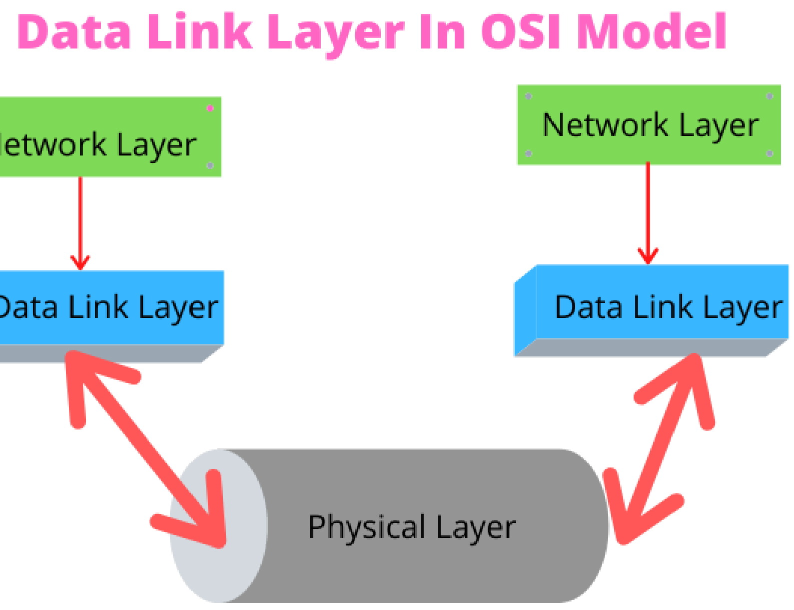
Mobile and Wireless Networks

Wireless transmission



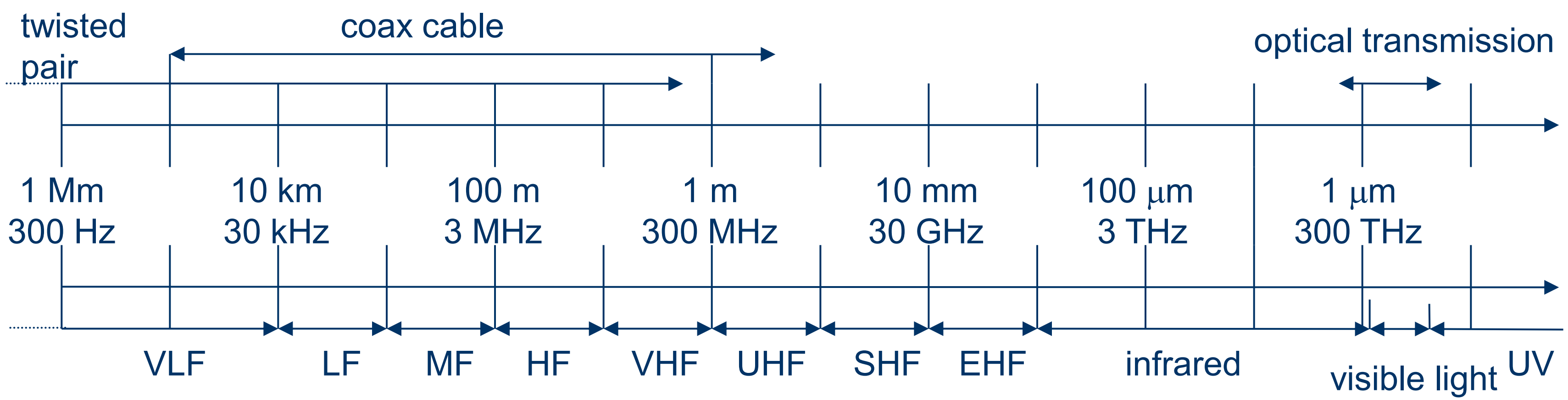
Wireless Transmission

- Based on the capability of electrons to move creating electromagnetic waves
  - To all directions
  - With the speed of light
  - Even in space

- Main characteristics of wireless transmission
  - Frequency ***f*** = number of oscillations per second (Hertz)
  - Wave length ***λ* =** distance between two minimums or two maximums
  - ***λ*f*** = c (c=speed of light)

- The signals behavior depends on its frequency
  - Low frequency = the signal can go through obstacles, its power density is reduced slowly with distance but the information transferred is small
  - High frequency = The information transferred is larger, but the signal cannot go through obstacles so easily and the power density if reduced quickly with distance (path loss).

Spectrum Allocation



VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

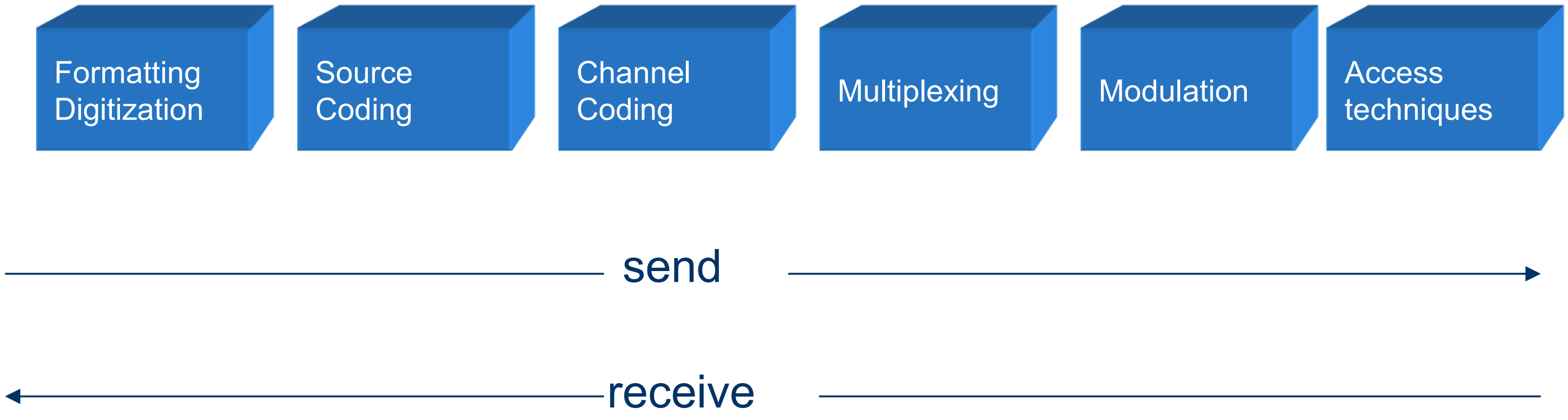
Relationship between frequency ‘f’ and wave length ‘λ’ :

$$\lambda = c/f$$

where c is the speed of light $\cong 3\times10^8$m/s

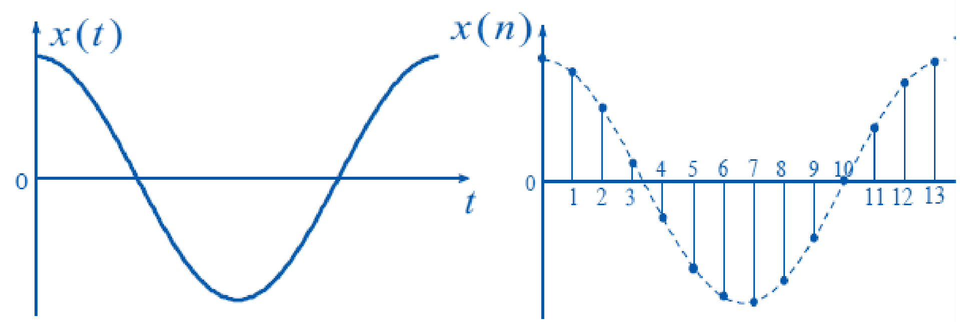
Communication System

- Structural modular approach
- Various components
- Of defined functions

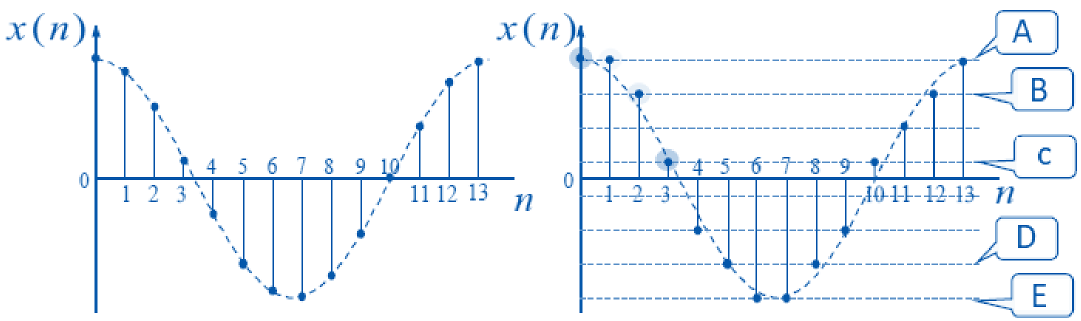


Digitization

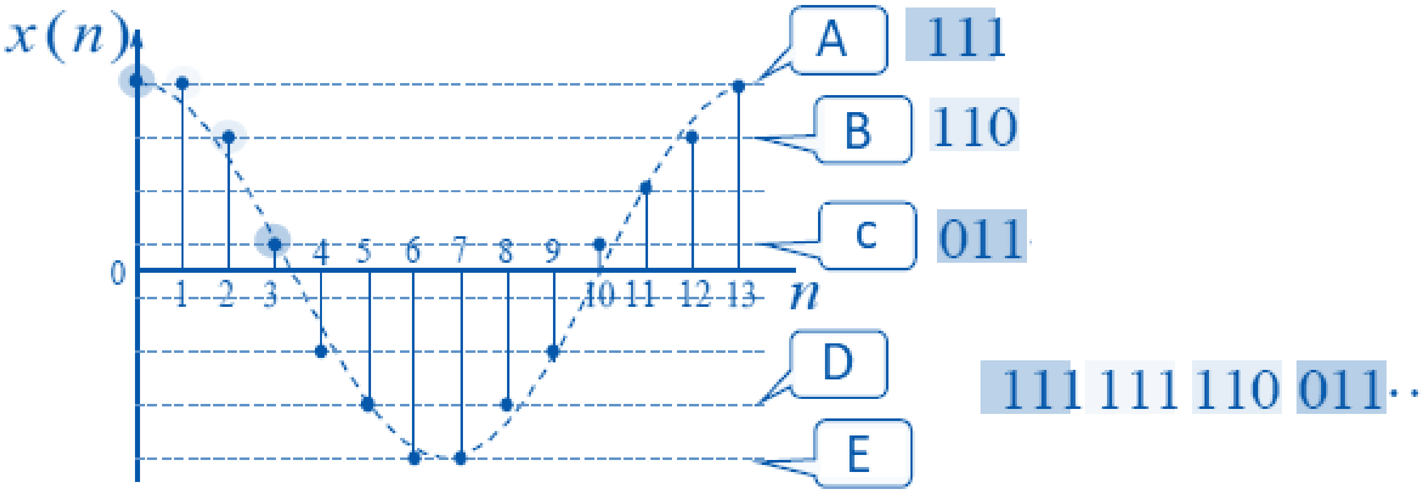
- Sampling



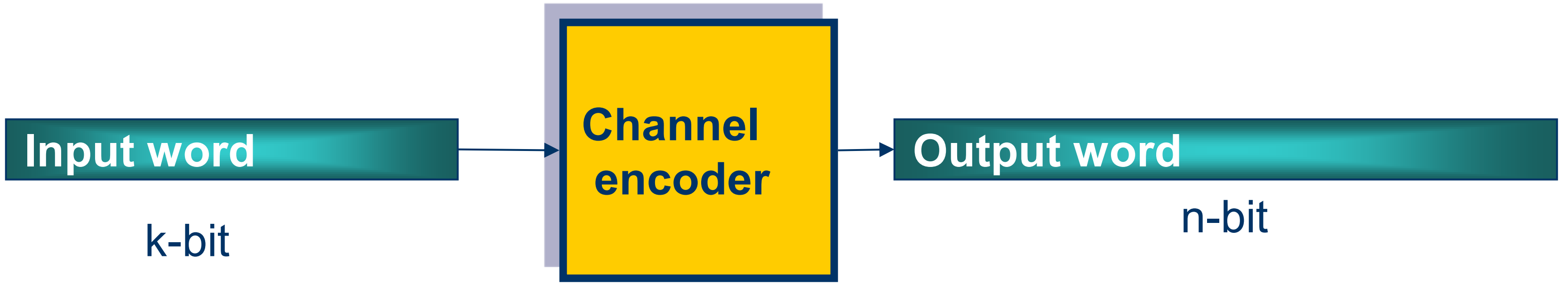
- Quantization



Source coding



Channel coding



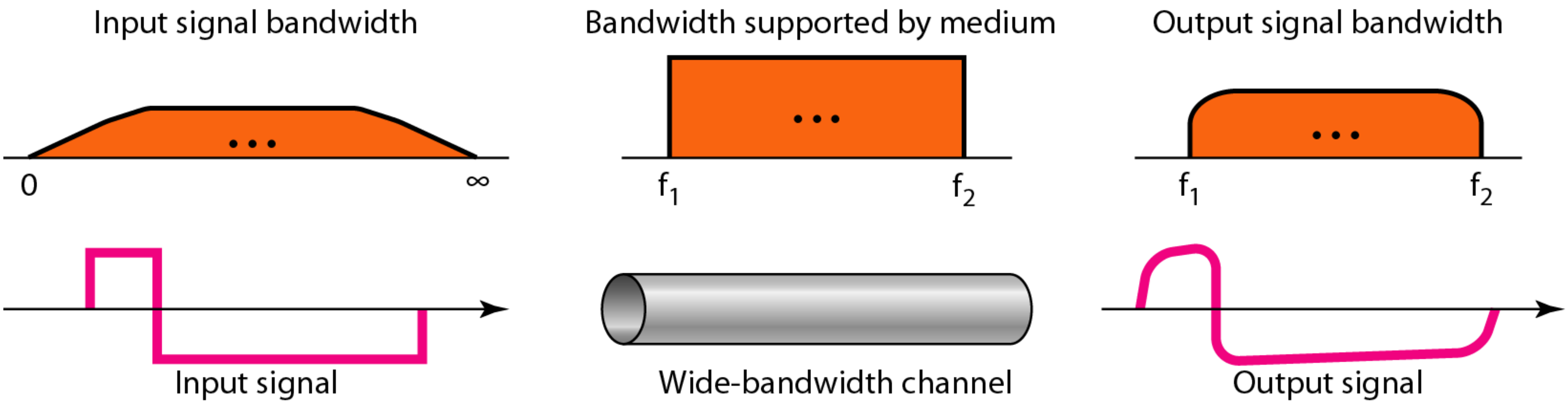
codeword

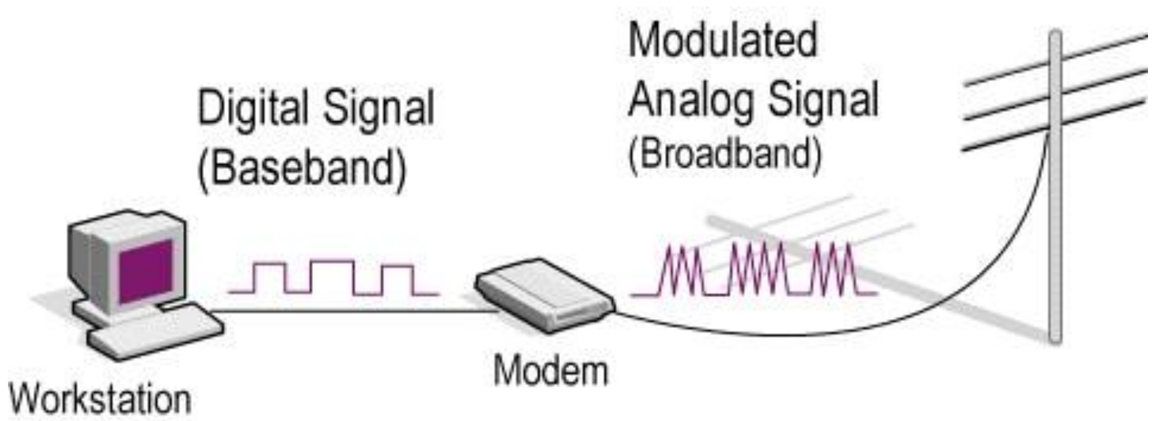
Code sequence

Redundancy = (n-k)

