



الجمهورية العربية السورية

جامعة دمشق

كلية الهندسة الميكانيكية والكهربائية

قسم هندسة الإلكترونيات والاتصالات

□

□ مقرر شبكات الاتصالات المعلوماتية

□ (بالغة الإنكليزية)

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□ الطلاب السنة الخامسة – هندسة إلكترونيات واتصالات

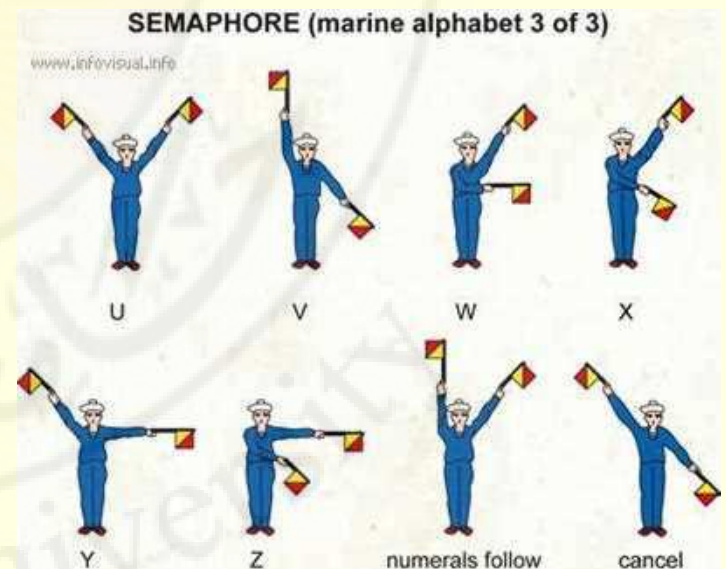
Damascus University

Introduction to Communication Systems and Networks

Dr. Farid Farahmand
Updated 8/31/2010

Telecommunications

- **Tele (Far) + Communications**
- Early telecommunications
 - smoke signals and drums
 - visual telegraphy (or semaphore in 1792)
- Telegraph and telephone
 - Telegraph (1839)
 - **Telephone (1876)**
- Radio and television
- Telephony
 - **Voice and Data**



Communications and Networks

■ Data Communications

■ Transmission of signals

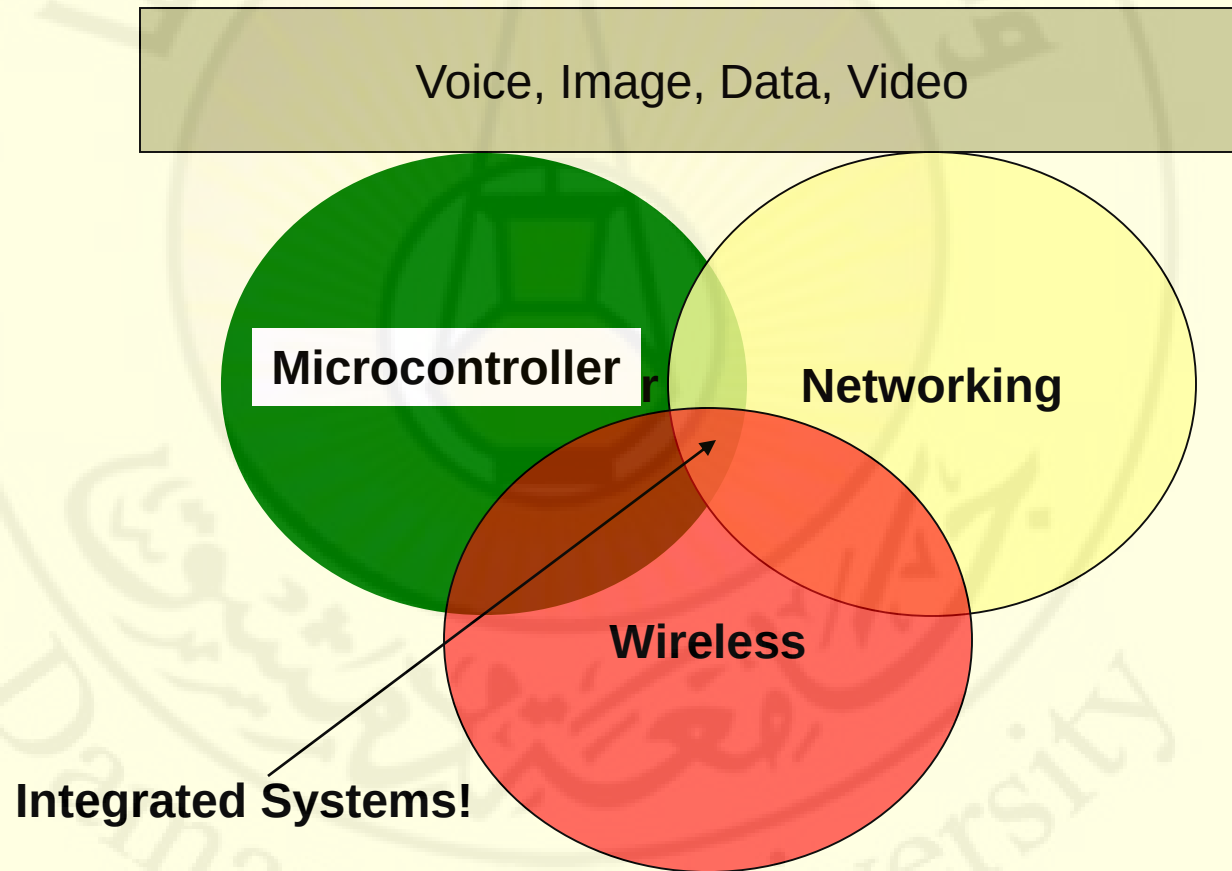
- Encoding, interfacing, signal integrity, multiplexing etc.

■ Networking

- Topology & architecture used to interconnect devices

■ Networks of communication systems

Network Trends (1980-Present)

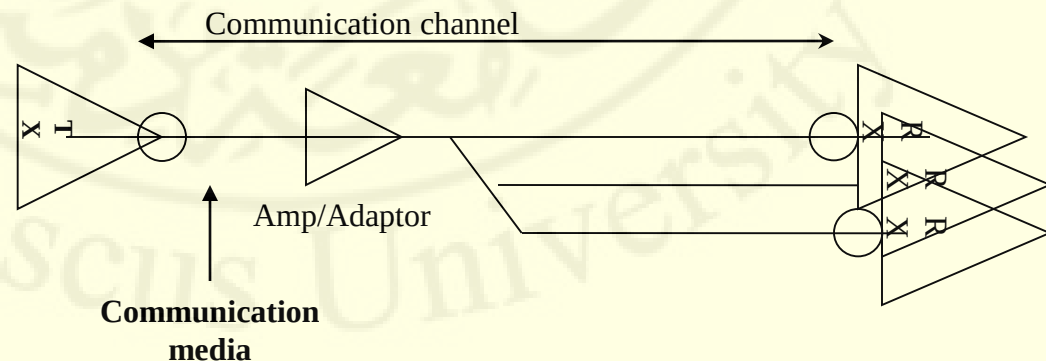


The background of the slide features a large, faint watermark of the Damascus University logo. The logo is circular, with a central emblem depicting a lantern or oil lamp with rays emanating from it. The emblem is surrounded by Arabic calligraphy. Below the emblem, the words "Damascus University" are written in English. The entire watermark is rendered in a light, semi-transparent grey color.

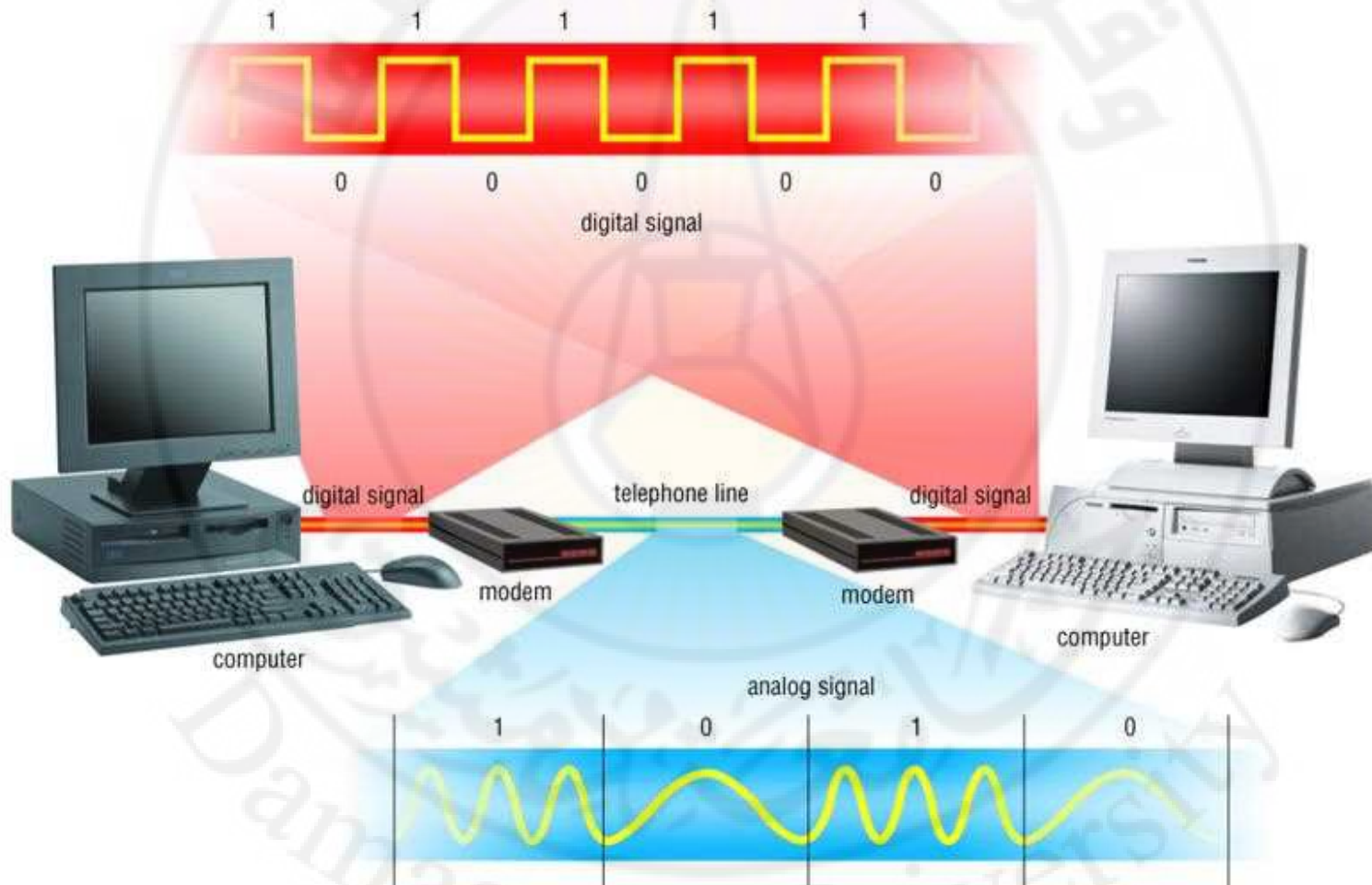
Communication systems

Communication Systems

- **Process** describing **transfer of information, data**, instructions **between one or more systems through some media**
 - Examples
 - people, **computers, cell phones**, etc.
 - Computer communication systems
- Signals passing through the communication channel can be **Digital, or analog**
 - Analog signals: continuous electrical waves
 - Digital signals: individual electrical pulses (bits)
- Receivers and transmitters: desktop computers, mainframe computers, etc.



Communication Systems

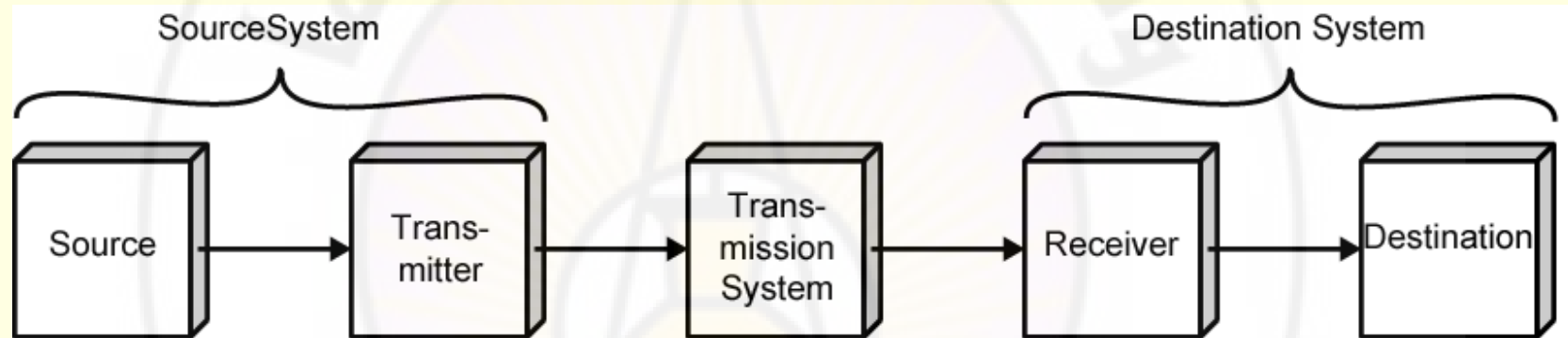


Communications Components

- Basic components of a communication system
 - Communication technologies
 - Communication devices
 - Communication channels
 - Communication software



A Communications Model



(a) General block diagram

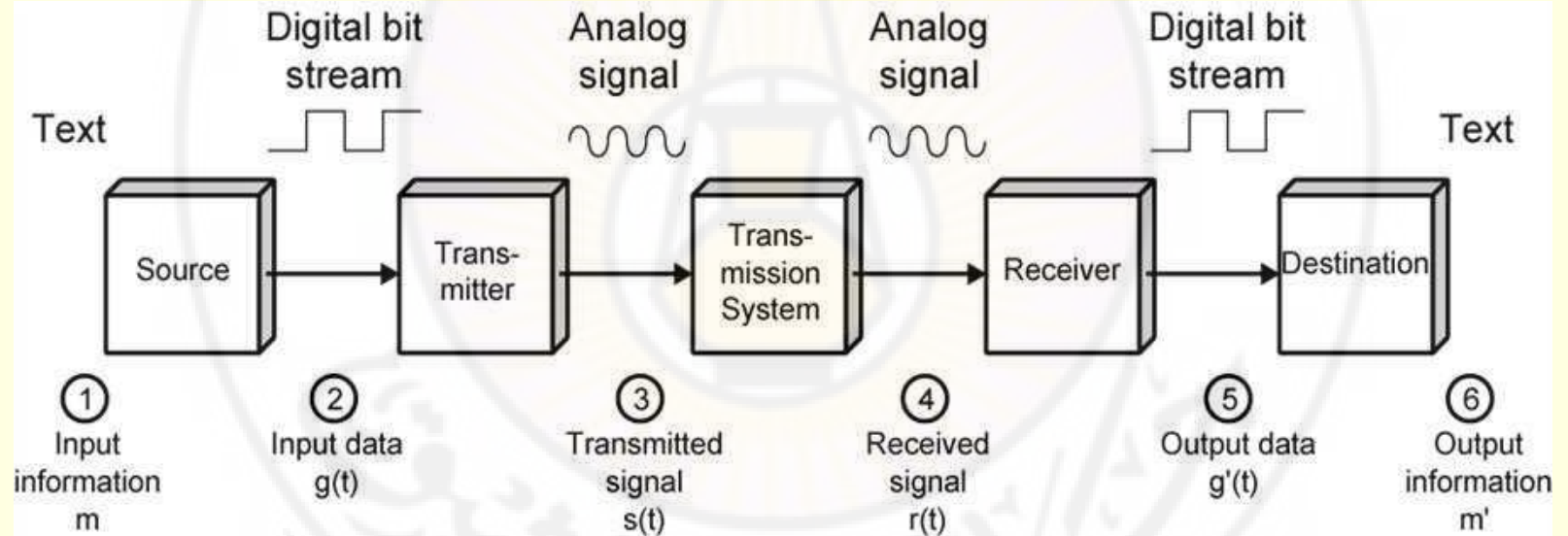


(b) Example

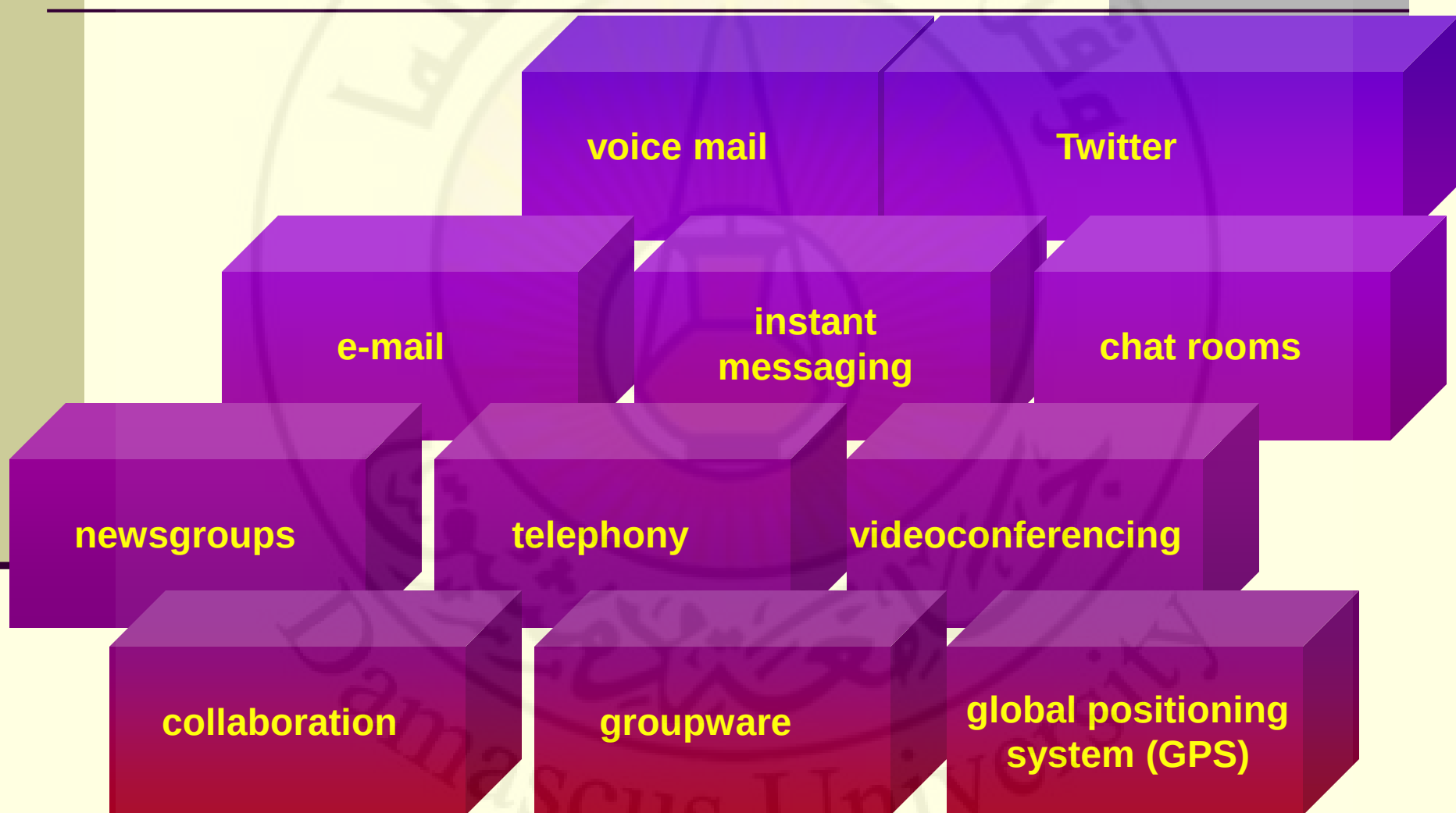
Communications Tasks

Transmission system utilization	Addressing
Interfacing	Routing
Signal generation	Recovery
Synchronization	Message formatting
Exchange management	Security
Error detection and correction	Network management
Flow control	

Data Communications Model



Communication Technology Applications



Communication Technologies - Applications

- Different technologies allowing us to communicate
 - **Examples:** Voice mail, fax, email, instant message, chat rooms, news groups, telephony, GPS, and more
- **Voice mail:** Similar to answering machine but digitized
- **Fax:** Sending hardcopy of text or photographs between computers using fax modem
- **Email:** electronic mail – sending text, files, images between different computer networks - must have email software
 - More than 1.3 billion people send 244 billion messages monthly!
- **Chat rooms:** Allows communications in real time when connected to the Internet
- **Telephony:** Talking to other people over the Internet (also called **VoIP**)
 - Sends digitized audio signals over the Internet
 - Requires Internet telephone software
- **Groupware:** Software application allowing a group of people to communicate with each other (**exchange data**)
 - Address book, appointment book, schedules, etc.
- **GPS:** consists of receivers connected to satellite systems
 - Determining the geographical location of the receiver
 - Used for cars, advertising, hiking, tracking, etc.

Communication Devices

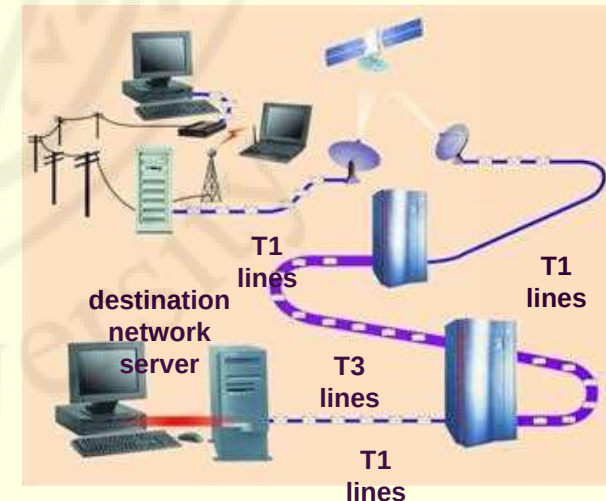
- Any type of **hardware** capable of transmitting data, instructions, and information between devices
 - Functioning as **receiver, transmitter, adaptor, converter**
 - Basic characteristics: **How fast, how far, how much data!**
- Examples: Dial-up modems, ISDN, DSL modems, network interface cards
 - **Dial-up modem**: uses standard phone lines
 - Converts digital information into analog
 - Consists of a modulator and a demodulator
 - Can be external, internal, wireless
 - **ISDN and DSL Modem**: Allows digital communication between networks and computers
 - Requires a digital modem
 - Digital is better than analog – why?
 - **Cable modem**: a modem that transmits and receives data over the cable television (CATV) network
 - Also called **broadband modem (carrying multiple signals)**
 - The incoming signal is split
 - Requires a cable modem
 - **Network interface cards**: Adaptor cards residing in the computer to transmit and receiver data over the network (NIC)
 - Operate with different network technologies (e.g., **Ethernet**)

Communication Software

- Examples of applications (**Layer 7**) take advantage of the transport (**Layer 4**) services of **TCP and UDP**
 - **Hypertext Transfer Protocol (HTTP)**: A client/server application that uses **TCP** for transport to retrieve HTML pages.
 - **Domain Name Service (DNS)**: A name-to-address translation application that uses both **TCP and UDP** transport.
 - **Telnet**: A virtual terminal application that uses **TCP** for transport.
 - **File Transport Protocol (FTP)**: A file transfer application that uses **TCP** for transport.
 - **Trivial File Transfer Protocol (TFTP)**: A file transfer application that uses **UDP** for transport.
 - **Network Time Protocol (NTP)**: An application that synchronizes time with a time source and uses **UDP** for transport.
 - **Border Gateway Protocol (BGP)**: An exterior gateway routing protocol that uses **TCP** for transport. BGP is used to exchange **routing information** for the Internet and is the protocol used between service providers.

Communication Channels

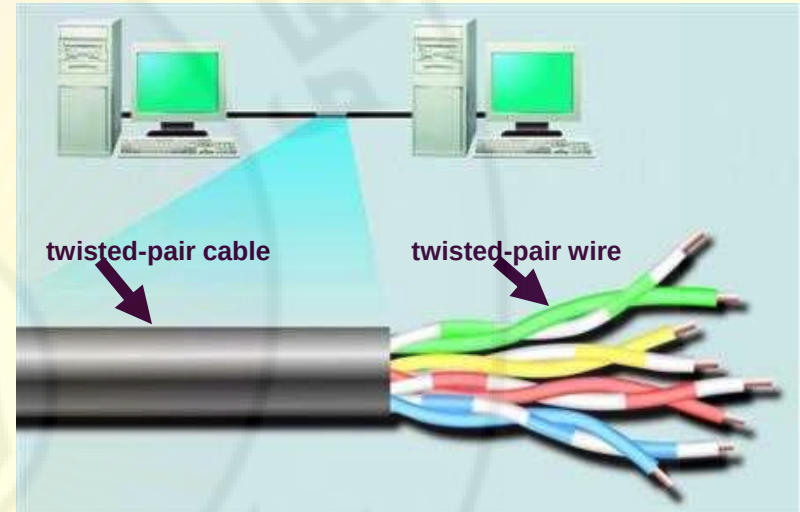
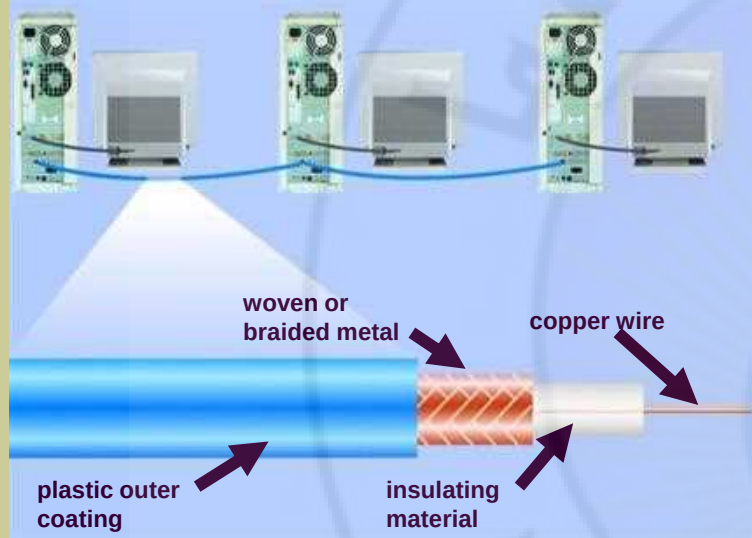
- A **channel** is a path between two communication devices
- **Channel capacity**: How much data can be passed through the channel (bit/sec)
 - Also called **channel bandwidth**
 - The smaller the pipe the slower data transfer!
- Consists of one or more **transmission media**
 - Materials carrying the signal
 - Two types:
 - **Physical**: wire cable
 - **Wireless**: Air



Physical Transmission Media

- A tangible media
 - Examples: Twisted-pair cable, coaxial cable, Fiber-optics, etc.
- **Twisted-pair cable:**
 - One or more twisted wires bundled together (why?)
 - Made of copper
- **Coax-Cable:**
 - Consists of single copper wire surrounded by three layers of insulating and metal materials
 - Typically used for cable TV
- **Fiber-optics:**
 - Strands of glass or plastic used to transmit light
 - Very high capacity, low noise, small size, less suitable to natural disturbances

Physical Transmission Media



Wireless Transmission Media

■ Broadcast Radio

- Distribute signals through the air over long distance
- Uses an antenna
- Typically for stationary locations
- Can be short range



■ Cellular Radio

- A form of broadcast radio used for mobile communication
- High frequency radio waves to transmit voice or data
- Utilizes frequency-reuse

Wireless Transmission Media

■ **Microwaves**

- Radio waves providing high speed transmission
- They are **point-to-point** (can't be obstructed)
- Used for **satellite** communication



■ **Infrared (IR)**

- Wireless transmission media that sends signals using infrared light- waves - **Such as?**

Physical Transmission Media

Type of Cable and LAN	Transfer Rates
Twisted Pair	
• 10Base-T (Ethernet)	10 Mbps
• 100Base-T (Fast Ethernet)	100 Mbps
• 1000Base-T (Gigabit Ethernet)	1000 Mbps
• Token ring	4 - 16 Mbps
Coaxial Cable	
• 10Base2 (ThinWire Ethernet)	10 Mbps
• 10Base5 (ThickWire Ethernet)	10 Mbps
Fiber-Optic Cable	
• 10Base-F (Ethernet)	10 Mbps
• 100Base-FX (Fast Ethernet)	100 Mbps
• FDDI (Fiber Distributed-Data Interface) token ring	100 Mbps

Wireless channel capacity:

Channel	Transfer Rates
Broadcast radio	Up to 2 Mbps
Microwave radio	45 Mbps
Communications satellite	50 Mbps
Cellular radio	9,600 bps to 14.4 Kbps
Infrared	1 to 4 Mbps

100 Mbps is how many bits per sec?

Which is bigger:
10,000 Mbps, 0.01Tbps or 10Gbps?

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Networks

Networks

- Collection of computers and devices connected together
- Used to transfer information or files, share resources, etc.
- What is the largest network?
- Characterized based on their geographical coverage, speed, capacities
- Networks are categorized based on the following characteristics:
 - **Network coverage:** LAN, MAN, WAN
 - **Network topologies:** how the computers are connected together
 - **Network technologies**
 - **Network architecture**

Network coverage

■ Local Area Networks:

- Used for small networks (school, home, office)
- Examples and configurations:
 - Wireless LAN or Switched LAN
 - ATM LAN, Frame Ethernet LAN
 - Peer-2-PEER: connecting several computers together (<10)
 - Client/Server: The server shares its resources between different clients

■ Metropolitan Area Network

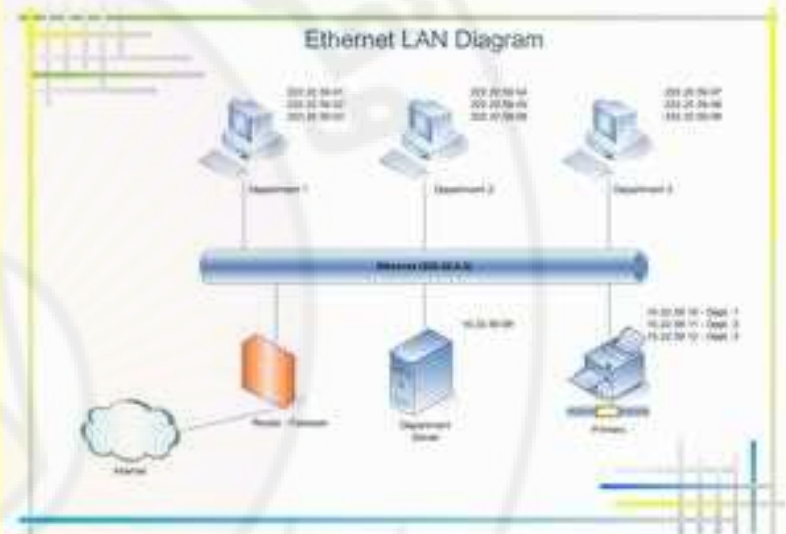
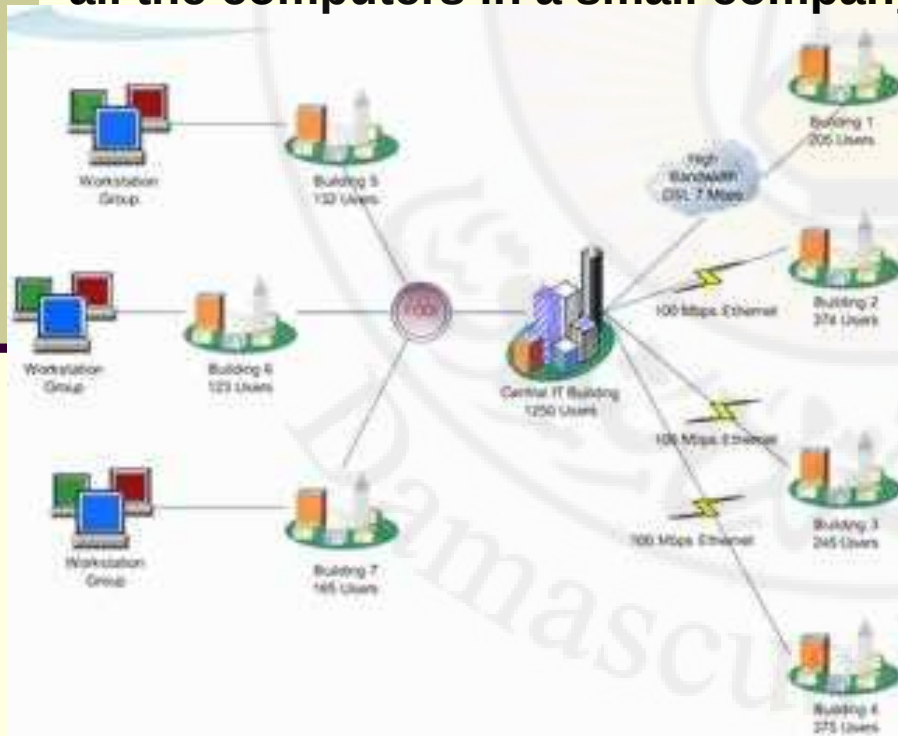
- Backbone network connecting all LANs
- Can cover a city or the entire country

■ Wide Area Network

- Typically between cities and countries
- Technology:
 - Circuit Switch, Packet Switch, Frame Relay, ATM
- Examples:
 - Internet P2P: Networks with the same network software can be connected together (Napster)

LAN v.s WAN

LAN - Local Area Network a group of computers connected within a building or a campus (Example of LAN may consist of computers located on a single floor or a building or it might link all the computers in a small company).

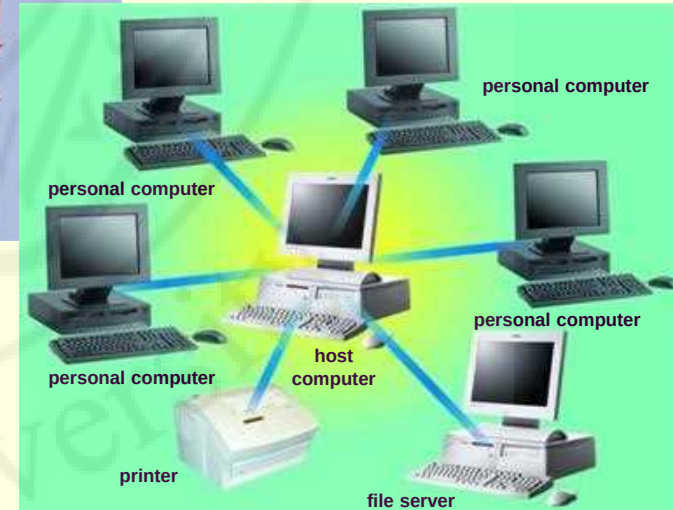
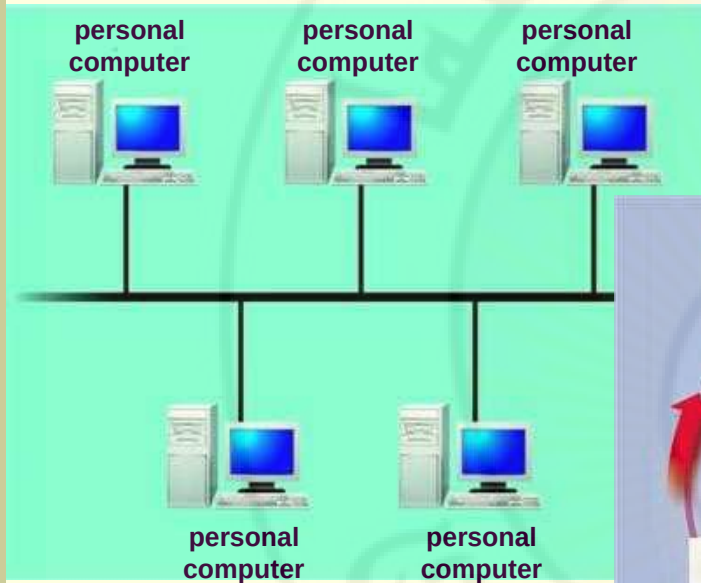


WAN - A network consisting of computers of LAN's connected across a distance WAN can cover small to large distances, using different topologies such as telephone lines, fiber optic cabling, satellite transmissions and microwave transmissions.

Network Topologies

- Configuration or physical arrangement in which devices are connected together
- **BUS networks:** Single central cable connected a number of devices
 - Easy and cheap
 - Popular for LANs
- **RING networks:** a number of computers are connected on a closed loop
 - Covers large distances
 - Primarily used for LANs and WANs
- **STAR networks:** connecting all devices to a central unit
 - All computers are connected to a central device called *hub*
 - All data must pass through the hub
 - What is the problem with this?
 - Susceptible to failure

Network Topologies



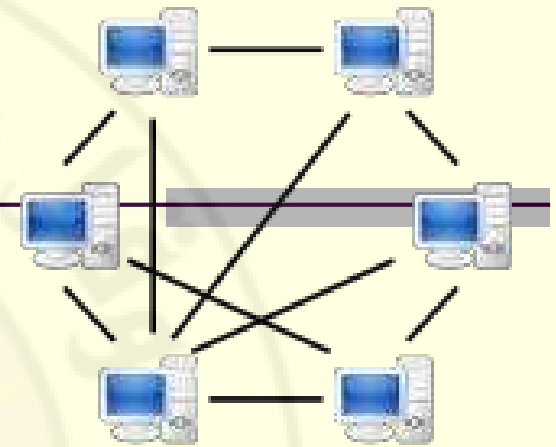
Network Architecture

- Refers to how the computer or devices are designed in a network
- Basic types:
 - **Centralized** – using mainframes
 - **Peer-2-Peer:**
 - Each computer (peer) has equal responsibilities, capacities, sharing hardware, data, with the other computers on the peer-to-peer network
 - Good for small businesses and home networks
 - Simple and inexpensive
 - **Client/Server:**
 - All clients must **request** service from the server
 - The server is also called a **host**
 - Different servers perform different tasks: *File server, network server, etc.*

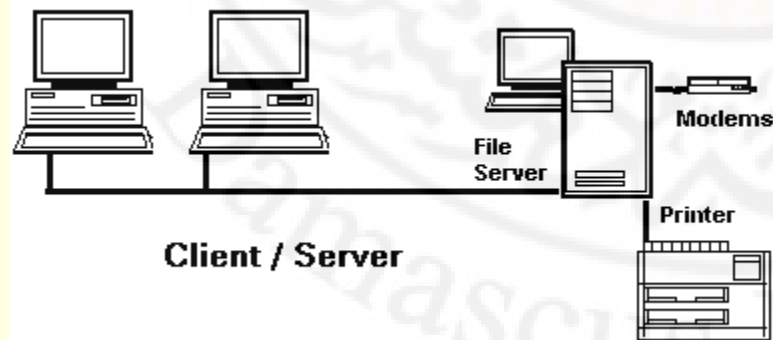
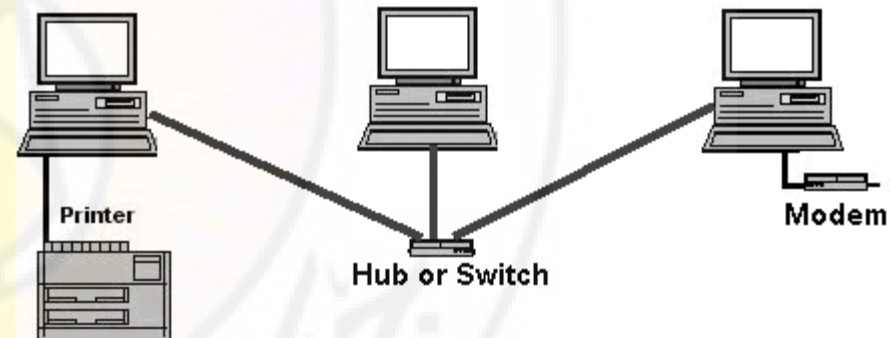


P2P vs Client-Server

Peers make a portion of their resources, such as processing power, disk storage or network bandwidth, directly available to other network participants, without the need for central coordination by servers or stable hosts



Peer-to-Peer Examples



(Data) Network Technologies

- Vary depending on the type of devices we use for interconnecting computers and devices together
- **Ethernet:**
 - **LAN** technology allowing computers to access the network
 - Susceptible to collision
 - Can be based on **BUS or STAR** topologies
 - Operates at **10Mbps or 100Mbps**, (10/100)
 - **Fast Ethernet** operates at 100 Mbps /
 - **Gigabit Ethernet** (1998 IEEE 802.3z)
 - **10-Gigabit Ethernet** (10GE or 10GbE or 10 GigE)
 - 10GBASE-R/LR/SR (long range short range, etc.)
- Physical layer
 - Gigabit Ethernet using optical fiber, twisted pair cable or balanced copper cable

(Data) Network Technologies

■ Token Ring

- LAN technology
- Only the computer with the token can transmit
- No collision
- Typically **72-260** devices can be connected together

■ TCP/IP and UDP

- Uses packet transmission

■ 802.11

- Standard for **wireless LAN**
- Wi-Fi (wireless fidelity) is used to describe that the device is in 802.11 family or standards
- Typically used for long range (300-1000 feet)
- Variations include: **.11 (1-2 Mbps); .11a (up to 54 Mbps); .11b (up to 11 Mbps); .11g (54 Mbps and higher)**

(Data) Network Technologies

■ 802.11n

- Next generation wireless LAN technology
- Improving network throughput (**600 Mbps** compared to 450 Mbps) – thus potentially supporting a user throughput of 110 Mbit/s

■ WiMAX

- *Worldwide Interoperability for Microwave Access*
- Provides wireless transmission of data **from point-to-multipoint links** to portable and fully mobile internet access (up to **3 Mbit/s**)
- The intent is to deliver the last mile wireless broadband access as an alternative to cable and DSL
- Based on the **IEEE 802.16(d/e)** standard (also called Broadband Wireless Access)

Network Technologies



- **Personal area network (PAN)**
 - A low range computer network
 - PANs can be used for communication among the personal devices themselves
 - **Wired with computer buses such as USB and FireWire.**
- **Wireless personal area network (WPAN)**
 - Uses network technologies such as IrDA, **Bluetooth**, UWB, Z-Wave and ZigBee
- **Internet Mobile Protocols**
 - Supporting **multimedia Internet traffic**
 - IGMP & MBONE for multicasting
 - RTP, RTCP, & RSVP (used to handle multimedia on the Internet)
- **VoIP**

Network Technologies

- **Zigbee**
 - High level communication protocols using small, low-power digital radios based on the **IEEE 802.15.4**
 - Wireless mesh networking proprietary standard
- **Bluetooth**
 - Uses radio frequency
 - Typically used for close distances (short range- 33 feet or so)
 - Transmits **at 1Mbps**
 - Used for handheld computers to communicate with the desktop
- **IrDA**
 - Infrared (IR) light waves
 - Transfers at a rate of **115 Kbps to 4 Mbps**
 - Requires **light-of-sight** transmission
- **RFID**
 - Radio frequency identification
 - Uses tags which are places in items
 - Example: merchandises, toll-tags, courtesy calls, sensors!
- **WAP**
 - Wireless application protocol
 - Data rate of **9.6-153 kbps** depending on the service type
 - Used for **smart phones and PDAs to access the Internet** (email, web, etc)

Network Examples

■ IEEE 802.15.4

- Low-rate wireless personal area networks (LR-WPANs)
- Bases for e ZigBee, WirelessHART, and MiWi specification
- Also used for 6LoWPAN and standard Internet protocols to build a Wireless Embedded Internet (WEI)

■ Intranets

- Used for **private networks**
- May implement a firewall
 - **Hardware and software that restricts access to data and information on a network**

■ Home networks

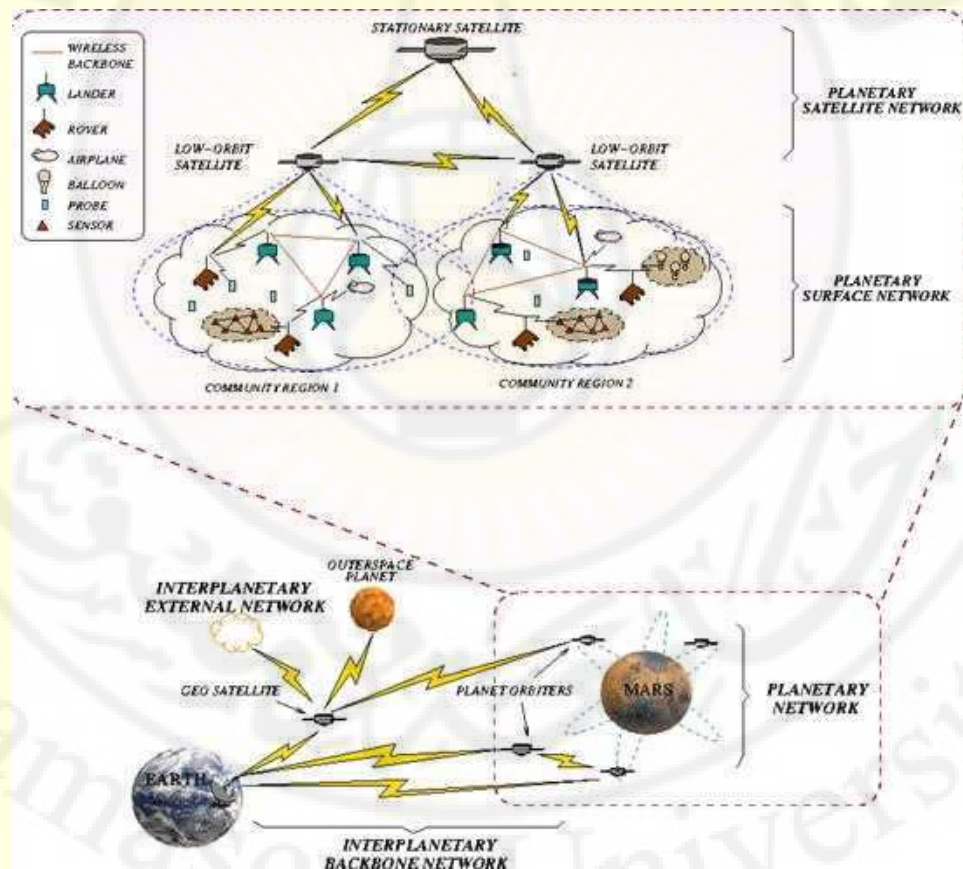
- Ethernet
- Phone line
- HomeRF (radio frequency- waves)
- Intelligent home network

■ **Vehicle-to-Vehicle (car2Car)** - <http://www.car-to-car.org/>

- A wireless LAN based communication system to guarantee European-wide inter-vehicle operability

Network Examples

■ Interplanetary (Internet) Network



Network Example:

Telephone Networks

- Called the Public Switched Telephone Network (**PSTN**)
- World-wide and voice oriented (handles voice and data)
- Data/voice can be transferred within the PSTN using different technologies (data transfer rate bps)
- **Dial-up lines:**
 - Analog signals passing through telephone lines
 - Requires modems (**56 kbps** transfer rate)
- **ISDN lines:**
 - Integrated Services Digital Network
 - **Digital transmission over the telephone lines**
 - Can carry (multiplex) several signals on a single line
- **DSL**
 - Digital subscribe line
 - **ADSL** (asymmetric DSL)
 - **receiver operated at 8.4 Mbps, transmit at 640 kbps**
- **T-Carrier lines:** carries several signals over a single line: T1,T3
- **Frame Relay**
- **ATM:**
 - Asynchronous Transfer Mode
 - Fast and high capacity transmitting technology
 - Packet technology

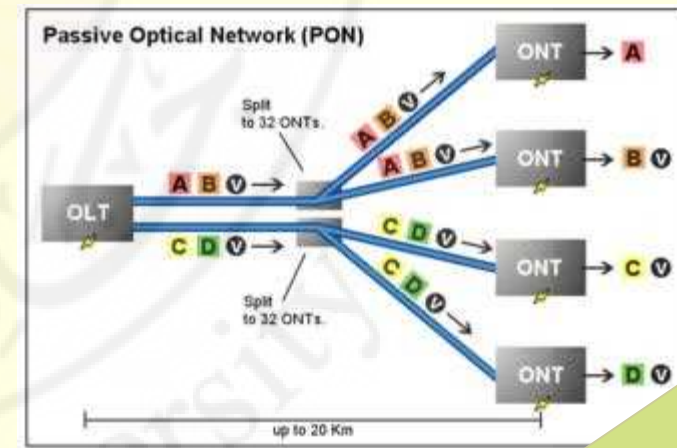
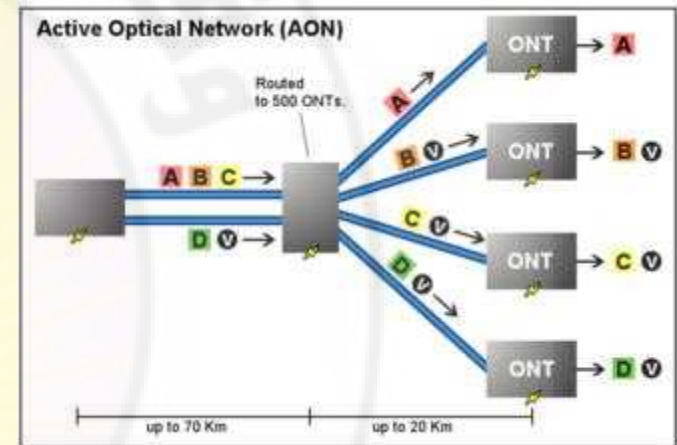
Switching Technologies: Technologies:

- Circuit Switching
- Packet Switching
- Message Switching
- Burst Switching

Network Example:

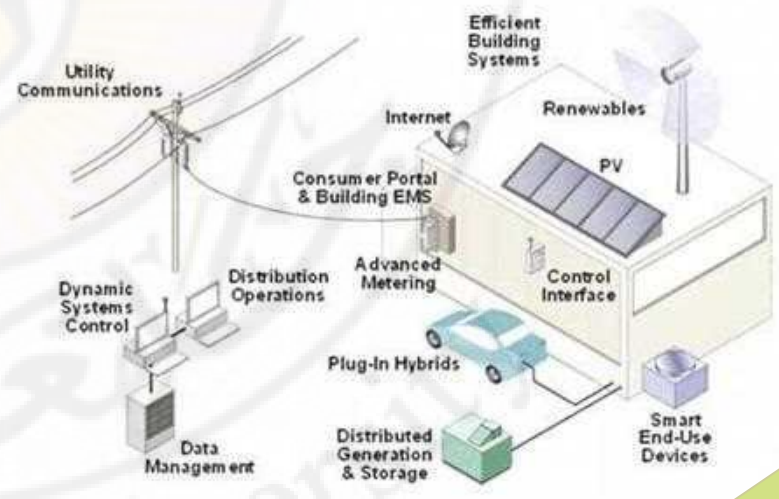
Optical Networks

- Fiber-to-the-x
 - Broadband network architecture that uses optical fiber to replace copper
 - Used for last mile telecommunications
 - Examples: Fiber-to-the-home (FTTH); Fiber-to-the-building (FTTB); Fiber-to-the premises (FTTP)
- Fiber Distribution Network (reaching different customers)
 - Active optical networks (AONs)
 - Passive optical networks (PONs)



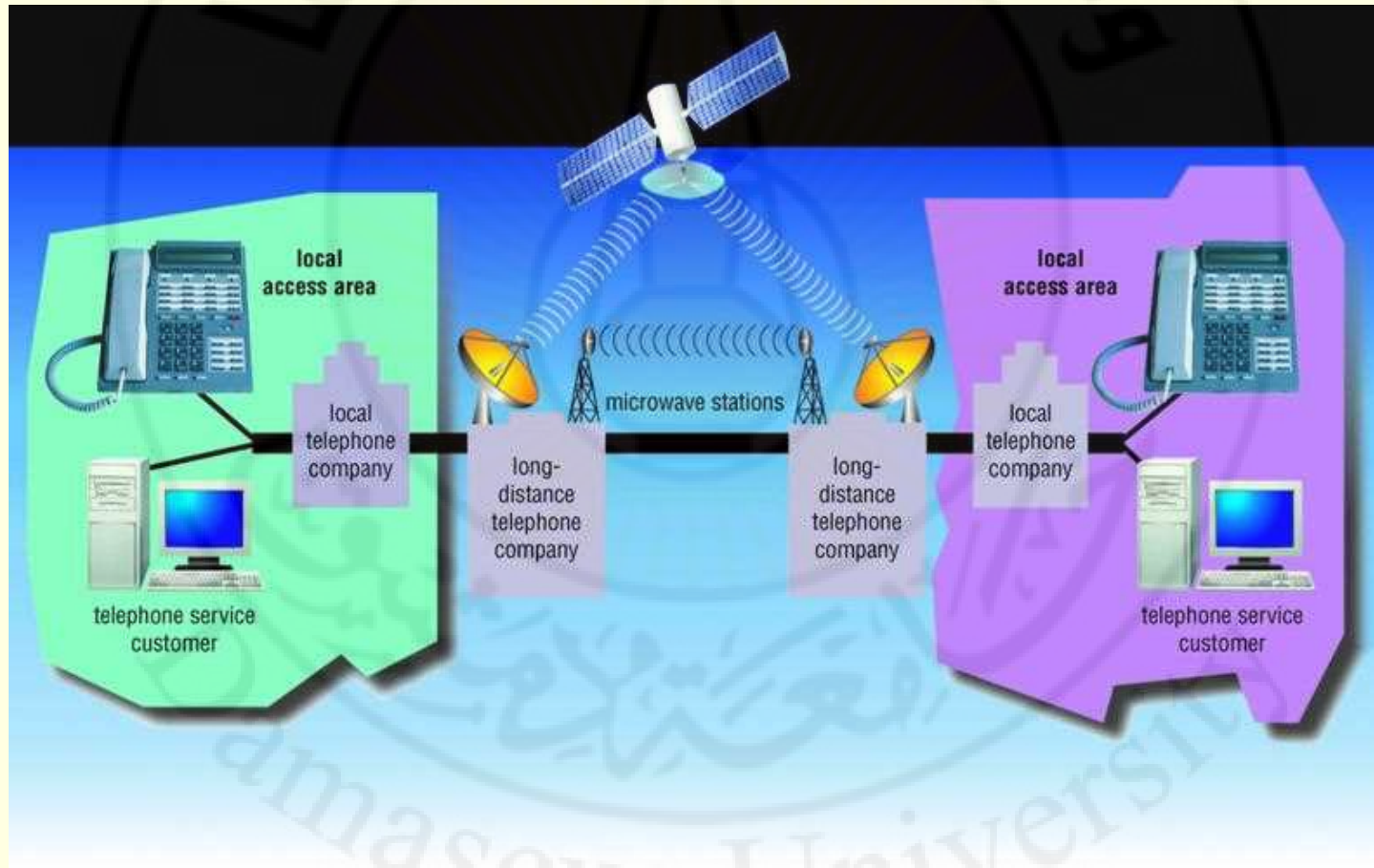
Network Example

- Smart Grid
 - Delivering electricity from suppliers to consumers using digital technology to save energy
- Storage Area Networks
- Computational Grid Networks



Network Example:

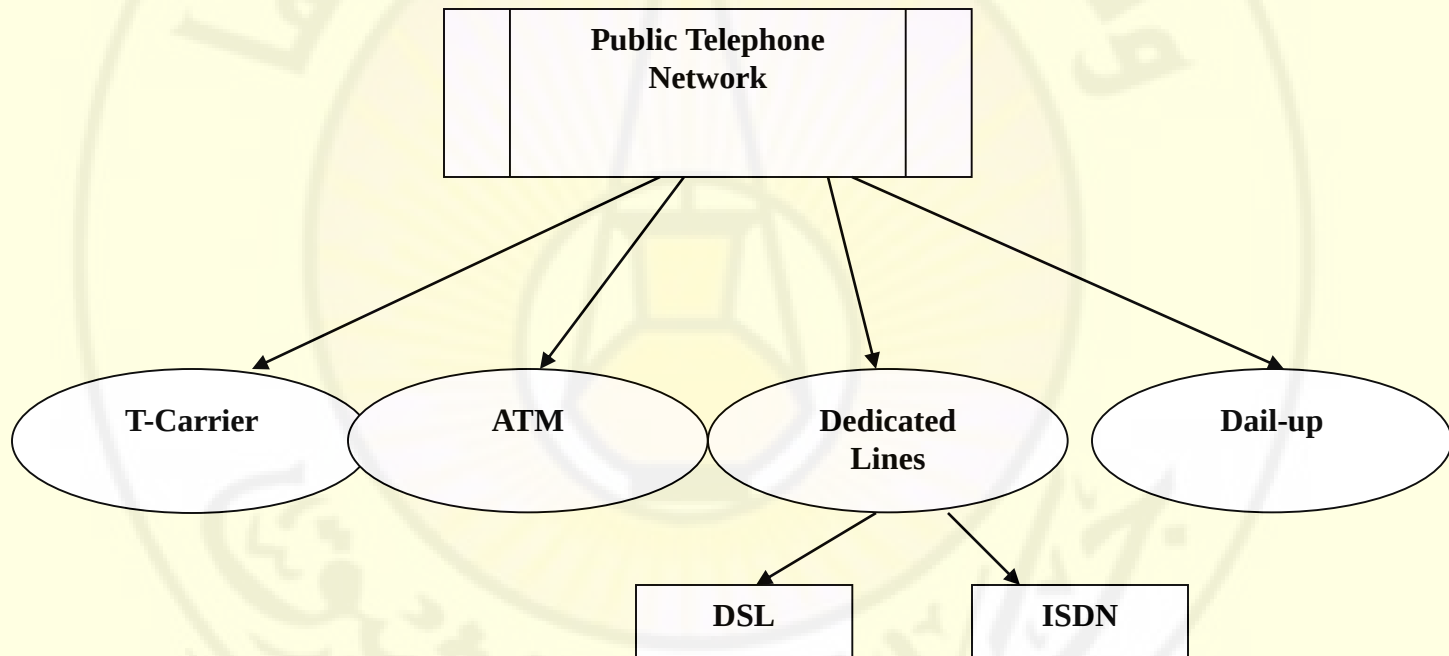
Telephone Networks



Network Examples

Type of Line	Transfer Rates	Approximate Monthly Cost
Dial-up	Up to 56 Kbps	Local or long-distance rates
ISDN (BRI)	Up to 128 Kbps	\$10 to \$40
ADSL	128 Kbps – 9 Mbps	\$40 to \$80
Cable TV (CATV)	128 Kbps – 2.5 Mbps	\$30 to \$50
T1	1.544 Mbps	\$1,000 or more
T3	44 Mbps	\$10,000 or more
ATM	155 Mbps to 622 Mbps	\$8,000 or more

Network Examples



What about Cable Internet Services?

