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Communication Performance of BLE-based IoT Devices and Routers for Tracking Indoor Construction Resources

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Abstract

Sensors collect information for Internet of Things (IoT)-based services. However, indoor construction sites have a poor communication environment and many interfering elements that make it difficult to collect sensor information. In this study, a network was constructed between a Bluetooth Low Energy (BLE)-based IoT device based on a serverless IoT framework and a router. This experimental environment was applied to large- and small-scale indoor construction sites. Experiments were performed to test the communication performance of BLE-based IoT devices and routers at indoor construction sites. An analysis of the received signal strength indication (RSSI) graph patterns collected from the communication between the BLE-based IoT devices and routers for different testbed site situation revealed areas with good communication performance and poor communication performance due to interfering factors. The results confirmed that structural components of the building as well as the materials, equipment, and temporary facilities used in indoor construction interfere with the communication performance. Construction project managers will require improved technical knowledge of IoT, such as optimizing the router placement and matching communication between the router and workers, to improve the communication performance for large-scale indoor construction.

Keywords: *Serverless IoT framework, BLE-based IoT device, router, indoor construction, RSSI*

1. Introduction

Construction projects have an extremely complicated work environment because of their dynamic characteristics and simultaneous use of numerous resources [1]. Thus, construction is recognized as one of the most dangerous industries in the world [2-5]. Serious safety accidents leading to the injury or death of workers may not only terminate construction projects but also cause social costs from disabilities and financial burdens from early retirement [6, 7]. To prevent such safety accidents, numerous practical guidelines have been developed on controlling a complicated work environment, using tools, and performing specific procedures the safest way. Developing and expanding construction management techniques not only helps deal with the complexity of the construction work environment but also provides tools necessary for

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reducing work-related safety accidents [8-9]. However, because safety plans are applied by workers, it is extremely difficult for a construction manager to simultaneously manage the status of multiple workers performing different tasks in a construction work environment [10].

Recently commercialized information and communications technology (ICT), such as the Internet of Things (IoT), provides the required background for developing a real-time construction management system that can be perfectly integrated into a construction project [11]. According to this new vision, future construction sites will be reorganized into a smart workplace where a decision-making system that recognizes context while monitoring and supplementing the self-adaptive sensor network and worker activities provides real-time support at every level [12, 13]. In the construction sector particularly, interest in the use of real-time locating system (RTLS) technology has surged [14]. RTLS is an application that identifies the current positions of people, materials, and equipment and facilitates data tracking and management; it combines hardware and software to automatically determine the real-time coordinates of an object within a limited area [15]. The data collected by RTLS can be used to manage resources in real time and can be applied through additional analysis after a series of data is collected [14].

RTLS has been widely applied to various industrial areas, including logistics [16], medicine [17], and construction [14]. Recently, RTLS applications have been extended from outdoor positioning to indoor location tracking [18, 19]. Previous studies have revealed its huge potential for indoor positioning [20, 21]. The quality of the indoor positioning service is determined by the quality of the collected and analyzed information [22, 23, 24]. The most fundamental objects of an RTLS that collect information are sensors [25, 26]. However, the work environment of an indoor construction site has many interfering elements (e.g., workers, columns, and materials) that make it difficult to collect information using sensors and produce extremely poor communication environment. Such an environment is a huge obstacle to constructing a sustainable IoT environment and cannot guarantee the service quality of developed systems. Developing application technologies while the fundamental communication performance has not been tested is time-consuming and costly. In this study, an experiment was conducted to examine the communication performance for wireless IoT devices and routers at an indoor construction site. The purpose of the experiment was not to estimate the exact position, which has been researched in previous studies, but to collect a database in real time using BLE-based tracking to infer the work status of workers. The results were used to consider the implications and future research directions for the development of IoT-based construction services.

2. Related works

2.1 IoT Service Framework

With the development of cloud computing and service-oriented architecture (SOA), a new system structure called function as a service (FaaS) has emerged. FaaS forms the basis of the serverless IoT framework. The backend system processes tasks asynchronously according to specific events. This gives FaaS the benefit that no separate server system management or server application program is required [27]. Furthermore, FaaS hardly uses shared memory to process data compared to existing service architectures. In particular, the sequence of events is important for systems that support tracking technologies [28]. In this case, controlling the sequence of each function is important because large amounts of computing resources are required. From this perspective, FaaS has the benefit of being able to organize a simple yet robust system.