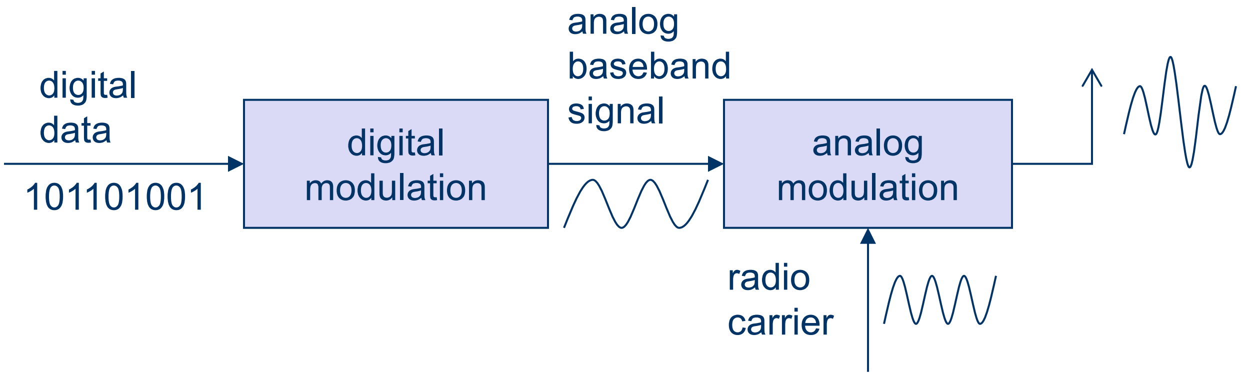
Code rate = k/n

Baseband transmission

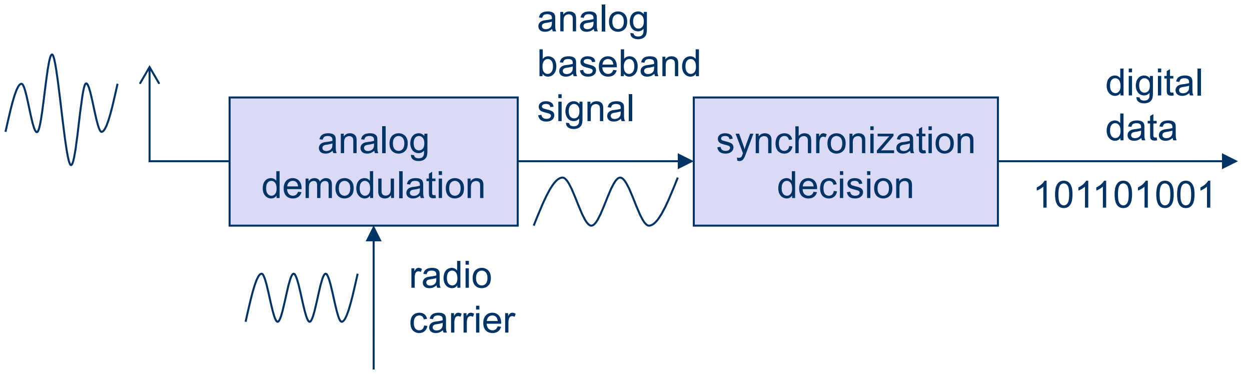




Modulation and Demodulation



radio transmitter



radio receiver

Signal Modulation

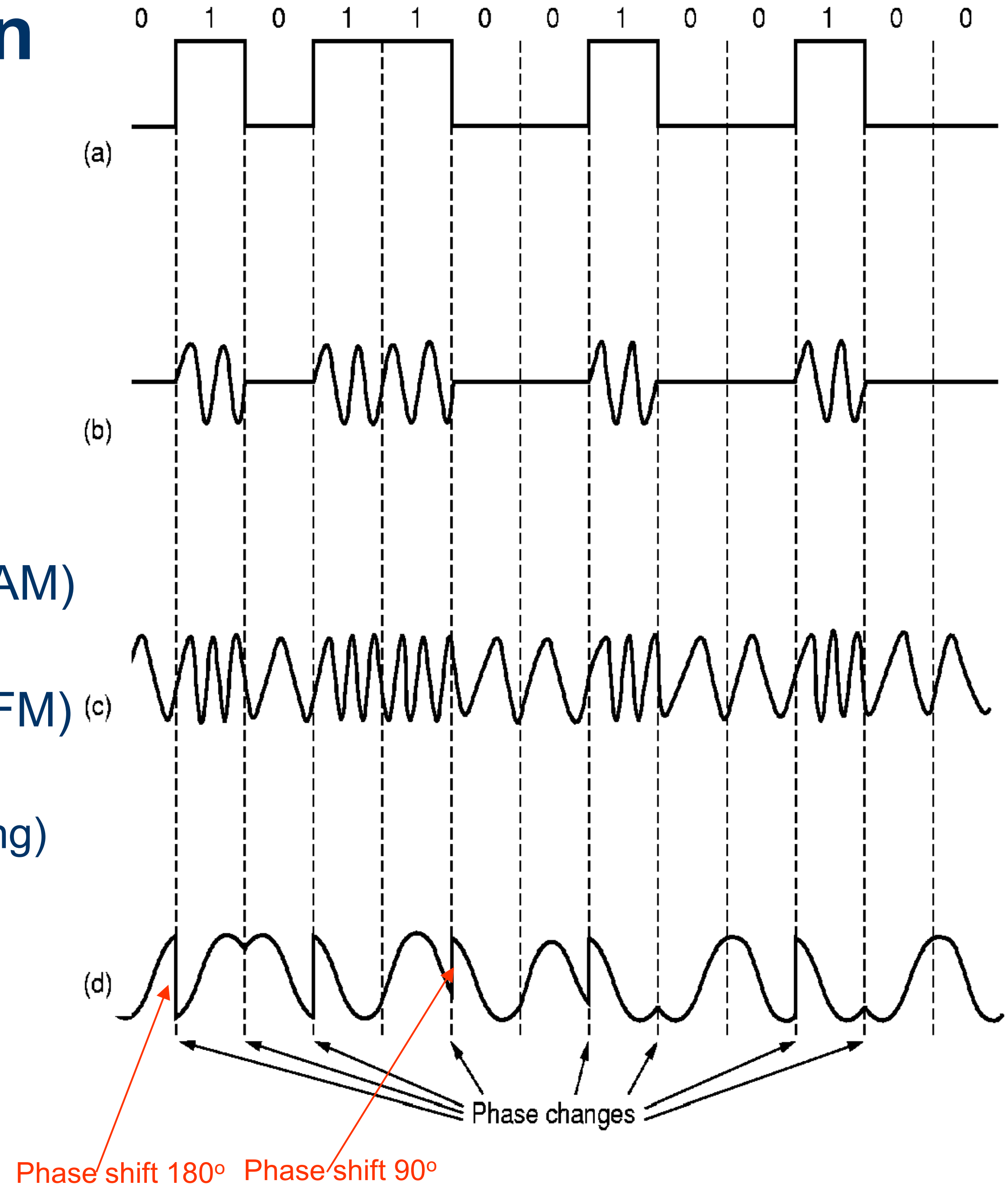
$s(t) = A(t) \cos(f(t)\, t + \phi(t))$

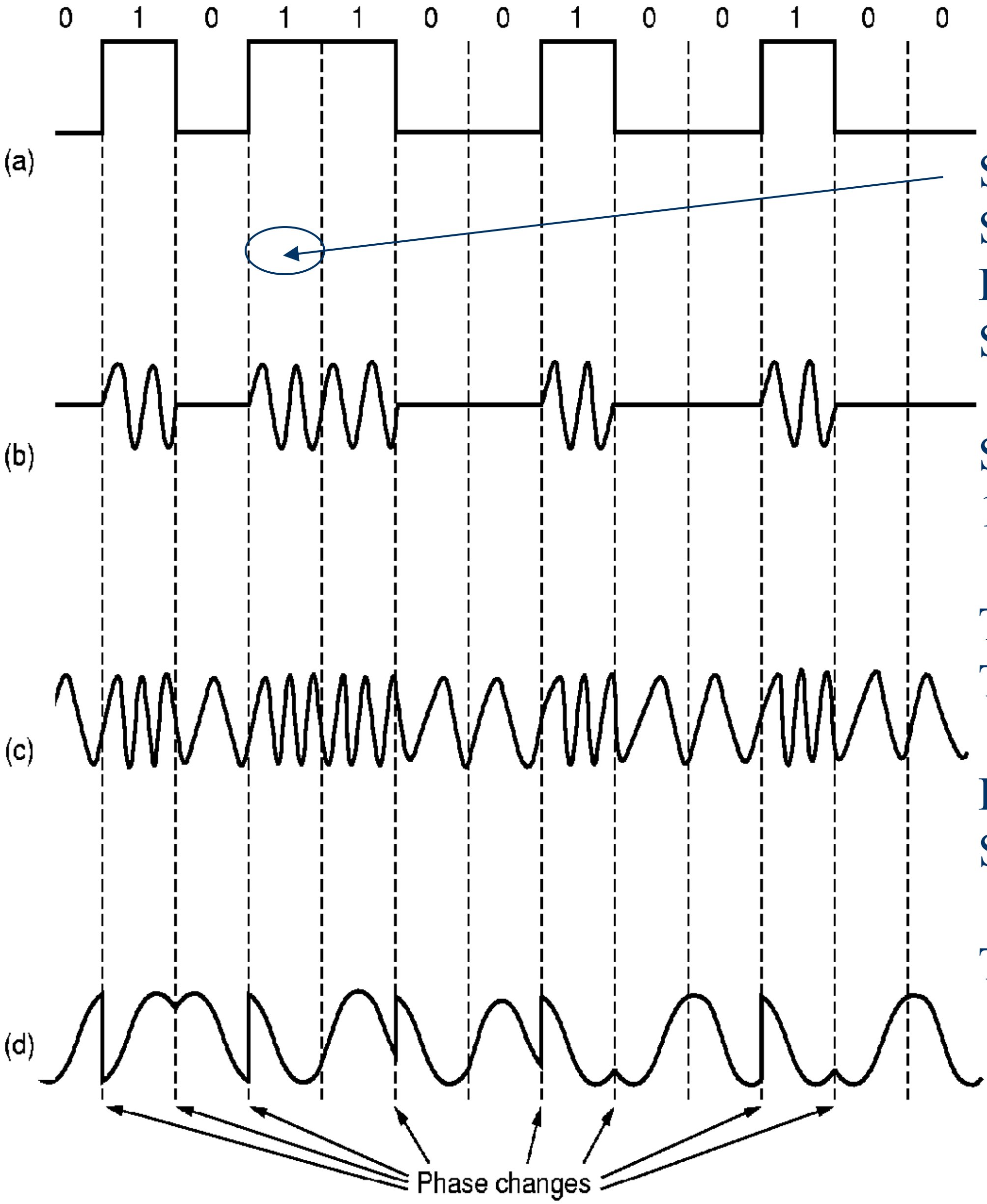
- (a) unmodulated (digital) signal
- (b) amplitude modulation (AM)

  $s(t) = A(t) \cos(f\, t + \phi)$
- (c) frequency modulation (FM)

  $s(t) = A \cos(f(t)\, t + \phi)$
  - FSK (frequency shift keying)
- (d) phase modulation (PM)

  $s(t) = A \cos(f\, t + \phi(t))$
  - phase shift keying (PSK)
- *f* : carrier frequency





Sample
Sample Rate=Samples/sec (Baud Rate)
During one Sample one **"symbol"** is sent
Symbol=piece of information=level of voltage