Cellular Network Examples

- 0G
 - Single, powerful base station covering a wide area, and each telephone would effectively monopolize a channel over that whole area while in use (developed in 40's)
 - No frequency use or handoff (basis of modern cell phone technology)
- 1G
 - Fully automatic **cellular networks**
 - introduced in the early to mid 1980s
- 2G
 - Introduced in 1991 in Finland on the GSM standard
 - Offered the first data service with person-to-person SMS text messaging

Cellular Network Examples

- 3G:
 - Faster than PCS; Used for multimedia and graphics
 - Compared to 2G and 2.5G services, 3G allows simultaneous use of speech and data services and higher data rates (up to 14.4 Mbit/s on the downlink and 5.8 Mbit/s).
- 4G:
 - Fourth generation of cellular wireless;
 - providing a comprehensive and secure IP based service to users "Anytime, Anywhere" at high data rates



Merging Technologies

- m-Cash
 - Pay using your cell phone
- Scan-free shopping using Radio frequency identification
- VeriChip
 - Implanted computer chip in the body!
- RFID
- Wearable computer technology
 - Implanting a cell phone in your tooth!
- Power over Ethernet (PoE)
 - Transferring electrical power, along with data, to remote devices over standard category 5 cable in an Ethernet network
 - PoE Plus (802.3at) provides more available power
 - Power over fiber?

Merging Technologies

- Ethernet over powerline
 - allowing to route data packets through the electrical lines
 - Up to 200 times faster than DSL (200 Mbps)
 - Useful when concrete, metal, or other obstructions in the walls and wireless cannot operate well
- Energy-efficient Ethernet
 - IEEE P802.3az Energy Efficient Ethernet Task Force
 - mechanism to reduce power consumption during periods of low link utilization
 - No frames in transit shall be dropped or corrupted during the transition to and from the lower level of power consumption
 - Uses low-power idle proposal for use with 100 Mbit and Gbit connections (causing possible latency for 10G-bit Ethernet)



Data and Computer Communications

Chapter 2 – Protocol Architecture, TCP/IP, and Internet-Based Applications

Eighth Edition
by William Stallings

Lecture slides by Lawrie Brown

Protocol Architecture, TCP/IP, and Internet-Based Applications

- *To destroy communication completely, there must be no rules in common between transmitter and receiver—neither of alphabet nor of syntax—On Human Communication,*
□ Colin □ Cherry

Need For Protocol Architecture

- data exchange can involve complex procedures, cf. file transfer example
- better if **task broken into subtasks**
- implemented separately **in layers in stack**
 - each **layer provides functions needed** to perform comms **for layers above**
 - **using functions provided by layers below**
- peer layers communicate with a **protocol**

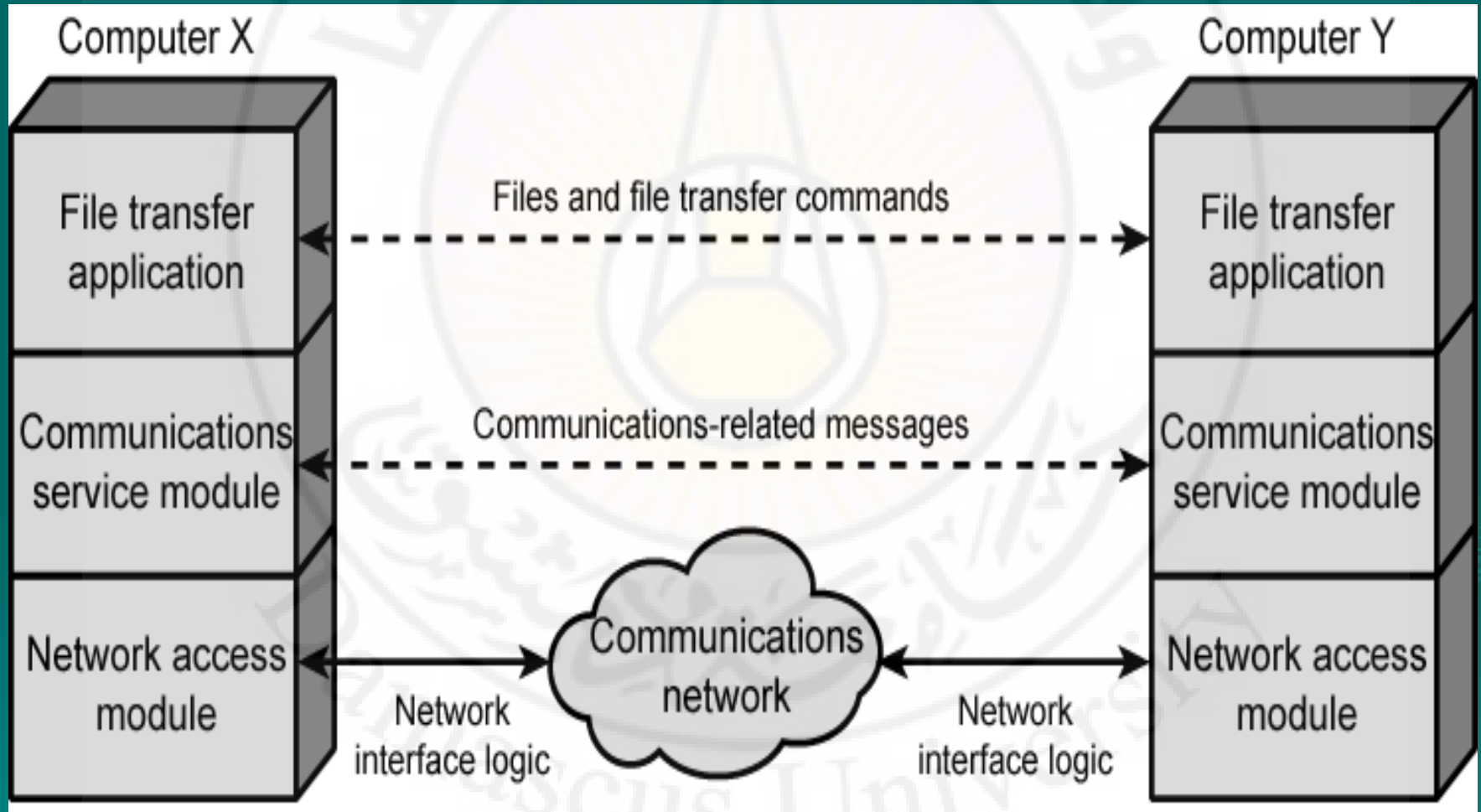
Key Elements of a Protocol

- **syntax** - data format
- **semantics** - control info & error handling
- **timing** - speed matching & sequencing

TCP/IP Protocol Architecture

- developed by US Defense Advanced Research Project Agency (**DARPA**)
- for ARPANET packet switched network
- used by the global Internet
- **protocol suite** comprises a large collection of standardized protocols

Simplified Network Architecture



TCP/IP Layers

- no official model but a working one
 - Application layer
 - Host-to-host, or transport layer
 - Internet layer
 - Network access layer
 - Physical layer

Application Layer

- provide **support for user applications**
- need a **separate module for each type of application**

Transport Layer (TCP)

- common layer shared by all applications
- provides **reliable delivery of data**
- in same order as sent
- commonly uses **TCP**

Internet Layer (IP)

- routing functions across multiple networks
- for systems attached to different networks
- using **IP protocol**
- implemented in end systems and routers
- routers connect two networks and relays data between them

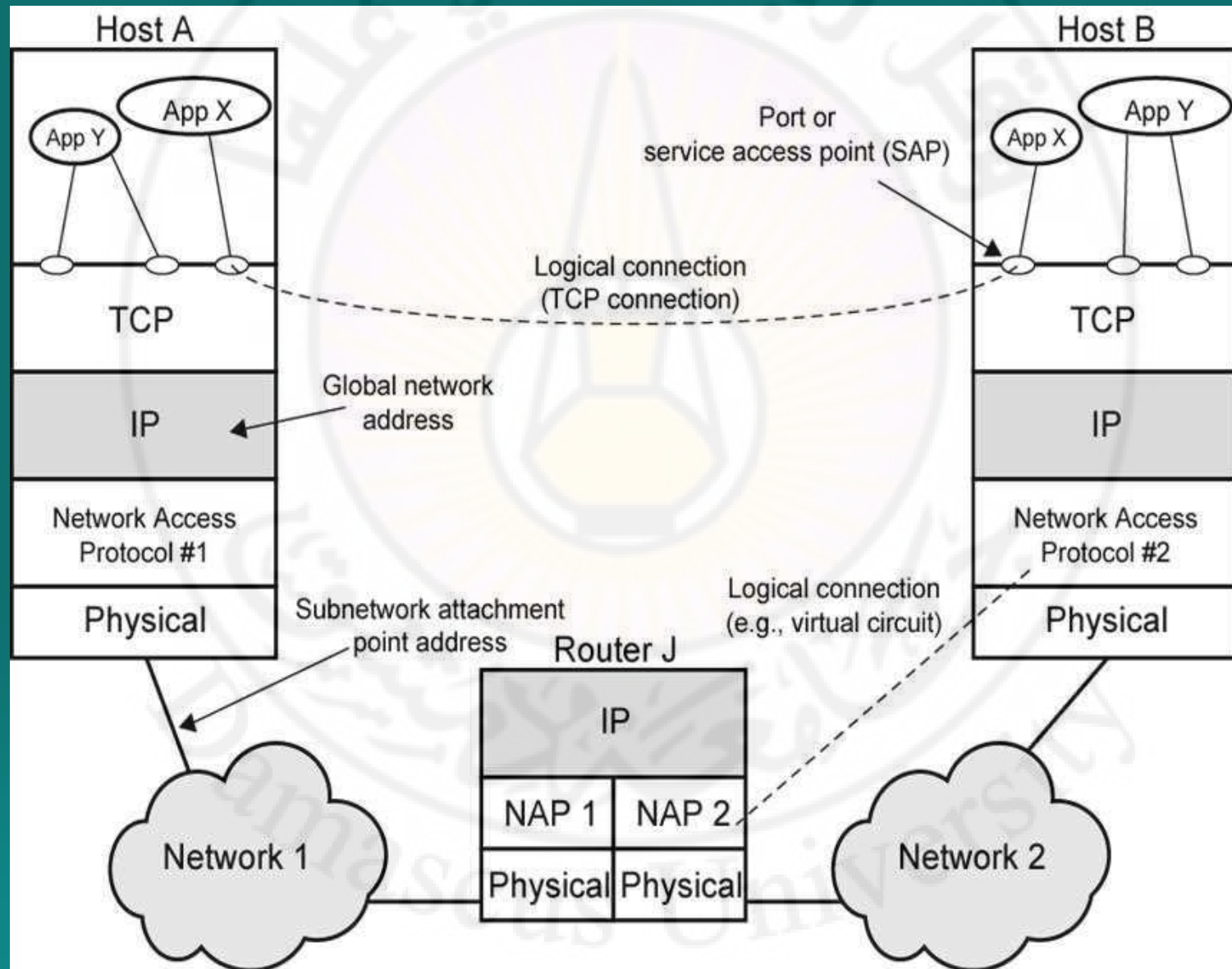
Network Access Layer

- exchange of data between an end system and attached network
- concerned with issues like :
 - **destination address** provision
 - invoking specific services like **priority**
 - **access to & routing data across a network** link between two attached systems
- allows layers above to ignore link specifics

Physical Layer

- concerned with **physical interface between computer and network**
- concerned with issues like:
 - **characteristics of transmission medium**
 - **signal levels**
 - **data rates**
 - other related matters

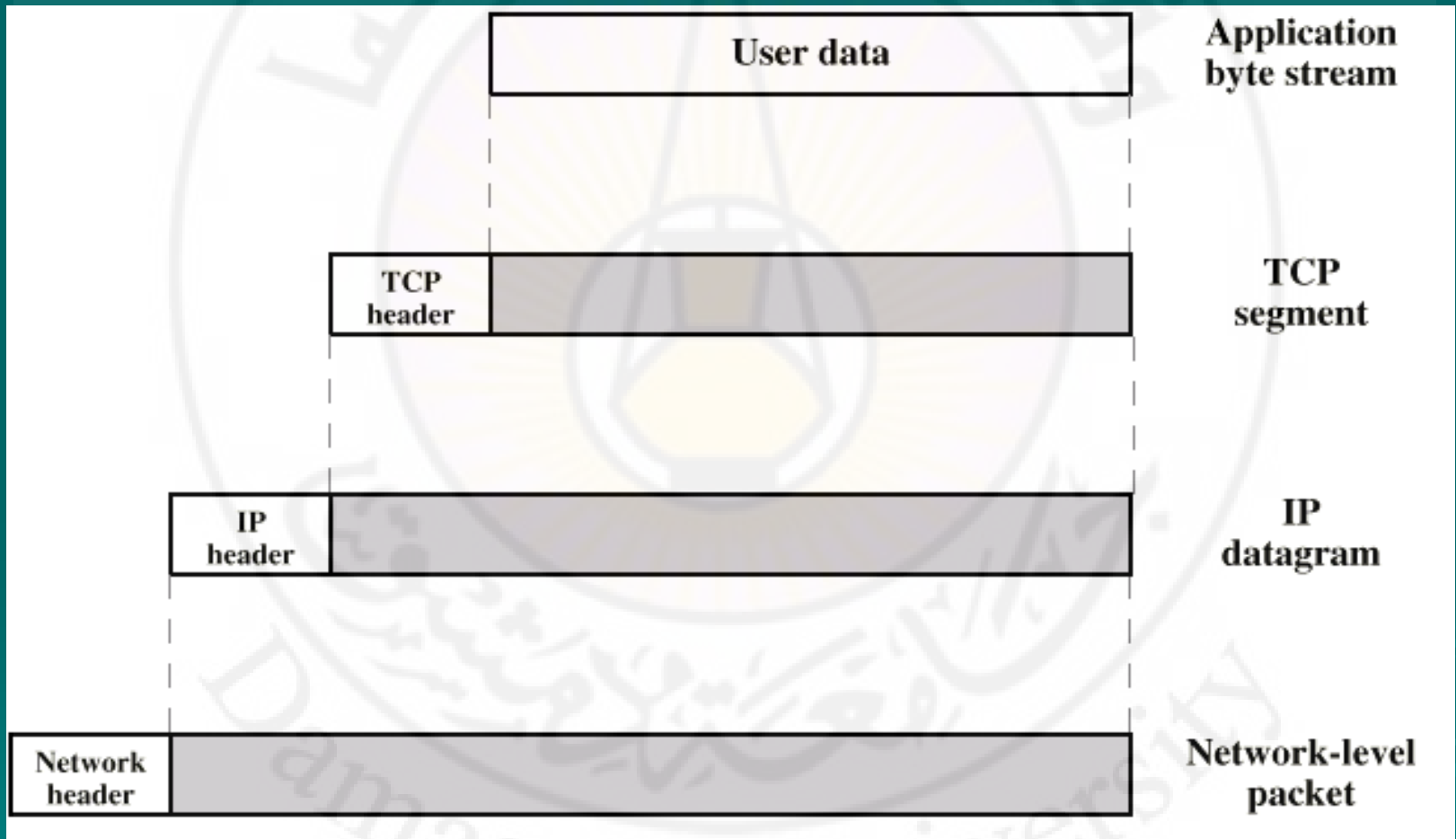
Operation of TCP and IP



Addressing Requirements

- two levels of addressing required
- each **host** on a subnet needs a **unique global network address**
 - its **IP address**
- each **application** on a (multi-tasking) host needs **a unique address within the host**
 - known as a **port**

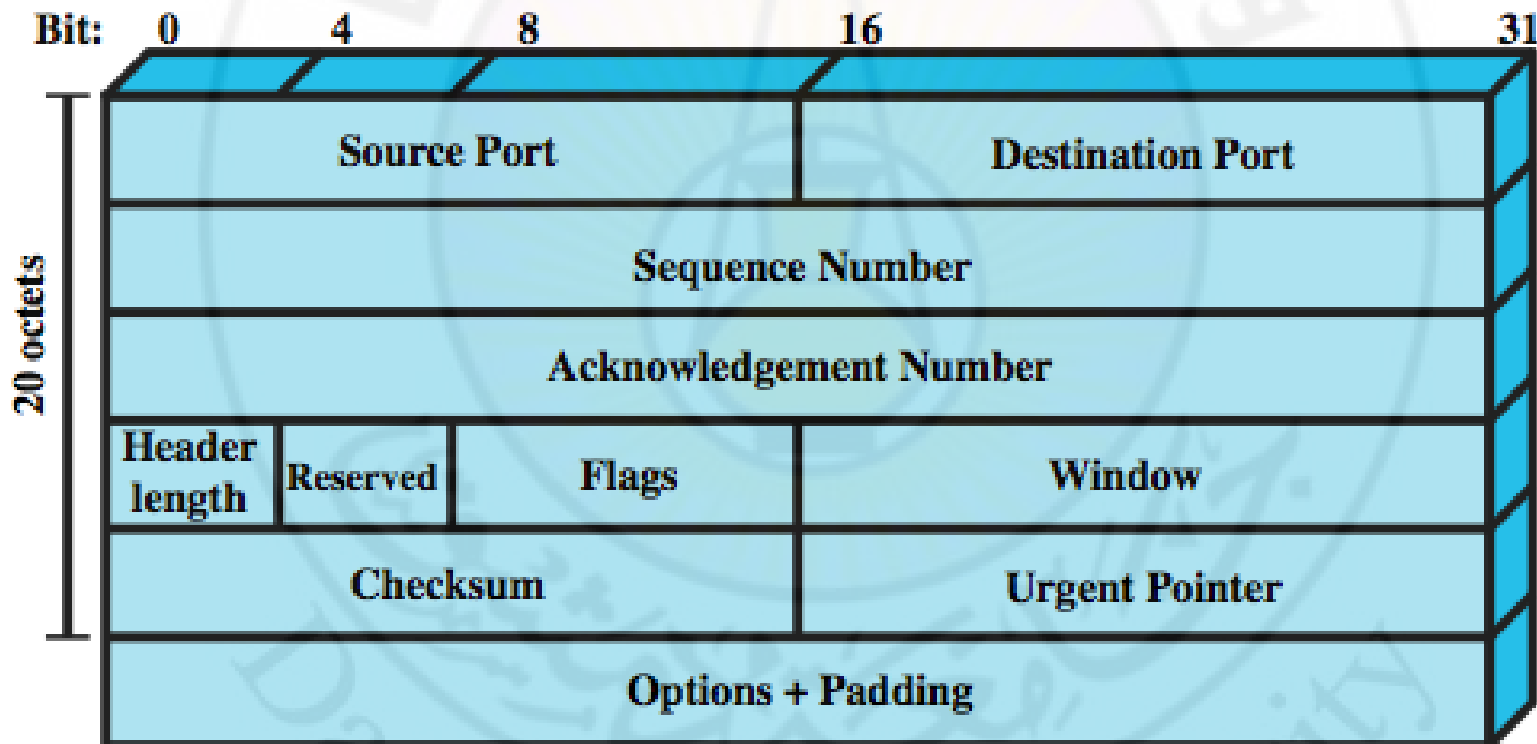
Operation of TCP/IP



Transmission Control Protocol (TCP)

- usual transport layer is (TCP)
- provides a **reliable connection** for transfer of data between applications
- a TCP segment is the basic protocol unit
- TCP tracks segments between entities for duration of each connection

TCP Header

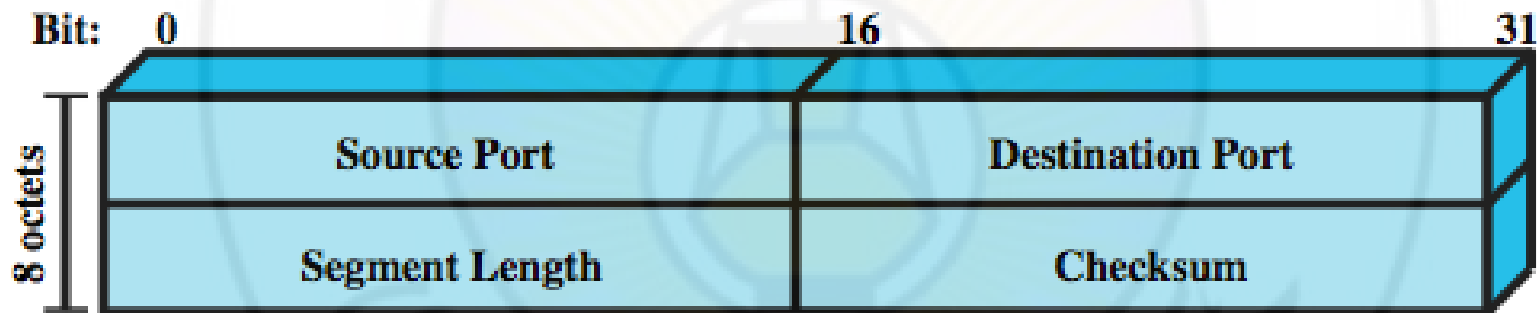


(a) TCP Header

User Datagram Protocol (UDP)

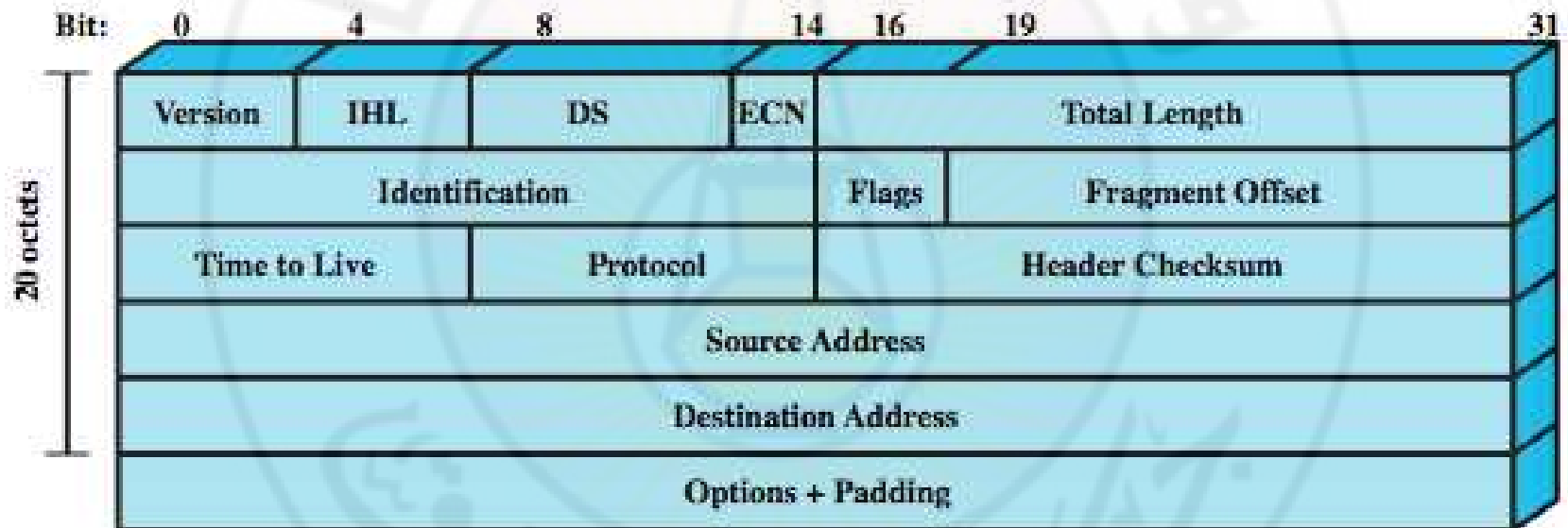
- an alternative to TCP
- no guaranteed delivery
- no preservation of sequence
- no protection against duplication
- minimum overhead
- adds port addressing to IP

UDP Header



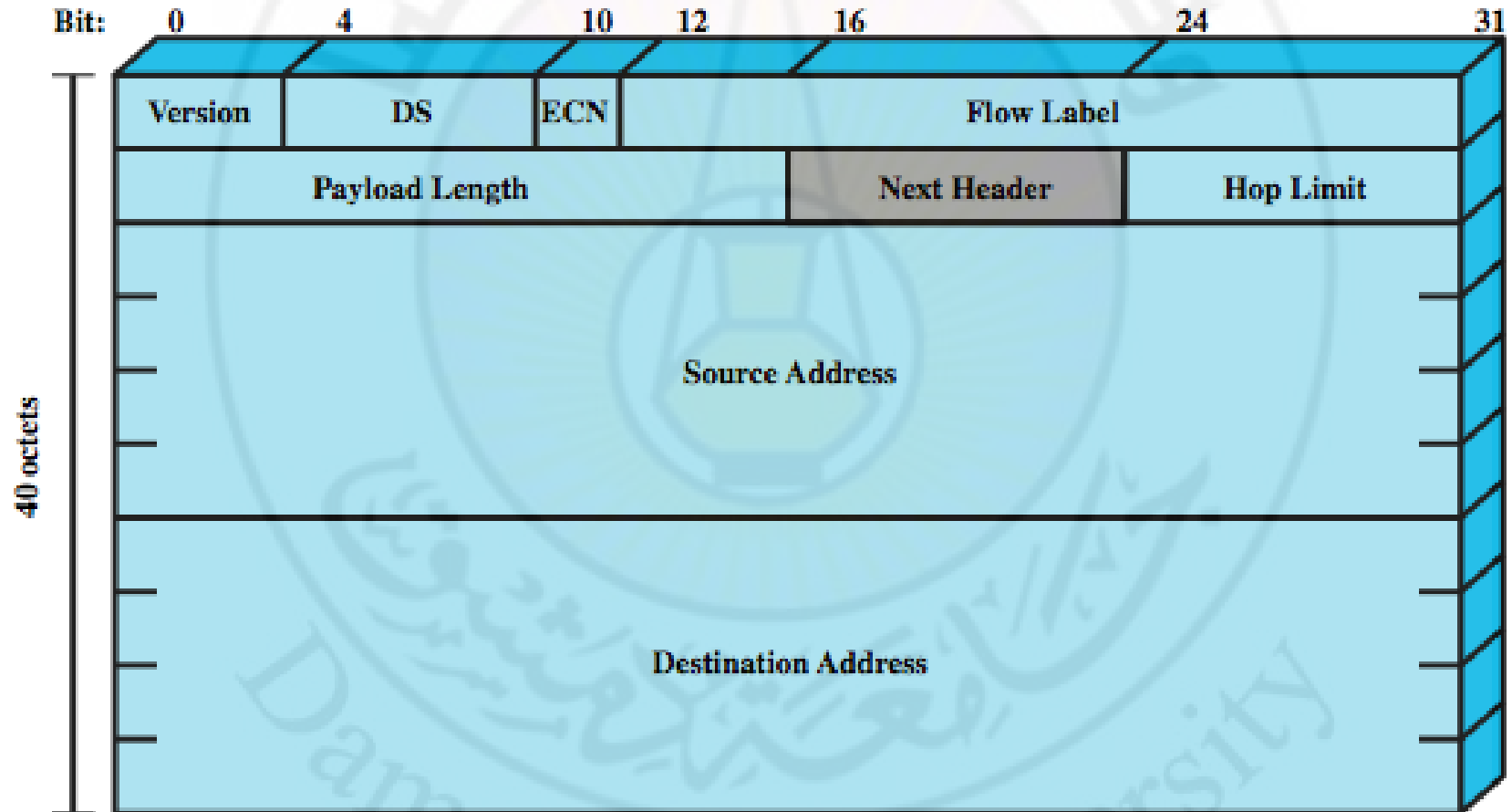
(b) UDP Header

IP Header



(a) IPv4 Header

IPv6 Header

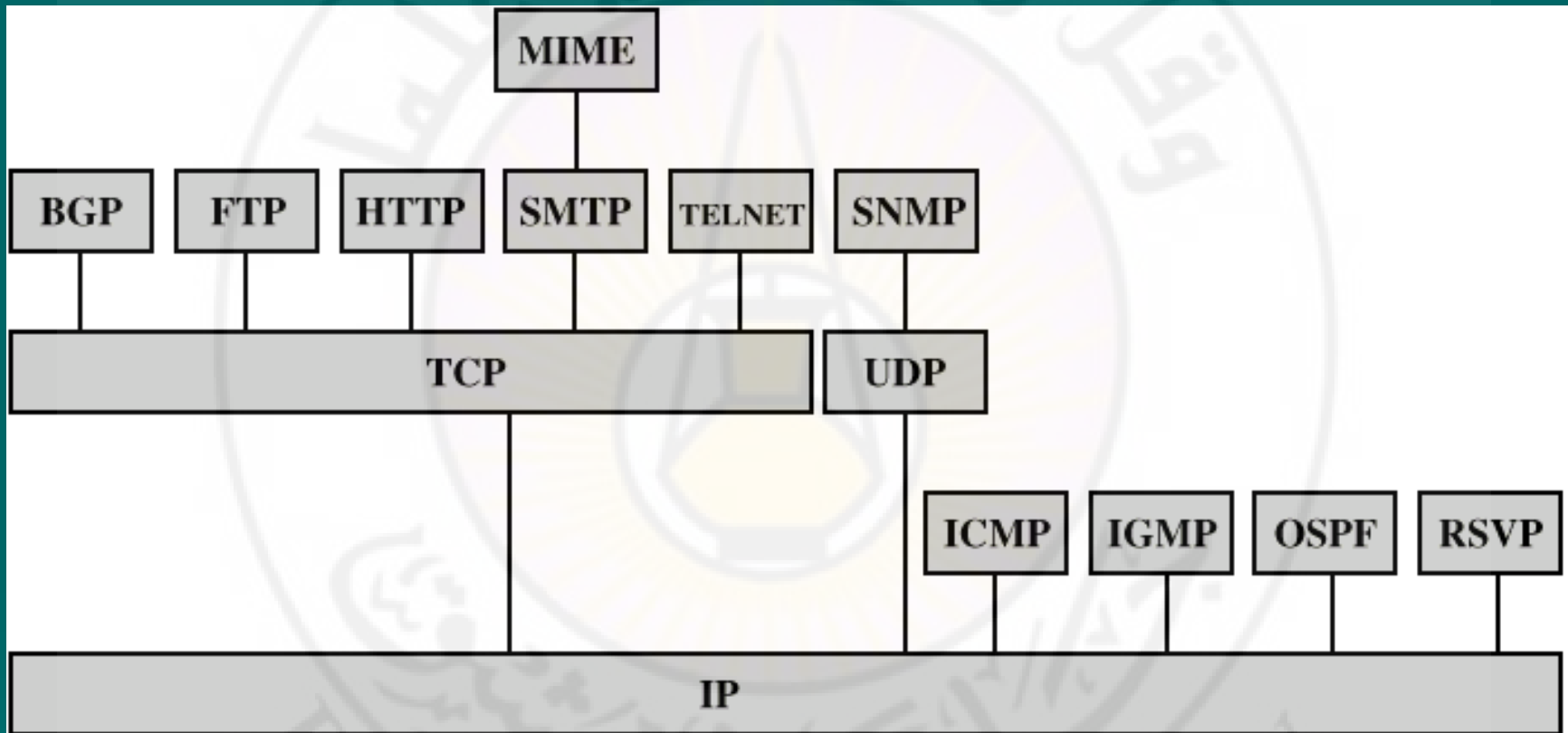


(b) IPv6 Header

TCP/IP Applications

- have a number of standard TCP/IP applications such as
 - Simple Mail Transfer Protocol (SMTP)
 - File Transfer Protocol (FTP)
 - Telnet

Some TCP/IP Protocols



BGP = Border Gateway Protocol

FTP = File Transfer Protocol

HTTP = Hypertext Transfer Protocol

ICMP = Internet Control Message Protocol

IGMP = Internet Group Management Protocol

IP = Internet Protocol

MIME = Multi-Purpose Internet Mail Extension

OSPF = Open Shortest Path First

RSVP = Resource ReSerVation Protocol

SMTP = Simple Mail Transfer Protocol

SNMP = Simple Network Management Protocol

TCP = Transmission Control Protocol

UDP = User Datagram Protocol

OSI

- Open Systems Interconnection
- developed by the International Organization for Standardization (ISO)
- has seven layers
- is a theoretical system delivered too late!
- TCP/IP is the de facto standard

OSI Layers

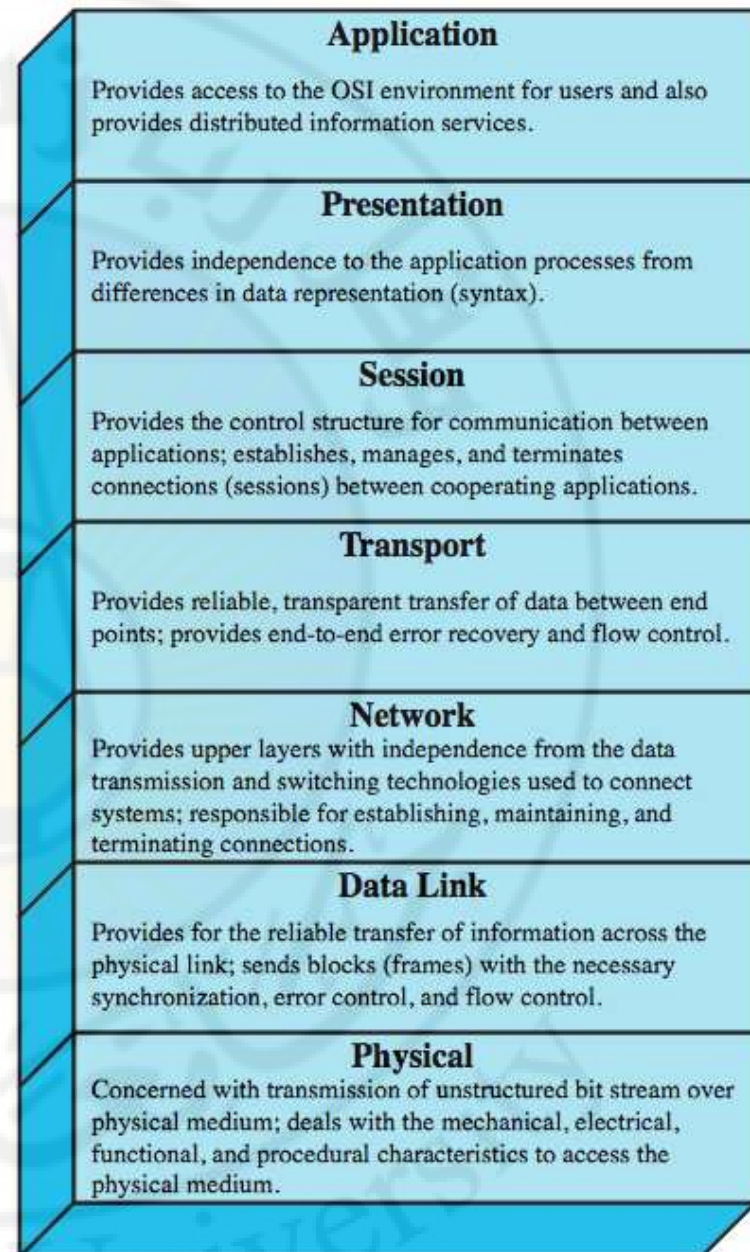
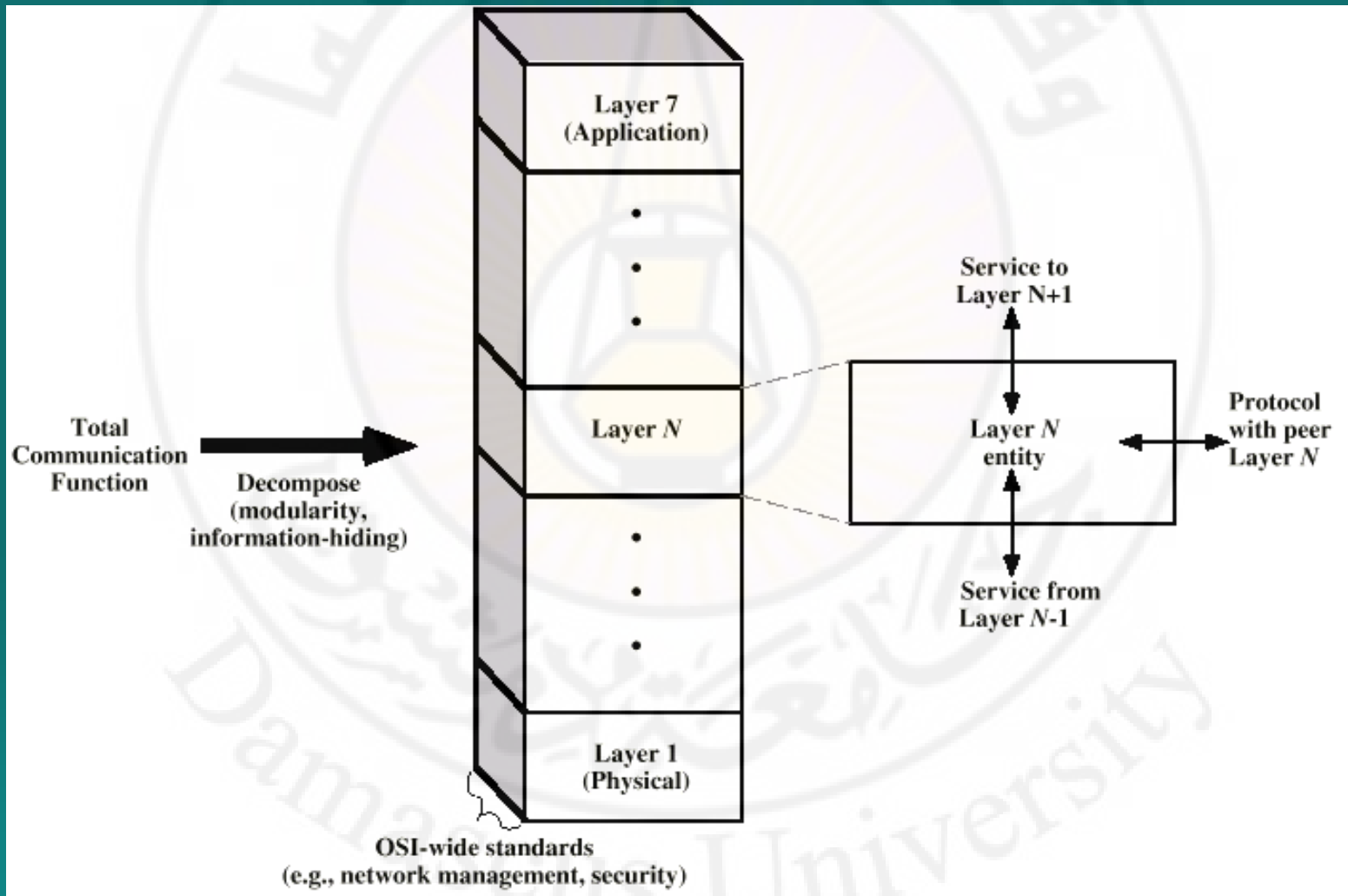


Figure 2.6 The OSI Layers

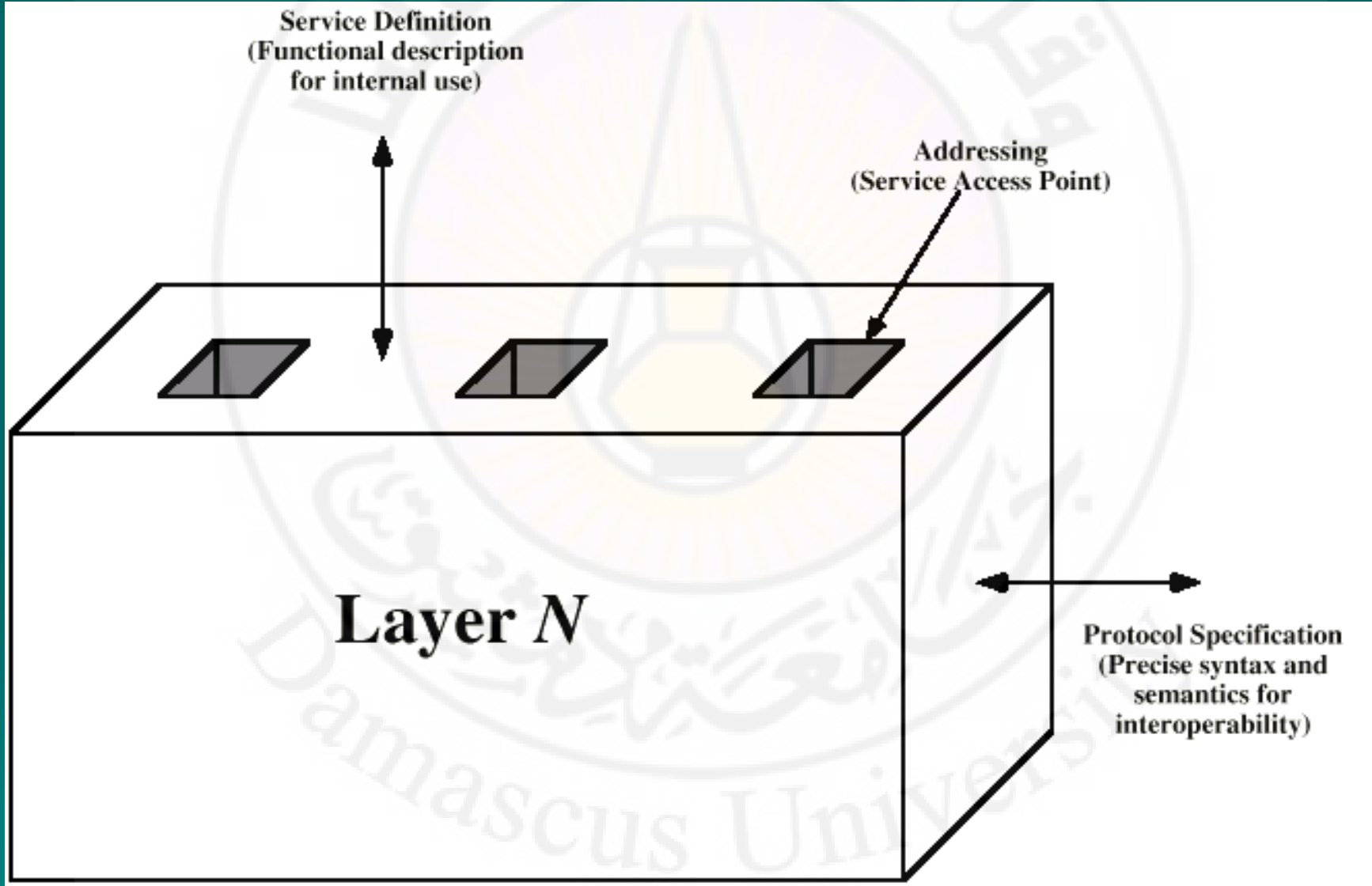
OSI v TCP/IP

OSI	TCP/IP
Application	Application
Presentation	
Session	
Transport	Transport (host-to-host)
Network	Internet
Data Link	Network Access
Physical	Physical

Standardized Protocol Architectures

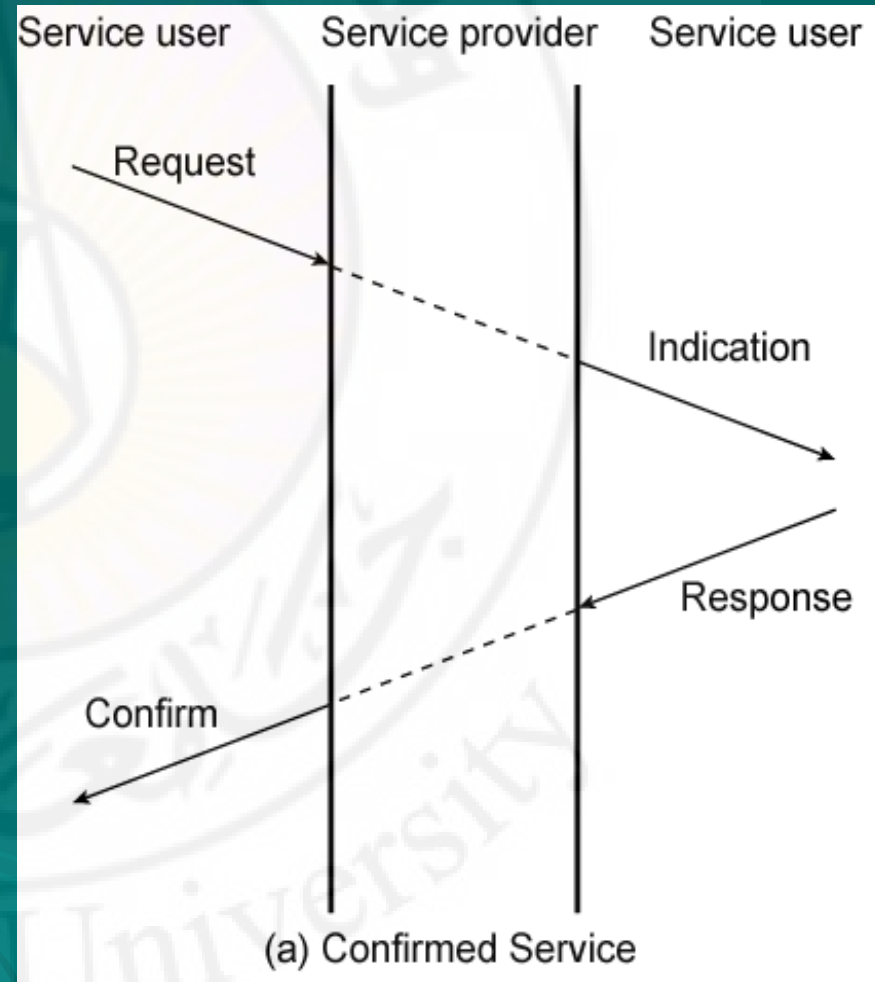


Layer Specific Standards



Service Primitives and Parameters

- define services between adjacent layers using:
- **primitives to specify function performed**
- **parameters to pass data and control info**



Primitive Types

REQUEST	A primitive issued by a service user to invoke some service and to pass the parameters needed to specify fully the requested service
INDICATION	A primitive issued by a service provider either to: indicate that a procedure has been invoked by the peer service user on the connection and to provide the associated parameters, or notify the service user of a provider-initiated action
RESPONSE	A primitive issued by a service user to acknowledge or complete some procedure previously invoked by an indication to that user
CONFIRM	A primitive issued by a service provider to acknowledge or complete some procedure previously invoked by a request by the service user

Traditional vs Multimedia Applications

- **traditionally** Internet dominated by info retrieval applications
 - typically using **text and image** transfer
 - eg. email, file transfer, web
- see increasing growth in **multimedia** applications
 - involving **massive amounts of data**
 - such as **streaming audio and video**

Elastic and Inelastic Traffic

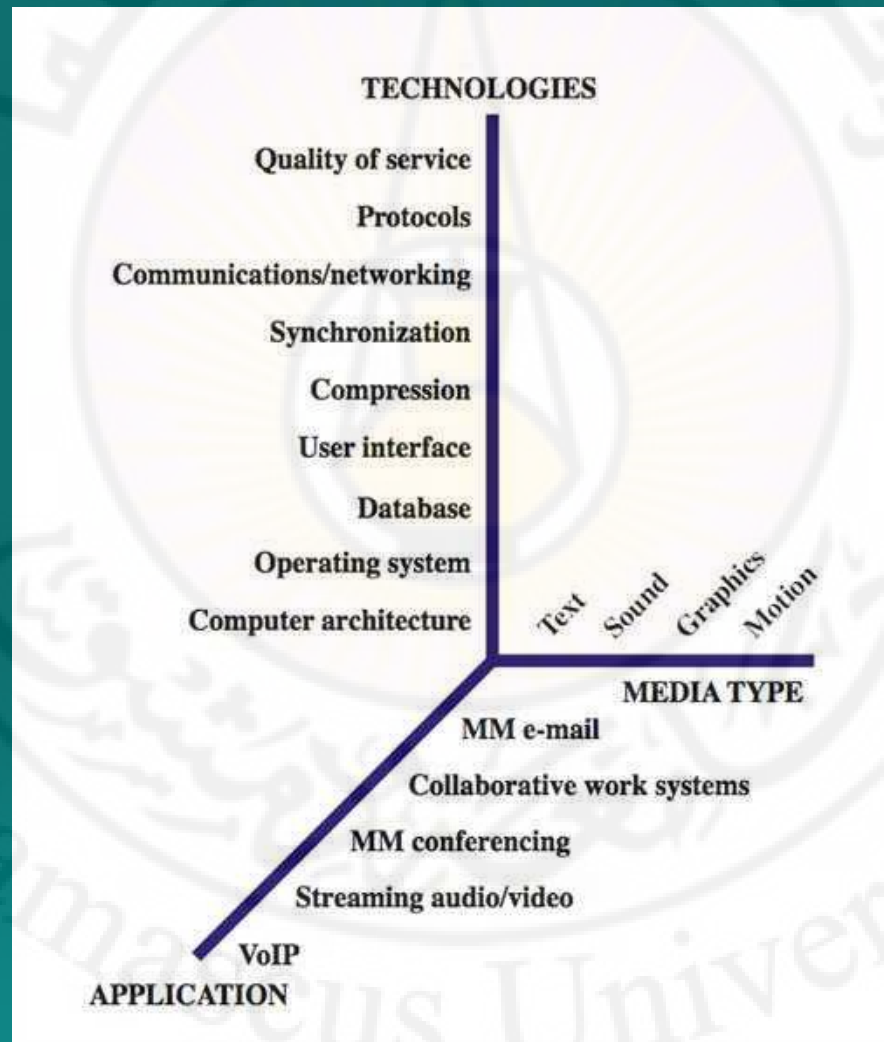
➤ elastic traffic

- can adjust to delay & throughput changes over a wide range
- eg. traditional “data” style TCP/IP traffic
- some applications more sensitive though

➤ inelastic traffic

- does **not** adapt to such changes
- eg. “real-time” voice & video traffic
- **need minimum requirements on net arch**

Multimedia Technologies



Summary

- introduced need for protocol architecture
- TCP/IP protocol architecture
- OSI Model & protocol architecture standardization
- traditional vs multimedia application needs

Data and Computer Communications

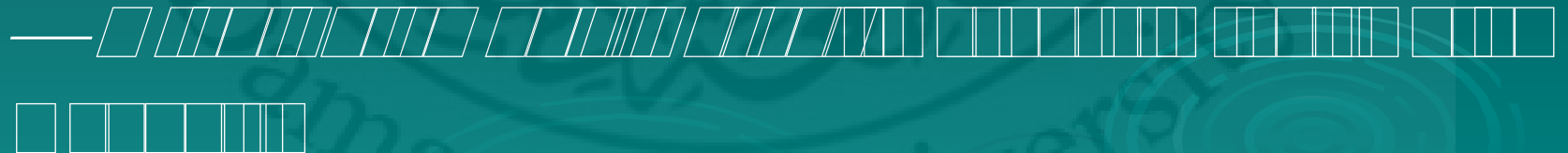
Chapter 10 – Circuit Switching and Packet Switching

Eighth Edition
by William Stallings

Lecture slides by Lawrie Brown

Circuit Switching and Packet Switching

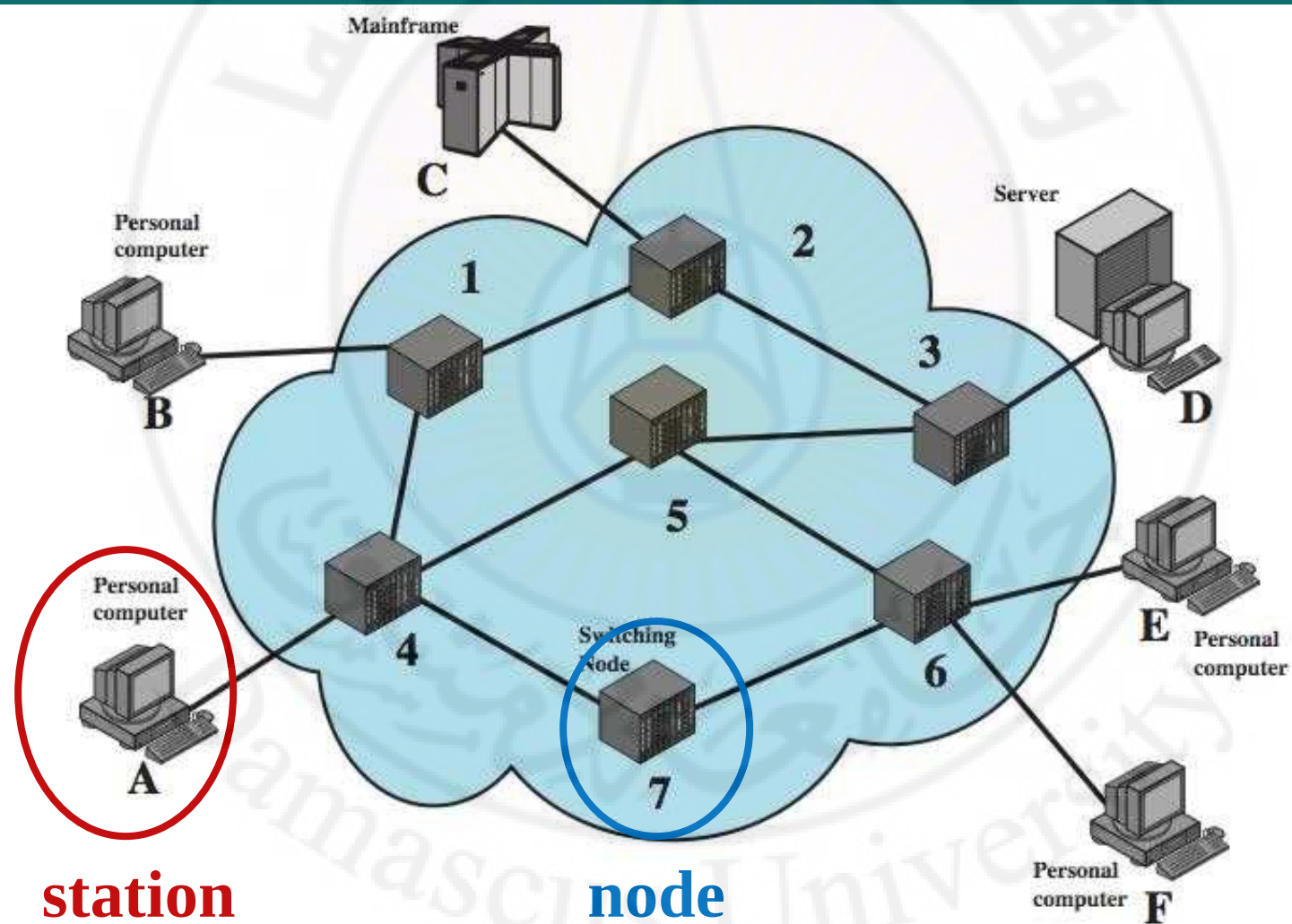
He got into a District Line train at Wimbledon Park, changed on to the Victoria Line at Victoria and on to the Jubilee Line at Green Park for West Hampstead. It was a long and awkward journey but he enjoyed it.



