World WLAN Application Alliance (WAA)

Smart Campus

Wi-Fi CSI Sensing Development and Use Cases White Paper

June 2025

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Preface

World WLAN Application Alliance (WAA) is an international organization registered with the Ministry of Civil Affairs of the People's Republic of China. It focuses on the development of the wireless local area network (WLAN) industry. Committed to providing the best WLAN experience for the digital world, WAA works with global industry partners to boost the growth of the WLAN industry.

WLAN applications have been widely used in various scenarios, such as home, office, education, production, and logistics. Critical to the national economy and public wellbeing, they form the key infrastructure of the digital economy. As WLAN technologies advance and service scenarios become more diverse, the industry needs to analyze service requirements and network construction standards in different scenarios, so as to further improve network quality and user experience.

This white paper analyzes the scenario characteristics and service requirements of WLAN in various enterprise application scenarios, as well as the latest development trend of WLAN technologies. It can be used as a reference for the construction and use of WLANs in enterprise scenarios.

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

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Chapter 1 Development Trend of Wi-Fi CSI Sensing

1.1 Wi-Fi CSI Sensing Overview

As a mainstream technology for next-generation campus wireless networks, Wi-Fi 7 is able to support a large number of new applications. These applications require high-quality wireless connections and highly precise, reliable sensing.

As wireless sensing and communication systems advance, they are able to support higher frequency bands, larger antenna arrays, and smaller designs. The hardware architecture, channel characteristics, and signal processing of these systems are becoming increasingly similar. This creates a unique opportunity to harness wireless infrastructure for sensing. In the future, wireless networks will expand beyond traditional communication services to provide ubiquitous sensing services for measurement and imaging of the surrounding environment. The sensing capability and the network supporting the collection of environment sensing data are recognized as enablers of learning and building intelligence in the future intelligent world. They could play a significant role in various positioning and environment sensing scenarios. To this end, there is an urgent need to jointly design sensing and communication systems for wireless networks. This has also triggered recent research on channel state information (CSI) sensing.

In this research, WLAN sensing is implemented primarily based on communication-centric technologies. The goal is to integrate sensing into existing or commercial communication waveforms or systems. Such CSI sensing strategies will play an important role in Wi-Fi 7.

1.2 Evolution of Wi-Fi CSI Sensing

1.2.1 Theoretical Model of WLAN Sensing

Traditionally, WLAN has been used as a wireless communication technology. It modulates electromagnetic waves to carry service data and implement information exchange between devices at the transmit and receive ends. The propagation characteristics of radio signals are that the electromagnetic wave signals radiated by a transmit antenna can reach a receive antenna through a direct path, or by reflection off the surrounding environment (such as walls, human bodies, and furniture). Finally, the electromagnetic wave signals reaching the receive antenna are the superposition of direct-path signals and multiple reflection-path signals. This is also called the multipath effect of radio signal propagation.

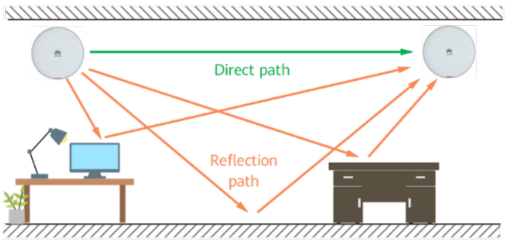

Figure 1 Multipath effect of radio signal propagation

By harnessing the propagation characteristics of electromagnetic waves, WLAN sensing enables WLAN devices to detect the impact of dynamic environment changes on radio signals. For example, human movement can change the propagation paths of electromagnetic waves. By analyzing the dynamic changes of received signals, WLAN devices can detect human presence, identify their behavior, and even measure weak fluctuations such as breathing and heartbeats. WLAN sensing can be classified as bi-static sensing or mono-static sensing. Bi-static sensing involves two devices: One transmits and one receives WLAN signals. Mono-static sensing uses only one device to transmit and receive WLAN signals.

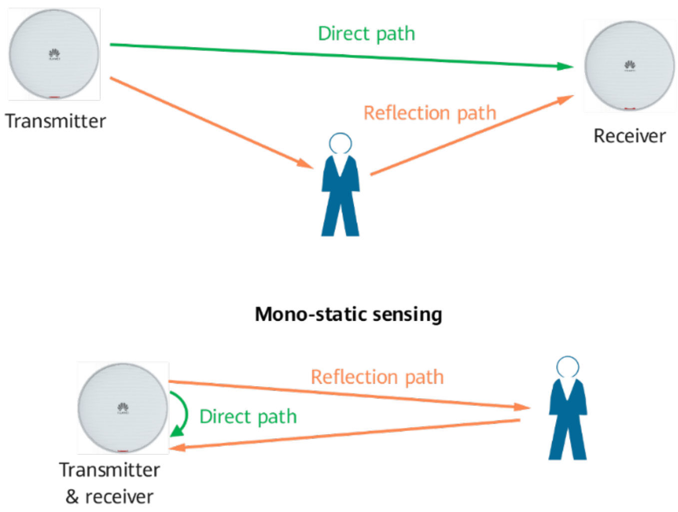

Figure 2 Bi-static sensing and mono-static sensing

The following describes how WLAN sensing works using a mathematical model of radio signal propagation. The preceding figure shows a simple scenario with only one direct path and one dynamic reflection path. Assume that the amplitudes of the direct path and a dynamic path are A_0 and A_1, respectively, with the propagation delays of d_0 and $d_1(t)$, respectively. Due to the motion of a reflective object (human body in this example), the propagation delay $d_1(t)$ dynamically changes. In the following figure, the channel response, H(f, t), at moment t and frequency f, is the result of adding the static path and dynamic path in the complex number field. The final amplitude of the channel response |H(f,t)| is related to the phase difference between the two paths. Specifically, if the phase difference between the two paths is (–π/2, π/2), the amplitude is enhanced after the static path and dynamic path are superimposed. If the phase difference is (π/2, 3π/2), the amplitude is weakened after the two paths are superimposed. In this way, the amplitude of the channel response stays in a periodic constructive and destructive relationship with $d_1(t)$ in a dynamic environment.

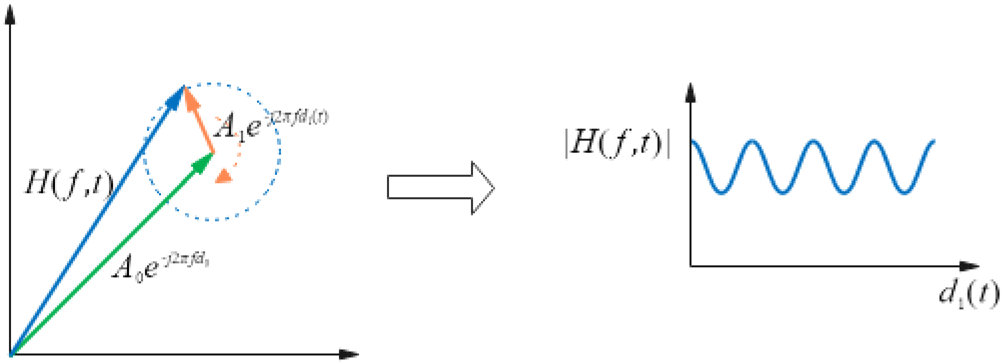

Figure 3 Radio signal transmission model

Further analysis shows that if the dynamic path changes by half a wavelength, |H(f,t)| changes from the peak value to the trough value (or from the trough value to the peak value). For example, the center frequency of channel 36 on the WLAN 5 GHz frequency band is 5.18 GHz, and the wavelength is about 5.7 cm. This means that a 2.85 cm change in the wave path of the dynamic path can cause a significant change to the CSI.

