|  |  |
| --- | --- |
| Analysing The Raspberry Pi as a COST-EFFECTIVE Solution for SMEs  Cardiff University School of Computer Science and Informatics | Abstract  This project will analyse the Raspberry Pi as a low energy consumption and low-cost solution for SMEs and start-ups. This will look at the Raspberry Pi vs a traditional server set up vs a cloud solution.  Rhys Connor  Supervisor: Martin Caminada Moderator: Crispin Cooper |

# Acknowledgements

I would like to thank my supervisor Martin Caminada and my parents for all the support throughout the project. As well as all the support received from Cisco Systems, Country Connect in helping facilitate physical elements of the project and Dave Smith for providing layer 1 support on the UCS used in the project.

Table of Contents

[Acknowledgements 2](#_Toc97726748)

[Table of Figures 5](#_Toc97726749)

[1 Introduction 7](#_Toc97726750)

[Requirement 1 7](#_Toc97726751)

[Requirement 2 7](#_Toc97726752)

[Requirement 3 7](#_Toc97726753)

[Requirement 4 7](#_Toc97726754)

[Explanation of Services 8](#_Toc97726755)

[Pi-Hole/DNS 8](#_Toc97726756)

[NAS 9](#_Toc97726757)

[Webserver 9](#_Toc97726758)

[AD 9](#_Toc97726759)

[Honeypot 9](#_Toc97726760)

[DHCP 10](#_Toc97726761)

[CRM 11](#_Toc97726762)

[IPS and IDS 11](#_Toc97726763)

[Other Services to Note 11](#_Toc97726764)

[E-Waste 11](#_Toc97726765)

[2 Background 11](#_Toc97726766)

[RPi 11](#_Toc97726767)

[Traditional Server Set-up 12](#_Toc97726768)

[Cloud 12](#_Toc97726769)

[SaaS 13](#_Toc97726770)

[PaaS 13](#_Toc97726771)

[IaaS 13](#_Toc97726772)

[Hardware Costs of Each System 13](#_Toc97726773)

[Raspberry Pi 13](#_Toc97726774)

[Cisco UCS C220-M3 13](#_Toc97726775)

[GCP 13](#_Toc97726776)

[3 Approach 14](#_Toc97726777)

[Hardware Decisions 14](#_Toc97726778)

[OS/Platform 15](#_Toc97726779)

[RPi OS 17](#_Toc97726780)

[Debian 17](#_Toc97726781)

[Proxmox/ESXi 17](#_Toc97726782)

[GCP 17](#_Toc97726783)

[Raw Performance 18](#_Toc97726784)

[CPU/Memory 18](#_Toc97726785)

[Network 18](#_Toc97726786)

[Results of Raw Performance Benchmarks 19](#_Toc97726787)

[How to Benchmark Performance of Different Services 28](#_Toc97726788)

[DNS 28](#_Toc97726789)

[AD 28](#_Toc97726790)

[Webserver 29](#_Toc97726791)

[DHCP 29](#_Toc97726792)

[IaC 29](#_Toc97726793)

[Docker Compose 29](#_Toc97726794)

[Portainer 29](#_Toc97726795)

[Bash 29](#_Toc97726796)

[4 Implementation 29](#_Toc97726797)

[Network Infrastructure 29](#_Toc97726798)

[Home 29](#_Toc97726799)

[DMZ 29](#_Toc97726800)

[Docker Infrastructure 29](#_Toc97726801)

[VM Infrastructure 29](#_Toc97726802)

[IaC Examples 29](#_Toc97726803)

[5 Results and Evaluation 29](#_Toc97726804)

[Raw Performance Results 29](#_Toc97726805)

[Sysbench 30](#_Toc97726806)

[Timed Linux Kernel Compile 30](#_Toc97726807)

[6 Future Work 30](#_Toc97726808)

[7 Conclusions 30](#_Toc97726809)

[8 Reflection on Learning 30](#_Toc97726810)

[References 30](#_Toc97726811)

# Table of Figures

[Figure 1 – A Live/Production Pi-Hole dashboard using Pi-Hole’s Dark Theme 8](#_Toc97728978)

[Figure 2 – An example Honeynet from imperva.com (Imperva, 2022) 10](#_Toc97728979)

[Figure 3 – A demo glass-isc-dhcp dashboard (Miles, 2020) 11](#_Toc97728980)

[Figure 4 Mechanical Drawing of Raspberry-Pi 4 to illustrate the size of the device (Raspberry Pi Foundation, 2022) 12](#_Toc97728981)

[Figure 5 A pricing table for Microsoft Azure (Microsoft Azure, 2022) 13](#_Toc97728982)

[Figure 6 - Hardware Requirements for Server OS Installations 14](#_Toc97728983)

[Figure 7 – Cisco UCS M3 Boot Screen 15](#_Toc97728984)

[Figure 8 - docker-compose.yml file to Create a Pi-Hole Container 17](#_Toc97728985)

[Figure 9 – Table from Veritis comparing CSPs (Veritis, n.d.) 18](#_Toc97728986)

[Figure 10 - Average Deviation of Linux Kernel Compile Runs (Open Benchmarking Org, 2022) 19](#_Toc97728987)

