Assignment Report

TERM: **Spring, 2023-2024**

Module: **EE3627 Modern Communication Network**

CLASS: 34092102

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11, June 2024

Assignment 1

1. Introduction

A network consists of several nodes and links connecting these nodes. The nodes in the network can be computers, hubs, switches, routers, and so on. According to the scope of the network, it can be classified into **wide area network (WAN)** and **local area network (LAN)**. The **Internet** is a global computer network system, which is composed of numerous local area networks and wide area networks interconnected through standard network protocols, forming a global network system.

Wide area network (WAN) is a remote network that connects computers in different regions of local area network (LAN) or metropolitan area network, usually covering a large physical range, ranging from tens of kilometers to thousands of kilometers. Local area network (LAN) is the most common network type in the world, and the shadow of LAN can be found in almost all large and medium-sized office buildings. The transmission speed of LAN is very fast, and the transmission distance is limited, generally not exceeding several kilometers. There are various transmission media for LAN, including twisted pair, coaxial cable, optical fiber, etc. The topological structure of LAN includes bus, ring, star, tree, mesh, etc.

Table 1: The use of network in modern communication systems

Application	Explain
LANs and WANs	**LANs** are commonly used in offices, schools, or homes for sharing files, printers, Internet connections, etc. **WANs** are usually composed of multiple LANs for data transfer across long distances.
Internet communication	Internet communications include Web browsing, E-mail, and instant messaging over the network, enabling users to access information, send and receive messages, and communicate in real time, worldwide.
Mobile communication	**Cellular network**: Mobile phone use cellular network realize voice calls and data communication, such as 2G/3G/4G/5G. **Internet access**: Mobile devices are connected to the Internet via cellular networks or Wi-Fi to enable Internet services such as web browsing, social media, and email. **Location service**: Through the satellite network, GPS or other systems are used for positioning, navigation and other services

Internet of Things (IoT)	The network connects various devices and sensors to support smart homes, smart cities, and industrial automation.
Virtual private network (VPN)	VPNs are often used to protect data transmission and remote work by creating secure private communication tunnels over public networks.

2. Question 1

Table 2: Evolution of Topology

Topology	Application	Applicable communication technology	Driving forces
P2P	Early stage	Telephone, telegraph	Simple communication requirements, initial technical limitations
Bus	Early days of LAN	Ethernet, token bus	Simple network structure, low cost
Ring	Early to mid-term LAN	Token ring, FDDI	High reliability, low cost
Mesh	Mid-term LAN	Early ARPANET, WMN, WAN	High reliability, burst of users
Star	Modern LAN	Ethernet, WLAN	High reliability, low cost, burst of users
Tree	Large LAN and WAN	Ethernet, DSL, optical fiber network	Layered network structure, large network requirements
Hybrid	Modern communication system	Large scale network, data center	Burst of services, high performance, flexibility

Table 2 summarizes the evolution of topologies and their driving forces, etc. The table represents the evolution of the topologies from top to bottom.

2.1. Different stages of topology

In the earliest communication networks, the **point-to-point topology (P2P)** was the most basic form. Each communication device is directly connected to another device, forming a one-to-one connection. This technology emerged from the initial requirements for communication, but the technology at the time only allowed simple direct communication. The earliest telephone and telegraph systems used point-to-point communication.

In order to reduce the cost of wiring and meet the simple requirements of resource sharing. In the early days of LANs, **bus topologies** were widely used, where applicable communication technologies included Ethernet and token buses.

In order to reduce costs and ensure reliable communication, **ring topology** was employed during the early to mid-term LANs. Relevant communication technologies included token ring and Fiber Distributed Data Interface (FDDI).

In mid-term LANs, **mesh topology** was adopted. Mesh topology structures offer high reliability, but their complexity, implementation costs, and management challenges are drawbacks. Mesh topology was used in early networks like ARPANET, driven by the need for high reliability and the explosive growth in the number of users.

In modern LANs, **star topology** is widely used. The applicable communication technologies include modern Ethernet and wireless LAN (WLAN), driven by high reliability, low cost, and rapid user growth.

Tree topologies use hierarchical structure, suitable for hierarchical management and control systems. Compared with the star topology, tree topologies communication line length is shorter, and the cost is lower.

In modern communication networks, **hybrid topologies** are commonly employed due to increased service demands and higher quality communication requirements. Hybrid topologies combine the advantages of multiple topology structures and are typically used in large-scale networks.

