 doi:10.20944/preprints201806.0009.v1

Article

Bluetooth Smart: Design and Implementation of Positioning Mechanism and System with Low Energy Wireless Sensor Network in Manufacturing Industry

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Abstract: To enhance industrial competitiveness and increase productivity, every country has strived to create a smart factory by introducing technologies such as Internet of Things, big data and artificial intelligence into production line and build cyber-physical system for the purpose of promoting manufacturing efficiency. For mission assignment, production line management or manufacturing field analysis, the location information of employee, machine and material is very essential. To promote manufacturing efficiency, of course, the location information became more important. A Bluetooth low energy (BLE) positioning system for the manufacturing is developed in this research. A "Tag tracking" mechanism is addressed and adopted, which uses Beacon to catch the location information and a BLE receiver is also used to receive the broadcasting information from Beacon. The position information from the BLE receiver will be compared with the data in the database for calculating the location of the target. The status of the target may also be obtained by using the data from the BLE receiver. Comparing with the mobile device, this method can reduce energy consumption and make the maintenance simple and easy. In the real applications, the target may not be limited to human. The "Regional label positioning technology" is also investigated in this research. Defining a suitable zone location and arranging BLE receiver location, and positioning analysis theory are the key factors included in this developed technology. The developed system will be tested for real industry applications. The test results show that the feasibility of this technology.

Keywords: Indoor Positioning Technology; Bluetooth 4.0; Manufacturing Private Cloud; Internet of Things; Indoor Positioning Technology;

1. Introduction

Most manufacturing enterprises would adopt IT system. IT system is mainly used to reduce the paper work. Enterprises are able to store the manufacturing data more conveniently and get the information more quickly by utilizing computers. IT system can also support decision making or data analysis. It truly helps the enterprises increase the performance of management [1]. In fact, IT system can almost be applied to everywhere in management. But not all of them can take the full advantage of IT system. Employee management is a conspicuous example. Supervising the employees in the factory is difficult because it is hardly to get the location of all employees in the factory. Traditionally, IT system doesn't record the location information of each employee. Without the location information, it is intuitive that managers can't schedule manpower of employees in different working area [2]. Besides, we also find a significant problem is that enterprises commonly consider the IT system as a tool and use it unilaterally. It is hardly to find a mutual cooperation between employees and IT system. Although this problem is not so serious, it cannot be neglected. If IT system can

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automatically send the information to specific employee, the whole production line operation must be smoother and the production would be more efficient [3,4].

To catch the location information of objects in production line, the most representative solution is utilizing indoor positioning technique. Although many diverse technologies such as (GPS, Wi-Fi, Bluetooth, ZigBee, Ultra Wide Band, Ultrasound, Infrared, etc…) can be used for indoor position system, we choose the BLE as the main protocol in this thesis. It's not an either-or proposition. It's about choosing the right technology to appropriately address the need on different situations.

There are a couple of reasons that we choose the BLE in this thesis. BLE both takes the advantages of low cost and high compatibility with large base of mobile phones, computers and tablets like BLE. Most important of all, indoor positioning technique based on BLE is popular applied in several commercial areas. However, this protocol is still not widely used in manufacture industry.

In this thesis, we proposed a framework based on BLE to develop a new model for manufacture industry to manage employee efficiently. A networked management system with cloud computing for this framework is also be implemented.

2. Previous Studies for Positioning Technology

2.1. Various types of positioning technology

Location information of employee, machine and material can improve the productivity for manufacturing industry, especially in logistics. In order to effectively capture the location of object, the introduction of indoor positioning technology for factory is essential [5,6]. Teixeira et al. have divided the perception of human into five major areas, namely, the existence of the environment, the number of environments, location, tracking and identification, as well as detailed technical descriptions and methods [7]. The sensors and rules for various technologies are also categorized as Table 1.

Before the rapid development of IoT-related technologies, Global positioning system (GPS) is the most common way to detect position of object. However, GPS is not be reliable enough in the indoor environment [5,6,8]. To achieve higher accuracy in indoor positioning, many other technologies include indoor GPS, motion and rotation sensors, ultrasound, infrared, ultra wide band (UWB), Zigbee, wireless local area network identification (RFID) and Bluetooth are studied on the use of various communication technologies for indoor positioning [6,8]. For example, Tesoriero et al. compared and analyzed positioning systems with different methods such as Wi-Fi, bluetooth, infrared, ultrasound and RFID. They focus on the seven key points include accuracy, scalability, portability, environmental variability, delay, cost, power consumption [8]; Li, Nan et al. arrange several of literatures and discuss the concept of different protocol used in indoor transmission [6], as shown in Table 2. They also provide three major methods include triangulation positioning, triangulation-based positioning and LANDMARC-based positioning to implement RFID positioning for the construction industry. They consider that approximate measurement is the most stable and most commonly used method in complex indoor environment [6]. Koch, Jan et al. deployed a large number of passive RFID tag in the plant area and used RFID reader which placed on the human foot to implement indoor positioning [5]; In the real applications, Tesoriero et al. used both active and passive RFID technologies to make the mobile device automatically display the necessary information according to the location of the user [9].