[Figure 11 - Time to Complete Linux Kernel Compile (Open Benchmarking Org, 2022) 19](#_Toc97728988)

[Figure 12 - CPU Benchmark of RPi 4 2Gb using Sysbench 21](#_Toc97728989)

[Figure 13 - Memory Benchmark of RPi 4 2Gb using Sysbench 21](#_Toc97728990)

[Figure 14 - I/O Benchmark on RPi 4 2Gb Using Sysbench 22](#_Toc97728991)

[Figure 15 - CPU Benchmark of UCS using Sysbench 22](#_Toc97728992)

[Figure 16 - Memory Benchmark of UCS using Sysbench 23](#_Toc97728993)

[Figure 17 - I/O Benchmark of UCS using Sysbench 23](#_Toc97728994)

[Figure 18 - Linux Kernel Compile Failed Attempt on RPi 4 24](#_Toc97728995)

[Figure 19 - First Run of defconfig Linux Kernel Compile on RPi 4 24](#_Toc97728996)

[Figure 20 - Second Run of defconfig Linux Kernel Compile on RPi 4 25](#_Toc97728997)

[Figure 21 - Third Run of defconfig Linux Kernel Compile on RPi 4 25](#_Toc97728998)

[Figure 22 - A Failed attempt to benchmark compiling the Linux Kernel on the UCS 26](#_Toc97728999)

[Figure 23 - First Run of defconfig Linux Kernel Compile on UCS 26](#_Toc97729000)

[Figure 24 - Second Run of defconfig Linux Kernel Compile on UCS 27](#_Toc97729001)

[Figure 25 - Third Run of defconfig Linux Kernel Compile on UCS 27](#_Toc97729002)

[Figure 26 - Table of Power Draw Readings Gathered from USB-C to USB-C Multimeter 28](#_Toc97729003)

[Figure 27 - Image of USB-C to USB-C Multimeter Reading Idle power draw of RPi 4 28](#_Toc97729004)

[Figure 28 - Table of Power Draw Readings Gathered from Panduit G5 Web GUI 28](#_Toc97729005)

[Figure 29 - Power Draw as Measured from Panduit Web GUI 29](#_Toc97729006)

[Figure 30 - Power Draw as Measured from CIMC 29](#_Toc97729007)

Table of Acronyms

|  |  |
| --- | --- |
| Domain Name Services | DNS |
| Dynamic Host Configuration Protocol | DHCP |
| Small-Medium Enterprises | SMEs |
| Network Attached Storage | NAS |
| Active Directory | AD |
| Customer Relationship Management | CRM |
| Packet Capture/Packet Analysis | PCAP/PA |
| Operating System | OS |
| Cloud Service Provider | CSP |
| Central Processing Unit | CPU |
| Error Correction Code | ECC |
| Random Access Memory | RAM |
| Double Data Rate 3 | DDR3 |
| Small Computer Systems Interface | SCSI |
| Serial Advanced Technology Attachment | SATA |
| Serial Attached SCSI | SAS |
| Redundant Array of Inexpensive Disks | RAID |
| Raspberry-Pi | RPi |
| Intrusion Prevention System | IPS |
| Intrusion Detection System | IDS |
| Not Suitable for Work | NSFW |
| Power Distribution Unit | PDU |
| Demilitarized Zone | DMZ |
| Infrastructure as Code | IaC |
| Google Cloud Platform | GCP |
| Value Added Tax | VAT |
| Virtual Machine | VM |
| Graphical User Interface | GUI |
| Cisco Integrated Management Console | CIMC |
| Unified Computing System | UCS |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

# 1 Introduction

The objective of this project is to analyse varying models of RPi’s as low energy consumption and low-cost solution for SMEs and start-ups. This will look at the RPi, analyse its performance and cost to performance when compared to a more traditional server set up and compare the cost of these solutions to what a company could also get within a cloud solution. This will also compare the reasons why these companies may want to or not want to use cloud or traditional server setups over a RPi.

This project aims to address the issue of rising energy costs and hardware costs for businesses by either initially hosting or migrating services from a traditional server or cloud infrastructure to a RPi or a cluster of RPi’s. Both the running costs and the initial hardware costs (if applicable) will be under investigation. Some of the services that will be tested on these systems will be AD, DNS, NAS and a company Webserver.

Although some practical uses of the RPi for business have been covered in the past these have been typically in-depth analysis of a single-use case of the RPi for a business, for example:

* Low-Cost network monitoring system (Maulana & Al-Khowarizmi, 2021)
* Low-Cost Real-Time System monitor (Nguye, et al., 2015)
* Intrusion Detection System (de la Cruz, et al., 2016)
* Low-Cost Small Business Brewing (Acácio de Andrade, et al., 2020)

The systems that will be analysed throughout this project are a RPi 4 Model B 2GB, RPi 4 Model B 4GB and a Cisco UCS C220-M3S.

Depending on the time constraints of the project services such as DHCP, Self-Hosted Company CRM, Honeypot and a PCAP/PA server can also be investigated.

To analyse this there will be a compilation of metrics gathered, raw performance metrics, power draw and performance statistics of the services hosted on these devices. Initial assumptions are that the RPi will be significantly lower power draw but also be significantly lower performance. This may however be ideal for services such as AD which are not as resource intensive as PA.