2.2. Driving force for the development of communication networks

The development of communication networks is driven by multiple factors. From the perspective of network topology evolution, the main driving forces include:

(1) **Technological Innovation**: With the emergence of new technologies, such as LANs, WANs, and Internet, network topologies continuously evolve to meet the demands for higher speeds, greater capacity, and lower latency.

(2) **User Demand**: Increasing user demand for higher data transmission speeds, network reliability, and low latency drives the evolution of network topologies towards more efficient and flexible designs.

(3) **Economic Factors**: Cost-effectiveness is a crucial driving force in the evolution of network topologies. Network design needs to balance cost and performance while also considering scalability and maintenance costs.

3. Question 2

Switching is the process of transferring data from one device to another over a **LAN**. Switching devices such as Ethernet switches decide to which port a packet should be sent based on the MAC address of the destination device. Switches are usually used inside the LAN to improve the efficiency and speed of data transmission. Switching can be simply understood as: you give me an eraser, and I give you a pencil. Two people exchange things with each other. Extended to computer networks, it is the exchange of data.

Routing is the process of transferring data from a source device to a destination device over a **WAN** or the **Internet**. The router determines the next hop path of the packet based on the destination IP address. Routers are often used to connect different networks and transfer data from one network to another.

3.1. Switching technology

Switching technology mainly refers to the method of transferring data between network devices.

Table 3: Different switching technology

Switching technology	Characteristics	Applications
Circuit switching	• Dedicated channels • Real time transmission • Fixed bandwidth • Low latency • Information is transparent	Public Switched Telephone Network
Message switching	• No dedicated channels • Adaptable • High latency	• Telegraph network • Early computer network
Packet switching	• Efficient use of bandwidth • No fixed path • High flexibility, strong fault tolerance	• Internet data transmission • LANs communications • Mobile communications network
Ethernet switching	• Fast forward • Full duplex communication • Wide range of applications	LANs communications
VLAN	• High safety • Simple management • Broadcast domain decrease	• Large enterprise network • Campus network

(1) Circuit switching

Circuit switching is the oldest type of switching, widely used in **telephone networks**. It is **connection-oriented**, establishing a dedicated physical path between two communicating parties for the entire duration of the call. The process of circuit switching involves three steps: **connection establishment**, **communication**, and **release of the connection**. Early telephone networks utilized circuit switching, which ensured the real-time and stable nature of calls, making it suitable for real-time voice communication.

The advantage of circuit switching is that there is a dedicated physical path between the two users, and during the whole time of communication, the two users always occupy the end-to-end line resources, and the transmission efficiency is high. However, additional time is required to establish or release connections, and the communication link is occupied by both parties, which is inefficient. Therefore, this switching technology is very suitable for telephone, because both parties need to communicate all the time, and the link setup time is tolerable.

(2) Message switching

In the 1940s, telegraph communications adopted packet switching technology based on the **store and forward principle**. In computer network, message can be understood as a large block of data to be transmitted. The message passes through several intermediate nodes during transmission, and each node stores the whole message before forwarding it to the next node. Message switching improved flexibility. However, but the message length is not the same, and the caching and forwarding overhead time is uncertain.

(3) Packet switching

Packet switching is the most used switching mode in modern communication networks. Packet switching is to divide the message into small packets, each packet is transmitted independently. At each switching node, the packet selects the best path according to the network conditions, and dynamically forwards to the destination through multiple nodes in the network.

Packet switching can be divided into **virtual circuit** and **datagram**. Virtual circuit is **connection-oriented**, datagram is **connectionless**.

Virtual circuit is a logical connection that establishes a path before sending data, and all packets are transmitted along this preestablished path, waiting instead of switching paths even if the path is congested. Virtual circuits can be Permanent (PVC, Permanent Virtual Circuit) or temporary (SVC, Switched Virtual Circuit). The application of virtual circuit are **ATM** and **frame relay**.

Datagram is a form of connectionless packet switching in which each packet is transmitted independently and can take different paths to reach its destination. There is no pre-established path in the network, and each packet contains complete destination information. The characteristic of datagram is high flexibility.

(4) Ethernet switching

An Ethernet switch is a common switching device used in local area networks (LANs) to forward data frames between network nodes. Ethernet switching is widely utilized in enterprise and data center networks, providing high-speed and reliable data transmission. It serves as the fundamental technology for constructing local area networks.

