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STUDY NOTES

COMPUTER NETWORKS

Unit I — Introduction to Computer Networks and Physical Layer

Topics Covered (09 Hours)

Introduction & Definition of Computer Networks
Uses of Computer Networks (Business, Home, Mobile Users)
Network Hardware Classification (PAN, LAN, MAN, WAN, Internetworks)
Network Software Architecture (Hierarchies, Protocols, Interfaces)
Design Issues for Layers (Error Control, Flow Control, Routing)
Connection-Oriented vs. Connectionless Services & Primitives
Reference Models (OSI 7-Layer and TCP/IP 4-Layer Models)
Comparison Between OSI and TCP/IP Architecture
Physical Layer: Guided Transmission Media (Coaxial, Fiber, Twisted)
Wireless Transmission & Electromagnetic Spectrum Basics
The Telephone System (PSTN Structure, Loops, Trunks, Switching)
Narrowband and Broadband Communication Systems

Compiled in a simple, easy-to-understand, book style format
for students of Computer Science and Engineering

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1.1 Introduction & Uses of Computer Networks

A computer network represents the core infrastructural backbone of modern IT services. Formally, we define a computer network as a set of autonomous, self-governing computing machines that are interconnected via physical or wireless communication media. The term 'autonomous' is crucial: it specifies that the network nodes operate independently. No single computer can arbitrarily control, shut down, or dictate the direct processing cycles of another node. Interconnections are established using copper cabling (twisted pair, coaxial), optical fibers, or wireless techniques (radio waves, microwaves, infrared, and satellite systems).

The historical transition from centralized mainframe computing (where multiple terminals accessed a single giant computer) to distributed networking (where multiple independent systems share the computational burden) marked a paradigm shift in how information is stored, processed, and retrieved. Today, computer networks form the underlying architecture for everything from global cloud data centers to small personal accessories.

> **Computer Network**
> *A computer network is an interconnected assembly of autonomous computing devices that exchange data, coordinate tasks, and share physical or logical resources by adhering to standard communication protocols and utilizing diverse transmission media.*

Detailed Analysis of Network Use Cases

To fully comprehend why networks are deployed, we must categorize their primary applications based on user environments. These are split into Business Applications, Home Applications, and Mobile Users.

1. Business Applications

For modern corporations, networks are a survival necessity. The primary driver is Resource Sharing. Instead of purchasing expensive hardware (like enterprise laser printers, high-capacity storage SANs, or mainframe database engines) for every employee, resource sharing allows all network nodes to access central hardware. Even more important is information sharing. Organizations store critical customer records, financial ledgers, and operational data on central databases (servers), which are accessed by remote terminals (clients).

This client-server dynamic forms the bedrock of business computing. A client process sends a request over the network to a server process, which processes the request, performs security checks, and returns the requested data. Additionally, businesses rely on networks for seamless internal communication (via email, instant messaging, VoIP, and video conferencing systems), e-commerce transactions (interfacing with supply chains, suppliers, and customer payments), and collaborative document editing in real-time.

2. Home Applications

For individuals in residential settings, networks provide access to the global Internet. Home networking has evolved from basic dial-up connections into high-speed fiber-optic or cellular links that support a multitude of applications. We can classify these home use cases into four categories:

- **Remote Information Access:** Users browse the World Wide Web, access digital libraries, retrieve news updates, read online blogs, search search engines, and access online banking and financial records.
- **Person-to-Person Communication:** This includes electronic mail (email), real-time messaging services, social networking platforms (like Facebook, Instagram, LinkedIn), blogs, and video-based calls connecting family members globally.
- **Interactive Entertainment:** High-definition video streaming (Netflix, YouTube, Prime), digital music streaming (Spotify), video-on-demand services, and online multiplayer gaming where users compete with players across different continents.
- **Electronic Commerce:** Online shopping platforms (Amazon, eBay, local grocers), home banking transactions, online auctions, and scheduling services from home.

