MCOMD3AOS – Advanced Operating Systems Assignment 2

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Due 11/5/22

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Introduction

Additive manufacturing is a process in which 'parts are built-up by adding new material in a layer-wise fashion, rather than removing material by machining or similar operations to achieve the final shape' (Sandia, 2022). The two main applications are rapid prototyping and 3D printing.

This process is becoming exponentially more popular, both for personal, in-home use and in industry. According to a report by Hubs (2021), the market value of additive manufacturing is set to grow exponentially:

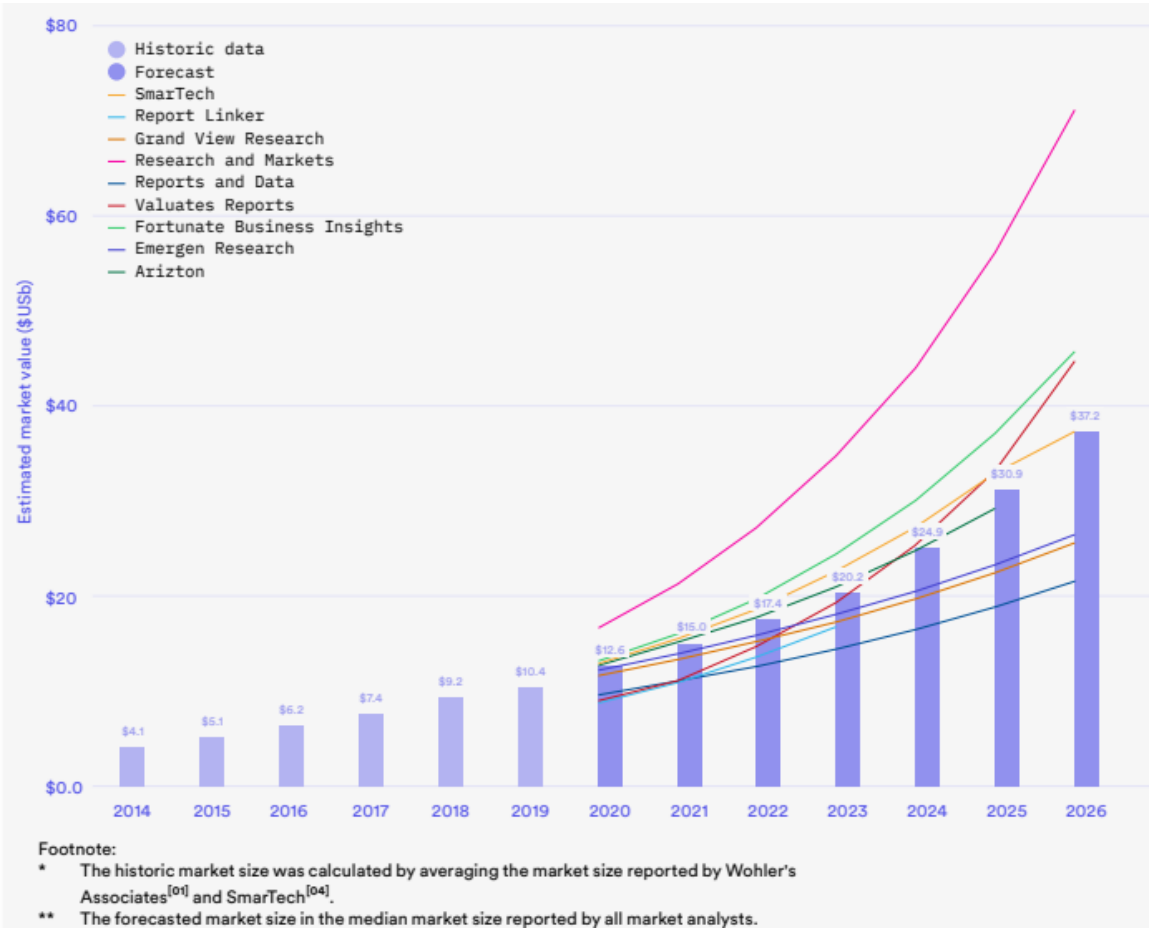

Figure 1- Graph Showing Projected Growth of 3D Printer Market with Historical Data[1]

However, these machines are still expensive, Ultimaker's (2022) cheapest machine in their current range is still ~£4,300, and the most expensive, the S5 is ~£6,800 (costs not exact as they can be customised depending on requirement).