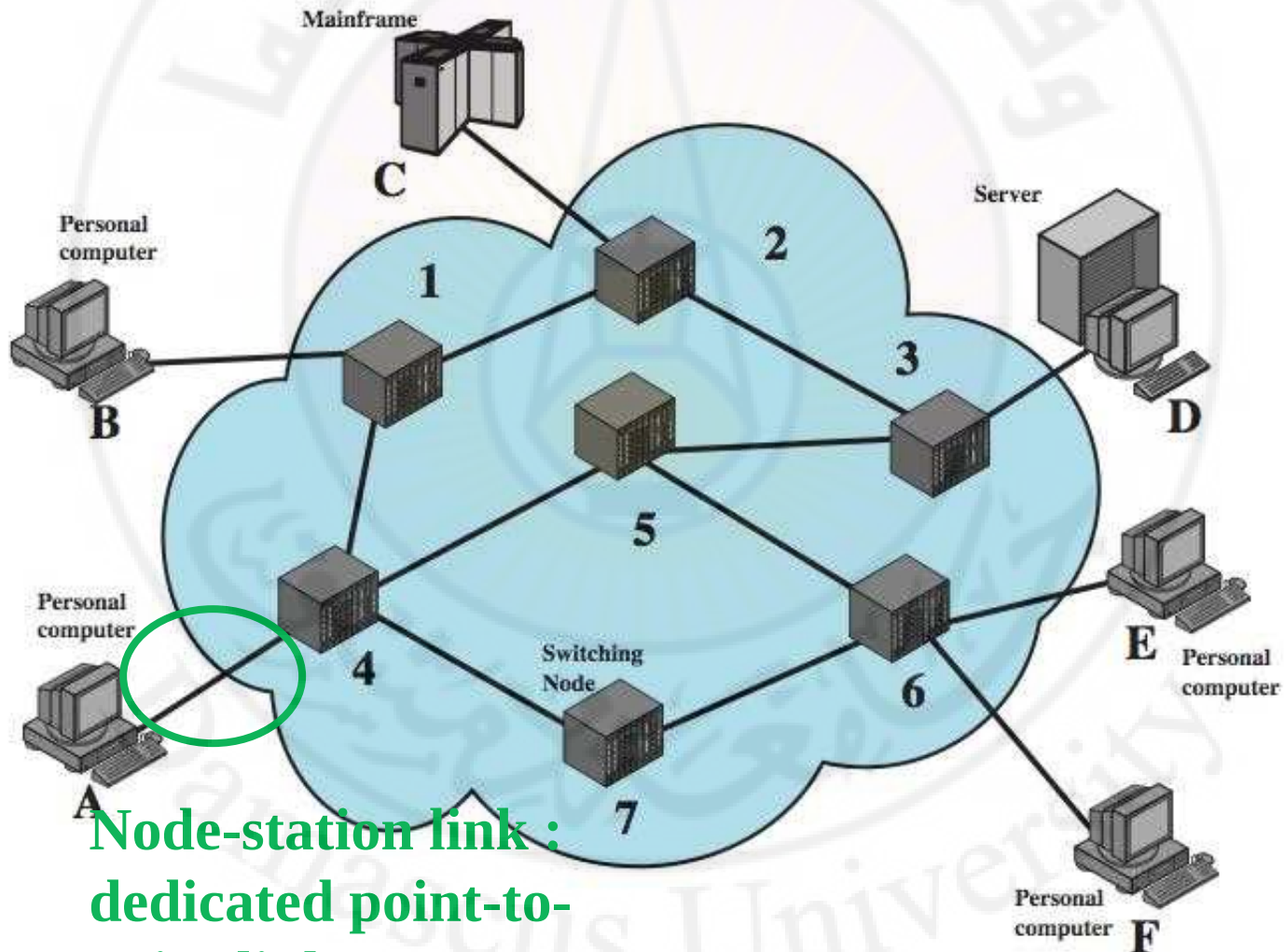
Switched Network

- For transmission of data beyond a local area, communication is typically achieved by **transmitting data from source to destination through a network of intermediate switching nodes**
- **Switching nodes:** provide a switching facility that will **move the data from node to node until they reach their destination**

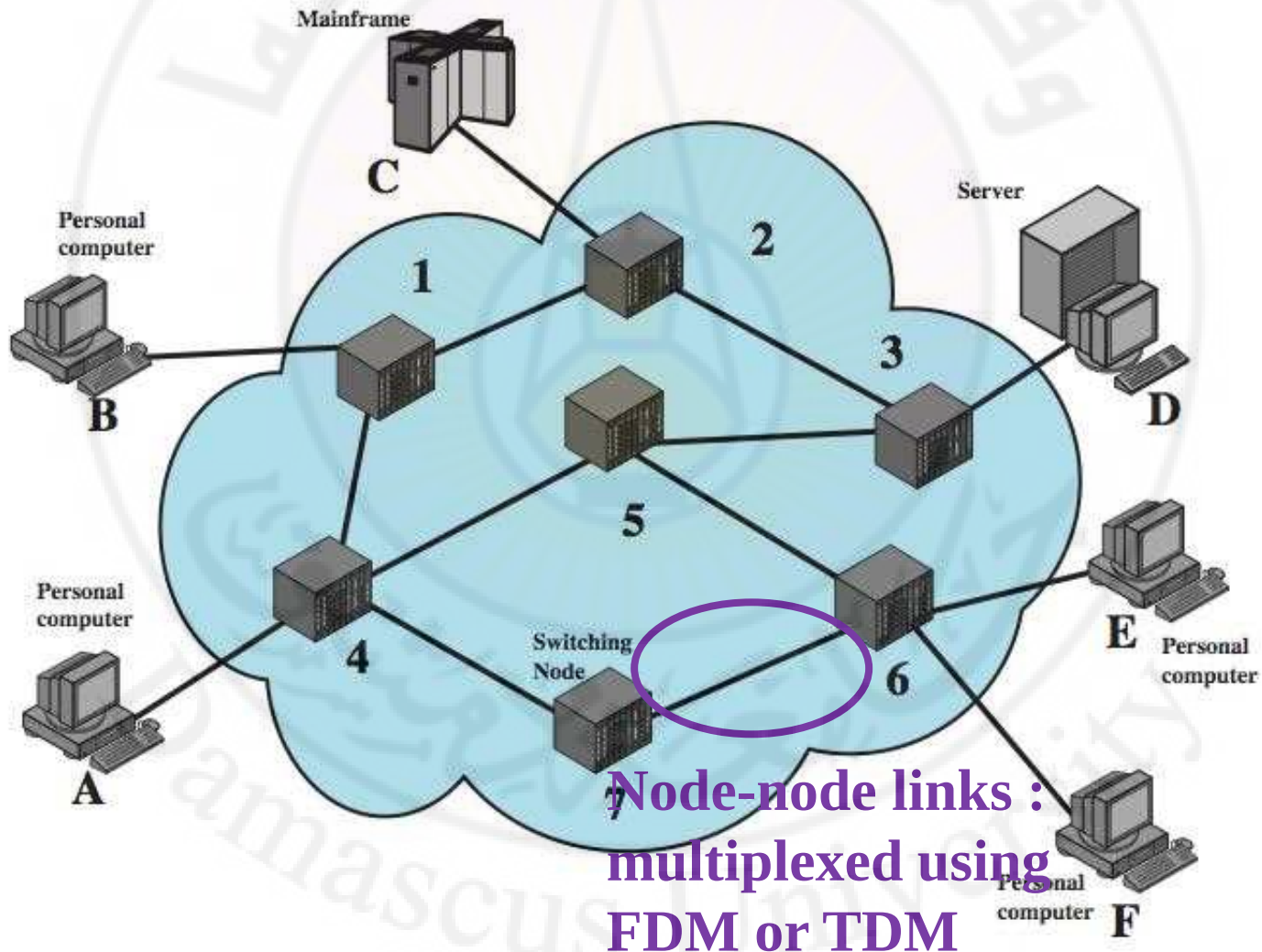
Switched Network



Switched Network



Switched Network



Nodes

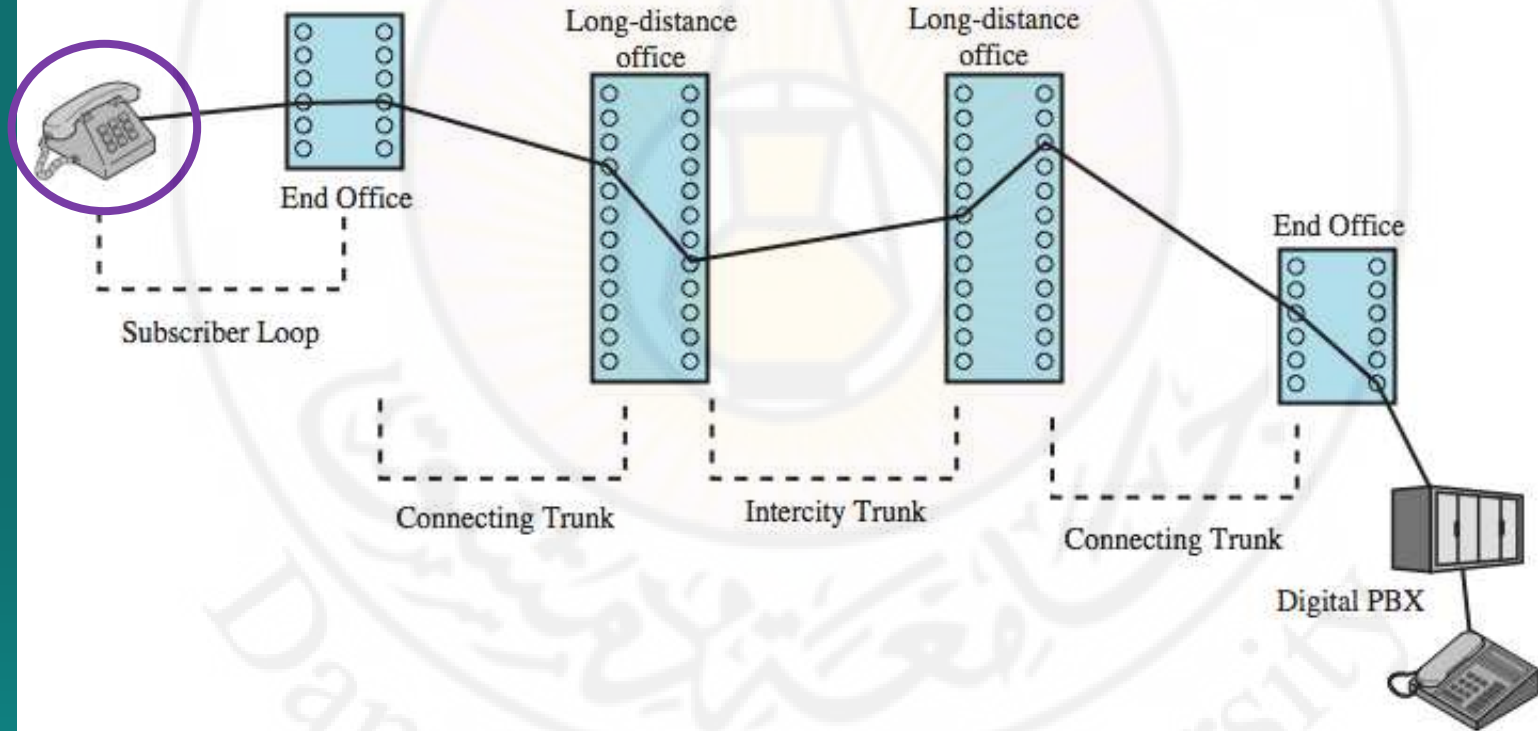
- **a collection of nodes and connections is a communications network**
- nodes may connect to other nodes only, or to stations and other nodes
- network is usually partially connected
 - some **redundant connections are desirable (enhance reliability of the network)**
- have two different **switching technologies**
 - **circuit switching**
 - **packet switching**

Circuit Switching

- uses **a dedicated path between two stations**
- has **three phases**
 - **Establish:** station-to-station circuit must be established
 - **Data transfer**
 - **Disconnect:** deallocate the dedicated resources
- **inefficient**
 - channel capacity dedicated for duration of connection
 - if **no data, capacity wasted**
- **set up** (connection) **takes time**
- once connected, **transfer is transparent**

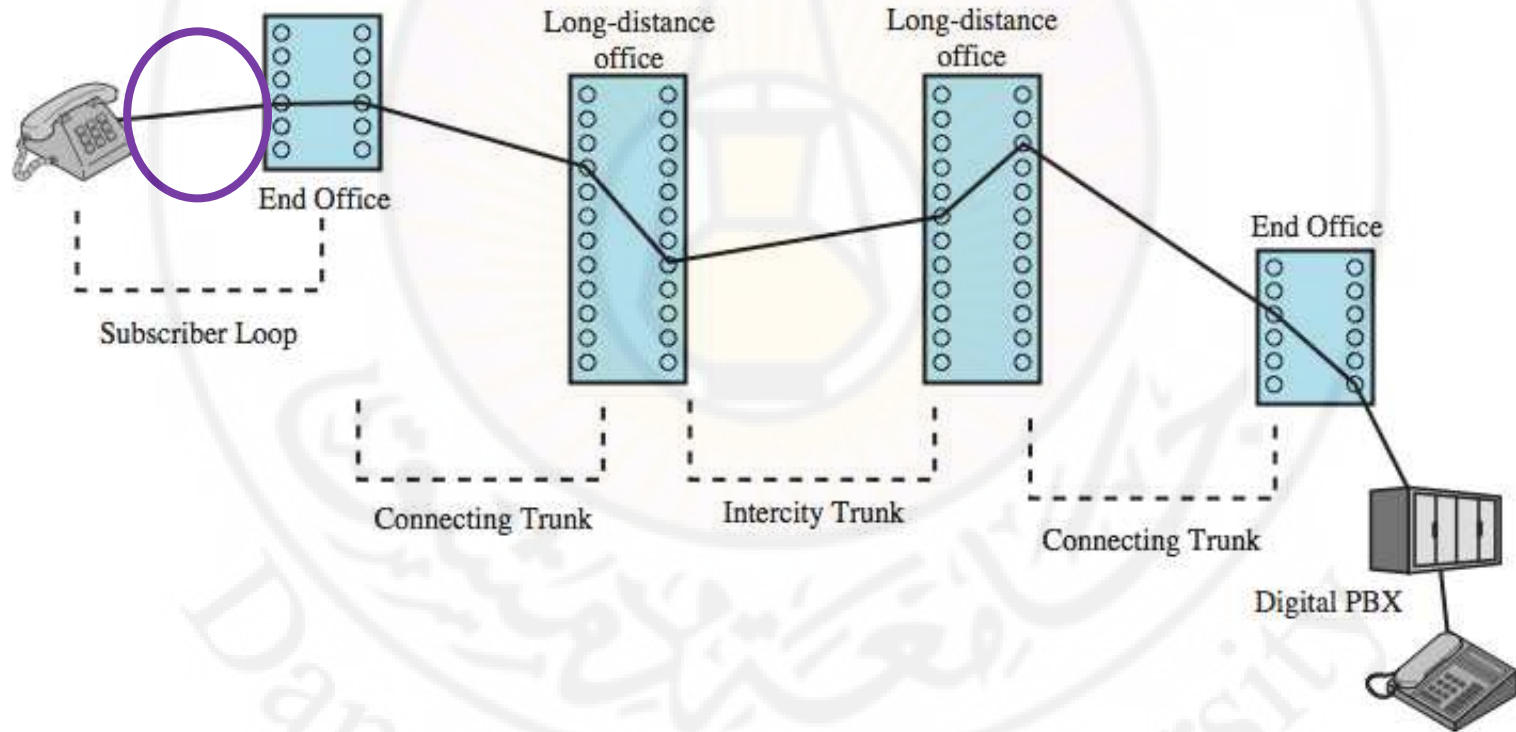
Public Circuit Switched Network

Subscriber



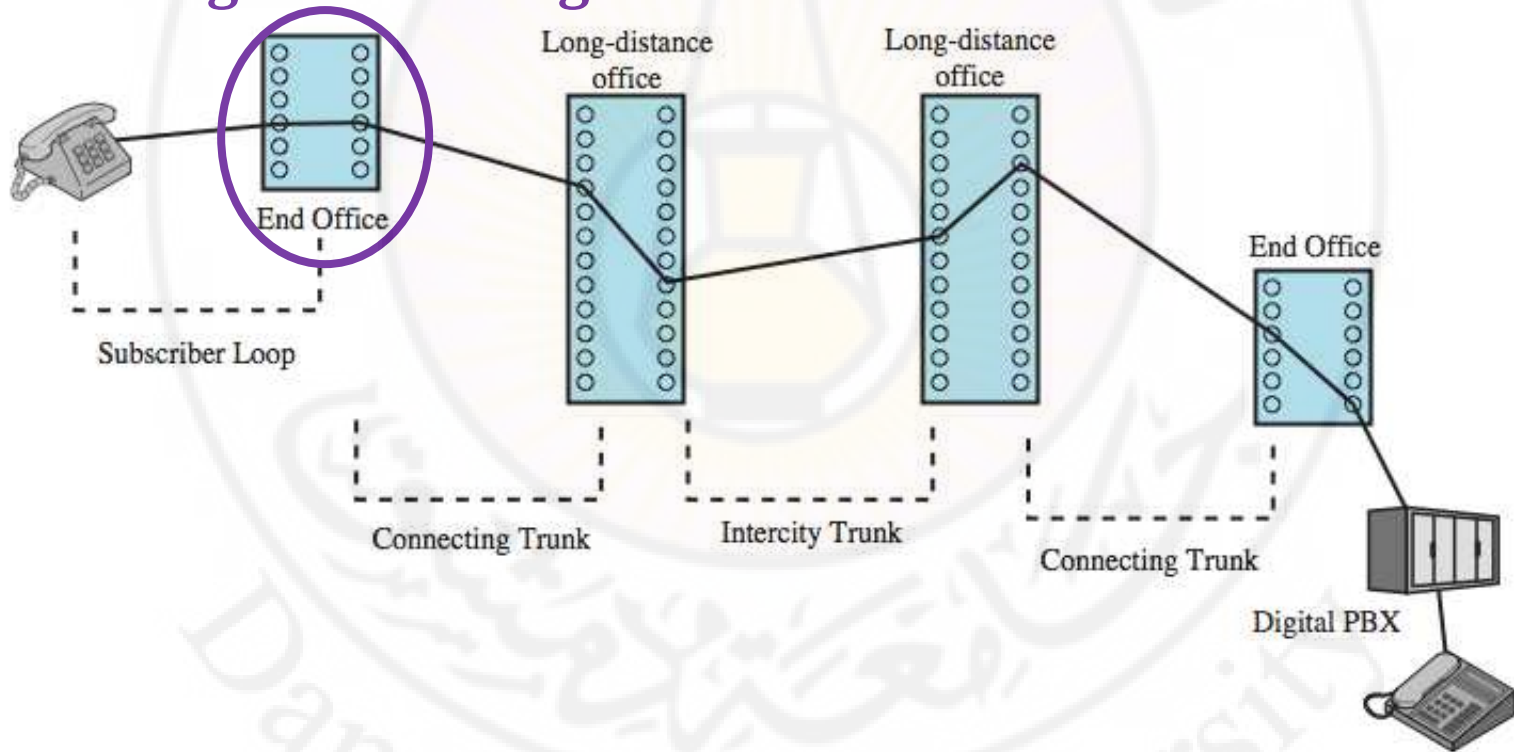
Public Circuit Switched Network

Subscriber line (subscribe loop) twisted-pair



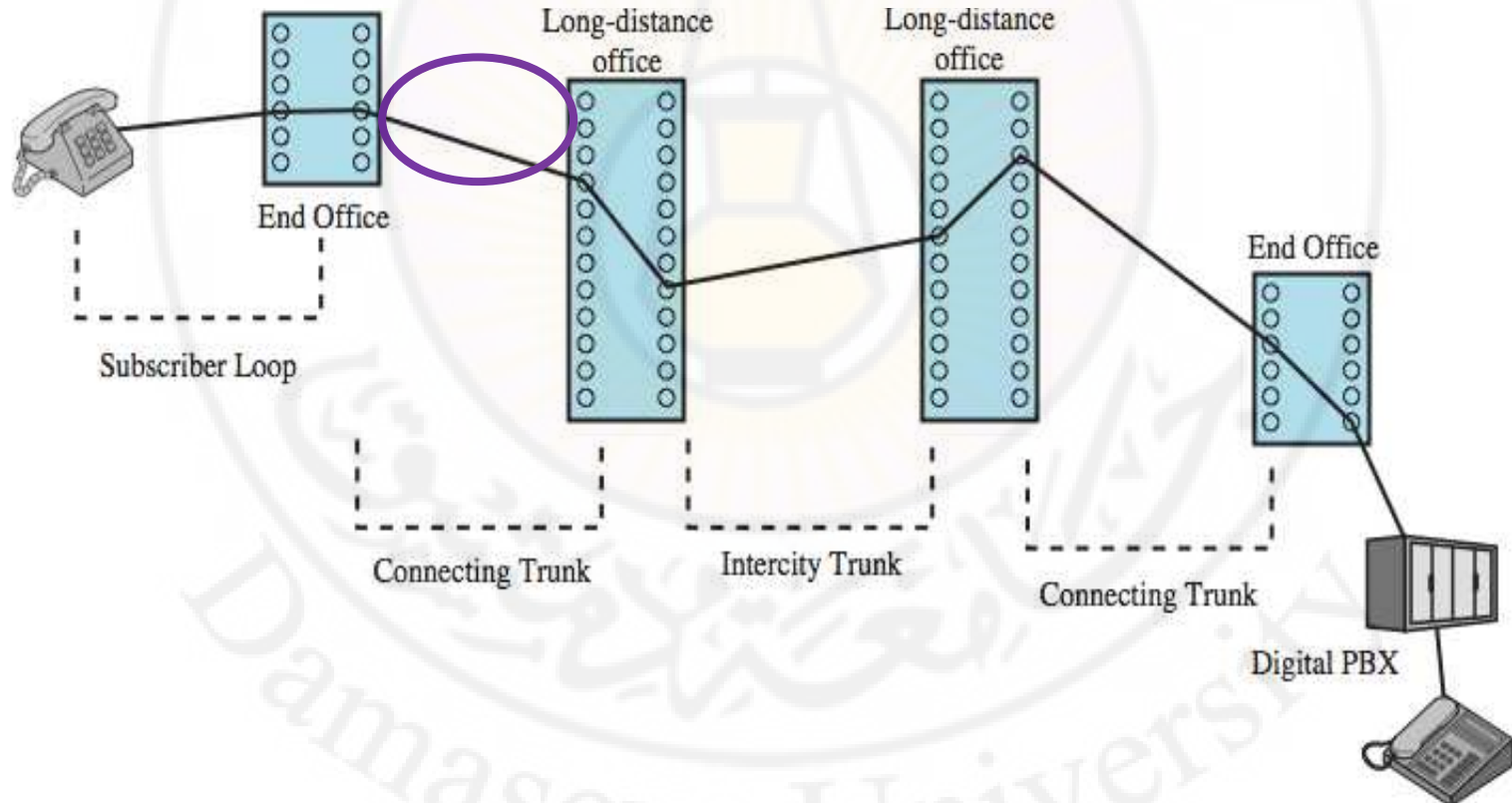
Public Circuit Switched Network

Exchanges: switching centers

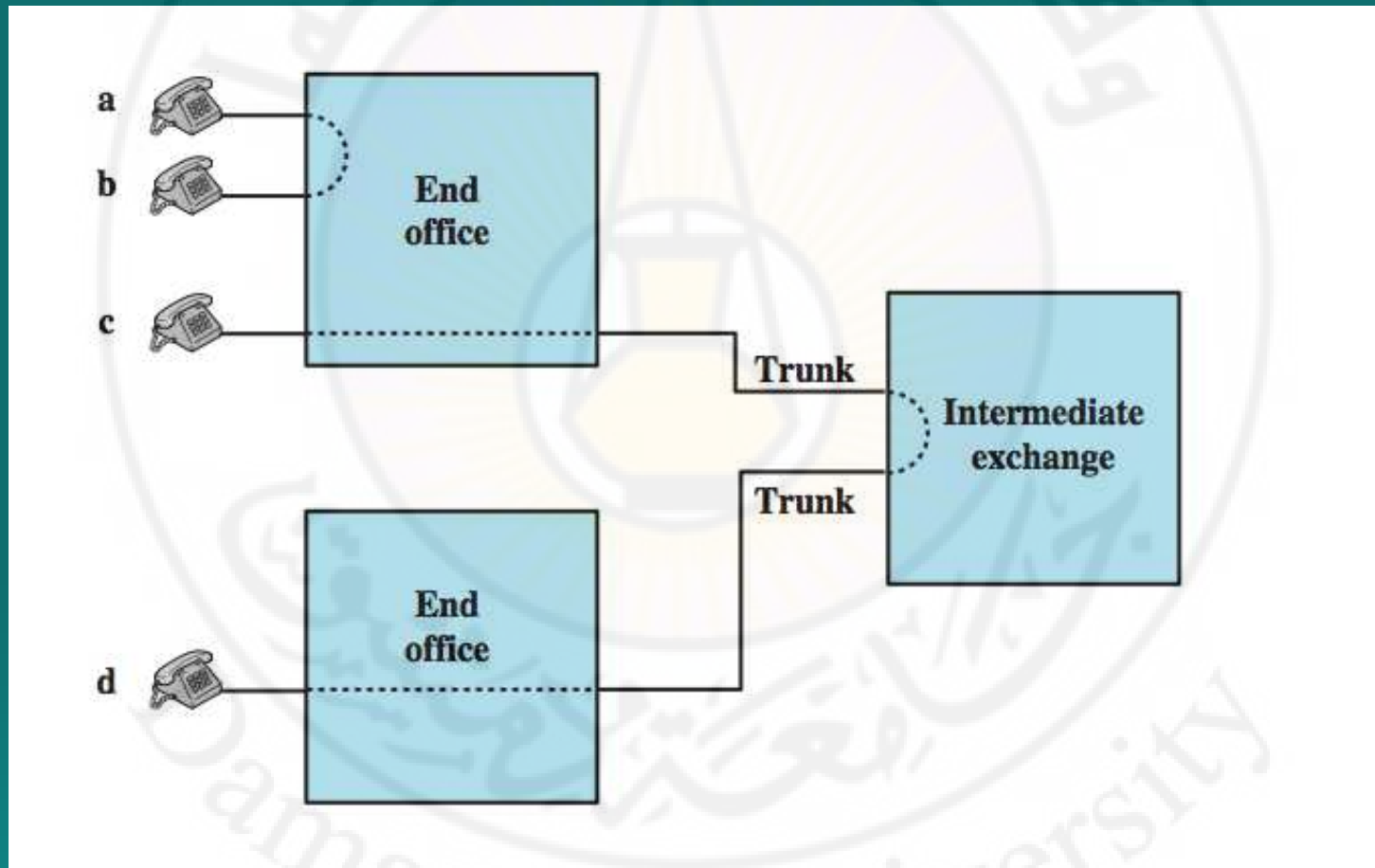


Public Circuit Switched Network

Trunks: branches between exchanges carry multiple voice-frequency circuits FDM/TDM



Circuit Establishment

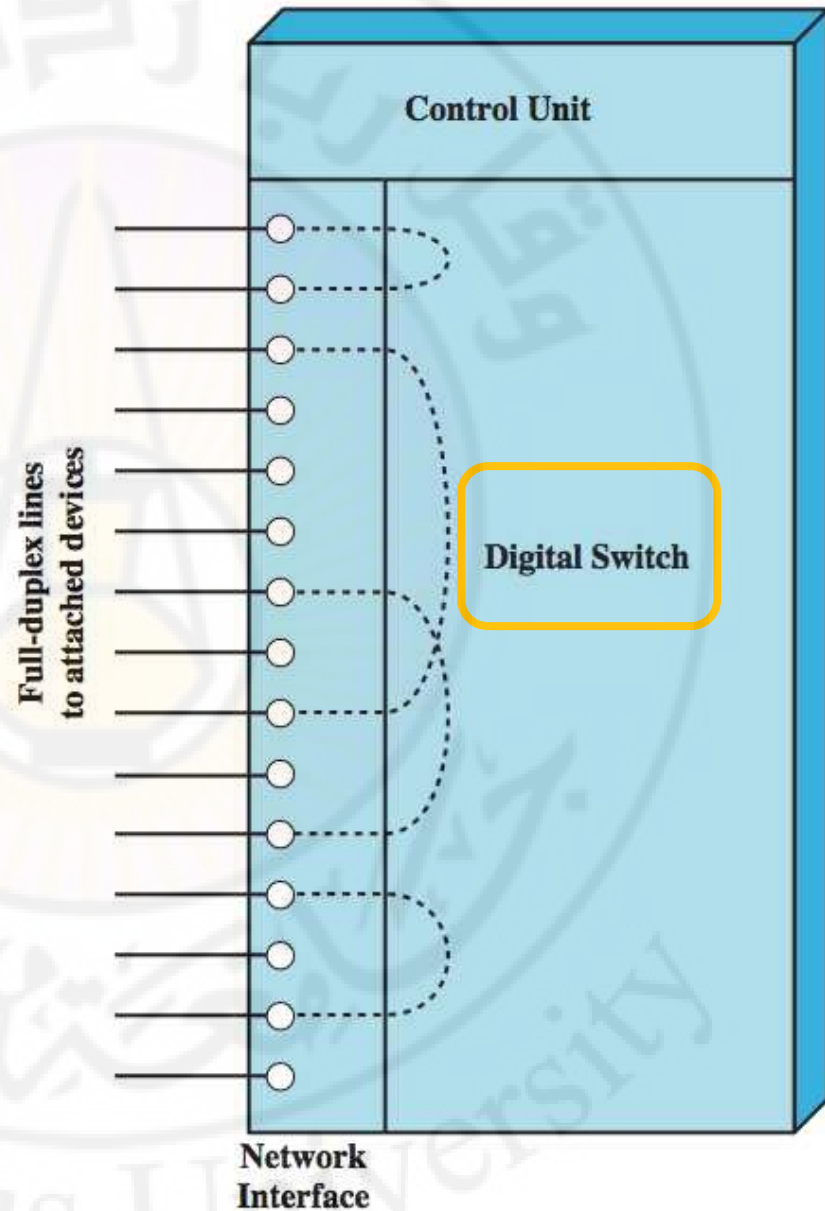


Circuit Establishment

- Circuit-switching:
- applications that **handle analog voice traffic**
- The **key requirements** for voice traffic is:
 - **virtually no transmission delay.**
 - **certainly no variation in delay.**
 - **A constant signal transmission rate** must be maintained, because transmission and reception occur at the same signal rate

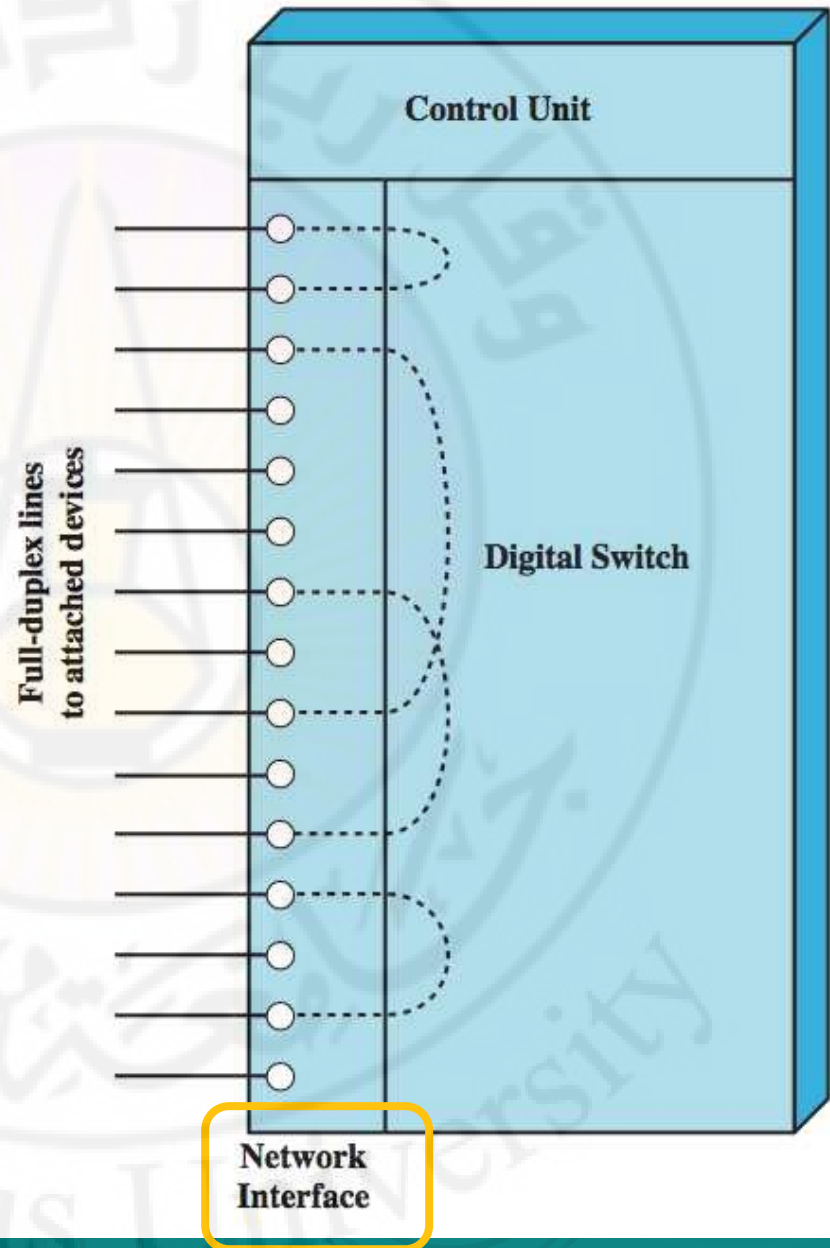
Circuit Switch Elements

Provide a transparent signal path between any pair of attached devices



Circuit Switch Elements

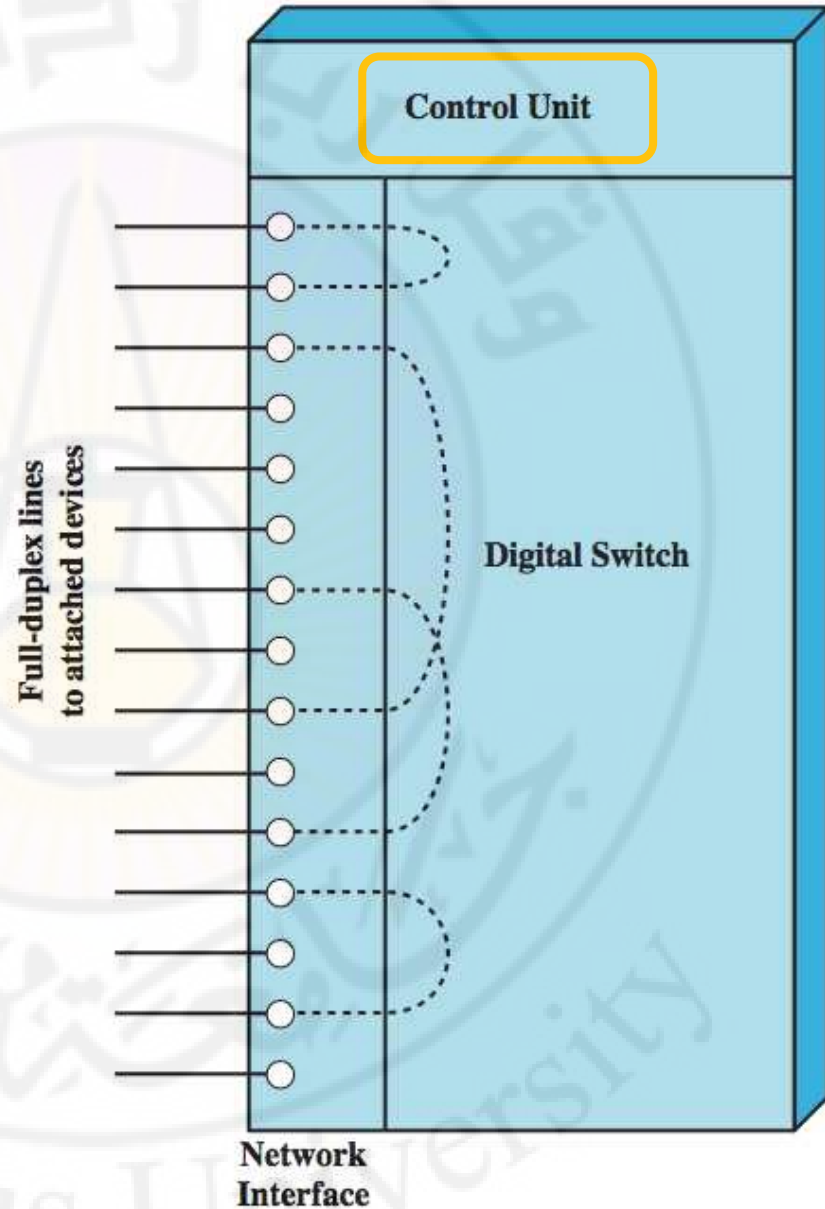
represents the functions and hardware needed to connect digital devices



Circuit Switch Elements

performs three general tasks:

- Establish connection
- Maintain connection
- Tear down connection



Blocking or Non-blocking

➤ **blocking** network

- may be **unable to connect stations because all paths are in use**
- **used on voice systems**

➤ **non-blocking** network

- **permits all stations to connect at once**
- **used for some data connections**

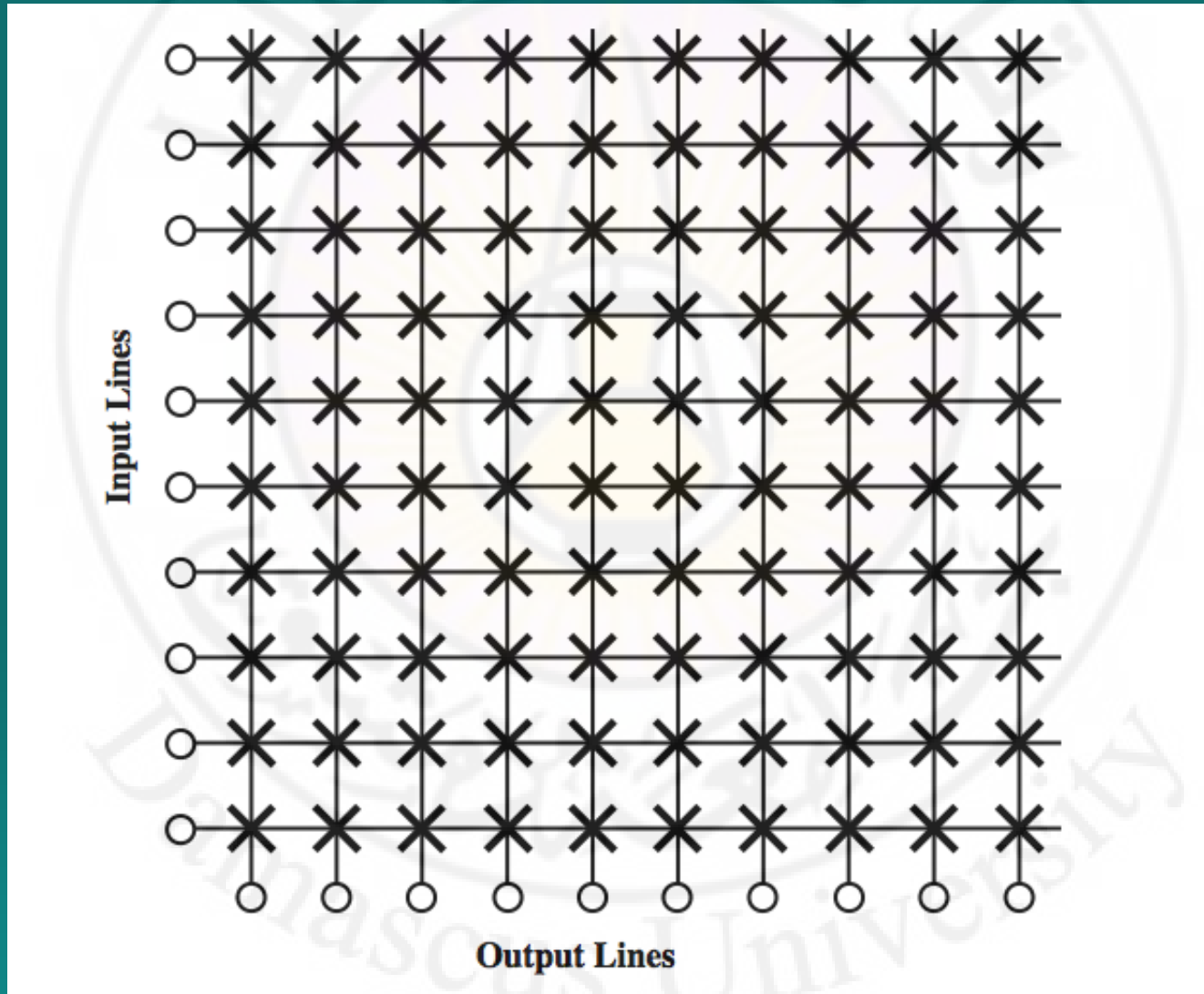
switching techniques internal to a single circuit-switching node

- Space Division Switch
- 3 Stage Space Division Switch
- Time Division Switching

Space Division Switch

- the signal paths are physically separate from one another (divided in space)
- a metallic crosspoint or semiconductor gate that can be enabled and disabled by a control unit

Space Division Switch

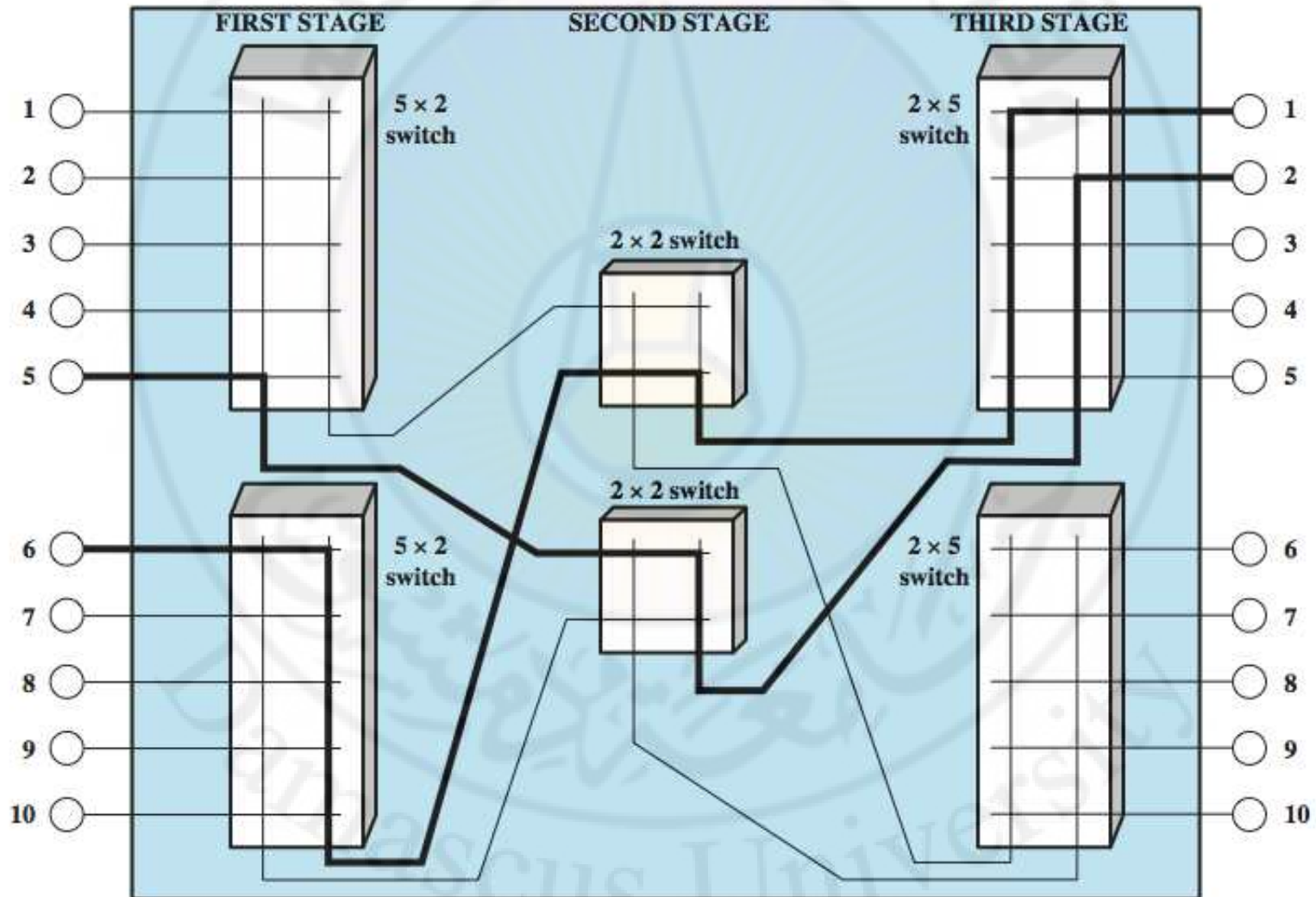


Space Division Switch

➤ has a number of limitations:

- The number of crosspoints grows with the square of the number of attached stations. This is costly for a large switch.
- The loss of a crosspoint prevents connection between the two devices whose lines intersect at that crosspoint.
- The crosspoints are inefficiently utilized; even when all of the attached devices are active, only a small fraction of the crosspoints are engaged.

3 Stage Space Division Switch



3 Stage Space Division Switch

- It has **two advantages** over a single-stage crossbar matrix:
 - The **number of crosspoints is reduced**
 - There is **more than one path through the network to connect two endpoints, increasing reliability.**
- But **requires a more complex control scheme**

3 Stage Space Division Switch

- a single-stage crossbar matrix is nonblocking
- multiple-stage switch can be made nonblocking by
 - increasing the number or size of the intermediate switches
 - but of course this increases the cost.

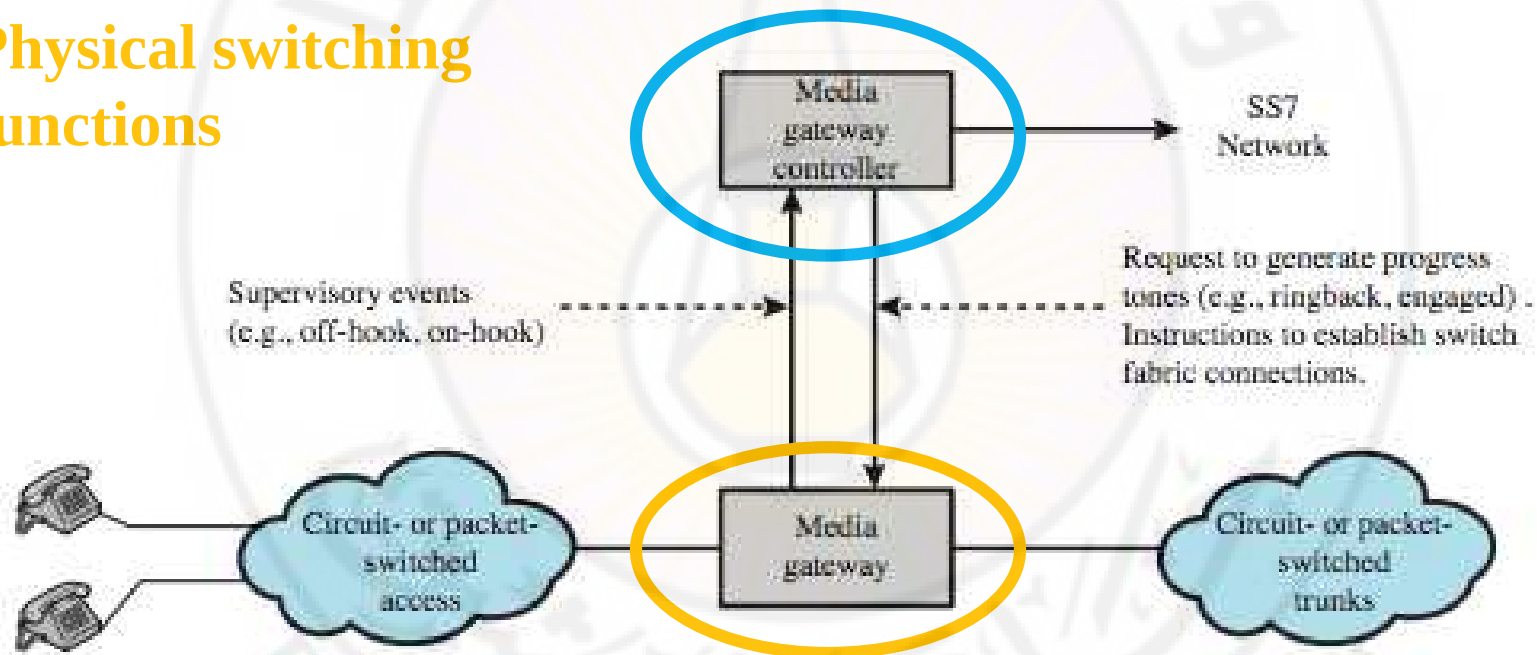
Time Division Switching

- modern digital systems use **intelligent control of space & time division** elements
- use digital time division techniques **to set up and maintain virtual circuits**
- **partition low speed bit stream into pieces that share higher speed stream**
- individual pieces manipulated by control logic to flow from input to output

Softswitch

Physical switching functions

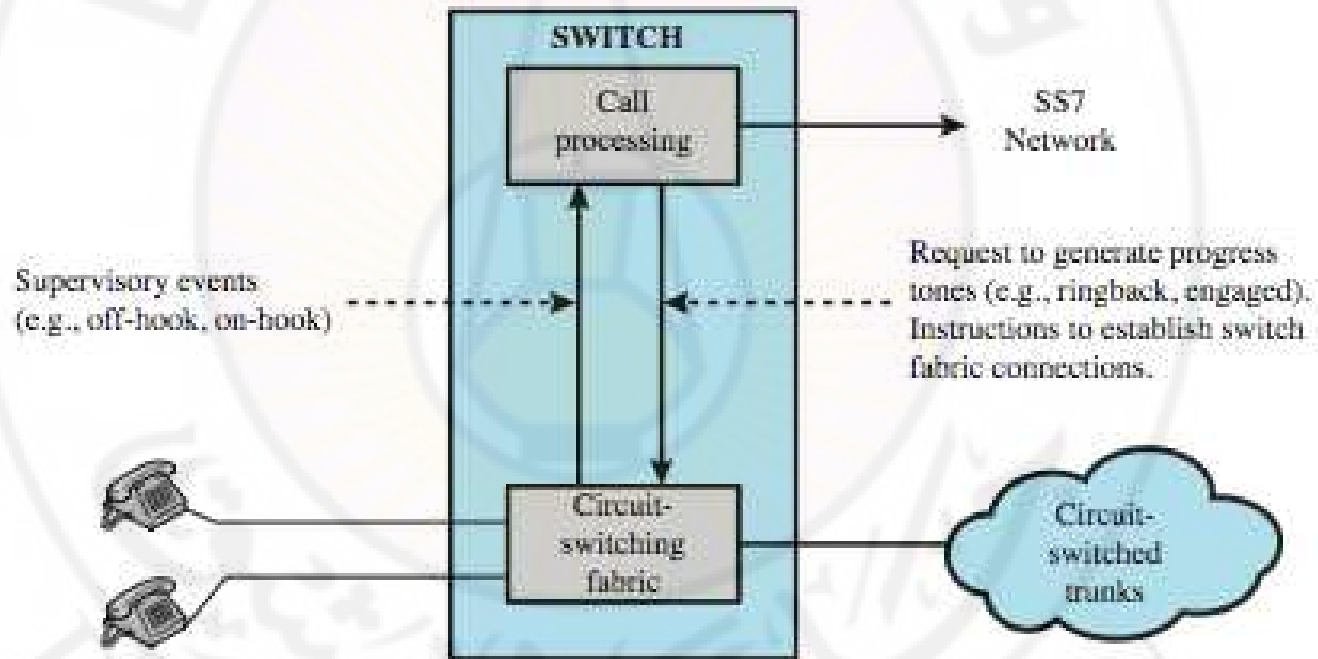
Call processing functions



(b) Softswitch architecture

- a general-purpose computer running specialized software
- cost significantly less than traditional circuit switches and can provide more functionality

Traditional Circuit Switching

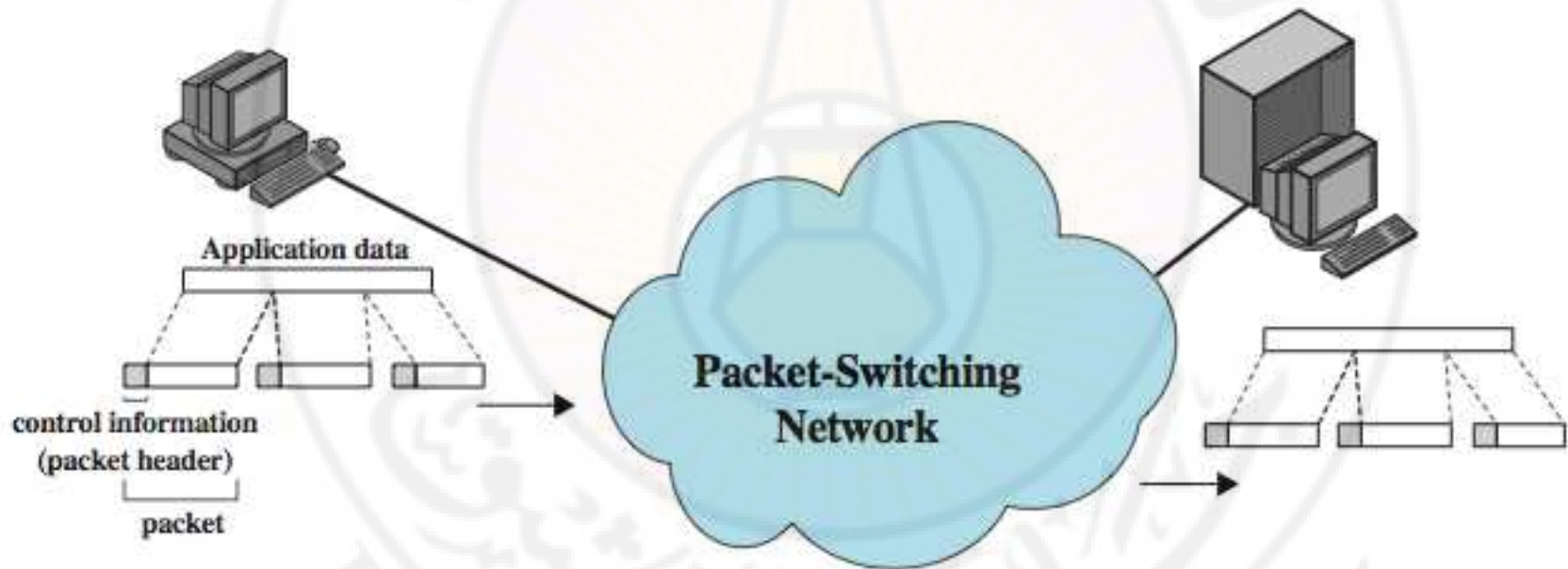


(a) Traditional circuit switching

Packet Switching

- **circuit switching** was designed **for voice**
- **packet switching** was designed **for data**
- transmitted in small packets
- **packets contains user data and control info**
 - user data may be part of a larger message
 - control info includes **routing (addressing)** info
- packets are received, stored briefly (buffered) and past on to the next node

