GANAPATI INSTITUTE OF ENGINEERING AND TECHNOLOGY

(POLYTECHNIC)

Mathasahi , Jagatpur , Cuttack - 754200, Odisha

"DATA COMMUNICATION AND COMPUTER NETWORK"

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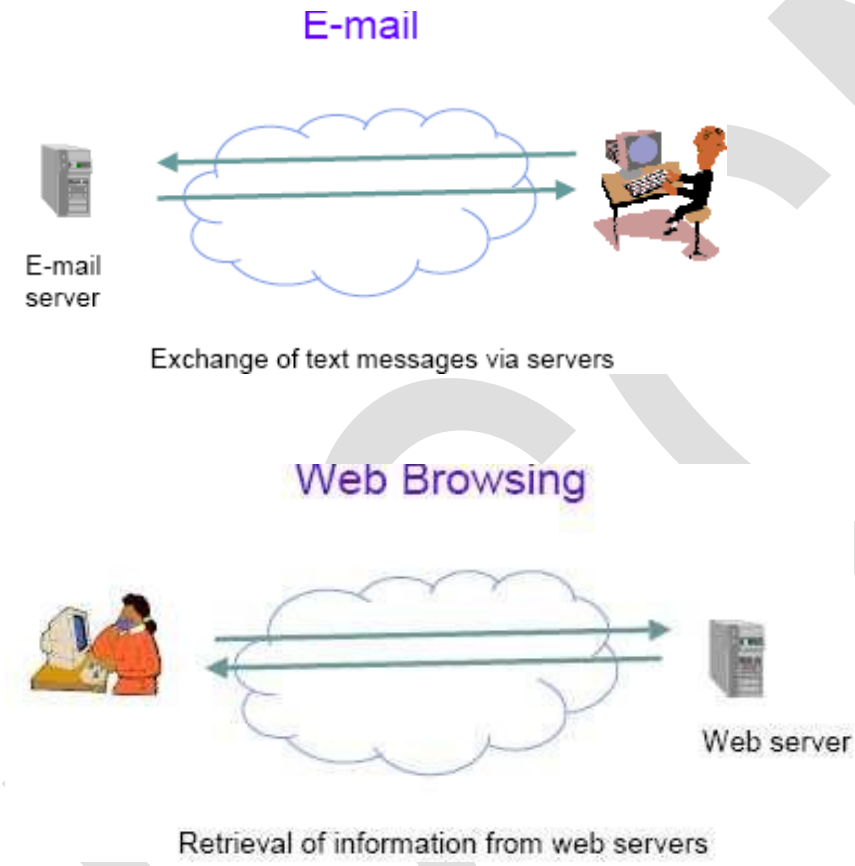
MODULE-I

OverviewofDataCommunication&Networking:

DataCommunication:
Theinformationissharedwhenwecommunicate.Thissharingcanbelocaloroverlongdistance.Data refers to information presented in whatever form is agreed upon by the parties creating and using it. Data communications are the exchange of data between two devices via some form of transmission medium suchasawire cable. Acommunication service enablestheexchangeof information between users at different locations. The communicating devices must be a part of a communication system made up of a combination of hardware (physical equipment) and software (programs).
Communicationservices&applicationsareeverywhere.Someexamplesaregivenbelow:



CharacteristicsofdataCommunication:
Theeffectivenessofadatacommunicationsystem dependsonFourfundamentalcharacteristics:
1. Delivery
2. Accuracy
3. Timeliness
4. Jitter

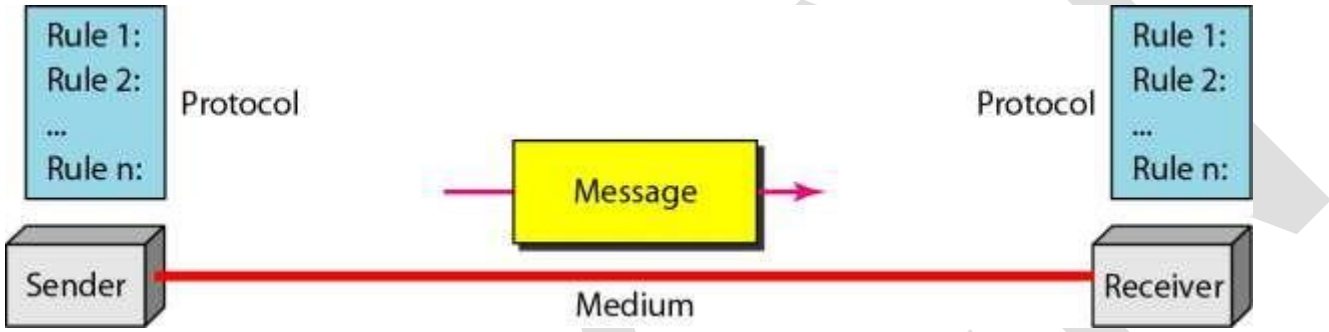
Delivery:Thesystemmustdeliver datatocorrect destination.
Accuracy: Thesystemmustdeliverdata accurately.
Timeliness: The system must deliver data in a timely manner. Timely delivery means delivering data astheyareproduced,inthesameorderthattheyareproducedandwithoutsignificantdelay.Thiskind of delivery is called real -time transmission.
Jitter:Jitterreferstothevariationinthepacketarrival time.

Simply wecansaythatadatacommunicationsystemmustdeliver datatothecorrectdestinationinan accurate and timely manner.

Components:

Theessentialcomponentsofadatacommunicationsystemare:

Message
Sender
Receiver
Medium
Protocol



Message: Theinformationtobecommunicated.Itcanconsistoftext,pictures,numbers,sound,video or audio.
Sender: The sender is the device that sends the data message. It can be a computer or workstation telephone handset, video camera and so on.
Receiver: The receiver is the device that receives the message. It can be a computer or workstation telephone handset, video camera and so on.
Medium: The transmission medium is the physical path connecting both the sender as well as the receiver by which a message travels from sender to receiver. It could be a twisted pair wire, coaxial cable, fiber optic cable, or radio waves.
Protocol: A protocol is a set of rules that governs data communications. It represents an agreement between the communicating devices.

Data representation:

Information canbeinanyformsuchastext,numbers,images, audioandvideo.
Text
Text isrepresentedasabit pattern
Thenumber of bits inapatterndependsonthenumberof symbols inthatlanguage. Code is the set of bit patterns designed to represent text symbols.
ASCII
The American National Standards Institute developed a code called the American Standard code for Information Interchange (ASCII) .This code uses 7 bits for each symbol.
Extended ASCII
Tomakethesizeofeachpattern1byte(8bits),anextra0isaugmentedatttheleftttheASCIIbitpatterns which doesn't change the value of the pattern.
Unicode
Torepresent asymbolorcodein anylanguageUnicodeisused.Ituses 32bitsto represent.
ISO
The international organization for standardization known as ISO has designed a code using a 32 – bit pattern.Thiscodecanrepresentupto4,294,967,296symbols.
Numbers

Numbers are also representedby using bit patterns. Instead of using ASCII to representnumbers, the number is directly converted to a binary number.

Images

Images are also represented by bit patterns. An image is divided into a matrix of pixels (The smallest element of an image) where each pixel is a small dot having dimension. Each pixel is assigned a bit pattern. The size and value of the pattern depends on the image.

Audio

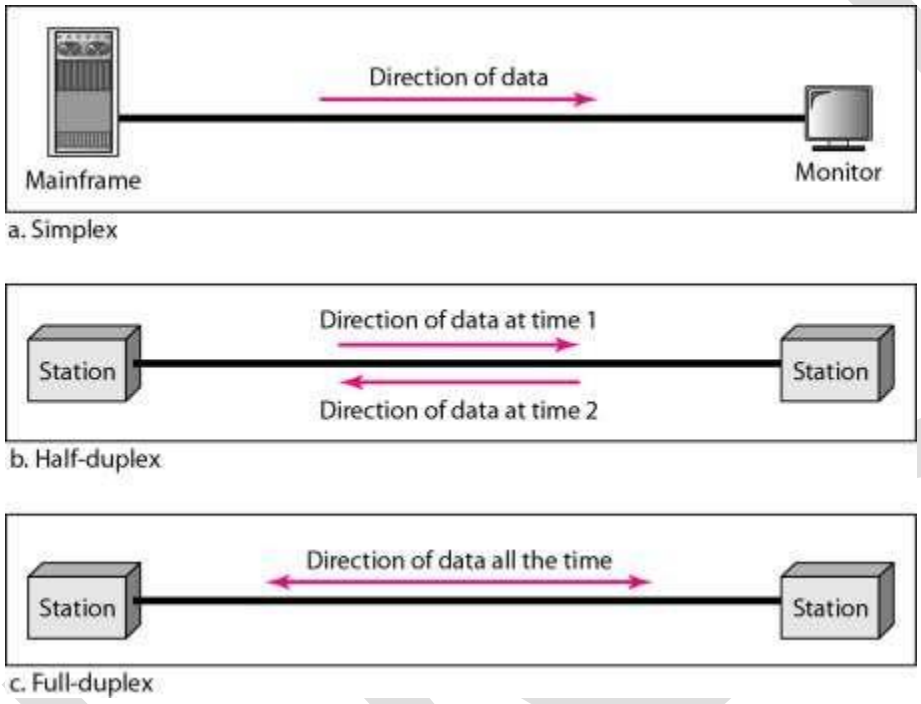
Audioistherecordingorbroadcastingofsoundormusic.Audioisbynaturedifferentfromtext,numbers or images. It is continuous not discrete.

Video

Video is the recording or broadcasting of pictureor movie. Video canbe produced either acontinuous entity or it can be a combination of images.

Directionofdata flow

Twodevicescancommunicateinsimplex,half-duplexorfull-duplexmode.



Simplex:

In simplex mode, the communication is unidirectional. Only one of the devices on a link can transmit; the other can only receive.

Ex.Keyboardand monitor

Half-duplex

In half-duplex mode, each station can both transmit and receive but not at the same time. When one device is sending, the other can only receive.

Ex.Walkie-talkiesandCB(citizenbandradios)

Full-duplex

Infull-duplexmode,bothstationscantransmitandreceivesimultaneously. Ex.

Telephone network

Whentwopeoplearecommunicatingbyatelephoneline, bothcanlistenandtalkatthesametime.

Network:

Definition:

- Anetworkisset ofdevices(nodes) connectedbycommunicationlinks(media)
- Anodecanbeacomputer,printer orotherdevicecapableofsending and/orreceiving data
- Linkconnectingthedevicesareoftencalledcommunicationchannels
- Mostnetworkusedistributedprocessing.

DistributedProcessing

Networksusedistributedprocessinginwhichataskdividedamongmultiplecomputers.Separate computers handle a subset instead of a single machine responsible for all aspects of a process.

Performance

Performancecanbemeasuredintermsoftransittime,responsetime,numberofusers,typeof transmission medium, and capabilities of the connected hardware and the efficiency of the software.

Transittime

Thetimerequiredforamessagetotravelfrom one devicetoanother.

Responsetime

Thetimespent between aninquiryandaresponse

Reliability

Itismeasuredbythefrequencyoffailureandtimerequiredtorecoverfromafailure.

Security

Networksecurityisprotectingdatafromunauthorizedaccess.

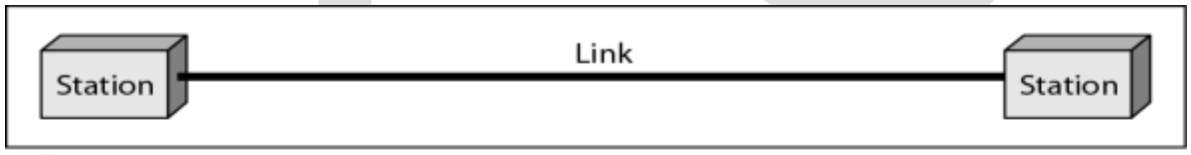
Typeofconnection

Twotypes ofconnections

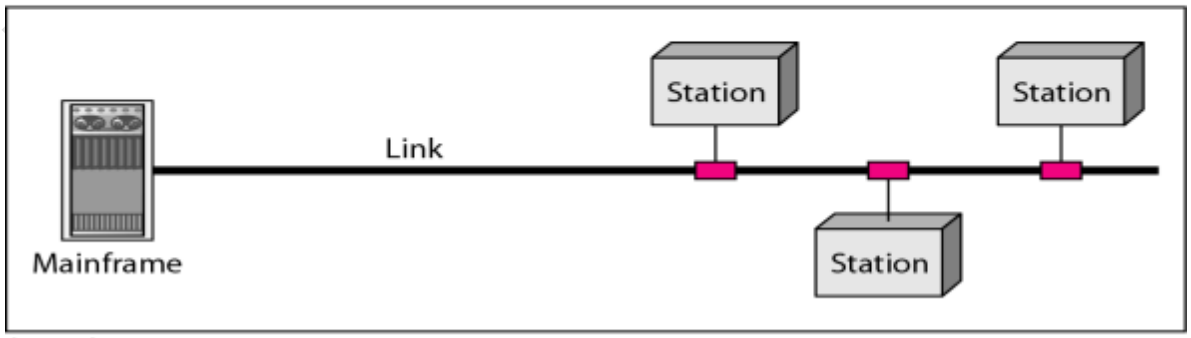
a. Point-to-point
b. Multipoint

In point-to-point connection the two devices are connected by a dedicated link. The entire capacity of the link is reserved for transmission between those two devices.

Amultipoint(alsoknownasmultidrop)connectionisoneinwhichmorethantwospecificdevicesshare a single link. The capacity of the channel is shared either spatially or temporally.



a. Point-to-point



b. Multipoint

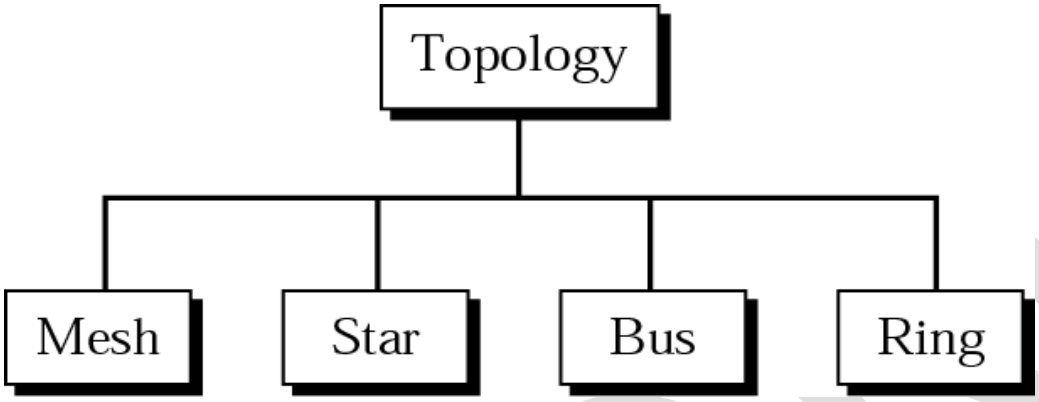
PhysicalTopology

Physical Topology refers to the way in which network is laid out physically. The topology of a network is thegeometric representation of the relationship of all the links and the linking devices. The physical or logical arrangement of a network is also topology.

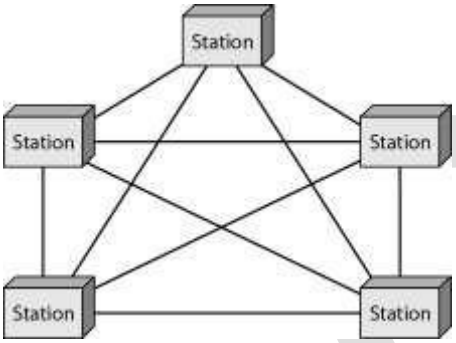
Thebasictopologies are

- Mesh

- Star
- Bus
- Ring



Mesh



- Dedicatedpoint-to-pointlinkstoeveryotherdevice
- Has*n*(*n*-1)/2physicalchanneltolink*n*devices
- Deviceshave *n*-1I/O

Advantages:

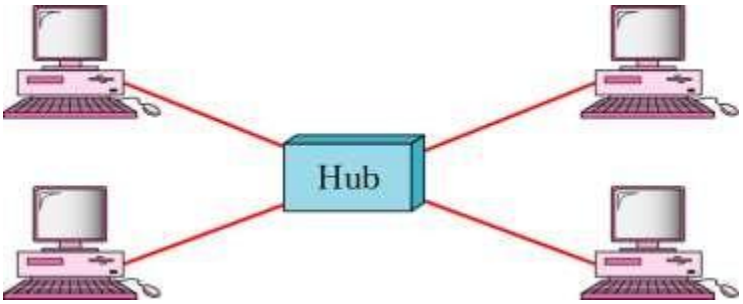
- Dedicatedlinkguaranteesthateachconnectioncancarryitsowndataloadandthuseliminatesthe traffic problems that occur when links shared by multiple devices.
- Ifonelink becomesunusable,itdoesnotincapacitatetheentiresystem.
- Aseverymessagetravelsalongadedicatedlineonlytheintendedrecipient,soitis secure.

Disadvantages

- Moreamountofcablingandthel/Oports required
- Installationandreconnectionaredifficult
- Thehardwarerequiredtoconnecteachlinkcanbeprohibitivelyexpensive.

Star

- Dedicatedpoint-to-pointlinkstocentralcontroller(hub)
- Controlleractsasexchange



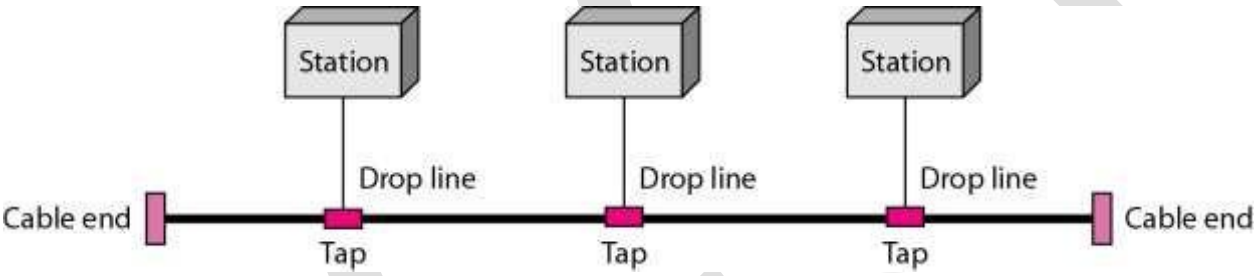
Advantages

- Less expensivethanamesh topology. Eachdeviceneeds onlyonelink andI/Oporttoconnect with Hub
- Installationandreconfigureiseasier.
- Ifonelinkfailsonlythatlinkisaffected.
- Requireslesscablethanamesh.

Disadvantages

- Yet requiresmorecablecomparedtobusandringtopologies.

Bus



- Multipointconfiguration
- Onelongcableactsasabackbonetolinkall devices.
- Stationsareconnectedthroughtap anddroplines.

Advantages

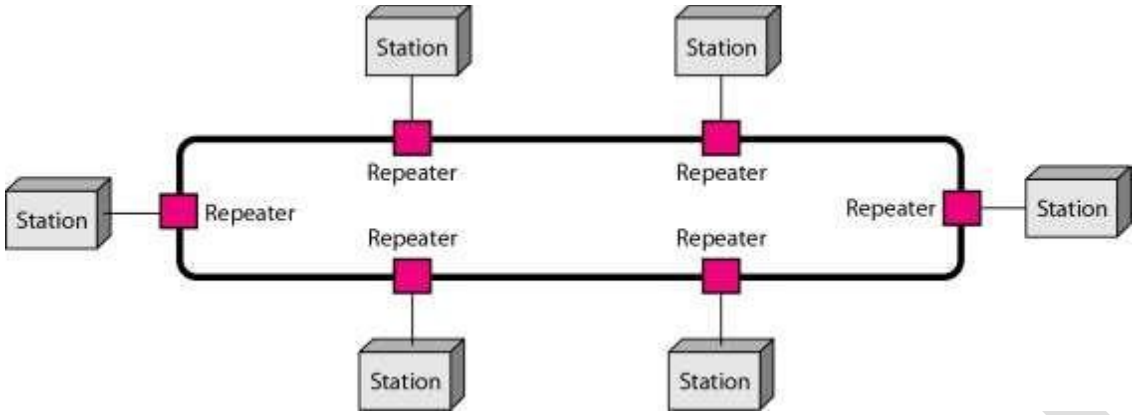
- Ease ofinstallation.
- Useslesscablingthanmeshorstartopologies.

Disadvantages

- Difficultreconnectionandisolation.
- Signalreflectionatthetapscancausedegradationinquality.
- Afaultorbreak inthe buscablestopsalltransmission.

Ring

- Dedicatedpoint-to-pointconfigurationtoneighbors
- Signalpassesfromdevicetodeviceuntilitreaches destination
- Eachdevicefunctionsasa repeater



Advantages

- Easytoinstallandreconfigure.
- Onlytwoconnections aretobechangedtoaddor deleteadevice.
- If onedevicedoesnotreceivethe signalwithina specified period,itissuean alarmthat alertsthe network operator to the problem and its location

Disadvantages

- Abreakintheringbreaks theentirenetwork.

Categories ofNetwork

Threeprimarycategoriesof network

- LocalAreaNetwork(LAN)
- MetropolitanAreaNetwork(MAN)
- WideAreaNetwork (WAN)

The categoryinto whicha networkfallis determinedbyits size, ownership, thedistanceit coversand its physical architecture.

LAN

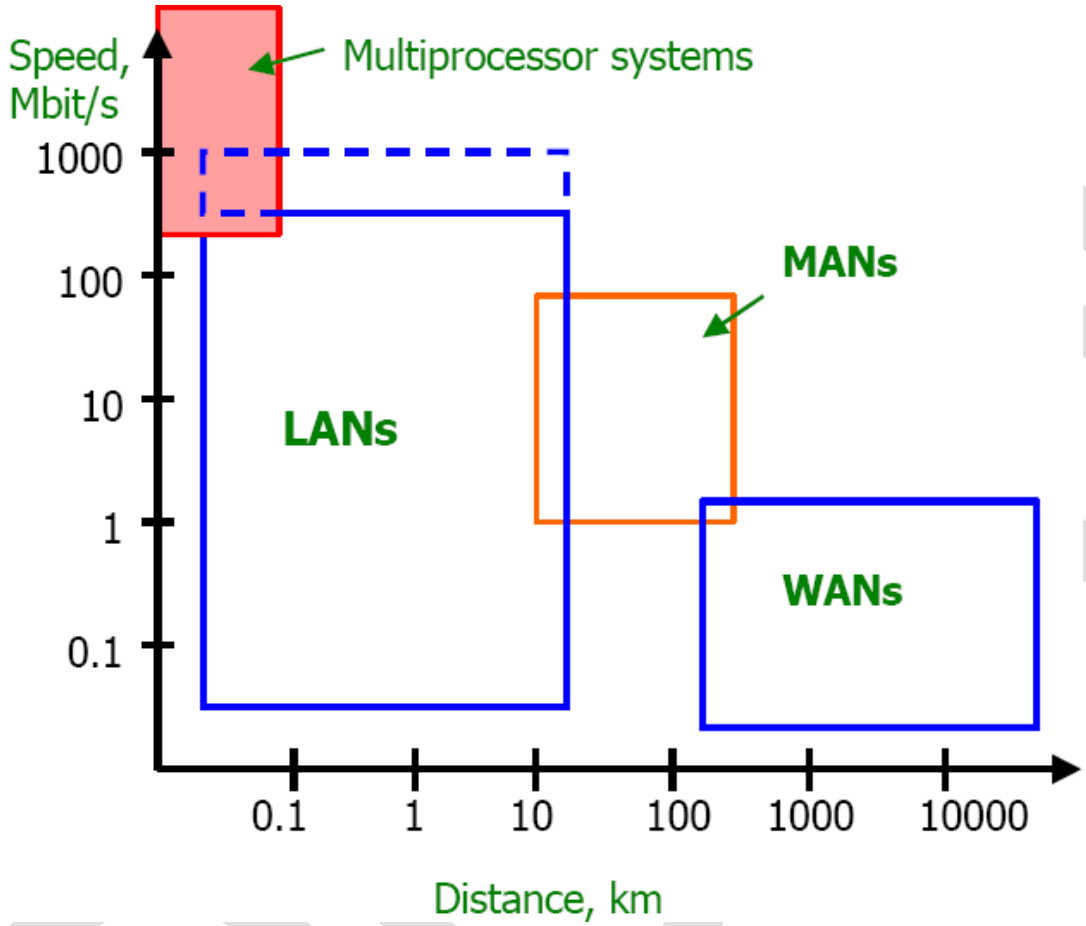
- Usuallyprivatelyownedandlinksthedevicesinasingleoffice,building,orcampus
- LANsizeislimitedtoafewkilometers.
- LANsaredesignedtoallowresourcestobeshared(hardware,softwareanddata)
- TodayLANsto have data ratesof100Mbpsto 10Gbps
- BackboneNetworks (BN), have a scale of afewhundredmeters toa fewkilometers. Include a high speed backbone linking the LANs at various locations.

MAN

- AMANis designedtocoveranentirecity.
- Maybe asinglenetworksuch ascableTVnetwork
- Maybe ameansofconnectinganumberofLANs intoalargernetwork
- MANshave dataratesof1Mbpsto100Mbps
- Resourcesmaybe sharedLANto LANas wellas deviceto device
- Acompanycanuse aMANtoconnecttheLANsinallitsofficesthroughoutacity.
- AMANcanbeownedbyaprivatecompanyoritmaybeaserviceprovidedbyapubliccompany ,suchaslocaltelephonecompany
- TelephonecompaniesprovideapopularMANservicecalled(SMDS)SwitchedMulti-megabitData Services.

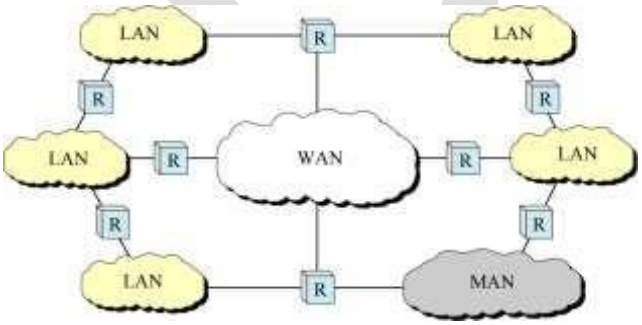
WAN

- WANprovideslongdistancetransmissionof data,voice, image,andvideoinformationover large geographical areas
- Compriseacountry, acontinent,oreventhewholeworld(InterlinkageofmanyLANsandMANs)
- Lowdatatransmissionrate(below1Mbps)
- Unlimitednumberofmilesexample:InternetNetwork



Internetwork

- Connection of two or more networks by the use of internetworking devices which include routers and gateways
- Internetisagenerictermusedtomeananinterconnectionofnetworks
- TheInternetisthenameofaspecificworldwidenetwork.



Protocols

- A protocol is a set of rules that governs data communication; the key elements of a protocol are

- Syntax–dataformatsandSignallevels
- Semantics–controlinformationanderrorhandling
- Timing–speedmatchingandsequencing

Standards are necessary to ensure that products from different manufacturers can work together as expected.

Standards

Whydowe needstandards?

- Tocreateandmaintainanopenandcompetitivemarketforequipmentmanufacturers
- Toguaranteenationalandinternationalinteroperabilityofdata,telecommunicationtechnologyand process
- Togiveafixed qualityandproducttothecustomer
- Toallowthe sameproducttobereusedagainelsewhere
- Toaidthedesignandimplementationofideas
- Toprovideguidelinestomanufacturers,vendors,governmentagenciesandotherserviceproviders to ensure kind of interconnectivity.

Datacommunicationstandardsaredividedintotwo types

Defacto(fromthefact):

- Standardsthathavenotbeenapprovedbyanorganized body.
- Ithasbeenadoptedasstandardsthroughwidespreaduse.
- This is often established originally by manufacturers to define the functionality of a new product or technology.

Dejure(bylaw):

- Thosethathavebeenlegislatedbyanofficiallyrecognizedbody.

Standardsorganizations

Standardsaredevelopedthroughthecooperationofstandardscreationcommittees,forums,and government regulatory agencies.

StandardsCreationCommittees

ITU,InternationalTelecommunicationsUnionformerlythe(CCITT):

- Itastandardfortelecommunicationingeneralanddatasystemsinparticular.

ISO,InternationalStandardsOrganization:

- Itisactiveindevelopingcooperationintherealmsofscientific,technologicalandeconomicactivity.

ANSI,AmericanNationalStandardsInstitute:

- Itisaprivatenonprofitcorporationandaffiliatedwiththe U.Sfederalgovernment.

IEEE,InstituteofElectricalandElectronicsEngineers:

- Itaimstoadvancetheory,creativity,andproductqualityinthefieldsofelectricalengineering, electronics radio and in all related branches of Engineering.
- Itoverseesthedevelopmentandadoptionofinternationalstandardsforcomputingand communications. See http://standards.ieee.org/

EIA,ElectronicIndustriesAssociation:

- Itisanonprofitorganizationdevotedtothepromotionofelectronicsmanufacturingconcerns.
- Itsactivitiesincludepublicawarenesseducationandlobbyingeffortsinadditiontostandards development.
- Italsomadesignificantcontributionsbydefiningphysicalconnectioninterfacesandelectronic signaling specifications for data communication.

Forums

- Itworkswithuniversitiesanduserstotest,evaluateandstandardizenewtechnologies.
- Theforumsareabletospeedacceptanceanduseofthosetechnologiesinthetelecommunications community.

- Itpresentstheir conclusionstostandard bodies.

RegulatoryAgencies:

- Itspurposeistoprotectthepublicinterestbyregulatingradio,televisionandwirecable communications.
- Ithasauthorityoverinterstateandinternationalcommerceasitrelatestocommunication.

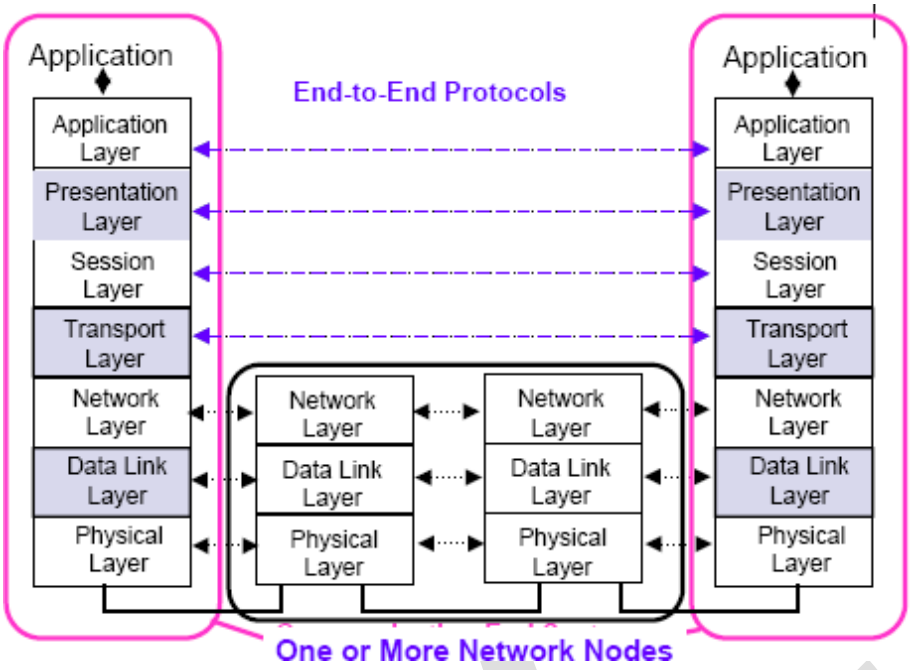
Internet Standards

- It is a thoroughly tested specification that is useful to and adhered to by those who work with the internet.
- Itisaformalizedregulationthatmustbefollowed.
- AspecificationbeginsasaninternetdraftandattainsInternetstandardstatus.
- AnInternetdraftisaworkingdocumentanditmaybepublishedasRequestforComment(RFC).RFC is edited, assigned a number, and made available to all interested parties.

OSIReferenceModel

Describesaseven-layerabstractreferencemodelforanetworkarchitecture

Purpose of the referencemodel was to provide a framework for the development of protocols



PhysicalLayer

- Itcoordinatesthefunctionsrequiredtotransmitabitstreamoveraphysicalmedium.
- Itdealswiththemechanicalandelectricalspecificationsoftheinterfaceandtransmissionmedia.
  Mechanical: cable, plugs, pins...
  Electrical/optical:modulation,signalstrength,voltagelevels, bit times,
- It also defines the procedures andfunctions that physical devices and interfaces have to perform for transmission to occur

MajorresponsibilitiesofPhysicallayerare

- **Physicalcharacteristicsofinterfacesandmedia:**
  Itdefinesthecharacteristicsoftheinterfacebetweenthedevicesandthetransmissionmedia. Alsodefinesthetypeoftransmissionmedium.
- **Representationof bits**:
  To transmit the bits, it must be encoded into electrical or optical signals. It defines the type of representation how 0s and 1s are changed to signals.
- **Datarate:**
  Thenumberofbitssenteachsecondisalsodefinedbythephysicallayer.
- **Synchronizationof bits:**
  Senderandthereceivermustbesynchronizedatthebitlevel.i.ethesenderandthe receiver clocks must be synchronized.

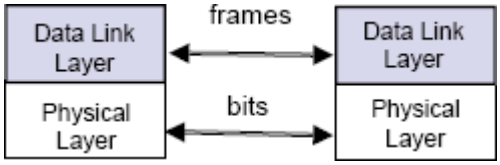
Datalinklayer

Thedata link layer isresponsible for hop-to-hop (node-to-node) delivery. It transforms the physical layerarawtransmissionfacilitytoareliablelink.Itmakesphysicallayerappearerrorfreetothenetwork layer. The duties of the data link layer are

- Framing:Thedatalinklayerdividesthestreamofbitsreceivedfromthenetworklayerintomanageable data units called frames.
- PhysicalAddressing:Iftheframesaretobedistributedtodifferentsystemsonthenetworkthedatalink layer adds a header to the frame to define the receiver or sender of the frame. If theframe is intended

for a system located outside the senders' network then the receiver address is the address of the connecting device that connects the network to the next one.

- Flow Control: If the rate at which the data absorbedbythe receiveris less than the rate produced in the sender, the data link layer imposes a flow control mechanism to overwhelming the receiver.
- Errorcontrol:Reliabilityisaddedtothephysicallayer bydatalinklayertodetectandretransmitlossor damagedframes.andalsotopreventduplicationofframes.Thisisachievedthroughatraileraddedto the end of the frame
- Access control: when two or more devices are connected to the same link it determines which device has control over the link at any given time.



NetworkLayer

The network layer is responsible for source-to-destination delivery of a packet across multiple networks. It ensures that each packet gets from its point of origin to its final destination .It does not recognize any relationship between those packets. It treats each one independently as though each belong to separate message.

Thefunctionsofthenetwork layer are

- Logical Addressing If a packet has to cross the network boundary then the header contains information of the logical addresses of the sender and the receiver.

Networking When independent networks or links are connected to create an internetwork or a large network the connective devices route the packet to the final destination.

TransportLayer

Thenetworklayerisresponsibleforprocess-to-processdeliverythatissourcetodestinationdelivery of the entire message.

TheresponsibilitiesofTransportlayerare

- Service-point (port) addressing: Computers run several programs at the same time. Source-to-destinationdeliverymeansdeliveryfromaspecificprocessononecomputertoaspecificprocesson the other. The transport layer header therefore includes a type of address called a service –point address.
- Segmentation and reassembly A message is divided into segments and each segment contains a sequence number. These numbers enable the Transport layer to reassemble the message correctly upon arriving at the destination. The packets lost in the transmission is identified and replaced.
- Connection control: The transport layer can be either connectionless or connection-oriented. A connectionless transport layer treats segment as an independent packet and delivers it to the transport layer. A connection-oriented transport layer makes a connection with the transport layer at the destination machine and delivers the packets. After all the data are transferred the connection is terminated.
- Flowcontrol:Flowcontrolatthislayerisperformedendtoend.
- Error Control: Error control is performed end to end. At the sending side, the transport layer makes sure that the entiremessage arrives at the receiving transport layer with out error. Error correctionis achieved through retransmission.

Session Layer: Session layer is the network dialog controller. It establishes, maintains, and synchronizes the interaction between communicating systems. Specific responsibilities of the layer are

- DialogControl:Sessionlayerallowstwosystemstoenterintoadialog.Communicationbetweentwo processes takes place either in half-duplex or full-duplex. Example: the dialog between a terminal connected to a mainframe. Can be half-duplex.

- Synchronization. The session layer allows a process to add checkpoints into a stream of data. Example If a system is sending a file of 2000 pages, check points may be inserted after every 100 pages to ensure that each 100 page unit is advised and acknowledged independently. So if a crash happens during the transmission of page 523, retransmission begins at page 501, pages 1 to 500 need not be retransmitted.

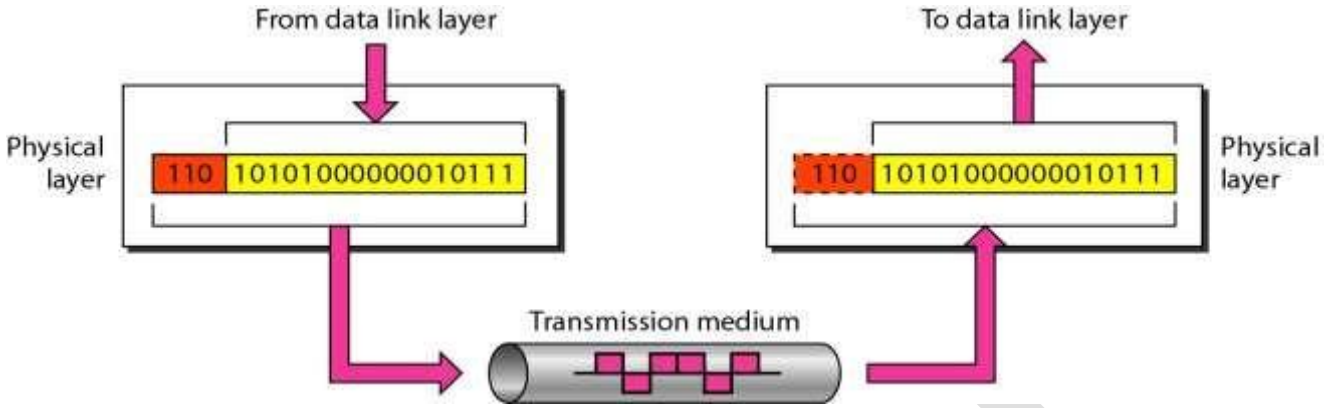
Presentation layer: It is concerned with the syntax and semantics of the information exchanged between two systems. Responsibilities of the presentation layer are

- Translation.Theprocessesintwosystemsareusuallyexchanginginformationintheformofcharacter strings, numbers, and so on. The Since different computers use different encoding systems, the presentationlayerisresponsibleforinteroperabilitybetweenthesedifferentencodingmethods.Atthe sender, the presentation layer changes the information from its sender-dependent format into a commonformat.Thepresentationlayerat thereceivingmachinechangesthecommonformatintoits receiver dependent format.
- Encryption. The sender transforms the original information from to another form and sends the resulting message over the entire network. Decryption reverses theoriginal process totransform the message back to its original form.
- Compression. It reduces the number of bits to be transmitted. It is important in the transmission of text, audio and video.

Application Layer: It enables the user (human/software) to access the network. It provides user interfaces and support for services such as electronic mail, remote file access and transfer, shared database management and other types of distributed information services. Services provided by the application layer are

- Network Virtual terminal. A network virtual terminal is a software version of a physical terminal and allows a user to log on to a remote host.
- File transfer, access and management. This application allows a user to access files in a remote computer, to retrieve files from a remote computer and to manage or control files in a remote computer.
- Mailservices.Thisapplicationprovidesthebasisfore-mailforwardingandstorage.
- Directory services. It provides distributed database sources and access for global information about various objects and services.

PHYSICALLAYER



Tobetransmitted,datamustbetransformedtoelectromagneticsignals.

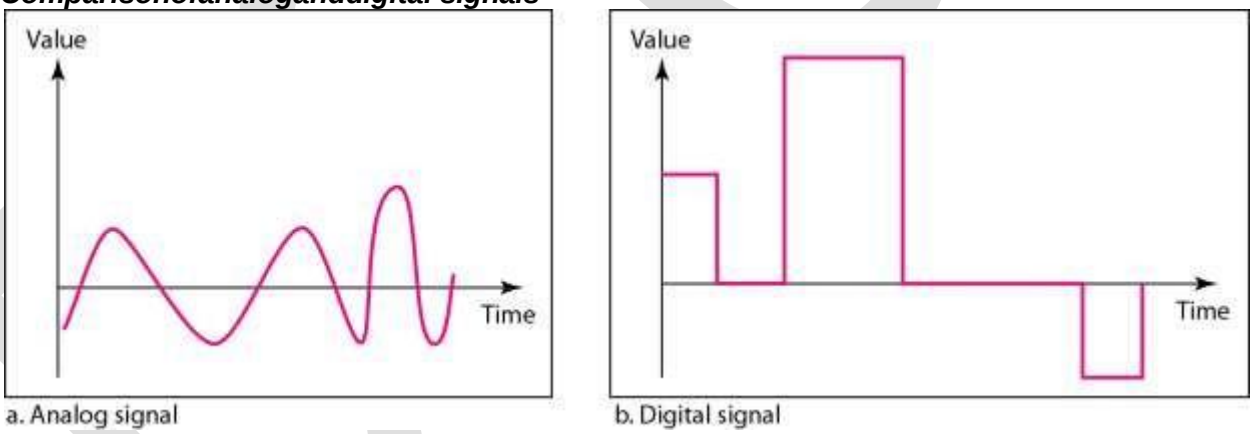
ANALOGANDDIGITAL

Datacanbeanalogordigital.Thetermanalogdatareferstoinformationthatiscontinuous;digital datareferstoinformationthathasdiscretestates.Analogdatatakeoncontinuousvalues.Digital data take on discrete values.

- Analogdatareferstoinformationthatiscontinuous
- Analogdatatakeoncontinuous values
- Digitaldatareferstoinformationthathasdiscretestates
- Digitaldatatakeondiscretevalues

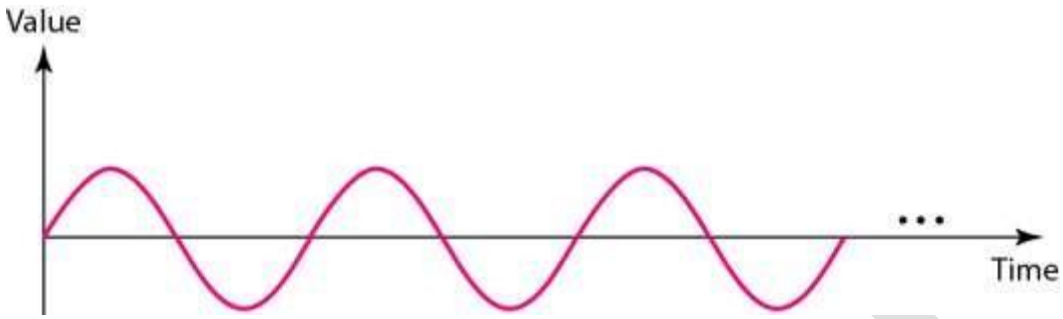
Like data signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.
Indatacommunications,wecommonlyuseperiodicanalogsignalsandnonperiodicdigital signals.

Comparisonofanalogandddigital signals



PERIODICANALOGSIGNALS

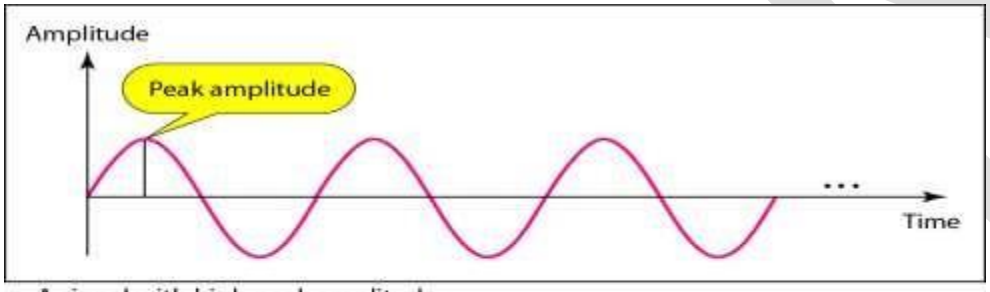
Periodicanalogsignalscanbeclassifiedassimpleorcomposite.Asimpleperiodicanalogsignal, a sine wave, cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.



Signal amplitude

Peak Amplitude is the absolute value of its highest intensity proportional to the energy it carries. The unit is either Amp or volt.

Figure*Twosignalswiththesamephaseandfrequency,butdifferentamplitudes*



a. A signal with high peak amplitude

b. A signal with low peak amplitude

Frequency

Frequencyistherateofchangewithrespecttotime.

- Changeinashortspanof timemeanshighfrequency.
- Changeoveralongspanof timemeanslowfrequency.
- If asignaldoesnotchangeatall, itsfrequencyiszero
- Ifasignalchangesinstantaneously,itsfrequencyisinfinite.

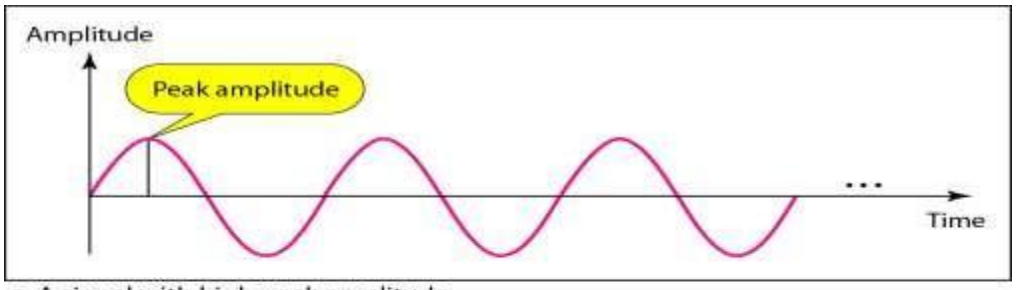
FrequencyandPeriod

Frequencyandperiodaretheinverseof eachother.

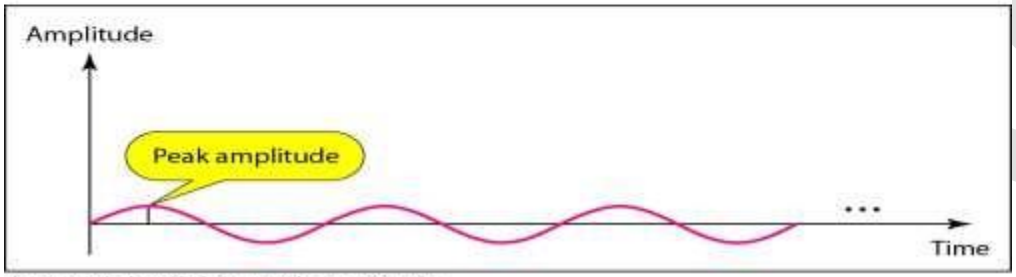
$$f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}$$

Theunits ofperiod andfrequencyaresecand Hz.

FigureTwosignals with thesame phaseand frequency,but differentamplitudes



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Examples:
Thepowerweuseathomehasafrequencyof60Hz. What istheperiodofthissinewave?

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^3\ \text{ms} = 16.6\ \text{ms}$$

Theperiodof asignalis100ms.Whatisitsfrequencyinkilohertz?
Solution
Firstwechange100mstoseconds,andthenwecalculatethefrequencyfromtheperiod(1Hz= 10^{-3} kHz).

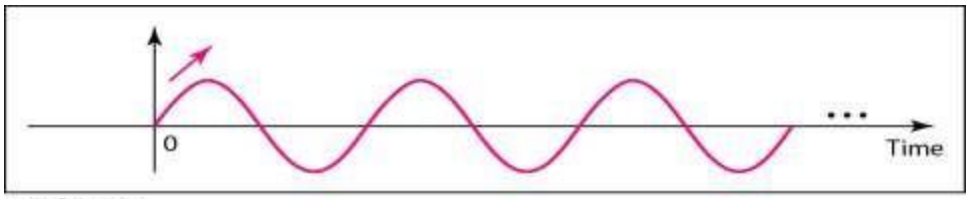
$$100\ \text{ms} = 100 \times 10^{-3}\ \text{s} = 10^{-1}\ \text{s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}}\ \text{Hz} = 10\ \text{Hz} = 10 \times 10^{-3}\ \text{kHz} = 10^{-2}\ \text{kHz}$$

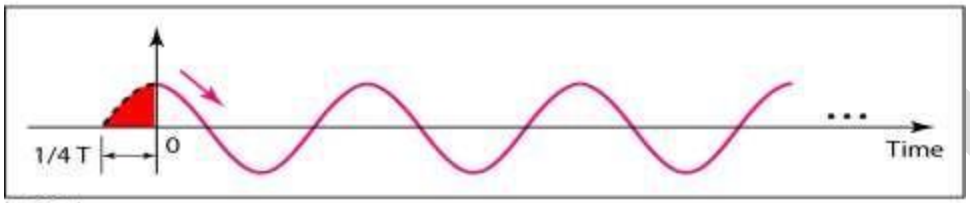
Phase

Phasedescribesthepositionofthewaveformrelativetotime0.

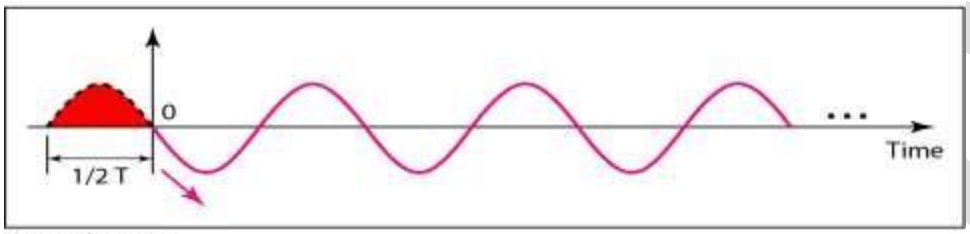
FigureThreesinewaveswiththesameamplitudeandfrequency,butdifferentphases



a. 0 degrees



b. 90 degrees



c. 180 degrees

Example

Asinewaveisoffset1/6cyclewithrespecttotime0.What isitsphaseindegreesandradians?

Solution

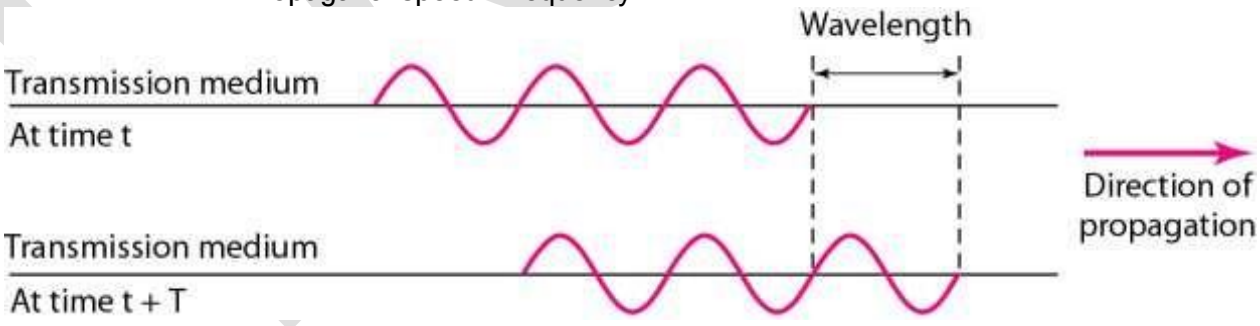
Weknowthat1completecycleis360°.Therefore,1/6cycleis

$$\frac{1}{6} \times 360 = 60° = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Wavelengthandperiod

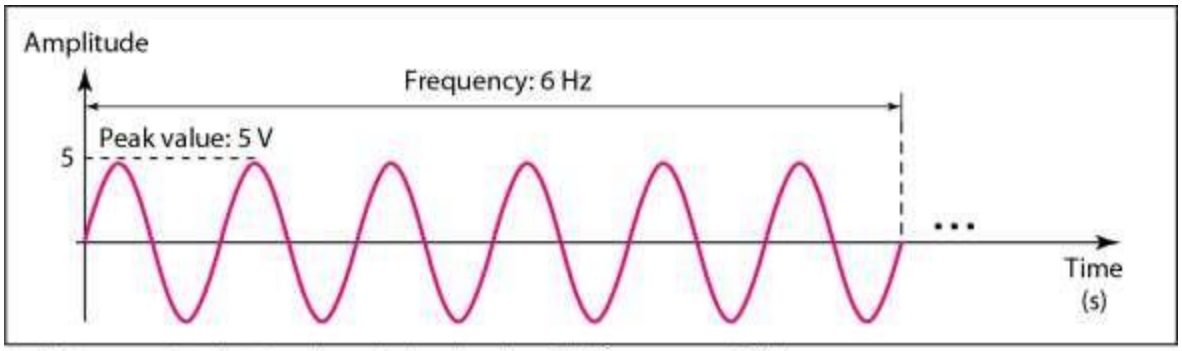
Wavelength=PropagationspeedxPeriod

=Propagationspeed/ Frequency

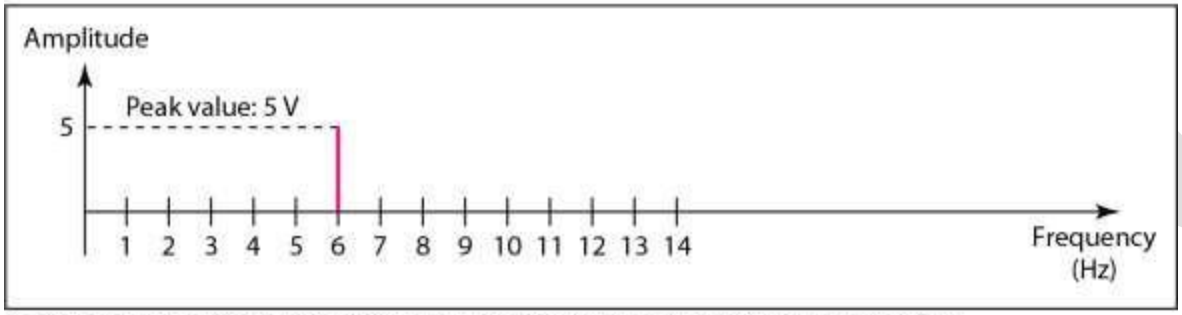


Time-domainandfrequency-domainplotsofasine wave

Acompletesinewaveinthetimedomaincanberepresentedbyonesinglespikeinthefrequency domain.

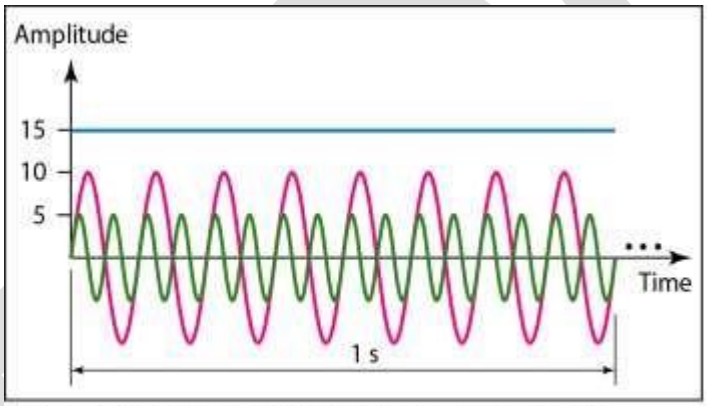


a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

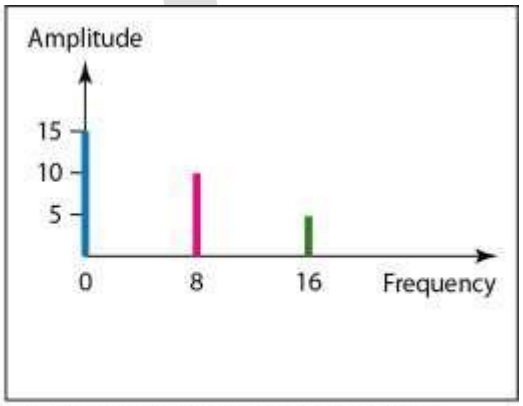


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

FrequencyDomain



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16



b. Frequency-domain representation of the same three signals

- Thefrequencydomainismorecompactandusefulwhenwearedealingwithmorethanone sine wave.
- Asingle-frequencysinewaveisnot usefulindatacommunication
- Weneedtosendacompositesignal, asignalmadeofmanysimplesinewaves.

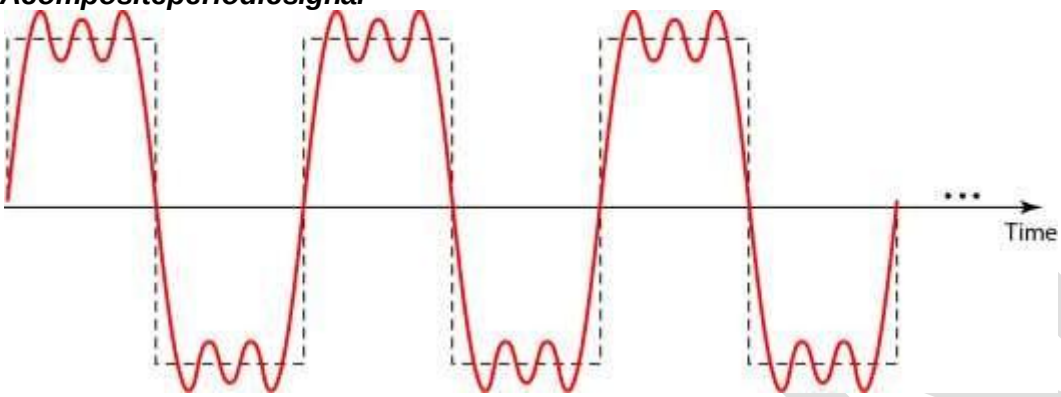
Asingle-frequencysinewaveisnotusefulindatacommunications;weneedtosendacomposite signal, a signal made of many simple sine waves.

Fourieranalysis

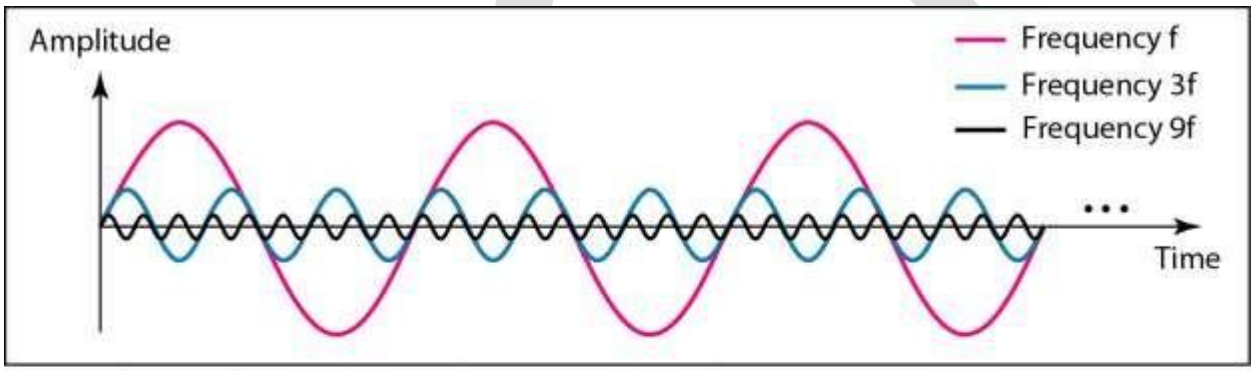
According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

- If the composite signal is periodic, the decomposition gives a *series of signals with discrete frequencies*;
- If the composite signal is nonperiodic, the decomposition gives a *combination of sine waves with continuous frequencies*.

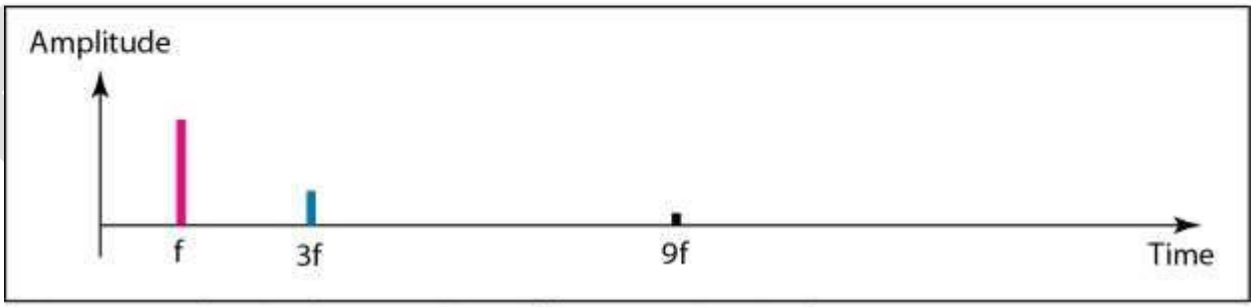
A composite periodic signal



Decomposition of a composite periodic signal in the time and frequency domains



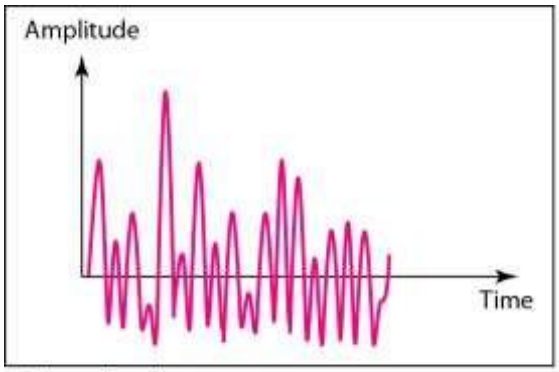
a. Time-domain decomposition of a composite signal



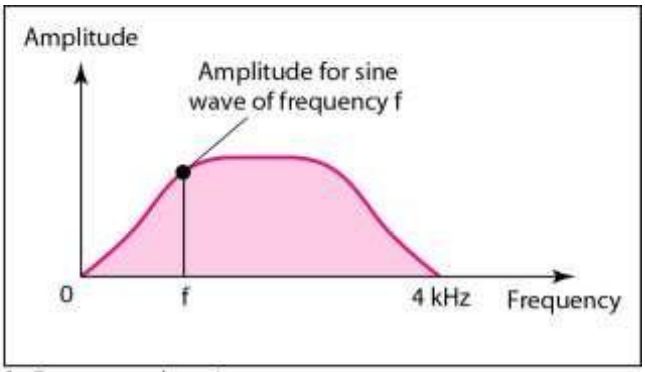
b. Frequency-domain decomposition of the composite signal

Time and frequency domains of a nonperiodic signal

- A nonperiodic composite signal
  - It can be a signal created by a microphone or a telephone set when a word or two is pronounced.
  - In this case, the composite signal cannot be periodic
    - because that implies that we are repeating the same word or words with exactly the same tone.



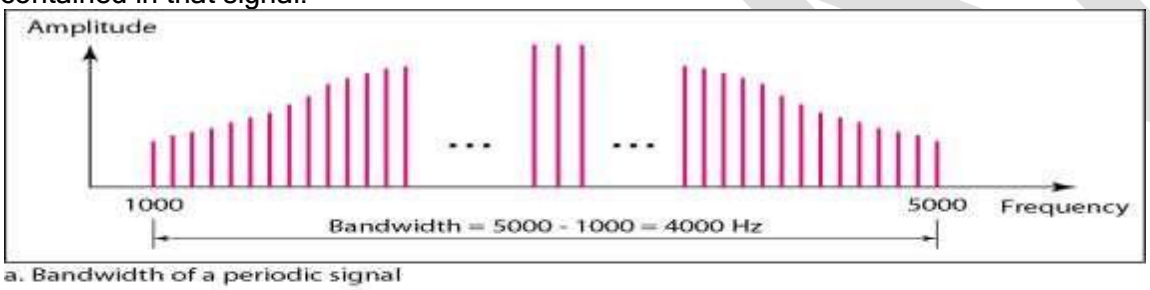
a. Time domain



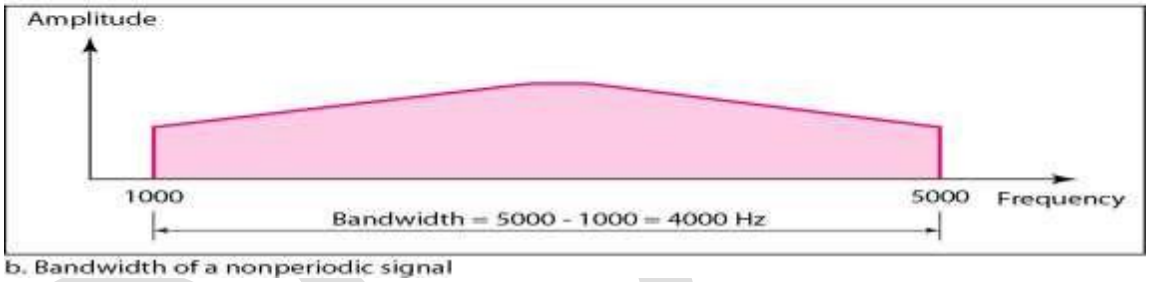
b. Frequency domain

Bandwidth

Thebandwidthofacompositesignalisthedifferencebetweenthehighestandthelowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example:

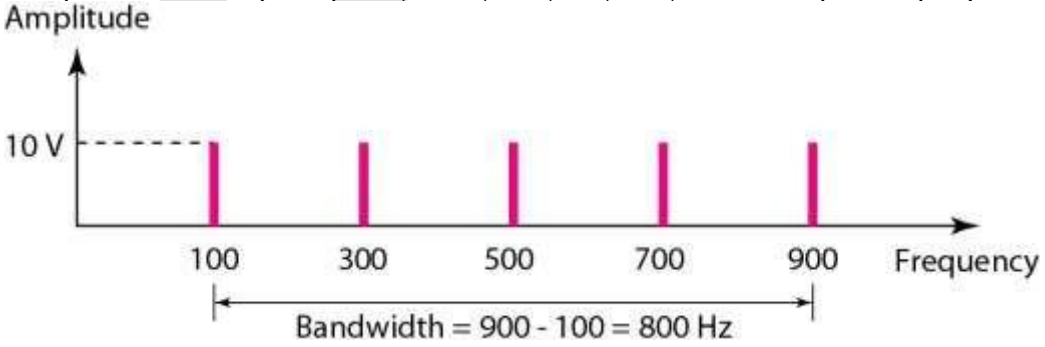
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

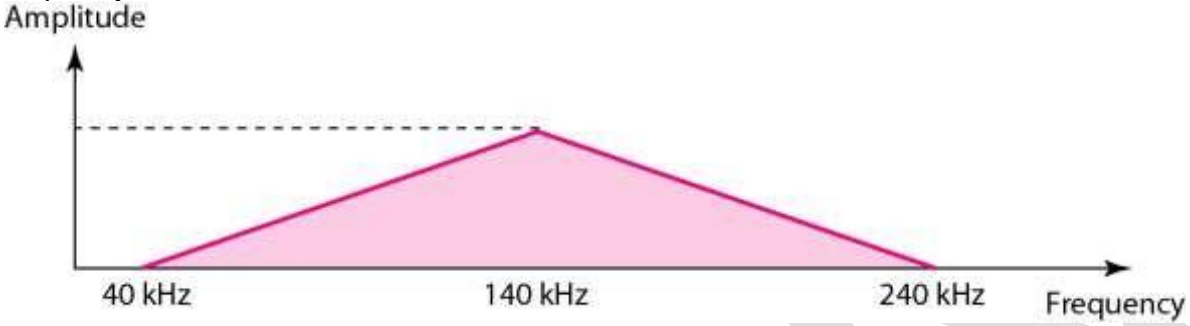
The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure)



Example:
Anonperiodic compositesignalhasabandwidth of 200kHz, withamiddlefrequencyof 140kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

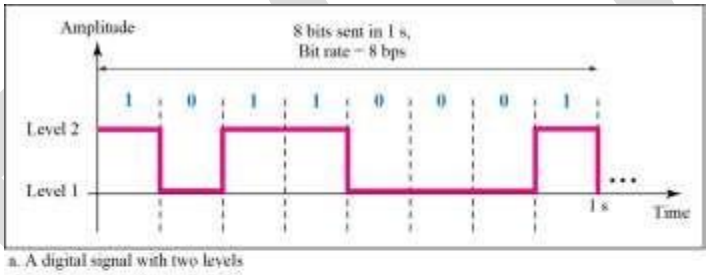
The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.



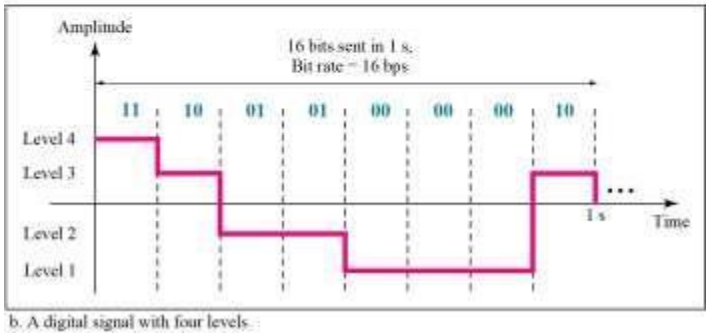
DIGITALSIGNALS

- Inadditiontobeingrepresentedbyananalogsignal,informationcanalsoberepresented by a digital signal.
- Forexample,a1canbeencoded asapositivevoltageanda0as zero voltage.
- Adigitalsignalcanhavemorethantwolevels.
- Inthiscase,wecan sendmorethan 1bitforeachlevel.
- Bitrateisthenoof bitstransmittedper sec.
- Bitintervalisthetimerequiredtosendonebit.
- Signallevelisthenoofbitsrequiredtorepresentaparticularsignal.
- Data levelisthe noof bits usedtorepresentthe data.

FigureTwodigitalsignals:onewithtwosignallevelsandtheotherwithfoursignallevels



a. A digital signal with two levels



b. A digital signal with four levels

Examples

1. Adigitalsignalhas8levels. Howmanybitsareneededperlevel? We calculate the number of bits from the formula

$$\text{Number of bits per level} = \log_2 8 = 3$$

Eachsignallevelisrepresentedby3 bits.

2. Adigitalsignalhas9levels. Howmanybitsareneededperlevel? Each signal level is represented by 3.17 bits.
   Thenumber of bits sentper levelneeds tobe aninteger aswellasa power of 2.
   Hence, 4 bits can represent one level.

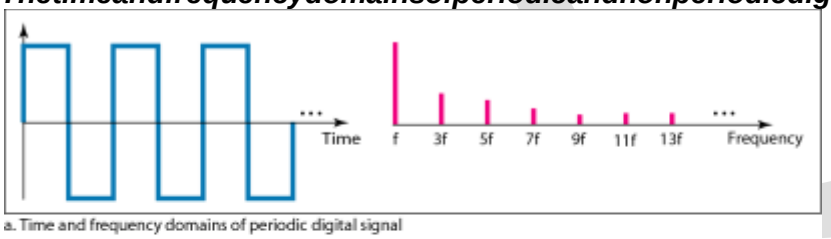
3. Assume we need to download files at a rate of 100 pages per minute. A page is an average of 24 lines with 80 characters in each line where one character requires 8 bits. What is the required bit rate of the channel?

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

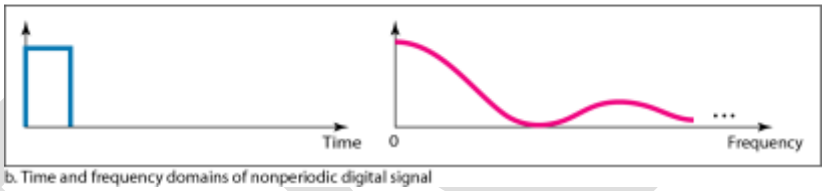
4. A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). Assume that each sample requires 8 bits. What is the required bit rate?

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

Thetimeandfrequencydomainsofperiodicandnonperiodicdigitalsignals



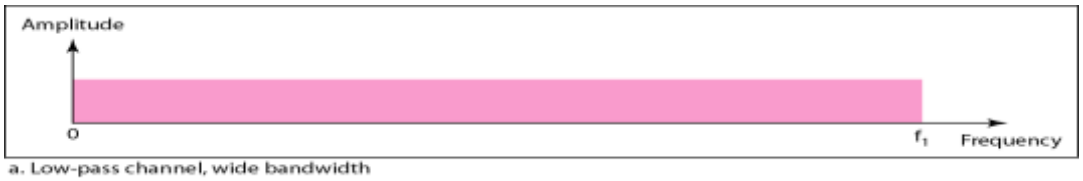
a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

Bandwidthsoftwolow-pass channels

Digital transmission needs a low-pass channel whereas analog transmission can use a band-pass channel. Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.



a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

DATARATELIMITS

A very important consideration in data communications is howfast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. Thebandwidthavailable
2. Thelevelofthesignalsweuse
3. Thequalityof thechannel(thelevelof noise)

Increasingthelevelsofasignalmayreducethereliabilityofthesystem

NyquistTheorem

Fornoiselesschannel,

BitRate=2xBandwithx$\log_2$Levels

In baseband transmission, we said the bit rate is 2 times the bandwidth if we use only the firstharmonic in the worst case.

However, the Nyquist formula is more general than what we derived intuitively; it can be applied to baseband transmission and modulation.

Also,itcanbeappliedwhenwehavetwoor morelevelsof signals.

Examples:

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. What is the maximum bit rate?

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Consider thesame noiseless channeltransmitting a signal withfour signallevels (for each level, we send 2 bits). What is the maximum bit rate?

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

ShannonCapacity

Inreality,wecannothaveanoiselesschannel.Fornoisychannel,

Capacity = Bandwidth x $\log_2$(1+SNR)

TheShannoncapacitygivesustheupperlimit;theNyquistformulatellsushowmanysignal levels we need.

Example:

Wehavea channelwitha 1-MHzbandwidth. TheSNRforthis channelis63. What are the appropriate bit rate and signal level?

Solution

First,weuse theShannonformulatofindtheupper limit.

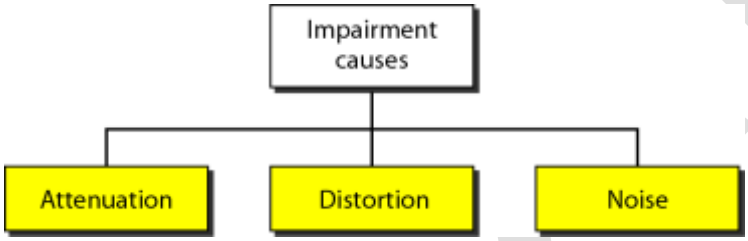
$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

TheShannonformulagivesus6Mbps,theupperlimit.Forbetterperformancewechoose something lower, 4 Mbps, for example.
ThenweusetheNyquistformulatofindthenumberof signal levels.

$$4\ \text{Mbps} = 2 \times 1\ \text{MHz} \times \log_2 L \quad \rightarrow \quad L = 4$$

TRANSMISSIONIMPAIRMENT

- Signalstravelthroughtransmissionmedia,whicharenotperfect.
- Theimperfectioncausessignalimpairment.
- This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.
- What issentis notwhatis received.
- Threecausesofimpairmentareattenuation,distortion,andnoise.



Attenuation: Loss of energy i.e. Loss in signal strength. It is measured in decibel (dB)
Suppose a signal travels through a transmission medium and its power is reduced to one-half. Thismeansthat $P_2$is$(1/2)P_1$. Inthis case,the attenuation (lossof power)can be calculatedas

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

Distortion: The change in shape or form of a signal. This occurs mainly in composite signals.
Noise: Unwanted signal mixed with the original signal. The noise can be of different types like Thermal Noise, Induced Noise, Cross Talk and Impulse Noise.
ThermalNoise:Producedduetorandommovementoffreeelectronsinawirecreatingextra unwanted signal.
InducedNoise:Producedif thesourceisanelectrical motororappliance. Cross talk: Effect of one wire over another.
ImpulseNoise:Isaspikeproducedduringearthquake,thunderandlightningetc.
Example:
The power of a signal is 10 mW andthe power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?
Solution
Thevaluesof SNRandSNR_{dB}canbecalculatedasfollows:

$$\text{SNR} = \frac{10{,}000\ \mu\text{W}}{1\ \text{mW}} = 10{,}000$$
$$\text{SNR}_{\text{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

More about Signals:

In data communication four other measurements are used. They are Throughput, Propagation speed, Propagation time and wave length.

Throughput: It isthemeasurementof howfastdatacanpassthroughanentity.

PropagationSpeed: It measures the distance that a signal or bit can pass through the medium in one second.

Propagationtime: Thetimerequiredbyasignaltotravelfromonepointoftransmissionto another.Propagation time= Distance/Propagation speed

Wavelength: Wavelength=PropagationspeedXperiod

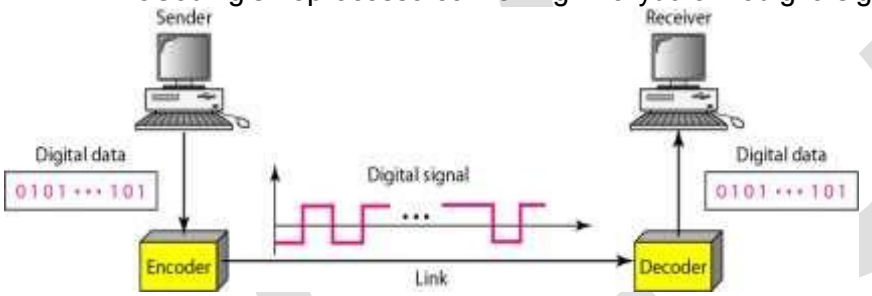
DIGITALTRANSMISSION

DIGITAL-TO-DIGITALCONVERSION:

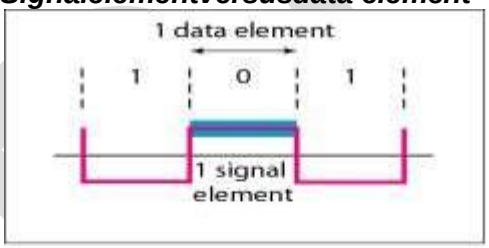
- Wecanrepresentdigitaldatabyusingdigitalsignals.
- Theconversioninvolvesthreetechniques:linecoding,blockcoding,andscrambling.
  - Linecodingisalwaysneeded.
  - Blockcodingandscramblingmayormaynotbeneeded.

LineCoding&Decoding:

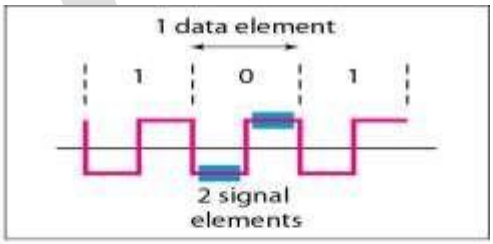
LineCodingistheprocessofconvertingBinarydataintodigitalsignals.



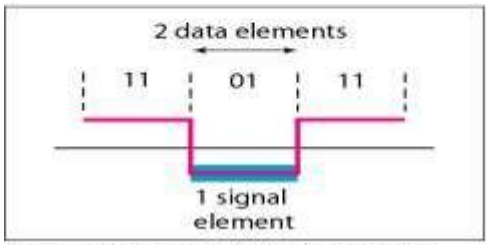
Signalelementversusdata element



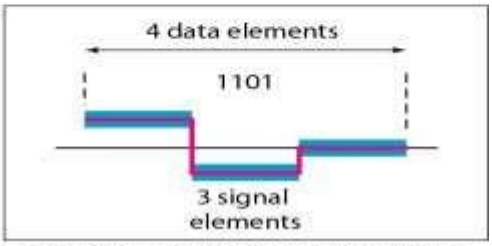
a. One data element per one signal element (r = 1)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element (r = 2)

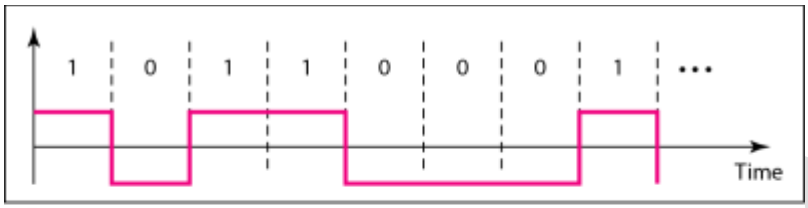


d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

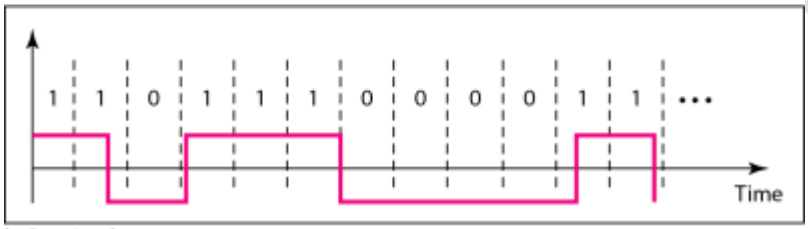
Effectoflackof synchronization

Self-synchronization To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactlytothesender'sbit intervals. If thereceiver clock isfaster or slower, the bit intervals are not matched and the receiver might misinterpret the signals.

A self-synchronizing digital signal includes timing information in the data being transmitted. This canbeachievedifthereareatransitionsinthesignalthatalertthereceivertothebeginning,middle, or end of the pulse. If the receiver's clock is out of synchronization, these points can reset the clock

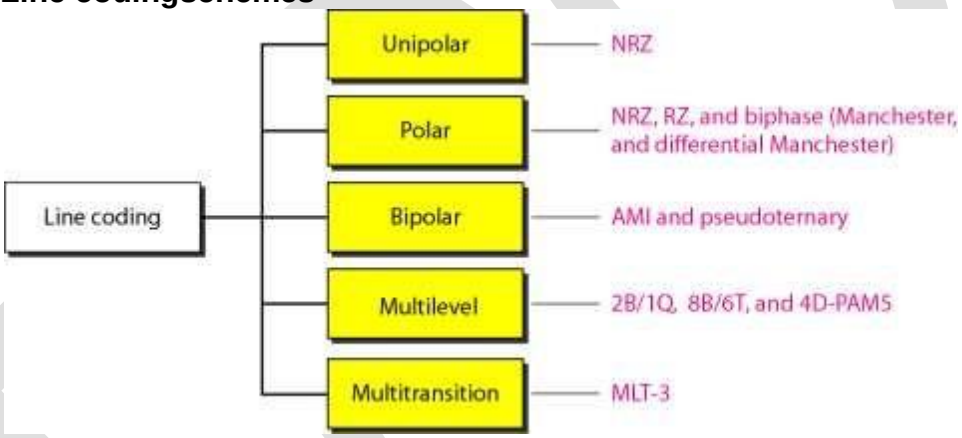


a. Sent



b. Received

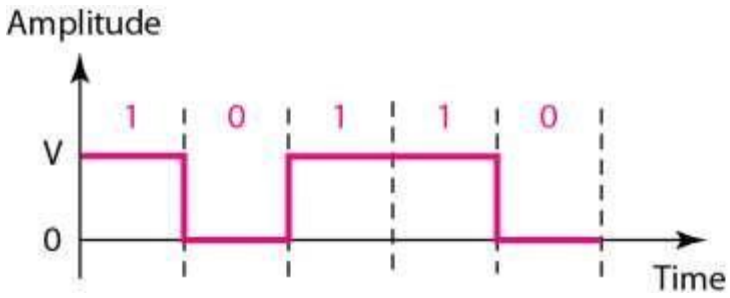
Line codingschemes



UnipolarNRZscheme:

Unipolarencodinguses onlyonepolarity.0 isrepresentedbyzerovoltage and1isrepresentedby positive voltage. It is inexpensive to implement. Unipolar encoding has two problems :

- Lackofsynchronization
- A dc component



$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

PolarNRZ-LandNRZ-I schemes:

NRZ

Thelevelofthesignalisalwayseitherpositiveornegative.

NRZ-L

Thelevelofthesignaldependsonthetypeofbititrepresents. The bit 0 is represented by positive voltage

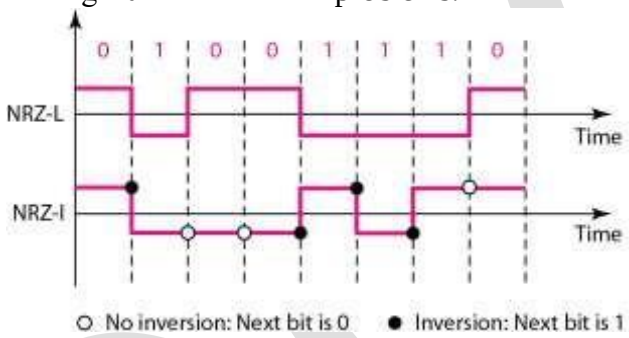
Thebit 1 is represented bynegativevoltage.

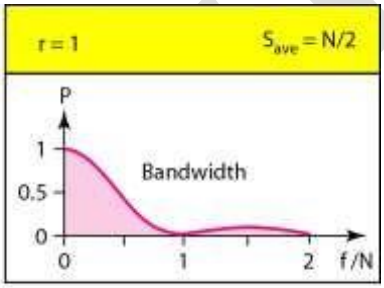
NRZ-I

The 1 bit is represented by an inversion (transition between a positive and a negative voltage) of the voltage level.

Theexistenceof 1'sin thedatastream allowsthe receiverto resynchronizeits timerto theactual arrival of the transmission.

Astringof0'scanstill causeproblems.





InNRZ-Lthelevelof thevoltagedetermines the value of the bit.InNRZ-Ithe inversion or the lack of inversion determines the value of the bit.

Polar RZ scheme:

RZ

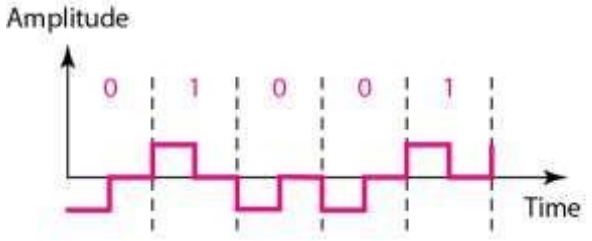
Itusesthree values

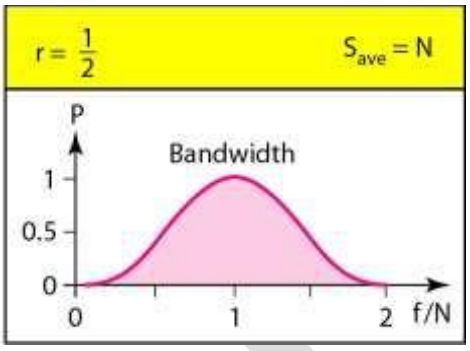
- Positive
- Negative
- Zero

InRZthesignal changes duringeachbit.A1bitisactuallyrepresentedbypositive-to-zeroand A 0 bit is actually represented by negative-to-zero.

Demerits

Itrequirestwosignalchangestoencodeonebit. It occupies more bandwidth.





Polarbiphase:ManchesteranddifferentialManchesterschemes:

Biphase

Thesignalchangesatthemiddleofthe bitintervalanddoesnotreturntozero. There are two types of biphase encoding

- Manchester
- DifferentialManchester

Manchester

- Itusestheinversionatthemiddleofeachbitintervalforbothsynchronizationandbit representation.
- Thebit1isrepresentedbynegative -to-positivetransition.
- Thebit0isrepresentedbypositive-to-negativetransition
  - Transitionatthemiddleisusedforsynchronization
  - Theminimumbandwidth is2timesthatofNRZ

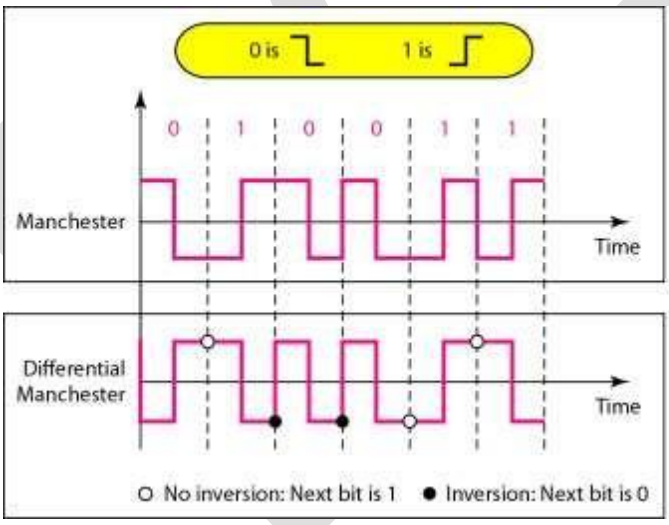
DifferentialManchester

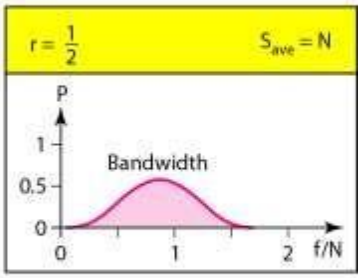
Inversionatthemiddleofthebitintervalisusedfor synchronization.

Presence or absenceofadditionaltransitionatthebeginning oftheintervalis usedtoidentifythe bit.

Abit0isrepresented byatransition.Abit1means notransition.

Itrequirestwosignalchangestorepresentbinary0,butonlyonetorepresentbinary1.





TheminimumbandwidthofManchesteranddifferentialManchesteris2timesthatofNRZ.

Bipolarschemes:AMIandpseudoternary:

Inbipolarencoding,weusethreelevels:positive,zero,andnegative.

- Thebit0isrepresentedbyzerolevel

- The 1s are represented by alternate positive and negative voltages. If the first 1 bit is represented by positive amplitude, the second will be represented by the negative amplitude, and so on.

BipolarAlternateMarkInversion

Abinary0isrepresentedbyzero voltage.

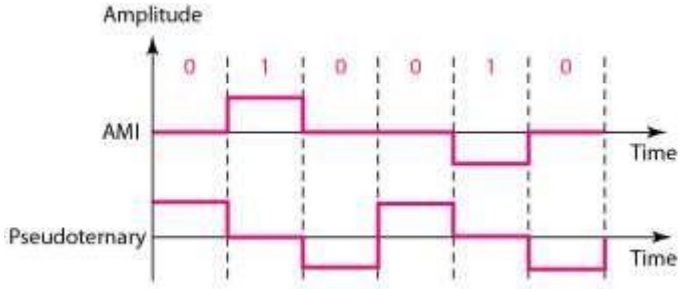
Abinary1sarerepresentedbyalternatepositiveandnegativevoltages.

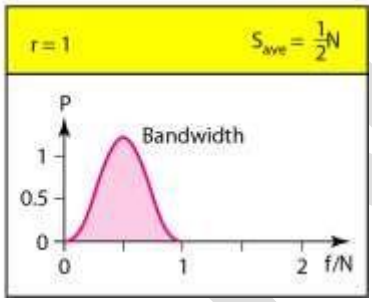
Merits

Byinvertingoneachoccurrenceof 1,Thedccomponent iszero A long sequence of 1s stays synchronized.

Pseudoternary

Abinary0alternatebetweenpositiveandnegativevoltages.



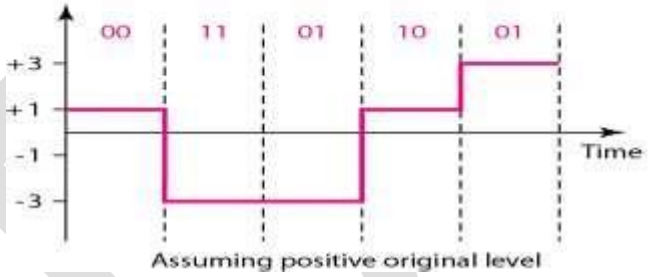


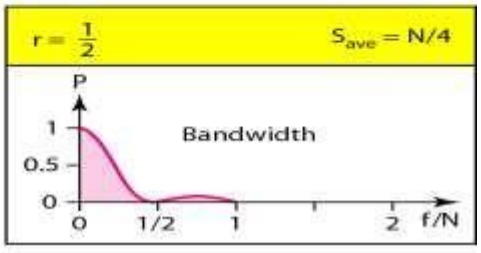
In *m*B*n*L schemes, a pattern of *m* data elements is encoded as a pattern of *n* signal elements in which $2^m \leq L^n$.

Multilevel:2B1Qscheme

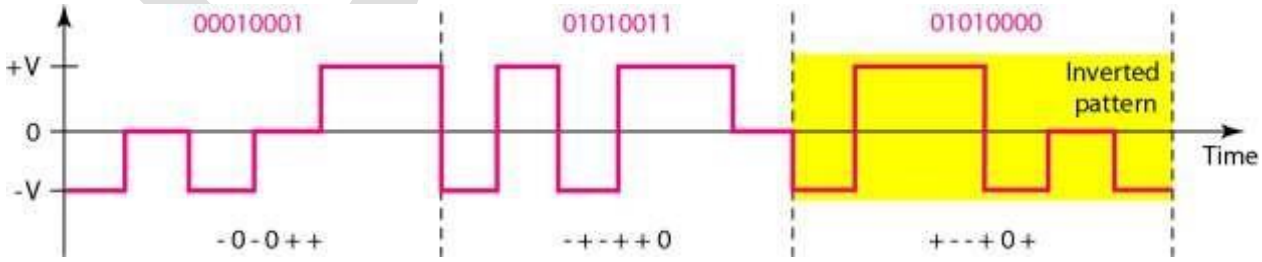
Next bits	Next level (Previous level: positive)	Next level (Previous level: negative)
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table

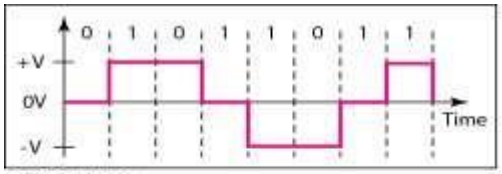




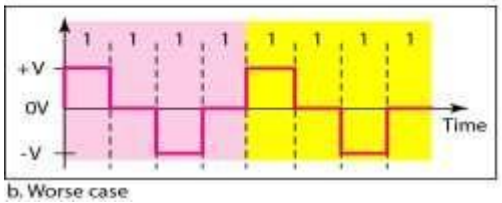
Multilevel:8B6Tscheme



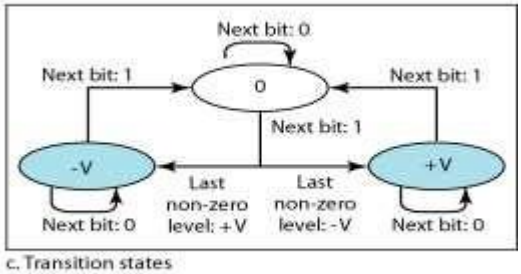
Multitransition:MLT-3scheme



a. Typical case



b. Worse case



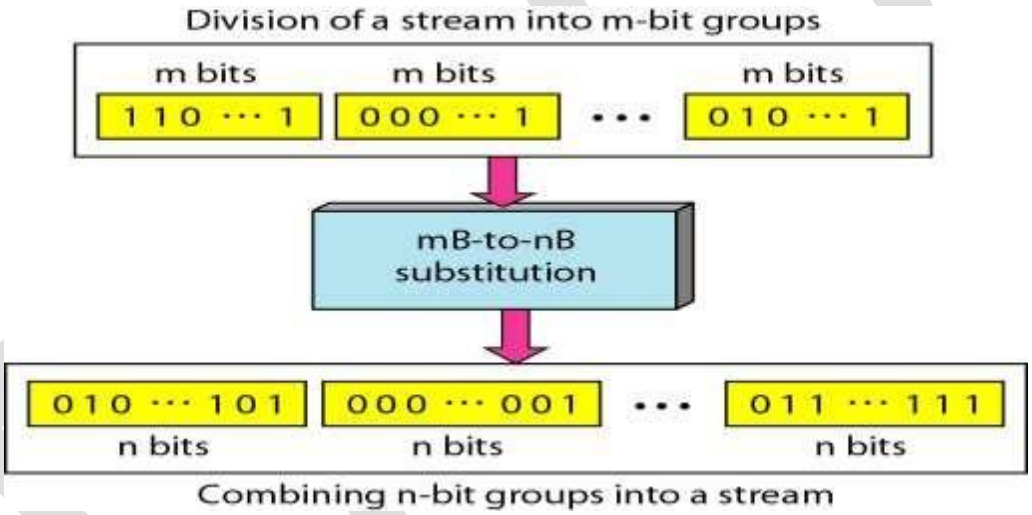
c. Transition states

Blockcodingconcept

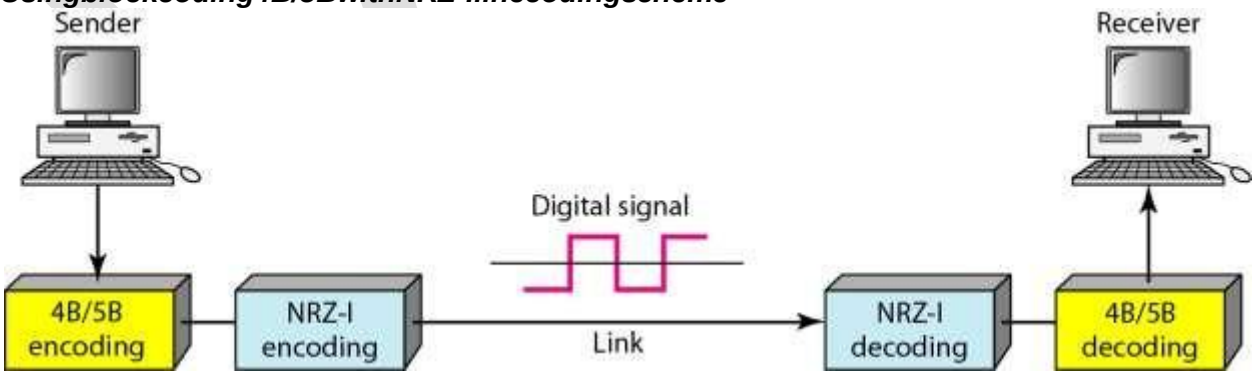
Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.

Blockcodingnormallyinvolvesthreesteps:

- Division :Inthedivision step,asequenceof bitsis dividedintogroupsofmbits.Forexample, in 4B/5B encoding, the original bit sequence is divided into 4-bit groups.
- Substitution:Insubstitutionstep,wesubstituteanm-bitgroupforann-bitgroup.Forexample, in 4B/5B encoding we substitute a 4-bit code for a 5-bit group.
- Combination: The n-bit groups are combined together to form a stream. The new stream has more bits than the original bits.



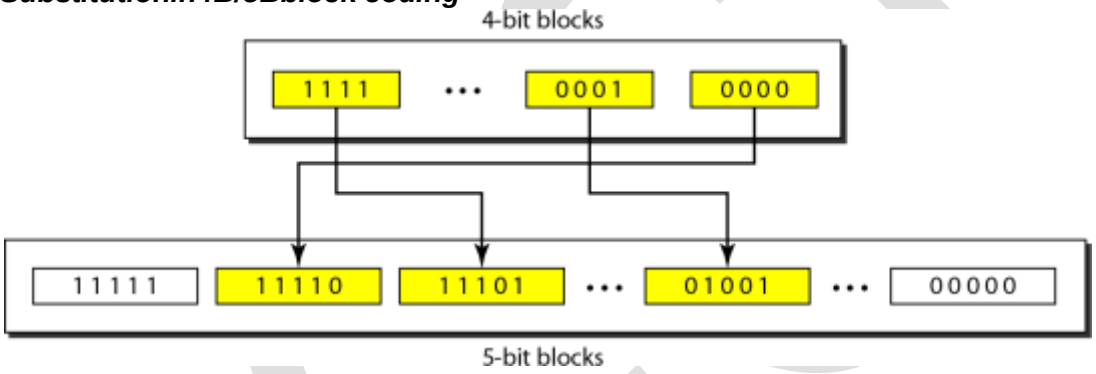
Usingblockcoding4B/5BwithNRZ-Ilinecodingscheme



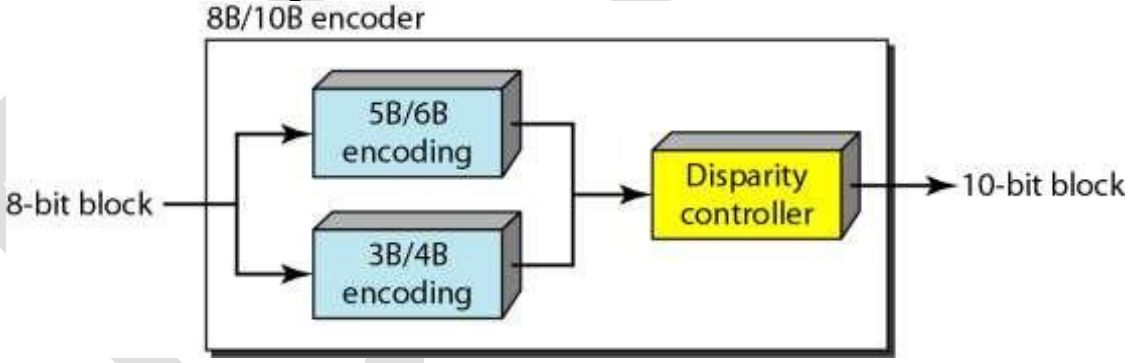
4B/5BMappingCodes:

Data Sequence	Encoded Sequence	Control Sequence	Encoded Sequence
0000	11110	Q (Quiet)	00000
0001	01001	I (Idle)	11111
0010	10100	H (Halt)	00100
0011	10101	J (Start delimiter)	11000
0100	01010	K (Start delimiter)	10001
0101	01011	T (End delimiter)	01101
0110	01110	S (Set)	11001
0111	01111	R (Reset)	00111
1000	10010		
1001	10011		
1010	10110		
1011	10111		
1100	11010		
1101	11011		
1110	11100		
1111	11101		

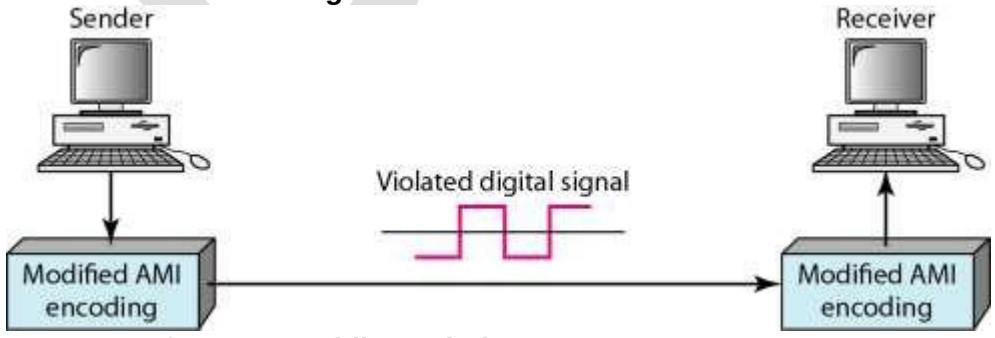
Substitutionin4B/5Bblock coding



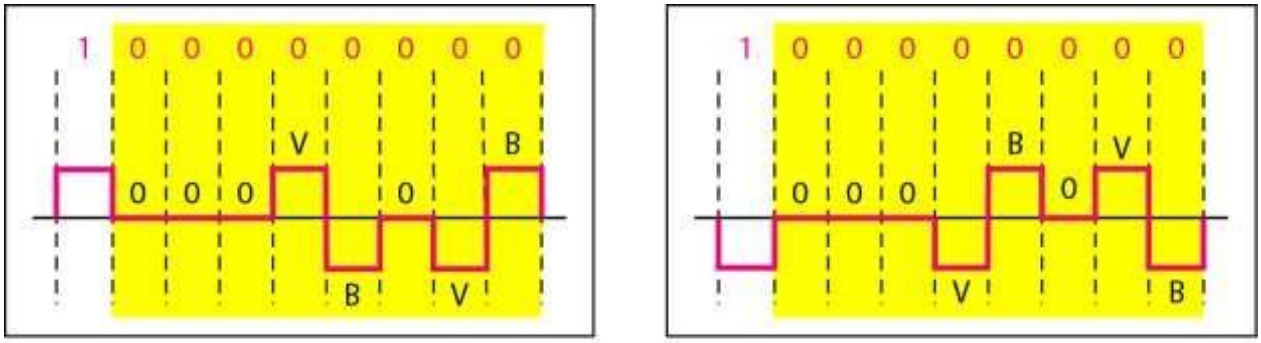
8B/10Bblockencoding



AMIusedwith scrambling



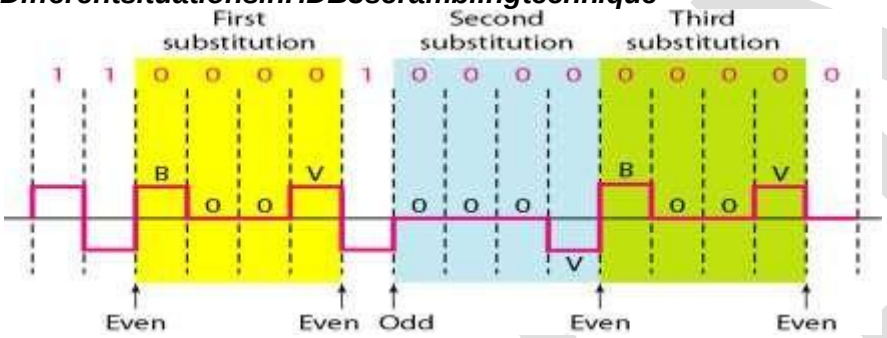
TwocasesofB8ZSscramblingtechnique



a. Previous level is positive. b. Previous level is negative.

B8ZSsubstituteseightconsecutivezeroswith000VB0VB.

DifferentsituationsinHDB3scramblingtechnique



HDB3substitutesfourconsecutivezeroswith000VorB00Vdependingonthenumberofnonzero pulses after the last substitution.

ANALOG-TO-DIGITALCONVERSION

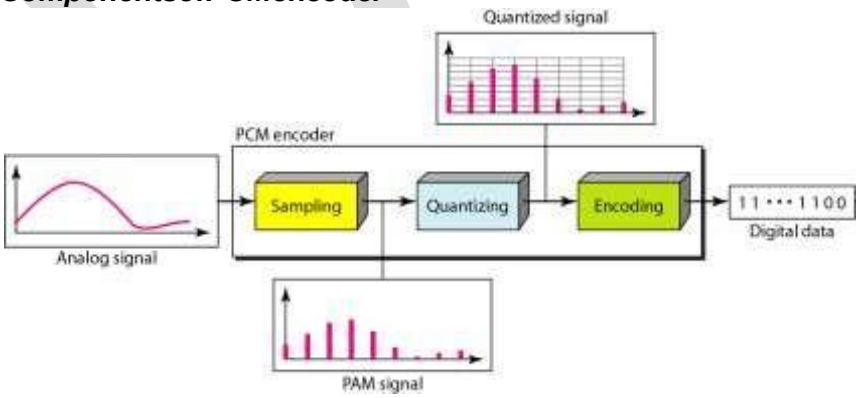
- Adigitalsignalissuperiortoananalog signal.
- Thetendencytodayistochangeananalog signaltodigitaldata.
- Inthissectionwedescribetwotechniques, pulsecodemodulationanddelta modulation.

PCM:

Themostcommontechniquetochange ananalog signaltodigitaldata(digitization) iscalled pulse code modulation (PCM). A PCM encoder has three processes.

1. Theanalogsignalis sampled.
2. Thesampledsignalisquantized.
3. Thequantizedvaluesareencodedasstreamsofbits.

ComponentsofPCMencoder



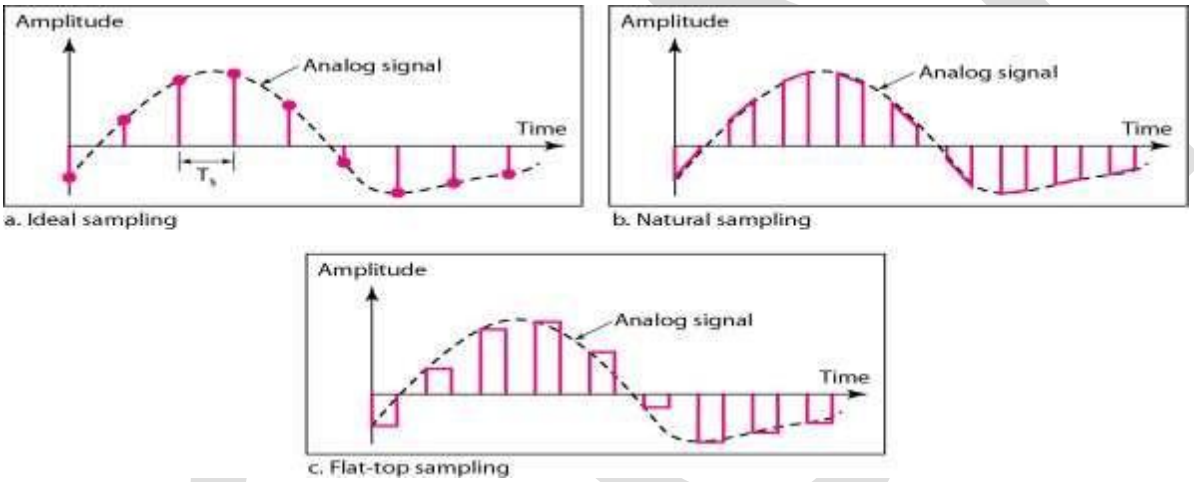
TheprocessofPulsecodemodulationconsistsofthefollowingsteps:

- Sampling:measuringtheamplitudeofthesignalatequalintervals.

