CPS 422
Computer Networks

Layered Approach To Network Design

- Networks are complex!
- Composed of many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

- **To better understand the issue let us first consider an analogy of "Air Travel Process"**

- **Can you break down the process of air travel into "sub-processes"**

Organization of air travel

Service Counter
(ticket purchase)

Check-in Counter
(baggage check)

gates (Departure)

runway (takeoff)

airplane routing

Service Counter
(Future Travel)

Check-in Counter
(baggage claim)

gates (Arrival)

runway (landing)

‰ a series of steps

Organization of air travel: a different view

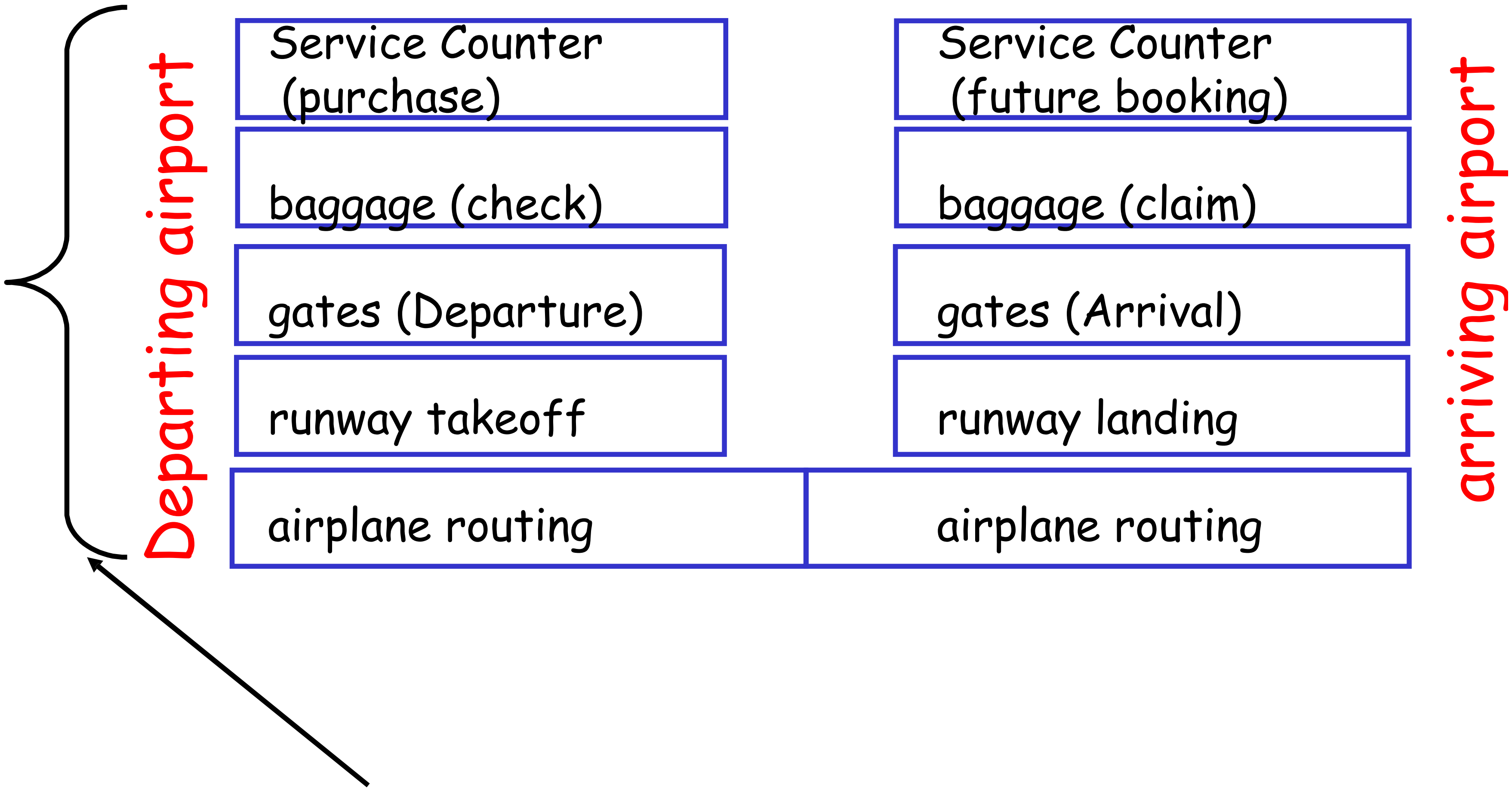
Service Counter (ticket purchase)	Service Counter (Future Travel)
Check-in Counter (baggage check)	Check-in Counter (baggage claim)
gates (Departure)	gates (Arrival)
runway (takeoff)	runway (landing)
airplane routing	

Layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

Layered air travel: services

Counter-to-counter Ticketing services
baggage-deposit-to-baggage-claim delivery
people transfer:Departure gate to Arrival gate
runway-to-runway delivery of plane
airplane routing from source to destination

Distributed implementation of layer functionality



We can refer to this collection as a "stack"

Similarly……

‰ While developing a model for network architecture, designers distilled the process of transmitting data into its most fundamental elements.

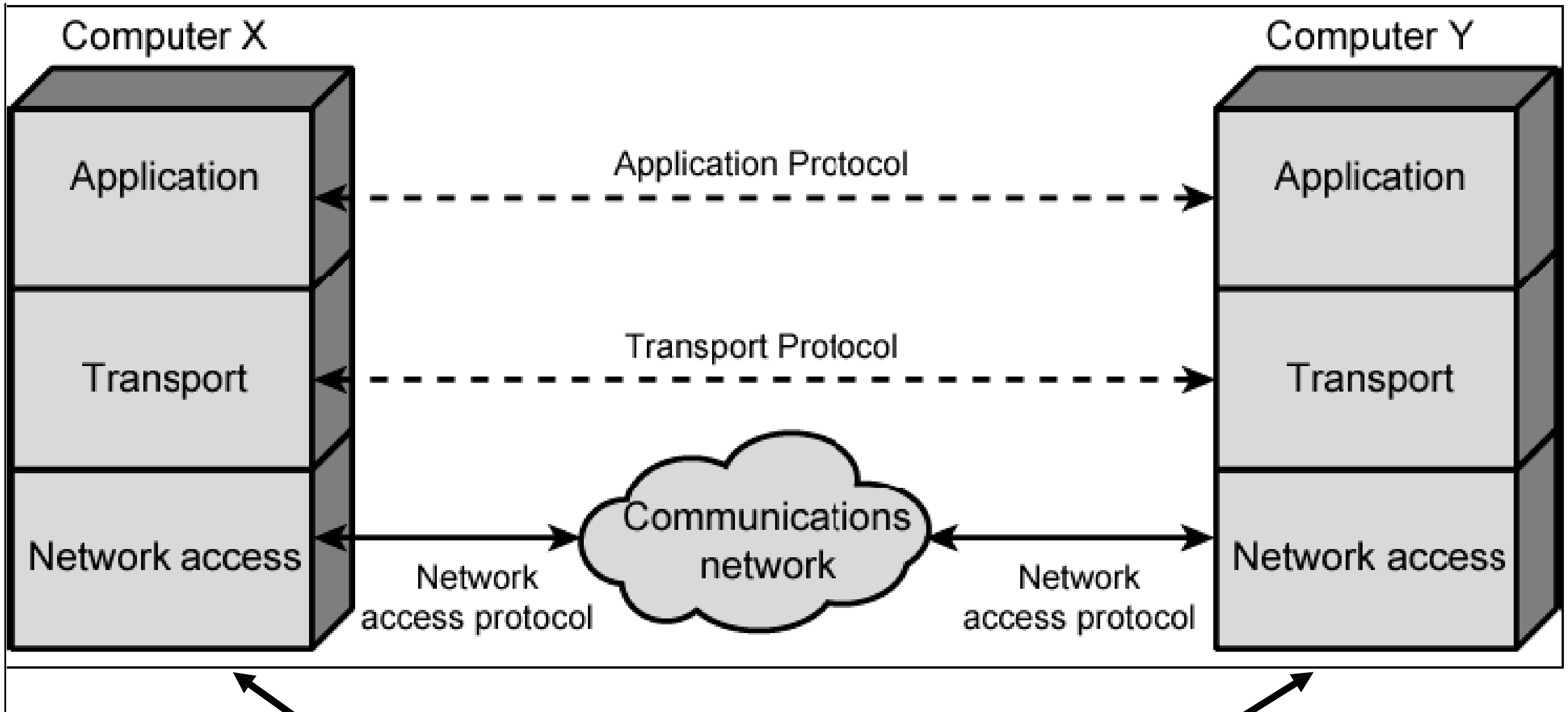
They identified which networking functions had related uses and collected those functions into discrete groups that became "Protocol Layers" which collectively form a "Protocol Stack".

