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Comparison of Energy Consumption in Wi-Fi and Bluetooth Communication in a Smart Building

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Abstract—Modern Smart Buildings will utilize sensor technologies to obtain current information of the occupants and use it to provide automatic services to improve the safety, efficient use, productivity, and comfort. Energy saving is one of the promises of Smart Buildings. This can be achieved by controlling the HVAC system, lights, and other energy consuming appliances in relation to the activities of people in the building. In particular, presence is an important factor to consider. By using beacons such as those based on Bluetooth Low Energy (BLE) and mobile phones, one can deduct occupancy information by interacting, over WiFi, with a central server. In the present study, we investigate BLE utilization for transmitting the occupancy data to the server using off-the-self devices with several parameters, e.g., distance, packet size, and line-of-sight state. Furthermore, we propose a utilization of size-constrained BLE packets for transmitting occupancy data, which was previously only possible by means of HTTP over WiFi. The result shows that it is possible to transmit occupancy data via BLE, despite of its resource constraints. Bluetooth is also shown to be about 30% more energy efficient than WiFi to perform occupancy data transmission, i.e., the mobile phone has 16 hours and 38 minutes of battery life when running on BLE communication scheme and 14 hours and 46 minutes in WiFi communication.

I. INTRODUCTION

A smart building supports an environment which can adapt to the user needs automatically, while optimizing its use of resources. Optimizations include the reduction energy footprint, while not sacrificing the level of safety, productivity, and comfort of the users. To achieve this, modern buildings may employ tailored monitoring, scheduling [1], and planning [2]. Occupancy detection [3], is also an alternative of an essential source of information to optimize building's resources.

Several methods have been proposed to address the issue of occupancy detection, such as WiFi based approaches, which rely on existing infrastructure though suffer from interference issues [4]. Another method is the placing of BLE beacons in several spots within a building [5]. These BLEs always transmit unique data packets that help self-localization. It assumes that the building occupants always bring their mobile phone with them [6]. That way an application can be installed on the mobile phone to scan for beacons, so that the application can estimate with good accuracy where the phone and user currently are.

Interoperability has been an issue of data transmission [7]. Thus, normally the occupancy application transmits the data

to the server through HTTP communication done via a Wi-Fi link [6], while the BLE is already used to sense beacons. However, WiFi is known to be energy expensive [6], [8]. As a matter of fact, BLE is initially designed to be implemented in devices coupled with limited source of energy, e.g., battery, and for transmitting low bit-rate data [9]. BLE offers an energy efficient alternative for the transmission of occupancy data to the server.

The present study investigates BLE utilization for transmitting the occupancy data to the server. In particular, we focus on monitoring and comparing the energy consumption of mobile phones when performing data transmission via WiFi and BLE. The present study also proposes a packet structure to overcome the size-constrained BLE packet for transmitting occupancy data.

The remainder of the paper is structured as follows. Section II presents the state of the art and related work. The occupant-aware architecture is illustrated in Section III, while its technical implementation is described in Section IV. The experimental study and the results are presented and discussed in Section V and VI, respectively. Section VII contains concluding remarks.

II. STATE OF THE ART

The topic of battery life and energy usage in mobile phones has been widely investigated, though rarely this has been done in connection with issues of localization. For instance, Friedman et al. (2013) investigate the correlation of throughput and power in WiFi and Bluetooth in mobile phones [9]. The study concludes that Bluetooth is more energy efficient than WiFi. The study considers Bluetooth versions before the release of BLE and does not consider localization as the possible application.

Yu et al. (2012) propose the use of a BLE module as a transmission link to transfer Electrocardiogram data to smart phones [10]. The claim is that of a significant reduction of power consumption compared to traditional wireless medical devices, though experimental data to substantiate the claim is not provided. Moreover, the authors do not mention how to overcome the size-constrained BLE packet.

