Title: Developing a Network Storage Device Using a Single Board Computer

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Developing a Network Storage Device Using a Single Board Computer

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Masters by Research Final Report

The University of Bedfordshire

A thesis submitted to the University of Bedfordshire, in fulfilment of the requirements for the degree of Master of Science by Research (MSc)

Supervisor Dayou Li

AY17/18
Abstract.

The aim of this project was to continue the work of the previous project “Developing a Network Storage Device Using a Single Board Computer” using the lessons learned to develop a new device for a different use case.

This project's aim was to determine the viability of a portable storage solution that could be powered by batteries. The hardware was a key area of this as a balance needed to be found between performance and power consumption. After researching different hardware options, the Raspberry Pi Zero W was selected for this project as it included features that were needed, such as Bluetooth and Wi-Fi, and used the same operating system as the original device and would support the same code.

Bluetooth audio receiver capabilities were later added as a required feature. Due to the hardware selection, an audio output needed to be added. This was done using a Hardware Attached on top, HAT, called the pHAT DAC, which added a 3.5mm audio jack to the Pi Zero W.

The device was tested at varying locations to determine how much interference factored into the user experience of the device. Multiple tests were run on different devices, due to the application used for testing, the tests were only done on Windows devices.

Acknowledgements.

I would like to thank the University of Bedfordshire's Institute for Research in Applicable Computing for their support throughout my research and this dissertation. I would also like to thank my friends and family for supporting me with my work and encouraging me to achieve my goals.
Author’s Declaration.

I, Christopher Maguire declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

• This work was done wholly or mainly while in candidature for a research degree at this University;

• Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;

• Where I have drawn on or cited the published work of others, this is always clearly attributed;

• Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

• I have acknowledged all main sources of help;

• Where the thesis or any part of it is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

• Either none of this work has been published before submission;

Dedication.

I dedicate this work the friends and family that have supported me to be able to achieve my goals and the staff of the University of Bedfordshire that have supported me throughout my research.
Keywords.

Single Board Computer
Samba
Wireless
Raspberry Pi
Bluetooth
NAS
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Chapter 1. Introduction.

This project is a continuation of the work completed in a previous project. The aim of that project was to develop a storage device using a single board computer and to determine how viable such a solution would be. Tests were carried out to determine the transfer speeds of the device.

This project aims to use the information from the previous project to refine and redevelop the device. The device developed during this project will include additional features not found on the original and will change the core use case of the device allowing for portable use.

Chapter 1.1 Aims & Objectives.

The aim of this project is to develop a portable storage solution that does not require mains power. The device may include a battery and charging circuitry to charge the batteries using a common Micro USB power supply.

The device may also be used to stream audio using Bluetooth from another device with audio output over an audio jack. The device could also be able to play local audio directly from its internal storage though, this may require a 3rd party device to function as the player by accessing the file from the device and streaming the audio back.

The new device should retain as much performance as possible from the previous project however as the intent is to make the device portable to do this a lower end lower power consumption device will be used. This means that the overall performance of the device will be lower before any additional features are added.

Based on the performance the development of the device may be changed if some areas of the task cannot be completed or if too much performance is lost. Software modifications or optimisations may also be possible to improve performance and will be done before any assessment is made to determine if all features are viable.
Chapter 1.2 Use Case & Benefits.

The core use case of this device is as an additional storage device for use with a smartphone. The device could be used to offload some data from the phone for example a video library, music or photos.

Doing this would free space from the user’s phone that would otherwise be taken up with media that does not require the speed of internal flash. This means that applications can be installed on the phone rather than Micro SD cards, some applications will not run or will provide a poor user experience if it isn’t running on the internal storage or if the phone has expandable storage which some such as IPhone do not.

This device could also save the user some data cost as rather than streaming music, through services such as Spotify or Google Music, they could listen to their music collection stored locally on the storage device.

Having a location to offload the storage requirements of a device means that the base specification that a user may need is reduced, as they can get a cheaper model with less internal storage. An example of this is the Samsung Galaxy S9+ with the base 128GB model costing £869 and the 256GB top of the range model costing £929, a difference of £60, and the cost is much more on the IPhone XS Max with a base model costing £1099 and the top model costing £1449, a difference of £350.


Chapter 1.3 Deliverables.

Hardware device with storage capabilities could be powered by 18650 batteries or a battery bank that can be recharged using micro USB power supply. The device could also be powered through mains power and Bluetooth audio receiver capabilities.
Chapter 2 Literature Review & Market Research.

This section of the report will evaluate the areas relating to the project and the technologies that will be used. This information will be used to make informed decisions on the potential use cases of the device as well as the types of technologies that could be used to achieve the goals of this project.

Chapter 2.1 Hardware
The most common remote storage devices that are used in both businesses and the home are NAS or Network Attached Storage device. An NAS is a device that acts as a network storage location for users of the network the types of device can range greatly as well as the features of these devices.

The most common feature of an NAS is redundancy though a feature such as RAID or some form of cloud backup. The redundancy, speed, and resilience of these devices will range depending on the quality of the device as well as the intended environment. A business class device will typically offer higher supported capacities more resilience data redundancy and other higher end features not found on consumer grade device.

Chapter 2.1.2 Hardware Features.
RAID or Redundant Array of Independent Disks is a data storage technology designed to connect multiple disks together to achieve a different goal depending on the RAID level. These can be redundancy, performance, or to a degree a compromise of both as it is a balance between redundancy and performance.

The RAID levels are as follows:

RAID 0

RAID 0 often referred to as striping uses 2 or more disks to split data across the drives the result of this is an increase in performance as data can be accessed off the separate drives at the same time giving a theoretical doubling of performance. This will also effectively double the capacity of the smallest drive in the array.
Whilst RAID 0 does offer some benefits it comes with the risk of losing all data if even one of the drives in the array fails, as the data is equally spread across the drives, because of this RAID 0 is not recommended for any important data that is not backed up or that cannot be recreated or re-downloaded.  

(Rouse, 2014)

RAID 1

RAID 1 also known as mirroring uses two or more drives these drives are copies of each other. This means that even if one drives fails the array can be rebuilt from the remaining drive. A RAID 1 array is only as big as the smallest disk in the array. The read performance of a RAID 1 array could theoretically be the total read speed of the disks in the array however, as the data is written to both disks the write speed of the array is equal to the slowest disk in the array.  

(Rouse, 2016)

RAID 5

RAID 5 also known as striping with parity uses 3 or more disks. In this array each drive has part of the information required to recover the data. The array is broken down such that the array can be recovered with if a single drive fails this is known as disk parity, this gives the array a fault tolerance of one drive before total loss of data.  

RAID 5 reads can be very fast as the data can be read from each of the drives in the array. Write speed is also faster than as single disk but will be slower than a RAID 0 array of the same number of disks. Write speeds may also be slowed down as the parity sector will need to be rewritten. This means that even a small change to the data on the array will require a write on each disk, this is called write amplification.  

(Rouse, 2014)
RAID 6

RAID 6 offers 2 parity drives meaning that 2 drives can fail before the array becomes unrecoverable. RAID 6 requires a minimum of 4 drives this can make implementation more expensive due to the number of drives needed for an array. The RAID 6 has some write performance drop due to the parity calculations that are required (Rouse, 2014)

Combined RAID levels are also available where in the case of RAID 10 (one, zero) both mirroring and striping are done simultaneously. This means that the array has the performance benefits of the RAID 0 array and the resilience provided by the RAID 1 array, however if 2 disks in the same group fail the data will be unrecoverable. (Rouse, 2014)

Chapter 2.1.2 Single Board Computers.

Single board computers have a wide range of uses and target markets from a simple computer for the elderly to a development platform for a wide range of projects ranging from weather stations to media centre systems.

The main aim of many of these organisations is to bring computers and development to a wider audience by bring the cost down and creating a set of resources for users to learn about computers and computer programming. Many of these devices come with a programme called Scratch which is designed to teach children Python and is used in schools.

One of the biggest successes in single board computers is the Raspberry Pi Foundations Raspberry Pi line of devices. With their first device the Raspberry Pi releasing in February 2012 with huge success. It was announced by one of the board producers in January 2013 they had “manufactured more than 500,000 Raspberry Pi’s since the launch in February last year”.

