Data Communication

Exchange of data b/w devices via transmission medium, where data is information presented in form agreed by involved parties. Termed from 'telecommunication' - communication at a distance

Components of Data Communication

- Message
- Sender
- Sending protocol
- Medium
- Receiver
- Receiving protocol

Node

Device capable of sending/receiving data to/from other notes on network

Network

Set of devices connected by communication links

Purpose

Share resourcces

- File sharing
- Hardware sharing
- Application sharing: Client/server apps
- Network graming
- User Commuication
  - Voice over IP (VoIP): allows calls over traditional IP rather than by traditional PTSN

Distance-Based Classification

	Range	**Example**
LAN	Short	Wifi
MAN	Specific area (city, campus)	Cable TV
WAN	Long	The Internet

Parts of Network

Part	**Role**
'The Internet'	
Router	Connect internet to 'The Internet' has intelligence (represented using $\otimes$)
Firewall	Rules to adhere on which messages to be allowed
Switch	Helps form a LAN (Local Area Network) No of ports will always be 2^n
File Server	
Database Server	
File Server	
WiFi Access Point	kinda like a wireless switch connected to wired swetch

Links between one/more routers should be a 'dedicated link'

Transmission Modes & Media

Type	Medium	Range	Requires	Example
Wired	Twisted Pair Cables	Short		Landline, Ethernet cable
	Coaxial Cables	Long		
	Fibreoptic Cables	Very Long		
Wireless (Frequency bands)	Radio Waves	Long	Omni-directional antenna	Car radio
	Micro Waves	Long	Uni-directional Microwave antenna Lon	Etisalat connection tower
	Infrared Waves	Short		Bluetooth

Wireless can

- Infrastructure-Based: Mobile Network
- Infrastructure-less: Bluetooth

IDK

Transmission Modes

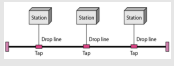
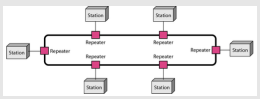
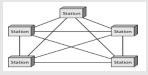
	Direction	Order	Example
Simplex	Uni		Car Radio
Half-Duplex	Bi	Sequential (one direction after the other)	Walkie-Talkie
Full-Duplex	Bi	Simultaneous (both directions at the same time)	Telephone

Line Configurations

	Example
Point-to-Point	Connection from ISP to home router
Multi-Point	Multiple devices connected to a single home router

Topology

Arrangement of nodes in a network

	Bus	Ring	Star	Mesh	Hybrid
Arrangement	Sequential	Each node connected to 2 adjacent nodes	Nodes directly connected to a central 'controller' (hub/switch/router)	Every device connected to every other device in point-point manner	Combination of star and bus
Working	Devices collectively help transfer data b/w points Terminators stop signals after reaching end of wire, to prevent signal bounce	Token-Passing (Token: Message which gives priority to a station to use ring) - Data hops from one device to another until it reaches its destination - Each device communicates its routing info to every other connected device - Each device then determines either passes/keep received data			
Device Used	Tap Drop line	Repeater			
Advantage	Simple Cheap Easy installation Node failure does not affect others	Easier to manage Easier to locate defective node/cable problem Great for transmitting signals over long distances on a LAN Handles high-volume network traffic Enables reliable communication	- Good for modern networks - Low startup costs - Easy to manage - Easy to expand - Great availability of equipment - Scalable - High security	Highest redundancy Low failure chance Low traffic Easy fault identification Robust	
Disadvantage	Not fault-tolerant Prone to congestion No security	Expensive Single point of failure Requires more cable & network equipment at start Fewer equipment options Fewer options for high-speed upgrades Only one station can send message Requires tokens Requires multiple repeaters No security	Single point of failure - If hub fails, everything fails Possible congestion at hub Requires more cables than bus	Expensive (Many cables, I/O port, connections)	Same as star
Method	Half-Duplex	Simplex	Duplex?		
Example	Ethernet			Between ISP routers	
Duplex/Half-Duplex links	1	0	n	$\frac{n(n-1)}{2}$	
Simplex links	0	1	$2n$	$n(n-1)$	
Diagram					

