THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Evaluation of Smart Watch Technology in Real-Time Energy Feedback

by

Zakary James Alexy Burke

School of Information Technology and Electrical Engineering,
University of Queensland.

Submitted for the degree of Bachelor of Engineering (Honours) in the division of Electrical and Computer Engineering.

Submitted 5th June 2023

Zakary James Alexi Burke
z.burke@uqconnect.edu.au

5th June 2023

Prof Michael Brünig,
Acting Head of School
School of Information Technology and Electrical Engineering
The University of Queensland
St Lucia QLD 4072

Dear Professor Brünig,

In accordance with the requirements of the Degree of Bachelor of Engineering (Honours) in the School of Information Technology and Electrical Engineering, I submit the following thesis entitled:

"Evaluation of Smart Watch Technology in Real-Time Energy Feedback"

The thesis was performed under the supervision of Dr Maxime Cordeil and Dr Stephen Snow. I declare that the work submitted in the thesis is my own, except as acknowledged in the text and footnotes, and that it has not previously been submitted for a degree at the University of Queensland or any other institution.

Yours sincerely,

Zakary Burke

Acknowledgements

I want to thank my supervisors, Dr. Maxime Cordeil, Dr. Stephen Snow and Mr. Alexander Balson for their support, insightful suggestions, and valuable guidance especially during the period of relocation where I was required to adapt to the new circumstances and change the direction of this research.

Steve and Alex, the original supervisors of this thesis, helped navigate me through the exploratory stages of this project. Their insightful meetings and initial guidance created a strong foundation for my research.

Maxime filled in for the latter half of my thesis. His proactive engagement in helping me redirect the project during this period was invaluable.

I consider myself very fortunate to have been supervised by such dedicated people, always ready to answer questions promptly and respectfully. Their combined wisdom, patience, and dedication to me and the project were instrumental in its success.

Abstract

Studies indicate that existing energy feedback tools, including in-home displays and mobile energy monitoring apps, do not effectively reduce long-term energy consumption. These devices often struggle to maintain user engagement, and the energy savings they produce are not statistically significant. Little to no research has been conducted on the usage of smart watches in real-time energy consumption visualisation. Given the constant connection between the user and the smartwatch, it offers a more personalised experience. Therefore, this project aims to create and explore this innovative feedback solution capable of fostering sustained user engagement. This is done through assessing the feasibility of the use of smart watches in household energy feedback and developing a working prototype to identify any technological barriers to entry. The prototype developed utilises a Samsung Galaxy Watch5 to interface with mock devices via a Bluetooth Mesh network, chosen for its potential to become a standard in smart home systems. Smart watches were discovered to become essential elements in home energy monitoring systems, even if primarily used for alerting users rather than directly displaying energy consumption data. Additionally, emerging advancements in smart watch technology have simplified and streamlined the development of new products. Despite the growing use of smart plugs and home hubs, energy consumption reporting methods have remained largely unchanged, introducing smart watches as a tool for energy reporting could be an innovative and effective solution. Further research needs to be conducted to assess the efficacy of a specific smart watch app in reducing energy consumption, investigate the practicality of utilising other networking protocols such as Bluetooth Mesh for large scale product development and explore how smart watch applications can fit into the existing smart home and energy consumption feedback landscape.

TABLE OF CONTENTS

List of Figures

Chapter 1

1 INTRODUCTION

Significant advancements in energy metering technology have been made since the widespread adoption of smart meters in the 21st century. Although household energy feedback systems have been researched for quite some time [1], smart meters have enabled even greater improvements in this area. These include enhanced billing, in-home displays, and energy monitoring mobile applications, providing consumers with real-time insights into their home's energy consumption.

The intention behind these devices was to grant users more control over their usage by identifying specific consumption areas. However, after the initial excitement surrounding these products, user engagement tends to decline. Recent research suggests that energy savings achieved through these devices are not statistically significant, indicating a need for the development of new energy feedback devices with a focus on sustained user engagement [2] [3].

The objective of this project is to develop and assess the effectiveness of a smart-watch application that wirelessly receives energy data from nodes linked to individual appliances. This design choice is influenced by recent improvements in processor speed, radio efficiency and the growing trend of wearable technology. Furthermore, the project seeks to address the existing gap in the literature and by doing so, contribute to the development of innovative energy feedback solutions that foster long-term user engagement and promote more sustainable energy consumption habits.

1.1 BACKGROUND

Household energy is the largest energy consuming sector in Australia, making up approximately 30% of the total energy usage [4], with UK and USA showing similar data [5] [6]. This has driven research into finding methods of reducing household energy consumption by giving data to the user related to their energy consumption, such as disaggregated energy monitoring, home energy management systems and enhanced billing methods.

Non-intrusive load monitoring (NILM), a form of disaggregated energy monitoring, is a growing technology, which is installed on a household's primary switchboard, that enables appliance-level energy tracking. This method allows for detailed energy consumption analysis without the need for invasive installation procedures. There are still numerous challenges that need to be addressed to make it a practically viable solution according to a study in 2012 [7], such as, being able to discern between the large variety of appliances. Artificial intelligence (AI) using supervised learning can be affected by subtle changes from the energy supplier (i.e. power factor correction) and being able to recognise new devices which haven't been 'trained' into the database. Advancements in AI have improved the accuracy of these devices, but as of 2020 there were "no accurate NILM device(s) available in the market" [8]. The sampling rate of smart meters can be as a low as 0.03Hz and up to 1Hz, which is why they measure steady state features [9]. A reason for this low sampling rate is to reduce the impact of a data leak which could let someone know when and how a family uses their energy. The sampling rate where disaggregation becomes useful is above 10kHz, which requires significant hardware and firmware upgrades to the existing devices in the market. The necessary upgrades for the successful implementation of NILM technology are elaborated upon in the referenced article [10].

As of December 1st, 2017, all new or replacement meters in Australia must be smart enabled [11] and these meters have an average lifespan of around 20 years [12]. Additionally, the Victorian government is subsidising *Powerpal* energy monitors [13], which require connection to a smart-enabled meter and allow users to track their appliances' real-time energy usage. However, this device does not disaggregate energy consumption; it merely enables users to observe a spike in power usage when activating an appliance, such as an air conditioner [14]. Typically priced at $129, the device is offered free of charge to residents in Victoria [13], which demonstrates that there has been, and will continue to be, a significant investment in smart meters that do not support disaggregation.

Home Energy Management Systems (HEMS) are an extension to the smart meter, like the *Powerpal* device, however, they generally include an In-Home Display (IHD) where users can see their energy usage on a dedicated device. Great Britain began offering domestic consumers an IHD, in addition to smart meters, in April 2011 [15]. There have been many studies done on the effectiveness of IHDs and energy feedback devices since their initial rollout, investigating the effectiveness of reducing energy consumption.

The socio-economic situation of users plays a significant role in the effectiveness of IHDs, for example, a study involving 1500 households in Austria [16] concluded that, low-income households were associated with low electricity use. As such, feedback had little to no effect on energy consumption and they were likely to raise electricity use in response to energy savings or an increase in income. Additionally, feedback had no effect on households in the upper income bracket because savings were an insignificant portion of overall income. Effects of feedback were most effective between the 30^{th} and 70^{th} percentile of income.

User engagement also plays a vital role in the effectiveness of energy feedback. A qualitative study concluded that “feedback only works if the participants are strongly motivated” and that users’ engagement is, in part, dependent on previous motivation to save energy [17]. However, this previous motivation cannot be too high, or else there is not enough room for improvement.

A Swedish field study investigated the effects of HEMS in energy reduction by interviewing 14 of the high-income, highly educated households, from a greater study of 154 households [18]. The study examined the reduction in energy consumption across all households, however, the qualitative data received from interviews gives a good insight on how to design a user-friendly device. All interviewees requested that feedback was given in a relatable way that they can understand, such as, avoiding displaying data in kilowatts. Secondly, all members of the household need to be somewhat motivated to reduce their energy consumption, or else, the most motivated member does not feel that their efforts are making a significant enough difference and ultimately, give up. Finally, the design of the device needs to be appeal to a greater scope of people, for example, one interviewee claimed, “… it’s obvious that it’s … for and by engineers … “. These interviews are conducted with people of highly educated households (tertiary education) and still finding it difficult to use or understand some of the aspects of the device. Therefore, it would be safe to assume that these are global issues which need to be considered when designing a new product.

Chapter 2

2 LITERATURE REVIEW

2.1 CURRENT STATE OF SMART WATCH TECHNOLOGY

Smart watches have many unique features from fitness; heart rate monitoring and step counter, health; fall detection and blood pressure monitoring [19], and convenience; mobile payments and making/receiving calls [20]. The popularity of smart watches has experienced significant growth, with around 90 million units shipped in 2019 and an estimated 130 million projected for 2023 [21]. A 2020 study revealed that 20% of Americans possess and actively use a smartwatch [22]. Although researched has examined the application of smart watches in various sectors, such as health and fitness, no studies have explored their potential for real-time energy feedback or household energy monitoring. This project aims to address this gap literature.

2.2 ANALYSIS OF ENERGY USAGE MONITORS

2.2.1 Standalone Smart Plugs

Standalone smart plugs are individual devices that plug into a conventional wall outlet and allow users to control and monitor the energy usage of a single connected appliance. They can be operated remotely using a smartphone app or voice-activated assistants like Google Home or Amazon Alexa. They offer the ability to turn the connected appliance on or off, set schedules and track energy consumption.

Some example products include the BN-LINK: BNC- 60 [23], Topgreener [24] and Eufy: Smart Plug [25], and range between $20-25 dollars each.

2.2.2 Standalone Energy Monitors

Standalone energy monitors are devices that measure the energy consumption of appliances in real-time. These monitors typically consist of a sensor that attaches to the power cable of an appliance and a display unit that shows the energy usage. Unlike smart plugs, standalone monitors do not offer remote control functionality but instead provide users with deeper insight into the devices energy consumption behaviour. This additional information may not be helpful to the average user and standalone smart plugs that can connect to a mobile phone app might be the better option.

Some examples of products include: Fayleeko, Poniie: PN2000 and Kill-a-Watt: P4460, and consumer range products can range anywhere between $35-200.

2.2.3 Home Energy Monitors

Home energy monitors provide a comprehensive overview of a household's energy usage, these devices are connected directly to the home's electrical panel, enabling users to track energy consumption of all connected devices in real-time. Home energy monitors often come with a dedicated In-Home Display and/or can be accessed via a smartphone app, providing detailed insights and analytics on energy usage patterns. However, as discussed earlier this information is generally either, not specific enough to analyse individual appliances, or the user loses interest in actively engaging with the IHD and/or mobile phone app.

2.2.3.1 Sense Energy Monitor

Sense Energy Monitor connects directly to the electrical panel using current sensor clamps and monitors the home's energy usage in real-time. It can identify individual devices and appliances by analysing their unique electrical signatures which inturn provides a detailed breakdown of energy consumption from each device [26]. It also provides historical information over time and can supposably identify trends or potential inefficiencies, for example, if a fridge begins cycling on/off more or less frequently, it could indicate a problem with the appliance. Additionally, alerts and notifications can be setup based on specific events, for instance, when a device has been left on for too long or when energy usage exceeds a certain threshold. It can integrate with solar energy systems, allowing users to track solar production and provide insights into the home's net energy consumption. Sense is also compatible with various smart home platforms such as Amazon Alexa, Google Assistant and IFTTT, allowing seamless integration [27].

Sense energy monitor utilises NILM and machine learning to identify various appliances in use within a home. As stated on their website, it takes typically 3 to 6 months for Sense to learn the behaviour of each device, after which it can provide valuable and appliance specific data, including the cost associated with each device's usage.

While many reviews are positive, some users have reported difficulties with Sense accurately detecting multiple appliances simultaneously, particularly when they exhibit similar load characteristics. With an initial investment of approximately $450 AUD [28], the monitor is not cheap. However, Sense claims that users can save around 9% on their electricity bills [29]. Considering the average Australian Electricity bill of $1,500 per year [30], it would take about three years to recoup the initial investment. It's important to acknowledge that the claims regarding the product's efficacy come from the company itself and no long-term studies have been conducted. There have only been individual case studies and user testimonials discussing the impact the product has had on them personally.

The product offers greater insights into customers' energy consumption compared to traditional monitoring systems, but it still relies on conventional methods like mobile apps or In-Home Displays for user interaction. This may result in users losing interest over time and the research discussed earlier [2] indicates that interest in IHDs and energy monitors typically diminishes after about a month of excitement. Since Sense requires 3-6 months to calibrate all devices, user motivation might decline during this period. Conversely, the gradual discovery of new devices over this timeframe could keep users engaged and maintain their interest. Without long-term studies on such devices, it is difficult to draw definitive conclusions.

2.3 Mobile Phone Applications

The integration of mobile phone applications with various devices, such as, standalone smart plugs, home energy monitoring systems, and certain smart meters, is currently a standard practice. Despite extensive research into the potential of these smart phone applications to mitigate electricity and gas consumption levels, there is not substantial evidence to suggest that they bring about any significant reductions. However, its worth noting that user interviews, such as the one conducted in the Swedish field study described in section 1.1, have indicated an improvement in energy literacy, even while energy consumption may not be significantly affected.

Chapter 3

3 THEORY

3.1 BLUETOOTH LOW ENERGY (BLE)

Bluetooth Low Energy (BLE) is a wireless communication technology designed for power-efficient and short-range communication between devices. It is a subset of the Bluetooth 4.0 specification and was introduced to address the increasing demand for low-energy devices in various industries, such as wearables, smart home appliances, and IoT (Internet of Things) devices [31].

BLE achieves its low-power consumption by employing a faster connection setup time, shorter data packets, and reduced duty cycles. This results in significantly reduced energy usage compared to traditional Bluetooth technology, allowing devices to operate for months or even years on coin-cell batteries [32].

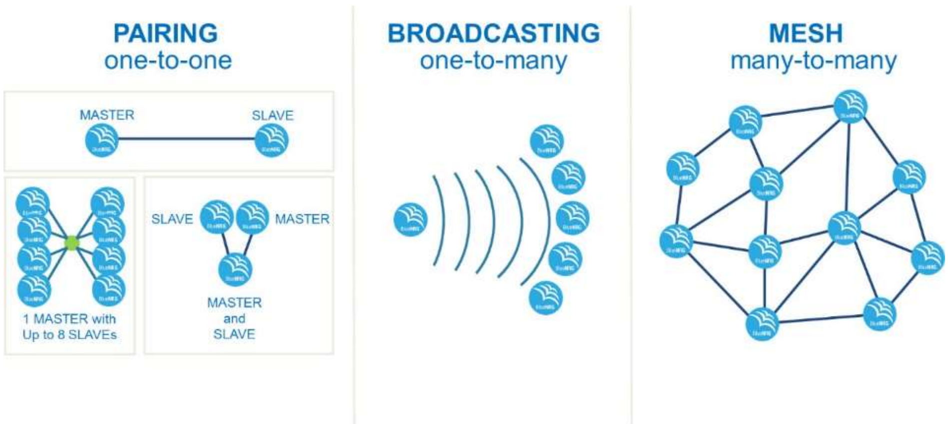


Figure 1: Typical Bluetooth Low Energy network topologies [33]

This project uses Bluetooth Generic Attribute Profile for pairing and Bluetooth Mesh for communication. The specific implementation details will be covered in the methodology section, while the fundamental concepts of each technology are discussed below.

3.1.1 Bluetooth Generic Attribute Profile (GATT)

Bluetooth GATT is a key part of the BLE protocol and defines the way in which devices discover, communicate and interact with each other using a structured framework for data organisation and exchange. GATT is built on top of the Attribute Protocol (ATT) and utilizes concepts such as services, characteristics and descriptors to organise and present data:

1. **Services**: A service is a collection of data and associated behaviours that represent a specific functionality of a device.
2. **Characteristics**: Each service can have multiple characteristics, which are individual data points or values related to the service.
3. **Descriptors**: Characteristics can have descriptors, which are additional pieces of information about the characteristic, such as its format, units and/or permissions. Descriptors also allow for specific client/server interactions with the characteristic, such as enabling notifications when a value changes.

GATT operates in a client-server architecture, where one device (the client) requests data or initiates operations on another device (the server). The server hosts the GATT services and characteristics, and the client reads, writes and/or receives notifications or indications about the characteristic values.

3.1.2 Bluetooth Mesh

Bluetooth Mesh was introduced in 2017 and is an extension of the BLE protocol. In a Bluetooth Mesh network, devices can act as nodes and relay messages for other nodes, extending the overall range of the network. This topology is particularly useful for large-scale IoT deployments where devices need to communicate efficiently and reliably over long distances.

Bluetooth describes its Mesh networking [34] as:

- **A Full Stack Solution**: This makes product development more straightforward as it encompasses everything from the low-level physical radio layer to the high-level application layer. As a result, interface changes won't impact product development life cycles since future Bluetooth versions will likely maintain backward compatibility.

- **Decentralized Control**: Every Bluetooth Mesh device is an integral part of the network and doesn't necessitate an external controller. This eliminates the need for a controller to interact with a Wi-Fi router, which would then communicate with each node individually through packets. Instead, the controller can directly communicate with its devices and its devices can directly communicate with it.
- **Publish & Subscribe Model**: This enables several devices with common characteristics or control needs to subscribe to a group address. Consequently, individual devices don't need their own dedicated packet, reducing potential network strain. This method considerably decreases messaging traffic across networks.

There is quite a significant amount of information involved with BLE and Bluetooth Mesh, as such, specific technical information, where relevant, will be described in the methodology section alongside its application to this project.

3.2 EMBEDDED SYSTEM DEVELOPMENT

3.2.1 Zephyr Real Time Operating System (RTOS)

Zephyr is an open source, scalable and modular real-time operating system designed for resource-constrained systems, such as microcontrollers and other embedded devices [35]. It is designed to accommodate a wide range of devices with a variety of capabilities meaning that programs developed for one device can be easily modified to fit the requirements of another. In situations involving sensitive data, such as household energy consumption, ensuring data security is crucial. Zephyr RTOS has been awarded the *Open-Source Security Foundation (OpenSSF) Gold Badge*, providing developers with confidence that their product developments will maintain a high level of security.

Zephyr's comprehensive documentation, code examples and active community forums facilitate access to information on specialised functionality. Additionally, Zephyr also includes support for various communication protocols, such as Bluetooth, Wi-Fi, LoRa and others, enabling the development of IoT applications.

