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School of Technologies

**Assessment**

**Brief**

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| --- | --- |
| **Module Code** | **Module Title** |
| CNT4001 | Data Communication |
| **Academic Year** | **Semester** |
| 2025 | 2 |
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**Assignment Cover Sheet**

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| --- | --- | --- |
| **Qualification** | | **Module Number and Title** |
| HD in Network technology and Cyber Security | | CNT4001 – Data Communication |
| **Student Name & No.** | | **Assessor** |
| L.H.G. Yasiru Prabodha (CL/HDNET/CMU/51/14) | | Mr. Sachintha |
| **Hand out date** | | **Submission Date** |
| 2025/04/23 | | 2025/06/11 |
| **Assessment type**  PORT-1 | **Duration/Length of**  **Assessment Type**  3 weeks (3000 Words) | **Weighting of Assessment**  100% |

|  |  |
| --- | --- |
| **Learner declaration** | |
| I, **L.H.G. Yasiru Prabodha**, certify that the work submitted for this assignment is my own and the research sources are fully acknowledged. | |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Marks Awarded** | | | |  |  |  | | First assessor | |  | |  |  |  | | IV marks | |  | |  |  |  | | Agreed grade | |  | |  |  |  | | Signature of the assessor |  | Date |  |  |  |  | |

**Feedback Form**

**International College of Business & Technology**

**Module:** Data Communication – CNT4001

**Student:** L.H.G. Yasiru Prabodha

**Assessor:** Mr. Sachintha

**Assignment:** Data communication concepts and usage

**Strong features of your work:**

**Areas for improvement:**

**Marks Awarded:**

**Modern Approaches to Data Communication Technologies**

Created by: **L.H.G. Yasiru Prabodha**

CMU ID: **st20330308**

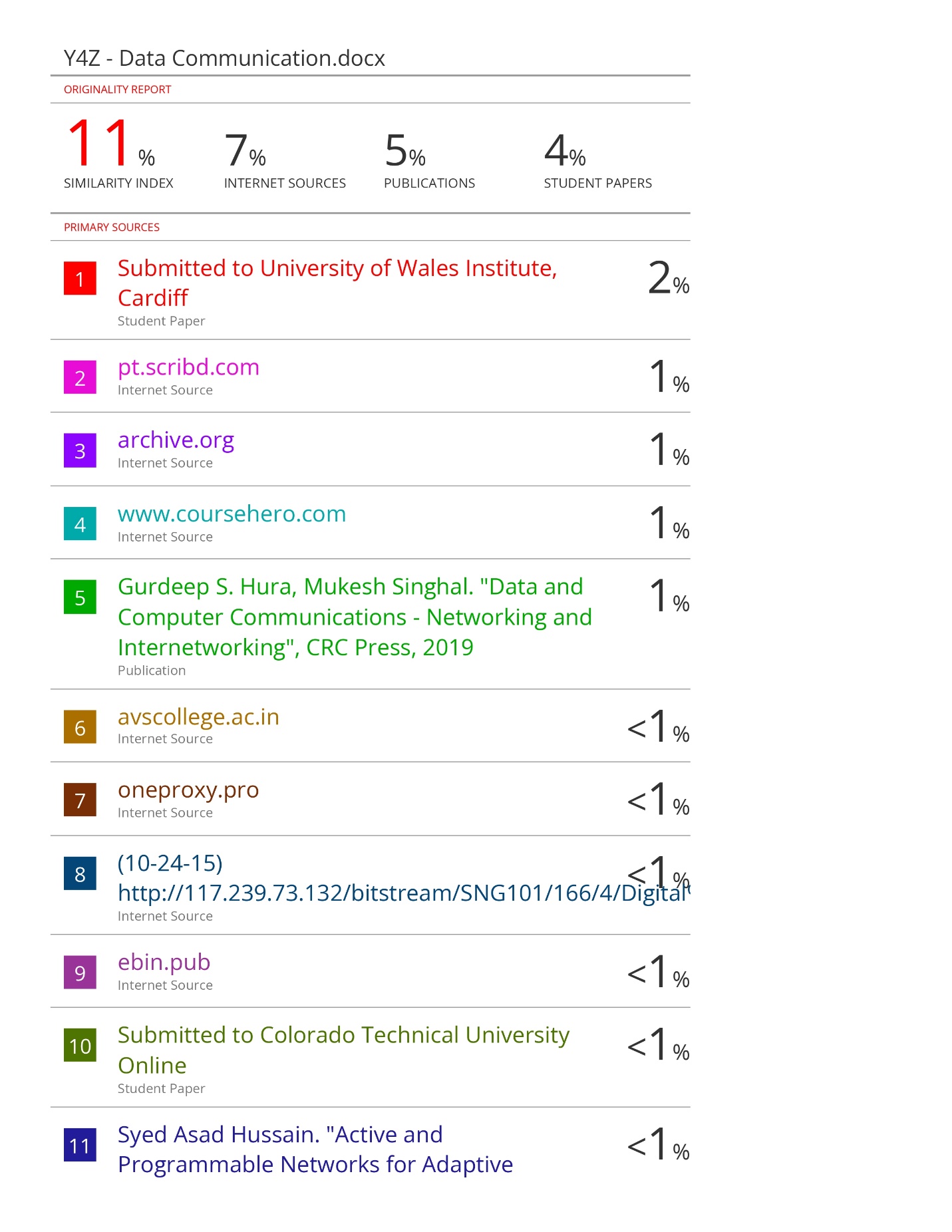
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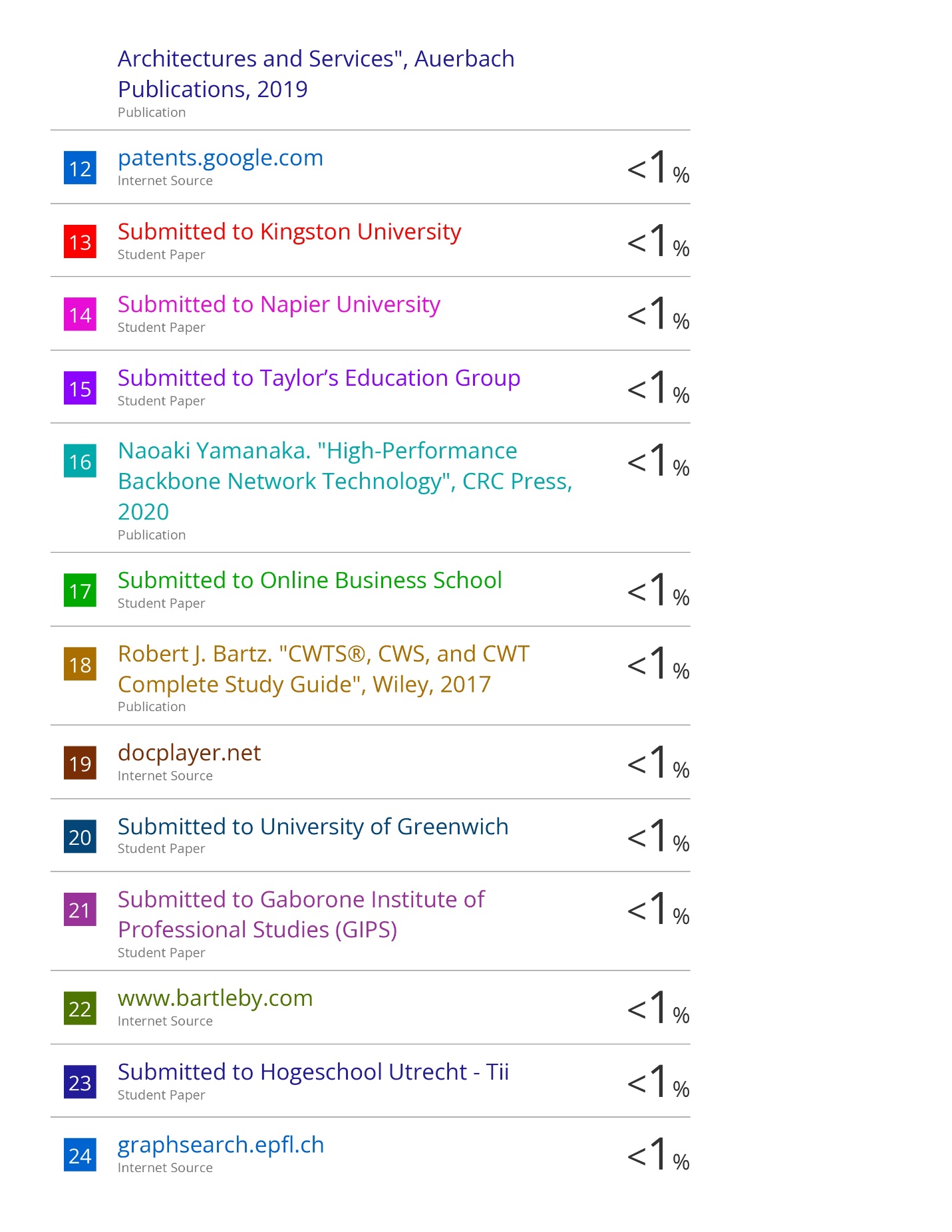
Course: **HD in Network Technology and Cyber Security**

Lecturer: **Mr. Sachintha**

Submit Date: **2025/04/12**

## Turnitinuk Report







## Acknowledgment

I would like to take this opportunity to thank my lecturer of Data Communication, Mr. Sachintha, for his insight, guidance, support, and encouragement throughout the course. His deep understanding of the topic and the way he elucidates abstract subjects in simple terms have made a significant contribution to my learning experience.