Network Devices

End Points	PCs, Servers, Printers, etc
Interconnections	Media, Connectors NIC(Network Interface Card)/LAN Card/Ethernet Card)
Bridge	(not used anymore)
Switches	Connects endpoints to LAN Multi-Port Bridge
Router	Connect multiple LANs to form internetworks Chooses best path between LAN & WAN
Repeater	Repeats Token in a round-robin fashion Helps overcome signal attenuation
Hub	Device without any intelligence Multi-port repeater Not used much anymore It will just broadcast every packet, as it cannot select devices.

Network Rules

Protocol

Consists rules for the following aspects

Aspect	Meaning
Syntax	Format of data
Semantics	Meaning of each section of bits
Timing	Timing and speed of data transfer

Layer	Protocol	Full Form	Details
	IP	Internet Protocol	
Network	ICMP	Internet Control Message Protocol	`ping` command uses this
Network	IGMP	Internet Group Message Protocol	
Network + Data Link (Hybrid)	ARP	Address resolution protocol	Convert ip address to mac address
Network + Data Link (Hybrid)	RARP	Reversed Address resolution protocol	Convert mac address to ip address (Only required when connecting to a network for the first time)

The Internet

Network of networks, consisting of

- Connected computing devices
- communication links
- Routers
- Protoctols
- Communication infrasture for distributed applications
- Communication services

Standard

Collection of protocols agreed by organizations, such as ITU, IEEE

De Facto Standards	De Jure Standards
Approved by organizations	Adopted through widespread use

For eg

- Wired LAN uses standard `IEEE 802.3`
- WiFi (WirelessFidelity) uses standard `802.11`

Internet Standards

- Internet draft
- RFC (Request for Comment)

Models

Model		Example
Client-Server	1 Client 1 Server	WWW Email
Peer-to-Peer	End devices use each other's resources	Torrenting Teleconferencing

Types of Services

	Connection-Oriented	Connection-Less
Stages	1. Set up connection 2. Receive acknoledgement 3. Send data 4. Receive acknowlegment 5. Repeat steps 3-4	Send data
Reliable	✅	❌
Flow Control	✅	❌
Congestion Control	✅	❌
Speed	Slower	Faster
Example Protocol	TCP (Transmission Control Protocol)	UDP (User Datagram Protocol)
Example Applications	HTTP (WWW) FTP (File Transfer Protocol) Telnet (Remote Login SMTP (Simple Mail Transfer Protocol)	Streaming media Teleconferencing Internet telephony

Data Transfer Types

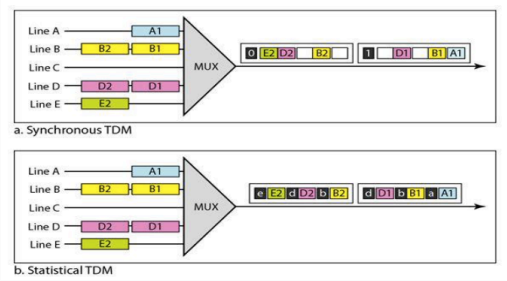
	Circuit Switching	Packet Switching
Type	Physical	Logical
	Dedicated circuit per call: telephone net	Data sent in discrete 'chunks' Each packet uses full link bandwidth
Steps	- Establish physical connection - Network resources divided into pieces - Pieces allocated to calls - Data Transmission - Teardown	- Split data into packets - Transmit packets one hope at a time - Packet reaches receiver
Disadvantage	Resource piece idle if not used by owning call (no sharing) Call setup required	
Total resource demand can exceed available?	❌	✅
Congestion Control?	❌	✅
Performance guaranteed?	✅	❌

Resource Division

1. Frequency division
2. Time division
3. Code division

TDM

Time Division Multiplexing



Subnet Mask

This is the value to perform `and` operation

To get the value, just make the network bits of the IP address as 1s and host bits as 0s Task of moving information b/w computers over the network is divided into smaller and more manageable problems.

