AMRITA VISHWA VIDYAPEETHAM

AHEAD Online

Computer Networks Introduction

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Chancellor's Inspirational Message

- ***"Along with a connection to the Internet, we also need to rediscover our 'Inner-net' connection.*** **Real Education teaches us how to manage both our internal and external worlds"**
  Amma, Sri Mata Amritanandamayi, Chancellor

Basics in the Network

Week1 Lecture1

Learn the Basics in the Network

- Understand the Network terminologies
- Analyse the hardware components of a network
- Internet as network of networks
- Discuss the Internet Components

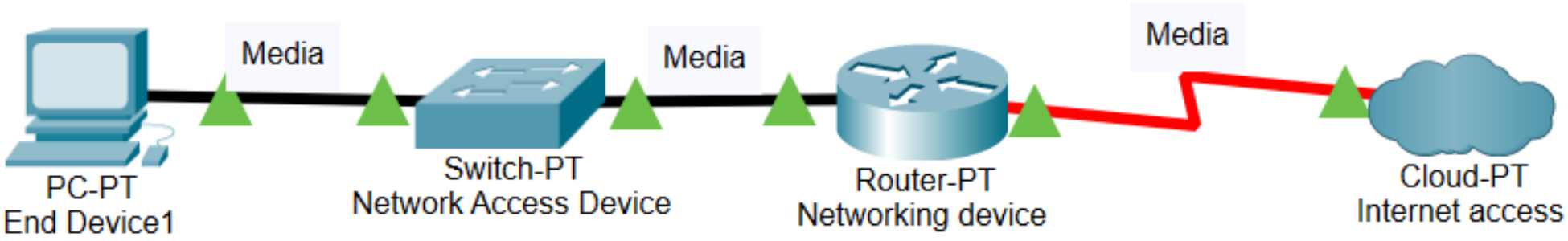
What is Internet?

- In today's world, we are online by connecting our laptops/cell phone through the Internet access.
- Internet = infrastructure providing services to applications
- Applications include Email, web surfing, video streaming etc
- Internet = network of trillions of computers and other electronic devices connected to share information globally.
- Internet can also be mentioned as network of networks.

https://www.freepik.com/

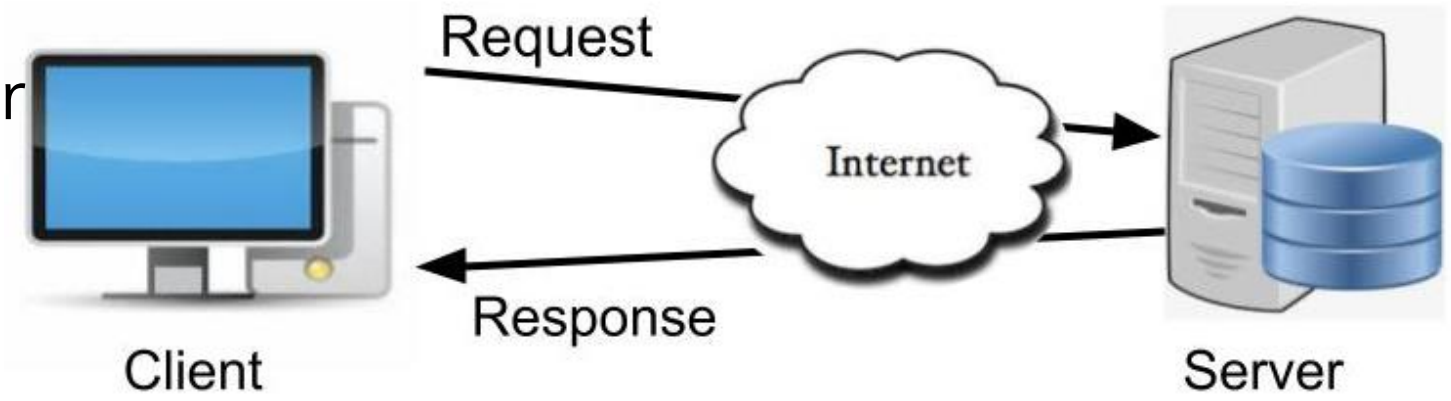
What is Network?

- A computer network is set of connected computers for sharing data
- Network = End devices + Media + Networking devices (hardware)
- End devices = Computer, Laptops, Mobile Phones etc
- Networking devices = Link Layer Switches, Access point, Routers etc
- Media = Communication medium connecting devices



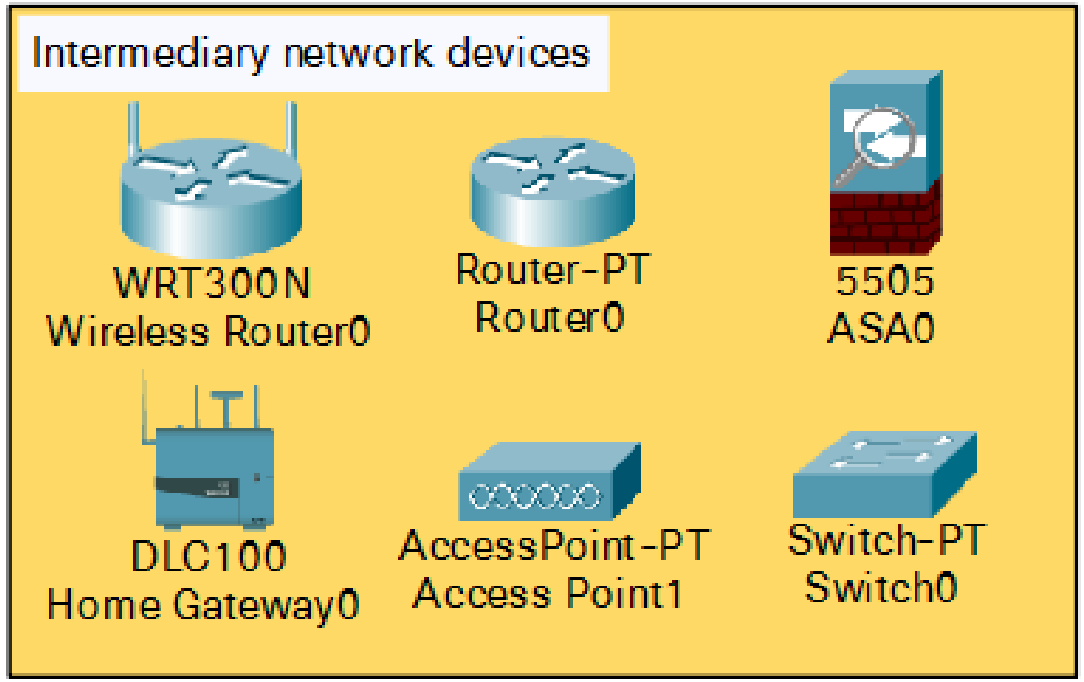
End Devices?

- An End device is where message is sent or received
- End Device = Host running network applications
- Servers are computers that provide information to the end devices
- Example – Web servers, Email servers, file server
- Clients are end device that send requests to the servers to retrieve information.
- Webpage request - browser



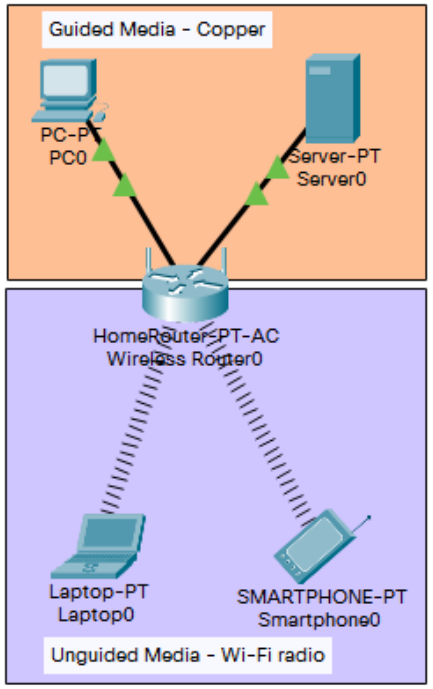
Intermediary Network Devices?

- Intermediary network devices interconnects end devices
- Example: Ethernet Switch, Wireless Access Point, Routers etc



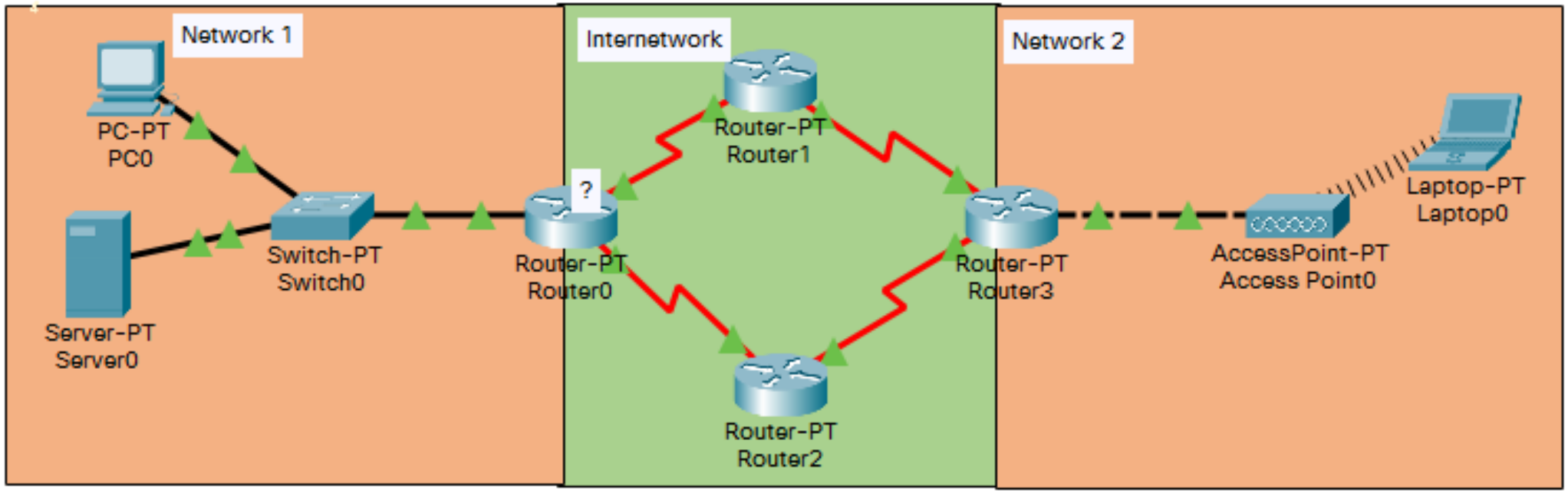
Physical Media?

- Physical link allows a message to travel from source to destination.
- Messages as Bits propagates between transmitter and receiver pairs
  - Transmitter = Encoding bits to signals
  - Receiver = Decoding signals to bits
  - Transmission Rate = bandwidth (bps)
- Guided Media: Signals propagate in solid media
  - Ex: copper, fiber, coax
- Unguided Media: Signals propagate freely
  - Signals carried in Electromagnetic spectrum
  - Ex: Radio – Microwave, Wi-Fi, Cellular, Satellite



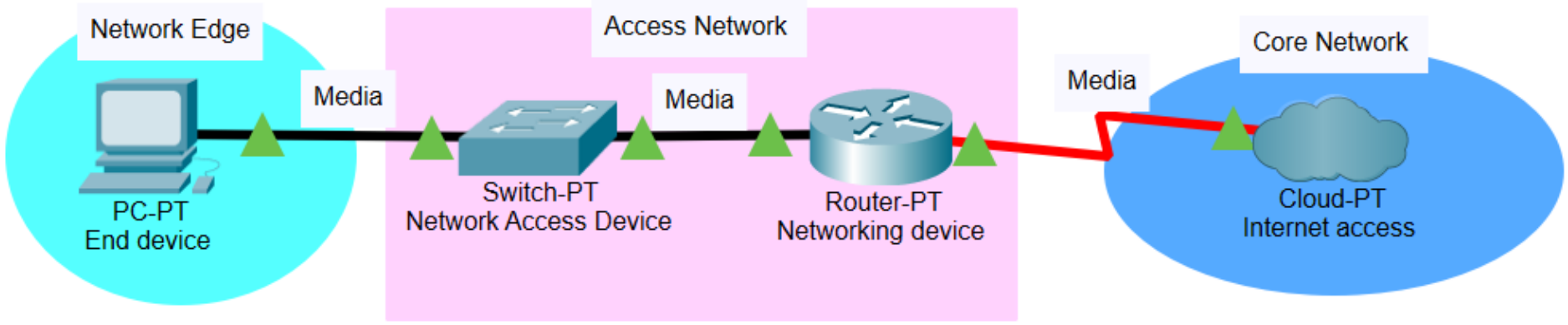
Data flow in the Network

Data originates with an end device from Network 1,
flows through the inter network by deciding the path of the messages,
and arrives at destination say an end device in another Network 2.



Internet components

- Internet = Network Edge + Access Network + Core Network
- Network Edge = End devices like computer, laptops, mobile connecting at the end of the network
- Access Network = Local network that helps the End devices to get connected to the core network
- Core Network = Backbone of the Internet



Summary of Network Components

- Hardware components of Network = End devices + Media + Networking Intermediary devices
- Internet Components = Network Edge + Access Networks + Core Networks
- Next lecture is about Network Classification

Network Classification

Week1 Lesson2

Network Classification

Understand the classification of network based on infrastructure

Understand the terms PAN, LAN, WAN, intranet, extranet and internet

Analyse the difference between physical and logical topology

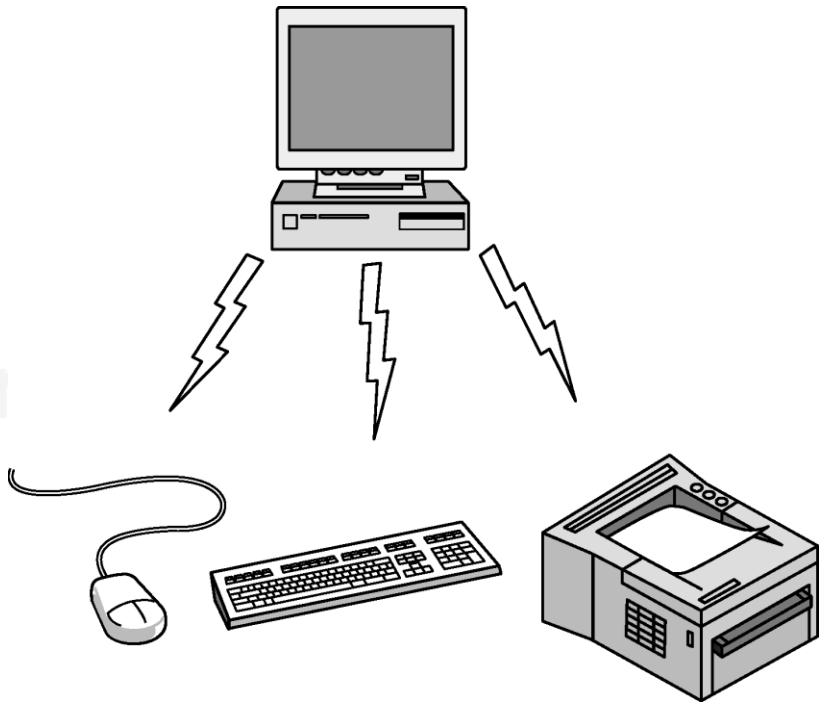
Network Infrastructure

- Network infrastructures/hardware vary greatly in terms of the Size of the area covered and number of users connected and in terms of services
- Most common Network classification based on hardware:

Network Types	Area covered	Example
Personal Area Network (PAN)	Few square meter	Bluetooth
Local Area Network(LAN)	Few kilometer – within a building or campus	Ethernet, Wi-Fi
Wide Area Network(WAN)	Devices within a country or continent	Connecting LANs in different cities
Internet	Entire planet	World Wide Web

