

Comparison of Energy Consumption in Wi-Fi and Bluetooth Communication: A Case Study on Context Aware Building

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Abstract—Context awareness has been an interesting topic recently. Its ability to infer whether a person exists on a particular room or building is really important for smart building. The result shows that Bluetooth is 29.97% more energy efficient than WiFi.

Index Terms—Context-aware, smart building, wi-fi, bluetooth low energy

1 INTRODUCTION

Smart building has been an interesting topic of research. Smart building aims to create a smart environment in a building which can adapt with the user needs. One portion of research in smart home is occupancy detection, which aims to detect whether a person is present in a particular location. Its importance to detect user presence is crucial in the building energy management, since the building can manage energy allocation efficiently regarding how many persons are present.

Mobile devices consider battery to be limiting resource.

Several methods have been proposed to overcome the occupancy detection. One of them makes use of Bluetooth Low Energy (BLE) beacon, as the beacon is useful because it always transmitting a unique data packet that indicates certain location information. Assuming that the users always bring mobile phone with them, an application can be installed on the mobile phone to scan a particular beacon, so that the application knows where currently the user is, then the application sends the data to the central server. The data can be analyzed later on to detect user presence.

Normally, the application sends the data to the server through HTTP communication done via Wi-Fi connectivity, as the BLE is already used to sense the beacon. No BLE utilization for data transmission to the server has been found. In fact, BLE is obviously more energy efficient compared to WiFi, as BLE is designed to be implemented in devices coupled with limited source of energy, e.g., battery.

This study tries to investigate BLE utilization for transmitting the occupancy data to the server. This study measures and compares the energy consumption of the mobile phone when performing data transmission via WiFi and BLE. A tailored application is developed and several possible scenario is also taken into consideration, such as number of detected sensor and user location relative to the server or access point. The result of this study may be useful for the future decision whether BLE will be implemented instead of WiFi to transmit occupancy data to the server.

The rest of this report is structured as follows. Section 2 presents other related work to this study. Methodology is described in section 3, while the results and discussion is discussed in section 4. Lastly, a conclusion is drawn in section 5

2 RELATED WORK

cite all the related work properly that you base your own work on - background - method - findings / results

Several works with regard to energy consumption investigation on mobile phones have been found, with or without a relation with smart building research topic. Most works that analyze the energy consumption deal with particular issues, for instance quantification of the consumption of components other than network interfaces, e.g.,

CPU, memory, and screen, and measurement of battery discharge state through available APIs.

A research [2] tried to study the implication of energy consumption in mobile phones with focusing on the three widespread networking technologies: 3G, GSM, and WiFi and using common mobile applications as the parameters. This study created model of energy consumption based on the measurements and developed TailEndr, a protocol that reduces energy consumption of common mobile applications.

Algorithmic effect in energy consumption is also investigated in [8]. It tested based on switching complexity and randomness, which have been tested in preliminary experiments.

A detailed anatomy of the per-packet consumption of 802.11 devices is presented in [7].

Another study also created a theoretical model for power consumption estimation of multiple components and applications based on 802.11 [10].

[12] compared Message Queuing Telemetry Transport Protocol (MQTT) with HTTP as a protocol to share location in mobile phones. MQTT offers better quality of user experience at comparable bandwidth and energy expenses.

More energy consumption analyses on GUI components and their usages are carried out in [3]. Its approach generates customized color palettes, which is acceptable by the questionnaire participants, that consumes 42% less energy on average than the original.

A study [6] alleges that using Bluetooth based architecture obtained energy saving of 15%. [6] also proposed a solution of occupancy detection using BLE beacons which is slightly similar with the architecture in this study. However, the technological deployment is different, this study utilizes Android devices.

Interestingly, [11] studies the diversity in mobile phone energy consumption. It uses blackberry and with over 1050 years of cumulative data. The results show three distinct user types: opportunistic chargers, light-consumers, and nighttime charges.

802.11n standard is also compared in low level, between the implementation in desktop/laptop and mobile phone, in [13]. The result shows that Rx power consumption increases significantly with the bitrate.

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3 METHODOLOGY

As a term project, this study was performed in three consecutive months. The main part of this study, the energy measurement, was carried out in iPhone 6, which runs iOS operating system. Additionally, Asus vivo mini PC, which runs Xubuntu as its operating system, was also utilized as a thin client that hosts the server application.

