- Access Networks: Type of network that connects an end system to the immediate router on a path from end system to any other distant end system eg: Ethernet, DSL

- packet switches — routers (network core) / link layer switches (access networks)] forward packets to their destination

- Hosts = end-system
  → client
  → server

- Protocol: Defines format + order of messages exchanged + actions taken on transmission/receipt of data
- Packet loss: when output queue is full and there are packets arriving. Either arriving packets dropped or the transmitting dropped

- Router examines a portion of packet's destination address, uses forwarding table to map address to the appropriate outbound link and forwards it
- Forwarding tables set by routing protocols

- Numericals
  → queing delay

- Constant transmission rate in circuit switching
  → Dedicated end to end connection

End-to-End connection: Direct connection without intermediary nodes for data processing and other stuff

- Communication Link: Transmission path → cables

- Frequency Division Multiplexing:
  → Link dedicates a frequency band to each connection for the duration of the connection
  → width of band is bandwidth

- Bandwidth: max amount of data that can be transferred over a network in a specific amount of time

- Time-Division Multiplexing:
  → Time divided into frames of fixed duration
  Each frame divided into fixed number of time slots

  → Network dedicates one time slot in every frame to this connection

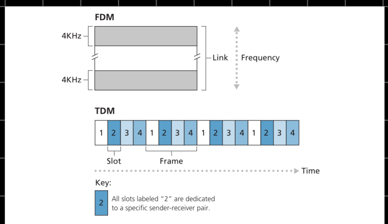


Figure 1.14 ♦ With FDM, each circuit continuously gets a fraction of the bandwidth. With TDM, each circuit gets all of the bandwidth periodically during brief intervals of time (that is, during slots)

- Silent Period: Connection established, but no data being sent on the link, causing wasteful of resources → circuit switching

Q- connection establish = 500 ms
TDM slots = 24
Bit rate = 1.536 Mbps ⇒ Transmission rate
File 640k bits

- Each circuit time = $\frac{1.536}{24}$ = 64 kbps
- Total time = $\frac{640,000}{64\times10^3}$ = 10s = 10+0.5 = 10.5s

- Access ISP: ISP dealing on the consumer end → small-scale
- global transit ISP: ISP which connects access ISPs → Large-scale

Delays

- Nodal processing delay
- Transmission delay
- queing delay
- propagation delay

} Total nodal delay

- Processing delay = Time required to analyze packet's header to determine where to send it, can include time to check for bit level errors

- Queing delay = Waiting time to transmit on the link.
  For a specific packet, length of the delay will depend on earlier arriving packets waiting to be transmitted.
  If no packet in queue, then delay is 0

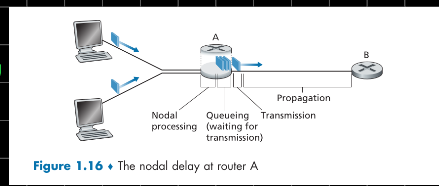


Figure 1.16 • The nodal delay at router A

- Transmission Delay: Amount of time to push/transmit packet's bits into the link
  $\frac{L}{R}$, L = # of bits / packet size
  R = Bandwidth

- Propagation Delay: Time taken to travel from one point to the other
  $\frac{d}{s}$, depends on physical medium

- congestion = traffic intensity
- packet loss increase as traffic intensity increase

=> Queing delay and traffic Intensity
→ R = transmission Rate
a = avg rate at which bits arrive in queue
L = All packets consists of L bits

$\frac{La}{R}$ = Traffic Intensity

- If $\frac{La}{R} > 1$, then average rate of bits arriving exceed the rate at which they can be transmitted from the queue

- N = total Nodes
- N-1 = total Routers

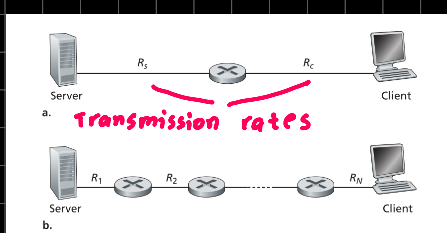
- $d_{end-end} = N(d_{proc} + d_{trans} + d_{prop} + d_{que})$

* Throughput
→ how much data actually reaches the destination in a specific time period (bps) // different from bandwidth

- Delay, packet loss, throughput as tools to measure network performance

- Instantaneous throughput: The rate at which the host is receiving the file (bps) (Speed test)
- Avg throughput = F/T bits/sec
  F = # of bits
  T = time for host to receive all F bit

- If $R_s < R_c$ → throughput = R_s
- If $R_c < R_s$ → throughput = R_c
  (undesirable)



R_s = 2 Mbps // 32 million bits
R_c = 1 Mbps

time for transfer = 32 s
Assuming no store and forward, processing and other delays

- Throughput = $\min(R_s, R_c, \ldots R_n)$
  ↳ transmission rate of bottleneck link → Bottleneck link

- Bottleneck links in network core
- R divided among 10 clients

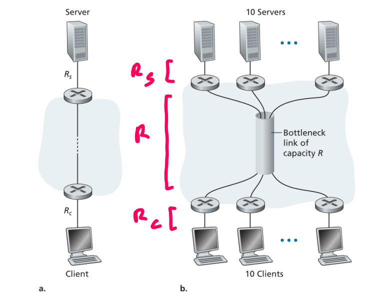


Figure 1.20 • End-to-end throughput: (a) Client downloads a file from server; (b) 10 clients downloading with 10 servers

- Protocol Layering
- Perform some actions within the layer
- Use services of the layer directly below

- Advantages
- Modularity makes it easier to update system components
- Structured way to handle/discuss system components

- Disadvantages:
- One layer may duplicate lower-layer functionality
- A layer might require data that is present in other layer

- Combine all 5 layers = Protocol stack

Application
Transport
Network
Link
Physical

- Application layer
- Network applications and their protocols reside
- HTTP, SMTP, DNS, FTP
- The protocols are distributed over multiple end systems
- Data/packet of info = message
- Allows to send, retrieve, manipulate data

- Physical
- moves individual bits within a frame from one node to the next
- Link dependant protocols and actual transmission medium
- Protocols for fibre etc..

- Transport:
- transmits/transports application-layer messages b/w application endpoints
- TCP, UDP
- Transport layer packet = segment

- UDP
- opposite of TCP apart from segments

- TCP
- connection-oriented
- guranteed delivery of messages
- Flow + congestion control
- source throttle its transmission rate
- Breaks messages into shorter segments

- Network
- Responsible of moving datagrams from one host-to-another
- Transport layer passes segment, and destination address to network layer
- IP
- Contains routing protocols to determine routes for datagrams
* IP more imp b/c it provides universal addressing and packet structure
- link layer dependant

Link:
- To move data from one node to the next node.
- transmits datagram from one node to the other
- At the next node datagram is passed to the network layer
- Ethernet, wifi
- packets on this layer are called frames
- Moves entire frame from one network element to another

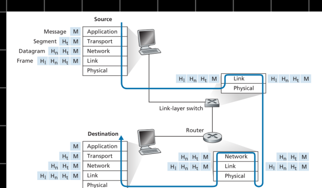


Figure 1.24 • Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality