Introduction to Computer Networks and Internet.

- Computer Network : It is a set of nodes connected by communication links.
- Node : any device that is able to send/recieve data generated by other nodes in a network is called a node.
- Communication link : It can be wired or wireless
  Links carry the information.
- Example for Nodes : Computer, switches, bridges, routers etc
- Example for Communication links : cable (wired), air (wireless)

In other words computer Networks can simply be defined as interconnection of multiple devices that are connected using multiple paths in order to send/recieve data.

- Computer network is mainly used for "resource sharing".

What is internet ?

It is a global network ~~connected by~~ comprised of many smaller networks that are interconnected using standardized communication protocols.

There is a layered system of protocols

① Application layer : Concerned with data (URL, type, etc)

② Transport layer : responsible for end-to-end communication

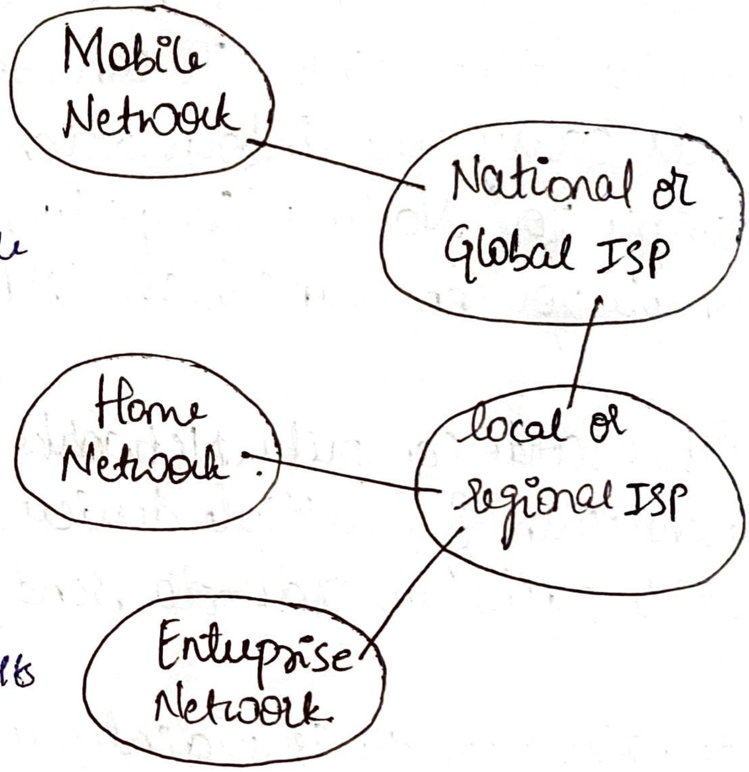
③ Network layer : provides data route.

Nuts and Bolts description

Internet is a computer network that connects multiple computing devices throughout the world. All these devices are called "hosts" or "end systems"

– End Systems (hosts)

- devices that are connected to the internet, for example computer, laptop, mobile etc are called as hosts.



- They are reffered as end systems because they sit at end/edge of the internet.
- They are also refered as hosts because they run application programs.
- They are connected by a network of communication links and packet switches.

coaxial cable, copper wire, optical fibre, radio spectrum are some types of communication links.

different link transfer data at different rates, measured in bits/second.

packet switch takes one packet from one communication link and forwards it to one of its outgoing communication link

- End systems access the internet through ISP
- Each ISP is a network of packet switches and communication links.
- ISP provides variety of types of network access to the end systems.
  - residential broadband access
  - high speed local area network access
  - wireless access
  - 56 kbps dial up modem access
- The internet is all about connecting the end systems to each other, so the ISP's that provide access to these end systems must also be connected.
- All the pieces of internet run "protocols" that controls the sending and recieving of information in the internet.
- The internet's principal protocols are collectively called as "TCP" (transmission control protocol) / "IP" (internet protocol)
  This specifies format of packets that are sent / recieved among the routers and the end systems.
- "Internet standards" these are developed by the the "internet engineering task force" and the IETF standard documents are called "Request for comments" (RFC)
  They define protocols such as TCP, IP, HTTP (for web) and SMTP (for emails) etc.

Service Description Internet is an infrastructure that provides services to applications. These applications could be anything like games, e-commerce etc, streaming services, file sharing services, cloud services etc.

- All the applications are called as distributed applications since they involve multiple end system that involve exchanging of data with each other.

- All these apps run on the end system and not on the packet switches. The packet switches facilitate the flow of data between the end systems but they are not concerned with the applications.

- For any application to run we need to transfer data from each end system related to the app.

- Hence to transfer the data from one end system to another so that the application works as intended we need to write the programs.

- These programs written in the language of your choice will work on different participating end systems to send and recieve data

- Each end system that is attached to the internet provides an API (Application programming ~~infe~~ interface)

- API is a set of rules that specifies how a program running on one end system should ask the internet infrastructure to deliver specific data to a specific destination program running on the other end system. The source of data must follow the API rules so that the internet can deliver the data to destination program.