3.2.2 ESP-WROOM-32

The ESP32 is a series of low-cost and low-power system on chip (SOC) microcontrollers with integrated Wi-Fi and Dual-Mode Bluetooth. Dual-Mode Bluetooth devices are those that support both Bluetooth Classic and BLE [36]. In addition to these features, Zephyr RTOS also supports XTENSA [37] boards which the ESP32 is based on, which makes it a good microcontroller for prototyping wireless IoT projects.

3.3 Android Studio & Wear OS – Wearable App Development Tools

In May 2021, Google and Samsung announced a partnership to merge their respective wearable platforms, Android Wear and Tizen, into a unified platform called Wear OS [38]. Tizen offered a lightweight design and efficient performance, resulting in better battery life [39]. Android Wear, being part of a Google's Android app development ecosystem, provided familiarity and improved compatibility between devices.

Tizen faced drawbacks such as insufficient documentation, making it challenging for developers to find necessary information for app development. In contrast, Android Wear had better development support and environment but lacked the efficiencies provided by Tizen. The partnership brought together the strengths of both companies, significantly reducing the app development lifecycle and enhancing app user-friendliness and efficiency.

Kotlin, Java and C++ are all programming languages that can be used to develop applications for Android Studio and Wear OS. These languages have their own strengths and weaknesses, making them suitable for different purposes in app development. Kotlin is a modern, expressive language preferred for Android and Wear OS development, offering interoperability with Java libraries. Java is versatile but more verbose and error prone than Kotlin. C++ is a high-performance language used for computationally intensive tasks and as such, is not encouraged to be used for Wear OS development.

Wearable devices running Wear OS share a lot of similarities with mobile phone app development. They both use the Android SDK and have access to a similar set of APIs. However, Wear OS apps are designed to run on smaller screens and use different UI components optimised for wearables.

Chapter 4

4 Research Design and Methodology

The methodology section of this thesis outlines the research design, development, implementation, and evaluation of a wearable-based system for providing energy consumption feedback. Current studies on energy consumption feedback primarily focus on the use of devices such as smart meters, in-home displays, and smartphone applications. However, these approaches are not as personalised and don't provide real-time feedback to the degree that wearable technology can provide. The prototype will be evaluated through a self-assessment based on existing literature on comparable products and implementations.

The git repository for this project is located at this link:

https://github.com/TheZakinator/energy_feedback_thesis

4.1 PROJECT DESIGN

The system consists of a *Samsung Galaxy Watch5,* one ESP32 which is the proxy 'bridge' between the Bluetooth Mesh network and the watch, and three ESP32s that are representative of electrical appliances (power nodes).

The ESP32's are within the Mesh Network while the watch communicates and connects directly with the Proxy Node.

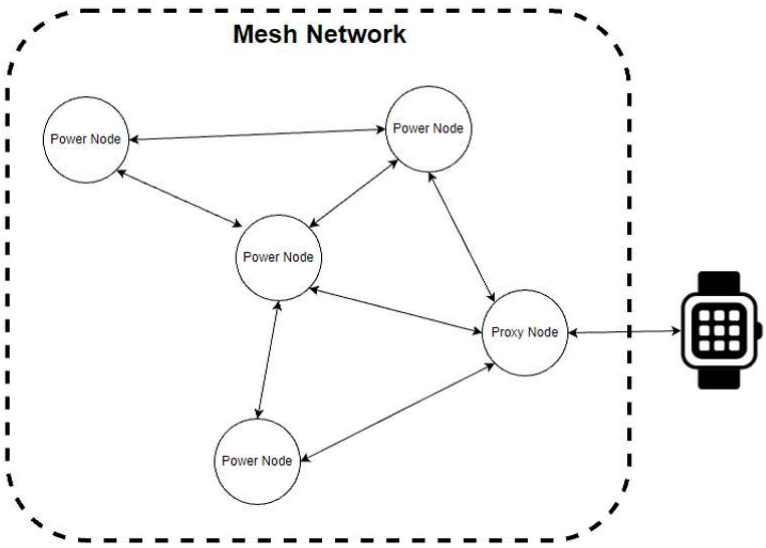


Figure 2: Top Level System Design

4.1.1 Embedded System Setup

4.1.1.1 Zephyr RTOS ESP32 Compilation, Programming and Code Structure

Zephyr RTOS development environment includes a build system, programming tools and comprehensive library of pre-built software components, such as, device drivers and communication protocols. The device drivers allow easy integration of the ESP32 XTENSA chip architecture and communication protocols allow for relatively simple development of systems involving networks, such as BLE Mesh. Additionally, configuration files (.conf) allow for the configuration of various components and features within a system. These files enable developers to easily enable or disable specific features, adjust settings and configure the build environment.

The code structure shown below shows the *main.c* files that initialise and configure the devices and then the BLE Mesh is described in the *ble_driver* folder. Power Nodes have multiple configuration files so that they can be programmed with the same code but with a different *BT_DEVICE_NAME*.

For example, when compiling Power Nodes, different build options should be used to ensure the compiler selects the appropriate configuration file. The build options modify the CMakeList file.

```
zakjab@ubuntu:~/energy_feedback_thesis/embedded_devices$ west build -p auto -b esp32 -- -DPWR_NODE_AIRCON=1
```

```
zakjab@ubuntu:~/energy_feedback_thesis/embedded_devices$ west build -p auto -b esp32 -- -DPWR_NODE_TV=1
```

```
zakjab@ubuntu:~/energy_feedback_thesis/embedded_devices$ west build -p auto -b esp32 -- -DPWR_NODE_WATER_HEATER=1
```

Figure 3: Power Node compile options

The Proxy Node employs the same build technique but without the build option.

```
oslib/ble_driver
├ ble_power.c
├ ble_power.h
├ ble_proxy.c
└ ble_proxy.h
power_node
├ CMakeLists.txt
├ src
│ └ main.c
├ inc
│ └ main.h
└ conf_files
  ├ prj.conf
  ├ pwr_node_aircon.conf
  ├ pwr_node_tv.conf
  └ pwr_node_water_heater.cc
proxy_node
├ CMakeLists.txt
├ src
│ └ main.c
└ prj.conf
```

Figure 4: Embedded system code structure

4.1.1.1.1 BLE Mesh Node Provisioning

Provisioning is the process of adding a new device to a BLE Mesh network. During provisioning, the device receives the necessary information and keys to become a functional part of the network. The provisioning process involves several steps:

Beaconing: The un-provisioned device broadcasts itself and that it is ready to be added to a Mesh network

Invitation: A provisioner (typically a smartphone), sends an invitation to the un-provisioned device, initiating the provisioning process.

Key Exchange: both devices exchange public keys to establish a secure communication. This is the time where both devices are susceptible to man-in-the-middle (MITM) attacks where a malicious device replaces the exchanged public keys with its own, however, most attacks can be prevented through proper system design and authentication methods [40] [41].

Authentication: This provisioner and un-provisioned device perform authentication to ensure they are communicating with the intended device. For this specific system, the Power Nodes and Proxy Nodes print out a static out-of-band (OOB) 4-digit value to a terminal screen, which is a randomly generated number that can be entered into the Provisioner.

Distribution of Provisioning Data: The Provisioner sends the necessary network information and keys to the newly provisioned node. Now when the provisioned node attempts to communicate with the Mesh network, it will use the Mesh network’s App Key.

With the device successfully provisioned, the Provisioned device gains the ability to access and adjust the configuration settings of the newly provisioned device. This includes defining the addresses to which the internal models of the device will publish and subscribe to, as well as associating the Mesh network’s application keys with these models.

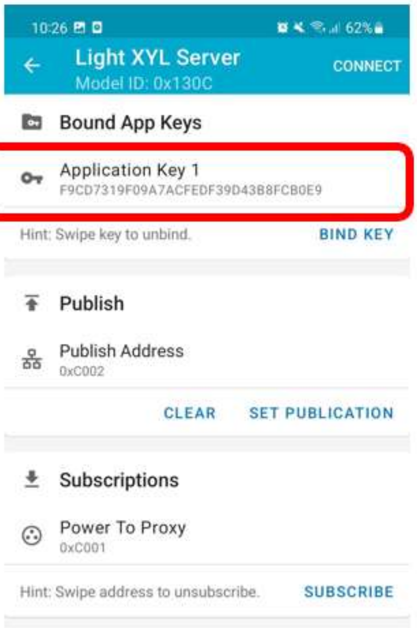


Figure 5: nRF Mesh Mobile Application. Within the model configuration screen, showing the application key that has been bound to the specific device.

4.1.1.2 Power Node Setup

The Power Nodes all have identical code but with different Bluetooth names, these are defined during compile time for this project, however, they are modifiable and so users can change the names to something meaningful to themselves in the future. For this project setup, the Power Nodes are all connected to 3 LEDs of different colours to represent the different modes:

All OFF: Power Node is disabled and is not transmitting any data.

Red ON: device is enabled and transmitting data, but appliance is OFF.

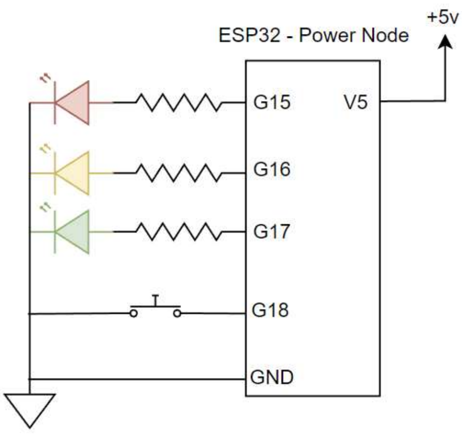
Yellow ON: device is enabled and transmitting data, medium power consumption.

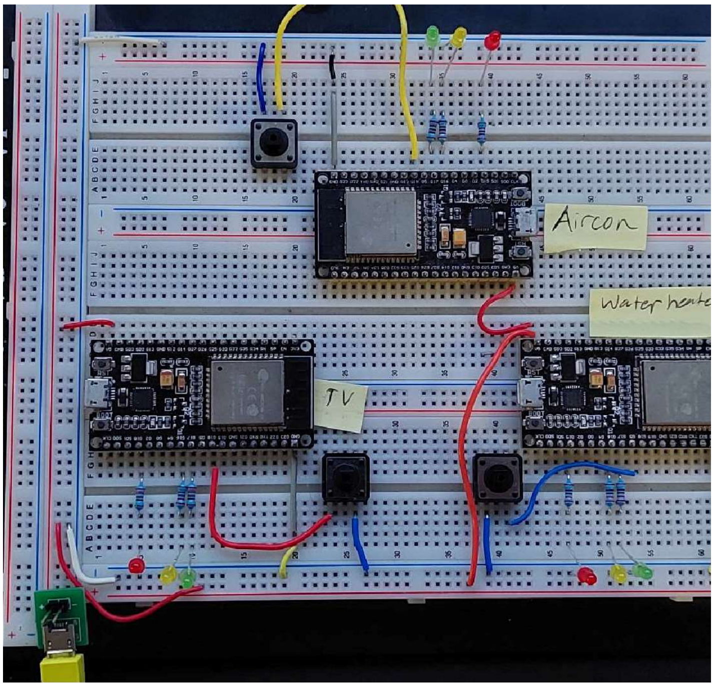
Green ON: device is enabled and transmitting data, high power consumption.

Additionally, there is an active-low push button that, when pressed, cycles through the LED colours, allowing transition between different modes. The buttons integrate debouncing techniques to eliminate false triggers and ensure accurate detection of each press and release caused by the mechanical nature of the button.

The system is arranged on a breadboard and, aside from a single USB power supply, has no connections between each device. One limitation of this setup is the inability to read and analyse actual appliance data. To do so would require using a current transformer wrapped around the live wire of the circuit, which is prohibited in Australia unless performed by a licensed electrician. An alternative option is to simulate real-world appliances using lab equipment. However, due to personal circumstances that required me to relocate, I no longer have access to university lab resources.

The Power Nodes are relatively simple as they only intermittently publish data throughout the network.





4.1.1.3 Proxy Node Setup

Setting up the proxy node is a slightly more complex process, as it necessitates not only the configuration of BLE mesh but also the establishment of its GATT server, which contains characteristics, services and descriptors.

This complexity is shown in the following code snippet, where the service is defined using a 128-bit UUID value. The characteristic grants connected GATT clients (e.g., smart watch) read permissions and allows for both reading and receiving notifications. The descriptor has read/write permissions, enabling the client to toggle notifications on or off. In practical terms, this means that if a user wishes to disable the smartwatch app, they can change a setting to stop receiving data, which will conserve battery life.

```
BT_GATT_SERVICE_DEFINE(proxy_svc,

                    BT_GATT_PRIMARY_SERVICE(&proxy_uuid),

                    BT_GATT_CHARACTERISTIC(&watch_uuid.uuid,
                                        BT_GATT_CHRC_READ | BT_GATT_CHRC_NOTIFY,
                                        BT_GATT_PERM_READ,
                                        read_chrc, NULL, &powerNodeData[0]),

                    BT_GATT_DESCRIPTOR(BT_UUID_GATT_CCC, BT_GATT_PERM_READ | BT_GATT_PERM_WRITE,
                                        NULL, write_proxy_ccc, &proxy_desc_val)
                    );
```

Figure 6: Bluetooth GATT service server top-level definition. write_proxy_ccc is call-back to enable notifications. read_chrc is call-back to the client reading a characteristic. oslib/ble_driver/ble_proxy.c

4.1.2 Watch Design and User Interface

The user interface is designed with a focus on functionality, and limited research has been conducted to determine the most suitable design for a watch. Nonetheless, the interface aims to be user-friendly and provide valuable information. A progress bar to display power data might not be the most effective approach, as prioritising notifications for the user could prove to be more advantageous. This is because many users neither comprehend nor require detailed power information about their devices. Instead, they need specific information that directly relates to their appliance usage and everyday tasks.

The app utilises a *ScalingLazyColumn*, exclusive to WearOS, which houses all the application cards. As the user scrolls, it smoothly adjusts the size of the cards in and out of view, efficiently utilising the screen real-estate. The figure below demonstrates this concept, as Node 2 comes into focus while the Bluetooth-enabled button transitions out of view.

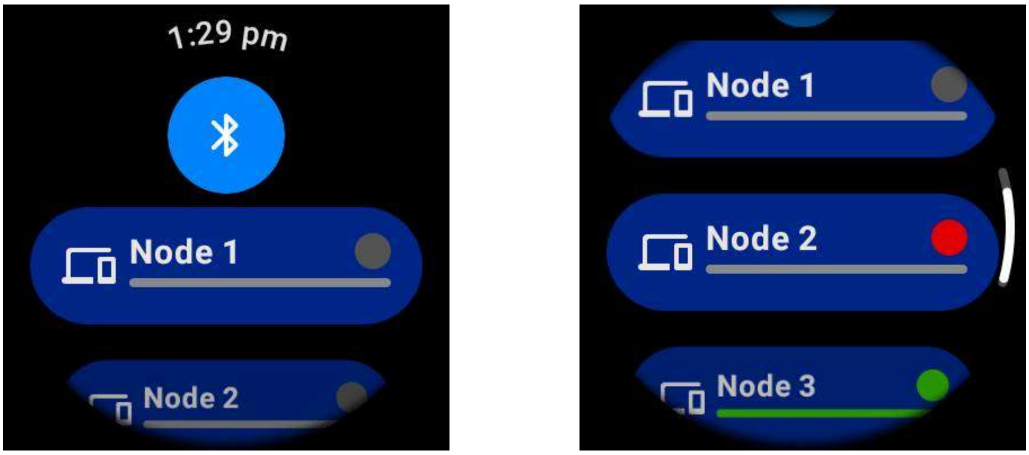


Figure 7: Smart watch landing page

The Bluetooth button indicates the Bluetooth status, where it's active or inactive. Upon clicking the button, users will be prompted to enable Bluetooth if it's disabled. Currently, there are no notifications outside the app to inform users when Bluetooth is disabled, which means they won't receive energy consumption notifications and may not understand the reason. Enhancing in-app documentation to clarify the need for Bluetooth activation could be a valuable improvement.

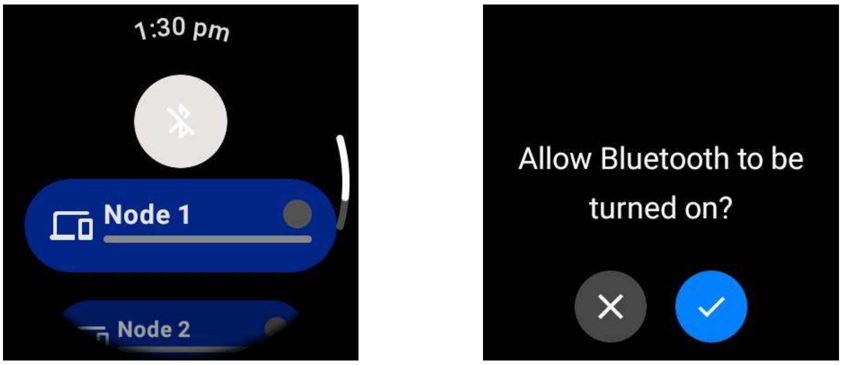


Figure 8: Smart watch Bluetooth disabled and user prompt to enable Bluetooth.

When the watch has not connected to a proxy node or is not receiving any data, all the nodes will show a grey status indicator and a grey progress bar. Wear OS features an external tile-style notification area that shows various app notifications for the user, such as messages, emails, daily steps and more. As the watch scans or tries to connect to a proxy node, the app-specific tile will display a notification that it's scanning for a Bluetooth node. However, there is no in-app indication of the ongoing scan, and adding this status feature could be a beneficial addition.

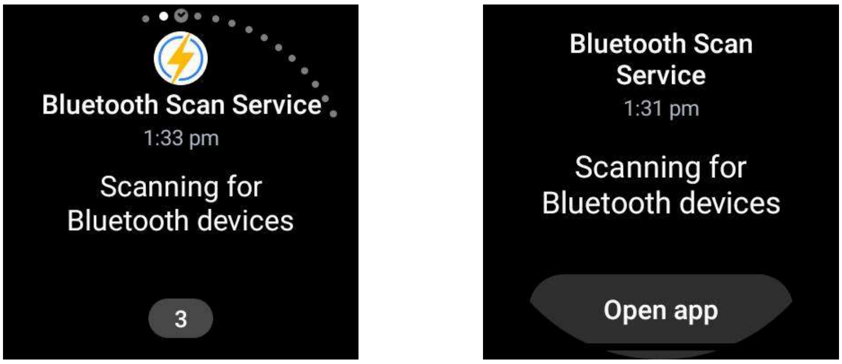


Figure 9: Tile notification showing that watch device is currently searching for a proxy node. To the left of the tick at the top of the watch are the tile notifications and to the right are the application tiles.