Personal Area Network (PAN)

- Connecting Devices within a square metres
- Bluetooth wireless technology is a short range communication used to replace wires
- Ex: Bluetooth keyboard, speakers, mouse, printer etc
- Bluetooth master in PC can connect up to 7 slave devices

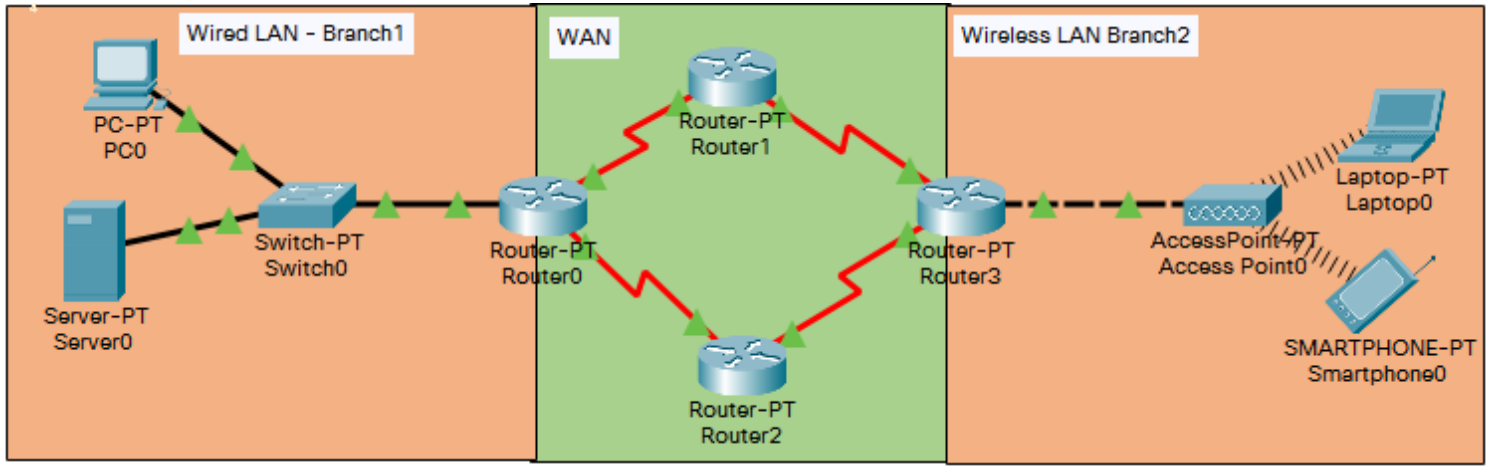


Bluetooth PAN configuration.

CN5E by Tanenbaum & Wetherell, © Pearson Education-Prentice Hall , 2011

LAN Vs WAN

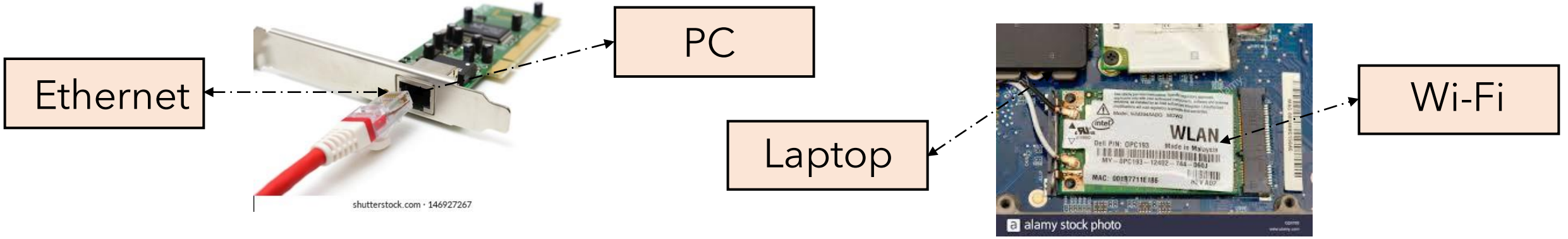
- A LAN is a network infrastructure that spans a small geographical area.
- Administered by a single organization or individual.
- A WAN is a network infrastructure that spans a wide geographical area.
- Typically administered by one or more service providers.



Wired LAN Vs Wireless LAN

- Wired LAN is also called as Ethernet.
- Wired Network Interface cards (NIC) are used to interface the end device to the media.

- Wireless LAN is also called as Wireless Fidelity (Wi-Fi).
- Wireless NICs are used
- Both these LAN types are shared medium

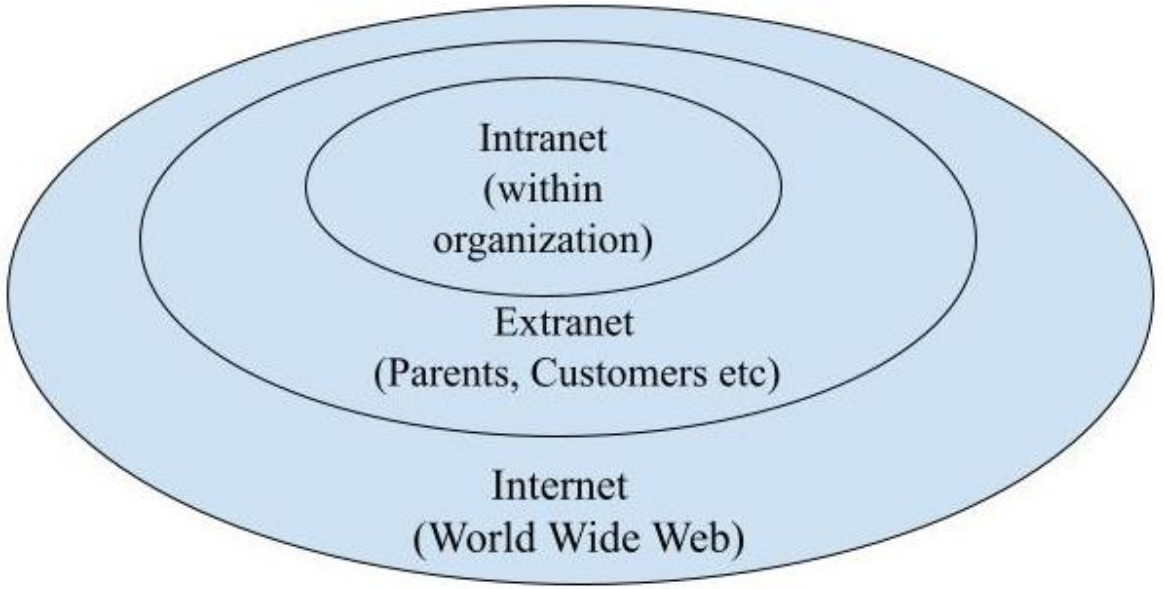


WAN Vs Internet

- Wide Area Network (WAN) helps in connecting different branches or sites or campus to single institutional network
- World Wide Web (www) Networks – connects hundreds of millions of computers world-wide – such as the internet
- The internet is a worldwide collection of interconnected LANs and WANs.
  - LANs are connected to each other using WANs.
  - WANs may use fiber optic cables, and wireless transmissions.
- The internet is not owned by any individual or group.

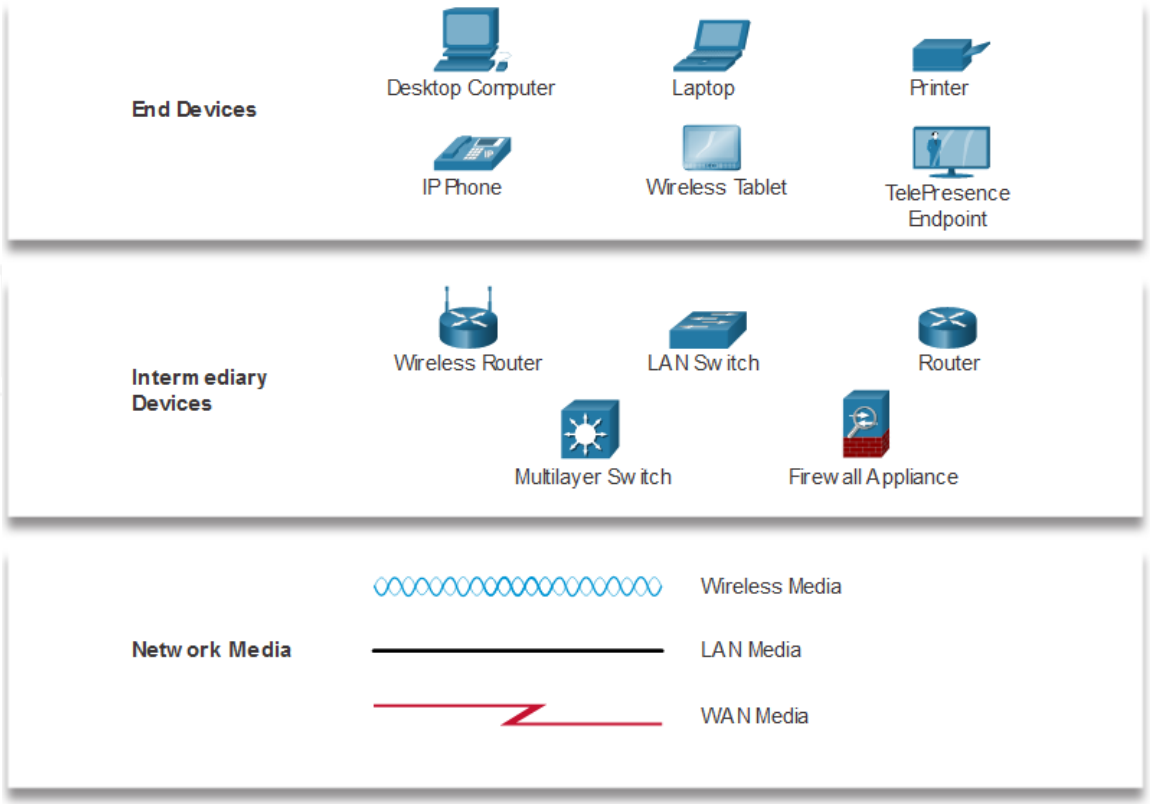
Intranet Vs Internet

- An intranet is a private collection of LANs and WANs used Ex: www.my.amrita.ac.in
- An organization might use an extranet to provide secure access to their data Ex: AUMS Parent Portal
- Internet is public access and is network of networks.



Network Representation

- Network diagrams also known as topology diagrams.
- Topology = Arrangement of devices in a network
- It use symbols to represent devices and links within the network.

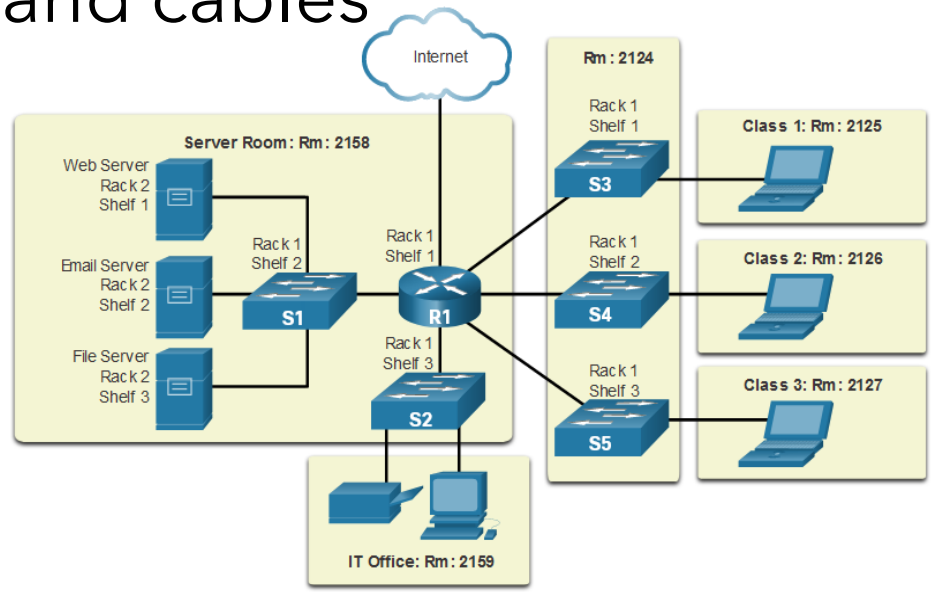


Ref: CCNA Introduction to Networks from Cisco Netacad

Topology Diagrams

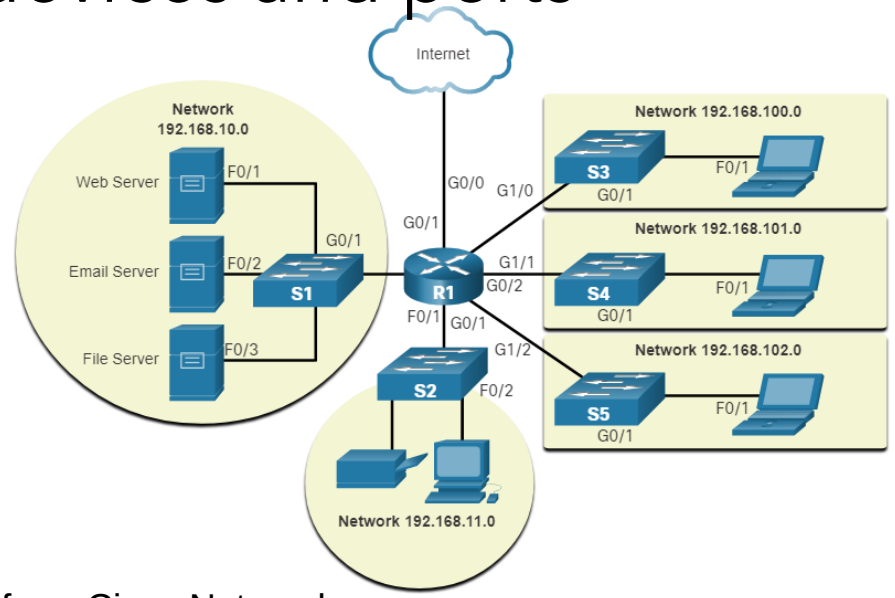
Physical Topology

- Diagrams illustrate the physical location of devices and cables



Logical Topology

- Diagrams illustrate the addressing scheme for devices and ports



Ref: CCNA Introduction to Networks from Cisco Netacad

Recap

- PAN, LAN & WAN
- Wired Vs Wireless LANs

- Intranet, Extranet & Internet

- Network Representation
- Topology diagrams

Network Structure

Week1

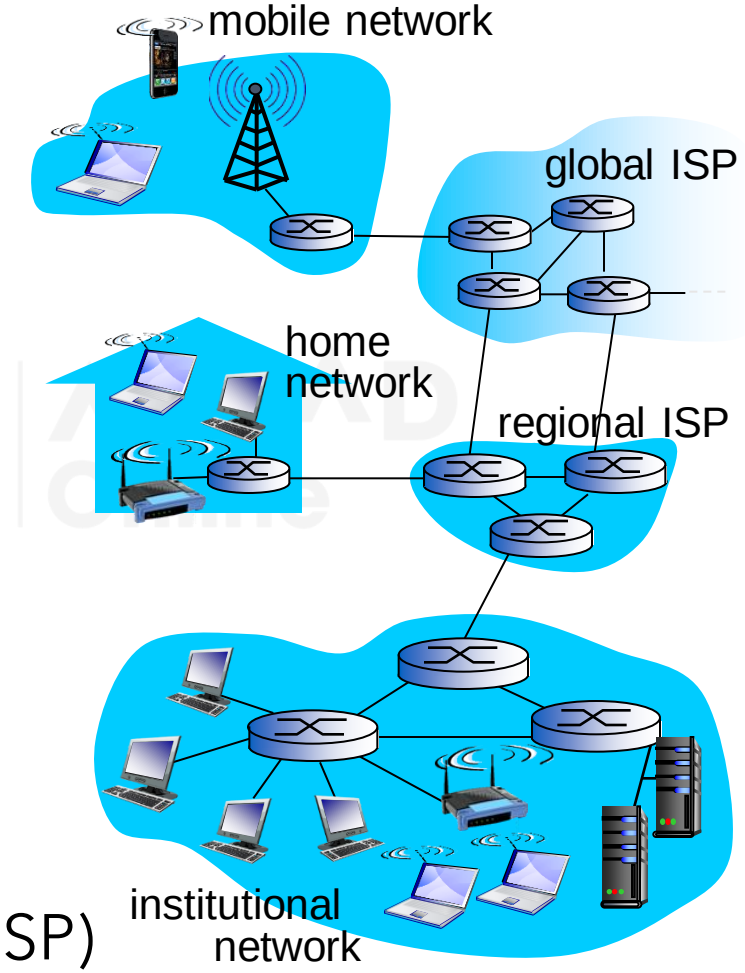
Lesson3

Key Points in Network Structure

- Analyze Network Structure
  - Understand Network Edge
  - Analyze Physical Media
  - Network Access
    - Who provides Internet Access?

