Fundamental Design for a Beacon Device Based Unconscious Participatory Sensing System

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***Abstract*—This paper proposes a beacon device based unconscious participatory sensing system consisting of beacon devices, smartphone devices, and management servers. Beacon devices installed at measurement locations find a neighbor smartphone device to request to relay measurement information to a management server or to request measurement with built-in sensors. The proposed processes can be carried out without participators' interaction behavior. Hence, the proposed system just requires participators to install the special smartphone application, and participators can easily join a sensing network and can work for participatory sensing unconsciously. We employ the Bluetooth Low Energy (BLE), which is a short-range wireless communication standard, to realize communication between the beacon device and the smartphone application. Additionally, we achieve low power operations of the smartphone application by employing iBeacon, which is a short-range recognition mechanism for BLE. To the best of our knowledge, this is the first attempt to propose the unconscious participatory sensing system with smartphone devices and BLE based beacon devices. From the experimental implementation with a Raspberry Pi and an Android OS 4.4 based smartphone, we have confirmed that the proposed signaling works well with the consumer devices.**

***Index Terms*—Unconscious participatory sensing, iBeacon, BLE, Smartphone device, Beacon device.**

I. INTRODUCTION

SENSOR networks have focused attention on their scalable and reasonable measurement functions to collect various types of information[1]. Several conventional researches employing smartphone devices with high-performance sensors have been proposed recently[2], [3], [4]. Conventional participatory sensing systems usually assume that participators join a sensing network voluntarily and request copious numbers of voluntary participators to collect information. Then participators, who accepted the demand, perform the requested sensing job and report measurement information to the system[5]. The participatory in sensing process realizes flexible and intelligent measurement.

Types of measurement information in participatory sensing systems are classified: abstract information that is evaluated by participators[6] and quantitative information that is measured by sensors[7], [8]. Measurement of abstract information is difficult to acquire by sensors. Therefore, participators should join the sensing process voluntarily to realize effective participatory sensing systems. Hence, many researches have been actively investigating techniques that incentive participators to join a sensing process[9], [10].

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Some researchers attempt to handle information of participatory sensing and social media compositely[11]. Additionally, balancing between measurement information and privacy protection is also studied because collected information is largely related to the private information of participators[12], [13].

Participatory sensing systems for quantitative information also require participators' interaction behavior such as checking measurement requests, moving to a measurement location, launching application, and reporting measurement information. Therefore, participators in conventional systems should take part in measurement operations consciously even if participators use sensors to acquire the required quantitative information. According to the above reasons, conventional participatory sensing systems currently assume early adopters who have an interest in the new service.

Some studies employ smartphone devices as a communication device and special measurement devices to achieve accurate measurement by a same type of sensors and a same condition of implementation[14]. Accuracy of measurement information by acceleration sensors, magnetism sensors, etc. is generally stable even if a sensor type is different because implemented condition is not liable to make a difference in accuracy. However, the accuracy of measurement information by temperature sensors, illumination sensors, etc. is expected to vary according to the precision of the sensor and implementation environment because different models of smartphone devices have different types of sensors and implementation condition of the sensors is also different. Therefore, different measurement values are obtained with different types of smartphone devices, even when the measurement is conducted in the same environment. As a result, built-in sensors in smartphone devices are not enough to acquire accurate measurement information in real situations.

This paper proposes a beacon device based unconscious participatory sensing system where beacon devices are installed at a measurement location, and trigger measurement. The proposed system assumes to be consisting of various numbers of beacon devices and smartphone devices. Each smartphone device has a special application for data relaying from a beacon device to a management server and for measurement with built-in sensors. Each beacon device has functions for data measurement and short-range wireless communication based on Bluetooth Low Energy (BLE)[15]. A beacon device tries to find a neighbor smartphone device, where the special application is working, to request to relay measurement information to a management server when it requires a communication function. Additionally, it can request a neighbor smartphone device to measure with built-in sensors when it requires measurement around it. Therefore, the proposed system can perform sensing operations with

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built-in sensors of a beacon device or a smartphone device.