To implement the IoT service framework, classifying the services to be provided is important. In general, services provided by cloud computing are classified as stateless or stateful. For stateless services, the processing time is short, and the processing status can be instantly expressed, such as providing user certification and webpages. Furthermore, the processing status of such services is managed on the client side. Stateless services are directly connected to the representational state transfer application programming interface (REST API) gateway and thus can provide instant responses. On the other hand, most stateful services have complicated processing structures. If the user has to request a map service or push service to track his or her movement in real time to the server, the events generated by the user are inserted into the server and the server must return responses in real time. In this study, a sensor network suitable for indoor construction sites was constructed, and the communication performance of BLE-based IoT devices and routers was tested in this system environment.

2.2 Serverless IoT Framework

Systems built with the typical server–client structure control responses by making threads to control each event and process. However, the IoT service framework shown in Figure 1 does not need thread generation. In other words, the IoT service framework acquires all of the results by inputting the sequence of a series of events to be controlled in the queue under the control of the service harmonizer, sorting the asynchronously returned callback responses in order, and sending them to other functions that produce results.

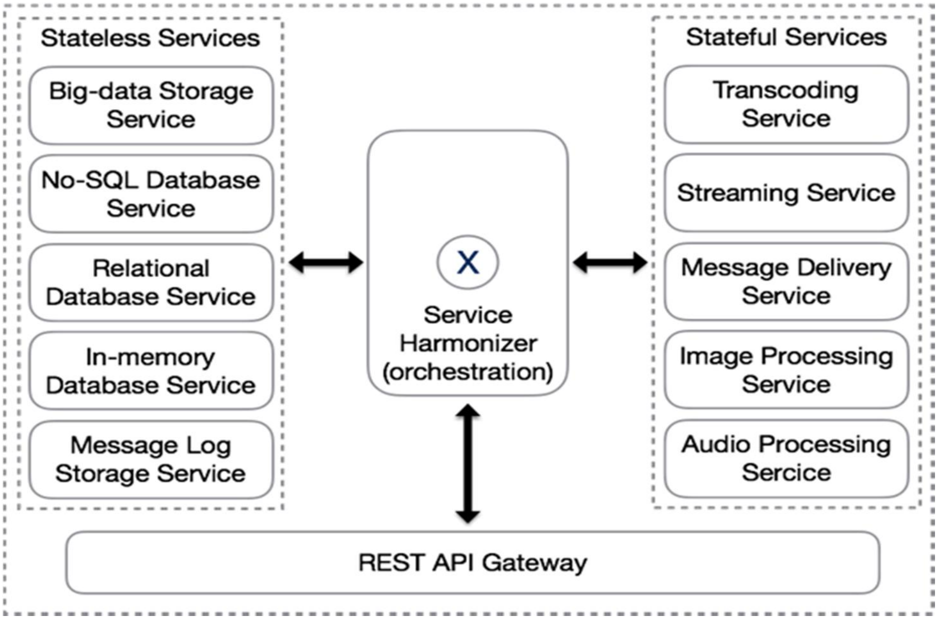


Figure 1. Diagram of the proposed system.

The IoT service framework may exhibit many possibilities. In particular, it has the huge benefit of implementing a platform that must process complicated operations requiring a long processing time, such as a sensor network utilizing IoT technology, according to the user input. In this study, therefore, a sensor network suitable for tracking the resources of an indoor construction site was constructed, and a platform that stores and analyzes the data collected from the communication between BLE-based IoT devices and routers was built. A new system that utilizes the internal message passing application protocol interface (IMPAPI) was proposed, where the Advanced Message Queueing Protocol (AMQP) is applied as the message protocol for interfaces between internal functions. This system environment was used to test the communication performance of BLE-based IoT devices and routers.