The project can be broken down into the following requirements:

### Requirement 1

What is the raw performance of the RPi vs server?

### Requirement 2

What is the difference in the power draw of the RPi vs server?

### Requirement 3

Using the data pulled from Requirements 1 & 2 we can then find the comparative performance per watt of the RPi vs server.

### Requirement 4

The performance of the RPi vs server when hosting the key requirement services listed below:

* AD
* DNS
* NAS
* Company Webserver

This project is intended to give a detailed insight into the tools and services that SMEs could utilise a RPi for without causing any impact on regular business operation.

## Explanation of Services

### Pi-Hole/DNS

Pi-Hole is a free open-source DNS sinkhole (Pi-Hole, 2022), this can also be referred to as a network-wide advertisement blocker and DNS forwarder. This can be utilised by SMEs and Startups as a tool to manage the websites that employees can access and filter out any websites that are NSFW. This can be beneficial as it can allow the company to monitor all the devices that are trying to access NSFW sites at work and identify any sites that may need blocking in the future. See the below Pi-Hole dashboard example taken from my home network set up:

Graphical user interface, chart

Description automatically generated

Figure 1 – A Live/Production Pi-Hole dashboard using Pi-Hole’s Dark Theme

*Note: This configuration of Pi-Hole is running on a docker container on a Raspberry-Pi 4 Model B 4GB*

* Does this explain that Pi-Hole isn’t itself a DNS server?
* Should I cover a dedicated DNS server as well or is Pi-Hole sufficient?
* Should I write up why Pi-Hole was used and not something like AdGuard – mention commercial versions
* <https://technitium.com/dns/>
* <https://nextdns.io/>

### NAS

A NAS can be utilised in several ways for the types of businesses studied in this project. This can be utilised as a generally shared network drive for all users, set up as a backup location for user’s documents and folders and even utilised as a shared drive with folders for individual teams that are managed using user groups to allow for the creation of groups for individual teams. This can be done by either setting up a samba (SMB) share for Linux this can be done by installing samba or with Windows this is supported natively the file system must be formatted in a format that is readable by both Windows and Linux for example File Allocation Table (FAT), Extensible File Allocation Table (exFAT)and New Technology File System (NTFS).

### Webserver

A webserver is utilised by businesses to host their customer-facing webpage and/or any custom internal tools that they may have built to streamline their internal processes.

### AD

AD is a Microsoft developed service that has alternatives and applications that allow for Linux servers to be the AD for the Windows clients. Microsoft defines AD as “*Active Directory stores information about objects on the network and makes this information easy for administrators and users to find and use. Active Directory uses a structured data store as the basis for a logical, hierarchical organization of directory information.”* (Microsoft, 2022). This is beneficial for all scales of business as it can allow for the creation of users and user groups. It also allows for the management of user permissions which can help a company to secure their network and devices from end-users installing malicious software. This can all be managed through a single AD server, instead of the local user approach where system administrators would have to go through each system when someone leaves to remove their user profile. AD resolves this by being the central management system for the businesses users and their permissions.

### Honeypot

A honeypot in terms of technology is a server that imitates another server that is of high interest to a malicious attacker. This can be beneficial as these can be configured to send notifications to the IT team of the business. With many of these Honeypots’ companies can also implement what is known as a Honeynet, this is a network of Honeypots that mimic a full company network. See the below diagram of an example Honeynet.

Graphical user interface, diagram

Description automatically generated

Figure 2 – An example Honeynet from imperva.com (Imperva, 2022)

### DHCP

DHCP is a protocol used within networking to provide client devices connecting to that network an Internet Protocol (IP) address and all the additional network configuration information required, for example, subnet mask and default gateway. This is under the optional requirements as a lot of business routers and ISP-provided routers will host their DHCP server making this a non-essential requirement, however, it may be beneficial for businesses to host their DHCP server like Linux’s isc-dhcp-server with a glass-isc-dhcp (Miles, 2020) web management portal as this will allow them to potentially have easier control over their DHCP leases and DHCP configuration than they may get with their ISP provided router. See the below example of glass-isc-dhcp’s dashboard:

Graphical user interface, application

Description automatically generated

Figure 3 – A demo glass-isc-dhcp dashboard (Miles, 2020)

### CRM

A CRM is a tool used by businesses to manage their customer relationships and even store information about customers who are potential leads. This tool will typically have a Webserver and Database element to it however a lot of CRM companies are now offering their services as a SaaS solution eliminating the need for a business to host this internally on their own servers.

### IPS and IDS

PCAP/PA is often utilised within systems to perform IPS and IDS for the LAN. This is a useful tool used by security analysts to monitor network traffic and can be used to identify any atypical and/or malicious network traffic. This can be helpful to identify if the business’s internal network has been compromised or if suspicious activity is occurring on the network. This has been previously investigated using a RPi 3 Model B, this worked, however, the researchers noticed a limitation with the RAM of the system (peaking at around 90% capacity) (de la Cruz, et al., 2016). This hardware limitation is where the RPi 4 Model B 4GB or 8GB models can further the throughput capacity as this system was tested with 5 clients and peaked around 29Mbps of network traffic.

### Other Services to Note

The below services will most likely not be tested within this project however are noteworthy as they either already have RPi distributions of the services themselves or they have low power requirements that allow them to be run on a RPi.