This phenomenon may also be explained by using a Fresnel zone. The Fresnel zone is defined as a cluster of ellipses with the receive and transmit devices at the two focuses. The equation for the boundary of an *n*th Fresnel zone is as follows:

$$|Q_nT| + |Q_nR| - |TR| = \frac{n\lambda}{2}$$

Q_n is a point on the *n*th ellipse, and T and R represent the transmitter and receiver, respectively. The area between the (*n* – 1)th ellipse and the *n*th ellipse is called the *n*th Fresnel zone. The wave path difference between the transmitter and receiver at the boundary of adjacent Fresnel zones is half a wavelength. When radio signals are reflected, the phase rotates additionally by π. As a result, the maximum signal degradation is generated at the boundary of an even Fresnel zone, and the maximum signal enhancement is generated at the boundary of an odd Fresnel zone.

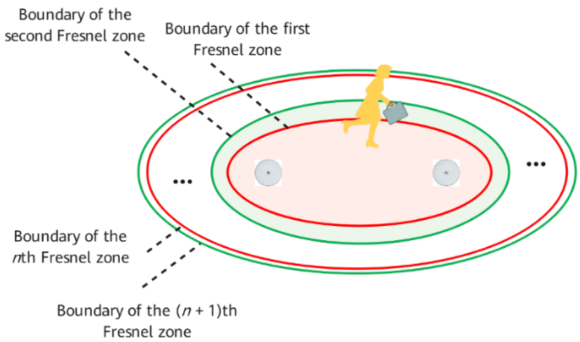

Figure 4 Fresnel zone diagram

In a WLAN sensing scenario, when a reflective object moves in the coverage area, the receiver can observe the signal fluctuations based on the real-time location difference of the object. In other words, WLAN devices can sense slight fluctuations (at the centimeter level) of carrier wavelengths, which lays a foundation for high-precision WLAN sensing.

Although CSI-based WLAN sensing is theoretically feasible, it faces many challenges in actual applications. WLAN sensing in most scenarios depends on the sensing of dynamic reflection paths, and the signal strength is extremely weak. It is difficult to extract such small changes. In addition, the CSI obtained by the actual WLAN receiver contains a large number of non-ideal factors (such as synchronization and channel impact). Before the actual dynamic environment information can be obtained from the CSI, the disturbance of these non-ideal factors must be eliminated.

1.2.2 Signal Processing Technology

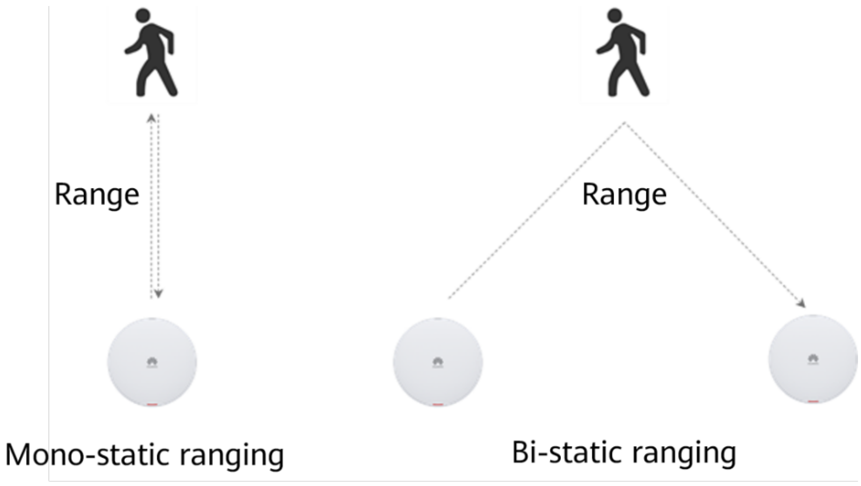

Figure 5 Mono-static and bi-static ranging

Range measurement: WLAN bi-static ranging is similar to radar ranging. It is used to determine the range between a target and a WLAN transceiver. Sensing-assisted bi-static ranging is used to estimate the length of the reflection path. The figure above shows the actual paths measured in mono-static and bi-static scenarios. The ranging resolution is usually determined by the signal bandwidth.

Speed measurement: WLAN sensing typically detects moving targets through CSI-based Doppler shift estimation. Doppler shift is the change in the frequency of a target due to the relative motion between the transmitter and receiver. When a target moves in the environment, the path length of the reflected signal changes, leading to a Doppler shift in the carrier frequency of the reflection signal.

In speed measurement algorithms, the short-time Fourier transform (STFT) or other time-frequency analysis algorithms are commonly applied to CSI for direct Doppler shift estimation. The Doppler shift occurs when the reflection path length changes. This makes it difficult to accurately calculate the target's velocity, and so the Doppler shift can only be used to make a rough estimate.

Angle measurement: Depending on the technical principles, this can be classified as angle of arrival (AoA) estimation and angle of departure (AoD) estimation. Both involve measuring the phase differences between signals received at different elements of an antenna array. Then, a signal angle estimation algorithm is used to determine the direction of arrival (DoA). In AoA estimation, a single-antenna device transmits signals, and a receiver calculates their direction using the phase differences generated when the antenna array receives them. AoD estimation is the opposite of AoA estimation. In AoD estimation, a transmitter with an antenna array sends signals, and a single-antenna receiver calculates their transmission angle using the received signals.

In actual applications, antenna arrays like linear, rectangular, and circular arrays are commonly used to determine the signal DoA. A linear array is typically arranged in a straight, one-dimensional line and can only be used to measure the azimuth angle. In contrast, rectangular and circular arrays can measure both azimuth and elevation angles. Indoor radio channels contain a large number of reflection paths. Many studies have been conducted on estimating the AoA of each path using array angle estimation algorithms. Common methods include multiple signal classification (MUSIC), maximum likelihood estimation (MLE), estimation of signal parameters via rotational invariant techniques (ESPRIT), and compressive sensing (CS) algorithms.

1.2.3 Application Layer Algorithm

Based on the dynamic changes obtained in physical spaces, the posture features of human bodies or objects need to be analyzed in conjunction with different scenarios. For periodic actions, traditional digital signal processing algorithms can directly extract the CSI. For example, when a person is sleeping, the only movement is the rising and falling of the chest due to breathing. In this case, the regular changes of the CSI can be extracted to estimate the respiratory rate.

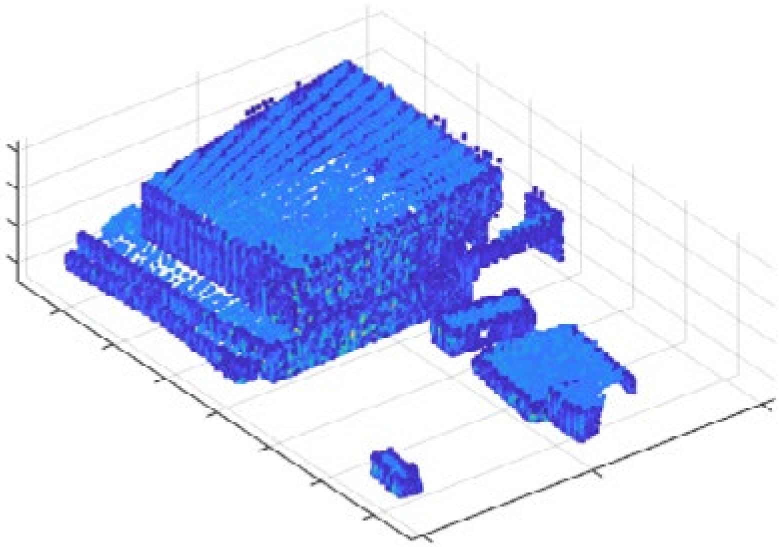

Figure 6 Fusion imaging result

The location of a single point can be determined based on the range and angle information extracted using the signal processing algorithm. After multi-point information is integrated, the point cloud information of an object can be generated. In scenarios with multiple access points (APs), each AP can create a point cloud in its direction. By merging the point cloud information from all the APs, a point cloud environment can be reconstructed. The preceding figure shows the fusion result of an imaging point cloud from six base stations. This result reflects a relatively complete contour of the target.

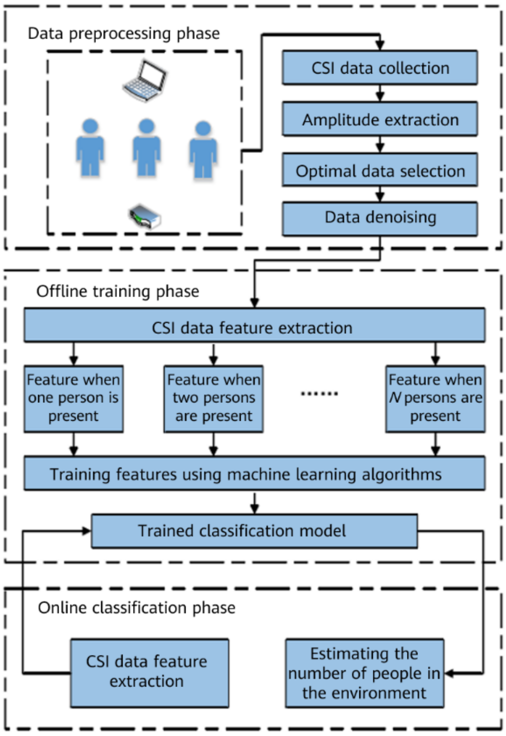

Figure 7 Processing procedure based on AI machine learning

In practice, there are many non-periodic actions that are difficult to analyze using traditional data processing algorithms. However, CSI changes caused by specific actions generally have similar characteristics. For this reason, AI machine learning can be used to extract and identify CSI change characteristics to map different actions. For example, signals fluctuate to different degrees depending on the number of obstacles in the environment. Similarly, the CSI data is scattered to different degrees depending on the number of people. If no person is detected in the environment, the CSI data curve remains stable and smooth. If more people enter the monitoring area, the curve fluctuates significantly. Therefore, when CSI fluctuations are used for feature extraction and the fluctuation feature is mapped to the number of people by using a deep neural network (DNN), the number of people in the space can be accurately identified, as shown in the preceding figure. Activities such as fall detection and gesture recognition can be implemented using similar principles.

In an open scenario, the angle and distance information of a moving target can be extracted to accurately locate and track the target. In a complex scenario, the target sensing area can be divided. Based on the spatial differences of radio signals in different environments, radio signal features at specific locations in the space can be used as fingerprints of the locations to establish a location-fingerprint relationship database. This enables user location estimation through fingerprint matching. Generally, areas are created so that CSI information is sampled in different areas, location information is recorded, and then offline training is performed on the collected CSI information to extract features. As a user moves to different locations, location mapping is performed based on CSI features to output location information.

1.2.4 Key Technologies for CSI Sensing

CSI feedback type and quantization: Since the release of IEEE 802.11ac, compressed CSI has become the sole explicit feedback type used by mainstream sub-7 GHz in IEEE 802.11 standard amendments (such as the IEEE 802.11ax and IEEE 802.11be). However, compressed CSI is designed for MIMO precoding and lacks complete CSI matrix information to better support sensing. Therefore, sensing measurement feedback has become a crucial topic of discussion in Task Group IEEE 802.11bf (TGbf). After extensive deliberation, TGbf has adopted the CSI matrix as the only explicit sensing measurement feedback type in sub-7 GHz sensing. In this feedback, the per subcarrier scaling has been replaced with per link scaling to mitigate the impact of unbalanced antennas during the quantization and feedback phases.

Security and privacy: There are two types of security and privacy issues: sensing reporting eavesdropping and sensing packet or signal eavesdropping. Possible solutions to sensing reporting eavesdropping include secure communication, which encrypts sensing measurements during feedback. Possible solutions to sensing data packet or signal eavesdropping include physical layer security methods that encrypt sensing data packets/signals for sensing measurements.

Multi-link sensing: Sensing in IEEE 802.11bf primarily involves a single radio link between peer stations (STAs). With the commercial use of Wi-Fi 7, more multi-link (ML) devices (STAs using multiple radio links) will be available on the market. To further enhance sensing performance, ML is a key technology that will need to be discussed in the IEEE 802.11. Devices with ML sensing capabilities can perform sensing simultaneously at a range of operating frequencies (such as, 2.4 GHz, 5 GHz, and 6 GHz) and provide diversity gains in observations across frequencies. In certain scenarios, coordinating different links can offer better support for both sensing and communication. For instance, in some scenarios where a higher sensing frequency is required, sensing measurement feedback can be performed on a link separate from the "sensing link." This approach reduces the occupation of the sensing link.

1.3 Development of Wi-Fi CSI Sensing Standards

Since its first standardization in 1997, Wi-Fi has become a widely used technology worldwide. In recent years, Wi-Fi sensing has gained increasing attention from the academic community and industry. To better support various Wi-Fi sensing applications while minimizing the impact of sensing on Wi-Fi communication performance, the IEEE 802.11 working group established a Task Group (TG), IEEE 802.11bf, in 2020. This TG aims to release a sensing standard amendment in 2025.

IEEE 802.11bf is a technology that uses radio signals received from IEEE 802.11 STAs to determine the features of intended targets, including range, velocity, angle, target detection, and image. This technology can be used to detect objects, humans, animals, and environments in various scenarios, such as rooms, houses, vehicles, and enterprises. IEEE 802.11bf aims to develop an amendment to support various sensing applications in daily life while ensuring backward compatibility and coexistence with existing or legacy IEEE 802.11 STAs operating in the same band.

The following figure illustrates the timeline and progress made toward the IEEE 802.11bf amendment. In July 2019, the IEEE 802.11 Wireless Next-Generation Standing Committee (WNG SC) discussed and approved the feasibility of WLAN to support sensing use cases and their requirements. In September 2020, a TG, IEEE 802.11bf, was officially established. In April 2022, the TG released the first draft (draft 0.1) of the 802.11bf amendment, and released draft 1.0 in January 2023. Following approval from the Standards Review Committee (RevCom) and IEEE SA Standards Board (SASB), the latest draft 4.0 is expected to be released as an amendment to the IEEE 802.11bf standard in June 2025.