Packet Switching



Advantages

➤ line efficiency

- single **link shared by many packets** over time
- **packets** queued and transmitted **as fast as possible**

➤ data rate conversion

- **stations connects** to local node **at own speed**
- **nodes buffer data** if required **to equalize rates**

➤ **packets accepted** even when **network is busy**

➤ **priorities can be used**

Switching Techniques

- station breaks long message **into packets**
- packets sent **one at a time** to the network
- packets can be handled in two ways
 - **datagram**
 - **virtual circuit**

Datagram Diagram

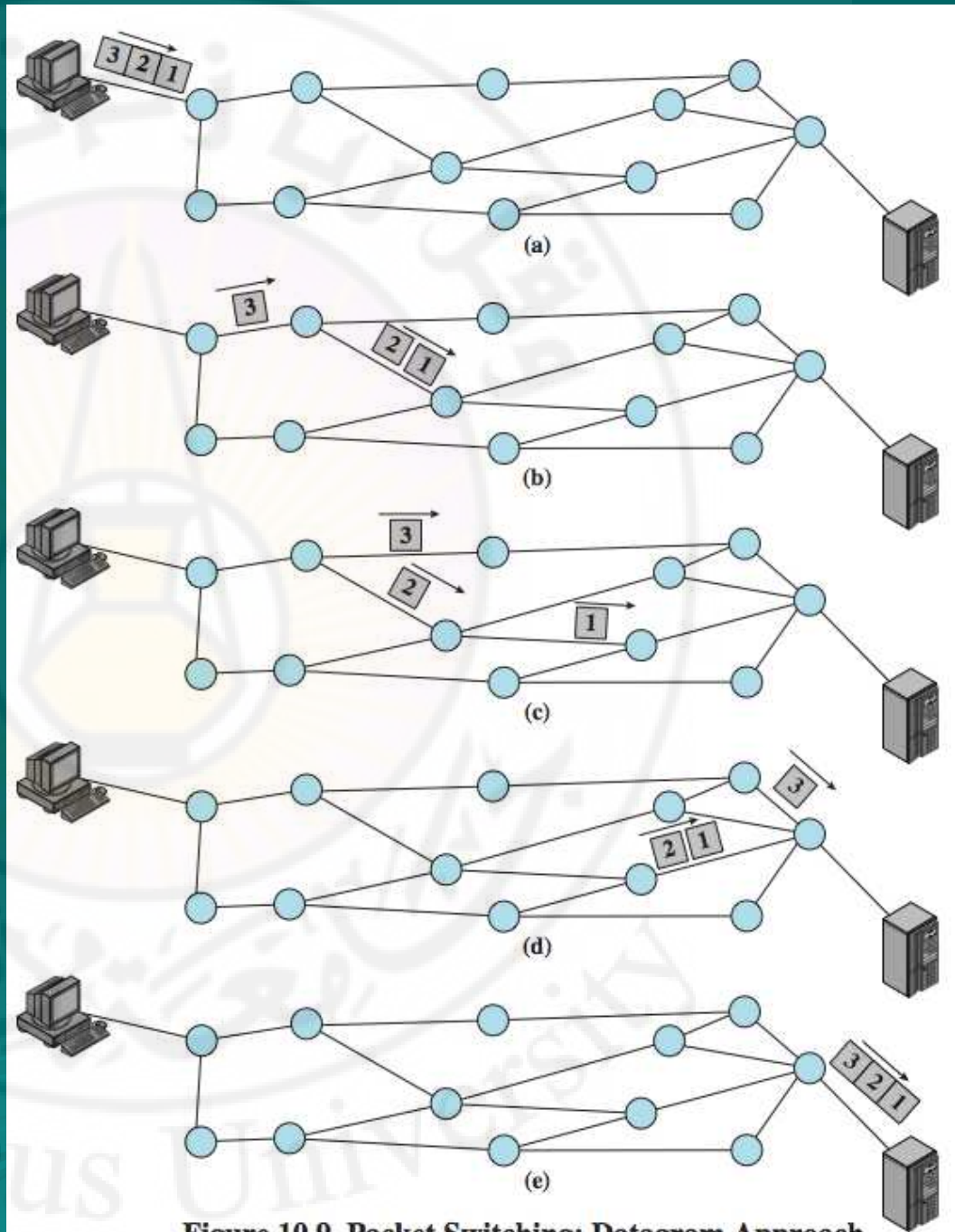


Figure 10.9 Packet Switching: Datagram Approach

Datagram

- each **packet** is treated **independently**
- **Each node chooses the next node on a packet's path**
 - taking into account **information** received from neighboring nodes **on traffic, line failures, ...**
- the packets with the same destination address **not all follow the same route**
 - may arrive **out of sequence**
 - possible for a packet to be **destroyed** in network

Virtual Circuit Diagram

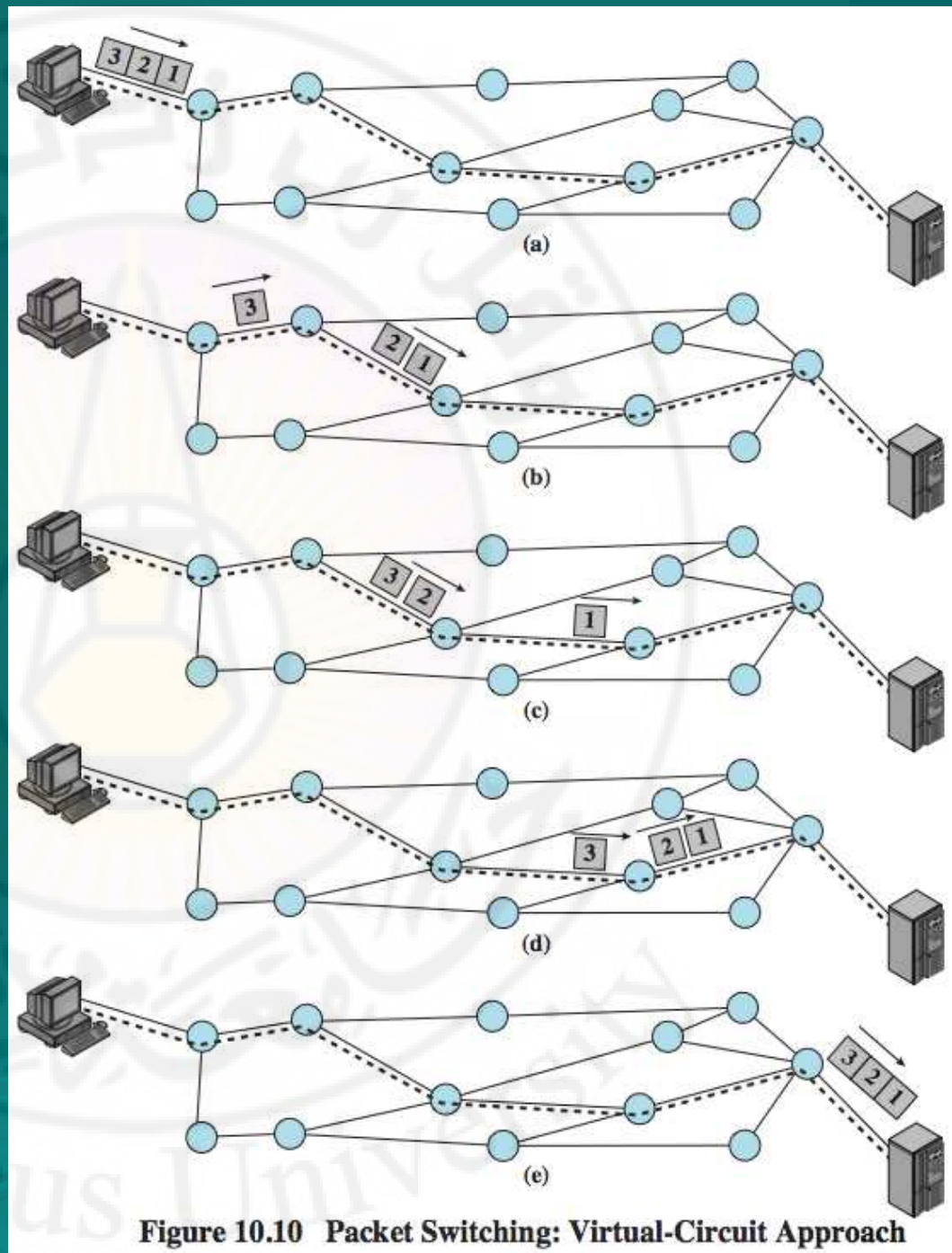


Figure 10.10 Packet Switching: Virtual-Circuit Approach

Virtual Circuit Diagram

- a preplanned route is established before any packets are sent.
- Once the route is established, all the packets follow this same route through the network.
- Each packet contains a virtual circuit identifier
- no routing decisions are required

Virtual Circuits v Datagram

➤ virtual circuits

- network can provide **sequencing and error control**
- packets are **forwarded more quickly**
- **less reliable**

➤ datagram

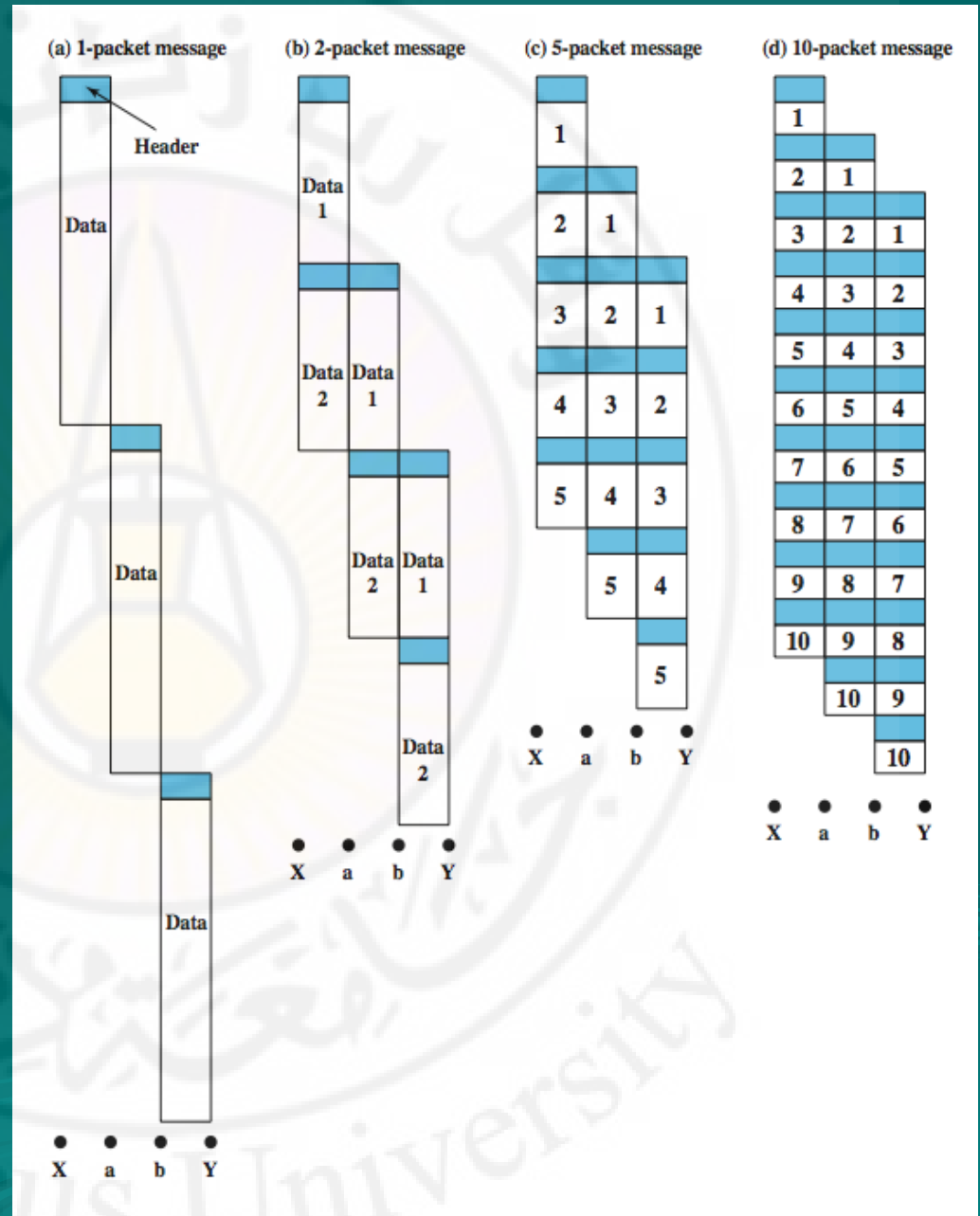
- **no call setup** phase
- **more flexible** datagrams can be routed away from the congestion
- **more reliable**

Packet Size

overlap in transmission,
the total transmission
time drops

Increased delay since each
packet contains a fixed
amount of header

processing and queuing
delays at each node are
greater when more
packets are handled



Circuit vs Packet Switching

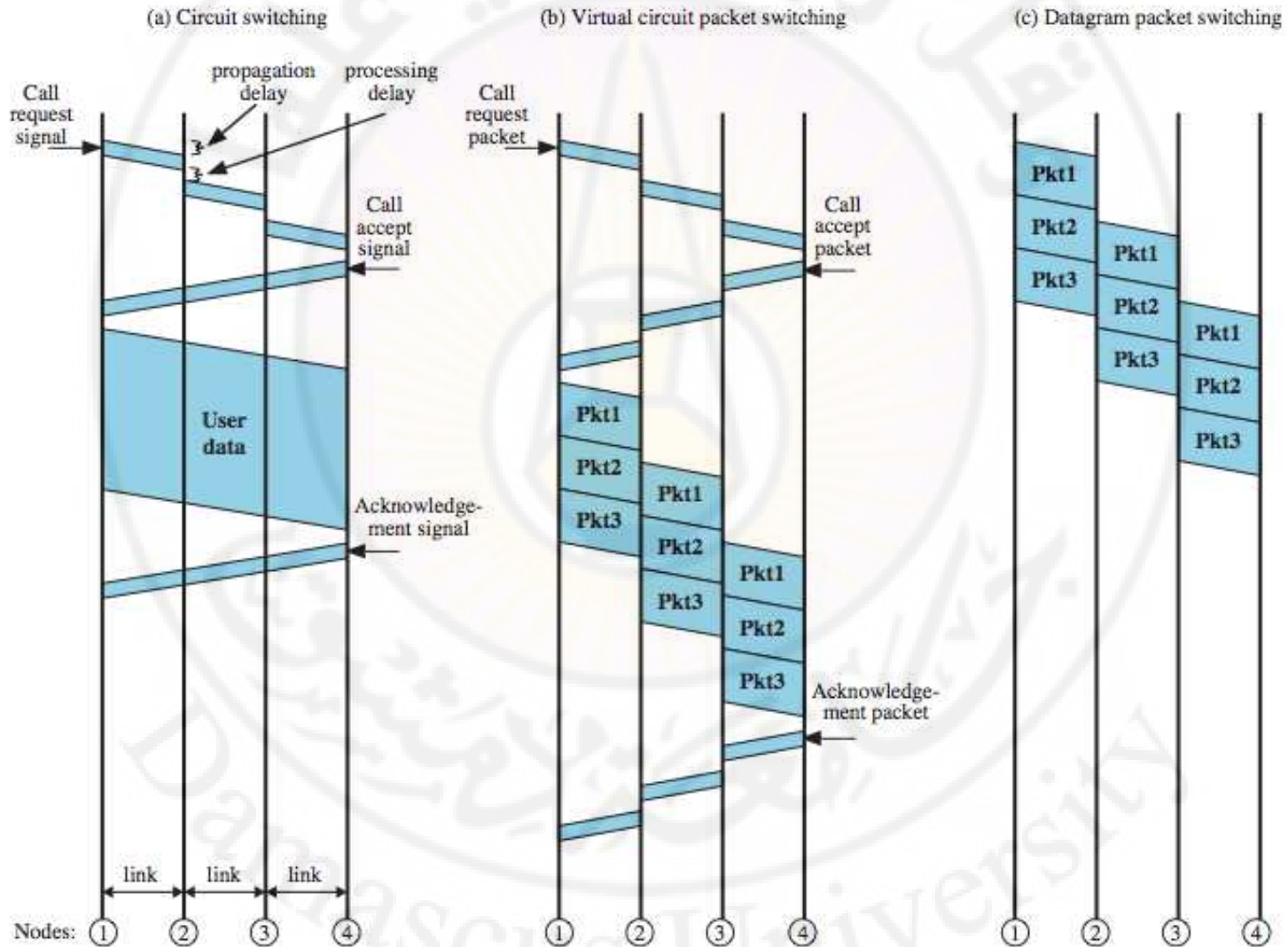
- performance depends on various delays
 - propagation delay: The time it takes a signal to propagate from one node to the next
 - transmission time: The time it takes for a transmitter to send out a block of data
 - node delay: The time it takes for a node to perform the necessary processing as it switches data

Circuit vs Packet Switching

➤ range of other characteristics, including:

- Transparency: Circuit switching is essentially a transparent service. Once a connection is established, a **constant data rate is provided to the connected stations.**
- amount of overhead: no overhead required to accommodate circuit switching.

Event Timing



X.25

- ITU-T standard for **interface between host and packet switched network**
- almost universal on packet switched networks and packet switching in ISDN
- defines **three layers**
 - **Physical**
 - **Link**
 - **Packet**

X.25 - Physical

- interface between station node link
- two ends are distinct
 - Data Terminal Equipment **DTE (user equipment)**
 - Data Circuit-terminating Equipment **DCE (node)**
- physical layer specification is X.21
- can substitute alternative such as EIA-232

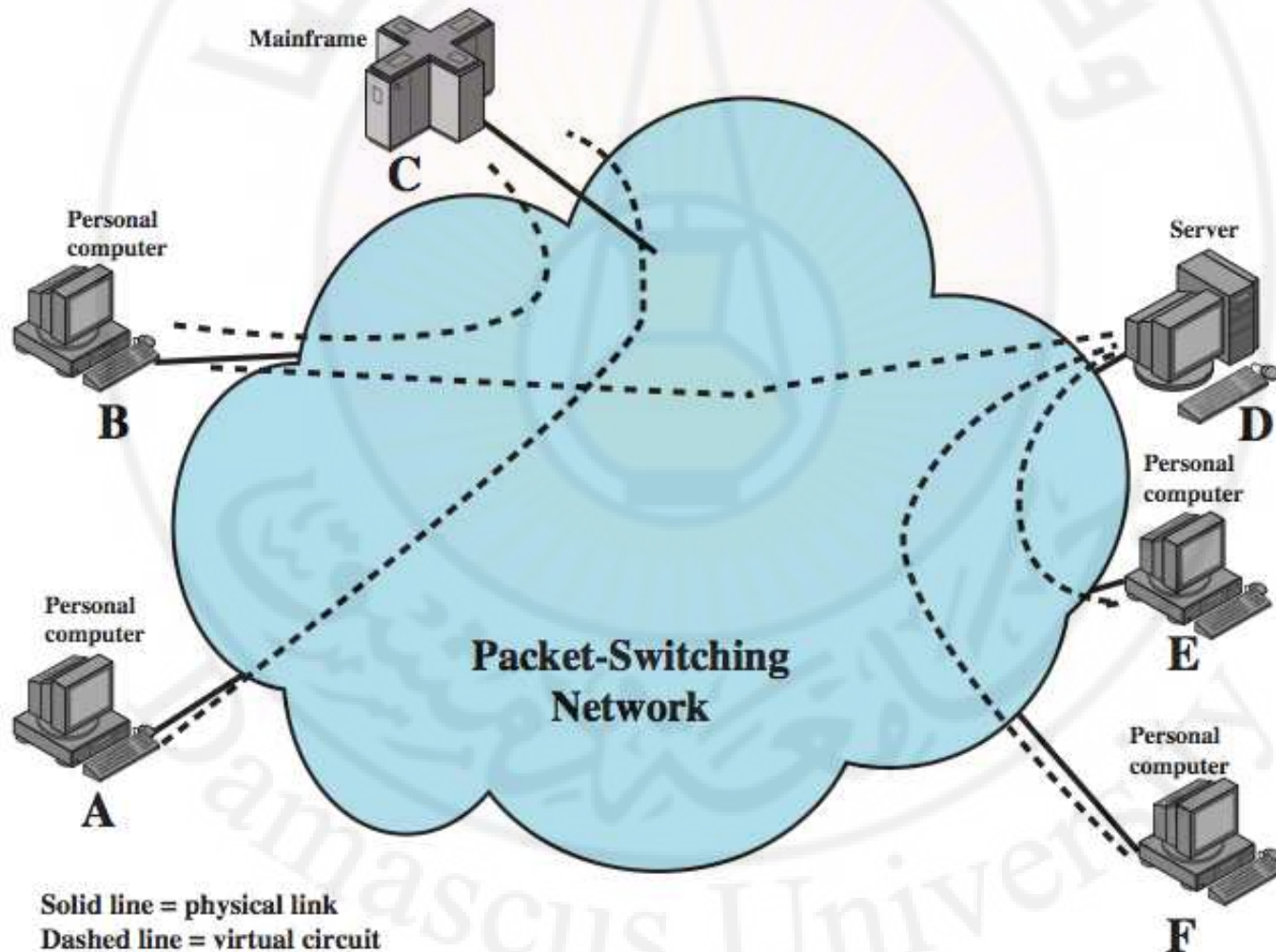
X.25 - Link

- Link Access Protocol Balanced (**LAPB**)
 - Subset of HDLC
 - see chapter 7
- **provides reliable transfer of data over link**
- **sending as a sequence of frames**

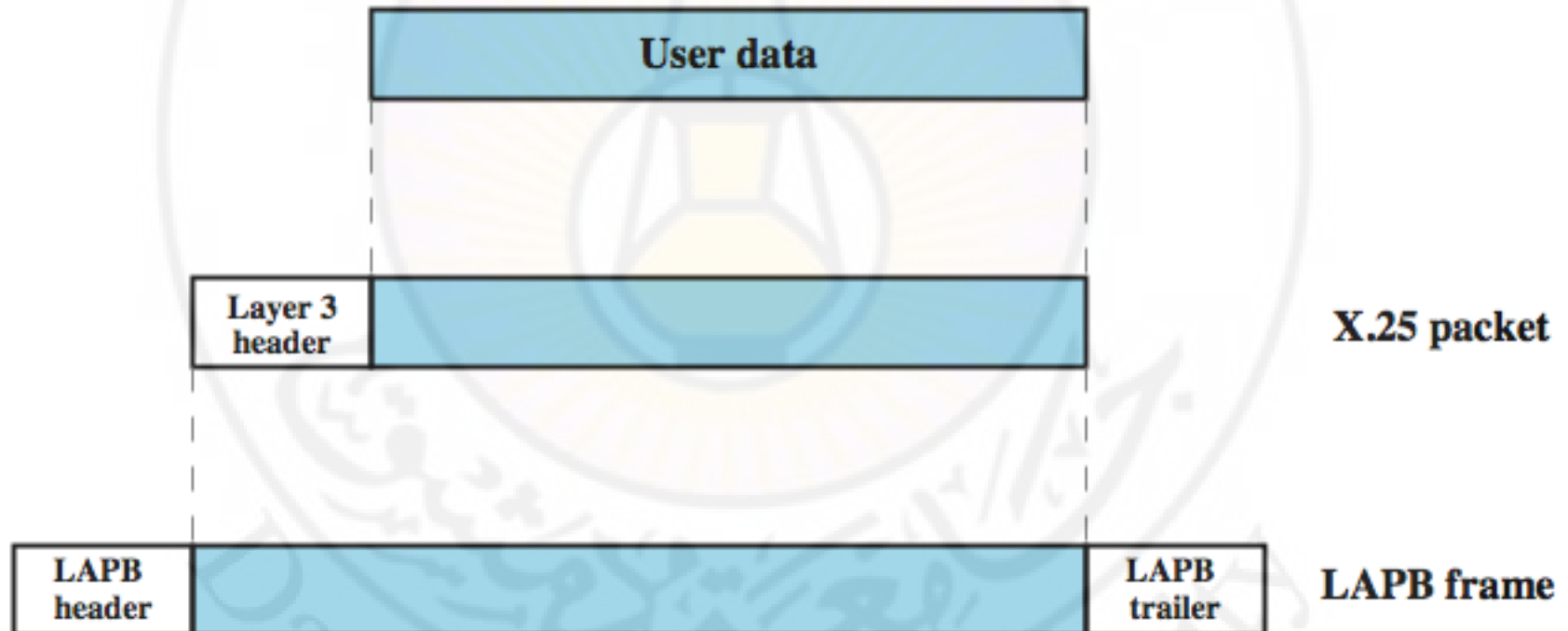
X.25 - Packet

- provides a logical connections (virtual circuit) between subscribers
- all data in this connection form a single stream between the end stations
- established on demand
- termed external virtual circuits

X.25 Use of Virtual Circuits



User Data and X.25 Protocol Control Information



Issues with X.25

- key features include:
 - **call control packets**, used for setting up and clearing virtual circuits, are carried on the same channel and same virtual circuit as data packets.
 - **multiplexing** of virtual circuits at **layer 3**
 - **layers 2 and 3** include **flow and error control**
- hence have considerable **overhead**
- not appropriate for modern digital systems with high reliability

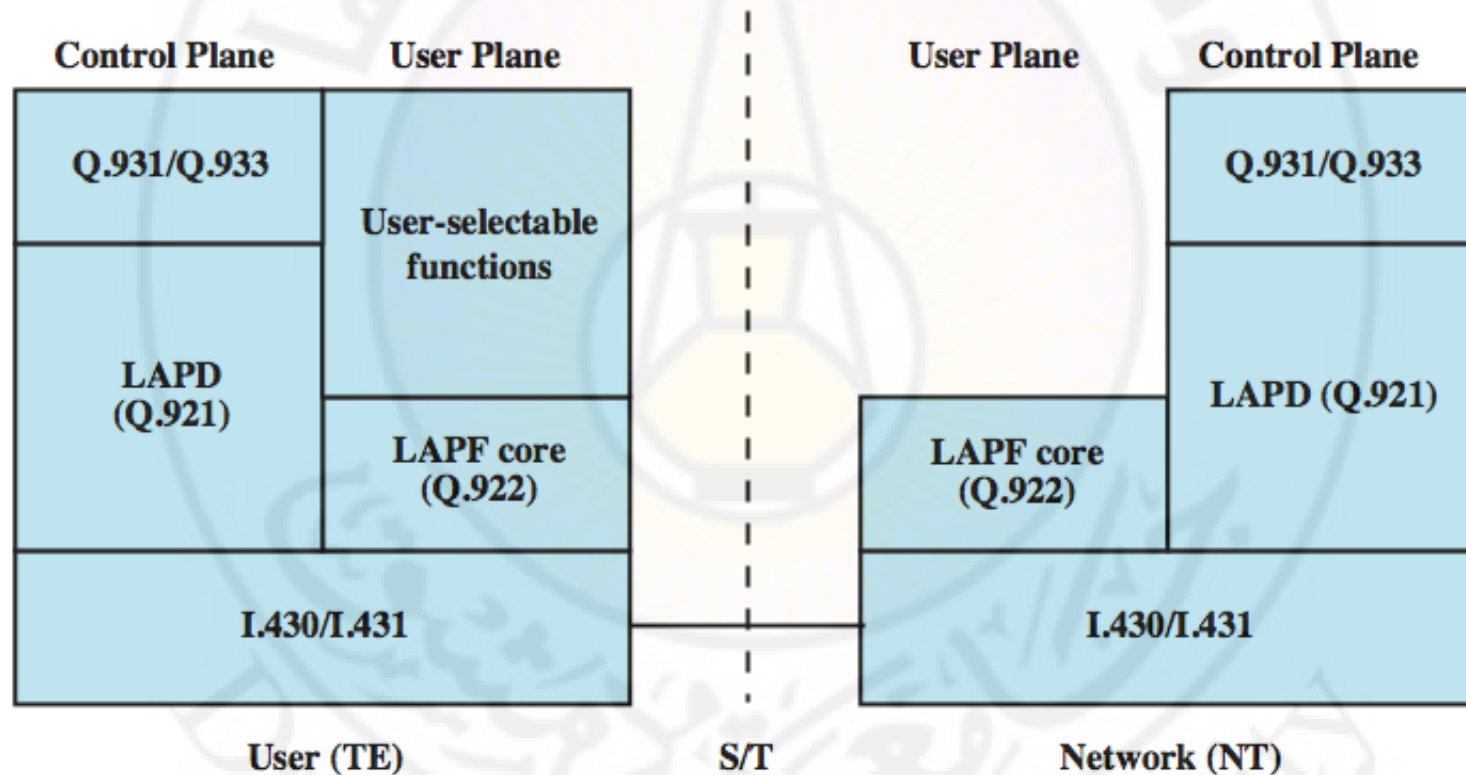
Frame Relay

- designed to **eliminate most X.25 overhead**
- has **large installed base**
- key differences:
 - **call control carried in separate logical connection**
 - **multiplexing and switching at layer 2**
 - **no hop by hop error or flow control**
 - hence **end to end flow and error control** (if used) are done by higher layer
- **a single user data frame is sent from source to destination and higher layer ACK sent back**

Advantages and Disadvantages

- **lost link by link error and flow control**
- increased reliability means less an issue
- streamlined communications process
 - **lower delay**
 - **higher throughput**
- frame relay can be used for **access speeds up to and over 2Mbps**

Protocol Architecture



LAPF Functionality

- **LAPF** (Link Access Procedure for Frame Mode Bearer Services) defined in Q.922
- only core functionality used:
 - **frame delimiting, alignment and transparency**
 - **frame mux and demux** using addressing field
 - **ensure frame is integral number of octets**
 - **ensure frame is neither too long nor short**
 - **detection of transmission errors**
 - **congestion control functions**
- form sub-layer of data link layer
 - data transfer between subscribers only

Frame Relay Data Link Connections

- logical connection between subscribers
- data transferred over them
- not protected by flow or error control
- uses separate connection for call control
- overall results in significantly less work in network

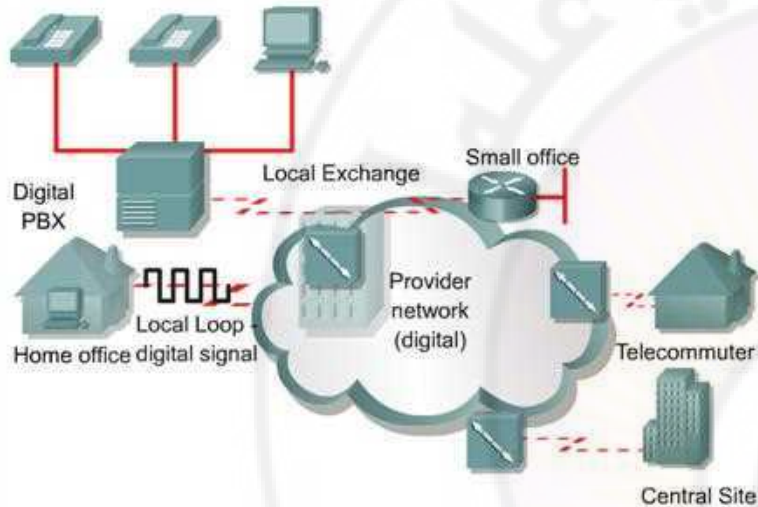
User Data Transfer

- only have **one frame type** which
 - carries user data
- **no control frames** means
 - no inband signaling
 - **no sequence numbers**
- address field carries **DLCI**
- DLCI (**Data Link Connection Identifier**) has local significance only

Summary

- circuit verses packet switching network approaches
- X.25
- frame relay

Introducing ISDN



- **Telephone companies** developed **ISDN (Integrated Services Digital Network)** as part of an effort to standardize subscriber services.
- This included the **User-Network Interface (UNI)**, better known as the **local loop**.
- The **ISDN standards define the hardware and call setup schemes for end-to-end digital connectivity**.
- These standards help achieve the goal of worldwide connectivity by ensuring that ISDN networks easily communicate with one another.
- In an ISDN network, **the digitizing function is done at the user site rather than the telephone company**.

Introducing ISDN

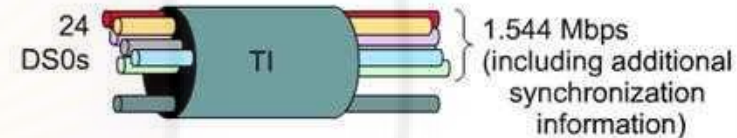
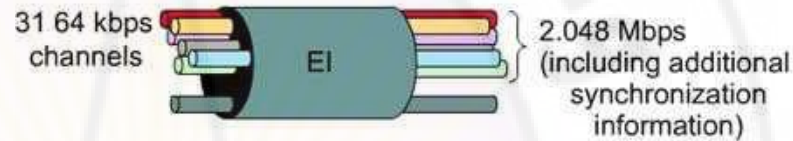
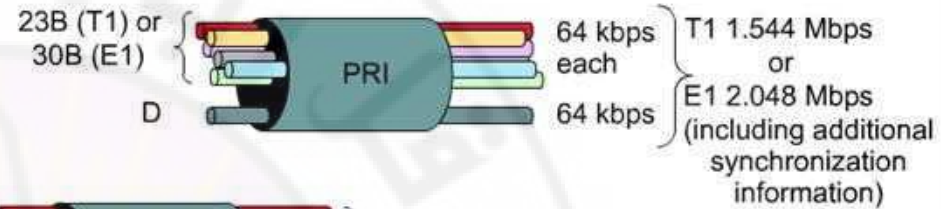
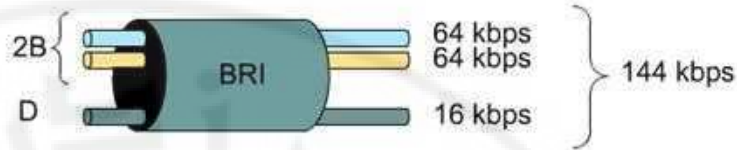
ISDN is a set of standards that defines an end-to-end digital network.

Benefits are:

- Carries many types of network traffic (for example data, voice, video)
- Sets up calls faster than basic telephone service
- Faster data transfer rate than modems

- Unlike plain old telephone system (POTS), **ISDN is digital from end to end**.
- With asynchronous connections (**POTS**) the **local loop is analog and requires PCM (Pulse Code Modulation)** - explained later.
- **Benefits of ISDN include:**
 - **Carries a variety of user traffic signals, including data, voice, and video**
 - **Offers much faster call setup than modem connections**
 - **B channels provide a faster data transfer rate than modems**
 - **B channels are suitable for negotiated Point-to-Point Protocol (PPP) links**

ISDN Advantages



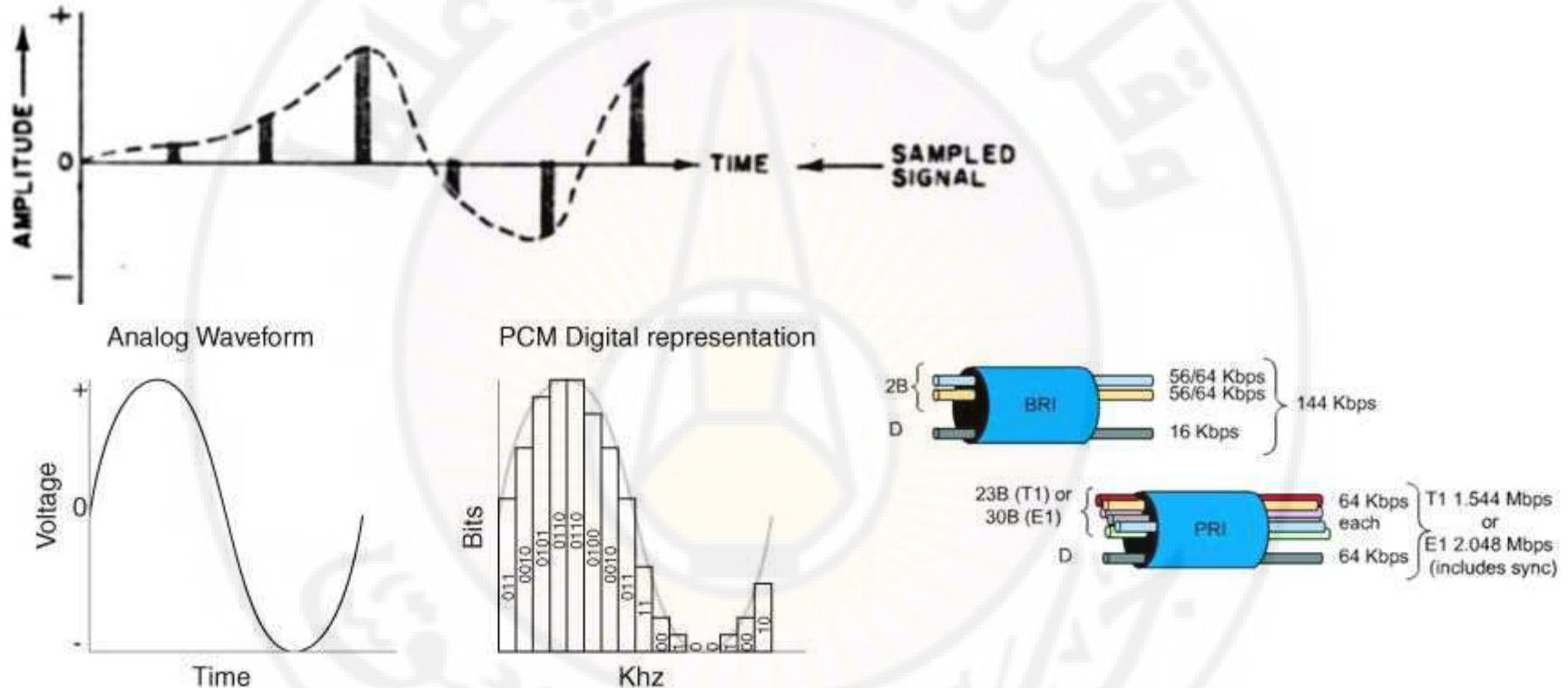
- ISDN also provides more bandwidth than a traditional 56 kbps dialup connection.
- ISDN uses bearer channels, also called B channels, as clear data paths.
- Each B channel provides 64 kbps of bandwidth.
- An ISDN connection with two B channels would provide a total usable bandwidth of 128 kbps.
- Each ISDN B channel can make a separate serial connection to any other site in the ISDN network.
- ISDN lines can be used in conjunction with PPP encapsulation.

ISDN Disadvantages



- BRI is slower than DSL and cable
- More expensive than DSL and cable
- Bottom line: ISDN, in its current form, is no longer a “first-choice” technology.

Why 64Kbps channels and what is PCM?



CCNP:

- This will be explained in a later presentation on T1.
- For now, 64,000 bps is what's required to carry a single phone call over a link (an analog call which has been digitized).
- PCM (Pulse Code Modulation) is how the analog signal is translated to digital and visa versa.

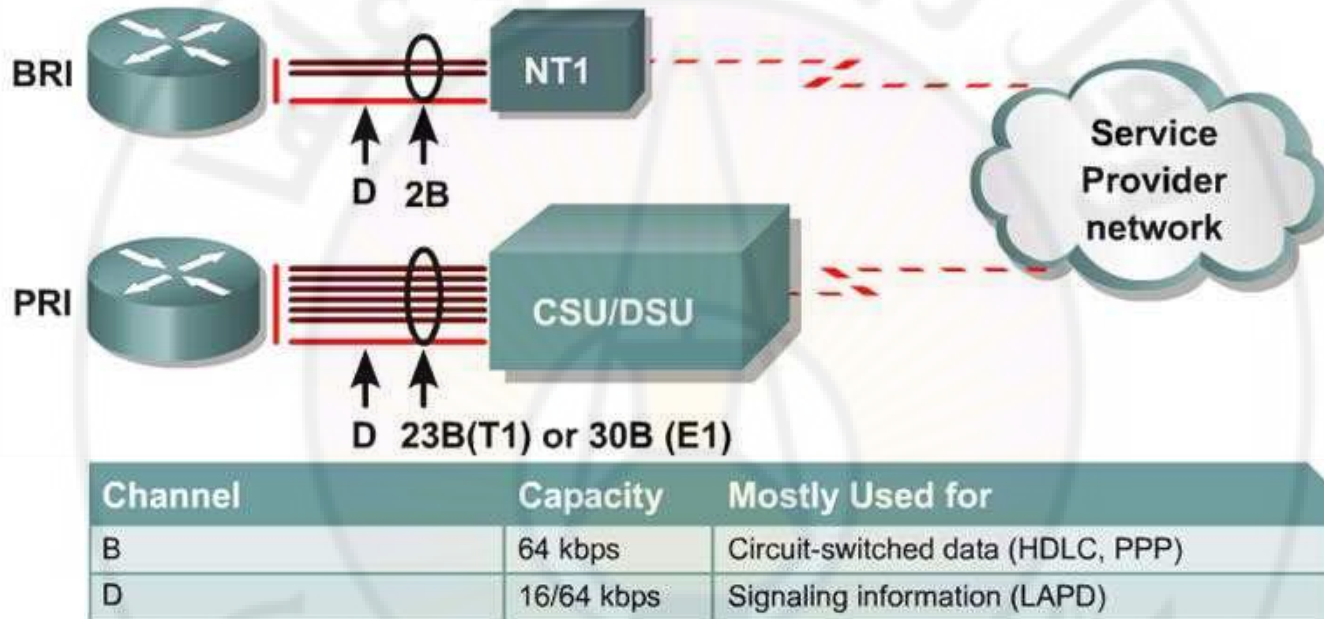
ISDN standards and access methods

Standards from the ITU-T (formerly CCITT)

Issue	Protocol	Key Examples
Telephone Network and ISDN	E-Series	E.164 – International Telephone Numbering Plan
ISDN Concepts, Aspects and Interfaces	I-Series	I.100 Series – Concepts, Structures, Terminology I.400-User-Network Interfaces (UNIs)
Switching and Signaling	Q-Series	Q.921 – LAPD (Link Access Procedure on the D channel) Q.931 – ISDN Network Layer between Terminal and Switch

- ITU-T groups and organizes the **ISDN protocols** according to the following **general topic areas**:
- **E Protocols** – Recommend **telephone network standards for ISDN**. For example, international addressing for ISDN.
- **I Protocols** – Deal with **concepts, terminology, and general methods**.
- **Q Protocols** – Cover how **switching and signaling** should operate. The term signaling in this context means the process of establishing an ISDN call.

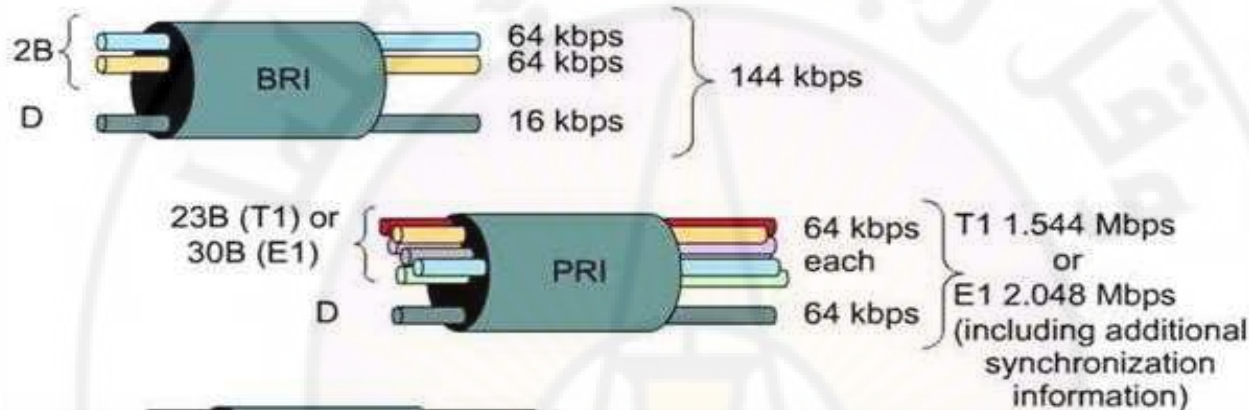
ISDN standards and access methods



ISDN standards define **two main channel types**

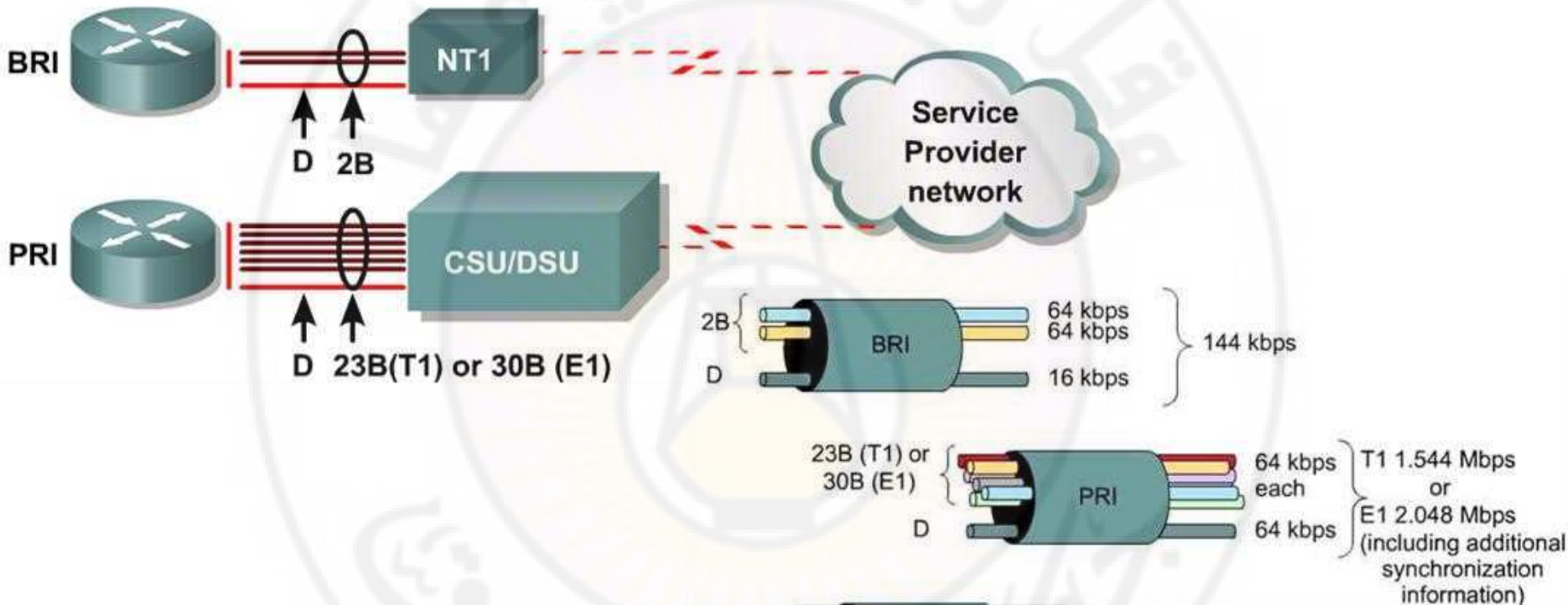
- The **bearer channel, or B channel**, is defined as a clear digital path of **64 kbps**
- The second channel type is called a **delta channel, or D channel**.
 - There can either be **16 kbps for the Basic Rate Interface (BRI) or 64 kbps for the Primary Rate Interface (PRI)**.

ISDN standards and access methods



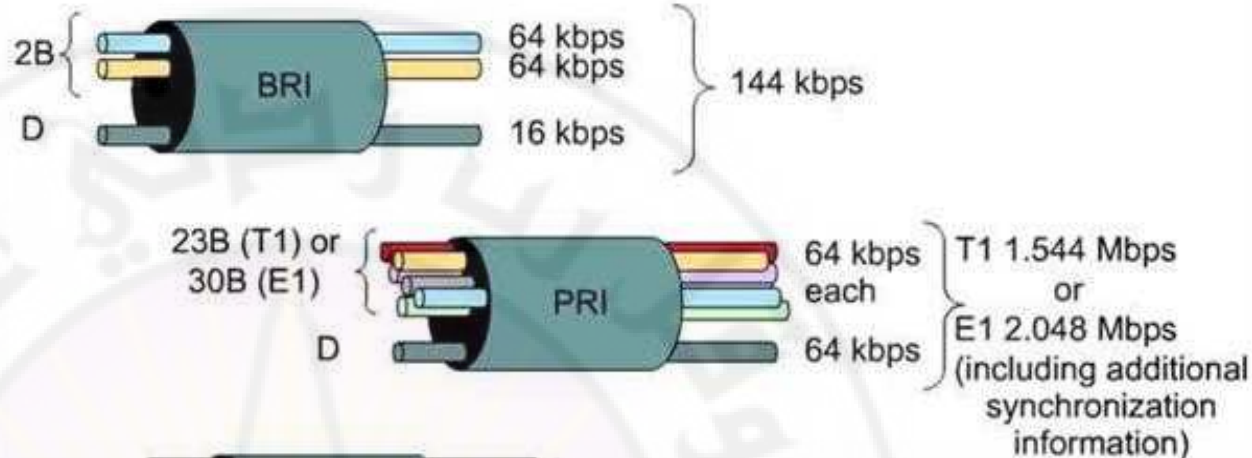
- ISDN is widely available in two flavors:
 - **BRI: Basic Rate Interface**
 - 2 64 Kbps Bearer Channels, 16 Kbps Delta Channel (for control information), 48 Kbps for framing and synchronization
 - 2B + 1D (2B+D)
 - 192 Kbps = 128+16+48
 - **PRI: Primary Rate Interface**
 - 23B + 1D (T1), the D channel is 64-kbps
 - 30B + 1D (E1), European E1
 - 1.544 Mbps (North America) or 2.048 Mbps (E1)

B Channels



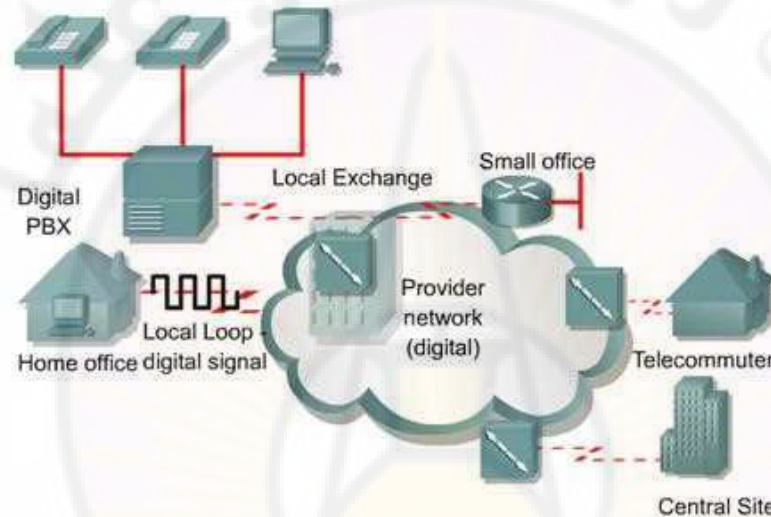
- The B channels can be used for relatively **high-speed data transport**.
- In this mode, the information is carried in **frame format, using either HDLC or PPP as the Layer 2 protocol**.
- **PPP is more robust than HDLC** because it provides a mechanism for **authentication and negotiation** of compatible link and protocol configuration.

D Channel



- When a **TCP connection is established**, there is an exchange of information called the **connection setup**.
 - This information is exchanged over the path on which the data will eventually be transmitted.
 - **Both the control information and the data share the same pathway.**
 - This is called **in-band signaling**.
- **ISDN** however, uses a **separate channel for control information, the D channel**.
 - This is called **out-of-band signaling**.
- The D channel carries signaling messages, such as **call setup and teardown, to control calls on B channels**.
- Traffic over the **D channel employs the Link Access Procedure on the D Channel (LAPD)** protocol.
- **LAPD is a data link layer protocol based on HDLC.**

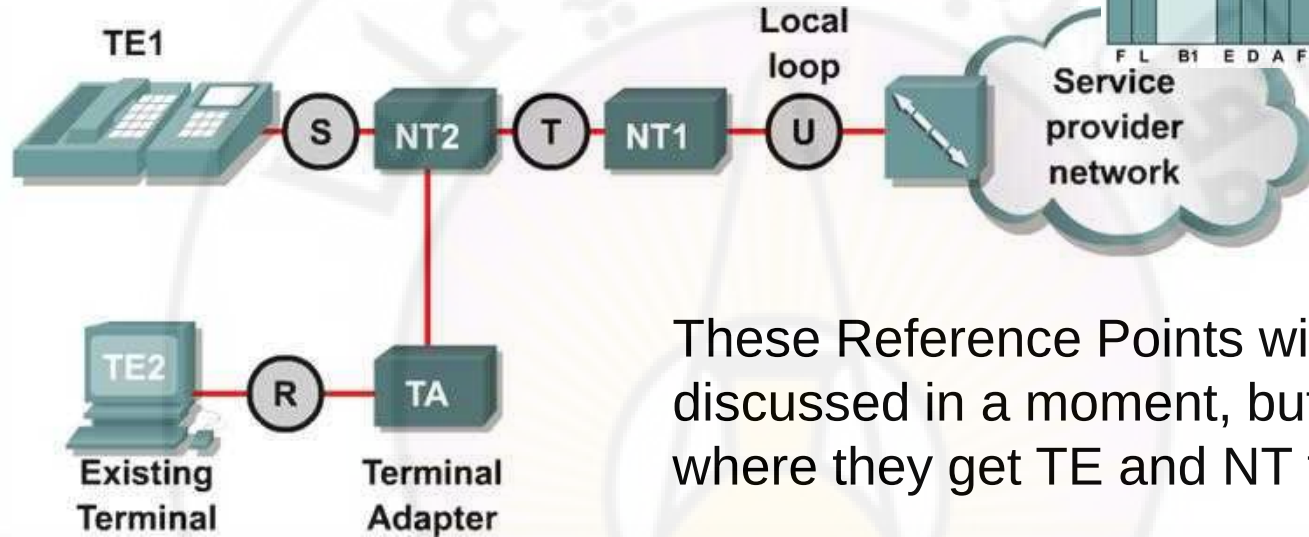
BRI Physical Layer



- **BRI** service is provided over a **local copper loop** that traditionally carries analog phone service.
- While there is only one physical path for a BRI, there are three separate information paths, 2B+D.
- **Information from the three channels is multiplexed into the one physical path.**
- ISDN physical layer, or Layer 1, frame formats differ depending on whether the frame is outbound or inbound.

