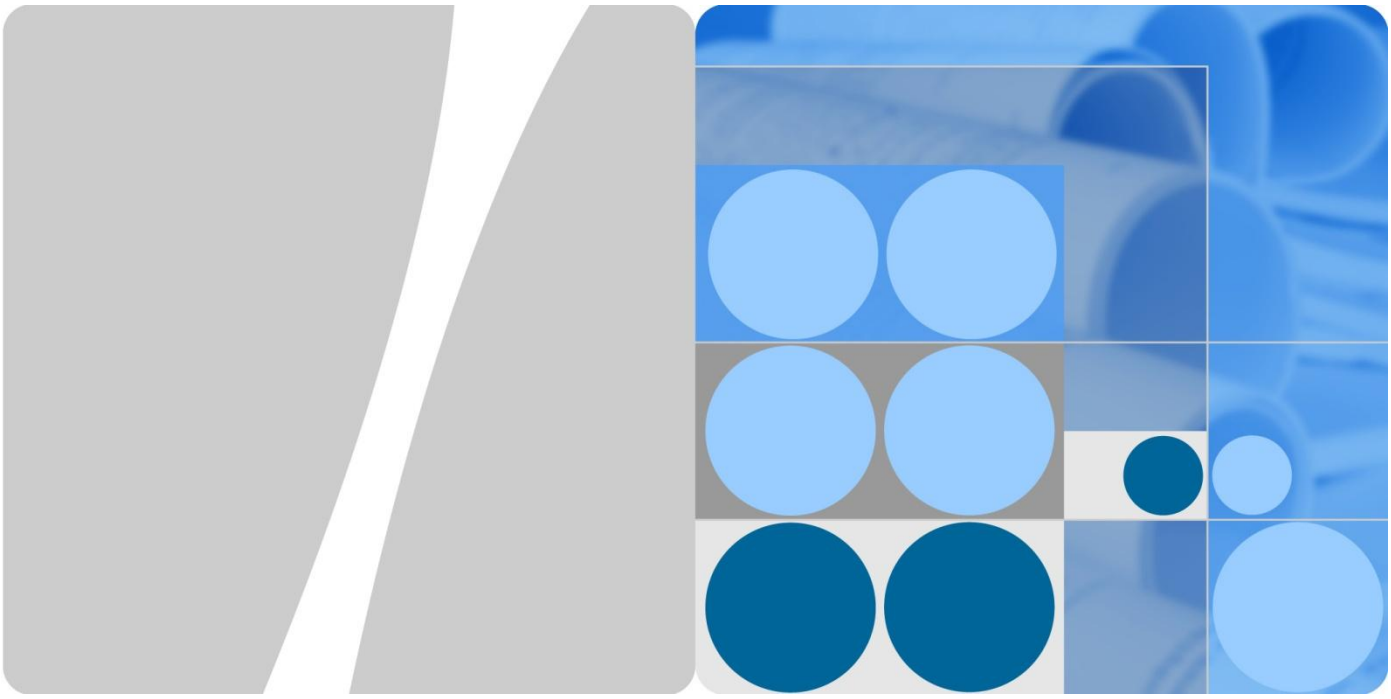

WLAN Smart Roaming Technology White Paper

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WLAN Smart Roaming Technology White Paper

Key word:

Sticky terminals, terminal identification, 802.11k, 802.11v, smart roaming

Abstract:

Some Wi-Fi terminals are insensitive to roaming. When the signals of their connected APs become poor, they stick to the connected APs but do not roam to APs with better signals. These terminals are called sticky terminals. Sticky terminals degrade network experience and affect the network capacity. To address the stickiness problem, Huawei develops the smart roaming feature. This document describes how smart roaming addresses the problems of sticky terminals.

Acronyms and Abbreviations

Acronyms and abbreviations	Full Name
AP	Access Point
AC	Access Controller
RRM	Radio Resource Management
SNR	Signal-to-Noise Ratio
CAC	Connection Access Control
RSSI	Received Signal Strength Indicator

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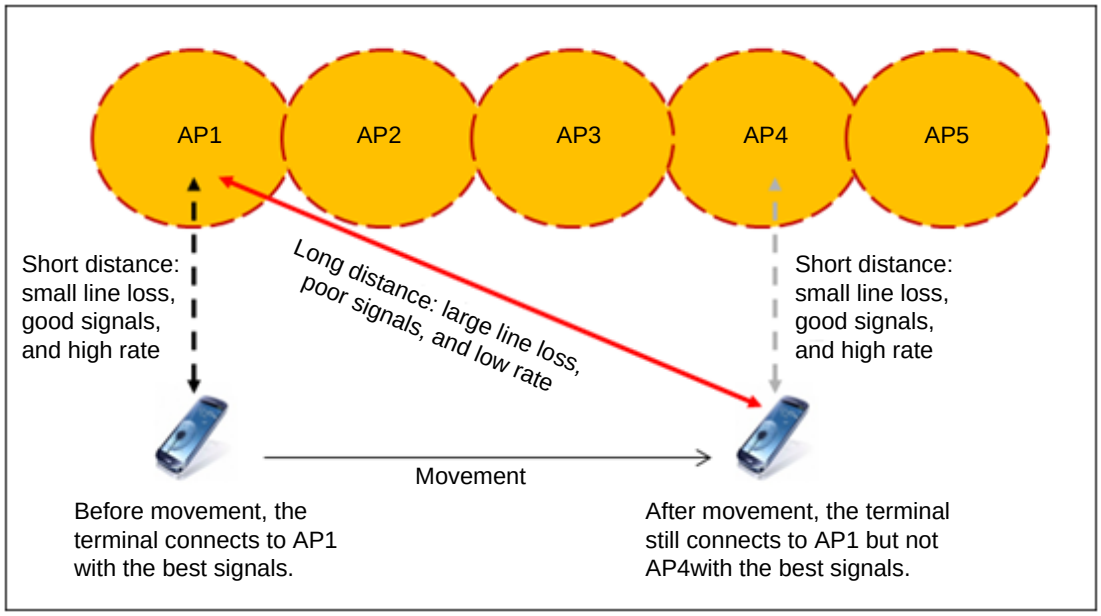
1 Background

In a 3rd Generation Partnership Project (3GPP) system, terminal behavior is controlled by the network side. For example, the switchover behavior of a terminal in mobile scenarios is controlled by the network side, including the switchover parameter configuration, switchover judgment, and switchover triggering. The terminal only executes the switchover. Such a switchover mechanism has two advantages. On one hand, the mechanism enables the switchover to be controlled globally and ensures good switchover performance. One the other hand, the mechanism shields differences among terminals to the maximum extent. The switchover (roaming) mechanism in the WLAN system is different. Before the 802.11k/v standards are introduced, parameter configuration, switchover judgment, and switchover triggering are all controlled by the terminal side. The roaming behavior of terminals varies due to difference in terminal implementation of various vendors. For example, some terminals are insensitive to roaming. When the signals of their connected APs become poor, they stick to the connected APs but do not roam to APs with better signals. These terminals are called sticky terminals.