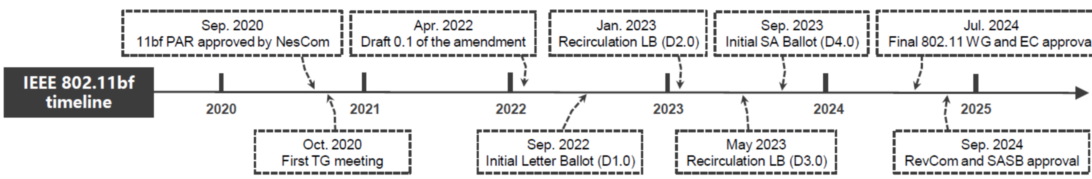

Figure 8 Timeline and progress for the IEEE 802.11bf amendment

Chapter 2 Wide Application of Wi-Fi CSI Sensing

2.1 Energy Saving

Requirements

Facing the impact of global warming on social development, economic development and environmental protection have always been key concerns. Against this backdrop, energy saving and carbon emission reduction have become the key goals in smart campus construction.

Campuses, as office scenarios, have many power devices and network devices that are used in both peak and off-peak hours. Therefore, if the devices can be adjusted in real time based on people flow, a large amount of energy can be saved through automatic adjustment methods, for example, automatic light brightness adjustment and automatic air conditioner temperature adjustment. However, from the perspective of privacy, it is not practical to directly collect statistics on people flow on a campus based on the camera monitoring system. In comparison, WLAN sensing can collect statistics on and analyze human activities in the physical space while ensuring privacy, especially when Wi-Fi communication can achieve full coverage in most campuses. As such, Wi-Fi CSI sensing has become the most feasible solution to saving energy and reducing carbon emissions in intelligent campuses.

Solution

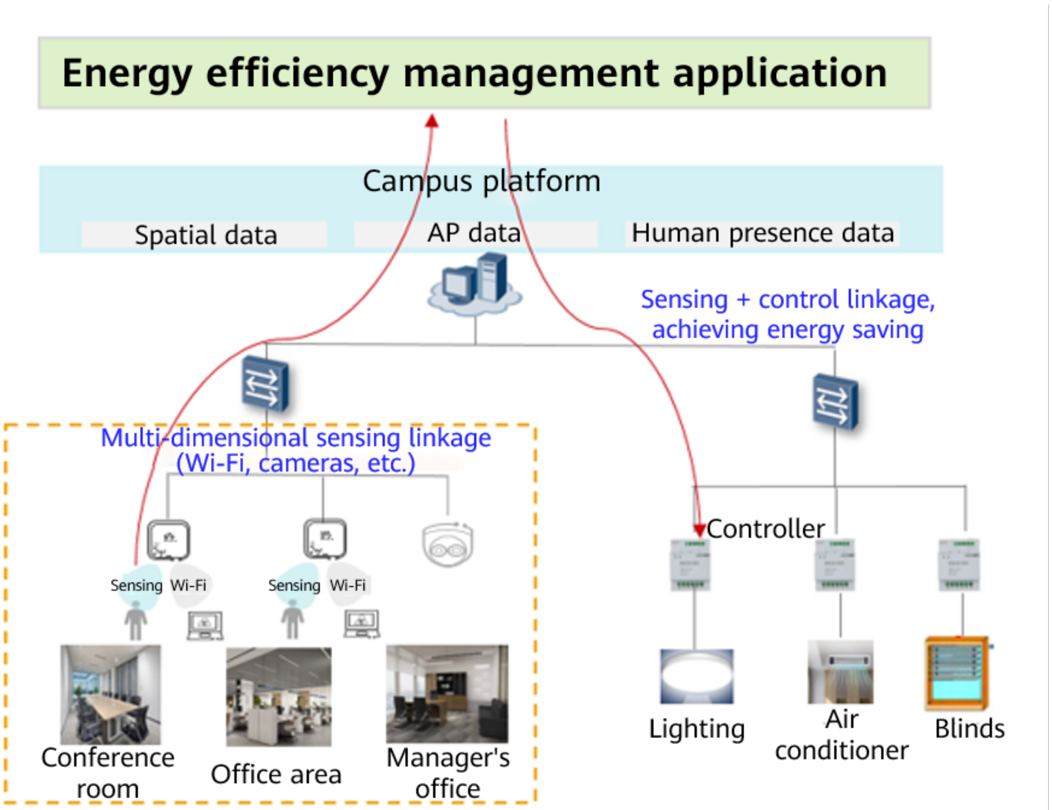

Figure 9 Campus energy efficiency management platform

- Solution design objectives: Wi-Fi CSI sensing can automatically adjust the power of power devices on the campus, so as to reduce the power consumption of the campus without affecting the experience of office personnel. This helps save energy and reduce carbon emissions.
- Application scenarios: closed conference rooms and open work areas on the campus
- Solution architecture:
  - Sensing layer: As CSI sensing devices cross two layers, WLAN devices sense moving objects in the environment based on CSI sensing and perform basic signal processing (such as noise cancellation) on the collected data. Then, the devices associate multi-dimensional sensing data, such as that from cameras, and send the data back to the platform layer via the network layer.
  - Platform layer: After receiving information from the sensing layer, the campus digital platform uses physical sensing and AI algorithms to comprehensively analyze human distribution in space. It then reports the analysis results (human presence and quantity) to the application layer.
  - Application layer: It includes applications related to energy efficiency management and space management. Based on factors such as human presence and physical space size, this layer determines the control status of power devices and delivers control instructions, such as turning lights on or off and lowering air conditioner temperature.
- Performance requirements: There are no missed or false alarms when human presence is detected. There is little delay for starting electrical appliances, and the power of electrical appliances can be adjusted in a fine-grained manner. These features aim to reduce lighting and cooling power by 7%.

2.2 Intelligent Conference Management

Requirements

More than 90% of enterprise decisions are made in conference rooms. As such, enterprise leaders are always striving to improve conference experience and efficiency. The demand for in-person conferences is increasing sharply, and the number of people on campus continues to grow. These factors exacerbate the shortage of conference rooms and make managing conference devices more difficult. However, the existing solution has the following drawbacks:

Poor human presence sensing accuracy: Traditional infrared devices have poor sensing accuracy, leading to frequent false negatives and false positives. For instance, seated personnel may go undetected.

Difficult cabling for traditional sensing: Traditional infrared and millimeter-wave sensing solutions require network cables and power cables to be separately deployed. In large conference rooms, deploying multiple cables is time-consuming and costly.

No linkage in the conferencing environment: Existing solutions do not support automatic environment linkage before conferences and automatic release of conference rooms after conferences. Consequently, conference room devices cannot be automatically shut down, which leads to low conference room utilization rates.

Wi-Fi CSI sensing can address these issues. APs have a sensing feature that can automatically power on devices when someone enters a conference room. They can also interwork with the platform to efficiently manage conference rooms.