When power is above a certain threshold, the watch sends a pop-up notification to the user and vibrates. The data can be accessed on the same notification-tile where scanning information is stored. Users can click on the notification for more details if wanted. The notification tile can accommodate multiple notifications simultaneously.

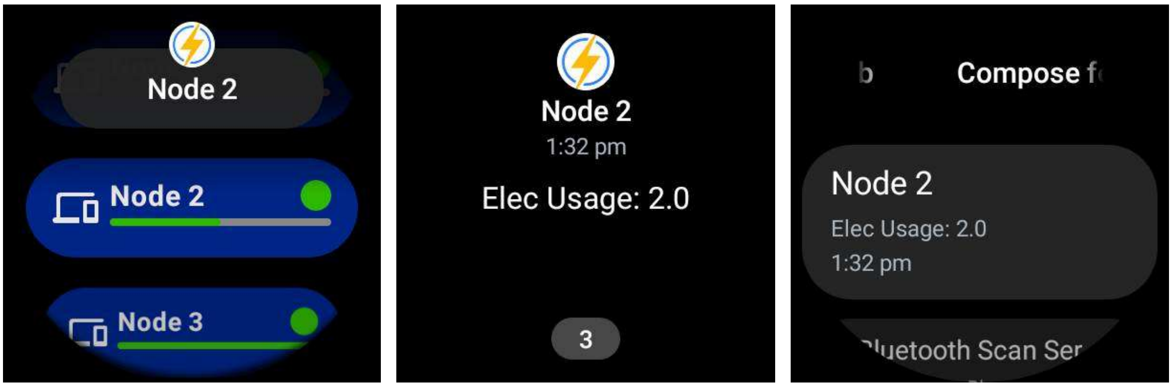


Figure 10: Pop-up notification, notification-tile and notification additional information

4.1.2.1 Smart watch connection procedure

BLE Scanning: The smartwatch captures BLE advertisements from a variety of devices with different UUIDs, using low-power, intermittent scans to conserve watch battery life. When away from home, the watch will continually seek out it’s BLE Mesh Proxy device, but due to the intermittent nature of this scanning, it should not greatly affect the overall battery life.

Device Filtering: BLE Mesh Proxy Service has a fixed 128-bit UUID which is ‘00001828-0000-1000-8000-00805F9B34FB’. This UUID is used to identify Mesh Proxy nodes and establish connections between them.

Attempt Connection: Once a BLE device with the Mesh Proxy Service UUID is scanned successfully, the watch will attempt to connect to it.

GATT Discovery: After establishing a connection, the watch requests service and characteristic details from the Mesh proxy, which replies with information on its services, characteristics, read/write permissions and other relevant data.

Enable Notifications: After completing GATT discovery, the watch verifies that the target device's services and characteristics match its requirements for communication. It then enables notifications for the relevant characteristic, allowing the watch to receive updates when the related data changes on the BLE device.

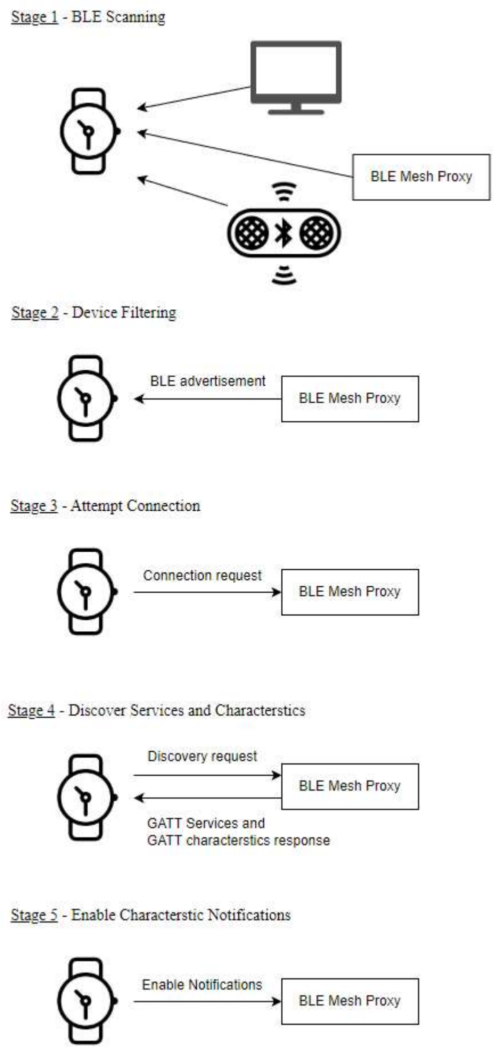


Figure 11: BLE GATT connection stages

4.1.2.2 *Smart Watch Application Structure*

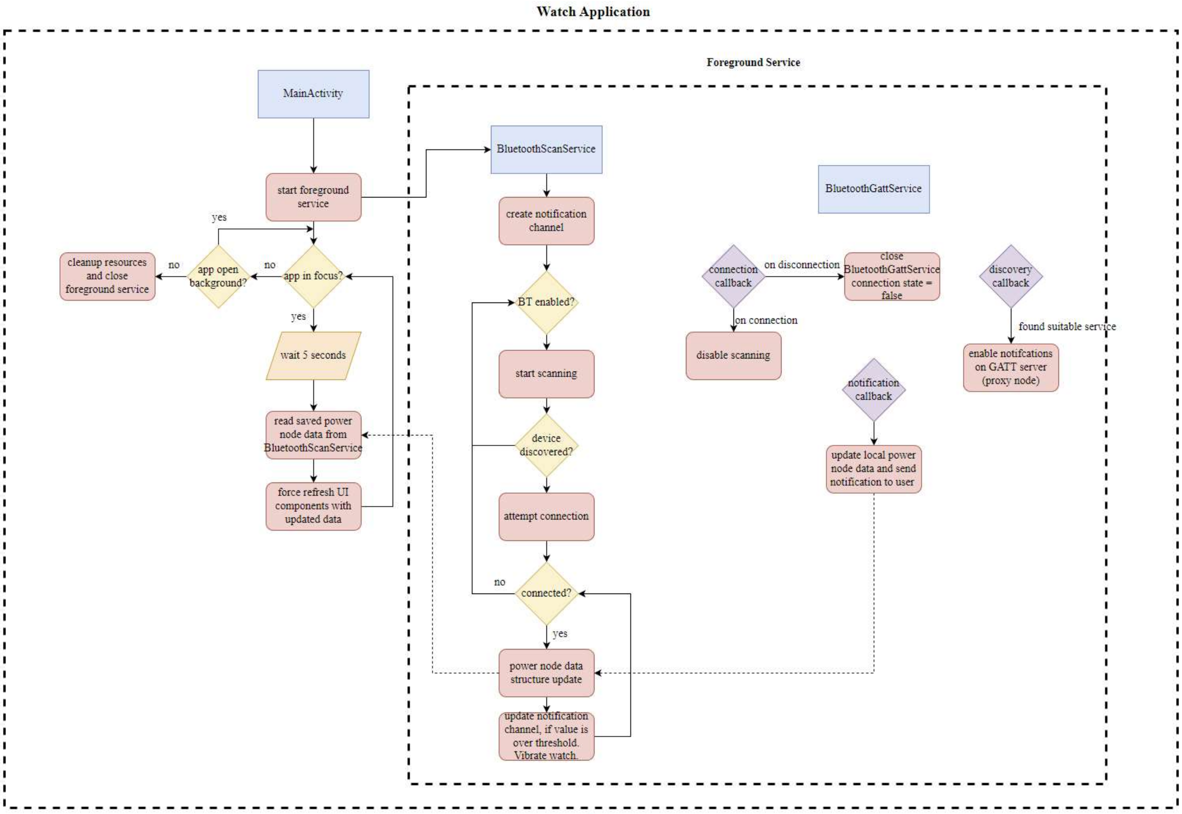


Figure 12: Smart watch top-level design. Blue objects, classes; Red objects, actions; yellow, conditions; orange, wait in real-time; purple, call-backs.

The diagram below shows the design of the watch application. Upon opening the app, *MainActivity* is initiated, and Wear Application UI appears. During this process, a foreground service is launched. This type of service remains active in the back of the watch, even if the app is minimised or the watch screen is turned off. The foreground service contains classes that control BLE scanning and GATT communication. It is difficult to illustrate ongoing checks in a sequential block diagram, however, the yellow conditional blocks are continually evaluating the state of Bluetooth, correct device discovery and device connection. These checks are implemented to prevent the watch from entering an uncertain state and to efficiently manage and release resources.

The watch app modifies its interface in response to user interactions and external elements, like a foreground service. This service actively refreshes the display to indicate changes in energy usage on each node's *progress bar*. These updates are intermittent as continuously updating the UI can significantly decrease performance and reduce battery life. The interface is forcefully refreshed every 5 seconds based on the incoming data, and this duration was chosen solely on the assumption that it shouldn't cause any problems. Further investigation into the ideal update interval should be performed.

