wave2 MU-MIMO technology, a gateway forwards multiple data streams to different user terminals at the same time. By using the elimination or nulling method at the Rx end, the downlink MU-MIMO separates data streams and transmits them to different terminals. Alternatively, beamforming is used at the Tx end to separate data streams for different terminals in advance. This simplifies the operation at the Rx end. If the home gateway and the STB or the STB AP support the MU-MIMO technology, this technology can be enabled so that the STB or the STB AP can reach the maximum gain to receive signals.

5.3.2 CAC Control and Airtime Assurance Preferentially for Video Services

If video services cannot occupy exclusive wireless channels, shared channels need to be preferentially provided for them. For example, when a home gateway is cascaded to an STB AP through a 2.4 GHz channel and is also connected to many other terminals through the same channel, this gateway needs to increase the time slice scheduling weight for the STB AP upon AP startup. In this example, the STB AP is considered as a terminal connected to the home gateway through the 2.4 GHz band.

WMM conditional access control (CAC) mechanism:

1. Terminals must obtain permissions from APs or home gateways before sending high-priority voice and video packets in the upstream direction. Generally, home gateways only allow STBs or STB APs to transmit voice and video packets in the upstream direction, but prohibit other terminals from sending such packets. In this way, in the downstream direction of the air interfaces of the home gateways, video packets face no competition.
2. When the Rx BERs of STBs or STB APs are degraded, the terminals with low-speed and weak signals are forced to go offline, preventing them from affecting downstream video services.

6 Home Wi-Fi Network Deployment Suggestions in Typical Scenarios

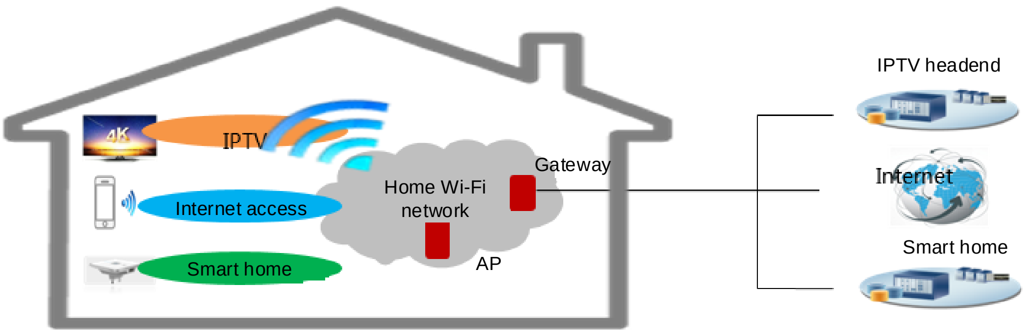
For high-value customers who live in large houses or villas, a single dual-band gateway cannot provide sufficient Wi-Fi coverage to ensure service experience. One smart dual-band gateway and multiple distributed APs can extend UBB to every corner in a house through media such as Ethernet cables, power lines, or Wi-Fi, so that users are able to enjoy over 100 Mbit/s bandwidth in all their rooms. In addition, the home network management platform makes home networks visible and manageable, and supports self-reliant home Wi-Fi management for users, enabling easy maintenance and usage. Through the cloud management platform and mobile phone App, home Wi-Fi networks can be rapidly installed, maintained, and managed, improving network operation efficiency.

6.1 Unified Multi-Service Network

As mentioned in the preceding, many problems occur when the IPTV service independently uses a LAN port on the CPE, for example, hindering the development of multi-service terminals. Operators need to reconstruct their service models to enable IPTV and HSI services to be carried over one physical home Wi-Fi network.

In the future, the home Wi-Fi network will be a multi-service network. On a physical network, voice, IPTV, OTT, HSI, and smart home services are logically isolated.

Figure 6-1 Integrated home network in the future



The home gateway identifies terminal types based on DHCP option 60 and assign certain user-side IP address. For the packets that are sent to the network side, they are identified based on their destination IP addresses and then sent to corresponding WAN ports when multiple WAN ports are used to differentiate services. For downstream packets, they are identified based on their source WAN ports, source IP addresses, and destination private network addresses. Different services can be isolated on a home network by using logical identifiers such as VLAN tags and SSIDs.

6.2 Multi-Media Expanded APs

Based on different upstream port modes, APs can be divided into Ethernet APs, Wi-Fi APs, PLC APs, and coaxial APs.