(5) Virtual local area network

VLAN is a logical network division method, by configuring VLAN on the switch, a physical network can be divided into multiple logical networks. VLAN technology is widely used in network environments where different user groups need to be isolated, such as large enterprises, campus networks, and data centers.

3.2. Routing protocol

A routing protocol is a set of rules and standards used to determine the best transmission path for a packet in a computer network. They are mainly used in WANs and between different network segments. Internet divided routing protocols into two categories:

$$\text{Routing protocol}\begin{cases}\text{Interior Gateway Protocol: RIP, OSPF}\\ \text{External Gateway Protocol: BGP}\end{cases}$$

Table 4: Routing protocols

Protocol	Describe	Characteristic
Routing Information Protocol (RIP)	Distance vector-based routing protocols, which use hop count as a metric, are suitable for small networks.	• Distance vector algorithm • Maximum hops limited are 15 • Update routing tables periodically • Simple • Need long time to find failure
Open Shortest Path First (OSPF)	The routing protocol based on link state uses Dijkstra algorithm to calculate the shortest path, which is suitable for large and complex networks.	• Link state algorithm • Fast convergence • Complex to configure and manage
Border Gateway Protocol (BGP)	Path vector protocol, which is mainly used for routing between autonomous systems, is a key protocol in Internet backbone network.	• Path vector algorithm • Highly flexible routing control policy • High extensibility
Enhanced Interior Gateway Routing Protocol (RIGRP)	Advanced distance vector routing protocol developed by Cisco, which combines the advantages of distance vector and link state, is suitable for medium and large networks.	• Hybrid routing algorithm • DUAL algorithms ensure no loop • Fast convergence

3.3. The significance of switching and routing technology in communication network

Switching technologies mainly serves LAN, **switch** works in **data link layer** of TCP/IP model. The switch can complete the transmission of frames in the LAN by forwarding, flooding, and dropping. Switches can efficiently process and forward data frames, thereby improving the performance and bandwidth utilization within the LAN. Switching technology significantly improves network reliability and transmission speed by full-duplex communication and reducing collision domains. Therefore, switching technology makes it possible to carry out reliable communication within the LAN.

Routing protocols mainly serves WAN, **router** works in **network layer**. Working in the network layer enables routers to choose the best path according to IP address, and implement path selection and packet forwarding in complex network environment by routing protocols such as RIP, OSPF, BGP, etc. Routing technology ensures efficient data transmission between WAN and different network segments through path selection, load balancing and redundant paths, and enhances the reliability and fault tolerance of the network. Therefore, routing protocols/technologies ensure that reliable communication can be carried out between different networks.

Overall, switching and routing technologies are the cornerstones of modern communication networks. They make data transmission faster, more reliable and more secure.

4. Question 3

In today's times, the new network service needs are concentrated in the following areas：

Table 5: New services demand

New services demand	Explain
Ultra-high bandwidth and low latency	To support the transmission of large amounts of data and real-time applications, networks need to provide ultra-high bandwidth and low latency connections, such as augmented reality (AR) and virtual reality (VR).
Large-scale connection	With the development of the IoT, the network needs to be able to support ultra-large-scale device connections.
Multi-cloud access and security	Organizations need to ensure that employees can securely access applications and data distributed across multiple cloud platforms [1].
Global network coverage	Communication is possible at high altitudes, at sea, and even globally.

Table 6: Network technologies

Network technologies	Explain
Optical communication	The use of fiber optics instead of traditional copper wires provides the basis for high-speed Internet connections.
Satellites network	At present, satellite communication is mainly used for positioning, and there are already mature satellite constellations, which provide the basis for large-scale mobile satellite communication in the future.
AI and machine learning (ML)	AI and ML will be widely used in network management and optimization to automate network traffic handling, predict failures, and make real-time adjustments. This will greatly improve the self-management ability and service quality of the network

Edge computing	Push data processing to the edge of the network to reduce latency and bandwidth usage
IoT	At present, the ultra-low latency of 5G technology can initially realize the IoT. Networks enable smart home and industrial automation by collecting and exchanging data

Based on these requirements presented in Table 5 and network technologies presented in Table 6, future network architectures can be analyzed. Reference [2] summarizes eight evolution trends of future network architectures: Cloud-Native Evolution, Global Network Coverage, Layered Distribution, Customized Scenarios, Network Intelligence, Application Enablement, Multi-Dimensional Sensing and Computing-Network Convergence. Reference [3] argues that new network architectures contain: Distributed network, Software defined network (SDN), LEO satellite network, etc. Reference [4] argues that B5G and 6G will become the mainstream of the future communication network and analysis their demands and challenges.