Figure 1-1 Sticky terminals in mobile scenarios



As Wi-Fi smart terminals and applications become popular, people pay increasing attention to impact of sticky terminals on the network. Particularly, sticky terminals have the following adverse effects on user experience and network performance in high-density scenarios with limited capacity, such as exhibition halls and sports stadiums.

1. Reduces the network capacity.

   If terminals roam to APs with better signals, the terminals will be under better signal coverage, and receive and send data at higher rates. However, the sticky terminals fail to roam properly but use low rates to receive and send data, which means longer time to occupy the air interface. This not only lowers the throughput of other terminals (especially high-rate terminals) connected to the same AP but also the overall AP throughput.

2. Lowers user experience.

   During movements, if a terminal cannot promptly switch to APs with better signals, signals of the terminal deteriorate and its rate decreases, resulting in poor user experience. When a terminal "hangs" on an AP, services will become unstable or even unavailable. In addition, low-rate sticky terminals occupy a large amount of air interface time, affecting service experience of other terminals.

3. Damage channel planning.

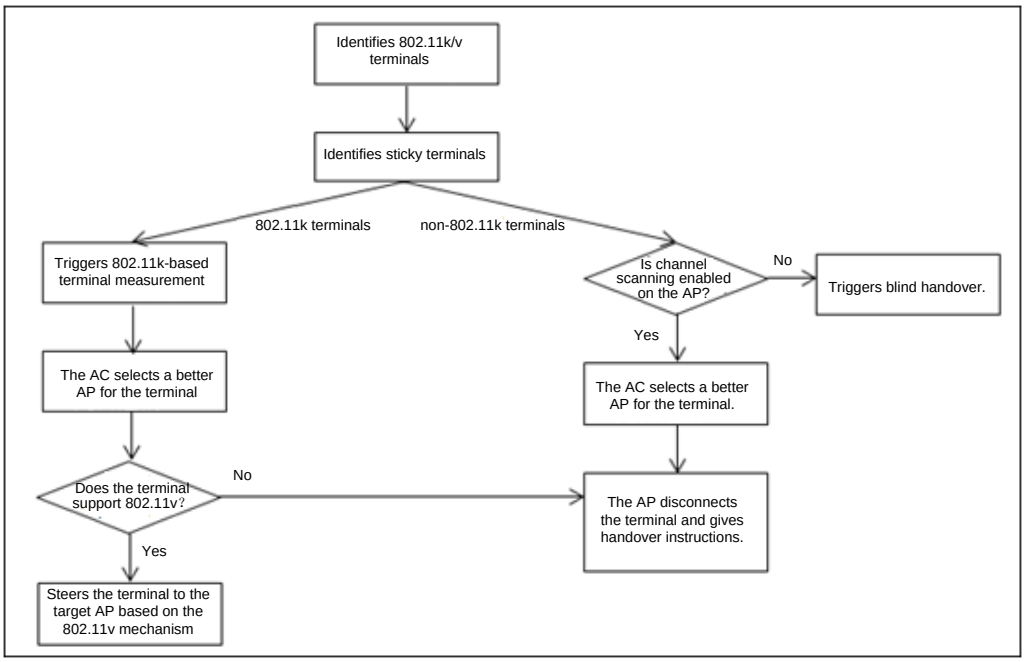
   To achieve a higher capacity, channel planning is performed for the deployed APs during network planning, which makes use of channel multiplexing to reduce interference between APs. However, stickiness of terminals damages the channel planning. Channels are introduced into an area where they do not belong, and may interfere with the existing channels in the area. Channel interference reduces network capacity and degrades user experience.

   Huawei designs the smart roaming feature to solve the problem of sticky terminals. The feature can identify sticky terminals on the network and select different modes to connect them to more suitable APs according to the terminal capability. Smart roaming can eliminate the effect of sticky terminals to improve user experience and increase the network capacity.

2 Implementation

Actually, not all terminals available on market are sticky terminals, but sticky terminals bring a significant impact. To settle the problem of sticky terminals, the sticky terminals must be identified first. As capabilities of sticky terminals vary, the sticky terminals also need to be classified according to their capabilities so that they can be steered to more appropriate APs in different modes.

Figure 2-1 Working principle of smart roaming



The figure shows the working principle of smart roaming. A roaming process involves three phases: roaming measurement, roaming decision, and roaming execution. The network side makes measurements and collects information to determine sticky terminals and their capabilities, and determine whether sticky terminals need to roam and which APs they roam to according to the decision mechanism and collected information, and help the sticky terminals roam to more suitable APs during roaming execution.

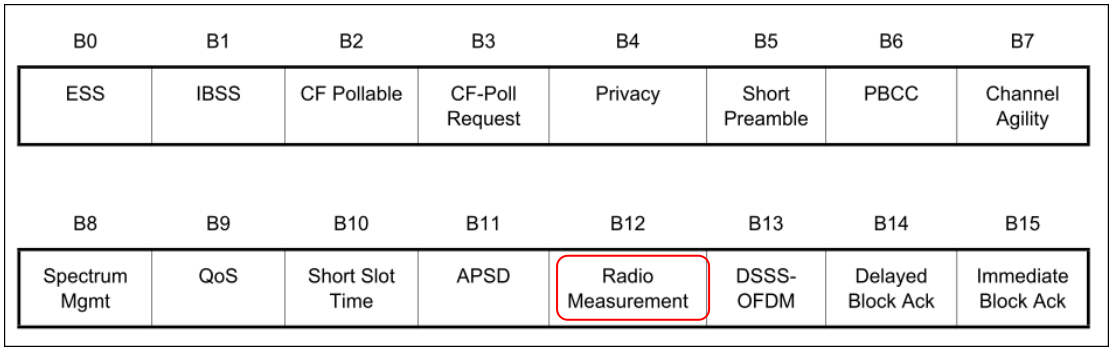
2.1 Identifying Terminal Capability

1. Identify 802.11k terminals.

   802.11k is a member of the 802.11 protocol family. It provides a Radio Resource Management (RRM) measurement mechanism, which includes the measurement contents of terminal statistics, hidden node, channel load, and roaming. Through 802.11k, the network side can obtain more information related to the radio environment. The information helps the network side to proactively manage and schedule terminal and network resources, improving radio resource usage efficiency and delivering better network performance and terminal experience.

