University of Hertfordshire
School of Computer Science
BSc Computer Science (Networks)

Module: Network Protocols and Architectures

Network Design Project Report

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Level 6

Academic Year 2020 – 21

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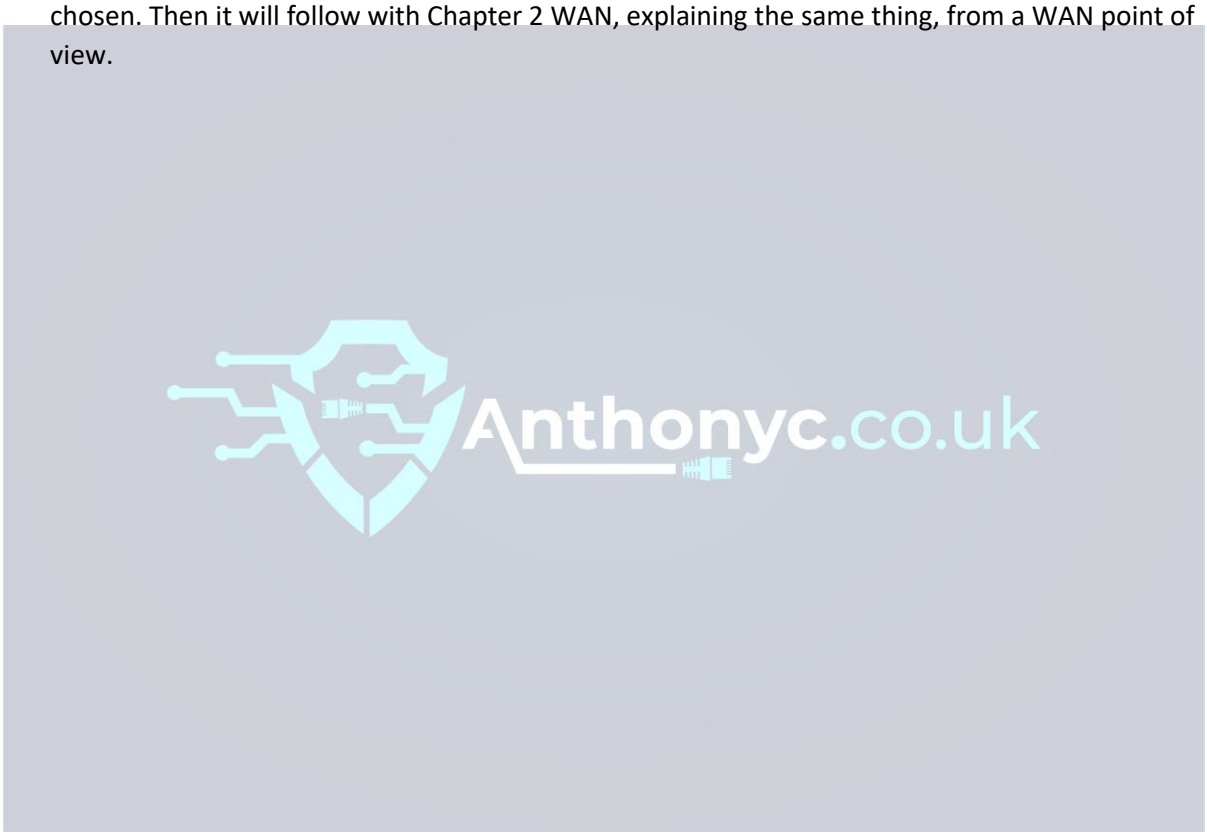
Implementing the Network Designs

1.0 Introduction

This report will be completed in response to the assignment requests for determining and evaluating three network diagrams illustrating the solution. One physical and one logical for the LAN network design and one logical for the WAN. The Network designs created is intended to fulfil the specifications and justify the choosing of the network hardware. Furthermore, the solution will present all network devices, hardware and cabling which is required for the project.