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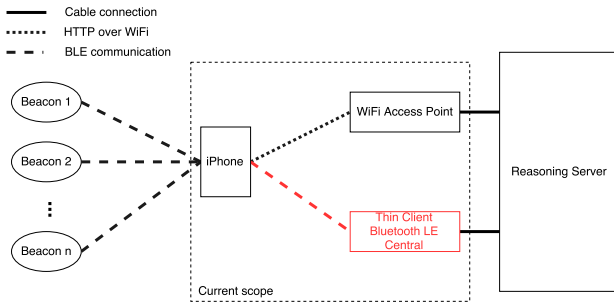


Fig. 1: System architecture overview.

3.1 System Architecture

This study is based on a study from Azkario, which attempts to extract occupancy data in smart building. This system consist of BLE beacons, which are placed accordingly in each room, a user's mobile phone, and a sensing infrastructure, which consists of WiFi infrastructure and sensing server. Currently, the user's mobile phone uses HTTP over WiFi to send occupancy data to the server, while Bluetooth is only used in mobile phone to or from BLE beacons. The Bluetooth communication in this study is intended to replace the mobile phone to server that is currently implemented using HTTP over WiFi. Briefly, the system architecture is depicted in Figure 1.

As seen in Figure 1, the thin client (colored in red), which acts as BLE central, is added to the Azkario's architecture. Later, energy consumption between BLE and WiFi are measured and compared. Although the result may be obvious that BLE is more energy efficient than HTTP over WiFi communication, this study aims to figure out how efficient is BLE communication compared to HTTP over WiFi in this context.

This study only focuses on mobile phone (iPhone) to WiFi Access Point (for HTTP over WiFi) or Thin Client (for BLE communication) for energy consumption measurement, which is surrounded in dashed box. The sensing part of the whole architecture, which is from beacons to iPhone, is neglected. As a consequences, dummy data that imitates the real data from beacons is used, which is sent from the mobile phone in every second.

3.2 Measuring the Energy Consumption

Energy consumption measurement or tracing is the core of this study. It is done by using untethered energy logging in iOS, in which the energy consumption data is logged internally in the device itself before imported to the computer by using cable connection. This method is selected because it has the flexibility over the other methods. Wireless logging, which does not involve internal logging in the device, is not used as it requires Bonjour enabled router that was unavailable.

Apple's Instrument application in Mac OS X was used to import the logged energy measurement in iPhone, as done in [5]. It does not show the measurement result in standard energy measurement format, e.g., mAh, but it shows that in its own format, which is scaled from 0 to 20. Each increment in the scale costs an hour of battery life [9]. Thus, phone running at level 1/20 will have 20 hours of battery life, while phone running at level 20/20 will have only 1 hour of battery life.

[Add image about the deployment]

Furthermore, export feature is limited in Apple's Instrument, i.e., it does not support energy consumption log exporting to other commonly used format, e.g., csv or xls file. However, manual copying and pasting on each row is still supported. An Apple script was used to automate the copying and pasting the energy log to Excel for further processing. However, it was also not stable. It encountered several errors during its runtime, which were caused by OS instability, and restarting the process was only way to overcome that.

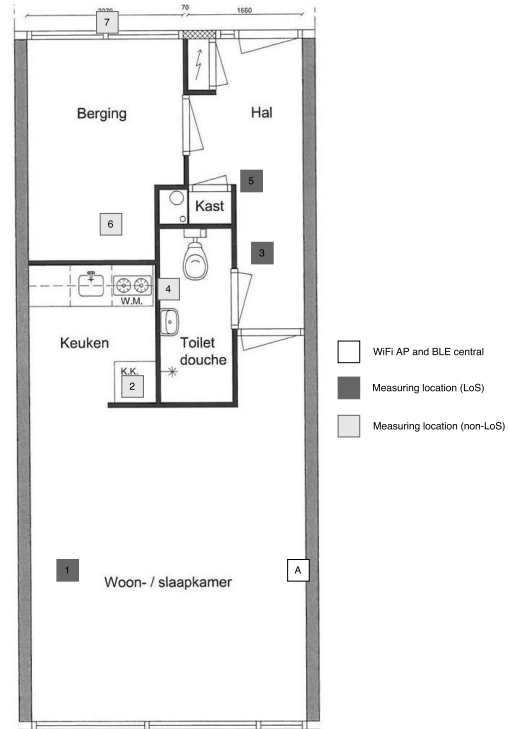


Fig. 2: A floor plan showing the location where the measurement takes place and where the WiFi AP and BLE central are placed. Dark gray indicates Line of Sight (LoS), while light gray indicates non-LoS communication.