Simpler :
1 symbol = 1 bit (0/1) = voltage/no voltage

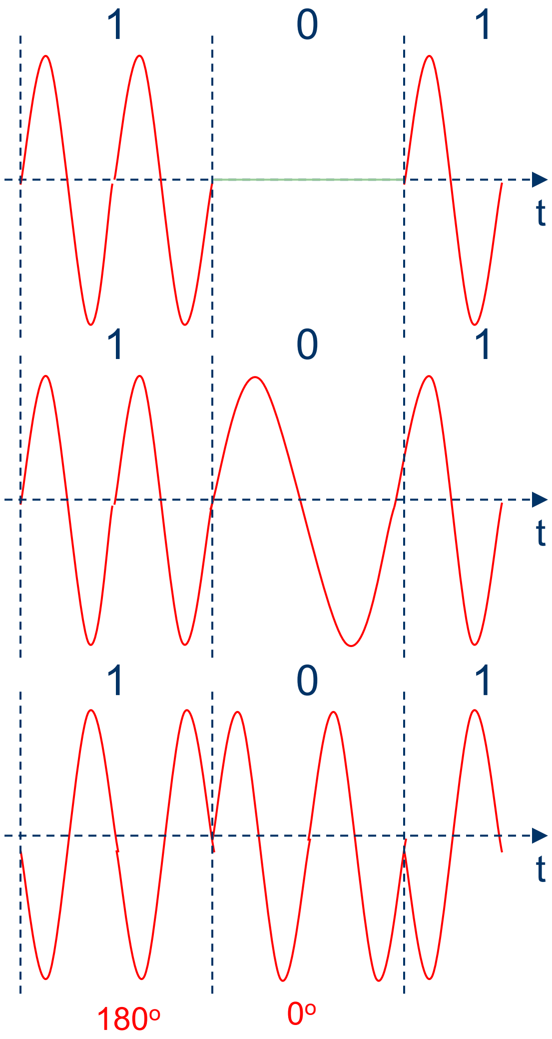
To increase the data rate we cannot reduce
The sample duration indefinitely

But we can increase the number of possible
Samples (e.g. amplitude levels)

This is usually combined with PSK

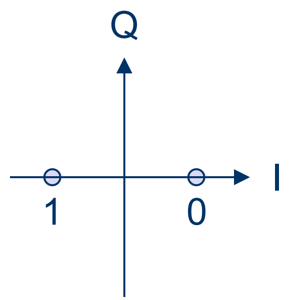
Digital Modulation

- Modulation of digital signals known as Shift Keying
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very sensitive to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - expensive

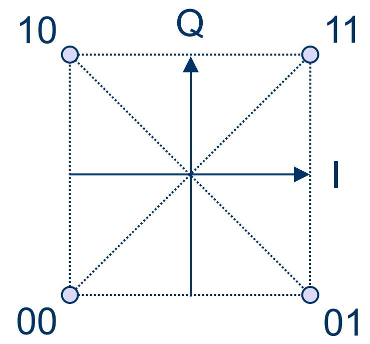


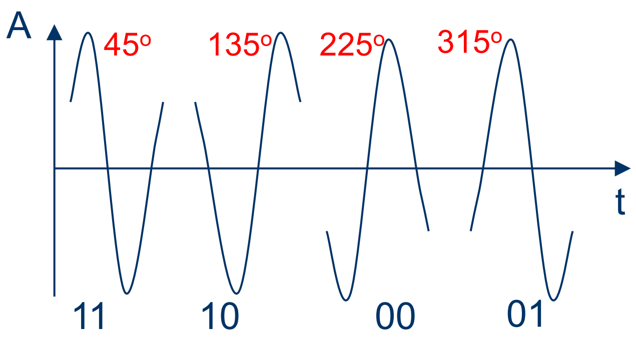
Advanced Phase Shift Keying

- BPSK (Binary Phase Shift Keying):
  - bit value 0: wave
  - bit value 1: inverted wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems

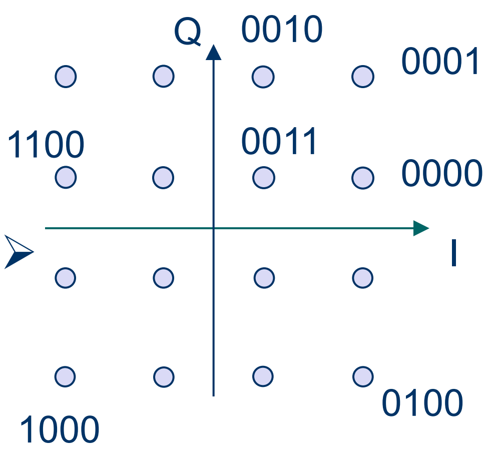


- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - more complex
  - better spectral efficiency



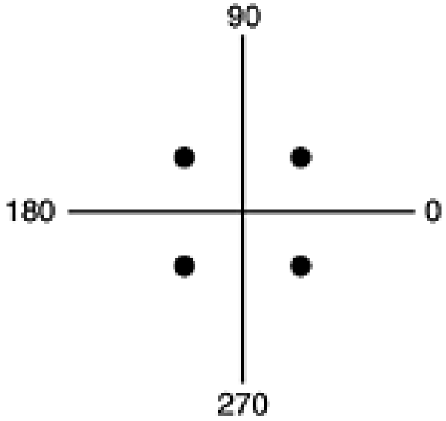


Quadrature Amplitude Modulation

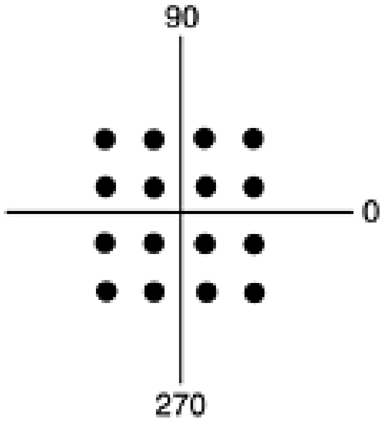
- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes
- 

Example: 16-QAM (4 bits = 1 symbol)

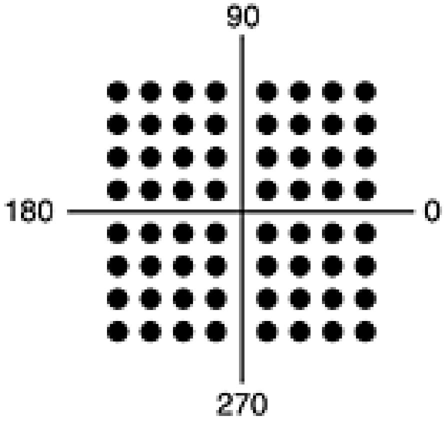
- BPSK (Binary Phase Shift Keying) = 2 phase shifts, 1 amplitude level, 1 bit/symbol
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



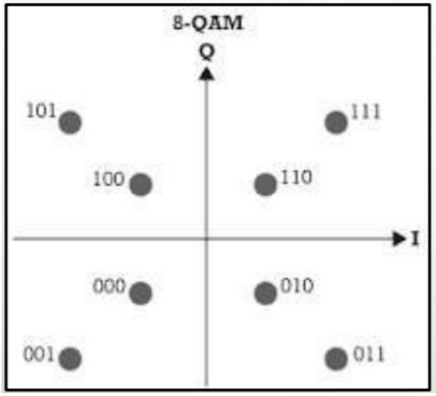
QPSK

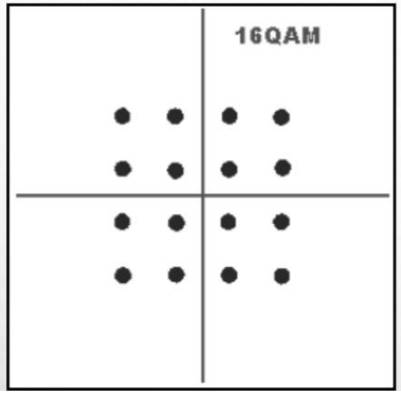


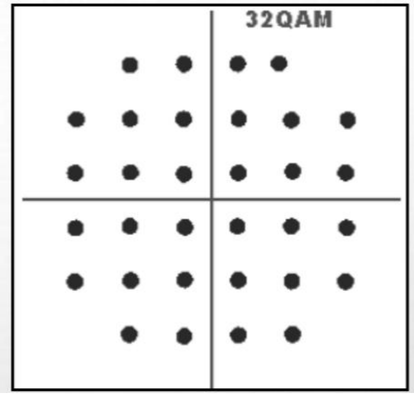
QAM-16

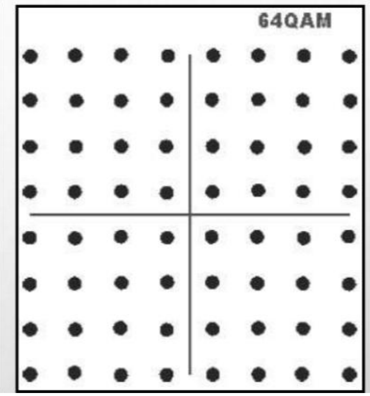


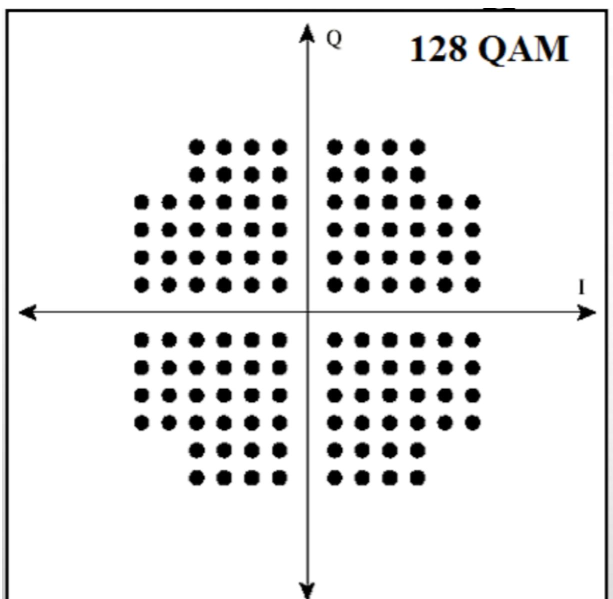
QAM-64

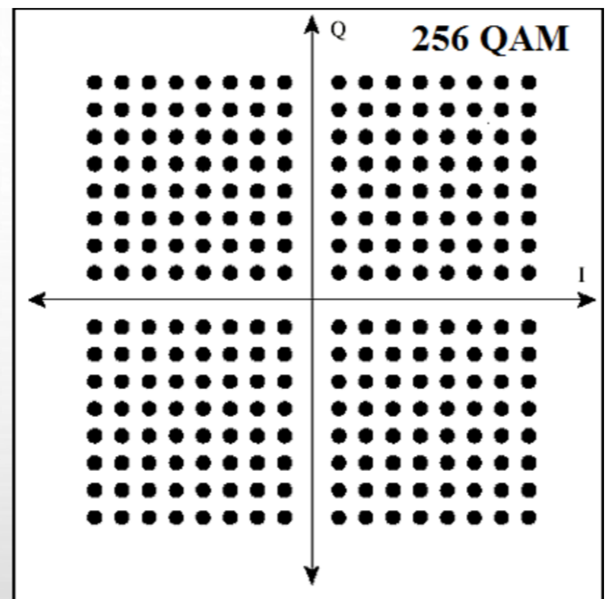

8-QAM
Q
I
101
111
100
110
000
010
001
011


16QAM


32QAM


64QAM

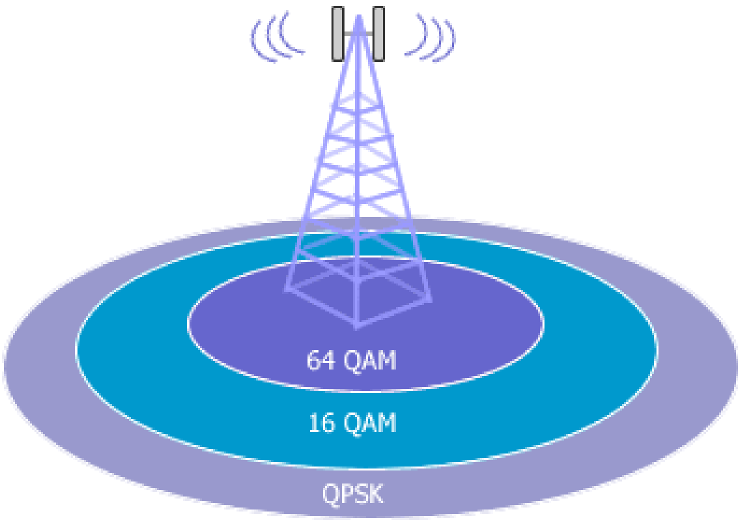

128 QAM
Q
I

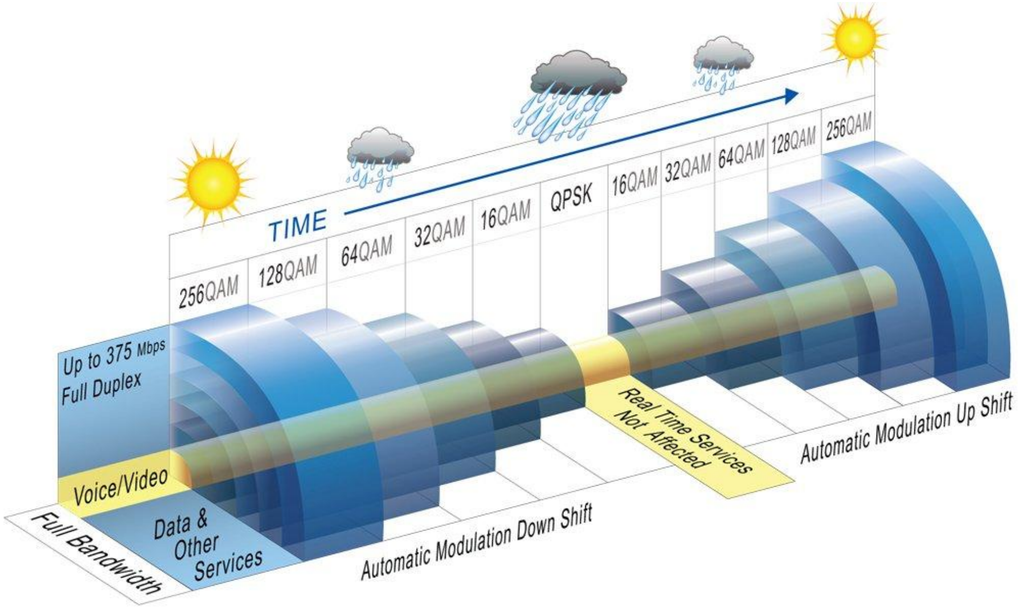

256 QAM
Q
I

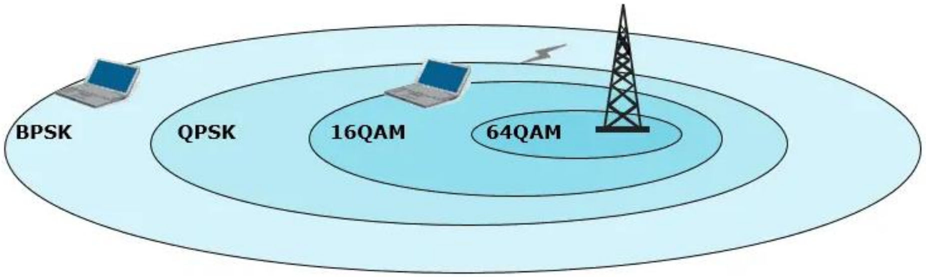
Number of States (*m*-ary)	Bits Transmitted Per Symbol
2	1
4	2
8	3
16	4
32	5
64	6
128	7
256	8

