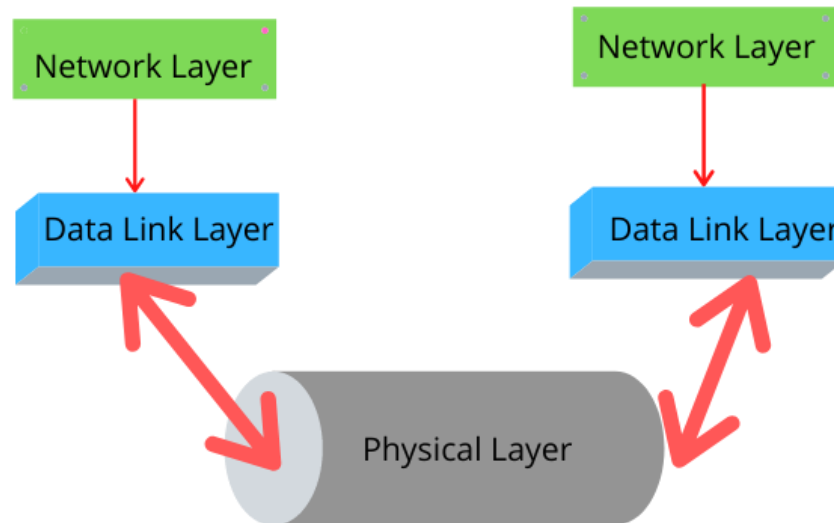


# Mobile and Wireless Networks

## Wireless transmission

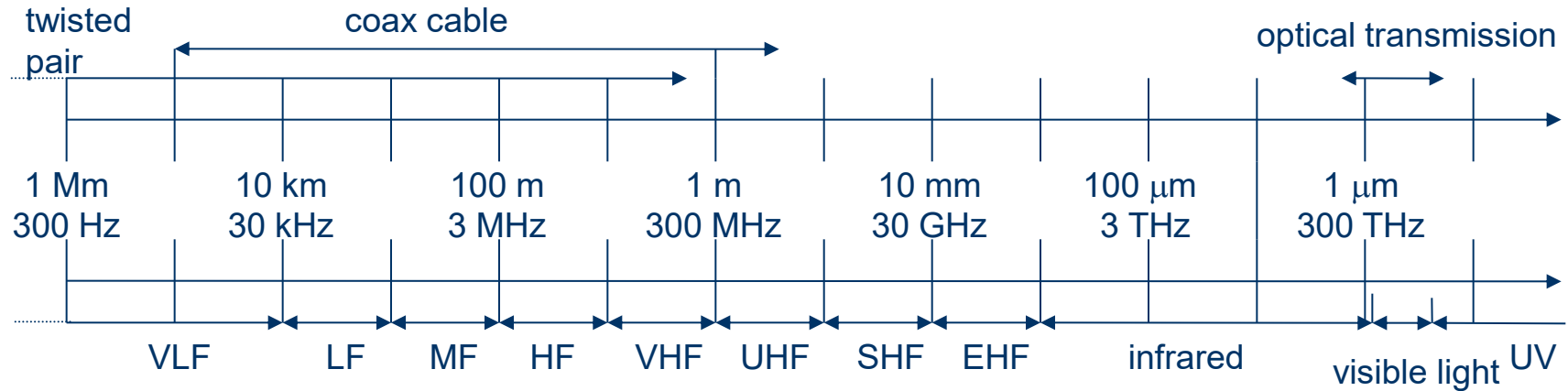
### Data Link Layer In OSI Model



# 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  $\lambda$  = distance between two minimums or two maximums
  - $\lambda * f = c$  (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 is 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

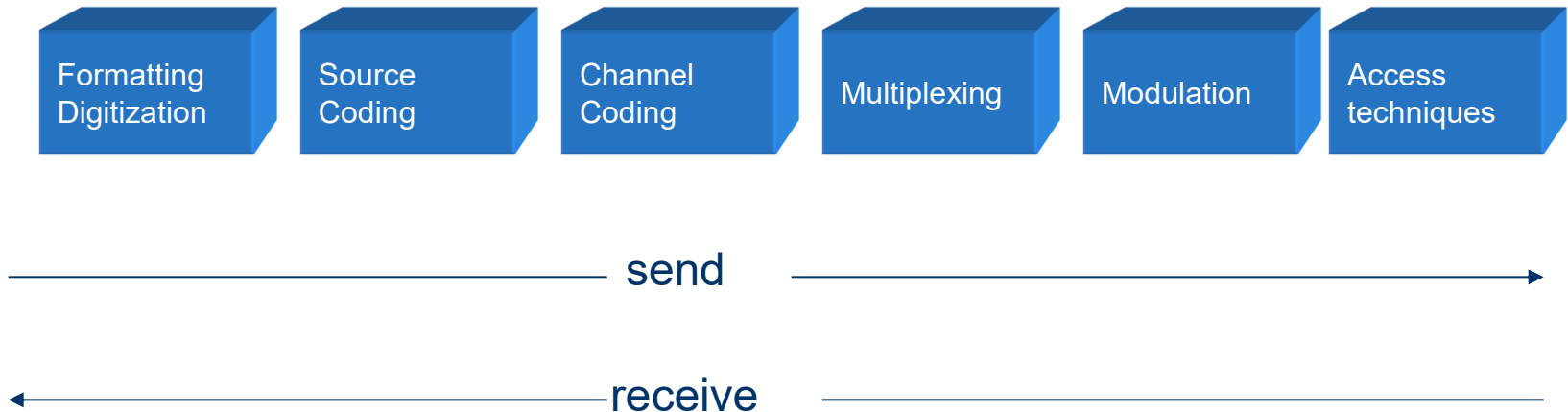
Relationship between frequency 'f' and wave length ' $\lambda$ ' :