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Table 1. Different Methods for the Perception of Human proposed by Teixeira et al. [7].

Sensing Modality	Example Sensors
Binary sensors	Contact sensors, Breakbeams, PIRs Ultrasound motion sensors
Motion sensors	PIRs, Scalar Doppker-shift sensors
Pressure sensors	Piezo-resistors, Pizeo-electric materials
Electric field sensors	Capacitive floor tiles, Capacitive antennas
Vibration sensors	Seismometers, Accelerometers, Electrostatic and Laser microphones
Scanning range-finders	Radars, Ladars, Sonars
Doppler-shift sensors	Radios, Ultrasound transducers
Shape-detecting networks	Radio-tomographic networks, Ultrasonic-ranging networks
Cameras	CMOS and CCD image sensors, Specialized motion- or edge-detecting imagers
Thermal imagers	Microbolometer arrays, PVDF(Ploy vinylidene Fluoride) arrays
Device-to-device ranging	Radio pairs, Radio-Ultrasound pairs
Envir. Recog. Sensors	WiFi fingerprinting, Wearable microphones, Wearable cameras
Inertial sensors	Accelerometers, Gyroscopes, Magnetometers
ID sensors	RFID, any radio or other means of communication
Chemosensors	CO2 sensors, Humidity sensors

Table 2. Communication Technology for Indoor Positioning proposed by Li, Nan et al. [6].

Technology	Accuracy	Affordability (S/m2)	No line of sight required	Wireless communication	Context independence	On-board data storage	Bulit-in power supplies	Wide application in the building industry
GPS	1-2 cm	380	X	X	X	√	√	√
INS	1.10~4.15 m	20	√	X	√	√	√	X
Infrared	30~50 cm	17	X	√	X	X	X	X
UWB	6~50cm	140	√	√	X	X	X	X
WLAN	4.53~6.89 m	3	√	√	X	X	X	√
RFID	1.55~3.11 m	25	√	√	X	√	X	√

2.2. Current Research based on Bluetooth Low Energy

Bluetooth Low Energy (BLE) was proposed as one of the Bluetooth 4.0 features in 2011. Andersson et al. propose five features of Bluetooth low energy as follow [10]:

1. Works well with high numbers of communication nodes with limited latency requirements.
2. Very low power consumption.
3. Robustness equal to Classic Bluetooth.
4. The system will compare the position of the BLE receiver to derive the beacon location.
5. Short wake-up and connection times.

Compared with other short-form wireless communication technologies, BLE has the characteristics of relatively low power consumption, active push-play, high-throughput, and can be combined with smart mobile devices for mobile computing [10,11]. As a result of inheriting many

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traditional Bluetooth features, BLE which is also called "Bluetooth Smart" can be deployed in harsh environment and is divided into single and dual transmission mode. The operation mechanism of BLE is shown in Figure 1.

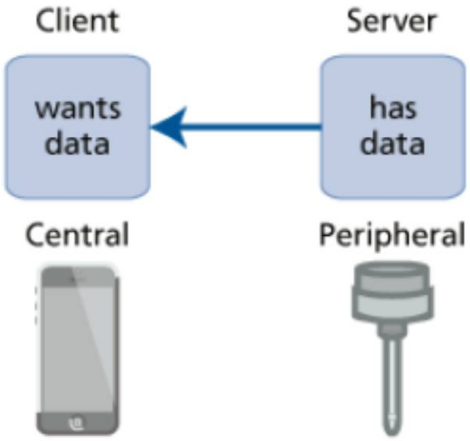

Figure 1. Client and Server Concept in BLE [6].

BLE server (Server) is generally a plug-in small Bluetooth signal transmission module, called Beacon. The main features of Beacon are the power saving, low price and flexible application. Beacon components that have their own unique identification code. The basic structure of unique identification code are three parts, UUID, Major value, Minor value. The UUID is a global independent identifier used to distinguish which App system or company the Beacon belongs to. The UUID contains 32 16-bit codes and is divided into five blocks. The Major value and Minor values are each a group of numbers from 1 to 65535 assigned to a Beacon for more precise identification of the Beacon's role and its use. The Major value is an identifier under the UUID and is usually used to identify a group of Beacon in the same geographical area. Minor number is more detailed identification code, usually used to identify individual Beacon.

Nowadays, the application of low-power Bluetooth positioning technology mainly uses "Mobile tracking" to track and implement indoor positioning. As shown in Figure 2, a smart phone with Bluetooth 4.0 technology is used as a data receiving client to scan nearby Beacon signals. After scanning the Beacon node, we can analyze the relative position of each Beacon and the mobile phone, and then learns the location of the current mobile phone body, that is, the position of the mobile phone holder.

Therefore, based on the above-mentioned form, the mobile phone begins to collect the Beacon signals nearby. Although Beacon itself is a proactive signal transmission, Beacon is actually a passive terminal in this architecture, and the smart phone is an active terminal that makes a real request. This format in shopping mall applications is indeed well-suited to push advertising or guide customer routes, which is quite reasonable and efficient. However, introducing it into the factory area is inadequate. The fundamental reason is that the functional requirements have different characteristics.