Network Structure

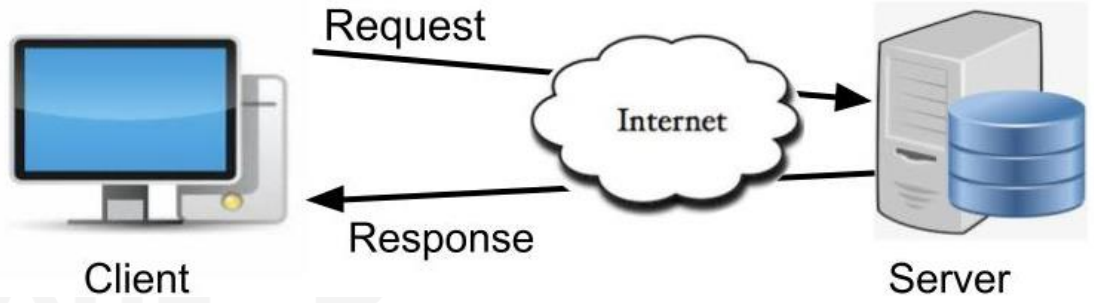
- Network Edge:
  - Hosts: clients and servers
  - Servers often in data centers
- Access Networks, Physical Media
  - Wired, wireless communication links
  - Residential home access
  - Institutional access
  - Mobile access
- Network Core
  - Interconnected routers
  - Access via Internet Service Provider (ISP)

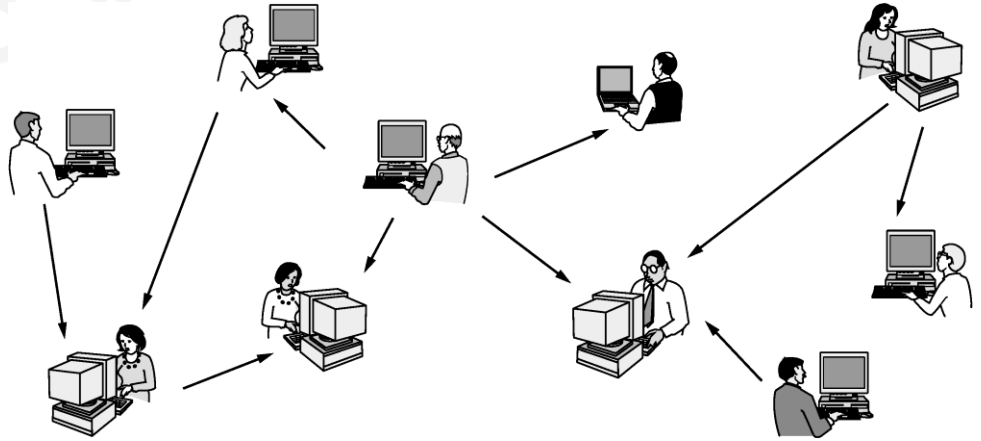


J. Kurose and K. Ross 2012, Computer Network,6th ed.

Network Edge

- End systems or hosts
  - at the end of the network
  - Runs application programs (Web, Email)
- Client/Server model
  - Client requests (Ex: Web browser)
  - Always-on-server responds (Ex: Webserver)
- Peer-Peer model
  - Minimal/ no use of dedicated servers
  - Ex: skype, BitTorrent



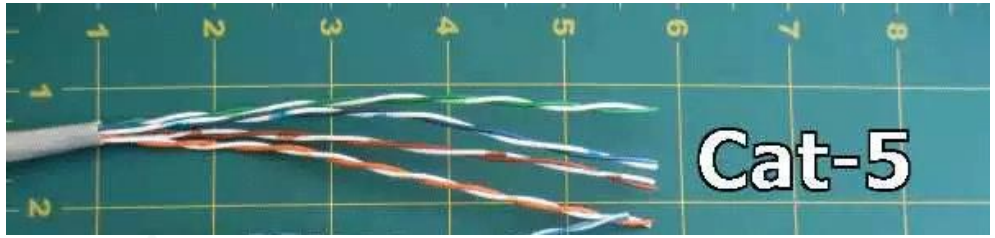


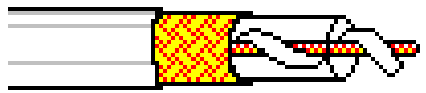
Peer-to-Peer model

CN5E by Tanenbaum & Wetherell, © Pearson Education-Prentice Hall , 2011

Guided Media

- Signals propagate in solid media.
  - Twisted Pair – 2 insulated copper wires
    - Bits are encoded as electric signals
    - Category 3: 10Mbps Ethernet
    - Category 5: 100 Mbps Ethernet
  - Fiber optic cable
    - Bits are encoded as light signals
    - High speed operation through Point-to-point transmission
    - Low error rate – immune to electromagnetic noise
  - Coaxial cable - 2 concentric copper conductors & bidirectional
    - Base band – single channel on cable. Ex: legacy Ethernet
    - Broad band – multiple channels on cable. Ex: Hybrid Fiber Coax (HFC)

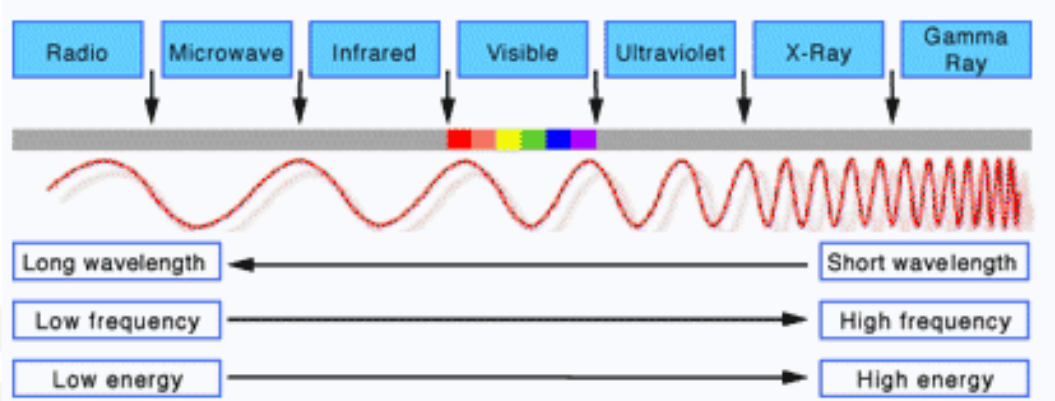


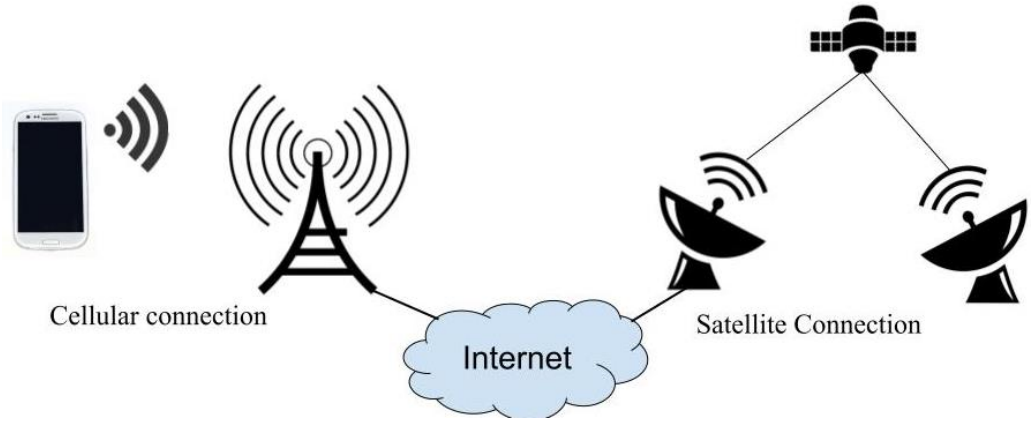


J. Kurose and K. Ross 2012, Computer Network,6th ed.

Unguided Media

- Signals propagate freely. Ex: Radio
  - Electro-magnetic spectrum
- Propagation environment effects
  - reflection, obstruction & interference
- Major radio types
  - Satellite Microwave
    - 11GHz to 14 GHz
  - Cellular for wide area
    - 20KHz to 300 GHz Radio Frequency
  - Wi-Fi LAN
    - Unlicensed 2.4 GHz and 5 GHz





Internet Access

- Access Networks helps End Systems to get the internet access by the help of Internet Service Provider(ISP) .
- ISP is an organization that provides internet access to the Internet to home, company and institution.
- Content Provider Network is a Private network that connects its data center to Internet. Ex: google.com
- ISP gives host address to the customers and content provider
  - Host address is Internet Protocol (IP) address to identify a host in the Internet
  - Ex: IP address of google.co.in is 192.168.42.129

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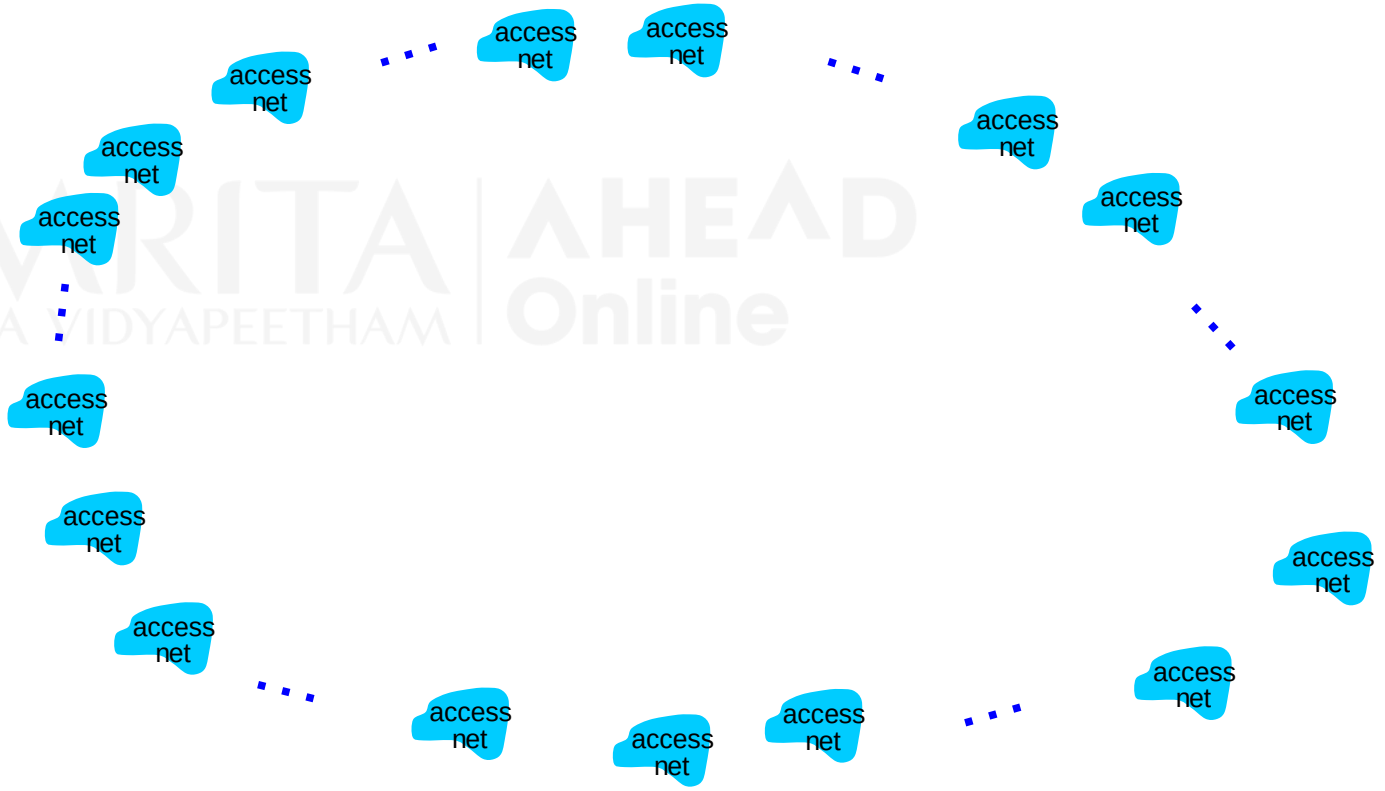
Internet structure

- How to connect millions of Access Networks together?