2.3 Tracking System for Indoor Construction Resources

Figure 2 shows the network configuration of the proposed system. Router 1 and Router 2 were installed at the site. Raspberry Pi 3, which is a type of single-board computer (SBC), was used as the mainboard of the routers. Raspbian Stretch, which is a distribution version based on Debian Linux, was installed as the operating system (OS). It was created by the developer of Raspberry Pi and is its official OS. Because Raspberry pi 3 has a built-in wired LAN, WiFi, and Bluetooth 4.0 chipset, the network could be constructed by installing software alone without additional devices. An additional LTE router was connected to Router 1 through the universal serial bus (USB) interface so that data could be transmitted to the external cloud. Router 2 formed the internal network with Router 1 through WiFi installed in the LTE router, and each router could be physically connected to a total of eight devices through BLE. In the experiment, four TI CC1350 Sensortags are received RSSI through the BLE network. Each router had the bluepy library installed for accessing the BLE devices through Python, and Python programs were created to access the Sensortags and receive data. Each Python program could be connected to one Sensortag. Thus, a Node.js-based program was created and operated as the subprocess so that multiple Sensortags could be accessed. The Node.js-based program received Sensortag data asynchronously, and the message generated in each process was stored in the SQLite embedded database with the Node.js-based program serving as the service harmonizer. At the same time, the message was transmitted to Amazon MQ through AMQP and finally saved in Amazon Lambda, which is a serverless service.