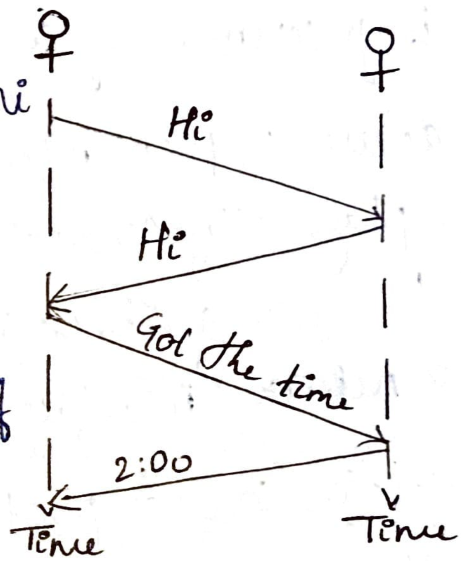
What is a protocol?

A protocol is a standardized set of rules for formatting and processing data. Protocols enable computers to communicate with one another.

- Human Analogy Consider what a human would do to ask someone time of the day.

– Human protocol dictates that one first offers a greeting to initiate communi-cation with someone else.

– The typical response to "Hi" is also "Hi", and this indicates that you can further proceed to ask the time, but if the response is "I'm busy" etc then we consider that as unwillingness or inability to communicate. In this case the human protocol would be to not ask the time.



– Sometimes there is no response given to the question asked even then the protocol is to ask the time.

– Clearly transmitted/recieved message, and actions taken when these messages are sent, play a vital role

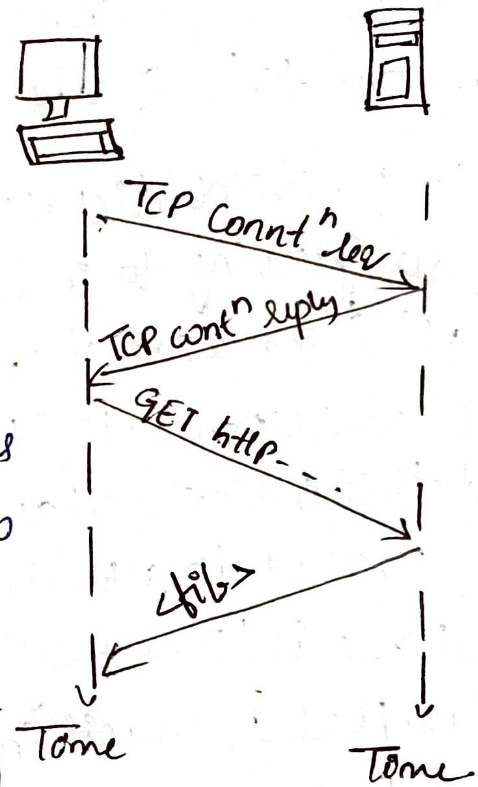
– If people run different protocols then the protocols do not interoperate and no useful work can be accomplished.

– In networking it takes two entities that are communicating with each other and are running the same protocol in order to accomplish a task.

• Network protocol This is similar to human protocol

- The entities exchanging messages (and communicating) and taking actions are hardware and software components of the same device
  Eg: Computer, smartphone, tablet etc.

- All the activities in the internet that involves two or more communicating entities is governed by a protocol.



Eg① hardware-implemented protocols in two physically connected computers control the flow of bits on the wire b/w the two network interface cards.

Eg② congestion control protocols in the end system control the rate at which the packet switchs are transmitted between the sender & reciever

Consider what happens when you make a request to a web server that is when you type the URL of a web page into your web browser

- First the computer will send a connection request message to the web server and ~~with~~ wait for a reply.
- The web server will eventually recieve your connection request message and return a connection reply message.
- Finally the web server returns the web page (file) to your computer.

Note ① In other words protocols can be defined as "format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

② Different protocols are used to accomplish different communication task.

Network Edge : It consists of end systems, access network and the communication links.

- hosts : clients and servers
  a client is nothing but the devices connected to the internet computer, laptop, mobile etc, these access different data in the internet
  a server : for example when you browse google, all the data is hosted in server form also called as 'data centers'

- access networks : to access the internet the devices (clients) must be connected to the internet. The access networks are wired or wireless communication links