The proposed system employs the iBeacon[16] function, which is a short-range recognition mechanism for BLE, to detect a neighbor smartphone device, and uses a data communication function over BLE to convey measurement information. The iBeacon function can trigger the unique dedicated application for background processing even if the application is suspended due to limitation of background processing in a Mobile OS. Therefore, the above processes can be performed without participators' interaction behavior and the participator is not necessary to recognize the measurement operation. Furthermore, the employing BLE and iBeacon can reduce the electrical power consumption for data communication and application processing. We believe that this work is the first attempt to propose a new type of unconscious participatory sensing system that achieves practical and reasonable measurement with smartphone devices and BLE based beacon devices.

II. Related Technology

A. Bluetooth Low Energy

BLE is a 2.4GHz based short-distance wireless communication standard with low electrical power consumption by Bluetooth Special Interest Group (SIG). It has no compatibility with Bluetooth 3.0 because it is derived from Wibree. BLE alleviates the demand of the frequency precision by reducing the number of channels from 79 to 40, and reserves three with the use of the advertise channel of the 40 channels. Therefore, the device detection period can decrease by checking only the advertise channels.

Fig. 1 shows the system model of the BLE. The system makes up of a peripheral and a central. The peripheral offers an advertising service for the central. Therefore, it broadcasts an advertisement message periodically on advertising channel. The central provides a detection service for the advertisement message that indicates offered service by the peripheral and data communication service as a master device.

The Bluetooth SIG has defined some application profiles such as a headset, a file transfer etc. On the contrary, Bluetooth 4.0 introduced Generic Attribute Profile (GATT) that is placed on top of the Attribute Protocol (ATT). The functions of GATT are to establish common operations and a framework for the data transported and stored by the Attribute Protocol. Attributes are formatted as services and characteristics. Services may contain a collection of characteristics. Characteristics contain a single value and any number of descriptors describing the characteristic value.

Fig. 2 shows the structure of GATT. The top level of the hierarchy is a profile. A profile makes up of one or more services. A service consists of characteristics or references to other services. Each characteristic has a value and may contain optional information about the value.

B. iBeacon

The iBeacon is one of the proximity position measurement methods that use BLE, and has been proposed by Apple. Therefore, a considerable amount of implementation was mainly pushed forward in the iOS system. Then, its implementation as a standard positional information service was conducted after the launch of iOS 7. On the other hand, only some Android devices implement BLE. A library for iBeacon has been developed for BLE after the launch of Android OS 4.3. iBeacon is expected to become available for not only iOS systems, but also for Android smartphone devices in the near future.

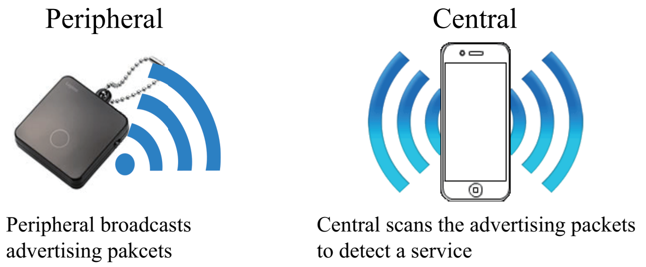

Fig. 1. System model of Bluetooth low energy.

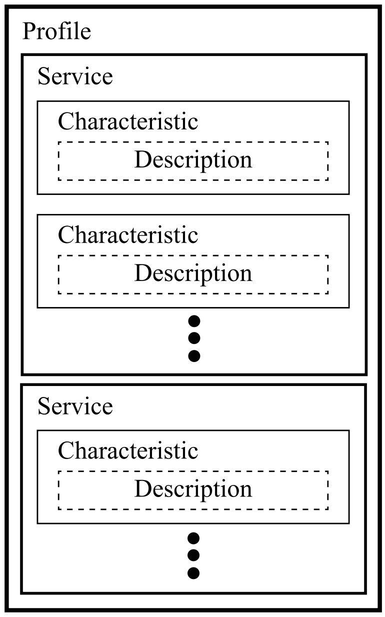

Fig. 2. GATT data hierarchy.