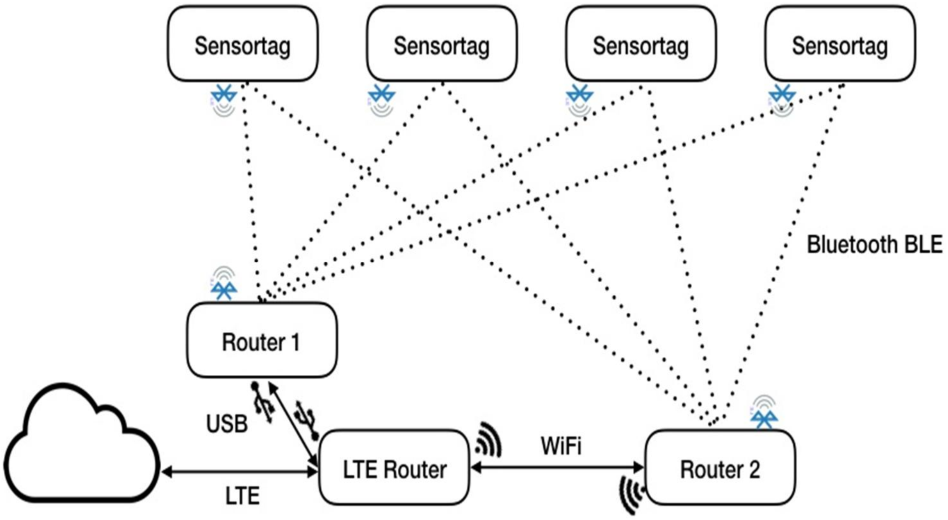


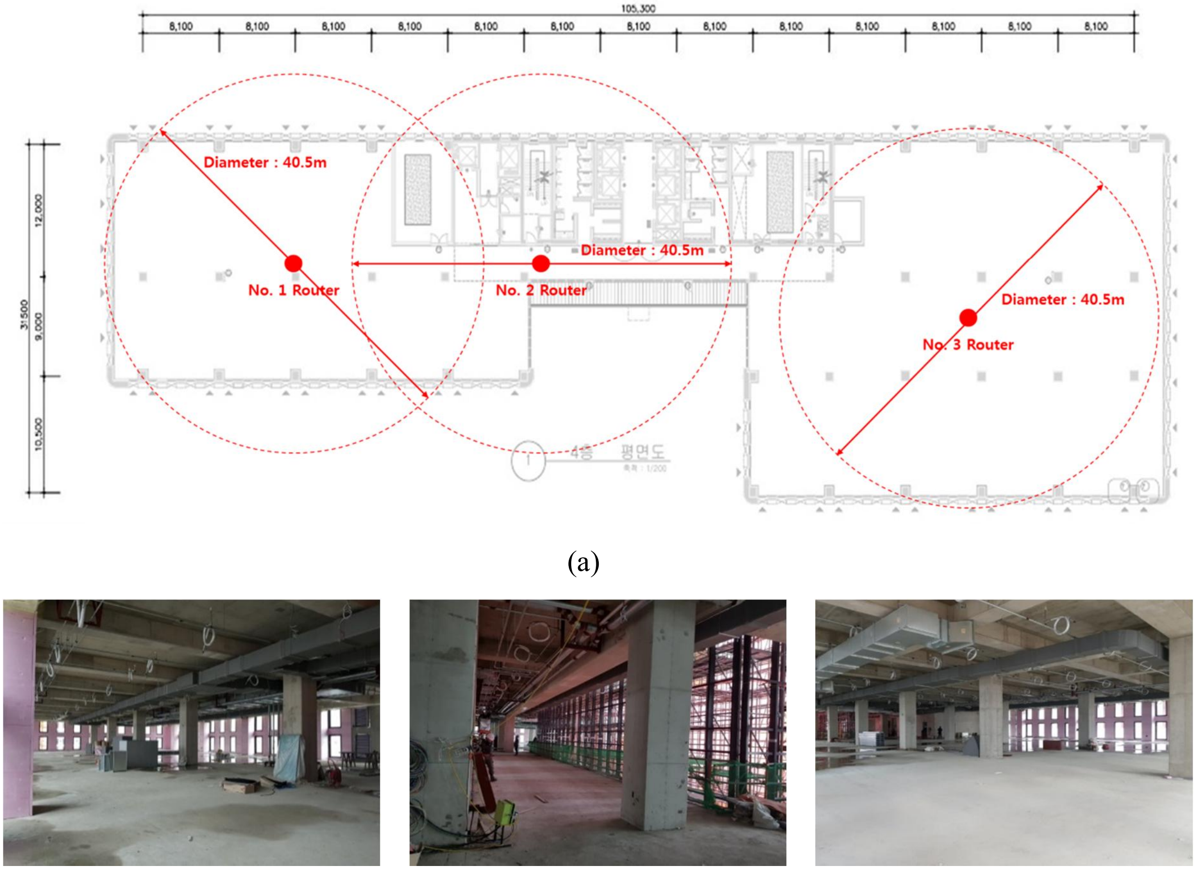
Figure 2. Network configuration of the proposed system.

3. Experiment of Communication Performance

3.1 Field Description

This was a basic experimental study on the communication performance of BLE-based IoT devices and routers. Therefore, the positions of the routers were fixed by considering the communication range, and RSSI data were collected while a worker wearing BLE-based IoT devices with a Sensortag moved around the site.

The communication intensity of the collected RSSI data was analyzed to derive implications for applying the proposed system to indoor construction. The first testbed site was a steel reinforced concrete (SRC) building with eight floors aboveground and two floors underground at 782 Woomyeon-dong, Seocho-gu, Seoul. In the building, indoor construction took place after the framework construction was completed. The size of the floor plan was too large (105.3 m × 31.5 m) to test the communication performance of the BLE-based IoT devices and routers. With a single router, it was not possible to collect the data received from the worker wearing BLE-based IoT devices with a Sensortag. Therefore, in this first experiment, three routers were installed by considering the RSSI data reception radius range for BLE-based IoT devices and routers, as shown in Figure 3.



(a)

(b) (c) (d)

Figure 3. First testbed: (a) floor plan and site photographs: (b) No. 1 router, (c) No. 2 router, and (d) No. 3 router.

BLE-based IoT devices with a Sensortag were attached to the safety gear used at construction sites (i.e., safety helmet, safety vest, and safety shoes), as shown in Figure 4. Because Sensortag includes various sensors, different data such as the worker situation and status and the indoor construction environment can be inferred by analyzing the sensor data with machine learning. However, this study was focused on the communication performance of BLE-based IoT devices and routers in an indoor construction environment.

(a) (b) (c)

Figure 4. BLE-based IoT device installation positions: (a) safety helmet, (b) safety vest, and (c) safety shoes.