[1] Roberts, Tess and Bartkova, Barbara (2021) *Additive Manufacturing Trend Report 2021*
Accessed at: https://www.hubs.com/get/trends/
Accessed on: 24.3.2022

Since they are expensive machines, users require a way to monitor them to ensure correct performance, to be able to remotely know if there is for example a simple issue of an item being printed incorrectly to the machine being physically broken.

This report describes a solution to this issue, by using an array of Single-Board Computers (SBC) with attached cameras to monitor each machine. The basic idea is that the SBCs will take pictures regularly, and these images will then be sent to the cloud where users can view them. This will allow them to leave the 3D printers alone and can remotely see how the process is going.

Background Information

Assumptions

For this project, several assumptions have been made:

Assumption	Explanation
30 Ultimaker S5 printers	Ultimaker is a leading 3D printer brand, and the S5 is their flagship device.
Existing infrastructure	The setup will be in a room with adequate and reliable power, and furniture to position the printers and other devices.
Room size	The minimum size of room needs to be 6 by 6.5 metres to accommodate the printers, furniture and space for the components needed for this solution. A larger room would be better for the operation to scale.

Criteria for Hardware and Software

The main criteria for choosing hardware and software are:

Criteria	Explanation
Cost	Cheaper is better. With regards to software, free/open source is preferable.
Mean Time Between Failures (MTBF)	The longer the time between the device failing, the better. It is measured in hours, and is calculated thus: MTBF = Total number of operational hours / Total number of failures.
Features	Some of the key features the SBC will need are: • Wi-Fi. If there is no built in Wi-Fi then a dongle and an additional USB port will be needed. • I/O – Camera, 1x USB, HDMI. If no camera input, an extra USB port is required. • At least 500 MB RAM • Ability to run Linux based OS The camera will need: • High quality images The routers will need to support at least 30 devices, and one will be needed that can handle streamed video.
Size (physical)	Smaller size is preferred as it makes mounting the device on the 3d printer easier.
Size (digital)	Software that takes up less space is preferable as it leaves more space for higher quality video and images.
Availability	With the current global chip shortage and supply crisis, sourcing components will be difficult.

Note that many of the requirements for hardware features were informed by the SBC choice.

Proposal

The intended solution is for each 3D printer to have an SBC with camera attached, that will take pictures regularly and send them to internet storage to be analysed.

Components

Hardware

The proposed SBC for this system is the Raspberry Pi Zero 2 W, with the Raspberry Pi Camera Module 2 attached using the Pi Zero short camera cable. Each will be powered by the official Raspberry Pi micro-USB power cable. Each Pi will also have its own case, the official Pi Zero case.

The chosen OS (Octopi, see below) allows the Pi to run headlessly out of the box, negating the need for additional peripherals. For the network, 3 routers are needed, 2 Linksys EA7500 routers and one MikroTik hAP AC Lite Router. Two Cat 6 cables are required to link the routers.

Software

The proposed OS is Octopi. This comes pre-installed with the camera packages as well as other software that can be used for monitoring printers.

Other software needed is the CPUFreqUtils package.

Physical Setup

Since an Ultimaker S5 is 495 x 585 x 780 mm (Ultimaker, 2022), This assumes at least 100 mm of space is between each printer to ensure space for the SBC and cooling, and there is a space in the centre of the room for the router as well as room between tables for people to walk. The printers and SBC systems will be set up like this:

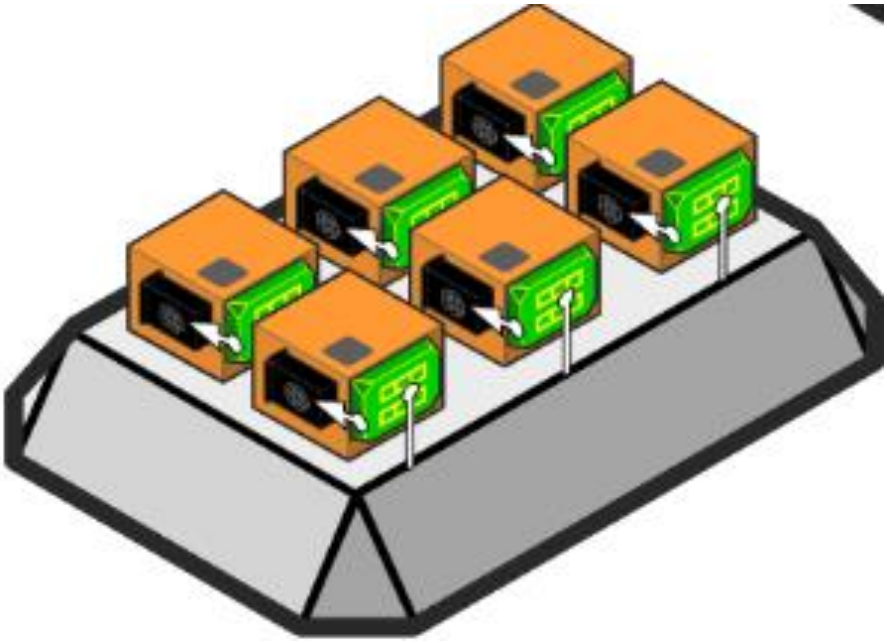

Figure 2- Setup for 1 table of printers, SBCs and Cameras

Putting them like this allows for the most efficient use of space. There will be one Linksys router for the SBCs and one for the printers, they will both be connected to the MikroTik router. They will be linked with Cat 6 cables, in this setup:

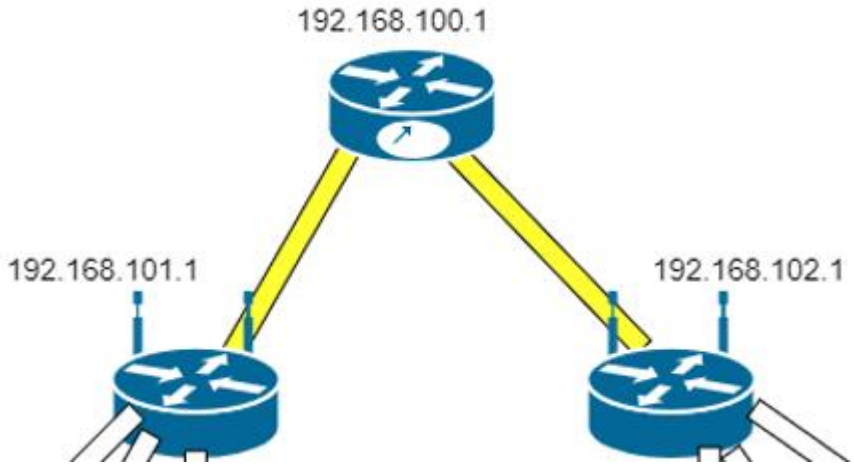

Figure 3- Setup of routers

The full logical and physical layout diagrams are in the appendices.

Technical Explanation

Hardware

SBC

For this hardware, several options were researched, including members of the Raspberry Pi range, ODROID hardware and other alternatives.

Raspberry Pi's

Raspberry Pi is the best know SBC brand, known for their affordability as well as versatility. They are primarily Linux based.

The main disadvantage with Pis currently is availability. Whilst all instances of computer hardware have been suffering from global supply problems, Raspberry Pi's have been hit particularly badly due to many people wanting to buy them over the pandemic. Eben Upton (2021), the founder and creator of the Raspberry Pi has said: 'The result has been a shortage of some products, notably Raspberry Pi Zero and the 2GB variant of Raspberry Pi 4.' The result of this was an increase in price to both these devices, and for a time there was a limit to how many could be purchased. Another update issued by Upton (2022) stated that currently they are going to 'prioritise commercial and industrial (customers)… There is currently enough supply to meet the needs of those customers.'