Why layering?

Dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion/design
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system

Protocols in Simplified Architecture

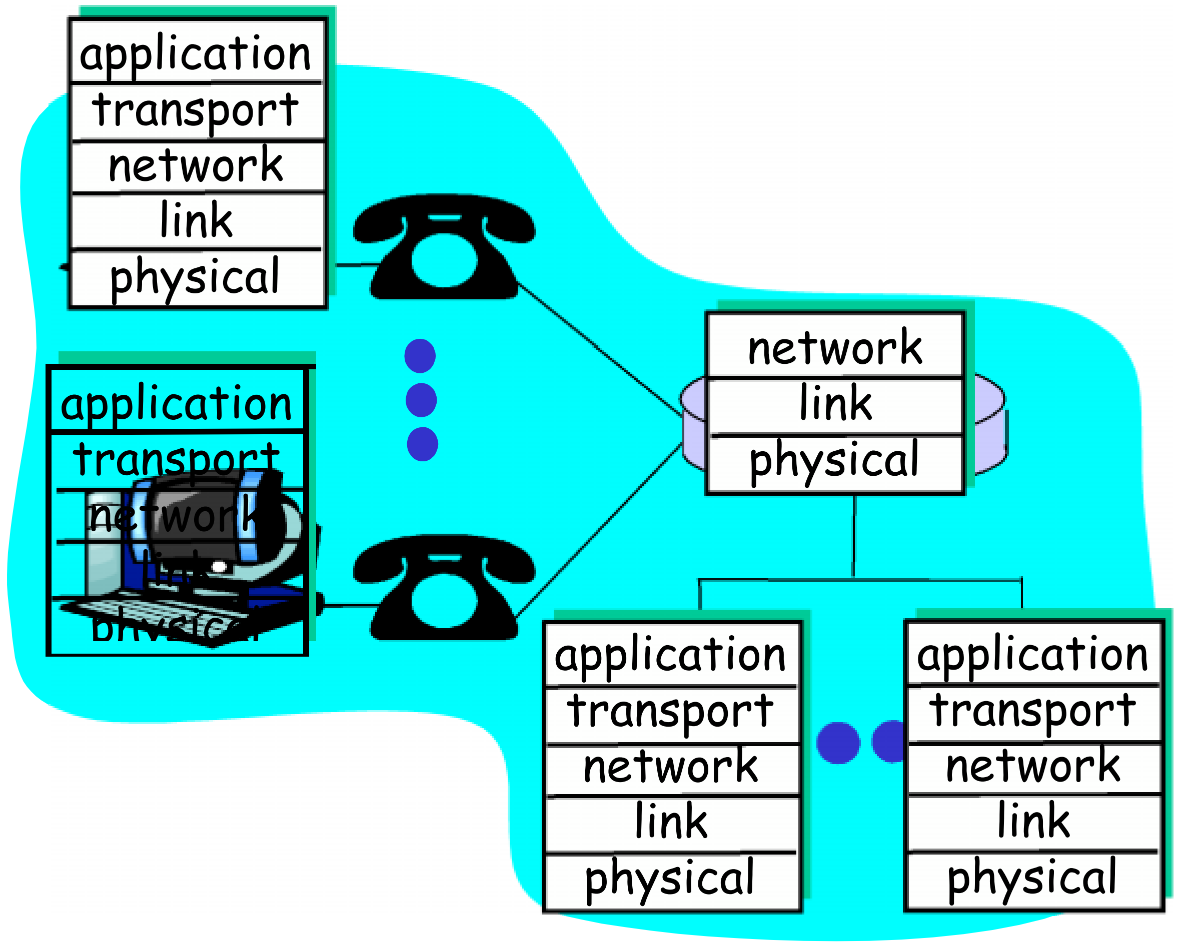


This is a "Protocol Stack"

Layering: logical communication

Each layer:

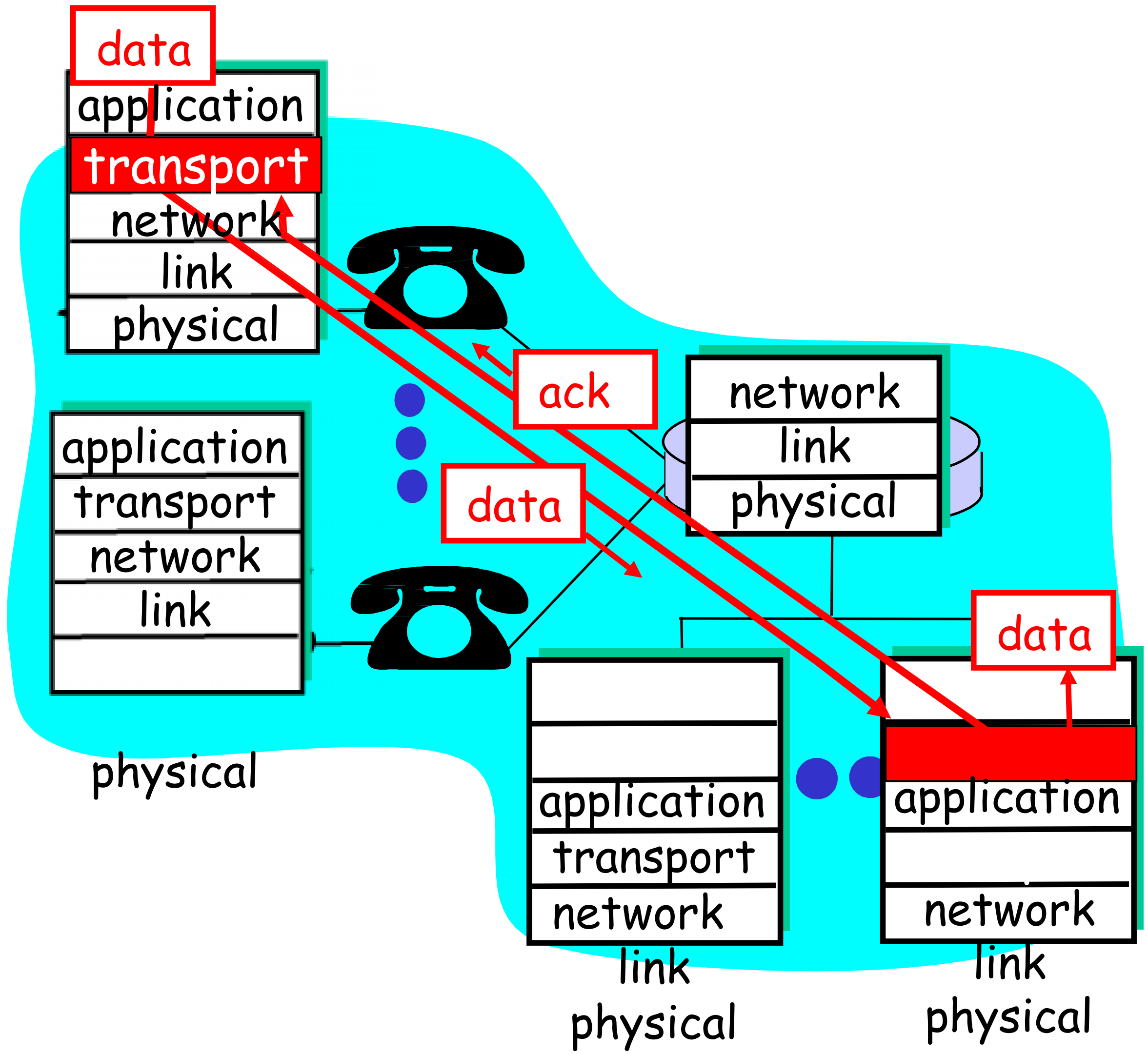
- distributed "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