Solution

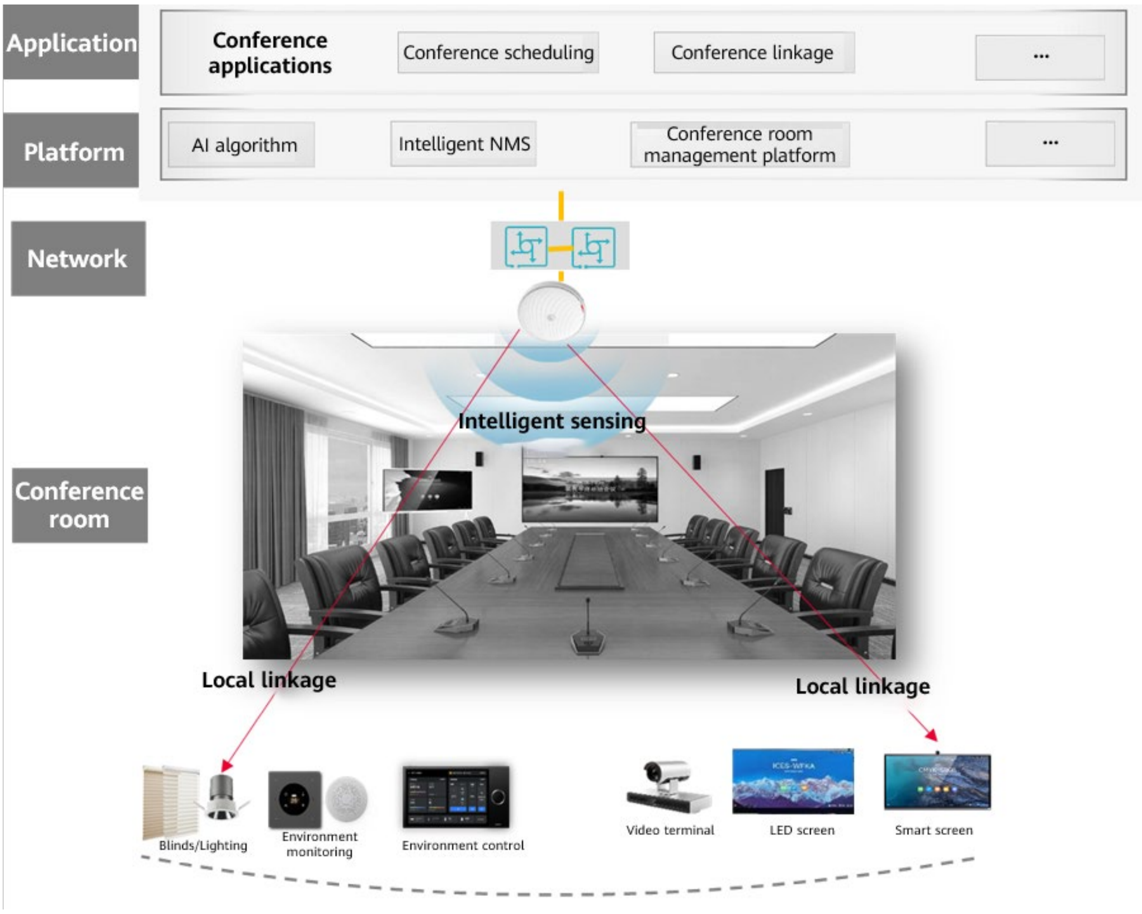

Figure 10 Intelligent conference management platform

- Solution design objectives: The following functions are implemented through Wi-Fi CSI sensing.
  (1) **Environment linkage:** When people enter a conference room, the environment devices (such as lights and blinds) and the conference audio and video devices (such as whiteboards, sound pickup, and playback devices) are automatically turned on, improving the conference experience. When people leave, the conference room devices are automatically turned off to save energy.
  (2) **Higher conference room utilization**: The conference sensing system works with the conference management platform to automatically release conference rooms when not in use, thereby increasing their utilization.
- Application scenarios: conference rooms
- Solution architecture:
  - Sensing/Network layer: As CSI sensing devices working across two layers, WLAN devices collect conference room personnel data based on Wi-Fi CSI sensing feedback. They then process the collected data (such as noise cancellation) and send it back to the platform layer.
  - Platform layer: It primarily refers to the IoT middleware platform. After receiving data from the network layer, the platform layer integrates the WLAN sensing information and feedback from

other devices. It then works with the conference room management platform to enable intelligent conference room management.

  - Application layer: It includes conference scheduling management and other software. The application layer manages conference scheduling information based on data reported by the platform.

- Performance requirements: There are no missed or false alarms when human presence is detected, leading to a 20% boost in conference room utilization.

2.3 Healthcare

Trends and requirements: In the healthcare industry, it is costly and labor-intensive to monitor patients or the elderly with speech difficulties around the clock. Wi-Fi CSI sensing enables 24/7 patient monitoring while protecting their privacy. It generates real-time alarms when abnormal behaviors, such as falling or getting out of bed, are detected. This leads to savings on labor costs. With improved sensing accuracy, Wi-Fi CSI sensing can also wirelessly sense some physiological features (such as respiration, blood pressure, and heartbeat), potentially replacing expensive physiological monitoring devices. More importantly, it can address situations where contact-based measurements are not feasible (such as in cases of burns).

2.3.1 Wireless Measurement of Physiological Indicators

Requirements

Vital sign monitoring technologies are shifting towards non-contact, high-precision, and long-distance monitoring. However, most existing technologies have the following drawbacks:

High costs and risks of manual measurement: Manual measurement requires attaching handheld instruments to patients' bodies. Periodic measurements are required for chronic disease care, which is labor-intensive and difficult for implementing long-term real-time monitoring. This method also increases the risk of virus transmission through contact.

Restrictions of fixed monitoring: Wearable devices, such as wristbands, wrist straps, physiological belts, and smart mattresses, require fixed contact measurement. These devices are inconvenient to wear, place restrictions on monitored objects, and require regular charging. For example, they are not suitable for some burn patients.

Privacy leakage risks of non-contact sensing: Cameras and other image sensors can be installed on walls or ceilings to monitor multiple points in real time, such as beds, wards, and bathrooms in hospitals. However, this poses a great risk of privacy leakage.

Wi-Fi CSI sensing can address these issues. It monitors patients' physiological indicators in real time over the long term without constraints while ensuring patient privacy.