$$\lambda = c/f$$

where c is the speed of light  $\cong 3 \times 10^8 \text{ m/s}$

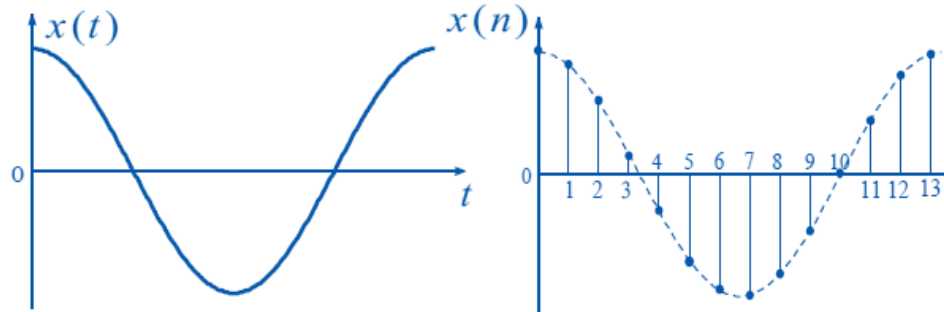
# Communication System

- Structural modular approach
- Various components
- Of defined functions

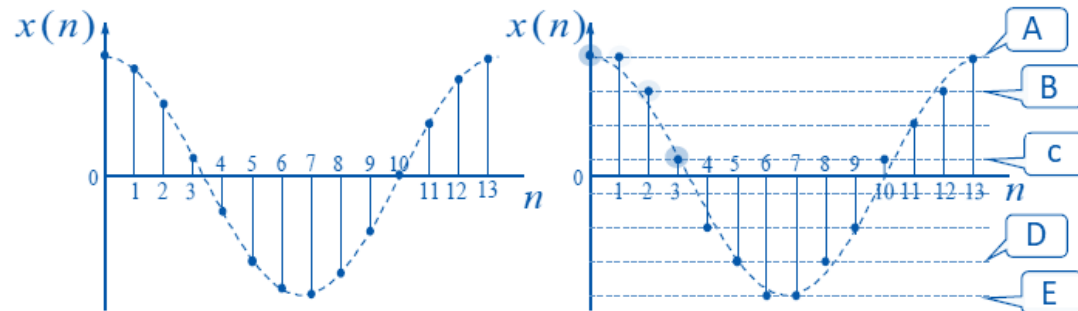


# Digitization

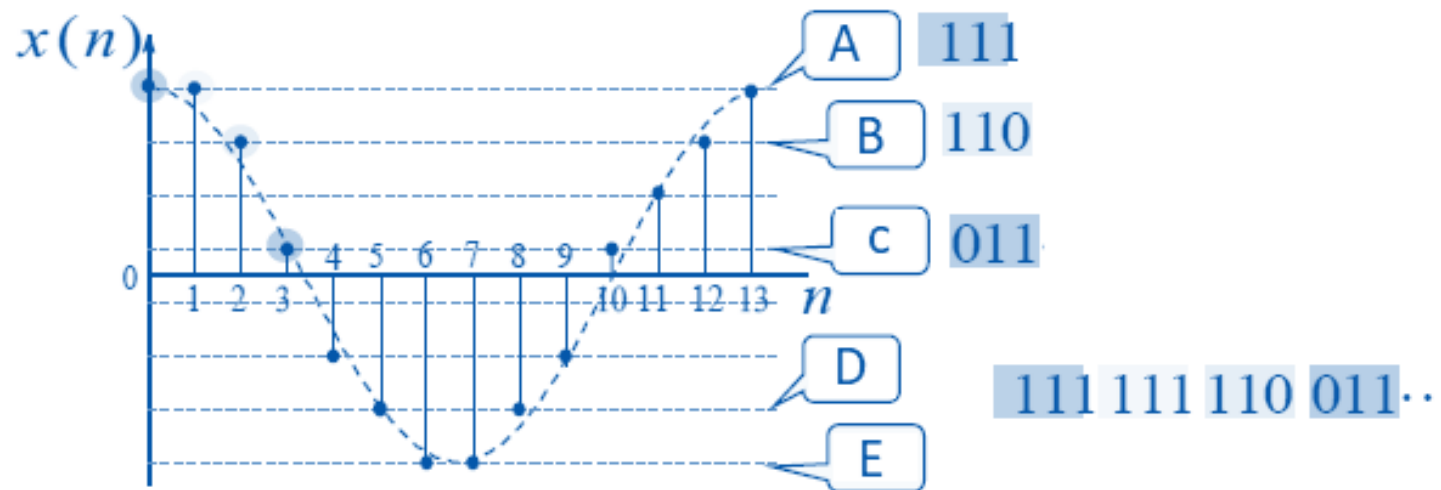
## ➤ Sampling



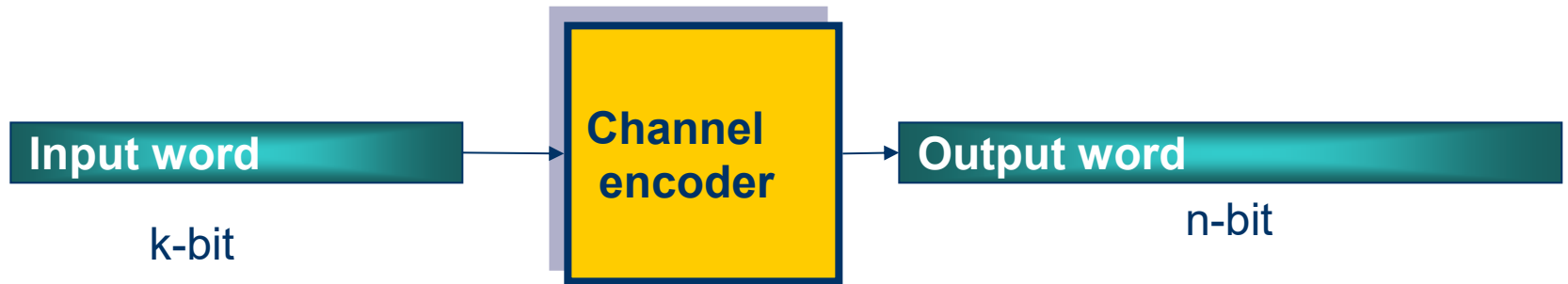
## ➤ Quantization



# Source coding



# Channel coding

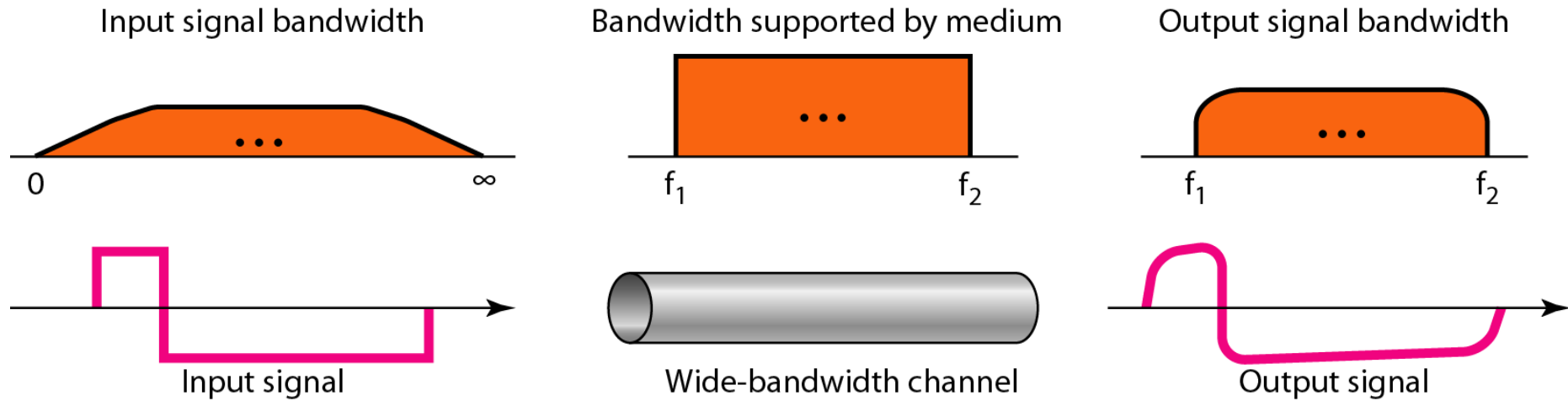
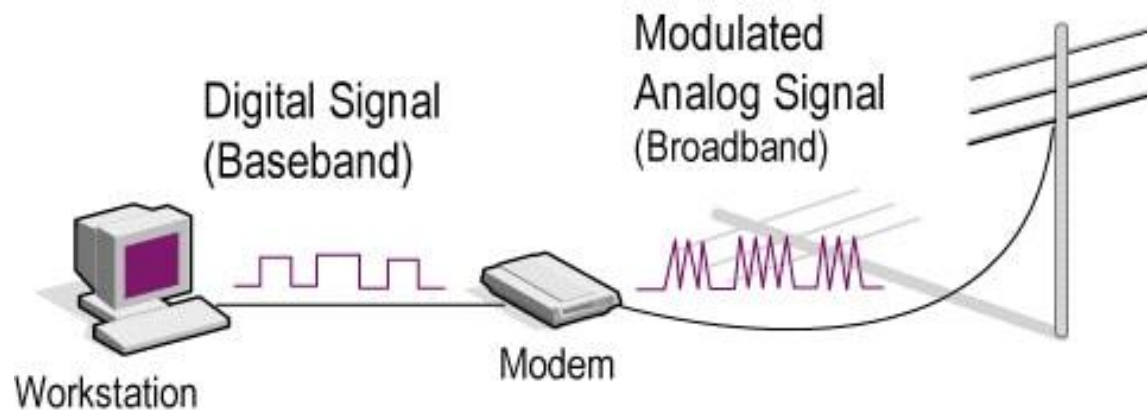