Furthermore, Conte et al. (2014) propose an architecture to tackle occupancy detection in a smart building [5]. It implements BLE beacons with iBeacon protocol [11] and occupants' mobile phones as sensors to gather occupancy data.

TABLE I: Standard Bluetooth and BLE comparison

	Standard Bluetooth	BLE
Energy	Around 2.5 mW (reference value)	Up to 0.01 of the Standard Bluetooth (use case dependent)
Mechanism	Unicast or multicast among paired devices	Broadcast tiny packet periodically
Packet Size	High bandwidth	Small packet (below 20 bytes)
Application Throughput	0.7 - 2.1 Mbps	Theoretically, 0.27 Mbps
Max. Active Nodes	7	Unlimited

However, some differences from our architecture exist. Firstly, [5] employs custom iBeacon protocol that dynamically alters the proximity UUID in a cyclical sequence when the beacons advertise themselves, while our architecture keeps the proximity UUID to be constant. Moreover, [5] uses location triggered sampling mechanism, while we do the sampling on a timely basis. Lastly, different machine learning algorithms are used to train and test the data. No energy comparison is discussed in [5].

Corna et al. (2015) [12] propose a similar approach to [5] with different machine learning algorithm. The authors discussed a energy comparison between BLE and WiFi. However, the discussion is substantially limited with no parameters provided to test the efficiency of BLE communication in comparison with WiFi. Moreover, [12] provides no energy comparison with baseline energy consumption as a comparison factor.

Another approach to indoor localization uses inertial measurement units as well as available RF signals, e.g., Bluetooth and WiFi [13]. The system described shows good performance, though no energy considerations are provided. Pei et al. (2012) investigate WiFi positioning in coexistence with Bluetooth [4]. The study shows how WiFi suffers from interference problems when coexisting with other high frequency wireless networks.

A. Standard Bluetooth and BLE

BLE, or sometimes referred as Bluetooth Smart [14], is a part of Bluetooth version 4.0 with a novel protocol stack for a quick construction of links [14] to give reduced power consumption and cost while keeping a comparable communication distance. The difference between BLE and Bluetooth standard protocols, introduced in Bluetooth v1.0 to v3.0, are summarized in Table I. One can see that there are some fundamental differences, for instance, the energy consumption, communication mechanism, packet size, and throughput. BLE offers more energy efficiency, but as a trade off, it has a limited bandwidth with small packets as opposed to classic Bluetooth. Furthermore, one can also see that BLE can be used further as a transmission channel that is more efficient than WiFi.

B. BLE for occupancy detection

To the best of our knowledge, there are no previous works that incorporate comparison parameters to compare Bluetooth energy consumption as well as detailed approach to overcome the limited throughput and size-constrained BLE packets.

To summarize, in this paper we propose:

- 1) a comparison of energy consumption in WiFi and BLE with several comparison parameters related to the occupant-aware building.

- 2) a beacon protocol/structure to overcome the limited throughput and size-constrained BLE packet so that it can be a method to transmit occupancy data.
- 3) an evaluation of the energetic benefits of BLE over WiFi communication for occupancy detection.

III. OCCUPANT-AWARE BUILDING ARCHITECTURE

We present a lightweight architecture to be integrated with the common building infrastructure (i.e., with a modern building management system) [15], [16] in minimal effort. The architecture consist of beacons placed in each monitored area, for instance, on the center of the ceiling or on the wall, and the occupant's mobile phone. An overview of the system architecture is shown in Figure 1.

The architecture requires minimally one beacon in each monitored room to map mobile phones to physical areas. These beacons broadcast a unique identifier to the nearby electronic devices. A beacon-sensing software is installed in the mobile phones to log the captured unique identifier and received signal strength indicator (RSSI) on a regular basis and to transmit this data to central server for processing via communication gateway. The communication gateways are integrated with the building's computer networking infrastructure that is also associated with the server. The server is responsible for delivering a service of occupancy data, e.g., for logging how many occupants are present in a particular space. We implemented the occupant-aware architecture and installed a number of BLE beacons in our own offices on the fifth floor of the Bernoulliborg of the University of Groningen.