Ethernet APs use Ethernet cables for upstream transmission and transform existing wired networks into Wi-Fi networks. These APs support bridging and routing modes.

The Wi-Fi and HomePlug standards are common home network standards while the G.hn standard is a new home network standard. PLC APs are mainly developed based on HomePlug AV2 or G.hn technologies. In current markets, HomePlug AV2-based PLC modems are mainly used. Compared with HomePlug AV2-based APs, G.hn APs have a better mechanism to resist neighbor interferences.

Table 6-1 Technical comparison between G.hn modems and PLC modems

Technical Feature	G.hn Modem	Current PLC Modem
Neighbor interference processing mechanism	Optimized neighbor interference processing mechanism, which fully considers dense residential scenarios	Limited neighbor interference processing mechanism (not standard), which was initially developed for non-dense residential scenarios
Neighbor network interference testing	Speed decreased by less than 10%–15%	Speed decreased by more than 60%
Anti-interference (charger)	Speed decreased by 15%–20%	Speed decreased by 20%–30%

Wi-Fi APs are connected to gateways through Wi-Fi. These APs work in the relay mode and repeat Wi-Fi signals to extend existing Wi-Fi coverage.

Coaxial APs use indoor coaxial cables to transmit signals and comply with the MoCA, DOCSIS, or G.hn standard.

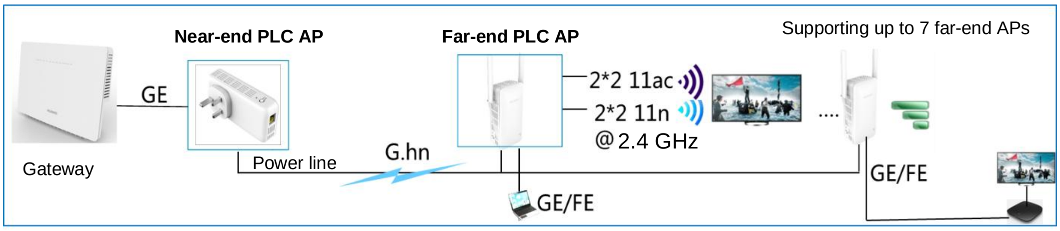
Table 6-2 Multi-medium extended APs

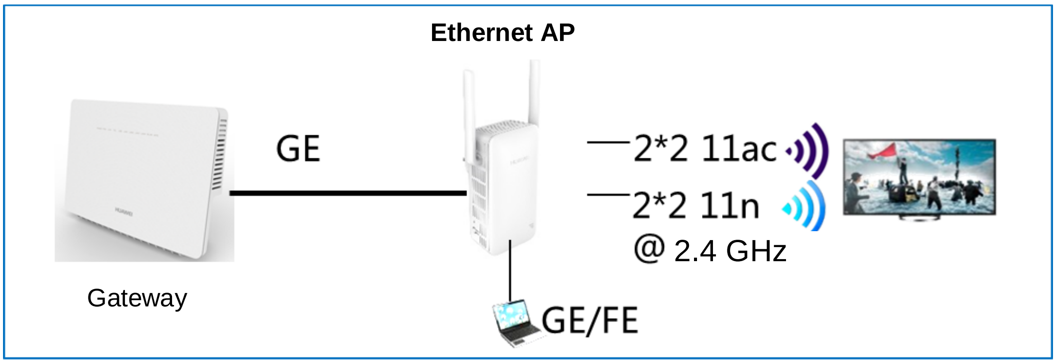
Device Model	Ethernet AP	Dual-band Wi-Fi AP	Tri-band Wi-Fi AP	G.hn PLC AP	G.hn Coaxial AP
Upstream port	1 x GE	5 GHz	5GHz band A	G.hn power line	G.hn coaxial cable
User-side air interface	2.4 GHz 5 GHz	2.4 GHz	2.4 GHz 5 GHz band B	2.4 GHz 5 GHz	2.4 GHz 5 GHz
User-side wireless port	N x GE	N x GE	N x GE	N x GE	N x GE