codeword  
Code sequence

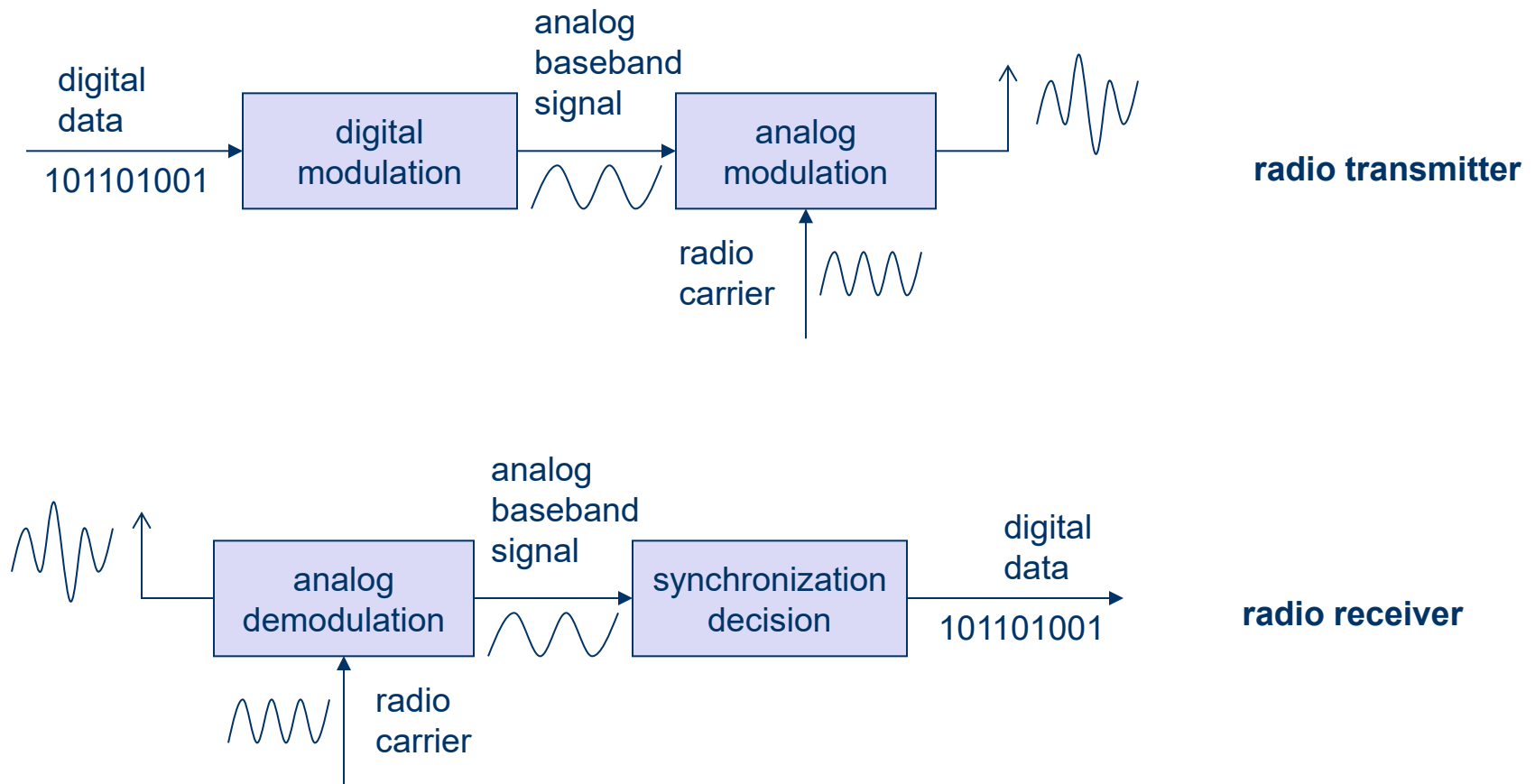
Redundancy =  $(n-k)$

Code rate =  $k/n$

# Baseband transmission



# Modulation and Demodulation

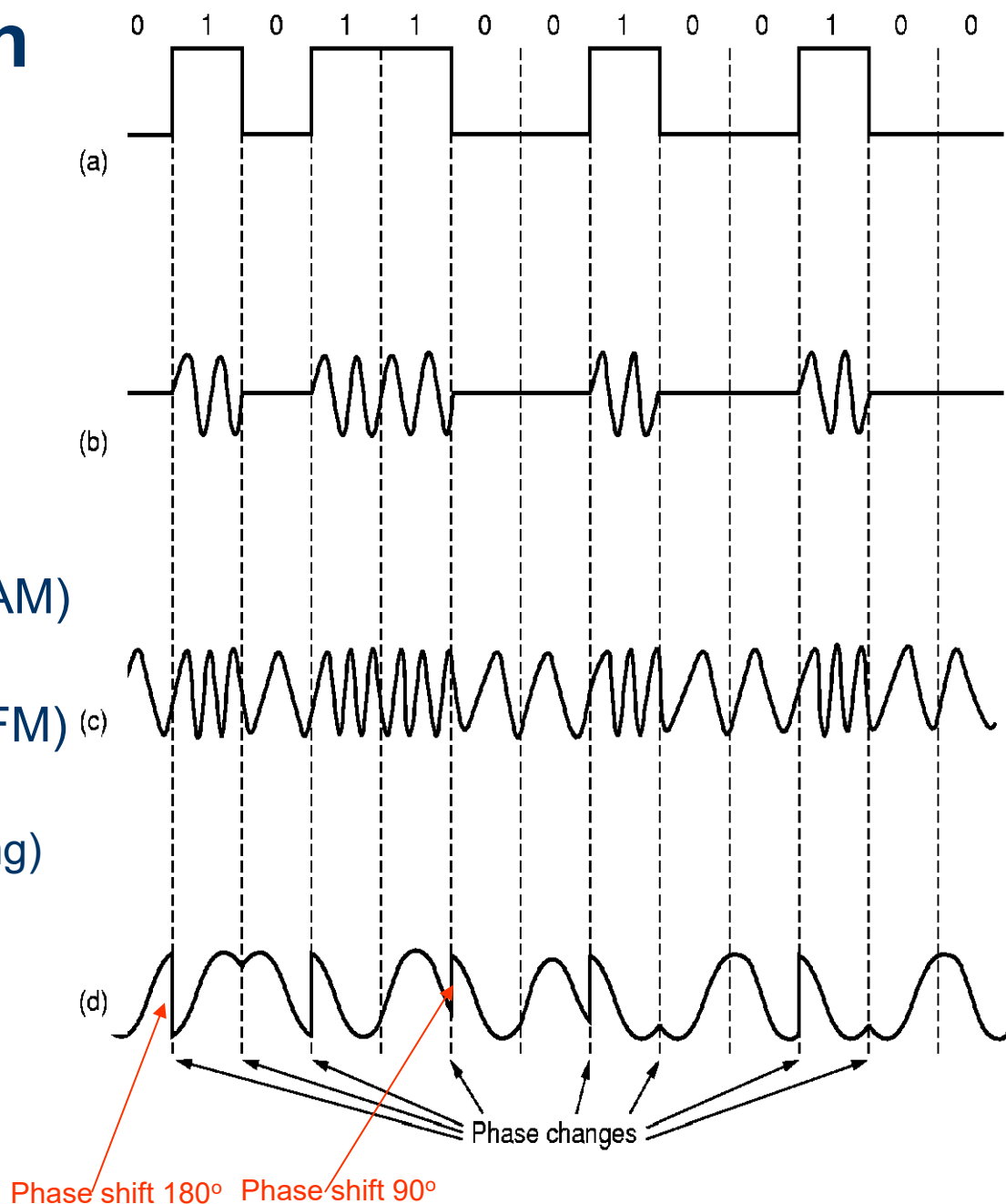


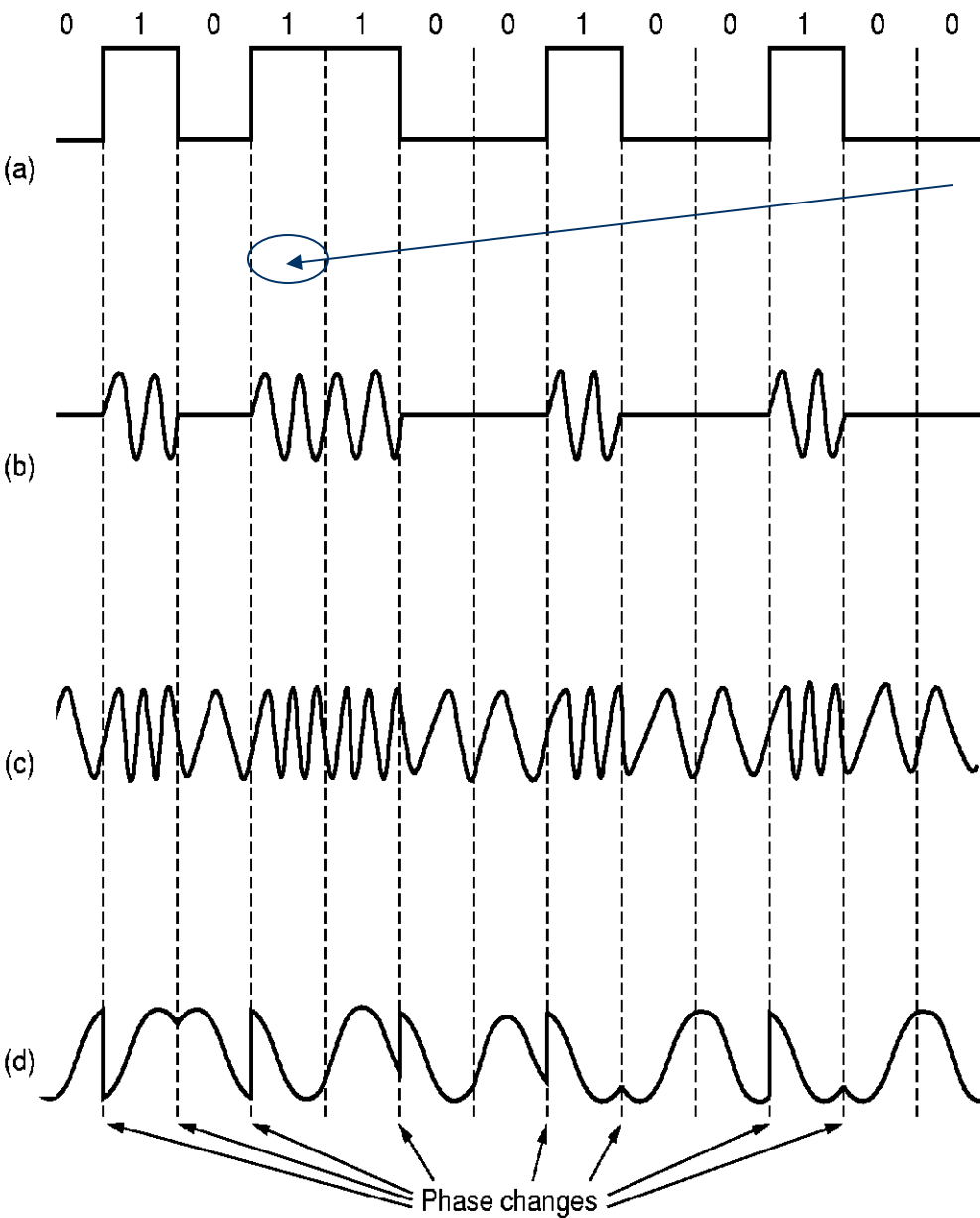
# Signal Modulation

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

- (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

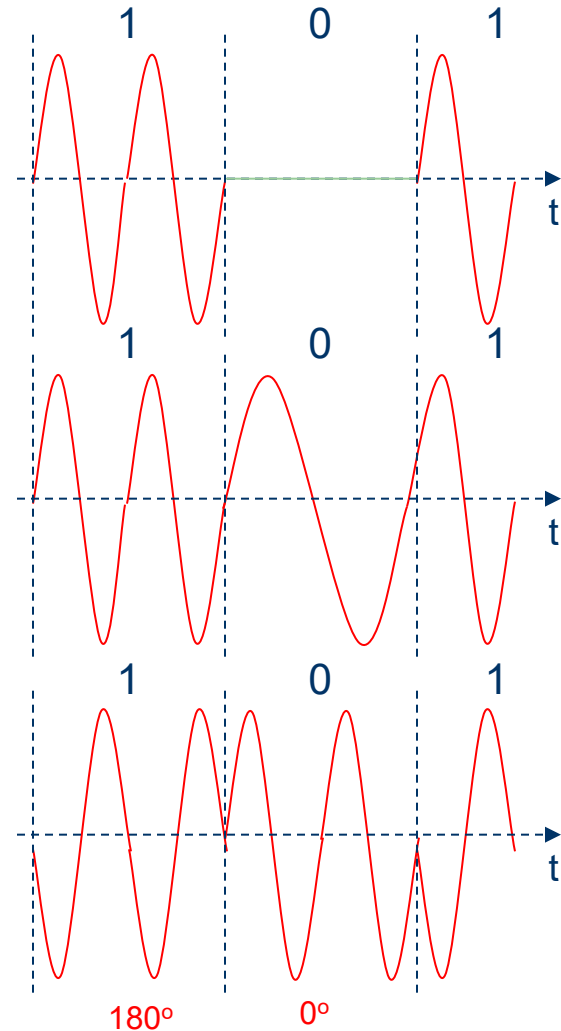
To increase the data rate we cannot reduce  
The sample duration indefinitely

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

This is usually combined with PSK

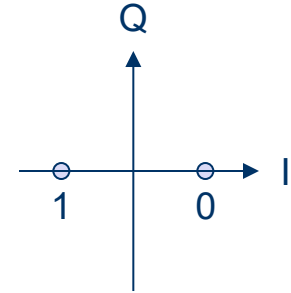
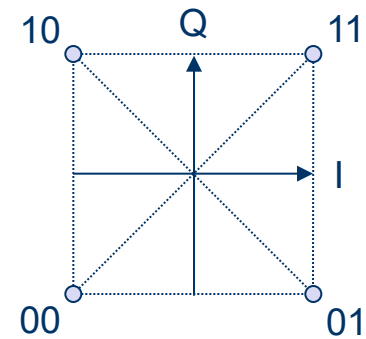
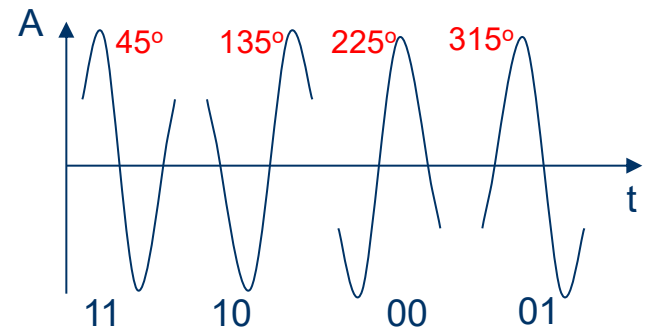
# Digital Modulation

- 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



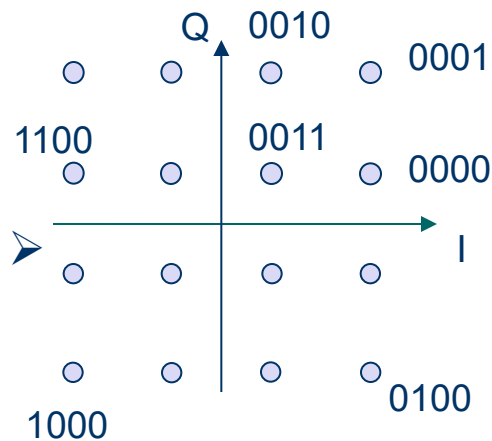
# Advanced Phase Shift Keying

- 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



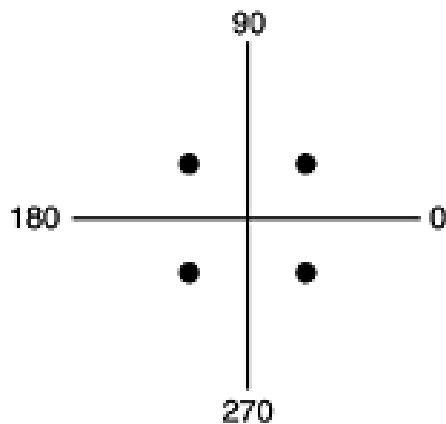
# Quadrature Amplitude Modulation

- 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

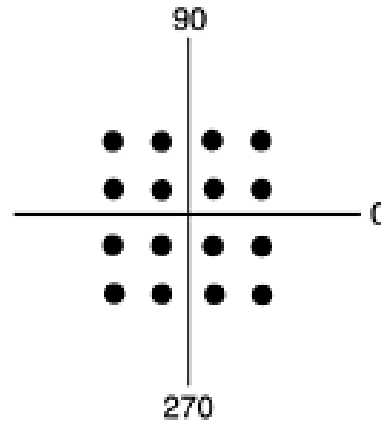


Example: 16-QAM (4 bits = 1 symbol)