Therefore, I think the future network architecture may have the following types:

(1) **B5G and 6G**: B5G (Beyond 5G) and 6G refer to the development stage after the fifth-generation mobile communication technology and the sixth-generation mobile communication technology, respectively. B5G enables higher frequency band communication, massive MIMO and further optimizes edge computing; 6G supports THz communication, massive connectivity and other technologies. Therefore, these technologies will be the network architecture of the future.

(2) **LEO satellites network**: Low Earth Orbit (LEO) satellite networks have advantages such as large spatial span, wide coverage, and strong anti-destruction capabilities. In addition, due to the low orbital altitude of LEO satellites, they offer short transmission delays and low path loss. Constellations composed of multiple satellites can achieve **truly global broadband satellite service** capabilities. Therefore, low-cost satellites phone communication may be a reality in the future.

(3) **Distribute architecture**: Through edge computing and fog computing technology, computing and storage resources are distributed to the edge of the network, reducing the burden of the centralized data center, improving data processing efficiency and response speed.

(4) **Software-defined network**: SDN separates the network control plane from the data plane and uses software to control network traffic, enabling programmability, flexibility, and efficient management of the network. SDN plays an increasingly important role in areas such as cloud computing, data centers, enterprise networks, and WAN, becoming a crucial component of future network architectures.

5. Conclusion

5.1. TCP/IP model

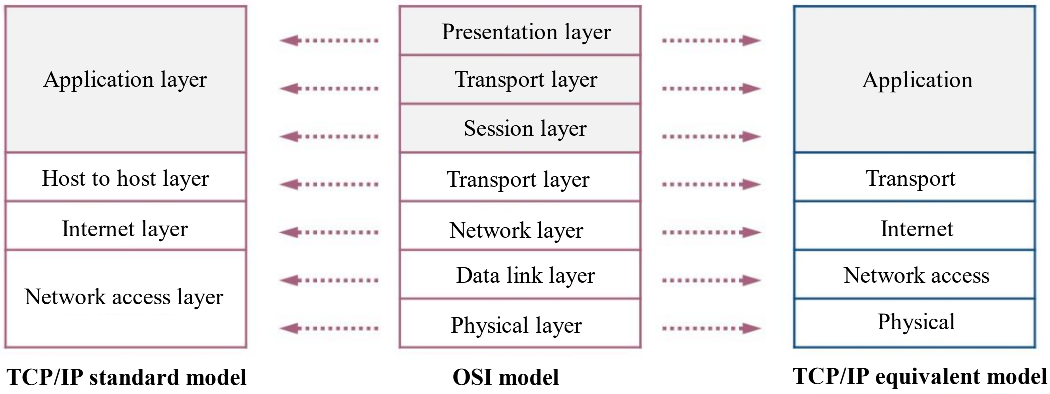

Figure 1: A comparison of the OSI and TCP/IP protocol architecture

OSI model and TCP/IP model are both frameworks to describe network communication, but their design purpose and application area are different. OSI model as a theoretical standard, helps to understand and design network systems. TCP/IP model as the basic architecture of the Internet, widely used in the actual network communication.

Overall, **OSI is a theory model and TCP/IP is a model used in practice**.

5.2. Physical layer

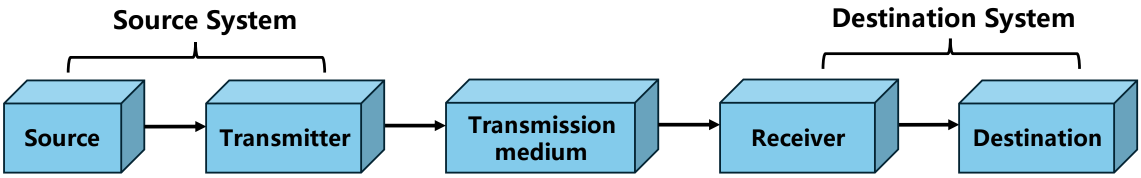

Figure 2: Data communication model

The physical layer is responsible for the raw bit transmission on the physical medium to ensure the correct transmission of binary bits. Telecommunication transmission theory is applied in this layer.