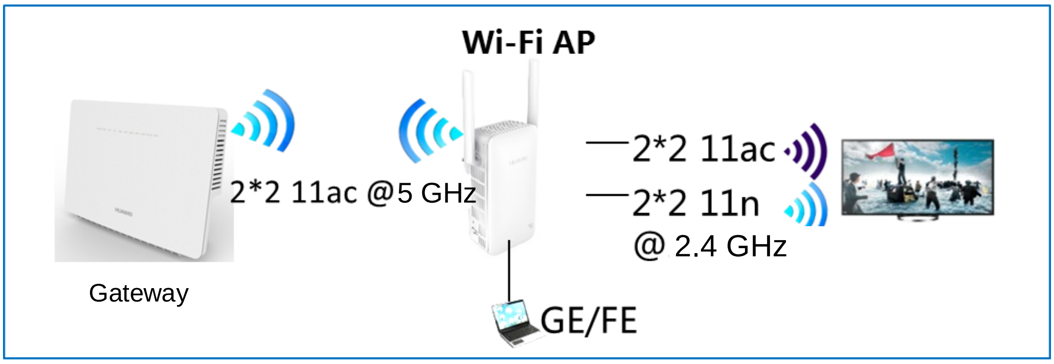
NOTE

1. Single-band APs are not recommended due to insufficient rates and anti-interference performance.
2. PLC APs and coaxial APs must work together with near-end G.hn PLC modems and coaxial modems.
3. HomePlug AV and HomePlug AV2 PLC APs are not recommended because they lag far behind G.hn APs in terms of anti-interference performance.

Figure 6-2 Wi-Fi extension of PLC, Ethernet, and Wi-Fi APs







From the perspective of performance, APs are ranked as follows: Ethernet AP > G.hn coaxial AP > G.hn PLC AP > Wi-Fi AP. From the perspective of networking convenience, APs are ranked as follows: Wi-Fi AP > G.hn PLC AP > Ethernet AP > G.hn coaxial AP. Different APs need to be combined based on room environments.

6.3 Deployment and Design Principles of Home Network Wi-Fi

1. Based on the size of a house and the number of rooms in the house, determine whether to use distributed APs and estimate the number of APs required.

Table 6-3 Distributed Wi-Fi coverage solution recommended based on house characteristics

House Type	1 Bedroom + 1 Living Room (< 40 m²)	2 Small Rooms (40–60 m2)	2 Large Rooms (70–80 m²)	3 Small Rooms (70–90 m²)	Large House (100–120 m²)	Large House with 2 Floors (Each Floor: 80 m²)	Villa with 3 Floors (Each Floor: 70 m²)
Wi-Fi device	Dual-band smart gateway	Dual-band smart gateway + 1 x AP	Dual-band smart gateway + 1 x AP	Dual-band smart gateway + 1 x AP	High-end dual-band smart gateway + 2 x AP	Floor 1: High-end dual-band smart gateway + +1 x AP Floor 2: 2 x AP	Basement: 1 x AP Floor 1: High-end dual-band smart gateway + +1 x AP Floor 2: 1 x AP Floor 3: 1 x AP

2. Note that load-bearing walls, floors, and metal coated glass may block Wi-Fi signals. For outdoor yards, large balconies, and compound rooms, independently add APs for good Wi-Fi coverage.

3. Determine the deployment positions of home gateways based on the positions of broadband drop cables. Generally, broadband drop cables are cross-connected in integrated information boxes and cannot be extended indoors. If the CPEs provided by operators are gateway CPEs, place them in the integrated information boxes.
4. Determine the deployment positions of gateways and APs based on house structures, indoor obstacles, and electrical appliance-caused interferences. If possible, put gateways and APs in the middle of a planned coverage area and ensure that no obstacles exist and they are placed at high positions for better coverage. In addition, keep them far away from electrical appliances such as microwave ovens, 2.4G cordless mice, and 2.4G cordless phones.
5. For video services, consider networking designs in advance. If possible, use network cables to connect STBs and gateways. If such operations are prohibited, try to use the G.hn PLC technology (gateway + near-end PLC modem + far-end PLC AP + GE port + STB). If sockets are unavailable or power meters are deployed between them, try to connect the STBs to the gateways through 5G Wi-Fi. If the STBs do not support 5G Wi-Fi, add APs beside the STBs.
6. For common services, attach great importance to Wi-Fi coverage. For common places where users access the Internet, such as a living room, study room, or master room, pre-evaluate whether their signal strength is strong enough. If the signal strength is insufficient, adjust gateway or AP positions or add new distributed APs.
7. After an overall plan is made, find out signal deadzones and optimize them accordingly. After an overall plan diagram is output, check for possible signal deadzones and areas with weak signal coverage. For example, if signals in yards or balconies are found to be weak, make partial optimizations: increase Tx power of the APs or slightly adjust their positions.
8. Networking design: Home network devices include the bridge CPE, home gateway, and distributed AP. The bridge CPE and the home gateway may be integrated into one device. When they are separated, try to connect them through a GE link instead of a FE link. For the backhaul link that connects the distributed AP to the gateway, use the Ethernet cable, G.hn power line, exclusive 5 Ghz frequency band, or shared 2.4 GHz frequency band (repeater mode) in the descending order of priority. One or more of them can be used based on situations.
9. RF design: For the AP and gateway using Wi-Fi frequency bands for backhaul, try to use a tri-band system. For other APs, use a dual-band system. Ensure that each frequency band supports as many antenna MIMO and working bandwidths (2.4 GHz: 20 MHz or 40 MHz; 5 GHz: 20 MHz, 40 MHz, 80 MHz, and 160 MHz) as possible. In addition, try to use the antennas that support large gains.
10. Subnet SSID design: Design different SSIDs, such as IPTV SSIDs, HSI SSIDs, children-intended HSI SSIDs, and guest SSIDs based on service types and user groups. All the SSIDs are encrypted through WPA2. It is optional to set passwords for guest SSIDs. The access permissions of guests can be controlled through mobile phone Apps.
11. Allow users to configure security functions, including MAC address access lists, parental control, MAC address-based traffic limitation, network address and port translation (NAPT) based on service requirements.

