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

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Abstract— Smart building aims to tackle the high wasteful energy consumption in a building, without sacrificing the level of comfort for the occupants. A tactic to prevent impractical use of energy is to know whether or not a person is present in a particular location. An approach to accomplish this is by using beacons placed in the room and occupants' mobile phones that sense those bacons using Bluetooth Low Energy (BLE) interface. Having the sensed occupancy data, the mobile phone then can transmits the data to the sensing server via HTTP over WiFi for further processing. However, WiFi is known to be energy expensive, while occupancy data is relatively small data with small size. As it is designed for devices coupled with limited source of energy, BLE offers another possibility to transmit the low bit-rate occupancy data to the server with lower energy profile. This study investigates BLE utilization for transmitting the occupancy data to the server using off-the-self devices with several benchmarking parameters. The result shows that Bluetooth is 29.97% 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. This shows that BLE might be a good candidate as a replacement for WiFI although other factors might also be taken into account, e.g., communication bottleneck or RF interference.

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. Furthermore, smart building also targets to tackle the high wasteful energy consumption in a building, without sacrificing the level of comfort. One portion of research in smart home is occupancy detection, which aims to detect whether or not 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.

Several methods have been proposed to overcome the occupancy detection, such as WiFi based approach, although it suffers from the interference in a coexistence environment [20]. Another method is proposed by using Bluetooth Low Energy (BLE) beacons [7], which always transmit unique data packets that indicate certain location information. As currently nearly half of the global population is benefiting from mobile communication [10], it can be assumed that the building occupants always bring mobile phone with them. That way, 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 WiFi is the main communication gateway [10] and the BLE is already used to sense the beacon. However, WiFi is known to be energy expensive, while mobile phone's main energy consuming part is wireless communication [9, 10]. As a matter of fact, recent model of mobile phones are also equipped with BLE, which 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, and for transmitting low bit-rate data [11]. That way, BLE offers another possibility to transmit the occupancy data to the server with lower energy profile.

This study investigates 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 the report is structured as follows. Section 2 presents other related works in relation 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

Several works in relation 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. The analysis is ranging from simulation to real hardware level analysis.

A somewhat similar architecture to this work, namely BLUESENTINEL, is proposed to tackle occupancy detection issue in a smart building [7]. It uses BLE beacons and occupants' mobile phones, as sensors, to gather occupancy data. However, this work only employs HTTP through WiFi to transfer occupancy data to server, thus, this work does not incorporate BLE. Furthermore, the same author as [7] alleged in different work [8] that Bluetooth based architecture obtained energy saving up to 15%. [8] also proposed a solution of occupancy detection using BLE beacons which is slightly similar with the architecture in this study. Another approach in indoor localization, which is closely related with user occupancy, is proposed by using inertial measurement units as well as available RF signals, e.g., Bluetooth and WiFi [17], namely SignalSLAM, which mainly relies on Simultaneous Localization and Mapping (SLAM). However, no energy concern are described in this work. Moreover, a study studies regarding localization, specifically about the issues regarding WiFi positioning [20]. It alleges that WiFi positioning suffers from the interference in a coexistence environment.

A study is inspecting energy profile or consumption in wireless communication of mobile phone without any relation to user occupancy, localization, or smart building. It studies the correlation of throughput and power in WiFi and Bluetooth [11], which resulted that Bluetooth is more energy efficient than WiFi. However, this study only incorporates classic Bluetooth and does not put BLE into account.

Several studies address power consumption of mobile phone from software perspective. For example, algorithmic effect in energy con-

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sumption is investigated in [13]. It tested the power consumption based on switching complexity and randomness, which have been tested in preliminary experiments. Another energy consumption that analyses GUI components and their usages is carried out in [4]. Its approach generates customized color palettes that consumes 42% less energy on average than the original, which is acceptable by the questionnaire participants. Another work in software perspective compared Message Queuing Telemetry Transport Protocol (MQTT) and HTTP as a protocol to share location in mobile phones [24]. The result alleges that MQTT offers better quality of user experience at comparable bandwidth and energy expenses.

