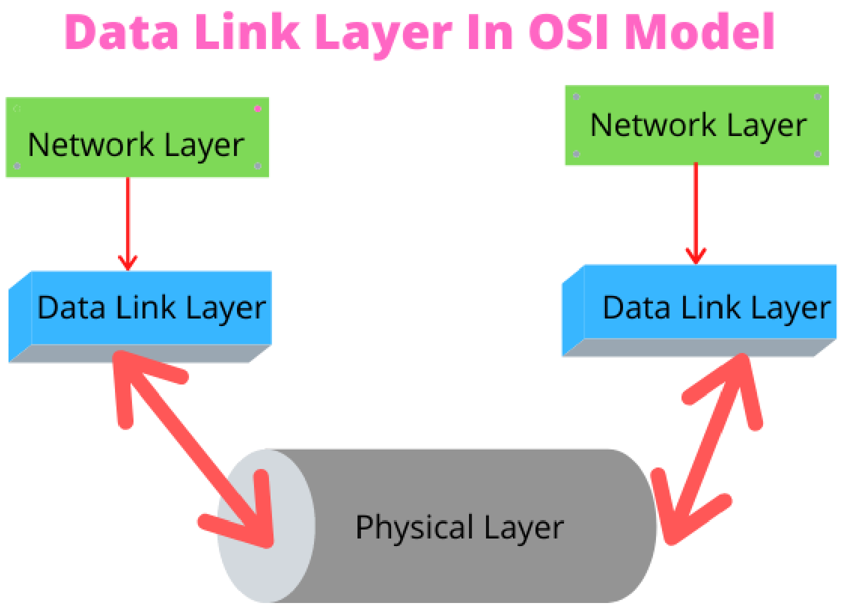
Mobile and Wireless Networks

Wireless transmission



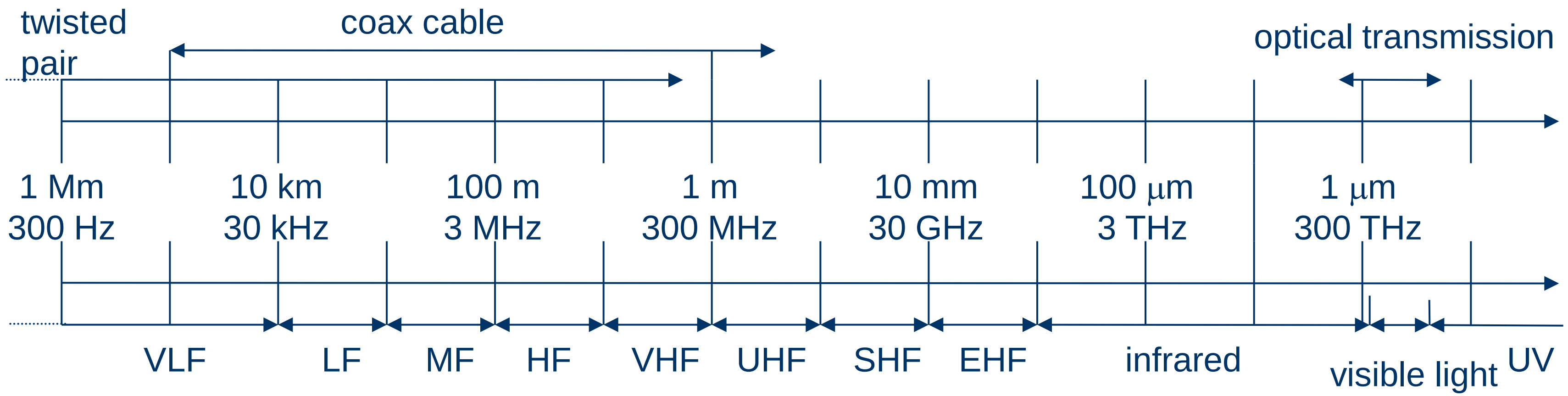
Wireless Transmission

- 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

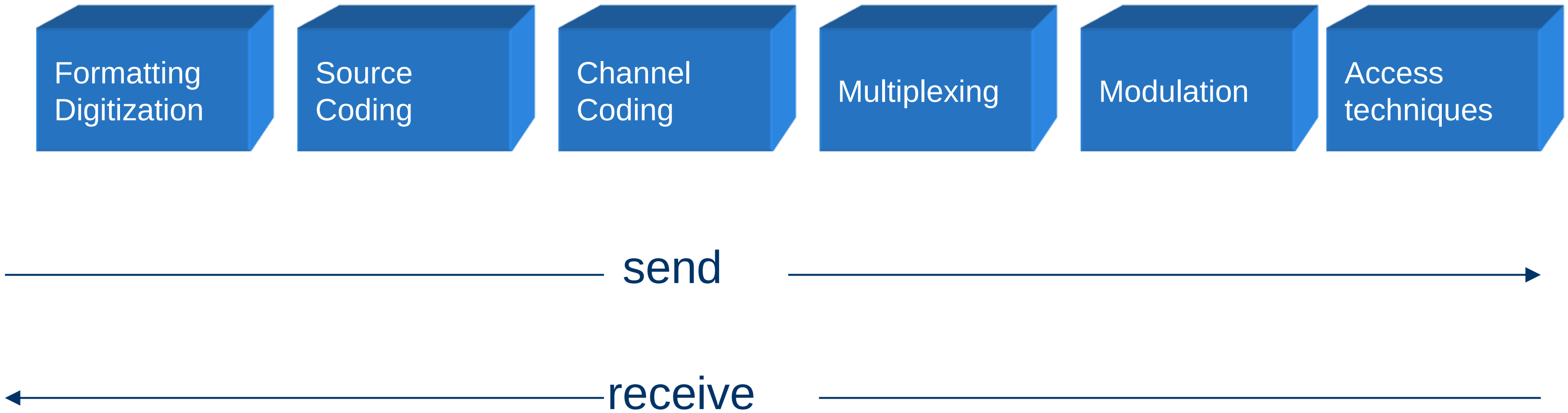
Relationship between frequency 'f' and wave length 'λ' :