3. Mobile Users

Mobile networking represents the fastest-growing sector of computer networks. It involves connectivity for devices that are not stationary (smartphones, tablets, laptops, vehicle trackers, smartwatches, and medical sensors). Mobile users rely heavily on wireless infrastructures like cellular towers (4G, 5G, and upcoming 6G) and localized Wi-Fi access points.

Key mobile network applications include mobile commerce (contactless payments, digital ticketing, mobile banking), location-based services (GPS navigation, localized search recommendations, ride-hailing apps like Uber), mobile healthcare (real-time telemetry of patient vitals sent to hospitals), and remote logistics (monitoring delivery fleets, tracking packages in real-time). The integration of mobile users has paved the way for the Internet of Things (IoT), where household appliances, smart meters, traffic lights, and environmental sensors communicate autonomously.

1.2 Network Hardware

Network hardware is classified based on its scale, geographic transmission range, and physical architecture. The scale of a network dictates the hardware design, routing requirements, and bandwidth capacities.

Geographic Scale Classification

From personal devices to the global Internet, networks are categorized into five major types. Below is an exhaustive structural breakdown:

- **Personal Area Network (PAN):** A PAN is designed for devices surrounding a single person's immediate workspace. The typical range is within 10 meters. The most common technology is Bluetooth (connecting a phone to wireless headphones, smartwatches, mouse, and keyboard). Other technologies include Zigbee and Ultra-Wideband (UWB).
- **Local Area Network (LAN):** A LAN is a privately owned network that spans a single room, home, office building, school, or university campus (ranging from 10 meters to 1 kilometer). LANs connect personal computers, workstations, and printers to share resources and exchange data. LANs are characterized by high data-transfer rates (typically 100 Mbps to 10 Gbps) and low error rates. The dominant wired LAN technology is Ethernet (IEEE 802.3), which uses twisted-pair or fiber-optic cables connected to physical switches. The dominant wireless LAN technology is Wi-Fi (IEEE 802.11).
- **Metropolitan Area Network (MAN):** A MAN covers an entire city or metropolitan region (spanning 10 to 50 kilometers). It is often owned by a consortium of users or a single service provider that sells services to businesses and individuals. A classic example of a MAN is the city-wide cable television network or municipal fiber-optic rings that connect local schools, government offices, and businesses to high-speed backbones.
- **Wide Area Network (WAN):** A WAN covers a large geographic area, such as a state, province, country, or even the entire globe (spanning hundreds to thousands of kilometers). It connects multiple LANs and MANs. WANs are managed by telecommunication companies, ISPs, or large multinational corporations. WAN hardware consists of two components: hosts (user machines) and the subnet (the communication subnetwork). The subnet is responsible for carrying messages from host to host, consisting of transmission lines (fiber-optic links, microwave channels) and switching elements (routers).
- **Internetwork:** An internetwork (or internet) is a collection of interconnected networks. The global Internet is the most prominent example. It connects millions of heterogeneous networks (LANs, WANs, and MANs) using standard hardware devices called routers and gateways, allowing them to communicate by adhering to the TCP/IP protocol suite.

Summary of Network Classification by Scale

Scale Type	Typical Transmission Range	Physical Location / Example	Primary Interconnect Hardware
PAN	1 m to 10 m	Personal desktop, smart wearable, Bluetooth link.	Bluetooth controller, wireless hub.
LAN	10 m to 1 km	Home, office suite, university lab, building.	Ethernet switches, Wi-Fi access points, hubs.
MAN	10 km to 50 km	Cable TV network, municipal city network.	Fiber switches, high-speed optical routers.
WAN	100 km to 10,000 km	National network, multinational enterprise WAN.	Routers, transmission trunks, satellites.
Internetwork	Global	The World Wide Web (The Internet).	Routers, gateways, firewalls, DNS servers.

1.3 Network Software

Modern computer network software is highly structured. To reduce the enormous complexity of network operations, software is organized as a vertical stack of layers or levels, each built upon the one below it. The exact number, names, contents, and functions of the layers differ from network to network.