3.2.1 Measurement Parameters

Some parameters were selected for measuring energy consumption, which are number of beacon and distance of communication. Three number of beacons are selected, which are 5, 10, and 20, because five beacons are the most common number of beacon sensed in real case, while 10 and 20 are the double size of it. Distance of communication is divided into two category, Line of Sight (LoS) and non-LoS. Line of Sight is a communication in which both communication endpoints can see each other without obstacle, while non-LoS means otherwise. Each of category has three distance. The set up of the measurement experiment is shown in Figure 2.

The experiment was carried out in a Planetenlaan flat, Groningen, which has a living/bedroom, a kitchen, a toilet and shower room, and a storage room, as shown in Figure 2. The WiFi Access Point and the thin client is located in the right of the apartment next to the wall. There are seven positions of measurement in this case, in which even number indicates non-LoS, e.g., 2, 4, and 6, while odd number indicates LoS, e.g., 1, 3, and 5. The last position, 7, is added to measure the effect when the mobile phone is located outside the apartment. During the experiment, energy consumption is recorded when the mobile phone is positioned to each of the locations. Each experiment is measured in 3 minutes time interval.

[although the communications are different: BLE- \rightarrow iPhone to thin client; WiFi- \rightarrow iPhone to Access Point, both of the end points are located closely together] [also add image about this]

At the time of experiment, flight mode was turned on to hinder Mobile data connection that may possibly affect energy consumption. Background application may affect energy measuring result. Background App refresh in iOS is also disabled to prevent significant impact of background processes. When measuring WiFi communication, the Internet on the WiFi Access Point is disabled to prevent any running background application from fetching data from Internet through WiFi connection. Furthermore, only one means of communication is turned on during experiment, i.e., when recording HTTP over WiFi commu-

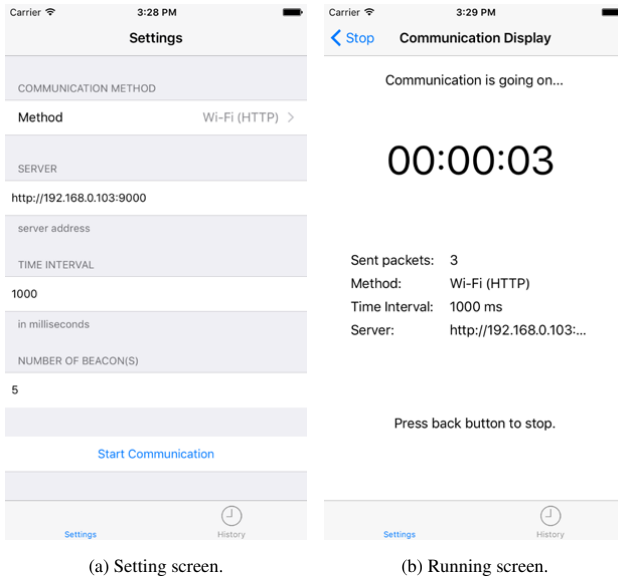


Fig. 3: Screenshots example of the application showing a view for setting up the experiment (a) and a view showing the experiment progress (b).

nication, WiFi is switched on and Bluetooth is switched off and vice versa.

3.3 Tailored Application Development

Unlike [2] that uses common tasks in mobile phone, such as Internet browsing and emailing, a tailored application that meets the requirements described in Section 3.2.1. This tailored application allows controlled environment that may focuses the energy measurement into several criteria, specifically for smart building application, with Azkario's architecture.

The application is written in Swift, which is the new general-purpose programming language developed by Apple Inc. Xcode, with Storyboard, is used to develop the application, with Git as the source code repository. A dummy occupancy data is sent to the server each time, as this study imitates the real implementation of user occupancy but not necessarily involves the sensing part. Each communication history is also saved using NSCoder in iOS for the sake of logging. The code is publicly stored in Github.com and is accessible at <https://github.com/gtrdp/cs-rug-internship>.