4.1.3 Messaging Protocol (Data Structure)

The power nodes intermittently transmit their data throughout the Mesh network through a group publish/subscribe approach.

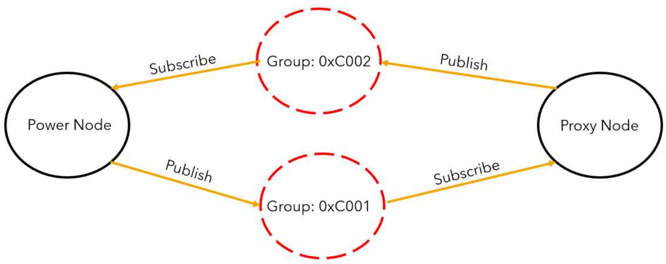


Figure 13: Group pub/sub addresses for power and proxy nodes

Power nodes publish data to group address 0xC001 and subscribe from 0xC002. Bluetooth Mesh employs BLE packets, broadcasting data to nearby devices, but only the intended recipients process it. Unreceived packets are re-advertised, but unique IDs prevent infinite relaying. The efficiency comes from the network protocol layer analysis which means that data does not need to reach the application layer before the device realises the packet was not intended for itself. This is illustrated in figure 14.

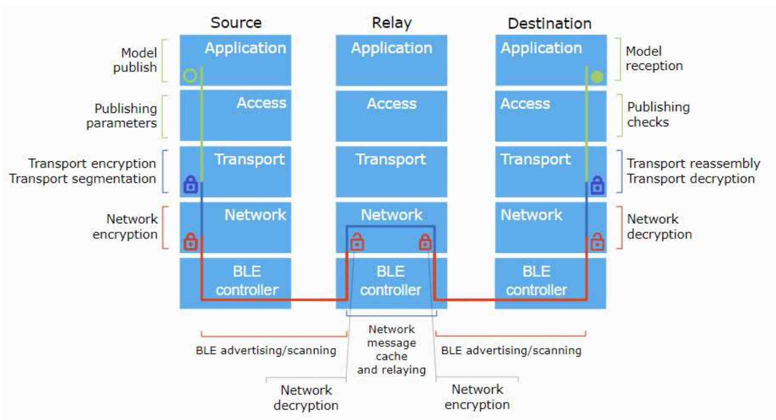


Figure 14: Data flow within a Bluetooth Mesh network [42]

The power node data structure holds a variety of data which may be relevant to the end user, the proxy node then relays this data from each node to the watch:

Node Number: *uint8_t*
Power node ID

Appliance On/Off: *uint8_t*
When an appliance generates power, the power node notifies the proxy node, which then relays the "ON" status to the user's watch. If the power node doesn't send any data, the proxy node communicates a "disconnected" status to the watch, providing an additional layer of information.

Hysteresis Level: *uint8_t*
This parameter is determined by the magnitude of change in power usage. When the power node detects a change above or below a predefined threshold, it communicates this information to the proxy node. The proxy node then processes the data and sends a signal to the user’s watch. As a result, the watch vibrates and displays a notification, providing the user with detailed information about the fluctuations in their power consumption.

Power Value: *uint32_t*
This is the value of power consumption. This prototype does not utilise real world data and instead uses dummy values, so this would need to be calibrated in future.

Chapter 5

5 RESULTS & DISCOVERY

The following section presents the key findings of the research and the insights acquired during the development of the smartwatch app and embedded system.

5.1 GOOGLE AND SAMSUNG COLLABORATION

The researched uncovered that the recent collaboration between Google and Samsung to develop Wear OS, a unified platform with extensive resources and support, has enhanced the feasibility of using smart watches for energy feedback. This collaboration has substantially reduced the development time and costs, allowing developers to share resources to create market ready energy feedback solutions quicker and more efficiently.

5.2 NEED FOR A COMPANION APP

During development of the smart watch app, it was clear that a companion app linking the smart watch to a mobile phone would significantly boost customizability. The smartwatch app needs to cater to a diverse range of household requirements and cannot be a one-size-fits-all solution. This highlights the importance of understanding user behaviour and preferences when designing smart watch and mobile applications, and how such an understanding can lead to the creation of more effective and user-friendly energy feedback systems.

5.3 POTENTIAL OF BLUETOOTH MESH FOR IOT APPLICATIONS

This project was designed with Bluetooth Mesh as the main network topology for communication between the devices and smart watch application. It has the potential to be a superior network topology for IoT applications as compared to traditional Wi-Fi. Its primary advantages are reduced power consumption and decreased load on the home's router, however, the major drawback is its complexity. Building, maintaining and integrating a Bluetooth Mesh network topology into existing households presents significant challenges.

5.4 Improvements in Non-Intrusive Load Monitoring

The advancements in non-intrusive load (NILM) monitoring suggests a shift in how power consumption data is gathered and analysed. These systems don't require individual appliance level power consumption monitoring and instead only require a singular installation to the homes' switchboard, reducing complexity significantly. NILM tracks devices that are not trackable via power points, unlike standard smart plugs (such as air conditioners and water heaters). However, unlike NILM, smart plugs provide direct control over devices, allowing manual or timed operation.

Chapter 6

6 DISCUSSION

The results from the research indicate that recent developments in technology, such as, improved developmental tools, improved smart watch capabilities and advanced network topologies, may significantly enhance the use of smartwatches for home energy feedback.

During the initial stages of prototyping, a Samsung Gear S3 Classic was utilised, developed using Tizen Studio. However, as mentioned in section 3.3 of this report, Tizen had many drawbacks when it came to creating smartwatch applications. The frontend application, written in CSS/HTML/JS, needed to be integrated with a backend solution coded in C/C++, in order to effectively function with the watch's hardware. This process involved setting up specific message ports with unique IDs for every message type to facilitate communication between the two applications, significantly increasing the complexity of the project.

The initial prototype was mostly operational, except for establishing the Bluetooth connection between the watch and the proxy node device. The lack of documentation and online resources for this specific application made debugging extremely difficult. Consequently, it was decided to transition to the newly released Samsung Galaxy Watch 5.

To put the development time into perspective, it took about three weeks of full-time development work to bring the initial watch to a somewhat operation state with minimal features. In contrast, it took approximately 1.5 weeks to configure the Wear OS device, which has an enhanced UI, notifications and a fully functional Bluetooth communication link with the proxy node. This period also included learning Kotlin, an unfamiliar coding language.

No user studies have been conducted on the usage of smart watches for real-time energy feedback, hence there is a lack of metrics and comparisons between the project's prototype and current market products. The UI is not the central focus of this project, however, throughout the development process, it was determined that a mobile phone companion application would be crucial to enhance the smart watch's customizability. This app would enable users to configure the watch app to display desired information like power consumption details of specific devices, device names and icons and to schedule notifications for consumption events or device issues. Given the watch face's limited size, this mobile app would be essential to ensure an easy setup.

This limitation of customizability and the research suggesting users discontinue the use of energy monitoring devices after the initial excitement, makes the smart watch better suited as a notification medium rather than a device for viewing energy consumption details. This is also confirmed as most users' do not understand what the details of their energy consumption means, they require tangible and relatable information.

Imagine a scenario where a user purchases a NILM device capable of identifying different devices used within their home, and this system comes with corresponding smart watch and mobile phone apps. The user could then initially set up personalised notifications that are relevant to their individual needs. Developing such as application that is both helpful and easy to use is the most important aspect of such a system.

Bluetooth Mesh is not widely used as the main network topology for smart home IoT devices as it is a relatively new technology. Its adoption has been slow despite its considerable advantages, including scalability and reliability [43].

Compared to Wi-Fi, Bluetooth Mesh offers low latency and can support a far greater number of nodes, which enhances it's utility in the context of IoT networks [44]. However, it does present limitations in terms of throughput, which makes it unsuitable for high data rate applications such as web applications or video streaming. Despite IoT devices requiring small amounts of data, connecting many devices to a home's modem can potentially strain the system due to the overhead associated with each Wi-Fi connection and packet transmission.

In Australia, most households have internet access at home. While some households may rely on cellular data, it's safe to assume that the majority of homes have a Wi-Fi router available for use as an IoT home hub, as indicated by data from Australian Bureau of Statistics [45].

Given the existing infrastructure, introducing Bluetooth Mesh as an additional technology would incur additional, potentially unnecessary, costs to users unless there is a clear significant advantage to using this new technology. There would need to be a mechanism to either integrate existing IoT devices with Bluetooth Mesh capabilities or to enable Wi-Fi routers to act as proxy nodes in the Bluetooth Mesh network, thereby reducing their workload. Another possibility is modifying in-home displays to act as proxy nodes.

In addition to the previously discussed features, Bluetooth Mesh possesses the ability to localise devices within its network when there's a sufficient and suitably positioned network of nodes. For instance, if every power socket and lightbulb has a Bluetooth Low Energy (BLE) control unit, it allows precise 3D positioning within the home. This works by utilising BLE advertisement packets and the strength of the signal received (RSSI) to approximate the smart watch's location relative to each node [46]. Such a setup could provide greater methods of control in a smart home, opening the possibilities for automated responses, such as lights turning on/off based on the user's location, or timers turning on lights once a room is vacated. Additionally, integrating Bluetooth Mesh sensors like indoor air quality meters can enable occupancy-based action [47]. The adaptability of Bluetooth Mesh for smart home usage extends beyond traditional Wi-Fi, and though it may not be fully market-ready, its usage could future-proof upcoming enhancements in smart homes.

