Smart Antenna White Paper

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1 Overview

The antenna is a key component of a wireless AP's radio frequency front-end. It is responsible for the energy conversion between guided waves and spatial electromagnetic waves, directly determining coverage range, link quality, and network capacity. During transmission, the antenna efficiently radiates the RF signal. During reception, it captures spatial electromagnetic waves and converts them into electrical signals.

Parameters such as gain, radiation pattern, beamwidth, polarization, and Voltage Standing Wave Ratio (VSWR) profoundly influence the coverage pattern: omnidirectional antennas achieve 360° horizontal coverage, directional antennas precisely cover specific areas, and high gain increases range but narrows the beam. In dense deployments, improper antenna selection can exacerbate co-channel interference and reduce overall network capacity.

Modern APs commonly use built-in antenna arrays, leveraging beamforming and antenna selection algorithms to dynamically optimize coverage and improve edge rates. Therefore, the selection and deployment of antennas are foundational for balancing coverage, capacity, and interference, directly determining the user experience.

1.1 Introduction

Smart Antenna is a function that senses the client's state and intelligently adjusts the transmitting antenna, aiming to solve the problem of "where the signal should be transmitted and when to switch the transmission direction." Unlike AP-level antenna direction changes, Smart Antenna independently sets the transmitting antenna combination for each client, identifies the terminal's approximate spatial location and movement trends, and learns the optimal antenna for data transmission with that client. This allows the terminal to obtain higher effective signal gain and a more stable connection experience.

1.2 Background

Adjusting the antenna angle to optimize coverage is a common method in wireless networks. In traditional wireless networks, the radiation pattern of AP antennas is usually fixed or only supports coarse-grained switching. However, in real-world environments, client distribution is highly dynamic, such as client movement, changes in obstructions, and varying user densities in different directions in high-density scenarios. Fixed antenna directions cannot cope with signal changes in dynamic scenarios, while coarse-grained antenna switching can only optimize signal coverage in some areas, failing to improve, or even sacrificing, the signal gain of some terminals.

1.3 Purpose

1. Unify understanding and explain what Smart Antenna is.
2. Convey value, highlighting technical advantages and focusing on benefits perceivable by the client.
3. Build trust, providing explainable principles and processes to prove the achievability of the claimed advantages.

2 Introduction to Key Technologies

The Smart Antenna function is based on multi-antenna arrays, beamforming technology, and antenna selection algorithms. The multi-antenna array and beamforming technology are the source of signal gain, while the antenna selection algorithm selects the optimal antenna combination for each client.

2.1 Basic Concepts

Antenna Array: An antenna array is a system composed of multiple antenna elements arranged in a specific geometric shape (e.g., linear array, planar array, circular array, etc.). Compared to a single antenna, an array can form a more controllable radiation pattern in space through the superposition effect of multiple elements.

Beamforming: By applying different amplitude/phase weights to each antenna element in the array, signal energy is coherently superimposed and enhanced in the target direction, while partially canceled and suppressed in non-target directions, thereby forming directional radiation/reception characteristics.

Per-Packet Antenna Adjustment: The system supports independently selecting the antenna for each data packet to be sent during the packet-level scheduling process. The antenna configuration is completed before the packet is sent, allowing adjacent packets to be sent in different antenna/beam modes, but the antenna parameters remain unchanged during the transmission of a single data packet.

2.2 Technical Advantages

1. Antenna Array
    - **Higher Directional Gain:** Multi-antenna elements coherently superimpose in the target direction, concentrating energy and allowing terminals in that direction to obtain higher effective signal gain.
    - **Controllable Coverage Shape (Pattern Shaping):** Not only can the array enhance a certain direction but also adjust the shape of the coverage, e.g., making it flatter, wider, or more concentrated, matching different spatial characteristics like

corridors, conference rooms, and open-plan offices.

- **Potential for Interference Suppression:** Reducing radiation in directions where coverage is not needed helps reduce interference with neighboring areas.
- **Adaptation to Dynamic Scenarios (Dynamic Adaptation Foundation):** The array is the physical basis for adjustable antenna combinations. The number of small antennas in the array determines the number of states for the antenna combinations.