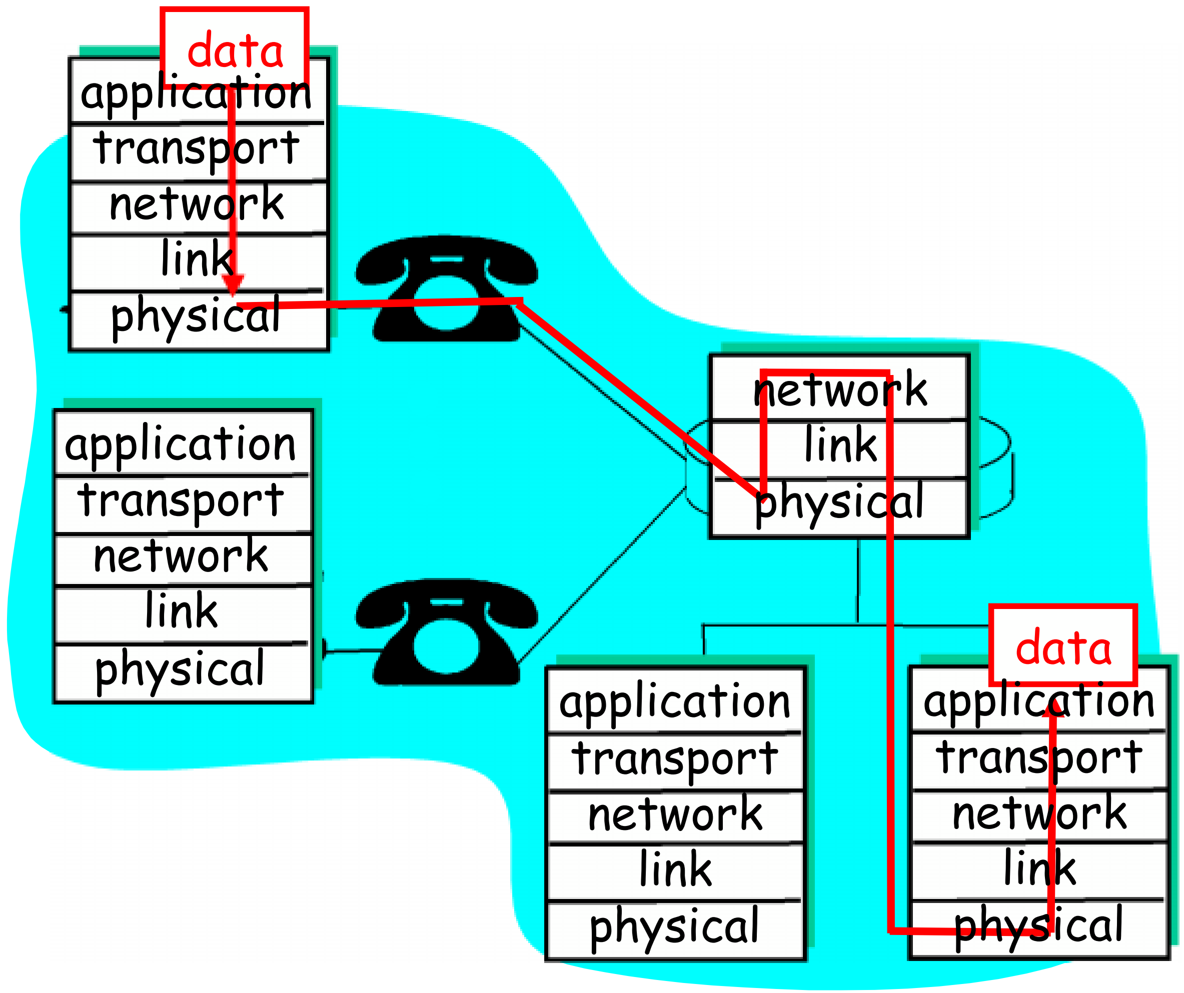
Layering: logical communication

E.g.: transport

- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office



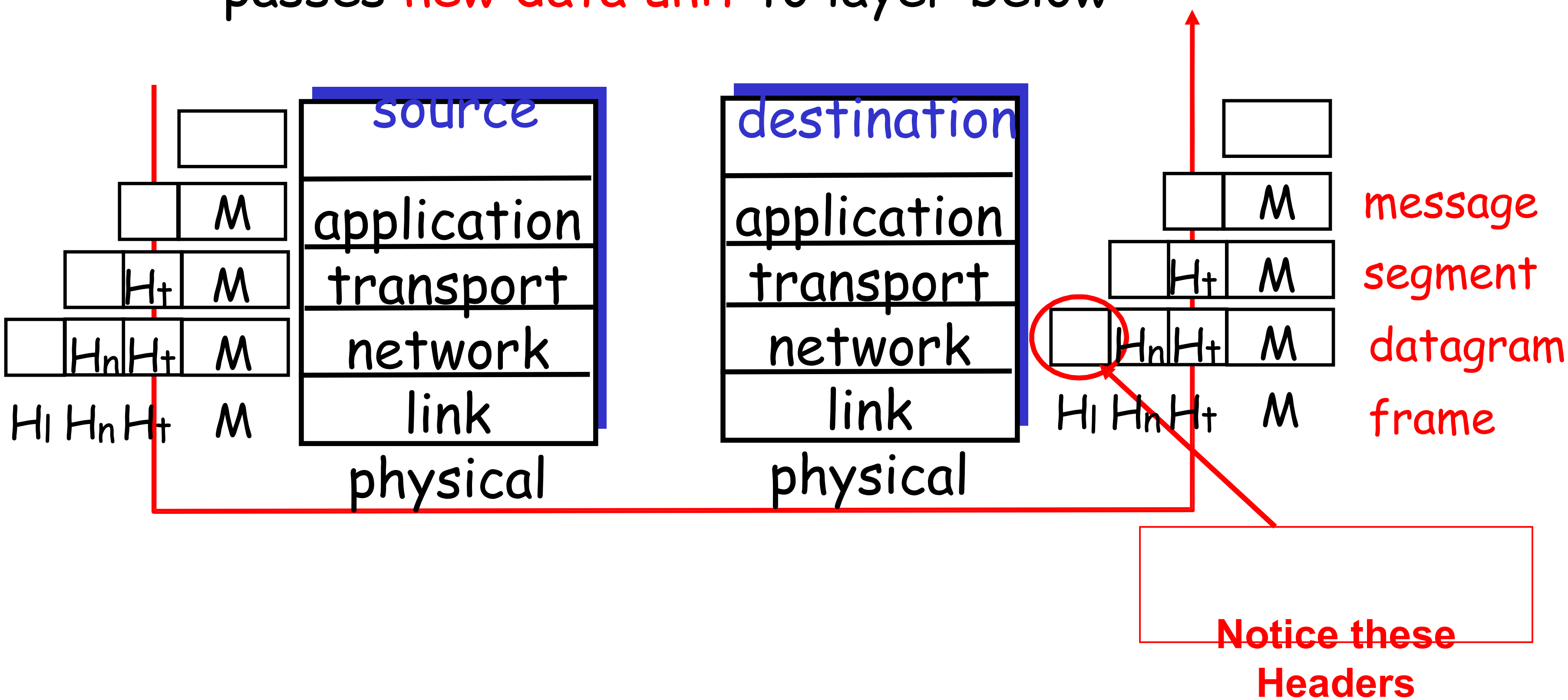
Layering: physical communication



Protocol layering and data

Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