Bluetooth Mesh works best on a large scale and with low data rate devices, which aligns with the requirements of IoT devices. However, converting existing IoT devices to either use Bluetooth Mesh or to be able to use both Bluetooth Mesh and Wi-Fi poses an economic feasibility challenge and requires further research. Nonetheless, Bluetooth Mesh presents a promising network topology for IoT devices in a smart home.

NILM will most likely become a standard in home energy monitoring due to its ability to track appliance-level energy use without needing to attach an energy monitor to each individual appliance. However, a key drawback is its inability to provide the control that smart plugs or smart lights offer.

If homes adopt NILM, the need for other energy monitoring technologies may reduce significantly. This is because NILM would handle the energy monitoring tasks, potentially rendering other similar technologies unnecessary. However, the control systems present in smart devices are a crucial feature and would remain relevant. Transitioning towards smart devices that are focused more on providing user control than monitoring energy could also lead to a potential reduction in costs. The smart devices would focus on providing control to the user, while all tasks relate to energy monitoring would be the responsibility of the NILM system.

Such a smart home setup could leverage Bluetooth Mesh for its low latency, low data rate, and better coverage as compared to Wi-Fi, and without the need for range extenders as is the case for some larger homes where Wi-Fi does not reach the entire property. This would centralise energy monitoring, while control is achieved through a mesh network where each device has an inexpensive Bluetooth Mesh control system.

In instances where device control is non-essential, a standalone NILM system solely providing energy consumption data might be sufficient. In these cases, given its ability to handle large data packets, a Wi-Fi network topology may be more suitable than a Bluetooth Mesh network.

Chapter 7

7 EVALUATION

This section will conduct a critical assessment to determine the strengths, weaknesses and validity of the utilisation smart watches in real-time energy feedback, examining the reliability of the research methodologies applied and the alignment of the findings with existing knowledge. The significance of these findings will also be considered, reflecting on whether any future research should be conducted or whether there is a practical use for smart watches, addressing the research objective "*assess the feasibility of the use of smart watches in household energy feedback*". This evaluation aims to link the discussion results with the developed prototype to aid in gaining a solid understanding of the project's implications and potential future directions.

The primary strength of this project design is in its novelty, as it introduces a unique approach that hasn't been previously attempted. The project uses smart watches in a new, more personalised way to present energy consumption information to users. While smart phones do have the capacity to deliver notifications and haptic feedback, smart watches offer a higher degree of personalisation by being continuously connected to the individual.

Within a household, the project design allows multiple users to utilise any number of smart watches to interact with their smart home system. Though initially costly, as the adoption of smart watches increases, and their prices continue to decrease, this operation will become increasingly feasible.

The introduction of smart watches as an alternative method of energy consumption feedback has the potential to reach a broader user base. When combined with traditional in-home displays and smart phone applications, it offers a more diverse selection of energy feedback options. This could potentially appeal to users who are uninterested in existing energy feedback options, thereby promoting improved energy literacy.

The choice between using Bluetooth Mesh versus Wi-Fi for smart homes, as discussed in this report, should not impact the effectiveness of the smart watch as an energy reporting device.

Nevertheless, this decision alters the overall design of the home energy monitoring system and must be considered when developing smart phone and smart watch applications, keeping in mind the user’s specific requirements and preferences.

7.1 Research Significance and Future Work

The research introduces a novel perspective on real-time energy feedback through smartwatches. The significance is not just in the immediate findings, but also the broader implications and potential to shape future studies, technological developments, and policy decisions.

1. **Pilot for Future Studies:** This research serves as a pilot study, providing a novel approach to real-time energy feedback through smart watches. It is the groundwork for future projects in this field, potentially influencing more comprehensive investigations.
2. **Environmental Implications:** By enhancing energy literacy and conversation, the research may encourage reduced consumption, contributing to global sustainability efforts.
3. **Influence of Future Product Development:** The findings from this research determined the feasibility for the use of smart watches in real-time energy feedback and, as such, could lead to technology companies to incorporate similar features in future devices.
4. **Scalability:** If smart watch energy feedback is successful at a household level using Bluetooth Mesh, the approach could also be expanded to larger applications, such as, commercial buildings or industrial facilities.
5. **Emphasis on Future User Experience Research:** With no existing studies or products using smartwatches for real-time energy feedback, this project highlights the need for future investigation into user experience when developing smartwatches or other smart device applications.

Future Work

- Perform user research investigations to assess the efficacy of a specific smartwatch app design and its interaction with users.

- Investigate the practicality of utilising other networking protocols such as Bluetooth Mesh for large scale product development.
- Explore the most suitable energy monitoring devices or systems for integration with a smartwatch while also considering UI/UX and network topology.

Chapter 8

8 CONCLUSION

Studies indicate that existing energy feedback tools, including In-Home Displays and mobile energy monitoring apps, do not effectively reduce long-term energy consumption. These devices often struggle to maintain user engagement, and the energy savings they produce are not statistically significant. Little to no research has been conducted on the use of smart watches in the use of real-time energy consumption visualisation. Given the constant connection between the user and the smartwatch, it offers a more personalised experience. This study set out to assess the feasibility of using smartwatches for household energy feedback and to develop a working prototype, identifying any potential technological barries to entry.

The findings of this research were that the collaboration between Google and Samsung to create Wear OS, a unified platform with extensive resources and support, has enhanced the feasibility of using smartwatches for energy feedback by reducing development time and costs. Creating a companion app between a watch and smart phone could allow for enhanced customizability. This is necessary because a watch app needs to cater to the unique requirements of households and cannot be a one-size-fits-all solution. Bluetooth Mesh, which was introduced in 2017, may be a better network topology than traditional Wi-Fi for IoT applications as it has reduced power consumption, reduces the load on the home's router and has potential for scalability. Lastly, improvements in non-intrusive load monitoring could soon make individual appliance power consumption monitoring obsolete.

Smart watches have the potential to become an integral component in home energy monitoring systems, even if only used as a medium for alerts/notifications, rather than directly displaying energy consumption. Although there has been an increased adoption of smart plugs and home hubs, the means of reporting energy consumption to the user has remained relatively stagnant. Introducing smart watches as a tool for energy reporting could be an innovative and effective solution.

This study reveals key areas for further research in using smart watches for energy feedback. These key areas include:

- Performing user research investigations to assess the efficacy of a specific smartwatch app design and its interaction with users;
- Investigating the practicality of utilising other networking protocols such as Bluetooth Mesh for large scale product development and;
- Exploring the most suitable energy monitoring devices or systems for integration with a smartwatch.

In conclusion, this study reveals the significant potential of smart watches as a tool for household energy feedback. While traditional energy feedback applications have shown limited success in the long-term, the novel use of smartwatches, thanks to their personalised and constant connection to the user, introduces a fresh perspective. The findings confirm the feasibility of such an approach. This innovative approach could transform energy monitoring systems, making smart watches an integral component for alerts and notifications directly to the user. This study also points to areas for future exploration, such as user experience research, further household networking protocol research, and the integration of different features into existing energy monitoring systems. Through further investigation, the full potential of smart watches could aid in fostering energy awareness, conservation and contributing to a more sustainable future.

9 BIBLIOGRAPHY

[1] C. &. D. J. M. Seligman, “Feedback as a means of decreasing residential energy consumption,” *APA PsycNet,* 1977.

[2] K. Buchanan, “The question of energy reduction: The problem(s) with feedback,” *ScienceDirect,* vol. 77, pp. 89-96, February 2015.

[3] S. Darby, “Making it Obvious: designing feedback into energy consumption,” in *Energy Efficiency in Household Appliances and Lighting*, Springer, Berlin, Heidelberg, 2001.

[4] ABS, “Energy Account, Australia,” 24 November 2021. [Online]. Available: https://www.abs.gov.au/statistics/industry/energy/energy-account-australia/latest-release#:~:text=In%202019%2D20%20energy%20use,%25%20to%201%2C515%20GJ%2F%20%24mGVA. [Accessed June 2022].

[5] U.S. energy information administration, “Total energy -> energy consumption by sector -> energy consumption estimates by sector,” [Online]. Available: https://www.eia.gov/totalenergy/data/annual/. [Accessed June 2022].

[6] Department for Business, Energy and Industrial Strategy, “Energy Consumption in the UK (ECUK) 2021,” 30 September 2021. [Online]. Available: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2021. [Accessed July 2022].

[7] A. Zoha, A. Gluhak, M. A. Imran and S. Rajasegarar, “Non-Intrusive Load Monitoring Approaches for Disaggregated Energy Sensing: A Survey,” *MDPI,* vol. 12, no. 12, 6 December 2012.

[8] R. Gopinath, M. Kumar, C. Prakash Chandra Joshua and K. Srinivas, “Energy management using non-intrusive load monitoring techniques – State-of-the-art and future research directions,” *Sustainable cities and society,* vol. 62, November 2020.

[9] E. Ebeid, R. Heick and R. Hylsberg Jacobsen, “Deducing Energy Consumer Behavior from Smart,” *future internet - MDPI,* vol. 9, no. 29, July 2017.