- Quantization: Process of assigning integral values in a specific range to the long range of sampled instances.
- BinaryCoding:Tobringintobinaryform
- LineCoding:conversionof binarydataintodigitalsignal.

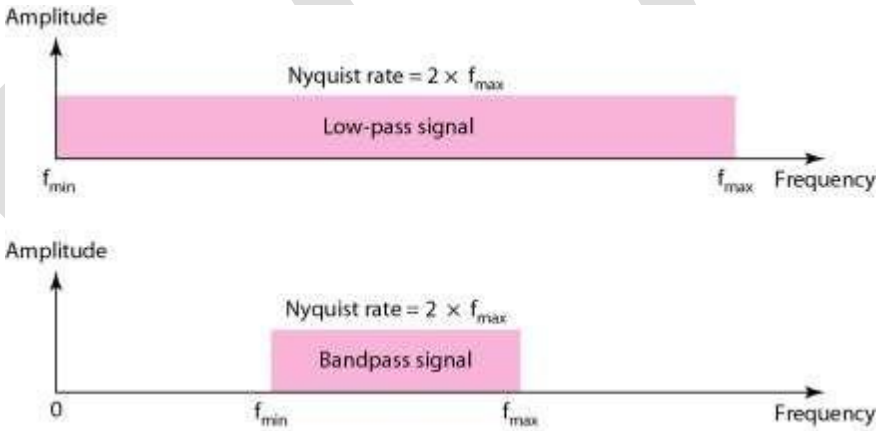
There are three sampling methods: ideal, natural, and flat-top.

- Inidealsampling, pulsesfromtheanalog signalaresampled.This is anidealsampling method and cannot be easily implemented.
- In natural sampling, a high-speed switch is turned on for only the small period of time whenthe sampling occurs.Theresult is asequenceof samplesthatretainstheshapeof the analog signal.
- Themostcommonsampling method, calledsampleandhold,however, createsflat-top samples by using a circuit.



Nyquistsamplingrateforlow-passandband-passsignals

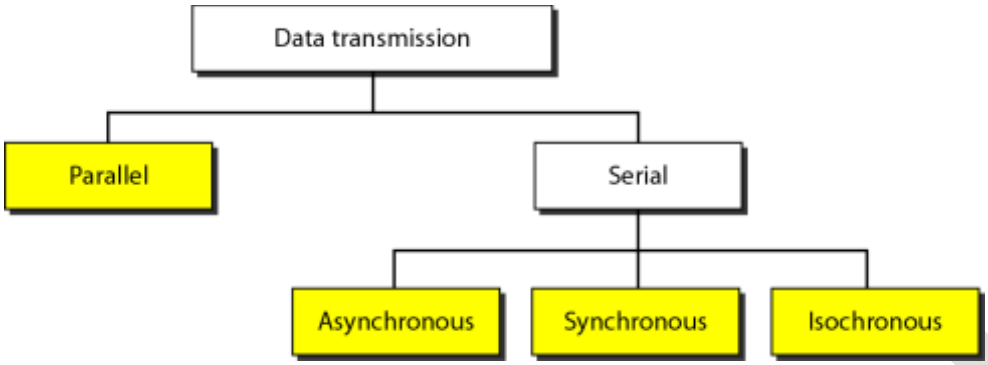
AccordingtotheNyquisttheorem,thesamplingratemustbeatleast2timesthehighestfrequency contained in the signal.



TRANSMISSIONMODES

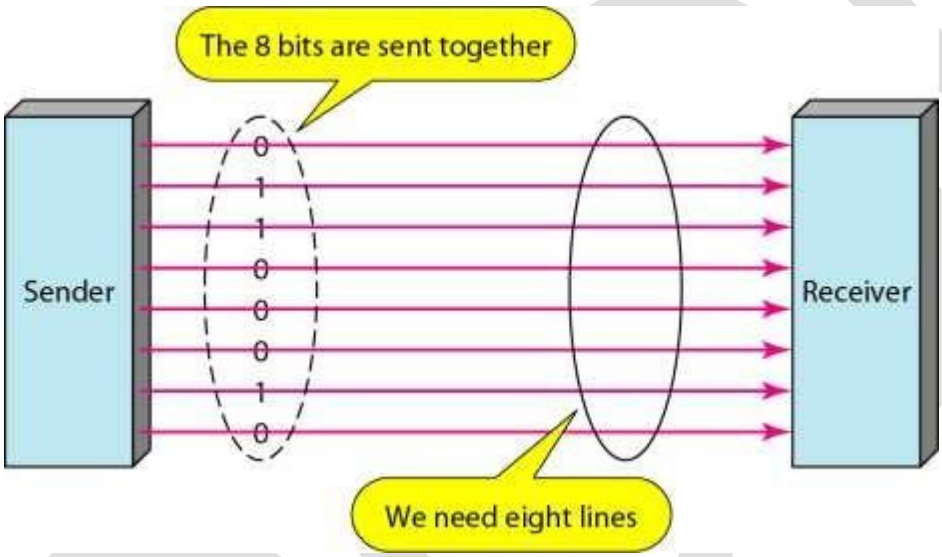
- Thetransmissionof binarydataacrossalink canbeaccomplishedineither parallelor serial mode.
- Inparallelmode,multiplebitsaresentwitheachclocktick.
- Inserialmode,1bitissentwitheachclock tick.
- Whilethereisonlyonewaytosendparalleldata,therearethree subclasses of serial transmission: *asynchronous, synchronous,* and *isochronous*.

Datatransmissionand modes

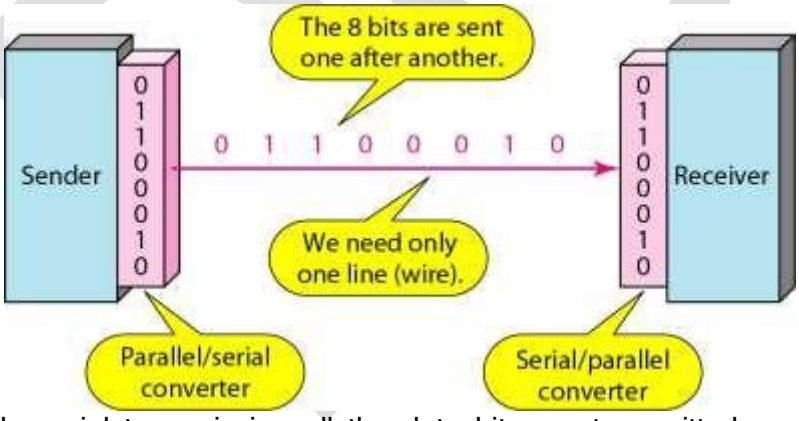


Paralleltransmission

The advantage of parallel transmission is speed. All else being equal, parallel transmission can increase the transfer speed by a factor of n over serial transmission. But there is a significant disadvantage:cost.Paralleltransmissionrequiresncommunicationlines(wiresintheexample)just to transmit the data stream. Because this is expensive, parallel transmission is usually limited to short distances.



Serialtransmission

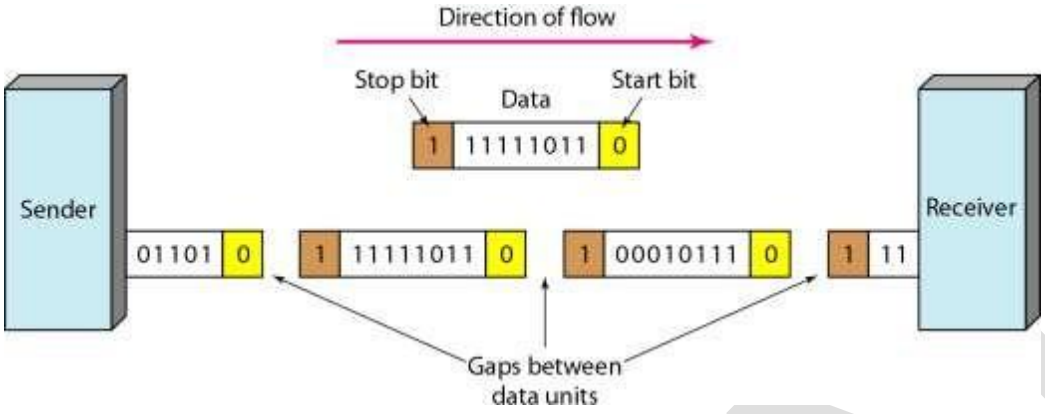


In serial transmission all the data bits are transmitted across a single wire in sequence. The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of n.

Asynchronoustransmission

Asynchronous transmission is so named because the timing of a signal is unimportant. We send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte.

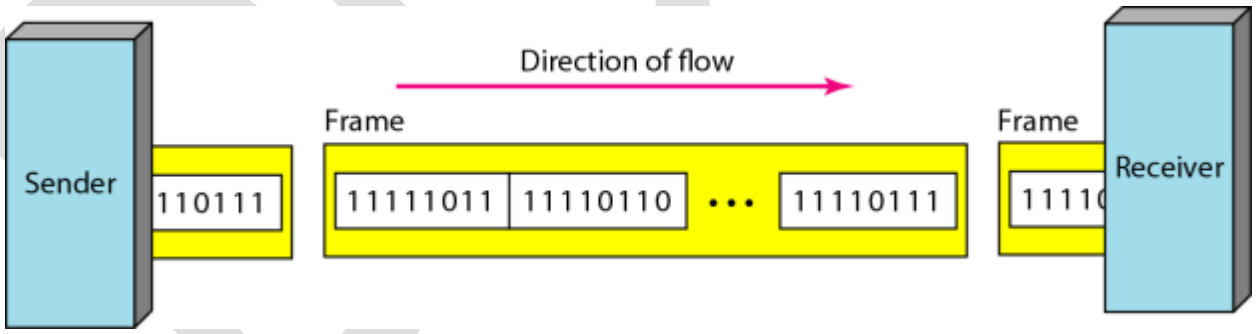
There maybea gapbetween eachbyte.



*Itis"asynchronousatthebytelevel,"bitsarestillsynchronized;theirdurationsarethesame.*The addition of stop and start bits and the insertion of gaps into the bit stream make asynchronous transmission slower than forms of transmission that can operate without the addition of control information. But it is cheap and effective, two advantages that make it an attractive choice for situations such as low-speed communication.

Synchronoustransmission

Insynchronoustransmission,wesendbitsoneafteranotherwithoutstartorstopbitsorgaps.Itis the responsibility of the receiver to group the bits. ***Timing*** becomes very important, therefore, because the accuracy of the received information is completely dependent on the ability of the receiving device to keep an accurate count of the bits as they come in. ***The advantage*** of synchronoustransmissionisspeed.Withnoextrabitsorgaps,synchronoustransmissionisfaster than asynchronous transmission.



Isochronous

In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails. For example, TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate. If each image is sent by using one or more frames, there should be no delays between frames. For this type of application, synchronization between characters is not enough; the entire stream of bits must be synchronized. The isochronous transmission guarantees that the data arrive at a fixed rate.

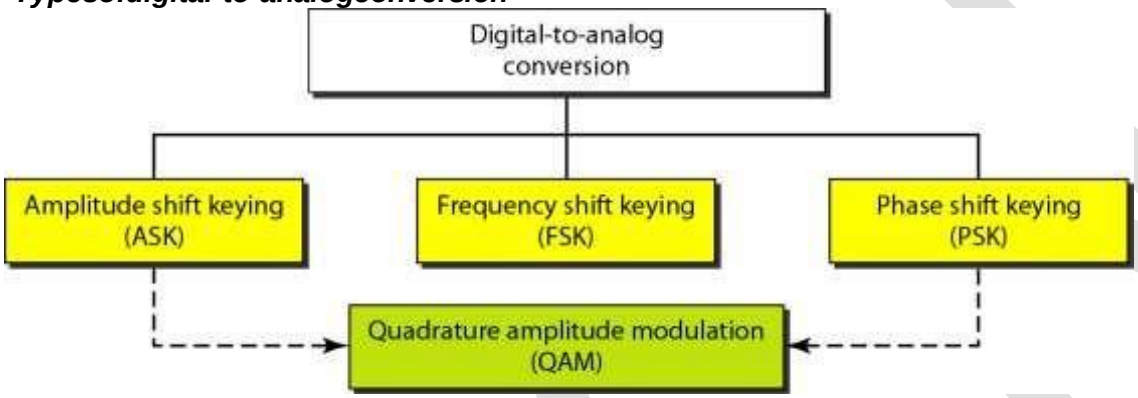
AnalogTransmission

DIGITAL-TO-ANALOGCONVERSION

Digital-to-Analogconversionistheprocessofchangingoneofthecharacteristicsofananalogsignal based on the information in digital data.

- Digitaldataneedstobecarried onananalogsignal.
- Acarrier signal(frequencyf_c) performsthefunction of transporting the digitaldatainan analog waveform.
- Theanalogcarriersignalismanipulatedtouniquelyidentifythedigitaldatabeingcarried

Typesofdigital-to-analogconversion



- Bit rateisthenumberofbits persecond.
- Baudrateisthenumberof signalelementspersecond.
- Intheanalogtransmissionof digitaldata,thebaudrateislessthanorequaltothebit rate.

Example

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

Inthis case, r=4,S= 1000,andNis unknown.Wecanfindthevalue ofNfrom

$$S = N \times \frac{1}{r} \quad \text{or} \quad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

Q.Ananalog signalhasa bitrateof8000 bps andabaudrateof1000 baud.

- Howmanydataelementsarecarriedbyeachsignal element?
- Howmanysignalelementsdoweneed?

Solution

S = 1000, N = 8000, and r and L are unknown.Wefindfirstthevalue of r

$$S = N \times \frac{1}{r} \rightarrow r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

$$r = \log_2 L \rightarrow L = 2^r = 2^8 = 256$$

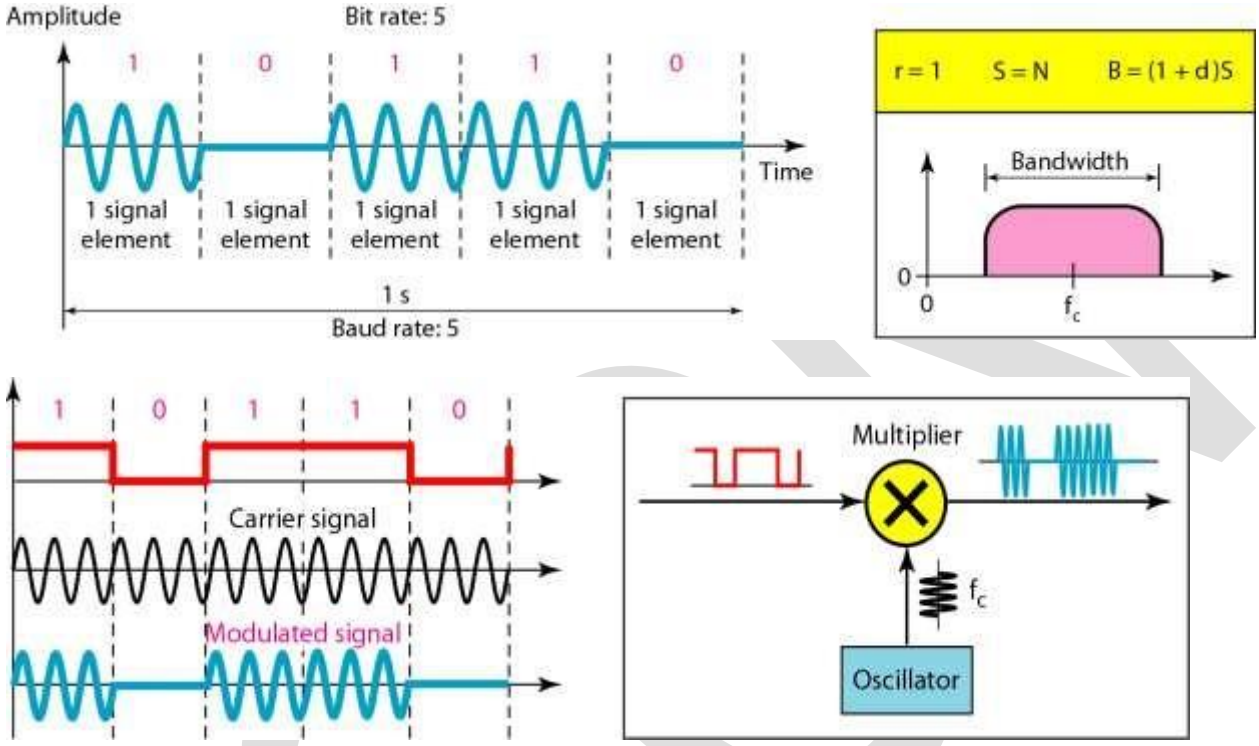
AmplitudeShiftKeying(ASK)

- ASKisimplementedby changingtheamplitudeofacarriersignaltoreflectamplitude levels in the digital signal.
- Forexample:adigital“1”couldnotaffectthesignal,whereasadigital“0”would,bymaking it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

BandwidthofASK

- Thebandwidth Bof ASKisproportionaltothesignalrate S. B = (1+d)S
- "d"isduetomodulationandfiltering,liesbetween0and1.

Binaryamplitudeshiftkeying



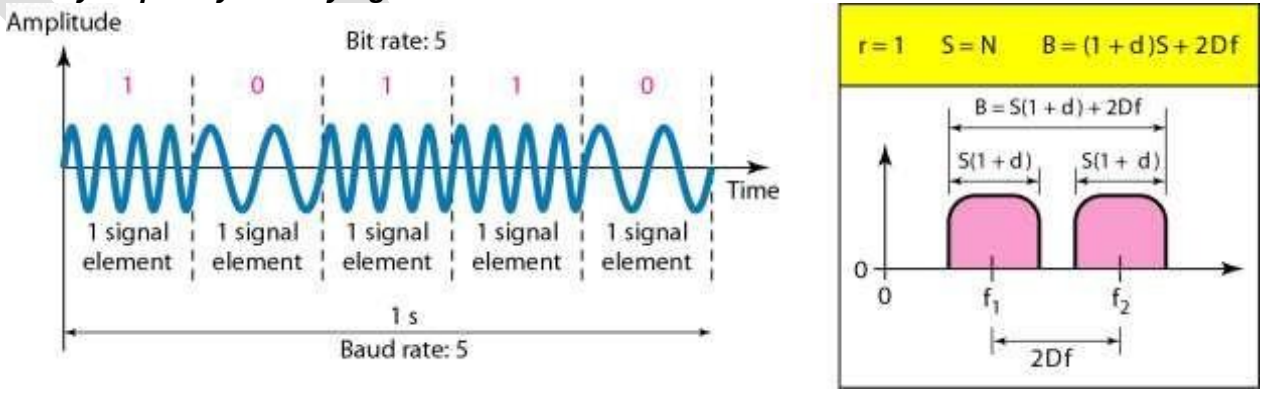
FrequencyShiftKeying

- Thedigitaldatastreamchangesthefrequencyofthecarriersignal, f_c.
- For example, a "1" could be represented by $f_1=f_c+\Delta f$, and a "0" could berepresented by $f_2=f_c-\Delta f$.

BandwidthofFSK

- Ifthedifferencebetweenthetwofrequencies($f_1$andf_2)is$2\Delta f$,thentherequiredBWBwill be: B = (1+d)xS +$2\Delta f$

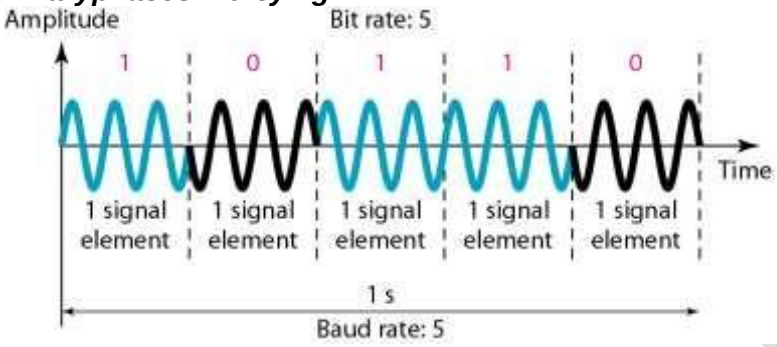
Binaryfrequencyshiftkeying

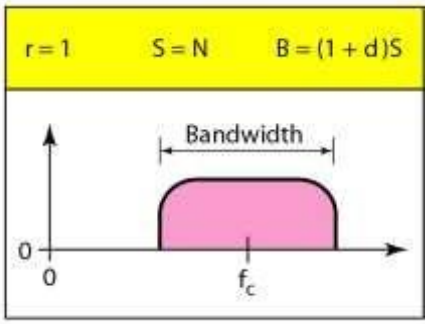


PhaseShift Keying

- Wevarythephaseshiftofthecarriersignal to representdigital data.
- Thebandwidth requirement,Bis: B= (1+d)xS
- PSKismuchmorerobustthanASKasitisnotthatvulnerabletonoise,whichchangesamplitude of the signal.

Binaryphaseshiftkeying





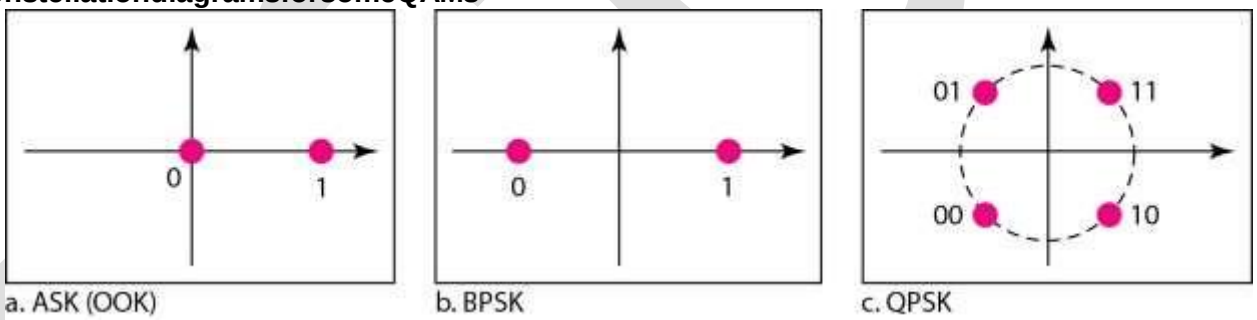
QuadraturePSK

- ❖ Toincreasethebitrate,wecan code2ormorebits ontoonesignalelement.
- ❖ In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90° from the other - in Quadrature.
- ❖ ThetwoPSKedsignalsarethenaddedtoproduceoneof 4signalelements. L=4here.
- ❖ QuadratureamplitudemodulationisacombinationofASKandPSK.

ConstellationDiagrams

- A constellation diagram helps us to define the amplitude and phase of a signal when we are using two carriers, one in quadrature of the other.
- TheX-axisrepresentsthein-phasecarrierandtheY-axisrepresentsquadraturecarrier.

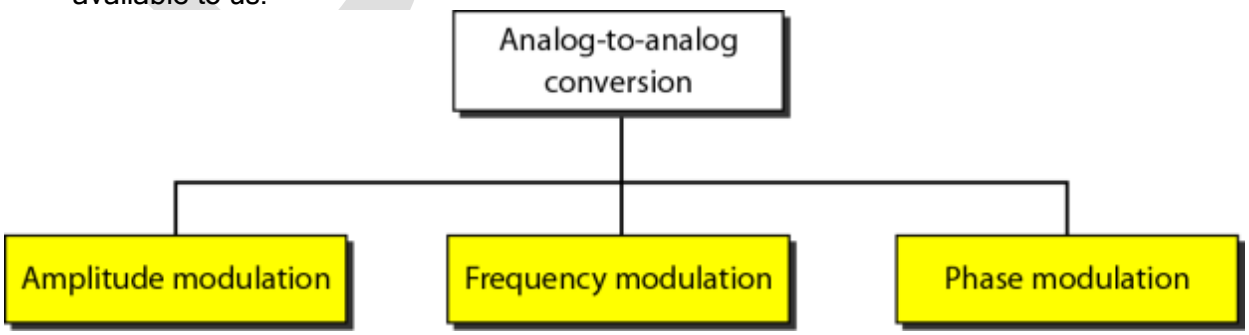
ConstellationdiagramsforsomeQAMs



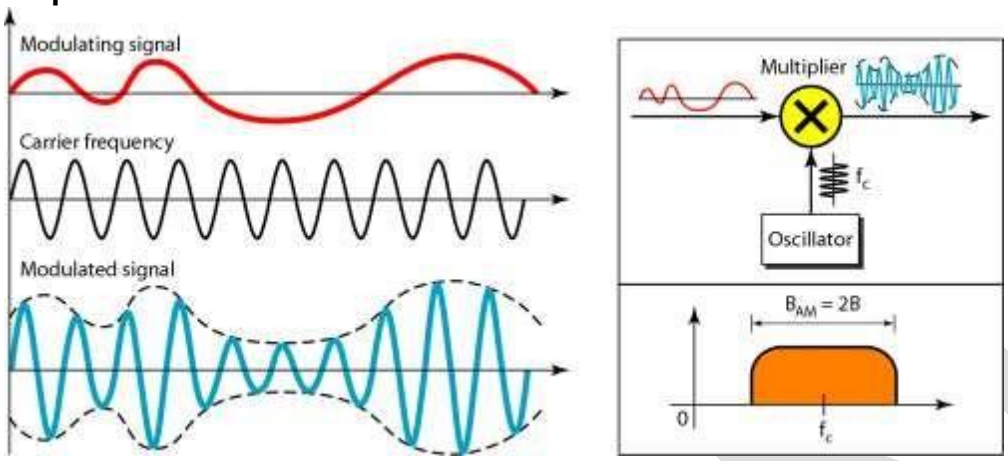
a. ASK (OOK) b. BPSK c. QPSK

ANALOG-TO-ANALOGCONVERSION

- ❖ Analog-to-analogconversionistherepresentationofanaloginformationbyananalog signal.
- ❖ Onemayaskwhyweneedtomodulateananalogsignal; itisalreadyanalog.
- ❖ Modulationisneeded if the medium is band-passinnatureor if onlyaband-passchannel is available to us.

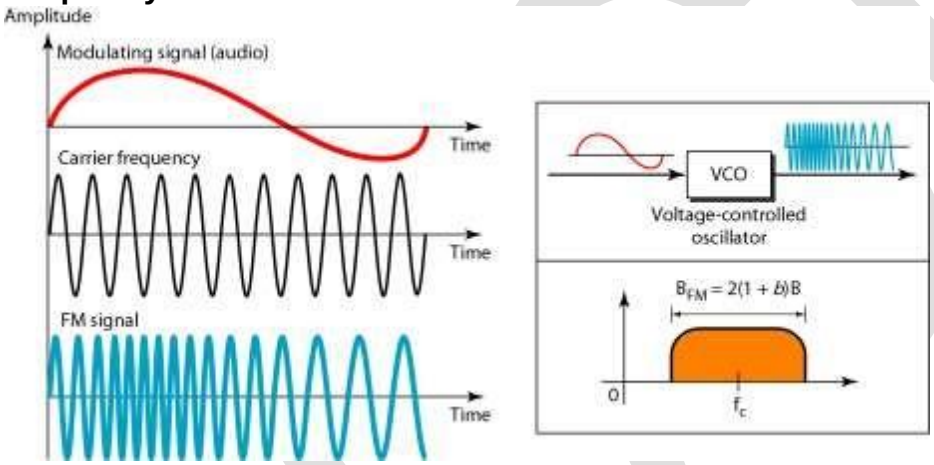


Amplitude Modulation



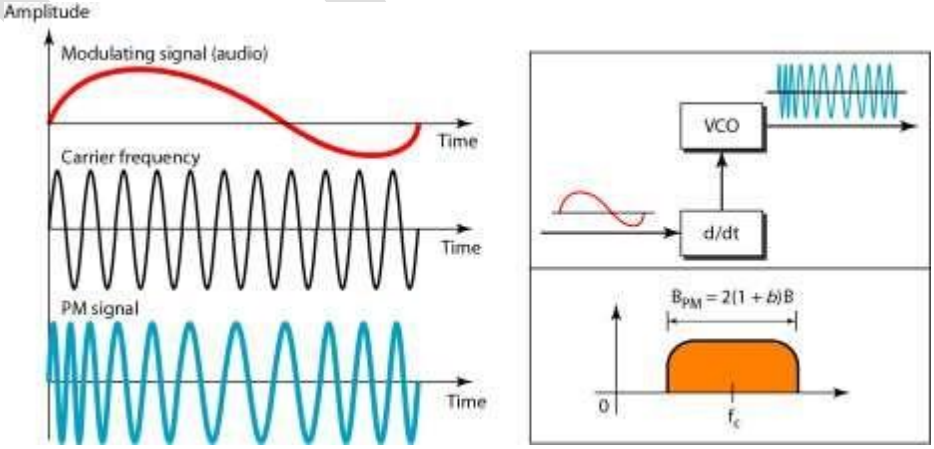
Thetotalbandwidth requiredfor AM can bedeterminedfromthe bandwidth of theaudiosignal: B_{AM}= 2B.

FrequencyModulation



The total bandwidth required for FM can be determined from the bandwidth of the audio signal: B_{FM}= 2(1 + β)B.

Phase Modulation



Thetotalbandwidth requiredfor PMcan bedeterminedfromthe bandwidth andmaximum amplitude of the modulating signal: B_{PM}= 2(1 + β)B.

TELEPHONE MODEM

MODEMS

Thetermmodemisacompositewordthatreferstothetwofunctionalentitiesthatmakeupthedevice; a signal modulator and a signal demodulator. A modulator creates a band-pass analog signal from binary data. A demodulator recovers the binary data from the modulated signal.
Modemstandsformodulatorand demodulator.

TELEPHONEMODEMS

Traditional telephone lines can carry frequencies between 300 and 3300 HZ, giving them BW of 3000 Hz;Allthisrangeisusedfortransmittingvoice,whereagreatdealof interferenceanddistortioncanbe accepted without loss of intelligibility.

Theeffective BW of atelephone line being usedfor dataTransmission is2400 Hz, coveringthe range from 600 to 3000 Hz.

Modem standards:

V-seriesstandardspublishedbythelTU-T.

- V.32
- V.32bis
- V.34bis
- V.90
- V.92

V.32

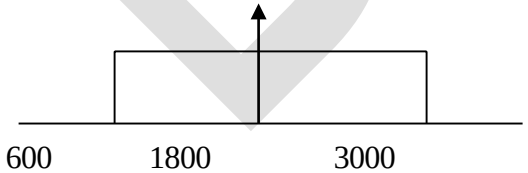
Thismodemusesacombinedmodulationanddemodulationencodingtechniquecalledtrellis-codedmodulation.TrellisisessentiallyQAMplusaredundantbit.TheDatastreamisdividedinto4-bit sections.Insteadofaquadbit,however,apentabitistransmitted.Thevalueoftheextrabitiscalculated from the values of the data bits.

In any QAM system, the receiver compares each received signal point to all valid points in the constellation and selects the closest point as the intended value.. A signaldistorted by transmission noise can arrive closer in value to an adjacent point than to the intended point, resulting in a misidentification of the point and an error in the received data.

By adding a redundant bit to each quad bit, trellis-coded modulation increases the amount of information used to identify each bit pattern thereby reduces the number of possible matches.

The V.32 calls for 32-QAM with a baud rate of 2400. Because only 4 bits of each pentabit represents data, the resulting speed is 4*2400=9600.

FDX2400baud9600bps2-wire



Bandwidthdiagram

V.32bis

TheV.32bismodemsupport14,400-bpstransmission.TheV.32uses128-QAM transmission.

V.34bis

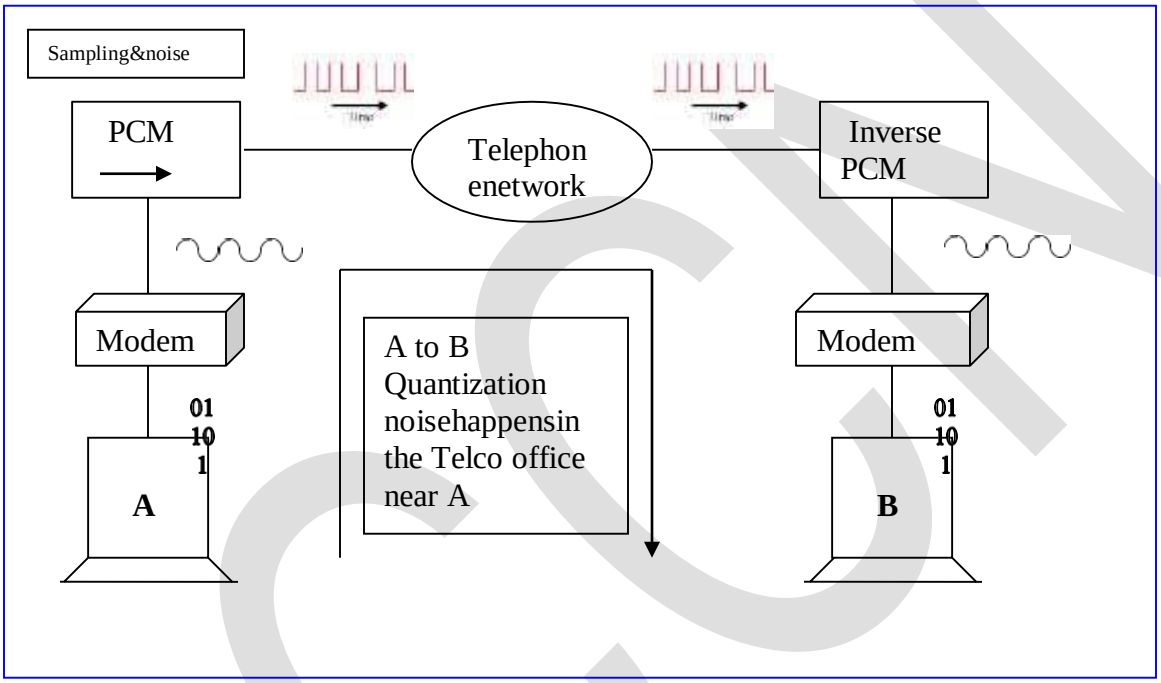
The V.34 bis modem support 28,800-bps transmission with a 960-point constellation to a bit rate of 33,600 with a 1664-point constellation.

V.90

Traditional modems have a limitations on the data rate.V.90 modems with a bit rate of 56,000 bps, called 56Kmodems, are available. Downloading rate is 56K, while the uploading rate is a maximum of 33.6 kbps.

Traditionalmodems

Intraditionalmodemsdataexchangeisbetweentwocomputers,AandB,Throughdigital telephone network.



After modulation by the modem, an analog signal reaches the telephone company Switching station. Where it is sampled and digitized to be passed through the digital network. The quantization noise introducedinthesignalatthesamplingpointlimitsthedatarateaccordingtothecapacity.Thislimitis 33.6 Kbps.

56K Modems

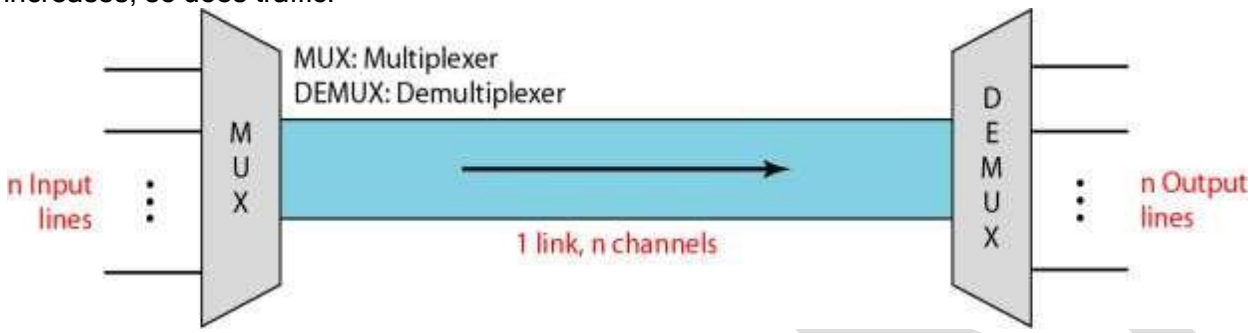
Communication today is via the Internet. In Uploading, The analog signal must still be sampled at the switching station, which means the data rate in the uploading is limited to 33.6 Kbps. There is no sampling in downloading. Data rate in downloading is 56Kbps.

V.92

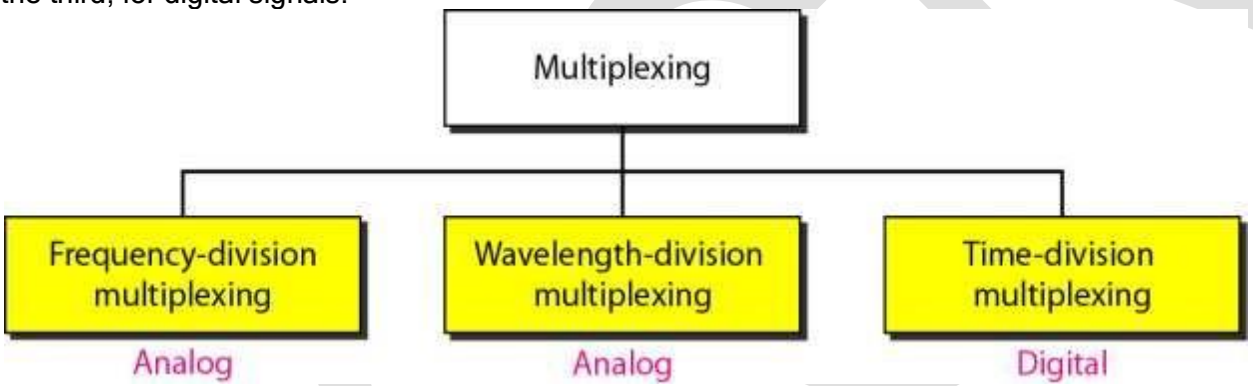
ThestandardaboveV.92iscalledV.92.Thesemodemscanadjusttheirspeed,andifthenoise allows, they can upload data at the rate of 48 Kbps. The modem has additional features. For example, the modem can interrupt the internet connection when there is an incoming call if the lineshas call-waiting service.

MULTIPLEXING

Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the (simultaneous) transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.



There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing. The first two are techniques designed for analog signals, the third, for digital signals.



In a multiplexed system, n lines share the bandwidth of one link. The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to-one).

Atthereceivingend,thatstreamisfedintoademultiplexer(DEMUX),whichseparatesthestreamback into its component transmissions (one-to-many) and directs them to their corresponding lines.

Inthefigure,theword ***link***referstothephysicalpath.Theword ***channel***referstotheportionof alink that carries a transmission between a given pair of lines. One link can have many (n) channels.

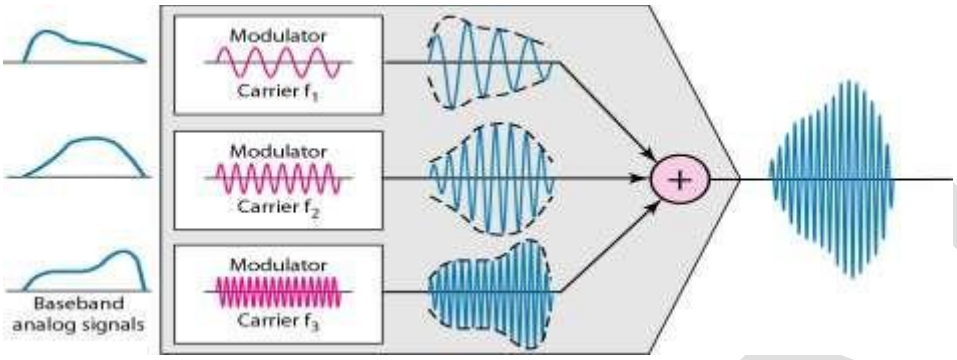
Frequency-divisionmultiplexing(FDM):

Itis ananalog techniquethatcanbe applied whenthebandwidth of alink (inhertz) isgreater thanthe combined bandwidths of the signals to be transmitted.

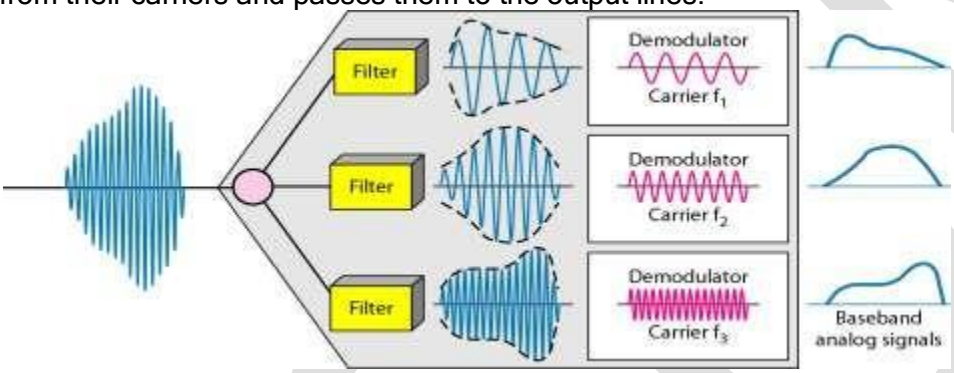
- In FDM, signals generated by each sending device modulate different carder frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel.

- Channelscanbeseparated bystripsofunusedbandwidth**guard bands** topreventsignalsfrom overlapping.

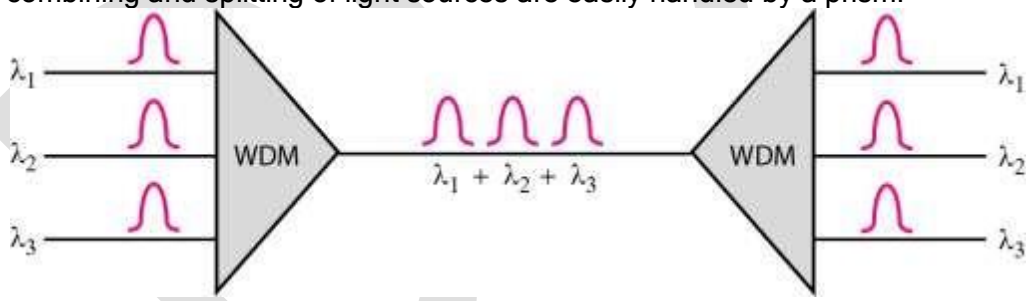
FDMProcess:



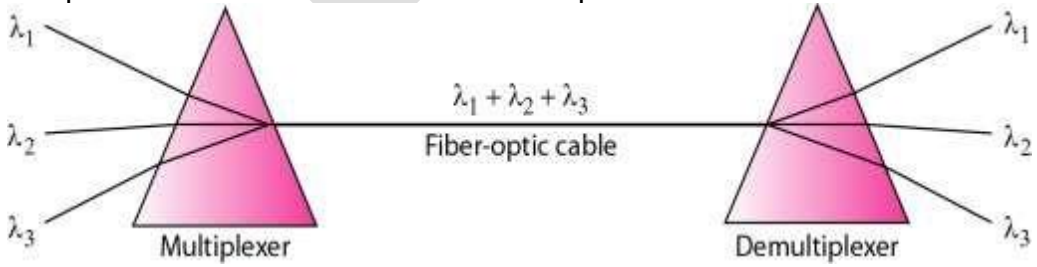
The de-multiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.



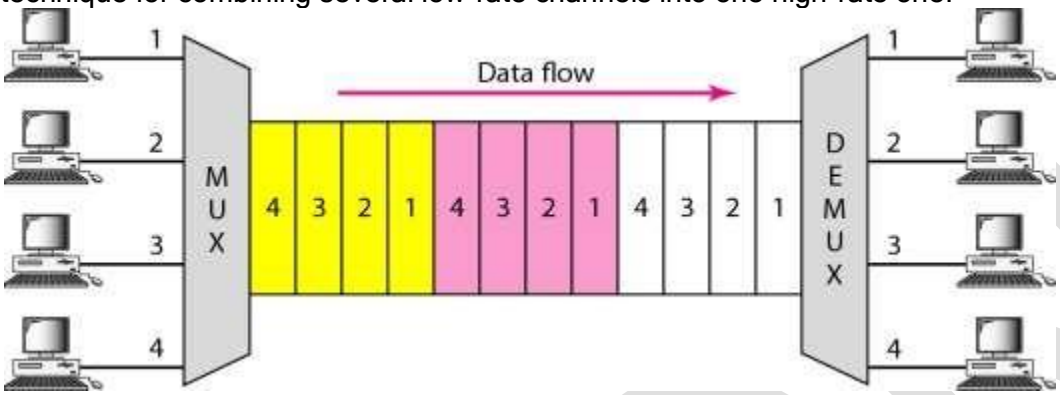
Wavelength-divisionmultiplexing(WDM) is designed to use the high-data-rate capability of fiber-optic cable. The optical fiber data rate is higher than the data rate of metallic transmission cable. Usingafiber-opticcableforonesinglelinewastestheavailablebandwidth.Multiplexingallowsusto combineseverallinesintoone.WDMisananalogmultiplexingtechniquetocombineopticalsignals. The combining and splitting of light sources are easily handled by a prism.



Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies. A de-multiplexer can also be made to reverse the process.



Time-DivisionMultiplexing:Time-division multiplexing (TDM) is a digitalprocessthat allows several connections to share the high bandwidth of a link. Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupiesa portion of time in thelink. Note that thesame link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially. TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.



WecandivideTDMintotwodifferentschemes:synchronousand statistical.
In synchronous TDM, each input connection has an allotment in the output even if it is not sending data. InsynchronousTDM, the datarate of thelink is *n*timesfaster, andthe unit durationis *n*times shorter.

Interleaving

- Theprocessoftaking agroupofbitsfromeachinputlineformultiplexingiscalledinterleaving.
- Weinterleavebits(1-n)fromeachinputontooneoutput.

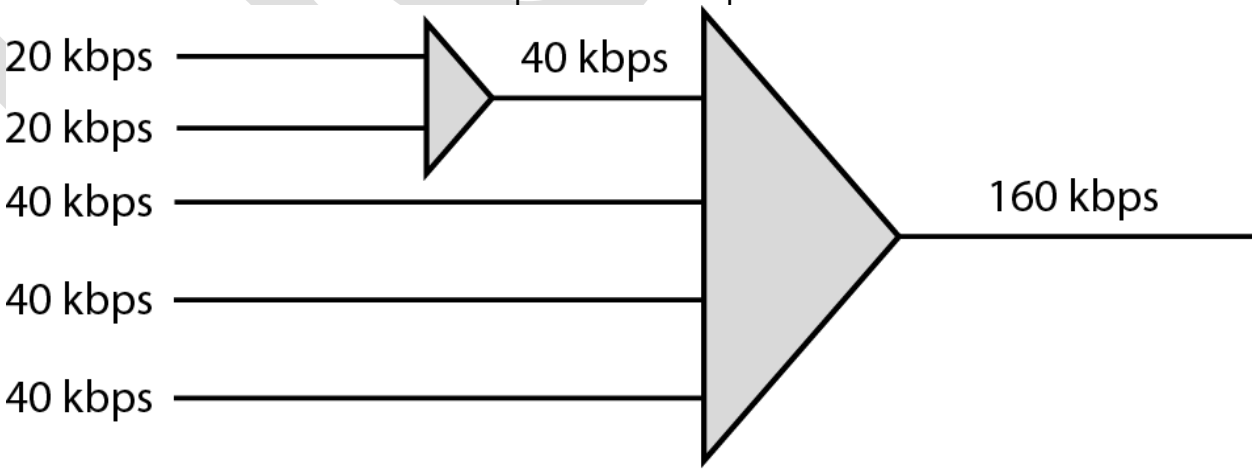
TDMcanbevisualizedastwofast-rotating switches, oneonthemultiplexing sideandtheother onthe demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called interleaving.

EmptySlots

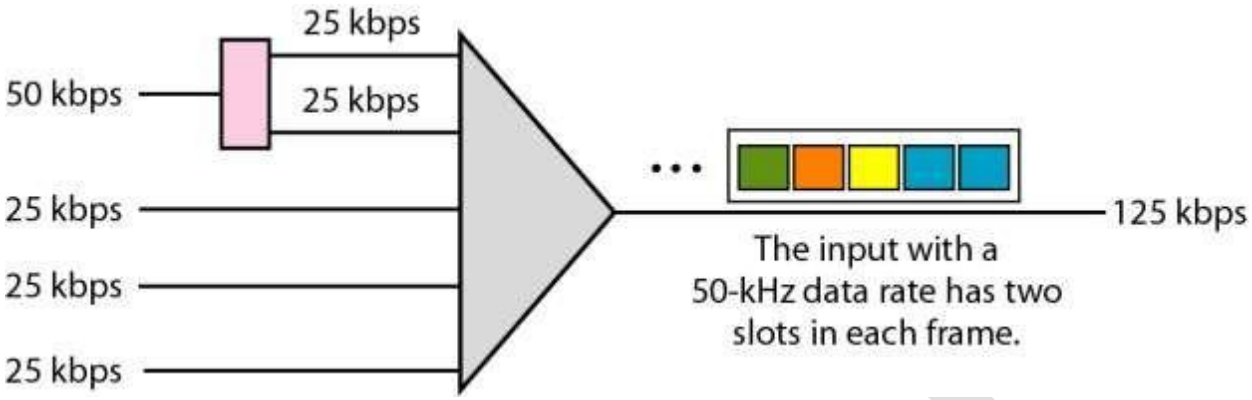
SynchronousTDMisnotasefficientasitcouldbe.Ifasourcedoesnothavedatatosend,the corresponding slot in the output frame is empty.

DataRateManagement:

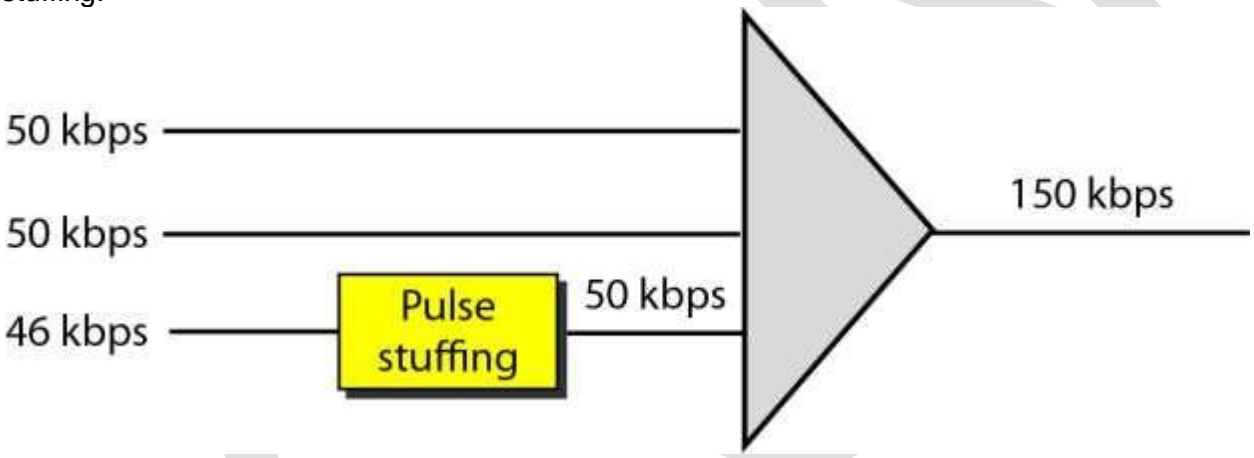
- Therearethreestrategiesthatcanbeusedtoovercomethedataratemismatch:multilevel,multislot and pulse stuffing
  - **Multilevel:**usedwhenthedatarateoftheinput linksaremultiplesofeachother.



  - **Multislot:** used when there is aGCD between the data rates. Thehigherbit rate channels are allocated more slots per frame, and the output frame rate is a multiple of each input link.



- **Pulse Stuffing** Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied. One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates.Thiswillincreasetheirrates.Thistechniqueiscalledpulsestuffing,bitpadding,or bit stuffing.



StatisticalTime-DivisionMultiplexing:AswesawinthepreviousSection,insynchronousTDM,each inputhasareservedslotintheoutputframe.Thiscanbeinefficientifsomeinputlineshave nodatato send. In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.Onlywhenaninputlinehasaslot'sworthofdatatosendisitgivenaslotintheoutputframe. In statisticalmultiplexing, the number of slots in eachframeis lessthanthe number of input lines.The multiplexer checks each input line in round- robin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

Addressing: in statistical TDM, a slot needs to carrydata as well as the address of the destination. In statisticalmultiplexing,thereisnofixedrelationshipbetweentheinputsandoutputsbecausethereare no preassigned or reserved slots.

Slot Size

Since a slot carries both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient.

NoSynchronizationBit

TheframesinstatisticalTDMneednotbesynchronized,sowe donotneedsynchronizationbits.

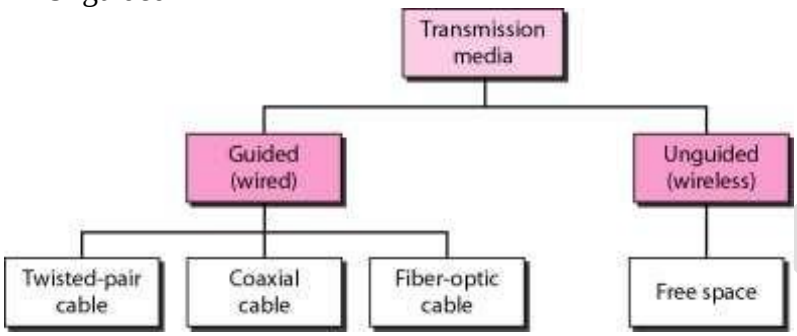
Bandwidth

In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel. The designers of statistical TDM define the capacity of the link based on the statistics of the load for each channel. If on average only x percent of the input slots are filled, the capacity of the link reflects this.

TransmissionMedia

Atransmissionmediadefineasanythingthatcancarryinformationfromasourcetoadestination. Transmission media are actually located below the physical layer and directly controlled by the physical layer. Transmissionmediacanbedividedinto twobroad categories

- Guided
- Unguided



Guided media

Guidedmedia,whicharethosethatprovideaconduitfromonedevicetoanother,includetwisted- pair cable, coaxial cable, and fiber-optic cable.

1. ***Twisted-PairCable***

A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.

One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference. The receiver uses the difference between the two. In addition to the signal sent by the sender on one of the wires, interference (noise) and crosstalk may affect both wires and create unwanted signals.

The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP). IBMhas also produced a version of twisted-pair cablefor its use called shielded twisted-pair (STP).STPcablehas ametalfoilor braided-meshcoveringthatencaseseachpairof insulated conductors. Although metal casing improves the quality of cable by preventing the penetration of noise or crosstalk, it is bulkier and more expensive.

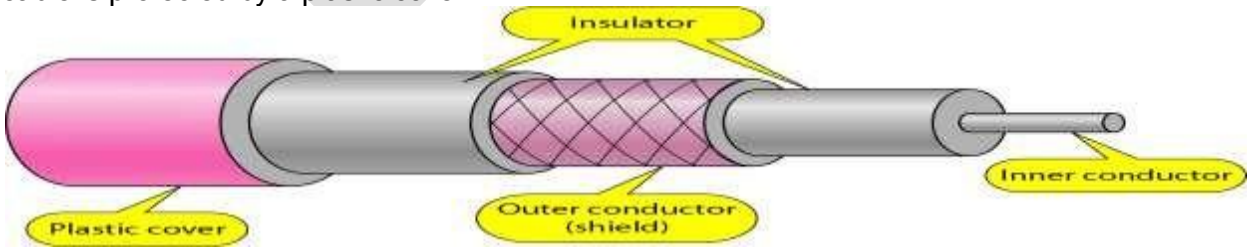
Connector: RegisteredJack(RJ45)

Applications

Twisted-paircablesareusedintelephonelinestoprovidevoiceanddatachannels.

2. ***Coaxial Cable***

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted- pair cable, in part because the two media are constructed quite differently. Instead ofhaving two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two. Theouter metallic wrapping serves both as a shield against noise and as thesecondconductor completing the circuit. This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover



Coaxial cableStandards

Coaxial cables are categorized by their radio government (RG) ratings .Each RG number denotes a set of physical specifications such as,

- wiregaugeoftheinner conductor
- thicknessandtypeoftheinnerinsulator
- theconstructionoftheshield
- thesizeandtype of outer casing

Categoriesofcoaxialcables

Category	Impedance	Use
RG-59	75Ω	CableTV
RG-58	50Ω	Thin Ethernet
RG-11	50Ω	Thickethernet

Coaxial Cable Connectors

Coaxial Cable Connectors are used to connect coaxial cable to devices. The most common type of connector is the Bayone Neill-concelman or BNC connectors. There are three popular types of connectors

- BNCconnector
- BNCTconnector&
- BNCterminator

BNCconnector

Itisusedtoconnect theendofthecableto adevicesuchasaTVset.

BNCTconnector

ItisusedinEthernetnetworkstobranchoutacableforconnectiontoacomputeror other devices.

BNCterminator

Itis usedat theend ofthecabletopreventthereflectionofthe signal.

Performance

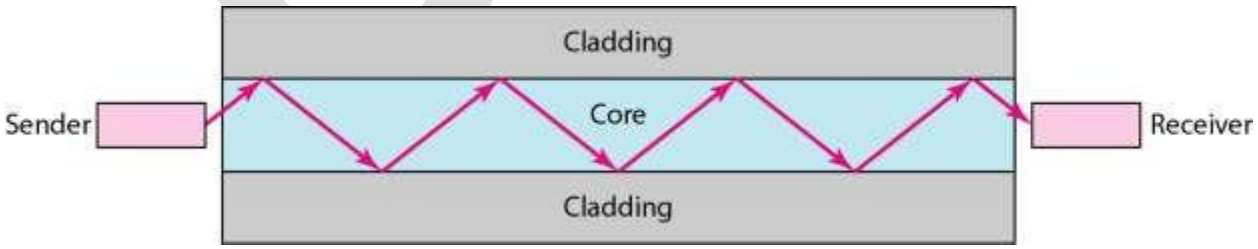
- Attenuationismuchhigherincoaxialcablesthanintwistedpair cable.
- Coaxialcablehasamuchhigherbandwiththesignalweakensrapidlyandneedsthe frequent use of repeaters.

Applications

- Coaxialcableisusedinanalogtelephonenetworkwhereasinglecoaxialcablecouldcarry 10,000 voice signals.
- It is also used in digital telephone network where a cable could carry digital data up to 600 Mbps.
- CableTVnetworksalsousedRG-59coaxialcables.
- ItisalsousedintraditionalEthernets.

FiberOpticCable.

A fiber optic cable is made of glass or plastic and transmits signals in the form of light. Optical fibers use reflection to guide light through a channel.



A glass or plastic core is surrounded bya cladding of less denseglass or plastic. The difference inthe density of the two materials must be such that a beam of light moving through the core is reflected off the cladding.

PropagationModes

Thereare twomodes forpropagatinglightalongopticalchannels;each requires fiberwithdifferent physical characteristics

- Multimode
- Singlemode

Multimode

Multiplebeamsfrom alight sourcemovethroughthecoreindifferent paths. Multimode can be implemented in two forms

- Step-index
- Gradedindex

MultimodeStep–indexfiber

- InMultimodeStep-indexfiberthedensityofthefiberremainsconstantfromthecentertothe edges
- Abeamof lightmovesthroughthisconstantdensityina straightline.
- When it reaches the interface of the core and the cladding, there is an abrupt change to a lower density that alters the angle of the beams motion.
- Step-index->thesuddennessofthis change.

MultimodeGraded-indexfiber

- Itdecreasesthedistortionofthesignalthroughthecable.
- Densityishighest atthecenterofthecoreanddecreasesgraduallytoitslowest attheedge.

Single-Mode

- It uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal
- The Single-Mode fiber itself is manufactured with a smaller diameter than that of multimode fiber and with lower density.
- Thisresultsinacriticalanglethatis closeenoughto90°tomakeithorizontal.
- All the beams arrive at the destination together and can be recombined with little distortion to the signal.

FiberSizes

Opticalfibersaredefinedbytheratiooftthediameteroftheircoretothediameteroftheircladding expressed in micrometers.

Fiber-opticcableconnectors.

Three different types of connectors are used by fiber –optic cable.

SC (subscriber channel) Connector:

Itis usedincableTV.

ST(Straight-tip)Connector:

Itisusedforconnectingcabletonetworking devices.

Performance:

- Attenuationisflatterthaninthecaseoftwistedpaircableandcoaxialcable.
- Fewrepeatersareneededwhenweusefiberopticcable.

Application

ItisusedincableTVandLAN(FastEthernet and100Base-X.

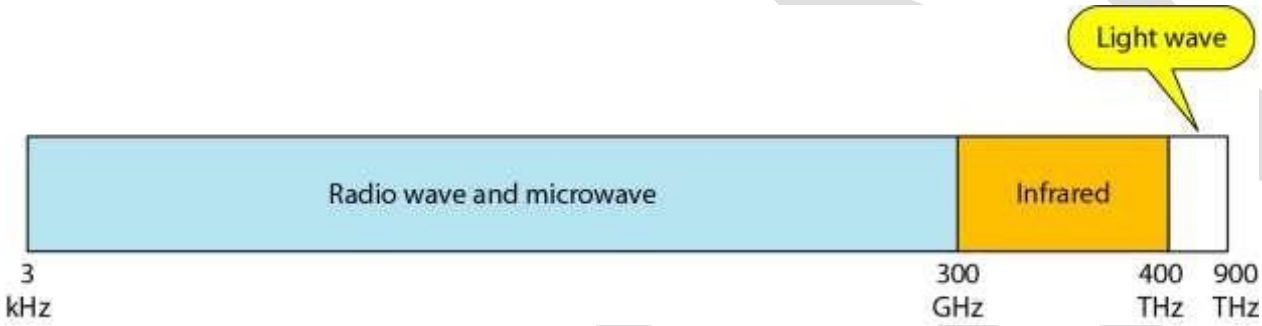
Advantages

Higherbandwidth:Itcansupporthigherbandwidththantwistedpairorcoaxialcable.

Less signal attenuation: Transmission distance is greater than that of other guided media. Signalscan be transmitted for 50 km without requiring regeneration.

Immunitytoelectromagnetic Interference:Electromagnetic noise can notaffectfiber-opticcables
Resistancetocorrosivematerials:glassismoreresistanttocorrosivematerials.
Light-weight:Itisoflessweightthanthecopper cables.
MoreImmunetotaping: Fiber-opticcablesaremoreimmunetotapingthancopper cables.

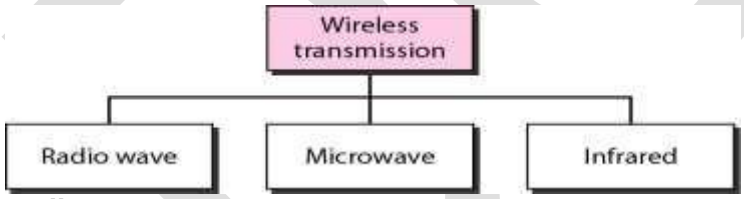
Disadvantages:
Installation/Maintenance. Installation/Maintenance need expertise since it is a new technology.
Unidirectional:Propagationoflightisunidirectional.Bidirectionalcommunicationisachievedby means of two optical fibers.
Cost: It is more expensive and the use of optical fiber cannot be justified if the need for bandwidth is not high.
UNGUIDEDMEDIA:WIRELESS
Unguidedmediatransportelectromagneticwaves without usingaphysicalconductor.Thistypeof communication is often referred to as wireless communication.



Unguidedsignalcantravelfromthesourcetodestinationinseveralways:
1. GroundPropagation:
- Radiowavestravelthroughthelowestportionoftheatmosphere,huggingthe earth.
- Thelowfrequencysignalfollows thecurvatureoftheplanet.
- Distancedependsontheamountofthepower.

2. SkyPropagation:
- Higherfrequencyradioradiateupwardintotheionospherewheretheyarereflectedback to the earth.
- Skypropagationallowforgreaterdistancewithlowerpower output.

3. line-of-sightPropagation: Veryhighfrequencysignalsaretransmittedinstraightlinesdirectlyfrom antenna to antenna.



RadioWaves:
- RadioWaves:Between3KHz-1GHz.
- Radiowavesuseomnidirectionalantenna.
- Radiowavesusedformulticastcommunication,suchasradioandtelevision.
- SkyPropagation.Thismakesradiowavesagoodcandidateforlong-distancebroadcasting such as AM radio.

MicroWaves:
1. Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall.
2. Veryhigh-frequencymicrowavescannotpenetratewalls.Thischaracteristiccanbeadisadvantage if receivers are inside buildings.

3. The microwave band is relatively wide, almost 299 GHz. Therefore widersubbandscan be assigned, and a high data rate is possible Use of certain portions of the band requires permission from authorities.

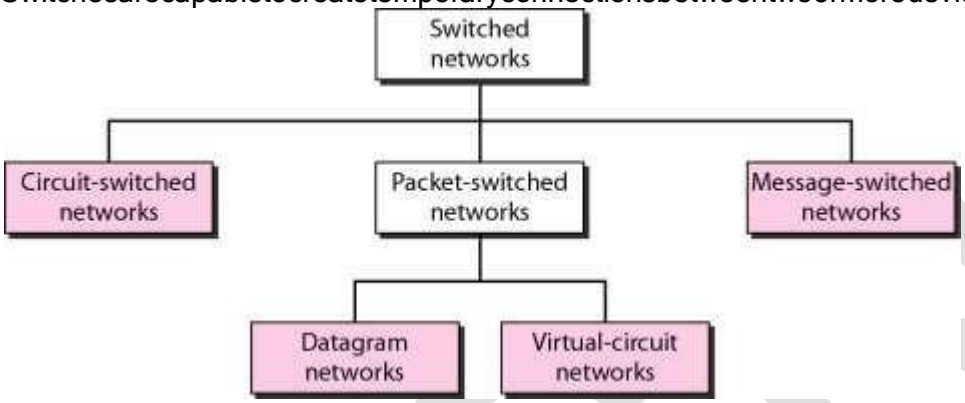
Infraredwaves:

- Between300GHz-400THz
- Usedforshort-rangecommunication.
- Verycommonwithremotecontroldevices,butcanalsobeusedfordevice-to-device transfers, such as PDA to computer.
- Line-of-sightpropagation.

CIRCUITSWITCHINGANDTELEPHONE NETWORK

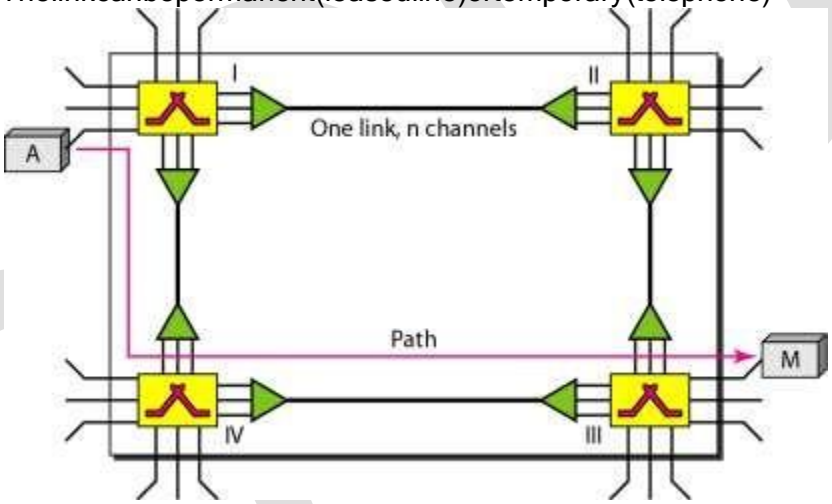
Introduction:

- Noneofthepreviousworksinlargernetworkswithlargephysicalseparationorconsisting of a large number of computers
- Thesolutionisaswitchingnetwork.
- Consistsofaseriesof interlinkednodescalledswitches.
- Switchesarecapabletocreatetemporaryconnectionsbetweentwoormoredevices

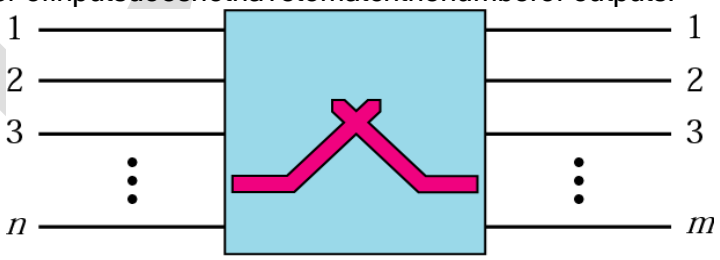


CircuitSwitching:

- Acircuit-switchednetworkconsistsofasetofswitchesconnectedbyphysicallinks.
- Aconnectionbetweentwostations isadedicatedpathmadeof oneormore links
- eachconnectionusesonlyonededicatedchanneloneachlink
- Eachlinkisnormallydividedintonchannelsbyusing FDMorTDM.
- Thelinkcanbepermanent(leasedline)ortemporary(telephone)



- Acircuitswitchisadevicewithninputsandmoutputsthatcreatesatemporaryconnection between an input link and an output link.
- Thenumber ofinputsdoesnothavetomatchthenumberof outputs.

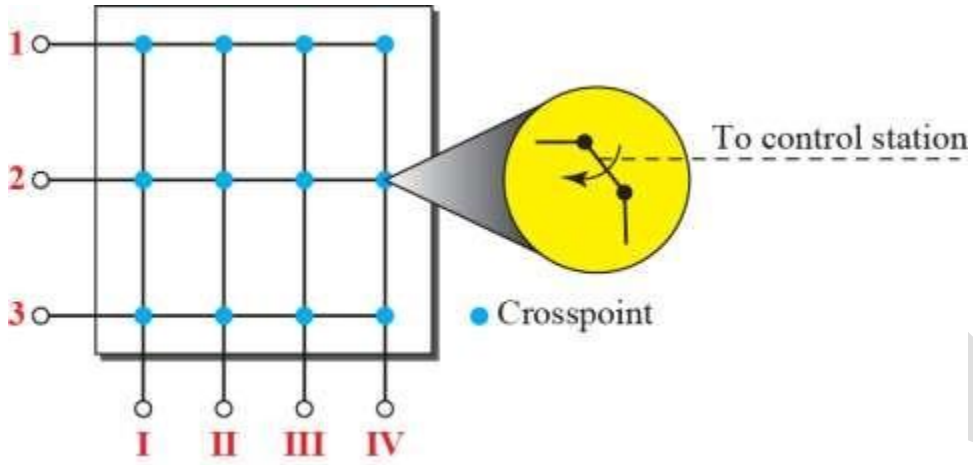


Thecommoncategoriesof switchare:

1. SpacedivisionSwitch
2. Timedivisionswitch

Spacedivision switch:

- Developedforanalogenvironment,buthasbeencarriedoverintodigital communication
- Requiresseparatephysicalpathsforeachsignalconnection
- Usesmetallicorsemiconductor“gates”



- ItsbasicdeviceistheCrossbar switch
- Numberofcrosspointsgrowsassquareof numberof stations
- Lossofcrosspointprevents connection
- Inefficientuseofcrosspoints
- Allstationsconnected,onlyafewcrosspointsinuse
- Non-blocking

- pathsinthecircuitareseparatedfrom eachotherspatially.

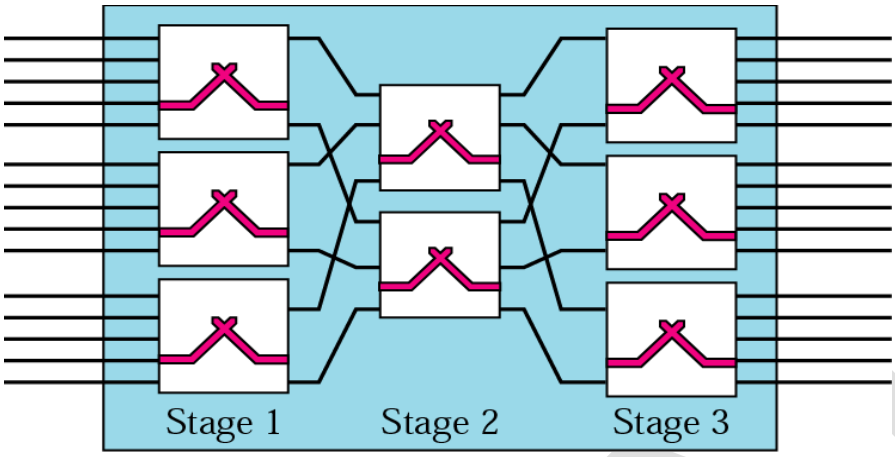
CrossbarSwitch

- Crossbarswitchconnects ninputstom outputs inagrid, usingelectronicmicro-switches (transistors) at each cross-point.
- Limitationisthenumberof cross-pointsrequired.

- Advantages:
  - simpletoimplement
  - simplecontrol
  - strictsensenon-blocking
  - Multicast
  - Singlesourcemultipledestinationports
- Drawbacks
  - numberofcrosspoints,N^2
  - largeVLSIspace
  - vulnerabletosinglefaults

Multistageswitch:

- Multistageswitchcombinescrossbarswitchesinseveralstages.
- Designofamultistageswitchdependsonthenumberofstagesandthenumberof switches required (or desired) in each stage.
- Normally,themiddlestageshavefewerswitchesthandothefirstandlast stages.



- Multiplepathsareavailableinmultistageswitches.
- Blocking referstotimeswhentwoinputs are looking forthesameoutput.Theoutput port is blocked.

Time-DivisionSwitch

- Time-divisionswitchingusestime-divisionmultiplexingtoachieveswitching.Two methods used are:
- Time-slotinterchange(TSI)changesthe orderofthe slots basedonthedesired connection.
- TDMbus

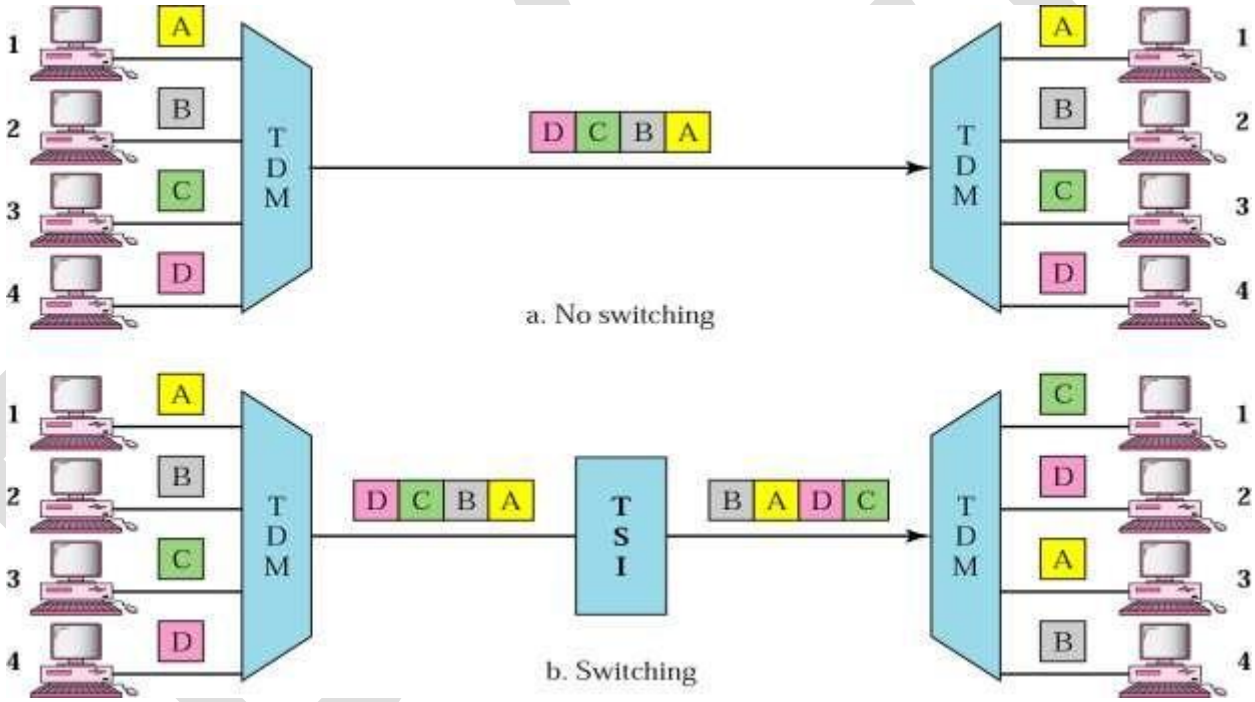
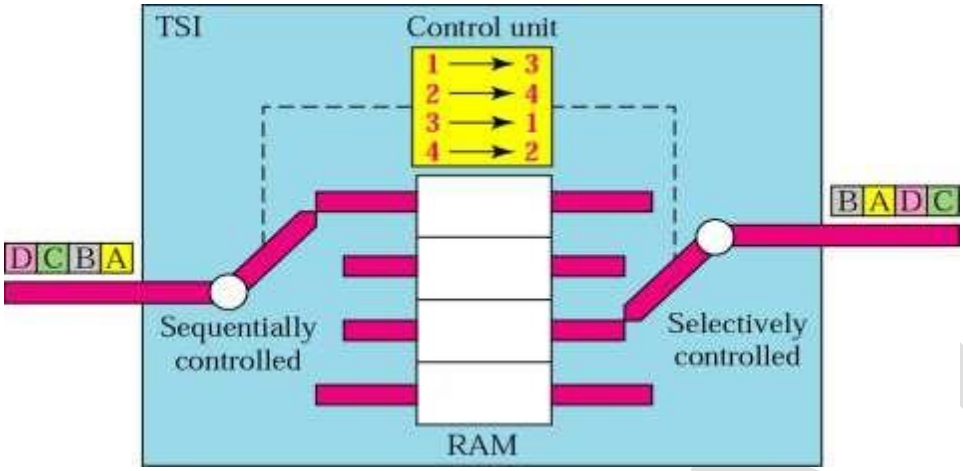


FIG:Time-divisionmultiplexing,withoutandwithatime-slotinterchange

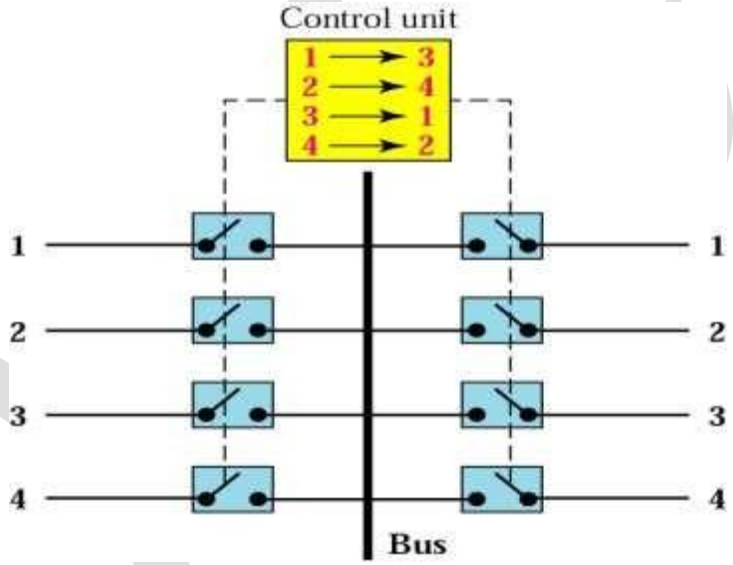
TimeSlotInterchange(TSI)

- TSIconsistsofrandom accessmemory(RAM) withseveralmemory locations.Thesize of each location is the same as the size of a single time slot.
- Thenumber of locationsis thesameasthenumber of inputs.
- TheRAMfills up with incoming datafrom timeslots intheorder received. Slots arethen sent out in an order based on the decisions of a control unit.



TDMbus

- Input and output lines are connected to a high-speed bus through input and output gates (microswitches)
- Eachinputgateisclosedduringoneof thefour slots.
- Duringthesametimeslot,onlyoneoutputgateisalsoclosed.Thispairofgatesallows a burstofdatatobetransferredfromonespecificinputlinetoonespecificoutputlineusing the bus.
- Thecontrolunitopensandclosesthegatesaccordingtoswitching need.

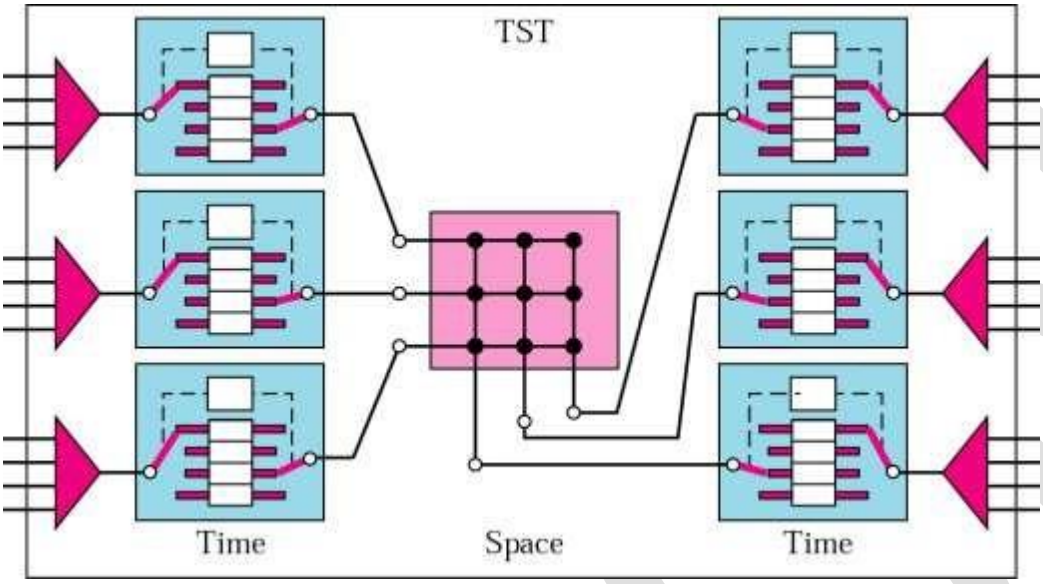


ComparisonofSDMandTDM

- SDM
  - Advantage:
    - Instantaneous.
  - Disadvantage:
    - Number ofcrosspointsrequired.
- TDM
  - Advantage:
    - Nocross points.
  - Disadvantage:
    - Processingdelay.

TSTswitch

- CombineSpacedivisionandtimedivisionswitching.
- Thisresultsinswitchesthatareoptimizedbothphysically(thenumberofcrosspoints)and temporally (the amount of delay).
- Varioustypesare:time-space-time(TST),time-space-space-time(TSST),space-time- time-space (STTS), etc.



TELEPHONENETWORK:

- Telephonenetworksusecircuitswitching.
- In1800s,Plainoldtelephonesystem (POTS)wasan analogsystemusinganalogsignals to transmit voice.
- In 1980s, POTS started carrying data along with voice and also has become digital instead of analog.
- MajorcomponentsofTelephonenetwork:Localloops,trunk,andswitchingoffice.
- Differentlevelsofswitchingoffices:Endoffices,tandemoffices,andregionaloffices.
- Local loop: Twisted pair cable that connects the subscriber telephone to the nearest end office or local central office. It has a bandwidth of 4000 Hz for voice. The first three digits of local telephone number define the office, and the next four digits define the local loop number.
- Trunks:Transmissionmediathathandlecommunicationbetweenoffices.Ithandleshundredsor thousandsofconnectionsthroughmultiplexing.Transmissionisusuallythroughopticalfibersor satellite links.
- Switching office: To avoid having a permanent physical link between any two subscribers, switches are located here. Switch connects several local loops or trunks and allows different subscribers to connect.

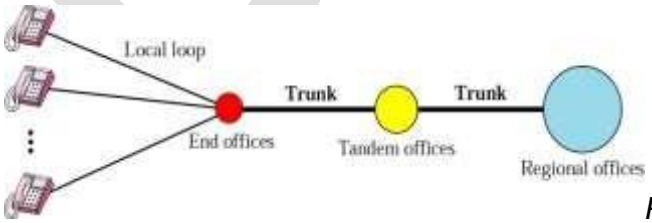


Fig:ATelephoneNetwork

- LATA(Localaccesstransportareas)
- Servicesoffered bythe commoncarriers (telephone companies) inside aLATAarecalled intra-LATAservices.Thecarrierthathandlestheseservicesiscalled alocalexchangecarrier(LEC).

- Intra-LATAservicesareprovided bylocalexchangecarriers.Since1996,therearetwotypesof LECs:incumbentlocalexchangecarriers(ILEC)andcompetitivelocalexchangecarriers(CLEC)
- ILEC would provide main services and owns the local loop. CLEC would provide other services suchasmobiletelephoneservice,tollcallsinsideaLATA,...
- Communicationinside aLATAis handledbyendswitches andtandem switches. Acallthat can be completedbyusing onlyend offices iscalledtoll-free. Acallthat hastogothroughatandem office (intra-LATA toll office) is charged.

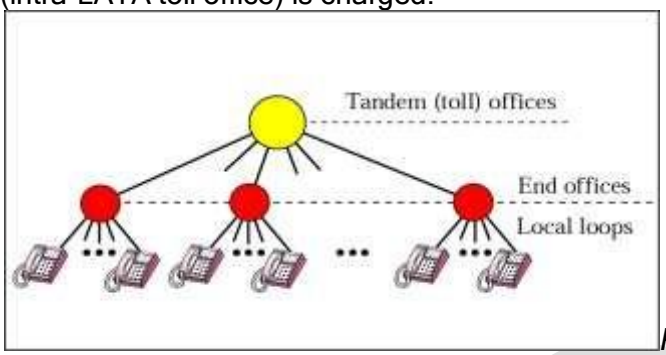


Fig. Switching offices in a LATA

- Interexchangecarriers(IXCs)orlong-distancecompanieshandleservicesbetweenLATAs.
- CarriersthatprovideinterLATAsincludeAT&t,MCI,WorldCom.
- AtelephonecallgoingthroughanIXCisnormallydigitized,withthecarriersusingseveraltypes of networks to provide service.
- Intra-LATA services can be provided by several LECs (one ILEC and possibly more than oneCLEC).
- PointofPresence(POP)isaswitchingoffice.
- EachIXCthatwantstoprovideinter-LATAservicesinaLATAmusthavea POPinthat LATA.

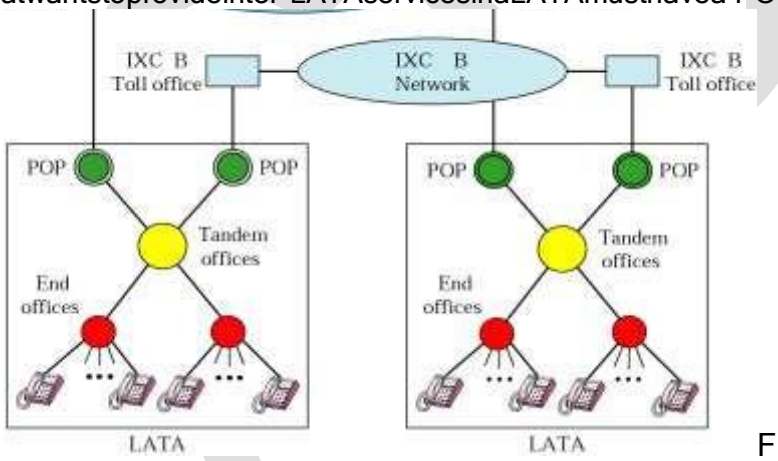


Fig: POPs

MakingaConnection:

- Accessingtheswitchingstationattheendofficesisaccomplishedthroughdialing.
- In thepast, telephonesfeaturedrotaryor pulse dialing, in which a digital signal was sent tothe end office for each number dialed. This type of dialing was prone to errors due to the inconsistency of humans during the dialing process.
- Today, dialing is accomplished through the touch-tone technique. In this method, instead of sendingadigitalsignal,theusersendstwosmallburstsofanalogsignals,calleddualtone.The frequency of the signals sent depends on the row and column of the pressed pad.
- Pressing number 8 will generate two bursts of analog signals with frequencies 852 and 1336 Hz to the end office.

AnalogServices[AnalogSwitchesService]

- Localloopisanalog;bandwidthisusuallybetween0and4000Hz.
- With switched lines, when the caller dials a number, the call is conveyed to a switch, or series ofswitches,attheexchange.Theappropriateswitchesarethenactivatedtolinkthecaller'sline tothat ofthepersonbeingcalled.Theswitchconnectsthetwolinesforthedurationofthecall.
- LocalCallservices: FlatmonthlyrateORrateforeachcallorasetof calls.
- TollCallservices:
  - Tollcallcanbeintra-LATAorinter-LATA.
  - Inter-LATA calls are long distance calls [that pass via a tandem office (toll office)] and are charged for.
- 800Services:
  - If a subscriber (normally an organization) needs to provide free connections for other subscribers(normallycustomers),itcanrequestan800service[also888,877,866].Call is free for caller but it is paid by the callee. Rate is less expensive than a normal long distance call.
- WATS:Wide-AreaTelephoneService
  - Itistheoppositeof800/888service.Chargedforoutboundcalls.
  - Serviceisalessexpensivealternativetoregulartollcalls;chargesarebasedonnumber of calls.
  - Service can bespecifiedas outboundcalls tothesamestate,toseveral states, or tothe whole country, with rates charged accordingly.
- 900Services:
  - Call is paid by the caller and is normally much more expensive than a normal long-distancecall.Thereasonisthatthecarrierchargestwofees;thefirstisthelong-distance toll, and the second is the fee paid to the callee for each call.
  - Thisserviceisusedbyorganizationthatneedstochargecustomersforitsservices.
- AnalogLeasedServices
  - Offers customers theopportunityto lease aline, sometimescalled a dedicated line, that is permanently connected to another customer.
  - Although the connection still passes through the switches in the telephone network, subscribersexperienceitasasinglelinebecausetheswitchisalwaysclosed,nodialing is needed.
- DigitalServices
  - Digital Services are less sensitive than analog services to noise and other forms of interference.
  - Commondigitalservicesareswitched/56anddigitaldataservice(DDS).
- Switched/56Service
    - Digital version of an analog switched line. It is a switched digital service that allows data rates of up to 56 Kbps.To communicate through this service, both parties must subscribe. A caller with normal telephone service cannot connect to a telephone or computer with switched/56 even if using a modem.
    - Onthewhole, digitalandanalog servicesrepresenttwo completelydifferentdomains for the telephone companies.
    - Switched/56 service is digital and so subscribers do not need modems to transmit digital data. However, the do need another device called a digital service unit (DSU). This device provides 56 Kbps and encodes the digital data in the format used by service provider.
    - Supports bandwidth on demand, video conferencing, fast facsimile, multimedia, fast datatransfer,etc.Alsoallowssubscriberstoobtainhigherspeedsbyusingmorethan one line (inverse multiplexing).

- DigitalDataService

- Digital version of an analog leased line; it is a digital leased line with a maximum data rate of 64 Kbps.

- Telephonehistory
  - Before 1984
    - Localandlong-distanceserviceswereprovidedbyAT&TBellSystem.
    - By law, this monopoly companywas brokeninto AT&T Long lines, 23 Bell Operating Companies (BOCs) and others.
    - Telephoneratesbecameloweraftherthislaw.
  - Between1984and1996
    - LATAs andIXCswereformed.
    - NoLECprovidelong-distanceservicesandnoIXCprovidelocalservices.
  - After 1996
    - A common carrier company provides both inside the LATA and between LATA services.
    - To avoid recabling of residents, the carrier that was given intra-LATA services (ILEC) continues to provide the main services; the new competitors (CLEC) provide other services.

ERRORDETECTIONANDCORRECTION

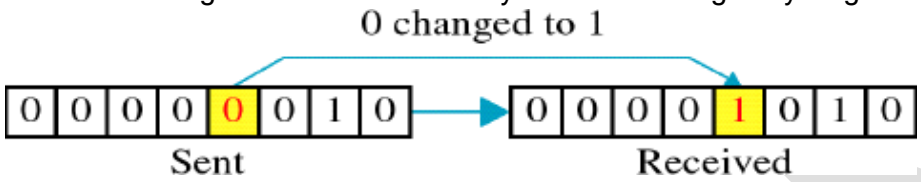
ERROR:

Datacanbecorruptedduringtransmission.Forreliablecommunication,errorsmustbedetected and corrected.

TYPESOF ERRORS:

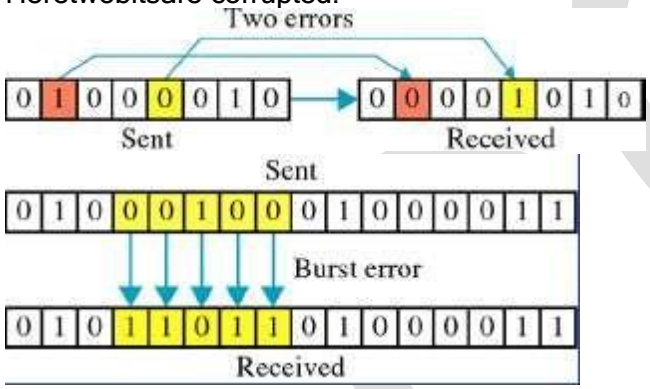
- **SinglebitError:**

The term single bit error means that only one bit of a given data unit is changed from 1 to 0 or 0 to 1. 010101 is changed to 110101 here only one bit is changed by single bit error.



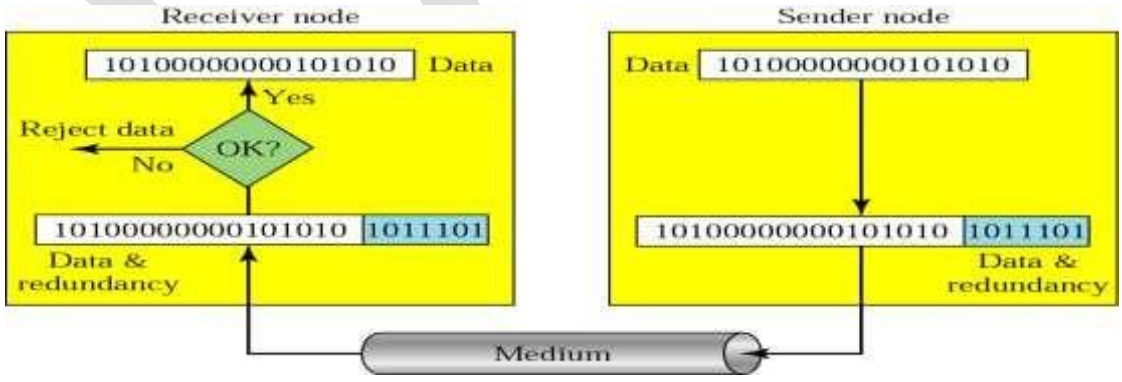
- **BurstError:**

Aburst errormeansthat2ormorebitsin thedataunit havechanged. Example:
Heretwobitsare corrupted.



Redundancy

Error detection use the concept of redundancy, which means adding extra bits for detecting errors at the destination .i.e., instead of repeating the entire data stream, a shorter group of bits may be appended to the end of each unit.



Detectionmethods

- **Paritycheck**
- **Cyclicredundancycheck**
- **checksum**

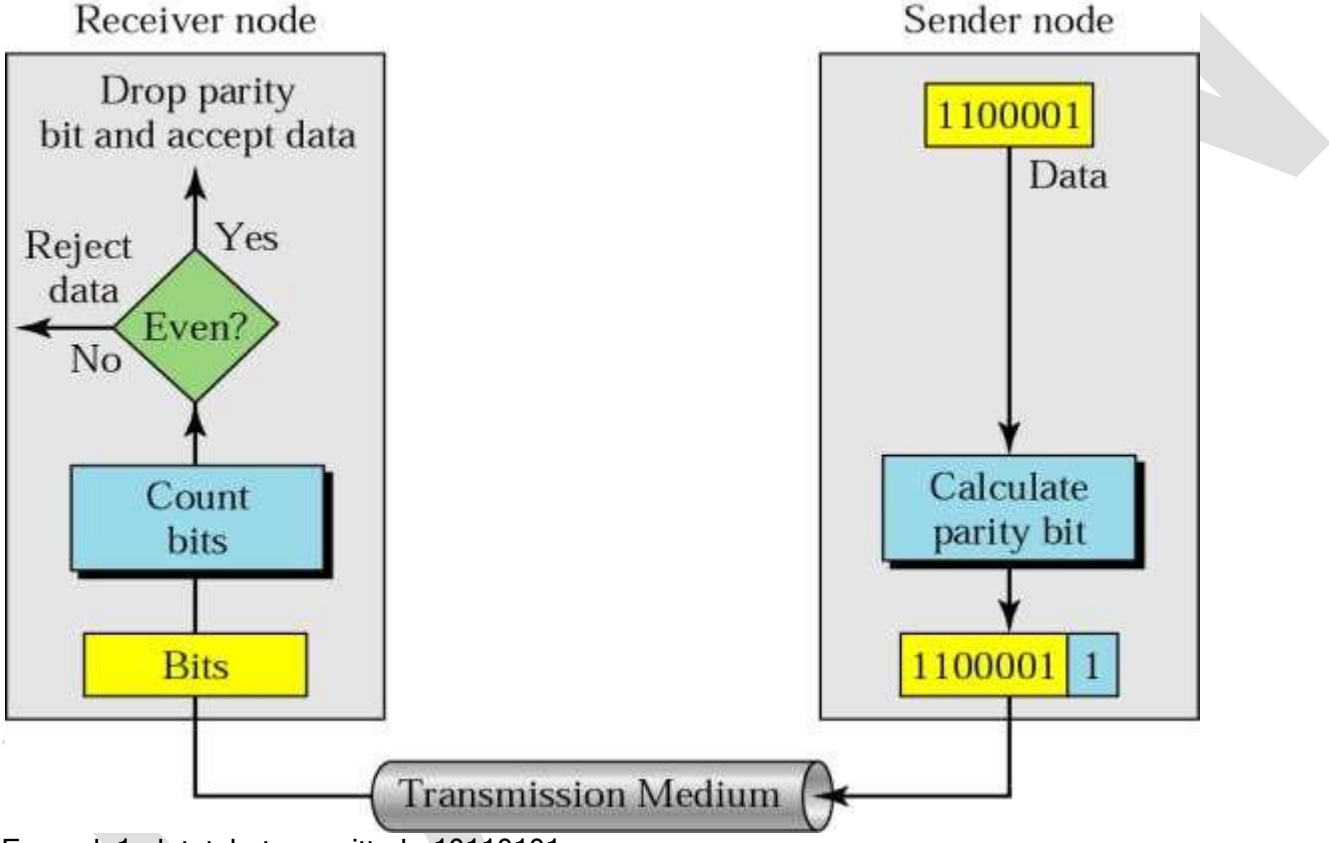
Paritycheck

A redundant bit called parity bit is added to every data unit so that the total number of 1's in the unit becomes even (or odd).

SIMPLEPARITYCHECK

In a simple parity check a redundant bit is added to a string of data so that total number of 1's in the data become even or odd.

Thetotaldatabitisthenpassedthroughparitycheckingfunction.Forevenparity,itchecks for even number of 1's and for odd parity it checks even number of 1's. If an error is detected the data is rejected.



Example1: datatobetransmitted= 10110101

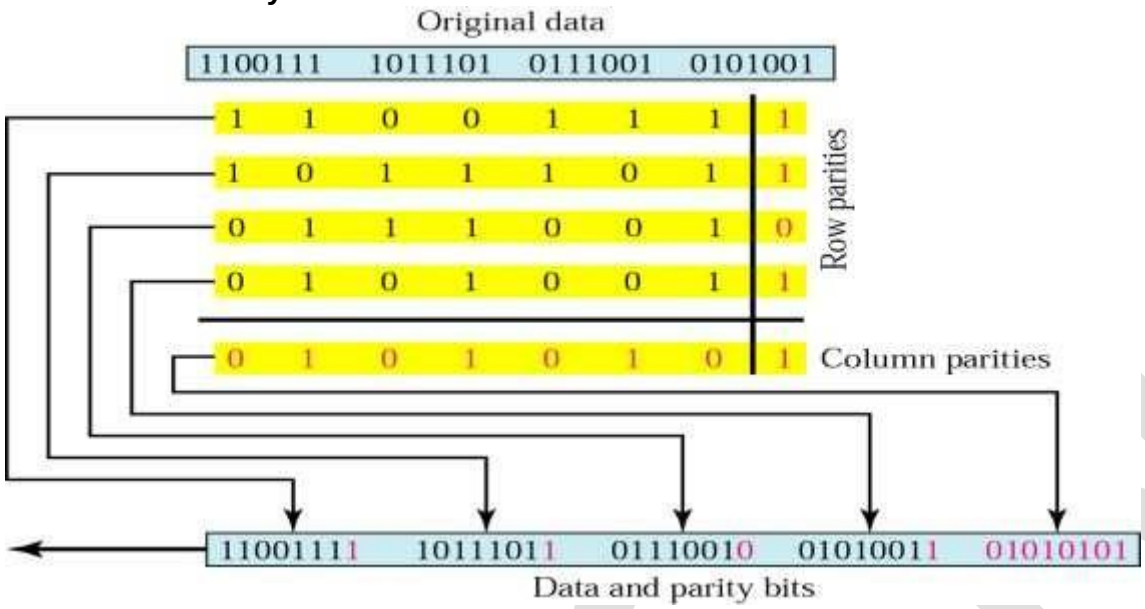
- 5 1'sin thedata
- Paritybitis1 tomake even
- Transmittedcodeword=101101011
- Ifreceivergets101101011,paritycheckok ---accept(OK)
- Ifreceivergets101100011,paritycheckfails---reject(OK),askforframetobere-transmitted
- Ifreceivergets101110011,paritycheckok ---accept(NOTOK: evennumberoferrorsundetected)
- Ifreceivergets001100011,paritycheckok---accept(NOTOK:evennumberoferrorsundetected)

Example2: datatobetransmitted= 10110001

- 4 1'sin thedata
- paritybitis0

- Transmittedcodeword=101100010

2-DimensionalParityCheck:



Formdataintoa2-dimensionalarray;addsingleparitycheckbitstoeachrowandeachcolumn; transmit row-by-row

Example:data=111000110001110011001

- Form3×7arrayandaddrowand columnparitybits:

Data bits

1110001 0

1000111 0 row

0011001 1paritybits

0101111 1

Columnparity bits

- transmitted:11100010100011100011001101011111
- Receiverknowstoformreceivedbitstringinto4×8array,thencheckthe rowandcolumnparitybits…
- Can **detect** any odd number of bit errors in a row or column, and can detect an even number of bit errors if they're in a single row (using the column parity checks) or in a single column (using the row parity checks); and can **correct** any single bit error

•Example(cont.):supposebitinposition(1,3)isreceivedinerror(inotherwords,1biterror)

1100 0010 row1paritycheckfails

1000111***0*** row2paritycheck ok

0011001***1*** row3parity check ok

0 101 11 11 row4paritycheckok

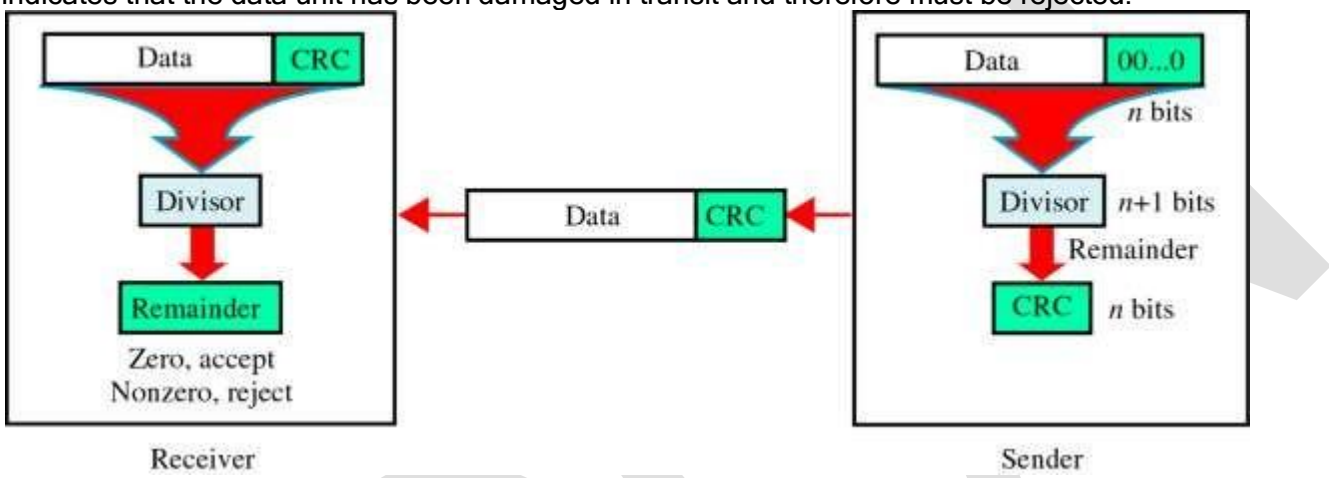
column1paritycheckfails
column 2 parity check ok
column3paritycheckfails
column 4 parity check ok
column 5 parity check ok
column 6 parity check ok
column 7 parity check ok

column8paritycheckok

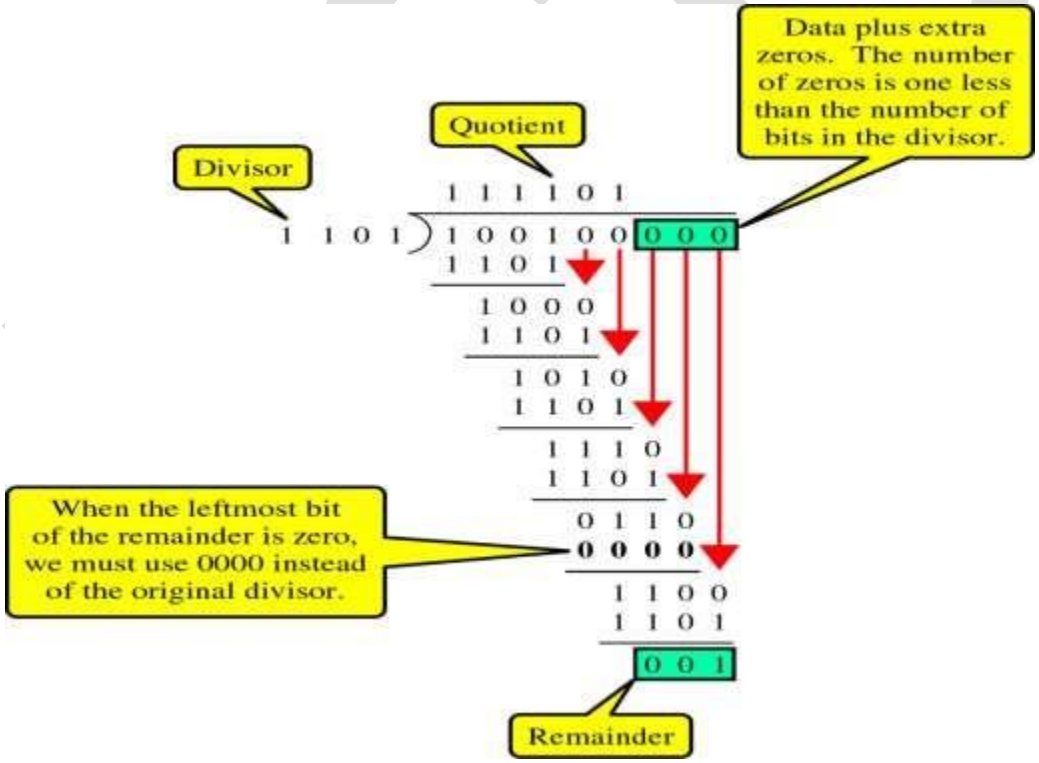
Thereforethereceiver can detectthatbiterrorsOccurred, but itcannot Correctthem(here,if theBit errors were in positions (1,3) and (2,1) instead, the receiver parity checks would be the same)

CYCLICREDUNDANCYCHECK

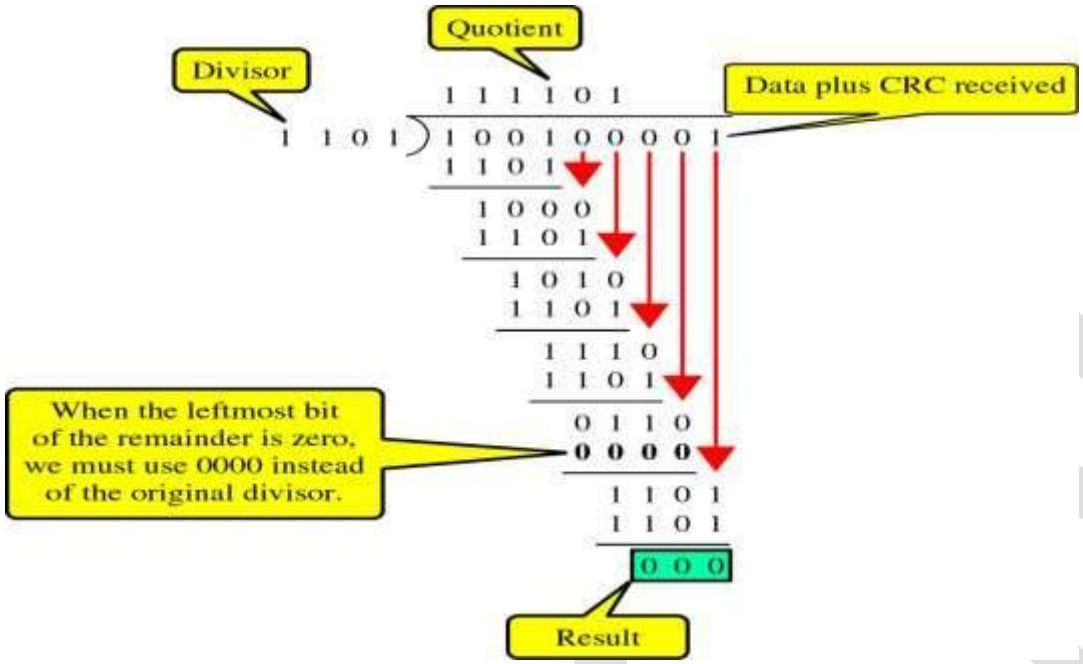
CRC is based on binary division. In CRC, instead of adding bits to achieve the desired parity, a sequenceof redundant bits, called theCRC ortheCRC remainder, is appended totheendof thedata unitsothattheresultingdataunitbecomesexactlydivisiblebyasecond,predeterminedbinarynumber. Atitsdestination,theincomingdataunitisassumedtobeintactandisthereforeaccepted.Aremainder indicates that the data unit has been damaged in transit and therefore must be rejected.