* Stratodesk – Can be used by MSPs like Country Connect
* Systems monitor (Grafana)
* The use of the RPi as a Desktop – Power consumption difference to SFF PC for web browsing
* Private Cloud using Nextcloud
* 3CX VoIP server <https://www.3cx.com/docs/recommended-hardware-specifications-for-3cx/>
* Mail server - <https://mailu.io/1.9/compose/setup.html>
* NTP server

Para to explain VDI

Para to explain Stratodesk

## E-Waste

Electronic waste (E-Waste) is the waste produced in both the production and disposal of electronic equipment. Over the past decade technology and electrical equipment have become far more ubiquitous than prior decades (Insert figure of how many devices are in a house now vs 10 years ago). This project hopes to highlight to businesses that firstly any old tech that they have can be utilised for tasks like these and that if they invest in technology like a RPi 4 Model B there are other non-traditional uses for this as they grow from a small into a medium and even large enterprise.

# 2 Background

## RPi

The RPi is a credit card sized computer that can be used for a wide range of applications from Robotics, Desktop computers, Interactive Museum exhibits and government call centres (Ltd, Raspberry-Pi. 2022). The aim of the Raspberry-Pi computers is to drive “down the cost of general-purpose computing…” (Raspberry Pi Foundation, 2022). The base cost of the RPi ranges from £34 for the 1GB Raspberry-Pi 4 Model B to £73.50 8GB Raspberry-Pi 4 Model B (The Pi Hut, 2022). Mechanical drawing of RPi 4 Model B below (Raspberry Pi Foundation, 2022):

Diagram, schematic

Description automatically generated

Figure 4 Mechanical Drawing of Raspberry-Pi 4 to illustrate the size of the device (Raspberry Pi Foundation, 2022)

## Traditional Server Set-up

Within lots of start-ups and small to medium enterprises they would “traditionally” utilise older refurbished enterprise hardware from companies such as Intelligent Servers (Intelligent Servers, 2022) and Bargain Hardware (Bargain Hardware, 2022). Both companies offer business class refurbished IT hardware such as Servers, Workstations, and Desktop PC’s/Laptops. This hardware can be brought at a wide range of prices starting from £125 (including VAT) for a barebones server up to a £69995 for a pre-configured Dell MD3420 (Bargain Hardware, 2022).

## Cloud

Over the past decade the utilisation of Cloud infrastructures has become more and more prevalent within large enterprise. The subscription-based offering provided by the cloud and its ease of scalability was beneficial to large companies as their hardware costs are higher than SMEs where they can also get exclusive contracts with cloud providers. These can then however be costly through the subscription, for example see the below pricing for Microsoft Azure’s mid-range Virtual Machine (VM) offering (Microsoft Azure, 2022):

Graphical user interface

Description automatically generated

Figure 5 A pricing table for Microsoft Azure (Microsoft Azure, 2022)

Do I mention SaaS, PaaS, IaaS?

### SaaS

### PaaS

### IaaS

## Hardware Costs of Each System

### Raspberry Pi

Currently when in stock the RPi 4 Model B can be found for the below prices:

* 1GB model £34
* 2GB model £43.50
* 4GB model £54
* 8GB model £73.50

The above prices all include VAT and reflect the price of the RPi 4 Model B as of February 2022 on the reseller sit [The Pi Hut](https://thepihut.com) (The Pi Hut, 2022). Although the RPi 3 is no longer commercially available the starter kits to these can be typically found for £40-60 on resale sites such as eBay, Facebook Marketplace, and Gumtree.

### Cisco UCS C220-M3

A similar model of Cisco UCS C220-M3S as the one used for this project can be seen as refurbished units for sale on sites like [IT in Stock](https://www.itinstock.com/cisco-ucs-c220-m3-ucsc-c220-m3s-2x-quad-core-e5-2643-330ghz-600gb-24gb-server-48623-p.asp) for £760 Ex VAT or £912 including VAT (IT in Stock, 2022).

### GCP

Although there are no initial hardware costs associated with the GCP the substantial subscription cost associated with this negates the hardware cost in a lot of instances.

# 3 Approach

This section will outline the justification of choices for Hardware, Software and Platforms used in the project.

## Hardware Decisions

The RPi 4 B was the first edition of RPi to offer varying RAM sizes with the RPi. The RPi 4 was also the first iteration of the RPi to include separate lanes to the CPU for network and USB. Prior to the RPi 4 the USB and network shared one CPU lane.