Solution

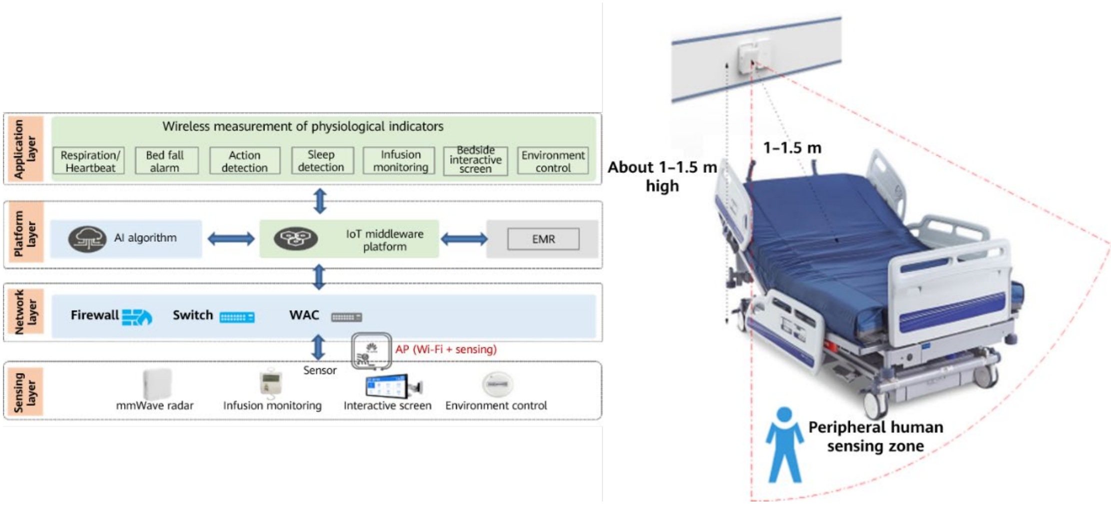

Figure 11 Healthcare solution

- Solution design objectives: Wi-Fi CSI sensing can be used for all-day, contactless, and wireless measurement of physiological indicators. This reduces the risk of virus transmission and avoids measurement restrictions for special cases. In this way, the Wi-Fi CSI sensing solution lowers the cost of measurement devices and labor.
- Application scenarios: This solution is primarily used in hospital wards and can also be deployed in facilities such as nursing homes, where many objects in a room need to be measured.
- Solution architecture:
  - Sensing/Network layer: As CSI sensing devices working across two layers, WLAN devices collect the posture changes of patients on beds based on CSI feedback. They then process the collected data (such as noise cancellation) and send it back to the platform layer along with data from other monitoring devices in the ward.
  - Platform layer: It primarily refers to the IoT middleware platform. After receiving data from the network layer, the platform layer integrates the WLAN sensing information and feedback from other devices to measure changes in the patient's body status (such as chest movement and rolling over).
  - Application layer: It includes some caregiver applications. Based on changes in body posture and other environmental factors transmitted by the platform layer, the application layer integrates AI algorithms to measure physiological indicators and generate alarms upon exceptions.
- Performance requirements: The solution allows for accurate measurement of physiological indicators, no missed alarms for identifying target risks, and real-time feedback.

Key Indicators

When measuring physiological indicators, the focus is on the accuracy of the results and the timeliness of risk reporting. The specific indicators include:

Scenario	Description	Deployment Type	Indicator
Respiratory detection	Monitors respiratory rate when patients are in a supine, lateral, or prone position.	Bedside	Accuracy deviation: < ±5%
Heart rate detection	Monitors heart rate when patients are in a supine position.		Accuracy deviation: < ±5%
Off-bed detection	Monitors patients' in-bed and off-bed conditions.		Accuracy: 99%
Fall detection	Tripping, slipping, fainting against the wall, etc.	Ceiling or wall mounting	Accuracy rate: > 99% Coverage: 10 m^2
Sleep detection	Monitors patients' awake/sleep status in bed and abnormal breathing events.	Bedside	Accuracy deviation: < ±5%
Action monitoring	Scheduled rollover, 45-degree lying posture, etc.	Bedside	--

Figure 12 Measurement results of physiological indicators

2.3.2 Unattended Care

Requirements

In the healthcare field, there is a high demand for healthcare quality control and human posture detection. This requires technical means to alleviate care pressure. Additionally, patient privacy must be considered. Therefore, the care solution must be free from risks of privacy leakage.

Effective detection of healthcare quality is required. According to the World Health Organization (WHO), a robust infection prevention and control plan can reduce healthcare-associated infections (HAIs) by 70%. In high-income countries, one out of every 10 patients is injured during treatment. This proportion is even higher in low- and middle-income countries.

Human posture detection is a crucial need. According to medical data, falls have become the leading cause of injury-related deaths among the elderly. Falls are especially harmful to the elderly when instant aid and rescue are unavailable. In a population of 10,000 elderly individuals, eight die prematurely from falls. Furthermore, 40% to 70% of them may not receive the urgent medical care they need following a fall, which significantly decreases their quality of life.

Solution

Figure 13 Unattended care solution

- Solution design objectives: In unattended care scenarios, Wi-Fi CSI sensing can continuously monitor user behavior patterns while preventing the privacy leakage of monitored objects. It can also report posture-related security risks and monitor caregiver operational compliance around the clock.
- Application scenarios: hospital wards and homes of the elderly or children living alone
- Solution architecture:
  - Sensing/Network layer: As CSI sensing devices working across two layers, WLAN devices sense moving objects in the environment based on CSI feedback or plug-in radars. They then process the collected data (such as noise cancellation) and send it back to the platform layer through the network layer.
  - Platform layer: It primarily refers to the IoT middleware platform. After receiving information from the network layer, the platform layer converts channel features into object posture features (such as distance, speed, angle, and quantity) based on physical sensing and AI algorithms.
  - Application layer: It includes some care-related application software. Based on the posture changes of objects in the physical space transmitted by the platform layer, the application layer

integrates AI algorithms to implement unattended care functions, such as fall detection, personnel trajectory tracking, and nursing posture monitoring.

Figure 14 Fall detection

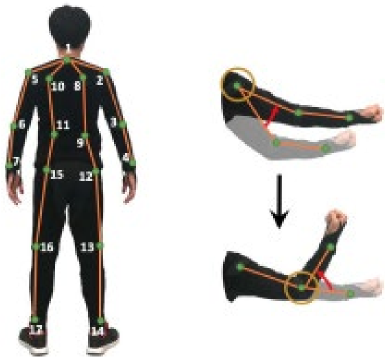

Figure 15 Body movement detection

- Performance requirements: There are no missed alarms for target safety risks, and real-time feedback is provided. Nursing quality monitoring has no blind spots and features accurate gesture recognition with no missed alarms.

Indicators

Unattended care indicators focus on identifying the body postures of patients, as well as the body movements and gestures of medical staff.

Ward (ICU/VIP/ common)

Shower room/ Bathroom

Requirement 1	Posture	Distance (m)	Indicator	Recognition Rate
Human body posture	Supine position	> 5	< 5°	> 95%
	Sitting position	> 5	> 30°	> 95%
	Standing position	> 5	-	> 95%
	Fall	**> 5**	**Yes/No**	**> 95%**
	Bed fall	**> 5**	**Yes/No**	**> 95%**

Requirement 2	Action	Distance (m)	Indicator	Recognition Rate
Healthcare action quality control	**Raising the headboard**	**> 5**	**30° to 45°**	**> 95%**
	Hand washing	> 5	Yes/No (20s)	> 95%
	Turning the body over	> 5	Yes/No	> 95%
	Wiping the body	> 5	Yes/No	> 95%

Figure 16 Results of unattended care indicators

2.4 Dormitory Management in Education Campuses

Requirements

Student safety is the top priority of schools. Bullying is a major concern, but it often takes place in spaces where cameras cannot be installed, such as dormitories and bathrooms. Dormitory inspections at night are mainly performed manually, which may wake students up. During holidays, students often forget to turn off the air conditioner and lighting device, posing safety risks. Huawei's Wi-Fi CSI sensing solution eliminates the blind spots where video security is unavailable. The solution helps to detect people's abnormal behaviors in private spaces, and accordingly sends alarms to faculty members for intervention in time. Also, this solution assists in interference-free dormitory inspections at night, ensuring student safety.