6.4 Home Wi-Fi Network Deployment in Typical Scenarios

6.4.1 Wi-Fi Solution Design for a Small House

Figure 6-3 Wi-Fi solution design for a house with a bedroom and a living room

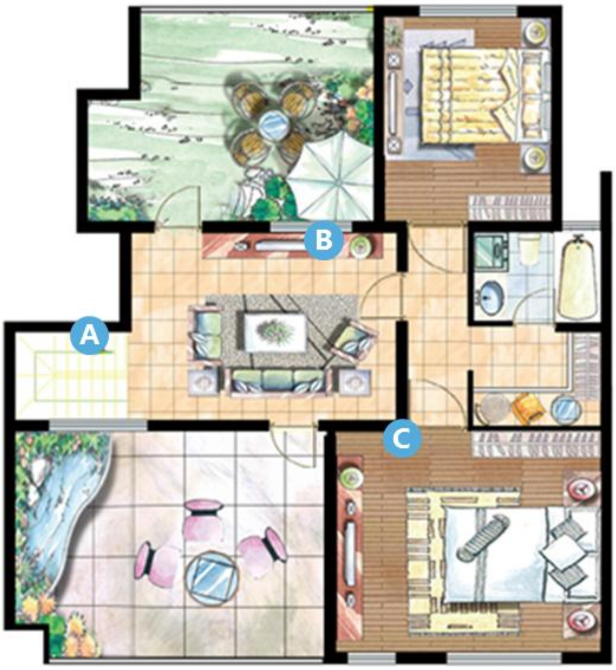
In the house with a room or with a bedroom and a living room, one dual-band gateway generally can meet requirements because there are few walls affecting signal transmission. In this scenario, determine whether to connect an STB through Wi-Fi. If this STB does not support 5 GHz Wi-Fi, it is recommended that a home gateway be deployed on the home information box and a distributed AP be deployed beside the STB, as shown in the preceding figure.

Figure 6-4 Wi-Fi solution design for a house with 2 small rooms

In the preceding scenario, one dual-band gateway deployed at position A generally can meet requirements. If an STB needs to be connected through 5 GHz Wi-Fi, it is recommend that the gateway be deployed at position B where an information box locates and the STB-intended AP be deployed at position A.

6.4.2 Wi-Fi Solution Design for a Medium House

Figure 6-5 Wi-Fi solution design for a house with 2 large rooms (tower-style)



In the tower-style house, the thick concrete walls are deployed around the living room, greatly affecting Wi-Fi transmission. In such a scenario, attach importance to Wi-Fi coverage in the living room and master bedroom. As there are doors and windows between the living room and 2 balconies, users in these balconies can receive Wi-Fi signals from the living room. To bear IPTV services over Wi-Fi, deploy a gateway at position A where an information box locates and respectively deploy a distributed AP at positions B and C.

Figure 6-6 Wi-Fi solution design for a house with 3 rooms

In the house with 3 square-like rooms, each AP can provide wider Wi-Fi coverage. To ensure good Wi-Fi coverage, deploy a gateway at position A where a home information box locates and deploy an AP at position B in the living room where an STB locates. This AP is used for STB backhaul and also provides Wi-Fi coverage in the living room. In addition, deploy a distributed AP at position C to provide Wi-Fi coverage in several bedrooms.