Fig. 3 shows the overview of iBeacon. The system consists of the peripheral that is transmitting a beacon and the central that detects the beacon. A significant advantage of iBeacon is that each application does not attempt to detect the beacon, and the operating system (OS) performs beacon detection in a lump as needed. Therefore, iBeacon can perform reasonable beacon detection with low electric power consumption.

iBeacon requests applications to register their dedicated information (UUID, major value, and minor value) which identifies a dedicated beacon. OS tries to find a beacon message including the dedicated information periodically. It notifies the applications when it finds the dedicated beacon message. The application receiving this notification can work in background even if it was suspended. The UUID is prescribed in RFC 4122, and the major value and the minor value are assigned to each set of 16 bits. Moreover, information about these identifiers needs to be managed separately in order to avoid duplication.

iBeacon is a broadcast-type service. A peripheral can coordinate the detectable domain for a central by controlling the transmission power of beacons. The central also measures

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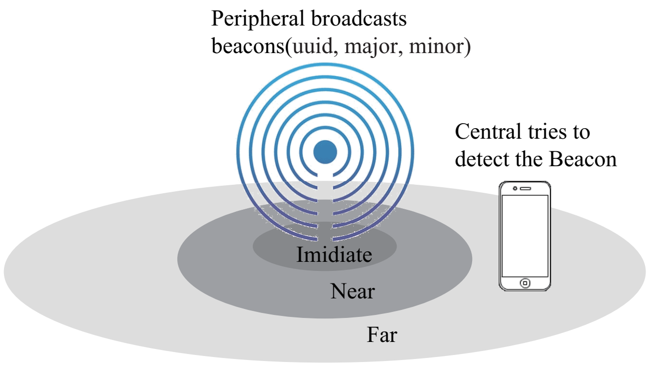

Fig. 3. Overview of iBeacon system.

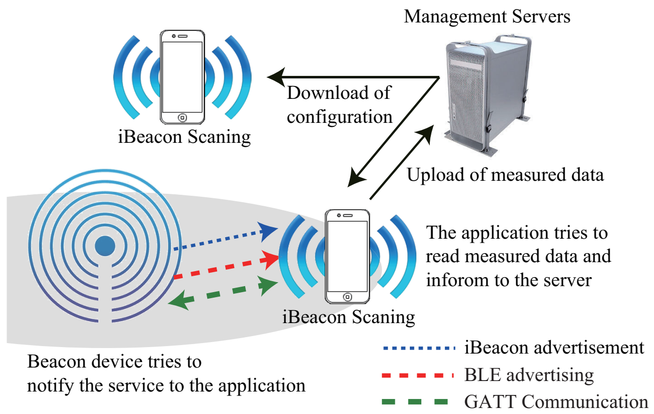

Fig. 4. Unconscious participatory sensing system.

the beacon reception strength from a peripheral and can acquire information about a distance at three levels.

III. Unconscious participatory sensing system

A. System model

Sensor networks can be easily developed according to release of low power sensors and cost-effective short-range communications equipment. On the other hand, long-range communication such as cellular is needed to collect information from sensor networks. The proposed system assumes a large number of smartphone devices and a large number of beacon devices installed at desired measurement locations. A beacon device transmits a broadcast message for a smartphone device to trigger measurement processing. A smartphone device searches for the broadcast message to find the desired beacon device. It obtains measurement information by communicating with the desired beacon device or measuring with built-in sensors. Then, it transfers the measurement information to a management server. The difference from conventional researches is that a beacon device requests a neighborhood smartphone device for relaying of measurement information from the beacon device side and measurement with built-in sensors, not to request a specific smartphone device. The changing the request device side makes the following benefits.

- Measurement with a same sensor can be performed.
- A specific place can be observed continuously.
- Preparation for a communication line for an individual beacon device is unnecessary.
- Privacy information likes as participators' positions is unnecessary.
- Communication of a sensing request from a server is unnecessary.
- Participators' interaction behavior for sensing is unnecessary.

Fig. 4 shows the overview of the unconscious participatory sensing system. The proposed system consists of a management server for management of beacon devices and measurement information, a scanning application in the smartphone OS for beacon device search and acquisition of measurement information and measurement with built-in sensors, and detectable beacon devices for beacon announcements and measurement with sensors. Each component includes the following functions.