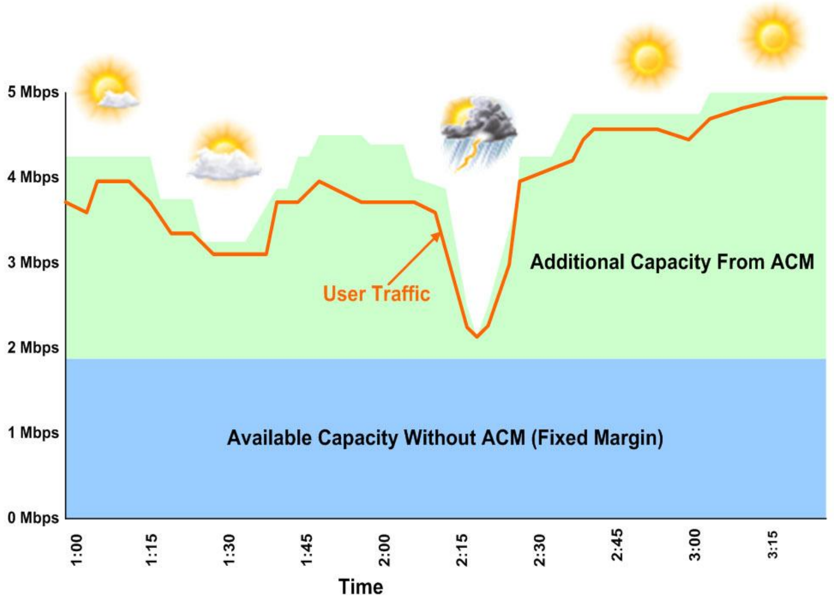
Modulation Scheme	Physical Data Rate
BPSK	6 Mbps
BPSK	9 Mbps
QPSK	12 Mbps
QPSK	18 Mbps
16 QAM	24 Mbps
16 QAM	36 Mbps
64 QAM	48 Mbps
64 QAM	54 Mbps

Adaptive (coding and) modulation









Adaptive (Coding and) Modulation (ACM)

- “Link Adaption” or “Dynamic Coding Modulation”

- Functionality
  - Observes change in Signal-to-Noise (SNR) of channel
  - Sends the Code and Modulation Information (CMI) in the header of a packet
  - Changes modulation scheme to optimize throughput

Requirements for ACM

1. Current channel conditions must be known with reasonable accuracy

- Open Loop Information
  - Received Signal Information
- Closed Loop (Feedback) Information
  - Receiver sends SNR Measurements to Transmitter
  - Requires a feedback channel

Requirements for ACM

2. Channel conditions must remain constant or change slowly relative to the adaption rate

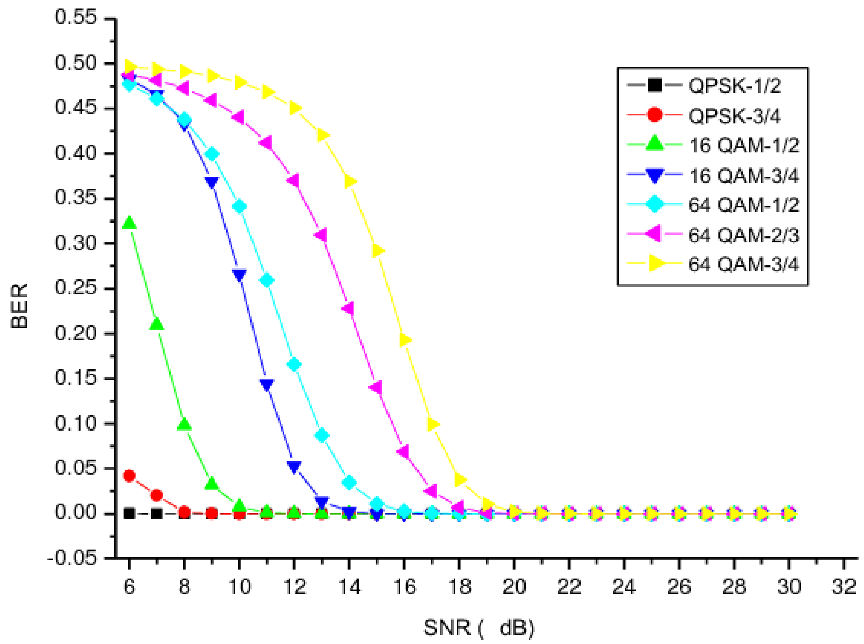
- Two Categories of Channel Fading Impairments
  - Fast Channel Fading (ex: Multi-Path)
  - Slow Channel Fading (ex: Shadow Fading)
- Goal is to adjust SNR update rates so that:
  - SNR updates slow enough to average fast fading effects
  - SNR updates fast enough to track slow fading effects

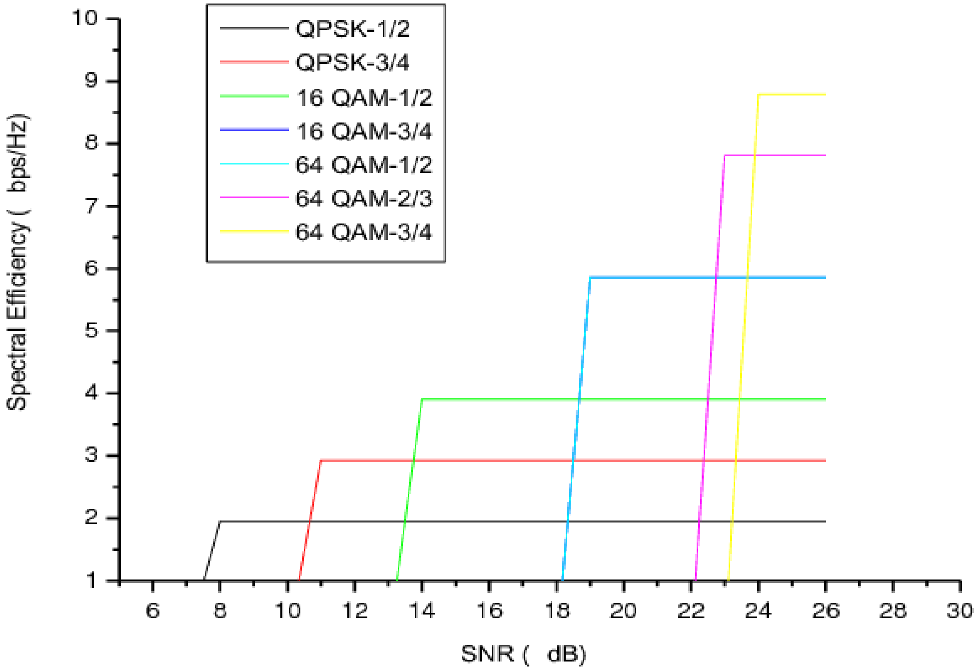
ACM schemes in LTE (4G)

ID (c_l)	level	$r(c_l)$ [bits/symbol]	SNR boundary [dB][1]
0	Silent	0	0
1	QPSK(1/2)	1	6
2	QPSK(3/4)	1.5	8.5
3	16QAM(1/2)	2	11.5
4	16QAM(3/4)	3	15
5	64QAM(2/3)	4	18.5
6	64QAM(3/4)	4.5	21

Trick question: What is the difference between LTE and 4G

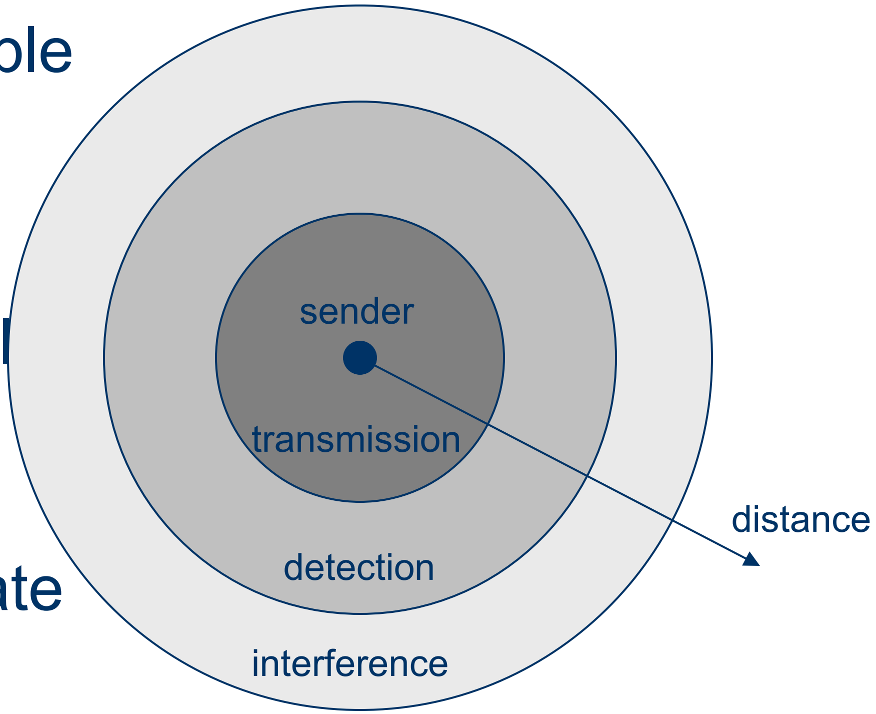
Adaptive (coding and) modulation





Signal Propagation Ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible, high error rate
- Interference range
  - signal may not be detected
  - signal adds to the background noise



Multiple Access Control
WiFi introduction

Multiple access protocols

Channel Types

- Broadcast channels
  - (at least) one transmits and (possibly) many receive (simultaneously)
- Multi-access channels
  - Many transmitters use one (single) channel to communicate with (at least) one receiver (not necessarily simultaneously)
  - Possibly communicate between themselves
- Example: Mobile phone and base station
  - Mobile phone → base station : multiple access channel (many transmitters send to a single receiver)
  - Base station → mobile phone: the sender broadcasts to many receivers

Multiple Access Control Channels

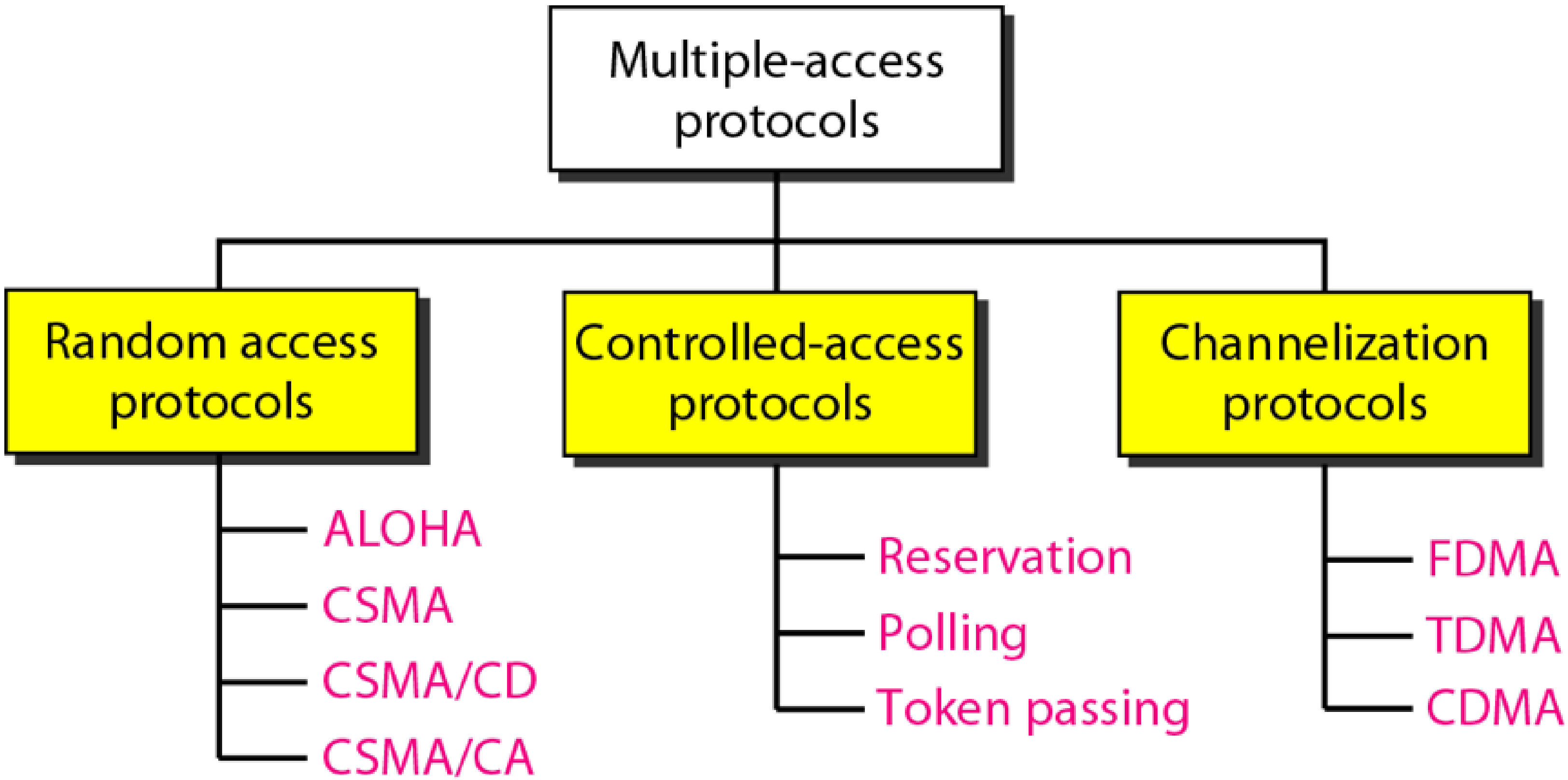
- N independent stations
  - Assumption of limited or unlimited number
  - Poisson arrivals
  - Fixed packet length
- Single Channel
- Collisions are possible
  - Carrier sensing
  - Collision detection
- Time assumptions
  - Segmented non-continuous time / Synchronous mode
  - Non-segmented continuous time / Asynchronous mode