Mr. Sachintha's commitment to establishing a firm grasp of the data communication concepts has improved my capacity to understand complex concepts and use them in real-world contexts extensively. His diligent feedback on the homework and his openness to offer further explanations outside class were totally essential. I have been inspired the most by the way he instructs, interweaving theoretical complexity with real-world usage, making the course material both understandable and applicable.

Additionally, his open-door policy, tolerance, and eagerness to help students with questions have fostered an atmosphere of academic development and personal self-worth. I am genuinely grateful for the privilege of studying under his tutelage, which has not only enhanced my studies but has also invited me to further study and develop as a professional in network technology.

Mr. Sachintha's dedication toward a student's success and passion for the subject are traits which I have the highest regard for. I highly appreciate his contribution to my success in studies and am eagerly anticipating its application in the future.

## Executive summary

This report presents a comprehensive examination of contemporary data communication technologies, network architecture models, digital transmission methods, and signal encoding schemes. The primary objective of the assignment is to develop a deep understanding of how different communication models, protocols, and encoding techniques operate within real-world networking environments. The study is divided into four distinct tasks, each addressing a key aspect of data communication and network design in alignment with academic learning outcomes and professional standards.

Task 1 focuses on network technologies and real-world scenarios. It begins with a critical comparison between Virtual Circuit Packet Switching (VCPS) and Circuit Switching, emphasizing the implications of node failures on communication reliability and performance. It further evaluates the suitability of Wide Area Network (WAN) technologies for multinational organizations, recommending Multiprotocol Label Switching (MPLS) based on its scalability, quality of service, and protocol interoperability. The task also explores the most appropriate internet connectivity and Virtual Private Network (VPN) solutions for small businesses, highlighting cost-effective methods to ensure secure and efficient communication.

Task 2 delves into the theoretical underpinnings of data communication. It offers a comparative analysis of the OSI model and the TCP/IP protocol suite, discussing their respective layer functionalities and data flow mechanisms. The roles of the Transport and Network Layers are examined in detail, with emphasis on their contributions to reliability, routing, and error control. The processes of encapsulation and decapsulation are analyzed as essential elements for structured data transmission, enabling interoperability and ensuring data integrity across different network layers.

Task 3 examines the analog-to-digital conversion process, with particular emphasis on Pulse Code Modulation (PCM). The stages of sampling, quantization, and binary encoding are explained in the context of both telecommunications and digital audio. The task further discusses the impact of bit depth and sampling rate on the resolution and precision of digital signals, highlighting the balance between signal quality and system resource requirements.

Task 4 applies theoretical knowledge to practical signal representation by illustrating various line encoding schemes such as Non-Return to Zero (NRZ), Manchester, Differential Manchester, and Bipolar AMI. These techniques are essential for ensuring reliable data transmission at the physical layer, supporting synchronization, error detection, and bandwidth optimization.

In summary, the report integrates theoretical frameworks with applied analysis to provide a holistic understanding of data communication systems. It demonstrates critical thinking, technical competence, and awareness of industry practice skills that are essential for modern network professionals. The assignment aligns with the broader goals of the Cardiff Met EDGE framework by promoting ethical, digital, global, and entrepreneurial capabilities in the field of network technology and cybersecurity.

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## Introduction

The rapid advancement of digital technologies has fundamentally transformed the way data is communicated, transmitted, and secured across modern networks. From personal communication to global enterprise operations, reliable and efficient data communication systems are essential for enabling seamless connectivity, high-performance computing, and secure information exchange. As organizations become increasingly dependent on networked environments, a comprehensive understanding of the principles, models, and mechanisms underlying data communication becomes crucial for professionals in the field of networking and cybersecurity.

This assignment aims to explore and critically analyze key concepts in data communication and networking, structured around four interconnected tasks. The report begins by examining the core differences between Virtual Circuit Packet Switching and Circuit Switching, highlighting how performance and reliability are influenced by node failures. It further evaluates the selection of suitable Wide Area Network (WAN) technologies for multinational corporations and the most appropriate Internet and VPN solutions for small businesses, addressing real-world networking requirements

The second task focuses on the theoretical frameworks that underpin communication protocols, specifically the OSI model and the TCP/IP suite. It investigates how data flows through network layers via encapsulation and decapsulation, and the role of the Transport and Network Layers in ensuring reliable data delivery. Understanding these layered models is critical for designing and troubleshooting modern communication systems.

The third task centers on the process of converting analog signals into digital form using Pulse Code Modulation (PCM). It discusses the significance of sampling, quantization, and encoding in achieving high-quality digital signal representation, especially in telecommunications and audio applications. The implications of bit depth and sampling rates on signal resolution and accuracy are also examined.

Finally, the fourth task applies signal encoding techniques to a given bit pattern, demonstrating how binary data is represented for physical transmission using various line coding methods. This practical component reinforces theoretical knowledge by illustrating how different encoding schemes impact synchronization, bandwidth usage, and error detection at the physical layer.