IV. IMPLEMENTATION

The present study focuses on the communication between the mobile phones and the communication gateways, especially from the energy consumption point of view (dashed box in Figure 1). The sensing part, which takes place between beacons and mobile phones, are replaced with dummy occupancy data.

We implemented a tailored software for the iPhone 6, which runs the iOS operating system version 9.0. Additionally, Asus vivo mini PC that runs Xubuntu 14.04 as its operating system was utilized as a thin client that hosts the server application.

A. Mobile Application Development

We develop a tailor-made application that meets the requirements for occupant-aware deployment. Dummy occupancy data, depicted in Table II is sent to the server in a regular basis, to imitate the real implementation of user occupancy without necessarily involves the BLE sensing part. The code and experiment results are publicly available online¹.

¹<https://github.com/gtrdp/wifi-ble-energy-comparison>

Fig. 1: System architecture.

TABLE II: Dummy Occupancy Data Example

Parameter	Value
proximity_zone	NEAR
proximity_distance	1.8456140098254021
rss_i	-81
major	2
minor	9999
user_id	pratama

Fig. 2: BLE packet structure consisting of occupancy data and user ID.

1) *WiFi Communication*: One of the communication methods in the application is WiFi, utilizing HTTP as the communication protocol. A JSON object, which contains occupancy data, is sent via the HTTP POST method at each time interval. The data consists of a `user_id` (who scan the beacons), beacon proximity data (indicating the distance between the phone and the beacons in meter and signal strength), and beacon unique identifier (denoted by the major and minor number of beacon [11]).

A HTTP server is built using the Play Scala framework version 2.5.3 to receive occupancy data. No logic is implemented in the HTTP server as it is irrelevant from the energy footprint point of view.

2) *BLE Packet Structure*: We selected BLE's notification characteristic as the communication method. This characteristic will build up a link between BLE peripheral and central. Once the link is constructed, the peripheral will notify the central if there is new data [17].

Dummy occupancy data is sent via the BLE communication as well. As BLE packet is too small to send occupancy data in the same JSON format, we provide an alternative packaging, as shown in Figure 2. In this format, 20 bytes of data represents a single beacon. Thus, if more than one beacon reading has to be transmitted, the peripheral will transmit the packets multiple times, one for each beacon.

The structure of the 20 bytes of data packet is depicted in Figure 2. The packet starts with proximity zone (PZ). This block has two possible values, e.g., NEAR or FAR, coded in binary. The `user_id`, coded in 32 bit unsigned integer, maps a particular user to unique integer value. The `proximity`, encoded in floating point data type, encodes the distance between the user's mobile phone and the sensed beacon in meter. RSSI data

is also incorporated in the structure within `rss_i` block, while beacon information is stored in `major` and `minor` block [11]. The BLE implementation spreads out those beacon data into single individual BLE packets, which would be received in the BLE central at different timestamp. To keep the separated occupancy data grouped together, a random 32 bit unsigned integer, namely `label`, is incorporated in the end of the packet. The last two bytes are not used.

B. Deployment Setup

We ran an experiment at Planetenlaan apartment, Groningen. It is a single floor apartment with dimension of about 10 x 4 meter. The layout of the apartment is shown in Figure 3. The WiFi Access Point and the thin client are located in the right wall of the apartment next to the wall. There are seven positions of measurement; these represent both Line of Sight (LOS) and non-Line of Sight (non-LOS) communication. The even numbers in Figure 3 indicate non-LOS, e.g., 2, 4, and 6, while odd numbers indicates LOS, e.g., 1, 3, and 5. The last position, number 7, is added to measure the effect when the mobile phone is located outside the apartment.