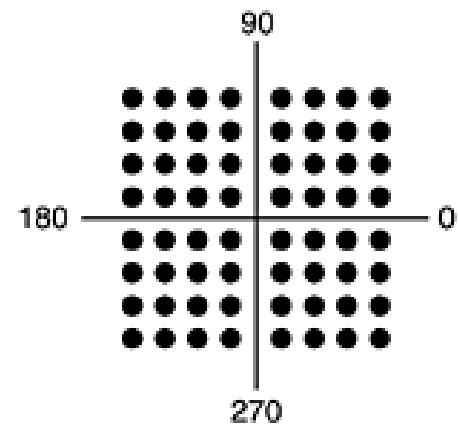
- BPSK (Binary Phase Shift Keying) = 2 phase shifts, 1 amplitude level, 1 bit/symbol
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



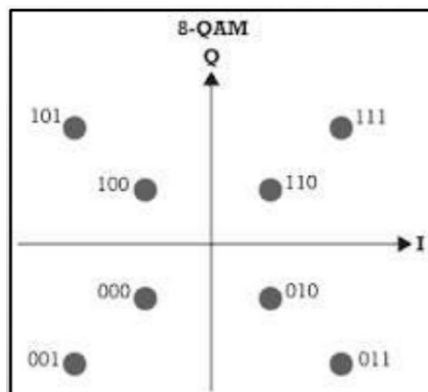
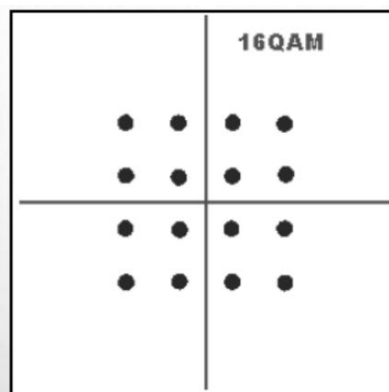
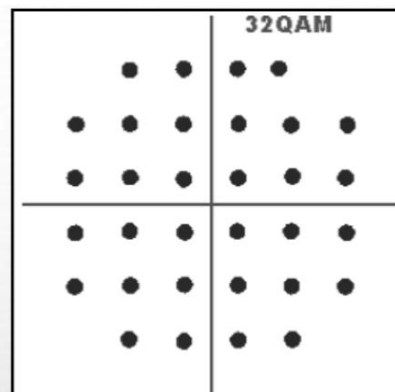
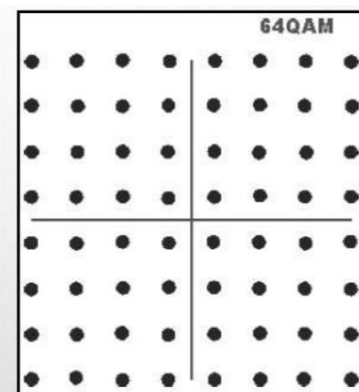
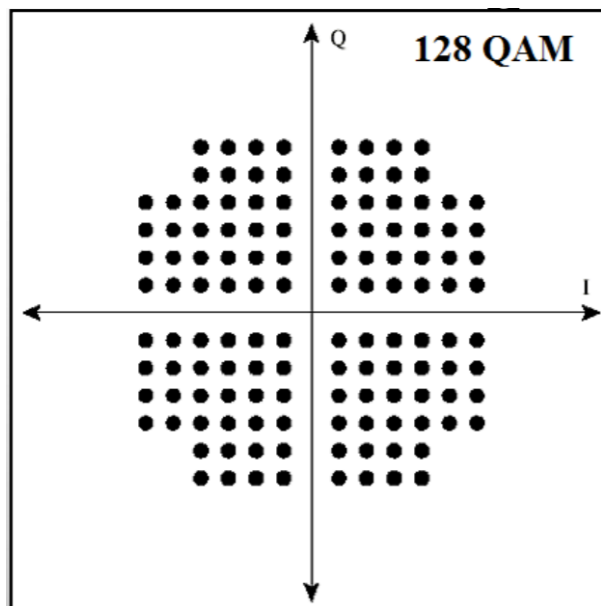
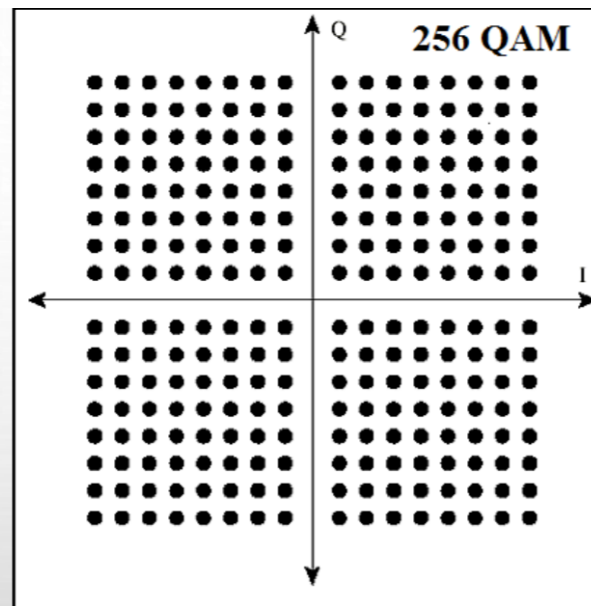
QPSK



QAM-16



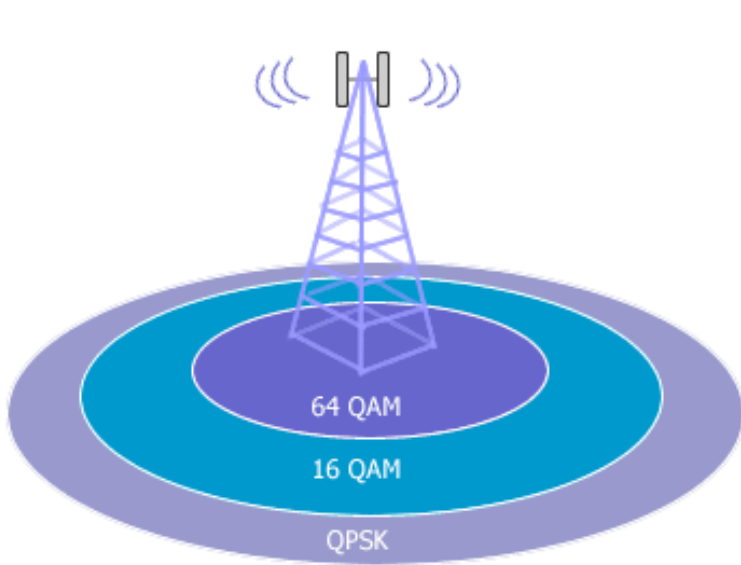
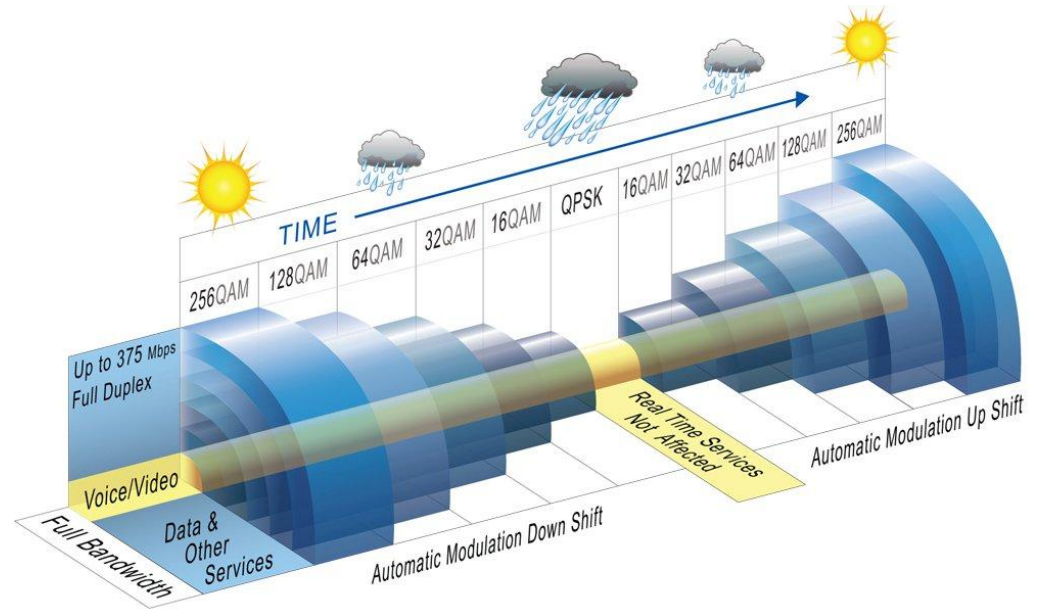
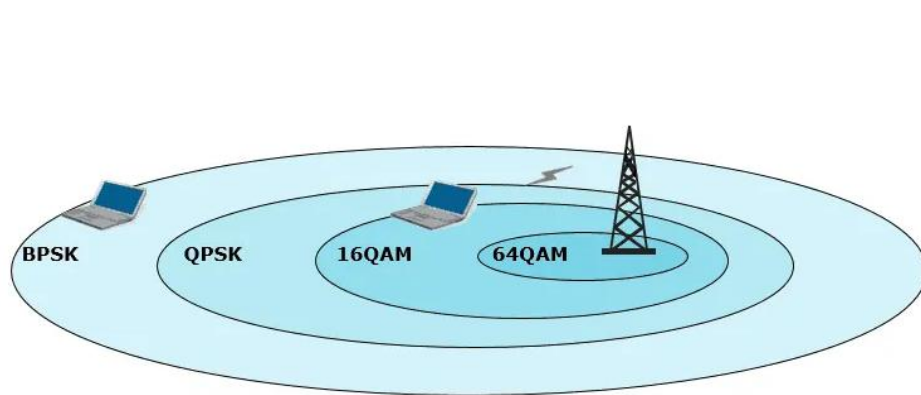
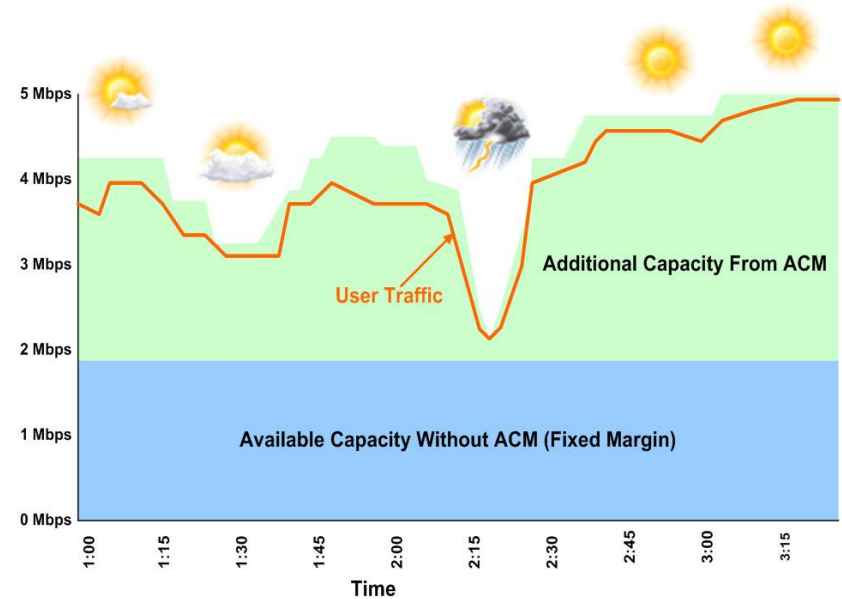
QAM-64



