Huawei CloudCampus WLAN Smart Antenna Technology White Paper

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Executive Summary

Smart antenna technology concentrates energy on the receive end by adjusting the transmit parameters on the transmit end to enhance signal coverage and increase wireless Access Point (AP) capacity. This document describes how Huawei-developed smart antennas and antenna selection algorithm are implemented, and their major applications on networks.

Contents

1 Overview

1.1 Background

Along with the continued development of the IEEE 802.11 protocol family, the physical-layer transmission rate of Wi-Fi products increases sharply. Currently, the physical-layer rate of 802.11ax products reaches up to 10 Gbit/s, which is several times that of 802.11ac Wave 2 products.

802.11n revolutionized Wi-Fi with the introduction of Multiple Input Multiple Output (MIMO). In MIMO mode, a single 802.11n radio module can transmit or receive multiple signals concurrently, and spatial multiplexing is used to improve the channel utilization. Wi-Fi devices earlier than 802.11ac Wave 2 support only Single User MIMO (SU-MIMO). That is, a wireless Access Point (AP) communicates with only one station (STA) at a time. 802.11ac Wave 2 starts to support Multi-User MIMO (MU-MIMO). Specifically, a wireless AP can communicate with several STAs at a time. MU-MIMO increases the number of access STAs and improves user experience.

As spatial streams increase, each Radio Frequency (RF) card needs to connect to multiple antennas. Due to MIMO technology, signal quality can be improved using a multipath phenomenon. Driven by the changes to physical transmission modes, a high physical-layer rate is expected to bring better user experience. This expectation is raising higher requirements for antenna radiation angles and antenna correlations.

Traditional AP antenna design adopts a set of fixed built-in or external antennas for each transmitted or received signal, and software-based algorithms are used to select data rates in different modulation modes to achieve the optimal results. However, in actual wireless implementations, users frequently move and spatial angles change accordingly. As a result, radio paths and transmission rates change easily and wireless performance fluctuates. All the consequences make it impossible to unlock the optimal performance of a wireless network.

In the current Wi-Fi network environment, three major difficulties need to be overcome:

- Coverage for STAs at the Wi-Fi network edge

Most APs use omnidirectional antennas with a limited antenna gain. Such APs can provide good services for short-distance STAs, but can provide only low-throughput services or even no service for medium- and long-distance STAs.

- Coverage over obstacles

  It is difficult to provide high-throughput coverage service for STAs over obstacles.

- High-density coverage

  In high-density network environments, multi-user concurrency greatly increases interference between links. Despite downlink MU-MIMO introduced in 802.11ac, the downlink transmission throughput still needs to be increased.

To overcome these difficulties and provide better coverage services in the Wi-Fi network environment, mainstream vendors in the industry start to introduce smart antenna technology – which is widely used in public mobile communication system such as 3G and 4G – into Wi-Fi networks. By doing so, they expect to improve Wi-Fi coverage, increase Wi-Fi system capacity, and enhance Wi-Fi user experience.

The smart antenna hardware is an antenna array consisting of multiple antennas. According to the antenna selection algorithm, specific antenna elements are selected to transmit and receive signals. Combining different antennas can form different signal transmission directions, providing STAs at different locations with optimal antenna combinations to improve received signal quality and system throughput.

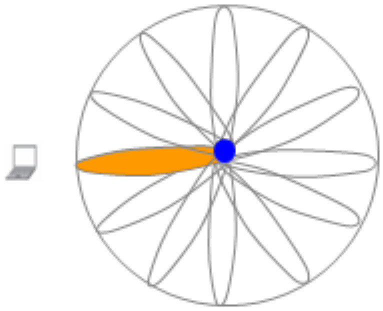
This document describes the implementation of smart antenna technology and its typical applications.

1.2 Technical Implementation

In the WLAN industry, smart antenna technology is implemented in two parts: One is the antenna array, that is, the antenna hardware, and the other is the antenna selection algorithm, that is, how to select antennas in an antenna array.

Antenna array implementation is a beam switching technology. An antenna array has multiple hardware antennas and intelligently selects multiple antenna elements based on the antenna selection algorithm to transmit and receive radio signals. Combining different antennas can form different signal transmission directions, providing STAs at different locations with optimal antenna combinations to improve received signal quality and system throughput.

Figure 1-1 Antenna beam switching diagram



The smart antenna selection algorithm is an important part of the WLAN link self-adaptation feature. By sending packets to STAs, a smart antenna determines STA locations. The smart antenna selection algorithm can then select appropriate antenna combinations from an antenna array to improve network performance. Directional beams are used to replace original omnidirectional beams to concentrate the energy, improving received signal quality and system throughput.