Protocol Revisited

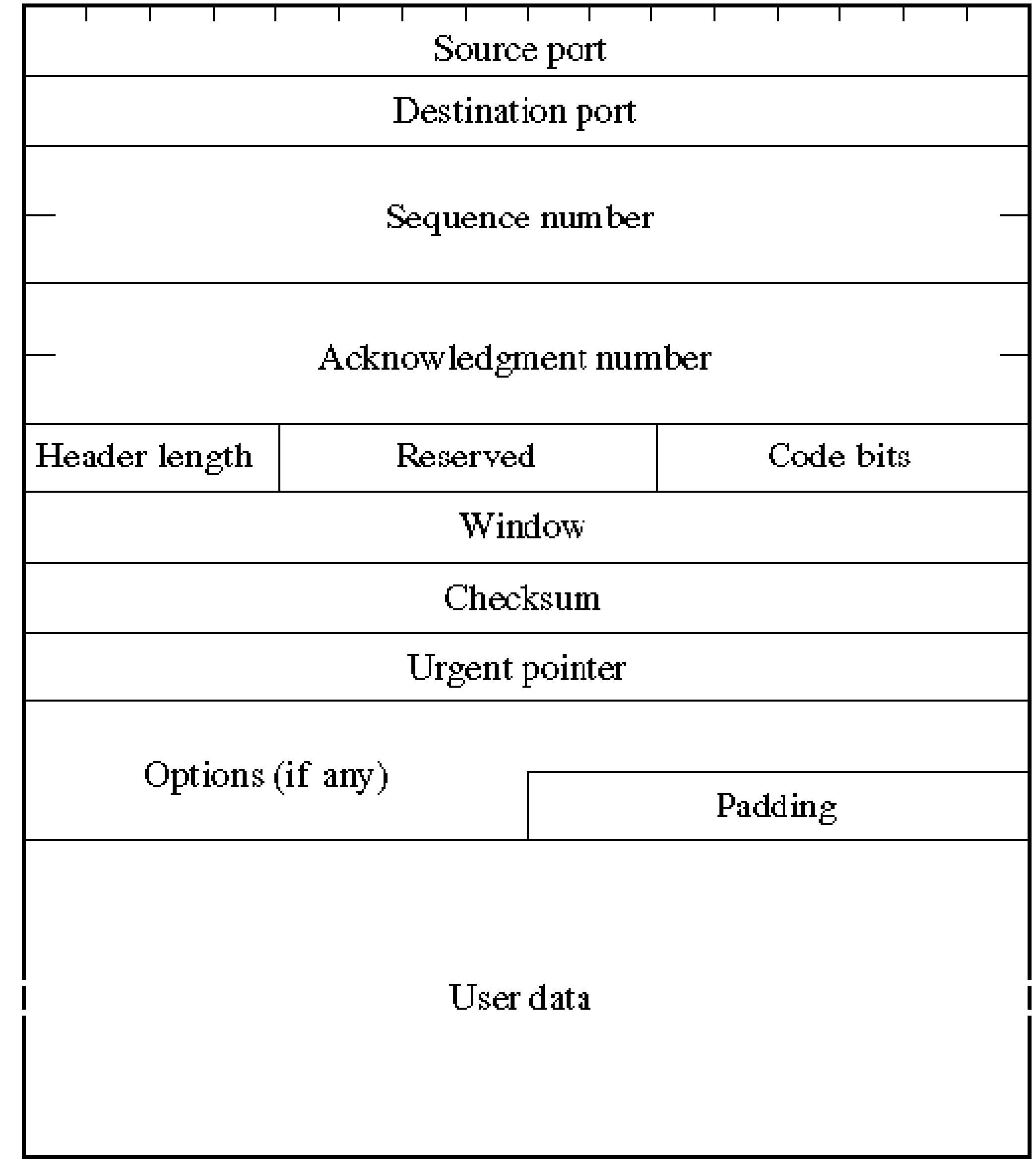
How does a Protocol Work ……

A Protocol implements its Functionality through its **"HEADER"**

A Header contains all the control information to complete the protocol's tasks

TCP - Protocol Data Unit (PDU)