Figure 3 denotes two example of the application screenshots of the tailored application. As seen in Figure 3a, the user could setting what communication method, the destination server, time interval (if needed), and number of beacon. When the measurement experiment is running, a progress screen is shown to the user that indicates the number of sent packets and current experiment runtime, as denoted in Figure 3b.

3.3.1 WiFi Communication Scheme

One of the communication method in the application is the WiFi communication. In this study, Alamofire library¹ is used to handle the HTTP communication as it encapsulates HTTP communication for easier and elegant use. A JSON object is sent via HTTP POST method in each time interval, i.e., 1000 ms, that contains occupancy data, as shown in Listing 1. The dummy data is derived from the real implementation of Azkario's architecture.

Listing 1: Example of dummy occupancy data in JSON.

```
{
  "nearby_data":
  [
    {"data":{"proximity_zone":"NEAR",
```

¹<https://github.com/Alamofire/Alamofire>

```
      "proximity_distance"
        ":1.8456140098254021,
        "rssi":-81},
      "minor":1,
      "major":2222
    },
    {"data":{"proximity_zone":"FAR",
      "proximity_distance"
        ":3.171936276300526,
        "rssi":-87},
      "minor":2,
      "major":9999
    }
  ],
  "userId":"pratama"
}
```

Listing 1 shows a JSON object that consists of two nearby beacons, denoted in JSON array, that is sensed by user with ID pratama. Each nearby data is composed of proximity data, which indicates the distance in meter and the signal strength, and beacon data, which is denoted by the major and minor number of beacon [1]. If more beacons are set in the setting view, see Figure 3a, nearby_data object will have more element in its JSON array.

Moreover, a HTTP server is also built by using Play Scala framework in order to receive occupancy data. No logic is implemented in this HTTP server as this server only reads dispatched data and shows the reception timestamp.

3.3.2 BLE Communication Scheme

There are two main actors in BLE communication, the central and peripheral. A peripheral is basically the device that owns the data, while a central is a device that uses the information presented by the peripheral to perform some desired jobs. Referring to the classic client-server architecture, a peripheral can be seen as a server that has the data and a central is the client who consumes the data. An illustration depicting central and peripheral device is shown in Figure 4.

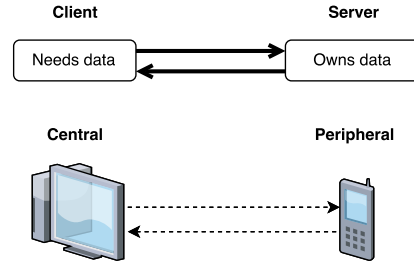


Fig. 4: Central and peripheral device illustration.

The way two BLE devices do data transmission is defined in Generic Attribute Profile (GATT) [4]. In this framework, GATT introduces concepts called Services and Characteristics. It utilizes a generic data protocol, namely Attribute Protocol (ATT), which is used to store Services, Characteristics and other related data.

According to [4], there four main methods to make use of BLE communication from central to peripheral that are defined in Characteristics Value Declaration, namely read, write, indication, and notification. Read and write characteristics are self-explanatory, i.e., it is used to read or write data from or to the peripheral. Indication and notification are the methods for pushing the data to central, which is good to send continuous data, e.g., heart rate. The important difference is indication characteristic requires an application level acknowledgment for every transmission of data. On the other hand, notification characteristics does not manage the acknowledgments by the application.

In this study, the iPhone, which provides occupancy data, serves as the peripheral, while the thin client acts as the central. Notification characteristic is used in this study because of its simplicity. Thus, the peripheral will advertise its characteristics with Unique User ID

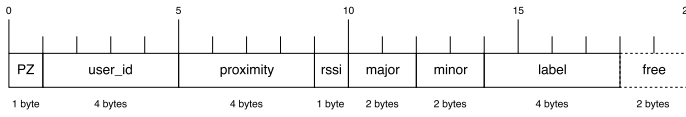


Fig. 5: BLE packet structure consisting of occupancy data and user ID.

(UUID) [4] and the central will subscribe for this characteristics in order to get updated for notification.

A dummy data is also sent in BLE communication, with the maximum user data in the packet is 20 bytes, as GATT protocol is used. This packet is relatively small to send occupancy data shown in Listings 1. That way, special format of data that can store all necessary data and fits with the constraints is created, as shown in Figure 5. In this format, 20 bytes of data represents a single beacon. Thus, if more than one beacon has to be transmitted, the peripheral will transmit the packets multiple times, e.g., 10 times of transmission for 10 beacons.

The structure of the 20 bytes of data packet is depicted in Figure 5. The packet starts with proximity zone, which is coded in PZ. This block may have two possibilities, either NEAR or FAR, which are coded in binary. The user_id is coded in 32 bit unsigned integer and a mapping between those numbers with particular users are also created. The proximity, encoded in floating point data type, discloses the distance between the user's mobile phone and the sensed beacon in meter. RSSI data is also incorporated in the structure, within rssi block, while beacon information is stored in major and minor block [1]. Referring to the JSON encapsulation of the occupancy data, shown in Figure 1, all beacons data are stored in single JSON file that marks out the same timestamp. The BLE implementation spreads those beacons data into single individual BLE packets, which would be separated and received in the BLE central in different timestamp. In order to overcome this problem, a random 32 bit unsigned integer label, which marks those separated BLE packets into the same timestamp, is incorporated in the end of the packet. Two bytes of free space is left for further research.

Speaking the technical implementation of the central application, initially Ian Harvey's bluepy library², a Python interface to Bluetooth LE on Linux, was utilized. However, further development revealed that this library does not work to handle the notification characteristic in BLE. Subsequently, Sandeep Mistry's noble³ library, a node.js BLE central module, was later used. It turned out that it is capable to handle notification characteristic in BLE communication to subscribe the update of occupancy data. In the peripheral implementation, i.e., the iPhone, native Swift CPeripheralManagerDelegate, is used to handle BLE communication.

Furthermore, Bluetooth in noble is turned out to be a little bit unstable since it always loses the connection when it reached the 29th data packet. As a solution, the central application always tries to reconnect to the peripheral when it disconnected. Moreover, Bluetooth connection requires manual trigger to start scanning the nearby BLE devices. Thus, to accomplish the experiment efficiently, a VNC server is also set beside SSH server that is used to access the thin client remotely.

4 RESULTS AND DISCUSSIONS

The data measurement experiment was carried out for ten times for each parameters for both WiFi and BLE. The main results for WiFi and BLE measurements are presented in Figure 6 and 7.

4.1 WiFi Communication Results

Figure 6 presents the measurement results graph of WiFi communication between iPhone and the WiFi Access Point. The value is scaled from 0 to 20. As explained in Section 3.2, the higher the value the more the iPhone consumes the energy or, in the other way, drains up the battery. 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

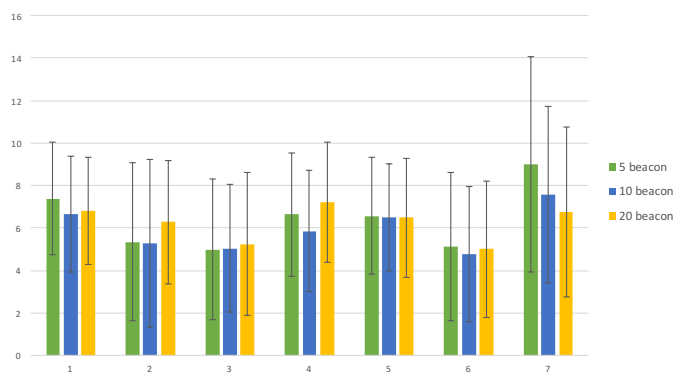


Fig. 6: HTTP over WiFi measurement result.

respectively. Measurement location number 1 to 6 are located inside the house, while number 7 is located outside the house. Furthermore, Line of Sight is incorporated in odd number of measurement location, while non-Line of Sight is in even number.

As the measurement location increases, the distance between the WiFi Access Point and the iPhone increases as well. That way, such escalation of energy consumption is expected. However, such case is not found in the experiment. As seen in the measurement data number 1 to 6, the results seem to be fluctuating rather than increasing. An increase, however, is observed in the measurement number 7, in which the result exceeds 8 scale for 5 as the number of beacon. This case may be due to the location of the measurement which is outside the house. Moreover, there are also no differences of LoS and non-LoS communication. Small increasing is only observable in measurement number 3 and 4.