Each problem is considered as a different layer in the network, which reduces complexity.

Each layer

- provides service to layer above & belo
- communicates with the same layer's software or hardware on other computer

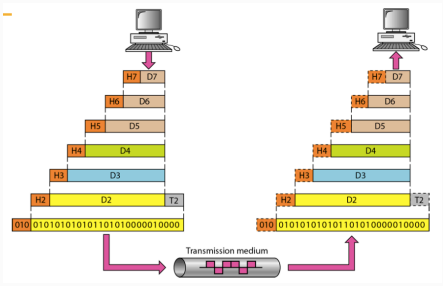
There are 2 network standards

ISO OSI Standard

Open System Interconnection

The upper 3 layers of the OSI model (application, presentation and session—Layers 7, 6 and 5) are orientated more toward services to the applications

Lower 4 layers (transport, network, data link and physical —Layers 4, 3, 2, and 1) are concerned with the flow of data from end to end through the network.



Type	Layer	Description	PDU	Device/Example	Address	Delivery	Protocols	Transmission Mode	Line Configuration
Logical	Application	Provides network-access services to user	Data/Page	Whatsapp Browser Mail client			HTTP FTP SMTP SNMP DNS NFS Telnet DHCP		
	Presentation	Data/File format Data Translation Protocol conversion Syntax & Semantics Compression/Decompression Encryption/Decryption	Data/Page				SSL TLS		
	Session	Session creation, maintainence, termination Dialogue control & synchronization b/w 2 end systems Token Management Password Validation Logical connection request Synchronization & checkpointing of pages	Data/Page				PPTP SIP SAP Net BIOS	Half-duplex Full-duplex	
	Transport	Ensuring reliable data exchange mechanism Error control (only end-systems: source-dest) Flow control Connection control Service point addressing Segmentation/Re-assembly into/from a packet	Segment		Port (identifies process/service)	Process-to-Process	TCP UDP	Multiplex	
Hardware	Network	Inter-Networking Routing algo IP addressing Congestion handling Packet sub-fragmenting	Packet/ Datagram	Router	IP	Host-to-Host	IPv4, IPv6 IPSec ICMP IGP EGP OGHP RARP ARP		
	Data Link	Ensuring reliable communication over physical layer 'Framing'/Reassembling Error control (router & end-system: source-dest + each hop) Error correction/handling Corruption detection/correction Flow control (pacing b/w adjacent sending & receiving nodes) Access control LAN formation Physical addressing	Frame	Bridges Switches	MAC	Hop-to-Hop Delivery	ATM SLIP Frame Relay PPP	Simplex Half-Duplex Full-Duplex	Point-to-Point Broadcast
	Physical	Convert signal b/w digital & analog Encryption & decryption Representation of bits Data rate Synchronization of bits Encoding Modulation Line Configuration Transmission medium Transmission mode Topology	Bitstream/ Raw Data	Hub Repeater			USB Bluetooth		

PDU

Protocol data unit

PDU's are used for peer-to-peer contact between corresponding layers

Packet

H3 (Header)	Data
Source IP address Destination IP address	

Frame

H2 (Header of layer 2)	Data	T2 (Trailer of layer 2)
Source MAC Address Destination MAC Address (found through Hop-to-Hop Delivery)		Usually a parity

TCP/IP

Transmission Control Protocol with inter-networking protocol

- Application
- Transport
- Network
- Data Link
- Physical

OSI vs TCP/IP

	OSI	TCP/IP
No of Layers	7	5
Transport Layer	Connection-oriented/Connection-less	Connection-oriented/Connection-less
Network layer	Connection-oriented	Connection-less
Delivery model	'Best'	'Best-effort'

Network Addresses

Address	Size (in Bits)	Denotion	Example	Separator	Connect device in ___ network	Set during	Fixed
Specific							
Port	16	Decimal	753 (0-1024 are reserved)	(none; it is a single no)			
IP/Logical	32	Decimal	192.168.22.5	Dot	different	Connection to network	❌
MAC(Medium Access Control)/ Physical/ Link	48 24 Vendor Code, 24 Serial No)	Hexadecimal	AA.F0.C1.E2.77.51	Colon (Linux) Hyphen (Windows)	same	Device manufacture	✅

The physical addresses will change from hop to hop, but the logical and port addresses usually remain the same. Huh???