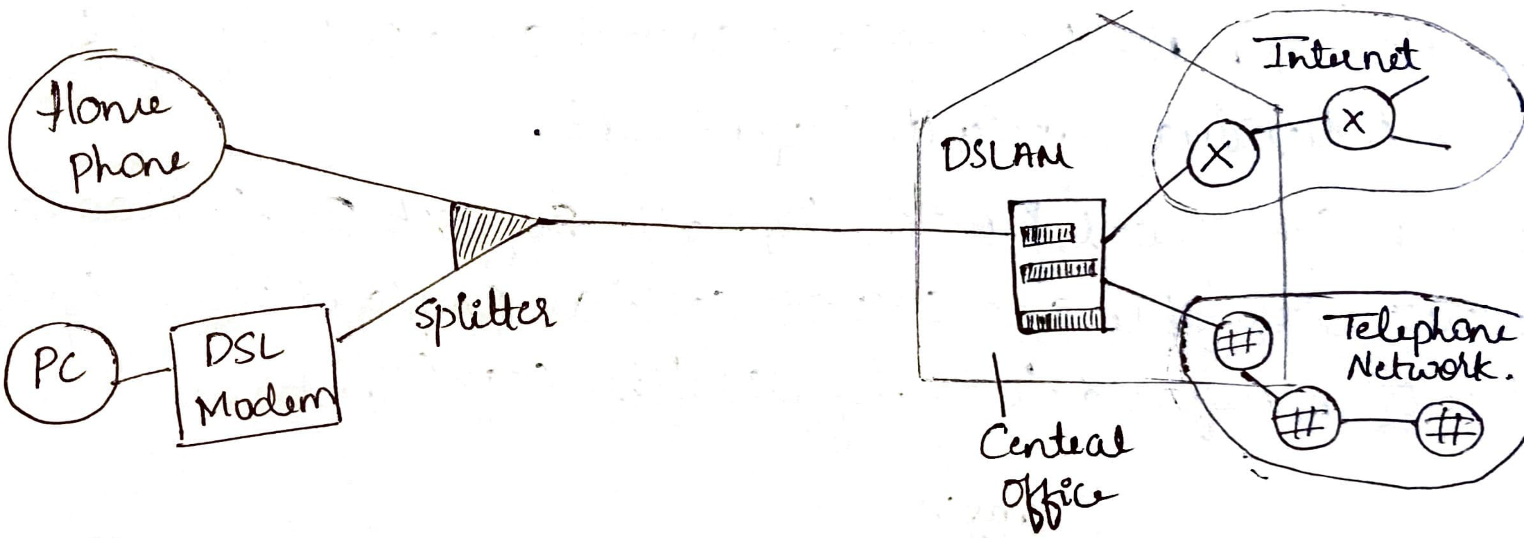
- network Core : consist of interconnected routers. This nothing but the network of the networks.

- Edge router is the router that helps you connect to the greater internet. To access the data through the internet the hosts must be connected to the router.
- Bandwidth: it is bits/second that you can send/recieve using a network.
- Shared/dedicated media.
  shared medium wireless medium (air)
  dedicated network wired (cable).

DSL (digital subscriber line)

- A digital subscriber line is a communication medium, which is used to transfer internet through a telecommunication line.
- A residence typically obtains DSL internet access from the same local telephone company that provides its wired local phone access. Thus when a DSL is used a customer's telephone company is also its ISP.
- Each customer's DSL modem uses the existing telephone line to exchange data with a digital subscriber line access multiplexer (DSLAM) located in the telephone company's local central office.
- The home's DSL modem takes digital data and translates it to high frequency tones for transmission over telephone wires to the central office.
- The analog signals from many such houses are translated back into digital format at the DSLAM.

- The residential telephone line carries both data and traditional telephone signals simultaneously which are enclosed at different frequencies.
  - A high-speed downstream channel, 50kHz to 1MHz band
  - A medium-speed upstream channel, 4KHz to 50kHz band
  - An ordinary two-way telephone channel, 0 to 4KHz band



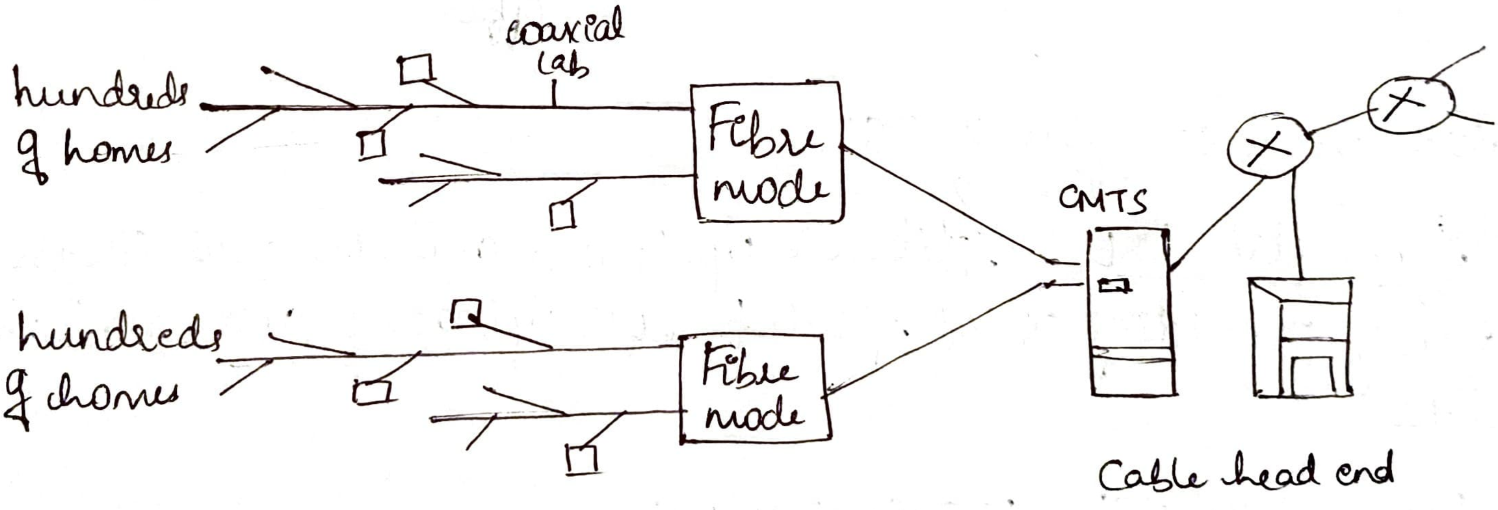
There are two types of DSL

① Symmetric DSL - splits the upstream and the downstream evenly, providing equal speeds to both uploading and downlo[ading] data

② Asymmetric DSL - provides a wider frequency range for downstream transfers. Since the downstream and upstream rates are different it is called as asymmetric.

Cable Networks

- It makes use of the cable television company's existing cable television infastructure.
- A residence obtains the cable internet access from the same company that provides its cable television.
- Fibre optics connect the cable head to end neighborhood-level junctions from which traditional coaxial cable is then used to reach individual houses and apartments.
- Each neighborhood junctions typically supports 500 to 5000 homes because both fibre and coaxial cable are employed in this system it is often referred to as hybrid fibre coax (HFC).

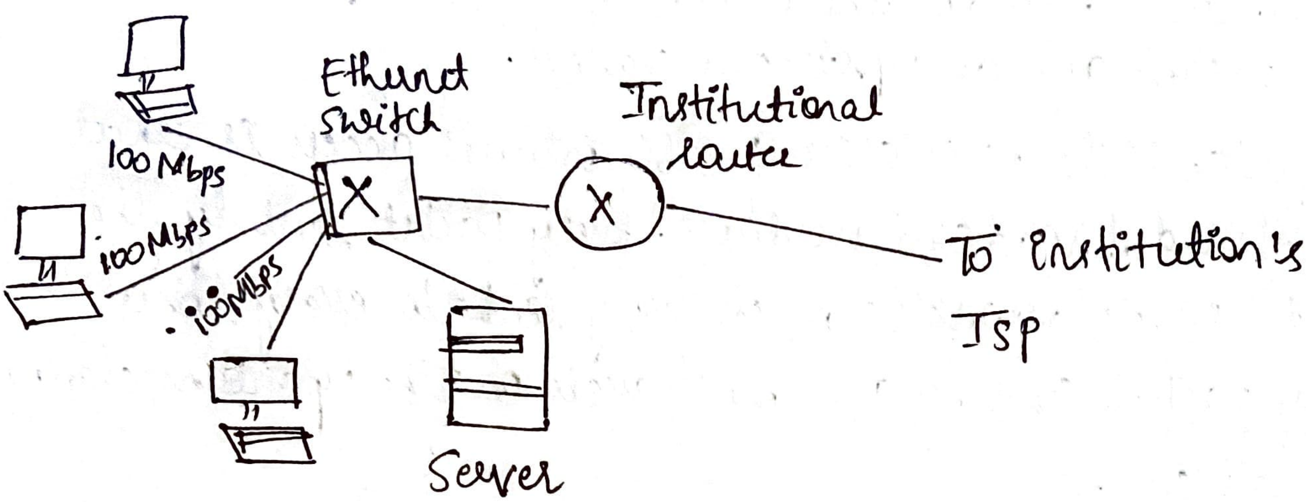


- Cable internet access requires a special modem called as the cable modems. The cable modem is typically an external device and connects to home pc through an Ethernet port.
- At the cable head end, the cable modem termination system (CMTS) helps in turning the analog signal sent from the cable modems in many downstream homes back into digital formats.

- Cable modems divides the HFC network into two channels, a downstream and an upstream channel.
- One important characteristics of cable internet access is that it is a shared broadcast medium. Every packet sent by the head end travels downstream on every link to every home and every packet sent by a home travels on the upstream channel to the head end.
- If several users are simultaneously downloading a video file on downstream channel the actual rate at which each user recieves its video file will be significantly lower than the aggregate cable downstream rate, on the other hand if there are very few active users then they may recieve the web pages at the full cable downstream rate.

Ethernet and Wifi

- Here a local area network (LAN) is used to connect an end system to the edge router.
- Ethernet is by far the most prevalent access technology in corporate, university and home networks.
- The ethernet users use twisted-pair copper wire to connect to an ethernet switch. The ethernet switch or a network of such interconnected switches is then in turn connected into larger internet.
- Users typically have 100 Mbps access to the Ethernet Switch whereas servers may have 1 Gbps to 10 Gbps access.



- In wireless LAN setting, wireless users transmit/receive packets to/from an access point that is connected into the enterprise's network, which in turn is connected to the wired Internet.

- Wireless LAN user must typically be within a few tens of meters of the access point.

Wide Area Wireless access

- This is basically a cellular wireless networks
- Devices like iphones, Blackberry and android employ the wireless infrastructure used for cellular telephony to send/recieve packets through a base station that is operated by cellular network provider.

The third generation (3G) wireless, provides packet-switched wide-area wireless internet access at speeds in excess of 1 Mbps
Now fourth generation (4G) have also been deployed.
LTE (long term evolution) has its root in 3G technology and can potentially acheive rates in excess of 10 Mbps.