   To implement the 802.11k measurement mechanism, both the network side and terminal side need to support the 802.11k measurement mechanism. The network side advertises its 802.1k capability through **Radio Measurement** of the **Capability IE** field in Beacon frames and Probe Response frames while the terminal advertises its 802.1k capability through **Radio Measurement** of the **Capability IE** field in Assoc Request frames. The network side can identify whether the terminal supports 802.11k by analyzing the **Capability IE** field in the Assoc Request frames. If **Radio Measurement** is set to 1, the terminal supports 802.11k; if **Radio Measurement** is set to 0, the terminal does not support 802.11k.

Figure 2-2 Capability IE



2. Identify 802.11v terminals.

   802.11v is a WLAN management protocol that provides energy saving, location, and terminal management capabilities. The smart roaming feature exploits the terminal management capability of 802.11v that enables the network side to steer the terminal to a specified AP. The terminal advertises whether it supports this steering mechanism in the **BSS Transition** field. By analyzing the **BSS Transition** field in Assoc Request frames of a terminal, the network side determines whether the terminal supports 802.11v. If **BSS Transition** is set to 1, the terminal supports 802.11v; if **BSS Transition** is set to 0, the terminal does not support 802.11v. The red box in the following figure shows the **BSS Transition** field.

Figure 2-3 Extended capability field

Bit	Information	Notes
14	Civic Location	The STA sets the Civic Location field to 1 when dot11RMCivicMeasurementActivated is true, and sets it to 0 otherwise. See 10.11.9.9.
15	Geospatial Location	The STA sets the Geospatial Location field to 1 when dot11RMLCIMeasurementActivated is true, and sets it to 0 otherwise. See 10.11.9.6.
16	TFS	The STA sets the TFS field to 1 when dot11MgmtOptionTFSActivated is true, and sets it to 0 otherwise. See 10.23.11.
17	WNM-Sleep Mode	The STA sets the WNM-Sleep Mode field to 1 when dot11MgmtOptionWNMSleepModeActivated is true, and sets it to 0 otherwise. See 10.2.1.18.
18	TIM Broadcast	The STA sets the TIM Broadcast field to 1 when dot11MgmtOptionTIMBroadcastActivated is true, and sets it to 0 otherwise. See 10.2.1.17.
19	BSS Transition	The STA sets the BSS Transition field to 1 when dot11MgmtOptionBSSTransitionActivated is true, and sets it to 0 otherwise. See 10.23.6.
20	QoS Traffic Capability	The STA sets the QoS Traffic Capability field to 1 when dot11MgmtOptionQoSTrafficCapabilityActivated is true, and sets it to 0 otherwise. See 10.23.9.

It is inaccurate to determine whether a terminal supports 802.11v according to the extended capability field in Assoc Request frames. Some terminals claim 802.11v support but do not support 802.11v in actual situations. A mechanism is therefore designed to identify terminals that make deceptive claims about 802.11v support. If a terminal fails to implement a handover through 802.11v three consecutive times, the terminal does not support 802.11v.

The AP report terminal capability identification results to the AC, and the AC records the capability of each terminal so that the network side can take measures accordingly.

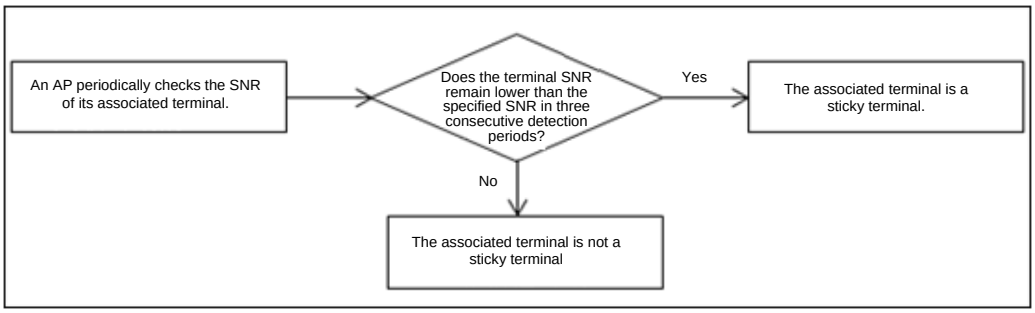
If the network side fails to trigger roaming of a terminal several consecutive times, the AC records the terminal "unable to roam". The network side does not trigger roaming of such type of terminals within a certain period even if these terminals are detected as sticky terminals. The roaming failure here includes:

- The terminal forced offline sticks to the last associated AP even if a better AP exists.
- The terminal does not associate with any AP after being disconnected. The terminal does not go online or roam to another AP within five seconds after it is forced offline.

2.2 Identifying Sticky Terminals

Each AP has a certain coverage range. During wireless network planning, an edge SNR is designed for each AP at the coverage edge to meet the edge throughput requirements. Each service area should have a primary service AP. When terminals are located in the core coverage range of the AP, there should be no neighboring APs with better signals for the terminals. If the SNR of terminals received by the AP is not lower than the edge SNR of the AP, terminal roaming does not need to be triggered. Therefore, sticky terminals can be identified based on the terminal SNR received by their associated APs.

Figure 2-4 Identifying sticky terminals based on SNR



An AP periodically checks the SNR of its associated terminal. If the terminal SNR remains lower than the roaming threshold in three consecutive detection periods, the current terminal is a sticky terminal. The AP then reports the MAC address and SNR information of the terminal to the AC. After a terminal is detected as a sticky terminal, the sticky identity of the terminal is valid for 40 seconds.