5.3. Data link layer

(1) Switching technology

$$\begin{cases} \textbf{Circuit switching} - \text{connection oriented} \\ \textbf{Packet switching} \begin{cases} \text{Virtual circuit} - \text{connection oriented} \\ \text{Datagram} - \text{connectionless} \end{cases} \end{cases}$$

- Connection oriented: TCP, ATM, frame relay
- Connectionless: UDP

$$\text{(2) Flow control} \begin{cases} \text{Stop and wait} \\ \text{Sliding} - \text{window} \end{cases}$$

Stop and wait flow control: After sending a frame, the sender must wait for an acknowledgment from the receiver before sending the next frame. The receiver can control the stopping of data transmission by whether to send an acknowledgment or not.

Sliding window: By sending multiple frames in batches, the receiver only needs to send an acknowledgment when a batch of frames has been transmitted.

(3) Error control $\begin{cases} \text{Stop} - \text{and} - \text{wait ARQ} \\ \text{Go} - \text{back} - \text{N ARQ} \\ \text{Selective} - \text{reject ARQ} \end{cases}$

Stop and wait ARQ means the source station transmits a single frame and then must wait an ACK, no other data frames can be sent until the destination station's reply arrives at the source station. Go back ARQ based on sliding window, start from where you sent the error and resend everything else. Selective reject ARQ means if the frame is wrong, the frame will be retransmitted.

(4) Routing strategy in packet switching network

$$\begin{cases} \textbf{Fixed routing}\text{: Simple, but inflexible} \\ \textbf{Flooding}\text{: High roubust, but data is too large} \\ \textbf{Random routing}\text{: Simple, roubust and small date} \\ \textbf{Adaptive routing} \end{cases}$$

(5) Local area network

LAN includes Ethernet network. From IEEE 802 standard, data link layer can be divided into **logic link control layer (LLC)** and **media/medium access control layer (MAC)**.

$$\text{MAC}\begin{cases} \text{Static channel partition} - \text{Channel partitioned MAC}\begin{cases} FDM \\ TDM \\ WDM \\ CDM \end{cases} \\ \text{Dynamic allocation channel}\begin{cases} \text{Polling access MAC} - \text{Token access control} \\ \text{Random access MAC}\begin{cases} \textbf{ALOHA protocol} \\ \textbf{CSMA protocol} \\ \textbf{CSMA/CD protocol} \\ \textbf{CSMA/CA protocol} \end{cases} \end{cases} \end{cases}$$

5.4. Network layer

The data link layer typically serves LANs and uses MAC addresses for addressing and data transmission. However, for multiple networks, this addressing method is too resource-intensive, hence IP addresses are introduced.

(1) Internet protocol (IP) $\begin{cases} \textbf{ARP}\text{: Address resolution protocol} \\ \textbf{ICMP}\text{: Internet control message protocol} \\ \textbf{IGMP}\text{: Internet group management protocol} \end{cases}$

- ARP

Regardless of the protocol used at the network layer, when transmitting data frames on the actual network link, hardware addresses must ultimately be used. Therefore, a method is needed to map IP addresses to MAC addresses. This is achieved by the Address Resolution Protocol (ARP), **whose task is to resolve a given IP address to its corresponding MAC address**.

- ICMP

ICMP is a protocol used to send error messages and operation information between network devices, which is encapsulated in IP datagrams

(2) IPv4

$$\text{Addressing method}\begin{cases}\text{Classful IP addressing}\\ \text{Subnetting}\\ \text{Classless inter domain routing (CIDR)}\end{cases}$$

(3) Routing protocol

$$\begin{cases}\text{Routing information protocol}(\textbf{RIP})-\text{Distance vector algorithm}\\ \text{Open shortest path first}(\textbf{OSPF})\end{cases}$$

5.5. Transport layer

$$\begin{cases}\text{Transmission control protocol}(\textbf{TCP})-\text{connection oriented}\\ \text{User datagram protocol}(\textbf{UDP})-\text{connectionless}\end{cases}$$

Reference

[1] Cisco, Inc. 2023 Global Network Trends Report [R]. 2023.

[2] ZTE, Inc. White paper on the Evolution Trend of future Mobile Core Network [R]. 2023.

[3] Ouyang Man, LIU Jiang, Liao Xinyue, et al. Research on the Development of new network Architecture [J]. Engineering Science, 2022,24(04):12-21.

[4] E. A. Kadir, R. Shubair, S. K. Abdul Rahim, M. Himdi, M. R. Kamarudin, S. L. Rosa. B5G and 6G: Next Generation Wireless Communications Technologies, Demand and Challenges[C]// 2021 International Congress of Advanced Technology and Engineering (ICOTEN), Taiz, Yemen, 2021: 1-6.