Other than the distance between the WiFi Access Point and the iPhone, the increasing of number of beacon is also assumed to intensify the energy consumption of the iPhone. However, the results asserts differently. As seen in all location of measurement, there are no clear trends that indicate energy increase. The only measurement that points an energy increase is only measurement number 3. Most measurements show that 10 number of beacon consumes least energy, as seen in measurement number 1, 2, 4, and 6. Surprisingly, the measurement number 7 shows a decline of energy consumption as the number of beacon decreases.

Summarizing those findings, there are no significant differences or trends in the WiFi energy measurement result. This situation may be caused by the distance difference that is not sufficiently far. The difference between each location is only one meter in length. Probably, significant difference could be noticed if the distance difference is increased. Furthermore, measuring the energy consumption using signal strength rather than distance can be an option.

4.2 BLE Communication Results

The BLE communication results, shown in Figure 7, are also presented in the same way with the WiFi communication, i.e., it is grouped to 7 groups based on location, in which each location consists of three combination of number of beacon.

The results of BLE energy consumption measurements also reveals slightly similar result with the WiFi energy measurements results. The results are also fluctuated and there are no such trends that marks out increasing energy consumption as the distance between iPhone and thin client increases. Looking at the LoS (odd number) and non-LoS communication, no significant differences are observable. Surprisingly, non-LoS communication in number 6 is much lower than the LoS counterpart, number 5. Unlike the WiFi counterpart, the last results of measurement, marked by number 7, does not significantly differ with the other measurement location.

No compelling trends or differences are observed, in terms of energy consumption for each number of beacon. Such relatively small increasing is only noticeable in measurement number 3, while small

²<https://github.com/IanHarvey/bluepy>

³<https://github.com/sandeepmistry/noble>

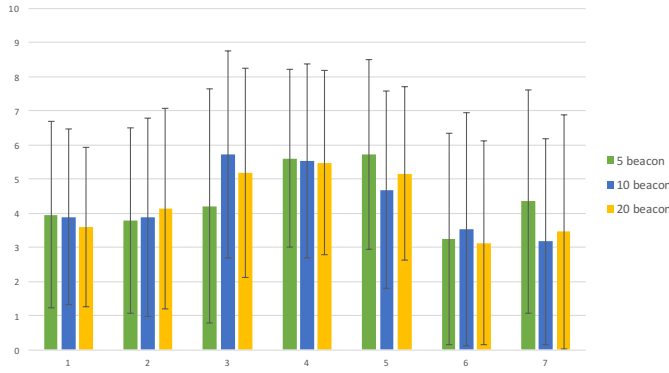


Fig. 7: BLE communication measurement result.

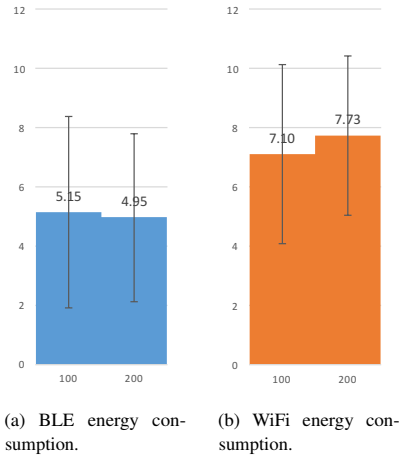


Fig. 8: Measurement result with 100 and 200 of beacons data for both BLE (1) and WiFi (2), measured in location 7.

decreasing is observable in measurement number 1 and 4. The other measurements reveals fluctuating values. However, those disparities are not somewhat significant, i.e., not more than scale 2. These findings are somewhat similar with those found in WiFi measurement result.

In conclusion, no significant differences or trends in the BLE energy consumption measurement are found. Although a small gain from location 2 to location 3 is observed it is not sufficiently substantial. The same cause as the WiFi measurement might be the reason of these findings, which is insignificant measurement difference between one location to another, as these measurement are also based on the same measurement locations. Measuring using signal strength rather than communication distance would be an option to make the measurement yields expected results. However, this would lead to unbalanced comparison since WiFi signal strength is normally measured using dBm, while BLE is using RSSI.