(JenCooke, 2013)
The Foundations current line includes both a high performance device, Raspberry Pi 3, and a low power consumption device, Raspberry Pi Zero WH. One of the biggest successes for the Pi Foundation was the release of the Pi Zero which was released in November 2015. This device brought the price down to just £5 for a board much smaller than the original Pi and with similar performance, part of the sales success was due to it being included with the MagPi magazine issue 40.

(eben, 2015)

The Raspberry Pi Foundation website states that -

“The Raspberry Pi Foundation is a UK-based charity that works to put the power of digital making into the hands of people all over the world, so they are capable of understanding and shaping our increasingly digital world, able to solve the problems that matter to them, and equipped for the jobs of the future.

We provide low-cost, high-performance computers that people use to learn, solve problems and have fun. We provide outreach and education to help more people access computing and digital making. We develop free resources to help people learn about computing and how to make things with computers, and train educators who can guide other people to learn.”

(The Raspberry Pi Foundation, n.d.)

Many companies are developing single board computers with varying markets. One example is the BBC Micro:Bit which was developed specifically for use in schools and for children. This is reminiscent of the original BBC Micro-computer of the 1980s which was also built for use as an education tool as part of the BBCs computer literacy project. The Micro:bit Educational Foundation was formed in September 2016 their website describes them as “a non-profit organisation enabling children around the world to get creative with technology and gain digital skills in school, in clubs and at home.” (The Micro:bit Educational Foundation, n.d.)
Single board computers will typically use a system on chip or SOC based on an Arm core design, Arm licence their core design these designs are part of almost all smartphones currently on the market. The specific chip or cores used will depend on the use case of the device, for example a high performance device may have a high core count and clock speed where as another device may focus on power efficiency and have fewer cores and potentially lower clock speeds to reduce the power consumption, the intended use of the device will typically govern the specifications of the device.

Whilst the Raspberry Pi line is one of the most recognisable names in single board computers there are a range of other devices that are designed for more specific markets or for higher performance tasks than the Pi.

An example of this is the Asus Tinker Board which offers may features missing from the Pi line such as 1Gb Ethernet and higher ram capacities with 2GB on board including Bluetooth and Wi-Fi, features missing from the Pi line-up until the release of the Pi 3. The Tinker Board also has a range of software included on its own Debian based operating system called TinkerOS such as Scratch.

Asus claims that the SoC on the Tinker Board offers higher performance then competitors boards with their chip clocking up to 1.8GHz with graphs comparing the Tinker Board beating a competitor SBC, which based on the information provided could be a Raspberry Pi 3, with the Tinker board showing the best results in all tests listed.

(ASUSTeK Computer Inc, n.d.)

The Odroid is a line of single board computers by a South Korean company called Hardkernel Co the company has released several boards since their first in 2009. Odroid boards are primarily designed for the Android operating system however their boards will also support a range of Linux based OSs such as Ubuntu.
Odroid devices tend to focus on more high-end features that are missing from other single board computers, such as 1GB Ethernet USB 3 and higher ram capacities. However due to these high-end specs, and shipping from Korea, the Odroid devices can be very expensive when compared to other single board computers. Due to their relative obscurity OS support for the Odroid devices can be an issue and can make the device more difficult to use.

The Odroid can use a micro SD card for its boot device like many other single board computers however an additional eMMC flash card can be added which offers far higher read and write performance when compared to a UHS-1 class micro SD card. However a separate eMMC to micro SD adapter is required to change the OS on the module adding further cost for this option.

Many of devices in the Odroid line also requires high amperage barrel connector power supply that is not included with the device. This further increases the cost compared to other single board computers which do not include a power supply but, use the ubiquitous and widely available micro USB connector and can be powered by a typical phone charger.

(Hardkernel co, n.d.)

Arduino is an open source hardware platform, the company also produces boards for a wide range of applications as well as letting users design their own custom boards. The Arduino is best described as a microcontroller more than a single board computer Where the Raspberry Pi is a more of a computer for general use that can be used in projects the Arduino was built from the ground up as a device for projects simply running a programme rather than running software as part of a full OS like the Pi. (Arduino, n.d.)

The C.H.I.P. computer is a single board computer released by Next Thing Co aimed at a similar market to the original Raspberry Pi with a lower price with their site claiming the C.H.I.P was “The World’s First $9 Computer”. The C.H.I.P offered a stronger feature set for its price and at the time offered has key features missing from the Raspberry Pi Zero such as Bluetooth and Wi-Fi on board. The C.H.I.P comes with 4GB of on-board storage reducing the parts required to get the device up and running.
The C.H.I.P runs a Debian based OS like many other single board computers of this type.

The C.H.I.P has since been discontinued by Next Thing Co however their site claims that “C.H.I.P. will return soon!” little is known about the hardware specifications of the new C.H.I.P or any new features that may be added. (Next Thing Co, n.d.)

The company has remained silent for some time and have not released any updates for the new CHIP computer they have claimed to be working on. Rumours online suggest that the company may have gone into insolvency. (List, 2018)

The Raspberry Pi Compute module is designed for more industrial applications the board itself does not have any IO. The module is designed to be connected to a custom board which would provide any connections that the specific application would require. The Foundation sells Computer Module IO Board for the module to provide an example board, the board is also open source, which can be used to develop the software end required for the specific application. The computer module also has flash storage built onto the board rather than relying on SD cards like the other Pi devices. (Adams, 2014)

Chapter 2.2 Software/Protocols.

SMB or Server Message Block is an application layer protocol which is for network file sharing and printer sharing. The protocol was developed by Barry Feigenbaum at IBM in the 1980’s. Microsoft included a modified version of SMB with Windows 95. Microsoft SMB is considered the standard version of the protocol and is native to Windows operating systems since the release of Microsoft SMB 1.0 with Windows 2000. The Microsoft SMB protocol is also supported on other OS through the use of third party applications, an example of this is Samba or Linux systems.

(Visuality Systems, n.d.)

NFS or Network File System is a protocol developed by Sun Microsystems to allow remote access to files over a network. Files that are shared with NFS are treated as if
they are stored locally on the device. NFS was designed to be platform agnostic and work independent of the hardware or operating systems used.

(Indiana University, 2017)

File size is an important consideration for lower end wireless data storage as a higher quality device may not have high enough bandwidth to stream it properly. A way to circumvent this issue is compression. Compression is a method of reducing the size of a file.

Another method to reduce the file size of a piece of media is to change the container or encoding of the media. The method of encoding determines how a file is played and the type of compression that is applied. Compression types are Lossy or Lossless for media and other files such as ZIP and RAR files that can be used as a container for a series of other files.

Lossless compression formats are designed to prevent any loss of quality of the file. However this means that Lossless formats will tend to be larger than their Lossy counterparts. Examples of formats that use Lossless compression include FLAC (Free Lossless Audio Codec) for audio and PNG (Portable Network Graphics) for images.

Lossy formats will lose some of the original data during compression. For example a song compressed using a Lossy format, such as MP3, may have higher frequency sounds that are difficult to hear or cannot be heard by humans removed. Different algorithms are used depending on the compression used to determine what sounds or frequencies can be removed. (Harris, n.d.)

Video compression is a core requirement for higher resolution media such as 4k and higher. The existing compression formats have been sufficient for resolutions such as 1080p. However with 4k being 4 times the resolution, in some cases, it can lead to extremely large files.

Newer encoding methods have been developed to reduce the file size of video files when compared to the current standard. One of the most common video encoding formats used is H.264. (Vcodex Limited, n.d.)
The new format that is aimed to replace H.264 is HEVC or High Efficiency Video Coding. Files encoded using this format will be smaller as the format uses more advanced compression techniques. This makes files encoded in the format more difficult to play however newer devices are being released that support hardware decoding of HEVC. (Vcodex Limited, n.d.)

Chapter 2.3 Wireless technologies/Protocols.

Wireless communication is an essential part of modern technology with the vast majority of people around the world using some form of wireless technology every day. One of the most common wireless technology used is Wi-Fi which is used to provide a wireless connection to a router which directs traffic on the network and to the internet if configured to do so.