More studies are interested in inspecting power consumption in IEEE 802.11 standard alone, such as a study that created a theoretical model for power consumption estimation of multiple components and applications based on IEEE 802.11 [16]. Moreover, a detailed anatomy of the per-packet consumption of IEEE 802.11 devices is presented in [12]. Multi-hop network effect on IEEE 802.11b wireless communication also turned out to be affecting energy consumption as well, as investigated in [18]. The study conducted a simulation, which then suggested that multi-hop topology may be an alternative green communication as it has better energy efficiency. IEEE 802.11n standard is also compared in low level, between the implementation in desktop/laptop and mobile phone [25]. The result shows that Rx power consumption increases significantly with the bitrate. Furthermore, energy efficiency analysis in WiFi communication with regard to video on demand transmission is investigated as well [22]. It utilized Android devices in a controlled IEEE 802.11g environment with five different quality levels of multimedia content. The results show that the quality of multimedia stream correlates with the energy efficiency, i.e., the better the quality levels of multimedia content the worse the energy efficiency. The results also show that TCP is more energy efficient than UDP in all situations.

Beside the power consumption analysis on IEEE 802.11, several works are also concerned about the energy usage on mobile network, e.g., 3G and 4G, as in [21]. It studies mobile data communication, such as GSM and UMTS, with common tasks on mobile phone, e.g., making a call and sending an SMS. It is presented to compare the energy usage for particular tasks in 2G and 3G [21]. Another low level analysis is also presented in mobile network on mobile phone [23]. The energy footprint is characterized by performing real hardware level measurements on a modern broadband module.

Beside power consumption profiling in Bluetooth, WiFi, or mobile phone's telephony network, energy conservation is also discussed in several papers, such as [3], which uses data driven approach to lessen the unnecessary scanning or idle mode WiFi energy consumption. A framework to conserve energy in wireless communication is also proposed in [6]. This framework, namely WINA (Wireless Interface Notification and Activation), introduces a low-powered auxiliary receiver that receives signal from access point to activate relevant wireless interfaces on the mobile phone. Furthermore, a research [2] tried to study the implication of energy consumption in mobile phones with focusing on the three widespread networking technologies, e.g., 3G, GSM, and WiFi, and using common mobile applications as the parameters. This study created a model of energy consumption based on the measurements and developed TailEnder, a protocol that reduces energy consumption of common mobile applications.

Other aspect that is also investigated is the diversity on power consumption [19], which focuses on blackberry device with over 1050 years of cumulative data. The results show three distinct user types: opportunistic chargers, light-consumers, and nighttime charges.

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 off-the-shelf smart phone, 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.

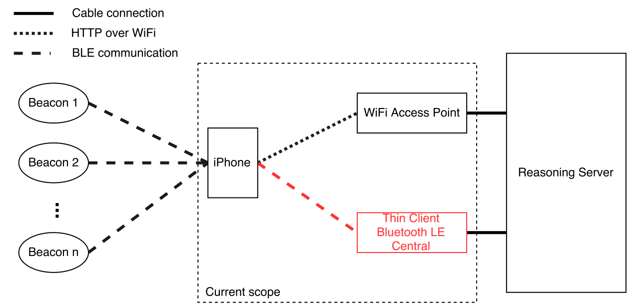


Fig. 1: System architecture overview.

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 monitored 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 BLE communication is, 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 by dashed box in Figure 1. The sensing part of the whole architecture, i.e., 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, which was unavailable.

Apple's Instrument application in Mac OS X was used to import the logged energy measurement in iPhone, as done in [7]. 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 [15]. 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.

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.

3.2.1 Measurement Parameters

Some parameters were selected for measuring energy consumption, which are number of beacon and distance of communication as wireless

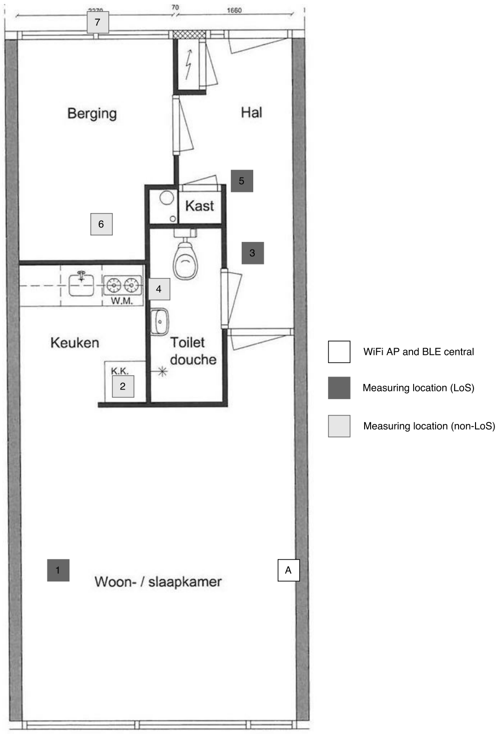


Fig. 2: A floor plan showing the location where the measurement takes place and where the WiFi AP and BLE central are placed. Dark gray indicates Line of Sight communication (LOS), while light gray indicates non-LOS communication.