Utilizing "Mobile tracking" as the positioning mechanism in factory area will lead to poor energy efficiency. To keep the response time of positioning in bound, mobile phones need to open the functions of Wi-Fi and Bluetooth to transmit data to the database at any time. It can be learned that the mobile phone will consume a lot of power by turning on the Wi-Fi and the Bluetooth at the same time. How to charge the battery to keep the whole position system running is a more difficult problem.

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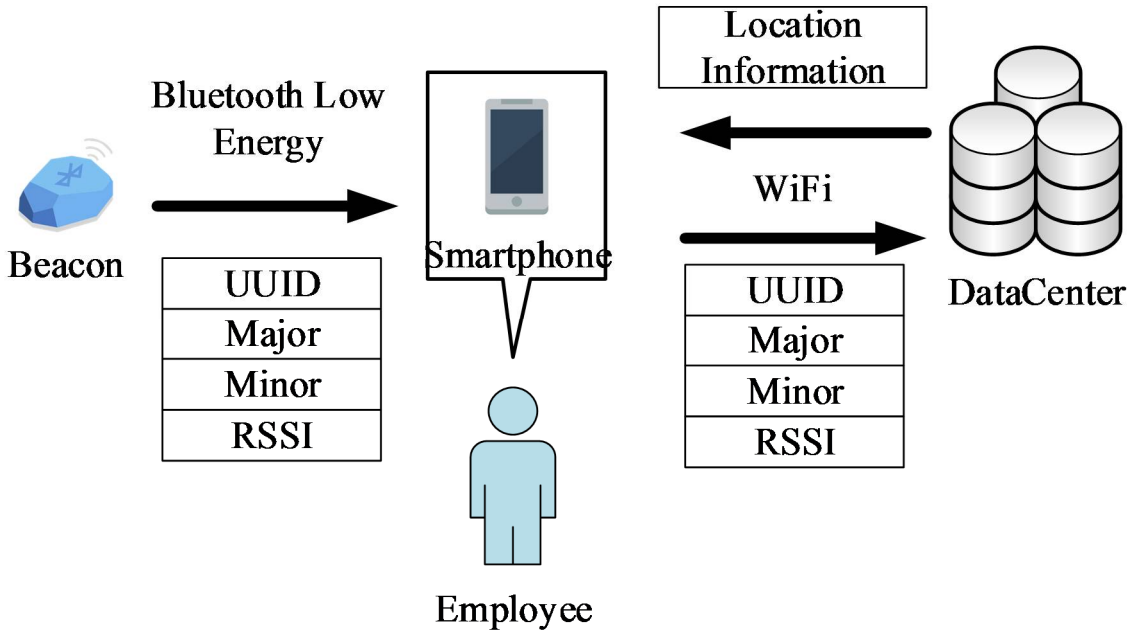

Figure 2. Mobile Tracking of BLE.

3. Design of Positioning Mechanism based on Bluetooth Low Energy

3.1. BLE-Based Location Positioning Mechanism

In this research, we propose a BLE-based location positioning mechanism named " Tag tracking". The functionality of mechanism is demonstrated in Figure 3. The concept of "Tag tracking" is as follow:

1. Deploying sensor nodes (called BLE receiver in this research) which can actively detect the BLE signal to build a sensing environment.
2. Under this environment, we will use beacon as a location detection object by collect BLE signals broadcasted by beacon.
3. After collecting these BLE signals, BLE receiver forward them to the cloud computing system.
4. The system will compare the position of the BLE receiver to derive the beacon location.

Using this format, system can capture information about the location of beacon-equipped personnel. As Beacon lives for up to one year, BLE Receiver will be deployed at a fixed point on the ceiling to avoid the problem of signal attenuation.

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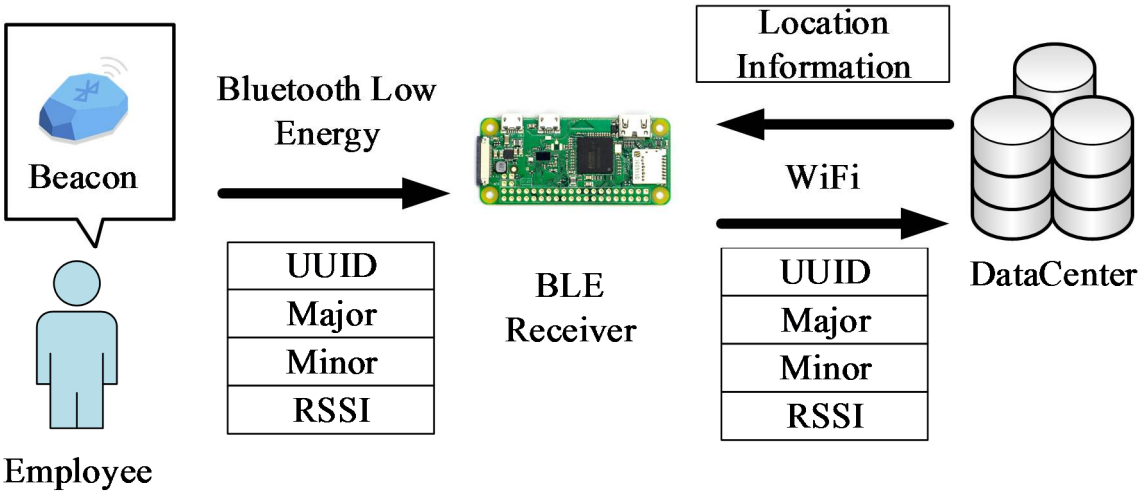

147 **Figure 3.** Tag Tracking of BLE.