Huawei smart roaming can also identify sticky terminals based on rate ratio check. The identification logic is similar to the SNR-based identification logic. The rate ratio can be calculated based on the following formula:

Rate ratio = Current link setup rate/Maximum rate supported by the terminal

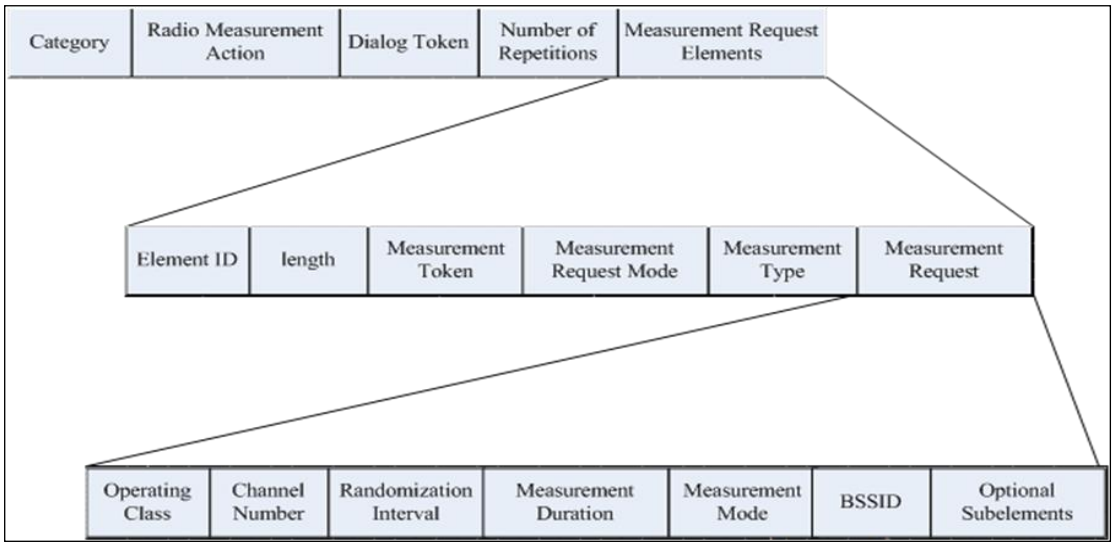
2.3 Measuring Neighboring APs

802.11k and non-802.11k sticky terminals are not differentiated. To help an identified sticky terminal selects a more suitable AP, the network side needs to collect information about APs around the terminal. 802.11k provides an information measurement and collection mechanism, which applies to terminals that support 802. 11k. For terminals that do not support 802.11k, the APs need to actively scan and listen on packets to collect information about neighboring APs.

1. 802.11k terminals

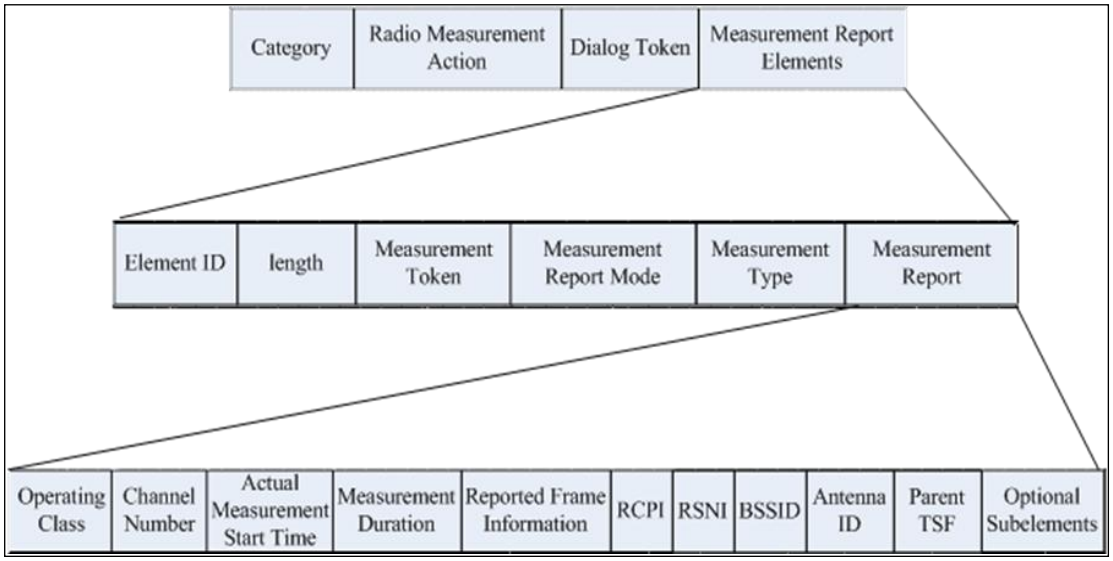
   When an AP detects an 802.11k sticky terminal, the AP triggers 802.11k-based neighbor measurement of the terminal to collect neighboring AP information and reports the collected information together with the sticky terminal information to the AC.

Figure 2-5 Radio Measurement Request frame format



In 802.11k, the network side and terminal side exchange measurement information through Radio Measurement Request and Radio Measurement Report frames. Roaming-related measurement is one of the measurement modes defined by 802.11k. The measurement modes of 802.11k use the same measurement frame format and are differentiated by setting different values for specific fields. The smart roaming feature uses Beacon Request frames (**Measurement Type** is set to 5) to provide measurement request information to terminals. The Beacon Request frames contain the channel set and SSID information to be measured.

Figure 2-6 Radio Measurement Report frame format



Terminals report the measurement information to APs through the Radio Measurement Report frames. The smart roaming feature uses Beacon Report frames (**Measurement Type** is set to 5) to provide the measurement information to APs. The Beacon Report

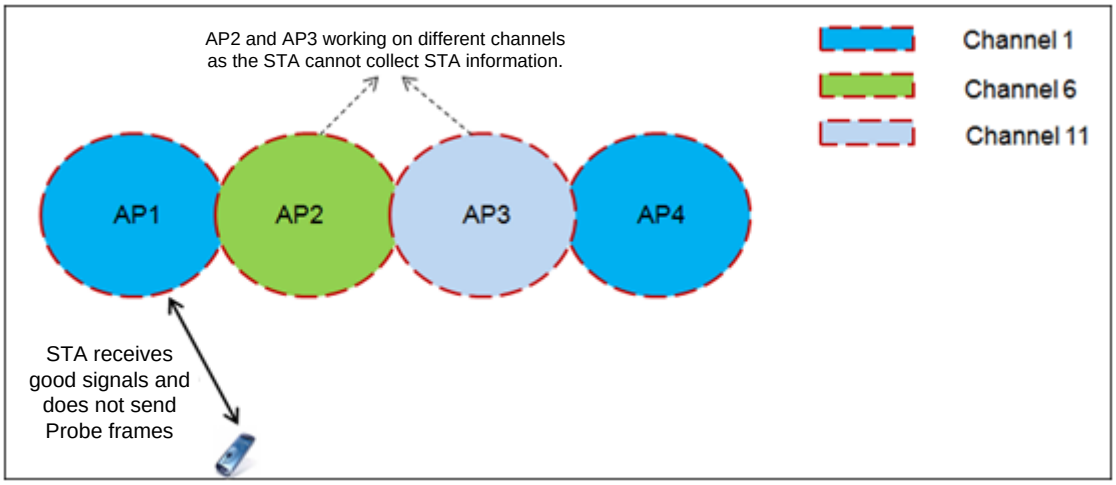
frames contain the BSSID, signal strength, and channel information of specific APs measured by the terminals.