- Beacon device
  The main functions of beacon devices are to trigger a scanning application installed on neighbor smartphone devices by using the iBeacon function, and to let the application detect the beacon devices themselves. Then, the application determines the legitimacy of the beacon device by evaluating the hash value after it detected the beacon device, and starts dedicated operations according to a beacon device configuration. The proposed system uses built-in sensors of smartphone devices and sensors of beacon devices because measurement information may be affected due to a difference of an implementation condition or a sensor specification. Therefore, the application transfers measurement information from a beacon device using BLE when sensors on the beacon device are used. The beacon device performs the measurement depending on predefined rules. For example, it starts the iBeacon function to trigger a neighborhood smartphone device after reduplicative measurement operations.
- Scanning application
  The functions of the scanning application are classified roughly into the search of the beacon device, acquisition of measurement information from beacon devices, measurement, and sending measurement information to a management server. The amount of electric power consumption of searching for beacon devices generally cannot be ignored for smartphone devices to realize longtime operations. The proposed system employs the iBeacon function to search for beacon devices with low power consumption. Additionally, the application performs operations, such as acquisition of measurement information from a beacon device, measurement with built-in sensors, transfer of the measurement information to the management server, depending on the operating rules obtained from the management server beforehand. Finally, it goes back to a suspended state after the operations. The proposed system does not request participators to handle the above operations because these operations are performed in background. Therefore, participators can easily contribute to participatory type sensing unconsciously.
- Management server

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The functions of the management server are information management for each beacon device and measurement information storing. A UUID, a major value, and a minor value are used as an identifier of each beacon device in iBeacon. Therefore, the management server should handle these parameters to identify beacon devices and measurement rules for them. Additionally, it should store the measurement information from the scanning application.

B. Pre-configuration

The proposed system should determine an identifier of a beacon device for iBeacon beforehand because a scanning application searches for a specific beacon device with the identifier such as a UUID, a major value, and a minor value. Conventional iBeacon systems generally assign a unique identifier to each iBeacon device. However, the same policy for identifier assignment is not realistic because OS should handle large number of identifiers to detect each beacon device in the proposed system. Therefore, the proposed system uses some same identifiers depending on the type of sensing operations.

A scanning application acquires an identifier of iBeacon from a management server when participators agree to join a sensing service. It also registers the acquired identifier to OS to start scanning operation of a desired beacon device. As a result, it can switch to a suspend state because OS can handle the desired beacons instead of the application.

C. Triggering neighborhood smartphone devices

A proposed beacon device triggers neighbor smartphone devices when it requires a data communication function or requests measurement with built-in sensors in smartphone devices. Therefore, it starts iBeacon function and a BLE function autonomously according to a predefined rule for beacon operations. An iBeacon advertisement packet is transmitted as a BLE advertisement packet. The iBeacon advertisement packet includes a UUID, a major value, and a minor value for identification. Additionally, BLE advertisement packet is transmitted separately from the iBeacon advertisement packet because a scanning application should search for the BLE advertisement packet to detect the beacon device to convey measurement information.

The scanning application is typically in the suspended status due to a limitation of background processing policy of a mobile OS, and cannot detect the BLE advertisement packet. Therefore, the iBeacon function in OS should scan the BLE advertisement packet and should handle the reception process instead of the application. It compares the identification in the received iBeacon advertisement packet to the registered identification by the application, and activates the application when both identifications match.