By integrating theoretical knowledge with practical analysis, this assignment seeks to enhance technical proficiency in network design, data transmission, and digital communication. The tasks reflect the module’s learning outcomes and contribute to the development of essential digital, ethical, and global competencies as outlined in the Cardiff Met EDGE framework.

## TASK 1 - Networking Technologies and Scenarios

### 1.A) Effect of Intermediate Node Failure in Virtual Circuit

Virtual Circuit Packet Switching (VCPS) and Circuit Switching are two fundamentally different paradigms in network communication, each with distinct mechanisms for data transmission and implications for performance and reliability. Circuit Switching establishes a dedicated, continuous communication path between two endpoints for the entire duration of the session. This path remains reserved exclusively for that session, ensuring consistent quality of service and predictable latency, which makes it particularly suitable for real-time voice or video communication. (Misra and Goswami, 2017)

In contrast, Virtual Circuit Packet Switching transmits data in the form of discrete packets. Although the packets follow a predefined virtual path created during the connection setup phase no physical resources are reserved along the route. Instead, each intermediate node maintains routing information (state) for the virtual circuit, forwarding packets based on virtual circuit identifiers. This allows for more efficient use of network resources through statistical multiplexing, as multiple virtual circuits can share the same physical infrastructure.

A critical vulnerability in VCPS arises from its reliance on the proper functioning of each intermediate node along the virtual circuit. If any one of these nodes fails, the virtual circuit becomes invalid, and all communication sessions passing through that node may be abruptly terminated. Unlike Circuit Switching, which often employs redundant systems and can rapidly re-establish a dedicated path, VCPS suffers from higher susceptibility to network disruptions. This is because all the packets in a virtual circuit are dependent on the continuity and operational status of all intermediate nodes involved in the path. Therefore, a single point of failure can impact multiple virtual circuits simultaneously. (J. Labetoulle and Roberts, 2013)

From a network criteria perspective, VCPS demonstrates superior performance in terms of efficiency and scalability, especially in large scale data networks such as the Internet. It allows dynamic bandwidth allocation and better utilization of the transmission medium. However, its reliability is inherently lower when compared to Circuit Switching, particularly in scenarios where uninterrupted communication is critical. Circuit Switching, although less efficient in its use of bandwidth, ensures a higher degree of reliability and predictability due to its dedicated path model.

### 1.B) Choosing WAN Technology for a Multinational Company

When designing a Wide Area Network (WAN) for a multinational company, the primary goal is to ensure secure, reliable, and efficient communication between geographically dispersed branch offices and the corporate headquarters. Among various WAN technologies, Multiprotocol Label Switching (MPLS) is widely regarded as the most suitable option for such an enterprise level application due to its ability to support quality of service (QoS), scalability, and secure data transmission.

From a message perspective, MPLS can handle multiple types of traffic such as voice, video, and data within the same infrastructure. This is particularly beneficial for a multinational organization that requires diverse forms of communication across departments and locations. MPLS assigns labels to packets, allowing them to be routed through predetermined paths, which enhances transmission speed and efficiency compared to conventional IP routing.

The transmission medium in an MPLS based WAN typically includes leased lines, fiber optics, or high-speed broadband connections. These guided media offer high bandwidth and minimal interference, ensuring low latency and reduced packet loss over long distances. In addition, MPLS can be integrated with virtual private networks (VPNs) to extend secure communication over the public Internet, which adds flexibility while maintaining data confidentiality.

Regarding the protocol, MPLS is protocol agnostic, meaning it can carry different types of network protocols such as IP, ATM, or Frame Relay. This interoperability allows the multinational company to leverage existing infrastructure while gradually upgrading network components. Furthermore, MPLS supports traffic engineering, which enables network administrators to prioritize business-critical applications and optimize network performance across all locations. (Satyanarayanan et al., 2019)

In summary, MPLS is a highly suitable WAN technology for a multinational company due to its support for diverse message types, use of high speed and reliable transmission media, and compatibility with multiple protocols. By addressing the essential data communication components message, medium, and protocol MPLS ensures a high performance and scalable networking solution that meets the complex demands of global business operations. (Taub and Cisco, 2018)

### 1.C) Best Internet & VPN for Small Business LAN

For a small company with 10 employees utilizing a Local Area Network (LAN) for internal communication, the most suitable Internet connection type would be a Fiber Optic Broadband Connection or, alternatively, a Cable Internet connection. Both these types offer high speed, reliable, and stable connections that are well suited for the bandwidth requirements of a small business.

A Fiber Optic Broadband connection is particularly recommended due to its high data transfer rates, which can handle heavy data traffic and support multiple devices without significant performance degradation. Fiber optic technology offers low latency and high bandwidth, making it ideal for small businesses that require seamless access to cloud services, file sharing, VoIP (Voice over IP), and video conferencing. For a small company with 10 employees, this type of connection would efficiently support the simultaneous use of internet-based applications, reducing the risk of network congestion and slowdowns, even with multiple devices connected.