V. EXPERIMENTAL EVALUATION

A. System Setup

At the time of experiment, the iPhone flight mode was turned on to hinder mobile data connection that might affect energy consumption. Furthermore, background app refresh in iOS was disabled. When measuring WiFi communication, the Internet on the WiFi Access Point was also disabled to prevent any running application from fetching data from the Internet through the WiFi connection. Furthermore, only one mode of communication is turned on during the experiment, i.e., when

Fig. 3: A floor plan showing the location where the measurement takes place and where the WiFi AP and BLE central are placed. Dark gray indicates Line of Sight communication (LOS), while light gray indicates non-LOS communication.

recording HTTP over WiFi communication, WiFi is switched on and Bluetooth is switched off and vice versa. We ran each experiment for 3 minutes with 1 second sampling rate.

B. Data Collection

To monitor the energy consumption of the iPhone, untethered energy logging in iOS is used. This mechanism employs internal logging of energy consumption of the iPhone during the experiment. Later, the logged data is imported using cable connection. The data is collected in each 3 minutes experiment and repeated ten times.

Apple's Instrument application in OSX was used to import the logged energy measurement in iPhone, as similarly done in [5]. It does not show the measurement result in standard energy measurement format, e.g., mAh, but it shows the result in its own format, which is scaled from 0 to 20. Each increment in the scale costs an hour of battery life [18]. Thus, a phone running at level 1/20 will have 20 hours of battery life, while a phone running at level 20/20 will have only 1 hour of battery life.

C. Parameters

To simulate the actual building conditions two parameters are devised. One represents the number of beacons in the space that

can be identified by a mobile phone, while the second one is the distance between the beacon and the mobile phone as this alters the signal strength. These parameters affect the communication power footprint because the latter is characterized by the packet size and also the signal strength [19].

Three values for the beacon number are selected for the experiment: 5, 10, and 20, because based on our experiment at the Bernoulliborg, five beacons are the most common number of beacons sensed in actual deployments, while ten and twenty are chosen by doubling the value five. Distance of communication is divided into two categories: Line of Sight (LOS) and non-LOS. Line of Sight is a communication in which both communication endpoints can 'see' each other without obstacles, while non-LOS means otherwise. There are six combination of location as shown in Figure 3.

Furthermore, very high number of beacons are tested for both WiFi and BLE in order to reveal more insights from the energy consumption point of view. In this way, the effect of packet size can be determined and a significant increase is expected to be present. 100 and 200 are selected as the number of beacons as it is the limit of the communication without losing some packets, identified in our preliminary tests. We select location 7 to perform this measurement and the rest of the configurations remain the same.

BLE communication power footprint is finally compared directly with WiFi's footprint along with the baseline energy consumption. Baseline energy consumption is a measure in which no unnecessary processes or communications is present on the iPhone. All of communication means are switched off, e.g., 4G, WiFi, and Bluetooth, and all of installed applications are halted.

D. Result

The resulting data set consists of the sampling of the monitoring experiment carried out ten times for each set of parameters. The main results for WiFi and BLE measurements are presented in Figure 4 and 5, while Figure 6 and Figure 7 present the case with the high number of beacons and WiFi vs BLE vs baseline comparison, respectively.

Figure 4 presents the measurement results graph of WiFi communication between the iPhone and the WiFi Access Point. The value is scaled from 0 to 20, as explained in Section V-B. The measurement is grouped based on the measurement location, numbered from 1 to 7, with each location consists of three combination of number of beacons, 5, 10, and 20, colored in green, blue, and yellow respectively. The BLE communication results, shown in Figure 5, are also presented in the same way with the WiFi communication.

VI. DISCUSSION

For both WiFi and BLE, an escalation of energy consumption is expected as the communication distance increases. However, such case is not found in the experiment. As seen in the measurement data number 1 to 6 in Figure 4 and 5, the results seem to be fluctuating rather than increasing. Looking at the LOS (odd number) and non-LOS (even number)

Fig. 4: HTTP over WiFi measurement result.