6.4.3 Wi-Fi Solution Design for a Large House

Figure 6-7 Wi-Fi solution design for a large house

A large house requires more APs to enhance Wi-Fi coverage. In the preceding scenario, deploy a gateway at position A where a home information box locates, deploy an AP at position B to meet STB demands, and respectively deploy an AP at positions C and D to provide Wi-Fi coverage in the bedroom and study room.

6.4.4 Wi-Fi Solution Design for a Multi-Floor House or Villa

Figure 6-8 Wi-Fi solution design for a multi-floor house or villa

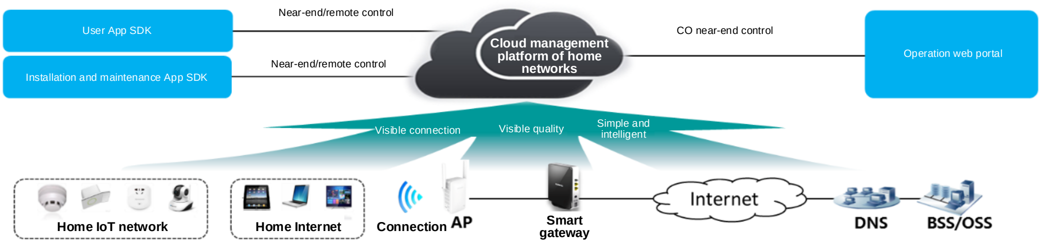
In the preceding scenario, try to put a home gateway at position A in the living room where an STB locates. If broadband cables are only available on an information box, place the gateway at position D. In addition, respectively deploy an AP at positions A, B, and C.

Figure 6-9 Wi-Fi solution design for a multi-floor (greater than 3 floors) house or villa

In the preceding scenario, deploy a home gateway at position A in the living room at floor 1, deploy an AP beside an STB in the entertainment room of the basement, and add an AP at position C to cover the dining room, kitchen, and garden. In addition, respectively deploy an AP at floors 2 and 3 to cover bedrooms.

6.5 Building Visible and Manageable Home Wi-Fi Networks

Figure 6-10 Visible and manageable home Wi-Fi networks



Operation Role	Key Features, Meeting Demands in All Phases of All Scenarios						Values
	Easy to Use	Visible Detection	Simplified Configuration	Remote Troubleshooting	Proactive Optimization	Operation Analysis	
User	▲	▲	▲	▲			Easy to use, customization, self-reliant management, and enhanced experience
Installation and maintenance personnel		▲	▲	▲			Fast networking and enhanced onsite maintenance capabilities
NOC		▲	▲	▲	▲		Visible network, remote troubleshooting, and proactive optimization
Operation Dept.					▲	▲	Measurement and analysis of home network experience indicators for better operations

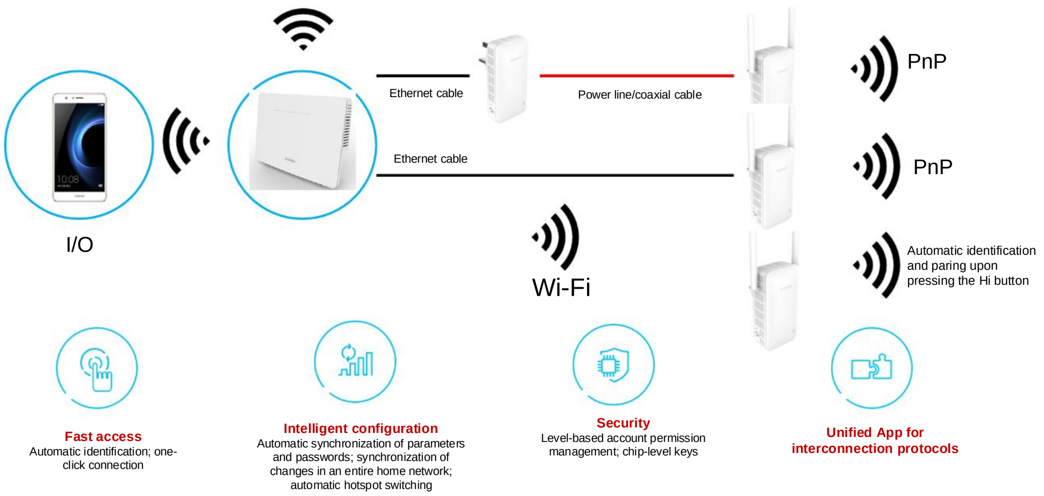
The operation and management architecture of home Wi-Fi networks includes the following logical components:

1. Home gateway:
   (1) Serves as a border between the home network and broadband network to identify videos and other services.
   (2) Serves as the center to manage and optimize home network topologies and Wi-Fi in a centralized way.
   (3) Provides topologies, network status data, logs, and event alarms for the management platform.
2. Basic home Wi-Fi network:
   (1) Uses distributed APs and user-side Wi-Fi components of gateways to provide Wi-Fi for upper-layer services.
   (2) Provides basic Wi-Fi running status for gateways.
   (3) Receives management instructions from gateways.
3. Home service network: consists of multiple service terminals, including STBs, tablets, and PCs of the basic Wi-Fi network.
4. Smart home IoT network: consists of the IoT components with low power consumption.
5. Cloud management platform:
   (1) Collects data and status of home Wi-Fi networks.
   (2) Provides functions including device management, troubleshooting, performance management, service data configuration, and logs for big data analysis.
   (3) Provides O&M APIs for portal components.
6. Portal components: include the O&M App, user App, and O&M portal.

6.5.1 AP PnP

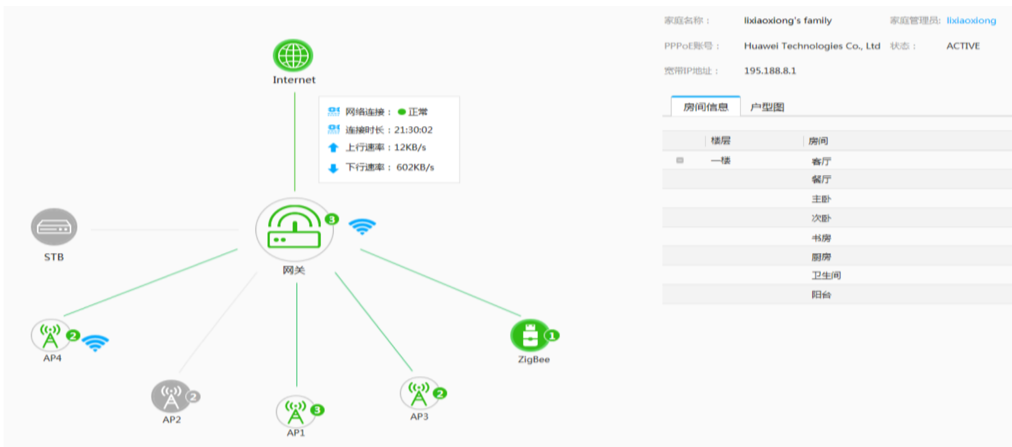
After a new AP is powered on, the gateway automatically discovers the AP and displays a prompt on the mobile phone App. Users can allow the AP to access through the App or by pressing the WPS button. By doing so, wireless configurations of the gateway are automatically synchronized to the AP.

Figure 6-11 Gateway and AP PnP



6.5.2 Visible and Manageable Home Wi-Fi Networks

Figure 6-12 Management over the home network topologies



The following information about home Wi-Fi networks need to be visible:

1. WAN-side connection status of home gateways
2. Status, topologies, link status, rates, and congestion conditions of gateways and distributed APs
3. Air interface status, channels, BERs, and power of gateway Wi-Fi components and APs

4. IP addresses, MAC addresses, access SSIDs, signal strength, BERs, and real-time upstream and downstream rates of all terminals connecting Wi-Fi
5. Home Wi-Fi devices can be managed as follows:
6. Gateway and AP software can be upgraded.
7. Gateways and distributed APs can be reset, removed from networks, and added to networks, and their ports can also be enabled or disabled.
8. Gateways and distributed APs can be set to perform loopback tests, rate testing, and hardware and software self-check. Their topologies can also be changed.
9. Terminals can be removed from networks, added to networks, or forcibly switched to new APs.
10. Home Wi-Fi data can be configured.
11. Information about channels, SSIDs, power, encryption, and passwords can be set and be automatically synchronized among APs.
12. Parental control, security policies, terminal rate limitation, and CAC policies can be configured.

The cloud management platform provides the installation and maintenance App, user App, and O&M portal with different visibility and management scopes.