If fiber optic broadband is unavailable or cost prohibitive, Cable Internet serves as a good alternative. It provides a consistent connection with decent speeds, albeit slightly lower than fiber optic connections. It is also more widely available in urban areas and can offer sufficient speeds for day-to-day business operations such as email communication, browsing, and cloud-based applications. (NARAYAN CHANGDER, 2023)

**Why Might the Company Use a VPN?**

The small company may choose to implement a Virtual Private Network (VPN) for several key reasons:

1. Enhanced Security and Privacy: A VPN allows employees to securely access the company's internal resources (such as file servers, databases, and applications) from remote locations. It encrypts the data transmitted over the Internet, ensuring that sensitive company information remains private, even on unsecured networks (e.g., public Wi-Fi). Given that cybersecurity is a critical concern for businesses of all sizes, a VPN ensures the company’s internal communications are safeguarded from potential cyber threats such as man in the middle attacks and unauthorized data breaches. (QuickTechie.com | A career growth machine, 2025)
2. Remote Access: A VPN is beneficial if employees occasionally need to work remotely or if the company plans to expand its workforce to include off-site employees. The VPN establishes a secure tunnel between the employee’s device and the company’s LAN, allowing access to the network as if the employee were physically present in the office. This ensures business continuity and flexibility without compromising security.
3. Cost Effective Solution: A VPN can also be an affordable alternative to a dedicated leased line or other more expensive network configurations. It enables the company to extend secure access to its internal network through the public Internet, without the need for physical infrastructure changes. This scalability is essential for small businesses with limited IT budgets.

In conclusion, a fiber optic broadband connection (or cable Internet, if fiber optic is not available) would be the best choice for a small company using a LAN, ensuring fast, reliable access to the Internet and internal resources. The use of a VPN enhances security and flexibility, offering remote access to employees while protecting sensitive company data from external threats.

## Task 02: Data Communication Concepts and Usage

### 2.a) OSI and TCP/IP Layer Functionality and Data Flow

Both the OSI (Open Systems Interconnection) model and the TCP/IP protocol suite form the basis upon which network communication is studied. The two are very different in structure, layer function, and data flow procedures, though.

**OSI Model**

Figure osi model

The International Organization for Standardization (ISO) developed OSI model is a conceptual model that divides and codifies the telecommunication or computer system's communications activity into seven layers. These are from data transfer at the physical level to application-level interface. (Ibe, 2017)

Physical Layer [Layer 1]

This is the lowest layer, which deals with physical transmission of raw data via the transmission media (cables, fiber optic, wireless signals). It specifies hardware, electrical signal, data rate, and media used for communication.

Data Link Layer [Layer 2]

The Data Link Layer guarantees error-free delivery of data frames from one node to another on the same network. It manages error correction, flow control, and physical addressing (MAC addresses).

Network Layer [Layer 3]

The major function of the Network Layer is routing information between different networks. It does logical addressing, most often with IP addresses, and establishes the best path for data transmission with the help of routers.

Transport Layer [Layer 4]

The Transport Layer provides end-to-end reliable data transfer from end systems. It performs segmentation, flow control, error detection, and retransmission of lost data. Both TCP and UDP are used here, where TCP delivers data reliably and in an ordered manner.

Session Layer [Layer 5]

The Session Layer controls the setup, support, and shutdown of the application-to-application communication sessions. It provides a means to ensure that the exchange of data happens in a structured way for enabling continued and coherent interaction.

Presentation Layer [Layer 6]

The Presentation Layer is tasked with formatting the data into a form that can be read by the application layer. This involves data encoding, compression, and encryption/decryption.

Application Layer [Layer 7]

Uppermost layer for intercommunication with end-user programs. It offers different types of services like file transfer (FTP), web surfing (HTTP), and mail (SMTP) to facilitate user processes directly.

**TCP/IP Protocol Suite**

Figure tcp/ip protocol suite

The TCP/IP protocol suite, the core of the Internet, is composed of four layers that loosely correspond to the seven layers in the OSI model. The suite is constructed more practically and streamlined with implementation of communication protocols in mind. (Tyagi, 2020)

Link Layer (Data Link + Physical Layer in OSI)

This level includes both the physical media, and the protocols utilized for transmitting data over it. All the hardware and protocols used to enable data to be transmitted between computers within the same network, usually through such technologies as the Ethernet or Wi-Fi.

Internet Layer (OSI Network Layer)

The Internet Layer maps directly to the Network Layer of the OSI model and provides routing of data between networks using logical addresses (IP addresses). IP, ICMP, and ARP are the base protocols on this layer.

Transport Layer (Identical to OSI)

Like the OSI model, TCP/IP's Transport Layer provides end-to-end communication. TCP facilitates reliable, connection-oriented communication while UDP provides connectionless, quicker communication.

Application Layer (Session, Presentation, and Application Layers in OSI)

It performs the functions of the top three OSI layers. It deals with high-level protocols like HTTP, FTP, and SMTP, data encryption, session establishment, and application-specific data formatting.