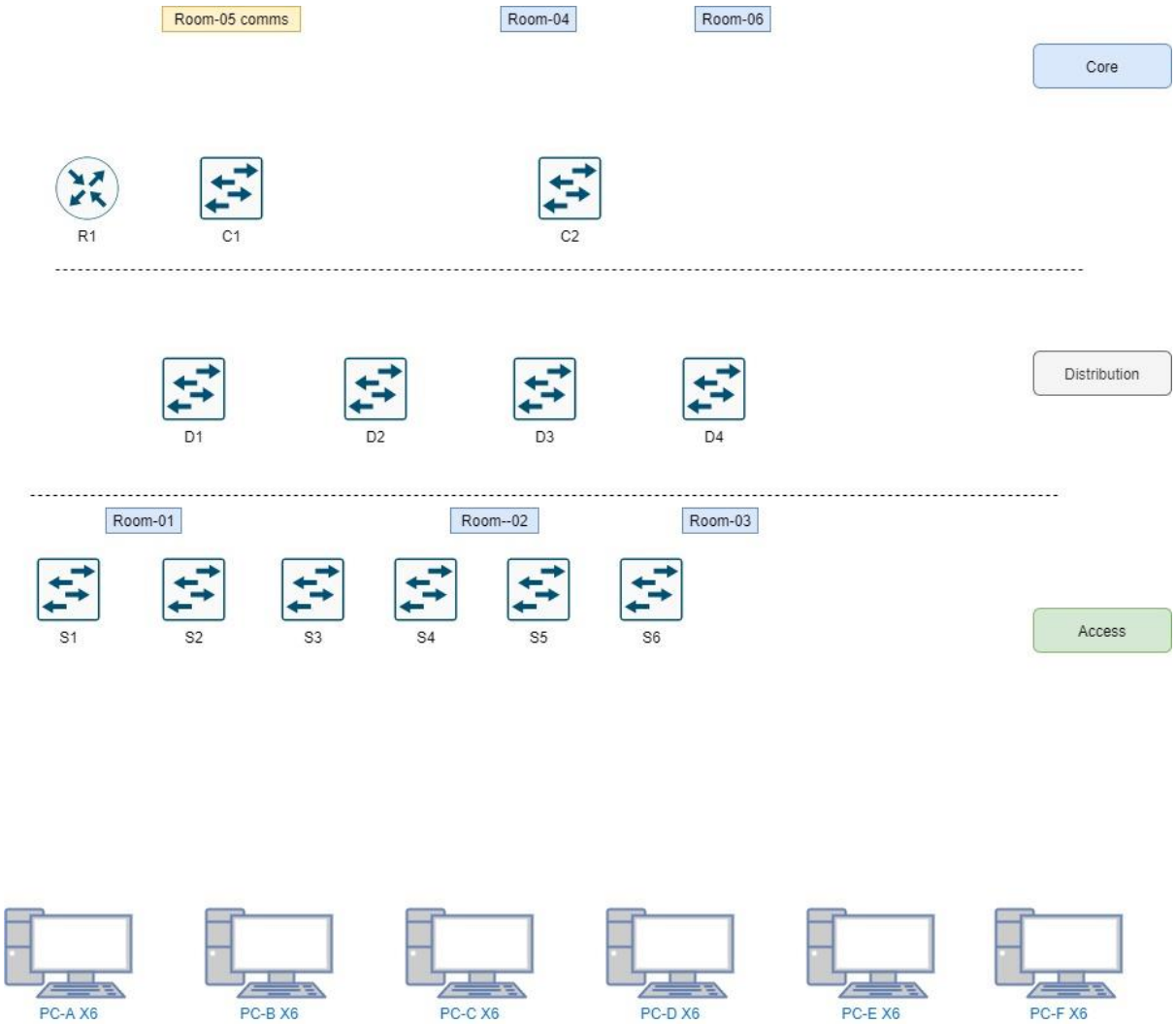
This report firstly describes the two diagrams within Chapter 1 LAN then, a justification of how the design and legends fulfil the specifications and a critical evaluation of the Network hardware chosen. Then it will follow with Chapter 2 WAN, explaining the same thing, from a WAN point of view.