[10] K. Carrie Armel, A. Gupta, G. Shrimali and A. Albert, “Is disaggregation the holy grail of energy efficiency? The case of electricity,” *Energy Policy,* vol. 52, pp. 213-234, 2013.

[11] “Types of meters,” Ausgrid, [Online]. Available: https://www.ausgrid.com.au/Your-energy-use/Meters/Type-of-meters. [Accessed June 2022].

[12] SkyVision Solutions, “A summary of "useful life" values for smart electric usage meters,” September 2018. [Online]. Available: https://skyvisionsolutions.files.wordpress.com/2018/09/summary-of-smart-meter-useful-life-values.pdf. [Accessed July 2022].

[13] powerpal, “Claim your free powerpal,” [Online]. Available: https://www.powerpal.net/claim-free-powerpal/. [Accessed July 2022].

[14] powerpal, “complete user guide pdf v1.3,” [Online]. Available: https://support.powerpal.net/hc/en-us/articles/4411831078809-Complete-User-Guide-pdf-V1-3. [Accessed July 2022].

[15] Great Britain publishing service, “Appendix 5.1: smart meter roll-out in Great Britain,” [Online]. Available: https://assets.publishing.service.gov.uk/media/56ebdf4ded915d117a000004/Appendix_5.1_-_Smart_meter_roll-out_in_Great_Britain.pdf. [Accessed July 2022].

[16] J. Schleich, M. Klobasa, S. Golz and M. Brunner, “Effects of feedback on residential electricity demand—Findings from a field trial in Austria,” *Energy Policy,* vol. 61, pp. 1097-1106, October 2023.

[17] C. Oltra, A. Boso, J. Espluga and A. Prades, “A qualitative study of users' engagement with real-time feedback from in-house energy consumption displays,” *Energy Policy,* vol. 61, pp. 788-792, October 2013.

[18] A. Nilsson, M. Wester, D. Lazarevic and N. Brandt, “Smart homes, home energy management systems and real-time feedback: Lessons for influencing household energy consumption from a Swedish field study,” *Energy and Buildings,* vol. 179, pp. 15-25, 15 November 2018.

[19] N. Healey, “Will wearables ever accurately measure blood pressure?,” Medical Device Network, 27 July 2021. [Online]. Available: https://www.medicaldevice-network.com/analysis/will-wearables-ever-accurately-measure-blood-pressure/. [Accessed August 2022].

[20] N. Gandhi, “Smartwatch Features to Consider While Buying It,” Cashify TechByte, 9 May 2022. [Online]. Available: https://www.cashify.in/smartwatch-features-to-consider-while-buying-it. [Accessed August 2022].

[21] F. Laricchia, “Smartwatch devices unit sales in the United States from 2016 to 2020,” 10 February 2022. [Online]. Available: https://www.statista.com/statistics/381696/wearables-

unit-sales-forecast-united-states-by-category/#:~:text=In%202019%2C%20an%20estimated%2020.1,these%20devices%20skyrocketed%20in%20popularity. [Accessed June 2022].

[22] E. A. Vogels, “About one-in-five Americans use a smart watch or fitness tracker,” Pew Research Center, 9 January 2020. [Online]. Available: https://www.pewresearch.org/fact-tank/2020/01/09/about-one-in-five-americans-use-a-smart-watch-or-fitness-tracker/. [Accessed August 2022].

[23] “Smart WiFi Plug Outlet Timer Function Compatible 2 Pack BN-LINK,” BN-LINK, [Online]. Available: https://www.bn-link.com/products/bn-link-2-pack-smart-wifi-outlet-hubless-with-energy-monitoring-and-timer-function-compatible-with-alexa-and-google-assistant. [Accessed 21 04 2023].

[24] “HEAVY-DUTY SMART WI-FI PLUG-IN (15A) WITH ENERGY MONITORING,” Topgreener, [Online]. Available: https://topgreener.com/product/heavy-duty-smart-wi-fi-plug-in-15a-with-energy-monitoring/?attribute_pa_color=white. [Accessed 21 04 2023].

[25] “Smart Plug Mini,” [Online]. Available: https://support.eufy.com/s/product/a085g000000Nm5AAAS/smart-plug-mini. [Accessed 21 04 2023].

[26] Sense, “Sense Energy Monitor,” Sense, [Online]. Available: https://sense.com/sense-monitor-int/. [Accessed 23 04 2023].

[27] M. Williams, “Sense energy monitor review: Your patience will be rewarded with great insight into your home's electricity use,” TechHive, 1 07 2021. [Online]. Available: https://www.techhive.com/article/583647/sense-review.html. [Accessed 23 04 2023].

[28] Sense, “Buy Sense,” [Online]. Available: https://sense.com/buy. [Accessed 23 04 2023].

[29] C. Yonkers, “2022 Sense Energy Monitor Review: What to Know Before Buying,” EcoWatch, 13 12 2021. [Online]. Available: https://www.ecowatch.com/sense-home-energy-monitor-review-2650422388.html. [Accessed 23 04 2023].

[30] momentum energy, “What's the average electricity bill in Australia?,” [Online]. Available: https://www.momentumenergy.com.au/blog/average-electricity-bill. [Accessed 23 04 2023].

[31] Bluetooth, “Bluetooth Technology Overview,” [Online]. Available: https://www.bluetooth.com/learn-about-bluetooth/tech-overview/. [Accessed 23 04 2023].

[32] E. Nesbo, “What is BLE and How Does It Work?,” Make Use Of, 27 12 2021. [Online]. Available: https://www.makeuseof.com/what-is-ble-bluetooth-low-energy/#:~:text=This%20is%20in%20contrast%20to,year%20on%20a%20single%20battery.. [Accessed 23 04 2023].

[33] M. Veneri, “Bluetooth mesh can result in a smarter industrial environment,” Embedded Computing Design, [Online]. Available: https://embeddedcomputing.com/application/industrial/industrial-networking-connectivity/blue-mesh-can-result-in-a-smarter-industrial-environment. [Accessed 23 04 2023].

[34] Bluetooth, “Mesh Networking,” [Online]. Available: https://www.bluetooth.com/learn-about-bluetooth/feature-enhancements/mesh/. [Accessed 23 04 2023].

[35] Zephyr Project, “About the Zephyr Project,” [Online]. Available: https://zephyrproject.org/learn-about/. [Accessed 23 04 2023].

[36] A. Nguyen, “What is Dual-Mode Bluetooth 5?,” Symmetry Electronics, 09 10 2018. [Online]. Available: https://www.symmetryelectronics.com/blog/what-is-dual-mode-bluetooth-5-symmetry-blog/. [Accessed 23 04 2023].

[37] Zephyr Project, “Supported Boards,” Zephyr Project, [Online]. Available: https://docs.zephyrproject.org/latest/boards/index.html. [Accessed 23 04 2023].

[38] C. Low, “Google and Samsung joined forces on the new Wear OS,” engadget, 18 05 2021. [Online]. Available: https://www.engadget.com/google-samsung-new-wear-os-rip-tizen-183031381.html. [Accessed 23 04 2023].

[39] Better Software Group, “What is the advantage of Tizen Over Other OS?,” 13 05 2021. [Online]. Available: https://www.bsgroup.eu/blog/what-is-the-advantage-of-tizen-over-other-os/. [Accessed 23 04 2023].

[40] S. Gupta and S. Vojjala, “Designing with Bluetooth Mesh: Privacy and Security,” 25 11 2019. [Online]. Available: https://www.embedded.com/designing-with-bluetooth-mesh-privacy-and-security/. [Accessed 28 04 2023].

[41] A. Lacava, V. Zottola, A. Bonaldo, F. Cuomo and S. Basagni, “Securing Bluetooth Low Energy networking: An overview of security,” *Computer Networks,* vol. 221, 2022.

[42] nRF Connect SDK, “Bluetooth mesh stack architecture,” Nordic Semiconductor, [Online]. Available:

https://developer.nordicsemi.com/nRF_Connect_SDK/doc/latest/nrf/protocols/bt_mesh/architecture.html. [Accessed 25 04 2023].

[43] N. Iynkaran, F. Niroshinie, L. Seng W. and W. Charitha, “Bluetooth Low Energy Mesh: Applications, Considerations and Current State-of-the-Art,” *National Library of Medicine,* 2023.

[44] RF Wireless World, “Difference between Bluetooth mesh and WiFi mesh,” RF Wireless World, [Online]. Available: https://www.rfwireless-world.com/Terminology/Difference-between-Bluetooth-mesh-and-WiFi-mesh.html.

[45] Australian Bureau of Statistics, “Household use of information technology - internet access,” 28 03 2018. [Online]. Available: https://www.abs.gov.au/statistics/industry/technology-and-innovation/household-use-information-technology/latest-release.

[46] Z. Burke and R. Yu, “Device localisation using Zephyr RTOS and BLE Mesh,” 2022. [Online]. Available: https://github.com/Raymond-Y/ares-aqua/wiki.

[47] K. Jeyyun, B. Jongll, C. Anseop, M. Hyuen Jun and S. Minki, “Estimation of Occupancy Using IoT Sensors and a Carbon Dioxide-Based Machine Learning Model with Ventilation System and Differential Pressure Data,” *Sensors,* vol. 23, no. 2, 2023.