Solution

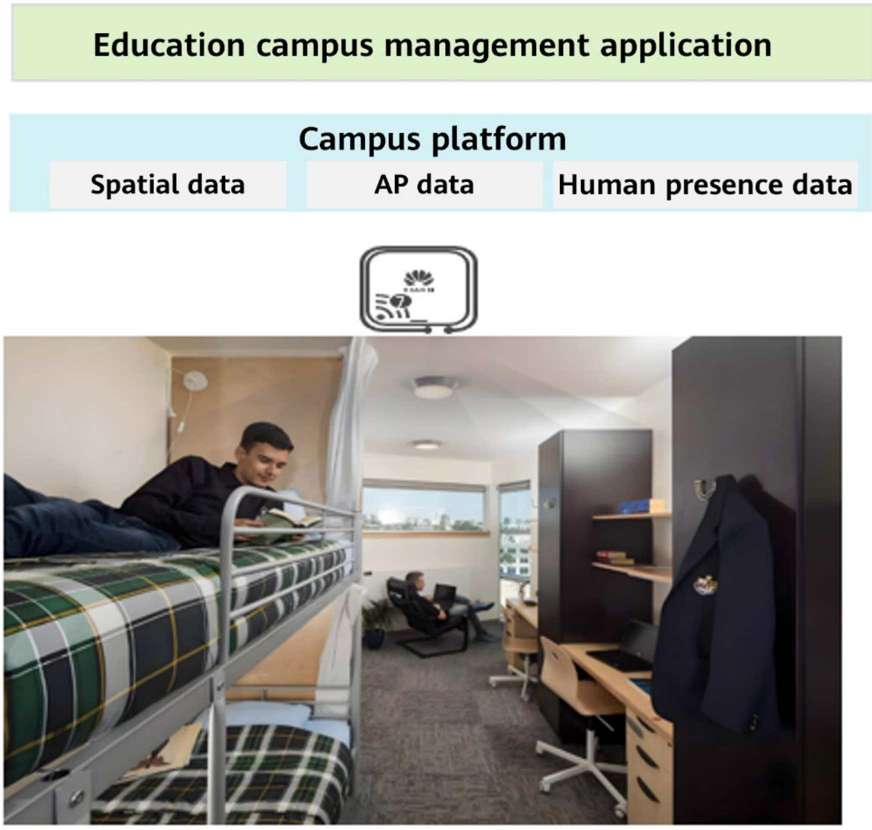

Figure 17 Campus management system

- Application scenarios: dormitories of colleges, universities, and higher-level vocational schools
- Solution architecture:
  - Sensing/Network layer: As CSI sensing devices, WLAN devices sense human body movement in the environment based on CSI feedback or plug-in radars, process the collected data (such as

noise cancellation), and send the processed data back to the platform layer through the network layer.

- Platform layer: It primarily refers to the IoT middleware platform. After receiving information from the network layer, the platform layer converts channel features into object posture features (such as distance, speed, angle, and quantity) based on physical sensing and AI algorithms.
- Application layer: It includes some application software relevant to school management. Based on the posture changes of objects in the physical space transmitted by the platform layer, the application layer integrates AI algorithms to implement many functions, such as security alarm reporting and abnormal gathering detection.

Security alarm reporting during holidays:

- Space setting: For the dormitories of colleges, universities, and higher-level vocational schools, there are 4 to 8 persons in each room, the floor height is 3 to 4 meters, and the area is smaller than 40 m^2. Each dormitory has a bathroom and balcony, which are separated by walls.
- Sensing range: It is the same as the WLAN coverage range.
- Status information sensing: Sense whether there is anybody in the dormitory (including the bathroom and balcony).
- Expected result: During holidays such as summer vacation, the system detects whether there is anybody in the dormitory. If the air conditioner or lighting device is still on when there is nobody, an alarm is generated to avoid fire and other safety accidents.
- Performance requirements: zero false negatives for person detection

Nighttime dormitory inspection without night patrol:

- Space setting: For the dormitories of colleges, universities, and higher-level vocational schools, there are 4 to 8 persons in each room, the floor height is 3 to 4 meters, and the area is smaller than 40 m^2. Each dormitory has a bathroom and balcony, which are separated by walls.
- Sensing range: It is the same as the WLAN coverage range.
- Status information sensing: Count the number of people in the dormitory (including the bathroom and balcony).
- Expected result: The number of people in the dormitory is sensed, dynamic and static human body detection is performed, and the information is reported to the dormitory management system. Automatic dormitory inspection is performed based on the time segment.
- Performance requirements: low latency in reporting person entry. The system can effectively recognize people in static and sleeping states and count the number of people, ensuring zero false negatives and zero false positives.

Abnormal crowd gathering detection in dormitories:

- Space setting: For the dormitories of colleges, universities, and higher-level vocational schools, there are 4 to 8 persons in each room, the floor height is 3 to 4 meters, and the area is smaller than 40 m^2. Each dormitory has a bathroom and balcony, which are separated by walls.
- Sensing range: It is the same as the WLAN coverage range.

- Status information sensing: Count the number of people in the dormitory (including the bathroom and balcony).
- Expected result: If the number of people in the dormitory is greater than 16, the information is reported to the dormitory management system. Additionally, warnings are generated when the number of people exceeds a certain number, which is decided based on the current dormitory area.
- Performance requirements: zero false negatives and zero false positives in head counting, as well as low latency in reporting person entry

2.5 Guest Room Management in Hotels

Requirements

In hotels, energy saving is achieved through a key card switch. However, guests may leave the key card in the slot when going out. This increases energy consumption. Some hotels have started to use infrared sensors in guest rooms to replace the key card switch. However, infrared sensors can cover only a small area and cannot accurately detect static human bodies. Additionally, some employees may commit fraud by not recording guests' actual check-in information in the hotel management system or concealing guests' check-in information to embezzle room fees or for other improper benefits. As such, technical means are required to obtain the actual occupancy of guest rooms.

Fraud may be related to food and beverage orders, guest room orders, business expense orders, and credit card orders. These behaviors bring economic losses and hinder the normal operations of hotels.

Accurate person detection and counting helps detect the number of dynamic and static people in the coverage area. This improves energy saving efficiency as well as providing an efficient and seamless statistics basis for occupancy rate inspection.