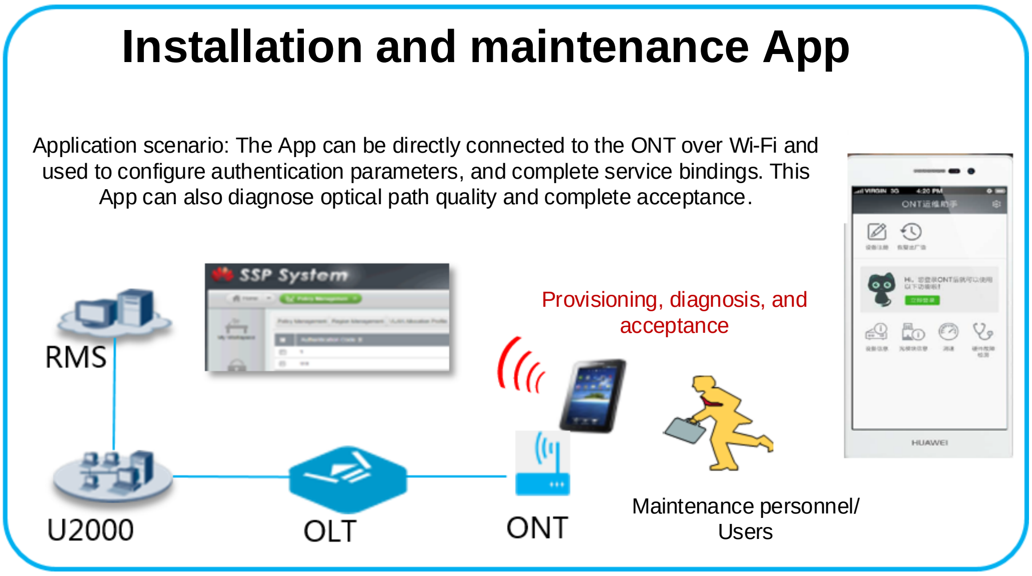
6.5.3 Remote O&M over Home Wi-Fi

The cloud management platform provides the following automatic O&M capabilities:

1. Collects home Wi-Fi network information in real time and automatically analyzes data including Wi-Fi and video services to detect abnormalities. If a threshold-crossing event occurs, an automatic handling process is initiated:
   (1) Check the broadband network and Wi-Fi network.
   (2) Test pre-configured service plug-ins.
   (3) Trigger partial or comprehensive Wi-Fi network optimization.
   (4) If abnormalities persist, report them to maintenance personnel for processing.
2. Outputs expected data based on the collected historical data of all users, and compares the expected data with the data collected in real time to detect abnormalities.
3. Learns and trains accumulated big data to improve algorithm accuracy to detect abnormalities.

6.5.4 Installation and Maintenance Tool of Home Wi-Fi Networks

Figure 6-13 Installation and maintenance App of home networks



The installation and maintenance App provides work order processing, site entrance planning, design deployment, project acceptance, and other functions. This App can:

1. Accept, process, and submit electronic work orders.
2. Analyze household characteristics, provide deployment suggestion, select APs, and output plans in the planning process.
3. Automatically connect to the cloud and gateways, obtain configurations, and complete the configuration of accounts, Wi-Fi, and APs through one click.
4. Provide professional automation test tools to evaluate quality and automatically output acceptance reports in the acceptance process.

This App can be used by community managers to rapidly resolve faults. Because this App is developed based on the cloud management platform, it enables people to obtain status data quickly. In addition, with the one-click detection tool package, this App supports real-time detection and fast fault identification.

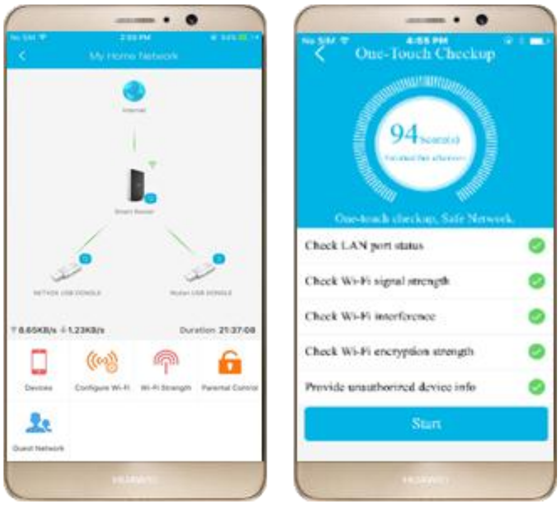
6.5.5 Performance Analysis Tool

The cloud management platform provides various performance analysis tools to support operations. Based on a large amount of historical Wi-Fi performance data, this platform can generate Wi-Fi performance quality reports from multiple dimensions, such as the dimensions of single-user historical data, regional Wi-Fi quality analysis, and community signal strength analysis.