Devices that facilitate wireless access are known as access points. Routers targeted for use in the home market are a router and access point combination. In an enterprise environment that requires wireless coverage over a wide area or support for a large number of devices simultaneously a separate router and access point will be used, multiple access points can also be used together to create a mesh network to provide better coverage or a more seamless transition between access points when moving around the coverage area.

The IEEE creates and maintains the 802.11 standards which is the standard used by wireless networks. Throughout its development the standards has used various frequencies such as 2.4 GHz, 5 GHz, and some of the latest versions of the standard used 60 GHz frequency.

Due to the prevalence of the Wi-Fi there is a great deal of interference on the more common frequencies such as the 2.4GHz range, which is used in many earlier Wi-Fi standards and even some current standards. To get around these frequencies issues newer standards used difference frequencies

Wireless N can be considered the standard version of the 802.11 standard used in most homes as the standards has been available since 2009 with most Internet Service Providers (ISPs) standard routers having wireless N as standard for years.
Wireless N can use both the 2.4 GHz and 5 GHz frequencies. The more modern and faster wireless AC standard, which uses the 5 GHz band, is becoming more common and the current routers offered by the biggest ISPs in the UK all feature wireless AC as standard as well as legacy wireless N to support older devices that use the 2.4 GHz frequency. (Shaw, 2018)

The Wi-Fi alliance has announced a new industry designation for Wi-Fi standards to simplify the different options available to consumers. The new system replaces previous letter-based designations such as G, N, and AC with a number system, previous Wi-Fi standards will be retrospectively be renamed to comply with the new designations. However as new hardware is released the new designations will become more common with Wi-Fi 6 based hardware expected in 2019 however some 802.11AX wireless routers are already available, though they do not meet the Wi-Fi 6 specifications, and some manufactures may choose to use the previous naming scheme. (Wi-Fi Alliance, 2018)

The new designations are as follows –

<table>
<thead>
<tr>
<th>Old Designation</th>
<th>New Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11AX</td>
<td>Wi-Fi 6</td>
</tr>
<tr>
<td>802.11AC</td>
<td>Wi-Fi 5</td>
</tr>
<tr>
<td>802.11N</td>
<td>Wi-Fi 4</td>
</tr>
<tr>
<td>802.11G</td>
<td>Wi-Fi 3</td>
</tr>
<tr>
<td>802.11A</td>
<td>Wi-Fi 2</td>
</tr>
<tr>
<td>802.11B</td>
<td>Wi-Fi 1</td>
</tr>
</tbody>
</table>

Table 1

(HOFFMAN, 2018)

The new designation also comes with the announcement of the latest Wi-Fi standard, under the old designation 802.11AX, Wi-Fi 6 that is designed to provide improved coverage, and performance. The standard also has a focus on larger networks with many devices connected simultaneously which would be the case in environments such as airports or concert venues. (Wi-Fi Alliance, 2018)
Whilst this new standard has been introduced the Wi-Fi alliance cannot force manufactures to use the standard and it is unlikely that existing devices will be renamed to comply with the new designations. (HOFFMAN, 2018)

Wi-Fi direct, also known as Wi-Fi P2P is a standard designed to allow devices to be directly connected without an access point as an intermediary device. This is designed as a convenient way to connect devices and can also be used as a quick setup for devices such as printers. (Wi-Fi Alliance, n.d.)

Bluetooth is a wireless standard commonly used to connect to a device for example wireless headphones to a mobile phone and for connecting controllers for some games consoles. Bluetooth was designed for short range connection of devices around a user with the intent of replacing cables linking devices together.

The type of network Bluetooth creates is sometimes known as a Wireless Personal Area Network or WPAN which is a wireless network centred on a single user and is designed for personal use. Bluetooth was standardised by the IEEE as IEEE 802.15.1 however they no longer maintain the Bluetooth standard. The standard is now maintained by the Bluetooth Special Interest Group or the Bluetooth SIG.

(Mitchell, 2018)

Chapter 2.4 Market Research.
This section of this report will cover devices that provide similar features to the end product of this project. However no devices were found that had all features so devices for each feature will be found.

Chapter 2.4.1 Wireless Storage.
The Seagate Wireless Plus is an external hard drive with wireless capabilities. The device creates its own Wi-Fi network that the devices that the user wants to access the drive with connects to. This devices offers high capacities with 1TB and 2TB models available however as the device uses a hard drive it is susceptible to shock
damage that could damage the platters in the drive causing data loss and potentially rendering the device inoperable.

(Seagate Technology LLC, n.d.)

The SanDisk Connect Wireless Stick is a USB flash drive with wireless capabilities available in capacities ranging from 16GB to 256GB. Much like the Seagate the device creates its own Wi-Fi network and the user joins it to access the data there are apps for both Android and IOS. The device does not need to be connected to a power source as it has its own internal battery. The device can also be used as a standard USB drive, when connected the internal battery of the device is also charged.

(SanDisk, n.d.)

Chapter 2.4.2 Bluetooth Audio Receiver.
The Sony RM-X7BT is a Bluetooth audio receiver with voice control and a hands free device. The device is designed for use in cars to add Bluetooth audio support to sound systems with 3.5mm audio aux ports. The device comes with a control unit, that lets the user the skip tracks play or pause and use the voice functions, and the audio receiver, that connects to the cars aux port and a power source either USB or USB through an adapter on the utility socket.

(Sony, n.d.)

The Aukey BR-C1 is a Bluetooth audio receiver and hands free device that is designed to be usable in many environments. The device has an internal battery and can be used to make wired headphones wireless without any additional power. The device can also be in a car that has an aux port to add Bluetooth audio support as well as hands free calls.

(Aukey, n.d.)
Chapter 3 Design.

This section of the report will cover the design process of the device and the steps taken to determine the exact hardware to be used. This will also cover the rationale behind the hardware as well as a breakdown of each component and the cost of the parts.

The Raspberry Pi Foundations Raspberry Pi Zero WH was selected for this project. This selection was made after some evaluation. The Raspberry Pi Foundation is a well-known charity that produces a range of single board computers with lower and higher end devices, they have also made several iterations of their 2 main lines. Their reputation and past user experience means that the hardware will be reliable.

The Pi was also selected for its availability with many sites offering next day delivery and some stores in the UK carrying some lines of the Raspberry Pi. This meant that there would be limited downtime between ordering the device and it arriving, unlike other hardware which may have had to ship from other countries which could have added significant delay.

The Pi also has a great deal of community support and has been used in many projects throughout the lines life time. This means that if any problems arise it is very likely that a solution is available online. This community support also extends to a wide range of software that is compatible with the Pi as well as operating systems that are constantly updated for security, features and stability.

Chapter 3.1 Hardware.
The table below lists the parts that were selected for this project. All parts were ordered from Amazon for convenience. The rationale behind the part selection will follow going into detail on the specific choices alternative options and any other details that informed the specific selection.
Raspberry Pi Zero WH is the latest model in the Zero line. The core difference between the Zero WH and the Zero W is that the GPIO port is pre-soldered on the WH there are no other changes to the board beyond the GPIO. This version of the Zero W comes at a slight premium due to the additional soldering however this is a nominal cost.

The Pi Zero WH was chosen as it is compatible with the software and operating system used in the original project. This means that the initial setup of the device and early development should be very similar to the Pi 3 used before. Power efficiency was also a key reason the WH was chosen for this project the single core SOC on the board uses far less power greatly reduces the battery requirements and increases the time between charges.

(RASPBERRY PI FOUNDATION, NA)
Samsung is a well-known brand has a reputation for high quality products. When buying batteries it is important to select a trusted brand as there are many cells available that claim a high capacity but are in fact much lower. 3000mAh cells were chosen as they should allow longer times between charges and will run the device for a long time.

A SanDisk micro SD card was selected as they are a well-regarded brand and produce a wide range of flash storage products, they are also a fabricator which means that they produce flash themselves. The model that was selected is the Ultra 16GB this model was chosen for both capacity and speed. 16GB will provide enough storage for the proof of concept testing. A larger micro SD card could be used once the device is known to work however the lower capacity will not affect any of the core functions of the device.