2. Beamforming
   - **Better Signal Gain (Better RSSI/SNR):** A stronger effective signal in the user's direction typically means higher link quality and more stable rates.
   - **Reduced Unnecessary Radiation, Cleaner RF Environment:** Energy is no longer scattered everywhere, potentially reducing interference with neighboring areas and co-channel contention pressure.
   - **Improved Edge Performance & Stability:** Weak signal areas benefit more, potentially reducing jitter and retransmission probability for video conferencing, voice, and interactive services.
   - **Enhanced Airtime Efficiency Under Load:** Better link → fewer retransmissions → more valid data per unit time → improved high-density concurrency experience.
3. Per-Packet Antenna Adjustment
   - **Per-packet antenna adjustment**, by flexibly configuring antennas or beams at the packet granularity, endows the system with stronger adaptability, higher spectral efficiency, and better anti-interference capability, providing effective support for multi-user scheduling and intelligent optimization.

2.3 Market Demand

The demand for Smart Antennas stems from the increasing complexity of wireless environments and stricter customer requirements for network experience.

1. **High density and concurrency are becoming the norm:** The wireless bottleneck is shifting from signal strength to airtime efficiency.
2. **Scenarios are more dynamic:** Static antennas struggle to cope with user movement, environmental fluctuations, hotspot drift, etc.
3. **Dense deployment of multiple APs is prevalent:** Interference and signal spillover mean a strong signal does not equal a good experience.
4. **Customer expectations for Wi-Fi have evolved** from usable to stable and reliable.

3 Key Technical Principles

3.1 Antenna Array

An antenna array is composed of a series of small antennas arranged together. The number of small antennas determines the number of states for the final antenna combination. Taking AP9788, equipped with Smart Antenna, as an example:

- The 2.4 GHz and 6 GHz bands each have 4 antennas.
- The 5 GHz band has 4 large-tilt antennas and 4 small-tilt antennas. RF switches can control whether each RF output connects to a large-tilt or small-tilt antenna, resulting in a total of 16 (or 2^4) antenna combinations.

Depending on the tilt angle configuration, each antenna element supports switching between large-tilt and small-tilt modes, with the default operating mode being small-tilt mode. The antenna tilt angle is defined as the angle between the antenna's main beam direction and the horizontal plane. By adjusting the tilt angle via algorithms, the radiation direction and coverage area of the electromagnetic wave can be optimized to meet coverage requirements and performance needs in different application scenarios. The gain radiation pattern resulting from the different tilt angles of the antennas is shown in Figure 3-1.