The RPi 4 has the following hardware outlined on their RPi 4 datasheet (Raspberry Pi LTD, 2019):

* Quad core 64-bit ARM-Cortex A72 @ 1.5GHz
* 1, 2 and 4 Gigabyte LPDDR4 RAM options
* H.265 (HEVC) hardware decode (up to 4Kp60)
* H.264 hardware decode (up to 1080p60)
* Supports dual HDMI display output up to 4Kp60
* IEEE 802.11 b/g/n/ac Wireless LAN
* Gigabit Ethernet port (supports PoE with add-on PoE HAT)

Comparatively the RPi 3 has the following hardware outlined on their RPi 4 datasheet (Raspberry Pi LTD, n.d.):

* Quadcore Broadcom Cortex-A53 @ 1.4GHz
* 1GB LPDDR2 SDRAM
* IEEE 802.11.b/g/n/ac wireless LAN
* Gigabit Ethernet over USB 2.0 (maximum throughput 300Mbps)
* H.264, MPEG-4 decode (1080p30)
* H.264 encode (1080p30)

The main differences between these systems are the RAM, CPU and network. The CPU processing power according to [PassMark](https://www.cpubenchmark.net/) almost doubles from the RPi 3 to the RPi 4. The score of the RPi 3’s Cortex A53 gets a CPU score of 357 compared to the Cortex A72 of the RPi 4’s CPU score of 666 (PassMark Software, 2022). These scores are calculated from other user’s submissions after running the PassMark benchmarking software.

Although it is already known that the RPi will be less powerful than the traditional server however it is also known that Linux has lower hardware requirements than a Windows server instance (see the below table).

|  |  |  |
| --- | --- | --- |
| Hardware Requirements | Debian 11 Server | Windows Server |
| CPU | 1GHz | 1.4GHz |
| RAM | 512MB | 512MB (2GB with Desktop Experience installed) |
| HDD | 10GB | 32GB |

Figure 6 - Hardware Requirements for Server OS Installations

The above table must also be considered alongside the hardware

For this project the “Traditional” server instance will be demonstrated using a Cisco UCS C220-M3S This is a 1U rackmount server with 2x X79 CPU sockets, up to 512GB DDR3 ECC RAM, up to four 3.5” or up to eight 2.5” SAS/SATA drives, 2 PCIe Gen 3 slots and 2 1GE LAN interfaces on the motherboard (Cisco Systems Inc, 2017). The 2 LAN interfaces will typically be connected with one allowing access to the servers CIMC platform, that can allow for remote configuration and management of the server. The second LAN port will then typically be utilised by the OS/Hypervisor installed on the system. For the instance of this project the hypervisor used will be ESXi installed onto the UCS C220-M3S. The hardware configuration of the UCS C220-M3S in this project is as follows:

* 2x Intel Xeon E5-2643 8 Core 16 thread CPUs @ 3.3GHz
* 16x 8GB 1600MHz DDR3 ECC RAM
* 1x LSI 9271-8i MegaRAID SAS Host Bus Adapter
* 4x 280GB 7200RPM 6Gb/s Toshiba HDD
* 4x 280GB 7200RPM 6Gb/s Seagate HDD

Text

Description automatically generated

Figure 7 – Cisco UCS M3 Boot Screen

Why was a UCS the used system for a “Traditional” Server?

The Cisco UCS C220-M3S, outlined above, was used in the place of the traditional server as it was available for me to have one racked in the Cisco Systems, Green Park, Reading Lab DMZ. This allows me to remotely access this UCS. With this available to me, the use of Panduit G5 IP managed PDUs gives greater insight into the power drawn by the server at the wall. Using the Cisco labs DMZ, I was able to access my UCS without access to Cisco’s internal corporate network. My former colleagues were also available to provide me with layer 1 support should I experience any issues.

## OS/Platform

This section will explain the platforms/OS used and why these platforms were chosen.

* Debian
* Raspian
* Proxmox/ESXi
* GCP

I will be using a hypervisor such as Proxmox/ESXi as this accurately represents both what I have seen being utilised in business and what I have read is best practice for servers. A hypervisor, also referred to as a Virtual Machine Monitor, is a piece of software that is used to create, manage, and run VMs (VMWare, 2022). Hypervisors can either be run on top of the host OS, these are classified as Type 2 hypervisors, the other one often behaves like a lightweight OS, and these are Type 1 hypervisors. For this project we Using a hypervisor has become common practice as it allows for the server’s resources to be split up into VMs that are easier to increase the CPU cores, RAM, and HDD space than on a barebones installation. This allows for Systems Administrators and IT team to increase the power of a server with the click of a few buttons as opposed to a barebones installation where the server could be down for hours whilst old CPUs, RAM modules and SSD/HDDs are removed, and new models added. The VM approach on the other hand can take a Systems Administrators and IT team 10-20 Minutes of downtime for the service which is a lot less impactful to everyday business use than the hours that may be needed for a barebones upgrade (Jackson, et al., 2020).

Following the advent of VMs and subsequentially DevOps another approach to hosting applications became more widespread. This technology is Containerization and was popularised by Docker. Docker became widely used and popular to remove the argument between Developers and Operations where applications wouldn’t work on the client machines/servers but would work on the developer’s machine. Docker provided a platform for Developers to build applications and run within a Docker container knowing that this will be platform independent so thus remove the former issue where applications would run on the Developers machine and not run in the production environment. Docker Compose was then developed as a tool to enable multi container applications, for example a developer could write one docker compose file and deploy a Linux-Apache-MySQL-PHP stack for a web application. See the below example of the Docker Compose file used to deploy Pi-Hole in the project:

version: "3"

# More info at https://github.com/pi-hole/docker-pi-hole/ and https://docs.pi-hole.net/

services:

  pihole:

    container\_name: pihole

    image: pihole/pihole:latest

    ports:

      - "53:53/tcp"

      - "53:53/udp"

      - "67:67/udp"

      - "80:80/tcp"