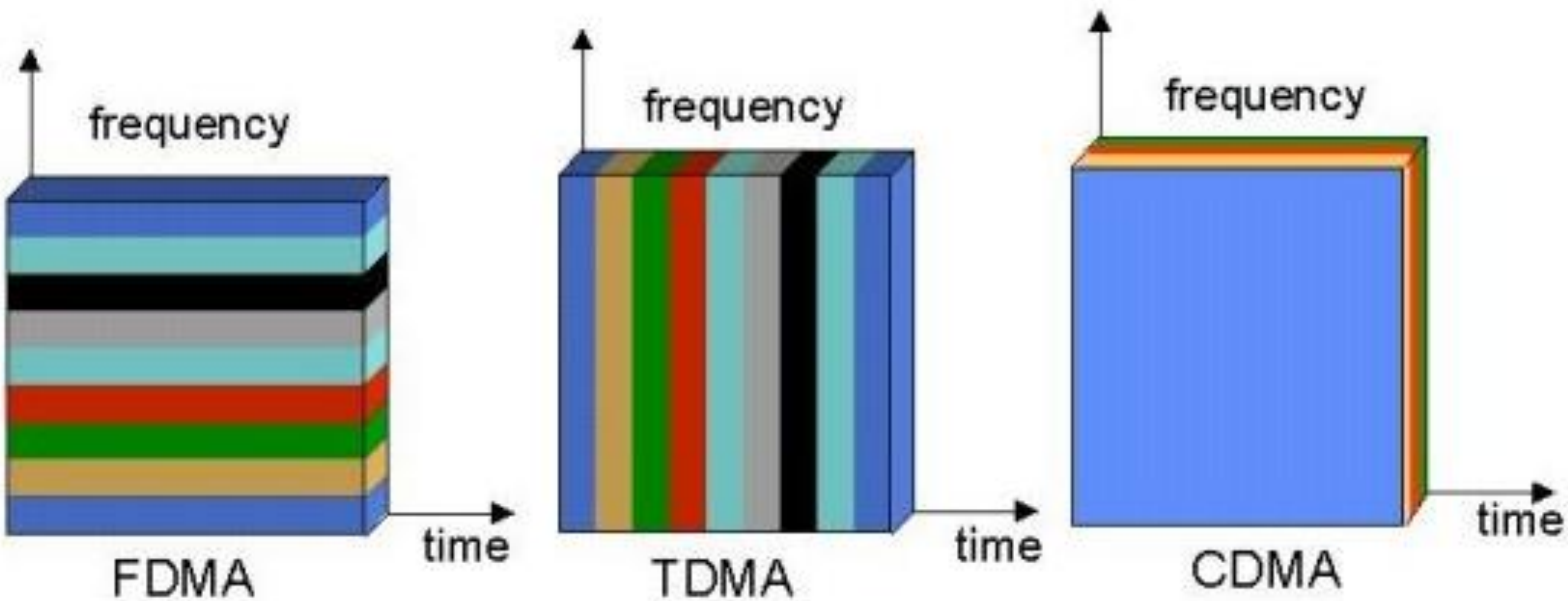
Multiplexing Techniques

- Multiplexing techniques are used to allow many users to share a common transmission resource. In our case the users are mobile and the transmission resource is the radio spectrum. Sharing a common resource requires an access mechanism that will control the multiplexing mechanism.
- As in wireline systems, it is desirable to allow the simultaneous transmission of information between two users engaged in a connection. This is called duplexing.
- Two types of duplexing exist:
  - Frequency division duplexing (FDD), whereby two frequency channels are assigned to a connection, one channel for each direction of transmission.
  - Time division duplexing (TDD), whereby two time slots (closely placed in time for duplex effect) are assigned to a connection, one slot for each direction of transmission.

Multiplexing

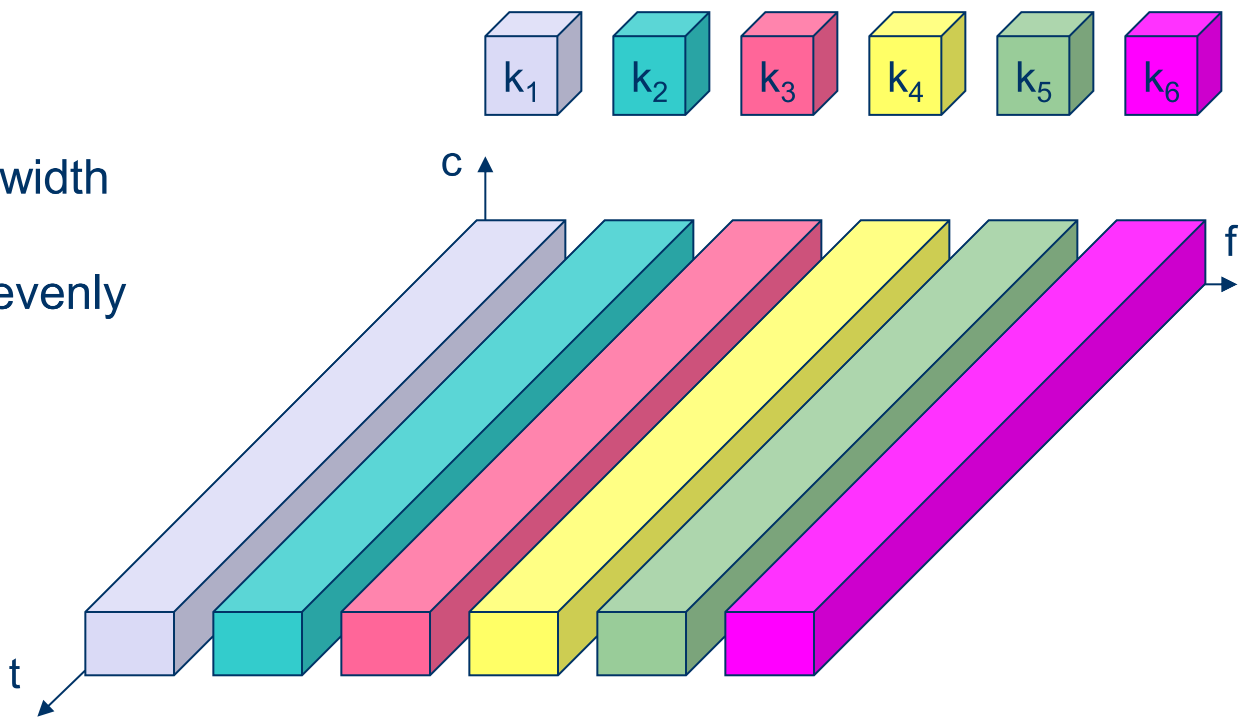
- Multiplexing allows parallel transmission from different sources, handling interference.
- Three basic kinds
  - **TDM/TDMA** (Time Division Multiple Access)
  - **FDM/FDMA** (Frequency Division Multiple Access)
  - **CDMA** (Code Division Multiple Access)
  - Combinations of the above


Multiple-access protocols
Random access protocols
Controlled-access protocols
Channelization protocols
ALOHA
CSMA
CSMA/CD
CSMA/CA
Reservation
Polling
Token passing
FDMA
TDMA
CDMA


frequency
time
FDMA
frequency
time
TDMA
frequency
time
CDMA

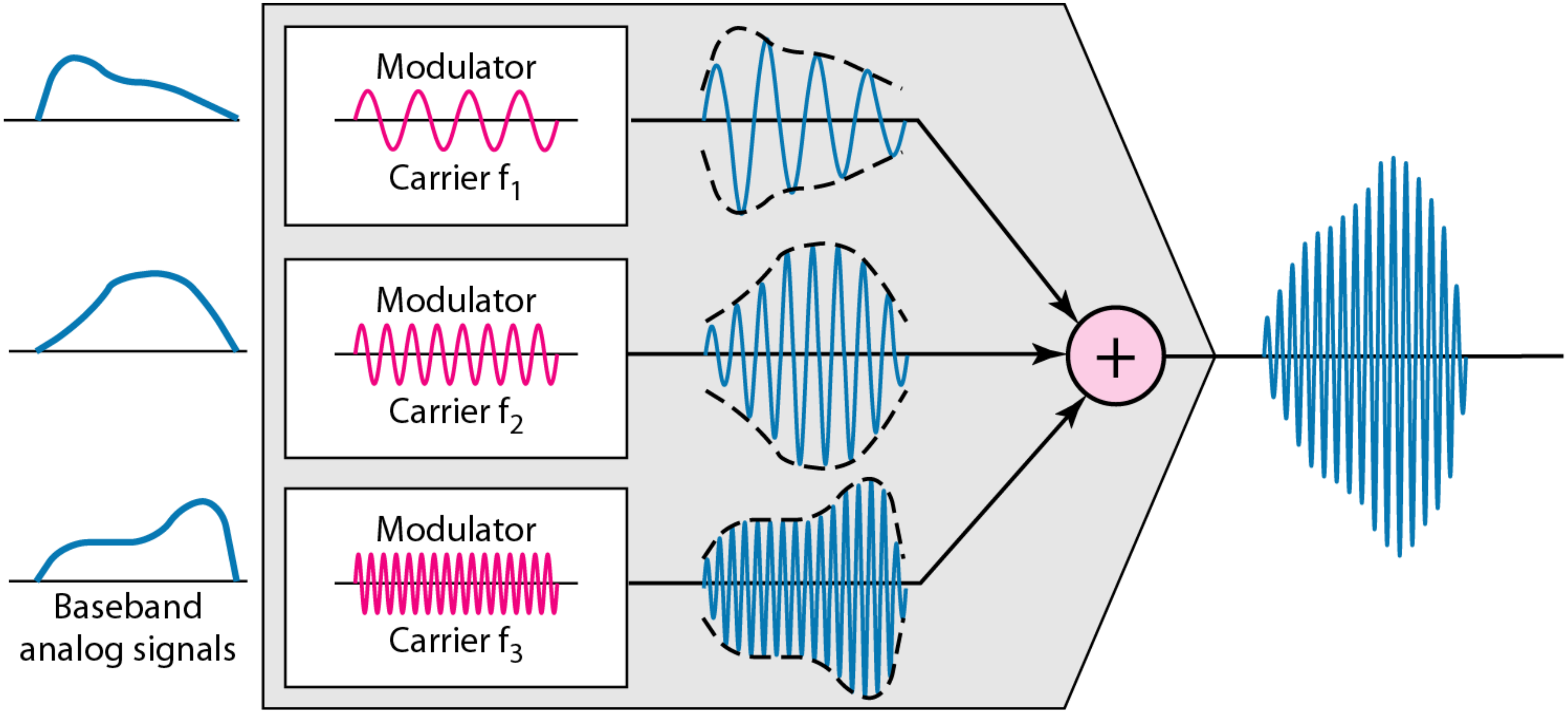
Frequency Division Multiplexing (FDM)

- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time
  Advantages:
  - no dynamic coordination necessary
  - works also for analog signals
  - cheaper
- Disadvantages:
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible

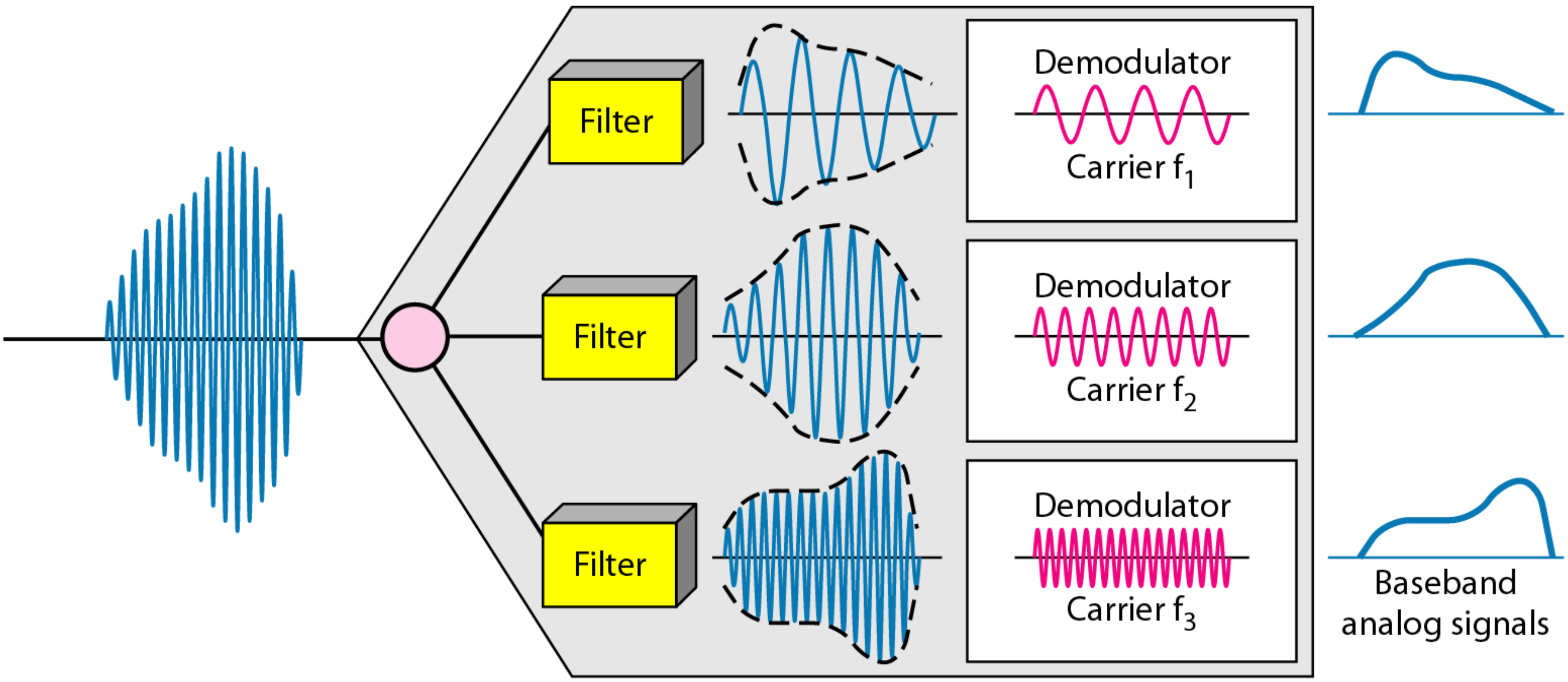


Frequency Division Multiplexing (FDM)