In the measurement result, Received Channel Power Indication (RCPI) and Received Signal to Noise Indication (RSNI) indicate the signal strength information. The smart roaming feature makes comparison and decision based on RCPI.

2. Non-802.11k terminals

Most terminals start channel scanning and send Probe frames when their signal strength is lower than a threshold. The threshold is usually lower than the roaming threshold. Some terminals have a long channel scanning period, which may cause the terminals unable to send Probe frames when they have good signals. As a result, neighboring APs cannot collect information of the terminals. The APs are therefore required to automatically switch channels to listen on frames of terminals and collect terminal information.

Figure 2-7 APs in different channels as the STA cannot collect STA information



APs need to work in hybrid mode to listen on radio frames sent by terminals. To reduce the impact of channel switching and scanning on performance, the scan channel, period, and interval can be flexibly configured according to actual requirements.

The scan channel configuration is described as follows:

The AP only needs to scan channels used by neighboring APs but not all channels. For example, if only channels 1, 6, and 11 are used, the AP only needs to scan the three channels. In high-density scenarios such as sports stadiums, APs are placed in close proximity. The APs only need to detect co-channel terminals, which can also solve the problem of a large number of sticky terminals. In this case, the APs only need to periodically work in hybrid mode, which has a little impact on the air interface performance.

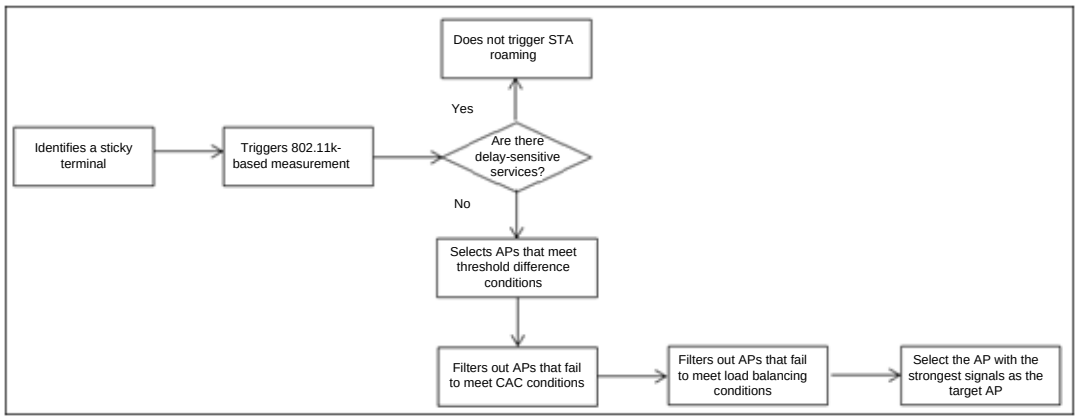
An AP periodically reports the detected SNR of terminals not associated with it to the AC. The AP does not report SNR of all detected terminals to the AC due to the following two reasons: it is a heavy burden for the AC to process all terminal information; only information of better-signal terminals is useful, and the report AP is possibly the target AP of the sticky terminal. Therefore, the AP filters the signal strength information and reports only information of terminals whose SNR exceeds the start SNR of the target AP.

2.4 Selecting a Suitable AP

1. 802.11k terminals

   After an AP identifies an 802.11k sticky terminal, the AP triggers 802.11k-based measurement of the terminal to collect information about neighboring APs. The AP reports the collected neighboring AP information to the AC, and the AC determines the target AP for the sticky terminal. The following figure shows the process that the AC uses to select a target AP for the sticky terminal.

Figure 2-8 Selecting a target AP for an 802.11k terminal



(1) Check whether there are delay-sensitive services.

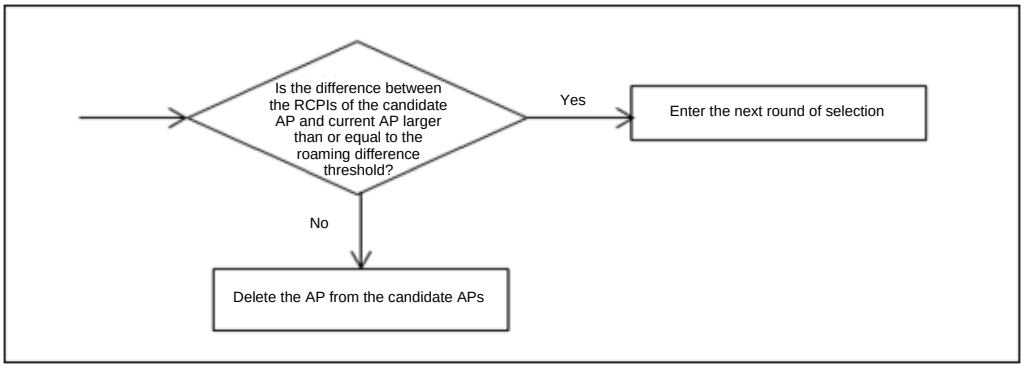
Roaming may interrupt delay-sensitive services. When there are delay-sensitive services, roaming is not recommended. To guarantee user experience, do not trigger smart roaming for terminals with delay-sensitive services.

Delay-sensitive services can be determined based on the voice optimization feature. Users can specify certain services as delay-sensitive services and configure follow-up actions to be taken on the services, for example, stop channel scanning on APs and stop roaming of sticky terminals running the services.

When APs are in centralized forwarding mode and application identification is enabled on the AC, delay-sensitive services on terminals can only be identified through the application identification module.

(2) Select APs that meet threshold difference conditions.