BRI Physical Layer

Short
Term
Memory

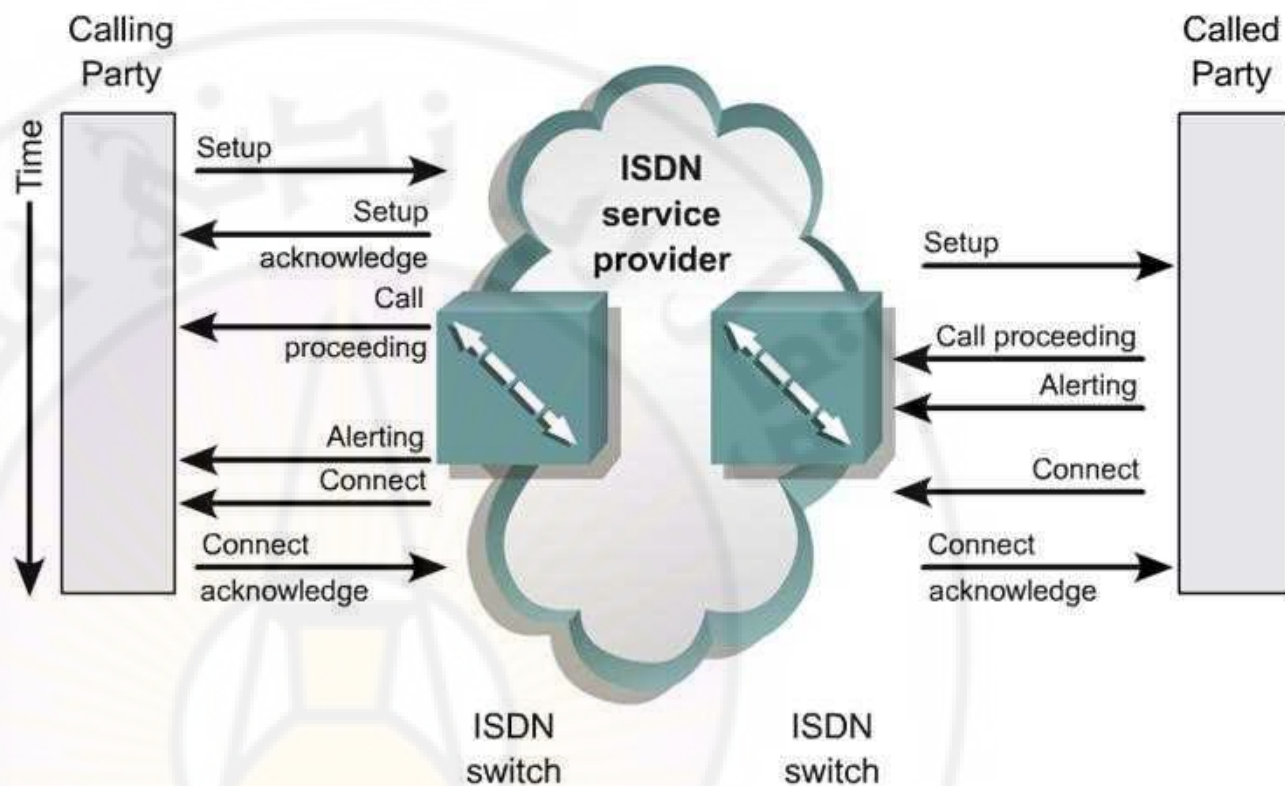


These Reference Points will be discussed in a moment, but this is where they get TE and NT from.

- If the frame is outbound, it is sent from the terminal to the network.
 - Outbound frames use the **TE frame format**.
- If the frame is inbound, it is sent from the network to the terminal.
 - Inbound frames use the **NT frame format**.

Call Setup

- Not an end-to-end function but processed by the switch.
- Depending upon the switch type, you may or may not get all of the steps show above.



Short Term Memory

- To establish an ISDN call, the D channel is used between the router and the ISDN switch to control functions such as call setup, signaling, and termination.
- Signal System 7 (SS7) signaling is used between the switches within the service provider network.
- These functions are implemented in the Q.931 protocol.
- The Q.931 standard recommends a network layer connection between the terminal endpoint and the local ISDN switch, but it does not impose an end-to-end recommendation.

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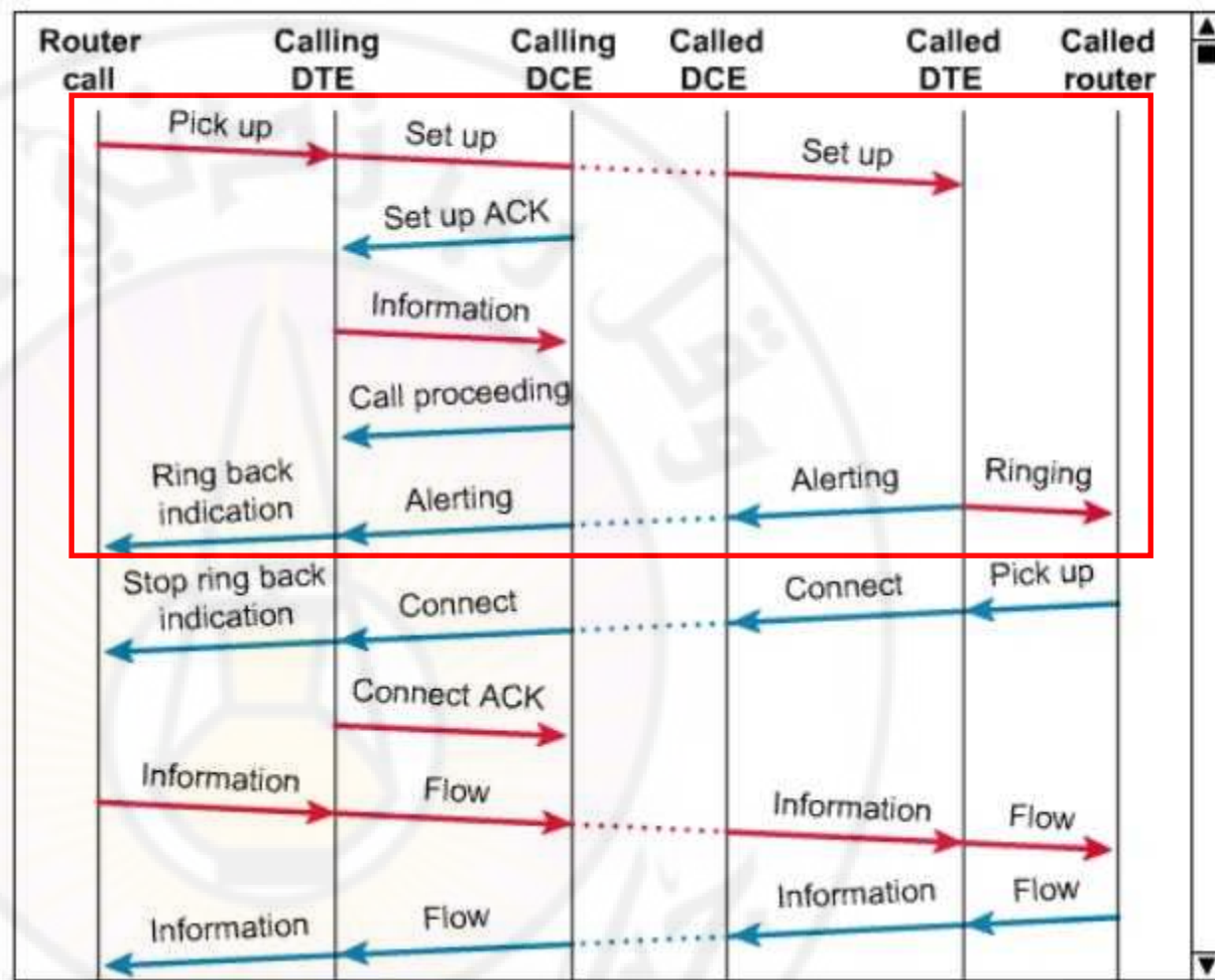
- FYI

Router call	Calling DTE	Calling DCE	Called DCE	Called DTE	Called router
Pick up	Set up		Set up		
	Set up ACK				
	Information				
	Call proceeding				
Ring back indication	Alerting		Alerting	Ringing	
Stop ring back indication	Connect		Connect	Pick up	
	Connect ACK				
Information	Flow		Information	Flow	
Information	Flow		Information	Flow	

D channel is used to **send the called number** to the **local switch**.

Local switch uses the **SS7 signaling protocol** to **set up the call** and **pass the called number** to the **remote ISDN switch**.

Remote ISDN switch **signals the destination** over the **D channel**.



1. The **D channel** is used to **send the called number** to the **local ISDN switch**.
2. The **local switch** uses the **SS7 signaling protocol** to set up a path and **pass the called number** to the **remote ISDN switch**.
3. The **remote ISDN switch** **signals the destination over the D channel**.

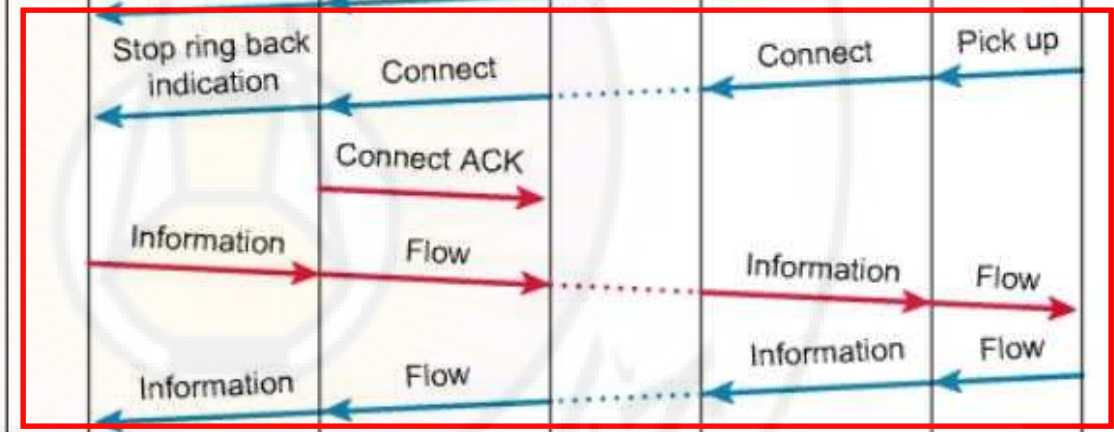
The diagram illustrates the sequence of events in a SIP call setup and information flow between three entities: Caller, Proxy, and Addressee.

- Caller** (Leftmost column)
- Proxy** (Middle column)
- Addressee** (Rightmost column)

The sequence of messages is as follows:

- Caller** sends **Set up** to **Proxy**.
- Proxy** sends **Information** to **Addressee**.
- Addressee** sends **Call proceeding** to **Proxy**.
- Proxy** sends **Alerting** to **Caller**.
- Caller** sends **Ring back indication** to **Proxy**.
- Proxy** sends **Connect** to **Addressee**.
- Addressee** sends **Connect ACK** to **Proxy**.
- Proxy** sends **Information** to **Caller**.
- Caller** sends **Flow** to **Proxy**.
- Proxy** sends **Flow** to **Addressee**.
- Addressee** sends **Information** to **Proxy**.
- Proxy** sends **Information** to **Caller**.

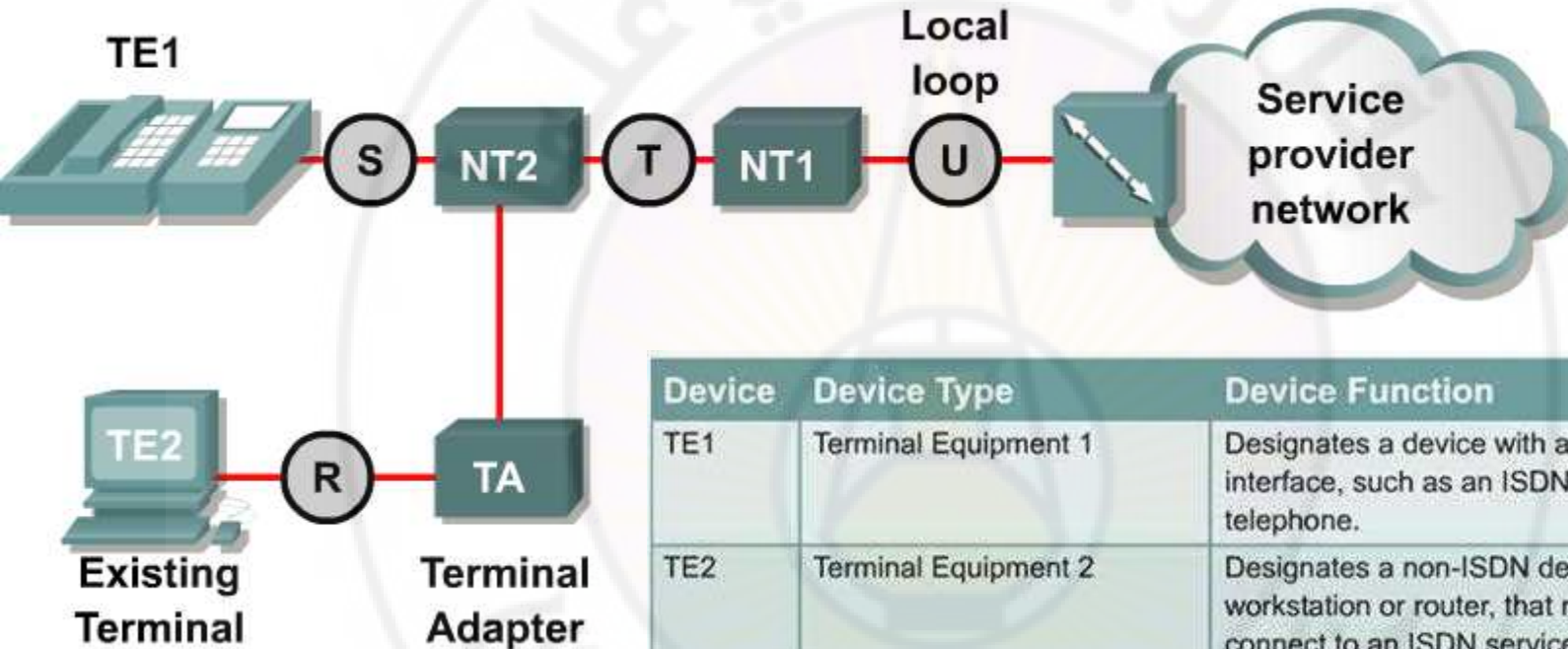
The diagram uses blue arrows for control/acknowledgment messages and red arrows for media/data flow. Dotted lines indicate that the sequence continues beyond the shown messages.



6. The **local ISDN switch connects one B channel end-to-end**, **leaving the other B channel available for a new conversation** or data transfer. **Both B channels can be used simultaneously.**

ISDN reference points

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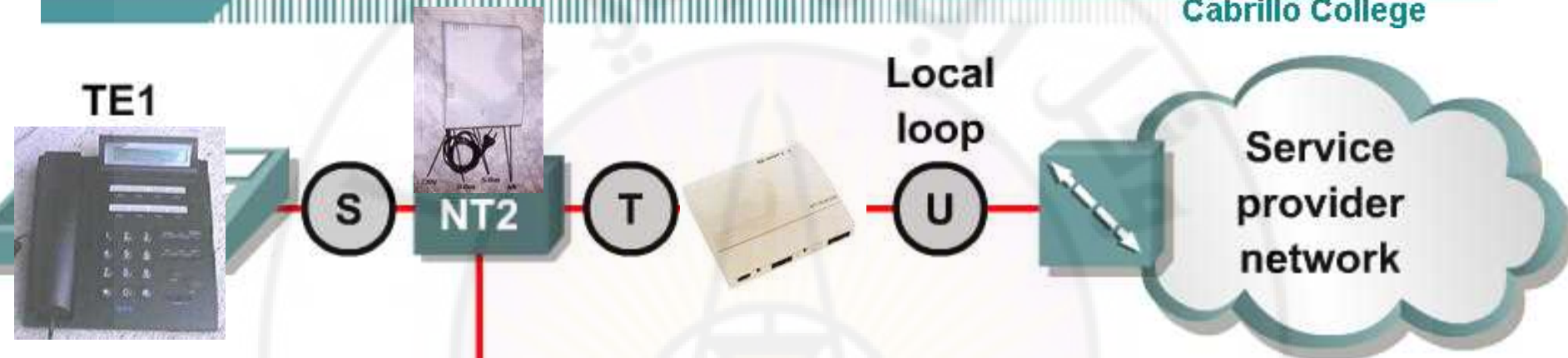


Short
Term
Memory

Device	Device Type	Device Function
TE1	Terminal Equipment 1	Designates a device with a native ISDN interface, such as an ISDN router or ISDN telephone.
TE2	Terminal Equipment 2	Designates a non-ISDN device, such as a workstation or router, that requires a TA to connect to an ISDN service provider.
TA	Terminal Adapter	Converts EIA/TIA-232, V.35, and other signals into BRI signals.
NT2	Network Termination 2	The point at which all ISDN lines at a customer site are aggregated and switched using a customer switching device.
NT1	Network Termination 1	Controls the physical and electrical termination of the ISDN at the customer's premises. Converts the four-wire BRI signals into two-wire signals used by the ISDN digital line.

ISDN reference points

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Existing
Terminal

R

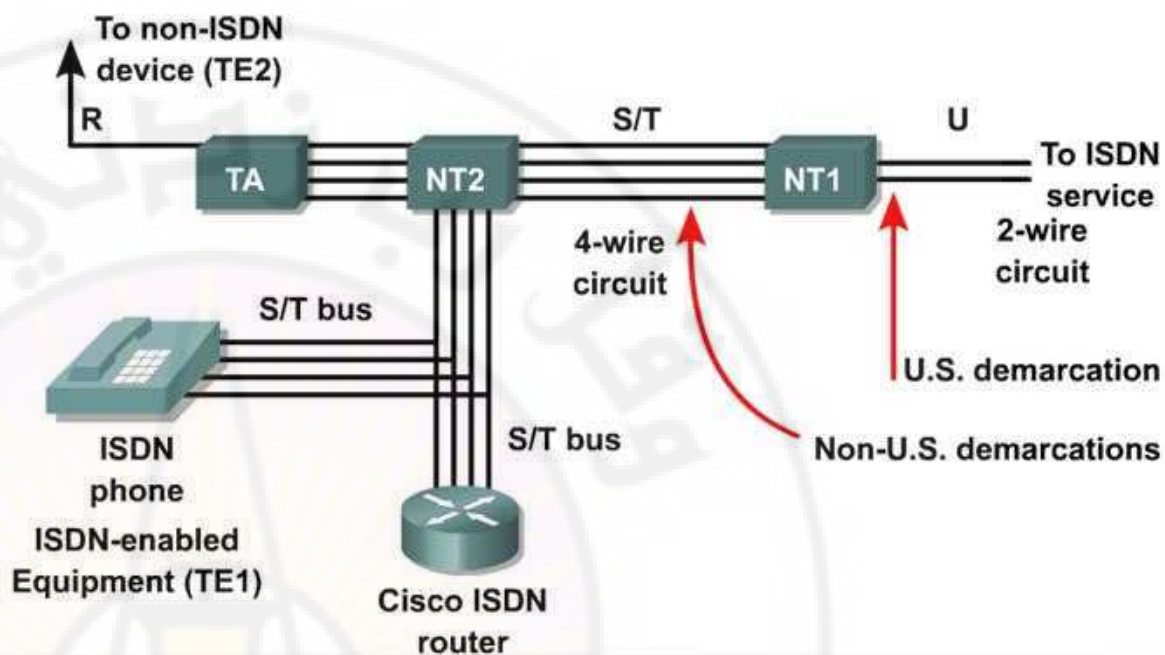


Terminal
Adapter

Short
Term
Memory

Device	Device Type	Device Function
TE1	Terminal Equipment 1	Designates a device with a native ISDN interface, such as an ISDN router or ISDN telephone.
TE2	Terminal Equipment 2	Designates a non-ISDN device, such as a workstation or router, that requires a TA to connect to an ISDN service provider.
TA	Terminal Adapter	Converts EIA/TIA-232, V.35, and other signals into BRI signals.
NT2	Network Termination 2	The point at which all ISDN lines at a customer site are aggregated and switched using a customer switching device.
NT1	Network Termination 1	Controls the physical and electrical termination of the ISDN at the customer's premises. Converts the four-wire BRI signals into two-wire signals used by the ISDN digital line.

ISDN Interfaces

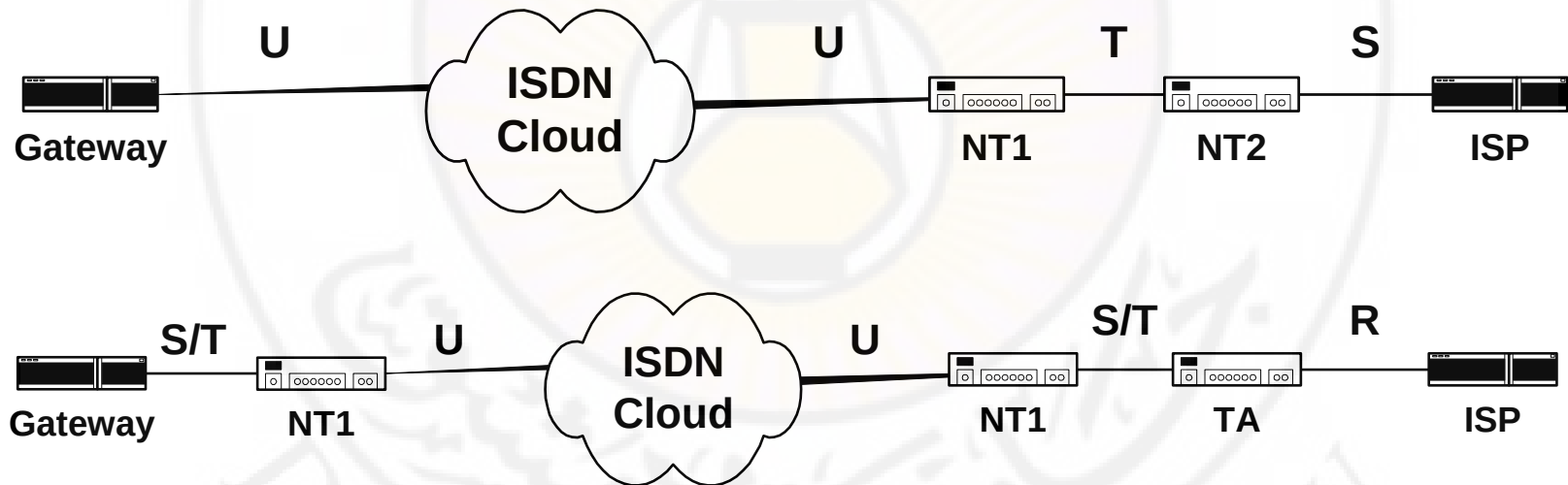


Short
Term
Memory

- To connect devices that perform specific functions, the **interface between the two devices** needs to be well defined.
- R** – References the connection **between a non-ISDN compatible device** Terminal Equipment type 2 (**TE2**) **and a Terminal Adapter (TA)**, for example an RS-232 serial interface.
- S** – References the points that connect into the customer switching device Network Termination type 2 (**NT2**) and enables calls between the various types of customer premises equipment. **TE1**
- T** – **Electrically identical to the S interface**, it references the outbound connection from the **NT2** to the ISDN network or Network Termination type 1 (**NT1**).
- U** – References the connection between the **NT1** and the **ISDN network** owned by the telephone company.

ISDN reference points

CAUTION: **Some routers contain NT1's.** Never connect a router with a U interface into a NT1. It will most likely ruin the interface. Know what type of interface your router has!



- Because the **S and T references are electrically similar**, some interfaces are labeled **S/T interfaces**. Although they perform different functions, the port is electrically the same and can be used for either function.

Cisco Interfaces

S/T interface requires an NT1 connection.



Figure 1-8: ISDN BRI WAN Module

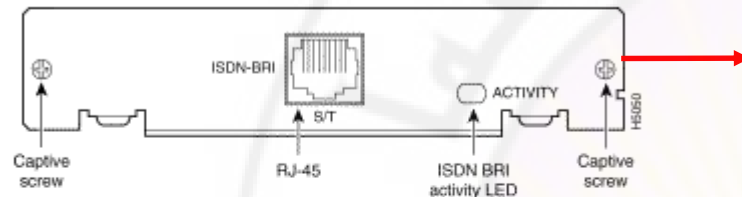
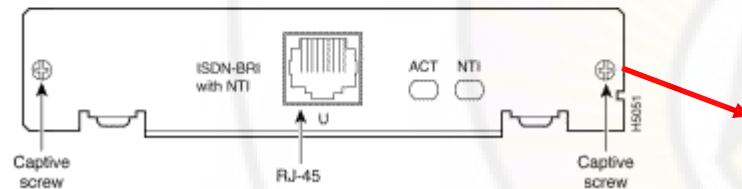
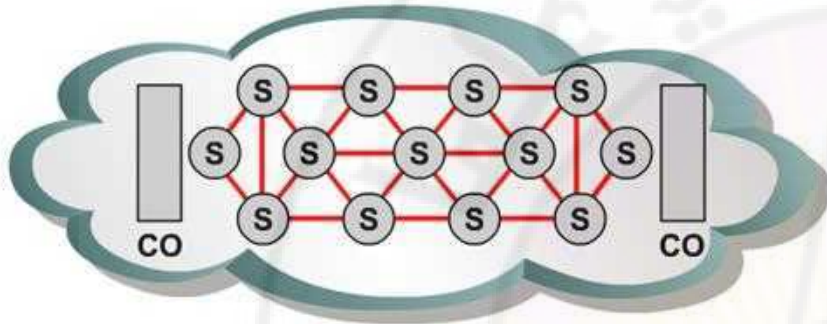


Figure 1-9: ISDN BRI with Integrated NT1 WAN Module



- In the United States, the customer is required to provide the NT1.
- In Europe and various other countries, the telephone company provides the NT1 function and presents an S/T interface to the customer.

ISDN switch types



Many providers and switch types



Services vary by regions and countries

- Routers must be configured to identify the type of switch with which they will communicate.
- Available ISDN switch types vary, depending in part on the country in which the switch is being used.
- As a consequence of various implementations of Q.931, the D channel signaling protocol used on ISDN switches varies from vendor to vendor.
- Before the router can be connected to an ISDN service, it must be configured for the switch type used at the CO.
- This information must be specified during router configuration.

ISDN switch types

Country	Switch Type
United States and Canada	AT&T 5ESS and 4ESS; Northern Telecom DMS-100
France	VN2, VN3
Japan	NTT
United Kingdom	Net3 and Net5
Europe	Net3

Switch types used for router configuration.

Switch Type	Description
basic 5ess	AT&T basic rate switches (United States)
basic-dms100	NT DMS-100 (North America)
basic-ni	National ISDN (North America)
basic-1tr6	German 1TR6 ISDN switches
basic-nwnet3	Norwegian Net3 switches
basic-nznet3	New Zealand Net3 switches
basic-ts013	Australian TS013 and TS014
basic-net3	Switch type for NET3 in United Kingdom and Europe
ntt	NTT ISDN switch (Japan)

SPIDs

Nortel DMS-100 Switch



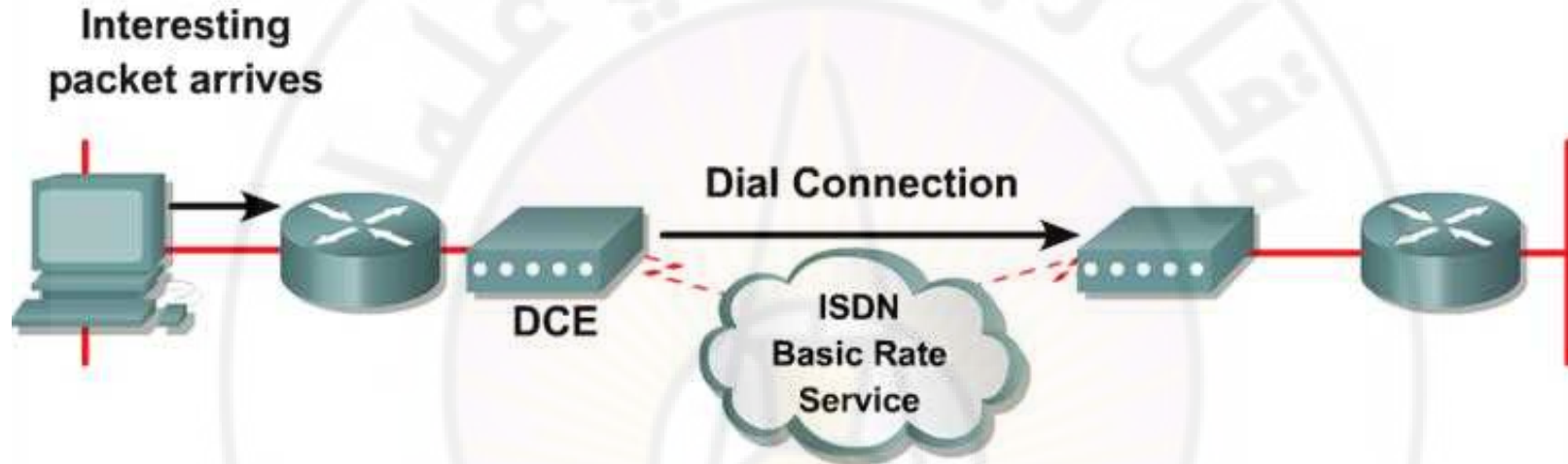
- In addition to knowing the switch type the service provider is using, it may also be necessary to know what service profile identifiers (SPIDs) are assigned by the telco.
- A **SPID** is a number provided by the ISDN carrier to identify the line configuration of the BRI service.
- SPIDs allow multiple ISDN devices, such as voice and data equipment, to share the local loop.
- SPIDs are required by **DMS-100** and **National ISDN-1** switches.
- SPIDs are used only in North America and Japan.
- In many cases when configuring a router, the SPIDs will need to be entered.

DDR – Dial-on-Demand Routing

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Damascus University

DDR operation



- Dial-on-demand routing (DDR) is triggered when traffic that matches a predefined set of criteria is queued to be sent out a DDR-enabled interface.
- The traffic that causes a DDR call to be placed is referred to as interesting traffic.
- Once the router has transmitted the interesting traffic, the call is terminated.

3 Use dialer map to access next hop router

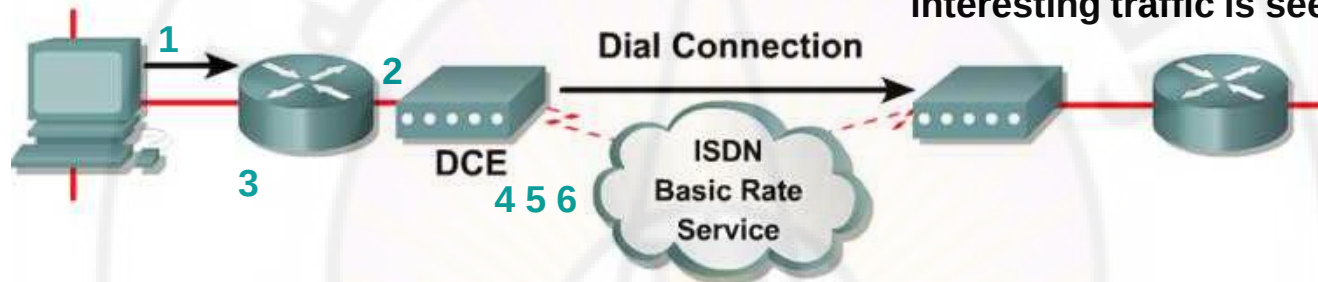
2 Exit inter DDR? If so, traffic interesting?
If not, stop here.

1 Interesting packet arrives → Routing Table → Exit inter

4 Dialer map in use? If so, send traffic. If not call remote router.

5 Transmit both interesting and non-interesting traffic.

6 After a specific amount of time, the idle timer disconnects link when no interesting traffic is seen.



1. The router receives traffic, performs a routing table lookup to determine if there is a route to the destination, and identifies the outbound interface.
2. If the outbound interface is configured for DDR, the router does a lookup to determine if the traffic is interesting.
3. The router identifies the dialing information necessary to make the call using a dialer map to access the next-hop router.
4. The router then checks to see if the dialer map is in use. If the interface is currently connected to the desired remote destination, the traffic is sent. If the interface is not currently connected to the remote destination, the router sends call-setup information through the BRI using the D channel.
5. After the link is enabled, the router transmits both interesting and uninteresting traffic. Uninteresting traffic can include data and routing updates.
6. The idle timer starts and runs as long as no interesting traffic is seen during the idle timeout period and disconnects the call based on the idler timer configuration.

3 Use dialer map to access next hop router

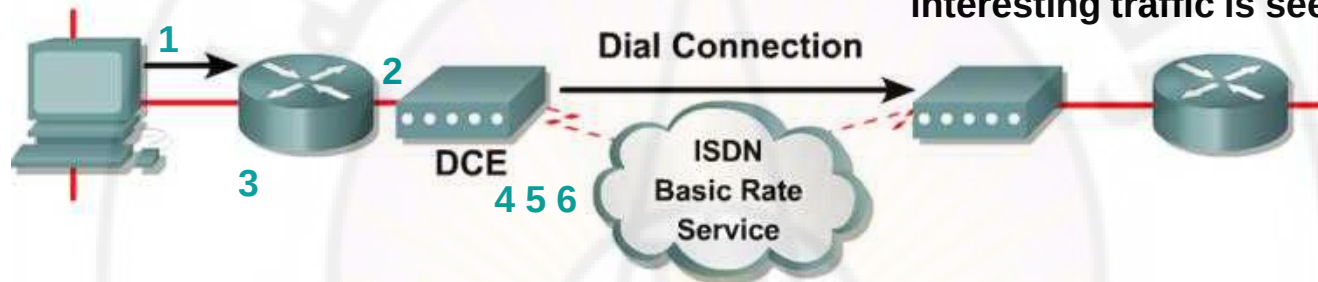
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4 Dialer map in use? If so, send traffic. If not call remote router.

5 Transmit both interesting and non-interesting traffic.

6 After a specific amount of time, the idle timer disconnects link when no interesting traffic is seen.



- The **idle timer** setting specifies the length of time the router should remain connected if no interesting traffic has been sent.
- **Once a DDR connection is established, any traffic to that destination will be permitted.**
- However, **only interesting traffic resets the idle timer.**
- **Note:** You should configure routing protocols as uninteresting in the interesting traffic definition to prevent periodic routing updates and hellos from resetting the idle timeout.



SAPIENZA
UNIVERSITÀ DI ROMA

Network Infrastructures

A.A. 2011-2012
Prof. Francesca Cuomo



XDSL

- DSL (or xDSL), is a family of technologies that provide digital data transmission over the wires of a local telephone network.
- DSL originally stood for digital subscriber loop, although in recent years, many have adopted digital subscriber line as a more marketing-friendly term

2



xDSL Family

- ISDN Digital Subscriber Line (IDSL)
- High Data Rate Digital Subscriber Line (HDSL)
- Symmetric Digital Subscriber Line (SDSL), a standardized version of HDSL
- Asymmetric Digital Subscriber Line (ADSL), a version of DSL with a slower upload speed
- ADSL "lite" (or g.lite)
- Rate-Adaptive Digital Subscriber Line (RADSL)
- Very High Speed Digital Subscriber Line (VDSL)
- Very High Speed Digital Subscriber Line 2 (VDSL2), an improved version of VDSL

3



Reasons for xDSL market

- More than 600 million copper wires worldwide
- Growing requests for data transmissions (mainly access to IP networks)
- Competition
- Deregulation
- Growing needs for POTS in developing countries

4



An example: copper wired access network Telecom Italia

- Number of network terminations: 33.576.600
- Number of Central Offices: 11.000
- Number of Street Cabinets: 150.000
- Amount of cables: above 105.700.000 km–pairs
- Mean distance from a CO and a user: 1,5 Km
(1,2 Km in urban areas)

5



Some history

- In the early 1980s, the idea of a digital subscriber line to provide access to an integrated services digital network (ISDN) was initiated
 - The initial throughput requirement was 160 kbit/s
 - Investigate even higher transmission throughputs approaching T1 speeds
 - The project was named High bit rate DSL (HDSL)
- Lately the interest towards asymmetry arose (for Video on Demand services)
- Joe Lechleider at Bellcore (now Telcordia Technologies) developed ADSL in 1988 by placing wideband digital signals above the existing baseband analog voice signal carried between telephone company central offices and customers on conventional twisted pair cabling

6



Current telco services

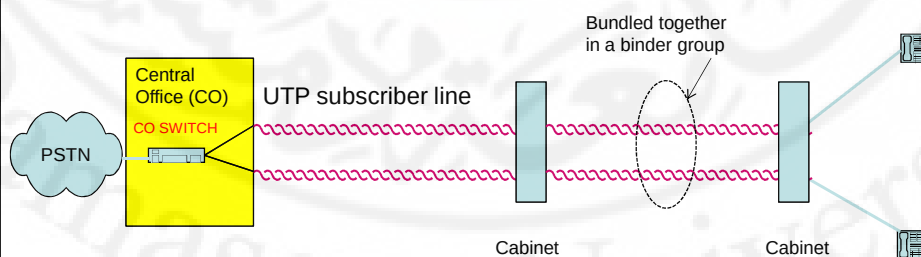
■ Bandwidth comparisons with phone wire

Service	Upper limit bandwidth
Voice service	3400Hz
ISDN(USA)	80kHz
ISDN(Germany)	120kHz
T1 Using 2B1Q	400kHz
ADSL	About 1MHz

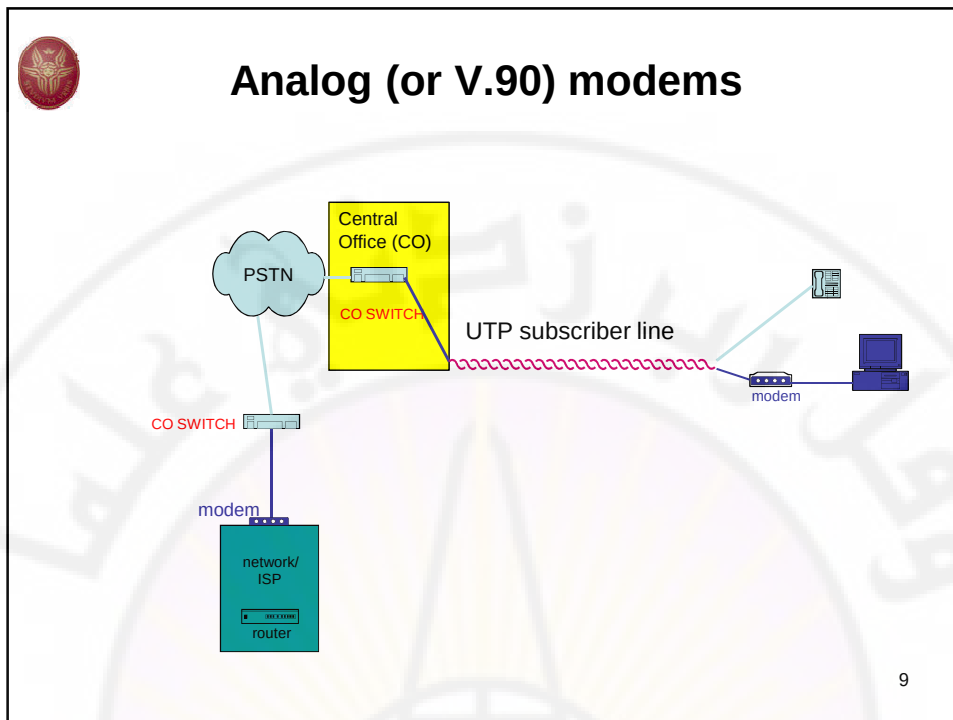
7



Wiring Schematic pre-DSL



8



- 
- ### Current telco services
- Limitations of current telco networks to upgrade service:
 - Space of CO
 - Distance of user from CO
 - Internet problems for POTS and ISDN
 - Both types of data services use existing CO voice switch, not optimized for data
 - Need to put data services to be handled by Data Communication equipment
- 10



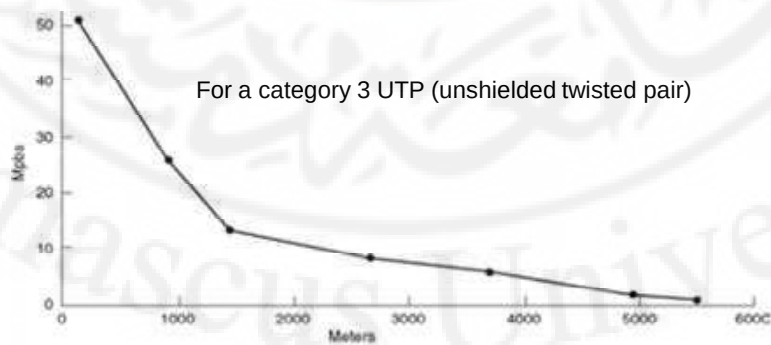
xDSL variations

- X = Variations:
 - Speed and distance
 - Symmetry
 - Support for POTS
 - Location of equipment

11



Bandwidth as a function of meters



12



High Data Rate DSL: HDSL

- Most widely deployed form of DSL
- Created to provide leased-line T1 service
- Adaptive line equalization and 2B1Q (2 binary, 1 quaternary)
- Heavily used in cellular telephone buildouts
- Drawbacks:
 - No provision exists for analog voice
 - HDSL has crosstalks at both ends for symmetric
- HDSL-2 with a single wire pair is a promising alternative to HDSL with 2 or 4 wire pairs

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Asymmetric DSL

- Original market driver: distribution of video on demand (VoD) (failed for this target)
- An ADSL local loop is for the exclusive use of the subscriber, with no contention for bandwidth on that local loop
- ADSL provides for passive transmission of analog voice service
- The distinguishing characteristic of ADSL over other forms of DSL is that the volume of data flow is greater in one direction than the other
- Providers usually market ADSL as a service for consumers to connect to the Internet in a relatively passive mode
 - able to use the higher speed direction for the "download" from the Internet but not needing to run servers that would require high speed in the other direction

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Speed

- Older ADSL standards can deliver 8 Mbit/s to the customer over about 2 km of unshielded twisted pair copper wire
- The latest standard, ADSL2+, can deliver up to 24 Mbit/s, depending on the distance from the central office

15

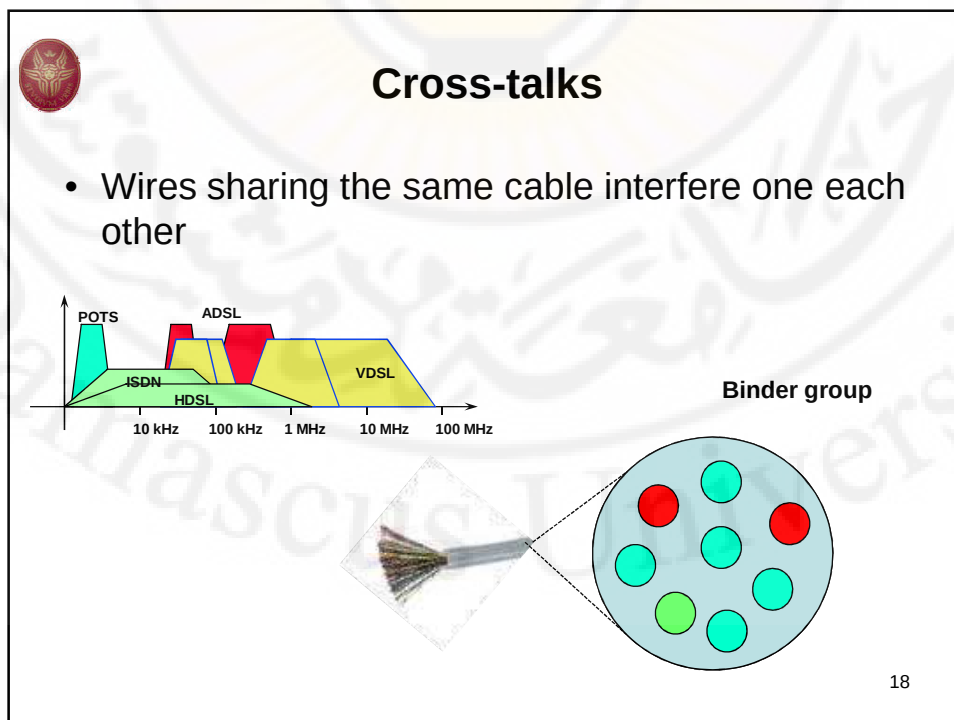
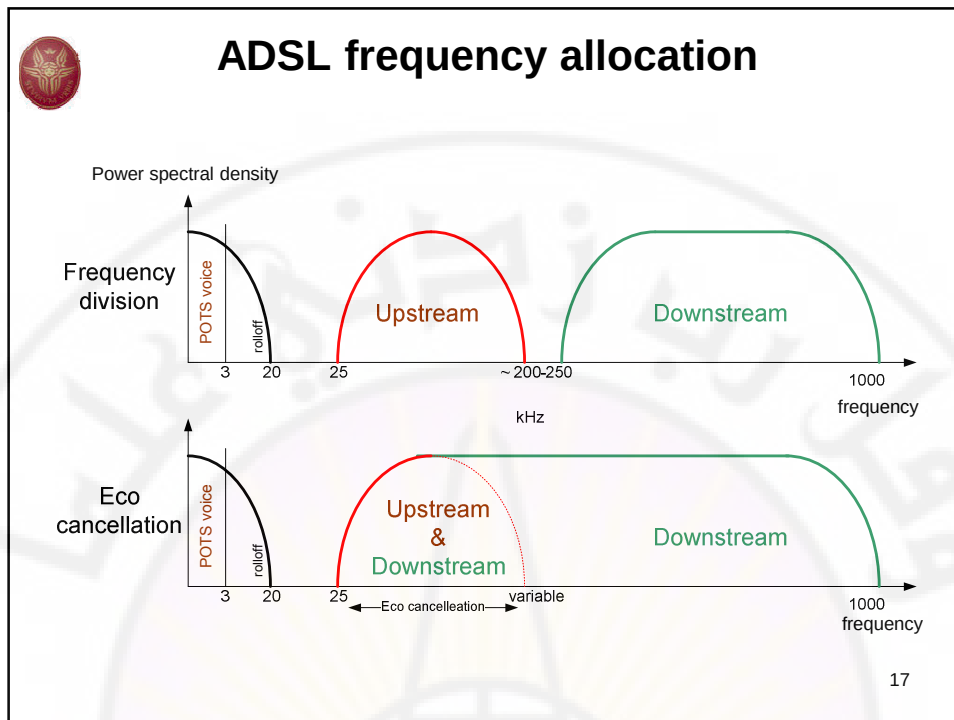


ADSL frequency bands

- ADSL uses two separate frequency bands, referred to as the upstream and downstream bands
- The upstream band is used for communication from the end user to the telephone central office
- The downstream band is used for communicating from the central office to the end user.
- With standard ADSL, the band from 25.875 kHz to 138 kHz is used for upstream communication, while 138 kHz – 1104 kHz is used for downstream communication



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ADSL and cross-talks

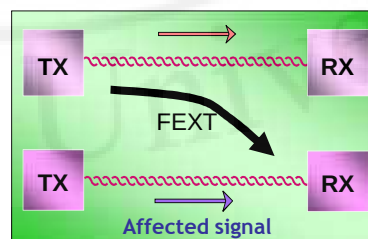
- Two kinds of cross-talk noise exist: far-end cross-talk (FEXT) and near-end cross-talk (NEXT).
- Depend on:
 - The power spectral density of the transmitted signal
 - The number of twisted pairs in the same cable
 - The overlapping of bandwidths of the useful signal and the interfering ones
- Crosstalk typically increases with frequency → significant impairment for high speed DSL

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FEXT

- FEXT is the cross-talk between a transmitter and a receiver placed on opposite sides of the cable
- FEXT signals travel the entire length of the channel
- Since for ADSL “short” cables are used, the signal carried on other pairs, even though coming from far away, are not strongly attenuated and create interferences that affect other pairs.
- To reduce this kind of noise a cable usually doesn't contain more than a dozen twisted pairs.



20

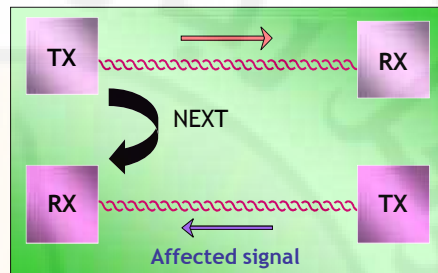


NEXT

- NEXT is the cross-talk between a transmitter and a receiver placed on the same side of the cable;

Receiver's signals are softer than transmitter's one, since come from far away and thus there is a strong interference which reduces quality of useful received data.

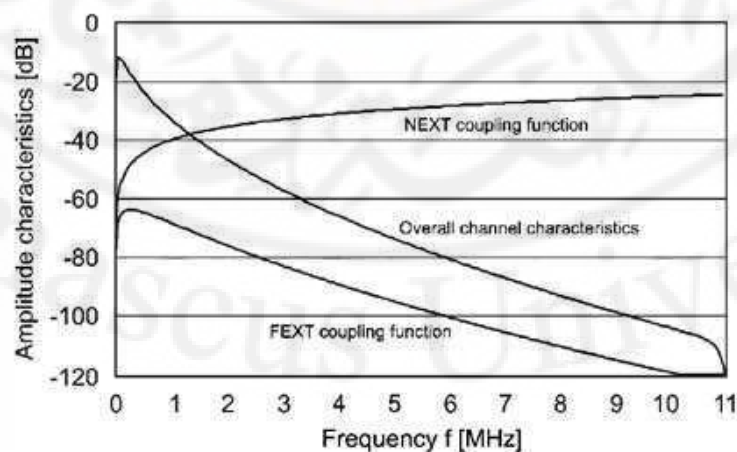
NEXT is one of the reason of the frequency division for upstream and downstream in ADSL.



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Average NEXT and FEXT coupling functions

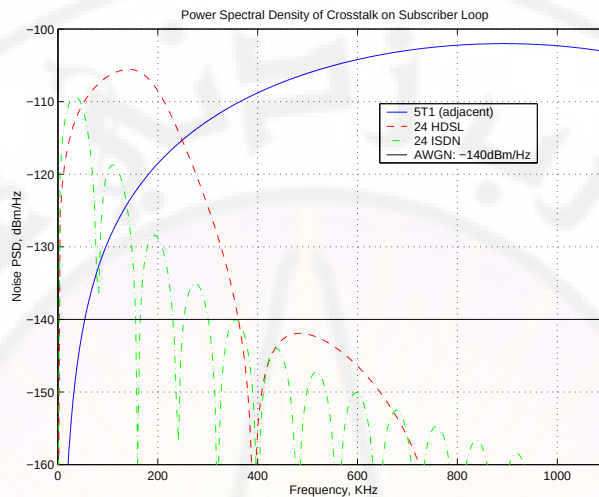


Local loop length= 1 Km

22



Crosstalk on Line



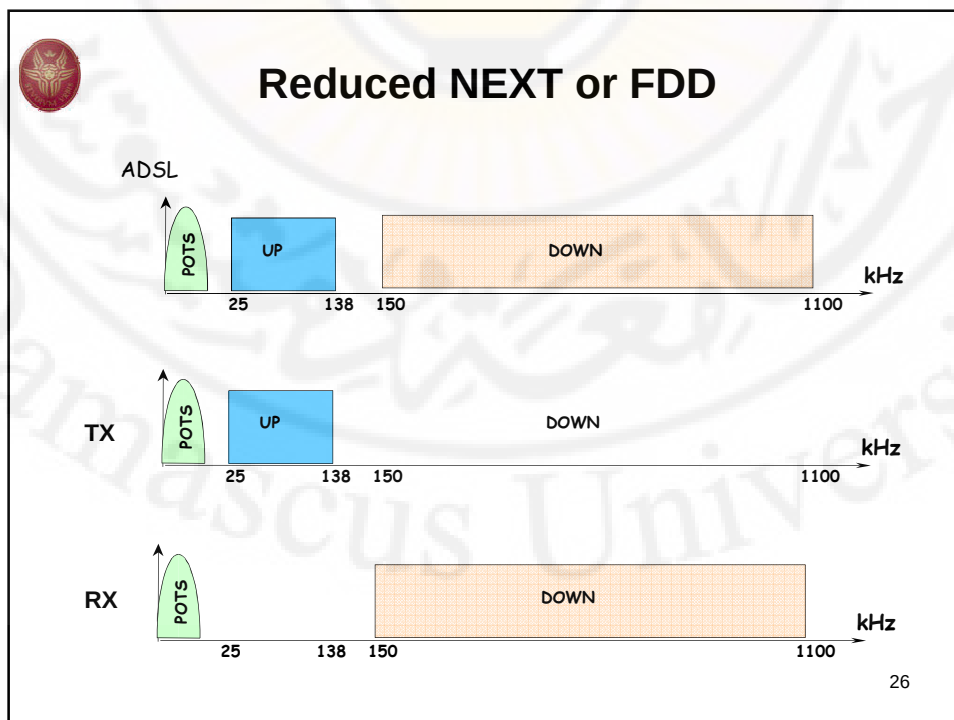
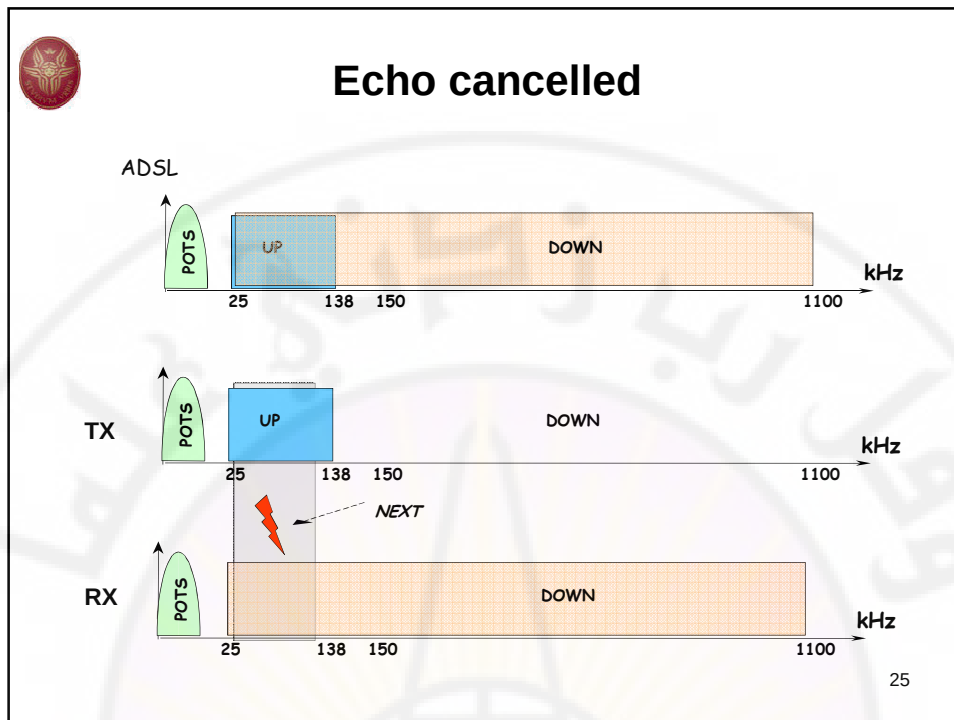
23



Filtering: splitters

- It is necessary to install appropriate frequency filters at the customers premises to avoid interferences with the voice service
 - either a splitter is installed before connecting the line to phone / DSL modem
 - or DSL signal is "filtered off" at each phone by use of a low pass filter, also known as microfilter.

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ADSL: Modulations

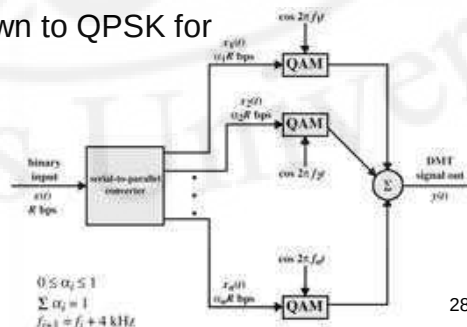
- Modulation: CAP
 - CAP stands for Carrier-less Amplitude/Phase modulation, and describes a version of QAM in which incoming data modulates a single carrier that is then transmitted down a telephone line.
 - The carrier itself is suppressed before transmission (it contains no information, and can be reconstructed at the receiver), hence the word “carrier-less” (single carrier but suppressed)

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ADSL: Modulations

- Modulation: DMT (Discrete Multi-Tone)
(multicarrier)
 - 256 sub-bands of 4,3125 kHz each, so occupying 1.024MHz
 - Each sub-band is QAM64 modulated for clean sub-bands, down to QPSK for noisier lines

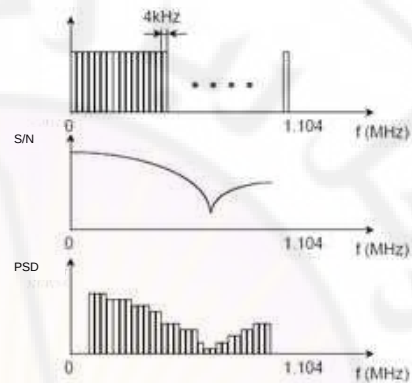


28



Principle of DMT modulation

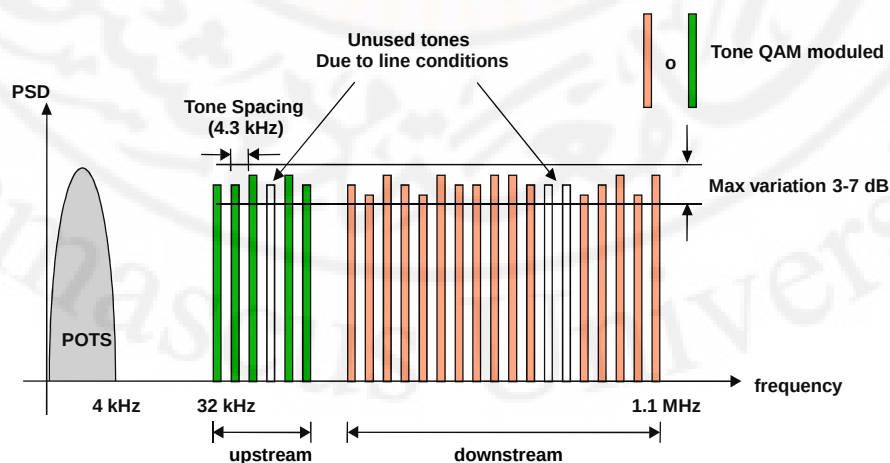
- Divide the operational ADSL bandwidth into very small subchannels
- Discrete carriers (or tones) are used in the center of each data subchannel
- These carriers are used to transmit data independently in each subcarrier by means of a specified QAM modulation.