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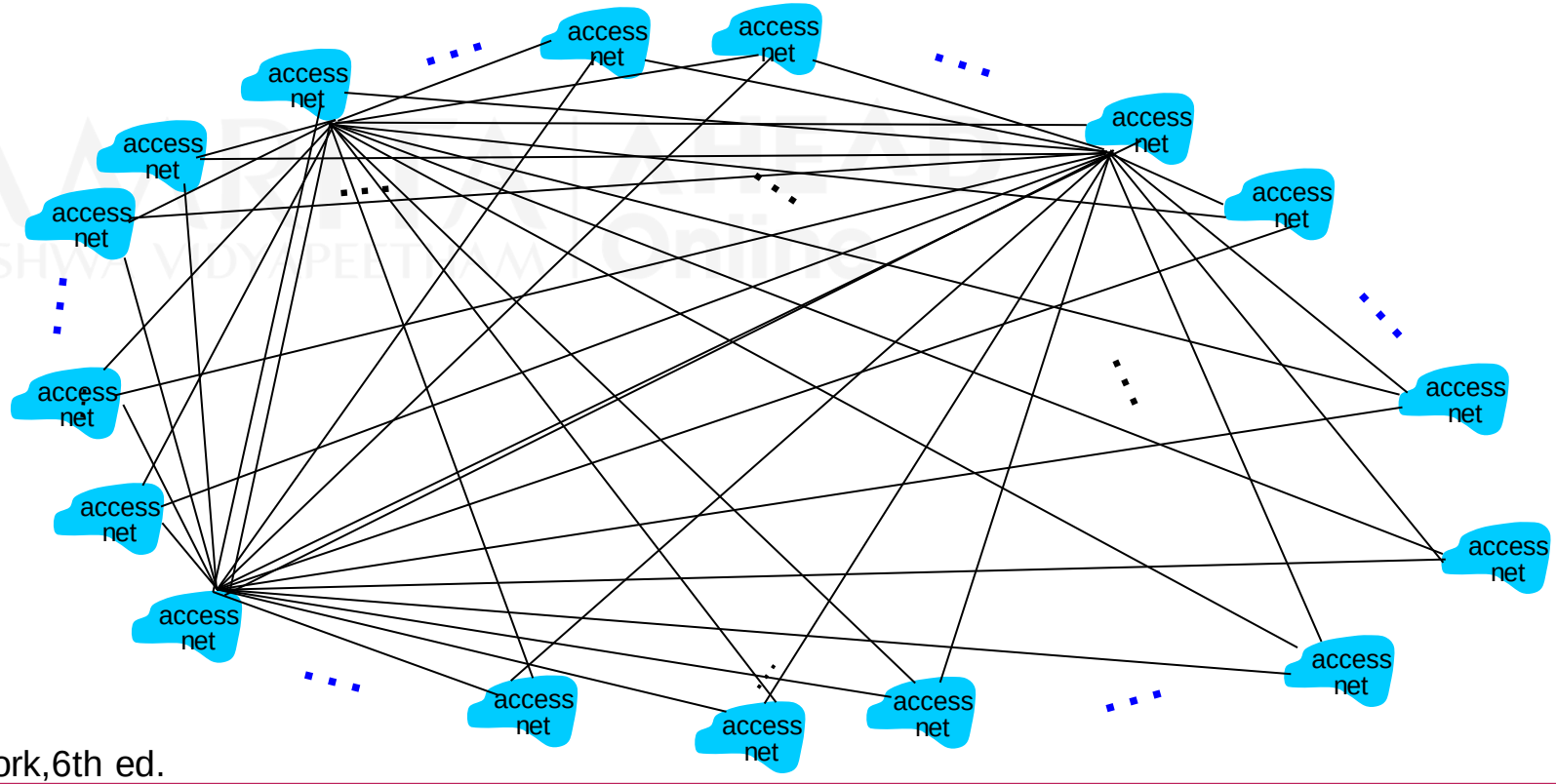
Internet structure

- Can we connect each access net with every other access net?
  - Scalability issue, having $O(N^2)$ connections



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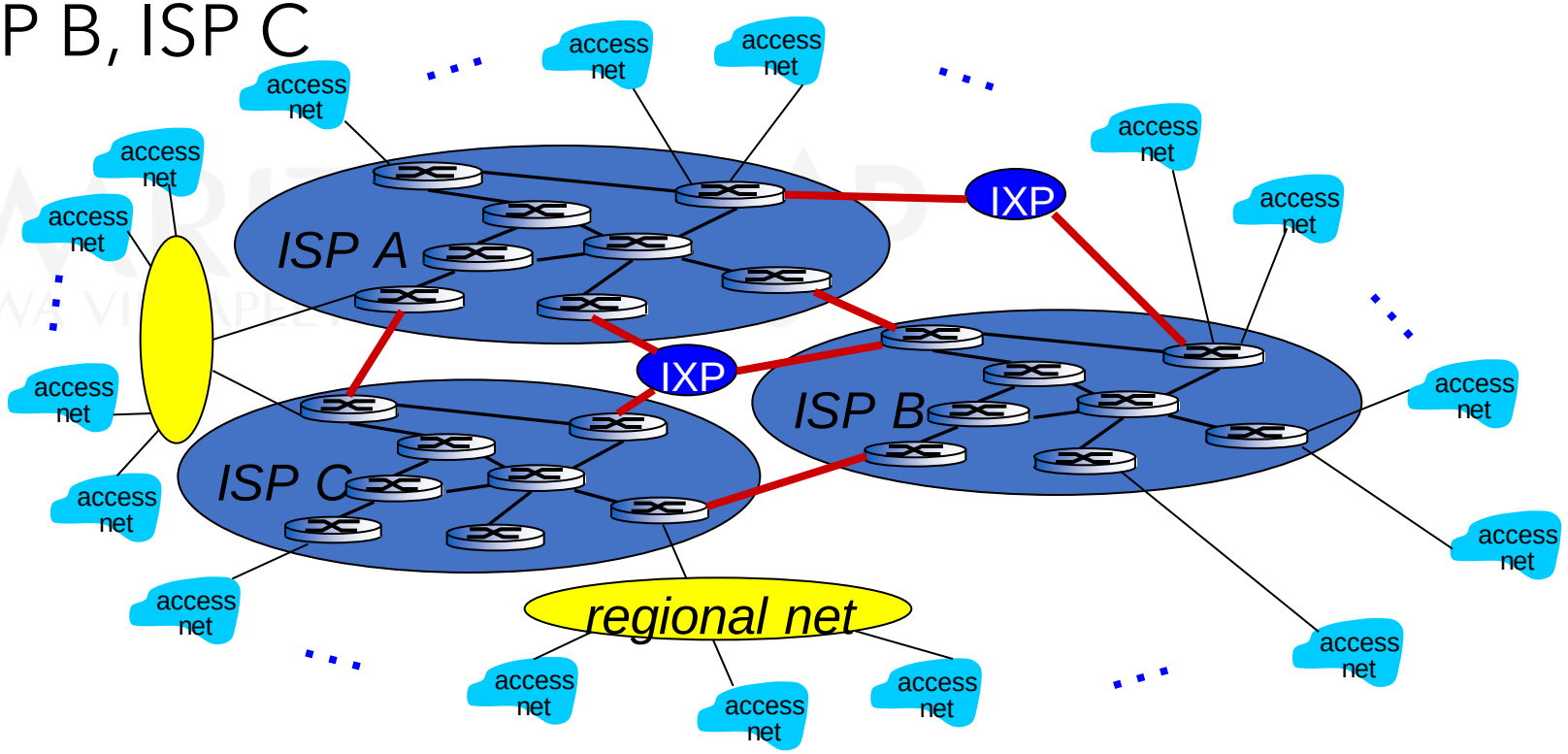
Internet structure

- Access ISP ->Regional ISPs -> Global ISPs
- Global ISPs – ISP A, ISP B, ISP C
- Internet Exchange Point(IXP) to link 2 different ISPs



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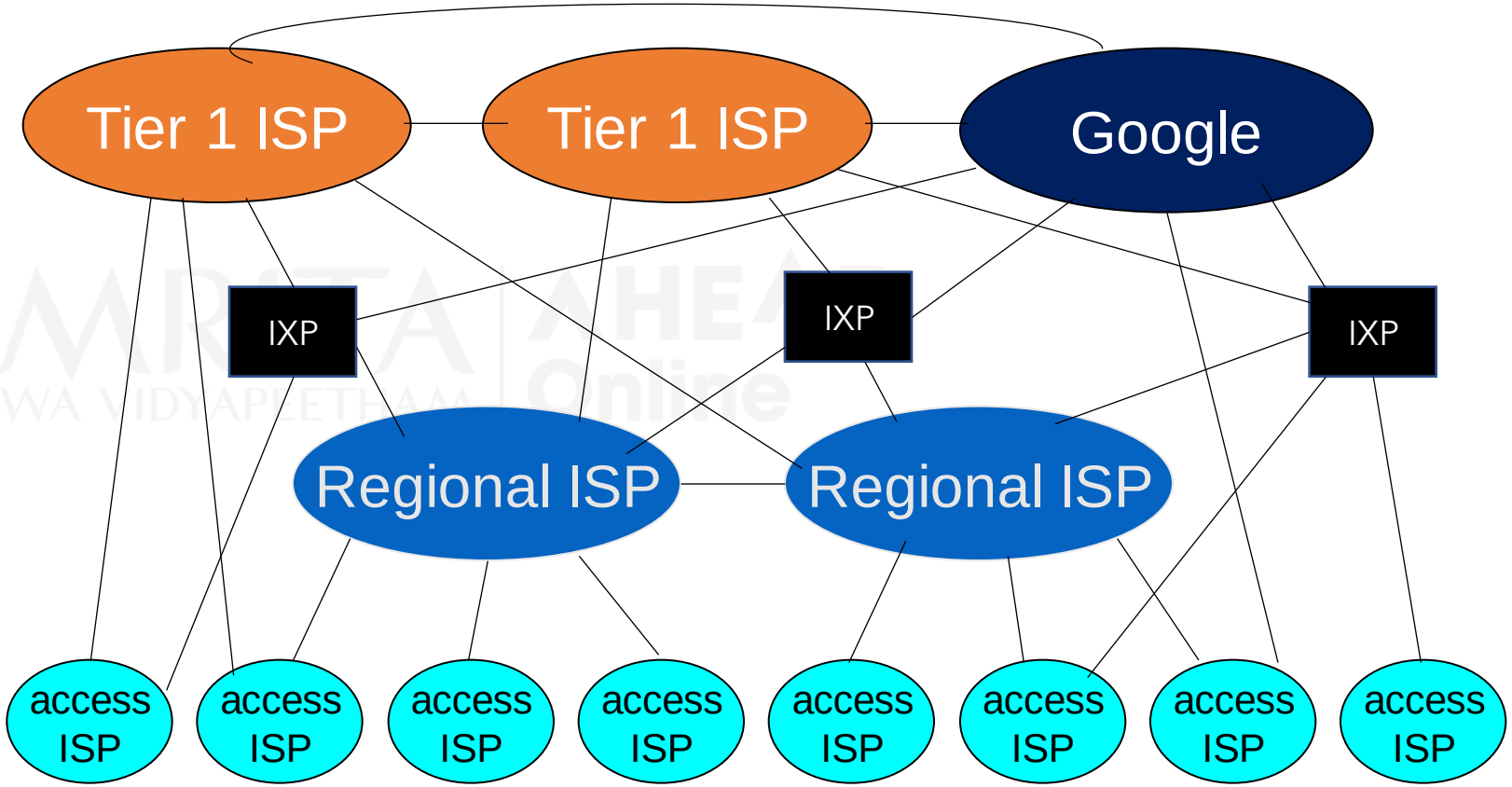
Internet Service Provider (ISP)

- Tier1 Commercial ISP
  - Ex: Sprint, AT&T, NTT
- Tier2 Regional ISP
- Tier3 Access ISP
  - Ex: Airtel, Idea etc
- Internet
  - Interconnected ISPs in hierarchical manner
  - Network of networks



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Summary

- Network Structure
  - Network Edge
  - Physical Media
  - Network Access
- Internet Structure - ISPs
- Next we will Discussed various ways to Network Access
  - Residential home access
  - Institutional access
  - Mobile communication access

Internet Access

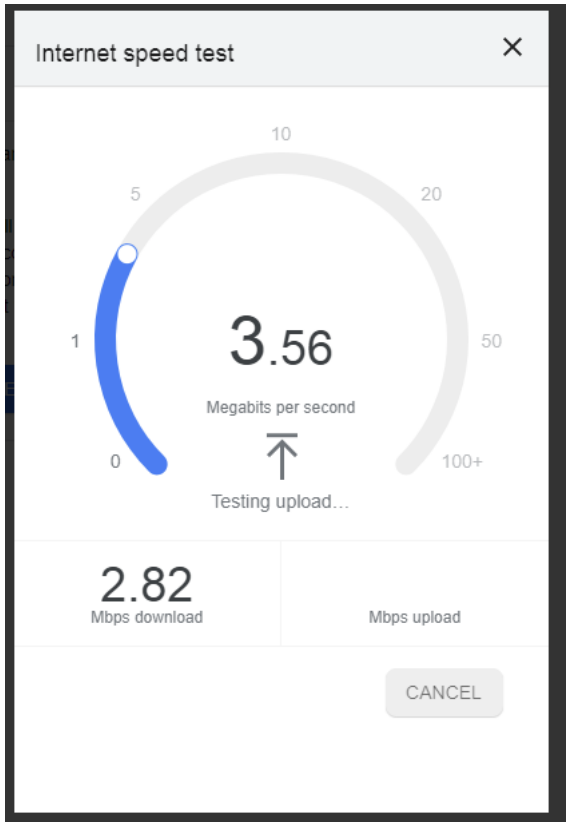
Week1 Lecture4

Key points to discuss in Internet Access

- Internet Access
  - Residential home access
    - DSL
    - Cable
  - Institutional access
  - Mobile access

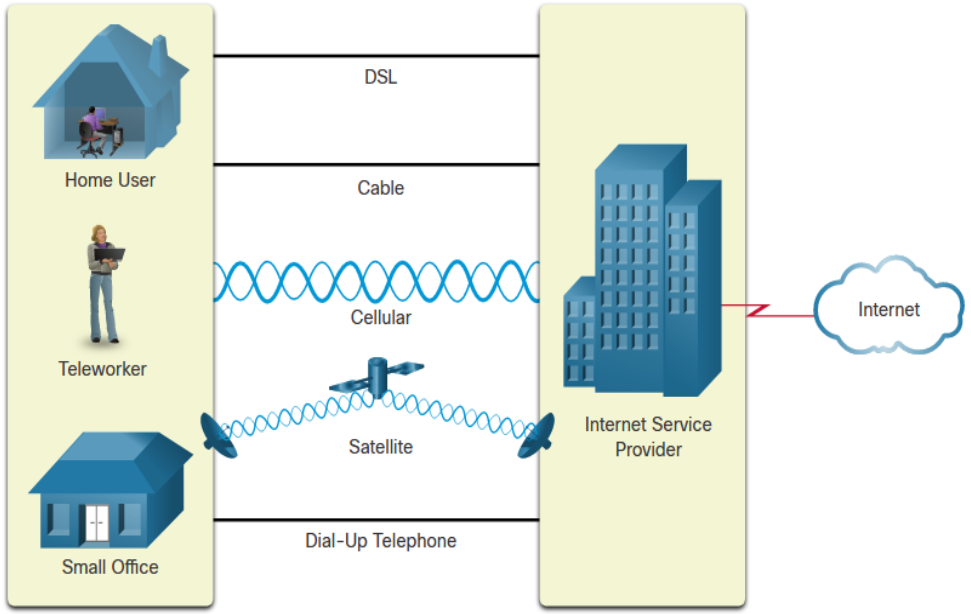
Internet access

- Access networks helps to connect end systems to the internet.
- Shared/dedicated access depends on the network classification
- Internet speed?
  - Also depends on the type of networks and link capacity
  - Measured in bits per second the (bps)
    - Download speed: Time taken for client end systems to access files from servers.
    - Upload speed: Time taken to upload files from clients to servers.



Home Access Methods?