Figure 2-9 Selecting APs that meet threshold difference conditions

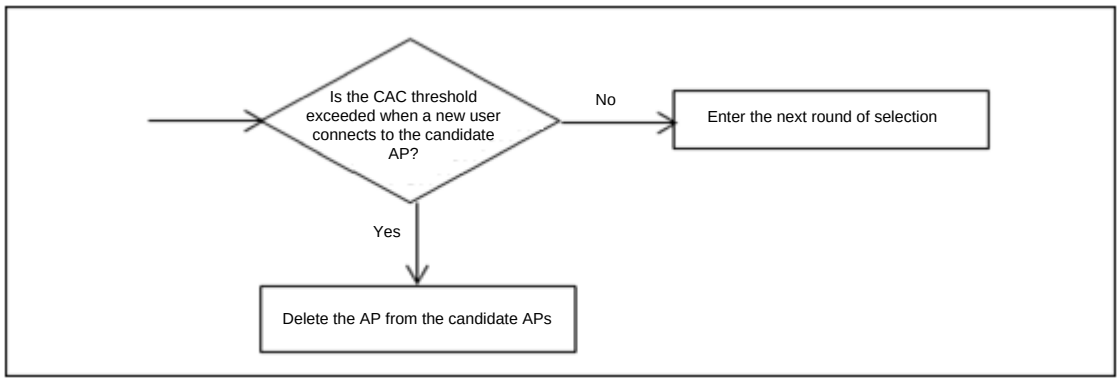


Only when the difference between the RCPIs of the candidate AP and current AP is greater than or equal to the roaming difference threshold, the AP can enter the next round of selection.

(3) Filter out APs that cannot meet CAC conditions.

On WLANs, users compete fiercely to occupy the channels as the number of online users increases. As a result, network experience of each user deteriorates. To ensure network access experience of online users, Calling Access Control (CAC) is configured. CAC allows an AP to control user access based on the CAC thresholds specified according to the radio channel usage and number of online users, which enables provision of quality network access services.

Figure 2-10 Filtering out APs that cannot meet CAC conditions

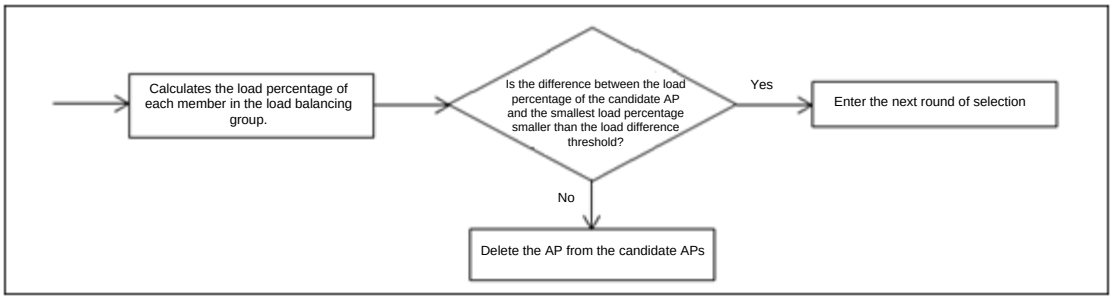


In smart roaming, CAC check is performed on APs that meet threshold difference conditions to prevent experience degradation of online users caused by roaming and ensure user experience of roaming terminals.

(4) Filter out APs that cannot meet load balancing conditions.

On networks enabled with load balancing, when a STA requests to associate with an AP, the AC first determines whether the number of access users on the AP exceeds the start threshold for load balancing. If not, the AC allows the STA to go online; if so, the AC determines whether the STA access is permitted based on the load balancing algorithm.

Figure 2-11 Filtering out APs that cannot meet load balancing conditions



Load balancing check is performed on APs that meet the CAC conditions. APs that fail to meet load balancing conditions are filtered out. The preceding figure shows the procedure. The AC calculates the load percentage of each radio in a load

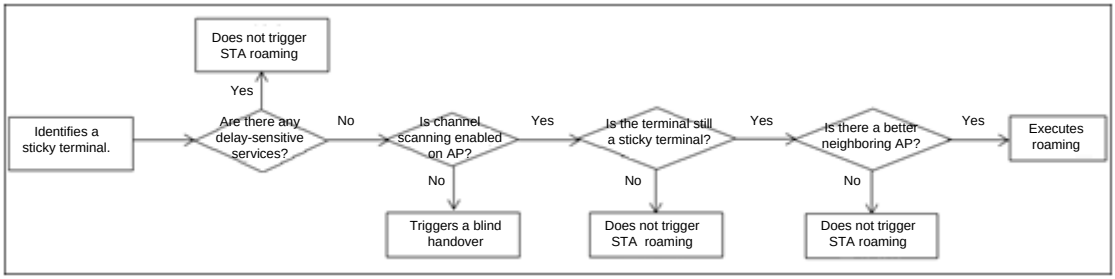
balancing group using the formula: Load percentage of a radio = (Number of associated STAs on the radio/Maximum number of STAs allowed on the radio) x 100%. The AC compares load percentages of all radios in the load balancing group and obtains the smallest load percentage value. When a STA requests to associate with an AP radio, the AC calculates the difference between the radio's load percentage and the smallest load percentage value and compares the load difference with the threshold. If the load difference is smaller than the threshold, the AC considers load balanced, allows the STA to associate with the radio, and allows the AP to enter the next round of selection. If not, the AC considers the load unbalanced and deletes the AP from the candidate APs.

(5) Select the AP with the strongest signals as the target AP.

The AC selects the AP with the strongest signals as the target AP from the qualified APs. The network side will steer the sticky terminal to the target AP during the handover execution phase.

2. Non-802.11k terminals

Figure 2-12 Selecting a target AP for a non-802.11k terminal



For non-802.11k sticky terminals, APs need to scan channels to obtain information about neighboring APs to determine whether better neighboring APs exist for the terminals. The preceding figure shows the process of selecting target APs for non-802.11k terminals.

(1) Check whether there are delay-sensitive services.

The delay-sensitive services are described in the preceding paragraphs and not provided there. For details, see related descriptions for 802.11k terminals.

(2) Check whether channel scanning is enabled on APs.

Channel scanning is already described in the preceding paragraphs. For details, see related descriptions in 2.3 Measuring Neighboring APs.

If channel scanning is disabled, a blind handover will be triggered. During a blind handover, the AP does not know whether there is a better AP and still disconnects a terminal to force the terminal to have a roaming attempt. If a terminal is detected a sticky terminal three consecutive times by the network side, a blind handover is triggered. If the blind handover of a terminal fails (the terminal cannot find a better AP) three consecutive times, the terminal is considered at the edge of blind spot areas, where no better neighbor exists. The terminal will not implement blink handovers any longer. After a period, the terminal may move to a non-edge area from the edge of the blind spot area. The state of the terminal at the edge of the blind spot area will be aged.