Raspberry Pi 4 Model B

This is the current flagship model of Raspberry Pi. It is the most powerful available and has 4 options for RAM (see technical comparison). For this project 1GB is sufficient, it would be unnecessary to purchase one of the other models. The 1GB model is not powerful enough to run Windows.

Raspberry Pi Zero 2 W

This is the latest version of the Pi Zero, which is a smaller, cheaper Pi designed specifically for projects as opposed to also for general computing. This was investigated over the original Zero W since it has a considerably more powerful CPU.

As with the Pi 4B, there is a limit on availability due to the global supply and chip crisis, but not to the extent as with the 4B.

ODROID

The next best known SBC brand is ODROID. There are several different models, and since this is an unfamiliar platform, the various devices available through ODRIOD European Distributor were a good starting place for a clear way to see the differences in the various hardware. As the name suggests, they can run Android as well as Linux.

ODROID-C1+

The device investigated is one that met the requirements, but only just as these would theoretically be the cheaper devices. This device released in 2015 features 1 GB of RAM with a 1.5GHz 4 core CPU. It is the least powerful, most recent device that can run Linux OS's. It features 4 USB ports, which will be used for the Wi-Fi dongle and camera. From the ODROID European Distributor (2022), they are £62.41 + 6.23 for PSU and £6.23 for a plastic case, for a total of £74.87 per unit.

Other

Mac Mini

Whilst not technically an SBC, the Mac Mini is an example of an SoC (System on a Chip). Whilst an unlikely choice, it was still beneficial to research an example that uses a different OS and is part of a different ecosystem. The Mac Mini uses the Apple M1 SoC, the only other component that is there is the RAM and storage.

Advantages and Disadvantages of SBC Options

Model	Advantages	Disadvantages
Pi 4B (Raspberry Pi Foundation, 2022)	• Power/price – For the price, a very powerful device. • RAM options – Can choose between 1 GB, 2 GB 4 GB and 8 GB. 1 GB is plenty for this project	• Availability – Like all similar hardware there is currently limited supply
Pi Zero 2 W (Raspberry Pi Foundation, 2022)	• Size. Due to not having ethernet or full-size USB ports, it is much less bulky and so will be much easier to mount on the printers with the camera. • Price – considerably cheaper than the main line of Pi's	• Unique camera connection cable required – An additional cost. However, is available bundled with cases
ODROID C1+ (ODROID European Distributor, 2022)	• Better supply – Less popular therefore easier to source than the market leader Raspberry Pi's. • Built-in heat sink – Cooling is less of a concern.	• Lack of built-in Wi-Fi – A USB dongle would have to be purchased for each device (it would not be practical to use ethernet cables for 30 computers). This is an additional cost • Lack of camera connection - An additional USB port is required to attach a USB camera. • Unit now discontinued. Whilst still available, may be hard to source more in the future if the project scales.
Mac Mini (Apple, 2022)	• Build Quality - Apple has earned a great reputation for this • iOS ecosystem – Could be considered the cheapest entry to the iOS ecosystem, if corporate higher-ups were insistent on using iOS devices. • 3-year warranty available • Considerably more powerful – one Mac Mini could handle cameras for multiple printers, so less would be required	• Price and the intentions of the device - Designed as a general desktop PC, rather than for hardware projects such as this one. • No longevity guarantee – No MTBF data provided, no guarantee as to how long the device will last. Whilst the aforementioned warranty is useful, it is more beneficial to know how reliable the device is from the outset. • Physical shape and size – may prove unwieldy for mounting on 3D printers.