- Home access methods: DSL, Cable, Dial-up & Satellite
  - Two Prevalent types of broadband residential access: DSL, Cable
  - DSL – Digital Subscriber Line

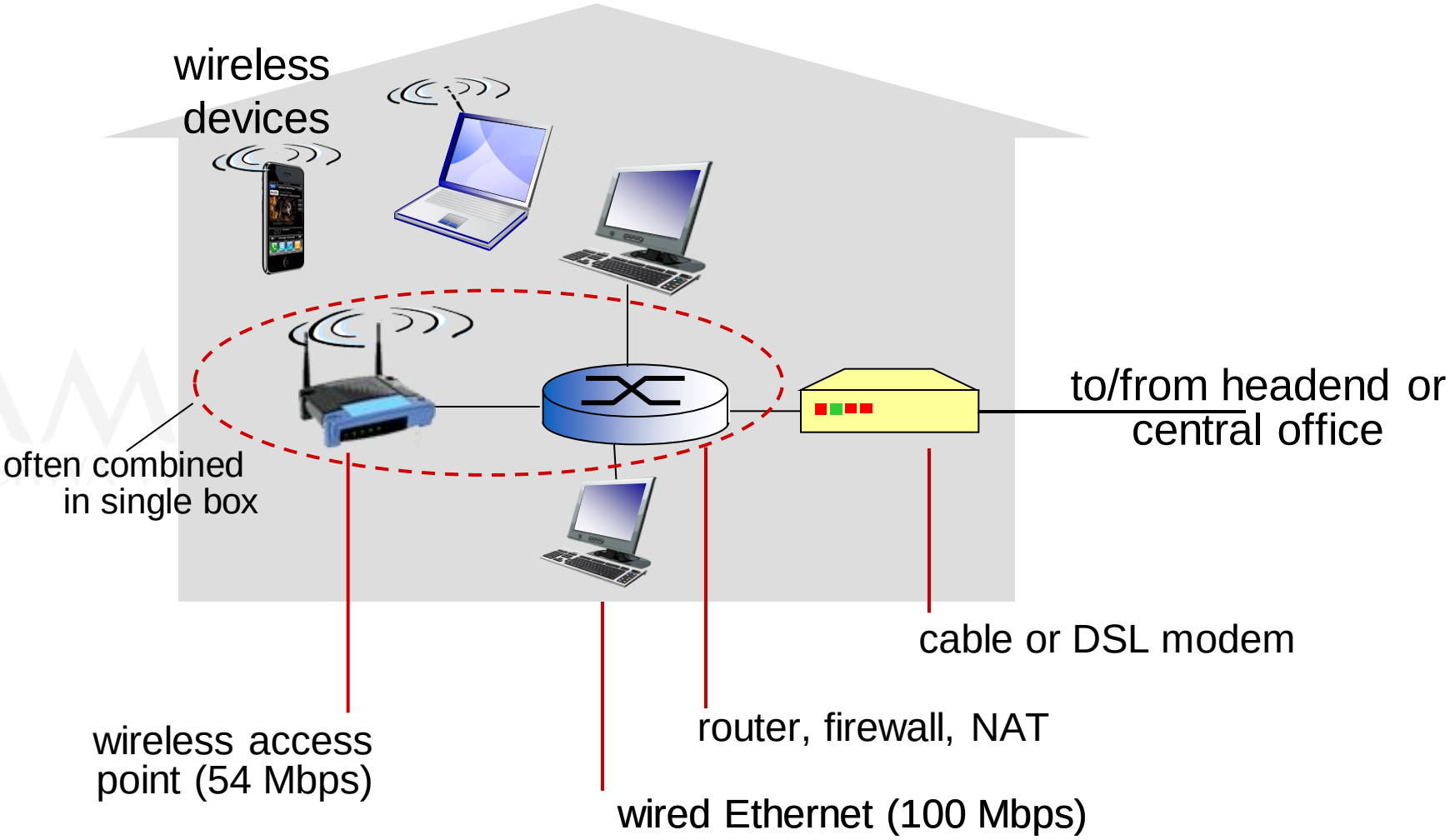


Ref: CCNA Introduction to Networks from Cisco Netacad

Connection	Description
DSL	high bandwidth, always on, internet connection that runs over a telephone line.
Cable	high bandwidth, always on, internet offered by cable television service providers.
Cellular	uses a cell phone network to connect to the internet.
Satellite	major benefit to rural areas without Internet Service Providers.
Dial-up telephone	an inexpensive, low bandwidth option using a modem.

Home Access Network

- Modem = modulator/ demodulator
- Hardware device
- Modulator = Converts digital data to analog
- Demodulator = Converts analog signals to digital form



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DSL

- Digital Subscriber Line (DSL) uses existing telephone

Infrastructure.

- DSL provider provide different transmission rates at different price
  - Speed affected by distance
- DSL Standards
  - 12 Mbps downstream & 1.8 Mbps upstream [ITU 1999]
  - 24 Mbps downstream & 2.5 Mbps upstream [ITU 2003]
- Internet access is asymmetric
  - Because the downstream and upstream speed are different

DSL

- @Customer Side
  - DSL Modem uses the existing telephone line(twisted pair)
  - Splitter separates the data and telephone signals arriving at home and forwards the data signal to the DSL modem
- @Telecommunication Side
  - DSL Access Multiplexer (DSLAM) separates the data and phone signals and sends the data into the internet
- Same DSL link shared for
  - Phone line
  - Upstream data
  - Downstream data

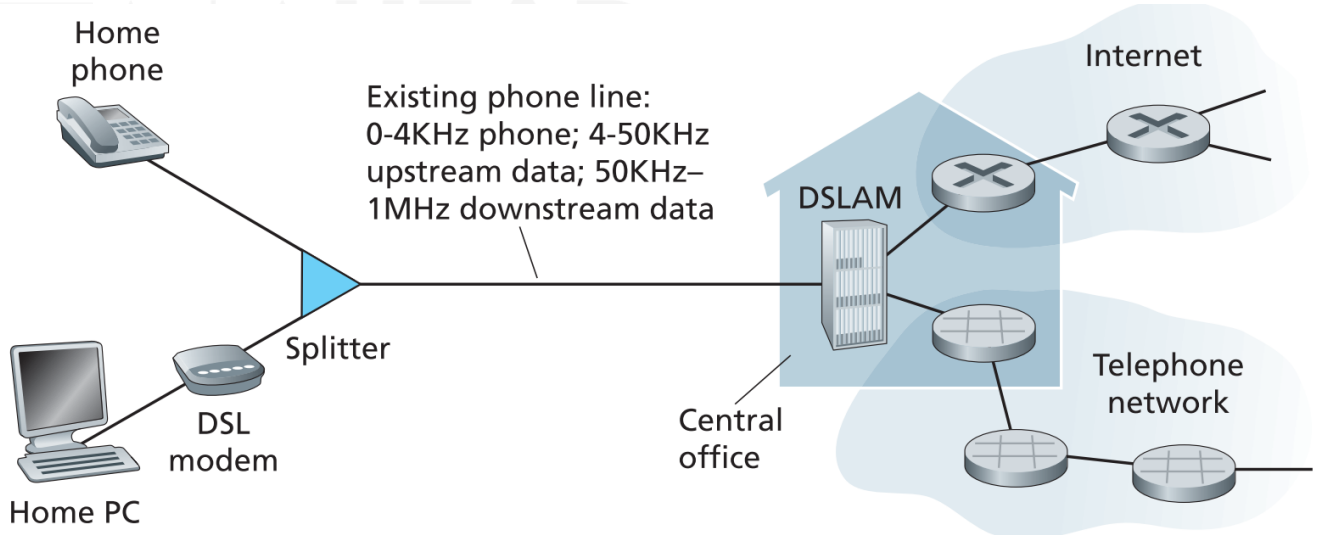


Figure 1.5 ♦ DSL Internet access

Cable Internet Access

- Cable Internet Access uses existing Cable TV infrastructure.
- Shared broadcast communication medium
- @Customer side
  - Cable modem divides the hybrid fiber coaxial (HFC) network into 2 channels (up and downstream)
  - HFC standards 42.8 Mbps downstream & 30.7 Mbps upstream
- @Telecommunications side
  - Cable Modem Termination System (CMTS) similar to DSLAM

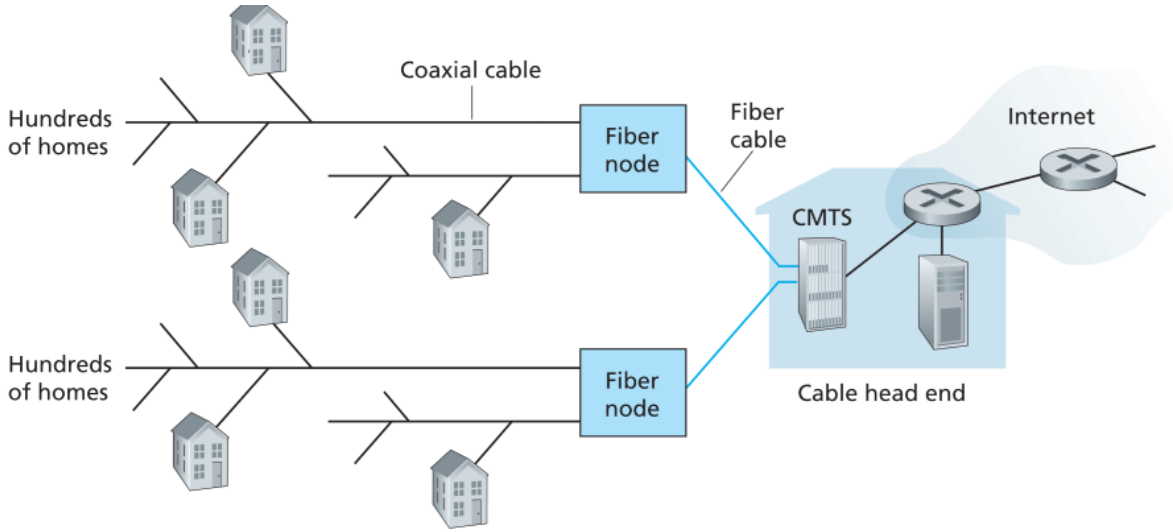
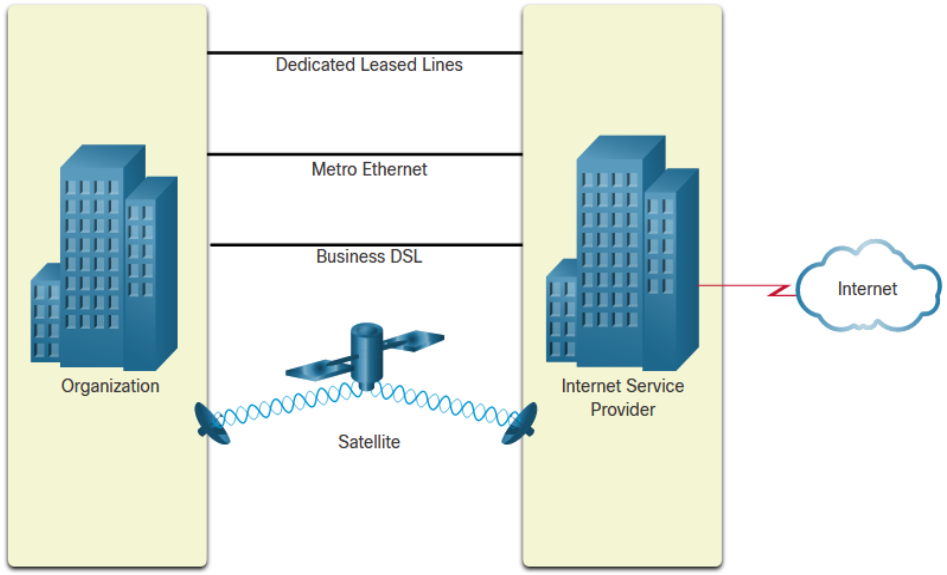


Figure 1.6 ♦ A hybrid fiber-coaxial access network

Institutional Access Network

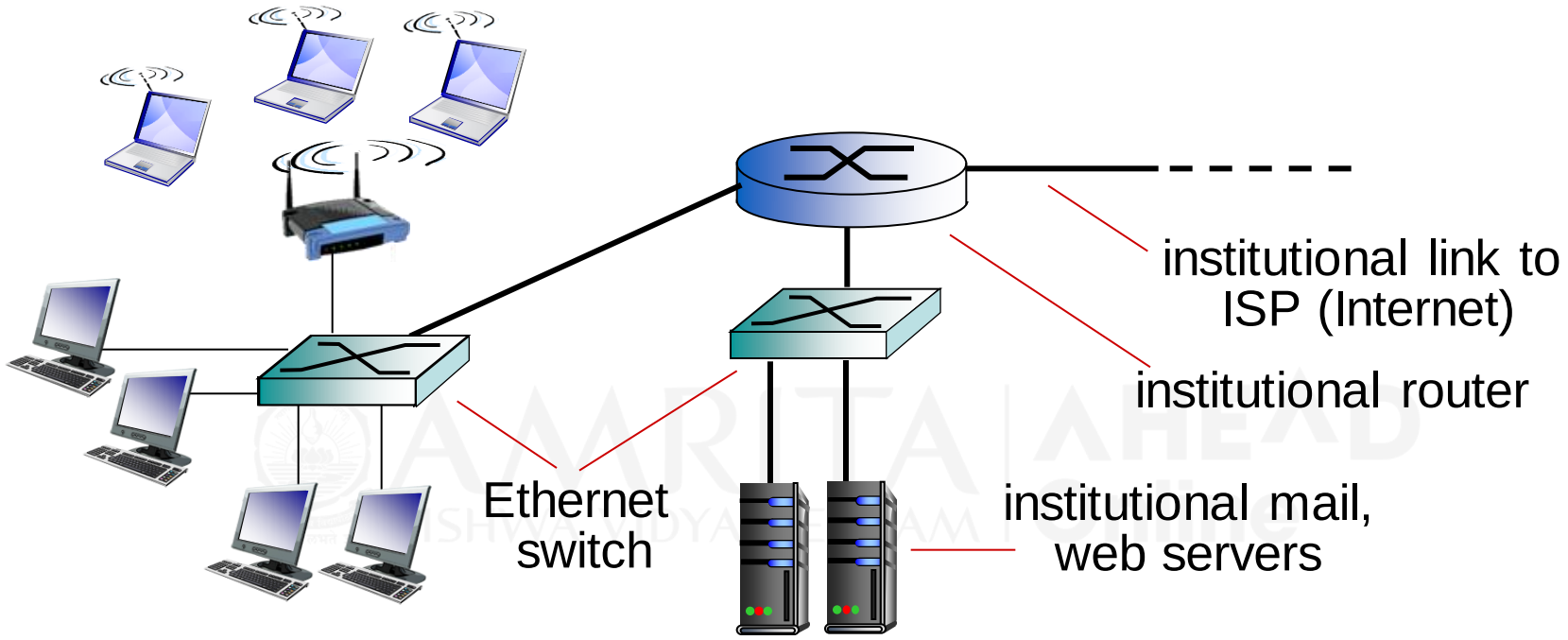
- Institutional/Corporate business connections require:
  - Higher bandwidth, dedicated connections, managed services
  - Accessing options type



Ref: CCNA Introduction to Networks from Cisco Netacad

Type of Connection	Description
Dedicated Leased Line	These are reserved circuits within the service provider's network that connect distant offices with private voice and/or data networking.
Ethernet WAN	This extends LAN access technology into the WAN.
DSL	Business DSL is available in various formats including Symmetric Digital Subscriber Lines (SDSL).
Satellite	This can provide a connection when a wired solution is not available.