148 *3.2. Regional Label Positioning*

149 Despite "Micro-positioning" has higher accuracy and lots of applications, which relatively has
150 larger requirements of digital resources, such as computing efficiency, storage resources and network
151 resources, and expensive costs of deployment and maintenance. In order to import positioning
152 technology into manufacturing process effectively, the "Regional label positioning technology" is
153 proposed to get the location information of target in manufacturing plant that partitions the location
154 of target by section.

155 The scenario will assume that the plant is divided into nine sections, and each block will be
156 installed a node which called BLE Receiver on the ceiling, and every staff will be equipped with a
157 Beacon as BLE signal source. The BLE Receiver captures signal from Beacon to confirm the section
158 that the staff is in. Therefore, the location information of staff can be known indirectly. The illustration
159 is shown in Figure 4.

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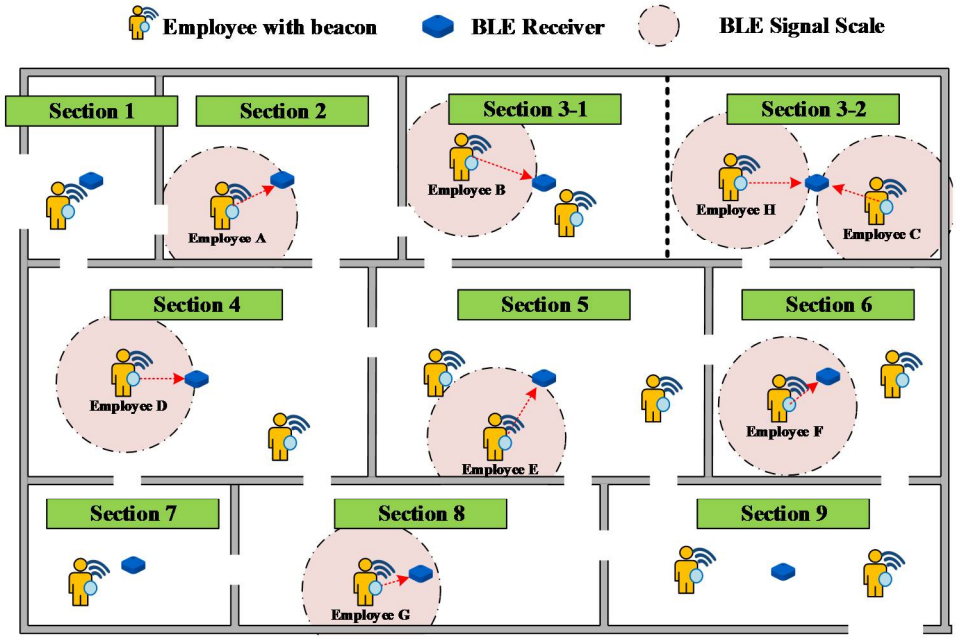

Target	Employee A	Employee B	Employee C	Employee D	Employee E	Employee F	Employee G	Employee H
Location	Section 2	Section 3-1	Section 3-2	Section 4	Section 5	Section 6	Section 8	Section 3-2

160 **Figure 4.** Regional Label Positioning.

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3.3. Indoor Positioning Framework based on BLE

In this section, we described the fundamental architecture of indoor positioning framework. It is the basic concept for enterprises to run the positioning system. Enterprises can implement it depending on the different situation. The fundamental architecture is shown in Figure 5. It is divided into three parts and is illustrated as below:

1. IoT based on BLE: Deploying the BLE IoT is the first step. The enterprise have to install the beacon sensors on each area in the factory. The main purpose is to provide an environment for indoor positioning. As long as we know which area that employees are located in the factory, we can efficiently run various management command by the employee distribution. In the proposed framework, we only need the area that employee located not the exact position. Therefore, the location with high precision is better but not necessary. The stability and reliability of the entire system is the more important. Without high precision, the system can be running smoothly. In this research, we propose a wireless sensor network to construct the environment for IoT based on BLE.