Technical Stats Breakdown and Comparison

SBC	Pi 4B	Pi Zero 2 W	ODROID C1+	Mac Mini
RAM	1/2/4 GB DDR4 (1 GB will be used)	512 Mb DDR3	1 GB	8 GB
CPU	4x USB, HDMI, Camera attachment	Mini HDMI, micro-USB	4x USB, HDMI,	2x Thunderbolt, 2x USB, HDMI
Built-in Connections	Wi-fi, Bluetooth and Ethernet	Wi-Fi, Bluetooth	Ethernet	Wi-Fi, Bluetooth and Ethernet
Size (mm)	85x56	65x30	85x56	197x197
Price	~£34 (More expensive for higher RAM models)(Farnell, 2022 [3]) Not currently widely available, quote required for cost and time.	£13.34 (Farnell, 2022[4])	£62.41 (ODROID European Distributor, 2022)	£622 (Amazon, 2022 [1])
Availability Notes		373 days – (Farnell, 2022 [4])	Only 9 can be purchased (ODROID European Distributor, 2022)	Only 2 can be purchased at a time (Amazon, 2022 [1])
Obsolescence	At least January 2026 (Raspberry Pi Foundation, 2022)	At least January 2028 (Raspberry Pi Foundation, 2022)	Now discontinued, but still available	Not available
MTBF	7-10 years (Fromaget, 2021)		Not found	Not found

Final Choice

The Raspberry Pi Zero 2 W was chosen due to it being the smallest, cheapest option whilst still fulfilling the needs.

Camera

Raspberry Pi themselves offer two cameras that would be relevant to this solution: the camera module 2 and the high-quality camera. Also available is the NoIR camera (No InfraRed filter), however this is not suitable as it is optimised for low light environments. Ultimaker machines have lights built-in making this feature redundant.

Camera Module 2

The standard Raspberry Pi camera, it 'has a Sony IMX219 8-megapixel sensor… (it) can be used to take high-definition video, as well as stills photographs'.

High-Quality Camera

This is larger than the standard camera, it is designed to support 'CS-mount lenses and, with the supplied adapter, C-mount lenses' (Raspberry Pi, 2022). This means it can take significantly higher quality images than the standard camera.

It is however considerably more expensive than the standard camera, costing £48.99. Also, it has a higher power requirement than the standard one. Whilst the high-quality camera is a viable option, ultimately for this system the images do not need to be higher quality, making this an unnecessary extra cost. If this option where to be chosen, more planning and work is needed for mounting the camera on the 3D printers due to its greater size.

Additional Camera Connection

Since the Pi Zero does not natively support the Camera module, another connector is needed. The official one is supplied with the official Pi case.

Network Hardware

Router

Since the Pi Zero 2 W has built in Wi-Fi and no ethernet port, routers should be used instead of switches. There will be one for the Pi's, one for the printers and another for linking them. The two would need to handle at least 30 devices and be reliable with a high-speed connection for streamed video.

The device suggested for the Pi's and printers the Linksys EA7500. According to Amazon (2022)[2], it has MU MIMO (Multi User Multiple Input Multiple Output) which provides Wi-Fi to multiple devices at once, at the same high speed.

The router that acts as a bridge will be the MikroTik hAP AC Lite Router as it is a cheap solution with good reviews (Linitx, 2022)

Cables

Cat 6 cables are to be used. These have better shielding than Cat 5e, and so less interference which means better performance. Using Cat 6 also helps future proof the system.

Other Hardware

Micro SD card

The Micro SD being used is the Samsung Pro Endurance 32GB. 32GB is the highest size that can be used with a Pi, and is the smallest size available of this card. According to Piltch (2022) it has “long lifespan….Strong app open, boot times…Leading 4K random reads”. Since video and high quality images are being used, the 4k read is useful. Also the higher size allows for scaling if later on more/larger software is needed. The price is fairly high for an SD card, (£15.54), but since this is likely the first hardware to fail it is worth paying more for better performance.

Power Supply

The Raspberry Pi Zero 2 W is powered by micro-USB power. Whilst there are countless examples of these available (a search on Amazon.co.uk yields over 70,000 results), the best option to go with is Raspberry Pi’s own example. This is because it has been tested to meet the exact power requirements for the Pi, and so should theoretically have a high MTBF.

Case

To protect the Pi, the official Pi Zero case will be used.

