[Interdisciplinary Studies]

Control and Management of Smart Buildings in Smart Cities

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Abstract: This study examines key performance indicators in smart buildings for smart cities, focusing on construction site ad-hoc networks and personnel location systems. We evaluate the outdoor base station transmission distance, building wall penetration, base station network formation, channel reception quality, and communication speed. These metrics are crucial for assessing the smart city infrastructure's reliability, security, and efficiency. Our detailed analysis aims to optimize smart building control and management systems in smart cities, ensuring stability and reliability. Additionally, we investigate the system's adaptability and flexibility in various environments to promote smart building technology innovation and application, furthering smart cities' sustainable development.

Keywords: smart city; smart building; construction site ad-hoc networking; personnel positioning system; performance testing

1. Introduction

Smart cities, as a new model of urban development, aim to integrate advanced information and communication technologies to enhance urban management and quality of life. Among them, intelligent buildings, as a critical component of smart cities, have control and management systems whose stability and performance are directly tied to the advancement of urban intelligence.

2. Detection Items and Methods

2.1 Outdoor base station transmission distance testing

In this study, a system was deployed at specific locations, and the transmission distance of outdoor base stations was thoroughly tested using LoRa wireless transmission technology. This was done to ensure that the system could maintain stable and reliable data transmission in complex urban environments. LoRa (Low Power Wide Area Network), as a long-range, low-power communication technology, provides extensive communication coverage for smart city infrastructure, making it widely adopted in practical applications.

To verify the transmission performance of the system in urban environments, we selected representative test locations, such as the Baiyun Investment Building and other urban landmarks. These locations typically encompass various physical obstacles and sources of interference found in cities, imposing higher demands on the system's transmission performance. By conducting system tests at these sites, we were able to more comprehensively evaluate the system's performance in real urban environments.

2.1.1 Test description

Equipment Deployment: A base station (Base Station ID: 4) was assigned and deployed on the balcony of the 9th floor of the Baiyun Investment Building, located on Guangyun Road, Baiyun District, Guangzhou. Additionally, one locator card (Locator Card ID: 1026) and one beacon (Beacon ID: 17887) were selected. The aforementioned base station, locator card, and beacon were then bound to the "South China Headquarters Base Project" test on the Kuoyu System platform.

2.1.2 Coverage transmission test

Two locations more than 1 km away from the base station were selected for the test:

- Location A: Detian Center, 406 Guangyun Road, Baiyun District, Guangzhou (1.1 km from the base station).
- Location B: Near Yunju Center, 2 Kangwei Road, Baiyun District, Guangzhou (1.3 km from the base station).

At Location A, a beacon was placed, and the test personnel carried the locator card, gradually approaching the beacon from a distance of 30 meters and then moving away from it. During this process, the Kuoyu System platform was monitored to check whether the platform recorded the positioning data. This operation was repeated 30 times.

The positioning success rate was calculated using the formula:

Positioning Success Rate = (Number of positioning records on the platform / Number of attempts to approach the beacon) × 100%.

At Location B, a similar test was conducted: a beacon was placed, and the test personnel carried the locator card, gradually approaching the beacon from a distance of 30 meters and then moving away from it. This operation was also repeated 30 times, with the Kuoyu System platform monitored for recorded positioning data.

The same formula was used to calculate the positioning success rate.

2.1.3 Test conclusion

Coverage Transmission: The outdoor base station transmission distance supports stable transmission of no less than 1,000 meters.

2.2 Building wall penetration testing

In this study, a specific method for testing building wall penetration was employed, with the wall thickness set at 120mm per wall, to thoroughly investigate the system's communication penetration performance in multi-story building environments. This test was conducted through practical application in multi-story buildings, aiming to comprehensively evaluate the system's communication capability in real and diverse building structures.

Experimental data showed that the system, using the 120mm-per-wall penetration testing method, exhibited excellent performance, effectively addressing the communication challenges posed by multi-story building environments. Specifically, in tests conducted between different floors, the system demonstrated strong penetration capabilities, successfully achieving stable and reliable communication through walls. For example, in the multi-story building environment of the Baiyun Investment Building, the system successfully penetrated walls with a thickness of 120mm per wall, enabling effective communication between floors.