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DMT modulation



30



DMT modulation

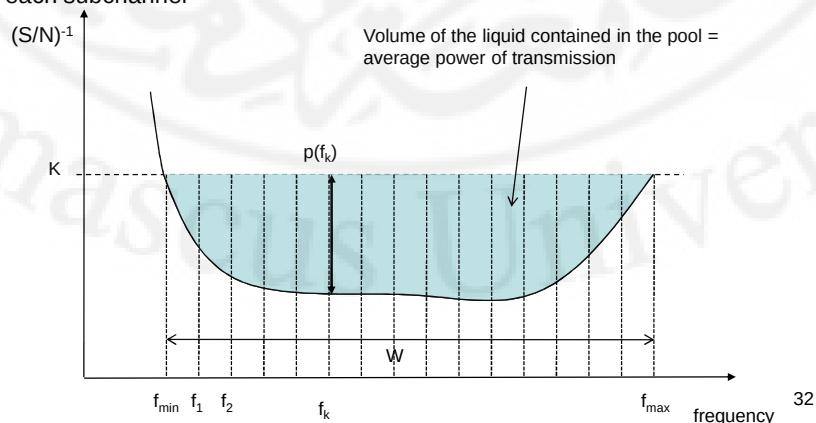
- Independent subchannels can be manipulated individually with consideration of the line conditions
- If a subchannel is experiencing external interference it may not be used in favor of other subchannels
- DTM can dynamically adapt the data rate to the line conditions
- Theoretical maximum upstream bandwidth:
 - 25 channels X 15 bit/s/Hz/channel X 4 KHz= 1.5 Mbit/s
- Theoretical maximum downstream bandwidth:
 - 249 channels X 15 bit/s/Hz/channel X 4 KHz= 14.9 Mbit/s

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Water filling

- The signal power for each subcarrier is determined as the depth of the liquid in a pool
- Knowing the discrete values of $p(f_k)$ for each subcarrier f_k one may deduce the number of bit per symbol to associate to the QAM constellation used in each subchannel



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ADSL: Modulation

- CAP and DMT compared for ADSL (see next Table)
 - Adaptive equalizer is required for CAP since noise characteristics vary significantly across the frequency passband.
 - DMT has the speed advantage over CAP
- DSP advances will enable the technologies to converge in cost and function

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Comparison of CAP and DMT for ADSL

	CAP	DMT
Power consumption	Lower, fewer gates	Higher peak/average, but will likely narrow gap
Forward carriers	1	256
Return carriers	1	32
Increment	320 Kb	32 Kb
Adaptive equalizers	Needed	None
Licensing	Globespan	Many sources
Standardization	In process	ITU and ANSI
Key competitors	Globespan, Paradyne, Westell	Conexant, Cisco, Alcatel, Amati (now Texas Instruments), Westell, Efficient Networks

CAP: Carrierless AM/PM
DMT: Discrete Multi-Tone

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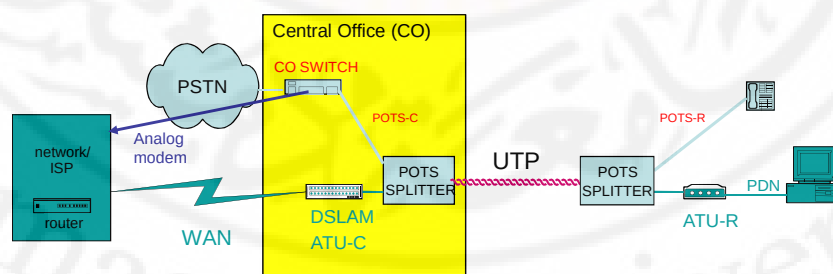
ADSL: Architecture

- CAP and DMP are coming together on further architectural elements of an ADSL system
- ADSL Forum provides much information (www.adsl.com)
- Content providers transmit information to the CO over the A9 interface (not shown) and the A4 interface.
- ATU-C: ADSL Transmission Unit – CO
 - Embedded in a line card in the DSLAM
 - One ATU-C per subscriber

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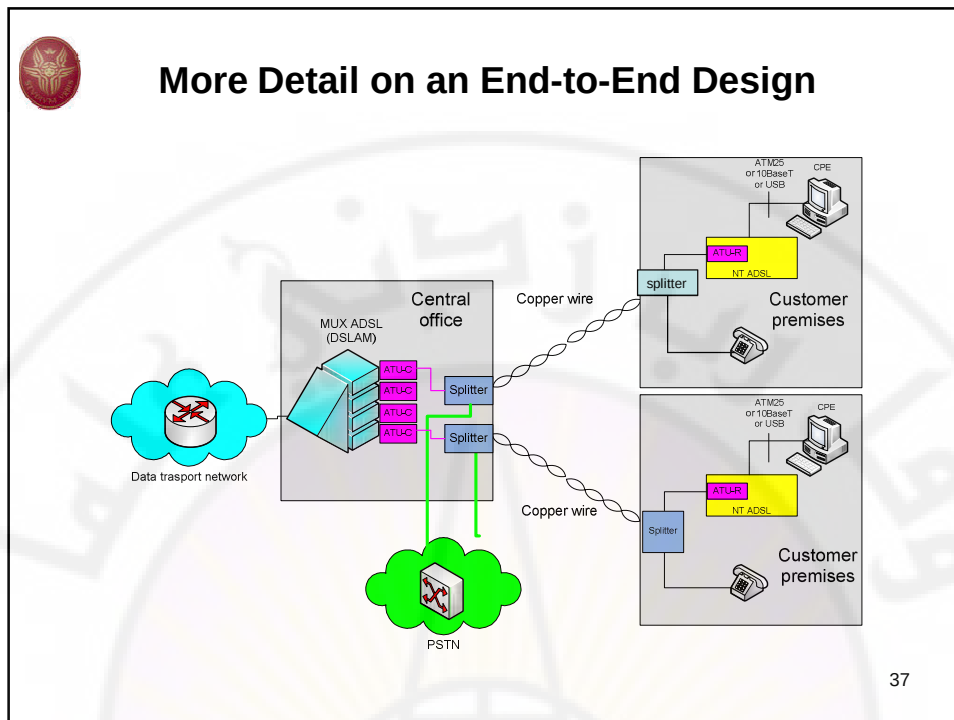


ADSL reference model



POTS Splitter: separates POTS from DSL signals
ATU-R: ADSL Termination Unit – Remote side
ATU-C: ADSL Termination Unit Central office side
DSLAM: DSL Access Multiplexer

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ADSL: Principles of Operation

- Two services
 - Transparent access to legacy voice service
 - High-speed digital service
- Voice service
 - POTS splitters used in home shunt the frequencies below 3400Hz to POTS wiring
 - Frequencies above the voice band are for high-speed data service to get to the ATU-R

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ADSL: Architecture

- ATU-R: ADSL Transmission Unit – Remote
 - Supports a multidrop or shared-home topology
- ATU-C: ADSL Transmission Unit – Central
 - ATU-C and ATU-R engage in physical-layer negotiations between the home and the CO and they can be considered modems
 - Keep management statistics, such as SNR at the physical layer; packet counts at the network layer, receive software updates; and be remotely manageable by the carrier
- POTS splitter (PS)
 - A low-pass/high-pass filter

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ADSL: Architecture

- ATU-C and ATU-R operations
 - Concerned with physical layer
 - Frequency allocation:
 - » Bandwidth on the phone wire is divided into three parts:
 - Legacy analog POTS service: below 3400Hz
 - Upstream digital service: 25-200kHz
 - Downstream digital service: 25/250-1000kHz (Echo cancellation/FDM: frequency division multiplexing)
 - Echo cancellation
 - » Both sides talk at the same time
 - » More bandwidth efficiently than FDM
 - » More complex and expensive
 - Rate adaption

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CPE interfaces

- 10baseT
 - 10Mbit/s on a 100m twisted pair
 - widely available on PCs
- ATM25
 - 25Mbit/s on a 100m twisted pair
 - Point-to-point
 - Not very common
 - More expensive
- USB
 - 12Mbit/s till 30m
 - widely available on new generation PCs
- Wi-Fi

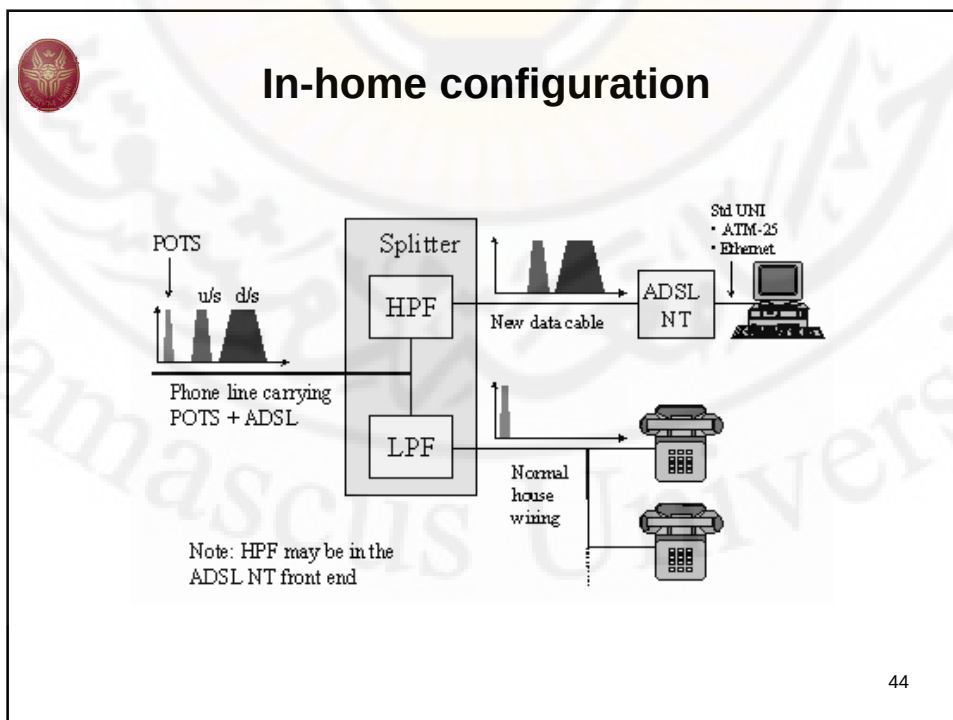
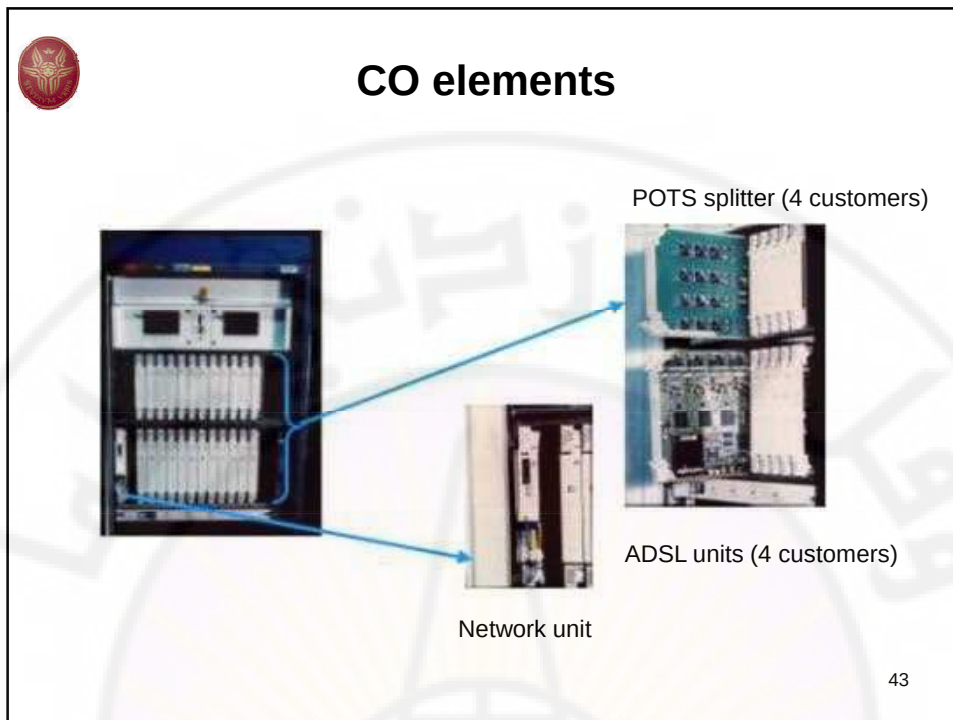
41



ADSL: Architecture

- DSL Access Multiplexer (DSLAM)
 - Primary functions:
 - » House a set of ATU-C interfaces
 - » Multiplex traffic
 - » Demultiplex traffic
 - » Negotiate line speed
 - » Serve as a central management platform
 - Locations:
 - » CO, adjacent site to CO, remote terminal, customer premises
 - Current DSLAMs may include up to a few hundreds

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Splitters

Splitter separates POTS from DSL signals

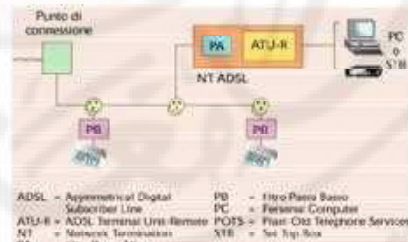
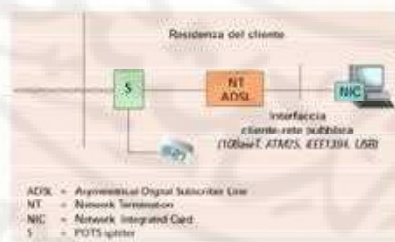
- Must guarantee lifeline POTS services
- Hence usually passive filter
- Must block impulse noise (e.g. ring) from phone into DSL
- It is not a simple cascade of a lowpass [0, 25 KHz] filter with a passband [25 KHz, 1,104 kHz] filter but a multiband (or hybrid) filter

45

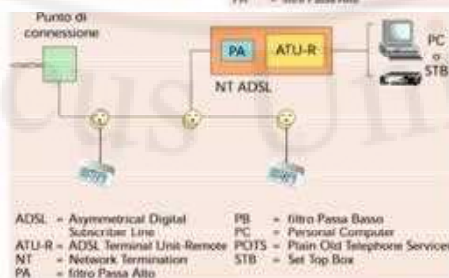


Splitter

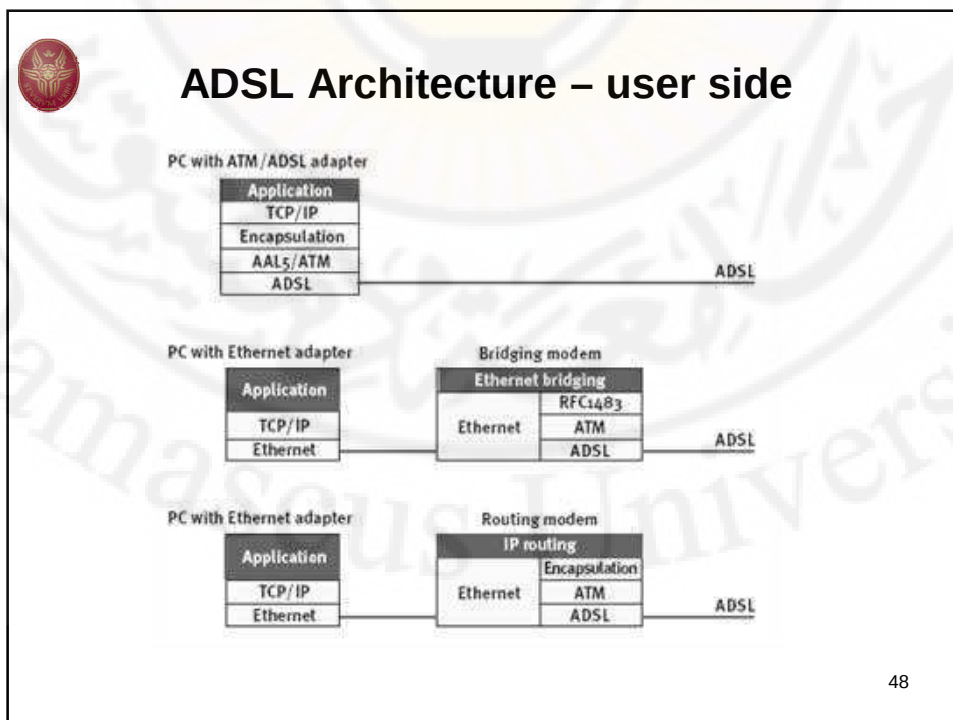
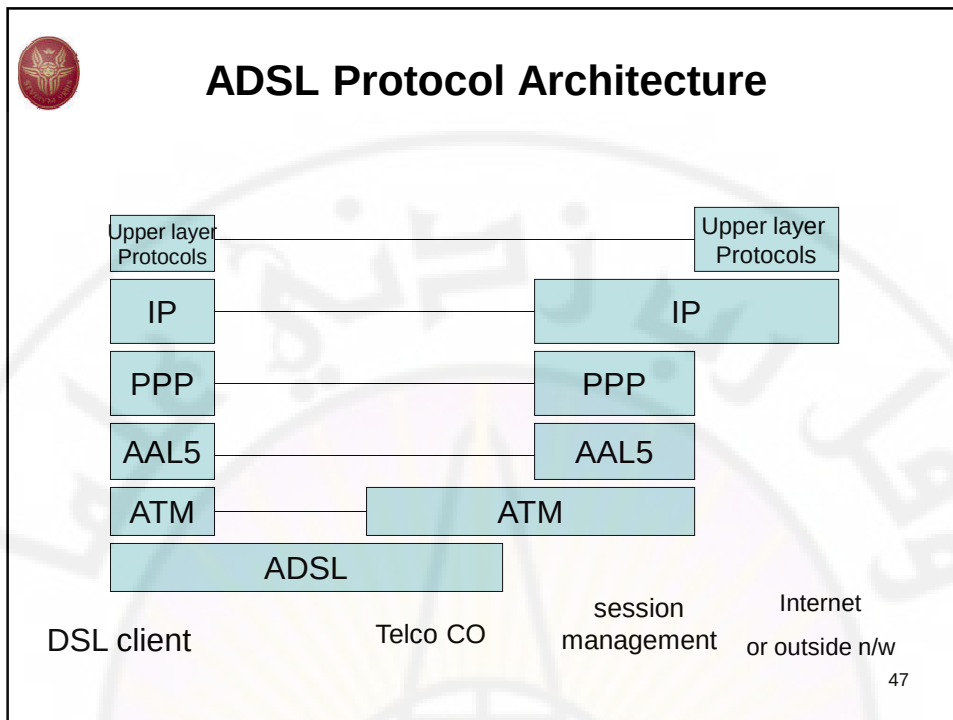
- Splittered
- Distributed splitters



- Splitterless (g.lite)

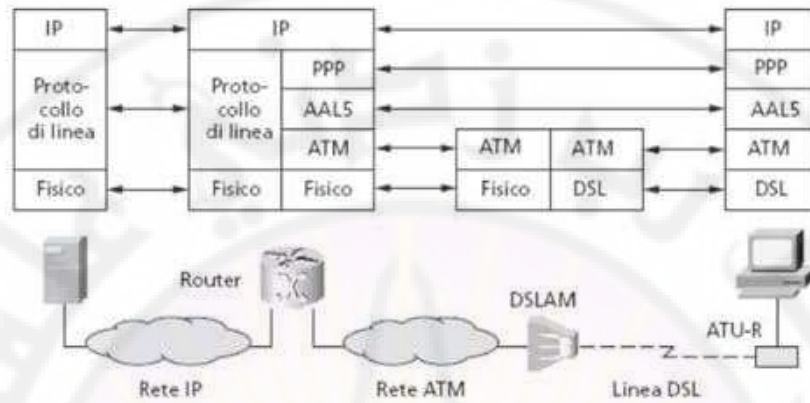


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ADSL Architecture – network side

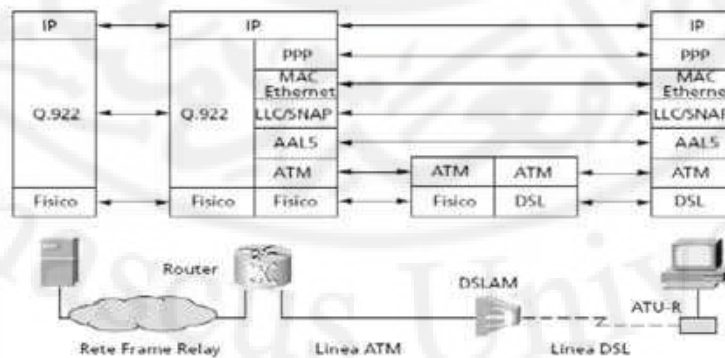


(da A. Pattavina, Reti di Telecomunicazione, 2° ed.)

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ADSL Architecture – network side



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ADSL: Principles of Operation

- Bit rate negotiation
 - Between ATU-R and ATU-C
 - Four start-up rate options, multiple of 32kbps
 - The entire process is about to take 12~20s (retaining period)
- Autoconfiguration
 - Configuring IP addresses & software filters to ATU-R

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ADSL: Principles of Operation

- Benefits and challenges of rate adaption
 - Increases bit rate for customers with good phone wire
 - Covers greater distances for service providers
- Challenges:
 - Technical:
 - » What metrics, algorithms and measurements?
 - » Agreement on different ATU-Rs and ATU-Cs
 - » How to synchronize information?
- Marketing:
 - How to set pricing and bandwidth guarantees?

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Very high data rate DSL

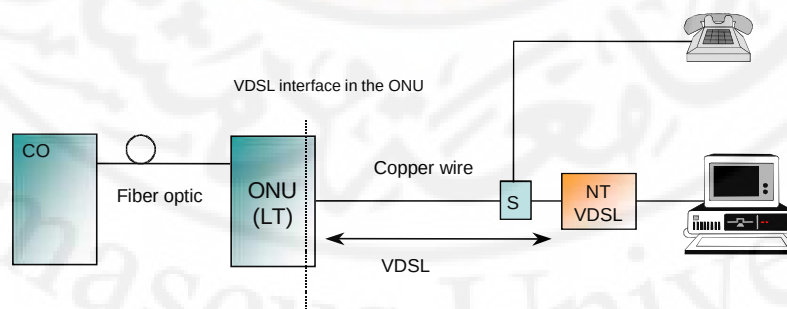
- VDSL pushes to the limit what can be transmitted over 24-gauge copper pairs.
- Service options:

– Upstream	Downstream	Distance
– 12.96 Mbps	12.96 Mbps	1000 m
– 2 Mbps	25.92 Mbps	1000 m
– 25.84 Mbps	25.92 Mbps	300 m
– 2 Mbps	51.84 Mbps/STS-1	300 m
- Key to fastest bit rate possible is to have the shortest possible length of copper wire

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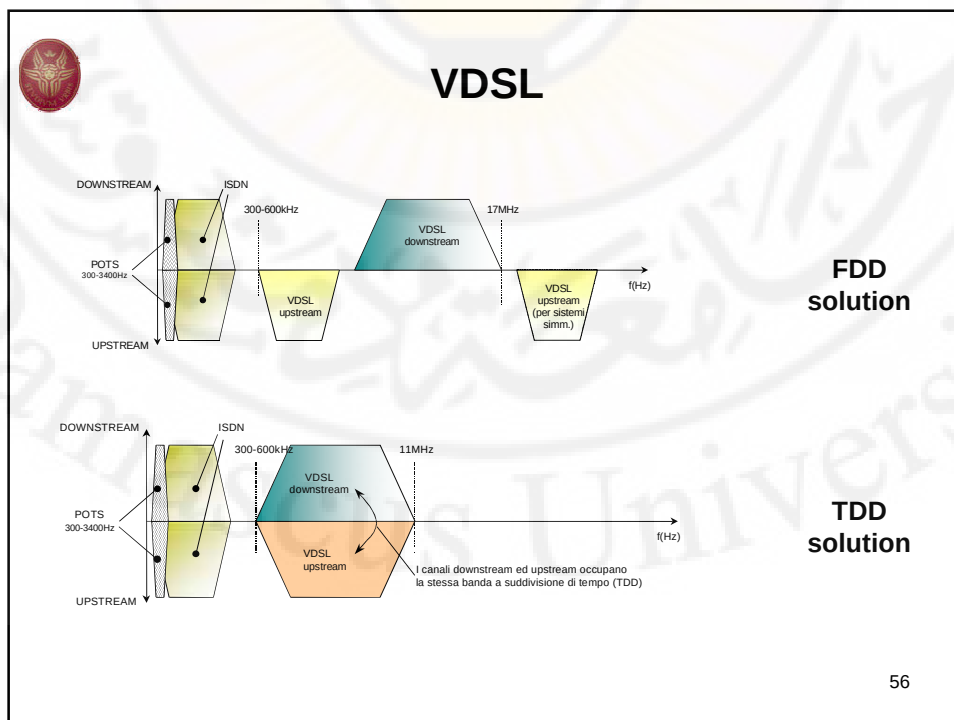
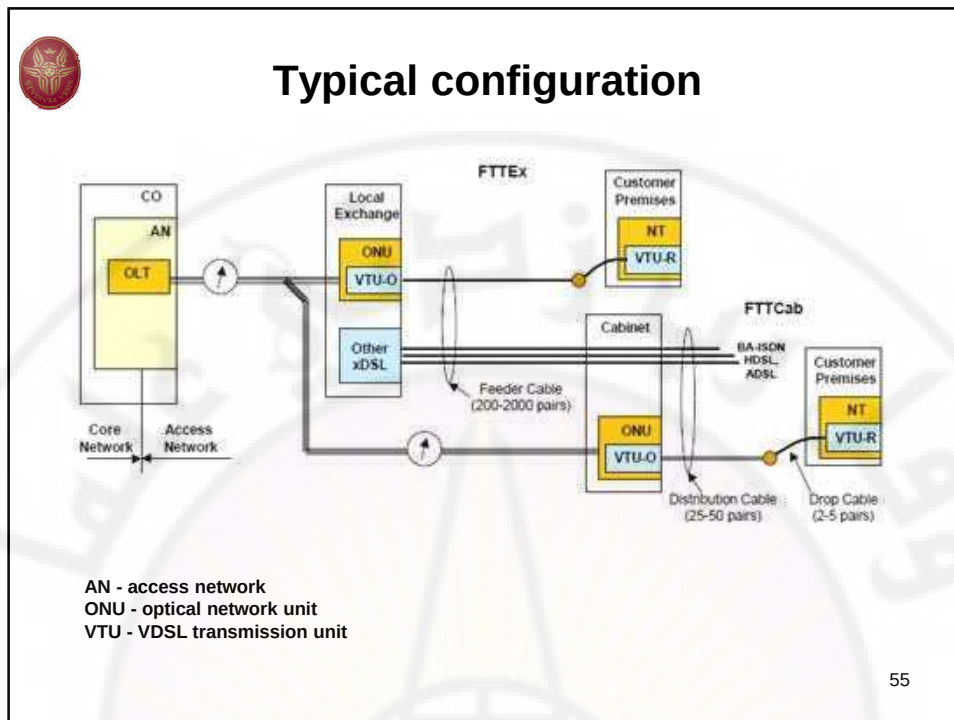


VDSL Architecture



ONU: Optical Network Unit
S: POTS splitter
NT VDSL: Network termination VDSL

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Comparison between ADSL and VDSL

	Full-Rate ADSL	VDSL
POTS/ISDN, therefore requiring splitters	Yes	Yes, VDSL subscriber unit will be powered from the home, but will revert to network powering in the event of a power outage.
Modulation technique	DMT, using 256 bands with 4 kHz spacing	DMT, CAP, or QAM DMT modulation would use 256 bands with 40 kHz spacing, or 2048 bands with 4 kHz spacing
Dual latency	Yes	Yes
Spectrum Allocation	Up to 1 MHz	Up to 30 MHz
Downstream bit rate	Various up to 8 Mbps	Various up to 51.84 Mbps
Upstream bit rate	Various up to T1	2 to 3 Mbps
Standardization	ANSI T1.E1 ADSL Forum ITU G.992.1	ANSI T1.E1 ADSL Forum ITU SG 15, G.vdsl, G.993
Distance to ONU	Up to 5000 meters	300 to 1000 meters

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DSL comparison

	Modulation Scheme	Downstream Bit Rate	Upstream Bit Rate	POTS Support	Comments
ISDN	2B1Q	64 Kbps, 128 Kbps	64 Kbps, 128 Kbps	No	ANSI T1.601 Uses 4B3Q coding in some European countries
IDSL	2B1Q	128 Kbps	128 Kbps	No	Uses ISDN TA
HDSL	2B1Q	Up to 2 Mbps	Up to 2 Mbps	No	Uses four wires; current T1 service
HDSL-2	PAM-16	2 Mbps	2 Mbps	No	Uses two wires; not rate-adaptable
SDSL (RTSD)	2B1Q	2 Mbps	2 Mbps	Yes	Uses two wires; rate adaptable
G.Lite	DMT	2 Mbps	512 Kbps	Yes	ITU G.992.2
ADSL	CAP	1.5 Mbps to 6 Mbps	64 Kbps to 800 Kbps	Yes	Mainly Paradyne
ADSL	DMT	1.5 Mbps to 7 Mbps	64 Kbps to 800 Kbps	Yes	ANSI T1.413
Multiple Virtual Line (MVL)	CAP	768 Kbps	768 Kbps	Yes	Paradyne
One Megabit Modem	QAM	1 Mbps	320 Kbps	Yes	Proprietary to Northern Telecom; resides in Nortel loop carrier system
VDSL	QAM/CAP DMT	12.96 Mbps to 51.84 Mbps	1.5 Mbps to 3 Mbps	Yes	Range of 300 meters for top speeds; ANSI T1.E1.4, ETSI and ITU Study Group 15

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XDSL family

Family	Racc. ITU	Name	Data	Maximum capacity (Mbit/s)
ADSL	G.992.1	G.dmt	1999	7 down 0.8 up
ADSL2	G.992.3	G.dmt.bis	2002	8 down 1 up
ADSL2+	G.992.5	ADSL2plus	2003	24 down 1 up
ADSL-RE	G.992.3	Reach Extended	2003	8 down 1 up
SHDSL	G.991.2	G.SHDSL	2003	5,6 up/down
VDSL	G.993.1	Very-High-data-rate DSL	2004	55 down 15 up
VDSL2-LR	G.993.2	Very-High-data-rate DSL2 Long Reach	2005	55 down 30 up
VDSL2-SR	G.993.2	Very-High-data-rate DSL2 Short Reach	2005	100 up/down

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Challenges to xDSL

- Technical:
 - Loop qualification
 - Crosstalk: shared media creates a loss of QoS
 - Bridged taps: a legacy of phone wiring installation practices of Y form, which can be a significant impairment for DSL services for the echo
 - Powering remote terminals
 - Spectral masking
 - Impulse noise
 - ATU-R maintenance

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Challenges to xDSL

- Industry:
 - Regulatory issues
 - Broadcast video
 - Home networking
- Successive factors:
 - How many systems will be updated to DSL for POTS services?
 - How many loops qualify?
 -

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Some References

- http://www.cisco.com/univercd/cc/td/doc/cisintwk/ito_doc/adsl.htm
- <http://www.adsl.com>
- Book: [Balaji Kumar](#), [Padmanand Warriar](#) "XDSL Architecture", Publisher: **McGraw-Hill** Companies (October 25, 1999)
- Book: Maurice Gagnaire "Broadband Local Loops for High-Speed Internet Access" (Artech House Telecommunications Library) (2003)

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Appendix: Point to Point Protocol: summary

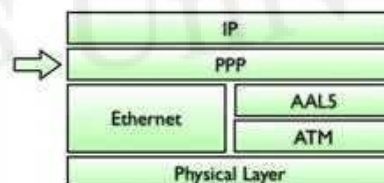
- PPP -designed for simple links to transport packets between two peers
- PPP encapsulation provides for multiplexing of different network-layer protocols simultaneously over the same link
- PPP provides a Link Control Protocol (LCP) which negotiates the establishment and termination of a PPP link.
- LCP also negotiates the options for encapsulation format, authentication and link quality monitoring

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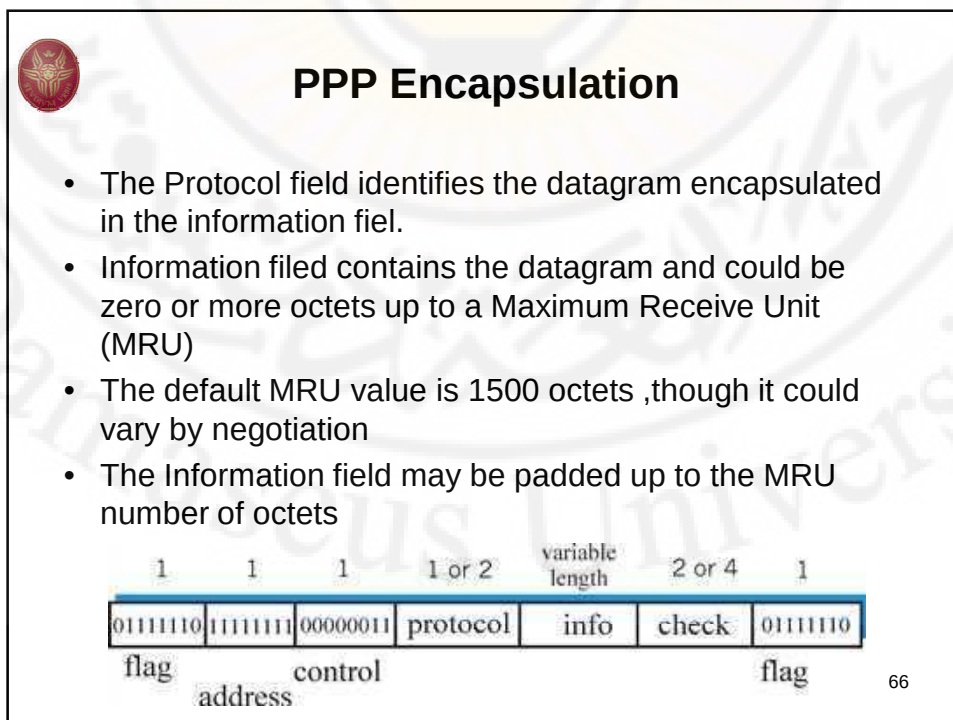
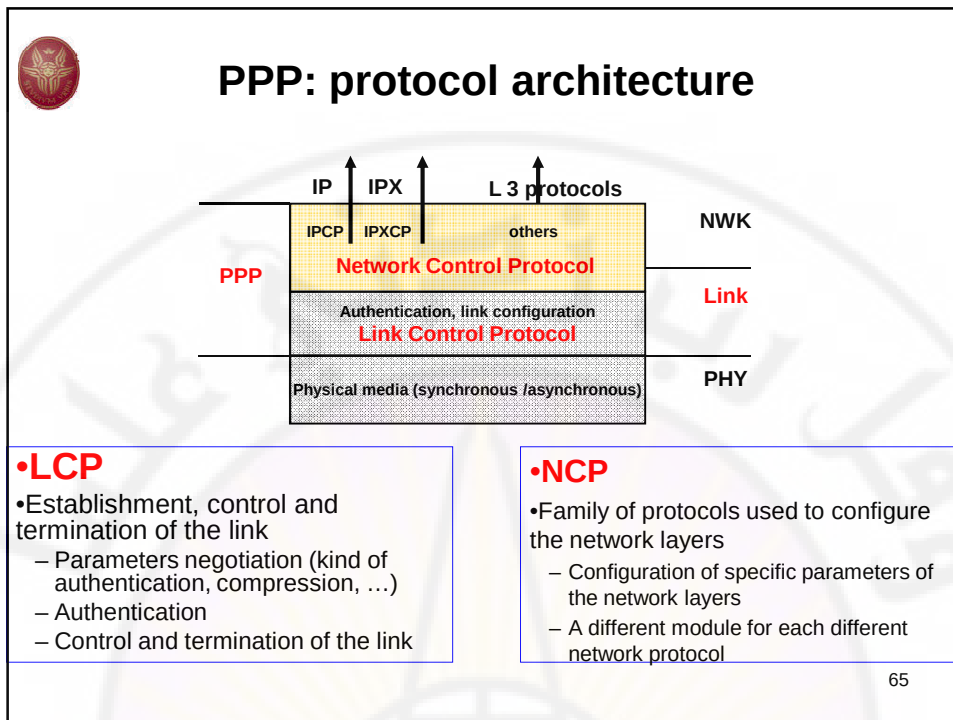


PPP

- It is used together with ADSL for its ability to directly connect the user to the Central Office of its ISP and its important functions like: authentication, authorization, automatic configuration of network interfaces and DHCP support.
- In the majority of European countries ADSL is based on the ATM protocol so PPP is encapsulated inside ATM cells (PPPoA).
- Nonetheless ADSL can stand on top of Ethernet and be encapsulated in Ethernet Frames (PPPoE).



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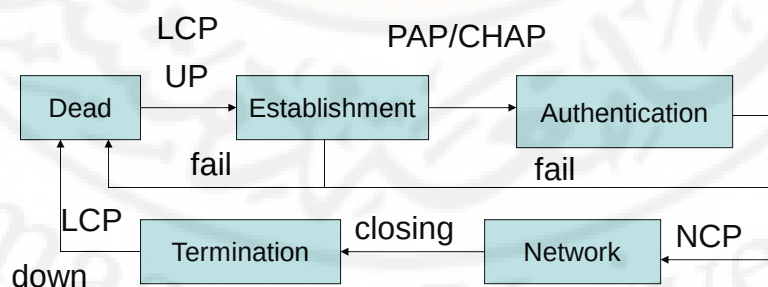
PPP Encapsulation

- The Protocol field identifies the datagram encapsulated in the information field.
- Information field contains the datagram and could be zero or more octets up to a Maximum Receive Unit (MRU).
- The default MRU value is 1500 octets, though it could vary by negotiation.
- The Information field may be padded up to the MRU number of octets.

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PPP Link Operation.



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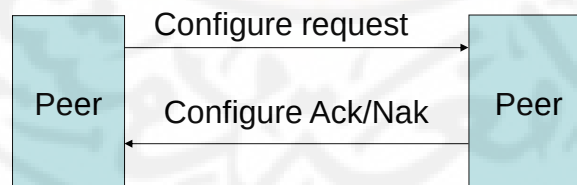
Link Establishment

- Link establishment phase uses the Link control protocol.
 - Link Configuration Options
 - » The Maximum Receive Unit size.
 - » Authentication and protocol to be used for authentication
 - » Protocol Field Compression
 - » Link quality monitoring
 - » Magic number option for detecting looped back links.
 - » Address and Control field compression

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Link Establishment Process



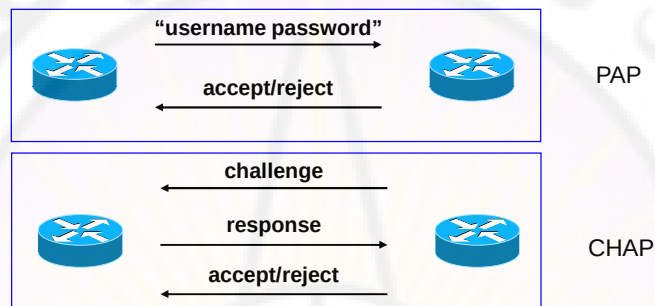
- The configure-request message is sent to request a link establishment and it contains the various options requested.
- This request is responded with a Configure-Ack if the negotiation is accepted.
- A Configure-Nak is sent if the negotiation is not acceptable and it suggests an acceptable negotiation.

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Authentication

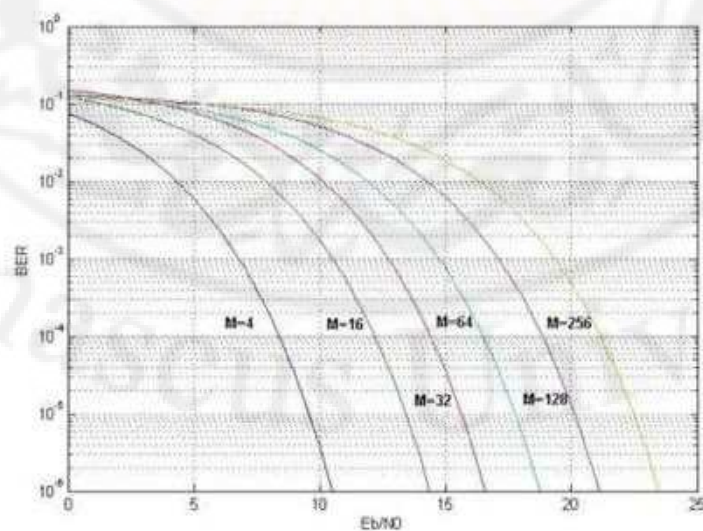
- Authentication Option uses Password Authentication Protocol (PAP) or Challenge Handshake Authentication Protocol (CHAP).
- The protocol used depends on negotiation.
- CHAP uses a one-way hashing algorithm which is known only to the user, to respond to a challenge sent by the authenticator.
- CHAP is more secure than PAP.



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QAM



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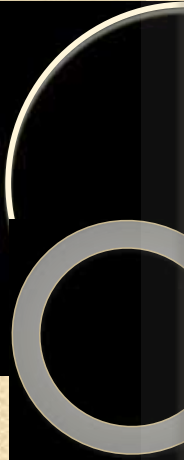


Network Topologies

LAN topologies

WAN topologies



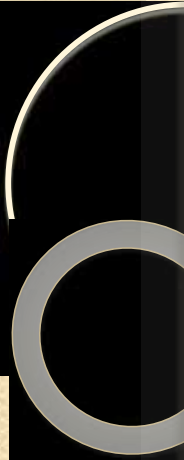


LAN topologies

- Physical
 - Describes the geometric arrangement of components that make up the LAN
- Logical
 - Describes the possible connections between pairs of networked end-points that can communicate

LAN Topologies(Physical)

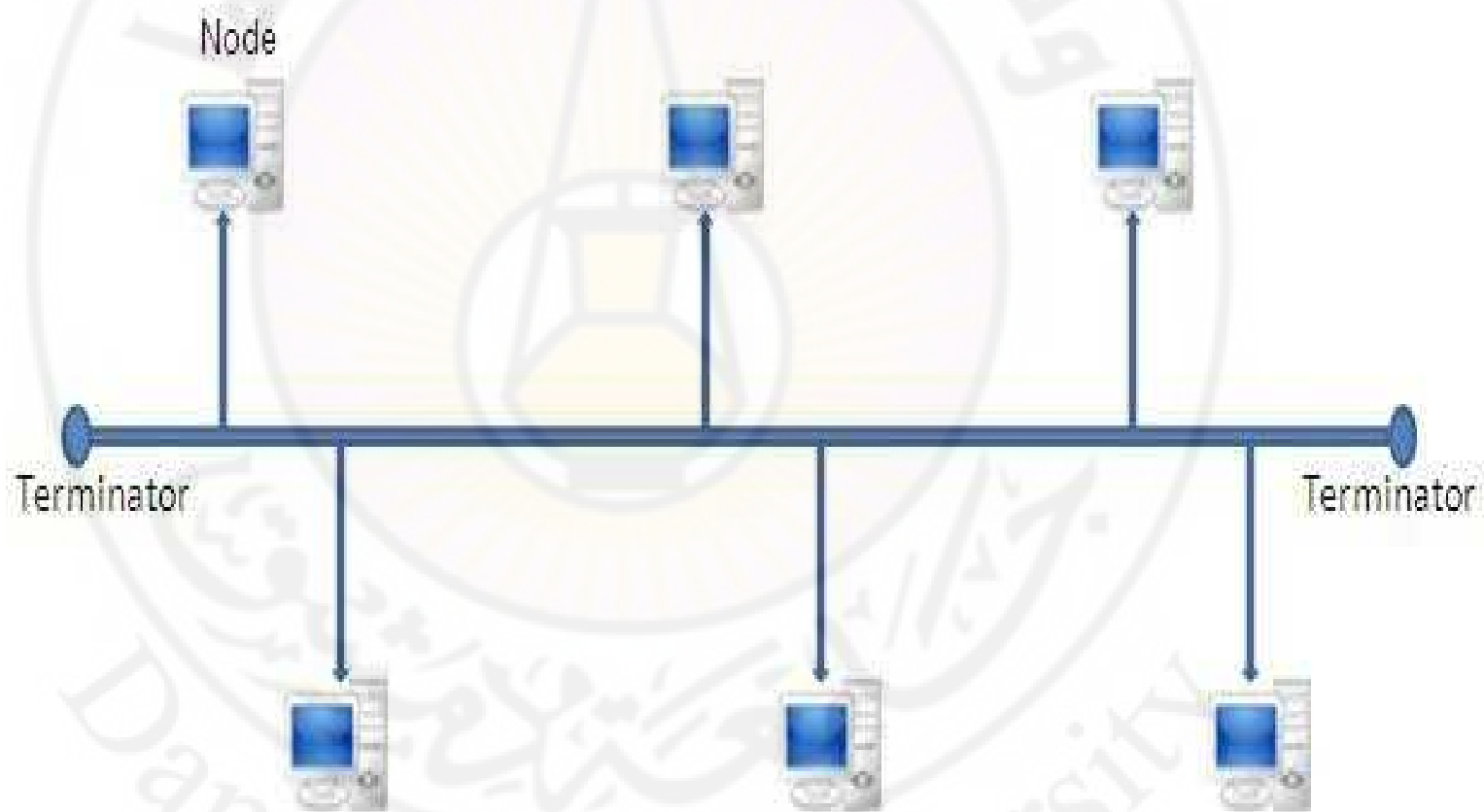
- 1) Bus
- 2) Star
- 3) Ring
- 4) Switched
- 5) Daisy chains
- 6) Hierarchies

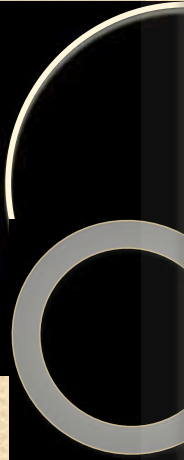


Bus topology

- All networked nodes are interconnected, peer to peer, using a single, open-ended cable
- Both ends of the bus must be terminated with a terminating resistor to prevent signal bounce

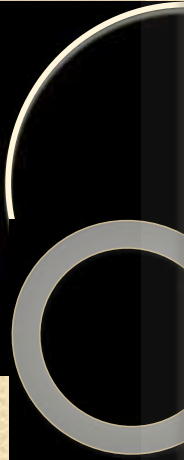
Bus topology





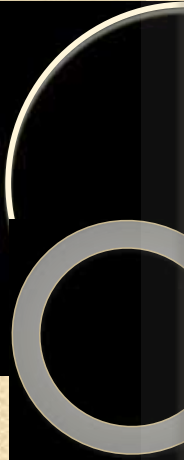
Advantages of Bus topology

- 1) Easy to implement and extend
- 2) Well suited for temporary networks that must be set up in a hurry
- 3) Typically the least cheapest topology to implement
- 4) Failure of one station does not affect others



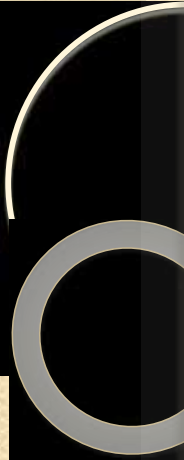
Disadvantages of Bus topology

- 1) Difficult to administer/troubleshoot
- 2) Limited cable length and number of stations
- 3) A cable break can disable the entire network; no redundancy
- 4) Maintenance costs may be higher in the long run
- 5) Performance degrades as additional computers are added



Ring topology

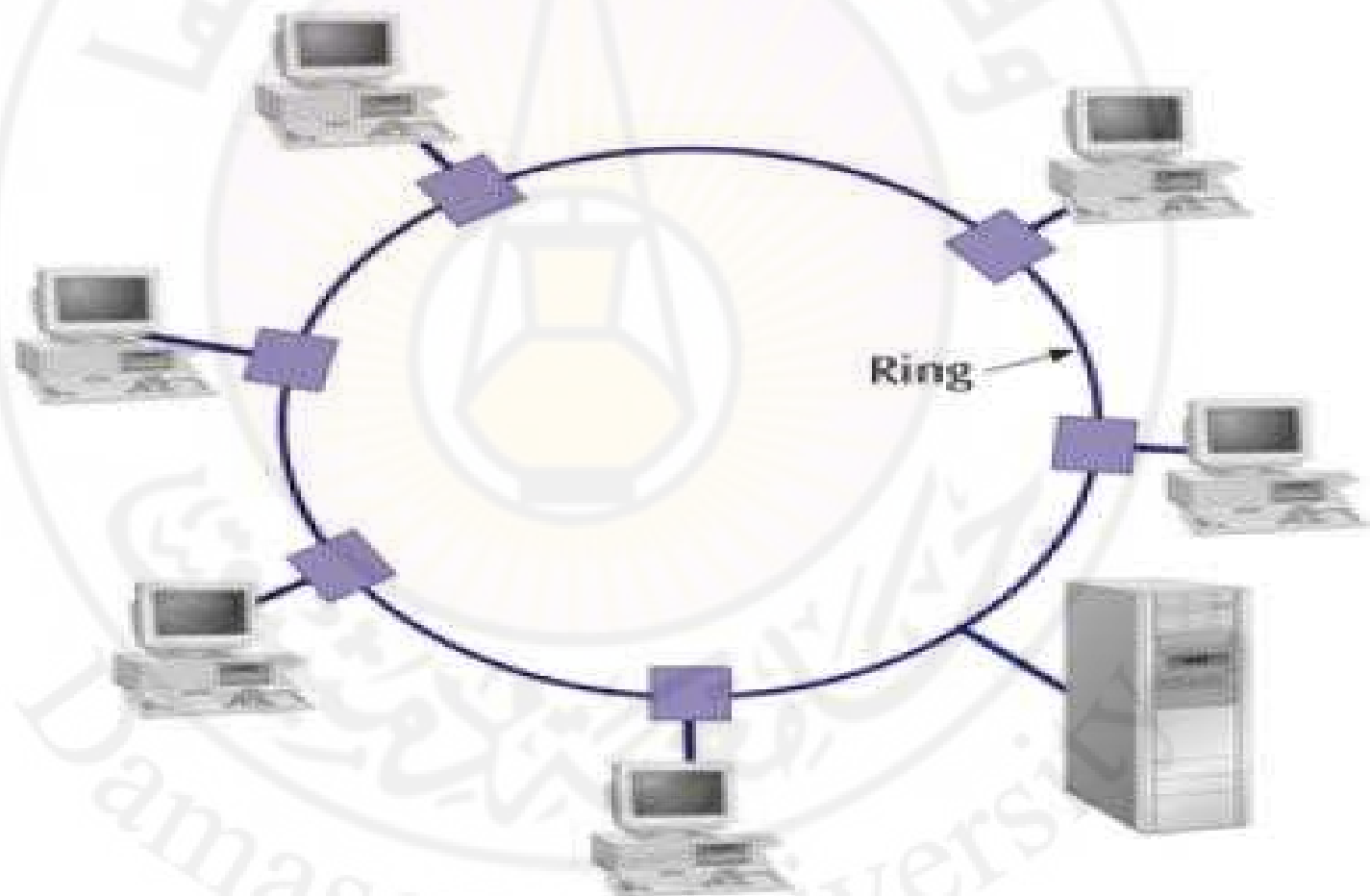
- started out as a simple peer-to-peer LAN topology
- Each networked workstation had two connections: one to each of its nearest neighbors
- Data was transmitted unidirectionally around the ring
- Sending and receiving of data takes place by the help of TOKEN

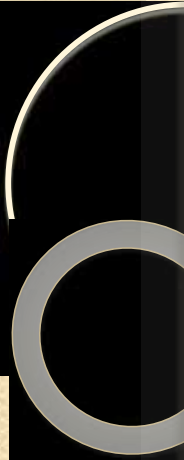


Token Passing

- Token contains a piece of information which along with data is sent by the source computer
- This token then passes to next node, which checks if the signal is intended to it
 - If yes, it receives it and passes the empty token into the network
 - otherwise passes token along with the data to next node

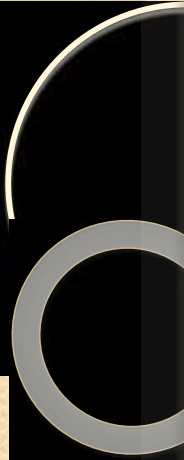
Ring topology





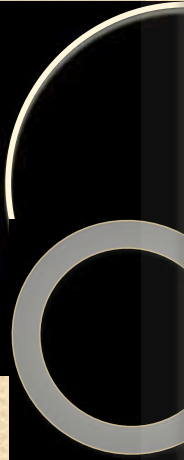
Advantages of Ring topology

- 1) This type of network topology is very organized
- 2) Performance is better than that of Bus topology
- 3) No need for network server to control the connectivity between workstations
- 4) Additional components do not affect the performance of network
- 5) Each computer has equal access to resources



Disadvantages of Ring topology

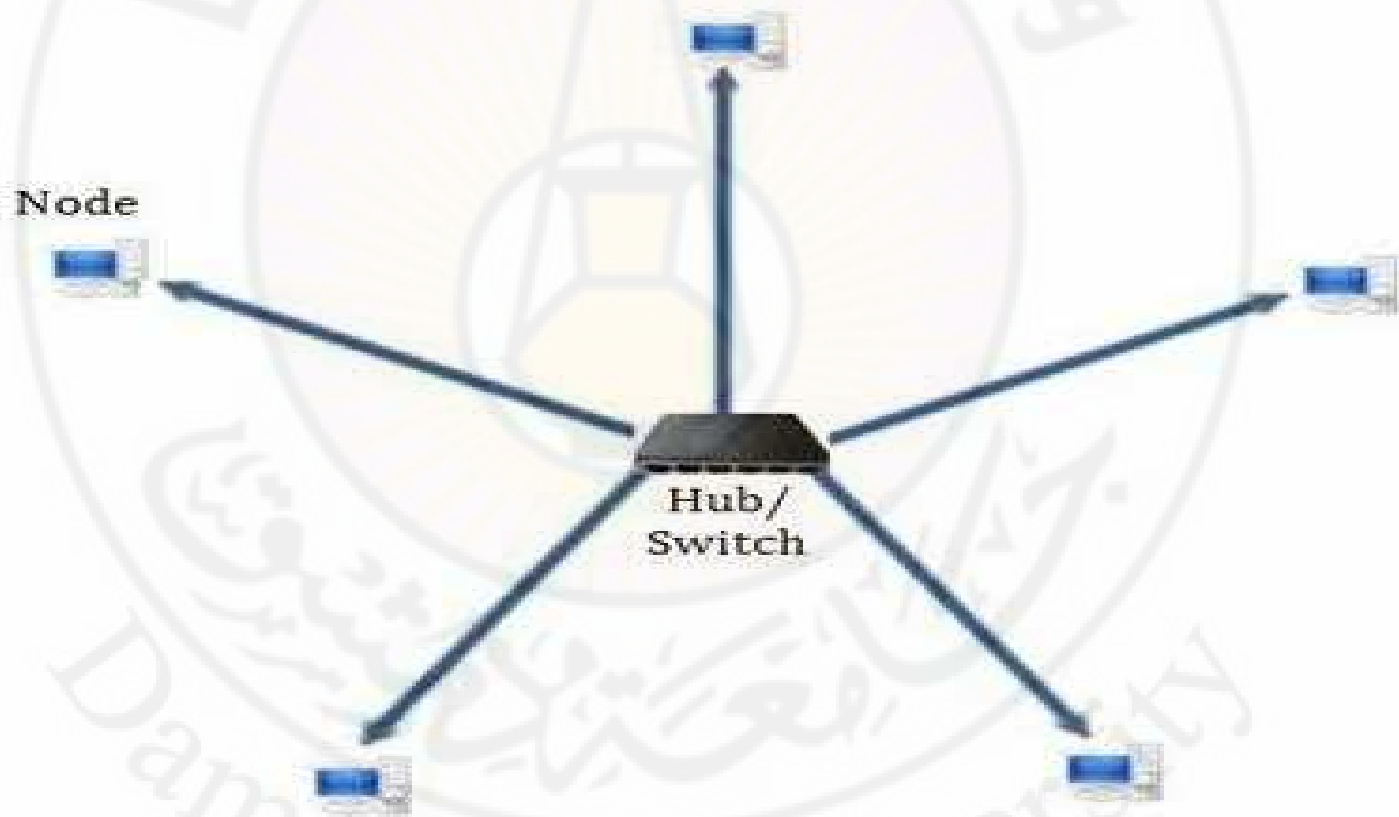
- 1) Each packet of data must pass through all the computers between source and destination, slower than star topology
- 2) If one workstation or port goes down, the entire network gets affected
- 3) Network is highly dependent on the wire which connects different components