Physical media

- Access networks are connected by the physical media
- bit : propogates between the transmitter/reciever pair
- When a bit travels from source to destination, it passes through a series of transmitter - reciever pairs. For each transmitter - reciever pair, the bit is sent by propagating electromagnetic waves or optical pulses across a physical medium.
- The physical medium can take many shapes and forms and does not have to be of the same type for each transmitter - reciever pair along the path.

  Eg: twisted pair copper wire, coaxial cable, multimode fibre optic cable, terrestrial radio spectrum and sattelite radio spectrum.
- Physical media falls into two categories

  ① Guided media - the waves are guided along a solid medium such as fibre optic cable, a twisted pair of copper wire etc.

  ② Unguided media - the waves propagate in the atmosphere and in outer space, such as in wireless LAN or a digital satellite ~~chat~~ channel.

Twisted pair copper wire

- It is the least expensive and most commonly used guided transmission medium.
- More than 99% of the wired connections from the telephone handset to the local telephone use twisted - pair copper wire
- It consists of two insulated copper wires each about 1mm thick arranged in a regular spiral pattern. The wires are twisted together to reduce the electrical interference from similar pairs close by.

- Typically a number of pairs are bundled together in a cable by wrapping the pairs in a protective shield.
- A wire pair consists of a single communication link. Unshielded twisted pair is commonly used for computer networks within a building ie LAN
- Data rates for LAN using twisted pair today range from 10Mbps to 10Gbps. The data rates that can be acheived depend on the thickness of the wire and the distance between the transmitter and reciever.

Coaxial Cable

- It consists of two copper conductors but they are concentric and not parallel.
- With the construction and special insulation and shielding, coaxial cable is quite common in television systems.
- In cable television and cable internet access the transmitter shifts the digital signal to a specific frequency band, and resulting analog signal is sent from the transmitter to one or more recievers.
- Coaxial cable can be used as guided shared medium. Specifically a number of end systems can be connected directly to the cable with each of the end systems recieving whatever is sent by the other end system.

Fibre optics

- An optic fibre is a thin, flexible medium that conducts pulse of light with each pulse representing a bit.
- A single optical fibre can support upto tens or even hundreds of ~~gigabytes~~ gigabits per second.
- They are immune to electromagnetic interference, have very low signal attenuation upto 100 km, and are very hard to tap
- Fibre optics is used as guided transmission media, particularly for overseas links. It is prevalent in the backbone of internet.
- It carries standard link speeds range from 51.8 Mbps to 39.8 Gbps, these speeds are often referred to as OC-n where the link speed equals n x 51.8 Mbps.

The Network Core

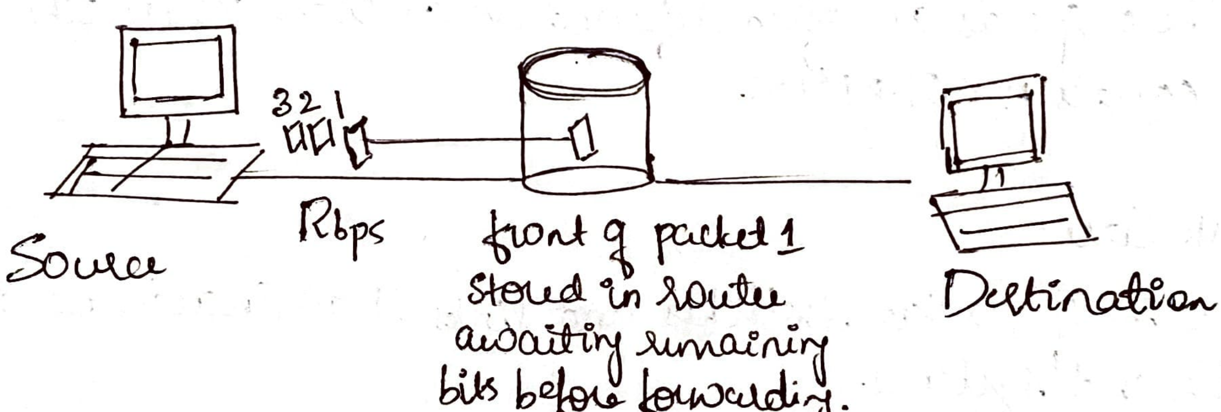
It is the mesh of packet switches and links that interconnect the internet's end systems.

Packet Switching

- In a network application, end systems exchange messages with one another. Messages can contain anything that the application designer wants. A message may perform a control function or contain data (email, JPEG image, audio file etc).
- To send a message from the source to the destination, the source breaks the ~~smaller~~ long message into smaller chunks called packets
- Between the source and destination, each packet travels through the communication links and the packet switches.
- Packets are transmitted over each communication link at a rate equal to the full transmission rate of the link.
- Time to transmit the packet is L/R seconds.

Store and Forward transmission

- It means that the packet switch must recieve the entire packet before it can begin to transmit the first bit of the packet on to the outbound link.
- Consider a simple network consisting of two end systems connected by a single router.
- A router will typically have many incident links since its job is to switch an incoming packet onto an outgoing link.
- The task of the router is to transfer the packet from one link to the only attached other link.