IPv4

Class	Byte 1 (Decimal)	Byte 1 (Binary)
A	0-127	0...
B	128-191	10...
C	192-223	110...
D	224-299	1110...
E	240-255	1111...

Network ID is the first IP address, for eg: `10.0.0.0, 20.0.0.0`. This is used to refer to all devices in a network.

Only end-devices and routers require IP address, as they belong to network layer.

Network Criteria

- Fault Tolerance
- Scalability

- QoS (Quality of Service)
  - High Throughput
  - High Bandwidth
  - Low Latency
- Security

Performance Criteria

Bandwidth	Max number of bits transferrable per unit time (In analog world, it is the range of accepted frequencies)
Throughput	Actual number of bits transferred per unit time
Latency/ Delay	Duration to send info & its earliest possible reception
End-to-End Delay	Duration to transmit packet along its entire path - Created by application - Handed over to OS - Passed to NIC - Encoded, transmitted over a physical medium - Received by intermediate device (switch, router) - Analyzed, retransmitted over another medium, etc.
Round-Trip-Time	Duration to send and receive acknowledge

Types of Delays

Delay	Duration of	Formula
Transmission	Placing bits onto transmission mediaum	$\frac{\text{Size}}{\text{Bandwidth}}$
Propagation	Travel for a bit from one end of medium to other	$\frac{\text{Distance}}{\text{Speed}}$
Processing	Error verification Routing decision, ie - analyze packet header - decide where to send packet	No of entries inrouting table Implementatio of data structures Hardware specs
Buffer/ Queuing	Packet to wait until it is transmitted	Traffic intensity Type of traffic

Latency = $\sum$ all the above delays

Mediums

Medium	Speed (m/s)
Vacuum	3×10^8
Cable	2.3×10^8
Fiber	2×10^8

It is a combination of hardware, software, and firmware (software for hardware)

It is implemented in NIC and attaches into host's system buses

Flow Control

Handles mismatch b/w sender's and receiver's speed

Control Method	Type	Meaning
Feedback-Based (More common)	Explicit	Permission required from receiver
Rate-Based	Implicit	Limit sending rate

Error Types

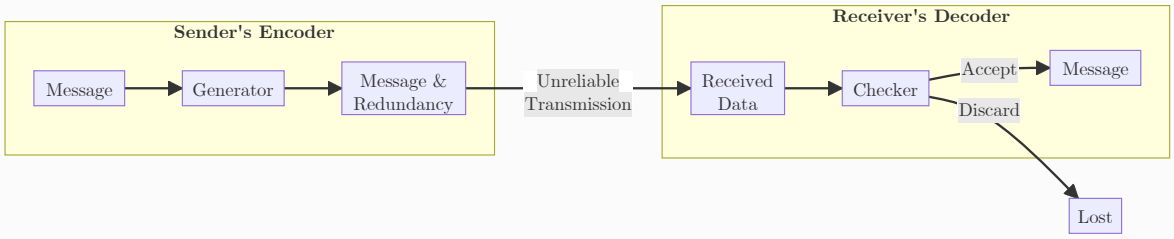
Type	No of Bits	Consecutive Bits?
Single-Bit	1	
Multiple-Bit	>1	❌
Burst	>1	✅

Error Control

Error detection codes	Detect error
Error/Forward correction codes (FEC)	Detect & correct error Use in wireless networks
Retransmission/ Automatic Repeat Request (ARQ)	Used along with error detection/correction Block of data with error discarded Transmitter retransmits that block of data