**Key Differences in Data Flow**

OSI Model: The OSI model passes data from the highest application layer down to the physical layer when transmitting. It moves from the original application, layer by layer, to the physical medium where it is sent across. When it arrives, it is decapsulated as it moves back up through the layers of the receiver in reverse encapsulation.

TCP/IP Model: Data passes through the layers in TCP/IP model but the model is not as complex. Data flow is comparatively simpler with each layer having the task of ensuring the maximum end-to-end communication over the Internet, from physical transmission to application processing.

### 2.b) Transport and Network Layer Roles in OSI and TCP IP

**Transport Layer**

Both in the OSI and TCP/IP protocol stack, the Transport Layer plays a key role in facilitating end-to-end connectivity between devices on various networks. It guarantees that data is delivered reliably, in proper order, and error-free.

In OSI Model:

* Transport Layer does the data segmentation and reassembly. It also takes care of error detection and correction, flow control, and reliability.
* Transmission Control Protocol (TCP) functions at this level, ensuring reliable, connection-oriented communication with attributes including sequence numbering, acknowledgement (ACK), and retransmission of lost packets. User Datagram Protocol (UDP) offers quicker but unreliable, connectionless communication.

TCP/IP Protocol Suite:

* In the TCP/IP protocol stack, the same is achieved by the Transport Layer but with TCP as the priority for guaranteed delivery and UDP as the fast, but unguaranteed, communication.
* TCP controls data segmentation, and a sequence number is given to each segment to provide order at the receiving end. Flow control through a sliding window mechanism also avoids flooding of the receiver by the sender and packet loss.

**Network Layer**

The Network Layer ensures that data can pass from one network to another, addresses the complexity of routing, addressing, and forwarding packets between nodes.

OSI Model:

* The OSI Network Layer performs the logical addressing (IP addressing) and forwarding packets to the destination over several networks. It learns the best path for the data using routing protocols.
* IP is the primary protocol of this layer, and packet forwarding is what it does. The Network Layer does not ensure delivery or reliability of data, though; these are addressed by the Transport Layer.

TCP/IP Protocol Suite:

* The Internet Layer in the TCP/IP model serves the same function as the Network Layer in OSI. It handles packet routing, logical addressing, and delivering the data to the right destination on multiple networks.
* The IP protocol works well here, whereby it properly forwards data from the source to destination. The ICMP protocol is responsible for error reporting (e.g., destination unreachable), but the Internet Layer does not provide guarantees of delivery and leaves the responsibility to the Transport Layer.

**Ensuring Reliable Data Delivery**

Transport Layer provides data reliability delivery by segmentation, error checking, flow control, and retransmission. Large data are segmented into small packets, data integrity is checked using checksums, transmission rate is controlled to avoid blocking, and lost packets are repeated using sequence numbers and acknowledgments to deliver with accuracy. All these components collaborate to provide reliable and efficient communication.

Network Layer offers routing but not reliability. It hands packets over to the Transport Layer for delivery to be made reliably. (Dr.V.V.S.S.S.Chakravarthy et al., 2023)

### 2.c) Encapsulation and Decapsulation in Data Transmission

Figure encap\_to\_decap

**Encapsulation Process**

Encapsulation is the process of placing headers (and sometimes trailers) on data at every layer as it travels down from the Application Layer to the Physical Layer. (Jones, 2024)

Application Layer

This information is constructed by the application, e.g., an email message or a file-transfer request. This is the raw data to send.

Presentation Layer

The data may be encoded, compressed, or encrypted to ensure that the format is transmittable.

Session Layer

The session is set up and sustained, and the data is laid out for orderly transfer from systems.

Transport Layer

The Session Layer data is divided into small pieces (segments in TCP/IP). A header is allocated to each segment with sequence numbers, acknowledgement details, and error-checking values.

Network Layer

Every bit of information is packaged into a packet, to which an IP header is attached. The IP header contains logical addressing information (e.g., destination and source IP addresses).

Data Link Layer

The packet is framed and enclosed in a header that has physical addresses (e.g., MAC addresses) for both the sender and receiver.

Physical Layer

It is transmitted into electrical impulses, light signals, or radio waves according to the transmission medium. It is now being transmitted by the physical medium (fiber, cables, wireless).

**Decapsulation Process**

Decapsulation is done on the receiving end and is a series of stripping headers at every layer to arrive at the original data.

Physical Layer

The signals are received and de-framed.

Data Link Layer

The frame is scanned for errors (by mechanisms such as CRC) and the packet is unwound from the frame.

Network Layer

The IP header is stripped off from the packet, leaving the segment exposed.

Transport Layer

The work is reconstructed if needed, and any needed error checking (e.g., checksums) is done.

Session Layer

The session is ended, and information is forwarded to the Presentation Layer.

Presentation Layer

Data may be decompressed, decrypted, or decoded.