Protocol Hierarchies

The layering model operates on the principle of encapsulation and abstraction. Each layer provides services to the layer immediately above it, while hiding the implementation details of those services. Peer entities—the corresponding software or hardware layers on different machines—communicate using a set of rules and formats called a Protocol.

In reality, no data is transferred directly from layer n on one machine to layer n on another. Instead, each layer passes data and control information to the layer immediately below it, until the lowest layer (the Physical Layer) is reached, which physically transmits the signal. Between adjacent layers lies the Interface. The interface defines which primitive operations and services the lower layer makes available to the upper layer. A set of layers and protocols is called a Network Architecture.

Key Design Issues for Layers

Every layer in the protocol stack must address a series of fundamental engineering challenges to ensure reliable, efficient data delivery:

- **Addressing:** Each layer must have a way to identify senders and receivers. Since a machine can run multiple applications, there must be a way to direct data to the correct process (using port numbers, IP addresses, or MAC addresses).
- **Error Control:** Physical channels are unreliable. Layers must agree on error-detecting and error-correcting codes, and implement retransmission protocols to handle lost or corrupted data.
- **Flow Control:** Preventing a high-speed sender from overwhelming a slow receiver. It requires buffer management and feedback mechanisms (like sliding windows).
- **Routing:** When multiple paths exist between source and destination, the network software must compute the optimal route.
- **Multiplexing & Demultiplexing:** Allowing multiple independent conversations to share the same physical link or channel.

Connection-Oriented vs. Connectionless Services

Layers can offer two distinct categories of services to the layers above them:

- **Connection-Oriented Service:** Modeled after the telephone system. To communicate, the sender first establishes a connection, transmits the data, and then terminates the connection. The service acts as a pipe: bits are delivered in the exact order they are sent. It is highly reliable. (Example: TCP).

- **Connectionless Service:** Modeled after the postal system. Each packet (called a datagram) carries the full destination address and is routed independently through the network. Packets can take different routes, arrive out of order, or be lost. It is fast and lightweight. (Example: IP, UDP).

Service Primitives

A service is formally specified by a set of primitives (system calls) that a user process can invoke to interact with the service. In a typical connection-oriented service, the primitives are:

- **LISTEN:** The server blocks, waiting for an incoming connection request.
- **CONNECT:** The client initiates a connection to a waiting peer.
- **ACCEPT:** The server accepts the client's connection request.
- **SEND:** One peer sends data to the other.
- **RECEIVE:** A peer blocks, waiting for incoming data.
- **DISCONNECT:** Terminates the active connection.

> **NOTE**
> It is critical to distinguish between Services and Protocols. A Service is a set of operations that a layer provides to the layer above it, defining 'what' the layer does. A Protocol is a set of rules governing the format and meaning of packets exchanged between peer entities within a layer, defining 'how' the layer achieves its task.

1.4 Reference Models: OSI vs. TCP/IP

We analyze network designs using two prominent reference models: the theoretical OSI model and the practical TCP/IP model.

The OSI Reference Model (7 Layers)

The Open Systems Interconnection (OSI) model was developed by the International Organization for Standardization (ISO). It is a 7-layer model designed to promote open standards. The layers are:

- **7. Application Layer:** Supports user applications. Contains protocols like HTTP (web browsing), SMTP (email), and FTP (file transfer).
- **6. Presentation Layer:** Handles data representation, syntax, compression, and encryption. It translates between different machine representations.
- **5. Session Layer:** Manages dialog control, session checkpointing, and synchronization between processes.
- **4. Transport Layer:** Provides reliable, end-to-end data transfer, flow control, and segmentation. (e.g., TCP, UDP).
- **3. Network Layer:** Responsible for routing packets across multiple networks, addressing, and congestion control. (e.g., IP).
- **2. Data Link Layer:** Ensures reliable frame transmission over a physical link, handling framing, addressing, and error detection.
- **1. Physical Layer:** Transmits raw bitstreams over physical media, defining electrical voltages, connector shapes, and timings.