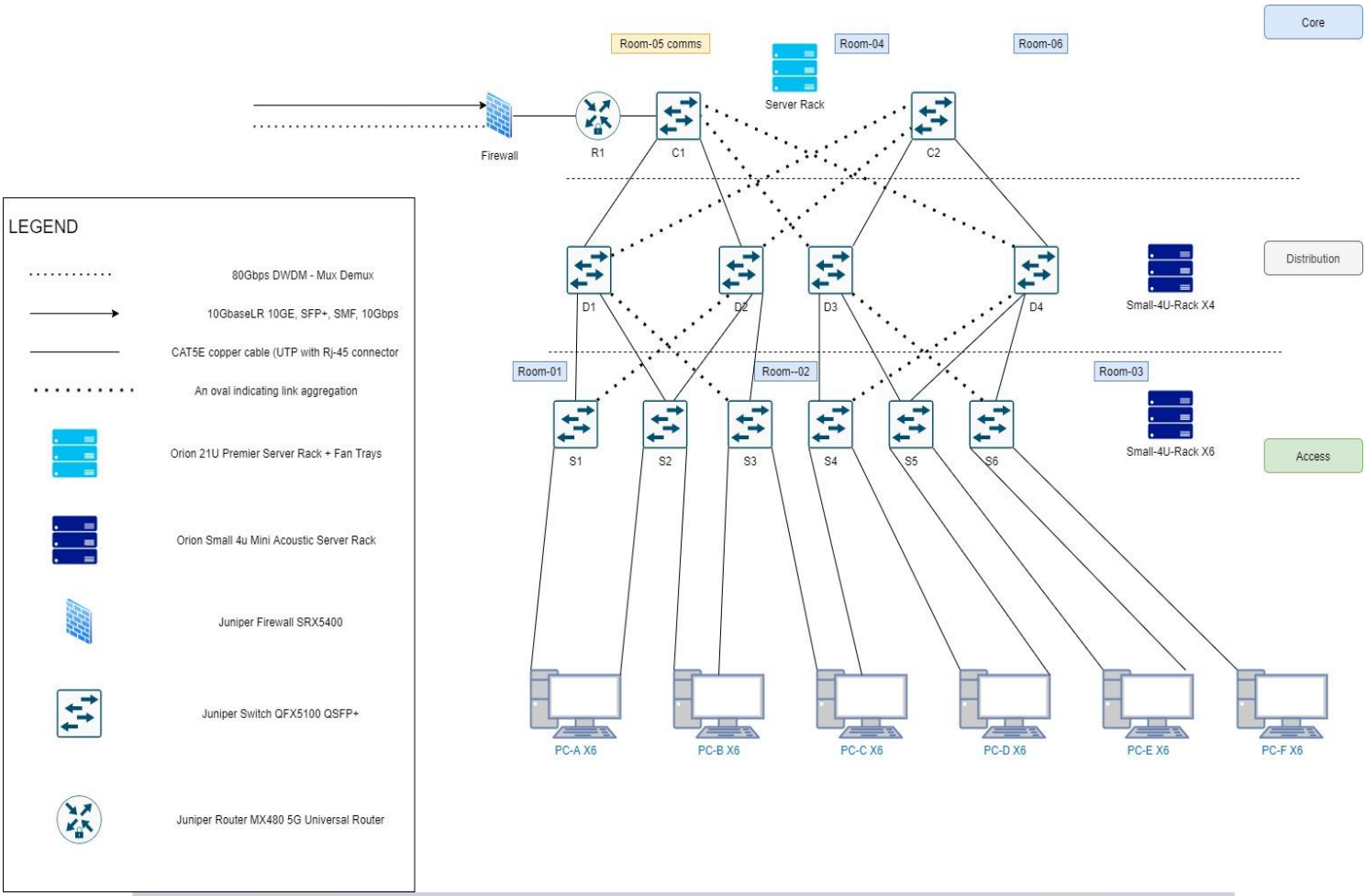
2.0 Chapter 1 - LAN

2.1 The Logical and Physical Diagrams

The image shown below represents the Logical diagram using the three-layered hierarchical cisco model.



The image shown below represents the physical diagram revealing all network devices, hardware and cabling required.



2.2 Design Description

This section will provide a justification of how the designs and legends shown above meet the specifications. For example, redundancy, scalability, benefits of the three-layered hierarchical cisco model, the design and cabling.

The first diagram shown in the images above is the logical diagram, and it shows that it uses the hierarchical cisco network design model as part of the LAN set-up. The logical design also reveals it has three different layers such as the Access, Distribution and Core layers. The Access layer consists of all end devices such as PCs, printers and telephones. the intended purpose is to connect these devices to the network and controls the access of which devices can communicate on the network. The Distribution layer is responsible for controlling the flow of network traffic, by using policies and aggregates the data incoming from the Access layer before transmitting it to the Core layer, for routing the next destination. Finally, the Core layer is essential for interconnectivity between Distribution layer devices, so it is also essential for the core layer to be highly available, redundant and top speed. Furthermore, the core area will also connect to the Internet for the intended purpose of this design, and the core will also aggregate the traffic incoming from the Distribution layer devices.

There are many benefits to using the Cisco model. One of the benefits of implementing the Cisco model regarding the LAN design, is that its easily manageable compared to a typical standard network setup. Another benefit the Cisco model provides here, is better performance overall, because it allows the potential to create high speed and performance networks. It also provides better scalability as the design allows to easily expand for future growth. As you can see from the image in the previous section, it was decided to implement Bandwidth Aggregation into the design represented by black dotted lines, which means by combining several parallel links between two switches into one logical link. As a result, by implementing link aggregation within the design, it has increased the overall reliability and availability of the network.

Overall, the design created in the image above provides better redundancy as multiple links across multiple devices are connected and therefore, if a switch goes down another switch is setup to alternate the path to reach its destination. As a result, this also improves the overall links between hierarchical network layers to ensure network availability. It could be said that it was decided to deploy 6 PC's in different lettered work groups as shown in the design, in order to to implement a Micro segmentation methodology which is aimed to increase the overall network performance and decrease packet collisions. Furthermore, it was decided not to daisy chain the network switches, as it could pose a potential threat of either overloading the network or if a Blackhat hacker, hacked one of the switches, they would have full access to all other the switches within the network, which could be a huge liability for the organisation.

2.3 Network Hardware

The second diagram reveal the physical layout of the LAN set-up. The design provides all the cabling required and additional hardware devices, as well as providing a legend to describe the network hardware devices chosen, which will be critically evaluated in this part of the report.

Device ID: 1
Device Name: Switch
Device Model: QFX5100-24Q 10/10GbE Ethernet switches
Reference: https://www.juniper.net/uk/en/products-services/switching/qfx-series/qfx5100/ by Juniper

Device Description:
The QFX5100 composes access and top-of-rack 10/10GbE Ethernet switches. The switch provides for universal building blocks for industry standard network architectures. It could also run up to 2.56Tbps which provides a seamless connection within the network.

Critical Evaluation:
The specification outlines x6 PCs are required for each office room and therefore, it has been decided to pick the QFX5100-24Q 10GbE switch model which supports up to 32 QSFP+ ports, which will provide for better scalability. The switch device also runs up to 2.56 Tbps, which will provide seamless connection throughout the network, within the organisation.

Device ID: 2
Device Name: Router
Device Model: MX480 5G 100GbE – Universal Router
Reference: https://www.juniper.net/uk/en/products-services/routing/mx-series/mx480/ by Juniper

Device Description:
The MX480 Universal router is SDN-enabled and offers up to 9 Tbps of system capacity in support of 10GbE, 40GbE and 100 GbE interfaces as well as SONET/SDH connectivity.

Critical Evaluation:
The specification requires the router to have a minimum of 8x10Gbps SFP+ ports to connect the WDM and therefore, it has been decided to choose the MX480 model which has 10x10Gpbs ports, which is SDH and supports STM64 to connect it.

The router is also SDN(software-defined networking) enabled which is a good approach to communicate with hardware and the direct traffic on a network. SDN consist of controllers which offers an overall view of the network and allows you to manage and control it. The MX480 also comes with 5G connectivity and therefore, if the switches fail, it could be said that 5G would be an alternate connection providing for better availability and redundancy within the network. The MX480 also has 10x10Gbps ports which is SDH and supports STM64 and therefore, it is fully compatible with the WDM.