Due to the lack of headphone port on the Raspberry Pi Zero line the pHAT DAC was required. This is an add-on board for the Zero line that adds a digital to analogue converter with headphone port to the device. This will be used as the output for the Bluetooth audio of the device. Other methods for adding audio output are available for the Zero however these methods require changing GPIO pins in software. The pHAT offers a more complete solution as it connects directly to the devices existing GPIO port and has a driver available from the manufacture as well as an install guide for manual configuration.

Charging can be very dangerous if not done correctly and with appropriate safety measures. As such the TP4056 Lithium battery charging protection board was chosen for this project. The board is designed to allow for the safe charging on lithium cells with protection from overcurrent, overvoltage, and short-circuit. These features when paired with a quality brand cells will provide some assurance of the reliability and safety of the device. The TP4056 is also well regarded in the hobbies community and is used in a range of projects to provide charging over USB safely with the appropriate protection.
Chapter 4 Project Plan.

This section of the report will evaluate the tasks required to complete the project and give a projection of the time required to complete each section. As the previous projects storage elements are used in this project the time taken will be used as a basis as the required time frame should be the same or very similar.

The project has three distinct elements as such these elements must be broken down into smaller tasks. Doing this will enable better time management and a clear structure to the workload. This approach is also required as some of elements of the device will not work unless earlier tasks have been completed.

Due to prior experience the first area of development will be the core storage element of the device. The first step will be replicating the configuration of the device used in the previous project. This can be used to directly compare the results of the previous device with the new one. It is expected that the new device will not perform as well due to a lower core count and clock speed.

The next area of development will be adding audio support to the device this will be done using the hardware add-on board which connects to the GPIO port on the Pi Zero W. This board requires soldering of the GPIO socket and some software configuration to function, a utility to do this is provided on the manufactures website as well as guide on how to install it. Both methods will be considered before deciding which will be used.

This device provides a guide on its configuration the device will be tested to ensure that it is functioning correctly. The device may require an amplifier depending on the output capabilities however this is a very subjective area and can only be tested once the device is installed and configured.

Once the device has been setup with audio support and tested the next development task can be undertaken. The device will be configured to act as a Bluetooth audio receiver this means that audio can be streamed to the device, the device will then output the audio through the 3.5mm audio jack.
This will be done using a guide designed for the original Raspberry Pi using a USB Bluetooth adapter. The process should be very similar for the Pi Zero W, though the complexity of the changes required will not be known until the work can be started.

The parts for this project were ordered by the university however due to miscommunications not all parts were ordered at once. The project was delayed as the hardware had not arrived.

<table>
<thead>
<tr>
<th>Project</th>
<th>Estimated Start</th>
<th>Estimate Finish</th>
<th>Estimated Work (in hours)</th>
<th>Estimated Duration (in days)</th>
<th>Actual Start</th>
<th>Actual Finish</th>
<th>Actual Work (in hours)</th>
<th>Actual Duration (in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Start</td>
<td>24/10/2018</td>
<td>25/04/2018</td>
<td>250</td>
<td>181</td>
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<td>30/03/2018</td>
<td>25</td>
<td>10</td>
<td>20/11/2017</td>
<td>04/12/2017</td>
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<td>14</td>
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<td>1</td>
<td>29/01/2018</td>
<td>20/06/2018</td>
<td>3</td>
<td>141</td>
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<tr>
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<td>44</td>
<td>05/02/2018</td>
<td>21/04/2018</td>
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<td>21/06/2018</td>
<td>23/06/2018</td>
<td>6</td>
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<td>7</td>
<td>25/06/2018</td>
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<td>10</td>
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<tr>
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<td>02/03/2018</td>
<td>10/03/2018</td>
<td>20</td>
<td>8</td>
<td>30/06/2018</td>
<td>10/07/2018</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
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<td>12/04/2018</td>
<td>40</td>
<td>31</td>
<td>10/07/2018</td>
<td>21/08/2018</td>
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<td>41</td>
</tr>
<tr>
<td>Testing</td>
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<td>19/05/2018</td>
<td>10</td>
<td>4</td>
<td>22/08/2018</td>
<td>31/08/2018</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
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<td>20/10/2018</td>
<td>299</td>
<td>148</td>
<td>01/09/2018</td>
<td>16/10/2018</td>
<td>200</td>
<td>45</td>
</tr>
</tbody>
</table>

The above times are estimates and may not be accurate or representative of the actual time required to complete the tasks, a more complete timeline could be created during development once the workload has been more accurately assessed.

The audio jack and Bluetooth audio will be combined during development as the Raspberry Pi Zero W does not have an audio jack by default. The storage device configurations will be added to the Bluetooth audio device and tested. The tests will
aim to determine what performance is lost by adding the audio and associated processes. The device will then be optimised as much as possible to improve transfer speeds but also to ensure that audio can still be streamed without issue, ideally the device should be able to transfer files and play audio at the same time even if the transfer speeds are slower during this use case.

The biggest setback for the project was the delay on the delivery of key parts this meant that the project was effectively stalled as none of the research could be implemented on hardware during the initial delays, the charging circuit boards were delayed and arrived after some of the initial parts despite all parts being ordered at the same time.

Chapter 5 Testing Methodology.

This section of the report will evaluate the testing methodology used in the previous project and evaluate a new methodology that will account for shortcomings or inaccuracies in the previous methods. The new method will be evaluated and compared to the method used in the previous project to break down the benefits and negatives of using this new method.

Chapter 5.1 Original Project Testing Methodology.
The test methodology of the previous project used file transfers. A test file was copied from the test system to the device the peak observed speed was taken and the time taken was measured. The time was then used to determine the average transfer speed. For read speed testing the file was copied from the device to the test system with the peak transfer speed and time taken being noted.

Human reaction time was a key factor for getting results using this methodology as the time was recorded using a smartphones stop watch starting the timer as the test began and stopping it as the file finished copying. This means that the accuracy of the results cannot be fully guaranteed due to human error.
The tests were carried out at a location on the outskirts of Bedford this location was chosen as it had limited Wi-Fi networks within range. However as only single location was tested the degree to which interference was an issue cannot be ascertained.

The testing was carried out with a range of devices including Windows 10 Desktop, Windows 10 laptop, Ubuntu Laptop, OnePlus 3T smartphone. These devices cover a wide range of the potential device that could be used and gave a broad view of how the device might perform for a user.

The previous testing used a simple file transfer for testing the file was copied from device to device and the time taken, using a phone stopwatch app, measured and the peak transfer speed shown in files explorers copy window noted. As a very basic test this works relatively well and can be easily repeated however there are several issues that are caused by the simplicity of the testing.

One of the biggest issues with the existing methodology was the reliance on human reaction time this meant that the results would always be out by some degree however negligible that time maybe. As the user would need to observe the screen to determine the peak speed, which could easily be missed given how frequently the transfer speed can fluctuate, and when the transfer completes this means that the time required for the result taker to observe the information and react to it will always be a factor in any given result using this methodology.

Another factor that could be considered and issues in the original testing was the use of a monitor with a refresh rate of 60Hz, refresh rate is how many times the screen refreshes a second, and this means that there may be a delay between the copy process finishing and the information being displayed on screen. A potentially way to mitigate this would be using a higher refresh rate monitor the highest refresh rate monitors that are widely available are 240Hz monitors with this refresh rate would update 4 times as often as a standard 60Hz monitor meaning that the more information is available to the user and the information is shown more quickly.

One of the most valuable benefits of using NAS Performance Tester is that the test can easily be repeated by anyone with an internet connection, assuming no geographical restrictions are in place, by simply downloading the application and
running it on their own device. This means that anyone can validate the results of the researchers testing if they have the hardware available.

Chapter 5.2 New Testing Methodology.
The new methodology uses an open source application called NAS performance tester by Ulrik D. Hansen he describes the application as follows “This free utility benchmarks the read and write performance in megabytes per second of network attached storage connected through SMB/CIFS network shares.”

(Hansen, 2014)

The application also allows for larger file sizes as well as a greater number of loops which could be used to give a more accurate average result. This means that a range of tests can be carried out to give a wider data set.

The application is only available for Windows this means that the range of devices the test can be performed on is limited. However a range of Windows devices can be tested to determine performance on different hardware. Alternative applications for Android were investigated however no suitable candidates were found.