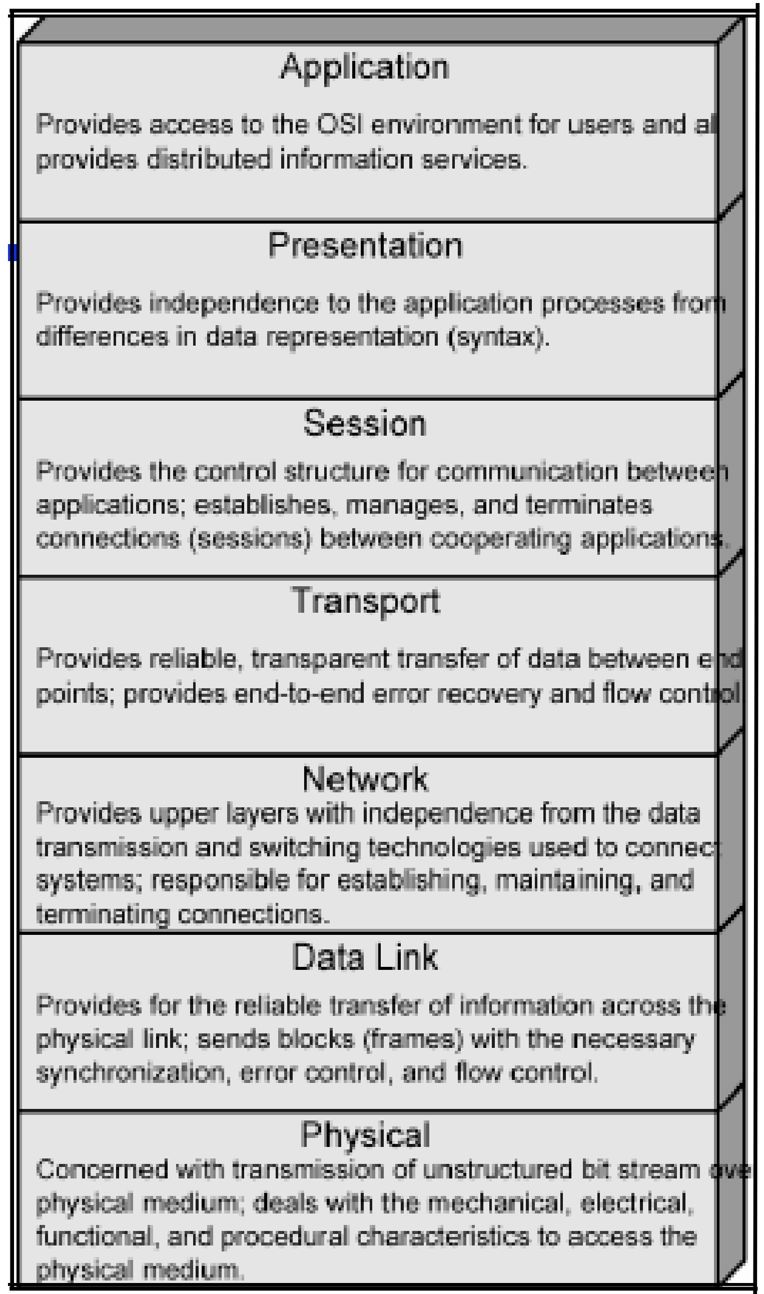
An - Example Header



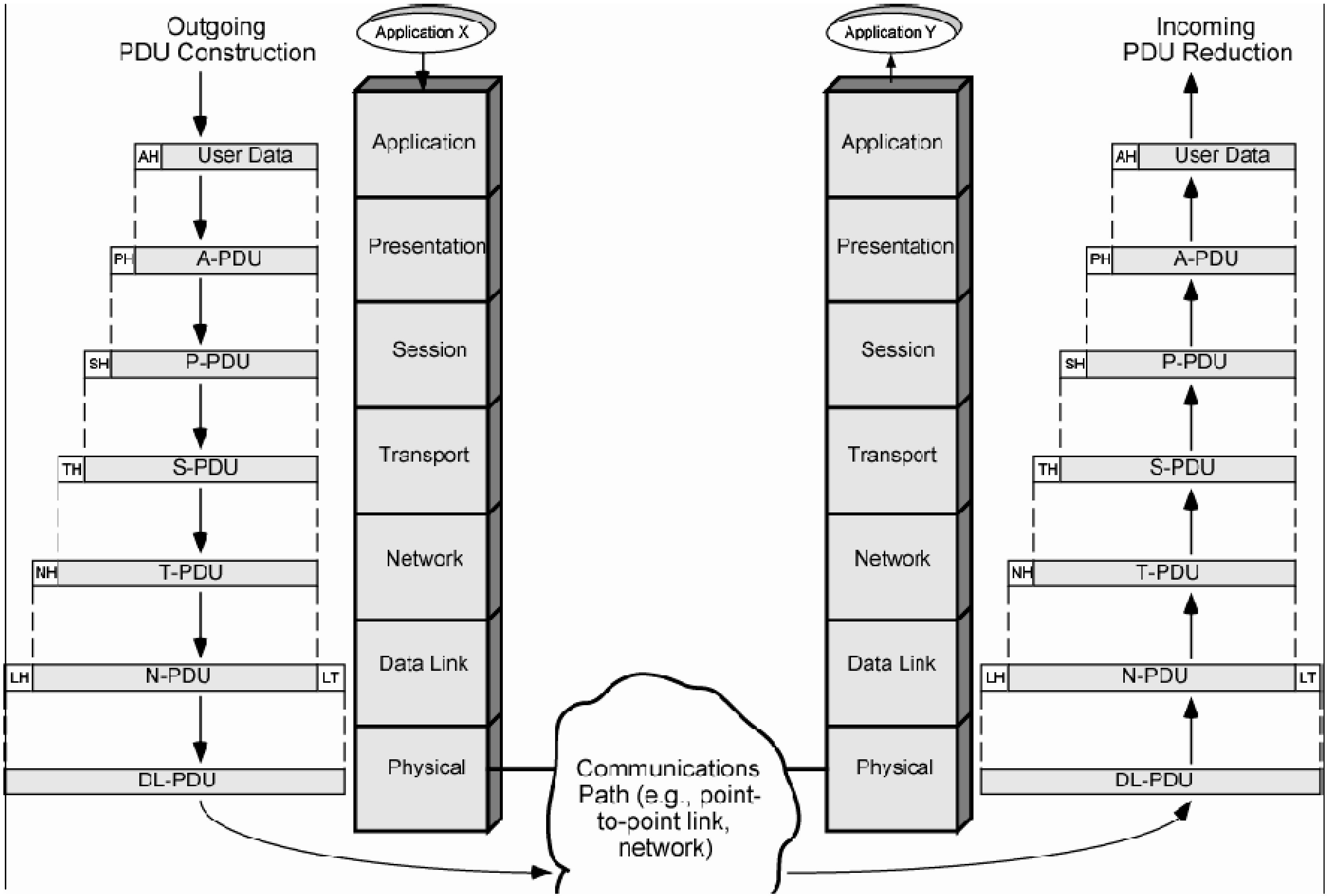
- Key Elements of a Protocol
  - Syntax - Format
  - Semantics - Control Info for Coord and error handling
  - Timings - Sequencing and Speed matching
- Categories of Protocol Functions
  - Segmentation and Re-assembly
  - Encapsulation
  - Connection Control
  - Ordered Delivery
  - Flow Control
  - Error Control
  - Addressing
  - Multiplexing
  - Transmission Services