CRCGENERATOR:

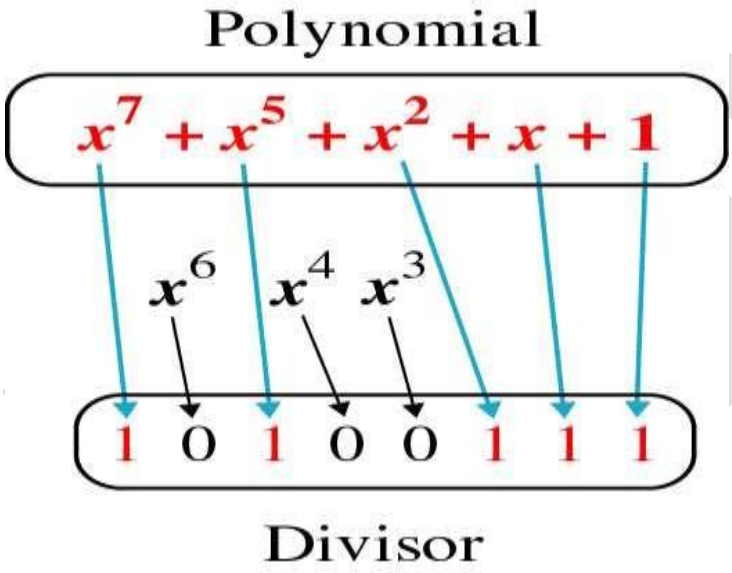


CRCCHECKER:



POLYNOMIALS

The divisor in the CRC most often represented not as a string of 1s and 0s, but as an algebraicpolynomial. The polynomial format is useful to solve the concept mathematically.



Standard Polynomials:

CRC-12

$x^{12}+x^{11}+x^3+x+1$

CRC-16

$x^{16}+x^{15}+x^2+1$

CRC-ITU-T

$x^{16}+x^{12}+x^5+1$

CRC-32

$x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^7+x^5+x^4+x^2+x+1$

Checksum:

~ usedbythehigherlayer protocols
~ isbasedontheconceptof redundancy(VRC,LRC, CRC….)

❑ Tocreatethechecksumthesender doesthefollowing:

❖ TheunitisdividedintoKsections, eachof n bits.
❖ Section1and2areaddedtogetherusing one'scomplement.
❖ Section3 isaddedtotheresultof thepreviousstep.
❖ Section4 isaddedtotheresultof thepreviousstep.
❖ Theprocessrepeatsuntilsectionkisaddedtotheresultofthepreviousstep.
❖ Thefinalresult iscomplementedtomakethechecksum.

AtSender:

Originaldata:1010100100111001
10101001
00111001

11100010 Sum
00011101 Checksum
10101001001110010001110 1

AtReceiver:

Receiveddata:10101001001110010001110 1
10101001
00111001
00011101

11111111 ←Sum
00000000 ←Complement

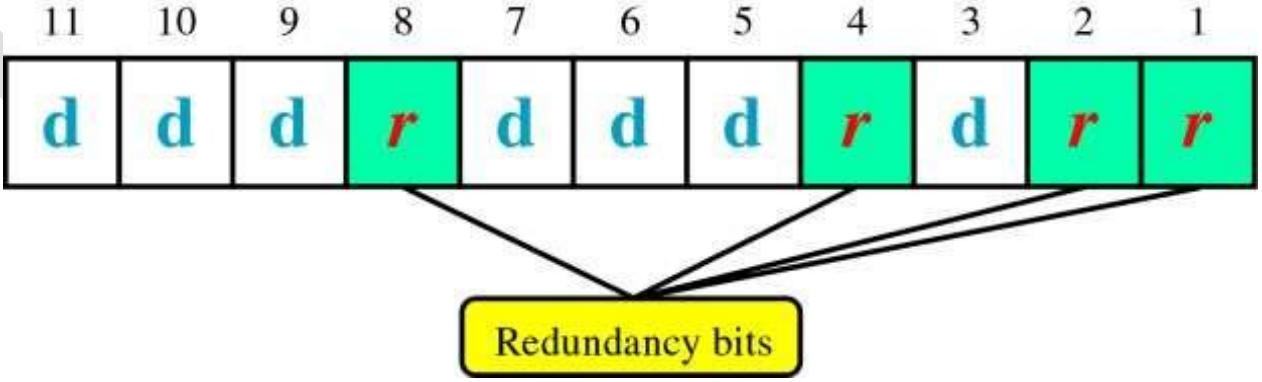
ErrorCorrection (HammingEncodingAlgorithm):

❑ RedundancyBits
Tocalculatethenumberof redundancybits(R)requiredtocorrect agivennumberofdatabit(M)

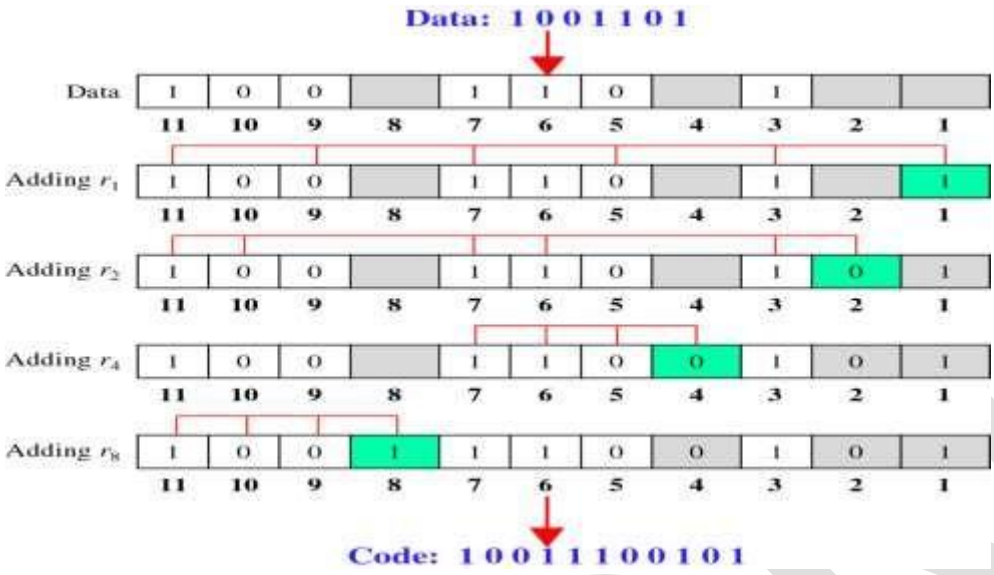
❑ If thetotal number of bitsin atransmittable unit ism+r, thenr must be ableto indicate at least m+r+1 different states
$2^r \geq m+r+1$

ex) For value ofm is7(ASCII),the smallestrvaluethat cansatisfythisequation is 4 $2^4 \geq 7$ + 4 + 1

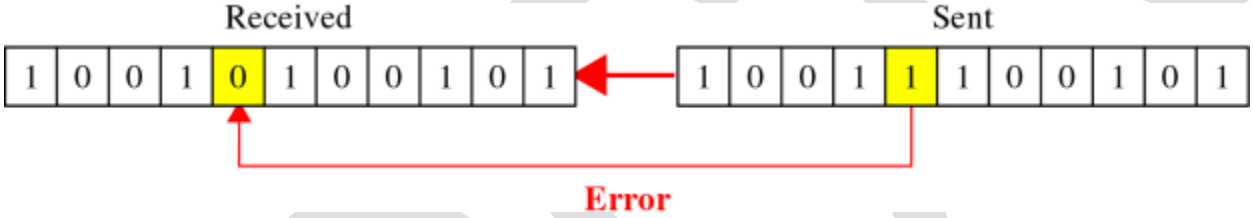
❑ **positions ofredundancybits in Hamming code:**



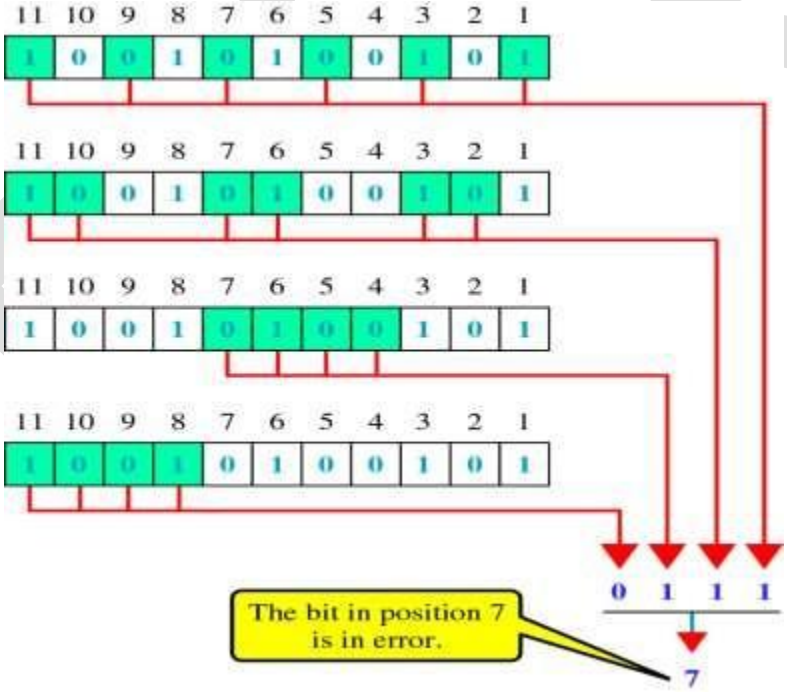
❑ eachrbit istheVRCbitfor onecombination of databits
r_1=bits 1, 3, 5, 7, 9, 11
r_2=bits2,3,6,7,10,11
r_4=bits4,5, 6,7
r_8=bits8,9,10, 11



- **ErrorDetectionandCorrection:**



- **ErrordetectionusingHamming Code**



FLOW CONTROLANDERRORCONTROL

Thetwomain featuresofdatakink layer are **flow**control anderror control.

.**FLOWCONTROL**

Flowcontrolcoordinatesthatamountofdatathatcanbesentbeforereceiving ACKItisoneofthe most important duties of the data link layer.

ERRORCONTROL

- ErrorcontrolinthedatalinklayerisbasedonARQ(automaticrepeatrequest),whichisthe retransmission of data.
- Thetermerrorcontrol referstomethodsof errordetectionand retransmission.
- Anytimeanerrorisdetectedinanexchange,specifiedframesareretransmitted.Thisprocessiscalled ARQ.

FLOWANDERRORCONTROLMECHANISMS

1. STOP-ANDWAITARQ.
2. GO-BACK-NARQ.
3. SELECTIVE-REPEATARQ.

STOP-AND-WAITARQ

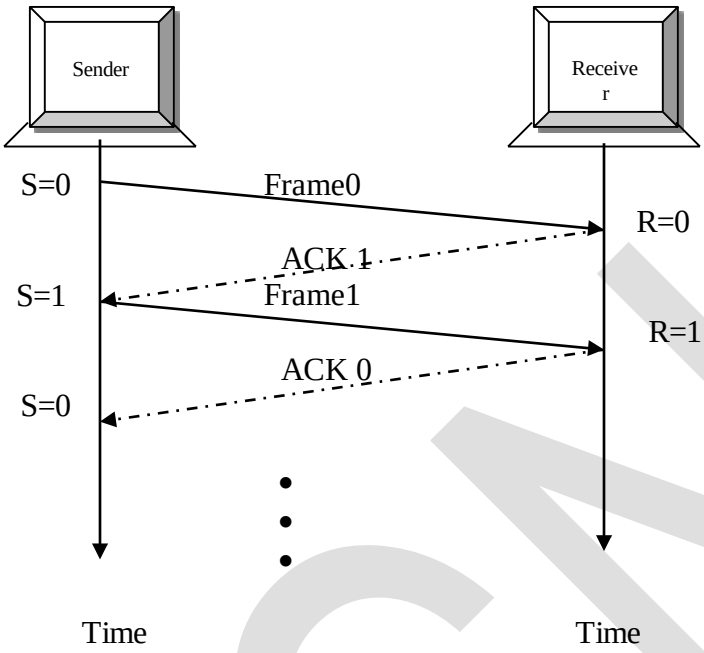
Thisisthesimplestflowanderrorcontrolmechanism.Ithasthefollowing features.

- The sending devise keeps the copy of the last frame transmitted until it receives an acknowledgement for that frame. Keeping a copy allows the sender to re- transmit lost or damaged frames until they are received correctly.
- Bothdataandacknowledgementframesarenumberedalternately0and1.Adata frame0is acknowledged by an ACK 1.
- Adamagedorlostframeistreatedinthesamemannerbythereceiver.Ifthereceiverdetectsanerrorin the received frame, it simply discards the frame and sends no acknowledgement.
- The sender has a control variable, which we call S, that holds the number of recently sent frame. Thereceiver has a control variable, which we call R that holds the number of the next frame expected.
- Thesenderstartsatimerwhenitsendsaframe.IfanACKisnotreceivedwithinanallottedtimeperiod the sender assumes that the frame was lost or damaged and resends it.
- The receivers send only positive ACK for frames received safe and sound; it is silent about the frames damaged or lost.

OPERATION:

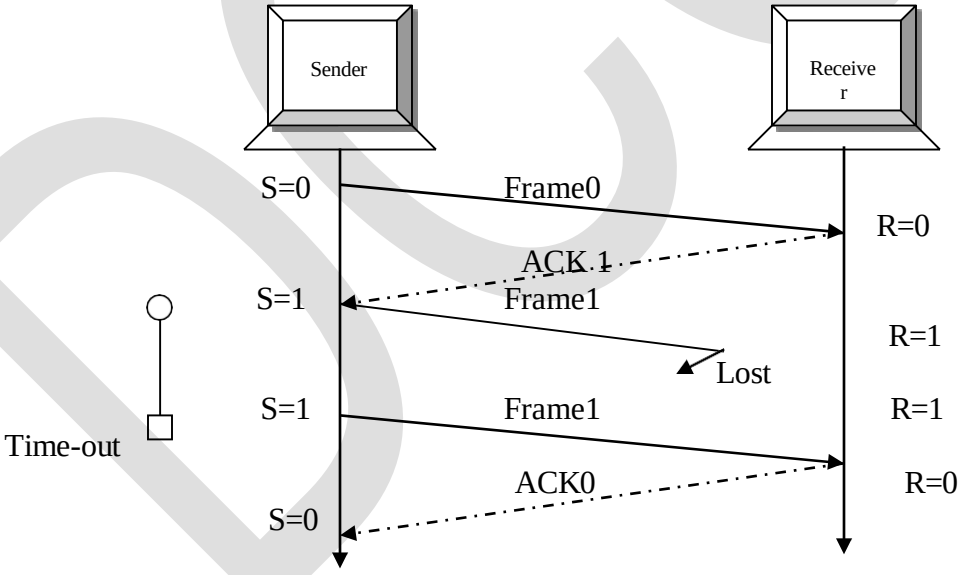
Thepossibleoperationsare
Normal operation
lost frame
ACK lost
delayedACK.
Thesendersendsframe0andwaittoreceiveACK1.whenACK1isreceiveditsendsframe1and then waits to receive ACK 0, and so on.

TheACKmustbereceivedbeforethetimeoutthatissetexpires.Thefollowingfigureshows successful frame transmission.



Lostordamagedacknowledgement

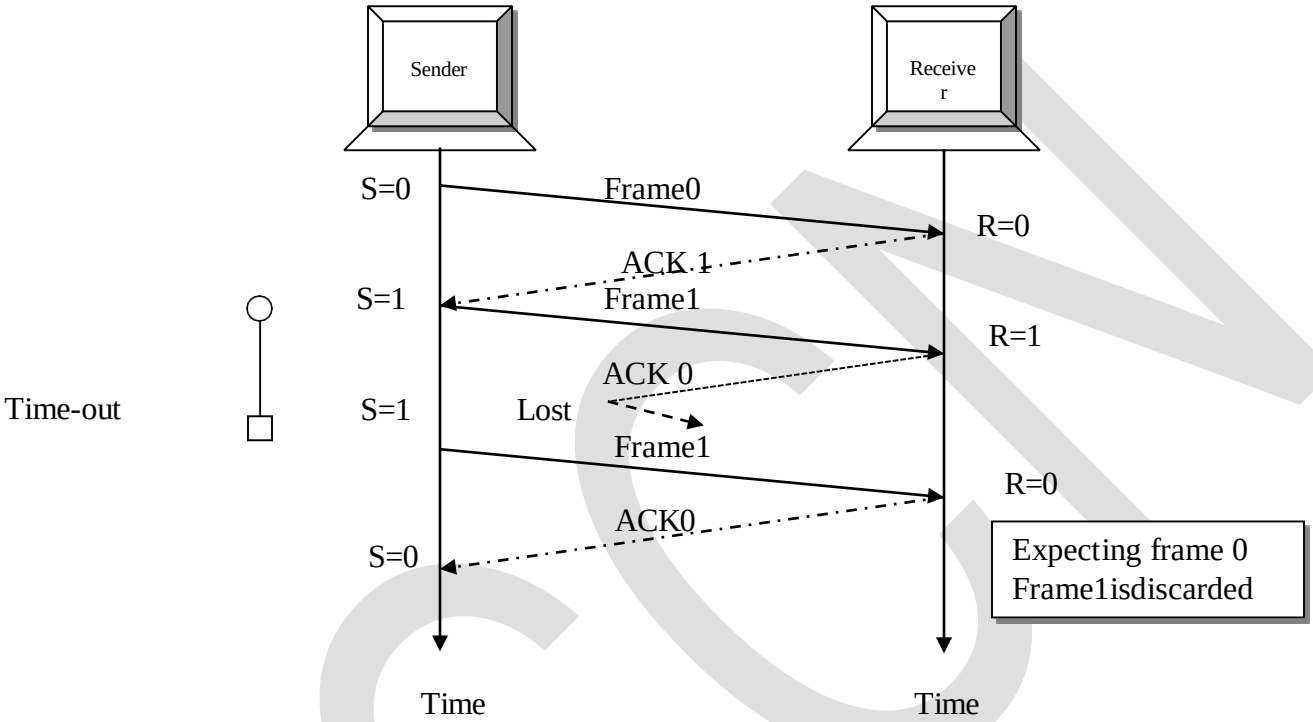
- When the receiver receives the damaged frame it discards it, which essentiallymeans the frame is lost. The receiver remains silent about a lost frame and keeps its value of R.
- Forexampleinthefollowingfigurethesendertransmitsframe1,butitislost.Thereceiverdoesnothing, retaining the value of R (1). After the timer at the sender site expires, another copy of frame 1 is sent.



Lost acknowledgement

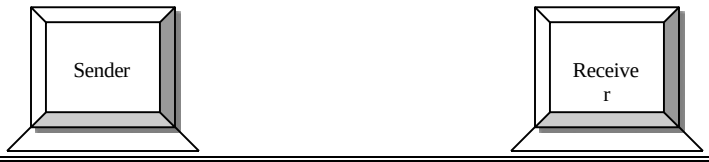
- AlostordamagedACKishandledinthesamebythesender;ifthesenderreceivesadamagedACK,it discards it.
- ThefollowingfigureshowsalostACK0.thewaitingsenderdoesnotknowifframe1hasbeenreceived. When the timer for frame 1 expires the sender retransmits frame 1.

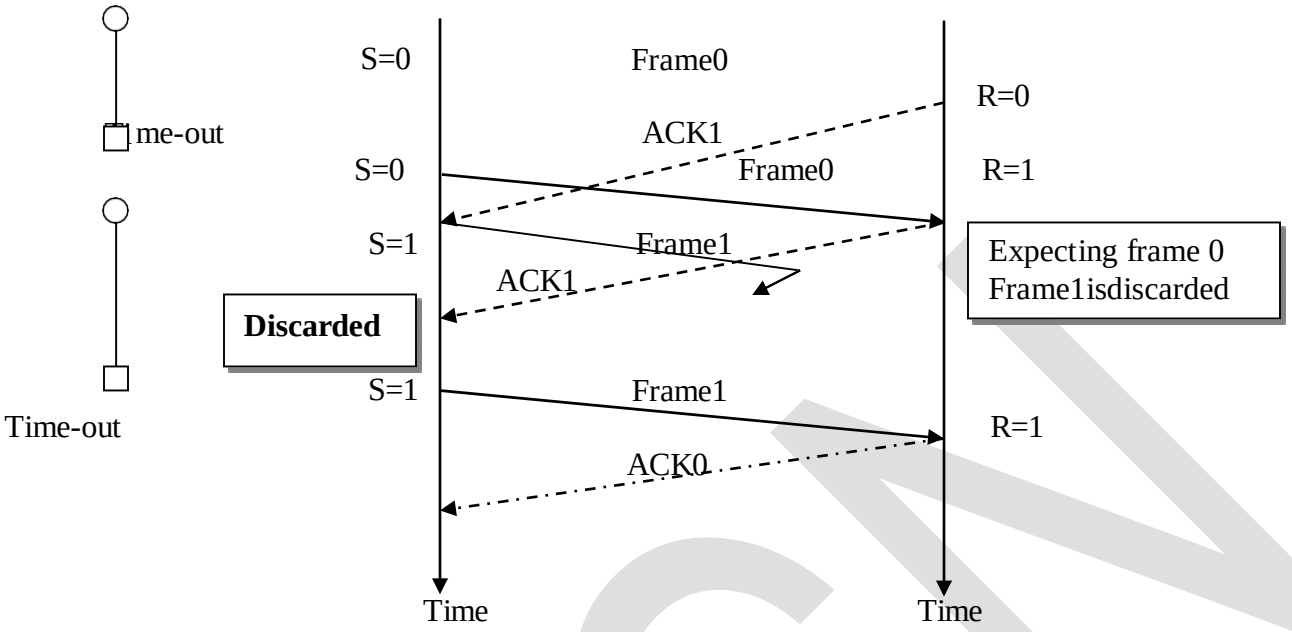
- Note that the receiver has already received frame 1 and is expecting to receive frame 0. Therefore, its silently discards the second copy of frame 1.
- ThefollowingfigureshowsalostACK0.thewaitingsenderdoesnotknowifframe1hasbeenreceived. When the timer for frame 1 expires the sender retransmits frame 1.
- Note that the receiver has already received frame 1 and is expecting to receive frame 0. Therefore, its silently discards the second copy of frame 1.



- **Delayed acknowledgement**

- An ACK can be delayed at the receiver or by some problem with the link. The following figure shows the delay of ACK 1; it ids received after the timer for frame 0 as already expired.
- Thesenderhasalreadyretransmittedacopyofframe0.Thereceiverexpectsframe1soitssimply discards the duplicate frame 0.
- ThesenderhasnowreceivedtwoACK's,onethatwasdelayedandonethatwassentaftertheduplicate frame 0 arrived. The second ACK 1 is discarded.



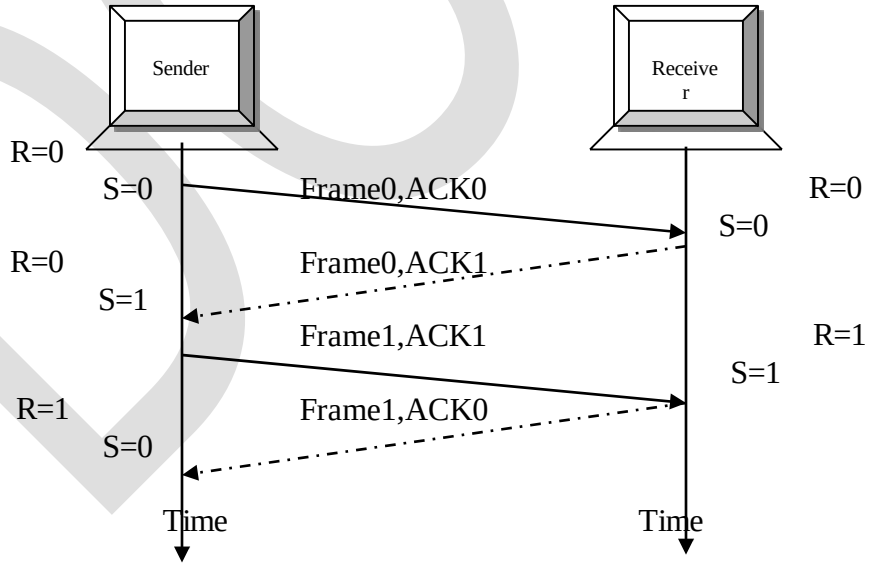


BIDIRECTIONALTRANSMISSION

Thestop–and–waitmechanismisunidirectional.Wecanhavebi-directionaltransmissionifthe twopartieshavetwoseparatechannelsforfullduplexcommunicationorsharethesamechannelforoff duplex transmission. In this case, each party needs both S and R variables to track frames sent and expected.

PIGGYBACKING

It's a method to combine a data frame with an ACK. In following figure both the sender and the receiver have data to send. Instead of sending separate data and ACK frames. It can save bandwidth because the overhead from a data frame and an ACK frame can be combined into just one frame.



GO-BACK-NARQ

- As in Stop-and-wait protocol senders has to wait for every ACK then next frame is transmitted. But in GO-BACK-N ARQ number of frames can be transmitted without waiting for ACK. A copy of each transmitted frame is maintained until the respective ACK is received.

FeaturesofGO-BACK-NARQ

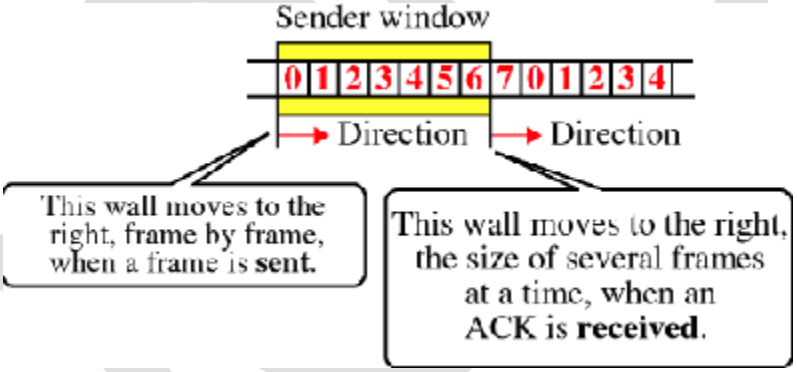
1. **sequencenumbers.**

Sequencenumbersoftransmittedframesaremaintainedintheheaderofframe.Ifkisthenumberof bits for sequence number, then the numbering can range from 0 to 2k-1. Example: if k=3 means sequence numbers are 0 to 7.

2. <u>senderslidingwindow:</u>

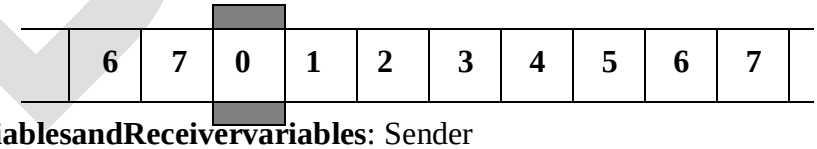
- Window is a set of frames in a buffer waiting for ACK. This window keeps on sliding in forward direction, the window size is fixed. As the ACK is received, the respective frame goes out of window and new frame to sent come into window. Figure illustrates the sliding window.
- IfSender receives.ACK 4,thenit***knowsFrames upto*** andincludingFrame3were***correctlyreceived***

Windowsize=7



3. <u>Receiversliding window:</u>

In thereceiversidesizeofthewindowis always one. Thereceiveris expectingto arriveframein specifies sequence. Any other frame is received which is out of order is discarded. The receiver slides over after receiving the expected frame. The following figure shows the receiver side-sliding window.



4. <u>Control variables:</u>

SendervariablesandReceivervariables: Sender deals with three different variables

S->sequencenumberof recentlysentframe

S_F->sequencenumberoffirstframeinthewindow. S_L->sequencenumberoflast frame in thewindow.

Thereceiverdealswith onlyonevariable

R->sequencenumberof frame expected.

5. Timers

Thesenderhasatimerforeach transmittedframe.Thereceiversdon'thave anytimer.

6. Acknowledgement:

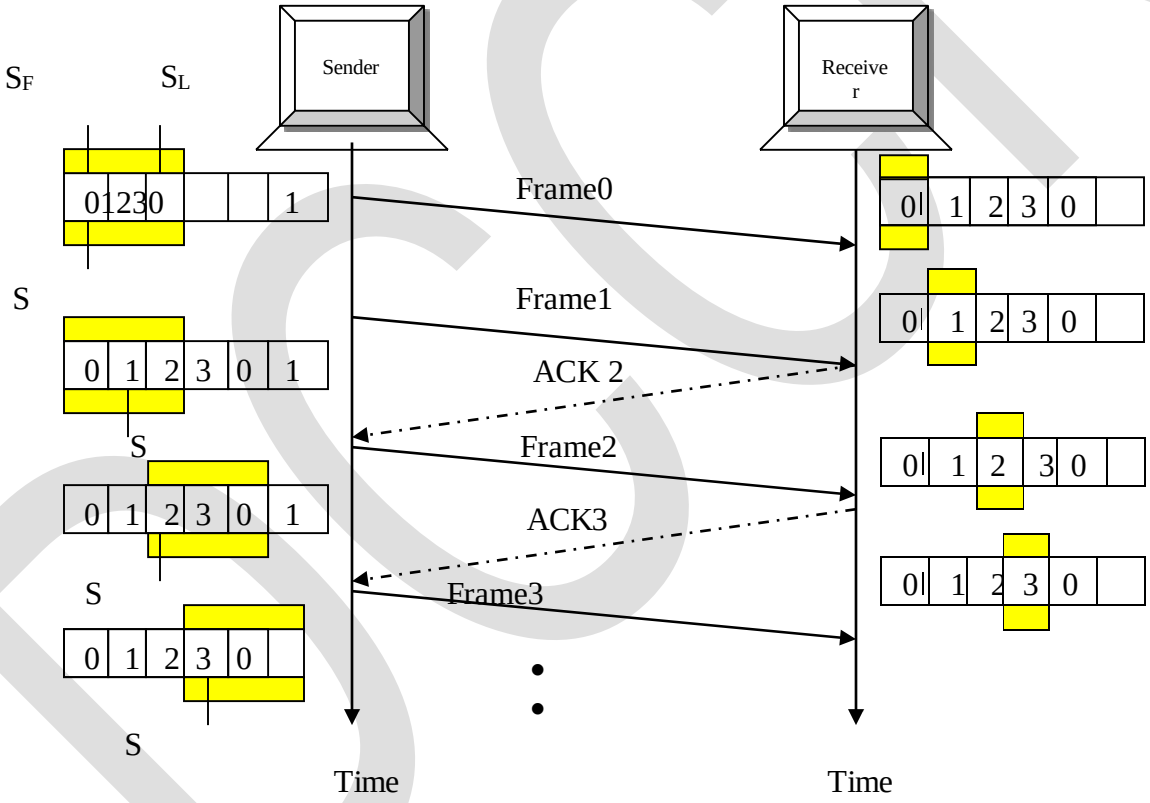
The receiver responds for frame arriving safely by positive ACK. For damaged or lost frames receiverdoesn'treply,thesenderhastoretransmititwhentimerofthatframeelapsed.Thereceivermay ACK once for several frames.

7. resendingframes:

Ifthetimerforanyframeexpires,thesenderhastoresendthatframeandthesubsequentframe also, hence the protocol is called GO-BACK-N ARQ.

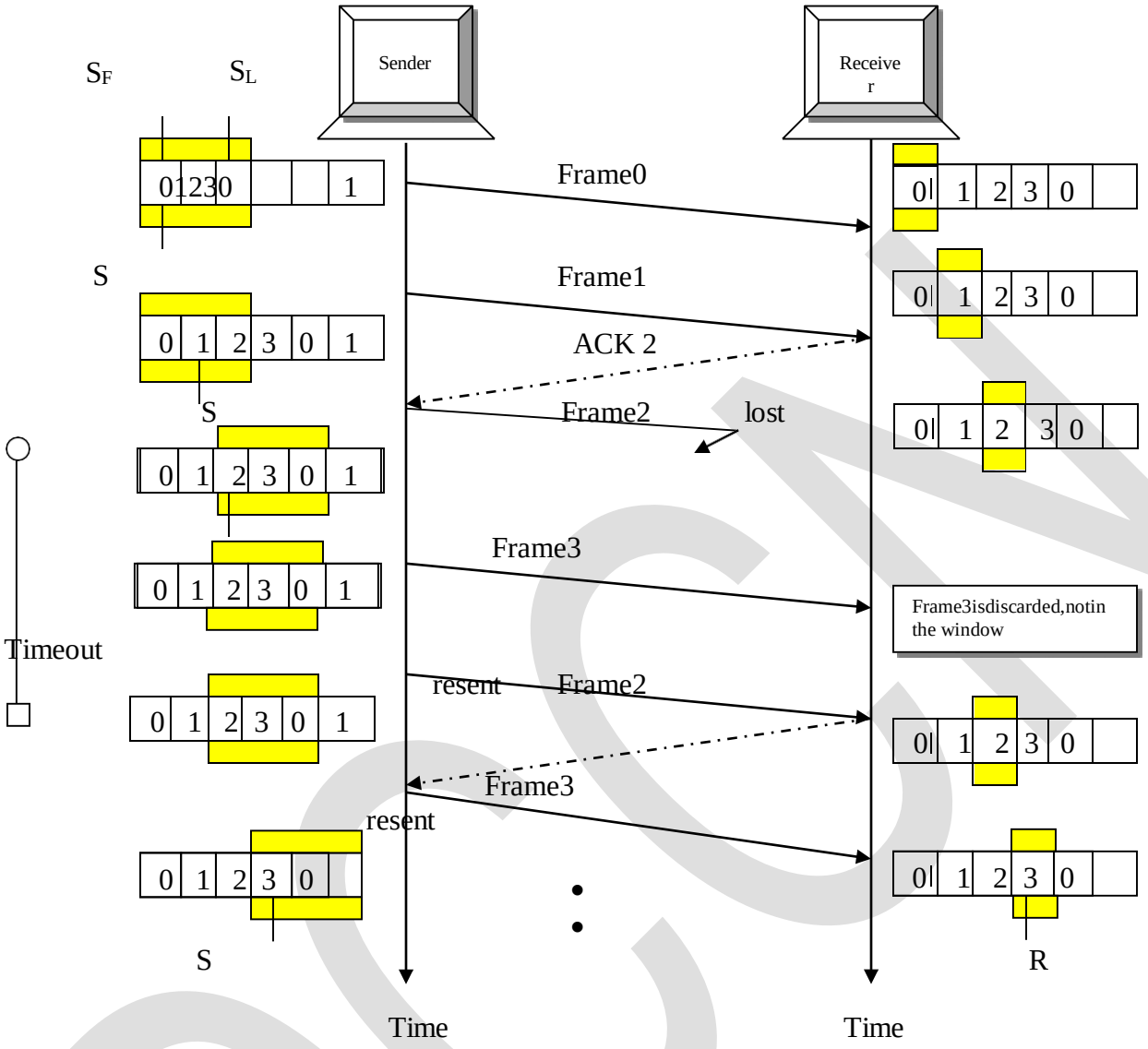
Operation

Normaloperation: Followingdiagramshowsthismechanism.Thesenderkeepstrackofthe outstanding frames and updates the variables and windows as acknowledgements arrive.



Damagedorlostframe:

Figureshowsthatframe2islost.Notethatwhenthereceiverreceivesframe3,itisdiscardedbecause the receiver is expecting frame 2, not frame3. after the timer for frame 2 expires at the sender site, the sender sends frame 2 and 3.



Damagedorlostacknowledgement:

If an ACK is lost, we can have two situations. If the next ACK arrives before the expiration of timer,thereisnoneedforretransmissionofframesbecauseACKarecumulativeinthisprotocol..ifthe nextACKarrivesafterthetimeout,theframeandalltheframesafterthatareresent.Thereceivernever resends an ACK.

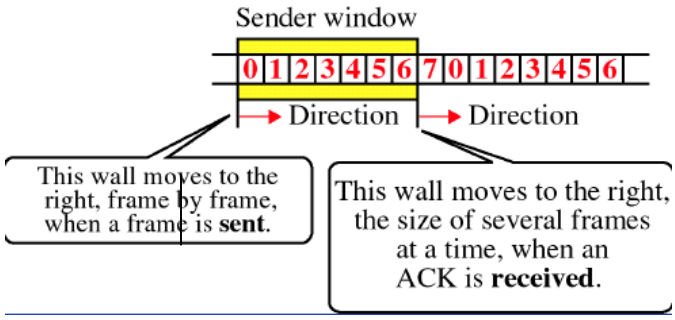
Fordiagramsreferyourclassworknotes.

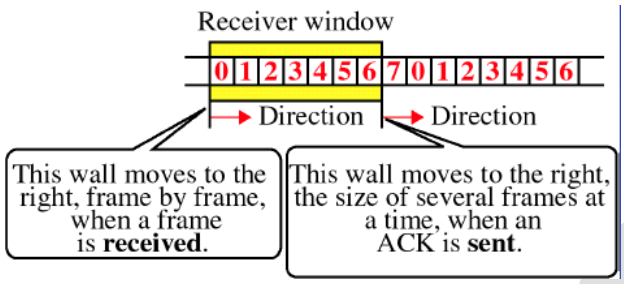
Delayed Acknowledgement:

AdelayedACK alsotriggers theresendingof frames.

SELECTIVEREPEATARQ:

- Theconfigurationanditscontrolvariablesforthis aresameasthoseselectiverepeat ARQ.
- Thesizeof thewindow shouldbe onehalf ofthevalue 2^m.
- The receiver window size must also be the size. In this the receiver is looking for a range of sequence numbers.
- Thereceiverhas controlvariables R_F and R_L to denote theboundaries of the window.

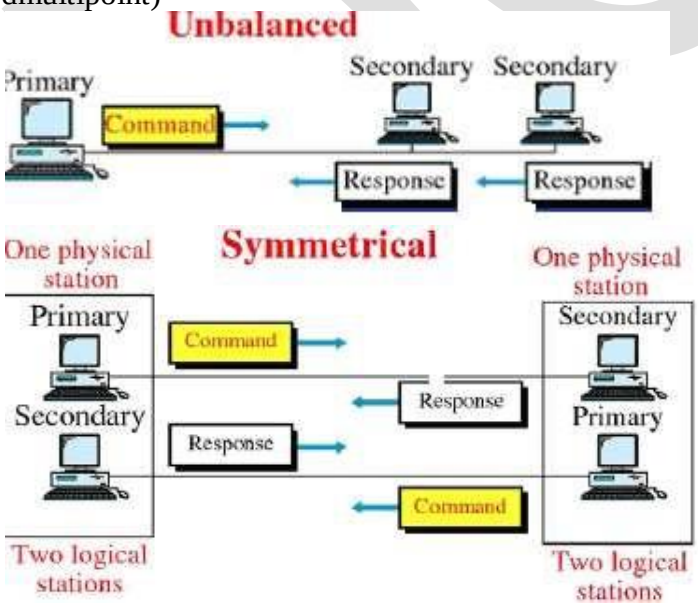


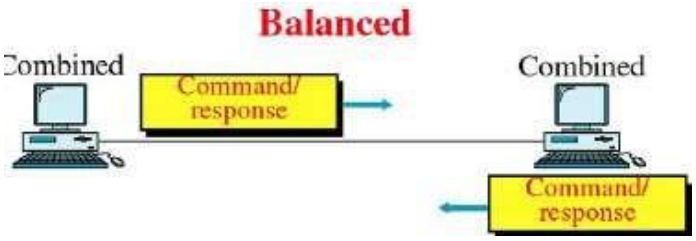


selectiverepeatalsodefinesanegativeACKNAKthatreportsthesequencenumberofadamagedframe before the timer expires.

High-levelDataLinkControl(HDLC)protocol

- HDLCstandardizedISO in1979 andacceptedbymost otherstandardsbodies(ITU-T,ANSI)
- 3typesofend-stations:
  - *Primary*–sends commands
  - *Secondary*–canonlyrespondsto Primary'scommands
  - *Combined*–canbothcommandand respond
- 3 types of configuration(Note:nobalance dmultipoint)





TRANSFERMODE

- NormalResponseMode(NRM)
  - unbalanced config,primaryinitiatestransfer
  - usedon multi-droplines, eghost+terminals
- AsynchronousBalancedMode(ABM)
  - balancedconfig,eitherstationinitiatestransmission,hasnopollingoverhead, widely used
- AsynchronousResponseMode (ARM)
  - unbalancedconfig,secondarymayinitiatetransmitwithoutpermissionfromprimary, rarely used

FRAMES:

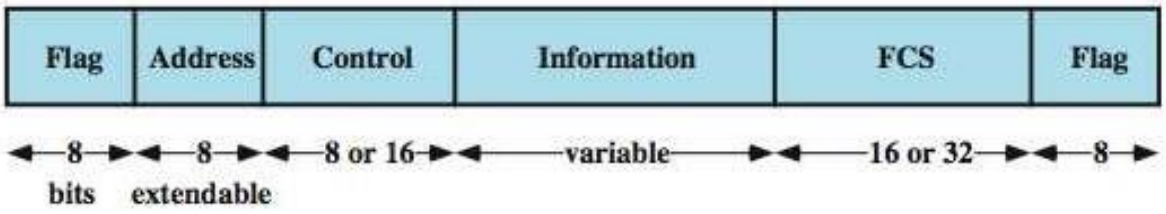
3typesofFramesare

I-Frame– transportsuserdataandcontrolinfo aboutuser data**.**

S-Frame– supervisoryFrame, onlyused for transportingcontrol information

U-Frame–unnumberedFrame,reservedforsystemmanagement(managingthelinkitself)

FRAMEFORMAT



(a) Frame format

Flag Fields:

- Delimitframeatboth ends
- 01111110
- Receiverhuntsforflagsequencetosynchronize
- Bitstuffingusedtoavoidconfusionwithdatacontaining 01111110
  - The transmitter inserts 0 bit after every sequence of five 1s with the exception of flag fields
  - Ifreceiverdetectsfive1sitchecksnextbit
    - If0, itisdeleted
    - If 1andseventhbitis0(i.e.,10),acceptasflag
    - Ifsixthandseventhbits1(i.e.,11),senderisindicatingabort

Original Pattern:

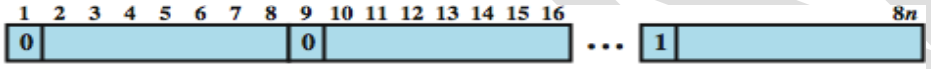
```
111111111111011111101111110
```

After bit-stuffing

```
111110111110110111110101111010
```

AddressField:

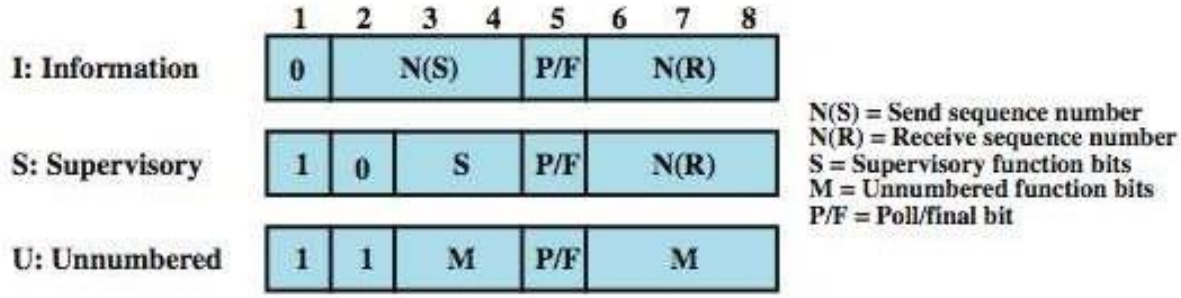
- identifiessecondarystationthatsentorwillreceiveframe
- usually8bitslong
- maybeextendedtomultiplesof7bits
  - LSBindicates if isthelast octet(1)or not(0)
- allonesaddress11111111is broadcast



- **(b) Extended Address Field**

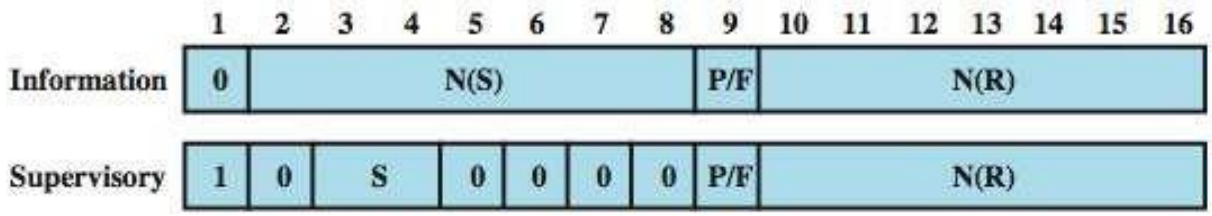
ControlField:

- differentfordifferentframetype
  - Information-datatransmittedtouser(nextlayerup)
    - Flowanderrorcontrolpiggybackedoninformationframes
  - Supervisory-ARQwhenpiggyback notused
  - Unnumbered-supplementarylinkcontrol
- first1-2bitsofcontrolfieldidentifyframetype



(c) 8-bit control field format

- useofPoll/Finalbitdependsoncontext
- incommandframeisPbit setto1tosolicit(poll)responsefrom peer
- inresponseframeisFbitsetto1toindicateresponsetosoliciting command
- seqnumberusually3bits
  - can extendto8bitsasshown below



(d) 16-bit control field format

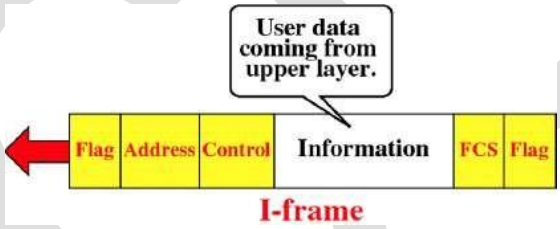
Information &FCS Fields:

- InformationField
  - ininformationandsomeunnumberedframes
  - mustcontainintegralnumberof octets
  - variablelength
- FrameCheckSequenceField (FCS)
  - usedforerrordetection
  - either 16bitCRCor32bitCRC

Poll/Final Bit

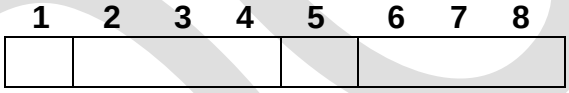
- Usedepends oncontext
- Commandframe
  - Pbit:usedforpollfrom primary
  - 1tosolicit(poll)responsefrom peer
- Responseframe
  - Fbit:usedforresponsefromsecondary
  - 1indicatesresponsetosoliciting command

I-Frames:



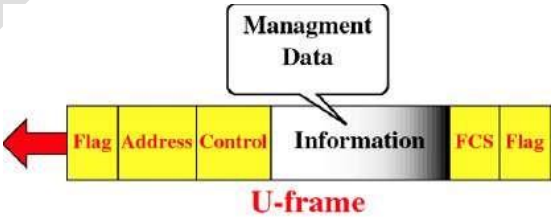
I-frame

- Containsthesequencenumberoftransmittedframesandapiggybacked ACK



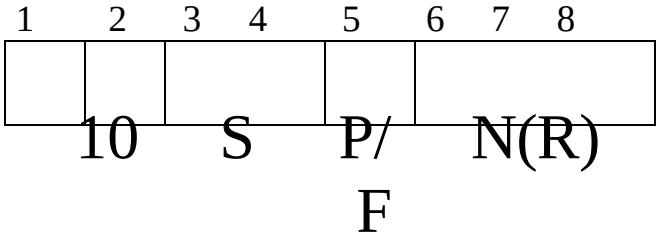
0 N(S) P/F N(R)

U-Frames:



U-frame

- Used forflowanderror control



P/F:

- RR---receiveready
- RNR---receivenot ready
- REJ---rejectonframeN(R)
- SREJ---selectiverejectonN(R)

S-Frames:

S-frame

- S-framesaresimilartounnumberedframes,themaindifferencebeingthattheydocarrysequence information.
- Somesupervisoryframesfunctionaspositiveandnegativeacknowledgements,theythereforeplay a very important role in error and flow control.
- Twobitsindicatetheframetype, sothattherearefour possibilities.
- ReceiverReady-RR(PositiveAcknowledgement)
- ReceiverNotReady-RNR
- Reject-REJ(NAKgo-back-N)
- SelectiveReject-SREJ(NAKselectiveretransmit)

HDLC Operation

- Initialization:S-framesspecifymodeandsequencenumbers,U-framesacknowledge
- DataTransfer:I-framesexchangeuserdata,S-framesacknowledgeandprovideflow/errorcontrol
- Disconnect:U-framesinitiateandacknowledge

Point-to–PointProtocol

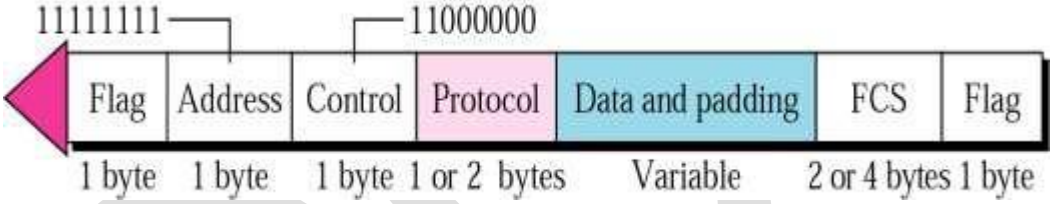
PPP

- In a network, two devices can be connected by a dedicated link or a shared link. In the first case, the link can be used by the two devices at any time. We refer to this type of access as point-to-pointaccess.Inthesecondcase,thelinkissharedbetweenpairsofdevicesthatneed to use the link.We refer to this type of access as multiple access.
- One of the most common protocols for point-to-point access is the Point-to-Point Protocol (PPP).

PPP services

- Itdefinestheformatof theframetobe exchangedbetweendevices.
- It defines how two devices can negotiate the establishment of the link and the exchanged of data.
- Itdefineshownetworklayerdataare encapsulatedinthedatalinkframe.
- Itdefineshowtwodevicescanauthenticateeachother.

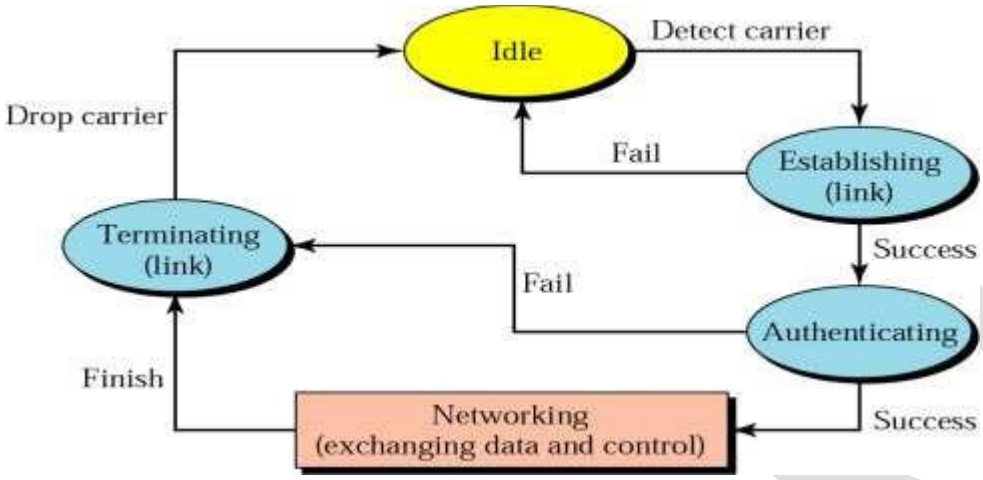
PPPFRAMEFORMAT



- Flagfield.Theflagfieldsidentifytheboundariesofa PPPframe.Itsvalueis01111110.
- Addressfield. BecausePPPis usedforapoint-to-point connection,ituses thebroadcast address of HDCL, 11111111, to avoid a data link address in the protocol.
- Controlfield.Thecontrolfield usestheformatoftheU-framein HDCL.See pages285-286.
- Protocolfield.The protocolfielddefineswhat is being carriedinthedatafield: userdataor other information.
- Datafield.Thisfieldcarrieseithertheuserdataorotherinformation.
- Framecheck sequence(FCS)field.Thisfieldisusedfor error detection.

Transition states

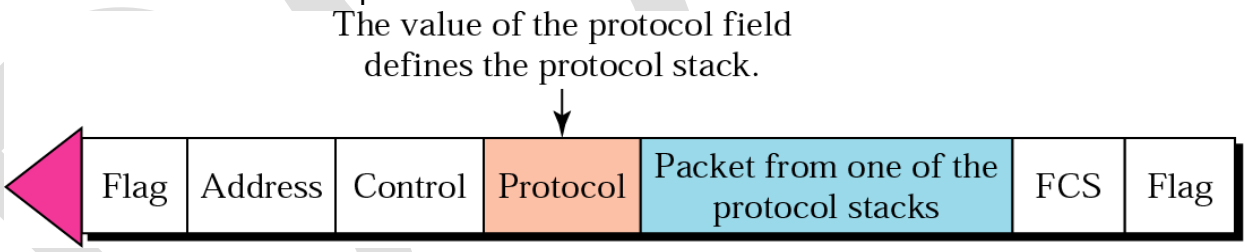
APPPconnectiongoesthroughdifferentphasescalledtransitionsates.



- Idle state. Theidle statemeansthatthe link is not being used.There is noactive carrier, and the line is quiet.
- Establishing link. When one of the end point starts the communication, the connection goes intothe establishing state.Inthisstate, optionsarenegotiated betweenthetwoparties.If the negotiation is successful, the system goes to the authenticating state (if authentication is required) or directly to the networking state.
- Authenticating state.The authenticating state is optional.If the result is successful, the connection goes to the networking state; otherwise, it goes to the terminating state.
- Networking State. When a connection reaches this state, the exchange of user control and data packets can be started. The connection remains in this state until one of the endpoints wants to terminate the connection.
- Terminating state.When the connection is in the terminating state, several packets are exchanged between the two ends for house cleaning and closing the link.

PPP Stack

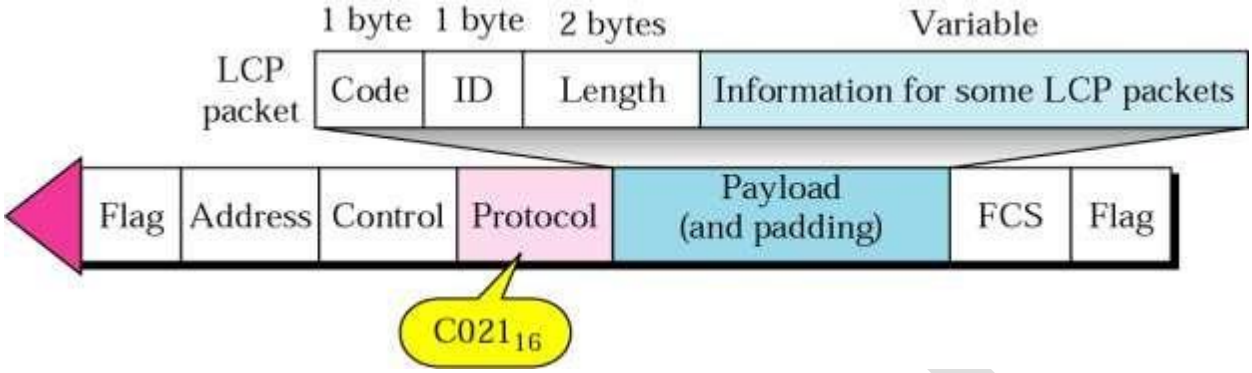
- Three sets of protocols are used by PPP: Link control protocol, authentication protocols, and network control protocol.



LinkControlProtocol(LCP)

- Itisresponsibleforestablishing,maintaining,configuring,andterminatinglinks.
- It also providesnegotiation mechanisms to set options between endpoints. Both endpoints ofthe link mustreachanagreement abouttheoptionsbeforethelinkcan be established.
- WhenPPPiscarrying anLCPpacket, itis either intheestablishing stateor inthe terminating state.
- All LCP packets arecarried in thedatafield of thePPPframe.What defines theframe as one carrying an LCP packet is the value of the protocol field, which is set to C021 (base 16).

LCPpacketencapsulatedinaframe



LinkControlProtocol(LCP)

- Code.Thisfielddefinesthetype of LCPpacket.
- ID. Thisfieldholds avalue usedtomatcharequest with reply. One endpoint insertsa value in this field, which will be copied in the reply packet.
- Length.Thisfielddefinesthelength oftheentireLCP packet.
- Information.ThisfieldcontainsextrainformationneededforsomeLCPpackets.
- Configurationpacketsareusedtonegotiatetheoptionsbetweenthetwoends.There are four different types of packets for this purpose: configure-request, configure-ack, configure-nak, and configure-reject.
- Link termination packets.Thelinkterminationpacketsareusedtodisconnectthelink between two endpoints.
- Therearetwotypes:**terminate-request**and**terminate-ack**.
- Link monitoring and debugging packets. These packets are used formonitoringand debuggingthelink.Therearefivetypes:**code-reject**, **protocol-reject**, **echo-reply**, **discard-request**.

AuthenticationProtocols

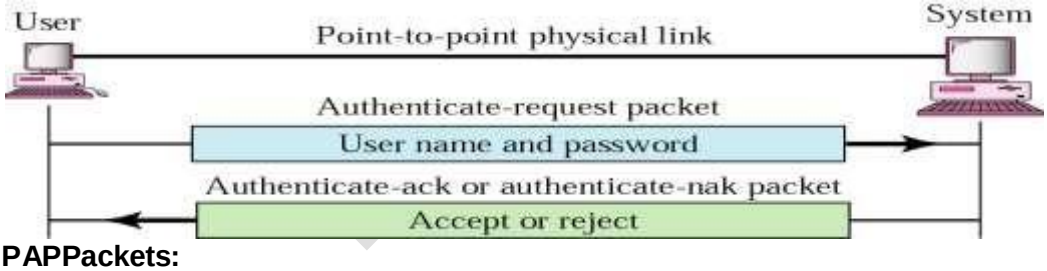
- Authenticationplaysaveryimportantrolein PPPbecausePPPis designedfor use over dial-up links where verification of user identity is necessary.
- Authenticationmeansvalidatingtheidentityof a user who needs toaccess aset of resources.
- PPPusestwoprotocolsfor authentication:PasswordAuthenticationProtocol(PAP) and Challenge Handshake Authentication Protocol (CHAP)

PAP

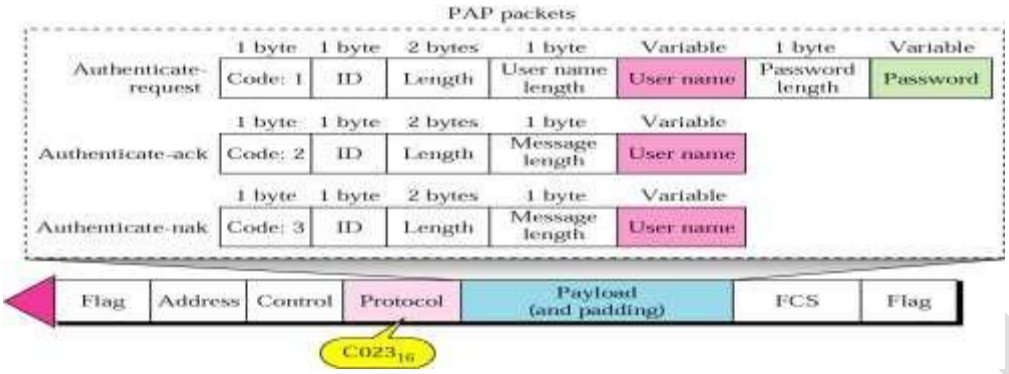
- ThePAPisasimpleauthenticationprocedurewithtwosteps:

1. Theuserwho wants toaccessasystemsendsan ID(identification)andapassword.
2. Thesystemchecksthe validityof the identificationandpassword andeitheraccepts or denies a connection.

- For those systemsthat requiregreatersecurity, PAP is not enough. Athird partywith accesstothe link can easilypick upthe password and accessthesystem resources.



PAPPackets:

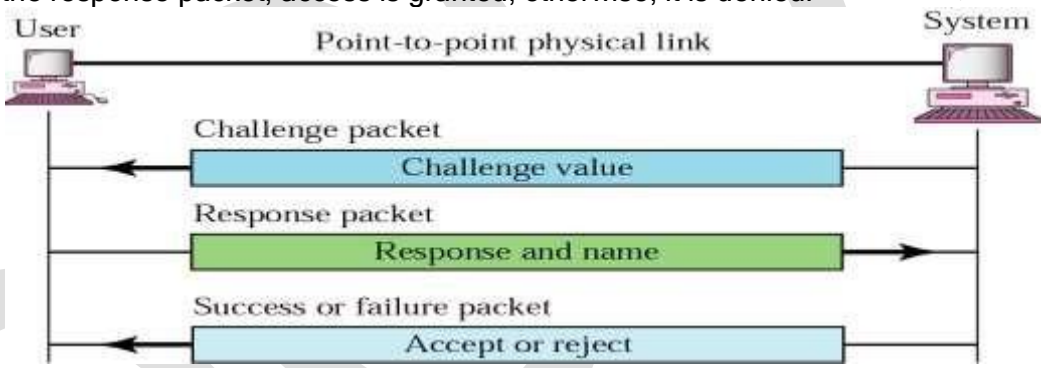


CHAP

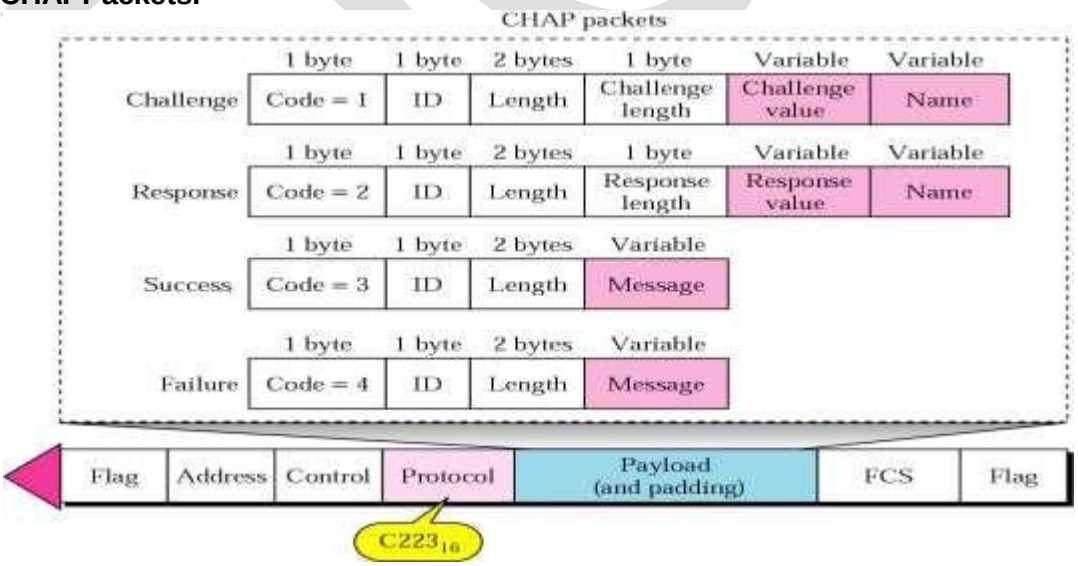
- TheCHAPprotocolisathree-wayhandshakingauthenticationprotocolthat provides greater security than PAP.
- Inthismethod,thepasswordiskeptsecret;itisneversenton-line.

Steps

- Thesystemsendstotheuserachallengepacket containing a challengevalue, usually a few bytes.
- Theuserappliesa predefinedfunctionthattakesthe challengevalue andthe user'sown password and creates a result. The user sends the result in the response packet to the system.
- Thesystemdoesthesame. It appliesthesamefunction tothe passwordof the user and the challenge value to create a result. If the result created is the same as the result sent in the response packet, access is granted; otherwise, it is denied.



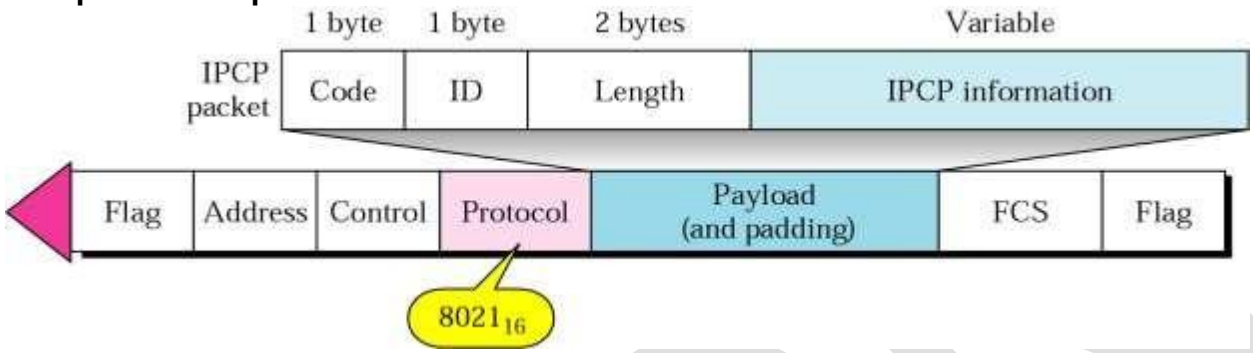
CHAPPackets:



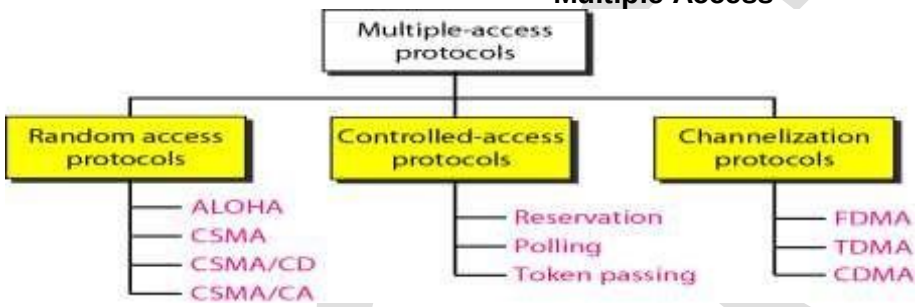
NetworkControlProtocol(NCP)

- After the link is establishedandauthentication (if any) is successful, the connection goes on the networking state.
- NCPis aset of controlprotocolstoallowthe encapsulationof datacomingfrom network layer protocols into the PPP frame.
- Thesetof packetsthat establishandterminateanetwork layer connectionis called InternetworkProtocol Control Protocol (IPCP).

IPCPpacketencapsulatedinPPPframe



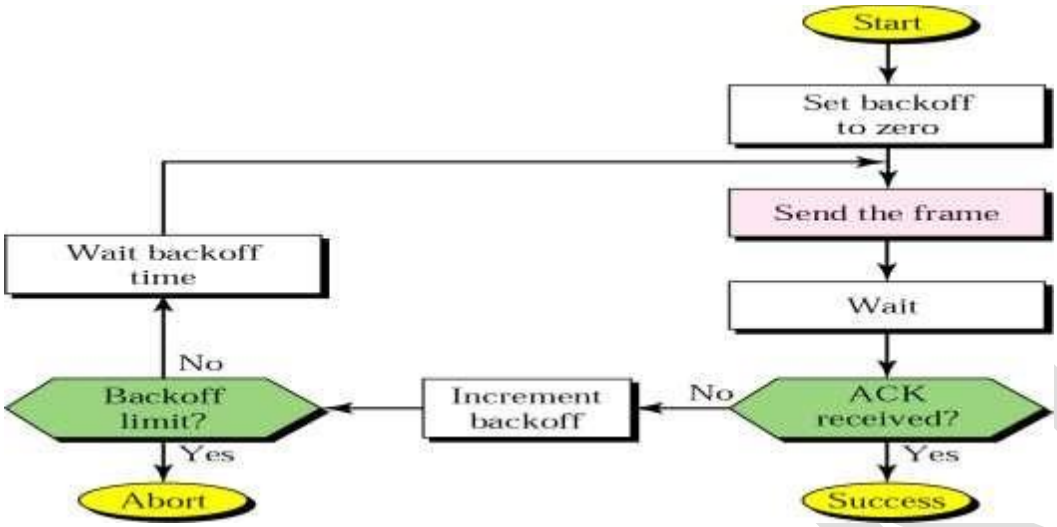
Multiple Access



RANDOM ACCESS:

- **RandomAccess(orcontention)Protocols:**
  - Nostationissuperiortoanotherstationandnoneisassignedthecontroloveranother.
  - Astationwithaframetobetransmitted**canusethelinkdirectlybased**onaprocedure defined by the protocol to make a decision on whether or not to send.
- **ALOHAProtocols**
- Wasdesignedfor**wirelessLAN**and canbeusedfor**anyshared medium**
- **Pure ALOHA**Protocol Description
  - Allframesfrom anystation areoffixedlength(**Lbits**)
  - Stationstransmitatequal**transmissiontime(*allstationsproduceframeswithequal frame lengths*)**.
  - Astationthat hasdata**cantransmitatanytime**
  - **After transmitting a frame**, the sender **waits** for an **acknowledgment** for an amount of time (time out) equal to the **maximum round-trip propagationdelay**= 2* t_{prop}(**see next slide**)
  - If**no ACK** was received, sender assumes that the **frame or ACK** has been destroyed and **resends** that frame after it **waits for a *random* amount of time**
  - IfstationfailstoreceiveanACKafterrepeatedtransmissions, **itgivesup**
  - **Channelutilizationorefficiencyor Throughput**isthe**percentage**ofthetransmitted frames that arrive **successfully** (without collisions) **or** the **percentage** of the **channel bandwidth** that will be used for transmitting frames without collisions
  - ALOHA Maximum channel utilization is **18%** (i.e, if the system produces **F frames/s**, then **0.18 * F** frames will arrive **successfully on average without the need of retransmission**).

Procedurefor ALOHAprotocol



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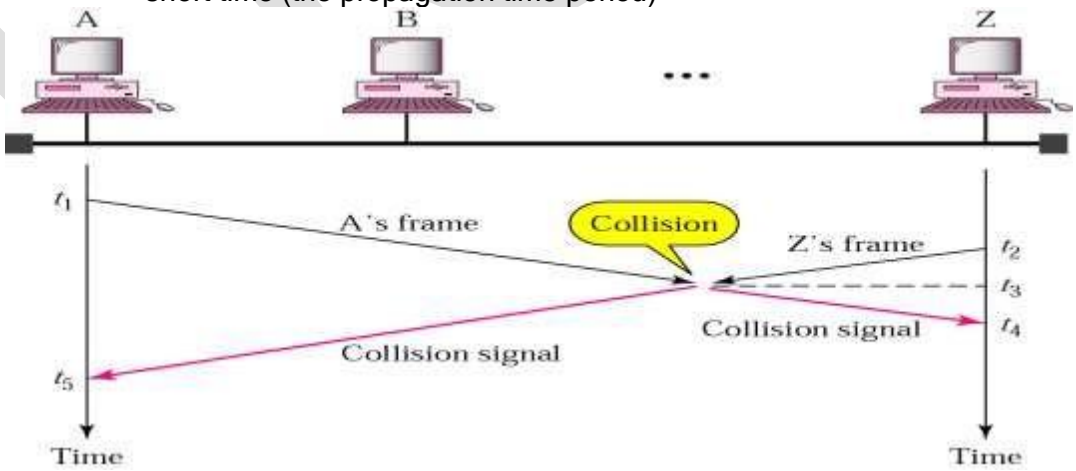
- AdvantageofALOHA protocols
  - A nodethat hasframesto betransmittedcan **transmit continuously**at the **full rate of channel (R bps)** if it is the only node with frames
  - Simpletobe implemented
  - Nomasterstationisneededtocontrolthemedium
- Disadvantage
  - If (M) nodes wanttotransmit,manycollisions can occurandthrateallocatedfor each node will **not be on average R/M bps**
  - Thiscauseslowchannel utilization

RandomAccess –CarrierSenseMultipleAccess (CSMA)

- Toimproveperformance,avoidtransmissionsthatarecertaintocausecollisions
- BasedonthefactthatinLANpropagationtimeisvery small
- ➔Ifaframewassentbyastation,Allstationsknowsimmediatelysotheycanwaitbefore start sending
  - ➔A station with frames to be sent, should sensethe medium for the presence of another transmission (carrier) before it starts its own transmission
- Thiscanreducethepossibilityofcollisionbutitcannoteliminateit.
  - Collision can onlyhappen when morethan onestation begin transmitting within a short time (the propagation time period)



TypesofCSMAProtocols

DifferentCSMAprotocolsthatdetermine:

- Whatastation should dowhen themediumisidle?
- Whatastationshoulddowhenthemedium is busy?
    1. Non-PersistentCSMA
    2. 1-PersistentCSMA
    3. p-PersistentCSMA

NonpersistentCSMA:

- Astationwithframestobesent,shouldsensethemedium
    1. Ifmediumisidle,**transmit**;otherwise,goto2
    2. Ifmedium isbusy, (**backoff**)wait a***random*amountoftime**andrepeat**1**
- Non-persistentStationsare**deferential(respectothers)**
- Performance:
    1. Arandom delayreducesprobabilityof collisionsbecausetwostationswithdata to be transmitted will wait for different amount of times.
    2. Bandwidth is **wasted**if waiting time(backoff) is largebecause medium will remainidlefollowing endof transmissionevenif oneormorestationshave frames to send

1-persistentCSMA

- Toavoididlechanneltime,1-persistentprotocolused
- Stationwishingtotransmitlistenstothemedium:
    1. Ifmediumidle,transmitimmediately;
    2. Ifmediumbusy,continuouslylistenuntilmediumbecomesidle;thentransmit immediately with probability 1
- Performance
    - 1-persistentstationsareselfish
    - Iftwoormorestationsbecomesreadyatthesametime, collisionguaranteed

P-persistentCSMA

- Timeisdividedtoslotswhere eachTimeunit(slot)typicallyequalsmaximum propagation delay
- Stationwishingtotransmitlistenstothemedium:

1. Ifmediumidle,
    - transmitwithprobability(p), OR
    - waitonetimeunit(slot)withprobability(1-p),thenrepeat1.
2. Ifmediumbusy,continuouslylistenuntilidleandrepeatstep1
3. Performance
    - Reducesthepossibilityofcollisionslikenonpersistent
    - Reduceschannelidletimelike1-persistent

CSMA/CD(Collision Detection)

- *CSMA(allpreviousmethods)hasan inefficiency:*
    - Ifacollisionhasoccurred,thechannelisunstableuntilcollidingpacketshave<u>beenfully transmitted</u>
- *CSMA/CD(CarrierSenseMultipleAccesswithCollision*

Detection) overcomes this as follows:

- Whiletransmitting,thesenderislisteningtomediumforcollisions.
- Senderstopstransmissionif collisionhasoccurredreducingchannelwastage.

CSMA/CD is Widely used for bus topology LANs (IEEE 802.3, Ethernet).

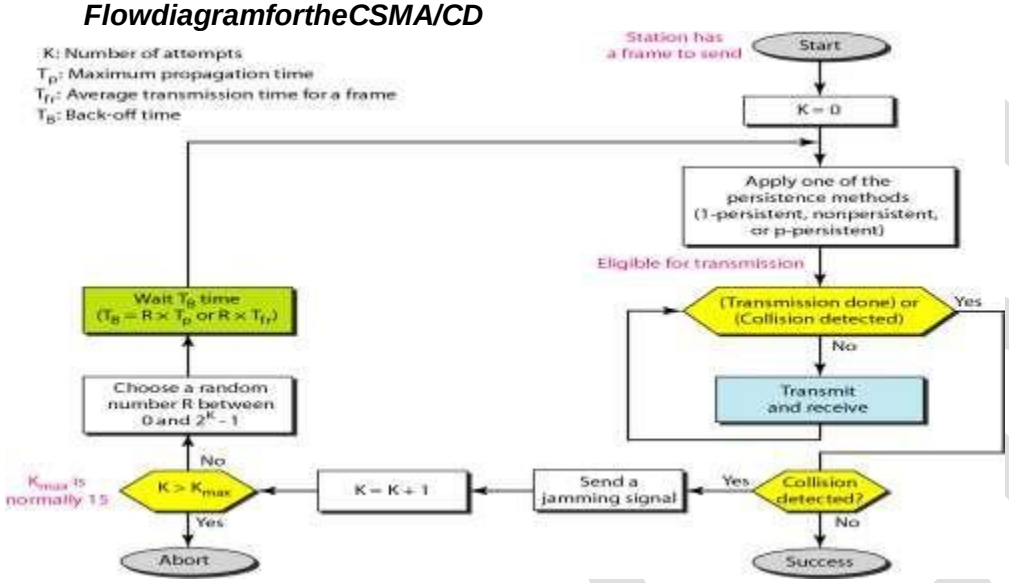
CSMA/CDProtocol

- UseoneoftheCSMApersistence algorithm***(non-persistent,1-persistent,p-persistent)*** fortransmission
- Ifacollisionisdetectedbyastationduringitstransmissionthenitshoulddothefollowing:
    - **Aborttransmission**and
    - **Transmita*jamsignal***(48 bit)tonotifyotherstations of collision sothattheywill **discardthetransmittedfra**mealsotomakesurethatthecollisionsignalwillstay until detected by <u>the furthest station</u>

- Aftersendingthe***jam signal***,**backoff(wait) for a*random*** amountoftime,then
- Transmittheframe again

- RestrictionsofCSMA/CD:
  - Packet **transmission time** should be **at least** as long as the time needed to detectacollision(2*maximumpropagationdelay+ *jamsequence*transmission time)
  - Otherwise,CSMA/CDdoesnothaveanadvantageoverCSMA

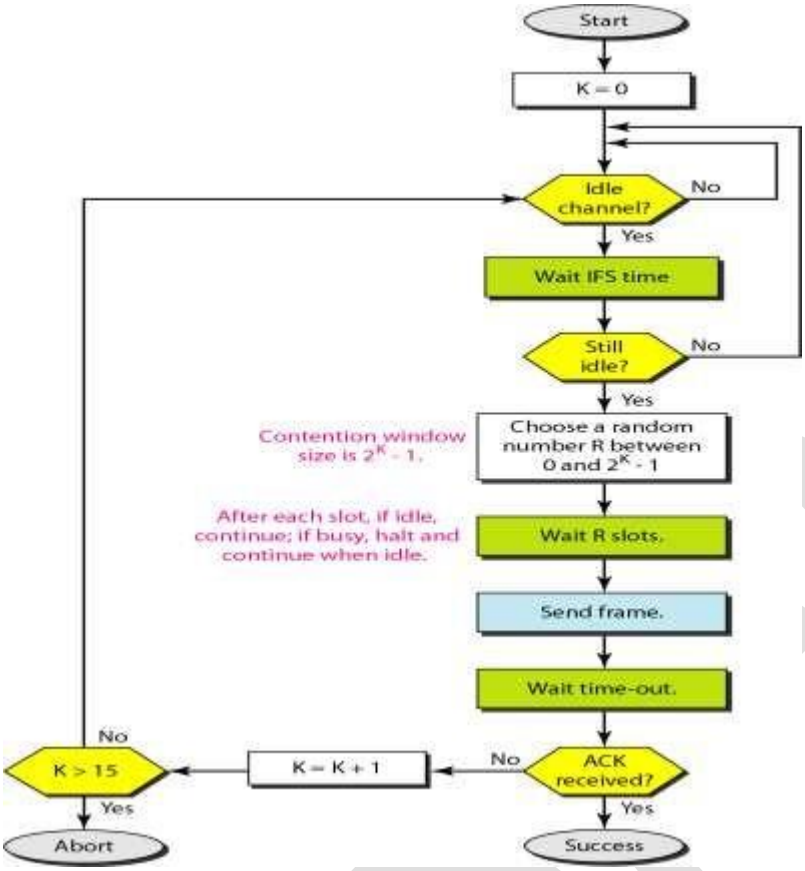
FlowdiagramfortheCSMA/CD



CSMA/CA(Collision Avoidance)

In CSMA/CA, the IFS can also be used to define the priority of a station or a frame.In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window; it stops the timer and restarts it when the channel becomes idle.

Flow diagramfor CSMA/CA

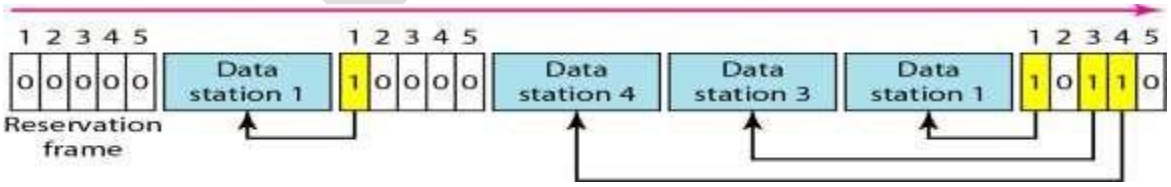


CONTROLLEDACCESS

- Provides **inorderaccess**tosharedmedium sothat everystation haschance totransfer (**fair protocol**)
- ***Eliminates***collisioncompletely
- **Threemethods**forcontrolledaccess:
  - Reservation
  - Polling
  - TokenPassing

1- Reservationaccessmethod

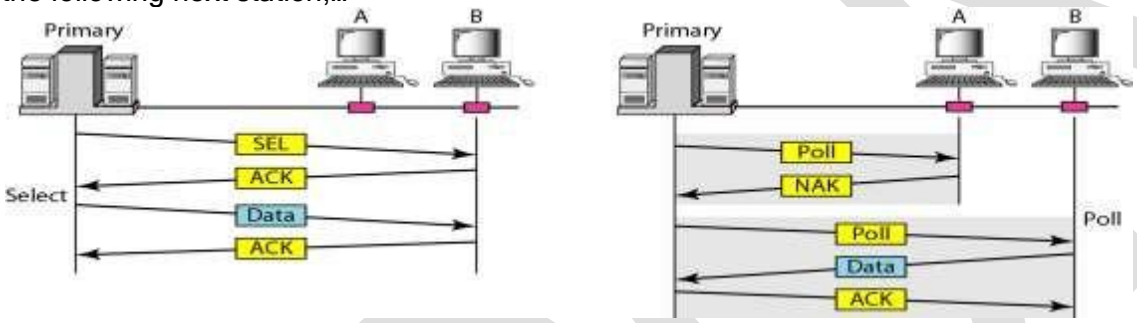
- Stationstaketurnstransmittinga singleframeatafullrate(R)bps
- Transmissionsareorganizedintovariablelengthcycles
- Each cycle begins with a reservation interval that consists of (N) minislots. One minislot for each of the N stations
- Whenastation needstosenda dataframe, itmakesareservationinitsownminislot.
- By listening to the reservation interval, every station knows which stations will transferframes, and in which order.
- Thestationsthatmadereservationscansendtheirdataframesafterthereservation frame.



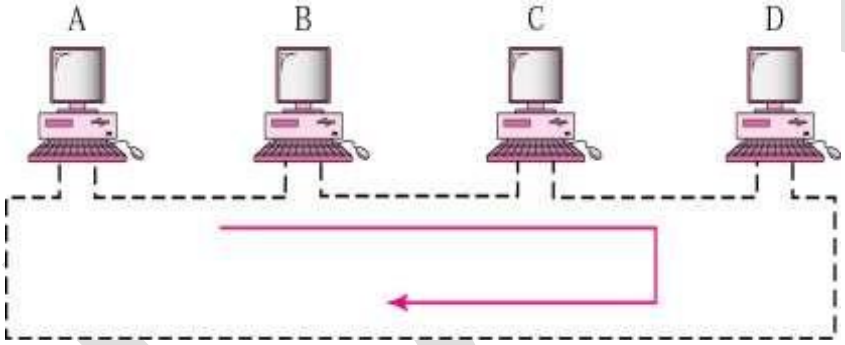
2- Polling

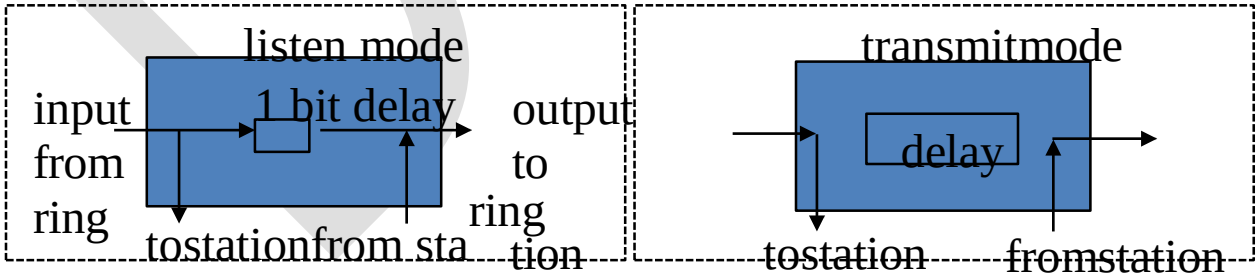
- Stationstaketurns accessingthe medium
- Twomodels:Centralizedanddistributedpolling
- Centralizedpolling
  - Onedeviceisassignedas primarystation andtheothersassecondarystations
  - Alldataexchangesaredonethroughtheprimary
  - When the primary has a frame to send it sends a select frame that includes the address of the intended secondary
  - Whentheprimaryisreadytoreceive datait sendaPollframeforeachdevice to ask if it has data to send or not. If yes, data will be transmitted otherwise NAK is sent.
  - Pollingcanbedoneinorder(Round-Robin)orbasedonpredeterminedorder
- Distributedpolling
  - Noprimaryand secondary
  - Stations have a known polling order list which is made based on some protocol

stationwiththehighestprioritywillhavetheaccessrightfirst,thenitpassestheaccessrighttothenext station(itwillsendapullingmessagetothenextstationinthepullinglist),whichwillpassestheaccess right to the following next station,…



3- Token-Passing network





Bitsarecopiedtotheoutputbitswithaonebitdelay **Bitsareinsertedbythestation**

- StationInterfaceisintwo states:

- Listen state: Listen to the arriving bits and check the destination address to see if it is its own address. If yes the frame is copied to the station otherwise it is passed through the output port to the next station.
- Transmit state: station captures a special frame calledfree token and transmits its frames.Sendingstationisresponsibleforreinserting thefreetokenintotheringmedium and for removing the transmitted frame from the medium.

CHANNELIZATION

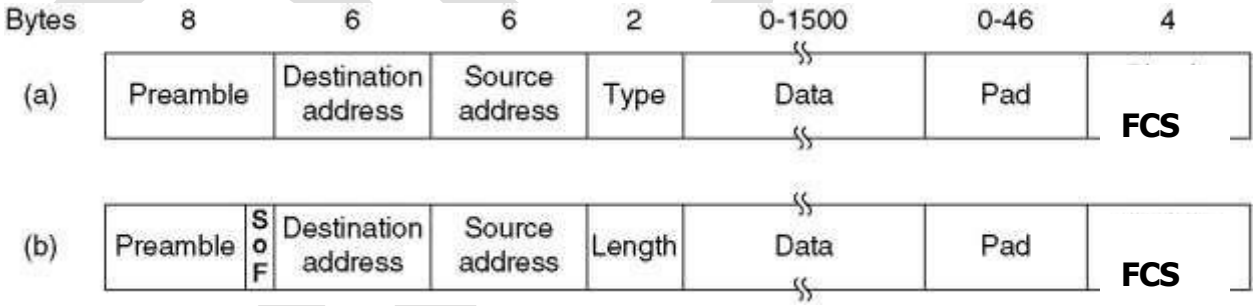
Channelizationisamultiple-accessmethodinwhichtheavailablebandwidthofalinkissharedintime, frequency,orthroughcode,betweendifferentstations.Inthissection,wediscussthreechannelization protocols.

- **FDMA:**FrequencyDivisionMultipleAccess:
  - Transmissionmediumisdividedinto**M**separatefrequencybands
  - Eachstationtransmits**continuously**ontheassignedbandatanaveragerateof**R/M**
  - Anodeis**limited**toanaveragerateequal**R/M**(whereMisnumberofnodes)evenwhen it is **the only node with frame** to be sent
- **TDMA:TimeDivisionMultipleAccess**
  - Theentirebandwidthcapacityisa**singlechannel**withitscapacityshared**intime**between **M**stations
  - Anodemust**always wait for its turn** untilitsslottimearrivesevenwhenitisthe**only node** with frames to send
  - A node is limited to an average rate equal **R/M** (where M is number of nodes) even whenit is the only node with frame to be sent
- **CDMA:CodeDivisionMultipleAccess**
  - InCDMA,**onechannel**carriesalltransmissions**simultaneously**
  - Eachstationcodesitsdatasignalbyaspecificcodesbeforetransmission
  - Thestationsreceiversusethesecodestorecoverthedataforthedesiredstation

LocalareaNetwork:Ethernet.

Ethernet:ItisaLANprotocolthatisusedinBusandStartopologiesandimplements CSMA/CD as the medium access method

EthernetFrameformat:

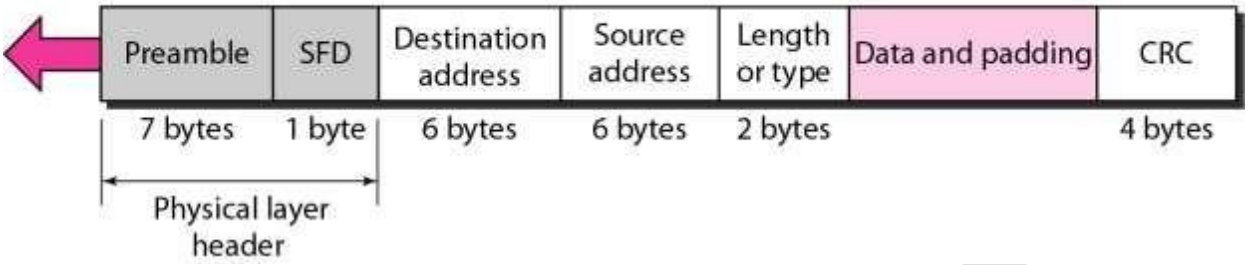


Frame formats.(a) DIXEthernet ,(b)IEEE802.3.

802.3MACframe:

Preamble: 56 bits of alternating 1s and 0s.

SFD: Start frame delimiter, flag (10101011)



- Preamble:
  - 8byteswithpattern10101010usedtosynchronizereceiver,senderclockrates.
  - InIEEE802.3, eighthbyteisstart offrame(10101011)
- Addresses:6bytes(explainedlatter)
- Type (DIX)
  - IndicatesthetypeoftheNetworklayerprotocolbeingcarriedinthepayload(data) field,mostlyIPbut others maybesupportedsuch asIP(0800), Novell IPX (8137) and AppleTalk (809B), ARP (0806))
  - Allow multiple network layer protocols to be supported on a single machine (multiplexing)
  - Itsvaluestartsat 0600h(=1536indecimal)
- Length(IEEE802.3): numberofbytesinthe datafield.
  - Maximum 1500bytes(=05DCh)
- CRC:checkedatreceiver,iferrorisdetected,theframeisdiscarded
  - CRC-32
- Data:carriesdataencapsulatedfromtheupper-layer protocols
- Pad: Zerosareaddedtothe datafieldtomaketheminimum datalength=46bytes

- InIEEE802.3EthernetDatalinklayerissplitintotwosublayers:
  - Bottompart:MAC
    - TheframeiscalledIEEE802.3
    - Handlesframing,MACaddressing,MediumAccesscontrol
    - SpecificimplementationforeachLANprotocol
      - DefinesCSMA/CDastheaccessmethodfor EthernetLANsand Token passing method for Token Ring.
    - Implementedinhardware
  - Toppart:LLC(LogicalLinkControl)
    - Thesubframe iscalledIEEE 802.2
    - Provideserrorandflowcontrolifneeded
    - Itmakesthe MACsub layertransparent
      - AllowsinterconnectivitybetweendifferentLANsdatalinklayers
    - Usedtomultiplexmultiplenetwork layerprotocolsinthedatalinklayer frame

Ethernet*address*:

- Sixbytes =48bits
- Flataddressnot hierarchical
- BurnedintotheNICROM
- First three bytes from left specify the vendor. Cisco 00-00-0C, 3Com 02-60-8C and the last 24 bit should be created uniquely by the company
- DestinationAddresscanbe:
  - Unicast:seconddigitfrom left iseven(onerecipient)

- Multicast:Seconddigitfromleftisodd(groupofstationstoreceivetheframe–conferencing applications)
- Broadcast(ALLones)(allstationsreceivetheframe)

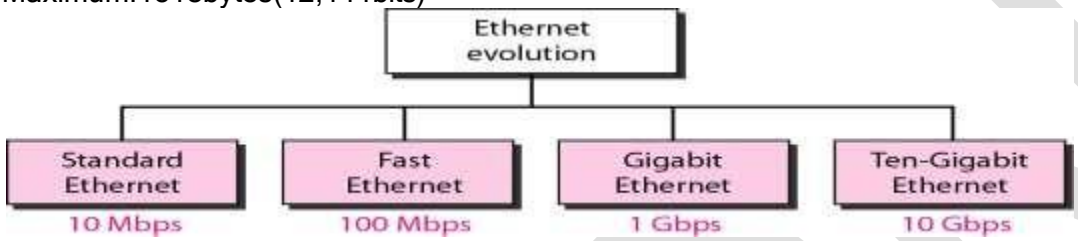
- SourceaddressisalwaysUnicast

Theleast significant bit of thefirst byte definesthe type of address. If thebit is 0, the addressis unicast; otherwise, it is multicast. The broadcast destination address is a special case of the multicast address in which all bits are 1s.

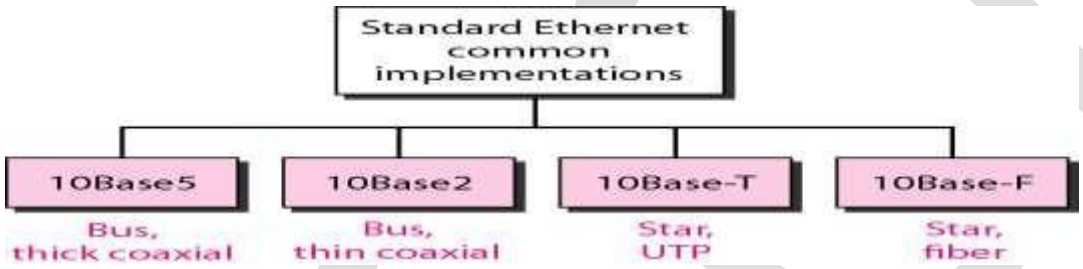
Frame length:

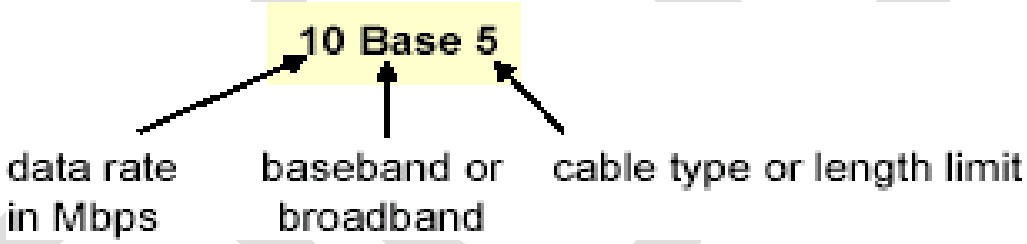
Minimum:64bytes(512bits)

Maximum:1518bytes(12,144bits)

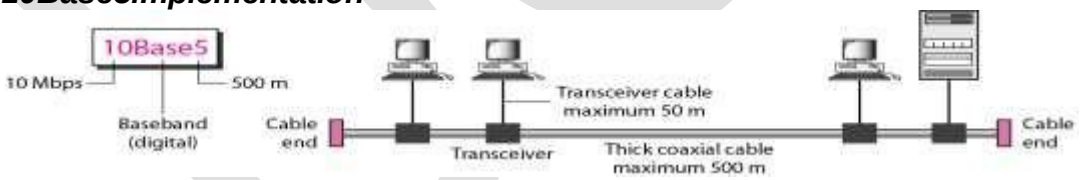


Standard Ethernet:

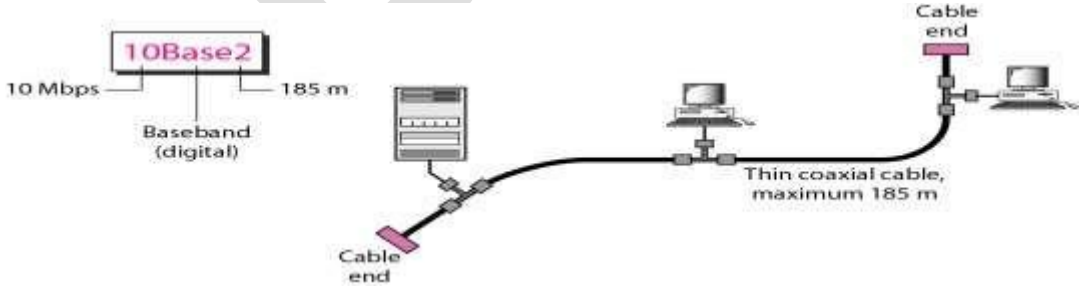




10Base5implementation



10Base2implementation



10BaseT

UsestwistedpairCat3cable

- Star-wiretopology

• Ahubfunctionsasarepeaterwithadditionalfunctions
• Fewercableproblems,easiertotroubleshootthan coax
• Cablelengthatmost100meters

SummaryofStandardEthernet implementations

Characteristics	*10Base5*	*10Base2*	*10Base-T*	*10Base-F*
Media	Thick coaxial cable	Thin coaxial cable	2 UTP	2 Fiber
Maximum length	500 m	185 m	100 m	2000 m
Line encoding	Manchester	Manchester	Manchester	Manchester

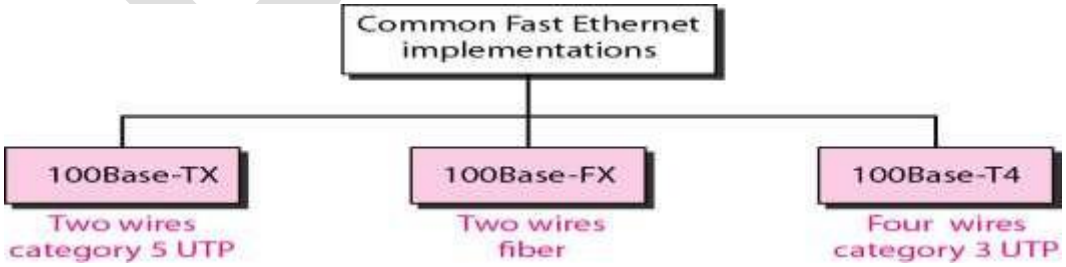
SwitchedEthernet:

- SwitchesforwardandfilterframesbasedonLANaddresses
  - It'snot abusorarouter(althoughsimpleforwardingtablesaremaintained)
- Very scalable
  - Optionsfor manyinterfaces
  - Fullduplexoperation(send/receiveframessimultaneously)
- Connecttwoormore"segments" bycopyingdataframesbetweenthem
  - Switchesonlycopydatawhenneeded
    - keydifferencefrom repeaters
- Higherlink bandwidth
  - Collisionsarecompletelyavoided
- Muchgreateraggregatebandwidth
  - Separatesegmentscansendatonce

Fast Ethernet

- 100Mbpstransmissionrate
- sameframeformat,mediaaccess,andcollisiondetectionrulesas10Mbps Ethernet
- cancombine10MbpsEthernetandFastEthernetonsame networkusinga*switch*
- media:twistedpair(CAT5)orfiberopticcable(nocoax)
- Star-wiretopology
- Similarto10BASE-T

Name	Cable	Max. segment	
100Base-T4	Twisted pair	100 m	
100Base-TX	Twisted pair	100 m	**CAT3**
100Base-FX	Fiber optics	2000 m	**CAT5**



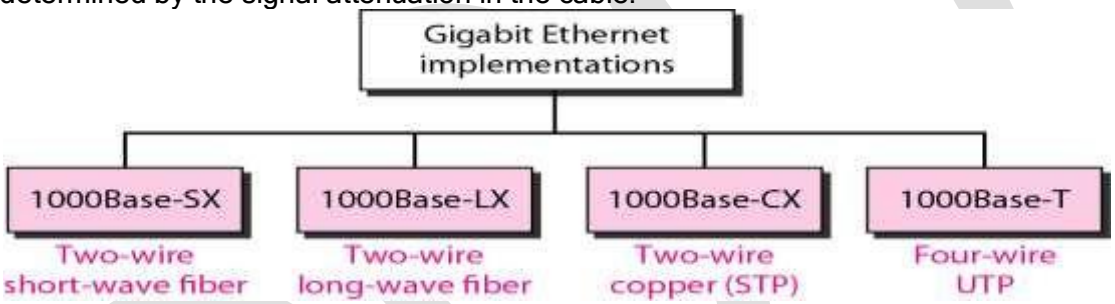
Characteristics	*100Base-TX*	*100Base-FX*	*100Base-T4*
Media	Cat 5 UTP or STP	Fiber	Cat 4 UTP
Number of wires	2	2	4
Maximum length	100 m	100 m	100 m
Block encoding	4B/5B	4B/5B	
Line encoding	MLT-3	NRZ-I	8B/6T

Gigabit Ethernet

- Speed1Gpbs
- Minimumframelengthis512bytes
- Operatesinfull/halfduplexmodesmostlyfullduplex

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

Inthefull-duplexmodeofGigabit Ethernet,thereis no collision;themaximum lengthofthe cableis determined by the signal attenuation in the cable.



10GbpsEthernet

- Maximum linkdistancescover 300mto40 km
- Full-duplexmodeonly
- No CSMA/CD
- Uses**opticalfiber**only

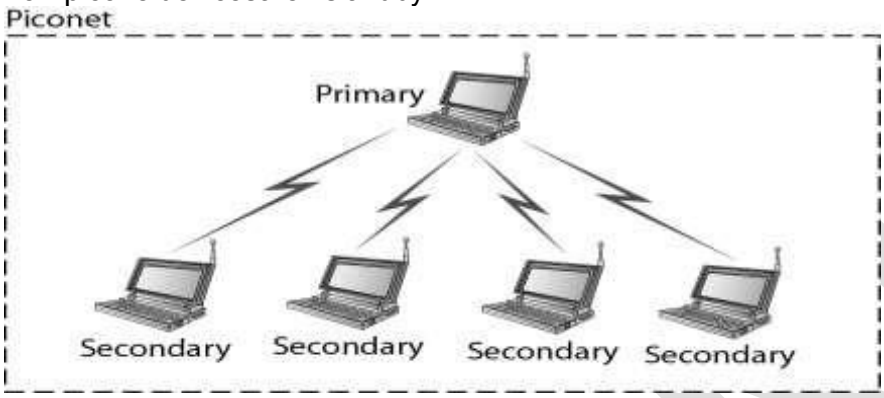
WIRELESSLAN

BlueTooth:

- IEEEhasdefinedthespecificationsforawirelessLAN, calledIEEE802.11, whichcovers the physical and data link layers.
- Bluetooth wireless technology is an **open** specification for a **low-cost**, **low-power**, short-rangeradiotechnologyfor **ad-hoc**wirelesscommunicationof **voiceanddataanywhere**in the world.
- Bluetooth is a wireless LAN technology designed to connect devices of different functions such astelephones, notebooks,computers,cameras,printers, coffeemakers,andsoon. A Bluetooth LAN is an ad hoc network, which means that the network is formed spontaneously.

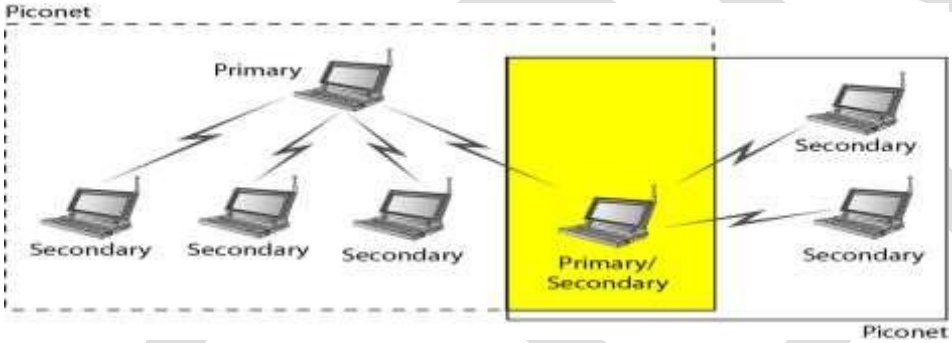
Piconet:

- Alldevicesinapiconethop together
  - Mastergivesslavesitsclockanddevice ID
- Non-piconetdevicesareinstandby



Scatternet:

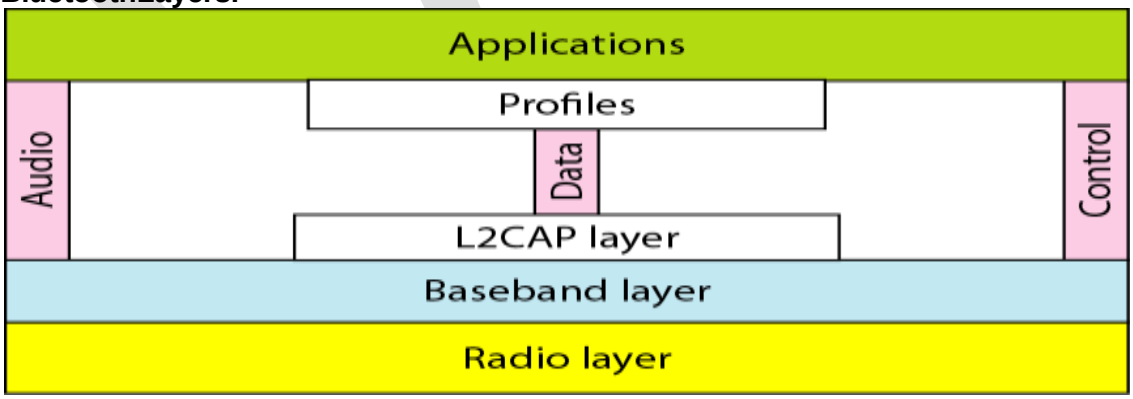
- Devicescanbeslaveinone Piconet andmasterofanother



Physicallinks:

- SynchronousConnectionOriented(SCO)
  - Supportsymmetrical,circuit-switched,point-to-pointconnections
  - Typicallyusedforvoicetraffic.
  - Datarate is64 kbit/s.
- AsynchronousConnection-Less(ACL)
  - Supportsymmetricalandasymmetrical,packet-switched,point-to-multipoint connections.
  - Typicallyusedfordatatransmission.
  - Upto433.9kbit/sinsymmetricor723.2/57.6kbit/sinasymmetric

BluetoothLayers:



Bluetooth Radio: specifics details of the air interface, including frequency, frequency hopping, modulation scheme, and transmission power.

- the lowest defined layer ofthe Bluetoothspecification
- operating inthe2,4 GHzISMBand
- accomplishesspectrumspreadingbyfrequencyhopping(FHSS)from2.402GHzto2.480 GHz
- 3differentpowerclasses
- PowerClass1:longrange (100m,100mW)
- PowerClass2:midrange(10m,1-2,5mW)
- PowerClass3:shortrange(0.1-10m,1mW)
- signalstrengthadjustment

Baseband:concernedwithconnectionestablishmentwithinapiconet,addressing,packetformat, timing and power control.

- thephysicallayeroftheBluetoothatprovides
- Errorcorrection
- Flowcontrol
- Hoppingsequence
- Security
- hoppingthrough79channels
- dataisdividedinpackets
- accesscode:e.g.timing synchronization
- header:e.g.packetnumbering,flowcontrol,slaveaddress
- payload:voice,dataorboth
- ConnectionModes
- describes the set of rules by which all bluetooth devices must abide in order to establish a link a communicate with one another
- STANDBY:notconnected ina piconet
- ACTIVE:activeparticipationonthechannel
- PowerSaving Modes
- SNIFF : slave listens to the channel at a reduced rate (decreasing ofduty cycle) leastpower efficient
- HOLD:datatransferisheldforaspecifictimeperiod,mediumpower efficient
- PARK:synchronizedtothepiconetbutdoesnotparticipateintraffic

Audio:

- two codecs:PCMandCVSD
- bothat64kbit/s
- synchronousconnectionoriented(SCO)links
- time-critical
- no retransmission
- errorsappearasbackgroundnoise

Link manager protocol (LMP): establishes the link setup between Bluetooth devices and manages ongoing links, including security aspects (e.g. authentication and encryption), and control and negotiation of baseband packet size.

- providesauthentication,linksetupandlinkconfigurationincludingpowersurveillance
- takesplaceasaservice provider
- communicationwithLMPDUs(protocoldataunits)

Logical link control and adaptation protocol (L2CAP): adapts upper layer protocols to the baseband layer. Provides both connectionless and connection-oriented services.

- providesaconnection-orientedandconnectionlessservicetoupper layer
- protocolswithquality-of-servicefunctionsusingmultiplexing,segmentationand reassembly
- twolinktypesdefinedinBasebandlayer:
- 1.SCO(synchronousconnection-oriented)
- 2.ACL(asynchronousconnection-less)
- BUT ONLY ACL issupportedbyL2CAP (SCO notplanned)

Servicediscoveryprotocol(SDP):handlesdeviceinformation,services,andqueriesforservice characteristics between two or more Bluetooth devices.

- discoverswhichservices areavailable
- identifiesthecharacteristicsofthe services
- uses a request/response model where each transaction consists of one request protocol data unit (PDU) and one response PDU
- SDPisusedwithL2CAP
- isoptimizedforthedynamicnatureofbluetooth
- SDPdoesnotdefinemethodsfor accessingservices

Host Controller Interface (HCI): provides an interface method for accessing the Bluetooth hardware capabilities. It contains a command interface, which acts between the Baseband controller and link manager.

- providesacommandinterfacetobasebandcontrollerandlinkmanager
- alsotohardwarestatus,controlandeventregister
- BluetoothdefinedHostControllerTransportLayers:
- UART(HCIoverserialinterface)
- RS232(HCIoverserialinterface)
- USB(HCIoverUSBinterfacee.g.USBdongle)

RFCOMM(RadioFrequencyCommunication):

- Providesemulationofserialports
- Supportsupto60simultaneous connections
- Differentiatesbetweentwodevicetypes:
- Type1:communicationendpoints(e.g.printeror headsets)
- Type2:deviceswhicharepart ofcommunication(e.g.modems)

VIRTUALCIRCUITSWITCHING

Circuit-Switching:

- Acircuit-switchednetworkconsistsofasetofswitchesconnectedbyphysicallinks.
- Aconnectionbetweentwostationsisadedicatedpathmadeof oneormore links
- eachconnectionusesonlyonededicatedchanneloneachlink
- Eachlinkisnormallydividedintonchannelsbyusing FDMorTDM.
- Thelinkcanbepermanent(leasedline)ortemporary(telephone)
- Switchingtakeplaceatphysicallayer
- Beforeanydatacanbesent,anend-to-endcircuitmust beestablished
- Thiscircuit ismaintainedforthedurationofthetransferofallthedata
- Thedatacanbedigitaloranalogandthesignalcanbeeithertypeaswell
- Connectionisusuallyfull-duplex
- Isinefficient- channelcapacity isdedicated for thedurationofthe connection

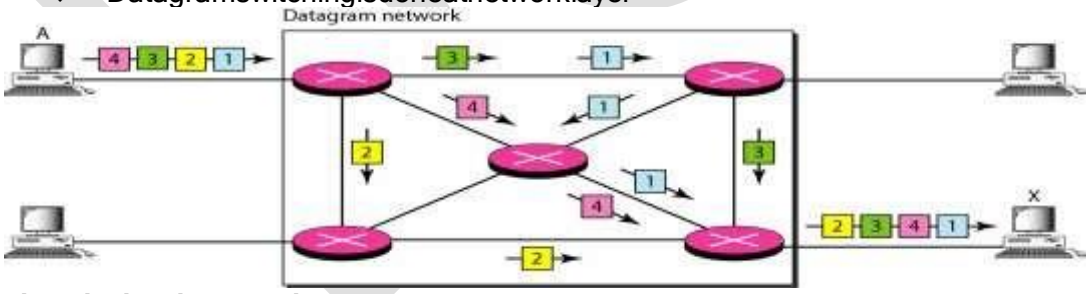
- Example-Pubictelephonesystem
- Resources
  - Suchasbandwidth inFDMandtimeslotinTDM
  - Switchbuffer
  - Switchprocessingtime
  - SwitchI/O ports
- Datatransferredarenotpacketized,continuousflow
- Noaddressinginvolvedduringdatatransfer

PacketSwitching:

- Stationbreakslongmessageinto packets
- Packetssent one atatimetothenetwork
- Verymuchlikemessageswitching
- Principalexternaldifferenceisthatthelengthofthemessagefoundinternallyhasa maximum length
- Atypicalmaximumlengthisseveralthousandbits
- Messages abovethemaximum length are divided upintosmaller units and sent out one at a time
- Thesesmallerunitsarecalledpackets
- Packets,unlikemessages,aretypicallynotfiledattheintermediatenodes
- Packetsarehandledintwo ways
  - Datagram
  - Virtualcircuit

DatagramNetworks:

- In datagram approach each packet is treated independently with no reference to packets that have gone before. No connection is set up.
- Thepacketsmaytakedifferentpathstothedestination
- Thepacketsmightarriveinadifferentsequencefromtheorderinwhichtheyweresent
- Thepacketsmayhavetobereordered atthedestination
- Packets maygomissing
- Uptoreceivertore-orderpacketsandrecoverfrommissingpackets
- Moreprocessingtimeperpacketpernode
- Sizeofthepacketdependsontheprotocoland network
- Packetsswitchednetworksareconnectionless,hencenoresourceallocation
- Connectionlessmeanstheswitchdoesnotkeepinformationabouttheconnectionstate.
- Datagramswitchingisdoneatnetworklayer

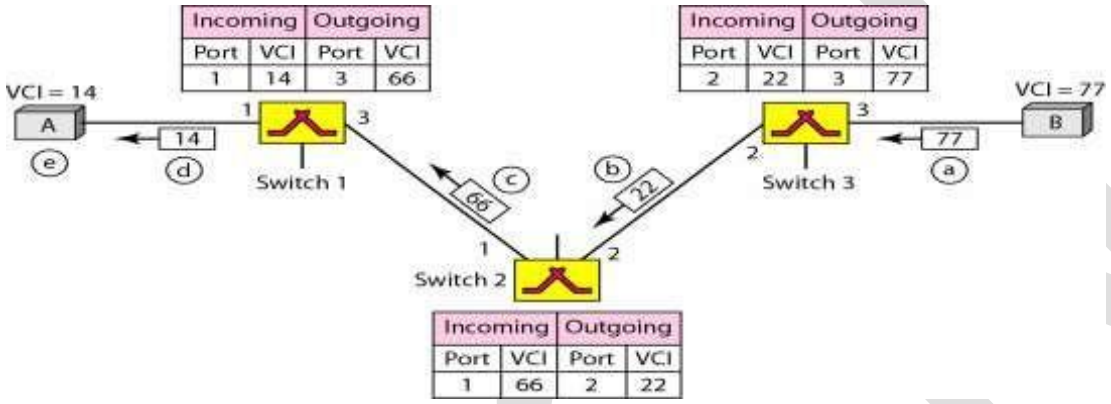


Virtual-CircuitNetworks:

- IntheVirtualCircuitapproachapre-plannedrouteisestablishedbeforeanypacketsaresent.
- Thereisacallset upbeforetheexchangeof data(handshake).
- Alogicalconnectionisestablishedbeforeanypacketsaresent
- Allpacketsfollowthesamepaththroughthenetwork
- Thisdoesnotmeanthatthereisadedicatedpath,asincircuit switching
- Allpacketsfollowthesamerouteandthereforearrivein sequence.

- Eachpacketcontainsavirtualcircuitidentifierinsteadof destinationaddress
- Moresetuptime
- Noroutingdecisionsrequiredforeachpacket-Lessroutingorprocessingtime.
- Susceptibletodatalossinthefaceoflinkornodefailure
- Clearrequesttodropcircuit
- Notadedicatedpath

Source-to-Destinationdatatransfer



Virtual circuits can be either permanent, called Permanent virtual Circuits (PVC), or temporary, called Switched Virtual Circuits (SVCs).

PermanentVirtualCircuit (PVC)

A Permanent Virtual Circuit (PVC) is a virtual circuit that is permanently available to the user. PVC is defined in advance by a network manager. The actual identifier used for data transfer is virtualcircuitidentifier(VCI).Ifpermanent,anoutgoingVCIisgiventothesource,andan incoming VCI is given to the destination.

ThesourcealwaysusesthisoutgoingVCItosendframestothisparticulardestination.

Thedestinationknowsthattheframeiscomingfromthatparticularsourceiftheframecarriesthe corresponding incoming VCI.

Onceacommunicationsessioniscomplete,thevirtualcircuitisdisabled.

SwitchedVirtualCircuit(SVC)

Aswitchedvirtualcircuitisanautomaticallyandtemporarilycreatedlogicalpathwithaidofsome switch control for a communication session switch control for a communication session

Onceacommunicationsessioniscomplete,thevirtualcircuitisdisabled.

FRAMERELAY:

- **X.25**
  - Interfacebetweenattachedstationandlinktonode
  - DataterminalequipmentDTE(user equipment)
  - DatacircuitterminatingequipmentDCE(node)
  - UsesphysicallayerspecificationX.21
  - Interfacebetweenhostandpacketswitchednetwork
  - AlmostuniversalonpacketswitchednetworksandpacketswitchinginISDN
  - Definesthree layers
  - Physical
  - Link
  - Packet
- **Frame Relay:**
  - FrameRelay(FR) is ahigh-performanceWANprotocolthatoperatesatthephysicaland data link layers of the OSI reference model.

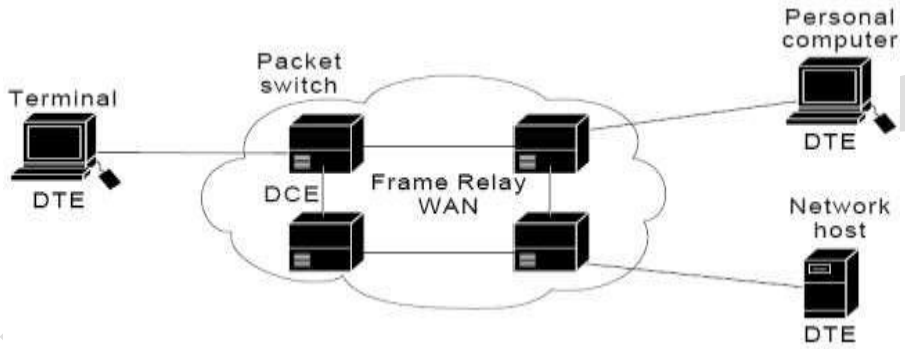
- ❖ FR originallywas designedfor use across Integrated Service DigitalNetwork (ISDN) interfaces.
- ❖ Today, itisusedover avarietyofothernetwork interfacesaswell.
- ❖ FRisanexampleofapacket-switched technology.
- ❖ Packet-switchednetworks enableendstationstodynamicallysharethenetwork medium and the available bandwidth.
- ❖ Packetswitchingsystemwithlowoverhead
- ❖ Assumesveryreliablehigh-qualityphysicalnetwork
- ❖ DevelopedforuseinISDN networks
- ❖ Usedwidelyinavarietyof privateandpublicnetworkswhicharenot ISDN
- ❖ Noerrorchecking andacknowledgmentatthedatalink layer
- ❖ Allerrorcheckingislefttotheprotocolsatthenetworkandtransportlayers
- ❖ operatesatonlythephysicalanddatalink layers

FrameRelayvs.X.25

- FrameRelayisaLayer2protocolsuite,X.25providesservicesatLayer 3
- FrameRelayoffershigherperformanceandgreatertransmissionefficiencythanX.25

FrameRelayDevices

- dataterminalequipment(DTE)
  - ☐ terminatingequipmentforaspecificnetwork
  - ☐ typicallyarelocatedonthepremisesofacustomer
  - ☐ Examples:terminals,personalcomputers,routers,andbridges
- datacircuit-terminatingequipment(DCE)
  - ☐ carrier-ownedinternetworkingdevices
  - ☐ toprovideclockingandswitchingservicesinanetwork
  - ☐ actuallytransmitdatathroughtheWAN



FrameRelayDevices

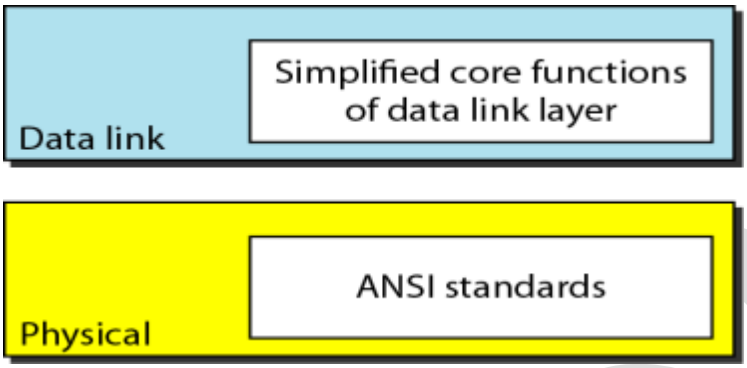
FrameRelayVirtualCircuits:

- providesconnection-orienteddatalinklayercommunication
- alogicalconnectionbetweentwodataterminalequipmentacrossaFrameRelay packet-switched network
- provideabi-directionalcommunicationspathfromoneDTEdevicetoanother
- Switchedvirtualcircuits(SVCs)
  - temporaryconnectionsrequiressporadicdatatransferbetweenDTEdevices across the Frame Relay network
    - *CallSetup*
    - *DataTransfer*
    - *Idle*
    - *CallTermination*
- PermanentVirtualCircuits(PVCs)
  - usedfor frequent andconsistent datatransfersbetween DTE devices across the Frame Relay network
    - *DataTransfer*

- *Idle*

FrameRelayLayers

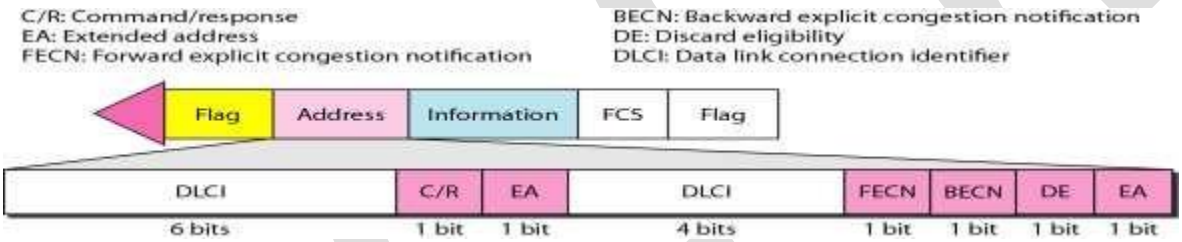
- FrameRelayoperatesonlyatthephysicalanddatalinklayers.
- Eliminatesallof thenetwork layerfunctionsandaportionof conventionaldatalink layer functions.



- PhysicalLayers: nospecificprotocolis definedforthephysicallayer. Itis lefttothe implementers.

DataLink Layer:

- employasimplified versionof HDLC -HDLCfieldsfor extensiveerrorcheckingandflow control not needed.
- Addressingandcontrolfieldscombinedintoonefield.



- Framefields
  - Addressing(DLCI)fields:twoparts(6bits,4bits). Apart ofthe 16-bit datalinkconnection identifier.
  - Command/Response(C/R): allowsupper layerstoidentifyaframeaseither acommandor a response.
  - Extendedaddress(EA):EA=0 another addressbytefollows, EA=1 thecurrentbyteisthe final one.
  - Forwardexplicitcongestion notification(FECN):initiatedwhenaDTEdevicesendsFrame Relay frames into the network. When the frames reach the destination DTE device, the frame experienced congestion in the path from source to destination. flow-control may be initiated, or the indication may be ignored.
  - Backwardexplicit congestionnotification(BECN): DCEdevicessetthevalueof theBECN bit to 1 in frames traveling in the opposite direction, informs the receiving DTE device thata particular path through the network is congested. flow-control may be initiated, or the indication may be ignored.
  - Discard eligibility(DE):(DE) bit isusedtoindicatethat a framehaslower importancethan other frames. When the network becomes congested, DCE devices will discard frames with the DE bit

FrameRelayOperation:

- Transmissionisbasedonpermanentvirtualcircuit
- DLCIidentifiesapermanentvirtualcircuitthatissetupwhenthesystemisputinplace

- Replay
  - Routinginformationisincludedinthedestinationinformation.
  - ThepathformpointAtopointDalways passesthroughthe samenode.
  - Thefunctionsofroutingandswitching canbehandledbythedatalinklayer.
  - Framerelay(frameswitching)occursatthedatelink layer wherethetransmissionunitis the frame
  - Packetswitchingoccursatthenetworklayerwherethetransmissionunitisthepacket
- Switching
  - Twooperationsofa switch
    - checksaframefor errorsusingtheFCSfield: if anerror, discardit
    - comparesthe DLCI toanentryin a switch tableandfind anoutgoing port for the PVC identified by the DLCI

- **Congestion Control**
  - doesnotsolvethe problem,butdoesprovide ways tolessentheprobabilityof its occurrence
  - Aswitchin aPVCwarns its downstreamswitches anddestination byturning ontheFECN bit
  - Thereceiver, in turn, set BECN to warn upstream switches and thesenderthat thelink is congested and to send frames more slowly.
  - This option cannot be used unlessthechannel is eitherfull- orhalf-duplexand the receiver is sending its own data or acknowledgments to the sender

FrameRelayImplementation

- Themostlikelyimplementation:
  UsedasaWANbackbone toconnect anumberofLANs usingT-1links
  - Frame relay assembler/disassembler(FRADs): assembles and disassembles packetscomingfromother protocolstoallowthem to becarried byframerelay frames

AsynchronousTransferMode(ATM)

- ATMis*AsynchronousTransfer Mode*.
- ATMisaconnection-oriented,high-speed,low-delayswitchingandtransmission technology that uses short and fixed-size packets, called cells, to transport information.
- ATM is originally the transfer mode for implementing Broadband ISDN (B-ISDN) but it is also implemented in non-ISDN environments where very high data rates are required
- astreamlinedpackettransferinterface
- similaritiestopacketswitching
  - transfersdataindiscretechunks
  - supportsmultiplelogicalconnectionsoverasinglephysicalinterface
- ATMusesfixedsizedpacketscalledcells
- withminimalerrorandflowcontrol
- dataratesof25.6Mbps to622.08Mbps

ATMOVERVIEW

- Used in bothWAN andLAN settings
- Signaling(connectionsetup)Protocol:

- Packets are called *cells*(53bytes)
  - 5-byteheader+48-bytepayload
- Commonlytransmittedover SONET
  - otherphysicallayerspossible
- Connectionscanbeswitched(SVC),orpermanent (PVC).
- ATMoperatesonabest effortbasis.
- ATMguaranteesthatcellswillnotbedisordered.
- Twotypes ofconnections:
  - Point-to-point
  - Multipoint(Multicast)
- FourTypes ofServices:
  - CBR(ConstantBitRate)
  - VBR(VariableBitRate)
  - ABR(AvailableBitRate)FlowControl,Rate-based,Credit-based
  - UBR(UnspecificBitRate)NoFlowcontrol.

ATMCharacteristics

- Noerror protectionorflowcontrolonalink-by-linkbasis.
- ATMoperatesinaconnection-orientedmode.
- Theheaderfunctionalityisreduced.
- Theinformationfieldlengthisrelativelysmallandfixed.
- Alldatatypes arethe same

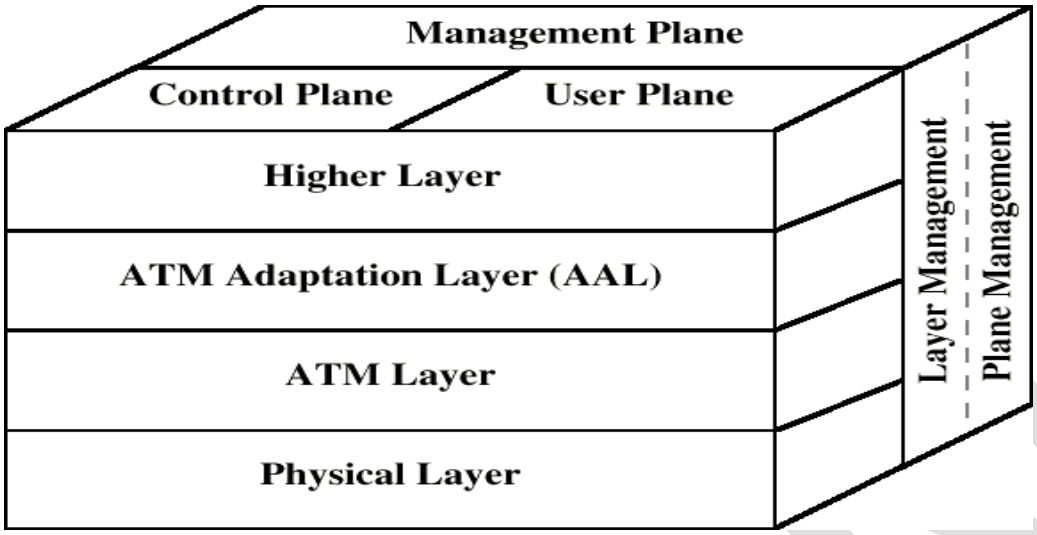
ATMNETWORKS

- PublicATMNetwork:
  - Provided bypublic telecommunications carriers(e.g., AT&T,MCIWorldCom,and Sprint)
  - InterconnectsprivateATMnetworks
  - Interconnectsremotenon-ATMLANs
  - Interconnectsindividualusers
- PrivateATMNetwork:
  - Ownedbyprivateorganizations
  - Interconnectslowspeed/sharedmediumLANs(e.g.,Ethernet,TokenRing,FDDI) as a backbone network
  - Interconnectsindividualusersasthefront-endLANforhighperformanceor multimedia applications

HowATMWorks?

- ATMis connection-oriented -- anend-to-endconnection must beestablished androuting tables setup prior to cell transmission
- Onceaconnectionisestablished,theATMnetworkwillprovideend-to-endQualityof Service (QoS) to the end users
- All traffic, whether voice, video, image, or data is divided into 53-byte cells and routed in sequence across the ATM network
- Routinginformationiscarriedintheheaderofeachcell
- RoutingdecisionsandswitchingareperformedbyhardwareinATMswitches
- Cellsarereassembledintovoice,video,image,ordataatthedestination

ATMProtocol Architecture



ReferenceModelPlanes

- userplane
  - providesforuserinformation transfer
- controlplane
  - callandconnectioncontrol
- managementplane
  - planemanagement
    - wholesystemfunctions
  - layermanagement
    - Resourcesandparametersinprotocolentities

ATMLogicalConnections

- virtualchannelconnections(VCC)
  - analogoustovirtualcircuitinX.25
- basicunitofswitchingbetweentwoendusers
  - fullduplex
  - fixedsizecells
- also for
  - user-networkexchange(control)

ATMVIRTUALCIRCUITS

- VCtransport:cellscarriedonVCfromsourceto destination
  - callsetup,teardownforeachcall*before*datacanflow
- eachpacketcarriesVCidentifier(notdestinationID)
- *every*switchonsource-destpathmaintain"state"foreachpassing connection
- link,switch resources (bandwidth, buffers) may be *allocated* to VC: to get circuit-like perf.
- PermanentVCs(PVCs)
- longlastingconnections
- typically:"permanent"routebetweentolProuters

- SwitchedVCs(SVC):
  - dynamicallysetuponper-call basis
- The virtual channel (VC) is the fundamental unit of transport in a B-ISDN. Each ATM cell contains an explicit label in its header to identify the virtual channel.
  - aVirtualChannelIdentifier (VCI)
  - aVirtualPathIdentifier(VPI)

- A *virtual channel (VC)* is a communicationchannel that provides for the transport of ATM cells between two or more endpoints for information transfer.
- A Virtual Channel Identifier (VCI) identifies a particular VC within a particular VP over a UNI or NNI.
- Aspecificvalueof VCIhasnoend-to-endmeaning.

ATMProtocolLayer

- **Physical Layer:** The lowest layer in the ATM protocol. It describes the physical transmissionmedia.Wecanuseshieldedandunshieldedtwistedpair,coaxialcable,and fiber-optic cable.
- **ATM Layer:** It performs all functions relating to the routing and multiplexing of cells over VCs. It generates a header to the segment streams generated by the AAL. Similarly, on receiptofacellstreams,itremovestheheaderfromthecellandpassthecellcontentsto the AAL protocol. To perform all these functions, the ATM layer maintains a table which contains a list of VCIs.
- **ATM Adaptation Layer**: Top layer in the ATM protocol Model. It converts the submitted informationintostreamsof 48-octetsegmentsandtransportstheseinthepayloadfieldof multiple ATM cells. Similarly, on receipt of the stream of cells relating to the same call, it converts the 48-octet information field into required form for delivery to the particular higherprotocollayer.Currentlyfiveservicetypeshavebeendefined.Theyarereferredto as AAL1-5. AAL1 and AAL2 are connection oriented. AAL1 provides a constant bit rate (CBR) service, where as AAL2 provides a variable bit rate (VBR) service. Initially, AAL 3 wasdefinedtoprovideconnectionorientedandVBRservice.Later,thisservicetypewas dropped and it is now merged with AAL 4. Both AAL ¾ and AAL 5 provide a similar connectionless VBR service.
- "adapts"upperlayers(IPornativeATMapplications)toATMlayer below
- AALexists onlyinendsystems,notin switches
- AALlayersegment(header/trailerfields,data)fragmentedacrossmultipleATMcells
- AAL Services
  - Handletransmissionerrors
  - Segmentation/reassembly(SAR)
  - Handlelostandmisinsertedcellconditions
  - Flowcontrolandtiming control

AALSUBLAYERS

- AALlayerhas 2sublayers:
  - ConvergenceSublayer(CS)
  - SupportsspecificapplicationsusingAAL
  - managestheflowofdata toandfromSAR sublayer
  - Timingandcelllossrecovery
- SegmentationandReassemblyLayer (SAR)
  - Packagesdatafrom CSintocellsandunpacksatotherend

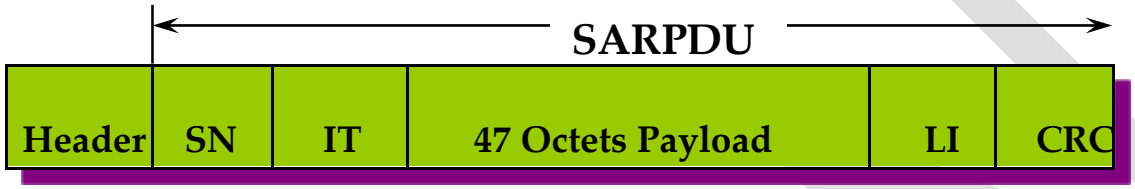
AALTypes:

AAL1 (ConstantBit Rate)Functions

- Constant-bit-ratesource

- SARsimplypacksbits into cellsandunpacksthem atdestination
- EmulationofDS1andDS3 Circuits
- Distributionwithforwarderrorcorrection
- Handlecelldelayforconstantbitrate
- Transfertiminginformationbetweensourceanddestination
- Transferstructureinformation(structurepointer)
- Provideindicationofunrecoverablelostorerrorinformation

AAL2ProtocolDataUnit(PDU)

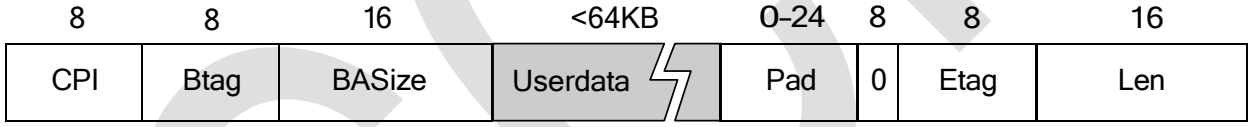


- SN:Sequencenumber
- IT:InformationType:BOM,COM,EOM,SSM
- Length Indicator

BOM: beginning of message
COM:continuationofmessage
EOM end of message

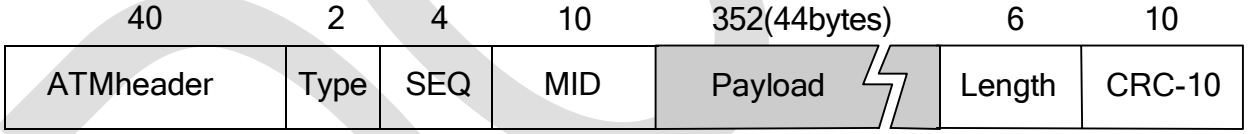
AAL3/4

- ConvergenceSublayerProtocolDataUnit(CS-PDU)



  - CPI:commercepartindicator(versionfield)
  - Btag/Etag:beginningandendingtag
  - BAsize:hintonamountofbuffer spacetoallocate
  - Length:sizeofwholePDU

Cell Format



  - Type
    - BOM:beginningofmessage
    - COM:continuationofmessage
    - EOMend ofmessage
  - SEQ:sequenceofnumber
  - MID:message id
  - Length:number of bytesofPDUinthiscell

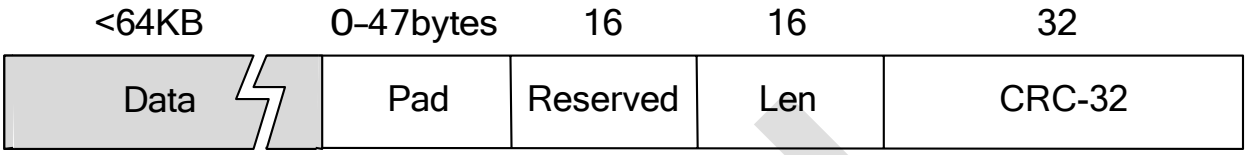
AAL5PDUStructure

- isusedtotransportIPdatagrams overATMnetworks.
- TheSimpleandEfficientAdaptationLayer(SEAL),attemptstoreducethecomplexityand overhead of AAL 3/4.
- Iteliminatesmostoftheoverheadof AAL 3/4.
- AAL5compriseaconvergencesublayerandaSARsublayer,althoughtheSARis essentially null.
- Streamlinedtransportforconnectionorientedprotocols
  - Reduceprotocolprocessingoverhead

- Reducetransmissionoverhead
- Ensureadaptabilitytoexistingtransportprotocols

AAL5

- CS-PDUFormat



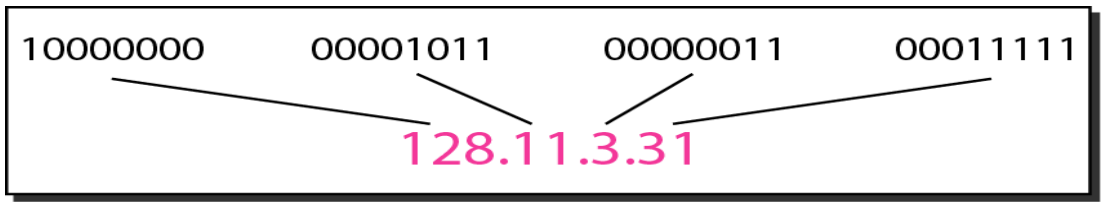
  - padsotraileralwaysfallsatendofATMcell
  - Length:sizeofPDU(dataonly)
  - CRC-32(detectsmissingormisorderedcells)
- CellFormat
  - end-of-PDUbitinTypefieldofATMheader

MODULEIII

Internetworking:

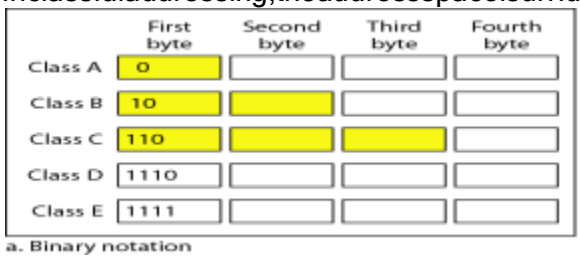
EachnetworkinterfaceontheInternetasauniqueglobaladdress,calledtheIPaddress.AnIPaddress- is 32 bits long. It encodes a network number and a host number. The address space of IPv4 is 2^{32} or 4,294,967,296.

IPaddressesarewritteninadotteddecimalnotation:

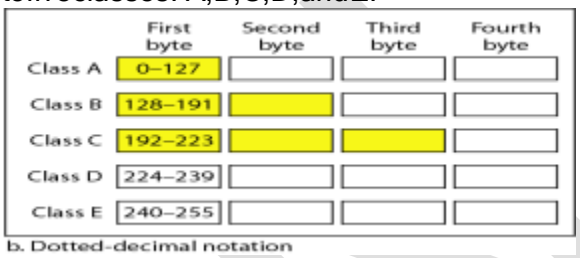


ClassfulAddressing:

Inclassfuladdressing,theaddressspaceisdividedintofiveclasses: A,B,C,D,andE.



a. Binary notation



b. Dotted-decimal notation

- **ClassAnetworks**
  -Firstoctetvaluesrangefrom1through127
  -Firstoctetstartswithbit0
  -Networkmaskis8bits,written/8or255.0.0.0
  -1.0.0.0through127.0.0.0areclassAnetworkswith16777214hostseach.
- **ClassBnetworks**
  -Firstoctetvaluesrangefrom128through191
  -Firstoctetstartswithbinarypattern10
  -Networkmaskis16bits,written/16or255.255.0.0
  -128.0.0.0through191.255.0.0areclassBnetworks,with65534hostseach.
- **ClassCnetworks**
  Firstoctetvaluesrangefrom192through223
  -Firstoctetstartswithbinarypattern110
  -Networkmaskis24bits,written/24or255.255.255.0
  -192.0.0.0through223.255.255.0areclassCnetworks,with254hostseach.
- **ClassDaddresses**
  - Firstoctetvaluesrangefrom224through239
  - Firstoctetstartswithbinarypattern 1110
  - ClassDaddressesaremulticast addresses.
- **ClassEaddresses**
  - Reservedforfutureuse.

Themask

•Thenetworkportionoftheaddressisseparatedfromthehostportionoftheaddressbyamask.
•Themasksimplyindicateshowmanybitsareusedforthenetworkportion,leavingtheremaining bits for the host portion.
•A24-bitmask indicatesthatthefirst24bitsof theaddressarenetwork bits, andtheremaining8 bits are host bits.
•A 16-bit mask indicates that the first 16 bits of the address are network bits, and the remaining 16 bits are host bits.

SubnetMask:

Subnet masks are used to make classful networks more manageable and efficient, by creating smaller subnets and reducing the number of host addresses per subnet to what is actually required.

• Subnetmaskswerefirstusedonclass boundaries.
• Example

– TakeclassAnetwork10.0.0.0 withnetworkmask255.0.0.0.
– Addadditional8subnetbitstonetworkmask.
– Newsubnetmaskis255.255.0.0.
– Newsubnetsare10.0.0.0,10.1.0.0,10.2.0.0,andsoonwith65534hostaddressespersubnet. Still too many hosts per subnet.
• Example
– TakeclassAnetwork10.0.0.0withnetworkmask 255.0.0.0.
– Addadditional16subnetbitstonetworkmask.
– Newsubnetmaskis255.255.255.0
– Newsubnetsare10.0.0.0,10.0.1.0,10.0.2.0,…,10.1.0.0,10.1.1.0,10.1.2.0,…,10.2.0.0, 10.2.1.0,10.2.2.0, andsoonwith254host addressespersubnet.

ROUTING:

Static routing:

- Staticroutesaremanuallyenteredinto arouterorhost.
- Anadministratormustknowtheinternetworklayoutandthepathsthatexistbetweennetworks.
- Then the administratormust program eachrouter inthe internetwork with theproper routesto get from any given network to any other network.
- ThehostsobtaintheirroutesmanuallyorviaDHCP.

Dynamicrouting

- Dynamicroutesareroteslearnedviaoneormoreroutingprotocols.
- Routing protocolsareused byrouterstoinformoneanother oftheIP networks accessibleto them.
- Thereareclassfulrouting protocols,suchasRIPv1, thatdo not transmitmasksintheirrouting updates - the classful network mask is implied.
- Thereareralsoclassless routing protocols,suchasOSPF,thatdo transmit masks intheir routing updates.
- Routing protocolstypicallydo notapplytohosts. Hosts obtaintheirroutes bymanual configuration or by DHCP.

Staticvs.dynamicrouting

Themaindifferencebetweenstaticroutesanddynamicroutesisthatfirstoneisenteredin manually and the other is learned and/or calculated dynamically.

- Thebigdifferentiator,however,isinhowtheroutersadapttosporadicchangesinnetwork topology caused by outages.
- A statically routed network has almost no way of adapting to temporary topology changes. But routing protocols are designed for this purpose.
- A keyfactor in designing networks and choosing a routing protocol is convergencetime, which is the time it takes for the network as a whole to discover its topology and reach a steady state.
- In general, the shorter the convergences time the better. A network that converges quickly can better compensate for unexpected outages.

RoutingProtocolCategory:

- Exterior Routing Protocols – usedfor use between different organizations such as ISPs or ISPs and their customers.
  - Ex:BorderGatewayProtocol(BGP)
- Interior Routing Protocols – usedto distribute routing information inside a single organization.
  - Ex: RIP,IGRP,EIGRP,OSPF,IS-IS

Interiorvs.ExteriorGatewayProtocols

- IGPsareusedtoexchangerouting information withrouters inthesameautonomous system (AS).

- An AS is a collection of networks under a common administrative domain, which basicallymeansthatallrouterssharingthesamerouting tableinformationare inthe same AS.
- EGPsareusedtocommunicatebetweenAsssuchas inWANlinks.

ThreeClassesofRoutingProtocols:

- DistanceVector-findsthebestpath to a remote networkusing**hop count**.(RIP,IGRP)
- LinkState–(alsocalledshortest-path-firstprotocols) –therouterseachcreatethree separatetables. 1)keeps track of directlyattachedneighbors,2)topologyof network, 3) therouting table. (OSPF, IS-IS)
- Hybrid-usesaspectsofbothdistancevectorandlinkstate.(EIGRP)

ApproachestoRouting–Distance-vector

- Eachnode(routerorhost)exchangeinformationwithneighboringnodes
  - Neighborsarebothdirectlyconnectedtosamenetwork
- Nodemaintainsvector oflinkcostsforeachdirectlyattached network anddistanceand next-hop vectors for each destination
- UsedbyRoutingInformationProtocol(RIP)
- Requirestransmissionof lotsofinformationbyeachrouter
  - Distancevectortoall neighbors
  - Containsestimatedpathcosttoallnetworksin configuration
  - Changestakelongtimetopropagate
  - Inpractice,BellmanFordalgorithm

ApproachestoRouting–Link-state

- Designedtoovercomedrawbacksofdistance-vector
- Whenrouterinitialized,itdetermineslinkcostoneachinterface
- Advertisessetof linkcoststoallotherroutersintopology
  - Notjustneighboringrouters
- Fromthenon,monitorlinkcosts
  - Ifsignificantchange,routeradvertisesnewsetoflinkcosts
- Eachroutercanconstructtopologyofentireconfiguration
  - Cancalculateshortestpathtoeachdestinationnetwork
- Routerconstructsroutingtable,listingfirsthoptoeachdestination
- Routerdoesnotusedistributedroutingalgorithm
  - Useanyroutingalgorithmtodetermineshortestpaths
  - Inpractice,Dijkstra'salgorithm
- Openshortestpathfirst(OSPF)protocoluseslink-staterouting.

ExteriorRouterProtocols–Path-vector

- Dispensewithroutingmetrics
- Provide information about whichnetworkscanbereachedbyagiven router andASs crossed to get there
  - Doesnotincludedistanceorcostestimate
- Eachblock ofinformationlistsallASsvisited onthisroute
  - Enablesroutertoperformpolicyrouting
  - E.g.avoidpathtoavoidtransitingparticular AS
  - E.g. linkspeed,capacity,tendencytobecomecongested,andoverallqualityof operation, security
  - E.g.minimizingnumberoftransit Ass

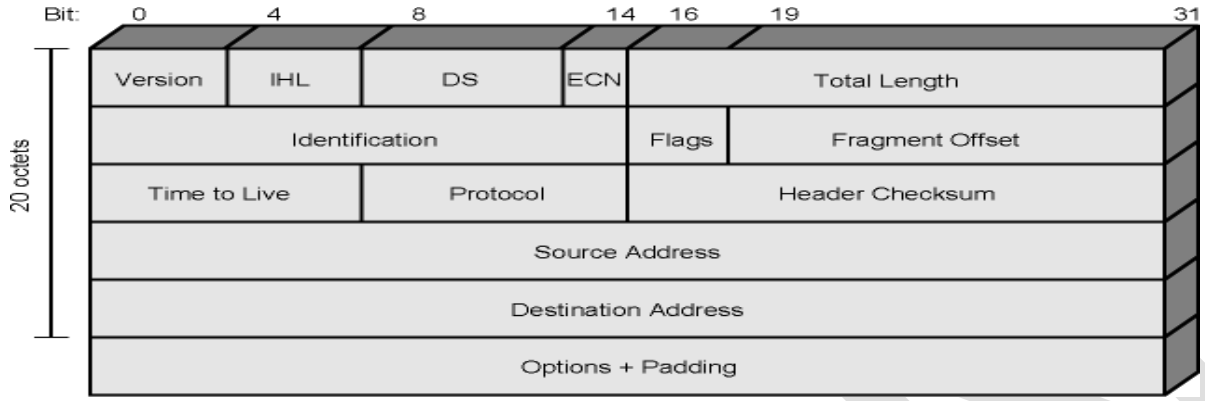
NETWORKLAYERPROTOCOLS

Internet Protocol (IP)

- IPisaconnectionless,unreliable,best-effortdeliveryprotocol.
- IPacceptswhatever dataispasseddowntoitfromthe upper layers andforwards the data in the form of IP Packets.

- ❖ Allthenodesareidentifiedusinganip address.
- ❖ Packetsaredeliveredfromthesourcetothedestinationusingipaddress

IPV4 Header:



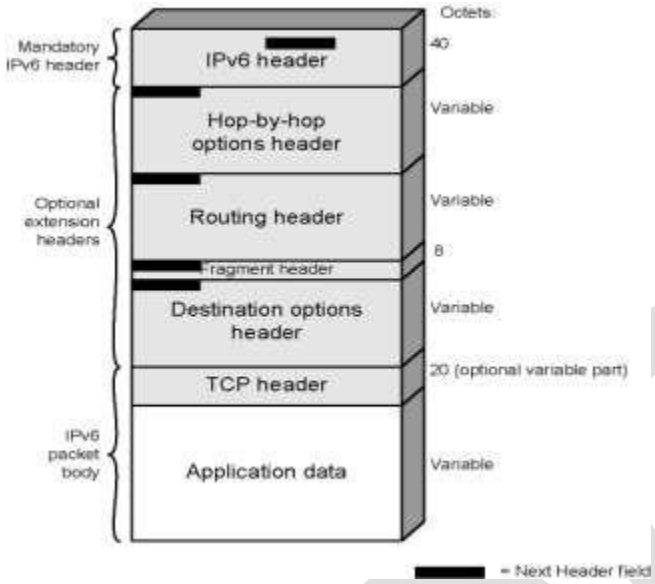
- Version
  - — Currently4
  - — IP v6-seelater
- Internetheaderlength
  - — In 32bitwords
  - — Includingoptions
  - — minimum5
- DS(DifferentiatedServices)andECN(ExplicitCongestionNotification)
  - — previouslyusedfor“TypeofService”
  - — nowusedby(interpretedas)DS andECN
  - — DSisforQoSsupport(that wewillnot cover)
  - — wewillseetheconceptofExplicitCongestionNotificationlater
- Totallength
  - — ofdatagram (header+data), in octets
- Identification
  - — Sequencenumber
  - — Usedwithaddressesanduserprotocoltoidentifydatagramuniquely
- Flags
  - — Morebit
  - — Don’tfragment
- Fragmentationoffset
- Timetolive
- Protocol
  - — Nexthigherlayertoreceivedatafieldat destination
- Header checksum
  - — Verifiedandrecomputedateachrouter
- Sourceaddress
- Destinationaddress
- Options
- Padding
  - — Tofilltomultipleof 32bitslong

AdvantagesofIPV6overIPV4

- Expandedaddressspace
  - — 128bit
  - — $6*10^{23}$addressespersquaremeter onearth!
- Improvedoptionmechanism
  - — SeparateoptionalheadersbetweenIPv6headerandtransportlayerPDU
  - — Somearenotexaminedbyintermediaterouters

- Improvedspeedandsimplifiedrouter processing
  - Easiertoextend withnewoptions
    - Flexibleprotocol
- Supportforresourceallocation
  - Labelingofpacketsforparticulartrafficflow
  - Allowsspecialhandling
    - e.g.realtimevideo

IPv6PacketwithExtension Headers



- Hop-by-HopOptions
  - specialoptionsthatrequirehop-by-hopprocessing
- Routing
  - Similartosourcerouting
- Fragment
  - fragmentationandreassemblyinformation
- Authentication
  - IntegrityandAuthentication
- Encapsulatingsecuritypayload
  - PrivacyandConfidentiality(plusoptionalauthentication)
- Destinationoptions
  - Optionalinfotobeprocessedatdestinationnode

IPV6HeaderField:

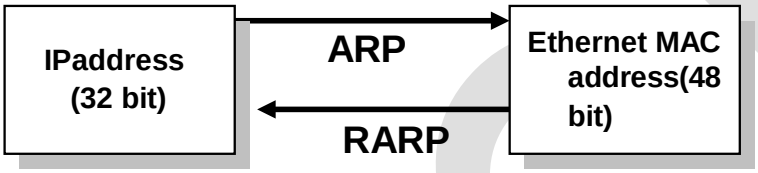
- Version
  - 6
- DS/ECN
  - Previously,TrafficClass(TypesofService)
    - Classesorprioritiesof packet
  - Nowinterpretationisdifferentasdiscussedinv4
- FlowLabel
  - Identifiesasequenceofpackets(aflow)thathasspecialhandling requirements
- Payloadlength
  - Lengthofallextensionheadersplususerdata
- NextHeader
  - Identifiestypeofheader

- Extensionornextlayerup
- Hop Limit
  - Remainingnumberofhops
  - As inTTLofIPv4,decrementedbyoneateachrouter
  - Packetdiscardedifreaches zero
- Source Address
- Destinationaddress
- Longerheaderbut lessnumberof fields
  - simplifiedprocessing

AddressResolutionProtocol(ARP)

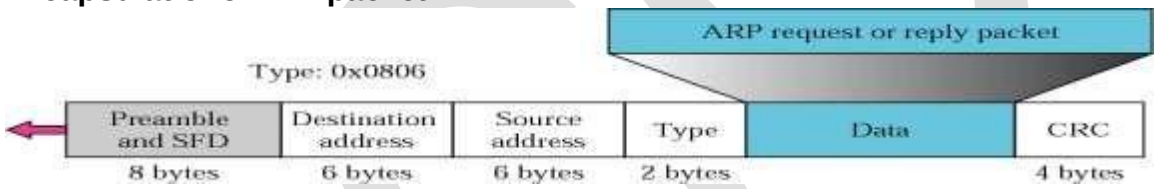
- TheInternetisbased onIPaddresses
- Datalinkprotocols(Ethernet,FDDI,ATM)mayhavedifferent(MAC) addresses

- TheARPandRARPprotocols performthetranslation betweenIPaddressesandMAC layer addresses



AnARPrequest isbroadcast whereasanARPreplyisunicast.

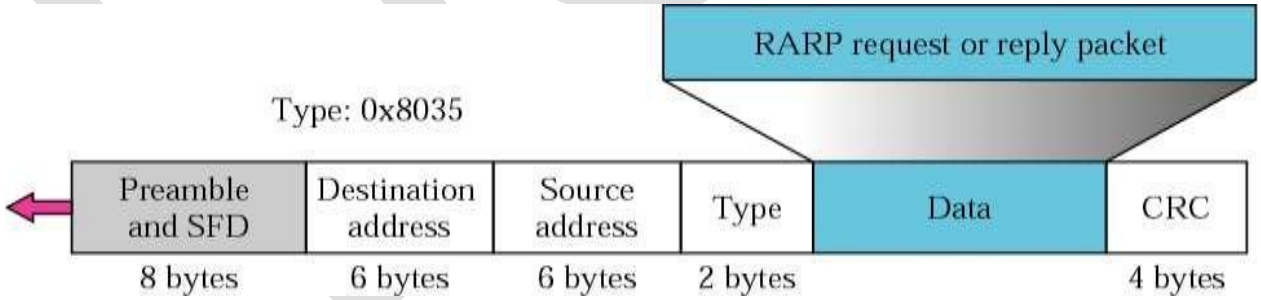
EncapsulationofARP packet:



RARP

RARPfindsthelogicaladdressforamachinethatonlyknowsitsphysicaladdress.
TheRARPrequestpacketsarebroadcast;theRARPreplypacketsareunicast.

EncapsulationofRARPpacket:



InternetControlMessageProtocol

- usedtoreportinformationand errors
- IPusesICMPwhenit sendsan error message
- ICMPuses IPtotransportmessages

ICMPErrorMessages

- SourceQuench
  - usedbyrouterwhenithasdiscardeddatagramduetounavailablebuffer memory.

- sent to source computerrequestingittoslowdown rateofdata transmission.
- TimeExceeded
  - whenever theTIME TOLIVEfield in adatagram is decrementedto0, therouter discards the datagram and sends a time exceeded message
  - eg. Traceroute sends datagrams to a destination host with TIME TO LIVE field set to 1,2,3… so that routers along the path will send time exceeded message back, allowing source to know of path or routes taken by datagram.
- DestinationUnreachable
  - sent byroutertosourcehost whenever router determinesthat adatagramcannot be delivered to its final destination. A"host unreachable" or "network unreachable" message is sent.
- Redirectmessage
  - sent byroutertosourcehost whenever router determinesthat ahost has incorrectly sent a datagramthat should be sent to a different router.
- Fragmentationrequiredmessage
  - sent byaroutertoa source host iftherouter needs tofragment a datagram but the DO NOT FRAGMENT bit had been set in the datagram header.Such a datagram is discarded by the router.

ICMPInformationalMessages

- EchoRequest message
  - sentto acomputerbysetting the *PROTOCOLTYPE*field in aIP header to 1, correspondingto *ICMP*
  - Usedby **Ping**totestforreachability.
- EchoReplymessage
  - SentbyICMPsoftwareondestinationcomputerinresponsetoechorequest.
- addressmaskrequest&reply message
  - canbe broadcasted byhost during bootup,askingforroutertosendanaddress mask reply that contains the correct 32-bit subnet mask for the network.

MulticastRouting

- Unicast: onesourcetoonedestination
- Multicast:onesourcetomanydestinations

InternetGroupManagementProtocol

- TheInternetGroupManagementProtocol(IGMP) is asimpleprotocolforthe supportof IP multicast.
- IGMPisdefinedinRFC1112.
- IGMPoperatesonaphysicalnetwork(e.g.,singleEthernetSegment.
- IGMPisusedbymulticastrouterstokeeptrackofmembershipinamulticast group.
- Supportfor:
  - Joiningamulticastgroup
  - Querymembership
  - Sendmembershipreports
- A host sendsanIGMP report when it joinsamulticast group(Note:multiple processes on a host can join. A report is sent only for the first process).
- Noreportissentwhenaprocessleavesagroup
- A multicast router regularlymulticasts anIGMP queryto allhosts(groupaddress isset to zero).

TRANSPORTLAYER

- The transport layer is an end-to-end layer – this means that nodes within the subnet do notparticipateintransportlayerprotocols–onlytheendhosts.
- As withotherlayers,transportlayer protocols senddataasasequenceofpackets (segments).
- Thenetworklayerprovidescommunicationbetweentwohosts.

- The transport layerprovidescommunicationbetweentwo *processes*runningon different hosts.
- Aprocessis aninstanceofaprogramthatisrunning onahost.
- There may be multiple processes communicating between two hosts – for example, therecouldbeaFTPsessionandaTelnetsessionbetweenthesametwo hosts.