4.3 Additional Results

In order to reveal more insights from the energy consumption comparison, the number of beacons are increased significantly for both of the communication methods. That way, the effect of packet size can be determined and a significant increase is expected to be present. Early testing revealed that it took roughly 4ms to send each BLE packet, i.e., sending 200 BLE packets would take around 800ms, which is lower than the sending interval (1000ms). Thus, current measurement uses 100 and 200 as the number of beacons because that is the limit to perform the communication without losing some packets. Location 7 is selected to perform this measurement with the same parameters for the other configuration. The result is shown in Figure 8.

As can be concluded from Figure 8, BLE communication consumes

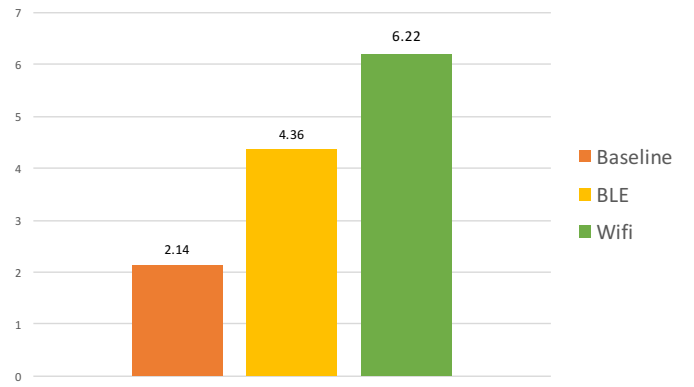


Fig. 9: The average of energy consumption for both BLE and WiFi along with baseline energy consumption as a comparison.

less energy than WiFi communication with roughly around 2 scale difference. However, there is no clear effect on the increase of the number of beacon in the results. 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 of the increase of number of beacon. Probably, the increase is quite small in size, i.e., bytes, so this small difference is actually consuming the roughly similar amount of energy, which leads to these results.

Previously, detailed results of energy measurements with arranged parameters for both WiFi and BLE have been presented. However, no direct comparison for both main communication is shown. In order to compare the energy consumption directly, a baseline energy consumption is introduced. It is a measurement in which no unnecessary processes or communications present in the iPhone. That way, all of communication means are switched off, e.g., 4G, WiFi, and Bluetooth, and all of installed applications are halted. Some background processes, however, are still able to interfere the experiment by consuming some energy unexpectedly, although it would be in a small effect. As previous measurements, this experiment is also carried out within 3 minutes of time frame and repeated for 10 times. The result is depicted in Figure 9.

Based on the measurements, the baseline energy consumption is nearly 2.15 out of 20 in average. According to the scale conversion in Section 3.2, 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 durability is somewhat low. However, the standard deviation is also fairly high, which is counted 2.6.

Figure 9 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 proven to be 29.97% more energy efficient than WiFi. This result is may limited only to smart building application because the metrics and the parameters used in this study are devised for smart building application.

5 CONCLUSION

Bluetooth Low Energy (BLE) and WiFi are the most popular means of communication in current modern smart phones. As most of the recent smart phones, ranging from the entry level to the top class phone, own that, such opportunities to make use of them for solving problems in smart buildings are present, for instance, the application of BLE and WiFi to solve occupancy problems. This study has presented the comparison of energy consumption in BLE and WiFi communication, specifically for the case of occupancy detection in smart buildings. This study only focuses 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.

In order to investigate the energy consumption in transmitting occupancy data, some parameters are designed, such as the number of beacon sensed and the distance between those communication end points with Line of Sight and non-Line of Sight communication. A tailored application is also developed to support the measurement using those parameters. As this study only focuses on transmitting the data, no sensing activity is performed and dummy occupancy data is sent.

The result alleges that BLE is actually 29.97% 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 on parameter change.

Some limitations and drawbacks, however, are still encountered. For instance, this study is only tested for iPhone 6 that runs iOS 9.3.2 as its operating system. Thus, different outcome may be resulted if the experiment is carried out in different mobile phone. Furthermore, instability was also observed during BLE experiment that might be caused by the BLE central library's bug or some code smells in the central applications. Surprisingly, in the experiment, brightness was proven to be one of significant source of energy loss as it consumes much energy to light up the screen during the experiment.

BLE has a promising advantage if it is implemented as a replacement for WiFi as it has better energy consumption efficiency. If BLE is implemented, some protocol of BLE sensing is required to prevent BLE bottleneck as both sensing and transmitting events will probably occur in the same time. Further research may be aimed to inspect the best timing for sensing and transmitting the data or to combine this implementation with real sensing activities.

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