Redundancy

Redundant bits added to data to detect & correct errors

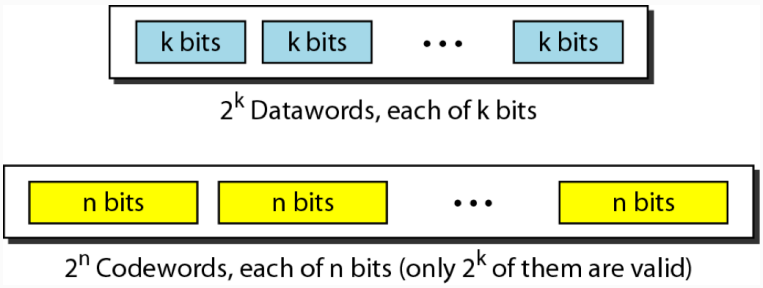


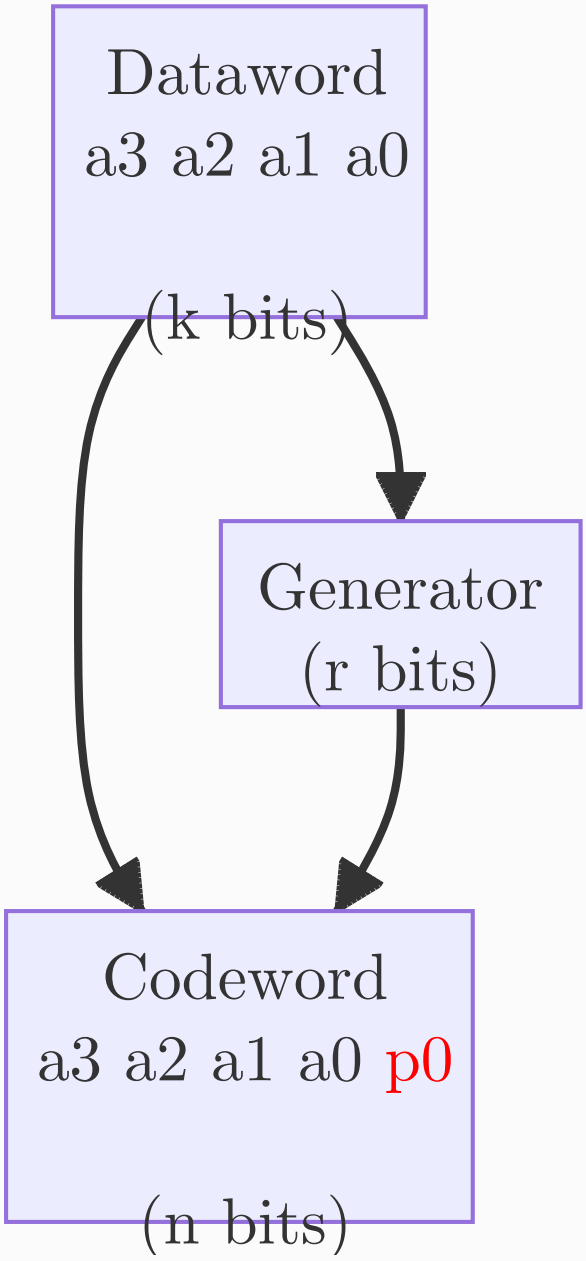
Coding

Process of adding redundancy for error detection/correction

Error-detecting code can detect only types of errors for which it is designed; other types of errors may remain undetected. There is no way to detect every possible error

Code	Steps	Redundant bits	Total bits n	Memoryless?
Block	Divide data into set of k-bit blocks (called datawords) Extra info attached to each block Combined blocks called codewords	r	$k+r$	✅
Convolutional	Treats data a series of bits Computes code over continuous series			❌ (Code depends on current & previous i/p)