Frequency Division Multiplexing (FDM)

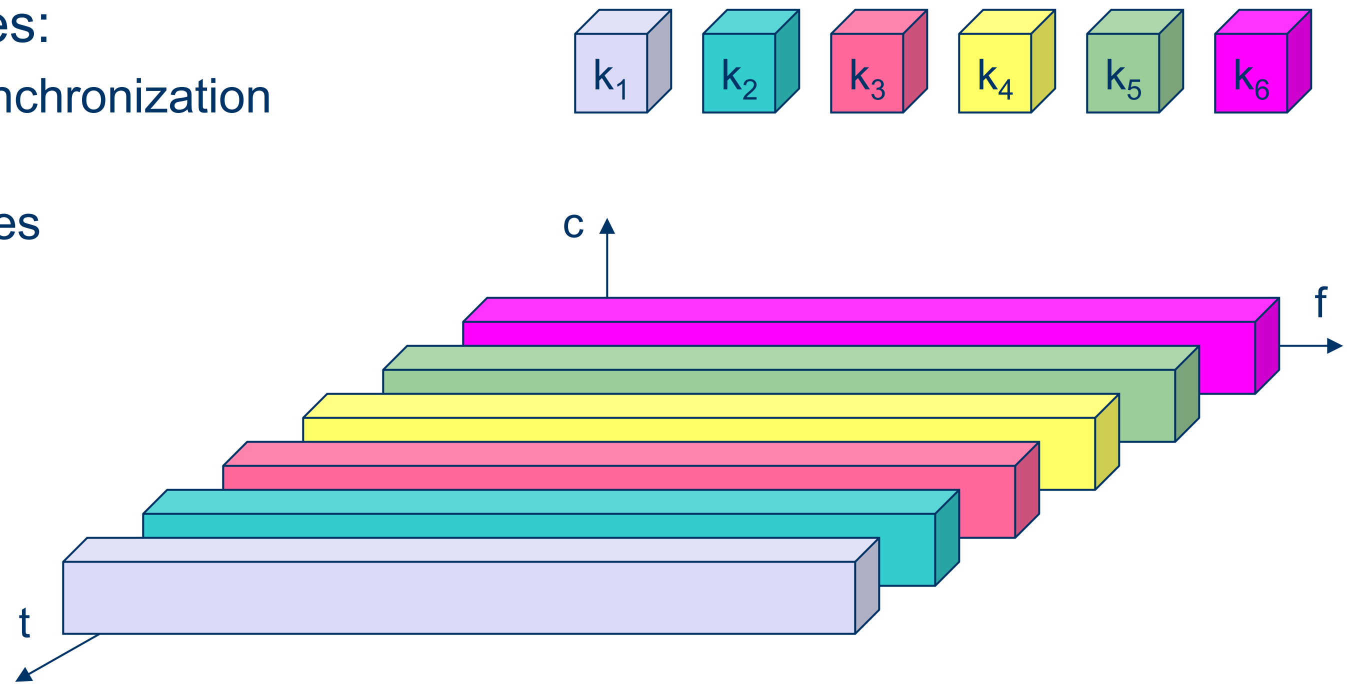


Frequency Division Multiplexing (FDM)

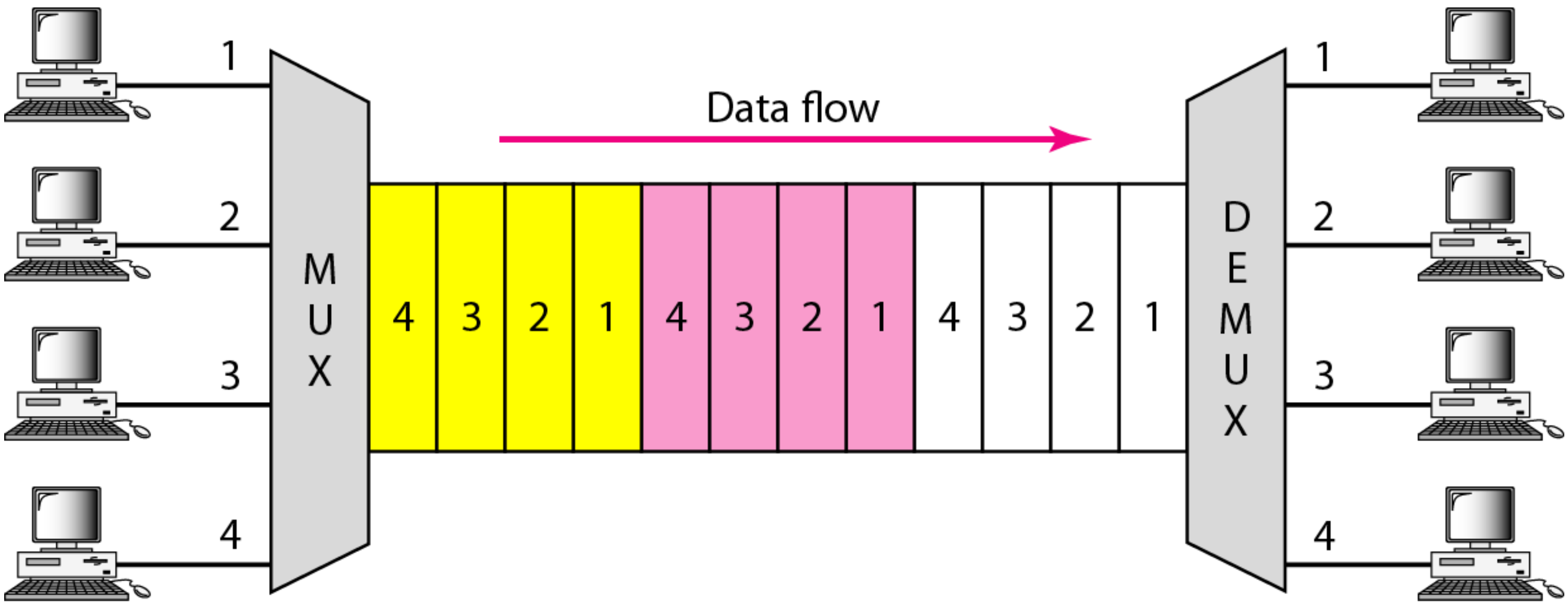


Time Division Multiplexing (TDM)

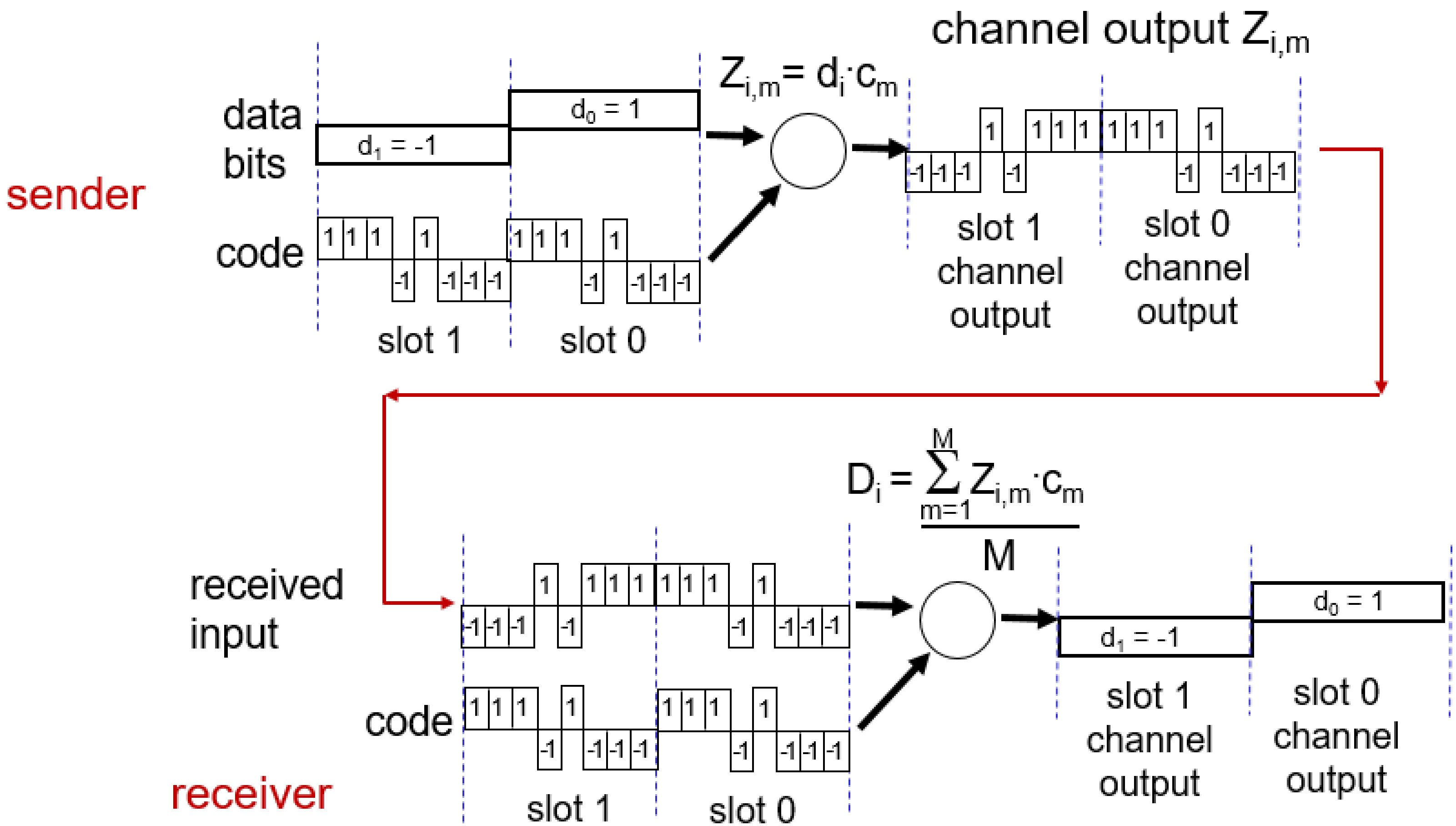
- A channel gets the whole spectrum for a certain amount of time
- Advantages:
  - only one carrier in the medium at any time
  - throughput high - supports bursts
  - flexible – multiple slots
- Disadvantages:
  - Precise synchronization necessary
  - high bit rates at each Tx/Rx



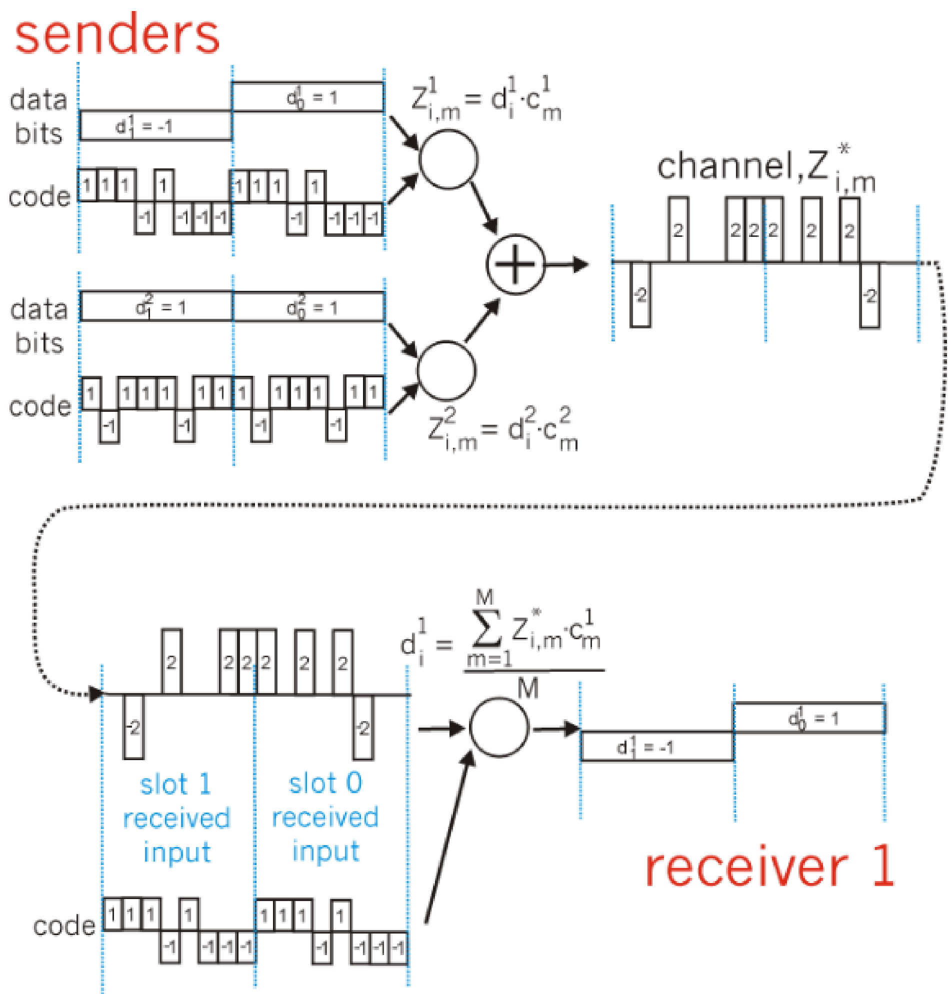
Time Division Multiplexing (TDM)



Code Division Multiple Access (CDMA)



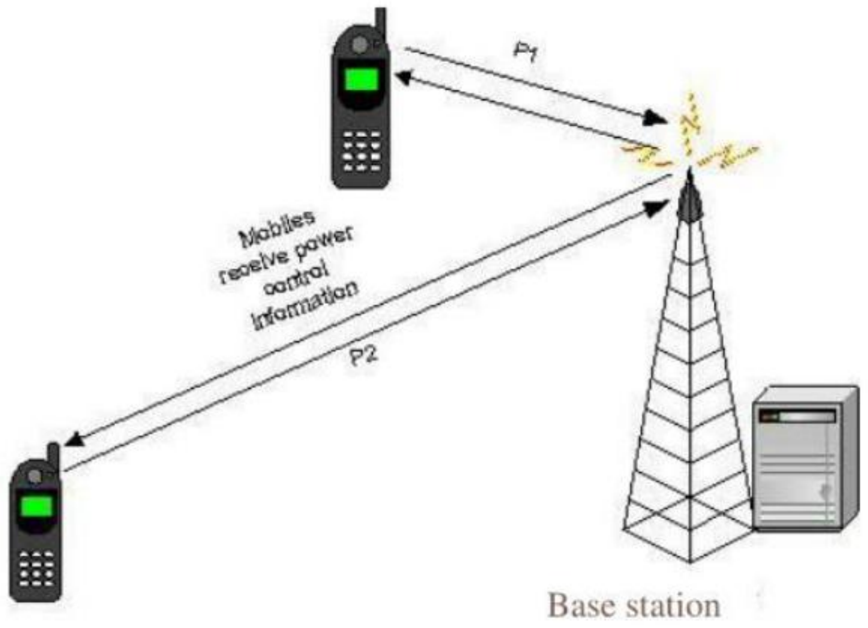
Code Division Multiple Access (CDMA)