Solution

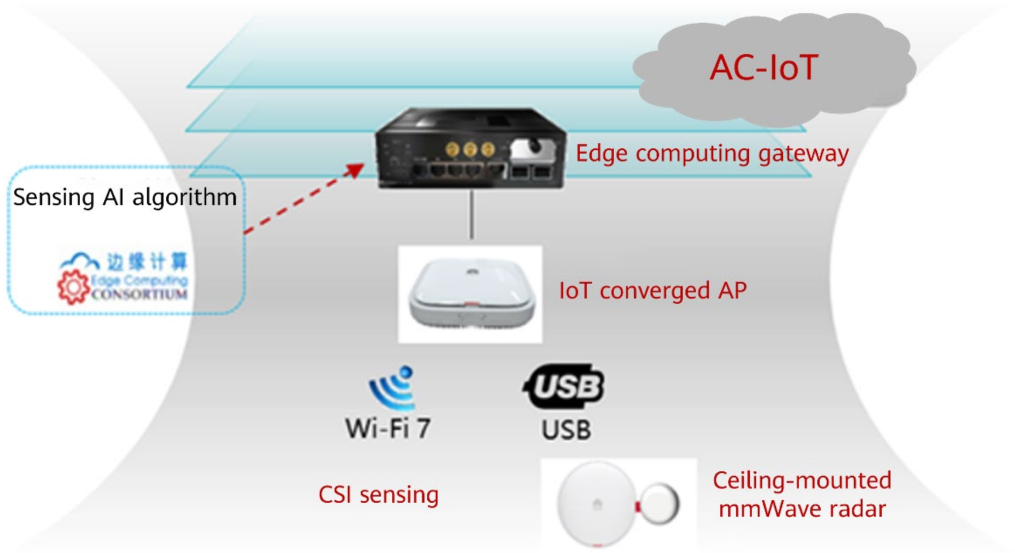

Figure 18 Hotel management system

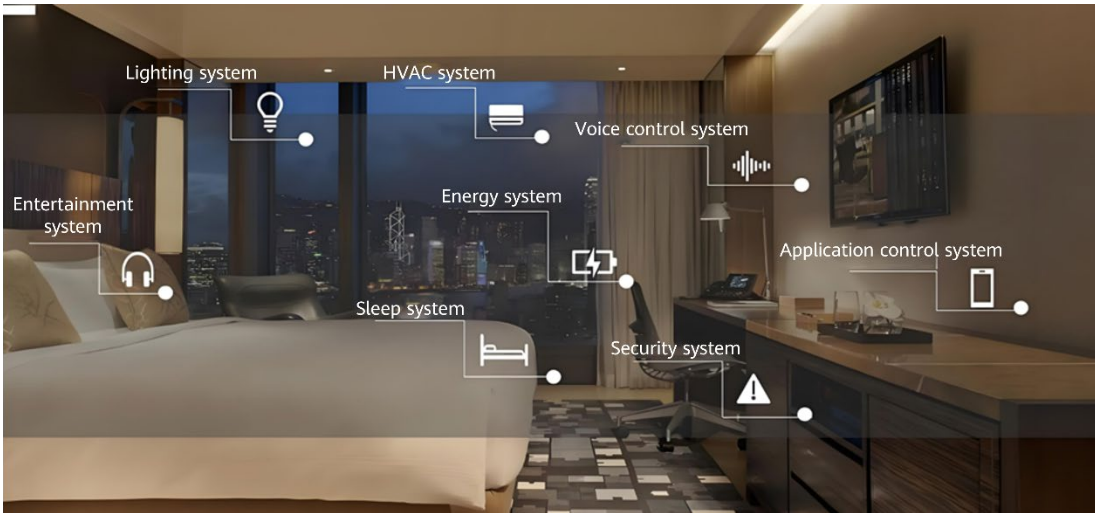

Figure 19 Hotel guest room management system

Automatic energy saving in guest rooms:

- Space setting: For guest rooms in the hotel, the floor height is 3 to 5 meters and the area is about 20 to 60 m^2. Each room has a bathroom, which is separated from the bedroom by walls.
- Sensing range: It is the same as the WLAN coverage range.
- Status information sensing: person counting in guest rooms (including the bathroom) and static human body detection
- Expected result: The number of people in the guest room is sensed, dynamic and static human body detection is performed, and the information is reported to the hotel management system. The power supply in guest rooms is also automatically controlled.

Performance requirements: low latency in reporting person entry. The system can effectively recognize people in static and sleeping states and count the number of people, ensuring zero false negatives and zero false positives.

Fraud detection:

- Space setting: For guest rooms in the hotel, the floor height is 3 to 5 meters and the area is about 20 to 60 m^2. Each room has a bathroom, which is separated from the bedroom by walls.
- Sensing range: It is the same as the WLAN coverage range.
- Status information sensing: Check whether the guest room has been occupied.
- Expected result: The occupancy status of guest rooms is sensed and reported to the hotel management system to prevent room fees from not being accounted.

Performance requirements: low latency in reporting person entry The system can effectively recognize people in static and sleeping states and count the number of people, ensuring zero false negatives and zero false positives.

Chapter 3 Industry Development Initiatives for Wi-Fi CSI Sensing

3.1 Accelerating Standard Formulation

Formulating technical standards is critical to the healthy development of the industry. Standards not only reflect technological innovation, but also serve as the basis for collaboration between upstream and downstream enterprises in the industry chain. To accelerate the development of Wi-Fi CSI sensing, relevant standards urgently need to be formulated.

Unifying technical specifications: There are no unified standards for network construction and testing related to Wi-Fi CSI sensing, and so WAA wants to work with vendors to formulate such standards. The aim is to avoid interconnection and interworking problems caused by differing technical standards between enterprises, thereby promoting the healthy development of the industry.

Improving industry coordination: Unified standard formulation can promote cooperation between upstream and downstream enterprises in the industry chain, especially the interconnection between device vendors and third-party systems. This accelerates the application and promotion of Wi-Fi CSI sensing.

WAA will continue to promote high-quality technical standard projects of Wi-Fi CSI sensing and lead the development of the WLAN industry.

3.2 Accelerating Industrialization

With the rapid development of wireless communications, WLAN has become an indispensable part of life and work. However, as user requirements become more diverse and complex, traditional WLAN technologies can no longer fully meet the requirements of people in the future intelligent society. To this end, Wi-Fi CSI sensing is proposed to integrate wireless communications and sensing technologies, so as to provide more efficient, secure, and intelligent network services.

The industrialization of the technology is a key step to promoting its wide application and development. The industrialization of Wi-Fi CSI sensing not only promotes the maturity of the technology, but also reduces costs, ultimately improving its market competitiveness. To accelerate the industrialization of Wi-Fi CSI sensing, the following must be met:

Market demand–centric: There is an urgent need for efficient and reliable sensing in various scenarios, such as enterprise energy saving, healthcare, intelligent conference management, enterprise office space management, education campus dormitory management, and hotel guest room management. Wi-Fi CSI sensing can effectively meet the requirements of these scenarios by seamlessly integrating short-range wireless communications with sensing, providing users with better services.

Technological innovation–driven: During the industrialization of Wi-Fi CSI sensing, technology-market interaction fuels further innovation. This drives enterprises to continuously improve the technology and enhance product performance, thereby forming a virtuous cycle.

3.3 Initiating Testing and Certification for Wi-Fi CSI Sensing

Testing and certification are important for ensuring the performance and reliability of technical products, and this is especially critical for Wi-Fi CSI sensing.

Ensuring product quality: Strict testing and certification can ensure that the communications and sensing functions of Wi-Fi CSI sensing devices achieve expected results for improved user experience.

Standardizing market order: Only products that have passed relevant Wi-Fi CSI sensing certification can be involved in project bidding and be sold in the market. This effectively prevents unqualified products from entering the market, standardizes market order, and protects consumer rights and interests.

Promoting technological progress: Testing and certification help identify the weaknesses of technologies, thereby prompting enterprises to make improvements and innovations, ultimately driving technological progress.