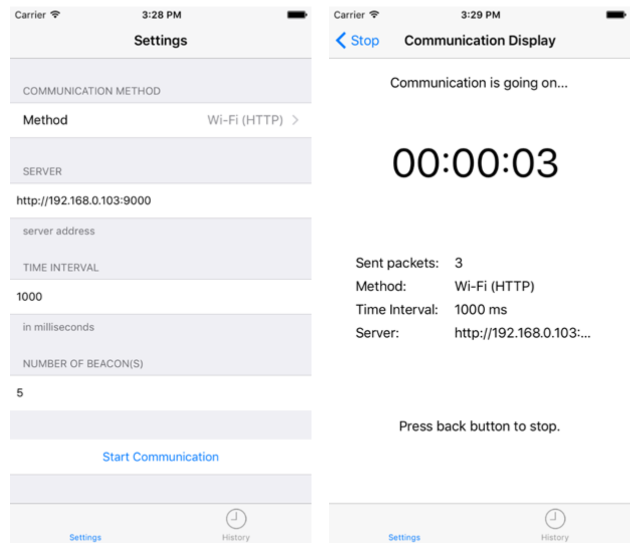
communication power footprint is not only characterized by the packet size, but also the signal strength [23]. The number of beacon has little effect on the packet size, i.e., more number of beacon will have bigger packet size, while communication distance affects the signal strength.

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 wall 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 on each of the locations. Although the communication routes are different, e.g., iPhone to BLE thin client for BLE and iPhone to Access Point for WiFi, both of the end points are located closely together as seen in Figure 3. Each experiment is measured in 3 minutes time interval.

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 disabled to prevent significant impact of background processes. When measuring WiFi communication, the Internet on the WiFi Access Point is also 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 communication, WiFi is switched on and Bluetooth is switched off and vice versa.

Fig. 3: Deployment server with TP-Link access point and Asus vivo mini PC.



(a) Setting screen. (b) Running screen.

Fig. 4: Screenshots example of the application showing a view for setting up the experiment (a) and a view showing the experiment progress (b).

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 focus 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 NSCoding 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 4 denotes two example of the application screenshots of the tailored application. As seen in Figure 4a, the user could setting the 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 4b.

3.3.1 WiFi Communication Scheme

One of the communication method in the application is the WiFi communication, which utilizes HTTP as the communication protocol. HTTP is chosen because it works on top of TCP, which is proven to be more energy efficient than UDP [22]. In this study, Alamofire library[1] 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",
               "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, which are 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 (Figure 4a), `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 5.

The way two BLE devices do data transmission is defined in Generic Attribute Profile (GATT) [5]. 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 [5], four main methods to utilize BLE communication from central to peripheral are defined in Characteristics Value Declaration: 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.,

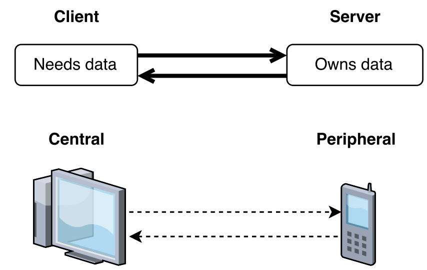


Fig. 5: Central and peripheral device illustration.

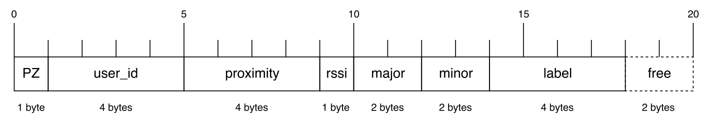


Fig. 6: BLE packet structure consisting of occupancy data and user ID.

heart rate. The important difference is that the 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 (UUID) [5] and the central will subscribe for this characteristics in order to get updated for notification.

A dummy data is also sent in BLE communication, which is only limited to 20 bytes as the maximum packet size of user data [5]. This packet is too 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 constrains is created, as shown in Figure 6. 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 6. 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 is 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]. While the JSON encapsulation of the occupancy data, shown in Listing 1, stores all beacons data in single JSON file with same timestamp, the BLE implementation spreads out those beacons data into single individual BLE packets, which would be transmitted 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. The rest of two bytes free space are left for further research.

Speaking the technical implementation of the BLE central application, Ian Harvey's bluepy library[2], a Python interface to Bluetooth LE on Linux, was utilized initially. However, further development revealed that this library does not work to handle the notification characteristic in BLE. Subsequently, Sandeep Mistry's noble[3] 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 `CBPeripheralManagerDelegate`, is used to handle BLE communication.