The OSI Reference Model
and
TCP/IP Protocol Suite

The OSI Reference Model

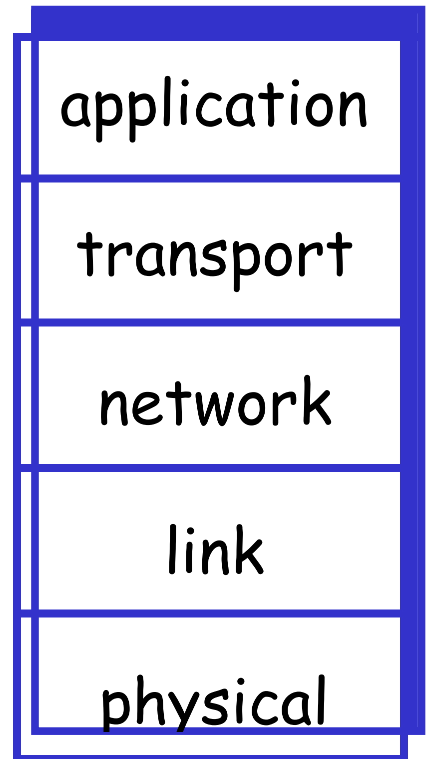


The OSI Environment

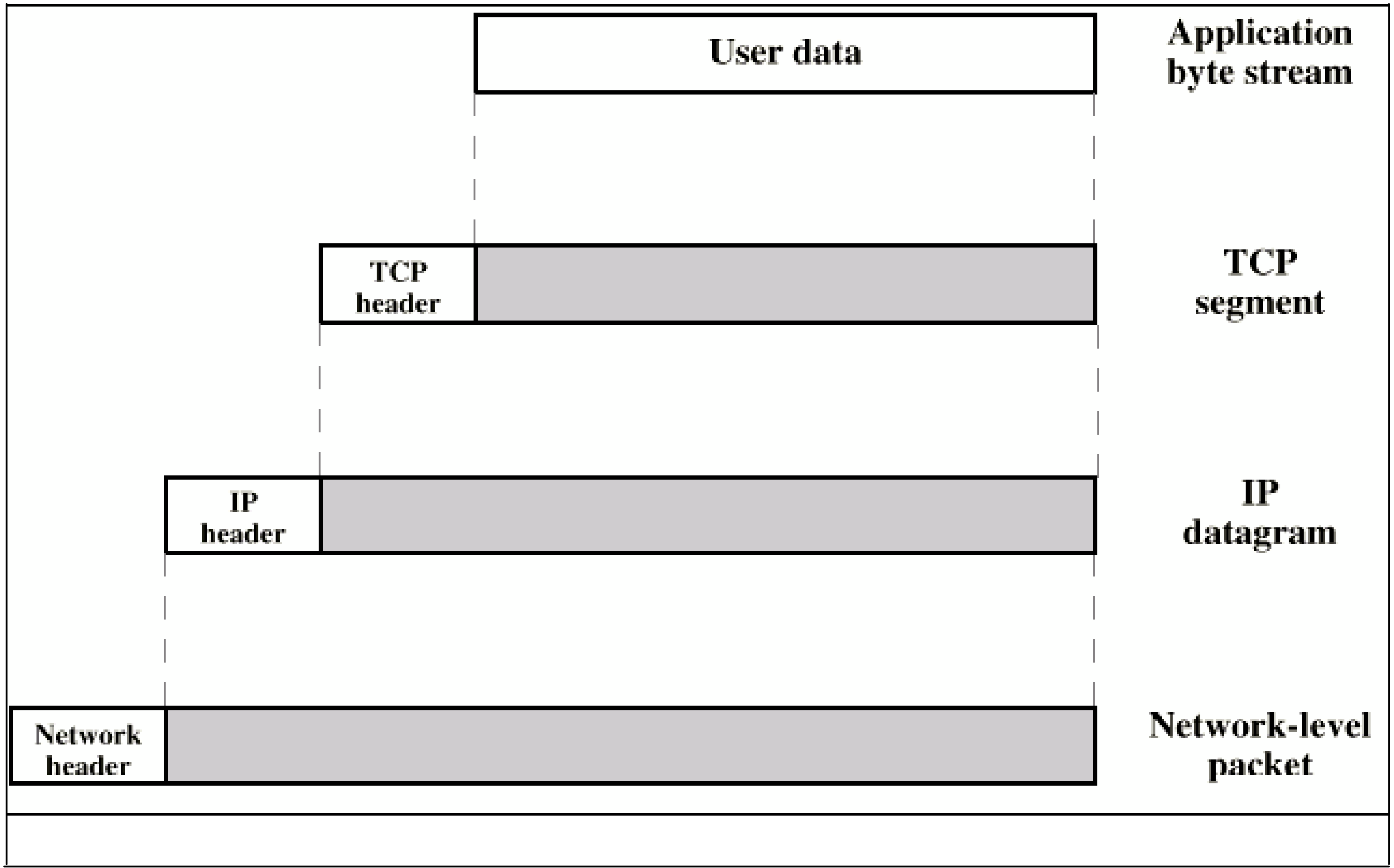


TCP / IP Protocol Suite

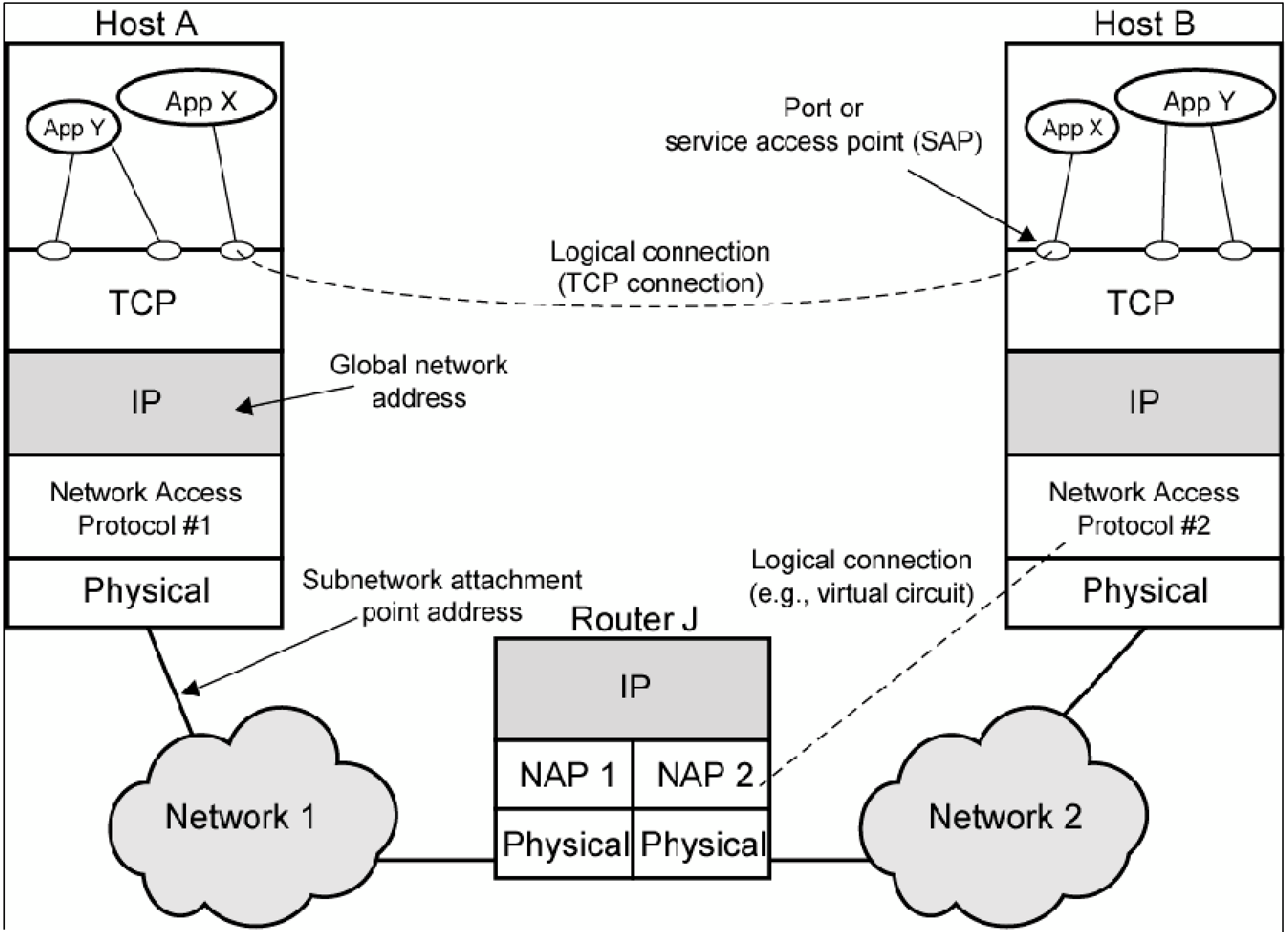
- application: supporting network applications
  - ftp, smtp, http
- transport: host-host data transfer
  - tcp, udp
- network: routing of datagrams from source to destination
  - ip, routing protocols
- link: data transfer between neighboring network elements
  - ppp, ethernet
- physical: bits "on the wire"