Network and Additional Hardware Breakdown

Component	Supplier	Availability	MTBF
Linksys EA7500	Amazon	In stock (Amazon, 2022) [1](As of 4/5/22)	Not found – but 3 years warranty available
MikroTik hAP AC Lite Router	Linitx	In stock (As of 4/5/22)	Approximately 100,000 hours at 25C (Mikrotik, 2022)
Camera module 2	RS	In stock (As of 1/5/22)	
Power supply	Farnell	In stock (As of 1/5/22)(Farnell, 2022 [5])	50,000 hours (EET, 2022)
Samsung Pro Endurance SD card	Farnell	36 day wait (Farnell, 2022 [2])(As of 2/5/22)	17,520 hours (Samsung proprietary, 2018)
Bel Cat 6 cables 1.8m	Farnell	In stock (Farnell, 2022 [1])	Not found

Software

With the choices of hardware made, the software that they would use then needed to be considered.

Operating System

Raspberry Pi OS

This is the default OS for the Raspberry Pi. It is a version of Debian that has been adapted for use with the Raspberry Pi. Since the Pi is designed as both a computer for use in projects and as an affordable solution for general purpose computing, it comes pre-installed with a GUI, web browser and the usual productivity tools (word processor, spreadsheets etc.). Since Raspberry Pi's are also intended for education, Python and other languages are pre-installed.

Octopi

Octopi is based off Raspberry Pi OS but is optimised for use with 3D printers. According to developer Guysoft (2021), it features 'OctoPrint host software for 3d printers out of the box… Raspbian tweaked for maximum performance for printing out of the box …. mjpg-streamer with RaspiCam support for live viewing of prints and time-lapse video creation.'

Advantages of this OS is its optimisation for controlling and monitoring 3D printers. The pre-installed OctoPrint software can turn this system from simply being for monitoring to actively controlling the printers. The MJPG streaming is also automatically set up when a camera is plugged into the Pi.

Another advantage is the OS image has Wi-Fi and SSH pre-enabled, these do not have to be configured, and peripherals do not have to be purchased for setting up the Pis. Since this OS is built off of Raspberry Pi OS, it gives access to the other features of that OS.

Other Software

CPUFreqUtils

This is a Linux package created by Dominik Brodowski that is 'a user-friendly alternative to using the Sys interface.' (ThinkWiki, 2007). It allows CPU frequency values to be manipulated using a single line command, rather than having to cd into different files to change values manually. This is especially useful as there can be issues with file permissions when handling this. It can be installed through the command line using `$ sudo apt-get install cpufrequtils`.

Bill of Material

All prices include VAT.

Material	Cost for 1	Quantity Needed	Total Cost	Supplier
Raspberry Pi Zero 2 W	£15.33 (delivery free when purchasing high volume)	32	£427.01	Farnell
Raspberry Pi Camera Module 2	£24.30	32	£715.96 (discounted by £2 each when buying in bulk)	RS
Raspberry Pi 12.5W Micro USB power supply	£7.12	32	£227.71	Farnell
Raspberry Pi Zero Case (comes with short camera cable)	£4.45	32	£142.46	Farnell
Samsung Pro Endurance SD card	£15.54	32	£497.28	Farnell
Linksys EA7500 router	£249.43	2	£498.86	Amazon
MikroTik hAP AC Lite Router	£42	1	£42	Linitx
Bel Cat 6 cable	£3.72	2	£7.44	Farnell

Totals

	One unit	All
Total cost per unit (SBC, camera, power supply, case, SD)	£66.74	£2,135.68
Total cost per core SBC (SBC, power supply, SD)	£37.99	£1215.68
Total cost per camera setup (Camera, case)	£28.75	£920
Total cost of network equipment (Routers, cables)		£548.30
Grand total (all hardware required)		£2,683.98

Conclusion

In conclusion, this system aims to provide the best value solution, whilst still being scalable and long lasting.

One of the main downsides with this project was availability of components, meaning that either there are long delays before the setup can be completed, or 2nd choices have had to be made with components. This was mainly with regard to the SBC due to the global chip shortage.