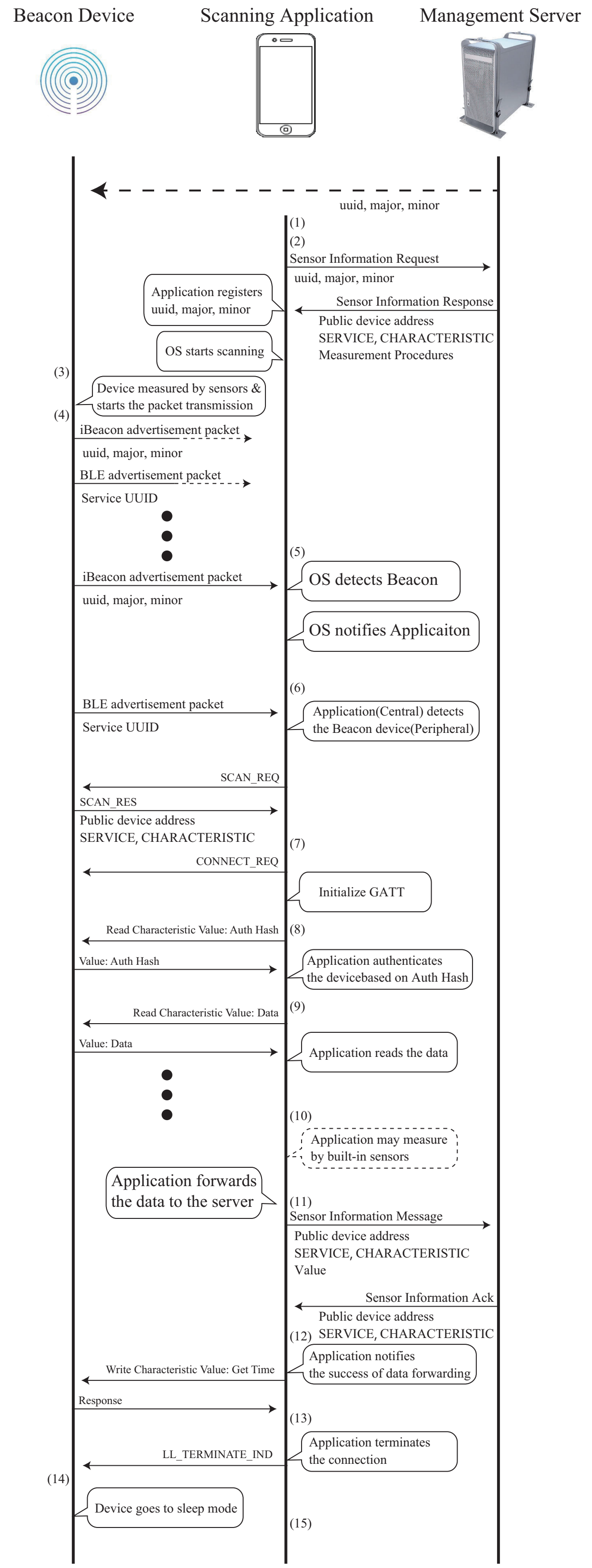

Fig. 5. Proposed signaling process.

D. Data acquisition by scanning application

The scanning application can process for a certain period in iOS when it receives a notification even if it was suspended. Therefore, it can start to receive a BLE advertisement packet immediately to search a beacon device. Then, it starts the communication process in BLE when it receives the desired BLE advertisement packet. It also obtains dedicated characteristic values, which are outlined in GATT, according to management information of beacon devices from a management server. Additionally, it may measure with built-in sensors according to measurement policies. Then, it transmits the measurement information to a management server. Finally, it registers the special value, that indicates that the transmission of the measurement information has been completed, to the dedicated characteristic value at the beacon device, and disconnects the communication session.

E. Operation example

Fig. 5 shows the signaling process of the proposed system.

1) Participators install the scanning application and provide access privileges for iBeacon and BLE to join the proposed participatory sensing system.
2) The scanning application should obtain information about beacon devices from a management server, and registers identification information of iBeacon to its OS.
3) The beacon device starts measurement operations according to a predefined rule set.
4) The beacon device starts a BLE function according to a predefined rule set. The BLE function transmits iBeacon advertisement packets and BLE advertisement packets.
5) OS notifies the received iBeacon advertisement packets to the scanning application when a neighborhood smartphone device moved into the detectable area of iBeacon.
6) The scanning application searches for a desired beacon device by checking a BLE advertisement packet in background processing.
7) The scanning application connects to the detected beacon device when it finds the desired beacon device.
8) The scanning application authenticates the connected beacon device by confirming a hash value from the beacon device because forgery of iBeacon information is possible.
9) The scanning application obtains the desired measurement information from the beacon device by BLE communication.
10) The scanning application measures with its built-in sensors when it need to perform measurement according to a predefined rule.
11) The scanning application transfers the measurement information to a management server.
12) The scanning application stores the acquisition time into the dedicated characteristic value in the beacon device when it has completed the transmission process of measurement information to the management server.
13) The scanning application terminates the communication session with the beacon device.
14) The beacon device changes its state to the sleep mode with low power consumption until the next measurement timing when it confirms that the measurement information has been transferred completely.
15) The application changes its state to the suspended state automatically by OS functions.

IV. Implementation

A. Beacon device

This paper has implemented the proposed beacon device functions on Raspberry Pi, which is the well-known ARM based microcomputer board. Fig. 6 shows the implementation design of the proposed beacon device. The developed application consists of the application manager, the iBeacon function, the BLE data exchange function, and the external sensor measurement function. The prototype application has implemented the communication functions such as the iBeacon function and the BLE data exchange function. We employ Raspbian OS, Bluez[17] library for BLE implementation, and Bleno[18] library for iBeacon implementation. The developed application on Raspbian OS can handle the iBeacon function and the BLE function by using the libraries. We have confirmed that the developed application can be detected by smartphone devices with the iBeacon function, and a smartphone application can communicate with the beacon device with the BLE function. We have a future schedule for implementing the same mechanisms on System-on-a-chip (SoC) of the BLE because SoC is the best device of realizing a feasible beacon device with low power consumption.