Transportservicesandprotocols

- provide*logicalcommunication*betweenappprocessesrunningondifferent hosts
- transportprotocolsruninendsystems
  - sendside:breaksappmessagesintosegments,passestonetworklayer
  - rcvside:reassemblessegmentsintomessages,passestoapplayer
- morethanonetransportprotocolavailabletoapps
  - Internet:TCPandUDP

TransportLayer Protocols:

- reliable,in-orderdelivery(TCP)
  - congestioncontrol
  - flow control
  - connectionsetup
- unreliable,unordereddelivery:UDP
  - no-frillsextensionof"best-effort"IP
- servicesnotavailable:
  - delayguarantees
  - bandwidthguarantees

UDP: UserDatagram Protocol

- "nofrills,""barebones"Internettransportprotocol
- "besteffort"service,UDPsegmentsmaybe:
  - lost
  - deliveredoutof ordertoapp
- *connectionless:*
  - nohandshakingbetweenUDPsender,receiver
  - eachUDPsegmenthandledindependentlyof others
- oftenusedforstreamingmultimedia apps
  - loss tolerant
  - ratesensitive
- other UDP uses
  - DNS
  - SNMP
- reliabletransferoverUDP:addreliabilityatapplicationlayer
  - application-specificerrorrecovery!

TCPService Model

- TCP Service is obtained by having both the sender and receiver create end points, called sockets. Eachsocket hasasocket number(address)consisting of the IPaddress of the host and a 16-bit number local to that host, called a port.
- ToobtainTCPservice, aconnectionmustbe explicitlyestablishedbetweena socketon the sending machine and a socket on the receiving machine.
- A socketmaybe usedfor multiple connections atthe sametime. In otherwords, two or more connections may terminate at the same socket.
- Port numbers below 1024 are called well-known ports and are reserved for standard services. For example, any process wishing to establish a connection to a host to transferafileusing FTPcan connect tothe destination host'sport 21tocontact itsFTP

daemon/service. Similarly, toestablisha remoteloginsession using TELNET, port 23 is used. Port 80 is used for HTTP, port 443 is used for SSL, etc.

- Portsbetween 1024 and5000 arecalled ephemeral and arefreeto use(not reserved). The client's socket would use such port.
- AllTCPconnectionsarefull-duplexandpoint-to-point. Fullduplexmeansthattrafficcan go in both directions at the same time. Point-to-point means that each connection has exactly two end points. TCP does not support multicasting or broadcasting.
- ATCPconnectionis bytestream, notamessagestream. Messageboundaries arenot preserved end to end.
- For example, if thesending process doesfour 512-byte writes toaTCP stream, these data may be delivered to the receiving process asfour 512-byte chunks, or two 1024-byte chunks, or one 2048-byte chunk, or some other way.
- When anapplication passes datatoTCP,TCPmaysend it immediatelyorbufferit (in order to collect a larger amount to send at once), at its discretion.
- EverybyteonaTCPconnectionhasitsown32-bit sequencenumber.
- The sending and receiving TCP entities exchange data in the form of segments. A segmentconsists of afixed 20-byteheader(plusan optionalpart)followedby0ormore data bytes. The TCP software decides how big segments should be. It can accumulate data from several writes into one segment or split data from one write over multiple segments.
- Twolimitsrestrictthesegmentsize:
- Eachsegment,includingtheTCPheader,mustfitinthe64KbyteIPpayload
- Each network hasamaximumtransfer unitorMTU, andeachsegmentmustfit inthe MTU.
- TCPusesaslidingwindowmechanismforflowcontrol
- Sendermaintains3pointersforeachconnection
- Pointertobytessentand acknowledged
- Pointertobytessent, butnotyetacknowledged
- *Senderwindowincludesbytessentbutnot acknowledged*
- Pointertobytesthat cannot yet besent
-

Port Numbers:

- Port numbers are16-bitintegers(0→65,535)
  - Servers use*wellknowports*, 0-1023 are privileged
  - Clientsuse*ephemeral*(short-lived)ports
- *InternetAssignedNumbersAuthority*(IANA)maintainsalistofportnumberassignment
  - Well-knownports(0-1023)→controlledandassignedbyIANA
  - Registered ports(1024-49151) →IANAregistersandlists useof portsasa convenience (49151 is ¾ of 65536)
  - Dynamicports(49152-65535)→ephemeral ports

SocketAddressing

- Process-to-processdeliveryneeds*two*identifiers
  - IPaddressandPortnumber
  - Combination of IPaddress andport numberis called asocketaddress(asocket is a communication endpoint)
  - Clientsocketaddressuniquelyidentifiesclientprocess
  - Serversocketaddressuniquelyidentifiesserverprocess
- Transport-layerprotocolneedsa*pair*of socketaddresses
  - Clientsocketaddress
  - Server socketaddress
  - For example,socketpairfor aTCPconnection isa4-tuple
    - ✓ LocalIPaddress,localport,and
    - ✓ foreignIPaddress,foreign port

Multiplexing and Demultiplexing:

Multiplexing

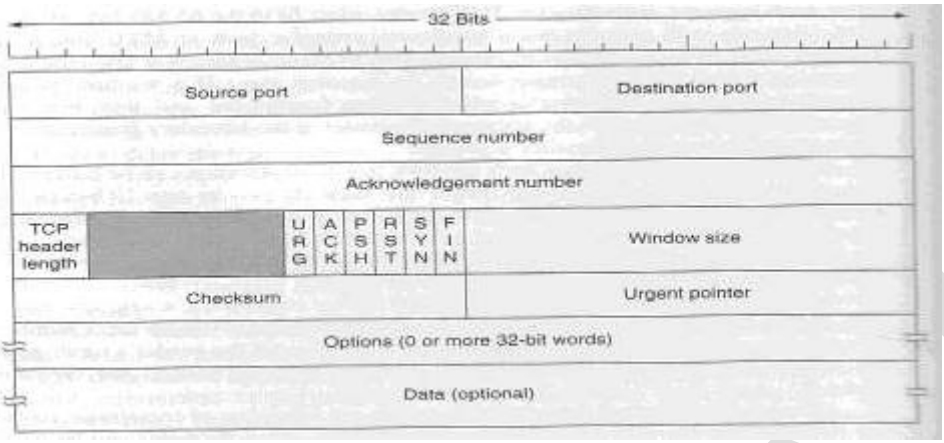
Sendersidemayhaveseveralprocessesthatneedtosendpackets(albeitonly1transport-layer protocol)

Demultiplexing

At receiver side, after error checking and header dropping, transport-layer delivers each message to appropriate process

- **FlowControl**
  - Tell peer exactly how many bytes it is willing to accept (advertised window →sender can not overflow receiver buffer)
    - ✓ *Senderwindowincludesbytessentbutnot acknowledged*
    - ✓ *Receiverwindow(numberofemptylocationsinreceiverbuffer)*
    - ✓ Receiveradvertiseswindowsizein ACKs
  - Senderwindow<=receiverwindow(flowcontrol)
    - ✓ Slidingsenderwindow(withoutachangeinreceiver'sadvertisedwindow)
    - ✓ Expandingsenderwindow(receivingprocessconsumesdata fasterthanitreceives →receiverwindowsizeincreases)
    - ✓ Shrinkingsenderwindow(receivingprocessconsumesdatamoreslowlythanit receives →receiver window size reduces)
    - ✓ Closingsenderwindow(receiveradvertisesawindowofzero)
- **Error Control**
  - Mechanismsfordetectingcorruptedsegments,lostsegments,out-of-order segments, and duplicated segments
  - Tools:checksum(corruption),ACK,andtime-out(onetime-outcounterpersegment)
    - ✓ *Lost segment or corrupted segment* are the same situation: segment will be retransmitted after time-out (no NACK in TCP)
    - ✓ *Duplicatesegment*(destinationdiscards)
    - ✓ *Out-of-order segment* (destination does not acknowledge, until it receives all segments that precede it)
    - ✓ *LostACK*(lossofanACKisirrelevant,sinceACKmechanismis cumulative)
- **CongestionControl**
  - TCPassumesthecauseofalostsegmentis duetocongestion inthe network
  - Ifthecauseofthelostsegmentiscongestion,retransmissionofthesegmentdoes not remove the problem, it actually aggravates it
  - Thenetworkneedstotellthesendertoslowdown(affectsthesenderwindowsize in TCP)
  - Actualwindowsize=Min(receiverwindowsize,congestionwindowsize)
    - ✓ Thecongestionwindowisflowcontrolimposedbythesender
    - ✓ Theadvertisedwindowisflowcontrolimposedbythe receiver

TCPsegment Header:



- SourceportandDestinationport-identifythelocalendpointsoftheconnection.
- Sequencenumberandacknowledgementnumber(specifiesthenextsequencenumber expected)
- TCP header length – tells now many 32-bit words are contained in the TCP header (becauseOptionsfieldisofvariablelength)
- Next comesa6-bitfieldthat is not used.
- Next come61-bitflags:
  - URG is set to 1 if the Urgent pointer is in use. The Urgent Pointer is used toindicate abyteoffset(fromthe currentsequencenumber) at which urgentdatais located
  - ACK is set to 1 to indicate that the acknowledgement number field is valid. Otherwise, if setto0,thenthissegment doesnotcontainanacknowledgment
  - PSHbit indicates PUSHeddata.Thereceiver herebykindlyrequestedtodeliver the data to the application upon arrival and not buffer it (done for efficiency)
  - RST bit is used to reset a connection that has become confused due to a host crash orsomeotherreason.Itis alsousedtoreject aninvalidsegment orrefuse an attempt to open a connection.
  - SYN bit is used to establish connections. SYN=1 and ACK=0 – connection request, SYN=1 and ACK=1 – connection accepted.
  - FIN but is usedtorelease a connection. It specifies that thesender has no more data to transmit.
- Windowsizefieldtellshowmanybytesmaybesent startingatthebyte acknowledged.
- A Checksum is also provided for extreme reliability – it checksums the header and the data.
- Options field was designed to provide a way to add extra facilities not covered by the regular header.Forexample, alloweachhosttospecifythemaximumTCPpayloadit is willing to accept. (using large segments is more efficient than using small ones)

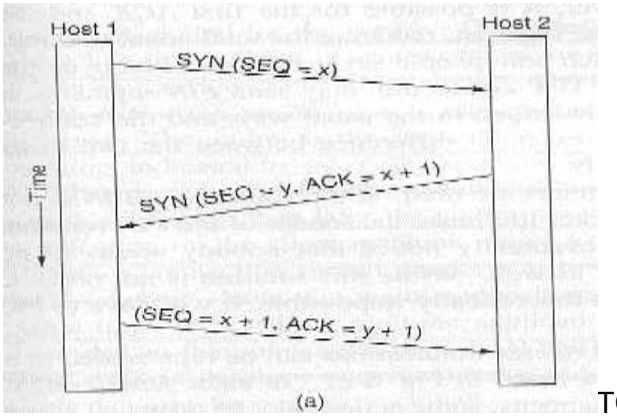
TCPConnectionEstablishment

- TCPusesa**three-wayhandshake**toopen aconnection:
  - **(1) ACTIVEOPEN:**Clientsendsasegmentwith
    - SYNbitset *
    - portnumber of client
    - initialsequencenumber(ISN)ofclient
  - **(2) PASSIVEOPEN:**Serverrespondswithasegmentwith
    - SYNbitset *
    - initialsequencenumberof server

– ACKforISNofclient

(3) Clientacknowledgesbysendingasegmentwith:

– ACK ISN of server (*countsasonebyte)



TCP connection Establishment

SYN: Synchronize
ACK:Acknowledge

TCPConnectionTermination

- Eachendofthedataflowmust beshutdownindependently**("half-close")**
- If oneendis doneitsendsa FINsegment.Thismeansthatnomoredatawillbesent
- Four steps involved:
  (1) X sendsaFINtoY **(activeclose)**
  (2) YACKstheFIN,
  (atthistime: Ycanstillsenddatato X)
  (3) and Ysendsa FINto X**(passive close)**
  (4) XACKstheFIN.

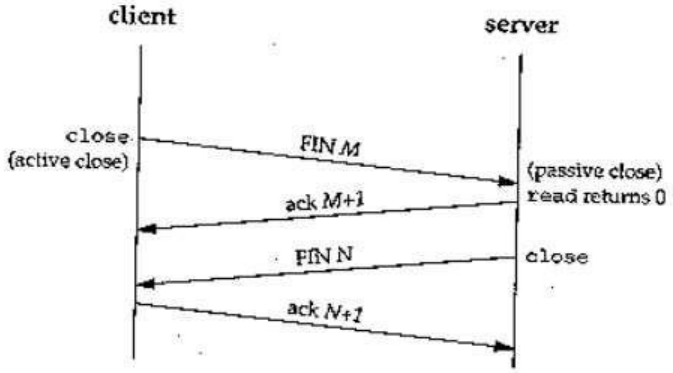
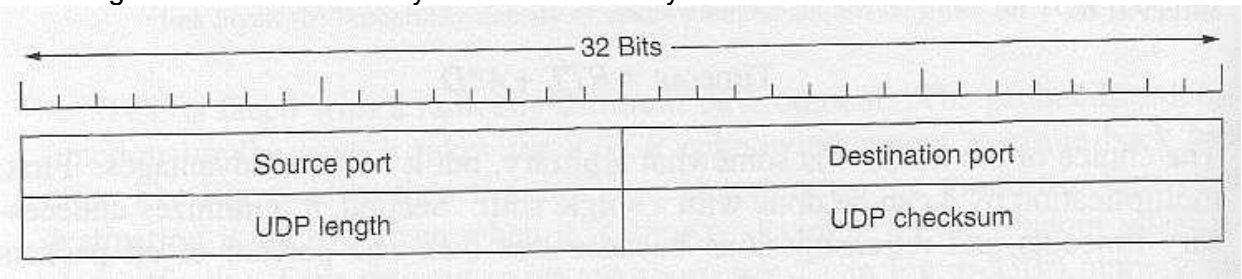


Figure 2.3 Packets exchanged when a TCP connection is closed.

- FIN:Finish
- Step 1canbesent withdata
- Steps 2and3canbecombinedinto1segment

UDP

- The Internet protocol suite also supports a connectionless transport protocol, UDP (User Data Protocol)
- UDP provides a wayforapplications tosend encapsulated rawIPdatagrams andsend them without having to establish a connection.
- Manyclient-server applicationsthathave1 request and1responseuse UDPratherthan go to the troubleof establishing and later releasing a connection.
- AUDPsegment consistsof an8-byteheaderfollowedbythedata.



UDPHeader

- Thetwo ports serve thesamefunction astheydoinTCP: to identifytheend points within the source and destination machines.
- TheUDPlengthfieldincludesthe8-byteheaderandthedata.
- TheUDPchecksum isusedtoverifythesizeof header anddata.

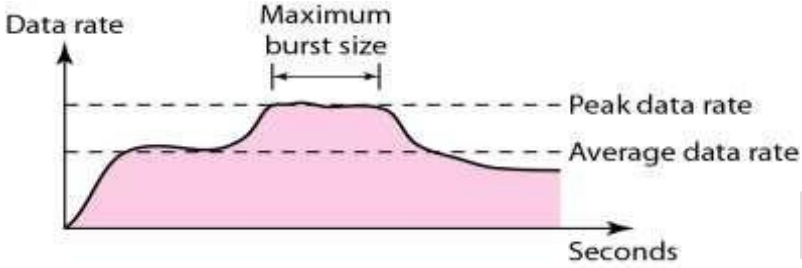
CongestionControlandQualityofservice

DATATRAFFIC

The main focus of congestion control and quality of service is data traffic. In congestion control we try to avoid traffic congestion. In quality of service, we try to create an appropriate environment for the traffic.

TrafficDescriptor

Traffic descriptors are qualitative values that represent a data flow. Figure shows a traffic flow withsome of these values.



AverageDataRate

Theaveragedatarateisthe numberof bitssentduringa period oftime,dividedbythe number of seconds in that period. We use the following equation:

Averagedatarate=amountof data/time

PeakDataRate

The peak data rate defines the maximum data rate of the traffic. The peak data rate is a very importantmeasurementbecauseitindicatesthepeakbandwidththatthenetworkneedsfortraffic to pass through without changing its data flow.

MaximumBurstSize

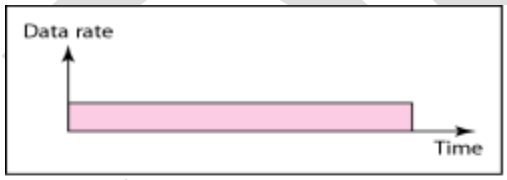
Althoughthepeak datarate is acriticalvalueforthe network,it canusuallybe ignored if the duration of the peak value is very short.

EffectiveBandwidth

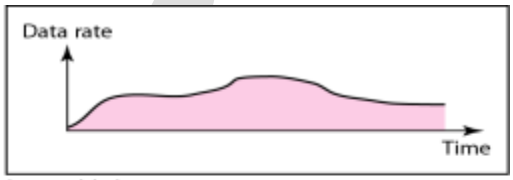
The effective bandwidth is the bandwidth that the network needs to allocate for the flowof traffic.Theeffectivebandwidth isafunctionof threevalues: averagedatarate, peakdatarate,andmaximumburstsize.

TrafficProfiles

For our purposes,adataflowcan haveoneofthefollowing trafficprofiles:constantbit rate, variable bit rate, or bursty as shown in Figure below.



a. Constant bit rate



b. Variable bit rate

c. Bursty

ConstantBitRate

A constant-bit-rate(CBR), orafixed-rate,trafficmodel hasa dataratethat doesnot change. In this type of flow, the average data ratc and thc peak data rate are the same.

VariableBitRate

In the variable-bit-rate (VBR) category, the rate of the data flowchanges in time, with the changes smooth instead of sudden and sharp.

Bursty

Inthe**burstydata**category, thedataratechangessuddenlyina veryshorttime.It mayjumpfrom zero,for example, to1Mbps in afewmicrosecondsand vice versa. Burstytraffic is one of the main causes of congestion in a network.

CONGESTION

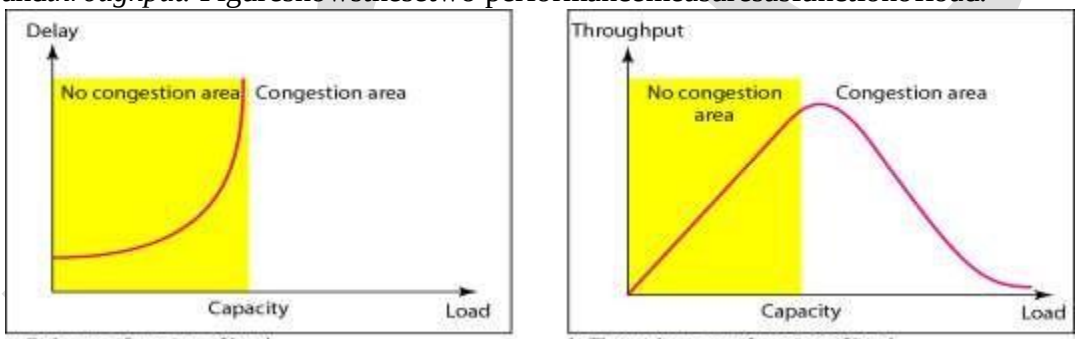
Congestion in a network mayoccur ifthe **load** on the network-the number of packets sent to the network-isgreaterthanthe*capacity*ofthenetwork-thenumberofpacketsanetworkcanhandle.

Congestion controlreferstothemechanismsand techniquestocontrolthe congestionandkeep the load below the capacity.

Congestioninanetworkorinternetworkoccursbecauseroutersandswitcheshavequeues-buffers that hold the packets before and after processing.

NetworkPerformance

Congestioncontrolinvolvestwofactorsthatmeasuretheperformanceof anetwork: *delay* and*throughput.* Figureshowsthesetwo performancemeasuresasfunctionofload.



a. Delay as a function of load

b. Throughput as a function of load

DelayversusLoad

When the load is much less than the capacityof the network, the delayis at a minimum. This minimum delay is composed of propagation delay and processing delay, both of which are negligible.However,whentheloadreachesthenetworkcapacity,thedelayincreasessharply.

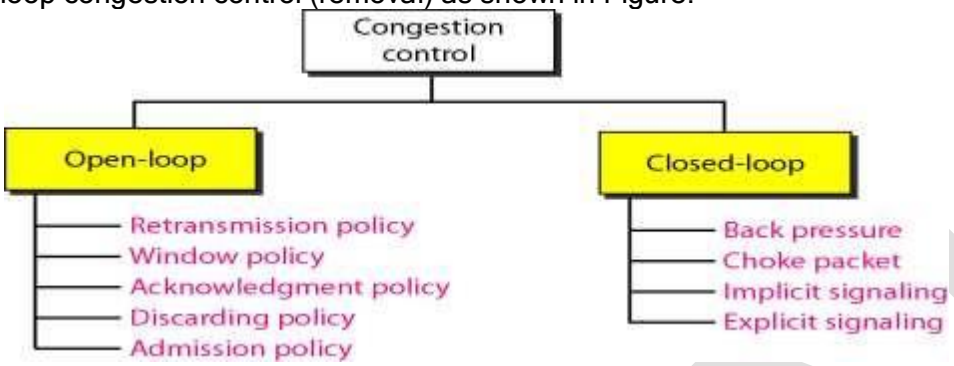
Throughput versus Load

Wecandefinethroughputinanetworkasthenumberofpacketspassingthroughthenetworkin aunitoftime.Fromtheabovefigureitcanbefoundthat whentheloadis belowthecapacityof thenetwork,thethroughputincreasesproportionallywiththe *load.*Weexpectthethroughputto remain constant after the load reaches the capacity, but instead the throughput declines sharply.

CONGESTION CONTROL

Congestioncontrolreferstotechniquesandmechanismsthatcaneitherprevent congestion,

beforeithappens,orremovecongestion,afterithashappened.wecandividecongestioncontrol mechanisms into two broad categories: open-loop congestion control (prevention) and closed-loop congestion control (removal) as shown in Figure.



Open-LoopCongestionControl

Inopen-loopcongestioncontrol,policiesareappliedtopreventcongestionbeforeithappens.

RetransmissionPolicy

Retransmission is sometimes unavoidable. If the sender feels that a sent packet is lost or corrupted, the packet needs to be retransmitted. Retransmission in general may increase congestion in the network. However, a good retransmission policy can prevent congestion.

WindowPolicy

Thetypeofwindowatthesendermayalsoaffectcongestion.TheSelectiveRepeat window is better than the Go-Back-N window for congestion control. The Selective Repeat window tries to send the specific packets that have been lost or corrupted instead of sending several packets.

AcknowledgmentPolicy

The acknowledgment policy imposed by the receiver may also affect congestion. If the receiver does not acknowledge every packet it receives, it may slow down the sender and help prevent congestion. Sending fewer acknowledgments means imposing less load on the network.

DiscardingPolicy

A good discarding policy by the routers may prevent congestion and at the same time may not harm the integrity of the transmission.

AdmissionPolicy

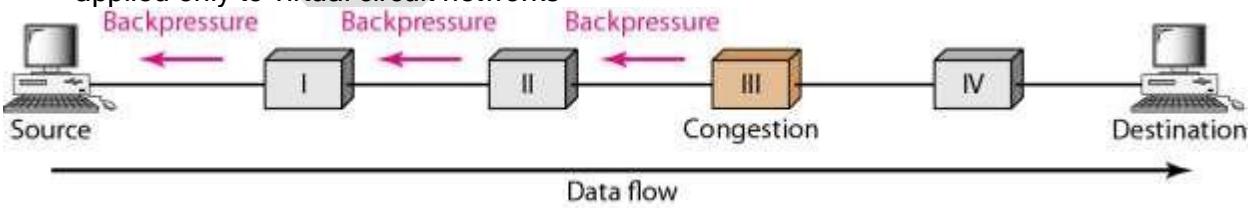
An admission policy, which is a quality-of-service mechanism, can also prevent congestion in virtual-circuit networks.

Closed-LoopCongestionControl

Closed-loopcongestioncontrolmechanismstrytoalleviatecongestionafterithappens.Severalpolicies are as follows:

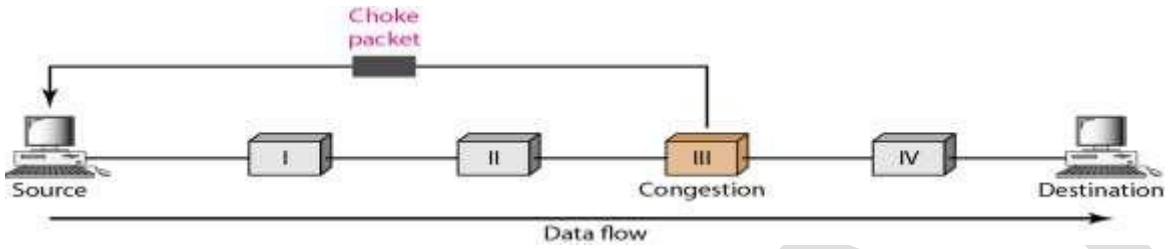
Backpressure

The technique of *backpressure* refers to a congestion control mechanism in which a congested node stops receiving data from the immediate upstream node or nodes. This may cause the upstreamnode ornodestobecomecongested,and they,inturn,reject datafromtheirupstream nodes or nodes. Backpressure is a node-to-node congestion control that starts with a node and propagates,intheoppositedirectionofdataflow,tothesource.Thebackpressuretechniquecan be applied only to virtual circuit networks



ChokePacket

Achokepacketisapacketsentbyanodetothesourcetoinformitofcongestion.In backpressure, the warning is from one node to its upstream node, although the warning may eventually reach the source station. In the choke packet method, the warning is from the router, whichhasencounteredcongestion,tothesourcestationdirectly.Theintermediatenodesthrough which the packet has travelled are not warned.



ImplicitSignaling

In implicit signaling, there is no communication between the congested node or nodes and the source. The source guesses that there is a congestion somewhere in the network from other symptoms.

ExplicitSignaling

The node that experiences congestion can explicitly send a signal to the source or destination. The explicit signaling method, however, is different from the choke packet method. In the choke packet method, a separate packet is used for this purpose; in the explicit signaling method, the signalisincludedinthepacketsthatcarrydata. Explicit signallingcanoccur ineithertheforward or the backward direction.

BackwardSignalingAbitcanbesetinapacketmovinginthedirectionoppositetothecongestion. This bit can warn the source that there is congestion and that it needs to slow down to avoid the discarding of packets.

Forward Signaling A bit can be set in a packet moving in the direction of the congestion.This bit canwarnthedestinationthatthereiscongestion.Thereceiverinthiscasecanusepolicies,such as slowing down the acknowledgments, to alleviate the congestion.

CongestionControlinTCP

- TCP'sgeneralpolicyforhandlingcongestionisbasedonthreephases:slowstart, congestion avoidance, and congestion detection.
- Intheslow-startphase,thesenderstartswithaveryslowrateoftransmission,but increases the rate rapidly to reach a threshold.
- Whenthethresholdisreached,thedatarateisreducedtoavoid congestion.
- Finallyifcongestionisdetected,thesendergoesbacktotheslow-startorcongestion avoidance phase based on how the congestion is detected.

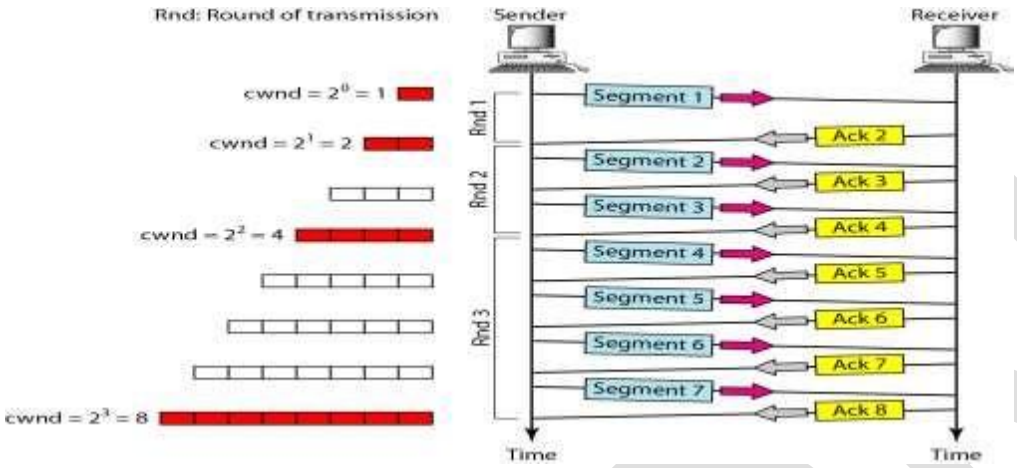
SlowStart:Exponential Increase

- Thesource startswith cwnd =1.
- Everytimean ACKarrives, cwnd isincremented.

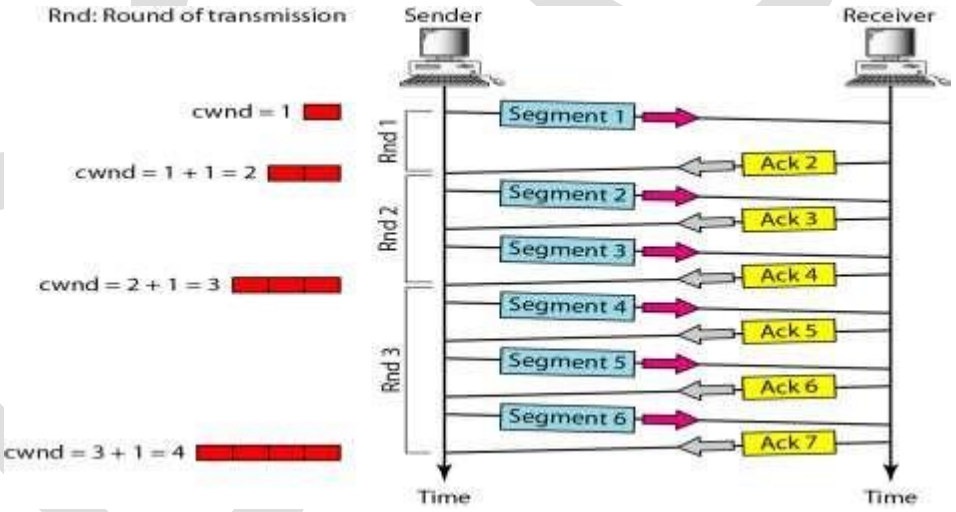
➔cwnd is effectivelydoubledper RTT “epoch”.

- Two slowstart situations:
  - Atthe verybeginningof aconnection**{coldstart}**.
  - Whentheconnectiongoesdeadwaitingforatimeouttooccur(i.e,the advertized window goes to zero!)
  - However,inthesecondcasethesourcehasmoreinformation.Thecurrent value of cwnd can be saved as a **congestion threshold.**
  - Thisisalso known asthe “slowstart threshold”**ssthresh**.

- Intheslow-startalgorithm,thesizeofthecongestionwindowincreases exponentially until it reaches a threshold.



Congestion Avoidance: Additive Increase If we start with the slow-start algorithm, the size of thecongestionwindowincreasesexponentially.Toavoidcongestionbeforeithappens,onemust slowdown this exponential growth. TCP definesanother algorithm called congestion avoidance, which undergoes an additive increase instead of an exponential one. When the size of the congestion windowreaches theslow-start threshold, theslow-start phasestops and the additive phase begins. In this algorithm, each time the whole window of segments is acknowledged (one round), the size of the congestion window is increased by 1.



In the congestion avoidance algorithm, the size of the congestion window increases additively until congestion is detected.

Congestion Detection: Multiplicative Decrease If congestion occurs, the congestion window size must be decreased. The only way the sender can guess that congestion has occurred is by theneedtoretransmitasegment. However,retransmissioncanoccurinoneof twocases:when a timer times out or when three ACKs are received. In both cases, the size of the threshold is dropped to one-half, a multiplicative decrease.

Animplementationreactstocongestiondetectioninoneofthefollowing ways:

❑ Ifdetectionisbytime-out,anewslowstartphase starts.

❑ IfdetectionisbythreeACKs,anewcongestionavoidance phasestarts.

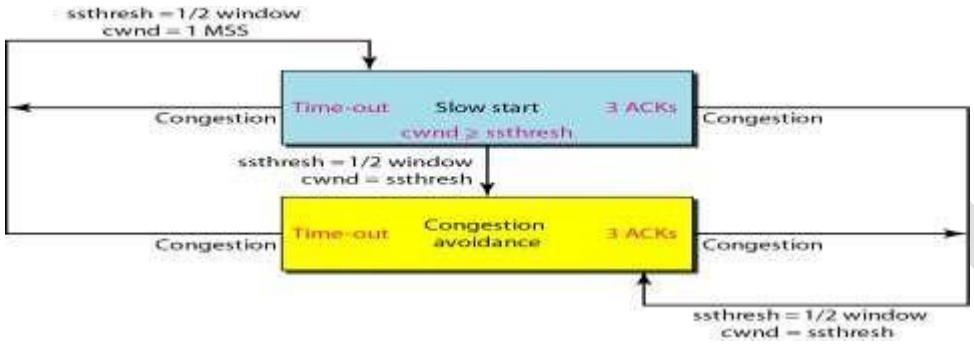


Fig.TCPcongestionpolicysummary

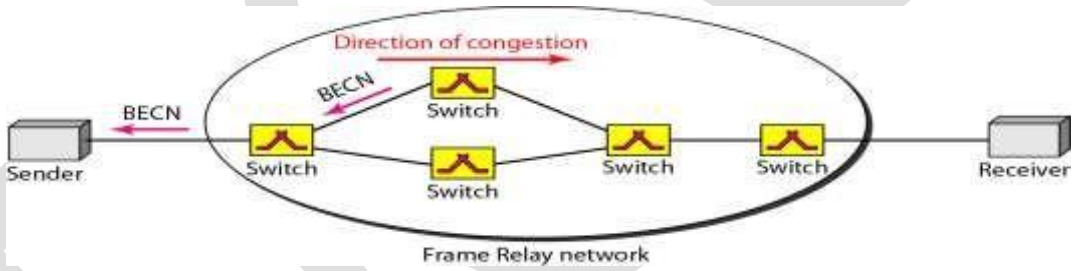
CongestionControlinFrameRelay

Congestion in a Frame Relay network decreases throughput and increases delay. A high throughputandlowdelayarethemaingoalsoftheFrameRelayprotocol.FrameRelaydoesnot have flow control. In addition, Frame Relay allows the user to transmit bursty data. This means that a Frame Relay network has the potential to be really congested with traffic, thus requiring congestion control.

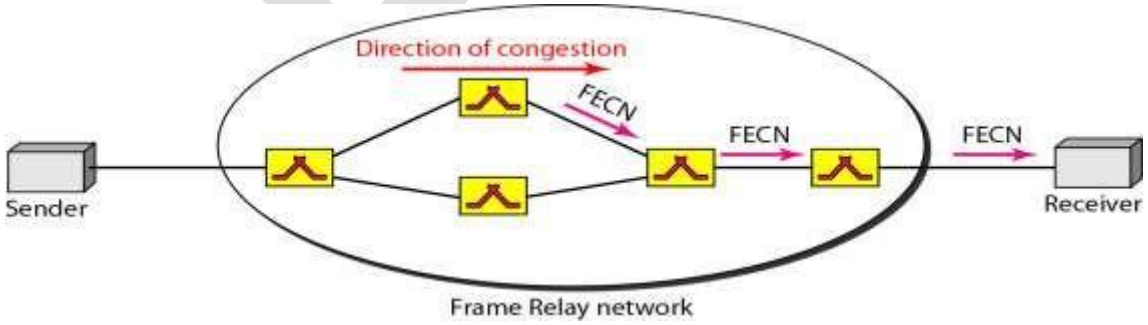
CongestionAvoidance

For congestion avoidance, the Frame Relay protocol uses 2 bits in the frame to explicitly warn the source and the destination of the presence of congestion.

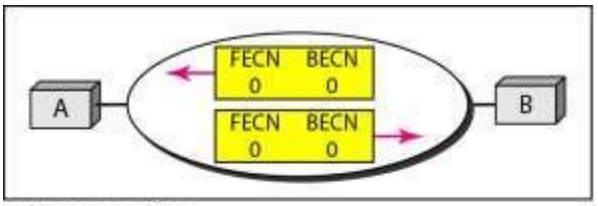
BECN The backward explicit congestion notification (BECN) bit warns the sender of congestion inthenetwork.Onemightaskhowthisisaccomplishedsincetheframesaretravelingawayfrom thesender.Infact,therearetwomethods:Theswitchcanuseresponseframesfromthereceiver (full-duplex mode), or else the switch can use a predefined connection (DLCI =1023) to send special frames for this specific purpose. The sender can respond to this warning by simply reducing the data rate.



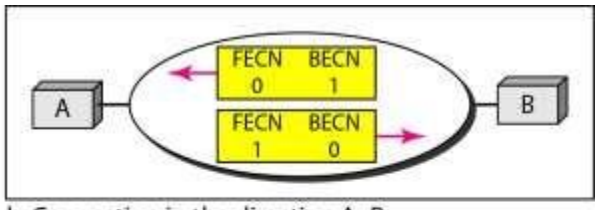
FECN The forward explicit congestion notification (FECN) bit is used to warn the receiver of congestion in the network. It might appear that the receiver cannot do anything to relieve the congestion. However, the Frame Relay protocol assumes that the sender and receiver are communicating with each other and are using some type of flow control at a higher level.



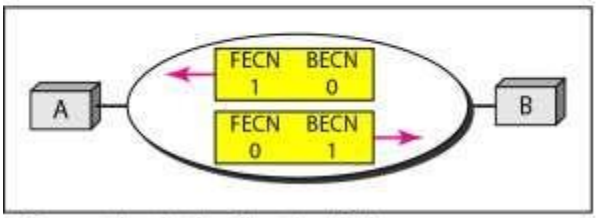
When two endpoints are communicating using a Frame Relay network, four situations mayoccur withregardtocongestion. Figureshows thesefour situations andthe values of FECNand BECN.



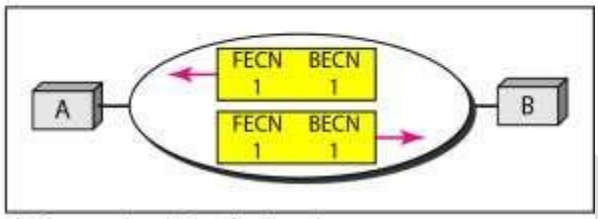
a. No congestion



b. Congestion in the direction A–B



c. Congestion in the direction B–A



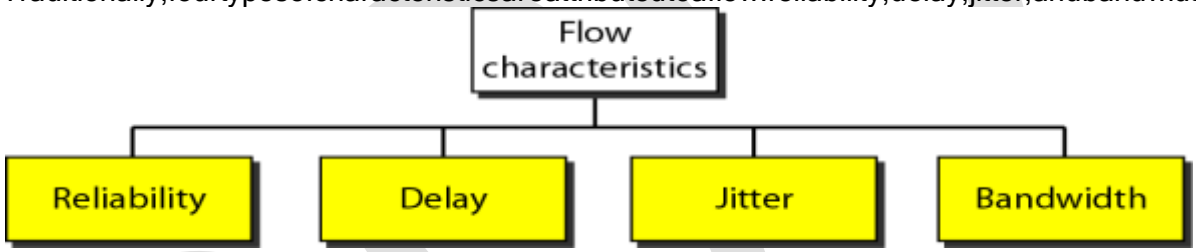
d. Congestion in both directions

QUALITYOFSERVICE

Quality of service (QoS) is an internetworking issue that has been discussed more than defined. We can informally define quality of service as something a flow seeks to attain.

FlowCharacteristics

Traditionally,fourtypesofcharacteristicsareattributedtoaflow:reliability,delay,jitter,andbandwidth.



Reliability

Reliabilityisacharacteristicthataflowneeds.Lackofreliabilitymeanslosingapacketor acknowledgment, which entails retransmission.

Delay

Source-to-destinationdelayisanotherflowcharacteristic.

Jitter

Jitteristhevariationindelayforpacketsbelongingtothesameflow.

Bandwidth

Differentapplicationsneeddifferentbandwidths.

TECHNIQUESTO IMPROVEQoS

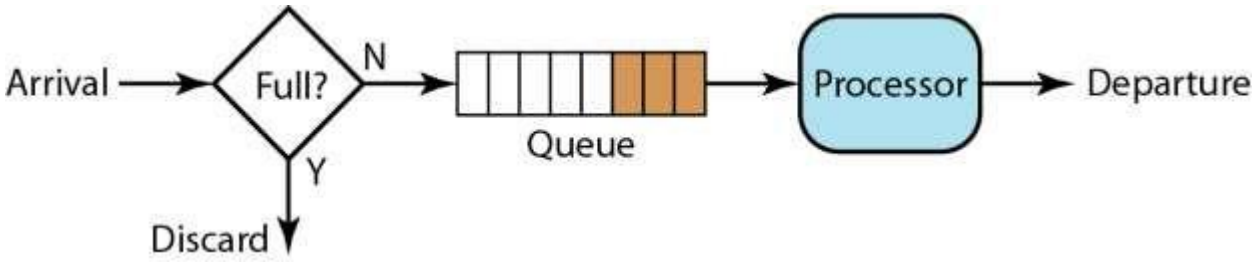
Webrieflydiscussfourcommonmethods: scheduling,trafficshaping,admissioncontrol,and resource reservation.

Scheduling

Packets from different flows arrive at a switch or router for processing. A good scheduling technique treats the different flows in a fair and appropriate manner. Several scheduling techniques are designed to improve the quality of service. We discuss three of them here: FIFOqueuing,priorityqueuing,andweightedfairqueuing.

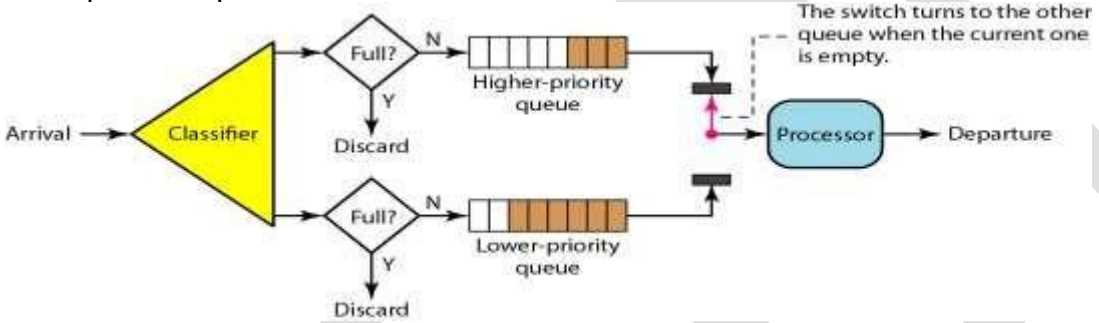
FIFOQueuing

Infirst-in,first-out(FIFO)queuing,packetswaitinabuffer(queue)untilthenode(routerorswitch) is ready to process them. If the average arrival rate is higher than the average processing rate, the queue will fill up and new packets will be discarded.



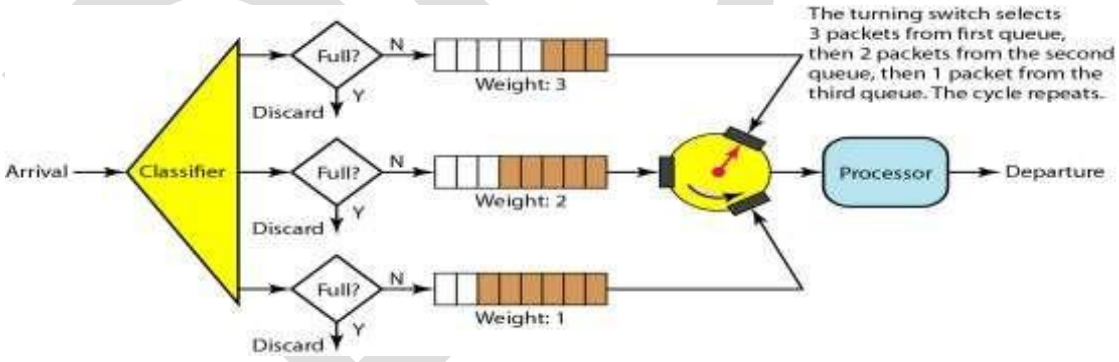
PriorityQueuing

In priority queuing, packets are first assigned to a priority class. Each priority class has its own queue.Thepacketsinthehighest-priorityqueueareprocessedfirst.Packetsinthelowest-priority queue are processed last.



WeightedFairQueuing

A better scheduling method is weighted fair queuing. In this technique, the packets are still assigned to different classes and admitted to different queues. The queues, however, are weighted based on the priority of the queues; higher priority means a higher weight. The system processes packets in each queue in a round-robin fashion with the number of packets selected from each queue based on the corresponding weight.

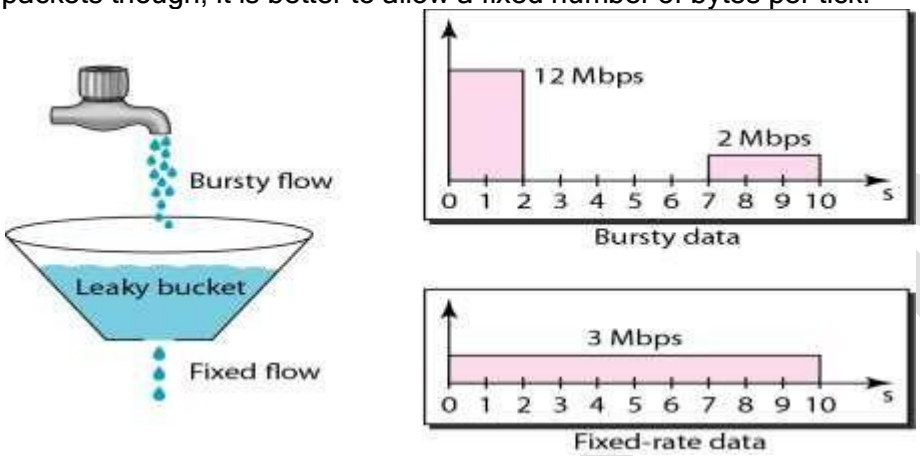


TrafficShaping

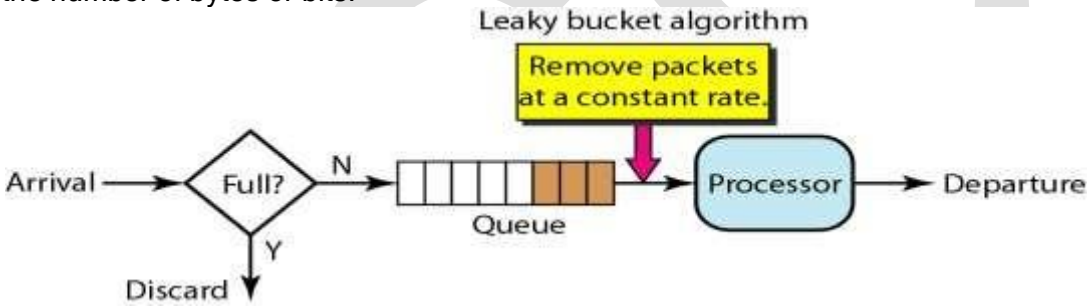
- Trafficshaping controlsthe *rate*atwhichpacketsaresent(notjusthowmany)
- Atconnectionset-uptime,thesenderandcarriernegotiateatrafficpattern(shape)
- Twotrafficshapingalgorithmsare:
  - Leaky Bucket
  - TokenBucket

TheLeakyBucket Algorithm

- The**LeakyBucket Algorithm** usedto controlrate in a network. It is implementedas asingle-server queue with constant service time. If the bucket (buffer) overflows then packets are discarded.
- Theleakybucketenforcesa constant outputrateregardlessofthe burstinessof theinput. Does nothing when input is idle.
- Thehostinjectsonepacket per clock tick ontothenetwork.This results inauniformflowof packets, smoothing out bursts and reducing congestion.
- When packetsarethesame size (asin ATMcells), theone packet per tick is okay. For variable length packets though, it is better to allow a fixed number of bytes per tick.



AsimpleleakybucketimplementationisshowninFigurebelow.AFIFOqueueholdsthepackets.Ifthe traffic consists of fixed-size packets theprocess removes afixed numberof packetsfrom thequeue at each tick of the clock. If the traffic consists of variable-length packets, the fixed output rate must be based on the number of bytes or bits.



TokenBucket Algorithm

- In contrast totheLB, theToken Bucket (TB) algorithm, allows the output rateto vary, depending on the size of the burst.
- IntheTBalgorithm, thebucket holdstokens.Totransmit a packet, the host must capture and destroy one token.
- Tokensaregeneratedbya clock attherateofone tokeneveryΔtsec.
- Idle hosts cancaptureand save uptokens(uptothemax. size of the bucket) in order tosend larger bursts later.
- Thetokenbucketallowsburstytrafficataregulatedmaximumrate.

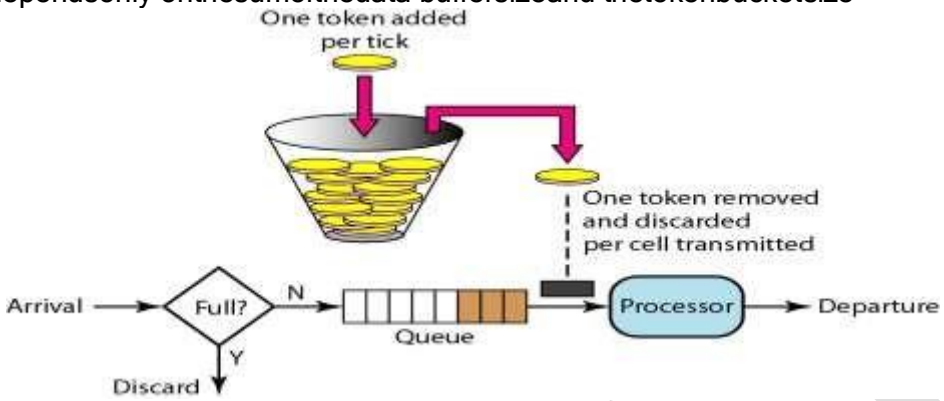
Tokenbucket operation

- TBaccumulatesfixedsizetokensinatokenbucket
- Transmits apacket (fromdatabuffer, if anyarethere) orarriving packet if the sumof thetokensizes in the bucket add up to packet size
- More tokens are periodicallyadded tothebucket (at rate Δt). If tokens areto beadded when the bucket is full, they are discarded

Tokenbucket properties

- Does not boundthe peak rate of small bursts, because bucket maycontain enoughtokentocover a complete burst size

- Performance dependsonly onthesumofthedata buffersizeand thetokenbucketsize



Nameservers

TheDNSnamespaceisdividedupintononoverlapping**zones**,Azonenormallyhasoneprimaryname server, which gets its information from a file on its disk, and one or more secondary name servers, which get their information from the primary name server

When a resolver has a query about a domain name, it passes the query to one of the local name servers.

- If the domain being sought falls under the jurisdiction of the name server, it returns the **authoritative records** (always correct).
- Once these records get back to the local name server, they will be entered into a cache there (timer controlled).

SNMP-SimpleNetworkManagementProtocol The
SNMP model

TheSNMPmodelofamanagednetworkconsistsoffourcomponents

1. Managednodes.
2. Managementstations.
3. Management information
4. Amanagementprotocol.Networkmanagementisdonefrom **managementstations**:general-purpose computers with a graphical user interface.

ASN.1-AbstractSyntaxNotation1

Theheart of theSNMP model istheset of objectsmanagedbytheagents andreadandwrittenbythe management station.

Tomakemultivendorcommunicationpossible,itisessentialthattheseobjectsbedefinedinastandard and vendor-neutral way.

Furthermore,astandardwayisneeded toencodethemfortransferover anetwork.

Astandardobjectdefinitionlanguage,alongwithencodingrules,isneeded.TheoneusedbySNMPis takenfrom OSI and called **ASN.1(Abstract Syntax NotationOne)**, defined in International Standard 8824.

TherulesforencodingASN.1datastructurestoabitstreamfortransmission aregiven inInternational Standard 8825. The format of the bit stream is called the **transfer syntax.**

Thebasic idea:

- TheusersfirstdefinethedatastructuretypesintheirapplicationsinASN.1 notation.
- Whenanapplicationwantstotransmit adatastructure, it passesthedatastructuretothepresentation layer (in the OSI model), along with the ASN.1 definition of the data structure.
- Using the ASN.1 definition as a guide, the presentation layer then knows what the types and sizes of the fields in the data structure are, and thus knows how to encode them for transmission according to the ASN.1 transfer syntax.
- UsingtheASN.1transfersyntaxasaguide,thereceivingpresentationlayerisabletodoanynecessary conversions from the external format used on the wire to the internal format used by the receiving computer, and pass a semantically equivalent data structure to the application layer.

Electronicmail

E-mailhas beenaroundforovertwodecades.

Thefirste-mailsystems:filetransferprotocolsplustheconventionthatthefirstlineofeachfile contained the recipient's address.

Complaints:

1. Inconvenientfor sendingtoagroupofpeople.
2. Messageshadnointernalstructure,makingcomputerprocessingdifficult.
3. Theoriginator(sender)neverknewifamessagearrivedor not.
4. Hardtoredirectincomingmailstoanotheraddress.
5. Poorintegrationoftheuserinterfacewiththetransmissionsystem.
6. Impossibletocreateandsendmessagescontainingamixtureoftext,drawing,facsimile,andvoice.

Architectureandservices

Anemailsystemnormallyconsistsoftwosubsystems:

1. **Useragents**:whichallowpeopletoreadandsend email.
2. **Messagetransferagents**: which move themessagesfromthesourcetothe destination. Five basic functions of an e-mail system:

1. **Composition**referstotheprocessofcreatingmessageandanswers.
2. **Transfer**referstomovingmessagesfromtheoriginatortotherecipient.
3. **Reporting**hastodowithtellingtheoriginatorwhathappenedtothemessage.
4. **Displaying**incomingmessagesisneededsopeoplecanreadtheir email.
5. **Disposition**isthefinalstep andconcernswhatthe recipientdoeswiththemessageafterreceivingit.

Advanced features:

- Automaticalforwarding.
- Automaticalreply.
- Mailboxs.
- Distributionlist.
- Registeredmail.
- Others:carboncopies,high-prioritymail,secret(encrypted)mail,alternativerecipients,etc.

Theuseragent

Theuseragentisnormally aprogram(e.g.,a mailreader)thatacceptsavariety ofcommandsthat relate to composing, sending, and receiving messages and manipulating mailboxes.

Sending email

Tosendanemail,ausermustprovidethemessage,thedestinationaddress(normallyinDNSformat), and possibly some other parameters (e.g., the priority or security level).

Most email system support mailing lists, so that a user can send the same message to a list of people with a single command.

Readingemail

Theuseragentprogramtypicallystartswithlookingattheuser'smailboxforincomingmailbefore displaying anything on the screen.