1.3 Customer Benefits

1. Better coverage

   Smart antennas provide better coverage in the target area. The four-sector design of antennas provides higher coverage strength. Antenna combinations in different directions in an antenna array provide longer-distance coverage than omnidirectional antennas, and are more flexible than directional antennas. In a complex radio environment, for example, when signal attenuation is obvious due to obstacles or distance increase, smart antennas can be used to improve coverage.

2. Higher throughput

   By selecting proper antenna combinations, smart antennas can improve the coverage of the target area and improve the throughput for STAs. The combination of the antenna selection algorithm and MU-MIMO enables STAs in the same direction to use the same directional beam for transmission. This improves the data throughput, greatly reduces mutual interference between STAs, and increases the user capacity per AP and of the entire network. These benefits are not compromised even in high-density scenarios.

3. Higher reliability

   The smart antenna algorithm can detect performance changes of antennas in the current working mode. If the performance changes frequently, the air interface environment has deteriorated. The smart antenna algorithm then quickly selects the optimal antenna combination in such an environment by antenna training. This ensures stable throughput in any environment and provides better user experience.

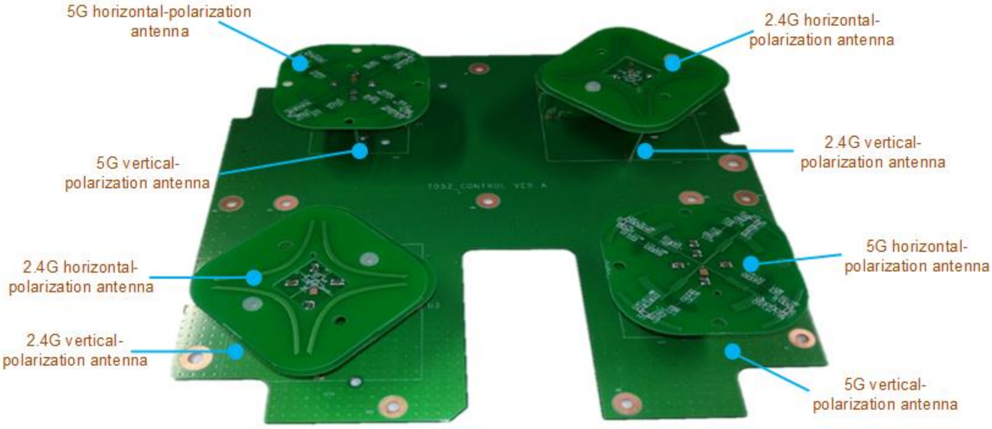
2 Implementation

Huawei smart antenna technology has two major parts: antenna array and antenna selection algorithm. The following will describe the two considerations one by one.

2.1 Smart Antenna Array

An antenna array is made up of a series of small antennas. Each small antenna can be an omnidirectional antenna or a directional antenna. The antenna arrangement depends on the gain, polarization mode, and radiation pattern of small antennas. The number of small antennas determines the number of final beams.

Figure 2-1 Smart antenna array arrangement

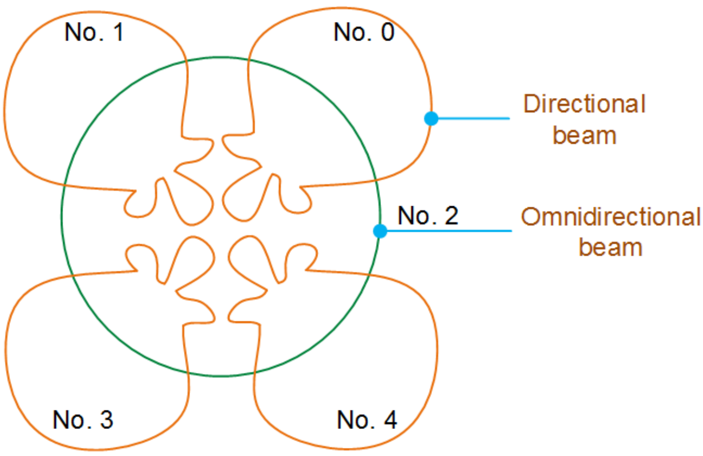


Huawei WLAN smart antennas are designed based on dual-band hybrid and dual-polarization overlap. Dual-band hybrid reduces the coupling between antennas and improves the radiation efficiency. Dual-polarization overlap miniaturizes antennas to save space and simplify the AP design. Four small antennas are available on each of the 2.4 GHz and 5 GHz frequency bands. Therefore, the entire antenna system consists of eight small antennas.