      - "443:443/tcp"

    environment:

      TZ: 'Europe/London'

      WEBPASSWORD: 'INSERT-PASSWORD'

    networks:

      your-network:

        ipv4\_address: 192.168.1.3

# Volumes store your data between container upgrades

    volumes:

      - './etc-pihole/:/etc/pihole/'

      - './etc-dnsmasq.d/:/etc/dnsmasq.d/'

    # Recommended but not required (DHCP needs NET\_ADMIN)

    #   https://github.com/pi-hole/docker-pi-hole#note-on-capabilities

    cap\_add:

      - NET\_ADMIN

    restart: unless-stopped

networks:

  your-network:

    external:

      name: name-of-your-docker-network

Figure 8 - docker-compose.yml file to Create a Pi-Hole Container

### RPi OS

For this project it has been decided that the OS to be used for the RPi will be RPi OS Lite (64-bit) for the RPi 4 and used for the RPi 3 to test the raw performance of this system. This is the chosen OS as this is developed and maintained by the RPi Foundation, the version used for the testing is as follows:

* Release date: January 28th, 2022
* System: 64-bit
* Kernel version: 5.10
* Debian version: 11 (bullseye)
* Size: 435MB
* SHA256 file integrity hash: d694d2838018cf0d152fe81031dba83182cee79f785c033844b520d222ac12f5

It was decided that for this testing the Lite version would be used as this share’s similarities to the Server releases of other Linux Distributions like Debian Server, Ubuntu Server etc.

### Debian

* I am most comfortable with Debian
* Raspian is Debian based
* Commands run here are the same as in Raspian so batch scripts will work on both
  + This is irrelevant for docker and docker-compose as platform independent

### Proxmox/ESXi

* Why did I choose to use a Hypervisor?
  + Most industry use them
  + Allow for better resource scaling to services and VMs on these
  + Cite (Jackson, et al., 2020) for Bare Metal vs Hypervisor installations
* Why ESXi and not Proxmox or Hyper-V?
  + Industry experience setting up and configuring ESXi
* Should I use Proxmox as it is free and open source? Especially as this is a cost-based report and analysis

### GCP

Can google be used as a good comparative for all CSP’s.

Key notes:

* Higher power models more expensive
* But for lower power models is cheaper

These differences mean that GCP is good to use for the small businesses as they will likely use the systems on the lower end of the scale.

<https://www.varonis.com/blog/aws-vs-azure-vs-google>

|  |  |  |  |
| --- | --- | --- | --- |
| Machine Type | AWS | Azure | GCP |
| Smallest Instance | An instance with 2 virtual CPUs and 8 GB RAM will cost you around USD69/month. | An instance with 2 virtual CPUs and 8 GB RAM will cost you around USD70/month. | Instance with 2 virtual CPUs and 8 GB RAM will cost you around USD52/month. |
| Largest Instance | Largest instance that includes 3.84 TB RAM and 128 vCPUs will cost you around USD 3.97/hour. | Largest instance that includes 3.89 TB RAM and 128 vCPUs will cost you around USD 6.79/hour. | Largest instance that includes 3.75 TB RAM and 160 vCPUs will cost you around USD 5.32/hour. |

Figure 9 – Table from Veritis comparing CSPs (Veritis, n.d.)

## Raw Performance

This section will outline how the raw performance benchmarks for each system will be achieved.

### CPU/Memory

To stress-test the CPU and memory in the system the following tools can be used to test these:

* GeekBench
* Sysbench
* Hard Info
* Phoronix Test Suite

The test suite that will be used for this project will be Sysbench/GeekBench. Testing will also be performed using Phoronix Test Suite to compile Firefox and timing how long this takes to compile. Compiling an application such as Firefox or the Linux Kernel is a good raw performance test of a system as this process puts a lot of strain on both CPU and Memory in the system, this is also very close to the real-world use of a software build server that is utilised in a development environment. Compiling software such as the Linux Kernel, Google Chrome and Firefox is often also used when technology reviewers like LinusTechTips, Level1Techs and Gamers Nexus.

The below commands

$ phoronix-test-suite benchmark build-linux-kernel

$ sudo apt-get install sysbench

$ sysbench –test=cpu run

$ sysbench –test=memory run

$ sysbench –test=fileio –file-test-mode=seqwr run

* <https://linuxconfig.org/how-to-benchmark-your-linux-system>
* <https://www.cpubenchmark.net/compare/ARM-Cortex-A72-4-Core-1800-MHz-vs-Intel-Xeon-E5-2643/4078vs1217>
* <https://write.corbpie.com/how-to-install-and-run-geekbench-on-ubuntu/>
* Mention defconfig option on the Linux Kernel Build

Chart, scatter chart

Description automatically generated

Figure 10 - Average Deviation of Linux Kernel Compile Runs (Open Benchmarking Org, 2022)

Chart

Description automatically generated

Figure 11 - Time to Complete Linux Kernel Compile (Open Benchmarking Org, 2022)

### Network

* Jeff Gerling RPi router video covers this <https://www.youtube.com/watch?v=w7teLVwi408&t=2s>

## How to Benchmark Performance of Different Services

This section will outline how each individual service is intended to be benchmarked.