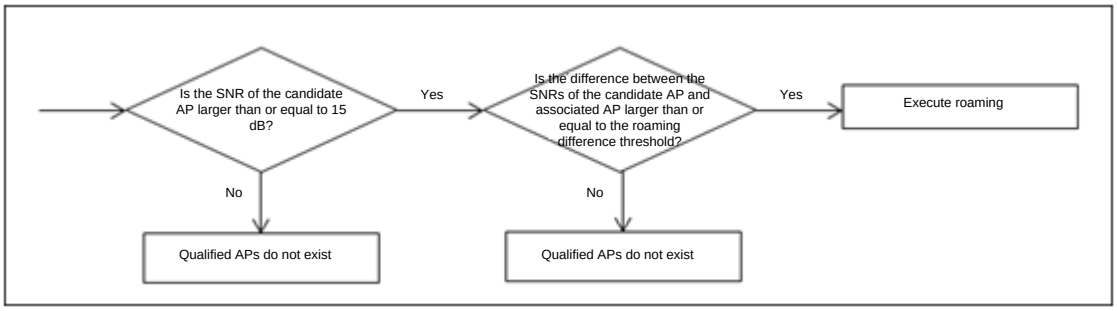
(3) Check whether the terminal is still a sticky terminal.

As there is a delay for the AP to periodically report measurement information to an AC, the AC needs to determine whether the reported terminal is still a sticky

terminal when using the reported terminal information. If the latest time when the terminal is marked as a sticky terminal does not exceed the aging time of the sticky state, the terminal is still a sticky terminal.

(4) Check whether a better neighboring AP exists.

Figure 2-13 Checking whether better neighboring APs exist for non-802.11k terminals



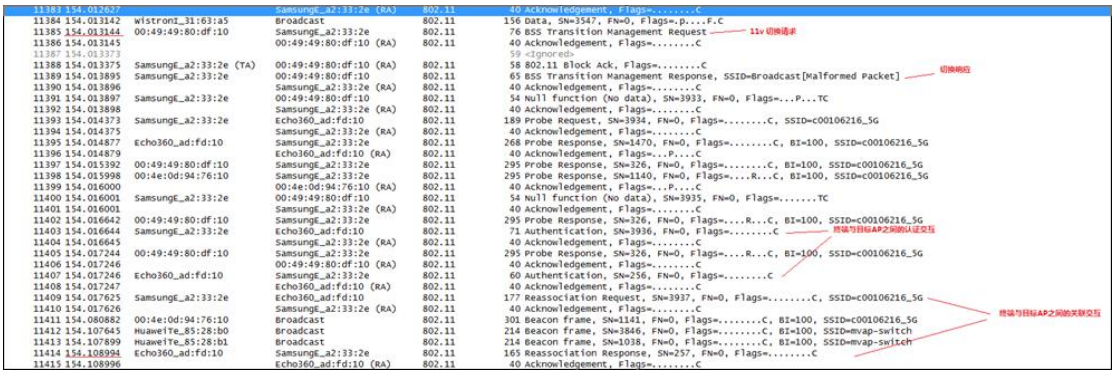
The SNR of the reported terminal must be larger than a certain SNR; otherwise, the AP to which the terminal roams cannot have signal quality guarantee. Signal difference check is performed on APs that meeting certain conditions. When the difference between the SNRs of the candidate AP and associated AP is greater than or equal to the roaming difference threshold, the AP is a better neighboring AP.

2.5 Executing Smart Roaming

1. 802.11v terminals

   The network side specifies target APs for terminals supporting 802.11v according to a certain selection process and sends target AP information to the terminals through BSS Transition Management Request messages. The following figure shows the obtained packets of an 802.11v SAMSUNG GALAXY NOTE3 terminal, which responds to BSS Transition Management Request messages of the AP with BSS Transition Management Response messages. After the terminal completes authentication interaction with the target AP, the terminal sends a reassociation message to connect to the target AP.

Figure 2-14 Packets of a GALAXY NOTE3 (802.11k, 802.11v) terminal

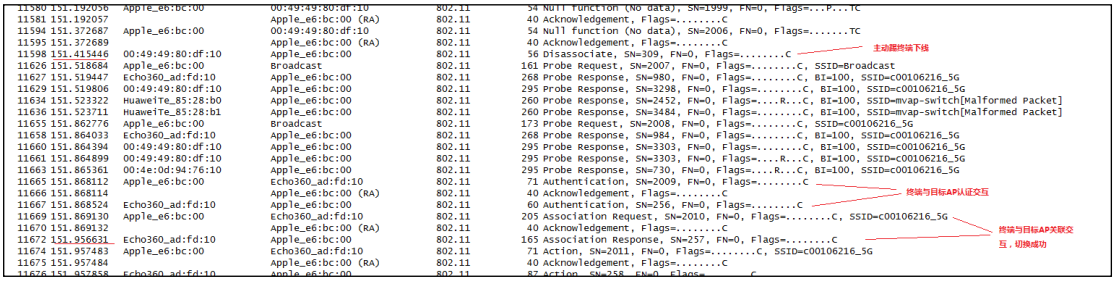


2. Non-802.11v terminals

The network side cannot specify target APs for non-802.11v terminals because the terminals cannot use the 802.11v interaction mechanism, and the network side cannot control the terminal behavior or to which AP the terminals will switch. In this case, it is meaningless to select specific APs for the terminals.

For terminals that do not support 802.11v, the AC instructs their associated APs to disconnect the terminals and add the terminals to the blacklists of the APs. The APs stop responding to probe frames of the terminals 10 times and refuse association of the terminals once.

Figure 2-15 Packets of an iPhone 5C (supporting 802.11k, but not 802.11v)



The preceding figure shows packets obtained during roaming of a iPhone 5C terminal (supporting 802.11k, but not 802.11v). The AP sends a Disassociation packet to disconnect the terminal. After the terminal completes authentication interaction with the target AP, the terminal sends a reassociation message to connect to the new AP.