2. Mobile application: One significant attribute of BLE is fully compatible with classic Bluetooth. Nowadays, almost all the mobile phones have deployed classic Bluetooth. Inevitably, a proper mobile application is necessary to support the BLE. Google's Android and Apple's iOS are operating systems used primarily in mobile technology. Comparing with iOS, android is easier to design the application program. The hardware cost is relatively lower too. For most of enterprises, the android-based mobile application is recommended. According to above, android-based mobile application is considered an important part in the architecture. The basic purpose of android-based mobile application is to make the communication of beacons and mobile phones. Receiving the UUID of beacon and send the data to the cloud computing system by Wi-Fi or 3G. Then the system will search the beacon information by the UUID and update employee's location according to the information. Moreover, enterprise can customize the function of the mobile application such as broadcast, map of the factory, punch in, etc… It's a wide range of uses. In this research, we utilize website with RWD instead of App as user interface to reduce the research cost.

3. Cloud Computing System: The third part of the architecture is cloud computing system. With the IT system, employee management will gain a lot of advantages. It reduces the paper work and make the management performance better. Another advantage is to make up the inadequacies of mobile application, the second part in the architecture. Thus, we consider that cloud computing system is a best solution. It offer the high ability of computing and data storing for the entire frame work. All related data (such as Beacon data, employee information, factory information, etc…) can store in the cloud data server. Moreover, utilizing cloud computing system to perform the complex operation instead of doing that by mobile device can reduce the load of mobile device. In ideal situation, we don't expect that mobile device consume too much energy. We considered the mobile device is only a middle tool to transmit the data and user command then display the result from the cloud computing system. Another reason of using cloud computing system is that it offers the enterprises much space to design the function of entire system. The Enterprises can extend the extra feature like monthly employee performance analysis. Besides, the concept of utilizing cloud computing system is combining the IT system into the proposed framework as the supplement. Therefore the proposed framework is compatible with ERP system. Enterprises can adopt ERP system into the fundamental architecture without much difficulty.

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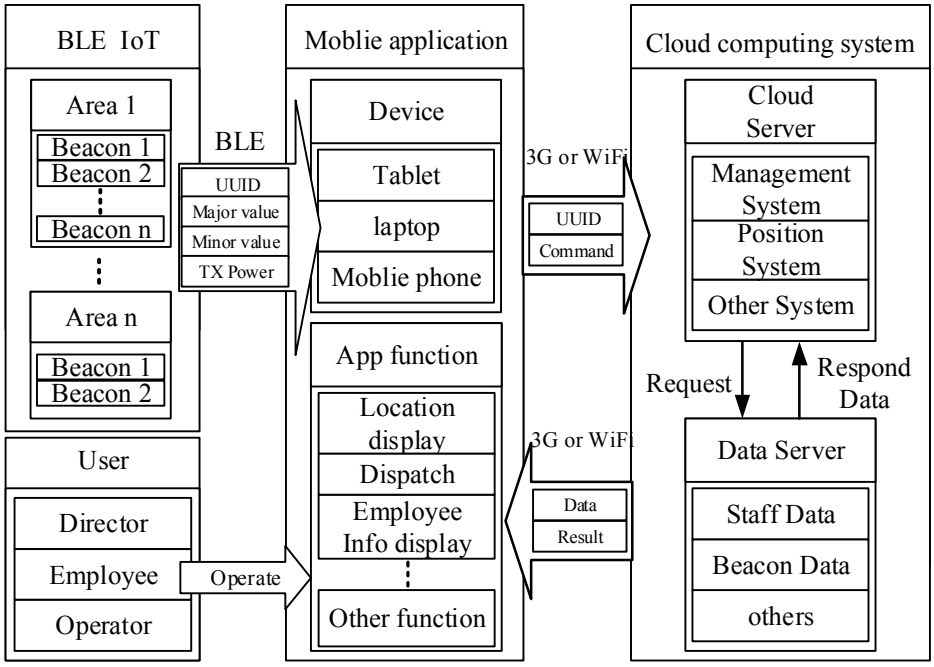

206 **Figure 5.** Indoor Positioning Framework based on BLE.

207 **4. Implementation of Positioning System Based on Bluetooth Low Energy**

208 *4.1. Deployment of BLE-Based Wireless Sensor Network*

209 The main purpose is to construct the wireless environment to transmit the data of element's
210 location information. There are three kinds of nodes in this wireless sensor network.

211 1. Beacon: Deployed on a specific object, which is usually the object that needs to retrieve location
212 information. This research is mainly conducted by field staff.

213 2. BLE receiver: Configured in a specific area for receiving signals from all location information
214 broadcast points in the area and forwarded to the data access point.

215 3. Access point: Receive the data forwarded from the location information collection point, and
216 send it to the data storage center.

217 In this study, a large number of Beacon, BLE receiver and access point are deployed in the factory
218 to make the intranet architecture. The deployment diagram is shown in Figure 6. In order to distribute
219 the signal of network evenly in the plant area, access point and BLE Receiver will be placed on the
220 ceiling of the plant to prevent the interference of the machine or personnel, which will lead to the
221 omission of signal reception.