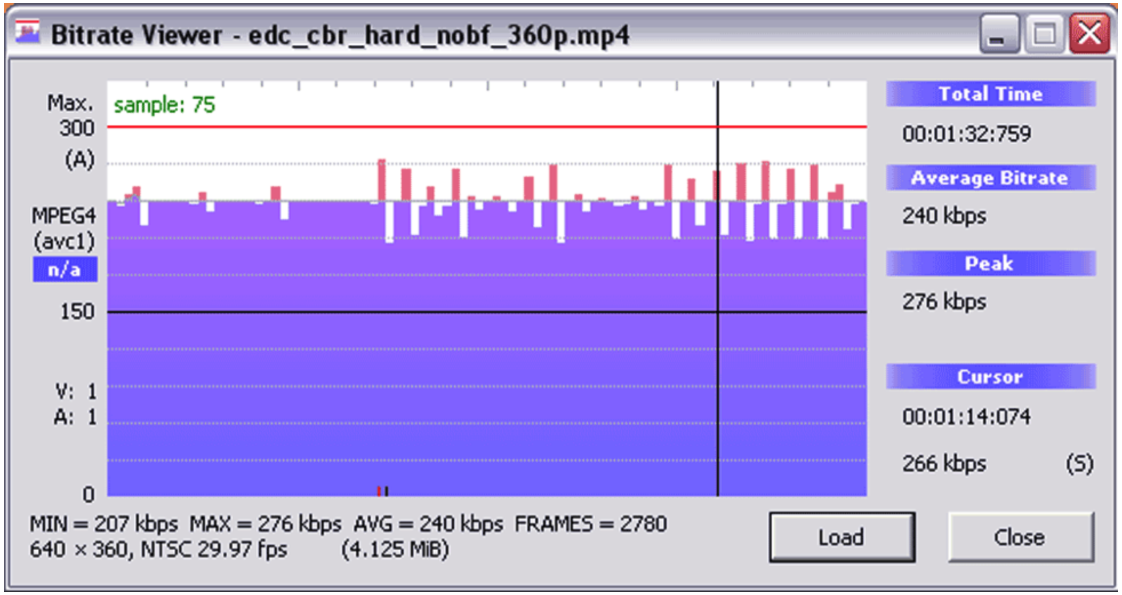
Near-far problem in CDMA

- A CDMA receiver cannot successfully de-spread the desired signal in a high multiple-access-interference environment
- Unless a transmitter close to the receiver transmits at power lower than a transmitter farther away, the far transmitter cannot be heard
- Power control must be used to mitigate the near-far problem
- Mobiles transmit at such power levels to ensure that received power levels are equal at base station

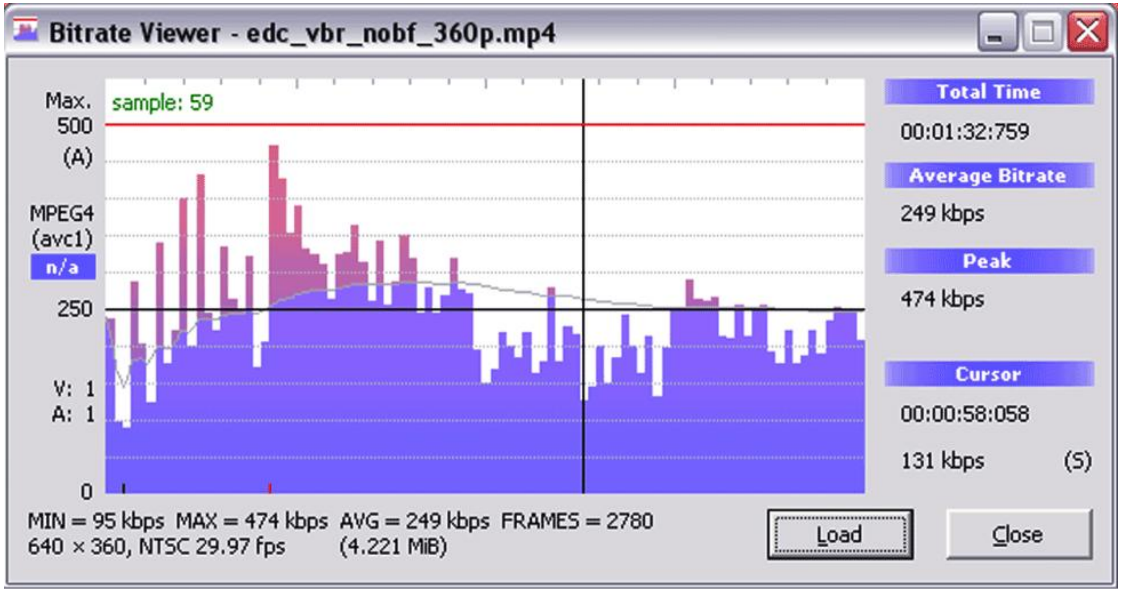
- Power control and channel problems!



Constant / Variable Bit Rate



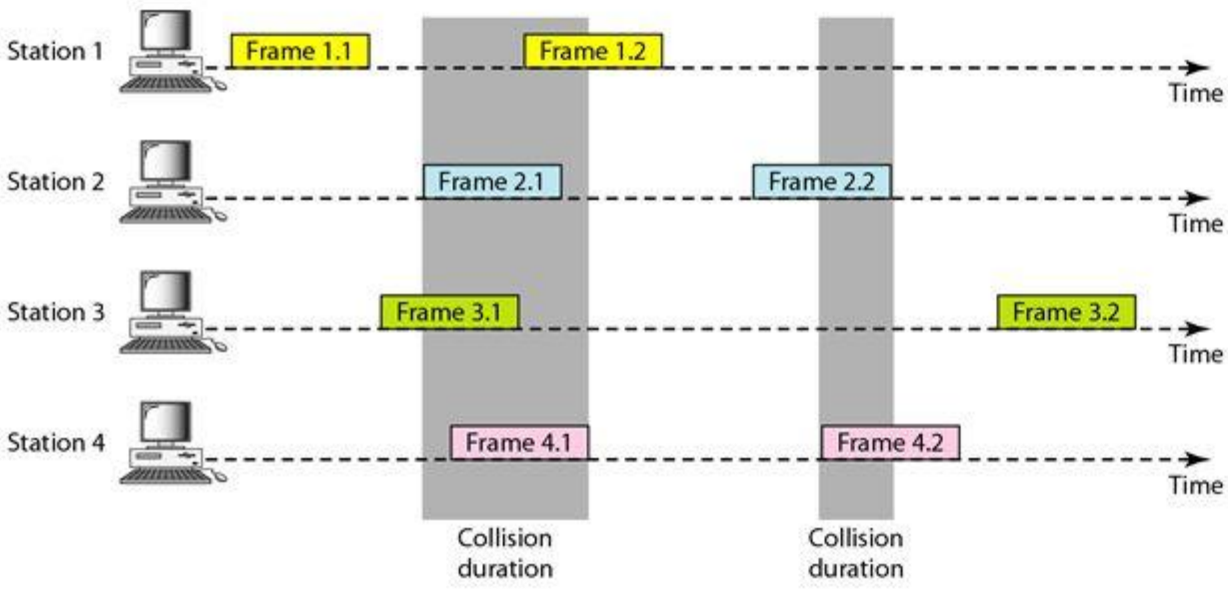
CBR



VBR

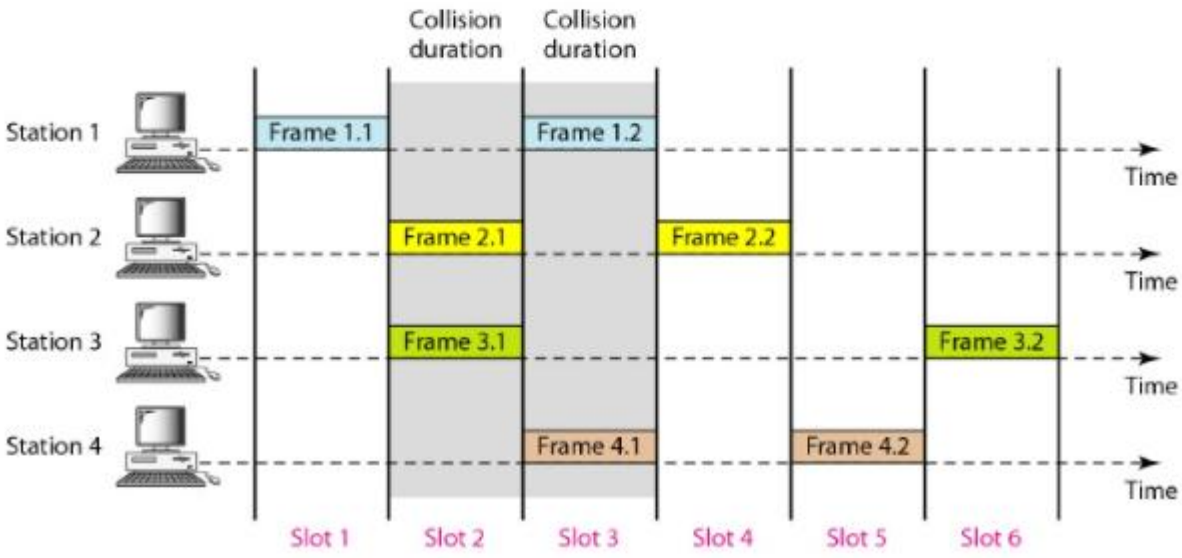
Pure ALOHA

- Continuous time, transmission at any moment.
- No synchronization, packet transmission upon arrival at the queue.
- On collision, the packet is retransmitted after random time.

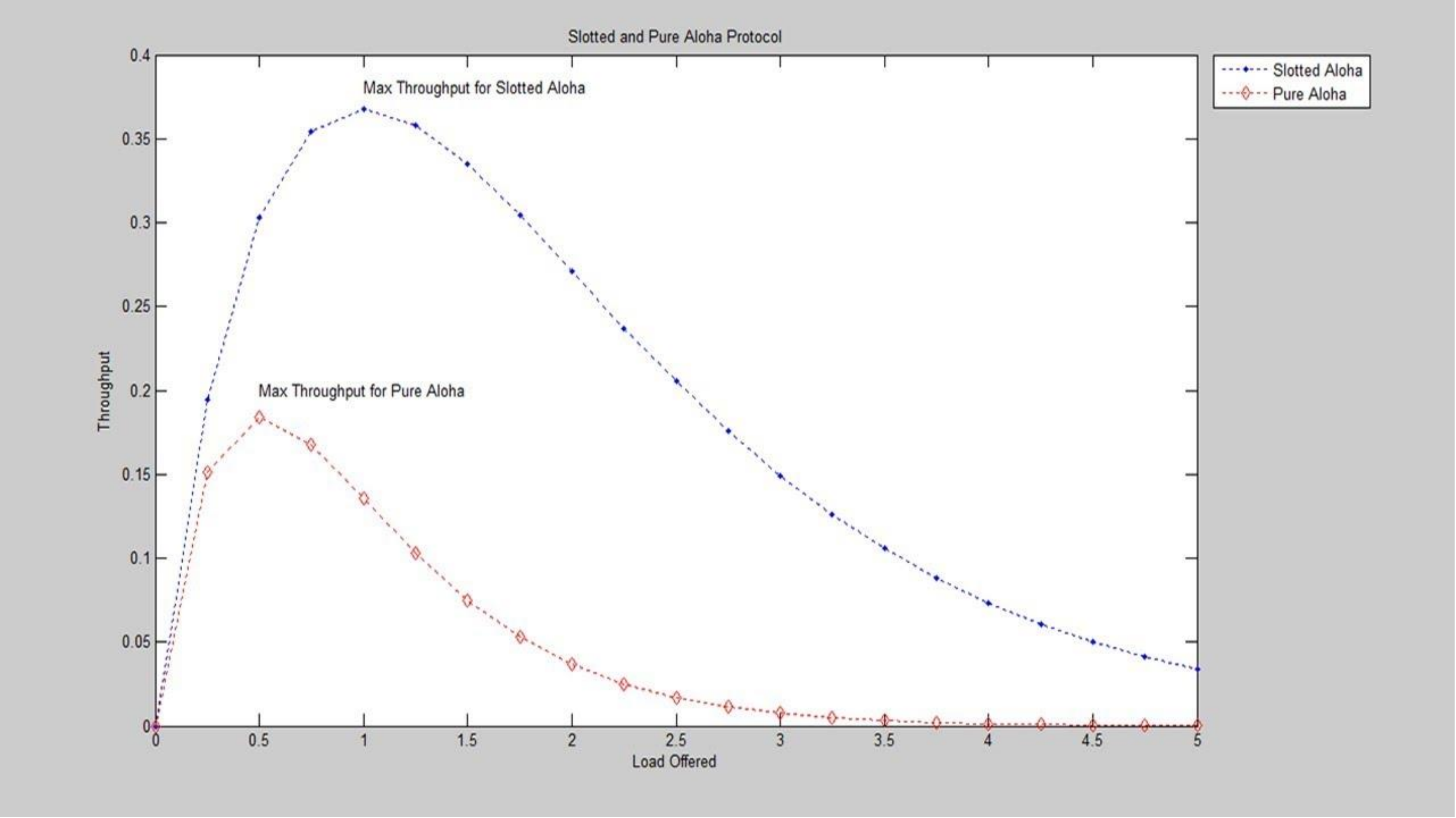


Slotted ALOHA

- Fixed packet length
- Timeslot=packet transmission time
- Each packet is transmitted at the first timeslot after arrival
- Synchronization is required
- On collision, the packet is retransmitted after random timeslots



Throughput



Slotted and Pure Aloha Protocol
Max Throughput for Slotted Aloha
Max Throughput for Pure Aloha
Slotted Aloha
Pure Aloha
Throughput
Load Offered
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