Whilst the new methodology does provide benefits over the previous method it is not without its own short falls. The primary short fall is the lack of Linux or Android compatibility this meant that testing was limited to Windows devices

Linux can in some cases run applications built for Windows using compatibility layers such as Wine. However this can be very buggy and many applications will either not run, will have very limited functionality, or will have very poor performance. Because of these issues it was determined that the risk of factors beyond the scope of this project causing inaccurate results was too high and as such Linux tests using NAS Performance Tester and Wine were not done.

The new methodology uses an open source application developed by Ulrik D. Hansen the programme provides a simple utility for testing both the read and Write speeds of a Network Attached Storage device and offers the ability to vary the number of
repetitions of the test as well as the file size, whilst the device is not a typical NAS this benchmark will still work as intended as the storage share is done using SMB.

(Hansen, 2011)

Whilst the new methodology does have some shortfalls these issues are relatively minor with little effect on the results. Whilst the previous method had a range of issues that meant that the accuracy of the results could not be insured. Based on a comparison of the short comings and advantages of both methodologies the new methodology using NAS Performance Tester was selected for testing as it provides a more reliable test giving more detailed and accurate results than human based testing can provide.

To eliminate any change in result though the use of a different wireless router the same device will be used at each location. The router that will be used is a Netgear WGR614 this router is extremely common as it was the OEM (Original Equipment Manufacturer) for most UK ISP with the SSID and an ISP specific UI skin being the only differentiating features. This router is low end and may have some impact on performance however the router was selected as it could be moved to each test location as needed preventing change of router being a factor.

The new methodology is easily repeated and can be applied to many different environments. This is because the test uses an open source application that can be downloaded by any user. The testing process has very little variance with the file size and number of iterations being the only changeable variable. The process to run the test is simple and does not rely on the users’ abilities or knowledge.

Chapter 5.3 Comparison of Methodologies.
This section will be a comparison of the new and old methodologies to determine which is best and select which will be used in this project.

The table below breaks down the advantages and disadvantages of each methodology.
<table>
<thead>
<tr>
<th>New Methodology</th>
<th>Old Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Eliminates human factor</td>
<td>Windows only</td>
</tr>
<tr>
<td>Easily repeatable</td>
<td>Any test file can be used</td>
</tr>
<tr>
<td>Gives detailed results with both read and write speeds</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

Based on the comparison of the two methodologies the new method has been selected as the testing procedure for this project. The method was chosen due to its repeatability and removal of much of the human dependence that the original method had.

**Chapter 5.4 Testing New Test methodology.**

The application lets the user select either the drive letter assigned to the network drive or the path to it. Once the path or letter has been selected the file size can be set with options of 100, 200, 400, 800, 1000, 2000, 4000, and 8000 megabytes. The number of loops can also be set with options for 1, 2, 3, 4, 5, 10, 20, and 40. Once the test parameters have been set the user clicks start to run the test.

An average speed in megabytes per second is calculated and displayed once each section, read and write, of the test has been complete each iterations result is also displayed this can be used to determine any anomalies in the results if any of the iterations is outside the expected margin of error the test should be rerun to ensure the accuracy of the data.

The application was tested on a Raspberry Pi 3, which is configured as a media centre using OSMC as its OS which is a fork of the Kodi OS both are Linux based. The results of the test can be seen in the screenshot below.
The application gives a wide range of data with the ability to set the file size and the number of iterations of the file transfer to be tested. This allows the average to be calculated and the application also does this. This makes it an extremely versatile testing tool which will work well for this project.

Chapter 6 Development.

This section of this report will be a description and guide of the development process of this project. Each section of the project will be broken down into the individual tasks. This will be done to make clear distinctions between the parts of the project and to determine functionality of each task independently.

Chapter 6.1 Device initial setup.
The first step in this project was getting the device ready to use this meant that the OS needed to be installed on the Micro SD card. The card used for this project was connected to a computer using a USB to Micro SD adapter.

The latest version of the Raspbian OS was downloaded from the official website the download is in the form of a zip file containing the ISO image of the OS. Before the
ISO can be written it must be extracted this can be done using the native windows utility or using a 3rd party programme such as 7zip or WinRAR.

When the ISO image has been extracted the programme to write the ISO to the Micro SD card can be started. Rufus is a programme that is used to create bootable drives using digital disk images such as ISO or DD file to flash media such as SD cards or USB drives.

The device to be written to is selected using a drop-down menu labelled “Device” the name of the device and the driver letter assigned to it are displayed. Once the target device has been selected the image to be written is selected from a drop-down menu labelled “boot selection” the device can also have a new name entered in the “Volume Name” field.

When the appropriate selections and changes are made the user can click start to begin writing the image to the device. A warning will be displayed informing the user that all data on the selected drive will be lost, if the user wishes to proceed they can click to continue and the device will be formatted and the image written.

Now that the image has been written to the Micro SD card it should be bootable in the raspberry Pi Zero W. The card is inserted in to the Pi for first boot, the device powered the initial boot is observed. If the device boots correctly it can be connected to the internet using the on-board Wi-Fi. On this is done the Pi can be updated this is done with two commands the first is “sudo apt-get update” this command uses the registered repositories to check for any updates to software installed on the Pi that need to be updated, the user may need to enter the password to run this command.

Once the updates command has been executed the command “sudo apt-get upgrade” can be run. This command will use the information from the updates command to determine what needs to be updated. The user will be told how much space the updates will take and asked if they wish to proceed type “y” to continue. The updates will then be installed on the PI.
Chapter 6.2 Storage configuration.

The Samba configuration file from the previous project will be used as a guide during the shared storage implementation. For this version of the device the Micro SD card will be used as the storage location, the previous project used a USB drive, a USB drive may be tested for comparative purposes. The installation and configuration can be found below.

Commands:

```
sudo apt-get install samba samba-common-bin
```

The first command used installs Samba and the required components, the application manager will also install any other dependencies as required. The user may need to enter their password after entering this command as it uses sudo, which is used run commands with elevated privilege similar to run as admin on Windows, the user will be asked if they wish to install type y or yes into the console and press enter to confirm, Samba will then be installed.

```
sudo nano /etc/samba/smb.conf
```

This command opens the Samba smb.conf file with a text editor, with elevated privileges, this file specifies what files are shared using Samba and how they appear to users. The pre-generated configuration file is deleted and replaced with the configuration found below.

Samba configuration used:

```
[global]
netbios name = PiDrive
server string = The Pi File
workgroup = WORKGROUP
hosts allow =
socket options = TCP_NODELAY IPTOS_LOWDELAY SO_RCVBUF=65536 SO_SNDBUF=65536
remote announce =
remote browse sync =
wins support = yes

client min protocol = SMB2
client max protocol = SMB3

[HOMEPI]
path = /home/pi
comment = No comment
browseable = yes
read only = no
```
valid users =
writeable = yes
guest ok = yes
public = yes
create mask = 0777
directory mask = 0777
force user = root
force create mode = 0777
force directory mode = 0777
hosts allow =
End of Samba configuration used

This command adds the user Pi to Samba this means they can remotely access information stored on the SMB shares. When connecting to the share the user will need to enter the username and password. When this command is entered the user will be prompted to enter the password for the account, this is confirmed with enter the user will then need to re-enter the password to confirm it for the account.

Chapter 6.2.1 Changes to connection process.
Previous versions of Windows, and those before the patch, allowed the user to navigate to the network tab in file explorer and if the device was connected to the network SMB shares could be seen and connected to simply by clicking on them and if applicable entering the appropriate credentials in the login window. Changes were made to the way that SMB shares can be accessed in Windows due to the Eternal Blue vulnerability which exploited weaknesses in SMB 1.

Eternal Blue was an NSA discovered vulnerability that exploited weaknesses in the way Microsoft SMB handled SMBv1. This meant that a remote attacker could execute code on the target device. The exploit was publicly released by a group known as the Shadow Brokers it was subsequently used in the WannaCry and NotPetya ransomware. (Thomson, 2017)

The exploit has subsequently been patched for all currently supported operation systems. However, many users had not installed the patch when the WannaCry ransomware started to spread. In response Microsoft released an emergency patch to Windows 7, 8, XP, and Server 2003. Microsoft has made statements blaming the
NSA for the damage caused by the exploit as they did not inform Microsoft after initially finding the exploit. (Newman, 2018) (Ribeiro, 2017)

Current versions of Windows however do not show SMB shares in the network tab. Instead requiring the user to manually configure a link to the network device. This is done through the add network location option which can be found by right clicking in the “This PC”, (previously my computer), menu and selecting in the option from the context menu.