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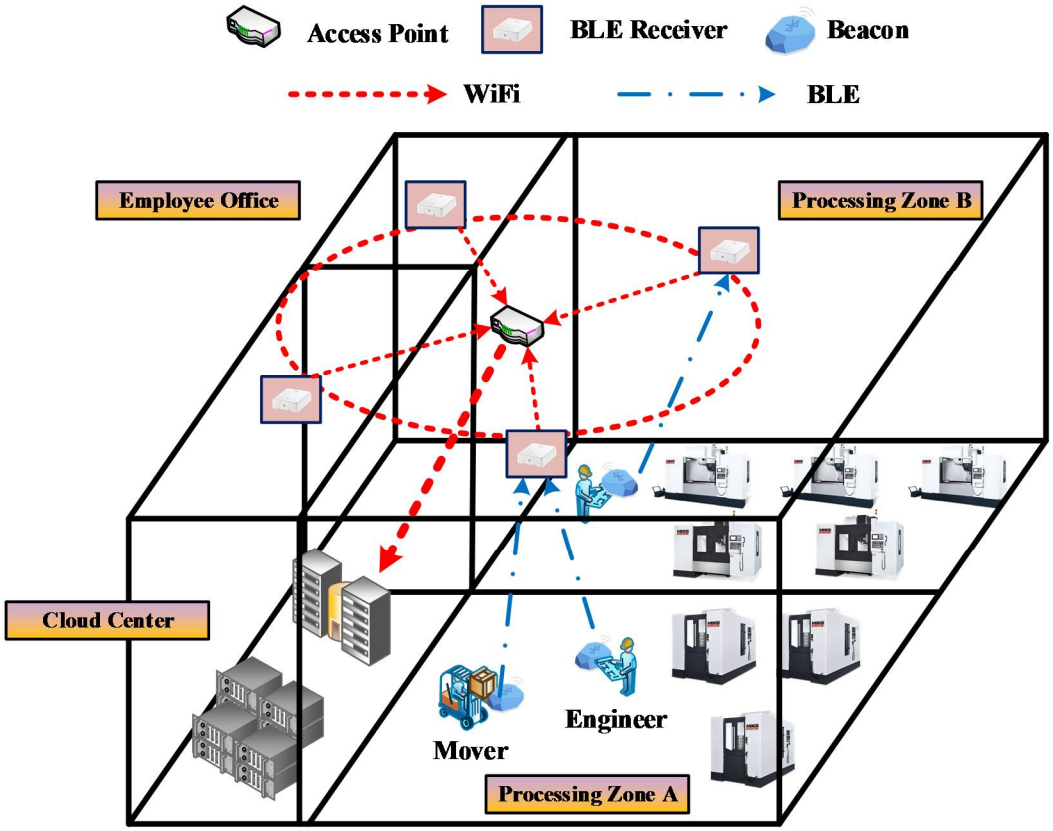

222 **Figure 6.** Illustration for Deployment of BLE-based Wireless Sensor Network.

223 *4.2. BLE Signal Acquisition Mechanism*

224 In this study, the part of BLE positioning information acquisition is divided into BLE signal
225 reception and data sending back to cloud database. First step is initialization, when BLE Receiver is
226 started, it will automatically connect to Wi-Fi on the factory and load the script to scan the
227 surrounding Signal from Beacon. After scanning completed, BLE Receiver detect the Beacon ID and
228 adopt signal acquisition algorithm to define the number of simultaneous connections, polling
229 interval, data sizes and error feedback. BLE Receiver filters the noise to improve the signal accuracy
230 and achieves high-performance in speed of data acquisition and reliability of connection, and then
231 send the signal from all of surrounding Beacon node back to the data center. The flow chart is
232 displayed in Figure 7.