Institutional Access Network

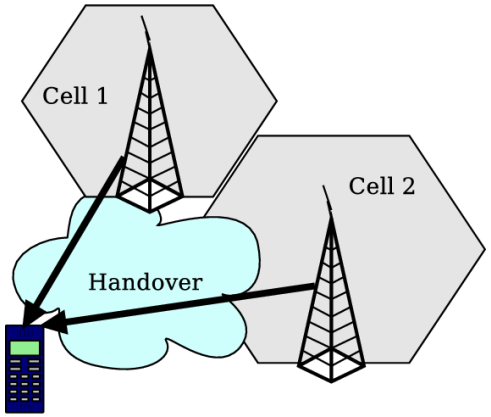


- Larger LAN typically used in companies, universities, etc.
  - 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
  - today, end systems typically connect into Ethernet switch

J. Kurose and K. Ross 2012, Computer Network,6th ed.

Mobile Access Cellular Network

- How Mobile/ Cell phone connected to the Internet?
  - Coverage area of one Base Station is termed as cell
  - Mobiles in one cell sends messages to the Base Station in that cell.
  - Base Station is connected to the Edge Router for Internet Access
- Mobility concept – Smooth transfer of data messages from one Base Station in a cell to the other known as handoff

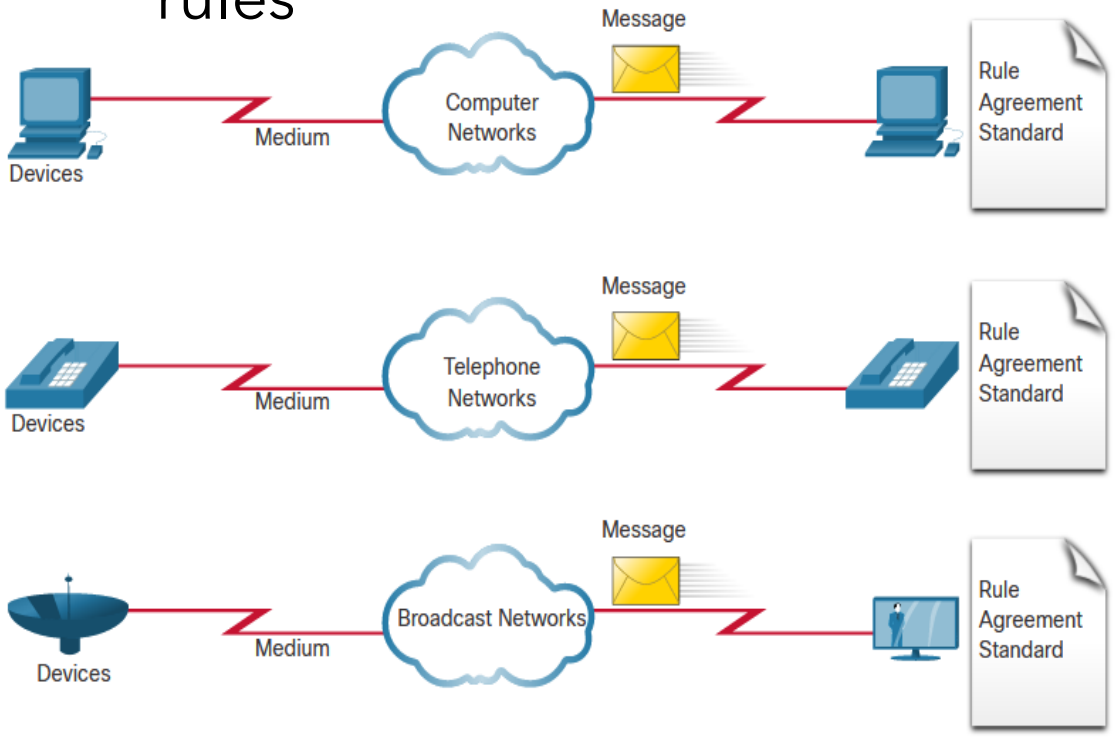


J. Kurose and K. Ross 2012, Computer Network,6th ed.

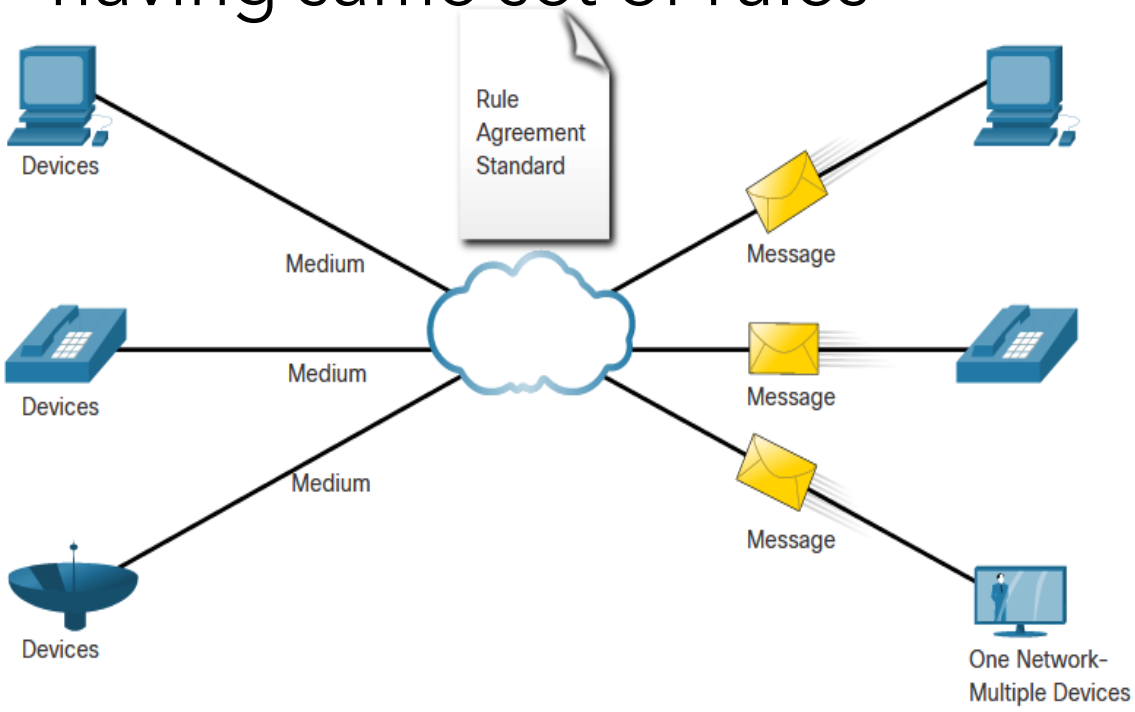
Krauthoff, Tobias. (2014). Measurement of Position-based Network-Characteristics in Cellular Networks while Moving. 10.13140/RG.2.2.31844.99206.

Converged Network

- Before Separate networks
  - using different technologies to carry signals based on specific rules



- Converged network deliver data, voice and video on one link having same set of rules



Summary

- Revised Network Structure
- Discussed various ways to Network Access
  - Residential home access
  - Institutional access
  - Mobile access
  - Converged networks
- Next lecture discussion
  - Network Core

Network Core

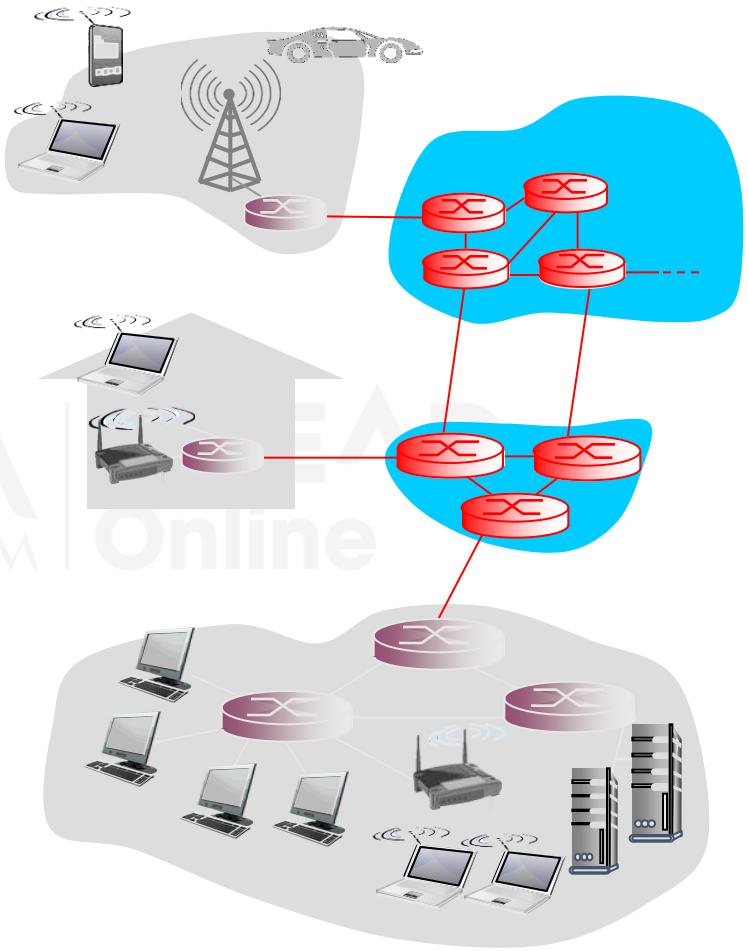
Week1 Lesson5

Learning Objectives in Network Core

- Understand Network core
- Analyze the difference between circuit switching and packet switching
- Analyze how different users share the link
- Understand the network core functions

Network Core

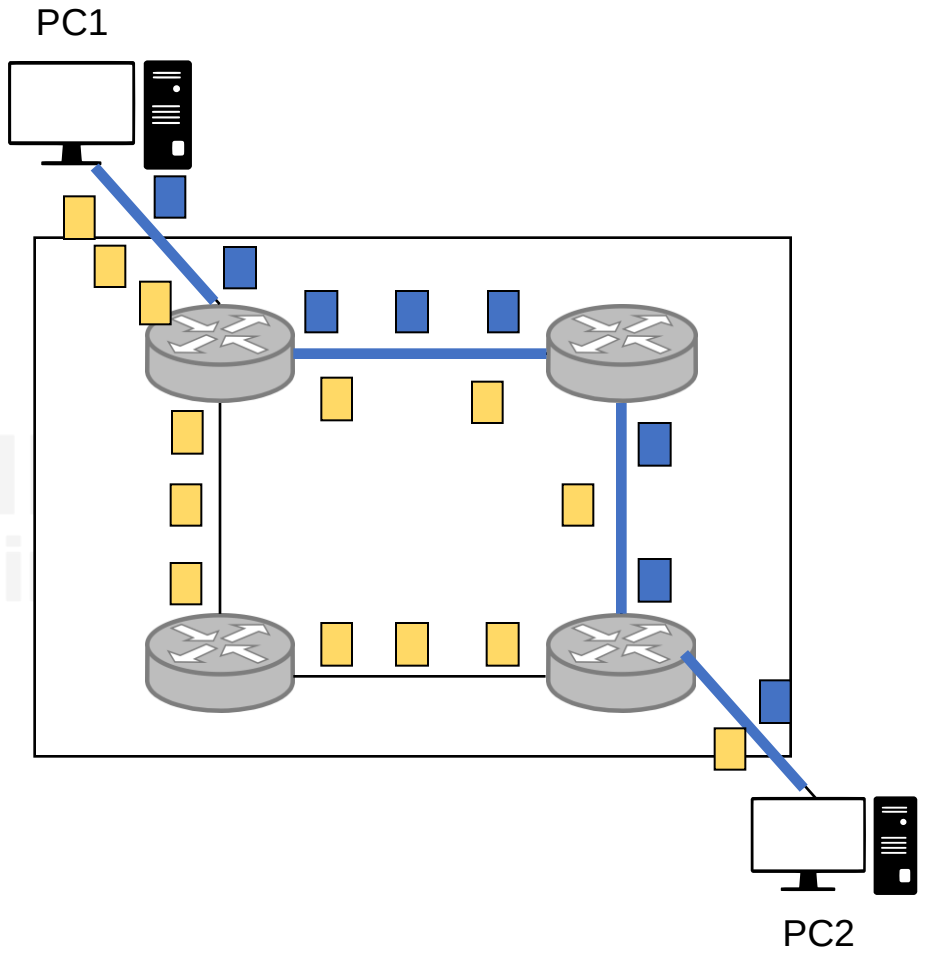
- Network Structure = End devices, Access Network & Core Network
- Network Edge = End Devices with Network Access devices like Edge router
- Network Core
  - Provides services to the Edge
  - Mesh of interconnected routers



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Network Core Implementation

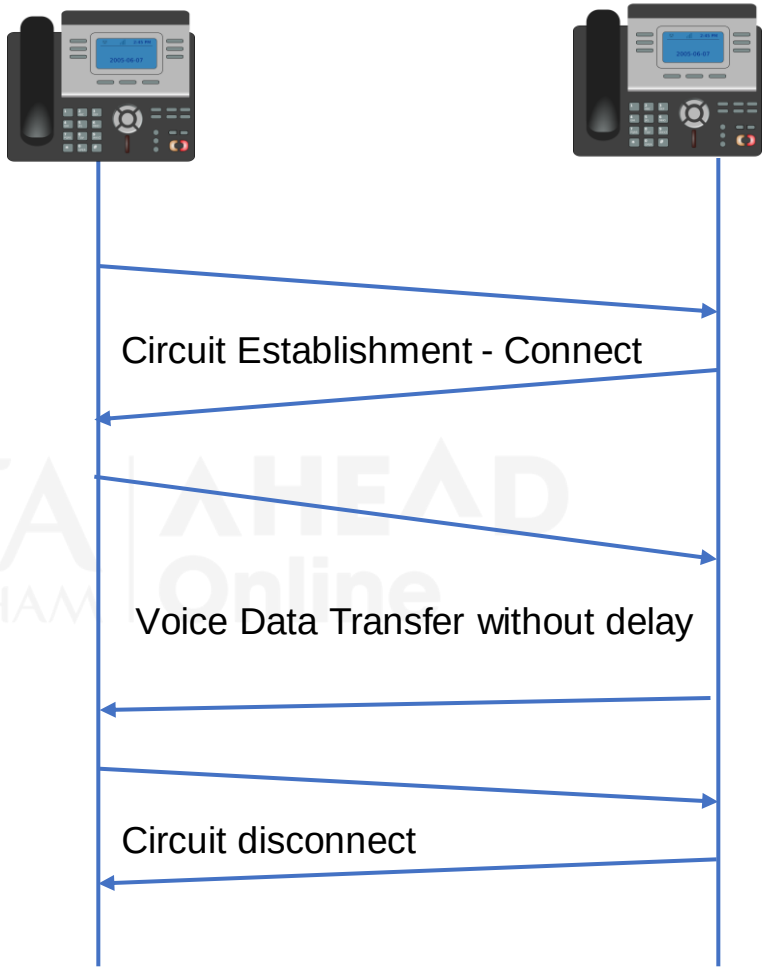
- Network Core answers – "How is data transfer through network?"
- Implemented by switching techniques
  - Circuit Switching
    - Dedicated circuit per call
    - Connection oriented service
    - Ex: telephone network
  - Packet Switching
    - Data or messages are divided into small chunks known as packets and they are sent through network
    - Connection less service
    - Ex: Ethernet network



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Circuit Switched Network

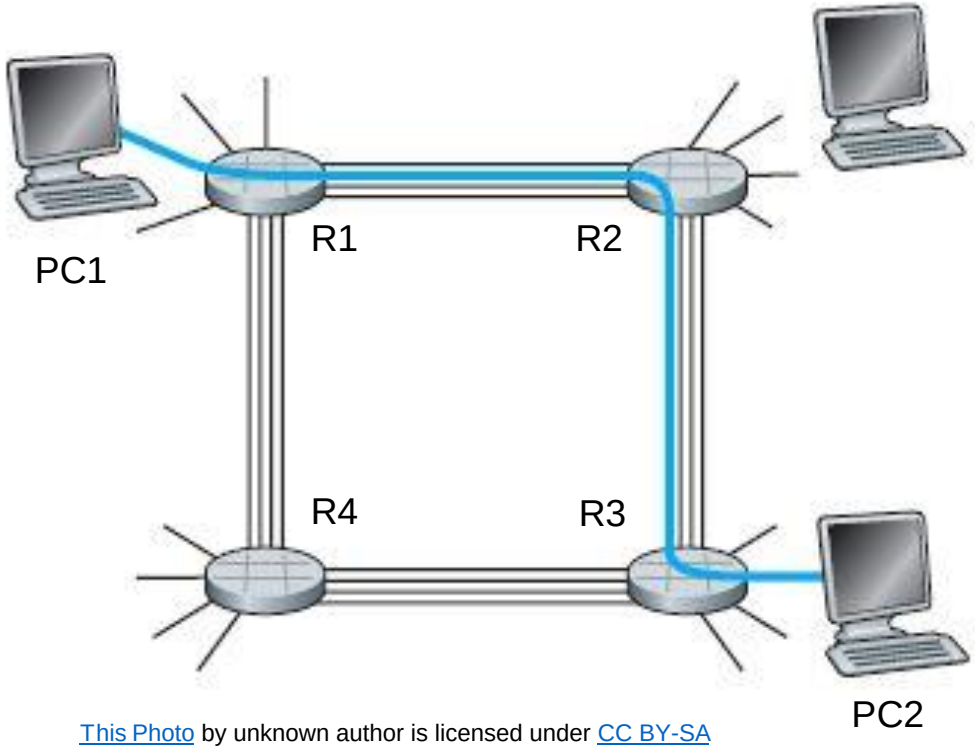
- Circuit = dedicated path between sender and receiver
- Mostly used for voice communication real time services to avoid delay
- Three phases involved in circuit switching
  - Circuit establishment
  - Data Transfer
  - Circuit disconnect