Application Layer

Data is then provided to the destination application, e.g., printing the message or reading in the file. (Marco, 2025)

### 2.d) Importance of Encapsulation and Decapsulation in Network Communication

Encapsulation and decapsulation are crucial operations in network communications as they help ensure that data is being transmitted precisely and effectively through the OSI model layers or TCP/IP protocol stack. (Jones, 2024b)

**Importance of Encapsulation and Decapsulation**

Data Integrity

Error-checking data like checksums at Transport Layer and CRC at Data Link Layer is incorporated into headers that are inserted by encapsulation to make the data integrity as it is transported in the network.

Modularity and Layered Communication

Each operation is offered by a specific layer, and encapsulation separates each layer to process the data. None of the actions of a layer are disrupted by inserting its own trailer or header.

Addressing and Routing

Encapsulation provides for necessary addressing information (e.g., IP addresses in the Network Layer and MAC addresses in the Data Link Layer) to be added so that the data will be routed properly to the destination.

Error Detection and Correction

With each layer the data goes through, error-checking headers guarantee that the data will remain unchanged during transit. Corrections or retransmission is made because of the errors discovered.

**Ensuring Data Integrity**

Encapsulation at every level enables the data to be structured and formatted with the appropriate headers in a way that it can be processed, forwarded, and checked for errors correctly. This guarantees the data to be delivered in the required order and unaltered to the destination.

Decapsulation ensures that every layer does its own unique task in the reverse order, removing the headers and delivering the original message along the way up from the Physical Layer all the way to the Application Layer.

## Task 03: Pulse Code Modulation and its Role in Data Communication

### 3.a) Pulse Code Modulation in Analog to Digital Conversion

Figure analog to degital

Pulse Code Modulation (PCM) is the most common technique for digitizing analog signals. It is a sequence of operations of sampling, quantization, and encoding that cumulatively convert a continuous time analog signal to a digital signal of discrete time. This is the way analog signals like audio and voice can be transmitted and stored in a digital manner with efficient efficiency. (Keiser, 2012)

1. Sampling

Figure pcm-sampling

The initial process of PCM is sampling, where the continuous nature analog signal is sampled at discrete time intervals. The sampling frequency must be as per Nyquist's theorem where the sampling frequency must be twice the highest frequency in the analog signal in order to prevent aliasing. The data received after sampling are processed for PCM. For example, in audio signals, the default sample rate is 44.1 kHz, far beyond recording the entire range of human hearing (20 Hz to 20 kHz)

1. Quantization

Figure pcm-quantization

Quantization follows, after sampling, where the sampled value for each is rounded to the nearest member of a finite set of levels. The levels are based on the number of bits being allocated to each sample. Quantization introduces a small error, called quantization error, that is proportional to the difference between the original sampled value and the quantized value. The accuracy of this process relies on the bit depth (bits per sample), with increased bit depths providing more accurate quantization levels and lower error. (Cao et al., 2022)

1. Encoding

The last operation in PCM is the encoding, where the quantized values are converted to a binary code for digital storage or transmission. Each of the quantized values is represented as a binary number to facilitate the successful data transmission over digital channels.

In telephony, PCM has widespread use in representing voice signals digitally. With the discovery of PCM, efficient voice transmission across digital networks like the Public Switched Telephone Network (PSTN), mobile telephony systems, and Voice over IP (VoIP) became possible. In high-fidelity audio digital recording, PCM serves as the foundation for the compact disc (CD) formats, and the audio record is taken with high fidelity and precision so that the listener can perhaps reproduce the original sound without loss. (Keiser, 2012b)

### 3.b) Sampling Process and PAM in Pulse Code Modulation

The sampling process in PCM is the first digitization of a continuous time signal to a discrete time signal. It is the process of sampling an equally spaced continuous analog signal at fixed intervals, thereby transforming the continuous time waveform into a set of discrete-time values. The sampling process is mathematically defined as:

Where is the continuous-time signal and is the sample period. The discrete-time signal so formed takes the amplitudes of the analog signal at instances in time but keeps the same amplitude values as of the continuous signal. (Ibe, 2018)

Pulse Amplitude Modulation (PAM) is a description of the sample output because sample values are pulses, in which the amplitude of each pulse is the value of the signal at the sampling instant. Thus, every sample of the PCM process is essentially a pulse whose amplitude is the value of the original signal at some moment in time. The acronym PAM is the result of how sample data is represented as a sequence of pulses with different amplitudes, relative to the instantaneous value of the original signal. PAM hence is a process in PCM where the analog signal is converted to pulses of different amplitudes. Quantization and coding in binary are utilized after sampling to complete conversion to a digital signal. (Bakshi and Late, 2020)

### 3.c) Impact of Sampling and Quantization on Digital Signal Quality

The process of sampling and quantization determines the accuracy and resolution of a digital signal to a considerable extent.