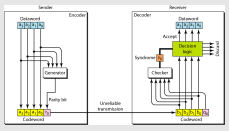
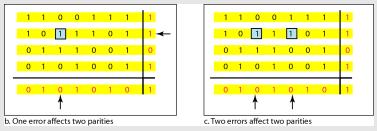
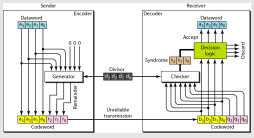
Code Rate

$$= \frac{k}{n}$$

Code Rate	$\Longrightarrow$	Error Correcting Capability	Bandwidth Efficiency
$\uparrow$		$\downarrow$	$\uparrow$
$\downarrow$		$\uparrow$	$\downarrow$

Error Detection Methods

If syndrome $= 0$ at the receiver, there is no error

	Simple parity check	Horizontal & Vertical Parity check	CRC (Cyclic Redundancy Check)	Checksum
	Use an odd/even parity bit	Use parity bit vertically and horizontally	Add r zeros to right of dividend, where r =no of redundant bits = length of divisor - 1 Long division using **XOR**	(not used in data link layer) Find sum of digits If overflow, perform padding Take 1s complement
Errors detectable	$\{1, 3, \ldots, 2n+1\}$ (odd no of errors)	$\{1, 2, 3, 5, 6, 7, \ldots\} \implies R - \{4n\}$	All	All
Can correct error?	❌ (error can be in any position including parity bit itself)			
				

Simple Parity

Parity	Parity bit = 0 means dataword has
Odd	Odd number of ones
Even	Even number of ones

Mac Layer Throughput

Number of bits sent by MAC (Data Link) layer in given period of time

$$\text{Throughput} = \frac{\text{Payload}}{\text{Total Time}}$$

Control Frame

Frames that only contain headers/trailers, and no payload

Access Protocols

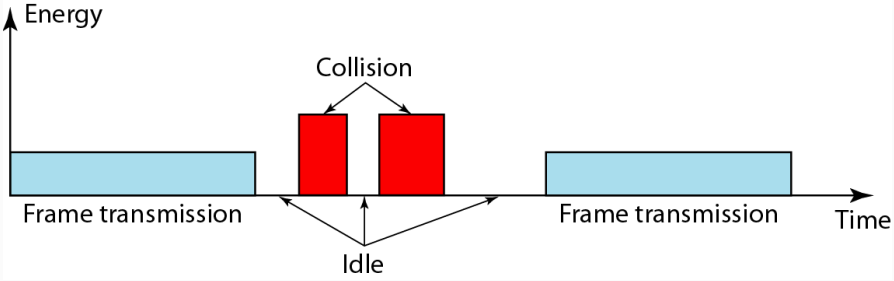
	Random-Access/ Contention	Controlled-Access	Channelization
	No station is superior to another No station permits another station to send at the same time Node with packet transmits at full channel data rate All transmission on shared channel		
Collisions	Moderate	Little-to-none	
Throughput for smaller networks	Low	High	
Throughput for larger networks	High	Low	
Easy to maintain?	✅	❌	
Commonly-used?	✅	❌ (Hard to control large networks)	
Example	ALOHA CSMA CSMA/CD CSMA/CA	Reservation Polling Token-Passing	FDMA TDMA CDMA

Collision

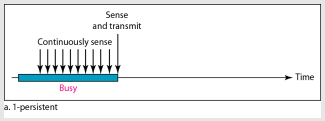
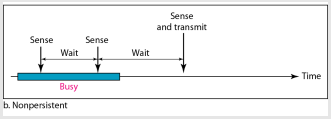
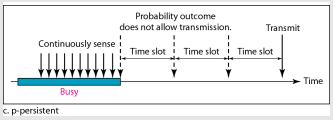
When 2 nodes transmit concurrently