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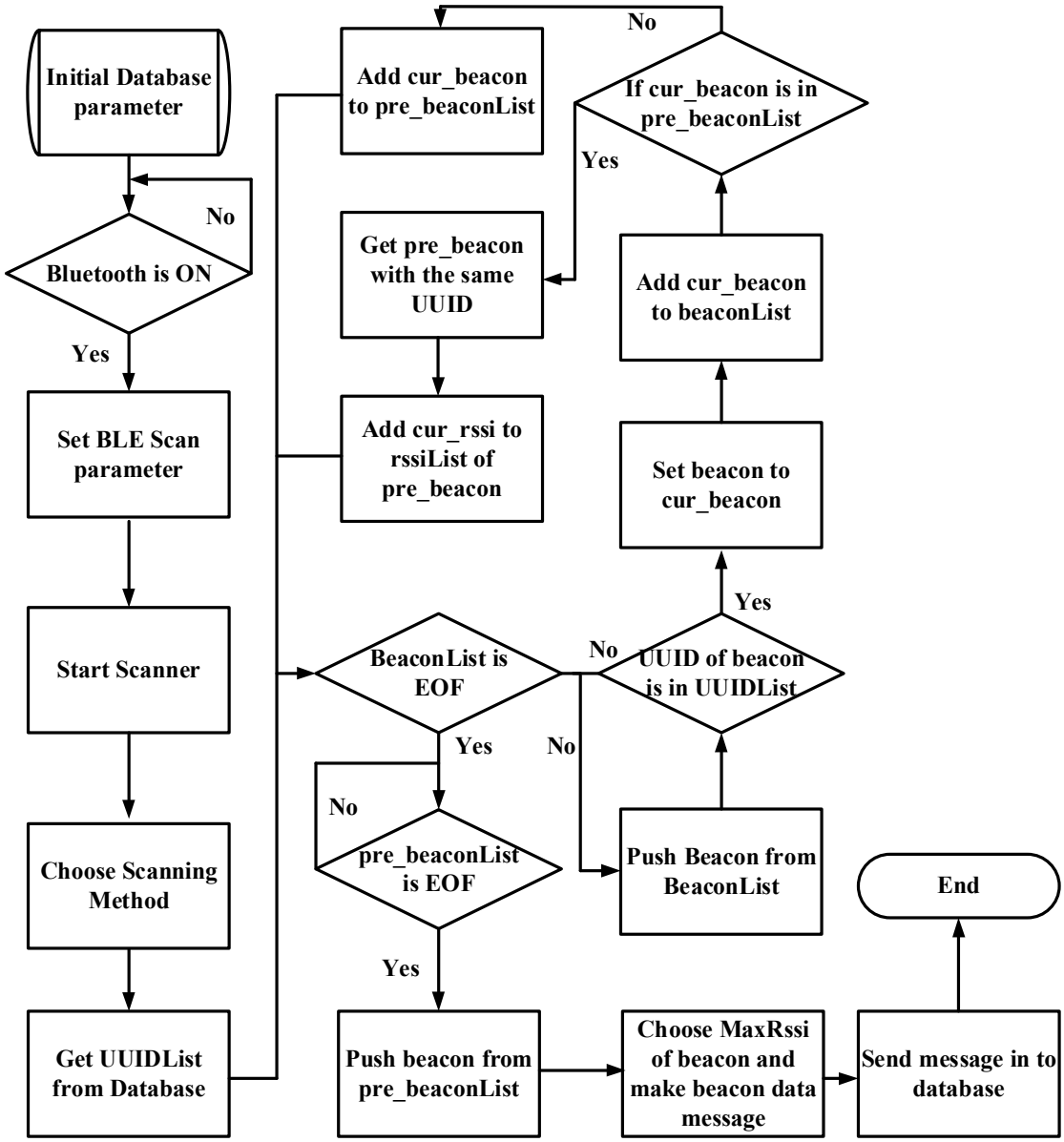

Figure 7. Flow Chart of Signal Acquisition Mechanism based on BLE.

4.3. Implementation of Program --- BLE Package

To implement signal acquisition mechanism based on BLE, we design a program, named BLE Package, which has two modules, BLERecBeater and BLERecScanner, to collection the Low-power Bluetooth signal data. BLE Package would keep running on Bluetooth receiver. It's coding by Python language which has high compatibility with raspberry pie zero, the Bluetooth receiver. Since the Bluetooth receiver will be deployed in a large number of factory environment, how to collection signal data efficiently and flexibly is key point. Therefore, BLE Package provides three signal acquisition methods depended on RSSI value of the collected Bluetooth signals in the period of data pre-processing. The three method would respectively choose the maximum RSSI value, the average RSSI value and the minimum RSSI value as the capture signal of the return information. Because BLE Package is written in kit style, users can directly run it by simply calling the BLERecStart function.

The data flow architecture of BLE package is shown in Figure 8. The main function, named "BLERecStart", will driver two modules, "BLERecBeater" and "BLERecScanner". The process of two modules as follows:

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1. BLERecBeater: To ensure BLE Package is in normal operation, BLERecBeater would periodically transmission data to update the operation status of BLE Receiver in datacenter. When the signal from BLERecBeater is interrupted, it can be determined that the BLE receiver is faulty. Moreover, a log file of this program will be constantly updated and record every steps when the heartbeat signal is sent to help engineers fix the program error.

2. BLERecScanner: This module dominates the scanning and preliminary data processing of the BLE signals around the area. It also generates a log file to help engineers tracking the related errors. The default signal acquisition method use maximum RSSI value as the primary returned value for datacenter.