As shown in Figure 2-1, the upper left and lower right antennas are 5 GHz horizontal- and vertical-polarization antennas, respectively; the lower left and upper right antennas are 2.4 GHz horizontal- and vertical-polarization antennas, respectively. Four beamforming structures are evenly distributed within the 360-degree scope of each antenna. The switchgear in the middle of each structure can be independently controlled. Each small antenna has 16 (that is, 2^4) modes according to the switches in different directions. Four antennas are available on each frequency band. Therefore, a total of 4^{16} antenna combinations are supported on a single frequency band. Based on theoretical analysis, the following five modes are selected from the 16 modes of each small antenna as the working mode of the antenna:

- Omnidirectional antenna mode, numbered 2
- Directional antenna modes in horizontal four directions, numbered 0, 1, 3, and 4, respectively

Figure 2-2 Five beams of a small antenna



There are four antennas on a single frequency band, each of which supports five available working modes. Therefore, 5^4 single-frequency array combinations are available. If too many antenna combinations are used, take performance loss generated during antenna selection and actual antenna combination test results into consideration.

Table 2-1 lists 15 combinations that can be used as available array combinations for smart antennas. Two working modes for antennas are specified: basic and enhanced. In basic mode, all the four antennas direct to the same direction. In enhanced mode, the horizontal- and vertical-polarization antennas direct to different directions. In the following table, the first two bits of a combination mode indicate the horizontal-polarization antenna, and the last two bits indicate the vertical-polarization antenna.

Table 2-1 Combination index table of the four antennas

Antenna Index	Combination Mode	Mode Description	Antenna Index	Combination Mode	Mode Description
0	0000	Basic	16	3322	Enhanced
1	1111	Basic	17	4400	Enhanced
2	2222	Basic	18	4411	Enhanced
3	3333	Basic	19	4433	Enhanced
4	4444	Basic	20	4422	Enhanced
9	1100	Enhanced	21	2200	Enhanced
13	3300	Enhanced	22	2211	Enhanced
14	3311	Enhanced			

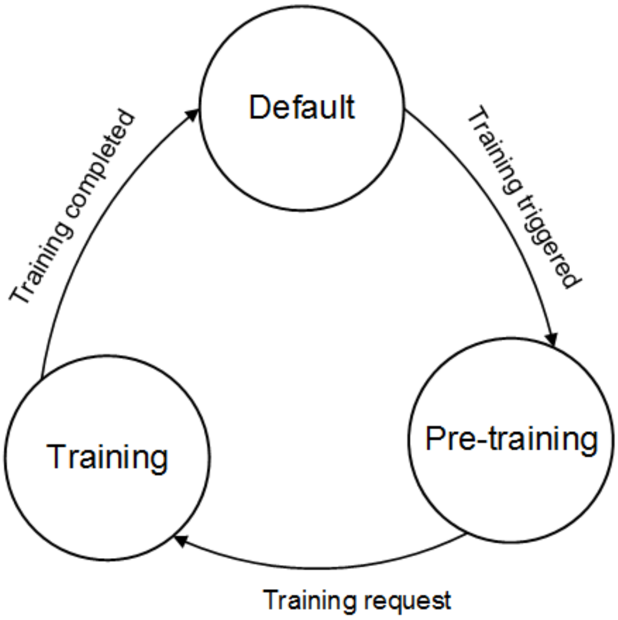
2.2 Antenna Selection Algorithm

Through training packets sent to different antenna combinations, the antenna selection algorithm can select the most appropriate antenna combination for STAs based on the packet error rate (PER) and received signal strength indicator (RSSI) provided by the STAs.

2.2.1 Antenna Training and Selection

Antennas in a system can work in three states: default, pre-training, and training states. The smart antenna selection algorithm is implemented based on the three-state switching of antennas.

Figure 2-3 Working state switching of antennas



- Default state

  Antennas in default state work properly with the current configuration without training. In this mode, however, the working state of an antenna is detected. When an antenna training triggering request is received or a sudden performance change occurs, the system sets the training request and triggers the training operation.