| Number of States<br>( $m$ -ary) | Bits Transmitted<br>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

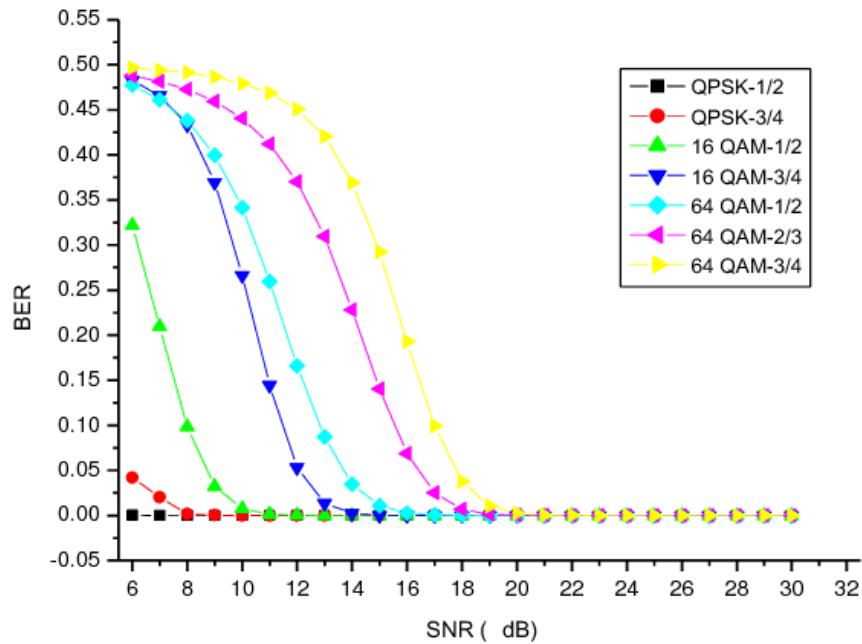
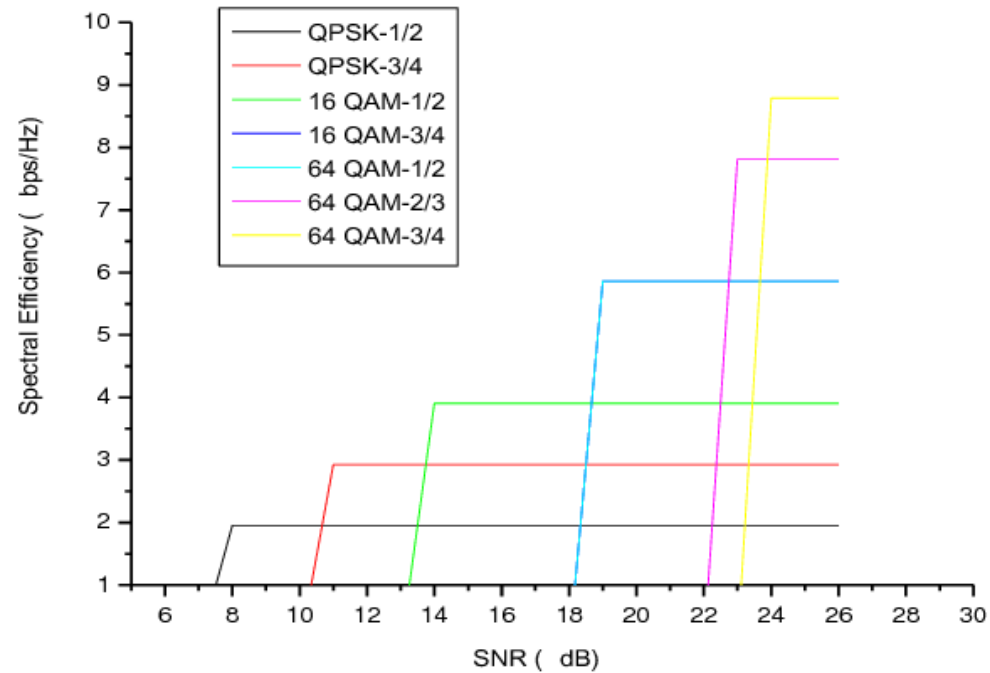
2. Channel conditions must remain constant or change slowly relative to the adaption rate
  - Two Categories of Channel Fading Impairments
    - Fast Channel Fading (ex: Multi-Path)
    - Slow Channel Fading (ex: Shadow Fading)
  - Goal is to adjust SNR update rates so that:
    - SNR updates slow enough to average fast fading effects
    - SNR updates fast enough to track slow fading effects

# ACM schemes in LTE (4G)

| ID ( $c_l$ ) | level      | $r(c_l)$<br>[bits/symbol] | SNR boundary<br>[dB] <sup>1</sup> |
|--------------|------------|---------------------------|-----------------------------------|
| 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                                |

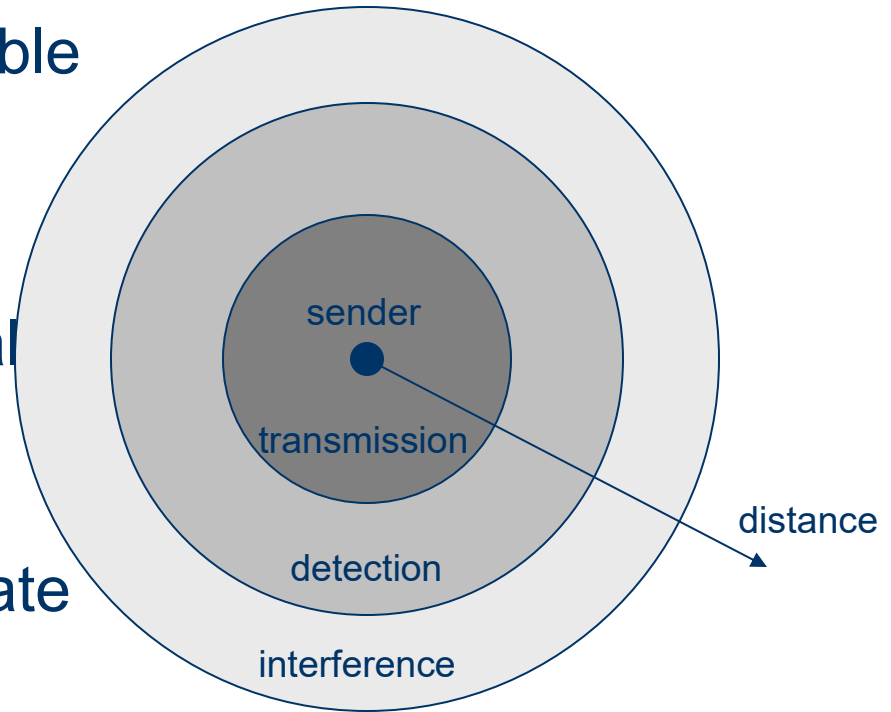
**Trick question: What is the difference between LTE and 4G**