For example, the cloud management platform can evaluate the quality of single-user data periodically and score data quality. It can also rank these scores to identify poor-quality users and then perform proactive maintenance and optimization. In addition, this platform can compare user quality scores before and after optimization, and evaluate optimization effects.

6.5.6 User App, Bringing Smart Wi-Fi Networks

Figure 6-14 User App of home networks



Users can install the mobile phone App to easily manage their Wi-Fi networks:

1. Remote management: Users can use the user App anywhere to manage and control their Wi-Fi networks.
2. Terminal-based policy formulation: Users can define policies such as bandwidth allowed or prohibited based on the terminals connecting to Wi-Fi.
3. Security management: The Wi-Fi function can be enabled on a regular basis, guest-intended SSIDs can be set, and guest devices can connect to Wi-Fi without password authentication.
4. Self-reliant service subscription: Users can subscribe for bandwidths based on demands and apply for bandwidth acceleration for video services.

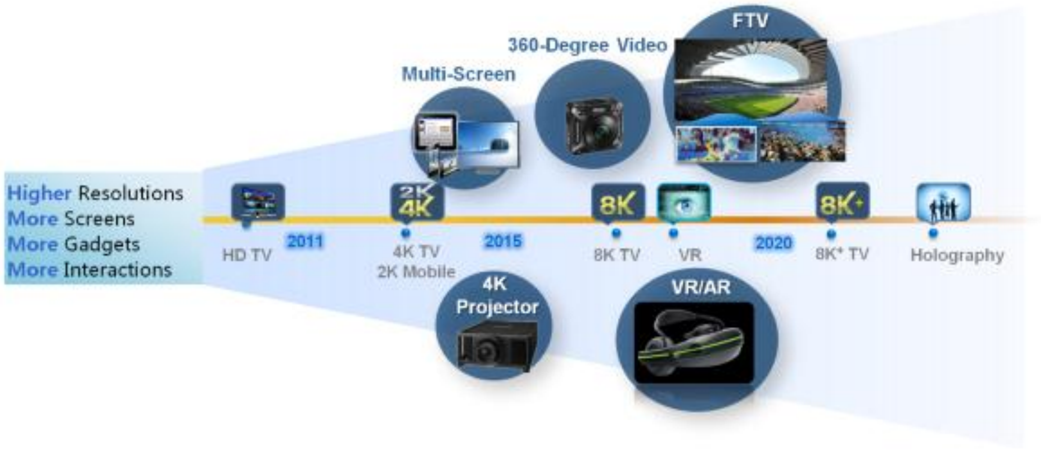
Users can use the mobile phone App to maintain Wi-Fi networks, relieving operators' pressures in maintenance. This App can enable users to:

1. Install new extended APs by themselves.
2. Identify connection and hardware faults on the visible home Wi-Fi interface.
3. Use the one-click detection tool to detect configuration faults.

7 Outlook

End users are always pursuing better service experience, higher definitions, more screens, and more watch modes, driving video traffic to grow continuously.

Figure 7-1 Endless pursuit of better service experience



The growing number of mobile terminals and gradual popularization of smart home pose increasingly high demands on Wi-Fi coverage, rates, and latency.

With the spring-up of 4K videos, 100 Mbit/s Wi-Fi will be commonly required. In the next few years, UHD video services such as 8K and VR will gradually emerge, demanding for over 100 Mbit/s bandwidth.

8 Appendix A: References

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2. TR 126: Triple-play services quality of experience (QoE)
3. IEEE 802.11n: Higher throughput improvements using MIMO
4. IEEE 802.11ac: IEEE standard for telecommunications and information exchange between systems - LAN/MAN specific requirements - Part 11: wireless medium access control (MAC) and physical layer (PHY) specifications: high-speed physical layer in the 5 GHz band

9 Appendix B: Acronyms and Abbreviations

Acronym and Abbreviation	Full Name
AP	access point
SSID	service set identifier
IPTV	Internet Protocol television
GE	Gigabit Ethernet
STB	set-top box
PLC	power line communication
WAN	wide area network
LAN	local area network
Wi-Fi	wireless fidelity

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