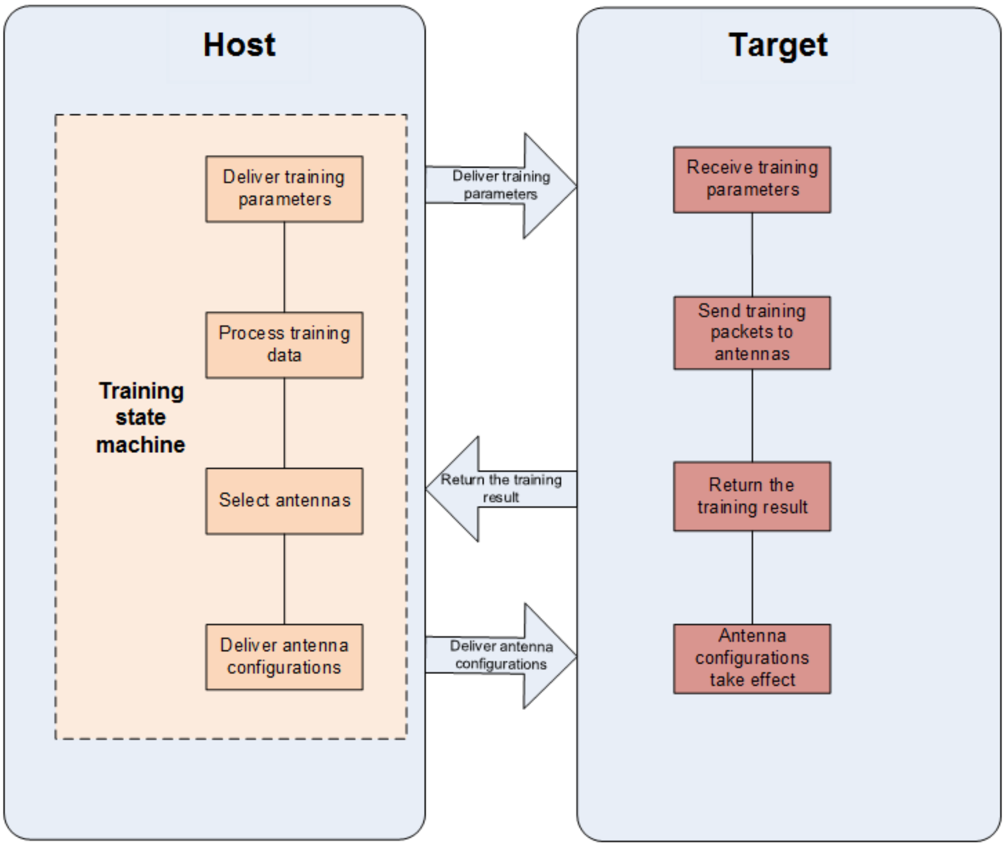
- Pre-training state

  Antennas enter this state to reduce the time and channel occupation during training. The training configuration of smart antennas is provided through implementation of the rate adaptation algorithm. The training request is set and training is triggered only when the number of training packets is no smaller than that specified by the system.

- Training state

  In this state, the system checks all antenna combinations based on the antenna configuration to find the optimal antenna combination.

Figure 2-4 Antenna training and selection



As shown in Figure 2-4, the Host maintains a training state machine, delivers training parameters, processes training data, selects antennas after training, and delivers antenna configurations. The Target receives training parameters from the Host, sends training packets, reports training results, and enables antenna configurations to take effect.

In MU-MIMO scenarios, after multiple users are paired, the antenna mode in multi-user (MU) mode is selected based on the antenna mode selected in single-user (SU) mode.

- If the antenna mode selected in MU mode is the same as that in SU mode, the antenna mode in MU-MIMO scenarios remains unchanged.
- If the antenna mode selected in MU mode is different from that in SU mode, the omnidirectional antenna mode is used in MU-MIMO scenarios.

2.2.2 Antenna Training Triggering

Antenna training can be triggered periodically or based on sudden performance changes.

Periodic Triggering

If the running time after the previous training exceeds the preset time period, re-training is triggered. The triggering interval is dynamically adjusted based on the number of STAs. A large number of access STAs requires a long triggering interval. This prevents frequent antenna training from occupying system performance and causing poor user experience.

Table 2-2 Relationship between the number of access STAs and the training interval

Number of Access STAs	≤ 5	5 < Number ≤ 10	10 < Number ≤ 20	> 20
Training Interval (s)	30	100	180	300

Triggering Based on Sudden Performance Changes

After becoming stable, the system collects the throughput and calculates the average accumulated throughput in a period as the reference value. The difference between the reference value and throughput of the current node is compared against the preset threshold. If the difference exceeds the threshold multiple times, the performance of the current node fluctuates greatly. In this case, the re-training mechanism is triggered.