The user can then follow the wizard through the process of connecting to their device. The user will need to know the network path of the device to be able to find it. In the case of this project the user enters “\\Pidrive\” and clicks browse this should find the device if it is connected to the same network as the computer.

The user can then select the device they will be prompted for the username and password for the device. When this has been entered the folder structure of the device can be seen. From here the user should select the main share directory which is the “homepi” folder from here complete the wizard to create the shortcut to the device.

Many Linux devices and Android apps can still find and connect to SMB shares by searching for them using the appropriate application, some versions of Linux include file explorers that include network tabs and can search for available network devices. A version of the Eternal Blue exploit was found in Samba however this was quickly patched.

Chapter 6.3 Adding Audio Jack.
The hardware chosen to add an audio jack to the Pi Zero W was the pHAT DAC by Pimoroni. The device is a board that is designed to attach to the Pi through the GPIO header, devices that are designed to stay on the GPIO header like this are referred to as HATs or Hardware Attached on Top. The board comes with the GPIO socket not attached to the main HAT board the user is required to solder the socket before the DAC can be attached to the Pi.
When soldering it is important to work in a safe environment and remove potential hazards. A clear workspace with only the items that need to be soldered and the supply’s required. Before powering the soldering iron check that there is enough room to safely use the iron ensure the cable does not snag on anything and that the cable is not tangled. The sudden jerk that could happen if the iron’s cable snagged could be dangerous when the iron is up to temperature.

Good air flow or some form of extractor is also important when soldering as the fumes from both the solder and flux can be harmful especially so if lead solder is used or rosin based flux.

When soldering to something with lots of points close together it is important to be aware of how much heat is being put into the board, as excess heat can damage components. To do this solder one point then move to the furthest away point. This also helps when soldering the GPIO on a HAT as it will hold the board in place.

Once the board is soldered it can be connected to the Pi ensure that it is not powered when connecting anything to the GPIO to prevent shorting. Ensure that the HAT is fully inserted on to the Pi as a poor connection could prevent the HAT functioning.

Command to install Audio Driver and configure device:

curl https://get.pimoroni.com/phatdac | bash
This command runs a script that will disable the default audio output, in the case of the Pi Zero W the HDMI audio, the user is warned of this and asked if they wish to continue type y and press enter to install the driver, this process will take some time.

Once the script has run the user will be asked if they wish to restart the device type y and press enter to reboot the Pi. The command is run a second time to test the audio output. The script will run as before again the user must accept that the default audio device will be disabled when this first stage is done the script will ask the user if they wish to test the device type y and press enter to run the test.

**Chapter 6.4 Bluetooth Audio Playback.**

**Commands**

```
sudo apt-get update && sudo apt-get install bluez pulseaudio-module-bluetooth python-gobject python-gobject-2 bluez-tools udev
```

This command checks the registered repository for any updates then install the required packages for this section of the project.

```
sudo rpi-update
sudo reboot now
```

This command is used to update the firmware of the Pi this can help with any issues relating to the hardware of the Pi such as the Bluetooth and Wi-Fi. Once the firmware has been updated the Pi is rebooted so the new firmware is used.

```
sudo usermod -a -G lp pi
```

```
sudo nano /etc/bluetooth/audio.conf
```

```
[General]:
Enable=Source,Sink,Media,Socket
```

The first command is used to edit the audio.conf file the section after is the configuration that is entered into that file.

```
sudo nano /etc/bluetooth/main.conf
```
This command is used to edit the main.conf file the class section of the file is edited and the new class “Class = 0x00041C” is entered, this defines the Pi as a device capable of receiving audio some devices such as phones may not show the Pi when scanning for Bluetooth devices if the class is incorrect.

    sudo nano /etc/pulse/daemon.conf

This command is used to edit the daemon.conf file the file is opened in nano and the resample-method section found the existing option is replaced with “resample-method = trivial”

    sudo pulseaudio –D

This command starts pulse audio as a service.

    aplay /usr/share/sounds/alsa/Front_Center.wav

This command tests the audio output of the Pi in this case as the audio driver for the pHAT DAC had been installed earlier the audio is routed through the audio jack on the HAT.

The following commands are to enable the Bluetooth and setup the Pi so that it is discoverable, visible to other Bluetooth devices, and pair-able, able to pair with Bluetooth devices.

    bluetoothctl
    agent on
default-agent
discovevable on
pairable on

The user can now connect their device smartphone, tablet, pc, ect. to the Pi by scanning for it in their Bluetooth application the Pi will show up with its host name as its Bluetooth name in this case “PIZeroW” connect to it.

When the user connects their device to the Pi the terminal will ask the user to confirm the pairing type yes in the terminal and press enter the device should then connect The audio from the device should now be routed through the pi this can be tested by opening a media player and playing some audio.

    trust (device Mac Address)
This command adds the device to the Pi Zero W trusted Bluetooth devices

This section of the project was done using various guides mainly a stack overflow thread. Changes were made where needed as the thread and answer used were from 2016. Some of the scripts that were used in the guide are not necessary for this projects implementation of Bluetooth audio. (xdhe, 2016)

During initial testing is was discovered that the device cannot do file transfers while Bluetooth audio is being played. However music that is already on the device can be played from a connected device, playing an audio file on the device on a phone and sending the audio to the Pi over Bluetooth.

Chapter 6.5 Battery and charging circuit.

This part of the project also required soldering as such the same safety procedures used for the audio device were implemented and adhered to.

The charging circuit for this project is a TP4056 this is a board designed to charge lithium cells, the particular model of the board used in this project also has various protections to ensure that the battery is charged safely, such as over current and over voltage protection.

The board is broken down into specific solder points for the various in and out puts the B+ and B- points are for the battery. The battery holders’ cables were soldered to the board’s battery solder points.
On the opposite end of the board to the battery connectors is the Micro USB port used to charge the batteries connected to the device. On either side of the USB port are solder points for a power input, this would be used if a non USB power supply was to be used to charge the batteries for example a bench power supply.

A Micro USB cable was cut to provide a connector for the charging circuit. This was done to make the mains power and battery power comparison tests easier. The section of cable with the Micro USB connector was soldered to the output solder pads on the charging boards.

Chapter 6.5.1 Issues.
Due to issues getting the charging circuit to power the Pi Zero W a portable battery bank was used for all testing as a replacement. The issue is likely due to the protection circuitry on the charging module causing the power to be cut off before reaching the Pi.

This issue is difficult to debug as the TP4056 is very common and has many slight variants. The version used in this project is from China and did not come with any documentation. This means that it is difficult to identify what exactly is causing the problem.
The battery bank that is replacing the charging circuit also uses 18650 cells it is an Anker Astro E1 gen 2 5200mAh. This should be more than enough to power the Pi and will provide a similar capacity to the cells that were going to be used in this project.

Chapter 7 Testing.

This section of this report will cover the results of testing the device the test results will be show as both charts and a table. Before the testing predictions will be made on the expected results of the device based on the previous project and the difference in specification as well as a discussion of the areas that are likely to impact performance for this device.

Chapter 7.1 Predicted Results.
The peak transfer speed that the researcher has previously observed from a Raspberry Pi 3 directly connected to a router using Ethernet is approximately 11.8MB per second this can be used as a starting point to predict the expected transfer speeds of the device.

The core differences between the Pi 3 and the Zero W used in this project is the SOC used with the Pi 3 being faster by 0.2GHz and a quad core, with the Zero W being a single core at 1GHz, there is also a potential IPC, Instructions Per-Clock, difference that would further alter the performance.

The previous performance numbers and the specification of the device can be used as general guide lines to estimate the performance of the device. However it is important to note that in real world testing the core difference and clock speed difference will not scale perfectly. There is also the consideration of changes in the level of interference as the device uses Wi-Fi the speed of transfer could change based on the number of other networks and the amount of active users on Wi-Fi networks as well as the performance of the wireless router used.
Based on the known factors and the performance of the previous device an approximate performance range can be made. The researcher estimates that the device will be able to perform with transfer speeds in the range of 2MB/s to 4MB/s.