Device ID: 3
Device Name: Firewall
Device Model: SRX5400
Reference: https://www.juniper.net/uk/en/products-services/security/srx-series/srx5400/ by Juniper

Device Description:
The SRX5400 firewall is a next-generation security platform designed for businesses and industries, which also offers up to 10 GbE, 40GbE and 100 GbE connectivity options.

Critical Evaluation:
The specification requires at least one hardware firewall to be connected to the border router. Therefore, the SRX 5400 was chosen as it has provided enough ports, which could be easily connected between the router and WDM. This is essential in order to monitor the network traffic and prevent any unauthorised access, entering the network incoming from outside of the organisation. The SRX5400 also provides 5G connectivity and therefore, if the cabling fails then it could be said that 5G would be a suitable alternative to keep the network up and running safely. It also provides up to 270 Gbps Firewall, and 60 Gbps VPN performance.

Device ID: 4
Device Name: Server rack
Device Model: Orion 21U Premier+ Fan Trays
Reference: https://www.rackcabinets.co.uk/products/21u-premier-server-rack-600-x-1200#features + https://www.rackcabinets.co.uk/collections/rack-cooling/products/fan-trays by Orion

Device Description:
The Orion 21U Premier Server rack is a sleek reinforced steel structure making them suitable for housing servers. It also includes a swing handle lock front door providing security and additional fans to keep the systems running smooth.

Critical Evaluation:
The specification requires that most devices in the Comms room will need racks. With that being said, the Orion 21U Premier rack is the most suitable option, as it comes with enough space to house many servers and potentially more for the scalability purposes of this project. It also comes with a handle lock as standard, which is essential for preventing any unauthorised users from touching the physical servers. Furthermore, the additional option to add fans to the rack which has been added, to prevent the servers from overheating and intended to keep them at a suitable temperature.

Device ID: 5
Device Name: Server rack
Device Model: Orion Small 4u Mini Acoustic
Reference: https://www.serverroomenvironments.co.uk/4u-racks/4u-mini-acoustic-server-racks-600-wide-800-deep by Orion

Device Description:
The Orion 4u Mini Acoustic server rack is a small server rack for applications requiring noise reduction and protection.

Critical Evaluation:
The specification suggests that a small 4u rack can be installed in any room if necessary. It was decided to add the small 4u racks to the Access and Distribution layers, to prevent any unauthorised users from touching the physical switches/servers. Furthermore, the 4u mini racks suggests that extra fans could be supplied as an option in order to increase heat dissipation which is essential, considering the quantity of switches running in each room. Lastly, as you can see from the network diagram, 6 racks have been deployed within the Access layer, and 4 deployed in the Distribution layer to house each server.

Device ID: 6
Device Name: Ethernet cable
Device Model: CAT5E Gigabit Ethernet
Reference: https://www.cablemonkey.co.uk/cat5e-cable/50518-ccs-cat5e-utp-cable-pvc-outer-sheath.html by Cablemonkey

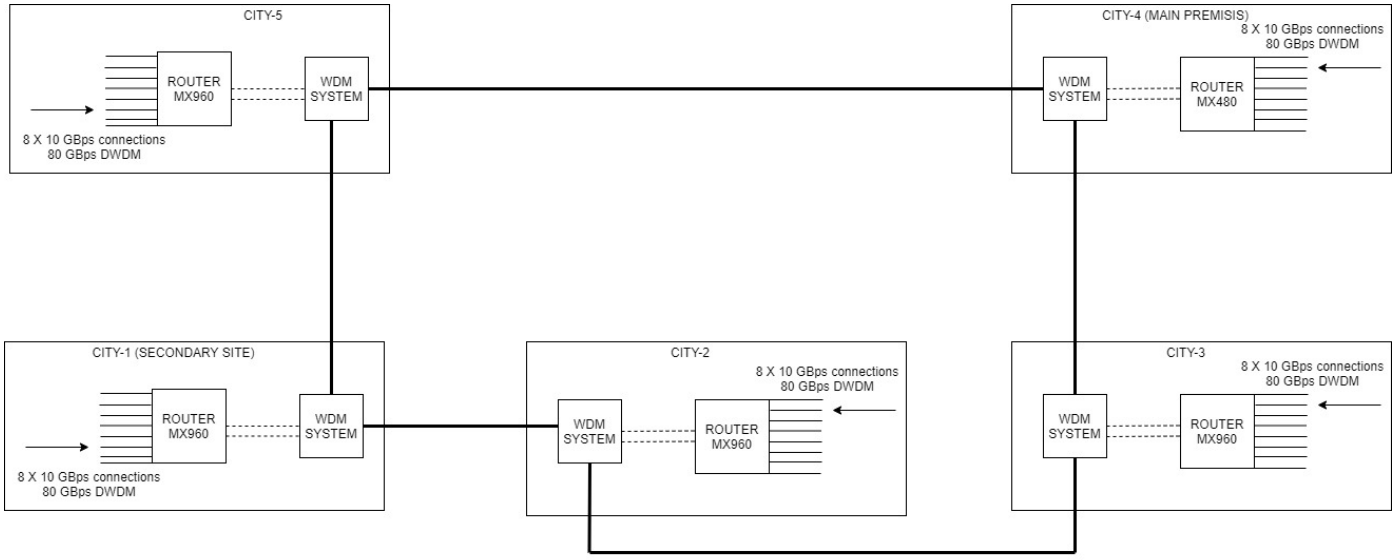
Device Description:
CAT5E which is an enhanced Cat 5 cable which is 1Gbps maximum speed. Also, CAT5e will support this speed better in larger distances (100m max) and noise.