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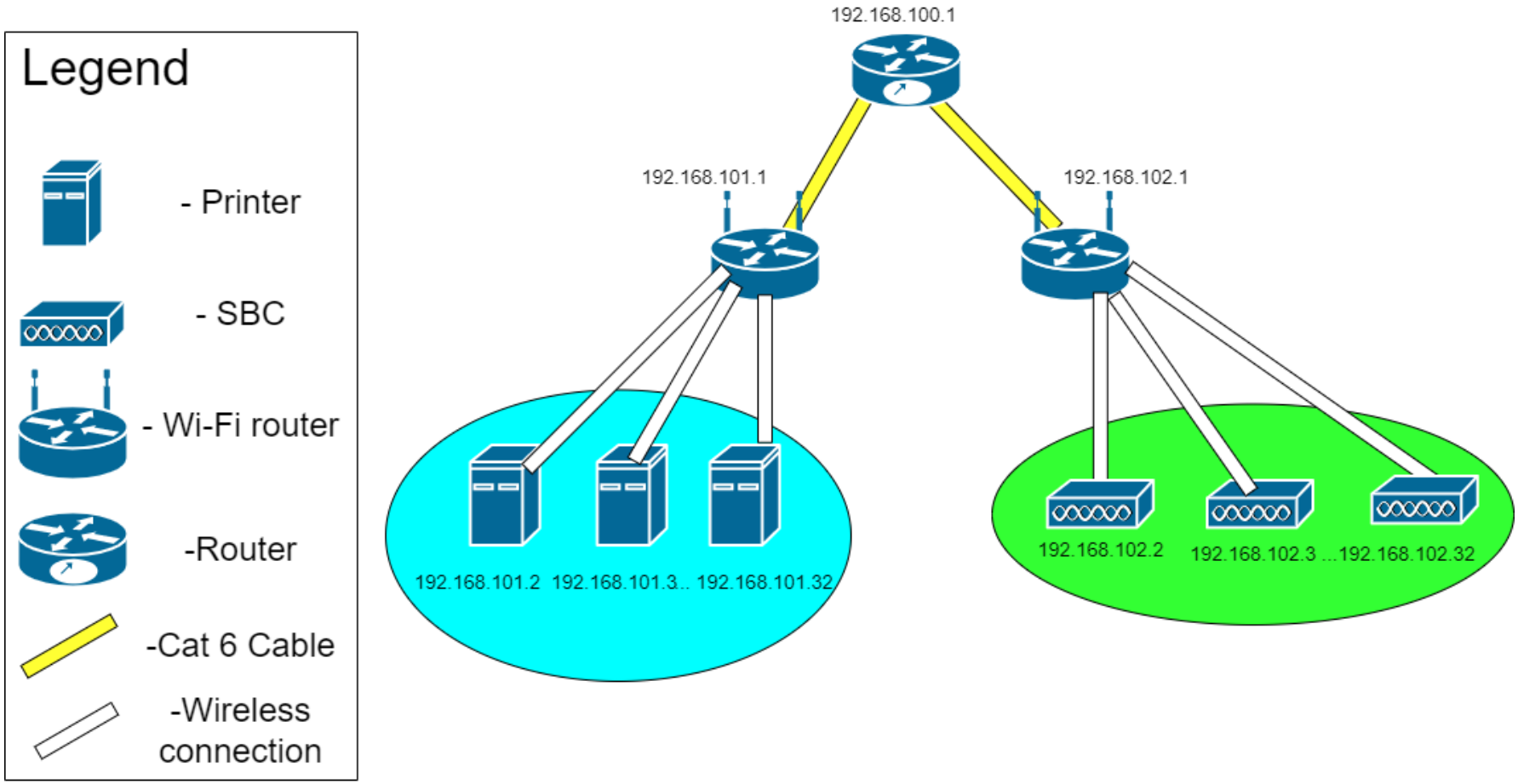
Figure References

Figure 1: Roberts, Tess and Bartkova, Barbara (2021) *Additive Manufacturing Trend Report 2021* Accessed at: https://www.hubs.com/get/trends/ Accessed on: 24/3/2022

Appendices

Logical View Diagram



Physical System Setup