### DNS

* How will DNS be benchmarked?
* <https://www.grc.com/dns/benchmark.htm>
* Time to Resolve?

### AD

* How do you even benchmark such a service?
* This is lightweight and typically a thousand requests can be handled per CPU core
* Can this be handled by the RPi? Could I set up a server and get hundreds of machines running joined to the AD?

### Webserver

* <https://geekflare.com/web-performance-benchmark/>

### DHCP

## IaC

This section outlines the IaC scripts and processes used for each of these.

### Docker Compose

* .yml files which utilise a Declarative IaC approach
  + Do I explain Declarative IaC?

### Portainer

* Typically run in its own docker container this can be used to manage multiple docker hosts and the containers running on them
* You can store docker compose templates which allow for an easy rebuild of the container

### Bash

* In terms of an IaC approach Bash scripts would be considered an Imperative approach
  + Do I explain Imperative IaC?

# 4 Implementation

## Network Infrastructure

### Home

* Network diagram
* Describe VLAN

### DMZ

* Brief network diagram (need to check it over with Dave)

## Docker Infrastructure

* Outline of the containers that will be run

## VM Infrastructure

* Outline the VM
  + The CPU cores (going to match the Pi)
  + Memory
  + Storage

## IaC Examples

# 5 Results and Evaluation

## Raw Performance Results

This section will analyse the results acquired by the raw performance tests below:

* Sysbench
* Timed Linux Kernel Compile

### Sysbench

#### RPi 4 – 2Gb

Sysbench CPU

Text

Description automatically generated

Figure - CPU Benchmark of RPi 4 2Gb using Sysbench

Sysbench Memory

Text

Description automatically generated

Figure - Memory Benchmark of RPi 4 2Gb using Sysbench

I/O

Text

Description automatically generated

Figure - I/O Benchmark on RPi 4 2Gb Using Sysbench

#### RPi 4 – 4Gb

#### UCS C220-M3S

Sysbench CPU

Text

Description automatically generated

Figure - CPU Benchmark of UCS using Sysbench

Sysbench Memory

Text

Description automatically generated

Figure - Memory Benchmark of UCS using Sysbench

Sysbench I/O

Text

Description automatically generated

Figure - I/O Benchmark of UCS using Sysbench

### Timed Linux Kernel Compile

#### RPi4 – 2Gb

Text

Description automatically generated

Figure - Linux Kernel Compile Failed Attempt on RPi 4

<https://openbenchmarking.org/result/2203072-FO-FIRSTRUNR33>

Text

Description automatically generated

Figure - First Run of defconfig Linux Kernel Compile on RPi 4

<https://openbenchmarking.org/result/2203070-FO-SECONDRUN71>

Text

Description automatically generated

Figure - Second Run of defconfig Linux Kernel Compile on RPi 4

Text

Description automatically generated

Figure - Third Run of defconfig Linux Kernel Compile on RPi 4

#### RPi4 – 4Gb

#### UCS C220-M3S

Text

Description automatically generated

Figure 22 - A Failed attempt to benchmark compiling the Linux Kernel on the UCS

Text

Description automatically generated

Figure - First Run of defconfig Linux Kernel Compile on UCS

Text

Description automatically generated

Figure - Second Run of defconfig Linux Kernel Compile on UCS





Text

Description automatically generated

Figure - Third Run of defconfig Linux Kernel Compile on UCS

#### RPi4 vs UCS C220-M3S

### Power Draw of Systems

#### RPi 4

|  |  |  |  |
| --- | --- | --- | --- |
| Workload | V | A | W |
| Idle | 5.25 | 0.3 | 1.575 |
| Linux Compile 1 | 5.25 | 0.8 | 4.2 |
| Linux Compile 2 | 5.25 | 0.9 | 4.725 |
| Linux Compile 3 | 5.25 | 0.7 | 3.675 |

Figure 26 - Table of Power Draw Readings Gathered from USB-C to USB-C Multimeter

* Initially thought these current figures were wrong
* <https://picockpit.com/raspberry-pi/how-much-does-power-usage-cost-for-the-pi-4/> Confirms similar A readings

A picture containing USB-C to USB-C multi meter readings

Description automatically generated

Figure 27 - Image of USB-C to USB-C Multimeter Reading Idle power draw of RPi 4

#### UCS C220-M3S

|  |  |
| --- | --- |
| Test | Average Power Draw in Watts |
| Idle | 115 |
| Linux Kernel Compile 1 | 300 |
| Linux Kernel Compile 2 | 298 |
| Linux Kernel Compile 3 | 299 |

Figure - Table of Power Draw Readings Gathered from Panduit G5 Web GUI

Background pattern

Description automatically generated with low confidence

Figure - Power Draw as Measured from Panduit Web GUI

Table

Description automatically generated

Figure - Power Draw as Measured from CIMC

# 6 Future Work

Testing of more tools

Deeper Analysis into the stability

# 7 Conclusions

# 8 Reflection on Learning

# References

Abu Sharkh, M., Jammal, M., Shami, A. & Ouda, A., 2013. *Resource allocation in a network-based cloud computing environment: design challenges,* s.l.: IEEE.

Acácio de Andrade, A., Batista Dietrich, Á., Francisco Blumetti Facó, J. & Reolon Jorge, R., 2020. *Low Cost Solution for Home Brewing and Small Brewing Business Using Raspberry Pi,* s.l.: Springer Nature.