2.2.1 Test description

Equipment Deployment: A base station (Base Station ID: 3) was deployed at the center of the 1st floor of the Baiyun Investment Building. One locator card and one beacon were selected, and the base station, locator card, and beacon were bound to the "South China Headquarters Base Project" test on the Kuoyu System platform.

Penetration Test: A beacon was placed at the center of the 5th floor. The floor slab thickness exceeded 120mm per wall.

Test personnel carried a locator card while walking around on the 5th floor, gradually approaching and moving away from the beacon. During this process, the Kuoyu System platform was monitored to check whether the positioning data was recorded. The same test was repeated on the 6th, 7th, 8th, and 9th floors.

The positioning success rate was calculated using the formula:

Positioning Success Rate = (Number of positioning records on the platform / Number of attempts to approach the beacon) × 100%.

2.2.2 Test conclusion

Penetration Performance: For building walls with a thickness of over 120mm per wall, the system demonstrated penetration capability through no fewer than four walls.

2.3 Three-sided composite positioning algorithm

Themulti-dimensional collaborative self-correction positioning algorithm is applied to scenarios involving wireless ad hoc network transmission. Its goal is to improve the accuracy of the positioning algorithm by performing multi-dimensional collaborative self-correction on spatial and temporal gap weight values. This algorithm incorporates on-site broadcasting beacons, locator cards, and project base stations to collect raw field data, which is processed via wireless ad hoc network data access. By integrating signal strength probability distribution and directional angle clustering algorithms, the algorithm achieves precise positioning of raw data in both planar and three-dimensional spaces.

In terms of data fusion, the algorithm merges multi-source data across spatial and temporal dimensions for a more comprehensive description of the target's location. Combining experience parameters from construction site scenarios, multiple rounds of iterative data calculations are conducted to ultimately determine the three-dimensional spatial coordinates of personnel. During this process, the three-sided composite positioning algorithm is utilized for 3D positioning. By leveraging the distance information from three known reference points, the algorithm achieves high accuracy and stability in positioning.

On the other hand, the intelligent positioning algorithm based on RSSI (Received Signal Strength Indicator) probability distribution is used for planar positioning correction. By modeling the probability distribution of received signal strength and integrating data from on-site broadcasting beacons, locator cards, and project base stations, this algorithm eliminates interference in the planar space, improving positioning accuracy. This approach has significant advantages in non-ideal scenarios, such as indoor environments.

2.3.1 Experimental results and analysis

Through a series of comprehensive performance tests, the system demonstrated outstanding performance across various metrics. Specifically, the system met the requirements set by the client in terms of outdoor transmission distance, building penetration, base station aggregation, reception channels, and communication rate, exhibiting excellent stability and reliability.

First, in the outdoor transmission distance tests, the system successfully achieved stable transmission in urban environments by utilizing LoRa wireless transmission technology. For example, in the coverage transmission tests, the system showcased exceptional performance, ensuring an outdoor transmission distance of no less than 1, 000 meters, thus providing a reliable communication foundation for applications in open environments.

Second, in the building penetration tests, the system employed a 120mm per wall penetration test method to verify communication penetration in multi-story buildings through field testing. For instance, the system achieved penetration through no fewer than four building walls during tests in multi-story building environments, providing strong support for communication reliability in densely built urban areas.

In the base station aggregation tests, the system used the Kuoyu System platform to determine the number of aggregated base stations it could support. Results showed that the system successfully supported the aggregation of 10 base stations, demonstrating its scalability for wide-area applications.

Finally, in the communication rate tests, the system achieved the required communication rate by configuring the LoRa module's spreading factor and bandwidth parameters. For example, by adjusting the spreading factor and other parameters, the system ensured a communication rate of no less than 5kbps, even in complex urban environments, providing reliable data transmission for practical applications.

3. Conclusion and Future Outlook

This study conducted a comprehensive performance evaluation of the construction site's self-organizing network and personnel positioning system, providing empirical support for the control and management of smart buildings in smart cities. Future research can further expand the exploration of smart city infrastructure, enhance the intelligence level of the system, and provide more scientific evidence for sustainable urban development.

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