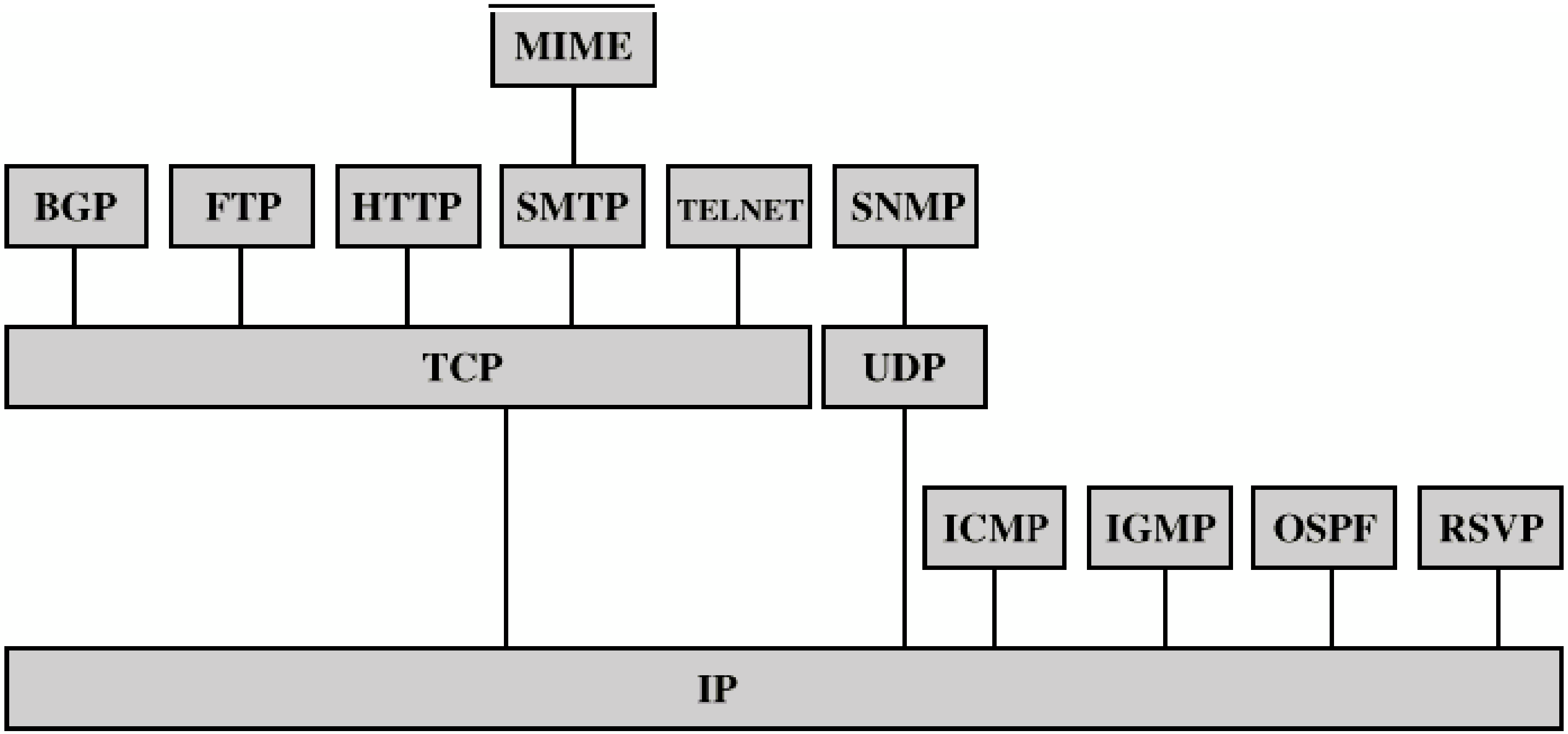
Some PDUs in TCP/IP



TCP / IP Concepts

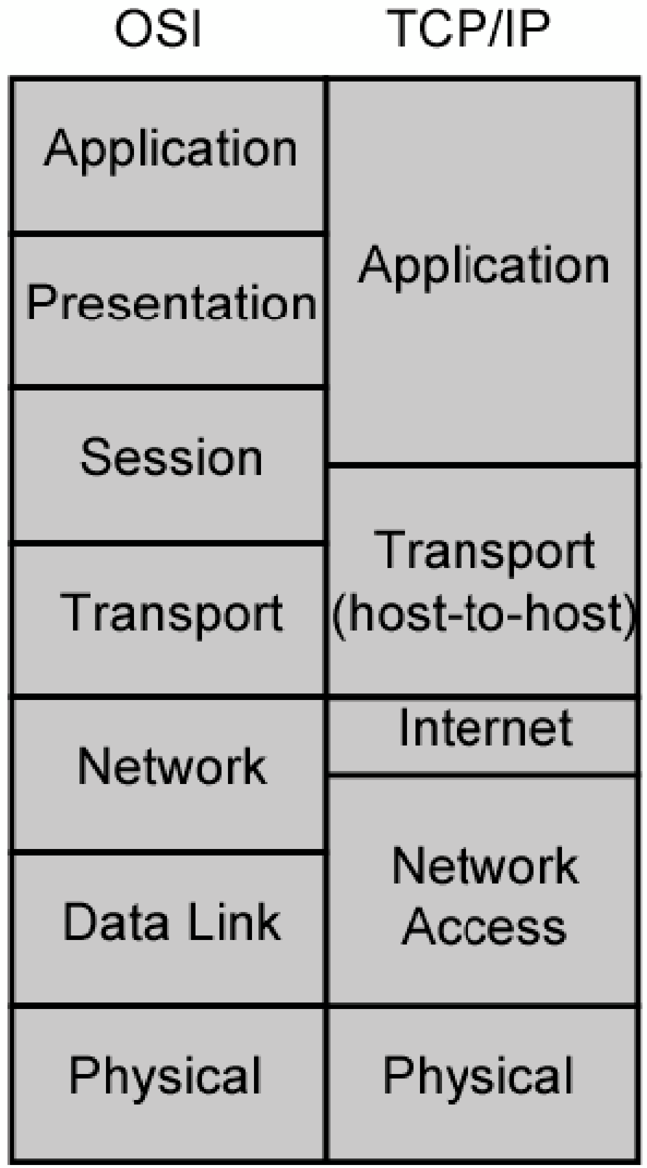


Some Protocols of TCP/IP Suite



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 - TCP/IP Comparison

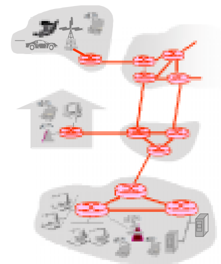


Computer Networks

Physical Layer Issues

The Network Core

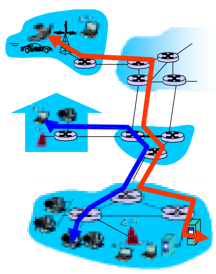
- mesh of interconnected routers
- the fundamental question: how is data transferred through the network?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent through network in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

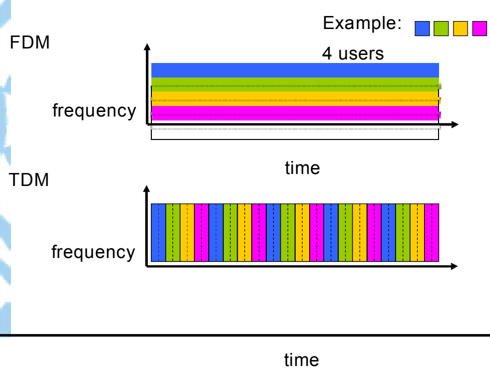
- link bandwidth, switch capacity
- no sharing
- guaranteed performance
- call setup required



Network Core: Circuit Switching

- network resources (e.g., bandwidth) divided and allocated to calls (Multiplexing)
- Resources remain idle if not used by owning call (no sharing)
- Techniques for dividing network resources into "pieces"
  - frequency division
  - time division
  - Any other multiplexing techniques?

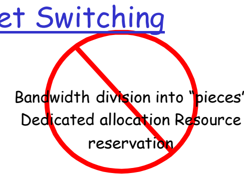
Circuit Switching: FDM and TDM

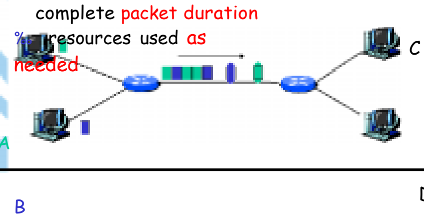


Network Core: Packet Switching

each end-end data stream divided into packets

- packets from hosts share network resources
- each packet uses full link bandwidth for complete packet duration
- resources used as needed





http://www.uandiStar.org

Network Core: Packet Switching

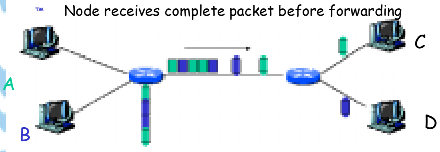
resource contention:

‰ aggregate resource demand can exceed amount available

‰ congestion: packets queue-up, wait for link use

‰ store and forward: packets move one hop at a time

™ Node receives complete packet before forwarding



Packet switching versus circuit switching

Is packet switching a "clear winner?"

‰ Great for bursty data

™ resource sharing

™ simpler, no call setup

‰ Excessive congestion: packet delay and loss

™ protocols needed for reliable data transfer, congestion control

‰ Q: How to provide circuit-like behavior for a packet switched network?