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Circuit Switching

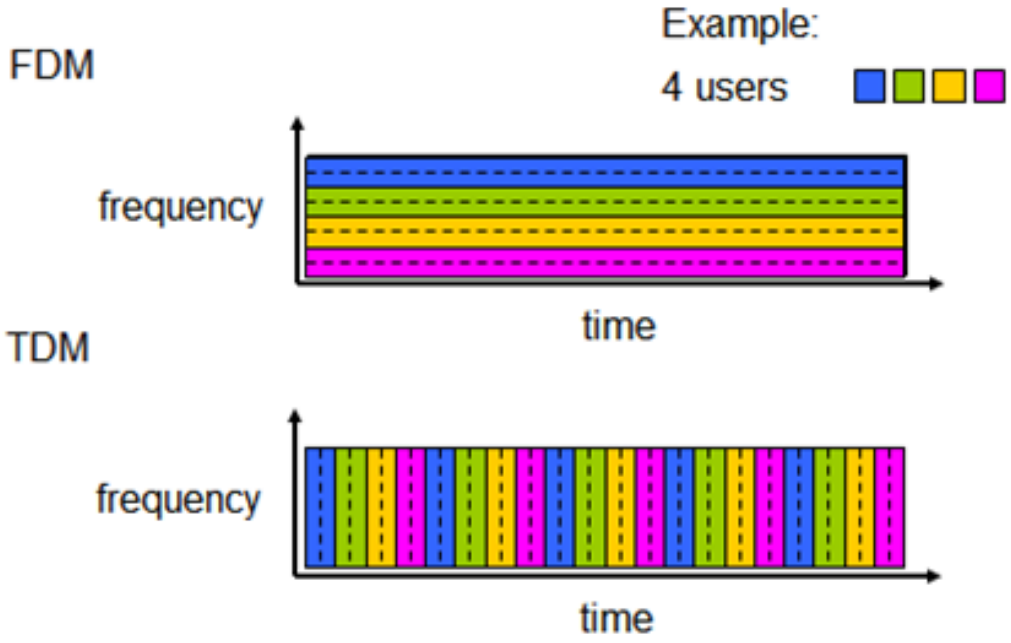
- One Communication link can have many circuits.
  - Here each link has 4 circuits
- Three phases involved in PC1 calling PC2
  - Dedicated path or circuit:
    - PC1-R1(2nd circuit)
    - R2-R2(1st circuit)
    - R3- PC2 – resources allocated
  - Data transfer between PC1 and PC2 in the circuit
  - Circuit disconnected after the call ends



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Sharing the link in Circuit Switching

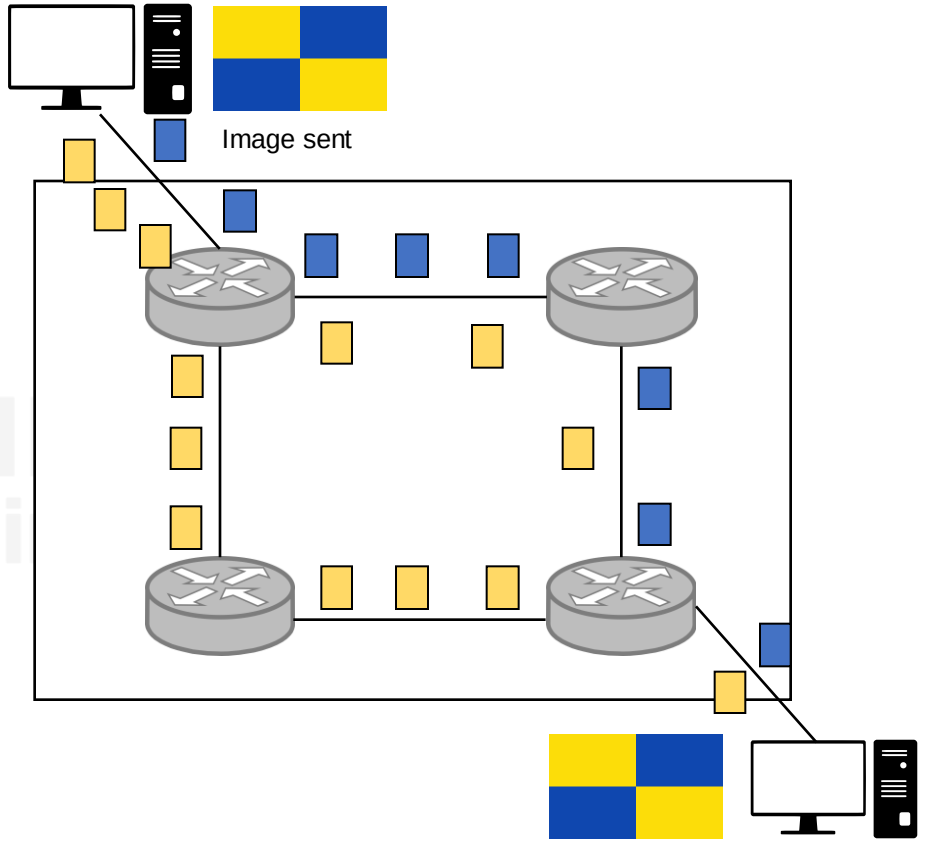
- How Communication link can be shared by different users?
- Multiplexing allows simultaneous transmission of multiple signals along the same link
  - Divides a link into multiple channels
  - Frequency Division Multiplexing (FDM) shares a portion of bandwidth among 4 users
    - Ex: AM and FM radio broadcasting
  - Time Division Multiplexing (TDM) shares time slots among 4 users
    - Ex: Radio programs at different time periods



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

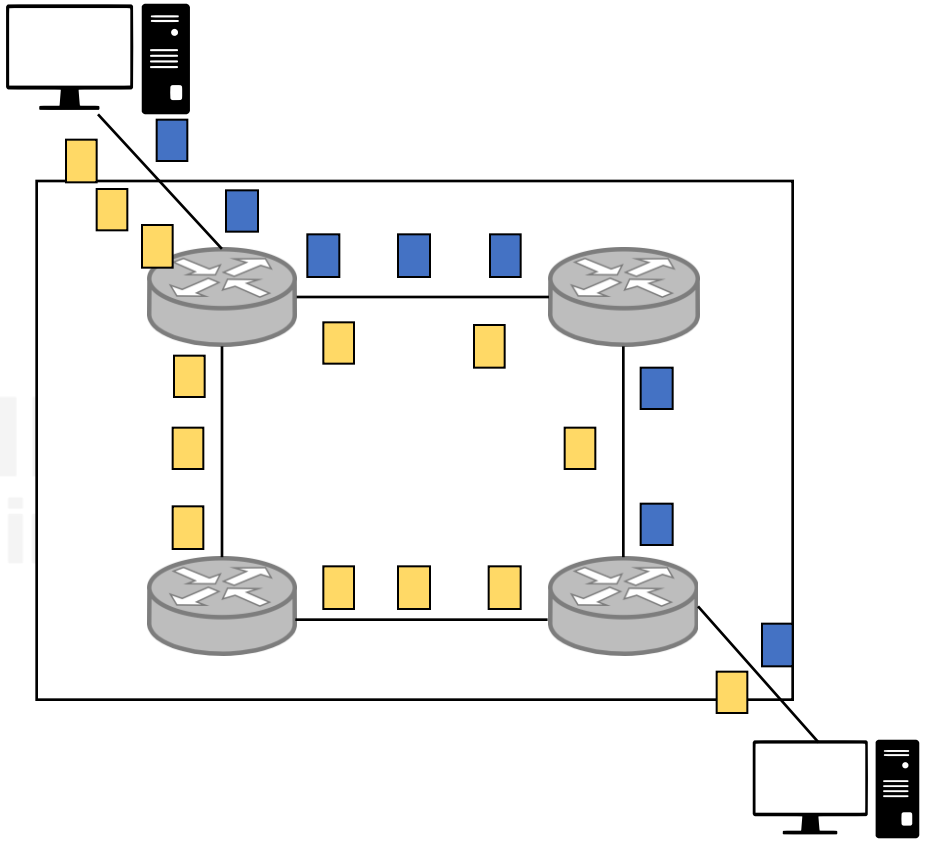
Packet Switched Network

- Used in the Internet and most LANs
- Host breaks the large messages into packets known as segmentation
  - Ex: Message such as Image or Video or audio file are segmented into small packets
  - Packets travel independently and need not take same path
- No bandwidth shared or time reserved in sending packets
  - No dedicated path or circuit
  - Resources used as needed
  - Reason for connection less service



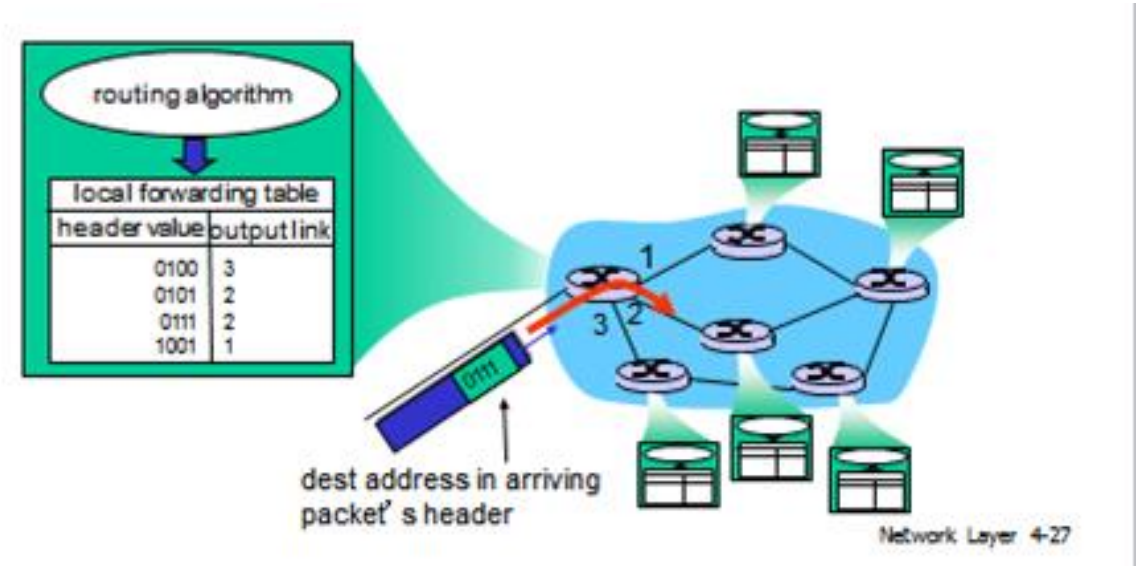
Packet Switching

- Statistical multiplexing
  - Packets from different incoming links are sent by router to different outgoing links based on demand
- Routers store and forward the packets
  - Entire packet must arrive at the router, stored in buffer and then forwarded
- Sending Packets from source to destination undergo random delay and loss in each of the intermediary devices or hops in between
  - Each packet transmitted at the full link capacity



Network Core Functions

- Routing determines the route or path based on the destination host address
  - Here path or route to reach 0111 destination address is referred
  - Routing algorithm maintains table specific for each router
- Forwarding moves packet from the incoming link to the right outgoing link
  - Here packet is forwarded to the output link 2 for dest addr 0111



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Summary

- Network Core Switching
  - Circuit Switching
    - FDM & TDM multiplexing
    - Connection oriented service
    - Guaranteed service
  - Packet Switching
    - Statistical Multiplexing
    - Connection less service
    - Best effort service
  - Routing Vs Forwarding
- Next lecture discussion
  - Delays, Loss, Throughput in netw

Delays

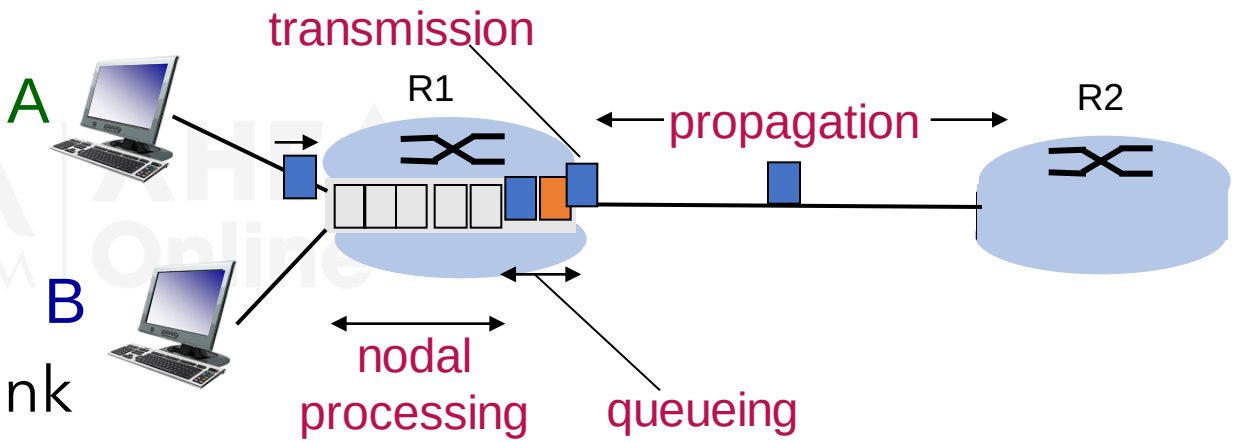
Week1 Lecture6

Key points in Delay, Loss and Throughput in Networks

- Understand different delays in a network
  - Transmission delay
  - Propagation delay
  - Processing delay
  - Queuing delay
- Packet Loss
- Throughput
- Real Internet delays

Four sources of Packet Delay

- Transmission delay d_{trans}
  - Time taken to drop the packet into the output link for transmission
  - Length of the Packet say L bits
  - Bandwidth of the link say R bps
  - d_{trans} = L/R seconds
- Propagation delay d_{prop}
  - Time - Bits to move in the media or link
  - Distance of Physical link – d meter
  - Propagation speed in medium – s
    - Ex: fiber optic – 0.7 * 3 *10^8 m/s
  - d_{prop} = d/s seconds