# 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

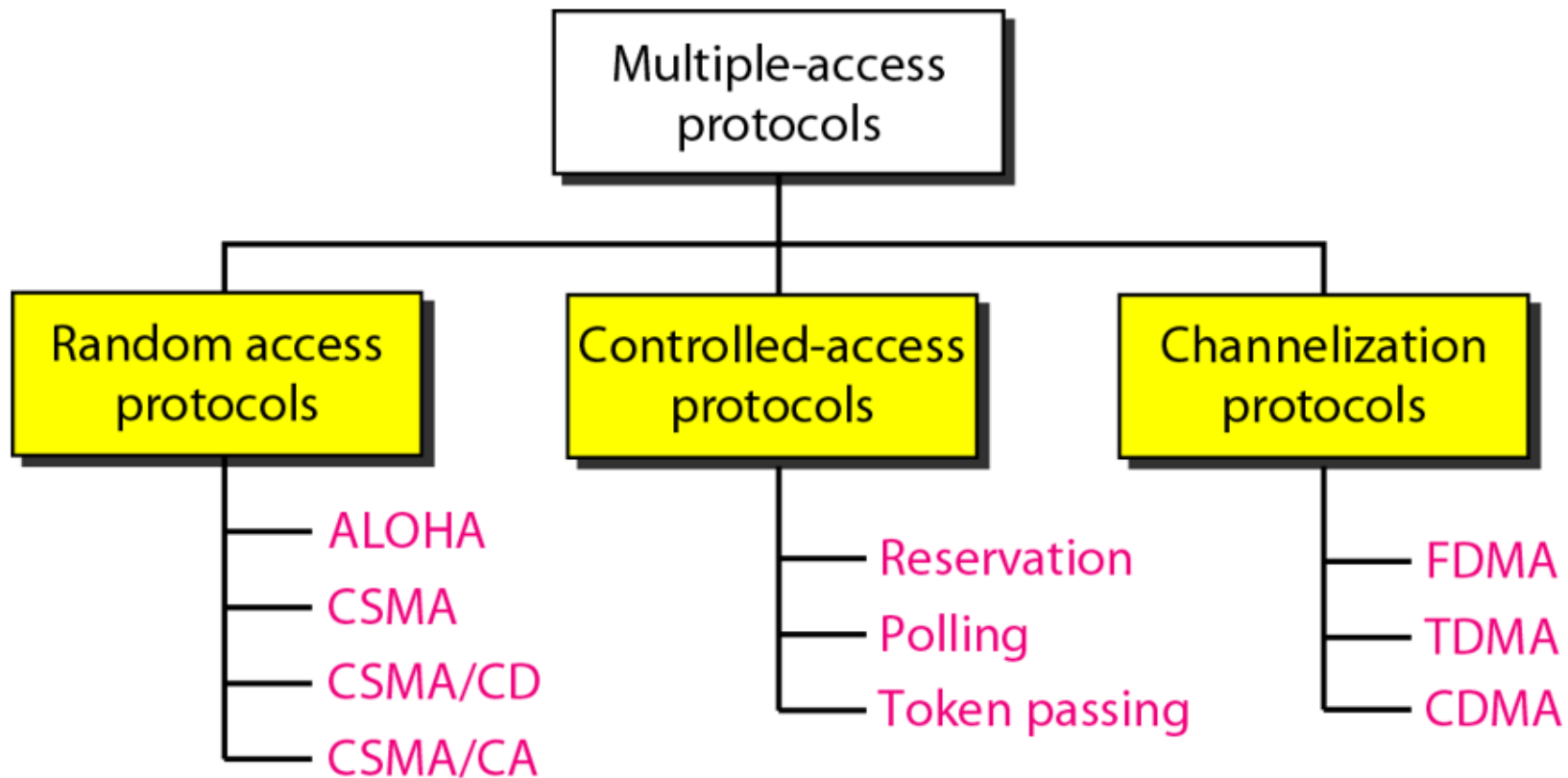
- N independent stations
  - ◆ Assumption of limited or unlimited number
  - ◆ Poisson arrivals
  - ◆ Fixed packet length
- Single Channel
- Collisions are possible
  - Carrier sensing
  - Collision detection
- Time assumptions
  - ◆ Segmented non-continuous time / Synchronous mode
  - ◆ Non-segmented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

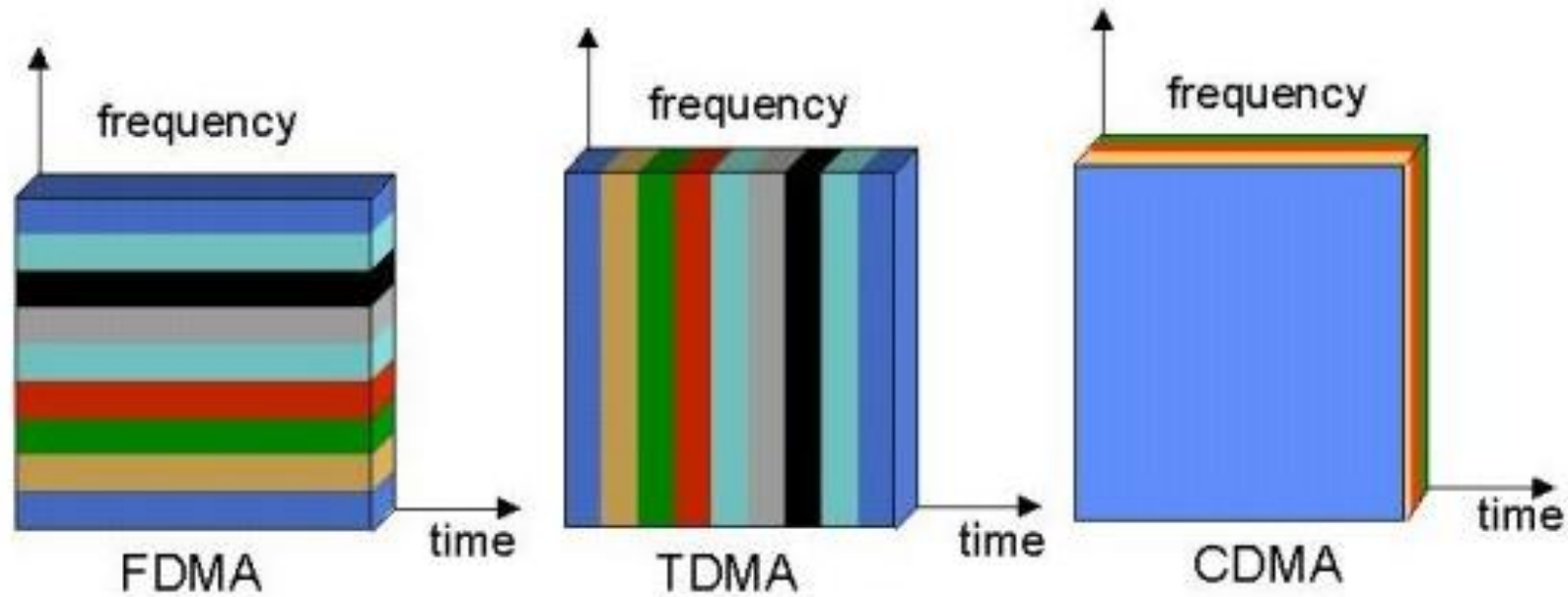
# Multiplexing Techniques

- 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





# Frequency Division Multiplexing (FDM)

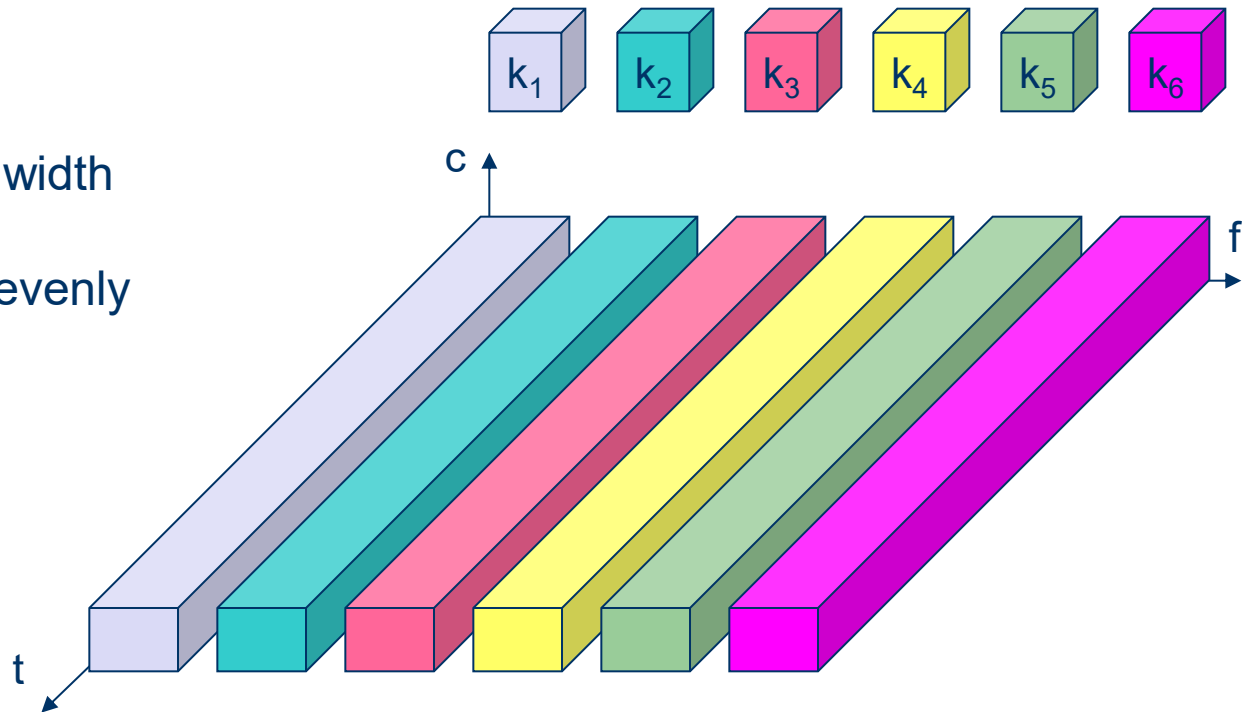
- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time

## Advantages:

- no dynamic coordination necessary
- works also for analog signals
- cheaper

## Disadvantages:

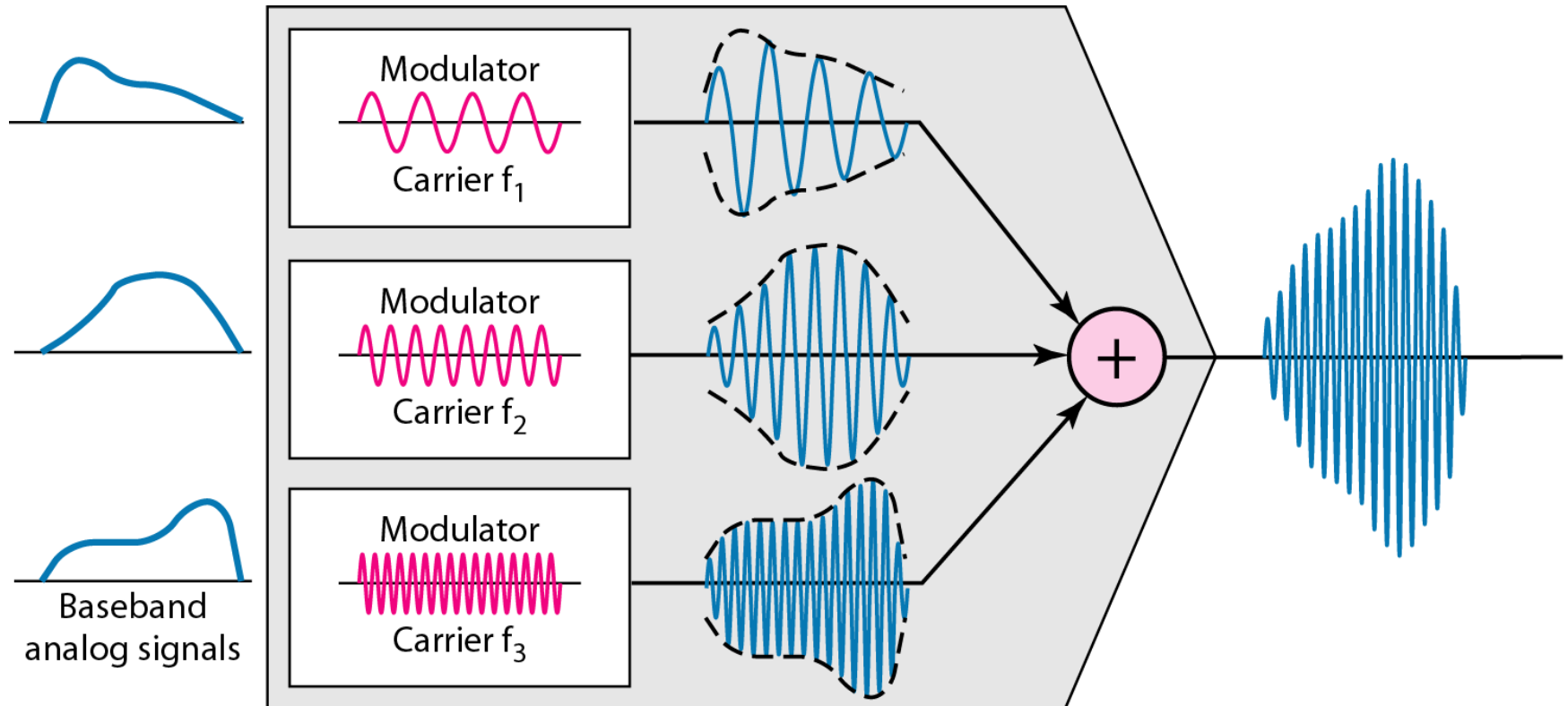
- waste of bandwidth if the traffic is distributed unevenly
- inflexible