™ bandwidth guarantees needed for audio/video apps

™ QoS – Quality of Service (will be studied later in TCP)

Packet-switched networks: Types

‰ Goal: move packets from source to destination

‰ Two types of packet switch networks

‰ datagram network:

™ destination address in packet determines next hop

™ routes may change during session

™ analogy: driving, asking directions

‰ virtual circuit network:

™ each packet carries tag (virtual circuit ID), tag determines next hop

™ fixed path determined at call setup time, remains fixed throughout the session/call

™ Pro: routers can perform resource reservation

™ Con: routers maintain per-call state (complex)

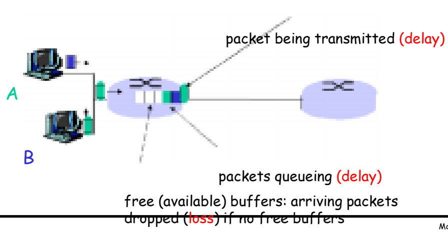
Delay, Loss and Throughput

How do loss and delay occur?

packets queue-up in router buffers

‰ packet arrival rate to link exceeds output link capacity

‰ packets queue-up, wait for turn



Four sources of packet delay

‰ 1. nodal processing:

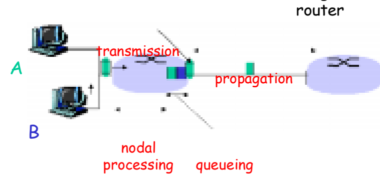
™ check bit errors

™ determine output link

‰ 2. queueing

™ time spent waiting at output link for transmission

™ depends on congestion level of router

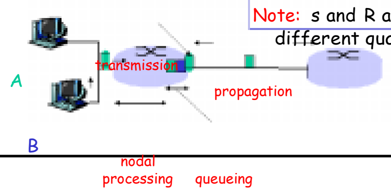


Delay in packet-switched networks

3. Transmission delay:
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:
- d = length of physical link
- s = propagation speed in medium (~2-3x10^8 m/sec)
- propagation delay = d/s

Note: s and R are very different quantities!



Nodal delay

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

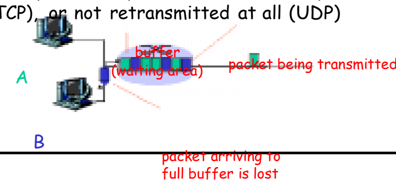
- d_{proc} = processing delay
- d_{queue} = queuing delay
- d_{trans} = transmission delay
- d_{prop} = propagation delay

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- Traceroute program: 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
  - sender times interval between transmission and reply.

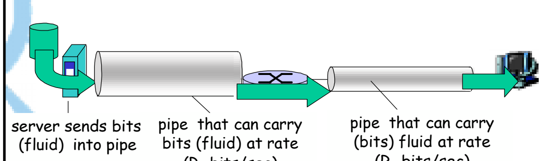
Packet loss

- queue (buffer) has finite capacity
- when packet arrives to full queue, packet is dropped (lost)
- Other sources of packet loss?
- lost packet may be retransmitted by source (TCP), or not retransmitted at all (UDP)



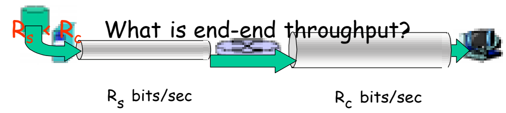
Throughput

- throughput: rate (bits/time unit) at which bits transferred between sender/receiver
  - instantaneous: rate at given point in time
  - average: rate over long(er) period of time

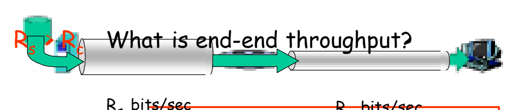


Throughput

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



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



bottleneck link

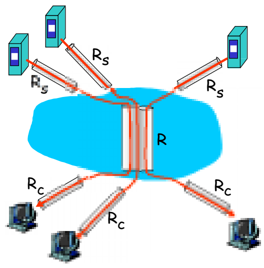
link on end-end path that constrains end-end throughput

http://www.uandiStar.org

http://www.uandiStar.org

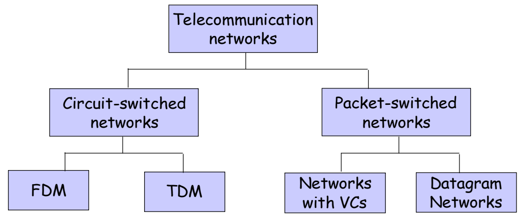
Throughput: Internet scenario

- per-connection end-end throughput: $\min(R_c, R, R_s)$
- R_c or R_s often the bottleneck link
- Is it the case nowadays?



Computer Science Department — Maj Faisal

Network Taxonomy



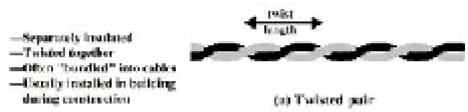
- Internet is a datagram / packet-switched network
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to applications.

Computer Science Department — Maj Faisal

Transmission Media

Computer Science Department — Maj Faisal

Twisted Pair (TP)



- Twists decrease the cross-talk
- Neighboring pairs have different twist length
- Most of telephone and network wiring in homes and offices is TP.

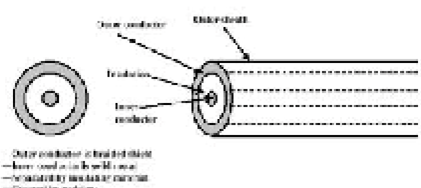
Computer Science Department — Maj Faisal

Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheap, Flexible ⇒ Easiest to install
  - No shielding ⇒ Suffers from external EM interference
  - Used in Telephone and Ethernet
- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive
  - Harder to handle (thick, heavy)
  - Used in token rings

Computer Science Department — Maj Faisal

Coaxial Cable



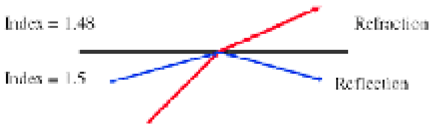
- Higher bandwidth than UTP. Up to 500 MHz.
- Used in cable TV

Computer Science Department — Maj Faisal

http://www.uandiStar.org

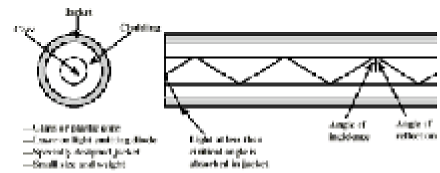
Reflection and Refraction

- Index of Refraction = Speed of light in Vacuum/Speed in glass = 300 m/µs / 200 m/µs = 1.5



- Refracted light bends towards the higher index medium

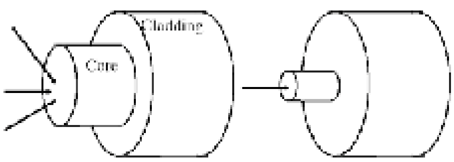
Optical Fiber



- A cylindrical mirror is formed by the cladding
- The light wave propagate by continuous reflection in the fiber
- Not affected by external interference ⇒ low bit error rate
- Fiber is used in all long-haul or high-speed communication

Types of Fibers

- Multimode Fiber: Core Diameter 50 or 62.5 µm
  Wide core ⇒ Several rays (mode) enter the fiber
  Each mode travels a different distance
- Single Mode Fiber: 10-µm core. Lower dispersion.

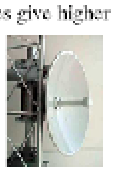


Antenna

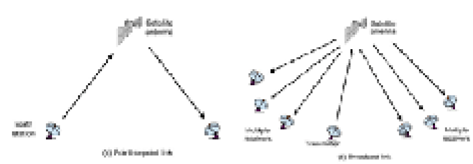
- Transmitter converts electrical energy to electromagnetic waves
- Receiver converts electromagnetic waves to electrical energy
- Same antenna is used for transmission and reception
- Omni-Directional: Power radiated in all directions
- Directional: Most power in the desired direction
- Isotropic antenna: Radiates in all directions equally
- Antenna Gain = Power at particular point/Power with Isotropic
  Expressed in dBi

Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications
- Higher frequencies give higher data rates



Satellite Microwave



- Relay station ⇒ Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Geo-stationary orbit: Height of 35,784km
- Point to Point or Direct broadcast satellite

Infrared

- Used in TV remote control
  IRD port of computers
- Modulate infrared light
- Line of sight (or reflection)
- Blocked by walls

Maj Faisal

Computer Science Department

Wireless Propagation

- **Ground wave**: Follows contour of earth. Up to 2MHz. AM radio
- **Sky wave**: Signal reflected (Actually refracted) from ionosphere layer of upper atmosphere.
- **Line of sight**: Above 30MHz.

Maj Faisal

Computer Science Department