The second testbed site was a small-sized house (9.840 m × 7.720m), which was much smaller than the first experiment site, where interior construction was taking place. The construction site was divided into the first and second floors. A router was installed on each floor to test the communication performance of the BLE-based IoT devices and routers, as shown in Figure 5. Because the floor plan size was not large, the reception radius was not considered specifically. However, the influence of internal brick walls or reinforced concrete walls on the communication intensity was considered.

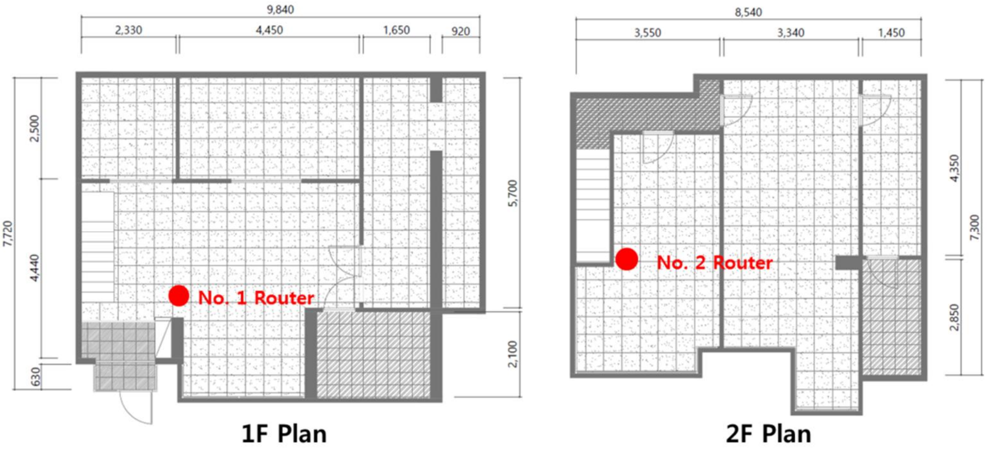


Figure 5. First- and second-floor plans for the second testbed.

3.2 Stable Reception Range and RSSI Data Analysis

The RSSI data collected while the worker wearing BLE-based IoT devices with a Sensortag moved around the sites were used to identify the ranges in which the sensor data were received in a stable manner. Figure 6 shows the areas in which the sensor data could be received in a stable manner through three routers at the first testbed site. While each router could collect data from multiple Sensortags, data were not communicated to other routers if the reception range of the fixed router was exceeded. While data disconnection when the Sensortag of the worker moved from one router to another can be a technical problem, it can be addressed by the construction project manager matching routers and Sensortags by considering the type of work and work group when assigning workers at the site. In addition, because the communication range varies depending on the routers for a large site, multiple routers must be placed depending on their communication performances.

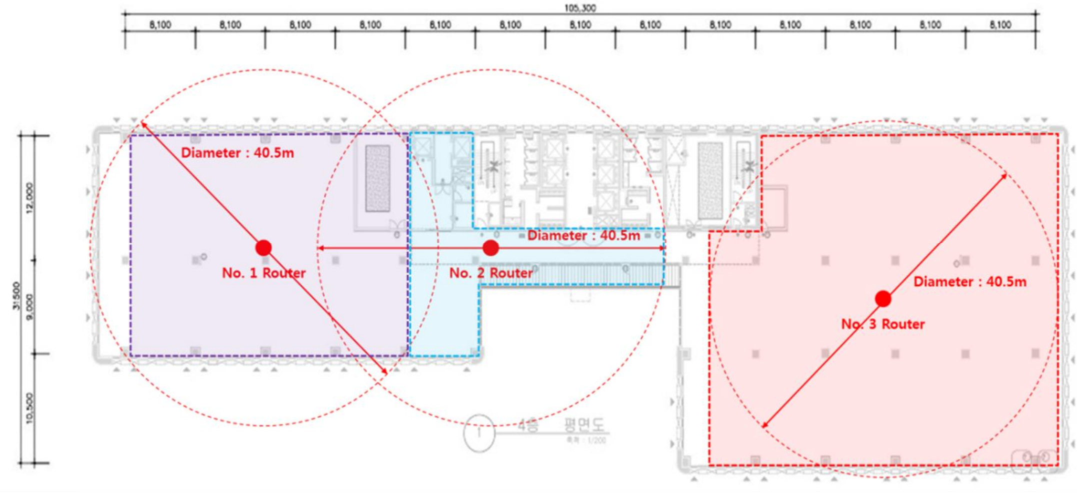
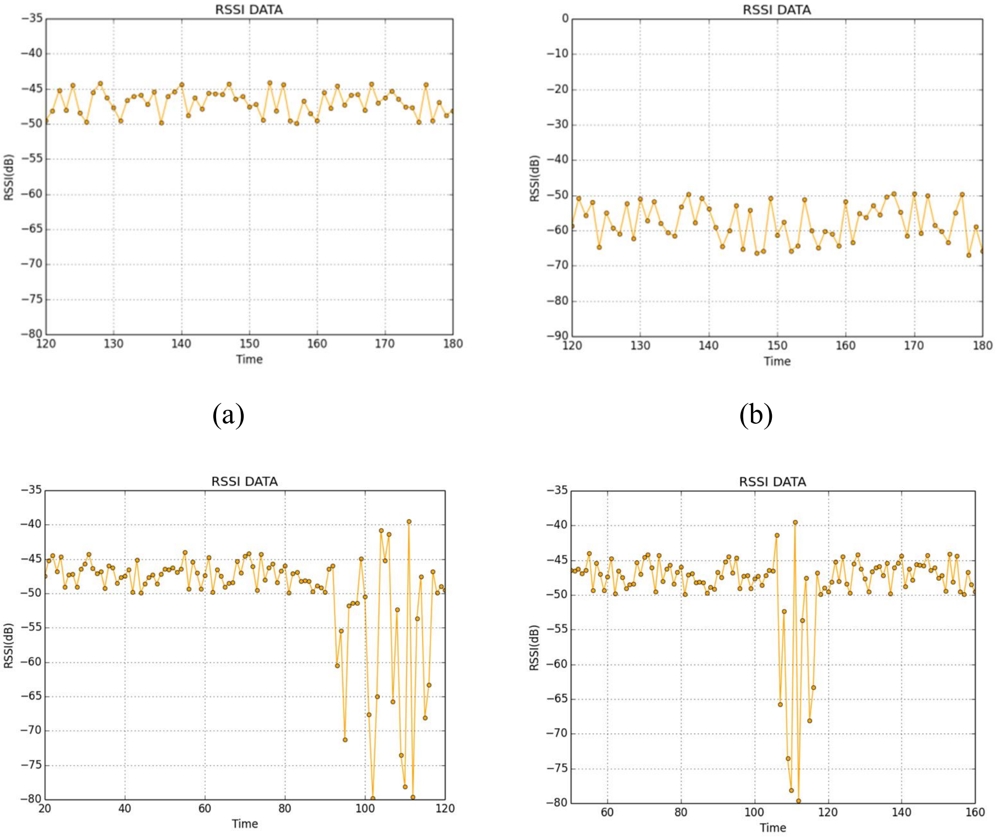


Figure 6. Stable reception range of the first testbed site.

Figure 7 shows the RSSI graphs according to the first testbed site situation. Figure 7a shows the RSSI graph recorded when the worker was relatively close to the router and reception was constant. Figure 7b shows the RSSI graph recorded when the worker was relatively far from the router and reception was constant. Figure 7c shows the RSSI graph recorded when the worker suddenly moved away from the router. The RSSI theoretically varies linearly, but it may actually change dramatically or fluctuate based on the sensor data acquisition speed of the experiment device and obstacles [29]. Figure 7d shows the RSSI graph when the worker approached steel members stacked at the site. Because the radio waves used for BLE are absorbed by structures with a large amount of steel components, the RSSI changed dramatically. The test at the second site confirmed that the communication between the routers and Sensortags was effective in most spaces, as shown in Figure 8. Figure 9 shows the RSSI graphs for different situations at the second testbed site. Figure 9a shows the RSSI graph recorded when the worker was relatively close to the router and reception was constant. Figure 9b shows the RSSI graph recorded when the worker was relatively far from the router and reception was constant. Figure 9c shows the RSSI graph recorded when the worker moved from the first floor to the second floor. While sensor data reception was unstable during the movement to the different floor, the reception stabilized rapidly once the movement was complete because the transceiver chipset adjusted the intensity of the radio waves. Figure 9d shows the RSSI graph when the worker was relatively far from the router and there were interfering elements that hindered the transmission and reception of sensor data between the worker and router.