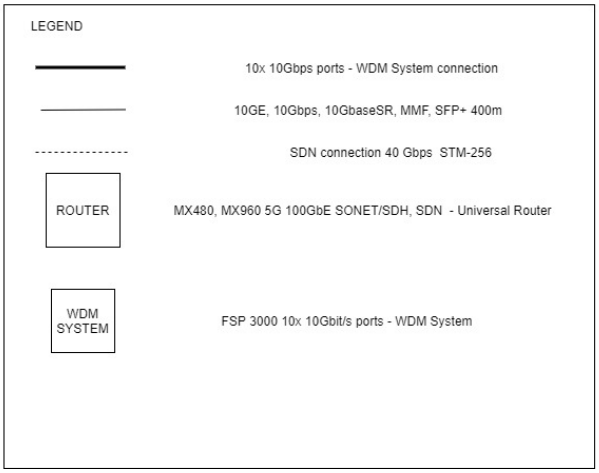
Critical Evaluation:
The specification suggests that all cabling is required to connect the hardware devices. Therefore, it was decided to choose CAT5E Gigabit Ethernet, due to it being the most common type of Ethernet cabling today and low cost. Nevertheless, it is simple to connect to the hardware devices, and requires a straight-through cable which connects to a PC, Switch, or router.

3.0 Chapter 2 - WAN

3.1 The Diagram

The image shown below represents an Optional network able to connect to the LAN in task 1, using the WDM to router model.





3.2 Design Description

This part of the report will provide a justification on how the WAN design and legends shown in the previous section, meet the specifications. For example, redundancy, scalability and the benefits of using the WDM to Router model.

The diagram shown in the image above represents an Optical network able to connect to the LAN in chapter 1, with the main premises of the organization. With that being said, the diagram also shows it uses the WDM to Router model which has many benefits.

The diagram shows that each city has its own premises network set-up and implementing the WDM to Router model. There is a total of five cities with the main premise (CITY-4),representing the LAN from chapter 1 to be connected to all other cities.

Furthermore, one of the benefits deploying the WDM to router model is that it implements a logical design, which ultimately allows the network to be more easily manageable. Another benefit would be to exploit the full potential of optical fibre cable, by *"allowing multiple beams of light at different frequencies to be transmitted over the same optical fibre cable" by Ali Grami 2016,* which then connects to the router providing the network for each city. An application of WDM is SONET/SDH(Synchronous Digital Hierarchy) and DWDM(Dense Wavelength Division Multiplexing) which both have advantages and use unique topologies. However, in this project it was decided to choose DWDM technology, as it could be said that DWDM will eventually prevail and become the choice of most standard network technology, because of its maintainability and is of newer technology. However, SONET/SDH is currently an alternative option, regarding the WDM, if the organization would decide to switch to SONET/SDH for any reason.

As you can see from the image in the previous section, each WDM system is connected to another WDM from/to another city creating a sort of loop. This provides for better redundancy and therefore, if CITY-2 were to go offline, the other cities could choose an alternate network path to keep the flow of traffic throughout the network. Furthermore, the router in premises CITY-4 remains the same however, it was decided to upgrade from the Juniper MX480 to the MX960 in all other cities. It could be said that by using identical routers will further improve redundancy within the network. Both the MX480 and MX960 provide 5G and therefore, it could be said that if the WDM goes offline, then 5G will be an alternative to keep the flow of traffic throughout the network running, ultimately improving the networks availability and redundancy.

Furthermore, due to the router upgrade from the MX480 to the MX960, will provide for better scalability. This is because the MX960 provides more SFP+ ports and if the organization decides to expand, it will be easier as the MX960 already provides the extra available ports. The MX960 also provides up to 12 Tbps capacity, whereas the MX480 only provides up to 9 Tbps. Also, the MX960 provides up to 12 slots whereas the MX480 provides only 6 slots. Overall, the MX960 will benefit from the extra speed and slots, which will improve the organisations overall speed and scalability.

3.3 Network Hardware

In this part of the report, the Network hardware shown in the WAN diagram section will be critically evaluated identical to the previous section in chapter 1.

Device ID: 1
Device Name: Router
Device Model: MX960
Reference: https://www.juniper.net/uk/en/products-services/routing/mx-series/mx960/ by Juniper

Device Description:
The MX960 Universal router is SDN Enabled and offers up to 12 Tbps of system capacity in support of 10GbE, 40GbE and 100 GbE interfaces, as well as SONET/SDH connectivity options.

Critical Evaluation:
The specification requires the router to have a minimum of 8x10 Gbps SFP+ ports to connect the WDM system. The MX960 supplies 10x10Gpbs ports which is SDH and supports STM64. As a result, we must use 4X10 Gbps ports to make 40 Gbps and another 4X10 Gbps ports to make a total of 80Gbps connectivity, in order to establish the connection.

Device ID: 2
Device Name: WDM
Device Model: FSP 3000
Reference: https://www.adva.com/en/products/open-optical-transport/fsp-3000-open-terminals by Adva

Device Description:
The FSP 3000 enables secure optical network solutions and accommodate most WDM system organization requirements. Furthermore, it has ultra-high-speed wavelengths with up to 800Gbit/s per single-port line which provides more scalability. The FSP 3000 also has 10x10 Gbit/s ports and supports STM64.