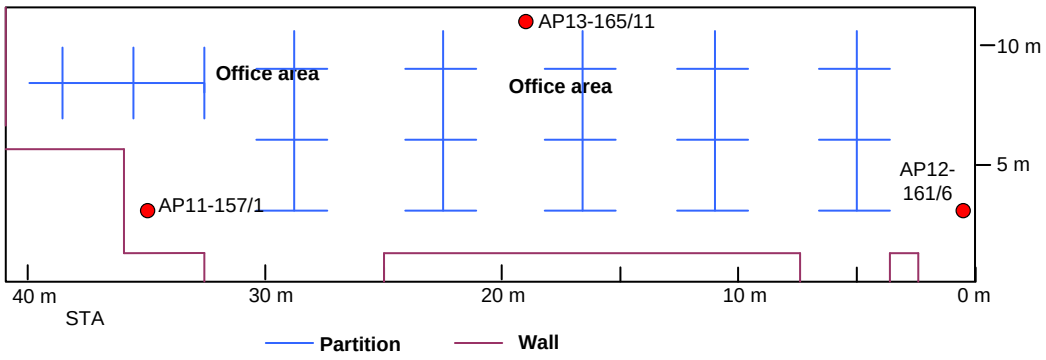
3 Customer Benefits

1. Improves user experience.

   During movements, if a terminal cannot promptly switch to APs with better signals, signals of the terminal deteriorate and its rate decreases, resulting in poor user experience. The smart roaming feature can identify sticky terminals and uses different methods to steer the terminals to APs with better signals based on terminal capabilities, improving the throughput and user experience.

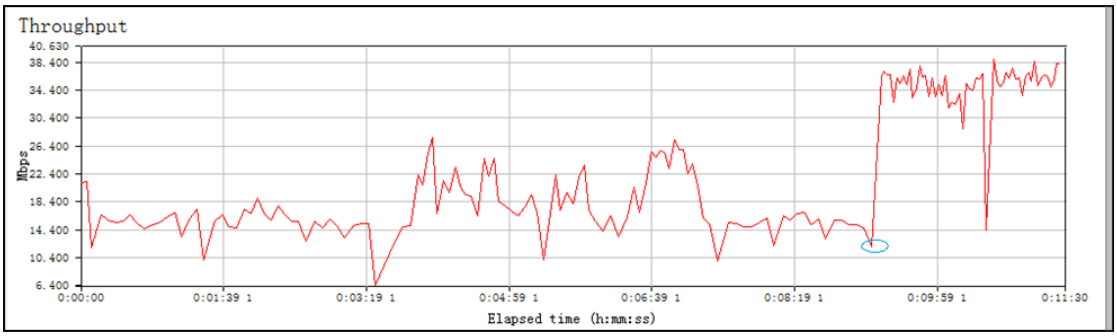
   The following figure shows a sticky terminal test (GALAXY NOTE3 supporting 802.11v, 802.11k, 802.11k neighbor information collection, and 802.11v handover). The test area has three APs (AP12, AP13, and AP14). When a terminal moves towards AP13, it associates with AP13. When the terminal moves to the position (3, 30), it still associates with AP13.

Figure 3-1 GALAXY NOTE3 test scenario



Smart roaming is enabled a few minutes after traffic sending is started. The terminal quickly roams from AP13 to AP11. The following figure shows the impact of handover on throughput after smart roaming is enabled. The blue circle indicates the occurrence of a handover. The throughput increases by more than 50% after the handover.

Figure 3-2 GALAXY NOTE3 performance comparison before and after the handover



2. Increases system throughput.

   Sticky terminals have poor signals and low rates because the handover is not performed in a timely manner. Low rates mean longer time to occupy the air interface. This not only lowers the throughput of other terminals (especially high-rate terminals) connected to the same AP but also the overall AP throughput. Smart roaming ensures that each terminal can connect to the optimal AP (generally the nearest AP) and obtain the best throughput experience, thereby increasing the overall system throughput of the AP and experience of all users connected to the AP.

3. Enhances network reliability.

   Based on the smart roaming feature, the network side can continuously optimize the connectivity performance of terminals and ensure that the terminals can connect to the network from the optimal APs and obtain the best performance. Smart roaming prevents terminal movements from deteriorating network performance of the local terminal and other terminals, and guarantees reliable network experience. It also reduces user complaints about unstable network connections.

4. Prevents terminal capability from affecting roaming performance.

   Terminals on the live network are of various types and capabilities. Roaming capability of different terminals also varies. Some terminals support smooth roaming but some are sticky terminals. Some terminals support 802.11k and 802.11v while some are legacy terminals and do not. The smart roaming feature can identify different terminal capabilities promptly and continuously help terminals with roaming difficulties to roam, ensuring that each terminal on the network has a smooth roaming experience.

4 Typical Applications

The smart roaming feature is designed for sticky terminal scenarios. Actually, sticky terminals may exist in any scenarios. These sticky terminals have a small number but a large impact on the network, especially in high-density scenarios that have high requirements on air interface performance, the impact of the sticky terminals on the network is multiplied.

Therefore, the smart roaming feature can be applied to any scenarios, and is especially effective for high-density scenarios.

4.1 Large News Conference

Figure 4-1 Large news conference

In some large news conferences, such as Huawei annual HNC, Huawei offers free Wi-Fi access services to guests and media personnel. High-quality Wi-Fi access enables easy Internet access, and receives praises and recognition from conference attendees. However, there are problems caused by sticky terminals. For example, an important guest needs to attend another session after finishing a session, but the two sessions are held in different conference rooms. The guest finds that the network access becomes very slow or the network even becomes unavailable after moving to the new conference room. The terminal displays weak signals. However, many APs are deployed in the conference room, and the signal coverage is good. Obviously, the poor signals are caused by terminal roaming. The terminal hangs on the old AP rather than roaming to a new AP with better signals. The roaming feature can identify sticky terminals on the network in time and use different methods to help sticky terminals roam to more suitable APs according to terminal capabilities. This resolves the sticky terminal problems, improves user experience, and increases network capacity.

4.2 High-Density Stadium

Table 4-1 High-density stadium

Deploying Wi-Fi in large sports stadiums has become a trend. In Europe, Huawei has successfully deployed high-density Wi-Fi networks for the Dortmund and Ajax stadiums. The Wi-Fi networks provide easy access for fans and facilitate game sharing, live sports, media playback, and online gaming. Fans may move around the stadiums before or after the matches, or during the halftime. The roaming requirements pose great challenges to the network performance. Since high-density stadiums have high requirements on the air interface performance, individual sticky terminals have great impact on the network performance. The roaming feature can identify sticky terminals on the network in time and use different methods to help sticky terminals roam to more suitable APs according to terminal capabilities. This resolves the sticky terminal problems, improves user experience, and increases network capacity.