Bargain Hardware, 2022. *Refurbished Servers, PCs, Workstations & Parts | Bargain.* [Online]   
Available at: https://www.bargainhardware.co.uk  
[Accessed 6 February 2022].

Cisco Systems Inc, 2017. *Cisco UCS C220 M3 Rack Server Data Sheet.* [Online]   
Available at: https://www.cisco.com/c/en/us/products/collateral/servers-unified-computing/ucs-c220-m3-rack-server/data\_sheet\_c78-700626.html  
[Accessed 11 February 2022].

de la Cruz, J. E. C., Goyzueta, C. A. R. & Cahuana, C. D., 2016. *Intrusion Detection and Prevention System for Production Supervision in Small Businesses Based on Raspberry Pi and Snort,* s.l.: IEEE.

Imperva, 2022. *What is a Honeypot | Honeynets, Spam Traps & more | Imperva.* [Online]   
Available at: https://www.imperva.com/learn/application-security/honeypot-honeynet/  
[Accessed 6 February 2022].

Intelligent Servers, 2022. *Intelligent Servers.* [Online]   
Available at: https://intelligentservers.co.uk  
[Accessed 1 February 2022].

IT in Stock, 2022. *Cisco UCS C220 M3 UCSC-C220-M3S 2x Quad Core E5-2643 3.30GHz.* [Online]   
Available at: https://www.itinstock.com/cisco-ucs-c220-m3-ucsc-c220-m3s-2x-quad-core-e5-2643-330ghz-600gb-24gb-server-48623-p.asp  
[Accessed 21 February 2022].

Jackson, C., Gooley, J., Iliesiu, A. & Malegaonkar, A., 2020. *Cisco Certified DevNet Associate DEVASC 200-901 Official Cert Guide.* s.l.:Cisco Press.

Maulana, H. & Al-Khowarizmi, 2021. *Analyze and Designing Low-Cost Network Monitoring System,* Medan, Indonesia: IOP.

Microsoft Azure, 2022. *Cloud Computing Services | Microsoft Azure.* [Online]   
Available at: https://azure.microsoft.com/en-us/  
[Accessed 2 February 2022].

Microsoft, 2022. *Active Directory Domain Services Overview.* [Online]   
Available at: https://docs.microsoft.com/en-us/windows-server/identity/ad-ds/get-started/virtual-dc/active-directory-domain-services-overview  
[Accessed 3 February 2022].

Miles, C., 2020. *GitHub - Akkadius/glass-isc-dhcp: Glass - ISC DHCP Server Interface.* [Online]   
Available at: https://github.com/Akkadius/glass-isc-dhcp  
[Accessed 4 February 2022].

Nguye, H.-Q., Loan, T. T. K., Mao, B. D. & Huh, E.-N., 2015. *Low Cost Real-Time System Monitoring,* s.l.: IEEE.

Open Benchmarking Org, 2022. *Timed Linux Kernel Compilation Benchmark - OpenBenchmarking.org.* [Online]   
Available at: https://openbenchmarking.org/test/pts/build-linux-kernel-1.13.0  
[Accessed 08 March 2022].

PassMark Software, 2022. *ARM Cortex A53 4 Core 1400 MHz vs ARM Cortex A72 4 Core 1500 MHz.* [Online]   
Available at: https://www.cpubenchmark.net/compare/ARM-Cortex-A53-4-Core-1400-MHz-vs-ARM-Cortex-A72-4-Core-1500-MHz/4143vs3917  
[Accessed 2 March 2022].

Pi-Hole, 2022. *Overview of Pi-hole - Pi-hole documentation.* [Online]   
Available at: https://docs.pi-hole.net/  
[Accessed 2 February 2022].

Raspberry Pi Foundation, 2022. *Raspberry Pi.* [Online]   
Available at: https://www.raspberrypi.com  
[Accessed 1 February 2022].

Raspberry Pi Foundation, 2022. *Raspberry Pi 4 Datasheet.* [Online]   
Available at: https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-mechanical-drawing.pdf  
[Accessed 3 February 2022].

Raspberry Pi LTD, 2019. *raspberry-pi-4-datasheet.pdf.* [Online]   
Available at: https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf  
[Accessed 1 March 2022].

Raspberry Pi LTD, n.d. *raspberry-pi-3-b-plus-product-brief.* [Online]   
Available at: https://datasheets.raspberrypi.com/rpi3/raspberry-pi-3-b-plus-product-brief.pdf  
[Accessed 1 March 2022].

The Pi Hut, 2022. *The Ultimate Raspberry Pi & Maker Store.* [Online]   
Available at: https://www.thepihut.com  
[Accessed 1 February 2022].

Veritis, n.d. *AWS Vs Azure Vs GCP – The Cloud Platform of Your Choice?.* [Online]   
Available at: https://www.veritis.com/blog/aws-vs-azure-vs-gcp-the-cloud-platform-of-your-choice/  
[Accessed 13 February 2022].

VMWare, 2022. *What is a hypervisor?.* [Online]   
Available at: https://www.vmware.com/topics/glossary/content/hypervisor.html  
[Accessed 21 February 2022].