- In the example above, the source has 3 packets each consisting of L bits to send to the destination. The source has transmitted some of packet 1, and front of packet 1 has already arrived at the router. Since the router employs store and forward transmission at this instant of time, it cannot transmit the bit it has recieved, instead it must first store.
- Only after recieving all the packet's bits it can begin to transmit the packet onto the outbound link.

Amount of time that elapses from when the source begins to send the packet until the destination has recieved the entire packet.

- The source begins to transmit at time 0; at time L/R seconds, the source has transmitted the entire packet and the entire packet has been recieved and stored at the router.
- At time L/R seconds, since the router has recieved the entire packet, it can begin to transmit the packet onto the outbound link towards the destination.
- At time $2L/R$ the router has transmitted the entire packet has been recieved by the destination. Thus the total delay is $2L/R$.

Considering general case of sending one packet from source to destination over a path consisting of N links each of rate R. The end to end delay is given as

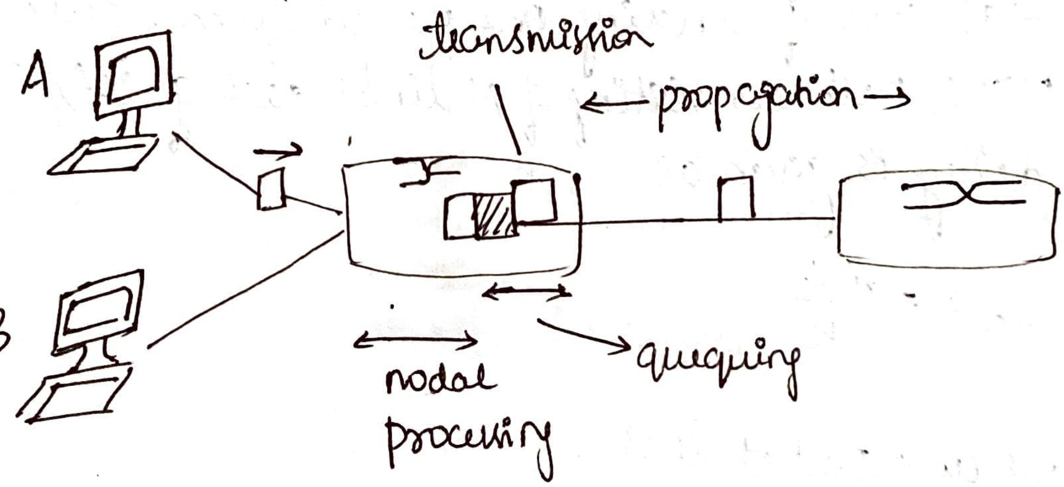
$$d_{end\text{-}to\text{-}end} = N\frac{L}{R}$$

Queuing delays and packet loss

- Each packet switch has multiple links attatched to it and for each attached link the packet switch has an output buffer which stores packets that the router is about to send into that link.
- If an arriving packet needs to be transmitted onto a link but finds the link busy with the transmission of another packet the arriving packet must wait in the output buffer.
- Thus in addition to the store and forward delays packets suffer output buffer called "queuing delays"

- These delays are variable and depend on the level of congestion in the network. Since the amount of buffer size is finite an arriving packet may find the buffer is completely full with other packets waiting for transmissions.
- In the above case, "packet loss" occurs, either the arriving packet or one of the already-queued packets will be dropped.

Four sources of packet delay
- packets queue in router buffer



- <u>nodal</u> <u>processing</u> <u>delay</u>: the amount of time the router takes for processing.
  - Here the router checks for the bit errors
  - If it has multiple out going links then it has to determine which among those should send the packet

f/d

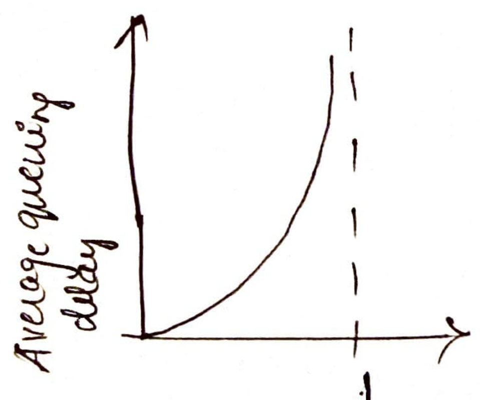
• queuing delay at a node: occurs if the packet arrival bit is greater than the o/p bit.
- this depends on the congestion level of router

• transmission delay : once the packet gets to head of the queue, the packet going to be transmitted is put onto the wire. Now the amount of wire taken to put the packet on the wire is transmission delay.
- packet is L bits and link is R bits per second
- total transmission delay: $d_{trans} = L/R$