ALOHA performance

- Unstable behavior: one packet can have low or high delay for the same throughput
- Low throughput = 18% ή 36%
- But
  - Very simple to implement
  - Low delay for low traffic
  - Delay independent to the total number of nodes

Carrier Sense Multiple Access(CSMA)

- One node can listen if other nodes transmit (this a small delay depending on distance
- Transmission can be postponed, if a collision is going to happen
- Not all collisions are avoided due to delay in signal propagation

CSMA PROTOCOLS

Non-persistent CSMA

- Packets arriving in empty slots are transmitted instantaneously
- If the slot is busy, the transmission is rescheduled after random time (virtual collision)
- Good throughput
- Good distribution of traffic in time
- Delay is increasing for higher traffic

CSMA PROTOCOLS

1-persistent CSMA

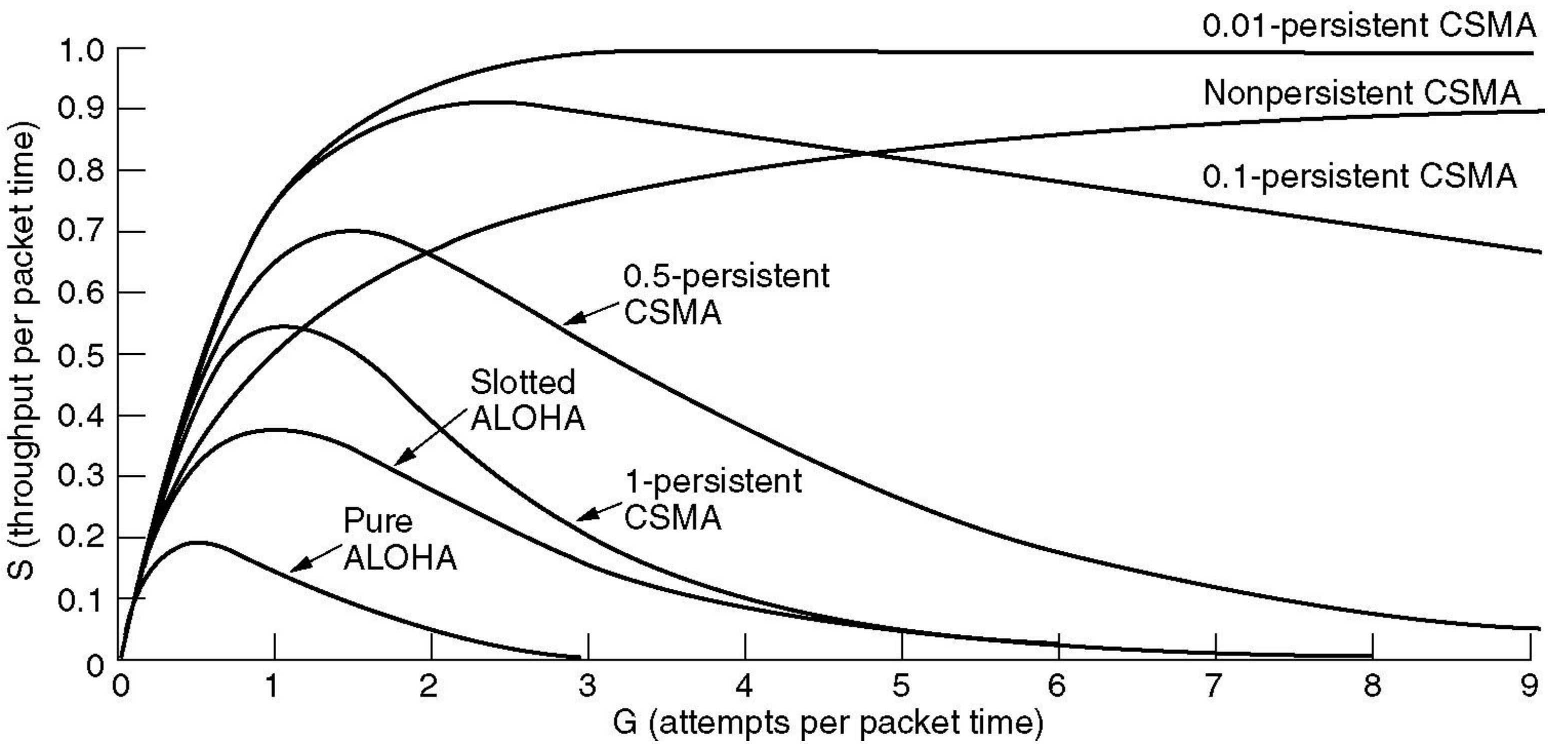
- Packets arriving in empty slots are transmitted instantaneously
- If the slot is busy, wait until the next empty slot and transmit
- Low delay in low traffic
- Max throughput not that impressive
- At the end of an existing transmission, collision probability if high

CSMA PROTOCOLS

P-persistent CSMA

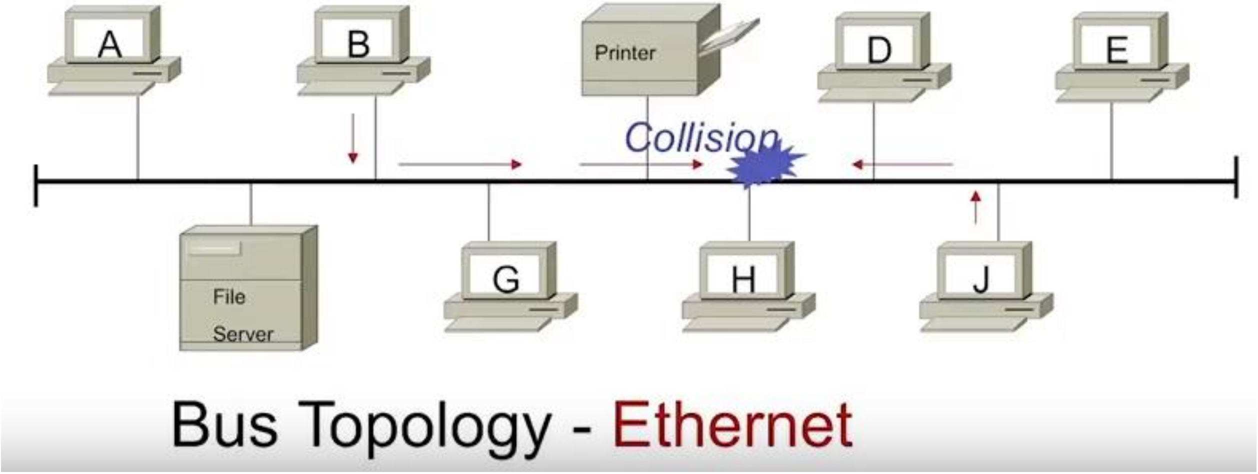
- Packets arriving in empty slots are transmitted instantaneously
- If the slot is busy, wait until the next empty slot and transmit with probability P
- With probability 1-P repeat the procedure in the next slot

A comparison of simple protocols

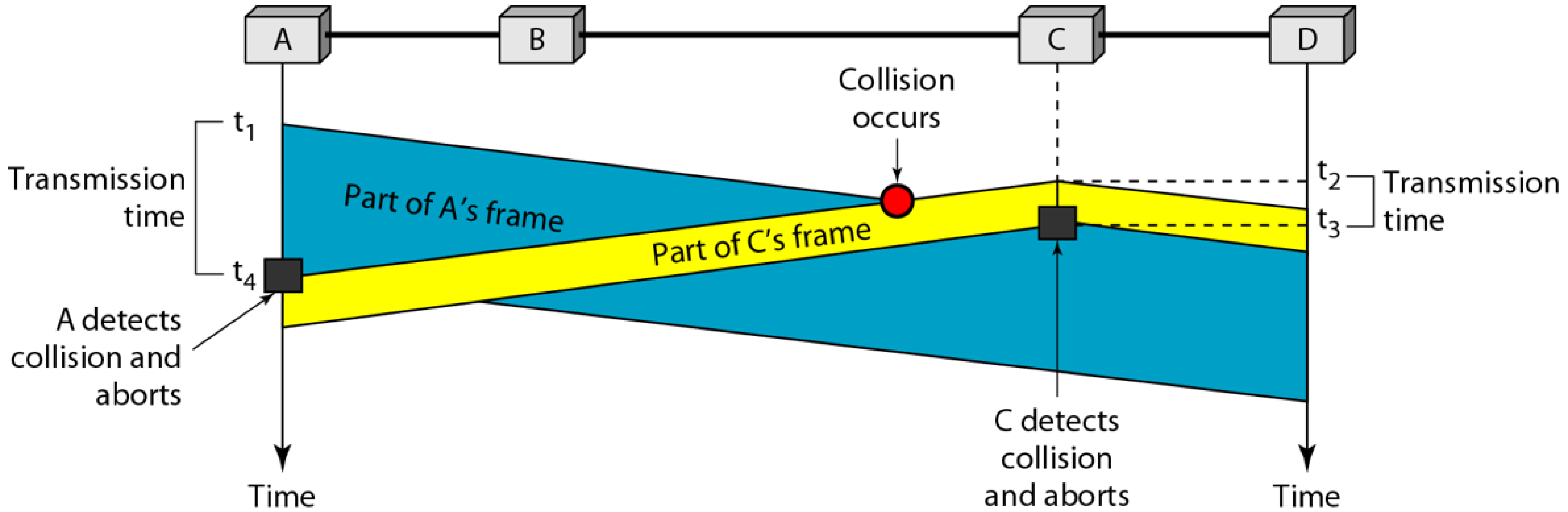


Carrier Sense Multiple Access Collision Detection (CSMA/CD)

- each node can listen to the medium **before transmission, while the channel allows listening while transmitting**
- On collision detection:
  - quits transmission
  - waits a random time period and retries
- **hard to implement in wireless communications**
- Used in Ethernet

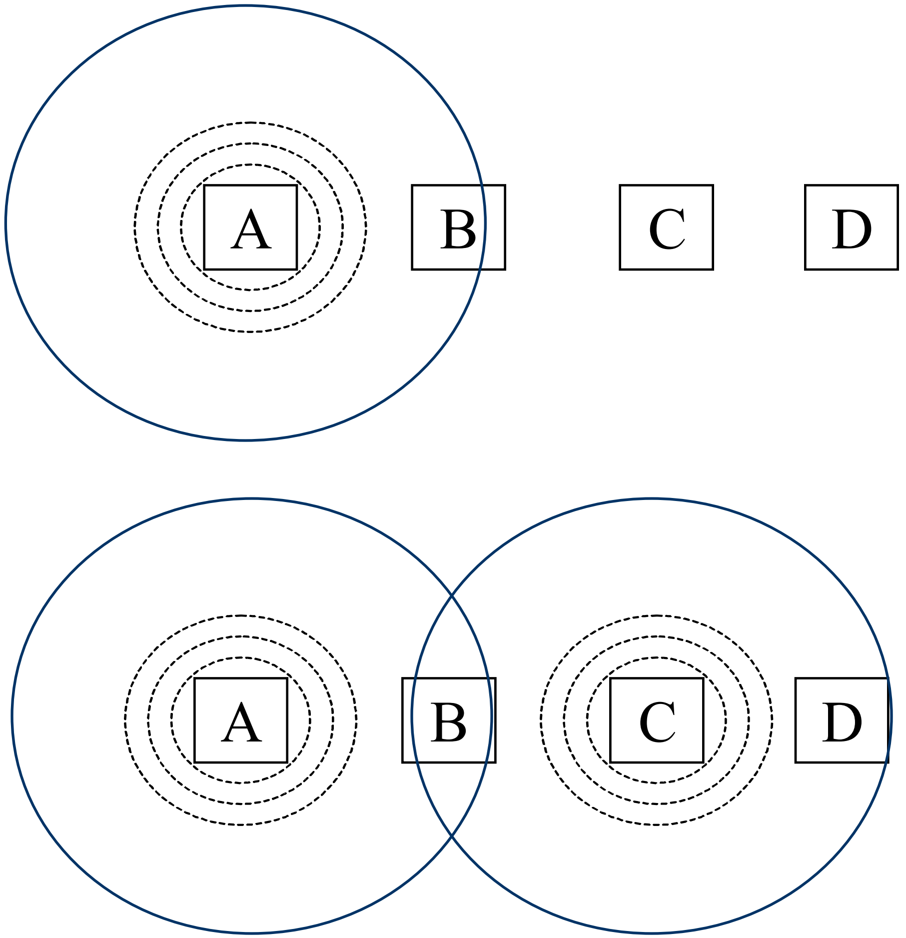


Carrier Sense Multiple Access Collission Detection (CSMA/CD)



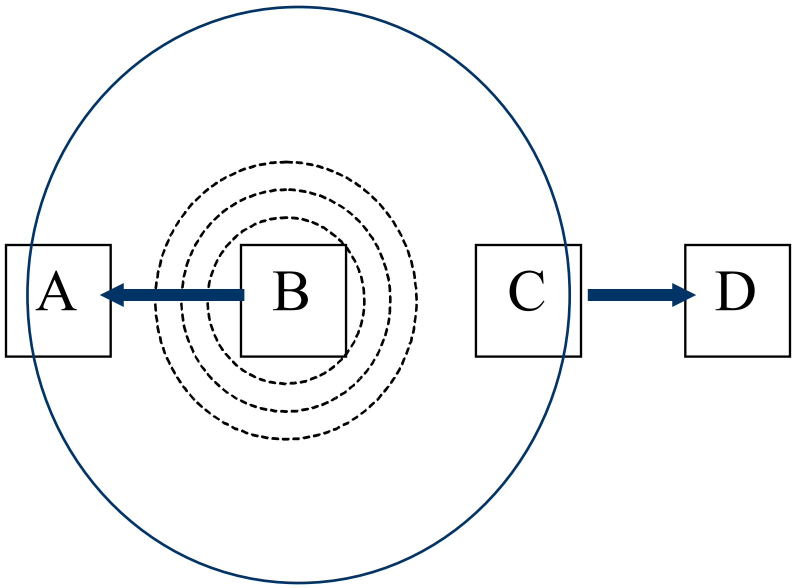
Hidden station problem

- A sends to B
- C does not listen to A
- C sends to B
- Collision at B
- A and C does not detect collision
- CSMA/CD not efficient in wireless



Visible station problem

- B sends to A
- C wants to send to D
- but
  - C listens to B
  - C does not transmit to D (while he could)



Collision Avoidance: RTS-CTS exchange