The device will also be tested using a portable battery bank to determine if being powered from batteries has any effect on the devices performance. Based on the knowledge of previous Raspberry Pi models and the power required for the Zero W battery power will have little to no effect the results will be within a margin of error of the mains powered tests.

Chapter 7.2 Results.
This section of the report will cover the results of testing on the device, testing was carried out at two locations to give a range of potential use environments. The results will be shown with charts of the average results to give a general overview, tables with the full results will also be included in a later section of this chapter.

Chapter 7.2.1 Bedford Results.
The Bedford test location is a residential property away from the town centre. This location was chosen as there are fewer wireless networks within the range of the exact test location in the house.
Figure 2

Bedford Test Location Write Tests Average Results

<table>
<thead>
<tr>
<th>Device</th>
<th>Transfer Speed MBps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pi 2 Laptop</td>
<td>1.07</td>
</tr>
<tr>
<td>Pi Zero W Desktop Wi-Fi</td>
<td>1.08</td>
</tr>
<tr>
<td>Pi Zero Battery Laptop</td>
<td>1.17</td>
</tr>
<tr>
<td>Pi 2 Desktop Wi-Fi</td>
<td>1.22</td>
</tr>
<tr>
<td>Pi Zero W Laptop</td>
<td>1.24</td>
</tr>
<tr>
<td>Pi Zero W Battery Desktop Wi-Fi</td>
<td>1.36</td>
</tr>
<tr>
<td>Pi Zero W Desktop Ethernet</td>
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</tr>
<tr>
<td>Pi 2 Desktop Ethernet</td>
<td>2.56</td>
</tr>
</tbody>
</table>

Figure 3

Bedford Test Location Read Test Average Results

<table>
<thead>
<tr>
<th>Device</th>
<th>Transfer Speed MBps</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Pi Zero Battery Laptop</td>
<td>0.79</td>
</tr>
<tr>
<td>Pi Zero W Laptop</td>
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</tr>
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<td>Pi 2 Desktop Wi-Fi</td>
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<tr>
<td>Pi Zero W Battery Desktop Wi-Fi</td>
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</tr>
<tr>
<td>Pi Zero W Battery Desktop Wi-Fi</td>
<td>0.88</td>
</tr>
<tr>
<td>Pi 2 Laptop</td>
<td>0.88</td>
</tr>
<tr>
<td>Pi Zero W Desktop Ethernet</td>
<td>1.78</td>
</tr>
<tr>
<td>Pi Zero W Battery Desktop Ethernet</td>
<td>1.92</td>
</tr>
<tr>
<td>Pi 2 Desktop Ethernet</td>
<td>2.02</td>
</tr>
</tbody>
</table>
Chapter 7.2.2 Sandy Results.
The Sandy test location is a flat located just off of the town high street. This location is more densely populated and as a result has many more wireless networks. This means that the device is more likely to suffer from interference due to the number of networks and the proximity.
Chapter 7.3 Full Results.
This section of this report will contain the full results of testing. The results will be broken down into the test locations and displayed as tables for each of the write and read tests at each location.

### 7.3.1 Bedford Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
<th>Iteration 4</th>
<th>Iteration 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2.41 MBps</td>
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<td>2.26 MBps</td>
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</tr>
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<td>2.32 MBps</td>
<td>2.56 MBps</td>
</tr>
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</tr>
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</tr>
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<td>1.21 MBps</td>
<td>1.22 MBps</td>
<td>1.17 MBps</td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Test</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
<th>Iteration 4</th>
<th>Iteration 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pi Zero W Desktop Ethernet</td>
<td>1.53 MBps</td>
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</tr>
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</tr>
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<td>2.01 MBps</td>
<td>2.02 MBps</td>
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<td>0.88 MBps</td>
</tr>
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<tr>
<td>Pi Zero Battery Laptop</td>
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<td>0.83 MBps</td>
<td>0.78 MBps</td>
<td>0.79 MBps</td>
</tr>
</tbody>
</table>

**Table 5**
## Sandy Results

### Sandy Test Location Write Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
<th>Iteration 4</th>
<th>Iteration 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>0.91 MBps</td>
</tr>
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</tr>
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<td>Pi Zero W Battery Laptop</td>
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<td>0.83 MBps</td>
<td>1.03 MBps</td>
<td>0.82 MBps</td>
<td>0.91 MBps</td>
</tr>
</tbody>
</table>

*Table 6*

### Sandy Test Location Read Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
<th>Iteration 4</th>
<th>Iteration 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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</tr>
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</tr>
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<td>0.69 MBps</td>
</tr>
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<td>1.62 MBps</td>
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<td>1.68 MBps</td>
<td>1.69 MBps</td>
</tr>
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<td>Pi Zero W Battery Laptop</td>
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<td>0.56 MBps</td>
<td>0.82 MBps</td>
<td>0.91 MBps</td>
</tr>
</tbody>
</table>

*Table 7*
7.3.3 Data Flow
The files transfer in this project uses the SMB protocol in this case both Microsoft, from Windows to the device, and Samba, from the Device to any other device, implementations of the SMB protocol are used.

There are nine steps required to connect to an SMB share and open a file. The first step requires that the client and server connect to each other, this is done using a TCP connection, once this is done the client creates a NETBIOS session request which is sent to the server using the TPC link.

The client can then begin negotiating the protocol version to be used with the server sending a negotiation packet. This packet includes all the protocols that the client can work with. When the server receives the packet its responds with its own negotiate packet identifying which protocol version will be used, an 8 byte authentication sting is also included.

Next the client and server begin setting up the SMB session the client first sends a packet detailing its capabilities. If the server accepts the packet a UID is created and sent in a packet back to the client, if the packet from the client is not accepted the server will send a packet containing an error code. The client will then request access to the share, this packet contains the full path of the requested share.

If the client has access to the requested share the server returns the corresponding information for that share, if the client does not have access to the requested share or the requested share cannot be found the server will return an error code.

The client can now request the server access files in the share on the client’s behalf, the packet used for this contains the name of the file to be opened. When the server receives the file if the client has permission to access the file the server will return the files ID, again if the file cannot be found or access is denied the server will return an error. Once the client has received the packet containing the file ID the client can ask the server to read data of the file and return it to the client, the file ID is included in this packet to allow the server to identify the file to be read. Once the server has received the packet containing the file ID the server will send the requested file to the client.
Bluetooth audio data flow

Before audio can be sent to the device form a phone the device needs to be configured to allow connections. This is done using bluetoothctl, which is a utility that is used to configure Bluetooth on Linux. A range of commands are available as part of the bluetoothctl utility however only some of these commands are used in this project. The device is made discoverable, pair able and the default agent is started, the agent handles pairing either sending or receiving codes.

(Byfield, 2017)

Once the device is configured to be discoverable and pair able the user can perform a Bluetooth scan with their phone or any Bluetooth device they may be using. The device should show up from the scan as “PIZeroW” the user should now be able to connect to the device, the connection will have to be accepted on the terminal of the Pi.

Once the connection has been established and the phone is sending its audio to the device a programme called Pluseaudio. Pluseaudio is designed to act as an interface between software and hardware the programme will manage audio devices on a given device. In this case the programme directs the audio that is received from the phone via Bluetooth the Pi default audio output. In this case the line out of the Phat DAC connected to the Pi this means that any audio from the phone is will be played through any speaker of headphones connected to the line out of the Phat DAC.

(Wiki Arch Linux, 2019)
Chapter 7.3.4 Results Analysis.
The testing process took longer than expected due to the slower transfer speeds than originally predicted. Due to the time taken for each test the chances of interference being a factor is much greater, despite the measures taken to limit the inference.

From the results it is clear, as with the original project, that any devices connected using Ethernet will have better transfer speeds than those using Wi-Fi, in the previous project it was determined that the best case scenario was for the storage device being connected by Ethernet.

The results show that the method of powering the device has little effect on the transfer speeds of the device, in some cases the transfer speed was faster on battery, with the speed differences that were observed being within what could be considered the margin of error or artefacts of variance in interference.