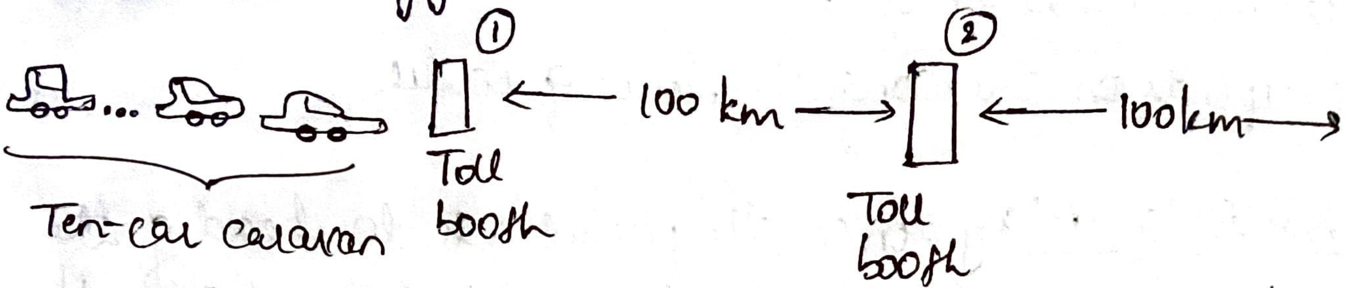
• propagation delay : Once the packet has been put onto the wire, the packet has to travel from one router to the other. Now the amount of time the packet takes to transmit on the wire is called propagation delay
- depends on the length of the wire and speed at which the packet travel.

- propagation speed is 2×10^8 m/sec (s) and d is the distance
propagation delay $d_{prop} = d/s$

Dependence of average queuing delay on traffic intensity



Caravan Analogy



- Consider a ten car caravan. Cars are travelling/propagating at the rate of 1000 km/hr ~~and~~
- There are two toll booths ar are 100km apart. Each toll booth takes one minute to service a car.
- The travelling delay between two toll booths is 6 minutes and time to serve a caravan is 10 minutes.
- In this case the first few cars from caravan ① will arrive the next toll booth before the last cars leave the toll booth.
- The above situation also occurs in the packet-switched networks. The first bits in a packet can arrive at a router while many of the remaining bits in the packet are still waiting to be transmitted by the preceding router.

The total delay is given by,

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

packet Loss

- queue is capable of holding an infinite number of packets.
- a packet can arrive to find a full queue. With no place to store such a packet, a router will drop that packet, that is the packet will be lost.
- lost packet can be retransmitted on an end to end basis in order to ensure that all data are eventually transferred from source to destination.

End to end delay

Considering total delay from source to destination

- Suppose there are $N-1$ routers ~~from~~ between the source host and the destination host, also consider for the moment that the network is uncongested.
- Let the processing delay at each router and at the source host be d_{proc}, the transmission rate out of each router and out of the source host is R bit/sec and the propagation on each link is d_{prop}. The nodal delays accumulate and give end to end delays.

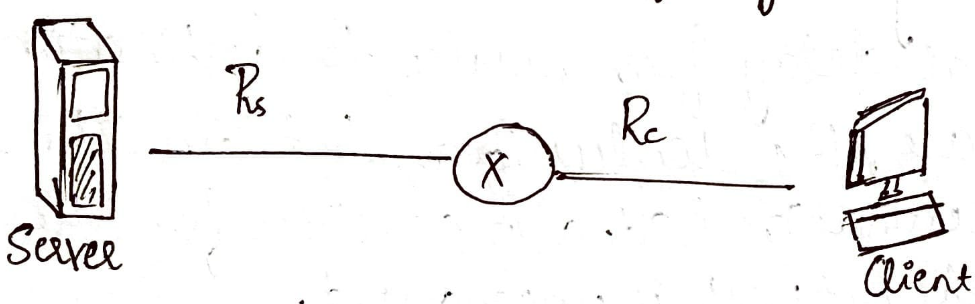
$$d_{end\text{-}to\text{-}end} = N(d_{proc} + d_{trans} + d_{prop})$$

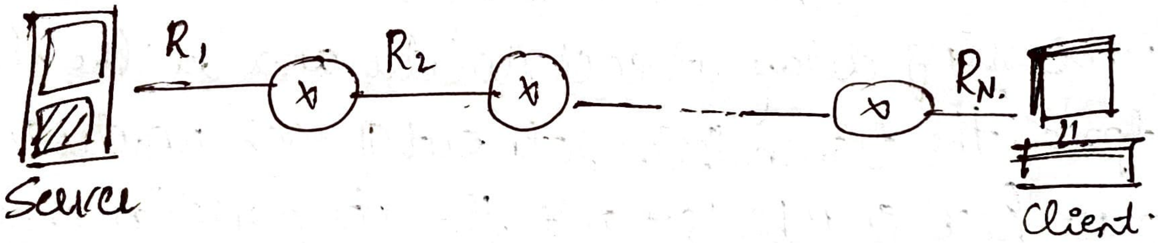
where $d_{trans} = L/R$ (L is the packet size).

Throughput in Computer Networks

- To define throughput consider transferring a large file from host A to host B ~~accor~~ across a computer network.
- The instantaneous throughput at any instant of time is the rate (in bits/sec) at which host B is recieving the file.
- If the file is F bits and the transfer takes T seconds for the host B to recieve all F bits then the average throughput of the file transfer is F/T bit/sec.

Throughput for a file transfer system.