Critical Evaluation:
The specification requires the WDM system to have a minimum of 8x10 Gbps QSFP+ ports to connect the router. The FSP 3000 supplies a total of 10x10 Gbit/s port which supports STM64, which makes it fully compatible and enough ports to connect to the MX960 router. Furthermore, it has ultra-high-speed wavelengths with up to 800Gbit/s, which provides for better scalability. The FSP 3000 is also fully open and programmable, which has easy integration into SDN-based environments. Lastly, an FSP 3000 Data sheet report has been acquired as part of this project and will be included within Appendix A.

4.0 Overall Conclusions and Reflections

Overall, the tasks that were carried out in this report has provided a good insight into Network Designs and Network Hardware.

What I have learned from this whole experience is how to create a network design. In this process I have learned how to prepare different network diagrams (LAN/WAN) intended to fulfil the specifications provided to me. I have also learned how to research and present all network devices, hardware and cabling required and be able to justify the choosing of them.

In conclusion, I believe I have further developed my current knowledge, and I am now able to better analyse problems carefully and sufficiently finding the problems to the solutions. Therefore, I understand the importance of being able to adapt in a Networking field and have a clear understanding of a client's requirements, which will be beneficial to me working within the Networking Industry in the future.

5.0 References

Juniper. (2020) MX480 Universal Routing Platform Available at: https://www.juniper.net/uk/en/products-services/routing/mx-series/mx480/ [Accessed 20th December 2020]

Juniper. (2020) MX960 Universal Routing Platform Available at: https://www.juniper.net/uk/en/products-services/routing/mx-series/mx960/ [Accessed 20th December 2020]

Juniper. (2020) QFX5100 Line of Ethernet Switches Available at: https://www.juniper.net/uk/en/products-services/switching/qfx-series/qfx5100/ [Accessed 21st December 2020]

Juniper. (2020) SRX5400 Services Available at: https://www.juniper.net/uk/en/products-services/security/srx-series/srx5400/ [Accessed 21st December 2020]

Adva. (2020) FSP 3000 Open Terminals Available at: https://www.adva.com/en/products/open-optical-transport/fsp-3000-open-terminals [Accessed 21st December 2020]

Adva. (2020) DWDM Available at: https://www.adva.com/en/products/technology/dwdm#:~:text=Dense%20Wavelength%20Division%20Multiplexing%20(DWDM,wavelengths%20on%20the%20same%20fiber. [Accessed 21st December 2020]

Orion. (2020) 21U Premier Server Rack 600x1200 Available at: https://www.rackcabinets.co.uk/products/21u-premier-server-rack-600-x-1200#features [Accessed 23rd December 2020]

Orion. (2020) 4U Mini Acoustic Server Racks 700 Wide 800 Deep Available at: https://www.serverroomenvironments.co.uk/4u-racks/4u-mini-acoustic-server-racks-600-wide-800-deep [Accessed 25th December 2020]

Orion. (2020) Fan Trays Available at: https://www.rackcabinets.co.uk/collections/rack-cooling/products/fan-trays [Accessed 25th December 2020]

Morris. (2014) SONET vs SDH vs DWDM, What Are their Differences? Available at: https://community.fs.com/blog/the-relation-and-difference-between-sonetsdh-and-dwdm.html [Accessed 25th December 2020]

Netgear. (2020) What are link aggregation and LACP and how can I use them in my network? Available at: https://kb.netgear.com/000051185/What-are-link-aggregation-and-LACP-and-how-can-I-use-them-in-my-network [Accessed 26th December 2020]

V skills. (2020) Using Switches and Their Advantages Available at: https://www.vskills.in/certification/tutorial/using-switches-and-their-advantages/ [Accessed 26th December 2020]

Ali Grami (2016) Communication Networks Available at: https://www.sciencedirect.com/topics/engineering/wavelength-division-multiplexing#:~:text=The%20advantage%20of%20WDM%20is,standard%20developed%20in%20North%20America. [Accessed 26th December 2020]

Cisco. (2020) What is software-defined networking? Available at: https://www.cisco.com/c/en_uk/solutions/software-defined-networking/overview.html#~services [Accessed 26th December 2020]

Juniper. (2020) Enabling Internet Access for Layer 3 VPNs Available at: https://www.juniper.net/documentation/en_US/junos/topics/topic-map/l3-vpns-internet-access.html [Accessed 26th December 2020]

Summit360. (2019) How to Build in Redundancy for a Reliable Network Available at: https://www.summit360.com/2019/01/09/how-to-build-in-redundancy-for-a-reliable-network/ [Accessed 26th December 2020]

Doug Lowe. (2020) An Introduction to Network Switches Available at: https://www.dummies.com/programming/networking/an-introduction-to-network-switches/ [Accessed 26th December 2020]

Fs. (2020) DWDM Mux Demux Available at: https://www.fs.com/uk/products/35887.html [Accessed 28th December 2020]

Misha chen. (2019) What is definition of SDH Available at: https://www.router-switch.com/faq/what-is-definition-of-sdh.html [Accessed 28th December 2020]

Trento systems. (2020) What is an SFP Port? Available at: https://www.trentonsystems.com/blog/what-is-an-sfp-port#:~:text=An%20SFP%20port%20is%20a,for%20the%20transmission%20of%20data. [Accessed 28th December 2020]

Router-Switch (2017) Cisco CCNA: Types of Ethernet Cabling. Network Cables in networking Available at: https://www.router-switch.com/faq/types-of-ethernet-network-cables-in-networking.html . [Accessed 28th December 2020]

Cheer Chen (2016) Difference between Straight-Through and Crossover Cable Available at: https://www.linkedin.com/pulse/difference-between-straight-through-crossover-cable-cheer-chen/ [Accessed 28th December 2020]