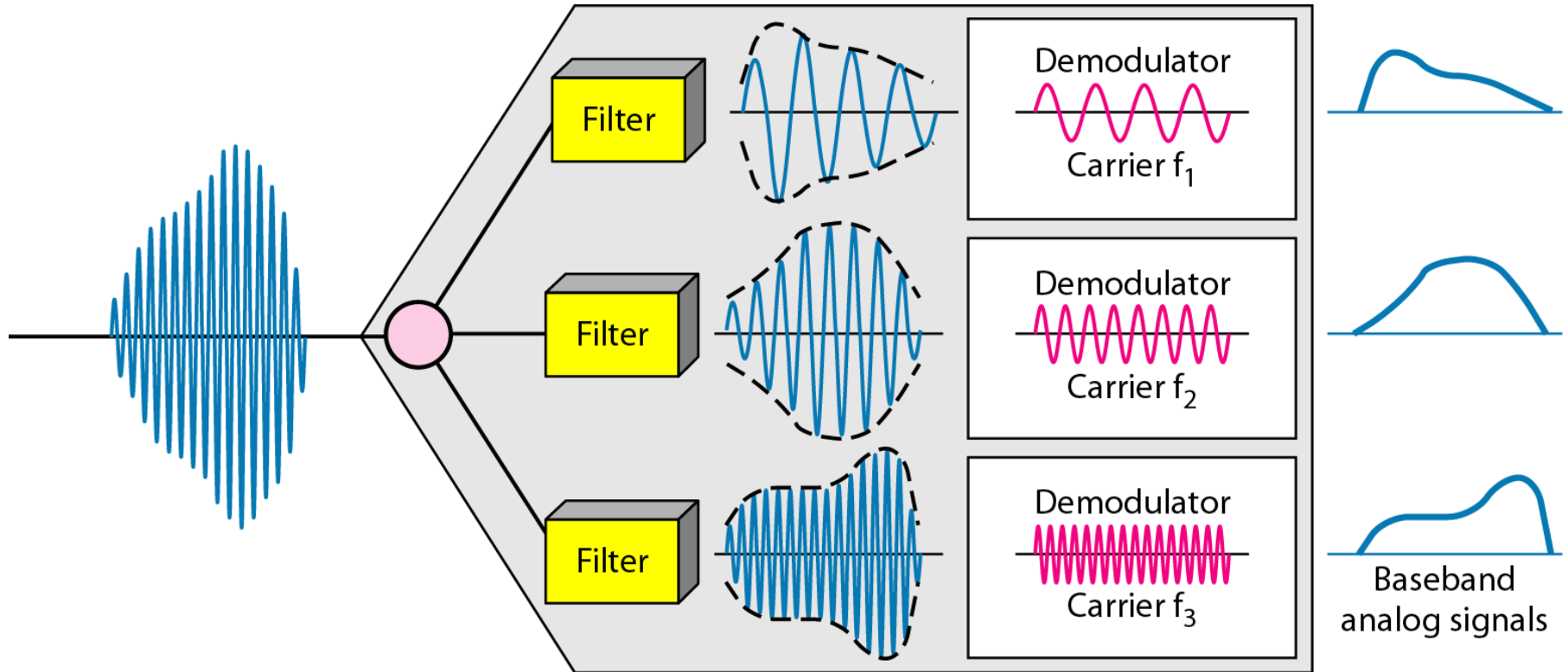
# Frequency Division Multiplexing (FDM)



# Frequency Division Multiplexing (FDM)

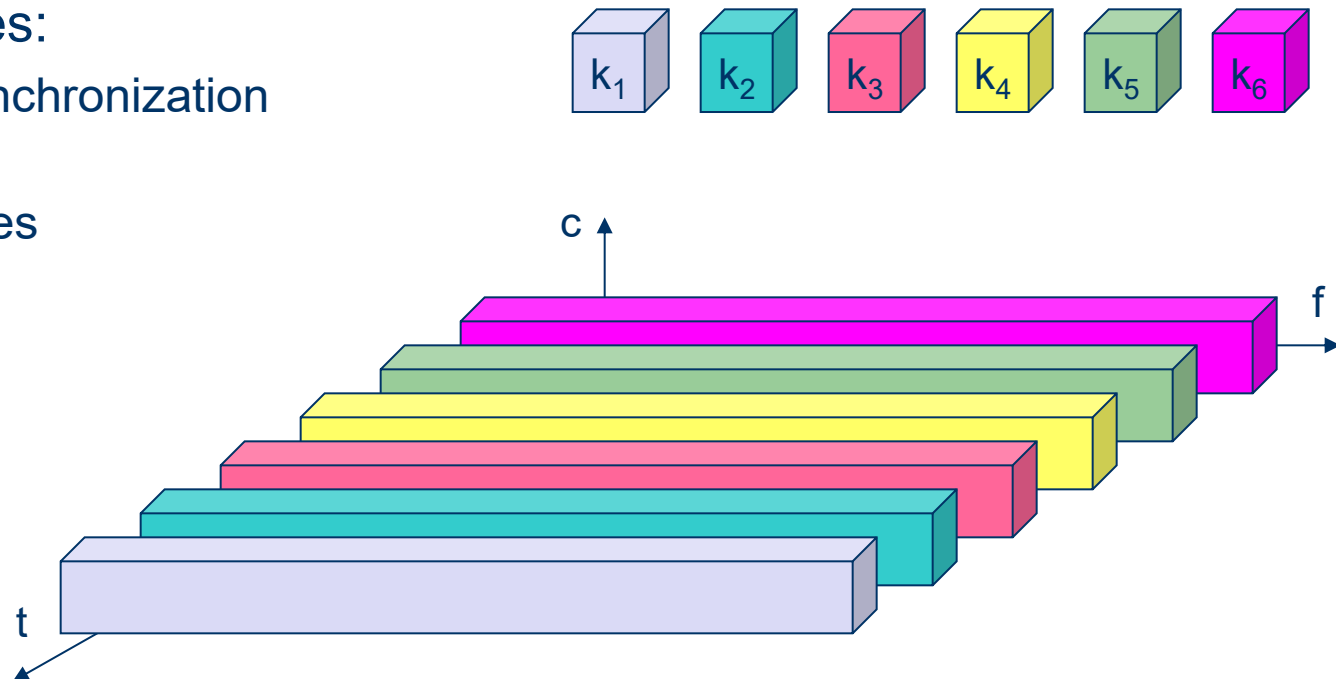


# Frequency Division Multiplexing (FDM)

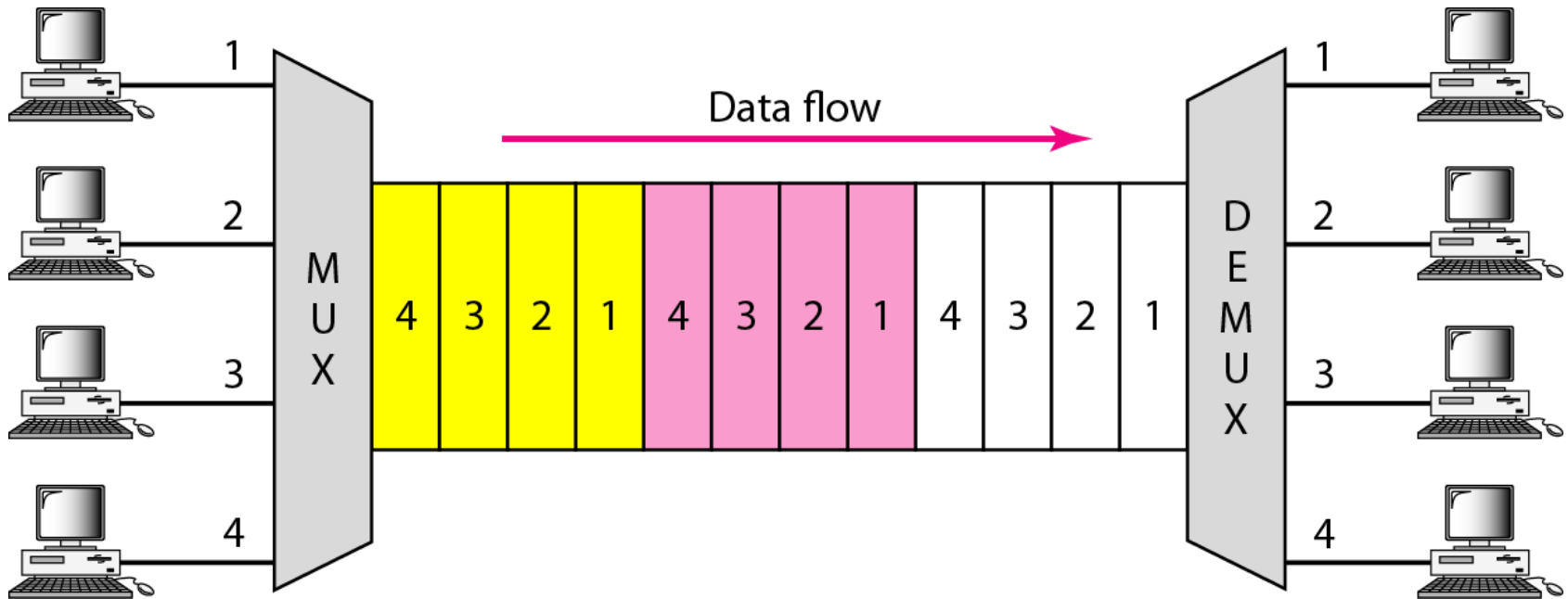


# Time Division Multiplexing (TDM)

- 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)

- a unique “code” is assigned to each user
  - all users share the same frequency, but each has their own “chipping” sequence (code) for encoding the data
  - allows multiple users to “coexist” and transmit simultaneously with minimal interference (if the codes are “orthogonal”)
- *encoded signal = (original data) × (chipping sequence)*
- *decoding: inner product of the encoded signal and the chipping sequence*

# Generating CDMA codes

## Example with 2 users

We start with one sequence:  $[+1]$

$+1$



Copy  
the sequence

User 1

$$c_1 = [+1, +1]$$



Copy and change  
the sign of the 2nd chip

User 2

$$c_2 = [+1, -1]$$

**Check:**  $c_1 \cdot c_2 = (+1)(+1) + (+1)(-1) = 0$

Two distinct, orthogonal codes of 2 chips.