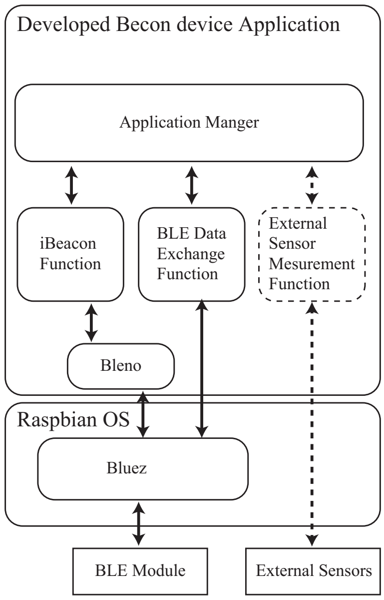

Fig. 6. Implementation model of a beacon device.

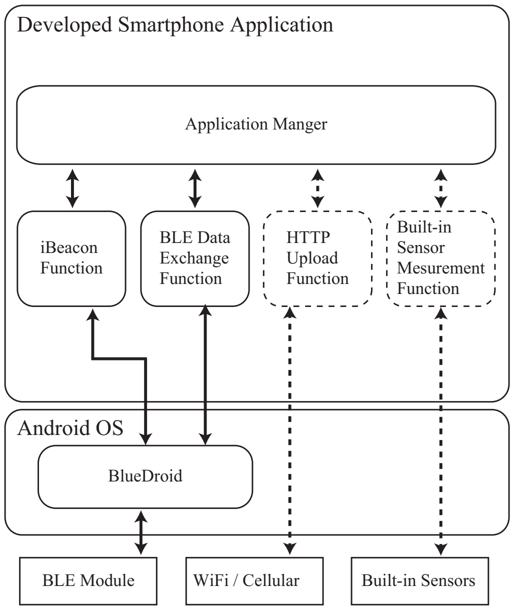

Fig. 7. Implementation model of an Android application.

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B. Scanning application

Requirement for the scanning application is to support BLE and iBeacon. We have been developing a prototype scanning application for Android OS 4.4, and have experimented the proposed signaling process with Nexus 5. Fig. 7 shows the implementation design of the proposed scanning application. The developed application consists of the application manager, the iBeacon function, the BLE data exchange function, the HTTP upload function, and the built-in sensor measurement function. The prototype application has also implemented the communication functions such as the iBeacon function and the BLE data exchange function. We employ BlueDroid[19] for Bluetooth implementation in Android OS.

The developed application can detect an iBeacon advertisement packet and can obtain characteristic values from the Raspberry Pi. On the contrary, Android OS does not support iBeacon function. Therefore, the developed application has also implemented iBeacon function in itself. As a result, the prototype application does not support an adequate low power operation. We are currently under a schedule to implement a new prototype application for iOS because iOS supports the iBeacon function and it can realize detection of iBeacon advertisement packets with the low power operation.

C. Management server

We employ the hypertext transfer protocol (HTTP) as a communication protocol between the management server and the scanning application because smartphone device OS prepares some APIs for HTTP communication. Therefore, the management server consists of Apache[21] as an HTTP server function and MySQL[20] as a database server function.

V. Conclusion

This paper has proposed a beacon device based unconscious participatory sensing system. The proposed system requires participators to install a special smartphone application to scan neighbor beacon devices and to relay measurement information to a management server. However, it does not prescribe participators' interaction behavior because the application works in background when OS notifies a reception of an iBeacon advertisement packet. As a result, participators can join the proposed sensing system unconsciously. The proposed system employs the iBeacon function, which is a short-range recognition mechanism for BLE, to detect a neighbor smartphone device, and uses a data communication function over BLE to convey measurement information. The iBeacon function can trigger the dedicated special application for background processing even if the application is suspended due to limitation of background processing. Therefore, the proposed system can realize a feasible scanning of neighbor beacon devices with low power consumption. As the prototype implementation, we have applied this proposed system for Raspberry Pi and Android OS 4.4. From the basic evaluation, we have verified that the proposed signaling works well with the consumer devices. We are due to implement a more advanced prototypes of a beacon device with SoC and a special application for iOS.

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