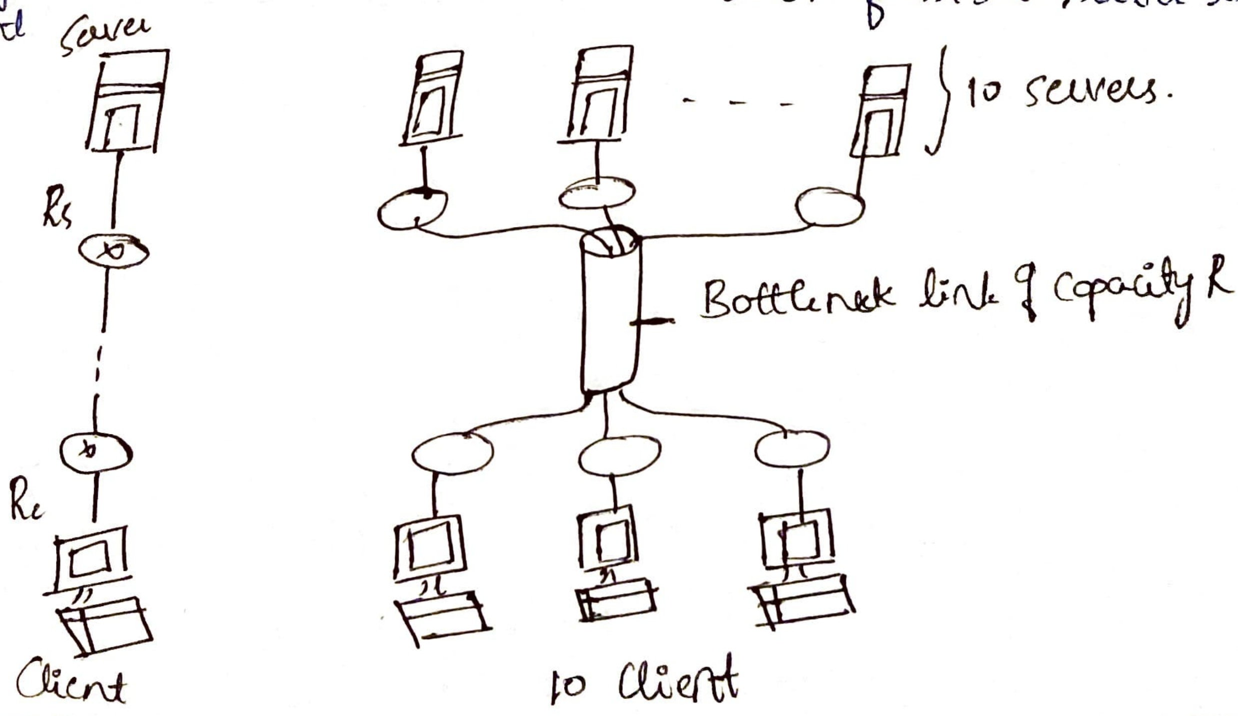


- Let R_s denote the rate of the link between the server and the router and let R_c denote the rate of the link between the router and the client.
- Clearly server cannot pump bits through its link at a rate a faster than R_s bps, and the router cannot forward bits at a rate faster than R_c bps.
- If $R_s < R_c$: then the bits pumped by server will flow right through the router and arrive at client at rate R_s bps giving a throughput of R_s bps.

- On the other hand if $R_c < R_s$, then the router will not be able to forward bits as quickly as it recieves them. In this case bits will only leave the router at rate R_c giving an end to end throughput of R_c bps
- Thus for simple two-link network, the throughput is $min(R_c, R_s)$ that is, it is the transmission rate of the "bottleneck link".

Now consider a network with N links between the server and the client, with transmission rates of N links being $R_1, R_2, R_3 ... R_N$
Applying the same analalysis as for the two-link network, we find that the throughput for a file transfer from server to client is $min(R_1, R_2 ... R_N)$

Now consider another example motivated by today's internet. There are two end systems, a server and a client, connected to a computer network
- The server is connected to the network with the access link R_s and the client is connected to the network with the access link R_c.
- Now suppose that all the links in the core of the communication network have very high transmission rates, also suppose that the only bits being sent in the entire network are those from the server to the client



- The rate at which bits can flow from source to destination is again the minimum of R_s and R_c that is throughput = min (R_c, R_s) Therefore the constraining factor for throughput in today's internet is typically the access network.

- Now consider 10 servers and 10 clients connected to the core of computer network. In this example there are 10 simultaneous downloads taking place involving 10 client-server pairs
- Lets suppose that all server access links have the same rate R_s, all client access links have the same rate R_c and the transmission rates of all the links in the core except the one common link of rate R, are much larger than R_s, R_c and R
If the rate of common link R is large say a hundred times larger than both R_s and R_c then the throughput for each download will once again be min (R_s, R_c)

The above example shows that throughput depends on the transmission rates of the links over which the data flows.

Protocol layers To provide structure to the design of network protocols, network designers organize protocols and the network hardware and software that implement the protocols in layers.

- Each protocol belongs to one of the layers, just as each function in the airline architecture belonged to a layer. We are again interested in the services that a layer offers to the layer above the so-called service model of a layer.
- Each layer provides its serviced by
  - performing certain actions within that layer
  - using the service of the layer directly below it.

Five-layer internet protocol stack

① Application layer: This is where the network applications and their and their application-layer protocol reside. The internet's application layer includes many protocols such as HTTP, (web document request & transfer) SMTP (e-mail messages), FTP (files b/w the systems)