Orthogonality requires time alignment.

# Example: 4 CDMA codes

$$H_2 = [ +1 \ +1 \ ; \ +1 \ -1 ] \rightarrow H_4:$$

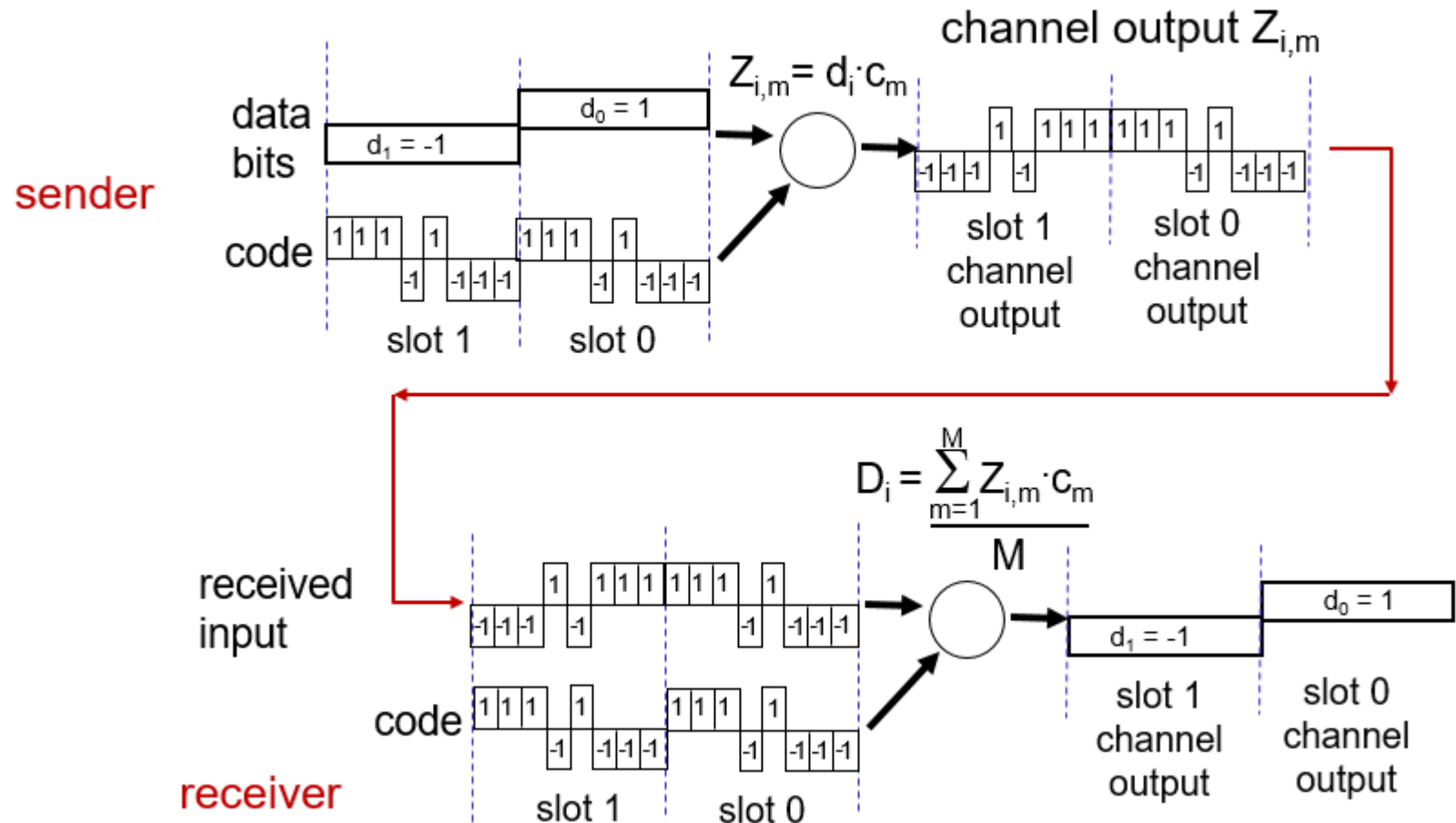
| Code  | chip 1 | chip 2 | chip 3 | chip 4 |
|-------|--------|--------|--------|--------|
| $C_1$ | +1     | +1     | +1     | +1     |
| $C_2$ | +1     | -1     | +1     | -1     |
| $C_3$ | +1     | +1     | -1     | -1     |
| $C_4$ | +1     | -1     | -1     | +1     |

**Orthogonality check for  $c_2$  and  $c_3$ :**

$$C_2 \cdot C_3 = 1 - 1 - 1 + 1 = 0$$

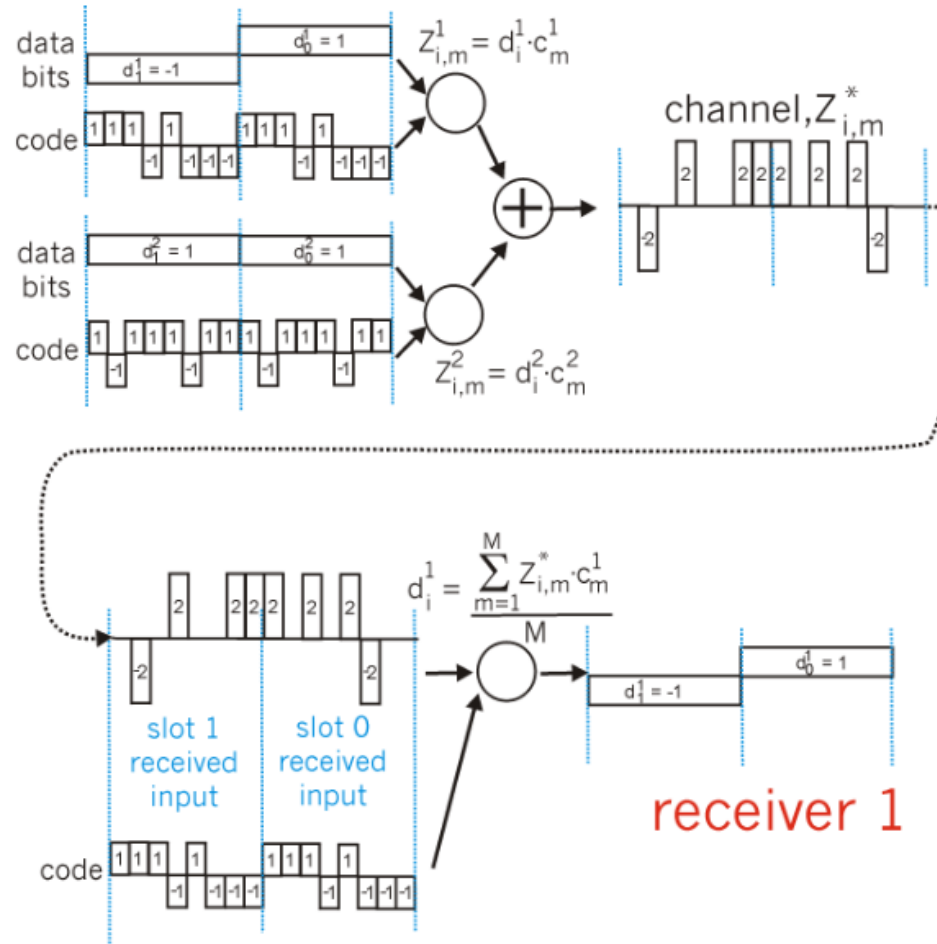
- Assign a different row to each user;  
then: data  $\times$  code.

# Code Division Multiple Access (CDMA)



# Code Division Multiple Access (CDMA)

senders



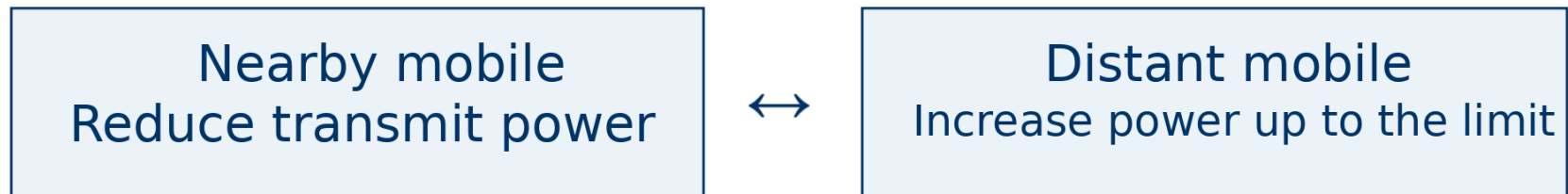
# CDMA: from theory to practice

- In the ideal example, the appropriate code allows recovery of the desired signal.
- In a real network, unequal powers, asynchronous arrivals and multiple paths occur.
- Codes do not always ensure complete separation: interference between users remains.
- Key consequence: quality and capacity depend on the overall interference level.

# CDMA: near-far problem

## (Near-far problem)

- A nearby mobile can reach the base station with a much stronger signal than a distant one.
- With non-ideal code separation, the strong signal makes the weaker one harder to detect.
- Fast and accurate power control is required, especially on the uplink.



# CDMA: capacity limit

- Each new active user usually increases interference to the others.
- An available code is not enough: the required connection quality must be maintained.
- Capacity depends on data rates, power control and interference from neighboring cells.
- Admission control for new connections is needed to prevent the cell from becoming overloaded.

# CDMA: multipath propagation

- Reflections create copies of the signal that arrive with different delays.
- On the downlink, orthogonality between users' codes may be lost.
- On the uplink, asynchronous arrivals also make signal separation more difficult.
- The receiver exploits multiple paths, but does not eliminate all interference.