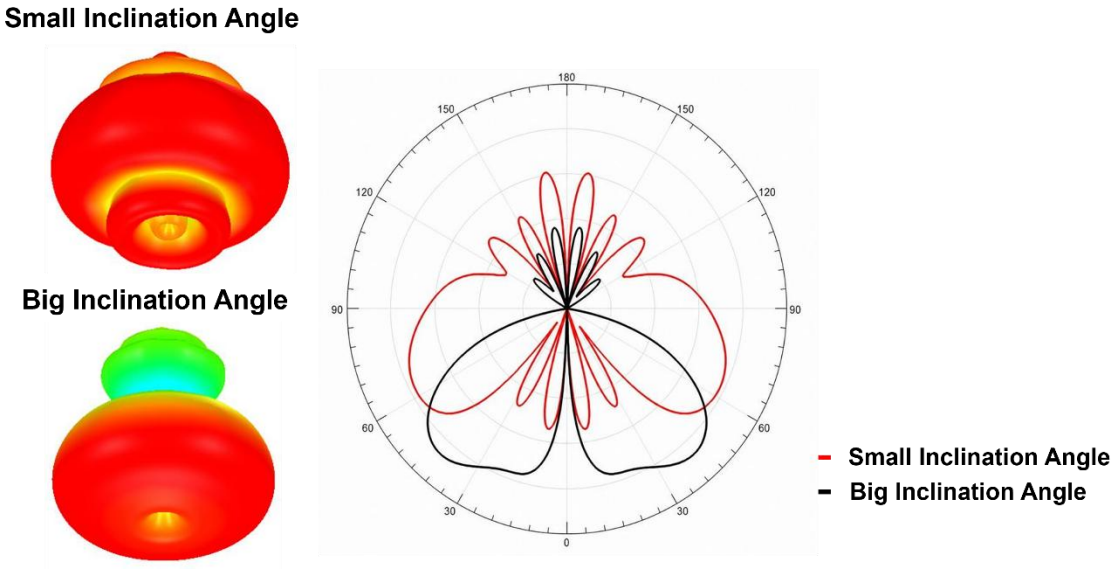


Figure 3-1: Smart Antenna Gain Radiation Pattern

3.2 Beamforming

In a multi-antenna AP, when signals from different antennas arrive in phase at the client side, the signal strength is significantly enhanced. If the phases are inconsistent, they cancel each other out. Beamforming is the process of adjusting antennas to enhance the signal strength at the receiver. The transmitter first determines the approximate channel

characteristics of the target receiving direction based on known or estimated channel information. Then, it sets appropriate phases (and amplitudes if necessary) for each transmitting antenna and transmits signals simultaneously to naturally form a directional beam. In this way, transmission energy is concentrated towards the target client, thereby improving received signal quality and transmission rate, while reducing interference in other directions and lowering overall transmission power for the same coverage effect.

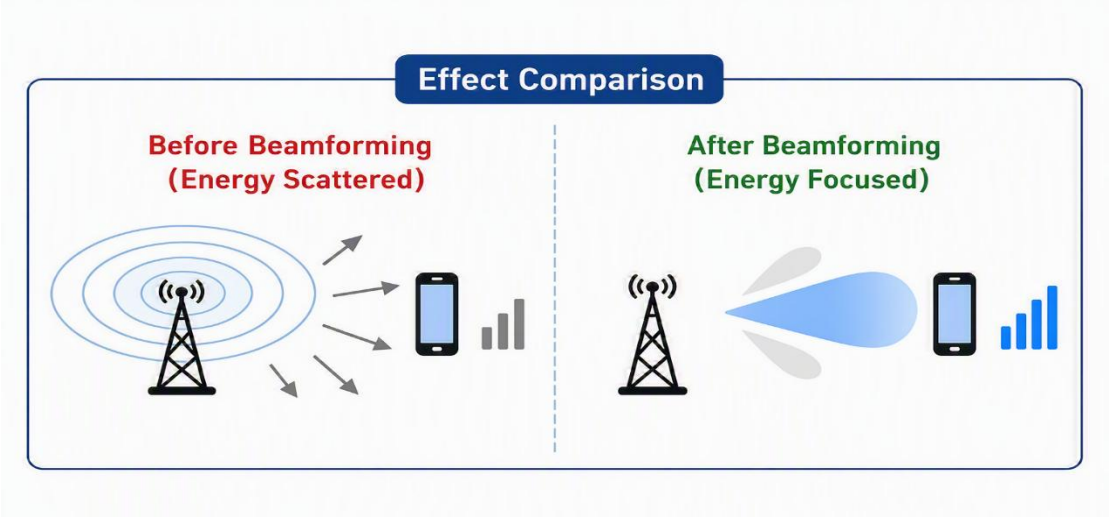


Figure 3-2: Beamforming Effect Diagram

3.3 Antenna Selection Algorithm

After sensing a change in the client's link condition, the antenna selection algorithm sends training packets using different antenna combinations and selects the best antenna combination for the current client based on data transmission feedback. The transmission feedback includes Transmission Rate (Tx Rate), Packet Error Rate (PER), and Received Signal Strength Indicator (RSSI). The following describes the timing and process of the antenna selection algorithm:

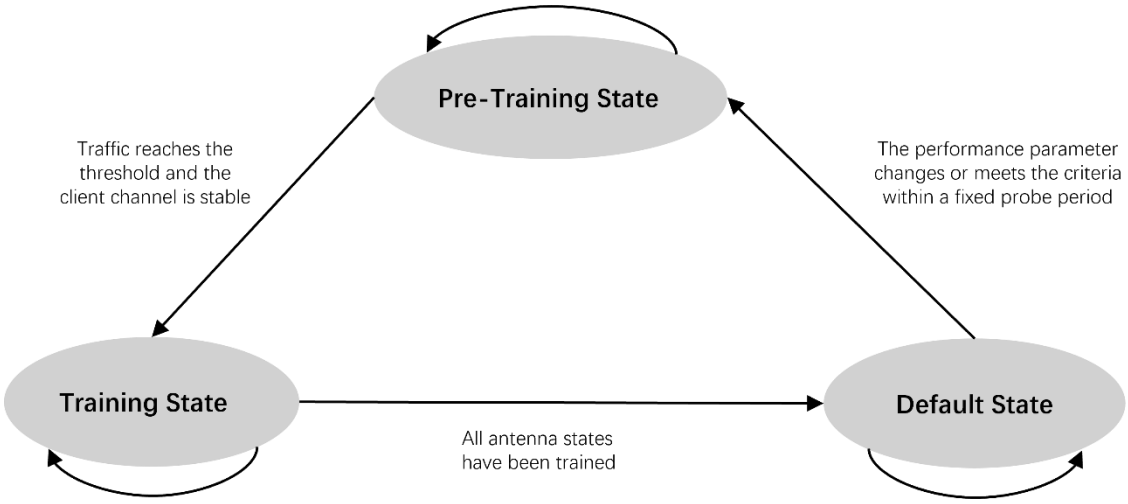


Figure 3-3: Algorithm State Transition Diagram

1. Client First Association

When a client associates, the default antenna combination is used to send data packets. Based on current traffic usage, detection for the optimal antenna combination is performed.

1) **Pre-Training State:** Statistics on traffic volume and channel stability are gathered. If conditions are met, it transitions to the training state.
2) **Training State:** All antenna combinations are traversed to send training packets. The Tx Rate, PER, and RSSI are recorded and compared to select the optimal antenna combination.
3) **Default State:** The best antenna combination and corresponding rate are used to send subsequent service data for the client.

2. Client Position Movement

The AP perceives the client's spatial position and movement status in real time. When the client's position changes significantly, the optimal antenna is reselected to adapt to the changed wireless state and provide continuous optimal wireless network performance.

1) If the client moves during the antenna training process, the training process is paused.
2) When the client is sensed to be stationary but has moved significantly, starting from the previously selected optimal antenna combination, all antenna combinations are traversed to send training packets. The Tx Rate, PER, and RSSI are recorded and compared to select the new optimal antenna combination.
3) The best antenna combination and corresponding rate are used to send subsequent service data for the client.

3. Link Quality Fluctuation

The AP monitors the communication link quality with the associated client through the

transmission rate. When the rate fluctuates significantly, the antenna selection algorithm is triggered to select the optimal antenna combination for the new wireless environment.

1) Starting from the previously selected optimal antenna combination, all antenna combinations are traversed to send training packets. The Tx Rate, PER, and RSSI are recorded and compared to select the optimal antenna combination.
2) The best antenna combination and corresponding rate are used to send subsequent service data for the client.

4. Periodic Trigger for Antenna Reselection

When neither movement detection nor link quality fluctuation is triggered, the optimal antenna for the client may change as the wireless environment slowly changes over time. Therefore, a periodic timer is set to trigger per-client antenna optimization.

1) When the periodic timer reaches 5 minutes, the algorithm starts from the previously selected optimal antenna combination, traverses all antenna combinations to send training packets, records and compares the Tx Rate, PER, and RSSI, and selects the optimal antenna combination.
2) The best antenna combination and corresponding rate are used to send subsequent service data for the client.

3.3 Application Scenario Analysis

1. Conference Room / Training Room / Multi-Function Hall

- **Scenario Characteristics:**
  High density of people, heavy traffic, and concentrated direction.
- **Typical Pain Points:**
  Clients connect simultaneously at the start of a meeting, causing high instantaneous concurrency and leading to lag in video conferencing/screen casting. Traditional antennas may result in strong signals in the front rows but weak coverage in the back rows.
- **Value of Smart Antenna:**
  Energy is more concentrated on the “main seating area/hotspot area”, improving link quality and stability.
  Reduces invalid overhead from retransmissions and airtime contention during concurrency, improving overall throughput efficiency.