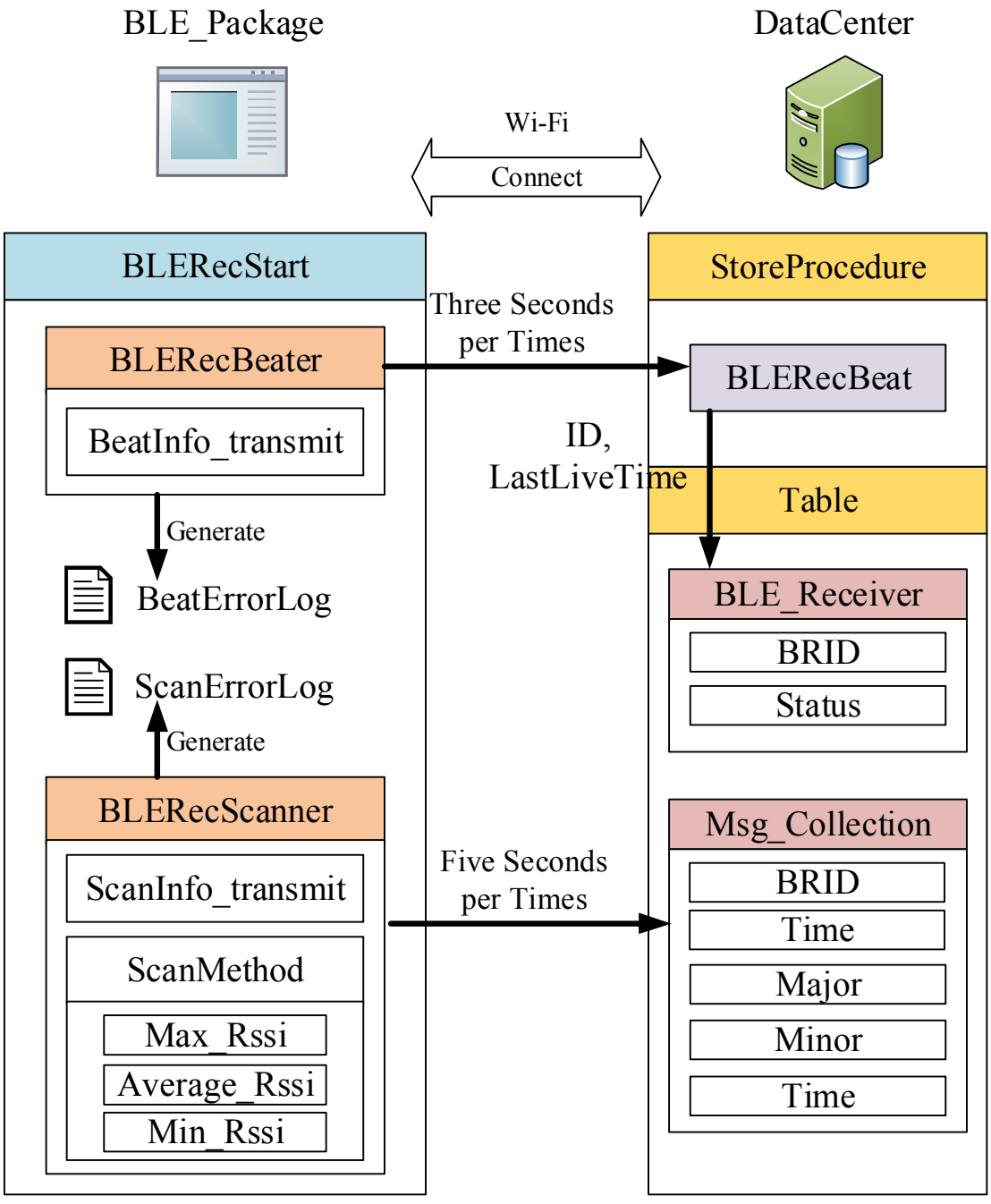

Figure 8. BLE Package Operation Diagram.

5. Discussion

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In this research, Bluetooth Low Energy (BLE) and Wi-Fi are used as the wireless communication protocol in the network. The WSN (Wireless Sensor Network) is deployed as the environment of IoT to integrate the cloud services The contributions of this research are as follows:

1. Providing a method to establish the WSN based on BLE in the factory. The location of employee, machine and product in the factory or in the manufacturing process can be collected effectively. This is the basis for developing the location-related application of manufacturing industry.
2. Develop a deployment strategy to achieve BLE signal collection in a factory environment so that enterprises can import IoT environments at low cost into the factory. A network management system which reduce the integration threshold and improve the flexibility of deployment and maintenance is also implemented to enhance the willingness of enterprises to deploy.
3. We purposed a novel framework for positioning based on BLE. Taking the advantage of BLE, manufacture enterprises can adopt the framework without spending high cost. The novel framework consists of IoT, Cloud Computing System and mobile application. It allows enterprises design customized function in CCS or in mobile application for the purpose.

Based on the indoor positioning technique, we also give the three basic instance to describe how the framework working. Although the framework has such many benefits, it has some problems to be solved. The biggest one is the signal propagation. In the factory, there are many factors will cause signal attenuation, such as temperature, transmission and reflection properties of building materials and machine, and interference from other devices [4].

Acknowledgments: We are grateful to Ministry of Science and Technology for providing funding and technical support for this study, serial No. 105-2221-E-006-093-MY2. Because of the support of MOST, this study could be conducted smoothly.

Author Contributions: Conceptualization, Shang-Liang Chen; Data curation, Cheng-Chia Hsu; Funding acquisition, Shang-Liang Chen; Investigation, Cheng-Chia Hsu; Methodology, Shang-Liang Chen; Project administration, Shang-Liang Chen; Software, Cheng-Chia Hsu and I-Ching Li; Supervision, Shang-Liang Chen; Validation, Cheng-Chia Hsu and I-Ching Li; Visualization, Cheng-Chia Hsu and I-Ching Li; Writing – original draft, Cheng-Chia Hsu; Writing – review & editing, Shang-Liang Chen and I-Ching Li.

Conflicts of Interest: The authors declare no conflict of interest.

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