Sampling

Sampling establishes the sampling rate at which the continuous time signal is sampled to produce a discrete time signal. Although it has no direct effect on the amplitude resolution, the sampling rate influences the temporal resolution of the signal. Higher sampling rate allows the representation of more rapidly changing signals with greater accuracy. Reducing the sampling rate below the Nyquist rate leads to aliasing and a distorted resulting signal. (Marco, 2025a)

Quantization

Quantization is the process of approximating the amplitude of every sample to the nearest from a finite number of quantization levels. The resolution of the digital signal is determined by the number of such levels, and it is directly proportional to the number of bits utilized in the process of quantization. For instance, in 8-bit depth there are quantization levels, and in 16-bit depth levels. Higher bit depths represent more precise quantization, yielding a more accurate representation of the signal amplitude and less quantization error. (SARAT, 2024)

Bit Depth and Signal Quality

The number of bits per sample is crucial in deciding the accuracy of the digital signal. The interdependency of the number of quantization levels L and the amount of bits n is expressed as:

For example, an 8-bit depth is equivalent to L=256 levels and a 16-bit depth is equivalent to L=65,536 levels. More bits provide greater quantization resolution that increases the precision of the digital representation and leads to a closer approximation of the original analog signal. This improves the digital signal directly by minimizing distortion and quantization noise (Widrow, 2008)

Therefore, sampling rate influences temporal resolution, and bit depth influences amplitude resolution. Increased bit depths equate to increased resolution, reducing distortion to offer greater quality for digital audio or data transfer.

### 3.d) Encoding Quantized Samples into Binary and Bit Calculation

Encoding Process

Each quantized value is represented in its binary representation. The number of bits representing each sample is a function of the quantization level number L. The equation for the number of quantization levels and the number of bits is

For example, if the quantization levels ,then the number of bits required to encode each sample is bits. Similarly, if , the number of bits required would be bits. (bin, 2023)

Bit Depth and Binary Representation:

The number of bits to be encoded per sample depends on the quantization resolution. More bits are used to encode every sample for higher levels of quantization (due to a higher bit depth). The binary encoding gives each sample of quantization a distinct binary code, which is stored or transmitted as digital. The bit depth directly affects the resolution and accuracy of the digital signal, with larger bit depths providing higher precision and signal quality. (Agarwal, 2024)

## TASK 4: Signal Patterns for Bit Pattern Using Different Encoding Techniques

### Non-Return to Zero – Inverted

Figure non-return to zero - inverted

### Non-Return to Zero – Level

Figure non-return to zero - level

### Manchester

Figure manchester

### Differential Manchester

Figure differrental manchester

### Bipolar – AMI

Figure bipolar - aim

### Unipolar NRZ

Figure unipolar nrz

### Return to Zero

Figure return to zero

### Pseudo ternary

Figure pseudo ternary

## Conclusion

This report has exhaustively addressed the basic and complex concepts of data communication, network technologies, and digital signal processing, theoretical know-how and practice. Through the orderly arrangement of each assignment, the study has illustrated the dependency of communication protocols, transmission methods, and network design in achieving effective, secure, and reliable data transfer.

In connection with contemporary networking, Virtual Circuit Packet Switching and Circuit Switching were contrasted on the basis of the inherent role played by structure in determining reliability as well as fault tolerance. Choosing MPLS as the most appropriate WAN technology for multinational enterprises was determined by virtue of extensive knowledge about data communication component message types, transmission media, and protocols indicating its scalability characteristics, performance, and integration capability. In the same vein, the suggestion of using fiber optic broadband and VPN by small businesses considered technical efficacy and data safety, observing best practices in remote access security and LAN connectivity.

Comparison of OSI and TCP/IP models emphasized the significance of the layer structure in solving the communication complexity problem. The functioning of Transport and Network Layers was examined in depth, with emphasis on their functions of error detection, flow control, and delivery of packets. Encapsulating and decapsulating operations were found to be as well as significant mechanisms for data integrity, addressability, and heterogeneity bridging interoperability between networks and systems.

The analysis of PCM provided insightful analysis of signal analog-to-digital conversion, especially in telecommunications and audio recording. Through the separation of sampling, quantization, and encoding processes, the report provided insight into technicalities influencing signal integrity and digital resolution. The discussion of bit depth and efficiency of encoding demonstrated how digital systems compromise between precision and resource consumption in practical implementations.

Finally, the illustration of different line encoding methods, i.e., NRZ, Manchester, and AMI, gave us an idea of how real binary data is encoded physically for transmission. All these are the cornerstone of network communication's physical layer, to ensure good synchronization, signal interpretation, and minimum transmission error.

Overall, the report addresses not only the intended audience's learning goals but also evidence of improved understanding of the driving forces necessary for proper network communication. The synthesis of theoretical frameworks with hands-on technical analysis improves the learner's existing skills in analyzing, designing, and administering contemporary data communication systems, and resolving the security and ethical issues crucial in today's networking and cybersecurity activities.

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