2. Open Office Area

- **Scenario Characteristics:**
  Users are dispersed and mobile; hotspots change over time.
- **Typical Pain Points:**
  Hotspot areas change during lunch breaks/commuting hours, and Wi-Fi speed

fluctuates.

Some workstations are permanently slow (due to a combination of weak coverage and interference).

- **Value of Smart Antenna:**

  Adaptively optimizes the coverage pattern based on changes in crowd aggregation, providing a more consistent experience.

  Provides higher effective gain for edge workstations, reducing rate fluctuations.

3. **Hotel Corridor / Guest Rooms**
   - **Scenario Characteristics:**

     Long corridors have strong directivity with significant signal attenuation through walls.
   - **Typical Pain Points:**

     Weak signals at the ends/corners of corridors and large differences in guest room experience. Spillover interference in multi-floor deployments leads to a seemingly full signal but slow speed.
   - **Value of Smart Antenna:**

     Provides directional coverage better suited to corridors, directing energy into effective areas.

     Reduces unnecessary spillover radiation, improving interference environments in multi-AP, multi-floor deployments.
4. **Retail Store / Supermarket**
   - **Scenario Characteristics:**

     Obvious hotspot areas, such as cash registers, promoted items, and event areas.
   - **Typical Pain Points:**

     Customer flow concentrates in one area during peak hours.

     Interference and congestion are more pronounced when customer Wi-Fi coexists with business Wi-Fi.
   - **Value of Smart Antenna:**

     Strengthens link quality in hotspot areas, ensuring critical services like payment/scanning.

     Reduces invalid radiation through spatial energy management, improving effective airtime utilization.

4 Application Scenarios and Solutions

4.1 Multi-AP Deployment in High-Density Scenarios

In densely populated scenarios, such as large transportation hubs (e.g., airports and stations), stadiums, and libraries, a large number of users accessing the network

simultaneously can easily lead to network congestion and co-channel interference. APs are located close to each other. Smart Antenna technology dynamically adjusts beam angles based on the deployment environment, combines with MIMO technology to enhance the signal strength of target clients, and effectively reduces signal leakage and mutual interference in adjacent areas.

- **Large Transportation Hubs (e.g., Airport Waiting Halls and Train Stations)**: High terminal mobility, high passenger density, and significant demand for real-time information queries and entertainment. Smart Antenna dynamically tracks mobile terminals, reduces AP co-channel interference, and supports stable connections under high concurrency.
- **Stadiums, Convention Centers, and Large Performance Venues**: Thousands of spectators connect simultaneously and share extensively online. Smart Antenna precisely focuses on the audience area, avoiding signal leakage to empty areas or adjacent AP coverage zones.
- **Libraries, Conference Rooms, and Large Office Areas**: Multi-type terminals are online simultaneously with multiple services running in parallel. Smart Antenna dynamically adjusts the antenna angle coverage range based on the terminal density within the area, ensuring critical services are guaranteed.