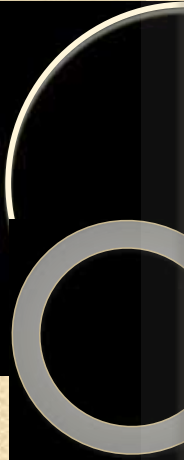


Star topology

- Have connections to networked devices that “radiate” out from a common point
- Each networked device in star topology can access the media independently
- Have become the dominant topology type in contemporary LANs
- Stars have made buses and rings obsolete in LAN topologies

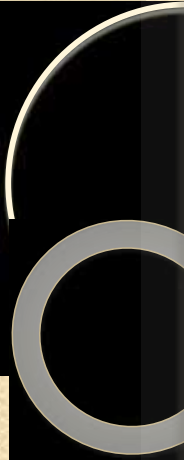
Star topology





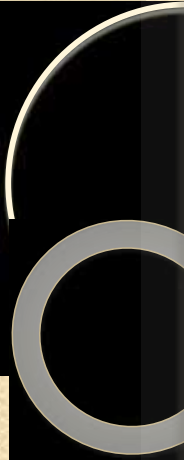
Advantages of star topology

- 1) Compared to Bus topology it gives far much better performance
- 2) Easy to connect new nodes or devices
- 3) Centralized management. It helps in monitoring the network
- 4) Failure of one node or link doesn't affect the rest of network



Disadvantages of star topology

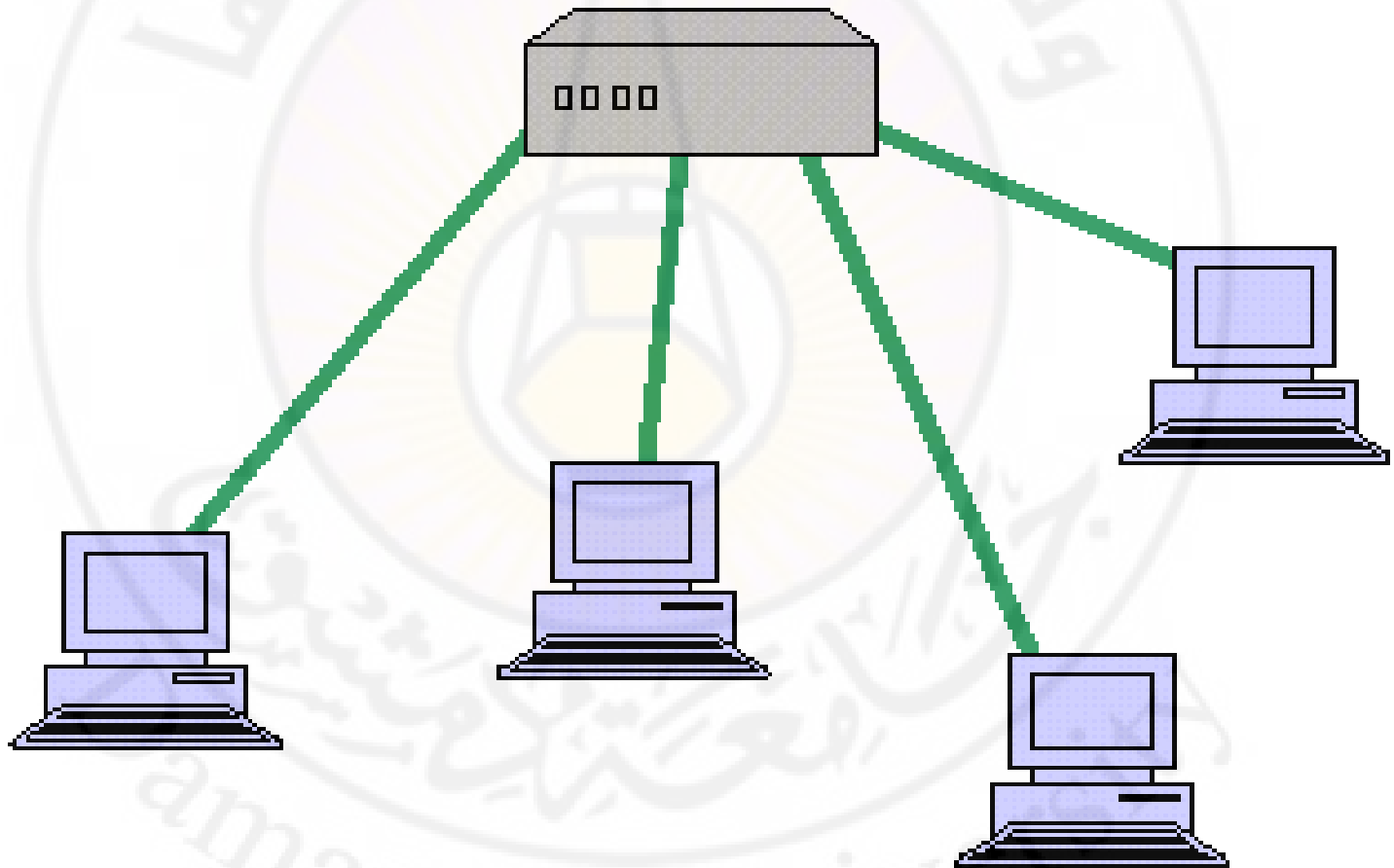
- 1) If central device fails whole network goes down
- 2) The use of hub, a router or a switch as central device increases the overall cost of the network
- 3) Performance and as well number of nodes which can be added in such topology is depended on capacity of central device

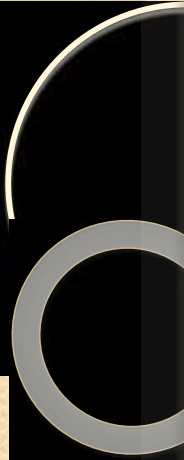


Switched topology

- A switch is a multiport, Data Link Layer device
- A switch “learns” Media Access Control addresses and stores them in an internal lookup table
- Temporary, switched paths are created between the frame’s originator and its intended recipient, and the frames are forwarded along the temporary path
- Switched topology features multiple connections to a switching hub/Switch
- Each port, and the device to which it connects, has its own dedicated bandwidth

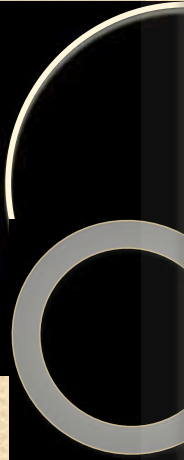
Switched topology





Advantages/Disadvantages of a Switched topology

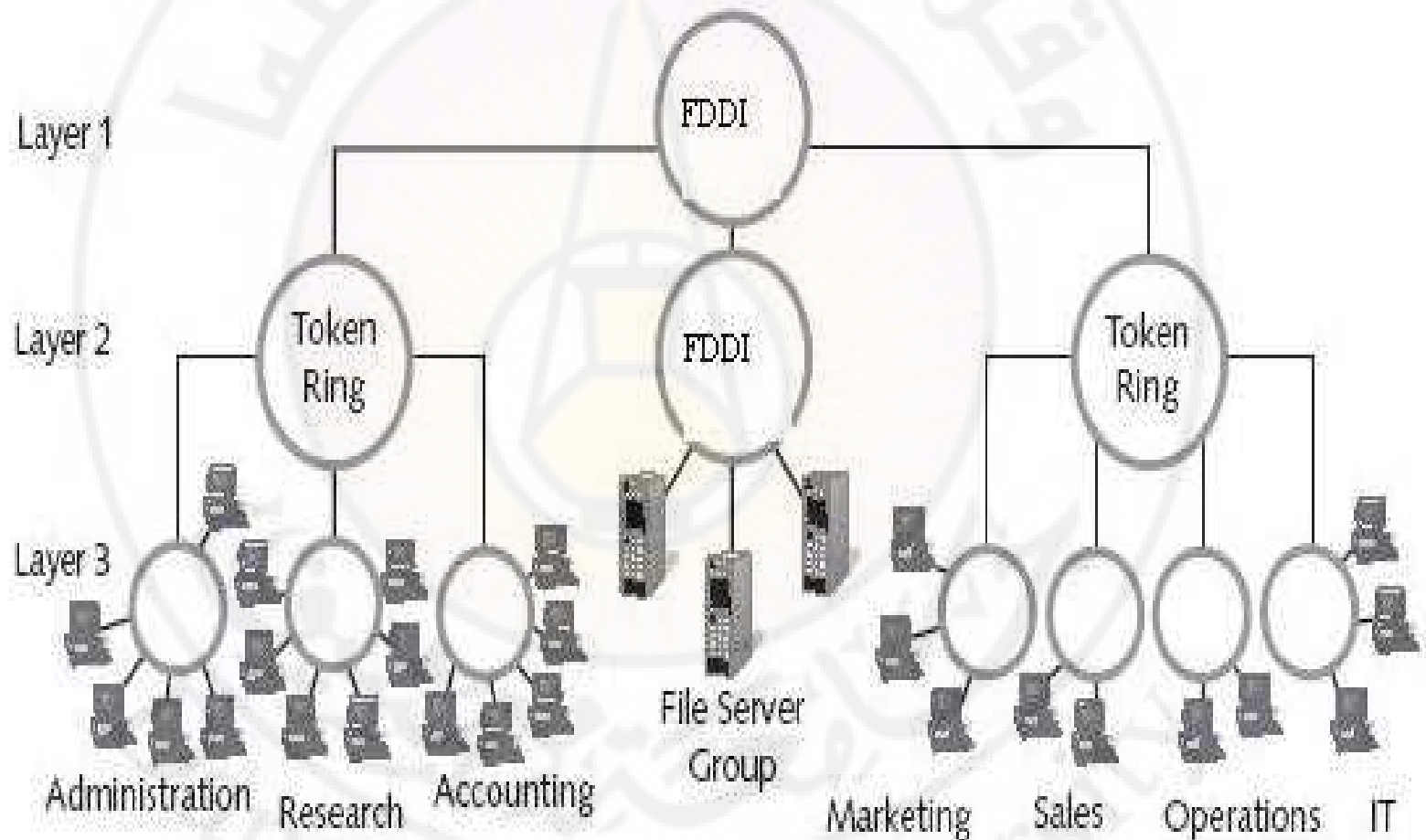
- Advantage:
 - Can improve LAN performance:
 - increase the aggregate bandwidth available throughout the network
 - reducing the number of devices forced to share each segment of bandwidth
- Disadvantage:
 - Large switched implementations do not isolate broadcasts



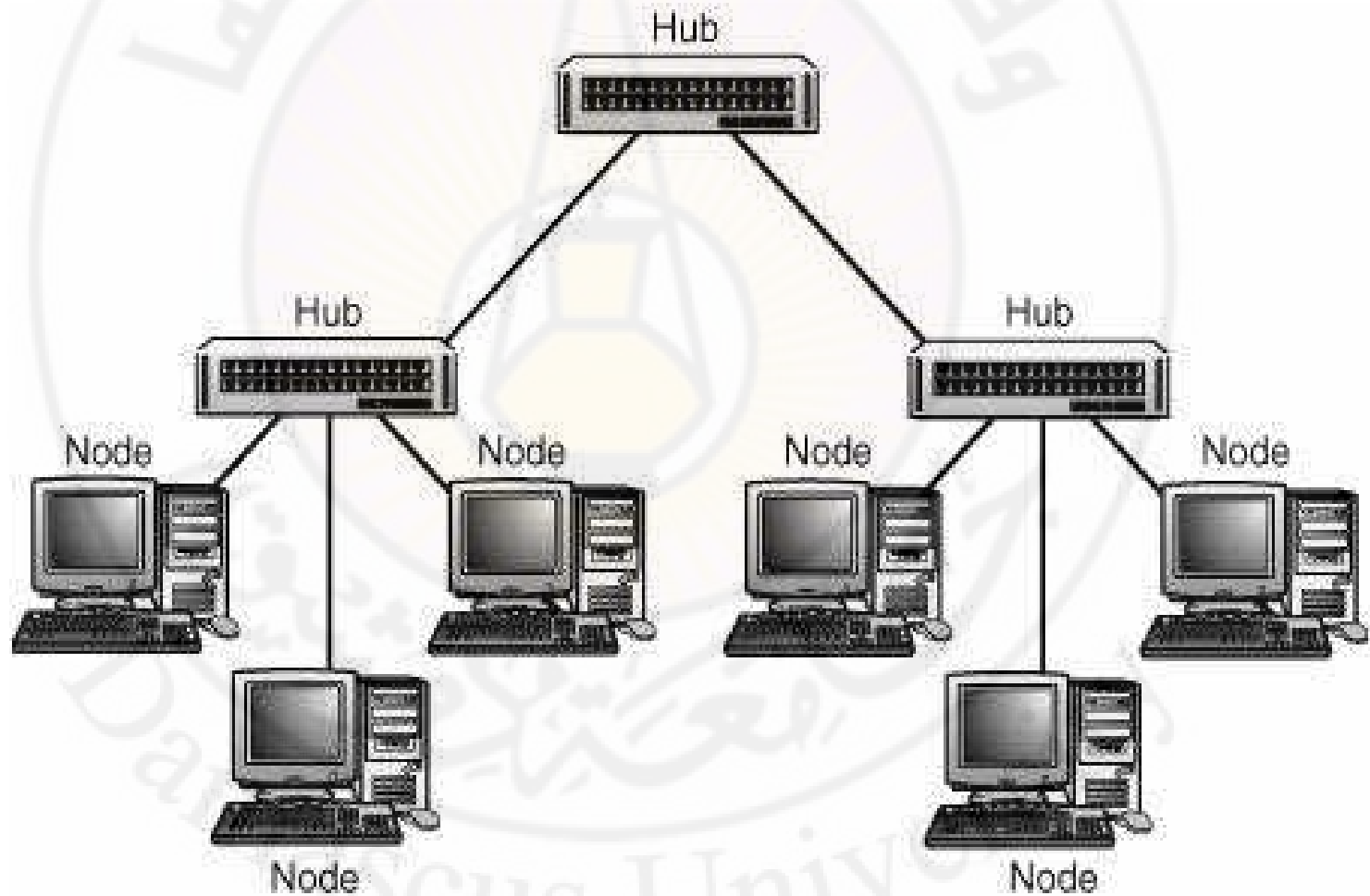
Hierarchies

- Hierarchical topologies consist of more than one layer of hubs. Each layer serves a different network function
- The bottom tier is reserved for user station and server connectivity. Higher-level tiers provide aggregation of the user-level tier
- A hierarchical arrangement is best suited for medium-to-large-sized LANs that must be concerned with scalability of the network and with traffic aggregation

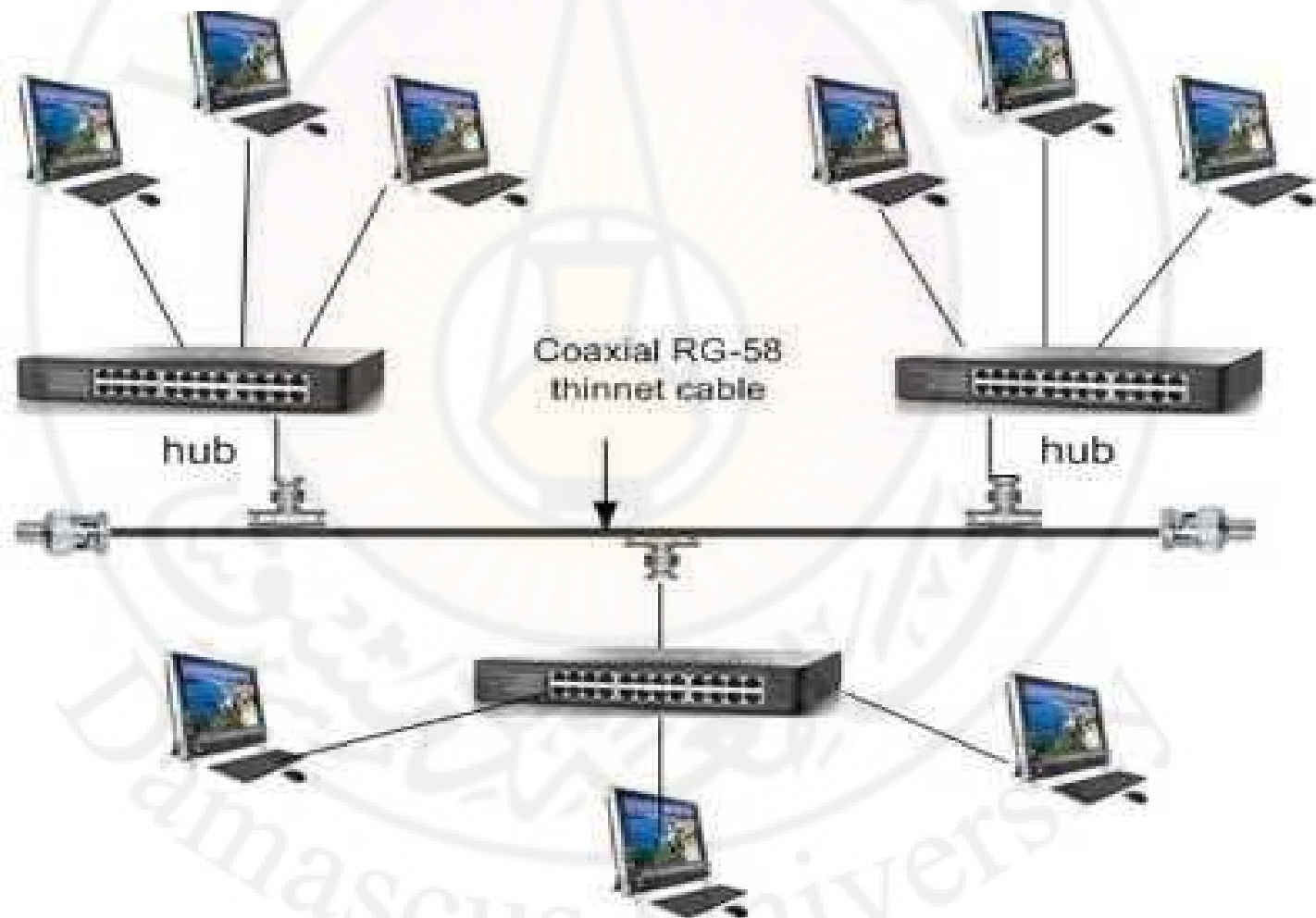
Hierarchical rings

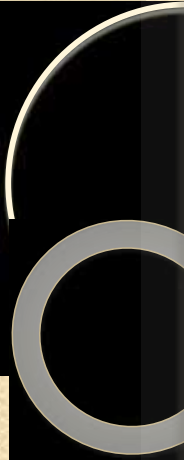


Hierarchical stars



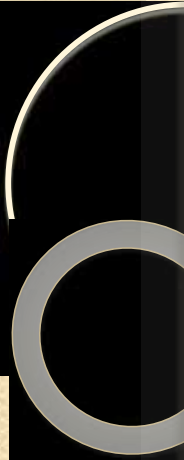
Hierarchical combinations





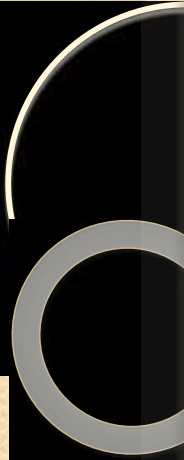
WAN Topologies

- The topology of a WAN describes the way the transmission facilities are arranged relative to the locations that they interconnect
- Numerous topologies are possible, each one offering a different mix of cost, performance and scalability



WAN Topologies

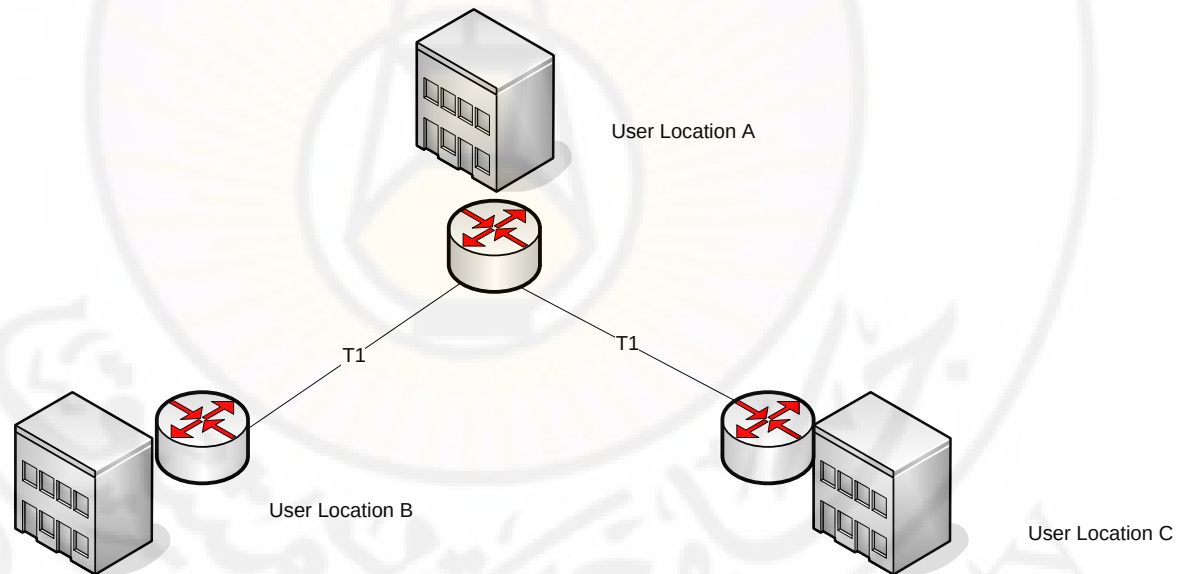
- 1) Peer-to-peer WANs
- 2) Ring WANs
- 3) Star WANs
- 4) Full-mesh WANs
- 5) Partial-mesh WANs
- 6) Two-tiered
- 7) Three-tiered
- 8) Hybrids

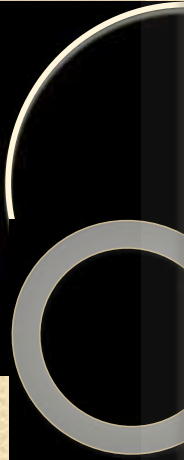


Peer-to-peer topology

- A peer-to-peer WAN can be developed using leased private lines or any other transmission facility
- This WAN topology is a relatively simple way of interconnecting a small number of sites
- Represents the least-cost solution for WANs that contain a small number of internetworked locations

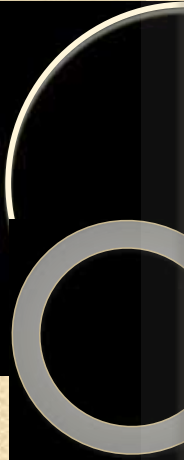
Peer-to-peer





Advantage/Disadvantage of Peer-to-peer

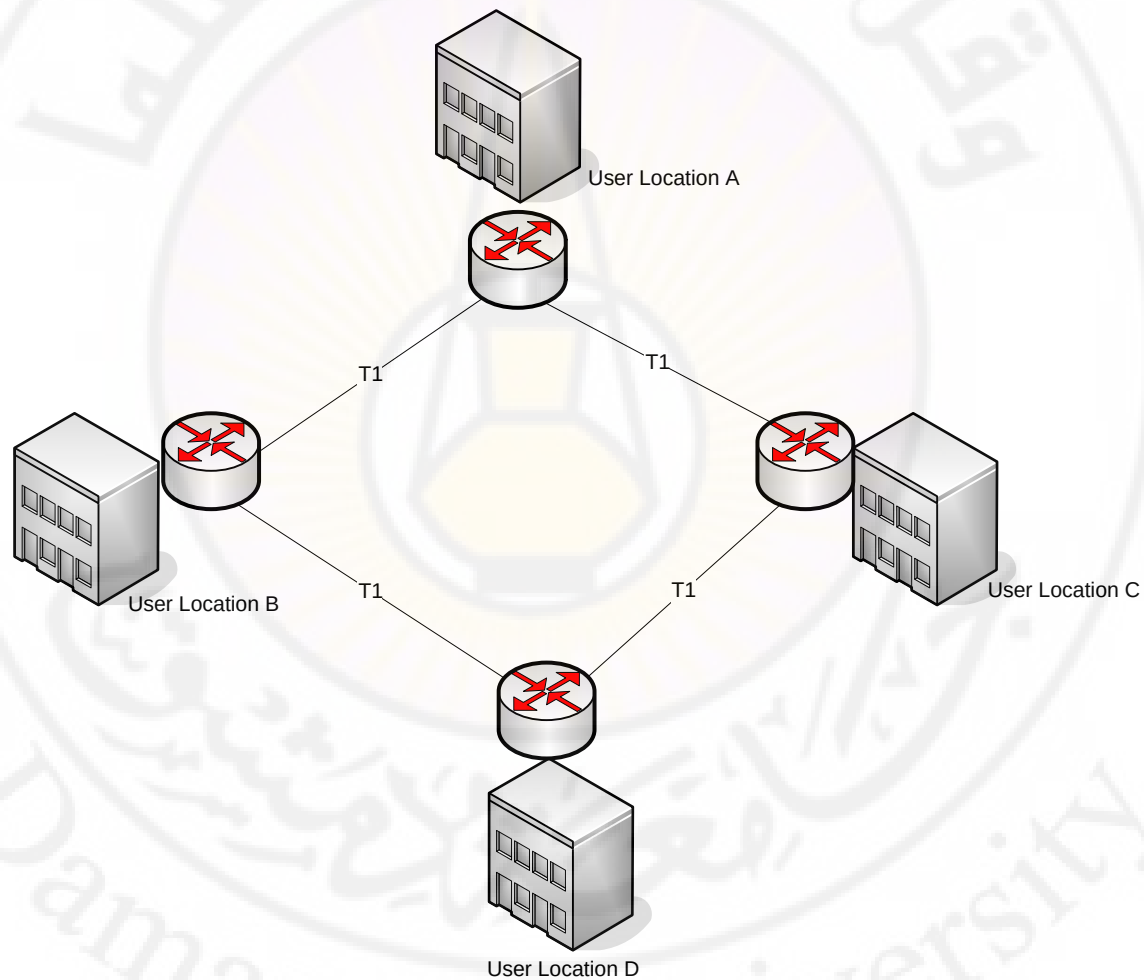
- Advantage:
 - It is inexpensive relative to other options
- Disadvantages:
 - They don't scale very well. As additional locations are introduced to the WAN, the number of hops between any given pair of locations remains highly inconsistent and has an upward trend
 - An equipment or facility failure anywhere in a peer-to-peer WAN can split the WAN

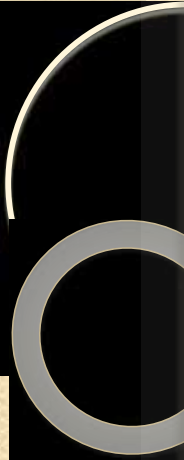


Ring topology

- Can be developed fairly easily from a peer-to-peer network by adding one transmission facility and an extra port on two routers
- A ring-shaped WAN constructed with point-to-point transmission facilities can be used to interconnect a small number of sites and provide route redundancy at a potentially minimal incremental cost
- Can use dynamic routing protocols

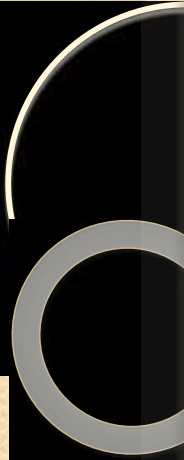
Ring topology





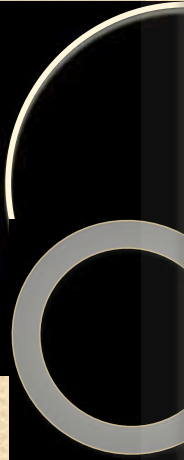
Advantages/Disadvantages of Ring topology

- Advantages:
 - It provides alternative routes
 - It is less expensive than all but the peer-to-peer WAN
- Disadvantages:
 - Depending on the geographic dispersion of the locations, adding an extra transmission facility to complete the ring may be cost prohibitive
 - Rings are not very scalable



Star network Topology

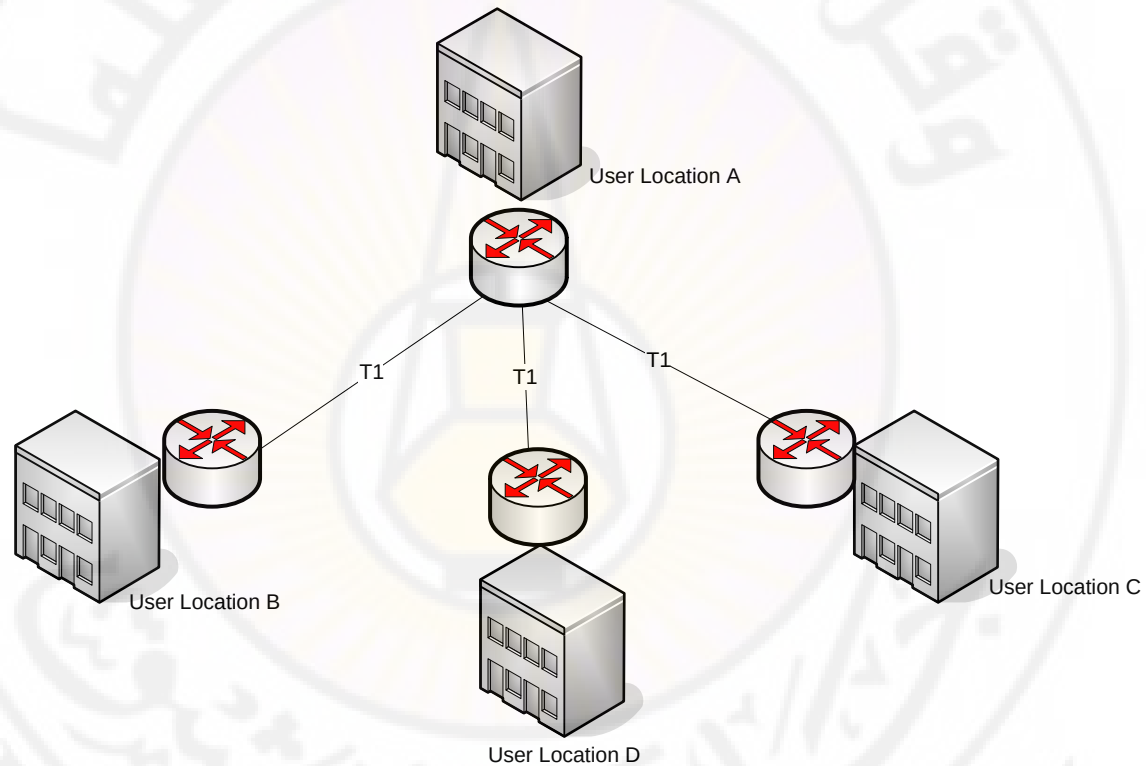
- constructed by homing all locations into a common location
- The star topology can be constructed using almost any dedicated transmission facility including frame relay and point-to-point private lines

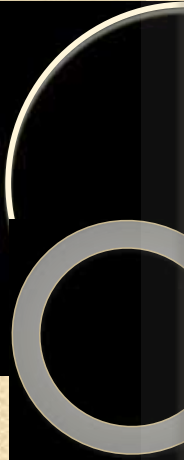


Advantages/Disadvantages of star topology

- Advantages:
 - More scalable than a peer-to-peer or ring network
 - Improved network performance. Hop count of three
- Disadvantages:
 - It creates a single point of failure
 - There is no route redundancy

Star topology

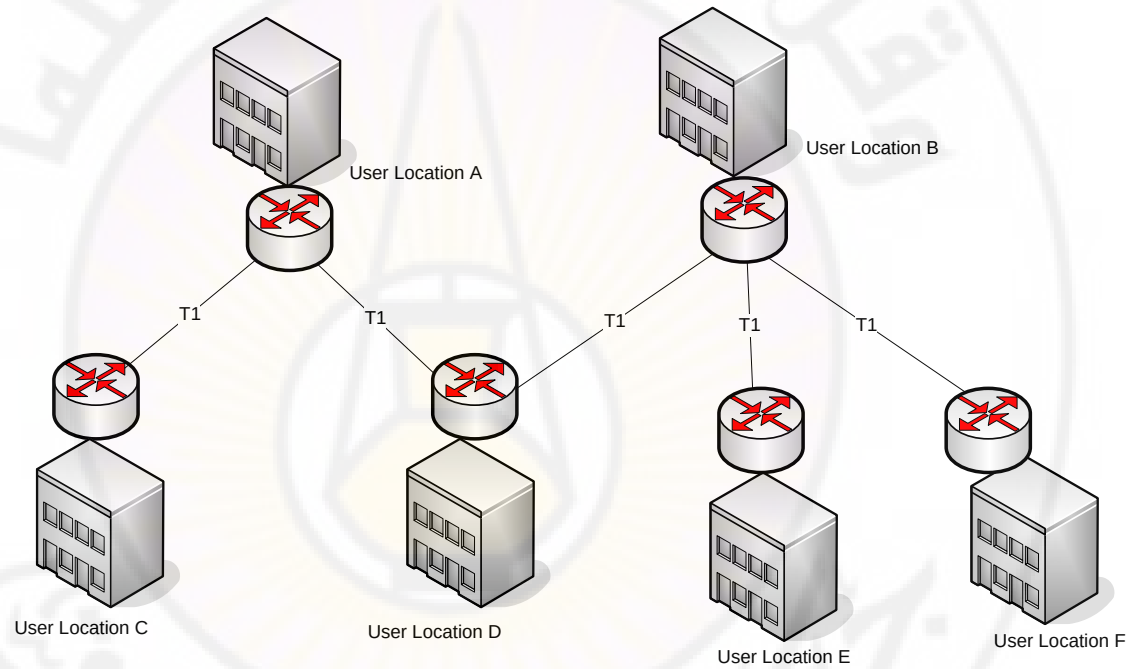


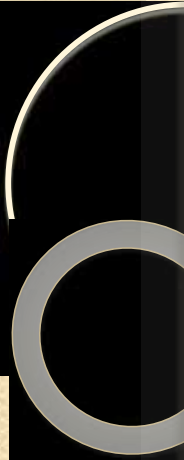


Two-tiered topology

- A two-tiered topology is a modified version of the basic star topology. Rather than single concentrator routers, two or more routers are used
- A two-tiered WAN constructed with dedicated facilities offers improved fault tolerance over the simple star topology without compromising scalability

Two-tiered topology

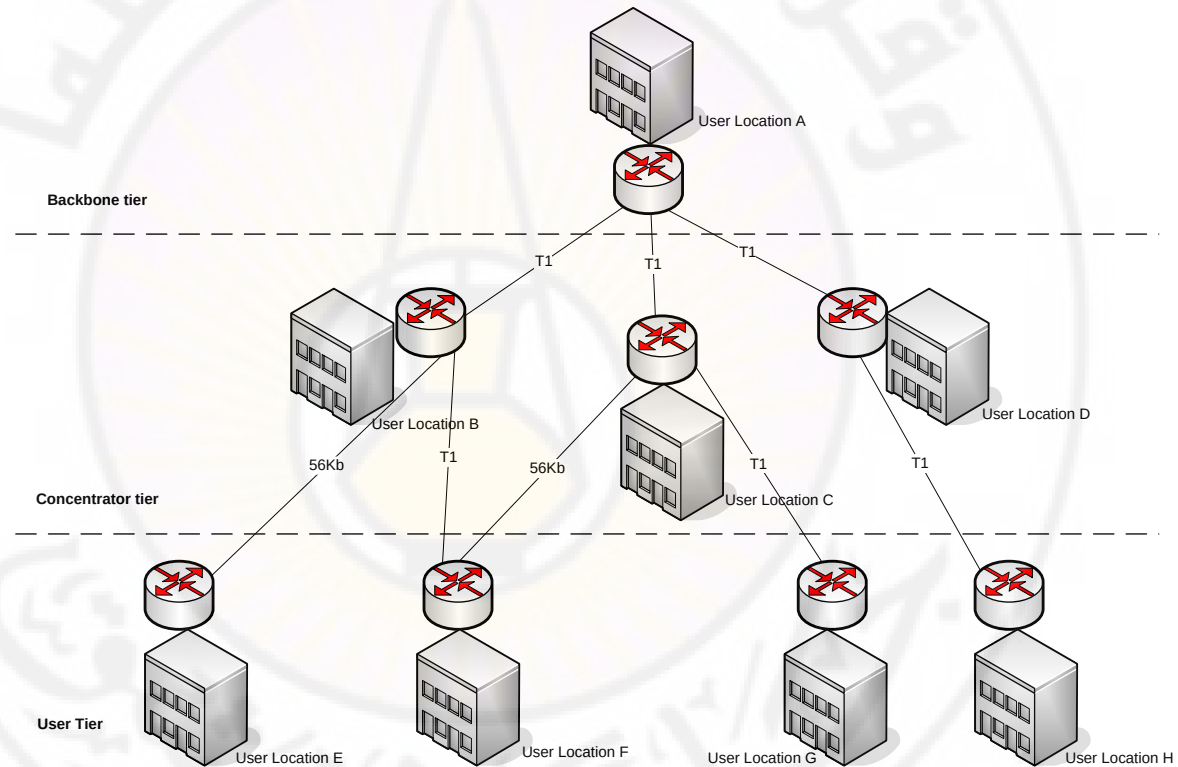


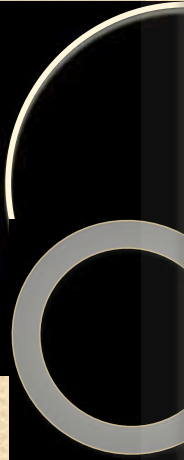


Three-tiered topology

- WANs that need to interconnect a very large number of sites, or are built using smaller routers that can support only a few serial connections, may find the two-tiered architecture insufficiently scalable.
- Therefore, adding a third tier may well provide the additional scalability they require

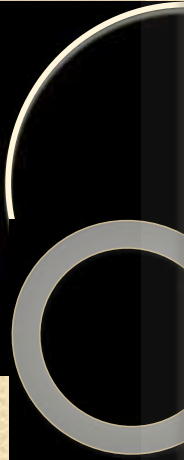
Three-tiered





Advantage/Disadvantage of three-tiered

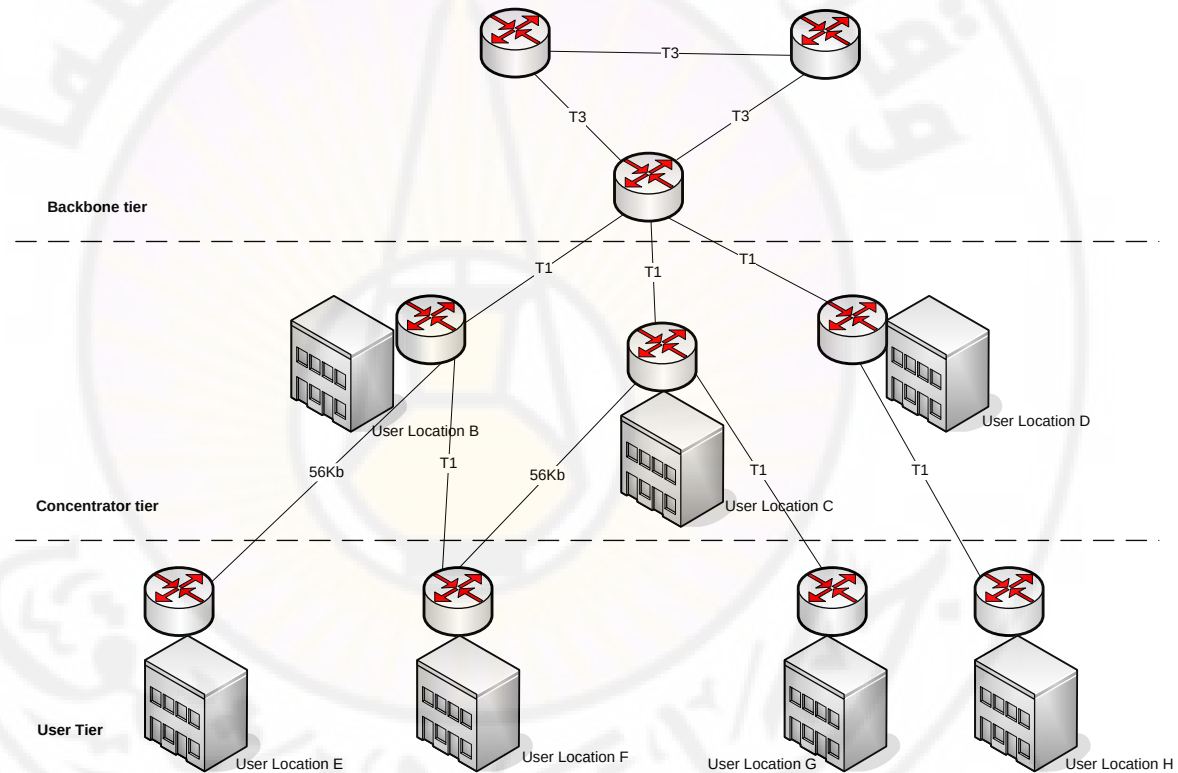
- Advantage:
 - A three-tiered WAN constructed with dedicated facilities offers even greater fault tolerance and scalability than the two-tiered topology
- Disadvantage:
 - Three-tiered networks are expensive to build, operate and maintain



Hybrid topologies

- Hybridization of multiple topologies is useful in larger, more complex networks
- Multitiered networks, in particular, lend themselves to hybridization. A multitiered WAN can be hybridized by fully or partially meshing the backbone tier of routers
- An effective hybrid topology may be developed in a multitiered WAN by using a fully meshed topology for the backbone nodes only

Hybrid topology



Data and Computer Communications

Chapter 12 – Routing in Switched Networks

Eighth Edition
by William Stallings

Lecture slides by Lawrie Brown

Routing in Packet Switched Network

- key design issue for (packet) switched networks
- select route across network between end nodes
- **characteristics required:**
 - correctness
 - simplicity
 - robustness
 - stability
 - fairness
 - optimality
 - efficiency

Performance Criteria

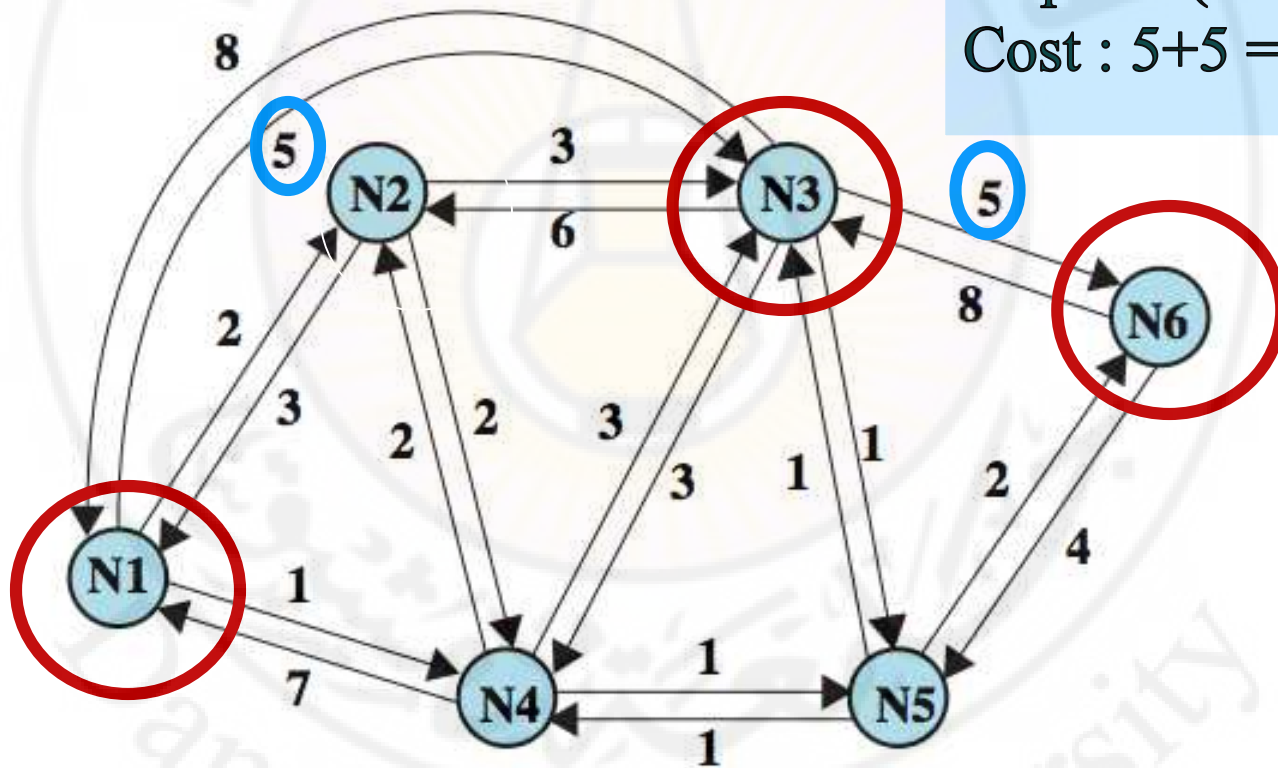
- used for selection of route
- **simplest** is “**minimum hop**”
- can be generalized as “**least cost**”

Example Packet Switched Network

Route from N1 to N6
N1-N3-N6

Hop : 2 (shortest)

Cost : $5+5 = 10$

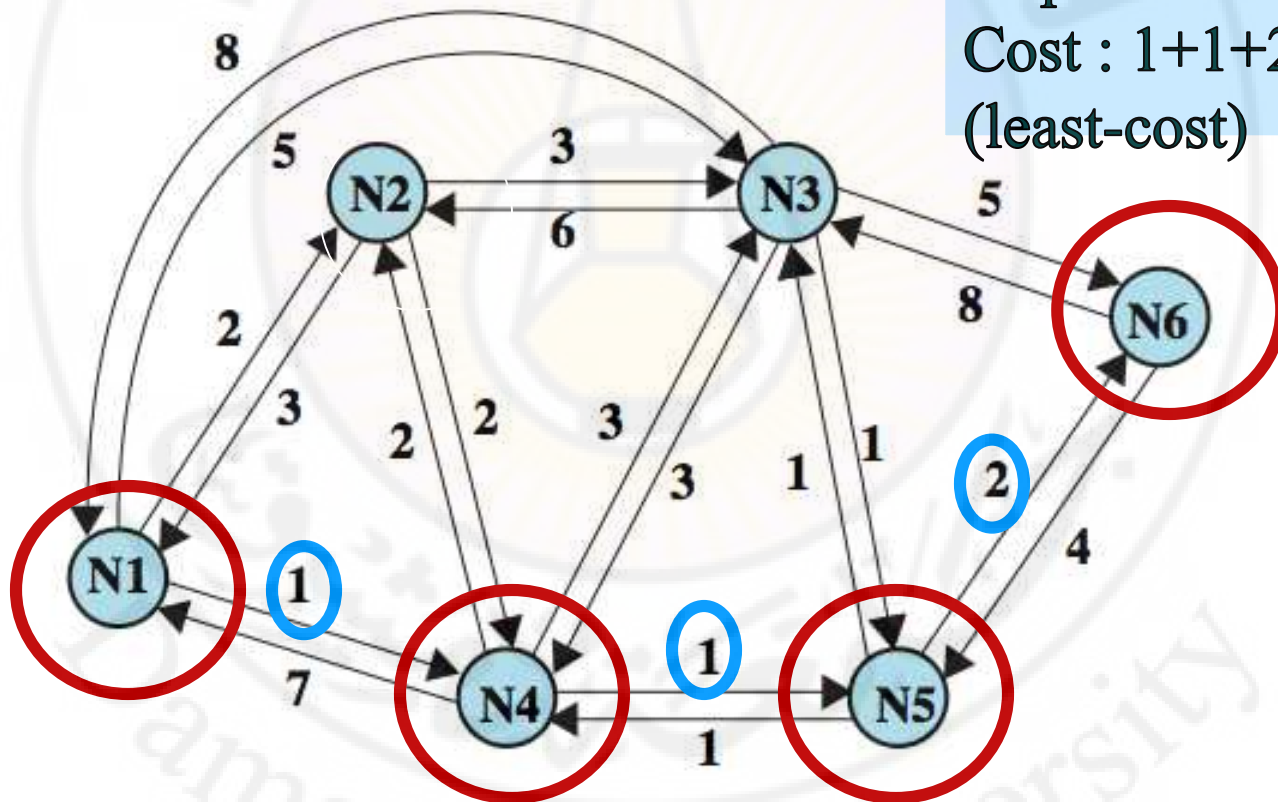


Example Packet Switched Network

Route from N1 to N6
N1-N4-N5-N6

Hop : 3

Cost : $1+1+2 = 4$
(least-cost)



Decision Time and Place

➤ time

- **packet** or **virtual circuit** basis
- fixed or dynamically changing

➤ place

- distributed - made by each node
- centralized
- source

Routing decision is made individually for each packet

Routing decision is made at the time virtual circuit is established

Decision Time and Place

➤ time

- packet or virtual circuit basis
- **fixed** or **dynamically** changing

➤ place

- distributed - made by each node
- centralized
- source

all packets using that virtual circuit follow the same route

the network may dynamically change the route assigned to a particular virtual circuit in response to changing conditions (e.g. overload or failure of a portion of the network).

