statistical multiplexing => allocate resource based on needs   Packet Header Overhead => packet header takes too much of space

circuit switching : A dedicated path is reserved for the duration of the communication
(reserved)

packet switching : Data is broken into pieces called packets. Packets are independently and reassemble
(on-demand) at the destination.

transmission delay = $\frac{\text{packet size}}{\text{bandwidth}}$ propagation delay = $\frac{\text{distance}}{\text{speed of signal}}$ (number of hops include itself)

Bandwidth-Delay Product (BDP) : how much data can be in-transit at any one time.

↳ Bandwidth × Propagation Delay = How many data are in flight

Modulation
- BPSK (Binary Phase Shift Keying) => 1 bit : each signal represents either 0 or 1
- QPSK (Quadrature Phase Shift Keying) : each signal represents 2 bits
- QAM (Quadrature Amplitude Modulation) : uses amplitude to represent (4 bits per signal)

Baud Rate : the number of signal changes per second   Data Rate : the number of bits per second

Symbol Rate : number of symbol that happened per second

Shannon Capacity : Maximum data rate we can send over a noisy channel while still being able to decode the data correctly.

depends on Signal-to-Noise Ratio : Used to measure the reliability of signal under noi
(SNR)   R: data rate bits/sec   B = bandwidth in Hz $SNR = 10 \cdot \log_{10} \frac{P_{signal}}{P_{noise}}$

formula

$$R = B \times \log_2(1 + SNR), \quad R \approx 0.332\, B \cdot SNR$$

MAC Protocols
- Channel Partitioning : each device gets dedicated time
- Taking Turns (Time Division Multiplexing) : one after anoth
- Random Access (CSMA, CSMA/CD) : check before sending

CSMA/CD in Ethernet
1. Carrier Sense : Listen first
2. Collision Detection : If detection occurs, device detects it
3. Exponential Backoff : the wait time grows exponentially

↳ TD ≥ 2 PD

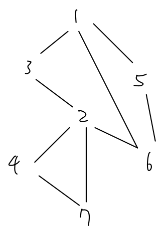
Bit Stuffing : to avoid confusion between payload and header. insert 0 for every five 1.

STP (Spanning Tree Protocol)

Convergence => as all the switches agree on the root and the shortest path, they stop updating information. The constructed spanning tree ensures:

1° No loop 2° Efficency 3° Redundancy

Flooding: Used when cannot find the MAC address of the receiver. The frame is sent to all ports except the one it came from. Need to do with STP to prevent broadcast storm.



① (Y, d, X) proposed root Y from node X with distance d

② Only receive new point of view from neighbors when $Y_{receive} < Y_{old}$

Initial State

Switch	Receive	Send	Next-hop
1		(1,0,1)	self
2		(2,0,2)	self
3		(3,0,3)	self
4		(4,0,4)	self
5		(5,0,5)	self
6		(6,0,6)	self
7		(7,0,7)	self

=>

First Round

Switch	Receive	Send	Next-hop
1	(3,0,3) (5,0,5) (6,0,6)		self
2	(3,0,3) (6,0,6) (4,0,4) (7,0,7)		self
3	(1,0,1) (2,0,2)	(1,1,3)	1
4	(2,0,2) (7,0,7)	(2,1,4)	2
5	(1,0,1) (6,0,6)	(1,1,5)	1
6	(1,0,1) (2,0,2) (5,0,5)	(1,1,6)	1
7	(2,0,2) (4,0,4)	(2,1,7)	2

$RTT = 2 \times PD$

Second State

Switch	Receive	Send	Next-hop
1	(1,1,3) (1,1,5) (1,1,6)		self
2	(1,1,3) (2,1,4) (1,1,6) (2,1,7)	(1,2,2)	3
3	(1,0,1) (2,0,2)		1
4	(2,0,2) (2,1,7)		2
5	(1,0,1) (6,0,6)		1
6	(1,0,1) (2,0,2) (5,0,5)		1
7	(2,0,2) (2,1,4)		2

=>

First Round

Switch	Receive	Send	Next-hop
1	(1,1,3) (1,1,5) (1,1,6)		self
2	(1,1,3) (2,1,4) (1,1,6) (2,1,7)		3
3	(1,0,1) (2,0,2)		1
4	(1,2,2) (2,1,7)	(1,3,4)	2
5	(1,0,1) (6,0,6)		1
6	(1,0,1) (1,2,2) (1,1,5)		1
7	(1,2,2) (2,1,4)	(1,3,7)	2

=> same hop should not be linked together (Cancel the redundant link)