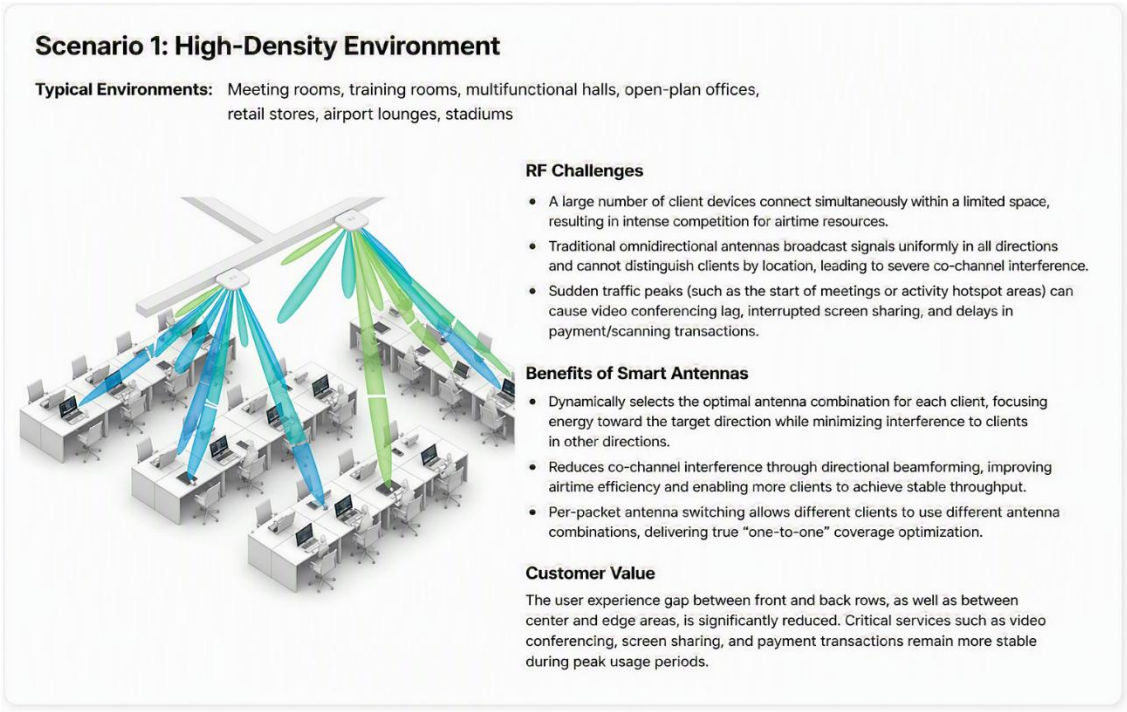


Figure 4-1: High-Density Application Scenario

4.2 Indoor Corridor Scenario

In indoor passage scenarios, such as large warehouse aisles, factory corridors, and hotel

corridors, traditional omnidirectional antenna signals attenuate with distance, resulting in extremely low rates or even disconnection at the edge. Smart Antenna technology selects appropriate directional beams for data transmission based on the terminal's position, effectively improving coverage capability for mid-to-far distance users and enhancing edge signal quality.

Smart Antenna adaptively selects the optimal transmitting antenna or beam based on the terminal's real-time position and link quality. When the terminal is at the edge of the coverage area, the system switches to a higher-gain antenna for transmission, thereby improving the received signal strength and SINR. When the terminal moves, the system dynamically adjusts the beam direction or switches to a new optimal antenna, always maintaining the best communication link. Compared to traditional omnidirectional coverage, this mechanism improves coverage capability for mid-to-far distance users and edge throughput.