The performance of the device was estimates to be around the 2MBps – 4 MBps range however many of the tests gave results below that range. This may have been due to the lower end router used in this project, the original project used an AC wireless router.

Given the planned use case and intended use of the device these performance results show that the device would be functional as a music storage device however, the larger file sizes of video files would mean that it would take a long time to load videos onto the device which would be frustrating for potential users.
Chapter 8 Conclusion.

This section of this report will evaluate the project as a whole and determine areas that were a success and areas that had issues or caused problems. This will range from direct factors based on issues with work such as issues that required extensive troubleshooting to external factors such as miscommunication and delivery issues.

Chapter 8.1 Project issues.
A key issue for this project was multiple delays in getting the hardware needed to begin work. The required hardware list was submitted to the university for approval and purchase however due to some miscommunications the researcher was told the items had been ordered but this was not actually the case. Once the order issues had been resolved and the items ordered only some of the items arrived. It was later discovered that not all the items had been ordered at the same time causing further delays as this was not discovered until after the initial items had arrived.

The TP4056 charge circuits where delayed for many weeks as they shipped from China. This meant that a core element of the project had to be put on hold. This also meant that battery powered testing could not be done at that time however, due to issues with the getting the charging circuits working it was later decided that a portable battery bank would be used for battery powered testing to mitigate the delays that had already occurred.

Chapter 8.2 Overview.
The project has achieved its core goals of creating a storage device that can be powered via battery power or the mains with Bluetooth audio receiver capabilities as an additional feature.

The project was broken down into individual tasks. This was done to make each part easier and to separate any issues that may arise to the specific part being worked on at the time.
The first task was the network storage device. This section was based on the original project and as such was simple as the hardware used for both projects was compatible with the same programme. This meant that the original configurations and settings could easily be adapted to the new device.

The performance of the new device was somewhat disappointing when compared to the original project. However it was expected that the device would provide lower transfer speeds than the Pi 3 used previously as the Pi Zero W is a lower power consumption device with fewer cores and a lower clock speed.

Whilst the transfer speed of the device was disappointing it is good enough for storing a music library. The device is also fast enough to stream 1080p video to a device wirelessly.

The Bluetooth audio part of the device functioned better than expected. Based on the research many users online claimed that the audio would be intermittent and may cut out at times. However this was not the case the Pi produced a clear representation of the source with no noticeable interference or audio skipping, the device also had surprising range with the audio only beginning to break up at approximately 8 meters.

Whilst the basic functions of the Bluetooth audio work well the process of connecting to the device is somewhat complex. This could make the device difficult to use for those that are not experienced with Linux. However this could be refined in a later project and this proved that a device of this type could function as both a storage device and a Bluetooth audio receiver. However the device cannot be used for file transfers while Bluetooth audio is being streamed however audio already on the Pi can be played back through Bluetooth.

The charging circuit for this project caused many issues throughout. Firstly being delayed by several weeks and then the lack of documentation causing issues in regard to getting the circuit to power the device. Based on the research that has been done the issue is likely related to the protections that are on the board causing the batteries to be cut off from the rest of the board when the protection trips.
The charging circuit was replaced with a portable battery bank when it became apparent that the issue would take too long to solve. This may not have been the case if the parts had arrived sooner however, due to time constrains a battery bank was the best available option that retained the features that were required for this project.

Overall this project achieved its goals and produced the deliverables that it set out to. The project could act as foundation to continue developing the ideas of this project and the previous one into a more refined product, the audio elements of this project could be moved from Bluetooth to using Wi-Fi this would reduce potential interference. As well as the possibilities of improving the project simply by using new or more powerful hardware or new technologies as they become available.

Chapter 9 Further work.

This section of the report will cover any potential work that could be undertaken to continue this project or to advance the ideas or technologies used in this project. This could range from refinement of the hardware and software used to a reapplication of the technologies used in a new area such as in a car or in the home.

Based on the results of this project it is clear that there is room for improvement in regards to the performance of the device. The exact approach to this can vary however using a device with a more power full SOC would be a simple step that would likely result in a device capable of higher transfer speeds. 

This project used the Raspberry Pi Zero W single board computer as it met the size and power consumption requirements. However other devices are available that have SOC with better performance which would translate to a higher transfer speeds.

Whilst the router used for this project is very common and a good reference for a minimum standard wireless router it is also a limiting factor. The Netgear router was even at the time of release a low end product and was not designed for large networks. The router also lacks many of the features found on modern devices such
as support for the 5GHz frequency range or higher speeds on the 2.4GHz range that modern wireless N or higher routers have had as standard for many years.

This project could benefit from replacing the older low end consumer router with something that would remove or reduce the router as a factor in testing. There are a range of potential devices that could be used such as enterprise grade products from the likes of Cisco or Ruckus that are designed for larger networks.

Alternatively one of the routing based operating systems could be used on a desktop computer for example pfSence using a computer allows for a specification to be selected that would almost completely remove the performance of the router as an issue. This would also allow for easy testing of different wireless technologies as a pc could be upgraded with the relevant networking hardware such as a new wireless card or 10GbE Ethernet.

To determine if the router was a factor a test was run using a wireless 802.11AC class router, a Virgin Media SuperHub 2AC. This router has far higher theoretical max speed and uses newer technology than the Netgear used for the main project the results of the test can be seen below.

![Figure 6](http://www.888.dk/?code-ohh9p-nas-performance)

This theory was confirmed as can be seen in the results of this test. With the write speeds being a full 1.46MBps faster with read speeds being 2.13MBps faster, when compared to the equivalent test on the Netgear router. This test was carried out at the Sandy location with a desktop connected to the router using Ethernet. This
difference in transfer speed clearly demonstrates the degree to which the router used can affect the performance of the device.

A potential limiting factor for this project is the wireless technologies that were available at the time. The two main frequencies that are used in the Wi-Fi specifications are 2.4 GHz and 5 GHz. Devices using these frequencies ranges have been around for many years now and most ISP routers feature support for both ranges. This means that there is a much greater chance of interference when using these frequency ranges.

60 GHz networking which being a new technology does not have a large market share and meaning that it is unlikely that many networks would be within a range as to cause interference. 60 GHz also offers higher transfer speeds than previous technologies meaning that the hardware limitations would be reduced over current wireless technology used in this project.

Due to the length of time that the tests required to fully run the chances of interference from other networks affecting the results are increased. This means that the results may not be as accurate as would be desired.

A solution to the problems that interference can cause would be to eliminate the interference. There are a few ways to achieve this these methods focus on either moving away from the interference, this could be done using a Wi-Fi analyser to find an area with no other Wi-Fi networks, or by insulating the device to be tested from the interference, this could be done by conducting testing in a faraday cage which blocks electromagnetic fields.

Alternatively a new testing methodology could be developed that would run for longer. A test procedure could be developed where tests are run continuously over the course of a day. This would also have a high change of being affected by interference however due to the length of time the test would run peak and average speeds would be more accurate and periods where interference was an issue would likely be visible in the data by determining areas that had a greater range of variance in the reported transfer speeds.
The current Bluetooth receiver configuration of this project requires that the user directly interacts with the device via the command line. This could make the device somewhat intimidating for some users and may result in users breaking the device by issuing the wrong commands.

The Bluetooth connection process for the device could be refined to make it easier to use. This would improve usability and make the device more accessible to users that do not have experience with the Linux command line.

Whilst this project used Bluetooth to allow the device to function as an audio receiver an alternative would be to use the Pi’s on board Wi-Fi to stream audio to the device. This would reduce the potential interference and may allow for file transfers during operation of the audio functions of the device.

Whilst the device is functional it is not very user friendly in its current form. For a future project more time should be spent on refining the design and making the device easier to use, in the current form if a user was to hold the device in the wrong way and bridge the wrong pads of the GPIO the board would power off.

The device could be refined simply by developing a case for it, this would remove the risk on users interacting directly with the boards PCB. A suitable case could be developed using cad software and 3D printed, if the device was ever moved to a mass production run the case could be made using injection moulding or some other form of plastic work.

Taking these steps would greatly improve the user experience of the device and would generally make it feel more like a product that someone may want to use on a regular basis. This would also improve the safety and durability as the user is separated from the PCB of the hardware that could be damaged by electrostatic discharge.
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