(a) (b)

(c) (d)

Figure 7. RSSI intensities at the first testbed site for different situations: (a) the worker is close to the router; (b) the worker is far from the router; (c) the worker suddenly moves away from the router; (d) the worker approaches steel members.

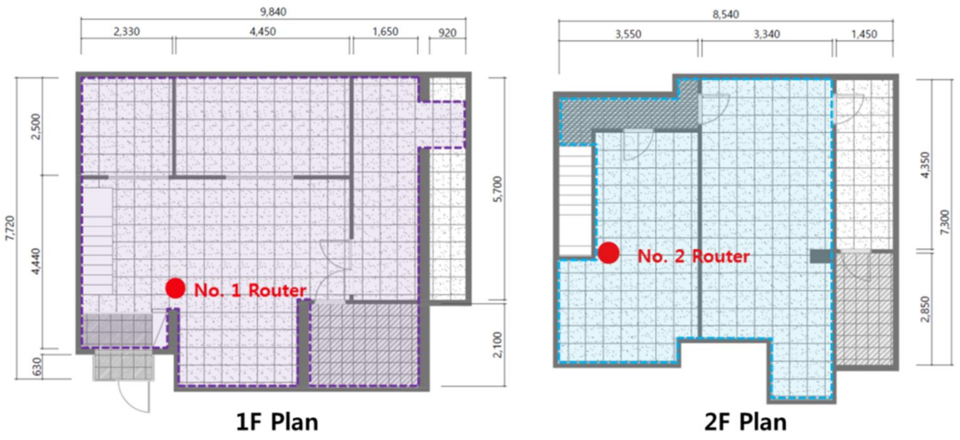
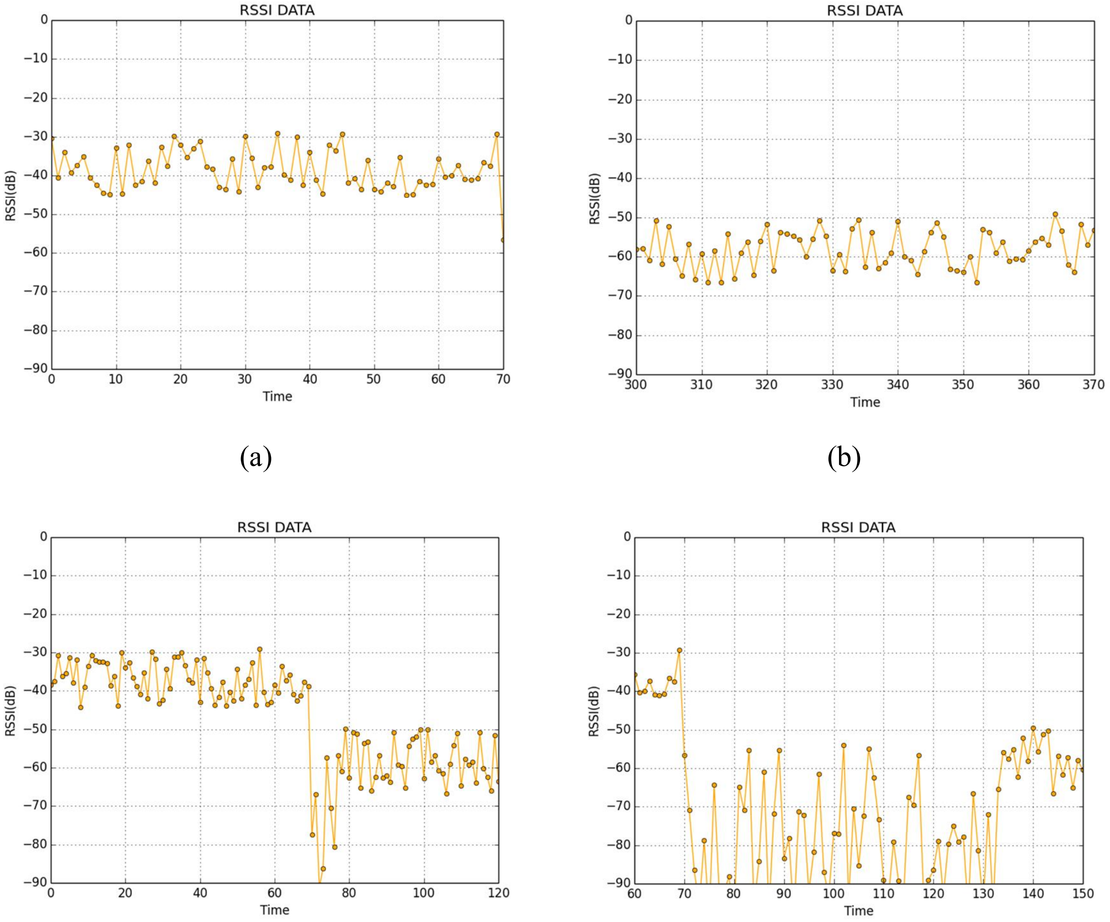