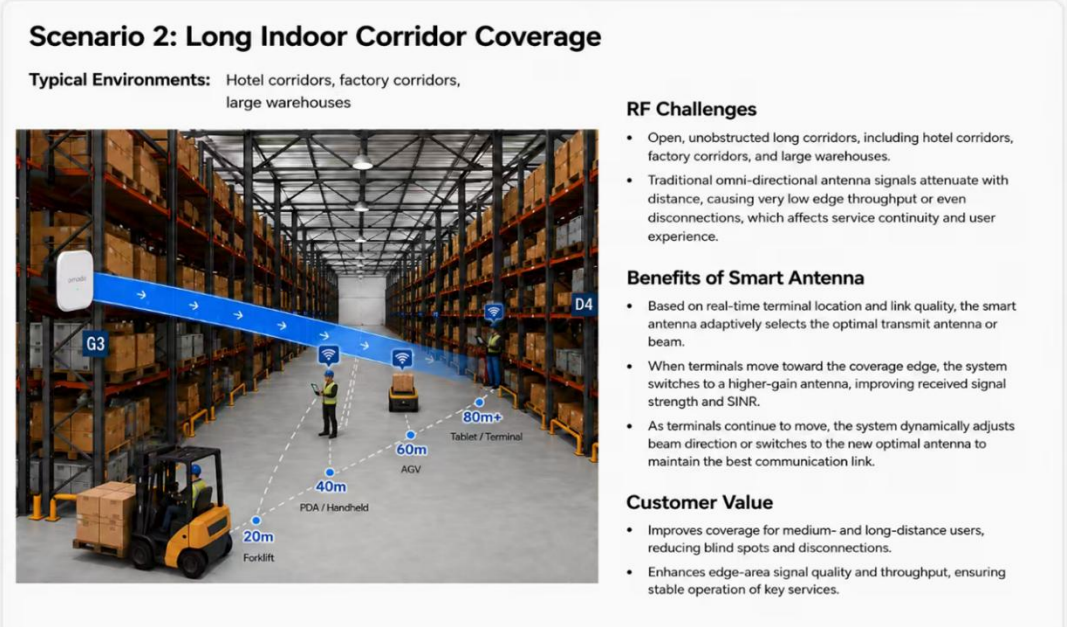


Figure 4-2: Indoor Corridor Scenario

4.3 High-Mount Deployment Scenario

In scenarios such as hospital lobbies, hotel corridors, production workshops, and airport terminals, due to constraints from decoration conditions, safety regulations, cabling difficulty, or maintenance requirements, high-mount deployment is often the only option. Traditional high-mount antennas often suffer from insufficient downward pressure on signals, dispersed coverage energy, and weak coverage in obstructed areas. Smart Antenna technology, through beamforming and per-packet dynamic tracking capability, precisely focuses wireless energy onto the target client, effectively compensating for coverage loss in high-mount deployment conditions and improving user experience.

In this scenario, APs are typically installed on ceilings, beams, or the tops of pillars. Due to the high installation height, traditional antennas spread energy uniformly in all directions, resulting in limited effective signal received by ground-level terminals. Compared to traditional omnidirectional antennas in high-mount deployments, Smart Antenna improves the gain coverage range.

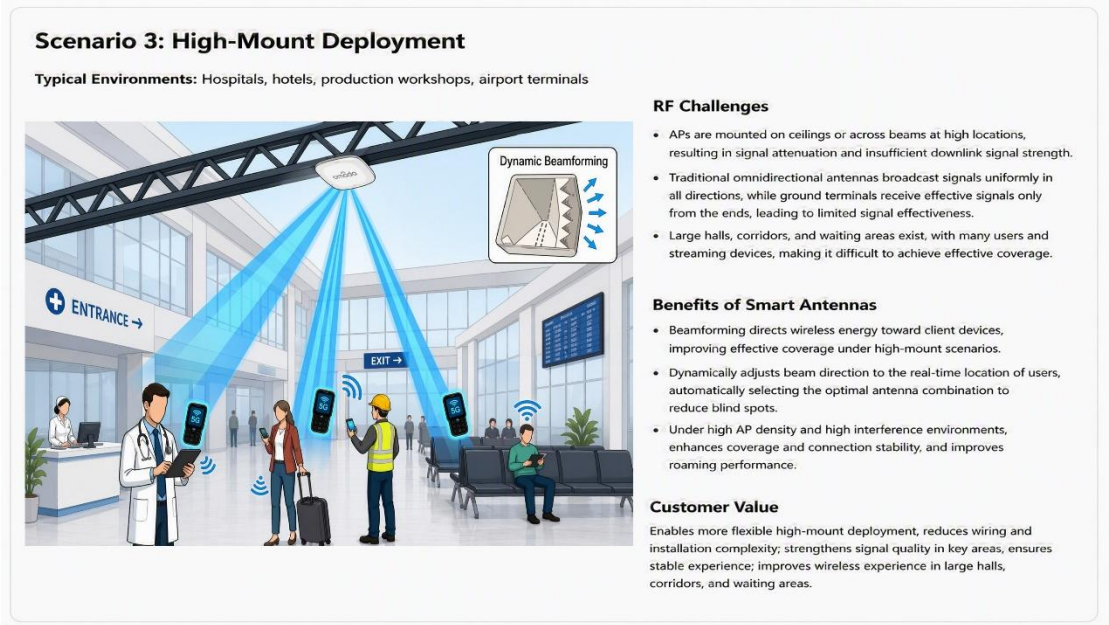


Figure 4-3: High-Mount Deployment Scenario

5 Representative Models

AP9788 – BE22000(US) / BE19000(EU) Ceiling Mount Wi-Fi 7 Access Point



Figure 1-1: EAP9788

- **Tri-Band Wi-Fi 7 Architecture:** AP9788 supports three bands: 2.4 GHz (2.400–2.4835 GHz), 5 GHz (5.150–5.850 GHz), and 6 GHz (6.105–7.125 GHz). The 5 GHz band supports

a maximum channel bandwidth of 240 MHz, providing greater beamforming optimization and spatial multiplexing benefits for the Smart Antenna algorithm.