The TCP/IP Reference Model (4 Layers)

The TCP/IP model was developed by the US Department of Defense (ARPANET) and is the practical model of the Internet. It is a 4-layer model:

- **4. Application Layer:** Combines the functions of OSI's Application, Presentation, and Session layers. Contains HTTP, SMTP, DNS, and FTP.
- **3. Transport Layer:** Handles host-to-host communication, connection setup, and flow control. Includes TCP (reliable) and UDP (unreliable).
- **2. Internet Layer:** Injects packets into the subnet and routes them independently to the destination. Uses the IP protocol.
- **1. Link Layer:** Defines how host network interfaces access the physical transmission medium (Ethernet, Wi-Fi).

OSI vs. TCP/IP Comparison

Feature	OSI Model	TCP/IP Model
Theoretical Base	High. Separates services, interfaces, and protocols clearly.	Low. It does not clearly separate these concepts.
Implementation	Unpopular. The software was historically heavy and slow.	Universal. It is the practical foundation of the modern Internet.
Layer Count	7 Layers	4 Layers
Network Layer Mode	Supports both connectionless and connection-oriented.	Supports only connectionless (IP) at the Internet layer.

1.5 Physical Layer: Guided & Wireless Media

The Physical Layer deals with the physical transmission media and the electromagnetic signals used to carry bits.

Guided (Wired) Transmission Media

- **Twisted Pair:** Consists of two insulated copper wires twisted in a spiral to reduce electromagnetic interference from neighboring pairs. Used in telephone networks and LAN cabling. Categorized as UTP (Unshielded Twisted Pair, cheap and flexible) and STP (Shielded Twisted Pair, has a metal braid shield for high-noise industrial environments).
- **Coaxial Cable:** Has better shielding than twisted pair, allowing higher bandwidth and longer distances. Consists of a central copper conductor, surrounded by insulating plastic, a braided outer conductor, and a plastic jacket. Used in cable TV networks.
- **Fiber-Optic Cable:** Transmits light pulses through ultra-pure glass fibers. Immune to electromagnetic interference, has extremely low attenuation, and offers massive bandwidth. Split into Single-Mode (core is so thin, light travels straight without bouncing, used for long-distance telecom) and Multi-Mode (thicker core, light bounces off walls, used for short-range LANs).

Wireless (Unguided) Transmission

- **Radio Waves:** Easy to generate, travel long distances, and penetrate buildings easily. They are omnidirectional, meaning they travel in all directions. Used for mobile phones, AM/FM radio, and wireless LANs.
- **Microwaves:** Travel in straight lines (directional). Require line-of-sight path between sender and receiver. Used for satellite communications and cellular backhaul.
- **Infrared:** Used for short-range, line-of-sight communication (remote controls, wireless keyboards). Cannot pass through walls, preventing interference.

1.6 Telephone and Communication Systems

The Public Switched Telephone Network (PSTN) was designed for analog voice but serves as a major data conduit.

Structure of the PSTN

- **Local Loop:** The analog copper wires connecting the customer's premises to the telephone central office (End Office).
- **Trunks:** High-capacity digital fiber-optic links connecting different central central offices.
- **Switching Offices:** Locations where calls are routed between trunks and local loops.

Narrowband vs. Broadband Communication

- **Narrowband:** Low-capacity voice-grade lines. Traditional dial-up (56 Kbps) uses modems to convert digital computer data to analog voice frequencies.
- **Broadband:** High-capacity lines (DSL, Cable, Fiber) transmitting multiple signals simultaneously. DSL (Digital Subscriber Line) splits the local loop's frequency spectrum, keeping voice on low frequencies and data on high frequencies.

Unit Summary

This unit introduced the basic concepts of Computer Networks and the Physical Layer.

- A computer network consists of autonomous, interconnected systems.
- Networks are classified by scale (PAN, LAN, MAN, WAN, Internetworks).
- Layered architectures separate services from protocols.
- The 7-layer OSI model is theoretical, while the 4-layer TCP/IP model runs the Internet.
- Transmission media include twisted pair, coaxial, fiber optics, and wireless spectrums.
- The PSTN uses local loops, trunks, and switching offices to route narrowband voice and broadband data.