Fig. 5: BLE communication measurement result.

Fig. 6: Measurement result with 100 and 200 of beacons data for both BLE (1) and WiFi (2), measured in location 7.

Fig. 7: The average of energy consumption for both BLE and WiFi along with baseline energy consumption as a comparison.

communication, no significant differences are observable. Other than the distance between both communication endpoints, the increasing of number of beacon is also assumed to intensify the energy consumption of the iPhone. However, the results go in a different direction. As seen in all location of measurement, there are no clear trends that indicate energy increase.

In summary, there are no significant differences or trends found on communication distance changes for both of the communication methods. This situation may be caused by the distance difference that is not sufficiently large, i.e., the difference between each location is only one meter in length. Probably, significant difference could be noticed if the distance difference is significantly increased, by ten meters or more. Furthermore, comparing the energy consumption using signal strength rather than distance can be an option.

Moreover, no compelling trends or differences in terms of energy consumption for different number of beacons are observed. Such relatively small increase is only noticeable in measurement number 3 (Figure 4). The other measurements reveal fluctuating values. However, those disparities are somewhat insignificant.

Furthermore, looking at Figure 6, BLE communication consumes less energy than WiFi with roughly 2 point difference. However, there is no clear effect on the high increase of the number of beacons. The energy consumption slightly decreases by 0.2 in BLE communication, while WiFi communication energy consumption increases by 0.63. The change is relatively small, however. Thus, a conclusion can be drawn saying that there is no significant effect by increasing the number of beacons significantly. Most likely, the increase is quite small in size, i.e., bytes, so the small difference is responsible for actually consuming a roughly similar amount of energy.

Based on the measurements depicted in Figure 7, the baseline energy consumption is measured nearly 2.15 out of 20 in average. According to the scale conversion in Section V-B, this value means that the iPhone will have 18 hours and 51 minutes of battery life when set in the baseline configuration. As the iPhone is totally passive, i.e., no applications are running and

all means of communication are switched off, this duration is somewhat low.

Figure 7 also presents the average value of BLE and WiFi energy consumption, which are 4.36 and 6.22, respectively. This value indicates that the iPhone will have 16 hours and 38 minutes of battery life in BLE communication and 14 hours and 46 minutes in WiFi. Based on this measurements, BLE is to be about 30% more energy efficient than WiFi.

VII. CONCLUDING REMARKS

Bluetooth Low Energy (BLE) and WiFi are the most popular means of communication in current modern smart phones. The present study is about the comparison of energy consumption in BLE and WiFi communication, specifically for the occupant-aware buildings, focusing on the energy consumption of the transmission of occupancy data from the user's mobile phone to the communication end points, e.g., WiFi Access Point or BLE central. Furthermore, this study also presents a data structure to overcome the limited throughput and size-constrained BLE packets for transmitting occupancy data.

We identify some parameters to investigate the energy consumption in transmitting occupancy data, such as the number of beacon sensed and the distance between those communication end points, with line-of-sight state. In order to transmit the occupancy data via BLE, we break down the JSON object into several BLE packets with less than 20 bytes of size. We also re-encode the occupancy data to fit it within the small BLE packets.

In our experiment we show that BLE is about 30% more energy efficient than WiFi to transmit occupancy data from user's smart phone to the communication endpoints. According to the measurement statistics, the smart phone has 16 hours and 38 minutes of battery life when running on BLE communication scheme and 14 hours and 46 minutes in WiFi communication. However, no significant effect are observed due to the parameter changes.

If BLE is chosen as an alternative of WiFi, then one has to consider protocols to prevent BLE bottleneck as both sensing and transmitting events will probably occur concurrently. Further research should inspect the best timing for sensing and transmitting the data or to combine this implementation with real sensing activities. Furthermore, interference between WiFi and Bluetooth signal is another factor to be considered [20], as possible interference may disturb the connection if multiple Bluetooth devices are running simultaneously.

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