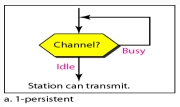
Carrier-Sensing

When the energy level is higher than usual, that means that there is a collision

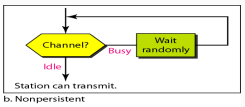


Persistence Methods

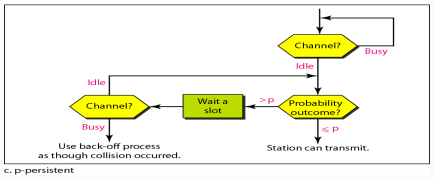
	1-persistent	Non-persistent	p - persistent
	Default persistent method		Probabilistic mixture of 1-persistent & non-persistent Assume channels are slotted One slot = contention period (one RTT) Used when time slot duration $\geq \max T_P$
Steps	1. Sense channel 2. if idle, transmit immediately 3. If busy, keep listening	1. Sense channel 2. If idle, transmit immediately 3. If busy, wait random amount of time and sense channel	- When station ready to send, it senses the channel - If channel is idle, transmits with probability pp - If channel is busy, station waits until next slot. - With probability $q = 1 - p$, the station then waits for beginning of next slot - If next slot also idle, either transmit/wait again with probabilities pp & q - Process repeated till either frame transmitted/another station starts transmitting - If another station transmits, station waits random amount of time & starts again
If collision occurs	Wait ranom amount of time & start over	Wait random amount of time & start over	
Diagram			



a. 1-persistent



b. Nonpersistent

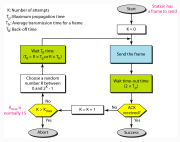
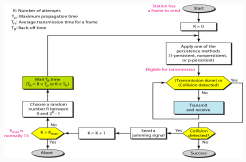


c. p-persistent

Let

Symbol	Meaning
T_{fr}	Time to transmit a frame
T_p	Propagation Delay
G	Average no of frames requested per frame-time
S	Throughput (Number of packets successfully transmitted per packet time)
V	Vulnerable Time Time bracket for potential collision

Protocols

	Pure ALOHA	Slotted ALOHA	CSMA	CSMA/CD	CSMA/CA
IDK			Carrier Sense Multiple Access Listen before transmission Node does not send if another node already sending Uses persistence methods	Collision Detection Listen to channel while packet being sent Node stops sending if ∃ interference	
Assumptions	Stations trying to transmit follow Poisson Distribution	All frames are of same size Time divided into equal slots (time to transmit a frame) Nodes start transmission only at start of slot If 2/more nodes transmit, all nodes detect collision	Constant length packets No errors, except ones caused by collisions Each host can sense transmissions of all other hosts Propagation delay is small compared to transmission delay	1. Check line is quiet 2. Detect collision ASAP 3. If collision detected, stop transmission; wait random time and start over	
Preferred for				Slow Networks (Efficiency reduces for faster networks)	Wireless Networks
Minimum Frame Length				Frame length such that $T_t > 2 \times T_P$	
V	$2 \times T_{\text{fr}}$	T_{fr}	T_P		
S	$G \times e^{-2G}$	$G \times e^{-G}$			
$G_{\max}$	$1/2$	1			
$(S_{\max})$	0.184	0.368			
Flowchart					

CSMA/CD

$$
\begin{aligned}
B &= \frac{\text{PD}}{\text{TD}} \\
&= \frac{\frac{\text{Distance}}{\text{Speed}}}{\frac{\text{Data Size}}{\text{Bandwidth}}} \\
&= \frac{\text{Distance} \times \text{Bandwidth}}{\text{Speed} \times \text{Data Size}}
\end{aligned}
$$

$$
\begin{aligned}
\text{Throughput } E &= \frac{1}{1+kB} \qquad (k \in [1, 10]) \\
&= \frac{1}{1 + k\left(\frac{\text{Distance} \times \text{Bandwidth}}{\text{Speed} \times \text{Data Size}}\right)} \\
\implies E &\propto \frac{1}{\text{Bandwidth}}
\end{aligned}
$$

CSMA/CD is preferred for slow networks. This is because, as bandwidth increases, efficiency decreases, due to more collisions.

Timeline Diagram

Vertical Format	Horizontal Format