[1] `https://github.com/Alamofire/Alamofire`

[2] `https://github.com/IanHarvey/bluepy`

[3] `https://github.com/sandeepmistry/noble`

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 7 and 8.

4.1 WiFi Communication Results

Figure 7 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, i.e., 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 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 number 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 of 5 as the number of beacon exceeds 8 scale. 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, i.e., 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 8, 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 (even number) 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.

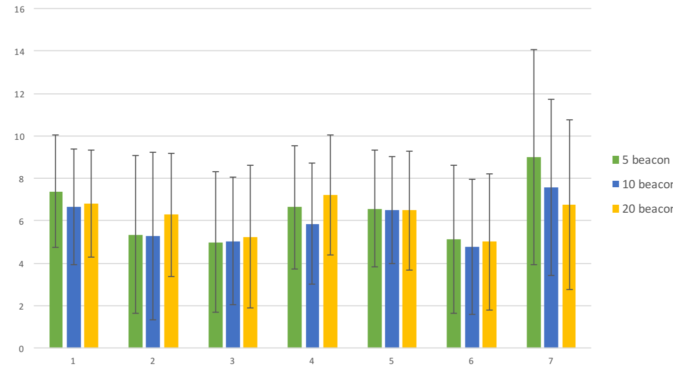


Fig. 7: HTTP over WiFi measurement result.

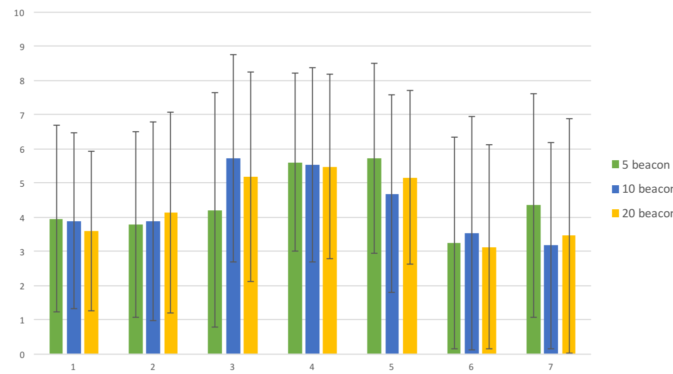


Fig. 8: BLE communication measurement result.

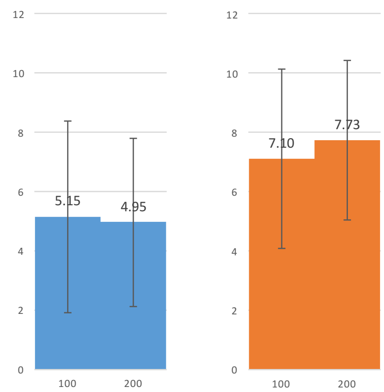
No compelling trends or differences are observed, in terms of energy consumption for each number of beacon. Such relatively small increasing is only noticeable in measurement number 3, while small decreasing is observable in measurement number 1 and 4. The other measurements reveals fluctuating values. However, those disparities are not somewhat significant, i.e., not more than 2 scale. 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. The 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 9.

As can be concluded from Figure 9, BLE communication consumes less energy than WiFi communication with roughly around 2 scale



(a) BLE energy consumption.

(b) WiFi energy consumption.

Fig. 9: Measurement result with 100 and 200 of beacons data for both BLE (1) and WiFi (2), measured in location 7.

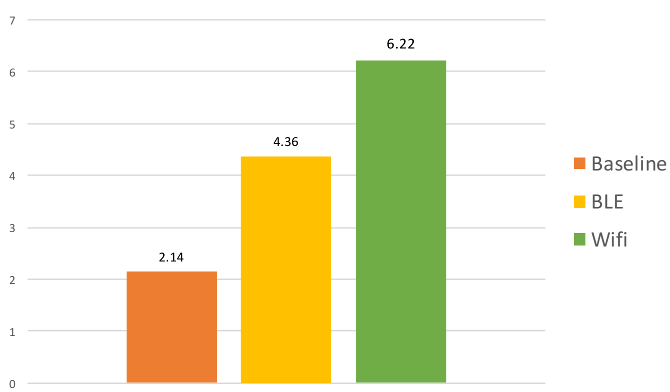


Fig. 10: The average of energy consumption for both BLE and WiFi along with baseline energy consumption as a comparison.

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 10.

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 10 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 room 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 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 benchmarking 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 and it is more resilient to interference by nearby transmissions. 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. Furthermore, interference between WiFi and Bluetooth signal could be another factor to be considered [14], as possible interference may disturb the connection if multiple Bluetooth devices are running simultaneously.

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