Figure 8. Stable reception range of the second testbed site.



(a) (b)

(c) (d)

Figure 9. RSSI intensities at the second testbed site for different situations: (a) the worker is close to the router; (b) the worker is far from the router; (c) the worker moves from the first floor to the second floor; (d) the worker is far from the router and there are structural or brick walls between them.

It was confirmed that there were positions on the first floor where communication was not possible because of the reinforced concrete walls, and communication was unstable at positions on the second floor with two brick walls between the worker and router.

3.3 Interfering Factors for Communication at Indoor Construction Sites

Figure 10 summarizes interfering factors that hinder communication based on the communication performance of BLE-based IoT devices and routers at sites where indoor construction was underway. In the case of construction materials, metal ducts and pipes, highly stacked gypsum boards, mortar, bricks, and PVC pipes affect the communication performance. In the case of indoor construction equipment and temporary facilities, communication interference due to rental equipment and scaffolding was confirmed. In addition, existing major structural members such as structural walls and columns were also confirmed to significantly degrade the communication performance.

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 10. Communication-interfering elements for indoor construction sites: (a) mortar, PVC pipes, and gypsum board; (b) bricks; (c) ducts; (d) ducts; (e) metal pipes; (f) rental equipment; (g) scaffolding; (h) structural columns; and (i) structural walls.

5. Discussion and Conclusion

This study focused on tracking the resources of indoor construction using BLE-based tracking technology. A serverless IoT framework was proposed and used to construct a server network for tracking indoor construction resources. The communication performance of BLE-based IoT devices and routers was tested in indoor environments. The communication performance test focused not on accurate position estimation, which has been considered in previous studies, but on collecting a database in real time with BLE-based tracking to infer the work status of workers. The patterns of RSSI graphs that were collected for communication between BLE-based IoT devices and routers in different situations at the testbed sites were analyzed. The implications of the experimental results are summarized below.

First, from a project scale perspective, when an IoT-based service is applied to a project with a large space, the placement of multiple routers to track construction resources must be reviewed by considering the communication performance of the BLE-based IoT devices and routers. Furthermore, specific routers and the work type of the worker wearing Sensortags must be matched appropriately to improve the reliability of data collection. Second, from a building structure perspective, fixed structural members such as structural walls, columns, and slabs were confirmed to clearly hinder communication. Considering these characteristics, the placement of routers needs to be optimized to collect quality sensor data from multiple workers. Finally, in the case of indoor construction, the fact that workers, materials, equipment, and temporary facilities will always be present in construction sites in a complicated manner is inevitable. Considering this fundamental nature of construction projects, the capabilities of construction project managers must be improved to enhance the applicability and quality of IoT-based services.

This was a basic study towards reaching the final goal of managing workers (e.g., work status, safety accident prediction, and health condition identification) by collecting big data on the movement of workers collected from the communication between BLE-based IoT devices and routers based on a serverless IoT framework and by understanding worker information through machine learning. Future investigations will focus on the power consumption due to operation of the proposed system, the performance of the server network, and work type classification and categorization for machine learning.

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