- **Full-Band 4×4 MU-MIMO:** All three radios (2.4 GHz, 5 GHz, and 6 GHz) support 4×4 Uplink/Downlink MU-MIMO and 4× spatial streams, enabling higher-dimensional beam control and user separation capability.
- **5 GHz Integrated Smart Antenna Module:** The 5 GHz radio features an Internal Smart Antenna module and supports two antenna modes: Mode 1 (4 × 7.02 dBi) and Mode 2 (4 × 7.42 dBi).
- **High PHY Rate and 4096-QAM Modulation:** The device achieves a maximum aggregate wireless rate of 21.5 Gbps, with the 5 GHz band reaching up to 8648 Mbps and the 6 GHz band up to 11528 Mbps. It supports Wi-Fi 7's 4096-QAM modulation. By improving RSSI/SNR, the Smart Antenna helps terminals maintain higher MCS levels, thereby achieving higher throughput.

6 Future Outlook

As wireless networks evolve towards Wi-Fi 8 and next-generation wireless communication technologies, the industry's focus is shifting from purely pursuing peak rates to high reliability, low latency, high concurrency, and intelligent network experiences. Future wireless networks need to achieve more stable connection quality, more efficient spectrum utilization, and more intelligent resource scheduling capabilities in complex environments. Going forward, the development of Smart Antenna technology can be anticipated from the following aspects.

6.1 Precise Coverage and Spatial Resource Coordination

The development focus of industry Smart Antenna modules will evolve from traditional coverage enhancement and signal gain to the refined scheduling capability of spatial resources. Future Smart Antenna modules will combine distributed coordination transmission and cross-AP coordination mechanisms to dynamically shape the wireless coverage pattern, achieving signal enhancement in target areas and interference suppression in non-target areas. In high-density scenarios such as airports, stations, libraries, and large office buildings, Smart Antenna technology will become a key infrastructure for wireless network spatial resource management. They will help improve spectrum utilization efficiency and coverage boundary controllability, providing users with a more stable and consistent connection experience.

6.2 Multi-User Spatial Multiplexing for Wi-Fi 8 Ultra-High Reliability

Future Smart Antenna modules will be deeply integrated with multi-user MIMO, coordinated airtime scheduling, and enhanced precoding technologies. Through more

precise spatial multiplexing and user grouping strategies, they will support higher concurrent access capabilities within limited spectrum resources. As the number of terminals continues to grow and applications like AR/VR, real-time collaboration, and industrial control develop, the demand for low-latency, high-stability connections increases. Smart Antenna technology will not only serve to enhance signals but also become a crucial component for improving spatial multiplexing efficiency, enabling wireless networks to continuously provide stable throughput, lower latency, and more predictable service experiences in high-density access environments.

6.3 AI-Driven Adaptive Beamforming

Future Smart Antenna modules will further integrate AI algorithms, environmental sensing, and real-time network analysis capabilities to achieve autonomous decision-making for beam configuration, direction selection, and link optimization. In scenarios such as warehouse logistics, smart manufacturing, and campus networks, the system can dynamically adjust coverage strategies based on changes in terminal position, service requirements, and the wireless environment, achieving more efficient link tracking and connection maintenance. In the future, Smart Antenna will gradually evolve from only improving signal quality to optimizing network experience, becoming a vital component of next-generation high-performance Wi-Fi networks.

7 Appendix

7.1 Glossary

Term	Explanation
AP	Access Point
RSSI	Received Signal Strength Indicator
SNR	Signal-to-Noise Ratio
Tx Rate	Transmission Rate
PER	Packet Error Rate
MIMO	Multiple Input Multiple Output