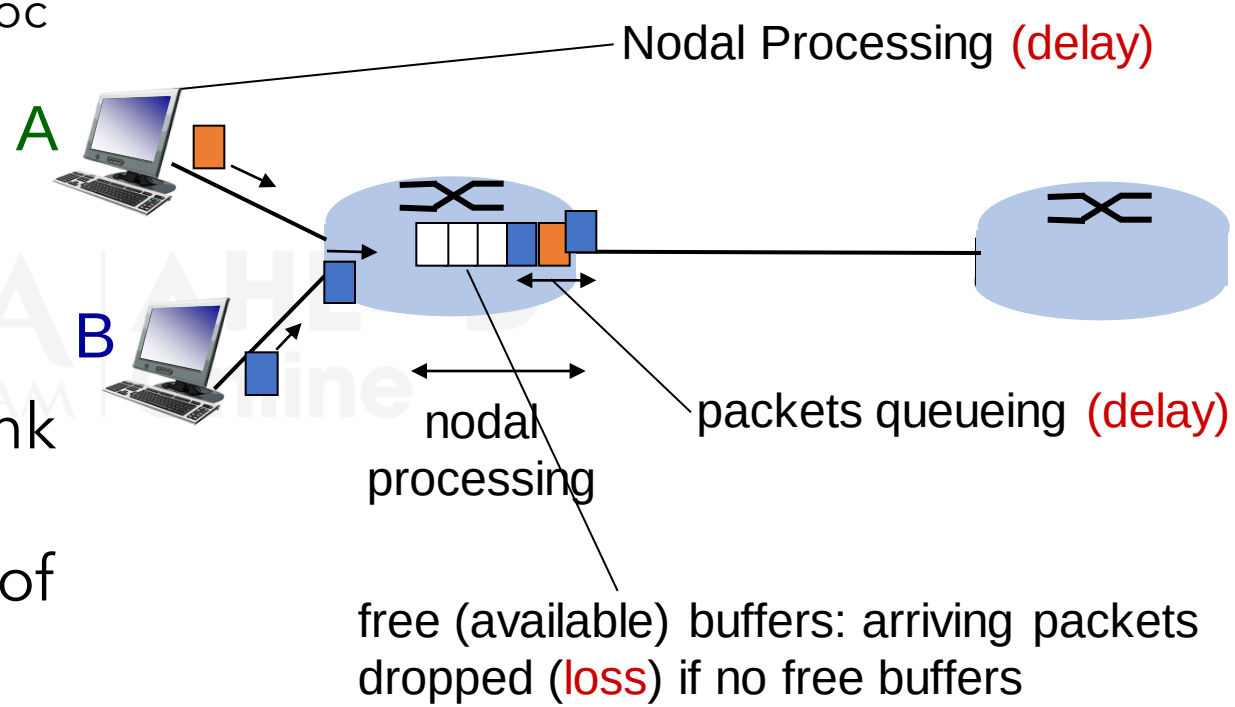


$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Four sources of Packet Delay

- Processing delay in all nodes d_{proc}
  - Check bit errors
  - Determine output link
  - Typically < msec
- Queuing delay in router d_{queue}
  - Time waiting in buffer at output link for transmission
  - Depends on congestion level of router
- Both delays depends on node hardware capacity

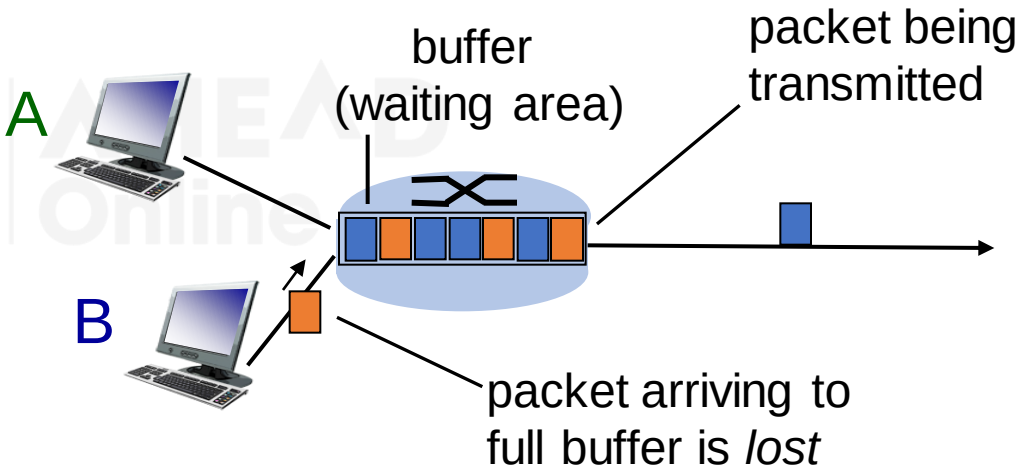


$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Packet Loss

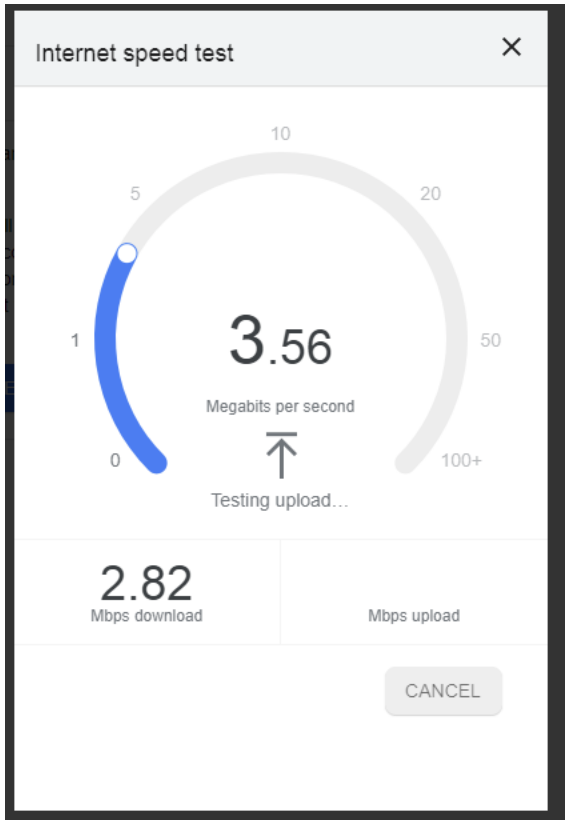
- Packets coming to the router are stored in buffer and waits there till it gets transmitted to the link.
- Buffer size are limited in the hardware.
- Arriving packets are dropped (loss) if there are no free buffer (full queue)
- Handling lost packets are discussed later in the course



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Bandwidth, Throughput and Speed

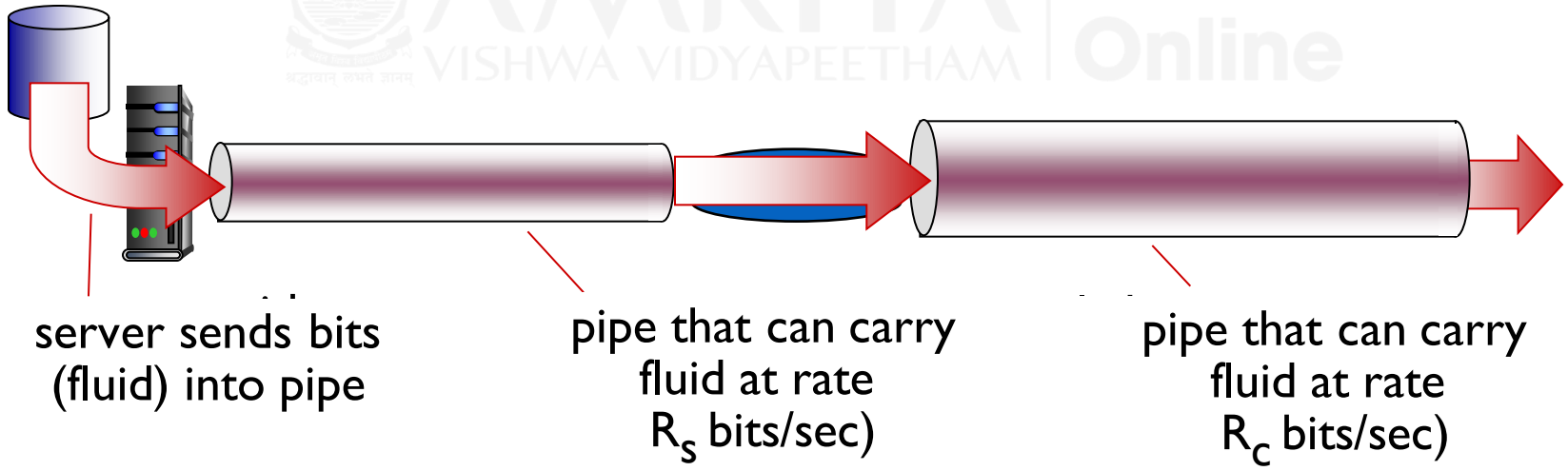
- Speed is a general term used by common user
- Measured in bits per second (bps)
- Bandwidth often refers to the maximum amount of data transfer per second
  - Refers to the physical total capacity
  - Ex: Gigabit Ethernet bandwidth – 1 Gbps
  - Analogy – 24 hours per day
- Throughput is actual amount of data passing through media or a connection
  - Analogy – working hours as 8 or 10 hours per day



Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Throughput

- Rate at which bits transferred between sender/receiver
  - Instantaneous: rate at given point of time
  - Average: rate over longer period of time
  - Measured in bits per second
- Analogy: Water flow through a pipe



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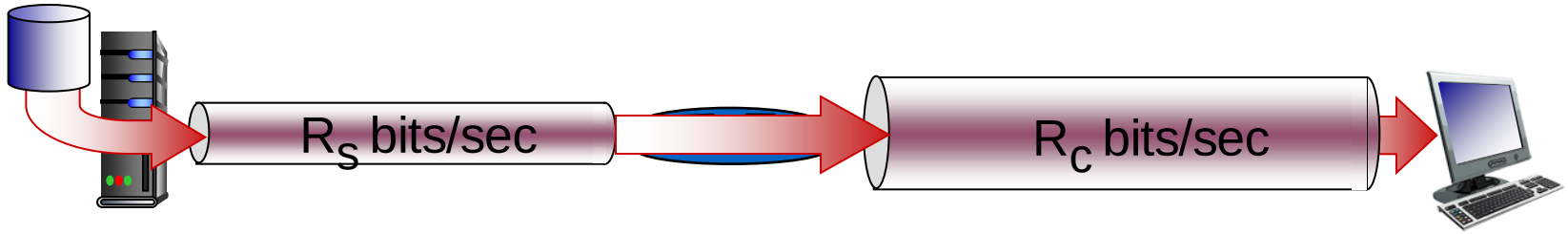
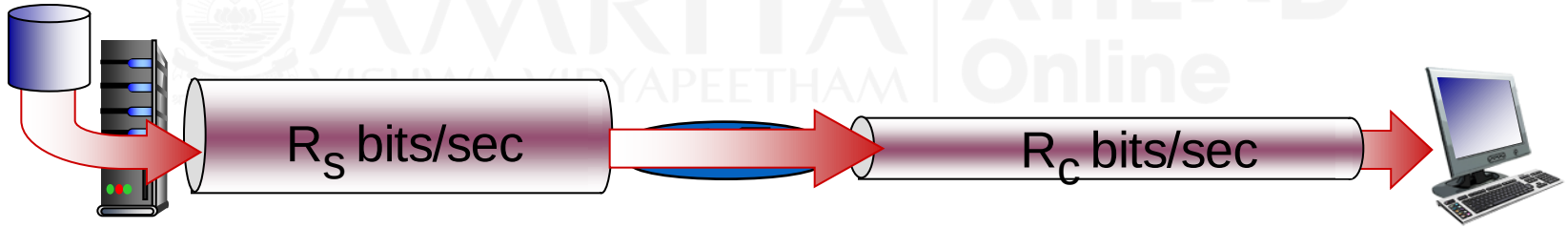
Throughput

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?



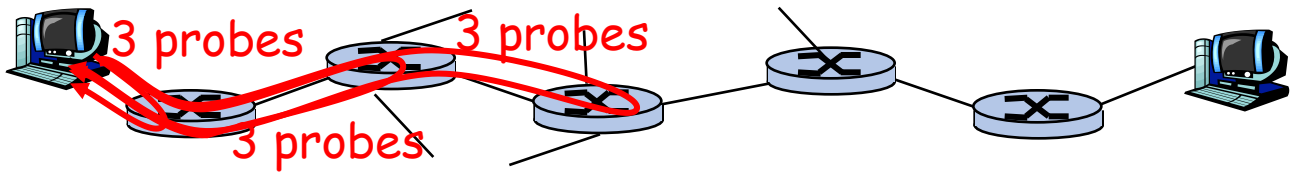
bottleneck link

link on end-end path that constrains end-end throughput

Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Real time Internet delays

- Delay = Time taken after the request before responding request
- How to understand Internet delay experienced by us?
- Traceroute: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender

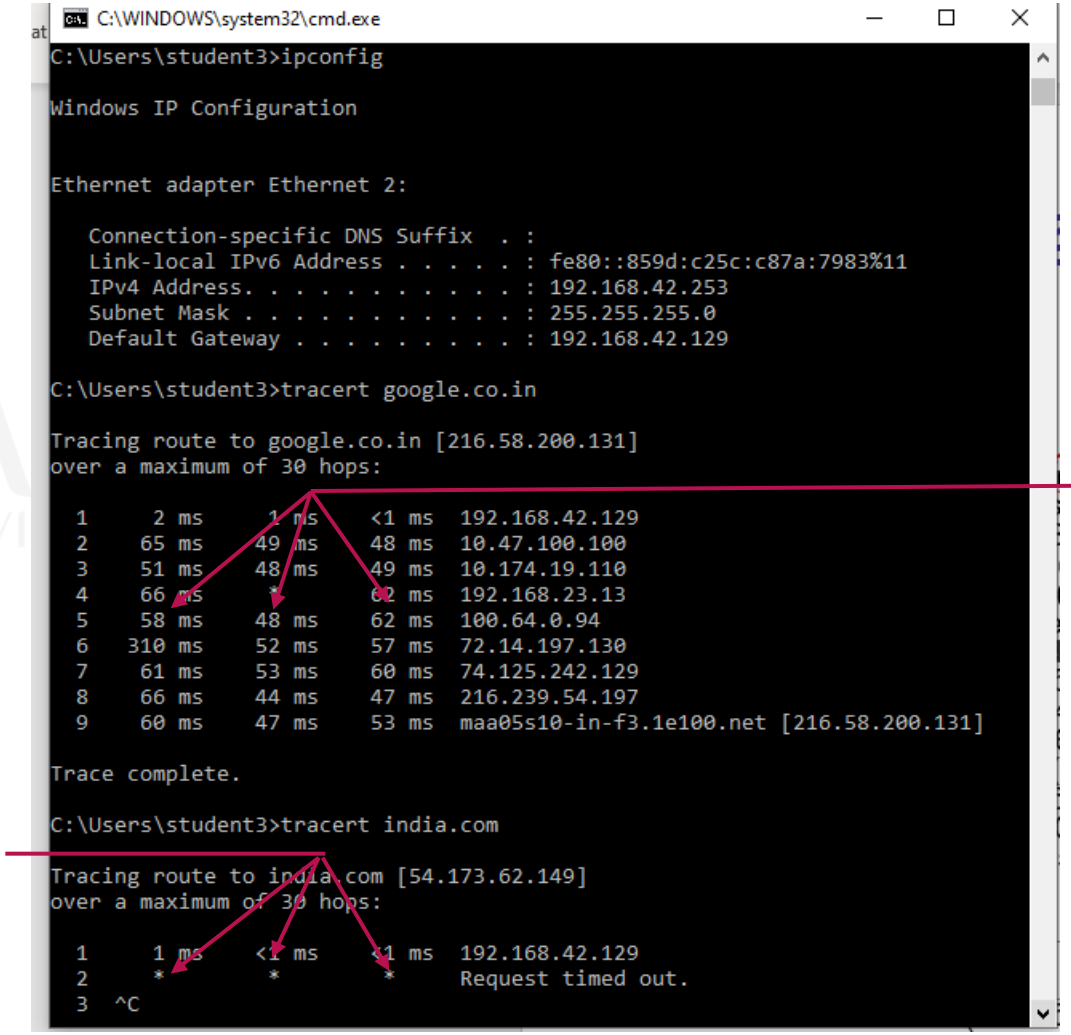


Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Tracert example

- Ex: tracert google.co.in from 192.168.42.253
- 8 hop routers
- 3 probe messages sent to each router
- No response to reach india.com hop routers

* means no response (probe lost, router not replying)



3 Packet delays measurements from the first router 192.168.42.129

Recap

- Different delays in a network
  - Transmission delay
  - Propagation delay
  - Processing delay
  - Queuing delay
- Packet Loss
- Bandwidth & Throughput
- Real Internet delays
  - Tracert command