Ciena. (2020) What is WDM or DWDM Available at: https://www.ciena.com/insights/what-is/What-Is-WDM.html [Accessed 28th December 2020]

(2020), LAN Architectures, lecture notes, Network Architectures and Protocols 6COM1067-0901-2020, University of Hertfordshire, delivered 05th October 2020

(2020), Optical Core networks, lecture notes, Network Architectures and Protocols 6COM1067-0901-2020, University of Hertfordshire, delivered 16th December 2020

(2020), Network Devices, Interfaces, Cabling and Hardware, lecture notes, Network Architectures and Protocols 6COM1067-0901-2020, University of Hertfordshire, delivered 09th December 2020

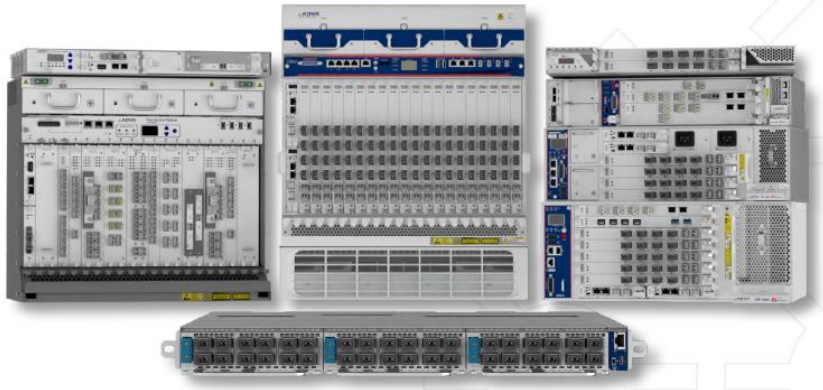
6.0 Appendix A

FSP 3000

Open and future-proof terascale optical transport

Today's optical transport demands are constantly changing. High-bandwidth services and cloud-based applications are booming and software-defined networking is evolving to the domain of transport networks. Network operators and enterprises need a flexible and scalable solution that increases agility and automation, while keeping cost and footprint at a minimum.

Our FSP 3000 is a scalable optical transport solution designed to efficiently deal with this new environment, lowering its complexity and minimizing cost-per-bit and operational efforts. With an open and modular design, our FSP 3000 supports a wide range of services and applications, from data center interconnect (DCI) to carrier-optimized infrastructure solutions. Incorporating the latest innovation in photonic networking and our innovative ConnectGuard™ low-latency encryption technology, FSP 3000 enables secure optical network solutions that can scale and accommodate tomorrow's needs. Moreover, with a high-density and energy-efficient design for smallest footprint and power consumption, our FSP 3000 meets the most stringent sustainability requirements.



Your benefits

- **Scalability**
  Ultra-high speed wavelengths with up to 800Gbit/s per single-port line interface; 38.4Tbit/s duplex capacity per fiber pair with best-in-class metrics; up to 3.6Tbit/s duplex capacity per 1RU chassis
- **Flexibility**
  From complete turnkey systems including all equipment necessary for end-to-end transport applications to disaggregated solutions
- **Pay-as-you-grow design**
  Modular and scalable architecture that ensures both low initial cost and flexibility into the future
- **Fully open and programmable**
  Open line system (OLS) architecture and YANG-based APIs (OpenConfig) for network disaggregation and easy integration into SDN-based environments
- **Dynamic and scalable optical layer**
  Multiple ROADM options from metro-optimized 2-degree ROADM to multi-degree ROADM for flexgrid optical layer
- **ConnectGuard™ encryption technology**
  Certified Layer 1 data encryption, approved for German government ("VS-V") and NATO-restricted ("NATO confidential") data transport

High-level specifications

General information

- Up to 38.4Tbit/s duplex capacity per fiber pair
- Point-to-point, ring and mesh topologies with optional protection mechanisms
- Open line system
- Flexgrid support
- Ensemble Controller and open APIs for mgmt. and control

Services

- Wide range of native service types: Ethernet, OTN, SONET/SDH, ESCON, Fibre Channel, FICON, Coupling Link, Infiniband, audio and video
- Continuous data rate support from 100Mbit/s to 425Gbit/s

Terminals

- Fixed line (<=100Gbit/s) and SW-defined (>=100Gbit/s) transponders/muxponders
- Up to 400Gbit/s per 1-slot card
- Up to 1.2Tbit/s per channel
- Up to 3.6Tbit/s per 1RU chassis
- 400 / 1200Gbit/s OTN switches
- 10Gbit/s QSFP-based service multiplexer (MicroMux™)

Photonic layer architectures

- DWDM: up to 128 channels
- CWDM up to 16 channels
- Hybrid CWDM + DWDM
- Wide variety of filters and ROADM options up to 32 degree
- Coherent and direct detection (PAM4) based solutions
- Optimized OLS for 400G ZR DCI
- OTC and OTDR (ALM)

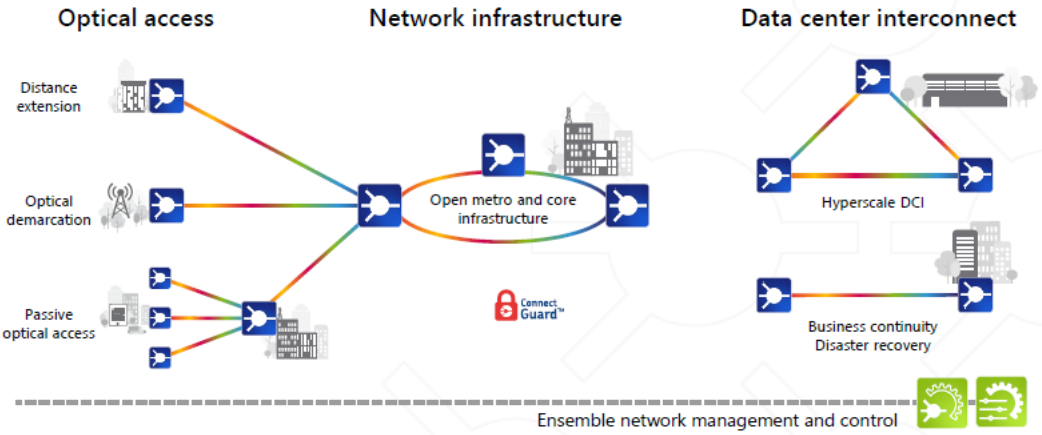
ConnectGuard™ encryption

- Layer 1 AES-256 encryption with ultra low latency and 100% throughput
- Dynamic key exchange <=4096 bit keys every minute
- FIPS 140-2 and CC EAL-2 certified. BSI approved
- Quantum-safe encryption via PQC or third-party QKD attach

Power and environmental

- Highest energy efficiency, TEER-proven Eco design
- Redundant power supplies for -48VDC or 100-240VAC PSUs
- Variety of active and passive chassis from 1RU to 12RU; 19in/ETSI/NEBS rack mounting

Applications in your network



End-to-end network infrastructure

- Scalable system architecture for cost-effective access, metro and backbone optical network infrastructure
- Built-in access for optical timing channel (OTC) and OTDR (ALM)

DCI for cloud and business continuity applications

- Terascale data center connectivity
- Open hardware architecture and YANG-based software (OpenConfig) modelling for easy integration into SDN-based environments

Wavelength technologies
- CWDM: 16 wavelengths/20 nm according to ITU-T G.694.2
- DWDM schemes
  - 4, 8, 16, 40 channel, C-band, 100 GHz spaced
  - 80-channel, C-band, 50 GHz spaced
  - 96-channel, C-band, 50 GHz spaced
  - 128-channel, C-band, 37.5 GHz spaced
  - Flexgrid with down to 6.25 GHz channel width granularity
- Hybrid CWDM/DWDM

Topologies
- Point-to-point
- Point-to-multipoint
- Linear add/drop
- Multiplexed add/drop (drop and continue)
- Ring (+ feeder + dual homing)
- Hubbed-ring
- Meshed

Maximum distance
- Total optical transparent distance (without regeneration) >3500km
- Maximum span budget: 50dB with full channel load and beyond 70dB with adapted capacity

Services
- Ethernet: FE, GbE, 10GbE (LAN and WAN), 25GbE, 40GbE, 100GbE and 400GbE
- ESCON and Fibre Channel/FICON 1Gbit/s, 2Gbit/s, 4Gbit/s, 8Gbit/s, 10Gbit/s, 16Gbit/s and 32Gbit/s
- InfiniBand 5G and 10G
- STM-1, -4, -16, -64 / OC-3, -12, -48, -192
- OTU-1, -2, -3 and -4
- Uncompressed video (SD-SDI, HD-SDI, 3G-SDI)
- CPRI up to 10Gbit/s

Service protection
- Versatile protection
- Channel protection
- Path protection
- Channel card protection
- Client layer protection

Channel modules with fixed line format
- Transponders (from 1G to 100G)
- Muxponders (aggregating services in the range from 100M to 40G)
- Add/drop multiplexers (dynamic routing of sub-aggregate traffic 100M to 40G services)
- OTN switch (for 10G services)

Channel modules with SW-defined line optics
- Transponders (from 100G to 400G)
- Muxponders (aggregating services in the range from 10G to 400G)
- Add/drop multiplexers (dynamic routing of sub-aggregate traffic 10G to 100G)
- OTN switch (for sub-aggregated services from 10G to 100G)

Optical layer
- Fixed filter from 1 to 128 channels WDM
- Reconfigurable optical add/drop modules (ROADM) from 1 to 32 degrees with multiple fixed, colorless, directionless and contentionless add/drop structures
- Multiple amplifications solutions using Erbium fiber and/or Raman amplifiers
- Automated optical layer with channel equalization and span loss equalization
- Optical supervisory functions like optical channel monitoring with full support of third-party wavelengths
- Tailored solutions for access, metro and regional/long-haul
- Dedicated amplifier suite for direct detect and coherent signals (like SmartAmp™ designed for PAM4 solutions)
- Dedicated OLS optimized for 400G ZR DCI links at over 25Tbit/s per fiber pair

Common equipment
- 1RU, 2RU, 3RU, 4RU, 7RU, 9RU and 12RU shelf variants
- Power supply modules from 50 to 1200W (AC, DC, full redundant)
- Various controller modules (from compact to redundant and high performance)
- Multiple management interfaces (USB, RJ45, digital IO-housekeeping)

Equipment management
- Embedded CRAFT/CLI
- Embedded web-based graphical user interface with “point and click” provisioning via HTTPS
- Full support of SNMP, TL1, REST, NETCONF (OpenConfig)
- Streaming telemetry (gRPC)
- Full support of FTP, SFTP, SCP, SSH, TELNET
- Remote authentication via RADIUS or TACACS+
- Equipment management using DCN or in-band management tunnels
- Enhanced user management with multiple security options
- Zero-touch provisioning methods using automated set-up, scripting environment like Ansible and network-wide profile management
- Use of augmented reality and equipment identification for guided installation and fault identification