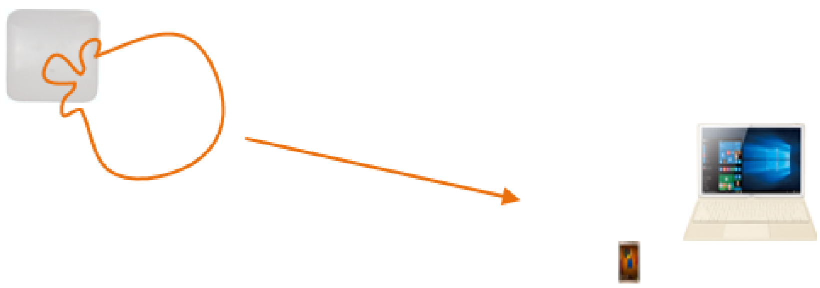
3 Application Scenario

Huawei smart antenna technology uses the dual-band hybrid and dual-polarization overlap design. Compared with dual-band smart antennas in the industry, Huawei's smart antennas provide higher radiation efficiency. The four-sector design also achieves higher gains than three-sector antennas in the industry.

3.1 Medium- and Long-Distance Network Coverage

When an AP sends data to STAs, the smart antenna algorithm selects the most suitable directional beam to replace the omnidirectional beam based on STA locations. The high-gain feature of the directional beam improves the AP's coverage capability for medium- and long-distance STAs, enhancing the coverage for edge STAs.

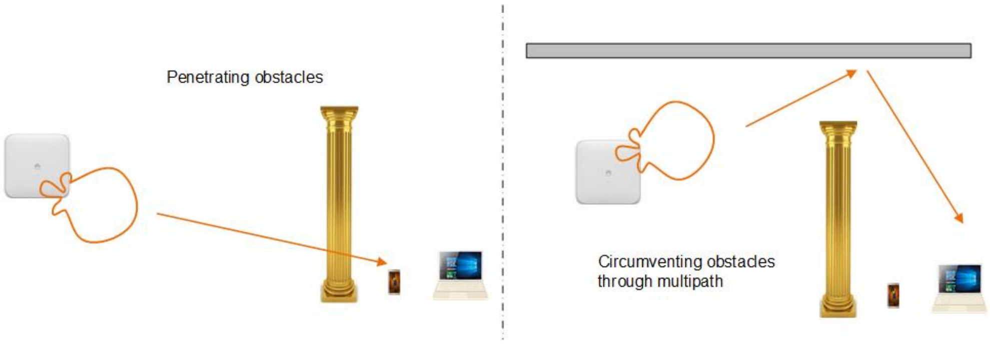
Figure 3-1 Smart antenna beam selection during medium and long-distance transmission



3.2 Complex Radio Environment

The antenna array of smart antennas provides better coverage in the target area. In an environment where radio signals need to penetrate floors and walls, directional beams have obvious penetration advantages due to their high gains. If obstacles that cannot be penetrated exist in the environment, smart antennas can select other directional beams for reflection and diffraction to overcome obstacles.

Figure 3-2 Smart antenna beam selection when obstacles exist

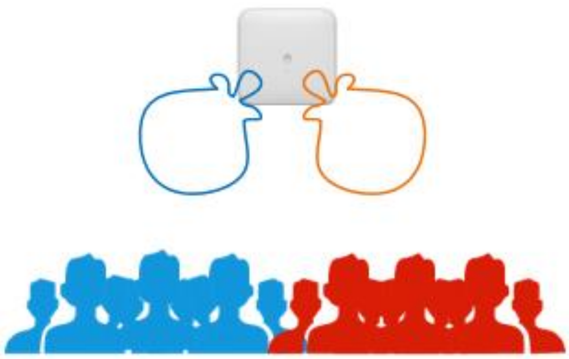


(In the left figure, obstacles are penetrated. In the right figure, obstacles are circumvented through multipath.)

3.3 Concurrent Downlink Transmission for Multiple STAs in High-Density Scenarios

In high-density scenarios, concurrent downlink traffic transmission is required (including downlink MU-MIMO). The directional beam selection supported by smart antennas aggregates STAs in the same direction to use the same directional beam for transmission. This improves the RSSI while reducing interference between STA data in different directions.

Figure 3-3 Concurrent downlink transmission for multiple STAs in high-density scenarios



A Acronyms and Abbreviations

A

AP	Access Point

M

MU	Multi-User
MIMO	Multiple-Input Multiple-Output

P

PER	Packet Error Rate

R

RSSI	Received Signal Strength Indication

S

STA	Station
SU	Single User

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