Decision Time and Place

➤ time

- packet or virtual circuit basis
- fixed or dynamically changing

➤ place

- distributed - made by each node
- Centralized – network control center
- Source – source station

refers to which node or nodes in the network are responsible for the routing decision

Network Information Source and Update Timing

- **routing decisions** usually based on **knowledge of network** (not always)
 - **distributed routing**
 - using **local knowledge**, info from **adjacent nodes**, info from all nodes on a potential **route**
 - **central routing**
 - collect info from **all nodes**
- issue of **update timing**
 - **when** is **network info** held by nodes **updated**
 - **fixed** - **never updated**
 - **adaptive** - **regular updates**

Routing Strategies - Fixed Routing

- use a **single permanent route** for **each source to destination pair**
- determined using a **least cost** algorithm
- **route is fixed**
 - at least until a change in **network topology**
 - hence cannot respond to traffic changes
- **advantage is simplicity**
- **disadvantage is lack of flexibility**

Fixed Routing Tables

CENTRAL ROUTING DIRECTORY

		From Node					
		1	2	3	4	5	6
To Node	1	—	1	5	2	4	5
	2	2	—	5	2	4	5
	3	4	3	—	5	3	5
	4	4	4	5	—	4	5
	5	4	4	5	5	—	5
	6	4	4	5	5	6	—

Node 1 Directory

Destination	Next Node
2	2
3	4
4	4
5	4
6	4

Node 2 Directory

Destination	Next Node
1	1
3	3
4	4
5	4
6	4

Node 3 Directory

Destination	Next Node
1	5
2	5
4	5
5	5
6	5

Node 4 Directory

Destination	Next Node
1	2
2	2
3	5
5	5
6	5

Node 5 Directory

Destination	Next Node
1	4
2	4
3	3
4	4
6	6

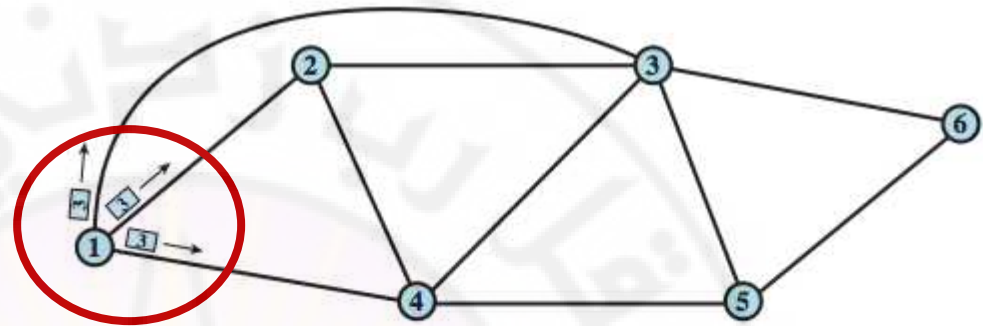
Node 6 Directory

Destination	Next Node
1	5
2	5
3	5
4	5
5	5

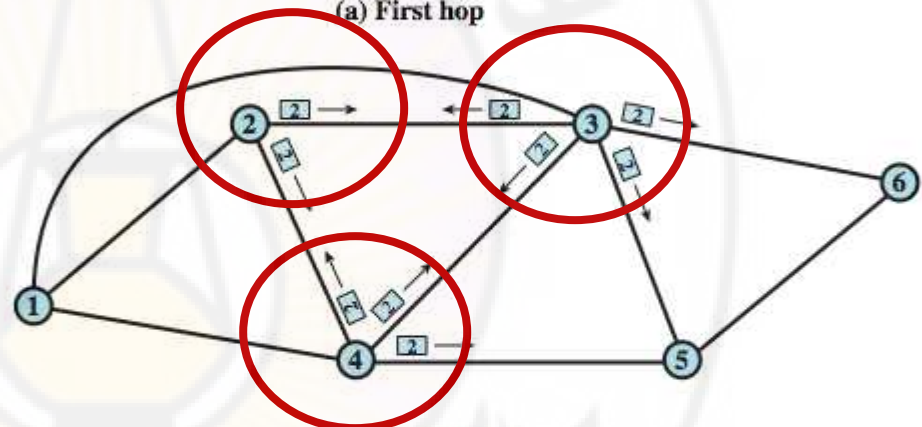
Routing Strategies - Flooding

- **packet sent by node to every neighbor**
- eventually **multiple copies** arrive at destination
- **no network info required**
- each **packet** is **uniquely numbered** so **duplicates can be discarded**
- need some way to **limit incessant retransmission**
 - nodes can **remember packets already forwarded** to keep network load in bounds
 - or include a **hop count** in packets

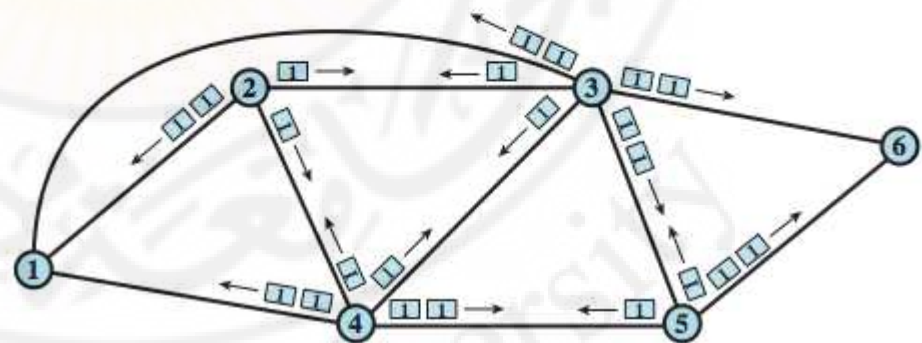
Flooding Example



(a) First hop



(b) Second hop



(c) Third hop

Properties of Flooding

- **all possible routes are tried**
 - very robust
- **at least one packet** will have **taken minimum hop count route**
 - can be used to set up virtual circuit
- **all nodes are visited**
 - useful to **distribute information** (eg. routing)
- **disadvantage is high traffic load generated**

Routing Strategies - Random Routing

- **simplicity of flooding with much less load**
- **node selects one outgoing path for retransmission of incoming packet**
- **selection can be random or round robin**
- **a refinement is to select outgoing path based on probability calculation**
- **no network info needed**
- **but a random route is typically neither least cost nor minimum hop**

Routing Strategies - Adaptive Routing

- used by almost all packet switching networks
- **routing decisions change as conditions on the network** change due to **failure or congestion**
- **requires info about network**
- **disadvantages:**
 - **decisions more complex**
 - **tradeoff** between **quality** of network info and **overhead**
 - **reacting too quickly can cause oscillation**
 - **reacting too slowly means info may be irrelevant**

Adaptive Routing - Advantages

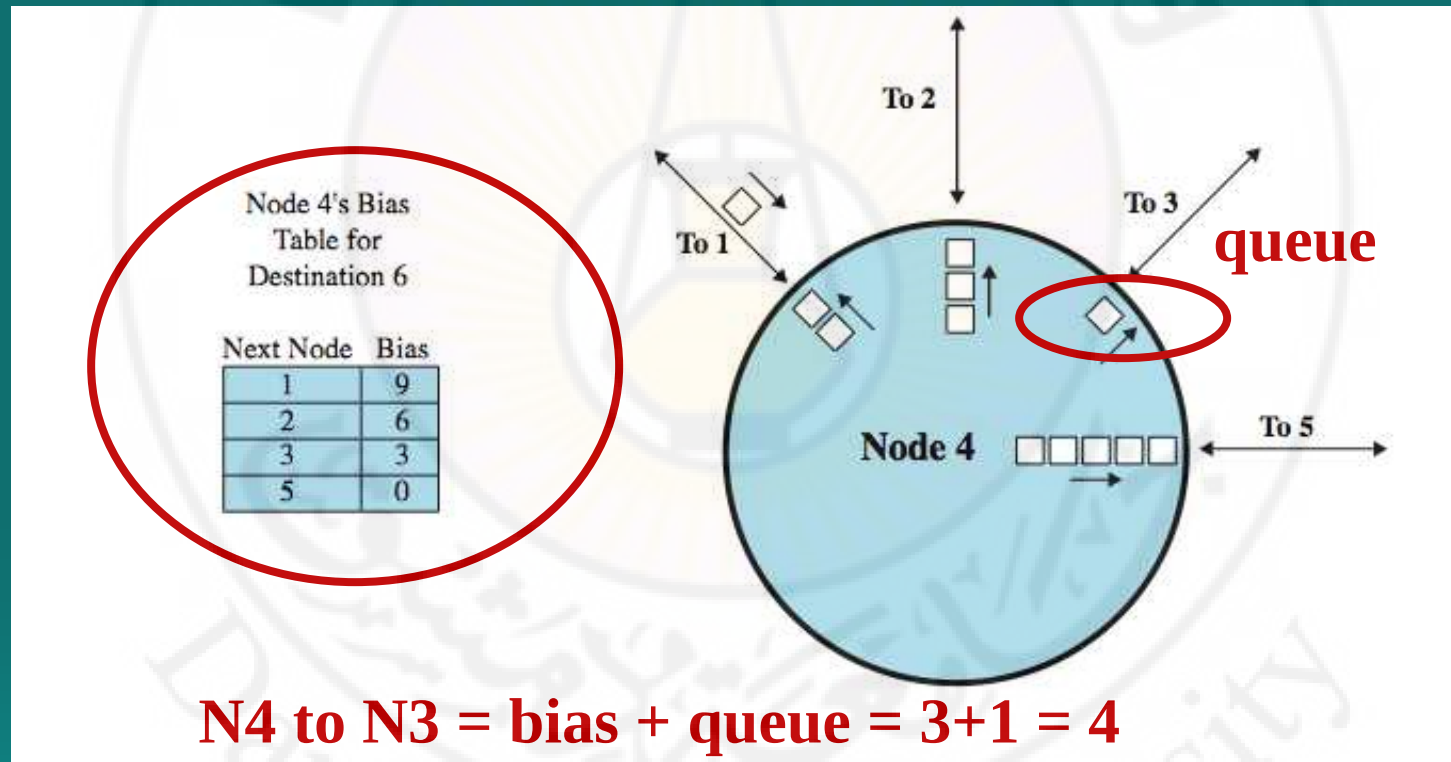
- improved performance
- aid congestion control
- but since is a complex system, may not realize theoretical benefits
 - cf. outages on many packet-switched nets

Classification of Adaptive Routing Strategies

➤ based on information sources

- **local** (isolated)
 - route to outgoing link with **shortest queue**
 - can include **bias for each destination**
 - Rarely used - does not make use of available info
- **adjacent nodes**
 - takes advantage on delay / outage info
 - distributed or centralized
- **all nodes**
 - like adjacent

Isolated Adaptive Routing



Least Cost Algorithms

- **basis for routing decisions**
 - can **minimize hop** with each link **cost 1**
 - or have link value **inversely proportional to capacity**
- defines **cost of path** between two nodes as **sum of costs of links** traversed
 - in network of nodes connected by **bi-directional** links
 - where each link has a **cost in each direction**
- for each pair of nodes, **find path with least cost**
 - nb. link costs in different directions may be different
- alternatives: Dijkstra or Bellman-Ford algorithms

Dijkstra's Algorithm

- finds shortest paths from given source node s to all other nodes
- by developing paths in order of increasing path length
- **algorithm runs in stages** (next slide)
 - each time adding node with next shortest path
- **algorithm terminates** when all nodes processed by algorithm (in set T)

Dijkstra's Algorithm Method

➤ Step 1 [Initialization]

- $T = \{s\}$ Set of nodes so far incorporated
- $L(n) = w(s, n)$ for $n \neq s$
- initial path costs to neighboring nodes are simply link costs

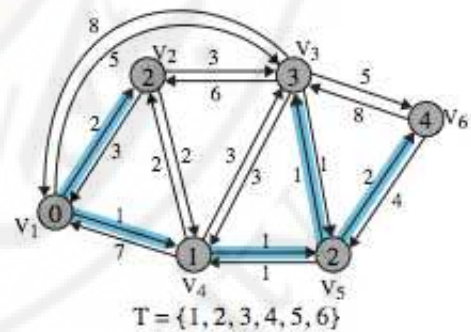
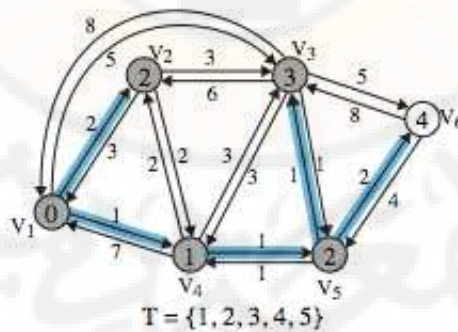
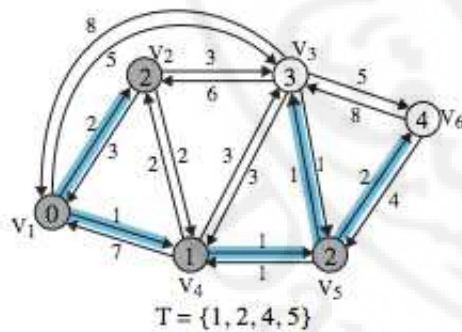
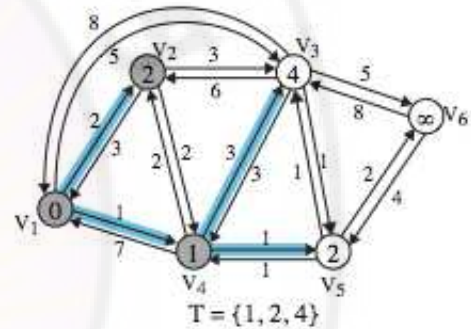
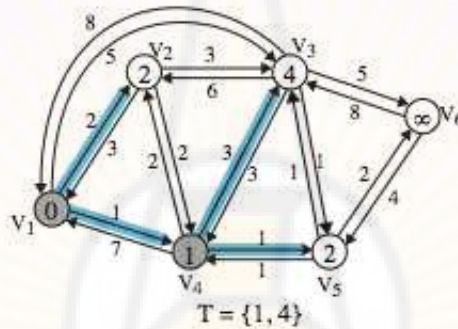
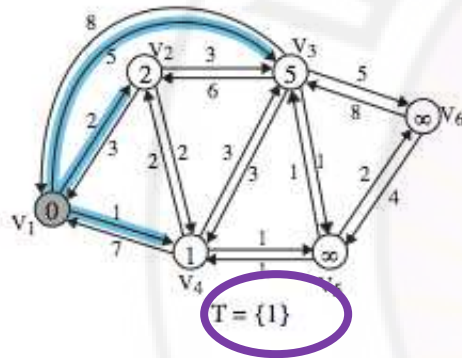
➤ Step 2 [Get Next Node]

- find neighboring node not in T with least-cost path from s
- incorporate node into T
- also incorporate the edge that is incident on that node and a node in T that contributes to the path

➤ Step 3 [Update Least-Cost Paths]

- $L(n) = \min[L(n), L(x) + w(x, n)]$ for all $n \notin T$
- if latter term is minimum, path from s to n is path from s to x concatenated with edge from x to n

Dijkstra's Algorithm Example



Start with Node 1 To find least cost path to all nodes

Dijkstra's Algorithm Example

Iter	T	L(2)	Path	L(3)	Path	L(4)	Path	L(5)	Path	L(6)	Path
1	{1}	2	1-2	5	1-3	1	1-4	∞	-	∞	-
2	{1,4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
3	{1, 2, 4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
4	{1, 2, 4, 5}	2	1-2	3	1-4-5-3	1	1-4	2	1-4-5	4	1-4-5-6
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Dijkstra's Algorithm Example

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2	{1,4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
3	{1, 2, 4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
4	{1, 2, 4, 5}	2	1-2	3	1-4-5-3	1	1-4	2	1-4-5	4	1-4-5-6
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Dijkstra's Algorithm Example

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3	{1, 2, 4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
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2	{1, 4}	2	1-2	4	1-4-3	1	1-4	2	1-4-5	∞	-
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Dijkstra's Algorithm Example

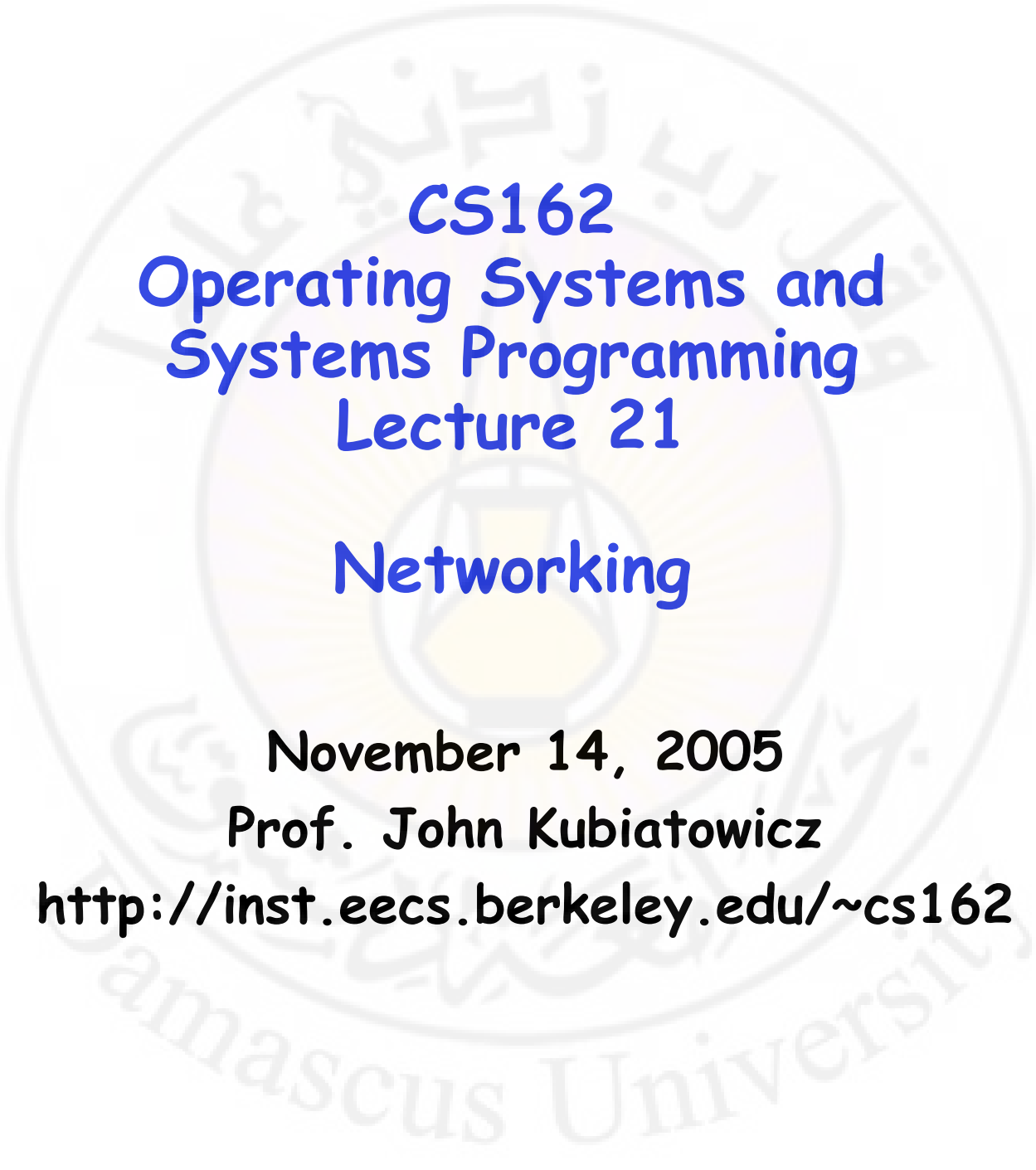
Iter	T	L(2)	Path	L(3)	Path	L(4)	Path	L(5)	Path	L(6)	Path
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Dijkstra's Algorithm Example

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6	{1, 2, 3, 4, 5, 6}	2	1-2	3	1-4-5-3	1	1-4	2	1-4-5	4	1-4-5-6

Summary

- routing in packet-switched networks
- routing strategies
 - fixed, flooding, random, adaptive
- ARPAnet examples
- least-cost algorithms
 - Dijkstra, Bellman-Ford

A large, faint watermark of the Damascus University seal is centered in the background. The seal is circular, featuring a central emblem with a sunburst and a shield, surrounded by Arabic calligraphy and the words 'Damascus University' at the bottom.

CS162

Operating Systems and Systems Programming

Lecture 21

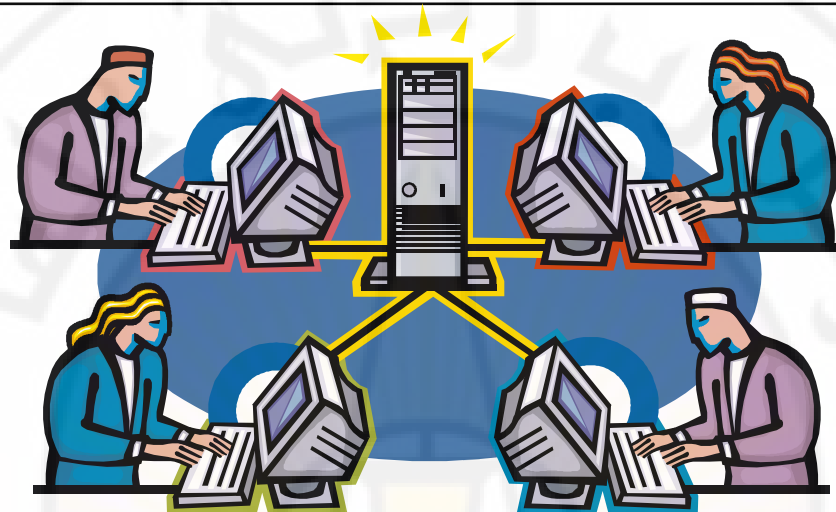
Networking

November 14, 2005

Prof. John Kubiawicz

<http://inst.eecs.berkeley.edu/~cs162>

Review: Networking Definitions



- **Network:** physical connection that allows two computers to communicate
- **Packet:** unit of transfer, sequence of bits carried over the network
 - Network carries packets from on CPU to another
 - Destination gets interrupt when packet arrives
- **Protocol:** agreement between two parties as to how information is to be transmitted

Goals for Today

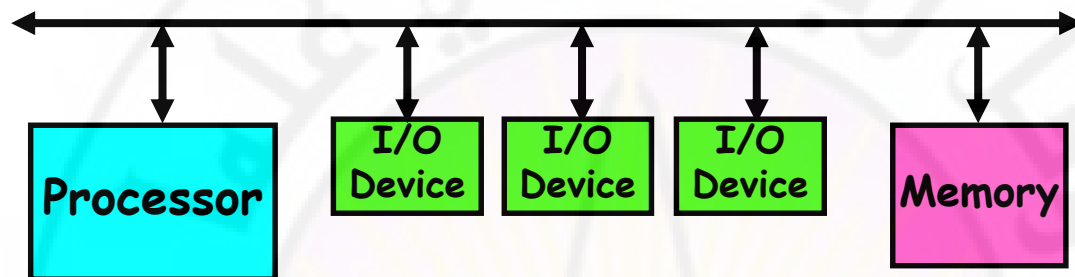
- **Networking**
 - Broadcast Networks
 - Point-to-Point Networks
 - Network Protocols

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne

Broadcast Networks

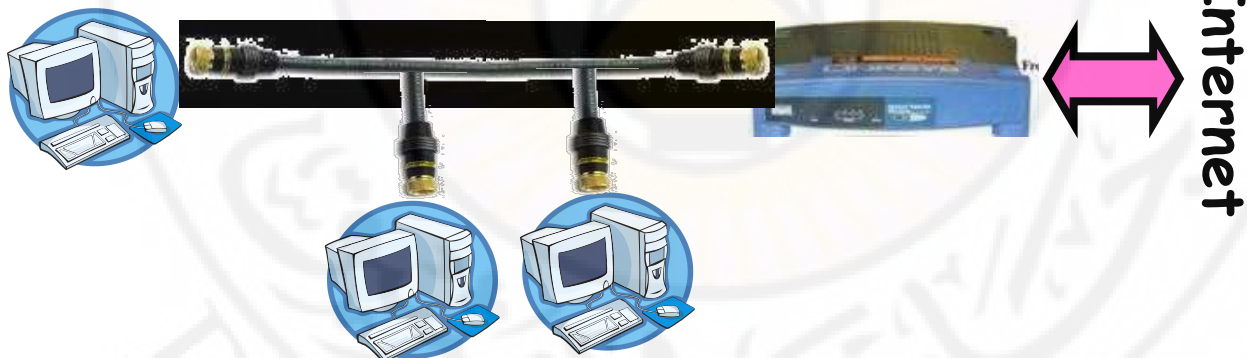


- **Broadcast Network:** Shared Communication Medium



- **Shared Medium can be a set of wires**

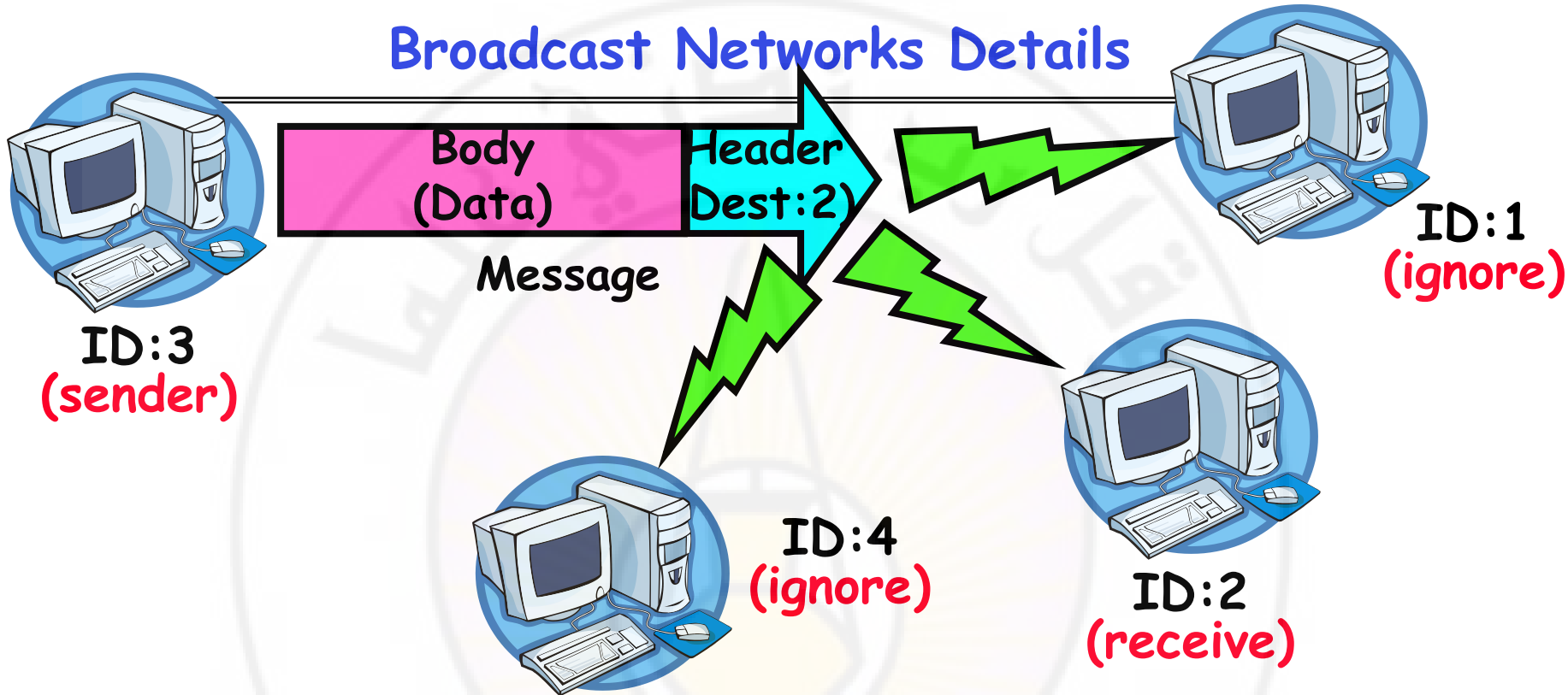
- Inside a computer, this is called a bus
- All devices simultaneously connected to devices



- Originally, **Ethernet** was a broadcast network

- All computers on local subnet connected to one another
- More examples (wireless: medium is air): cellular phones, **GSM GPRS, EDGE, CDMA 1xRTT, and 1evDO**

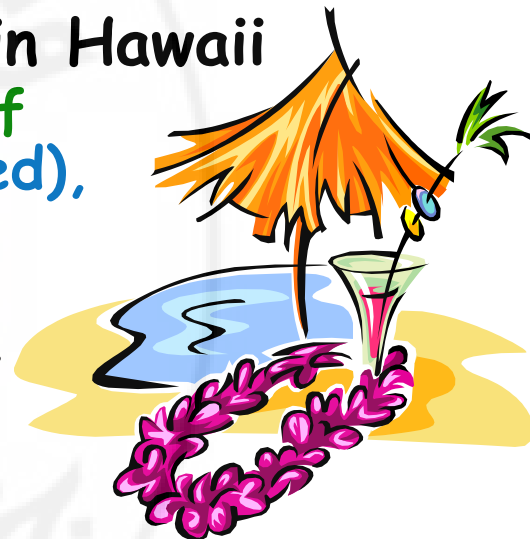
Broadcast Networks Details



- **Delivery:** When you broadcast a packet, how does a receiver know who it is for? (packet goes to everyone!)
 - Put **header** on front of **packet**: [**Destination** | **Packet**]
 - **Everyone gets packet**, **discards** if **not the target**
 - In Ethernet, this check is done in hardware
 - No OS interrupt if not for particular destination
 - This is layering: we're going to build complex network protocols by layering on top of the packet

Broadcast Network Arbitration

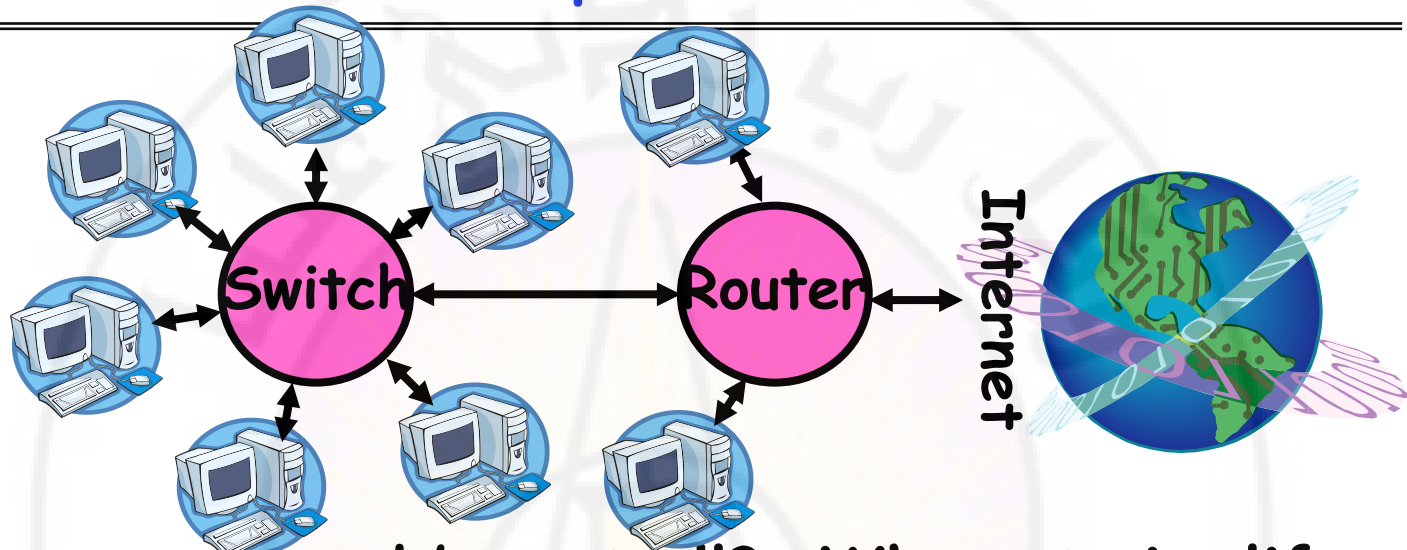
- **Arbitration: Act of negotiating use of shared medium**
What if two senders try to broadcast at same time? -
 - Concurrent activity but can't use shared memory to coordinate!
- **Aloha network (70's): packet radio within Hawaii**
 - Blind broadcast, with checksum at end of packet. If received correctly (not garbled), send back an acknowledgment. If not received correctly, discard.
 - Need checksum anyway - in case airplane flies overhead
 - Sender waits for a while, and if doesn't get an acknowledgement, re-transmits.
 - If two senders try to send at same time, both get garbled, both simply re-send later.
 - Problem: Stability: what if load increases?
 - More collisions $\Rightarrow$ less gets through $\Rightarrow$ more resent $\Rightarrow$ more load... $\Rightarrow$ More collisions...
 - Unfortunately: some sender may have started in clear, get scrambled without finishing



Carrier Sense, Multiple Access/Collision Detection

- **Ethernet** (early 80's): first practical local area network
 - It is the **most common LAN** for UNIX, PC, and Mac
 - Use wire instead of radio, but still **broadcast medium**
- Key advance was in arbitration called **CSMA/CD**:
Carrier sense, multiple access/collision detection
 - **Carrier Sense**: don't send unless idle
 - Don't mess up communications already in process
 - **Collision Detect**: sender checks if packet trampled.
 - If so, abort, wait, and retry.
 - **Backoff Scheme**: Choose wait time before trying again
- How long to wait after trying to send and failing?
 - What **if everyone waits the same length of time**? Then, they all collide again at some time!
 - Must find way to break up shared behavior with nothing more than shared communication channel
- **Adaptive randomized waiting strategy**:
 - **Adaptive and Random**: First time, pick random wait time with some initial mean. If collide again, pick random value from bigger mean wait time. Etc.
 - Randomness is important to decouple colliding senders
 - Scheme figures out how many people are trying to send!

Point-to-point networks

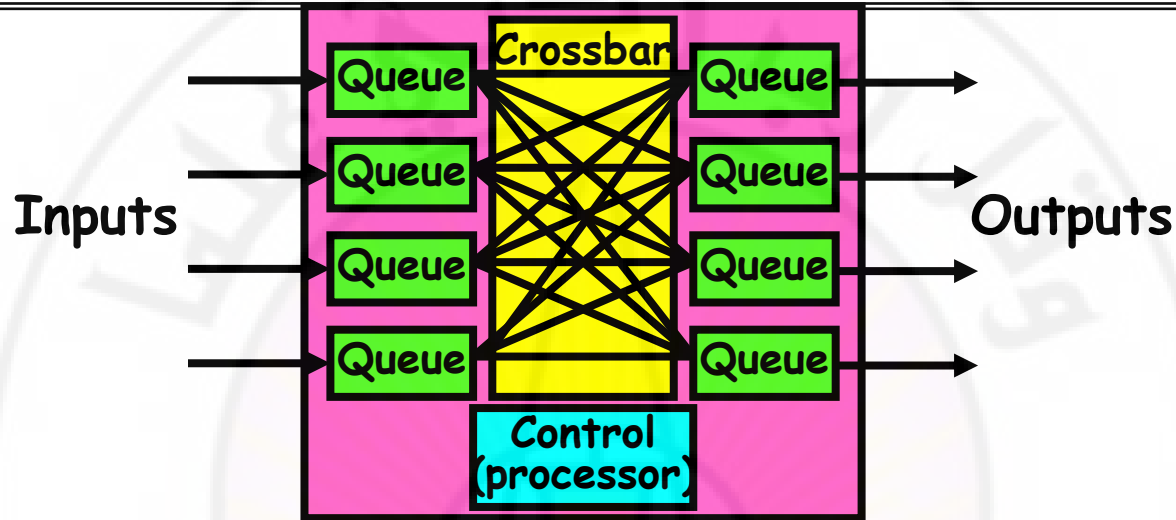


- Why have a shared bus at all? Why not simplify and only have **point-to-point links + routers/switches**?
 - Didn't used to be **cost-effective**
 - Now, **easy to make high-speed switches and routers that can forward packets from a sender to a receiver.**
- **Point-to-point network:** a network in which **every physical wire is connected to only two computers**
- **Switch:** a **bridge** that **transforms a shared-bus (broadcast) configuration into a point-to-point network.**
- **Router:** a **device** that acts as a **junction between two networks** to transfer data packets among them.

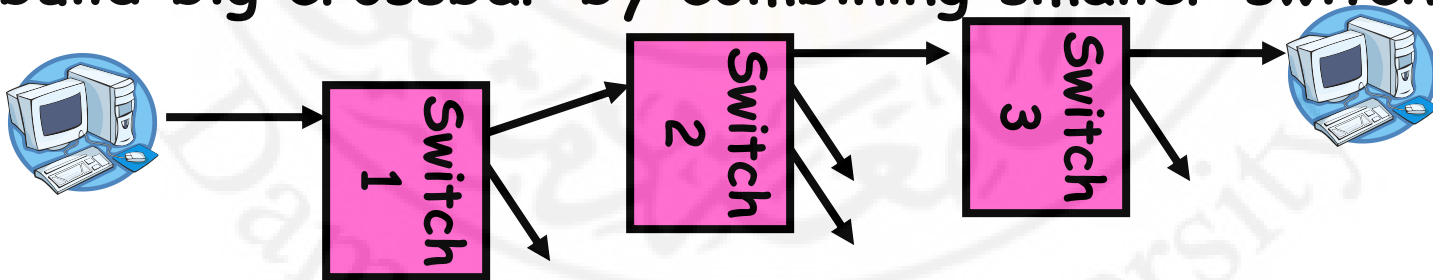
Point-to-Point Networks Discussion

- **Advantages:**
 - **Higher link performance**
 - Can drive point-to-point link **faster than broadcast link** since less capacitance/less echoes (from impedance mismatches)
 - **Greater aggregate bandwidth** than broadcast link
 - Can have **multiple senders at once**
 - **Can add capacity incrementally**
 - Add **more links/switches** to get **more capacity**
 - **Better fault tolerance** (as in the Internet)
 - **Lower Latency**
 - No arbitration to send, although need buffer in the switch
- **Disadvantages:**
 - **More expensive** than having everyone share broadcast link
 - However, technology costs now much cheaper
- **Examples**
 - **ATM** (asynchronous transfer mode)
 - The first commercial point-to-point LAN
 - Inspiration taken from telephone network
 - **Switched Ethernet**
 - Same packet format and signaling as broadcast Ethernet, but only two machines on each ethernet.

Point-to-Point Network design

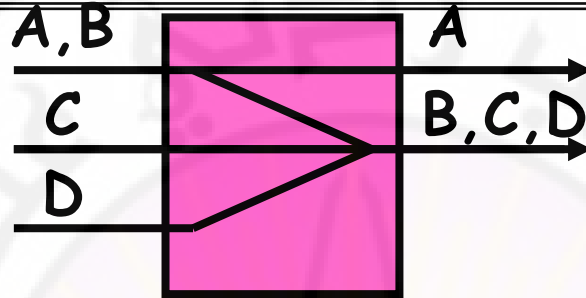


- Switches look like computers: inputs, memory, outputs
 - In fact probably contains a processor
- Function of switch is to forward packet to output that gets it closer to destination
- Can build big crossbar by combining smaller switches



- Can perform broadcast if necessary

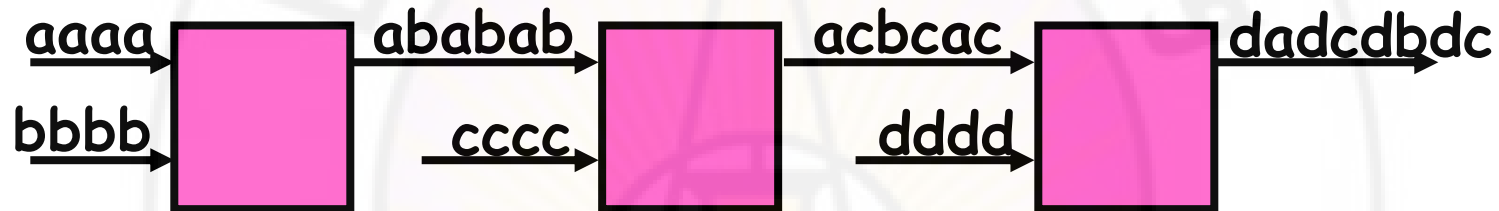
Flow control options



- What if everyone sends to the same output?
 - Congestion—packets don't flow at full rate
- In general, what if buffers fill up?
 - Need flow control policy
- Option 1: no flow control. Packets get dropped if they arrive and there's no space
 - If someone sends a lot, they are given buffers and packets from other senders are dropped
 - Internet actually works this way
- Option 2: Flow control between switches
 - When buffer fills, stop inflow of packets
 - Problem: what if path from source to destination is completely unused, but goes through some switch that has buffers filled up with unrelated traffic?

Flow Control (con't)

- **Option 3: Per-flow flow control.**
 - Allocate a separate set of buffers to each end-to-end stream and use separate "don't send me more" control on each end-to-end stream



- **Problem: fairness**
 - Throughput of each stream is entirely dependent on topology, and relationship to bottleneck
- **Automobile Analogy**
 - At traffic jam, one strategy is merge closest to the bottleneck
 - Why people get off at one exit, drive 50 feet, merge back into flow
 - Ends up slowing everybody else a huge amount
 - Also why have control lights at on-ramps
 - Try to keep from injecting more cars than capacity of road (and thus avoid congestion)

The Internet Protocol: “IP”

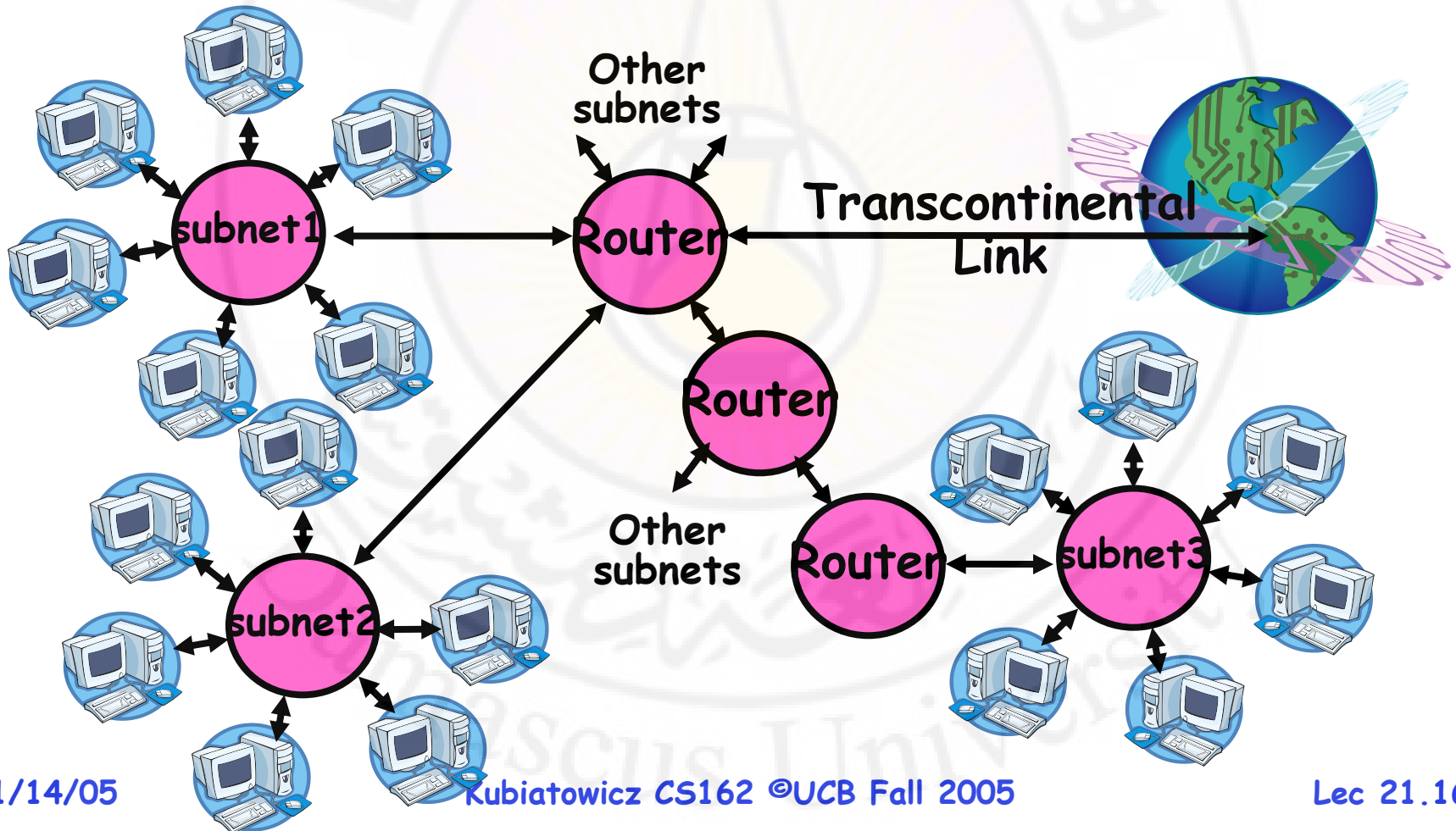
- **The Internet is a large network of computers spread across the globe**
 - According to the Internet Systems Consortium, there were over 353 million computers as of July 2005
 - In principle, every host can speak with every other one under the right circumstances
- **IP Packet: a network packet on the internet**
- **IP Address: a 32-bit integer used as the destination of an IP packet**
 - Often written as **four dot-separated integers**, with each integer from **0–255** (thus representing $8 \times 4 = 32$ bits)
 - Example CS file server is: **169.229.60.83** $\equiv$ 0xA9E53C53
- **Internet Host: a computer connected to the Internet**
 - Host has one or more IP addresses used for routing
 - Some of these may be **private** and **unavailable** for routing
 - **Not every computer has a unique IP address**
 - Groups of machines may share a single IP address
 - In this case, machines have private addresses behind a “**Network Address Translation**” (NAT) gateway

Address ranges and subnets

- **Address Ranges in IP**
 - IP address space divided into prefix-delimited ranges:
 - **NN.0.0.0/8:** Class A (10.0.0.0 private)
 - **NN.NN.0.0/16:** Class B (172.[16-31].0.0 private)
 - **NN.NN.NN.0/24:** Class C (192.168.xx.0 private)
 - Such ranges often owned by organizations
- **Subnet: A network connecting a set of hosts with related destination addresses**
 - With IP, all the addresses in subnet are related by a prefix of bits
 - The number of matching bits is called the "mask" and can be expressed as a **single value** (e.g. 24) or a **set of ones** in a **32-bit value** (e.g. 255.255.255.0)
 - A subnet is identified by 32-bit value, with the bits which differ set to zero, followed by a slash and a mask
 - E.g.: 128.32.131.0/24 designates a subnet in which all the addresses look like 128.32.131.XX
 - Same subnet: 128.32.131.0/255.255.255.0
- **Difference between subnet and complete network range**
 - **Subnet is always a subset of address range**
 - Once, subnet meant single physical broadcast wire; now, less clear exactly what it means (virtualized by switches)

Hierarchical Networking: The Internet

- How can we build a network with millions of hosts?
 - Hierarchy! Not every host connected to every other one
 - Use a network of Routers to connect subnets together
 - Routing is often by prefix: e.g. first router matches first 8 bits of address, next router matches more, etc.

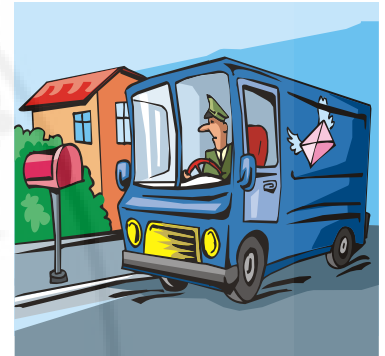


Simple Network Terminology

- **Local-Area Network (LAN)** - designed to cover small geographical area.
 - Multiaccess bus, ring, or star network
 - Speed $\approx 10 - 1000$ megabits/second
 - Broadcast is fast and cheap
 - In small organization, a LAN could consist of a single subnet. In large organizations (like Berkeley), a LAN contains many subnets.
- **Wide-Area Network (WAN)** - links geographically separated sites
 - Point-to-point connections over long-haul lines (often leased from a phone company)
 - Speed $\approx 1.544 - 45$ megabits/second
 - Broadcast usually requires multiple messages

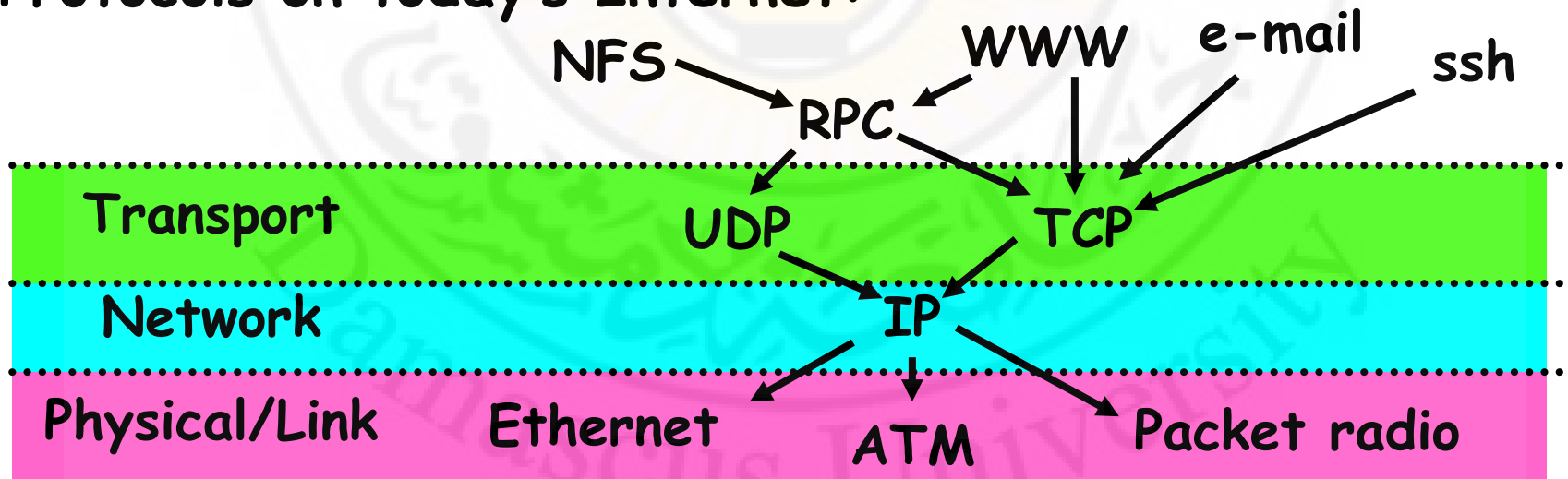
Routing

- **Routing: the process of forwarding packets hop-by-hop through routers to reach their destination**
 - Need more than just a destination address!
 - Need a path
 - Post Office Analogy:
 - Destination address on each letter is not sufficient to get it to the destination
 - To get a letter from here to Florida, must route to local post office, sorted and sent on plane to somewhere in Florida, be routed to post office, sorted and sent with carrier who knows where street and house is...
- Internet routing mechanism: routing tables
 - Each router does table lookup to decide which link to use to get packet closer to destination
 - Don't need 4 billion entries in table: routing is by subnet
 - Could packets be sent in a loop? Yes, if tables incorrect
- Routing table contains:
 - Destination address range → output link closer to destination
 - Default entry (for subnets without explicit entries)



Network Protocols

- **Protocol: Agreement between two parties as to how information is to be transmitted**
 - Example: system calls are the protocol between the operating system and application
 - Networking examples: **many levels**
 - **Physical level**: mechanical and electrical network (e.g. how are 0 and 1 represented)
 - **Link level**: packet formats/error control (for instance, the CSMA/CD protocol)
 - **Network level**: network routing, addressing
 - **Transport Level**: reliable message delivery
- **Protocols on today's Internet:**



Network Layering

- **Layering**: building complex services from simpler ones
 - Each layer provides services needed by higher layers by utilizing services provided by lower layers
- The **physical/link layer** is pretty **limited**
 - Packets are of limited size (called the "**Maximum Transfer Unit or MTU**": often 200-1500 bytes in size)
 - **Routing is limited** to within a physical link (wire) or perhaps through a switch
- Our goal in the following is to show how to construct a secure, ordered, message service routed to anywhere:

Physical Reality: Packets	Abstraction: Messages
Limited Size	Arbitrary Size
Unordered (sometimes)	Ordered
Unreliable	Reliable
Machine-to-machine	Process-to-process
Only on local area net	Routed anywhere
Asynchronous	Synchronous
Insecure	Secure

Building a messaging service

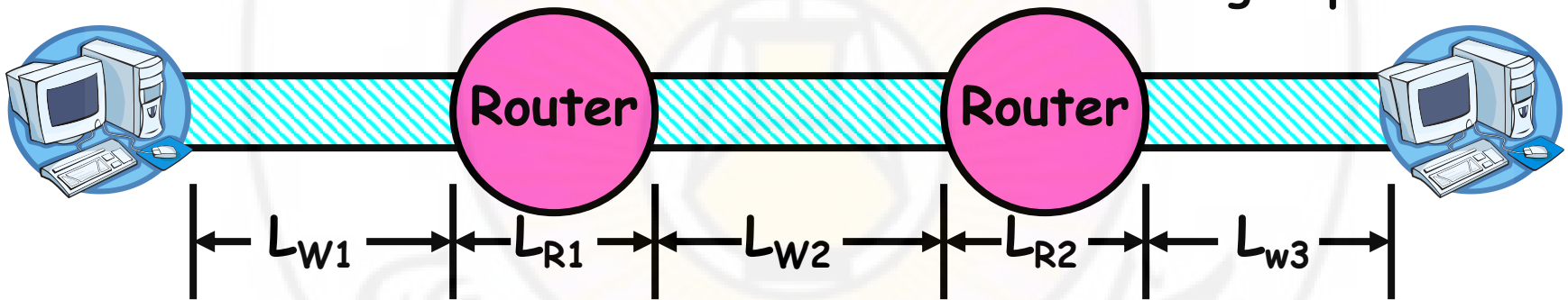
- **Handling Arbitrary Sized Messages:**
 - Must deal with limited physical packet size
 - Split big message into smaller ones (called fragments)
 - Must be reassembled at destination
 - Checksum computed on each fragment or whole message
- **Internet Protocol (IP): Must find way to send packets to arbitrary destination in network**
 - Deliver messages unreliably ("best effort") from one machine in Internet to another
 - Since intermediate links may have limited size, must be able to fragment/reassemble packets on demand
 - Includes 256 different "sub-protocols" build on top of IP
- **Process to process communication**
 - Basic routing gets packets from machine→machine
 - What we really want is routing from process→process
 - Example: ssh, email, ftp, web browsing
 - Several IP protocols include notion of a "port", which is a 16-bit identifier used in addition to IP address
 - A communication channel (connection) defined by 4 items:
[source address, source port, dest address, dest port]

Building a messaging service (con't)

- **UDP: The Unreliable Datagram Protocol**
 - **Datagram**: an unreliable packet sent from source→dest
 - UDP layered on top of basic IP (Call it UDP/IP)
 - Unreliable, unordered, user-to-user communication
 - Important aspect: low overhead!
 - Often used for high-bandwidth video streams
 - Many uses of UDP considered “anti-social” - none of the “well-behaved” aspects of (say) TCP/IP
- **Ordered Messages**
 - Ordered messages on top of unordered ones
 - IP can reorder packets! P_0, P_1 might arrive as P_1, P_0
 - How to fix this? **Assign sequence numbers to packets**
 - 0,1,2,3,4....
 - If packets arrive out of order, reorder before delivering to user application
 - For instance, hold onto #3 until #2 arrives, etc.
 - Sequence numbers are specific to particular connection

Performance Considerations

- Before continue, need some performance metrics
 - **Overhead**: CPU time to put packet on wire
 - **Throughput**: Maximum number of bytes per second
 - Depends on “wire speed”, but also limited by **slowest router** (routing delay) or by congestion at routers
 - **Latency**: time until first bit of packet arrives at receiver
 - Raw transfer time + overhead at each routing hop

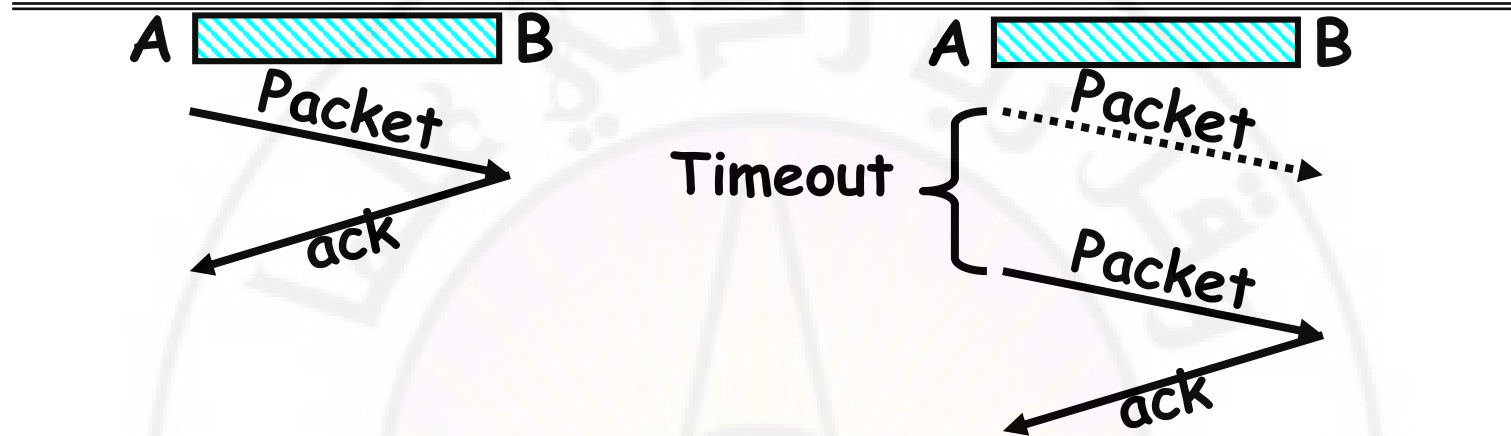


- Contributions to Latency
 - Wire latency: depends on speed of light on wire
 - about 1.5 ns/foot
 - Router latency: depends on internals of router
 - Could be < 1 ms (for a good router)
 - Question: can router handle full wire throughput?

Reliable Message Delivery: the Problem

- All physical networks can garble and/or drop packets
 - Physical media: packet not transmitted/received
 - If transmit close to maximum rate, get more throughput - even if some packets get lost
 - If transmit at lowest voltage such that error correction just starts correcting errors, get best power/bit
 - Congestion: no place to put incoming packet
 - Point-to-point network: insufficient queue at switch/router
 - Broadcast link: two host try to use same link
 - In any network: insufficient buffer space at destination
 - Rate mismatch: what if sender send faster than receiver can process?
- Reliable Message Delivery
 - Reliable messages on top of unreliable packets
 - Need some way to make sure that packets actually make it to receiver
 - Every packet received at least once
 - Every packet received only once
 - Can combine with ordering: every packet received by process at destination once and in order

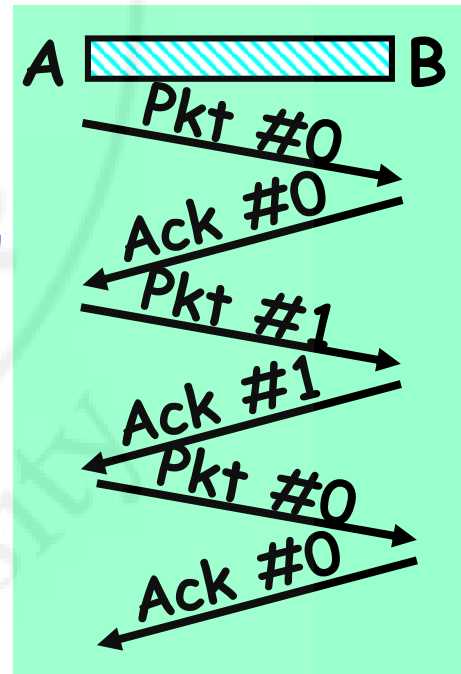
Using Acknowledgements



- How to ensure transmission of packets?
 - Detect garbling at receiver via checksum, discard if bad
 - Receiver acknowledges (by sending "ack") when packet received properly at destination
 - Timeout at sender: if no ack, retransmit
- Some questions:
 - If the sender doesn't get an ack, does that mean the receiver didn't get the original message?
 - No
 - What if ack gets dropped? Or if message gets delayed?
 - Sender doesn't get ack, retransmits. Receiver gets message twice, acks each.

How to deal with message duplication

- **Solution: put sequence number in message to identify re-transmitted packets**
 - Receiver checks for duplicate #'s; Discard if detected
- **Requirements:**
 - Sender keeps copy of unack'd messages
 - Easy: only need to buffer messages
 - Receiver tracks possible duplicate messages
 - Hard: when ok to forget about received message?
- **Simple solution: Alternating-bit protocol**
 - Send one message at a time; don't send next message until ack received
 - Sender keeps last message; receiver tracks sequence # of last message received
- **Pros: simple, small overhead**
- **Con: Poor performance**
 - Wire can hold multiple messages; want to fill up at (wire latency $\times$ throughput)
- **Con: doesn't work if network can delay or duplicate messages arbitrarily**



Conclusion

- **Network:** physical connection that allows two computers to communicate
 - Packet: sequence of bits carried over the network
- **Broadcast Network:** Shared Communication Medium
 - Transmitted packets sent to all receivers
 - Arbitration: act of negotiating use of shared medium
 - Ethernet: Carrier Sense, Multiple Access, Collision Detect
- **Point-to-point network:** a network in which every physical wire is connected to only two computers
 - Switch: a bridge that transforms a shared-bus (broadcast) configuration into a point-to-point network.
- **Protocol:** Agreement between two parties as to how information is to be transmitted
- **Internet Protocol (IP)**
 - Used to route messages through routes across globe
 - 32-bit addresses, 16-bit ports
- **Reliable, Ordered, Arbitrary-sized Messaging:**
 - Built through protocol layering on top of unreliable, limited-sized, non-ordered packet transmission links