$$\lambda = c/f$$

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

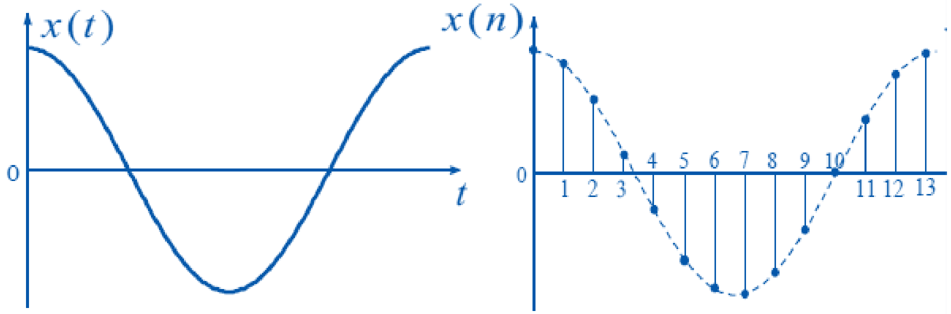
Communication System

- Structural modular approach
- Various components
- Of defined functions

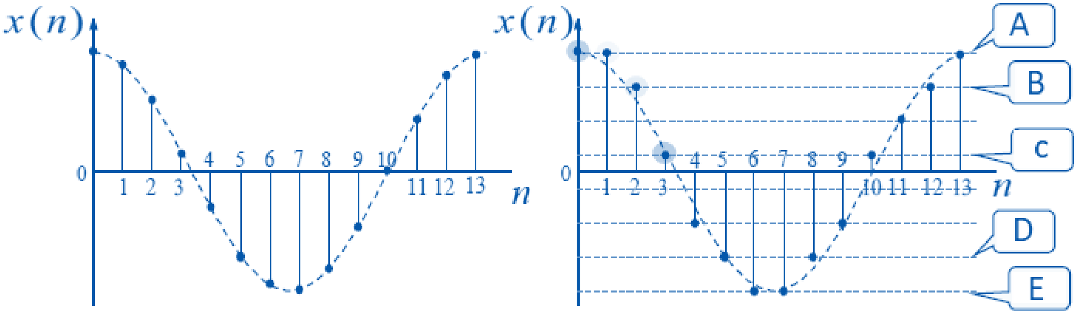


Digitization

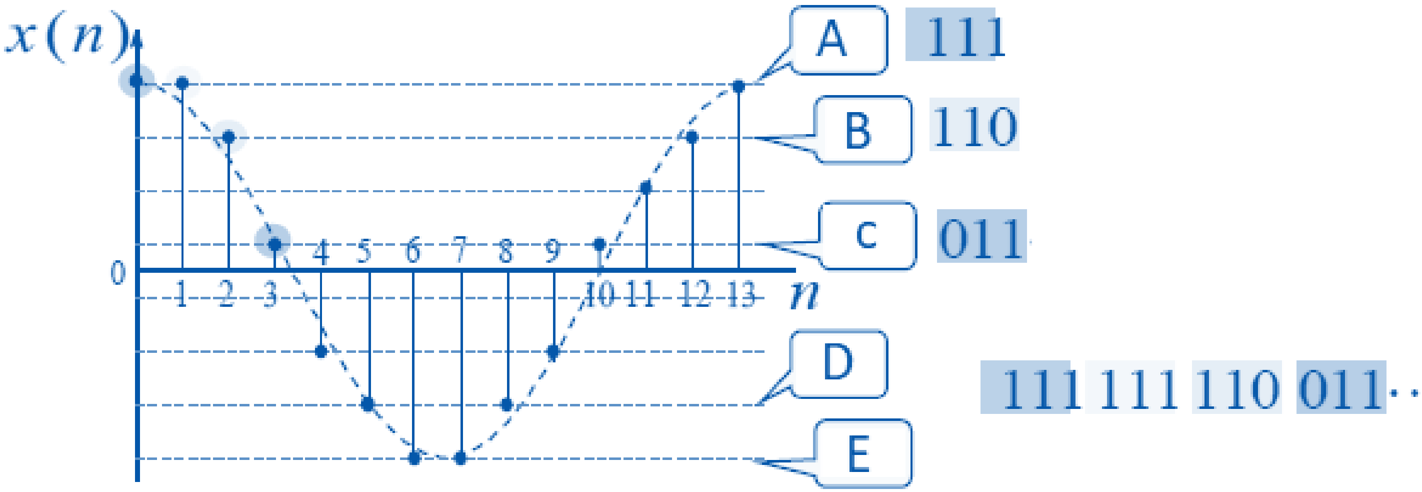
- Sampling



- Quantization

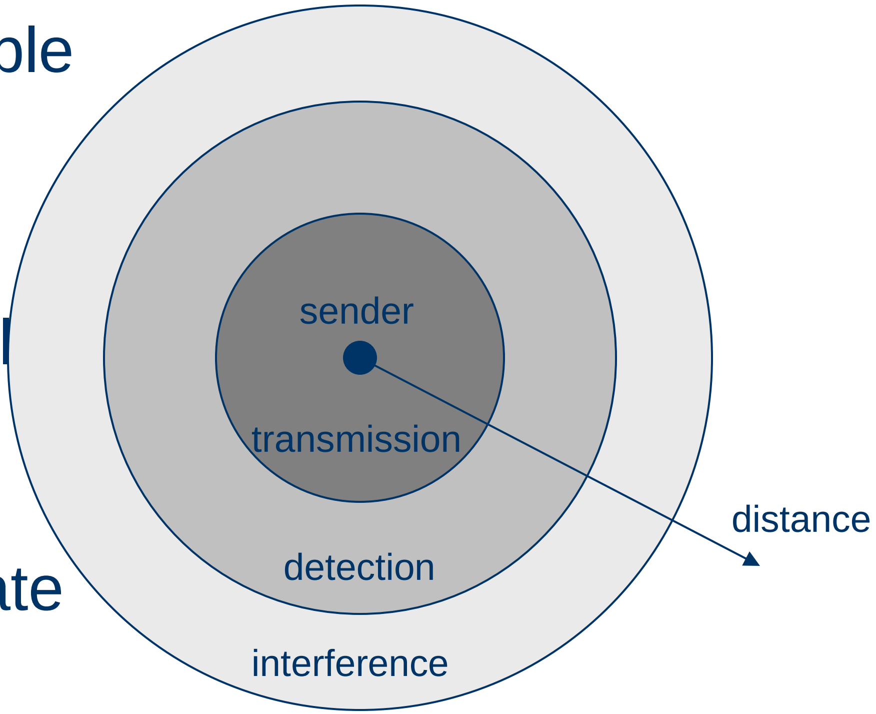


Source coding

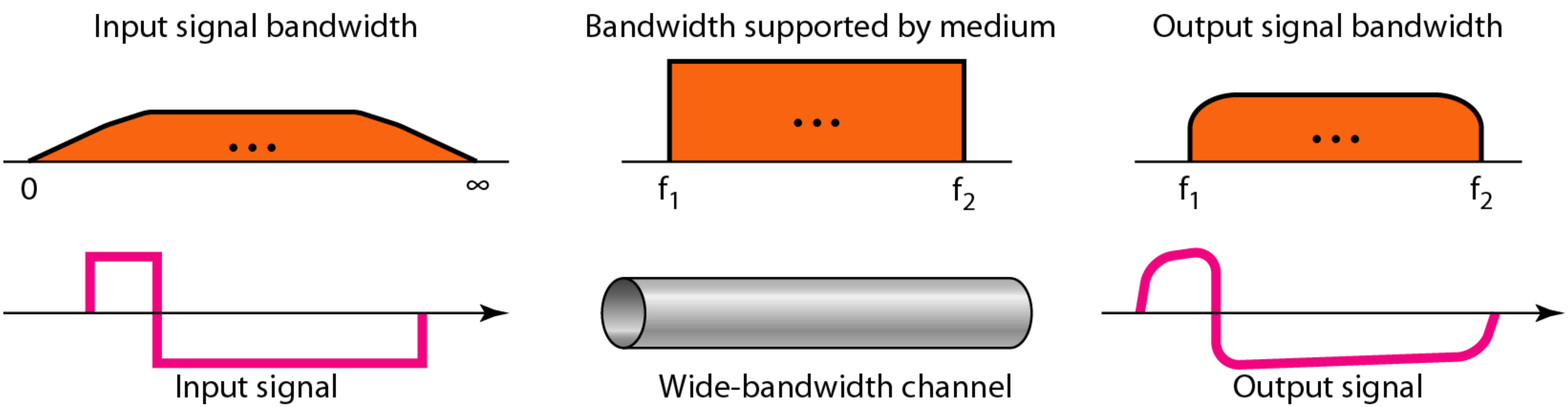


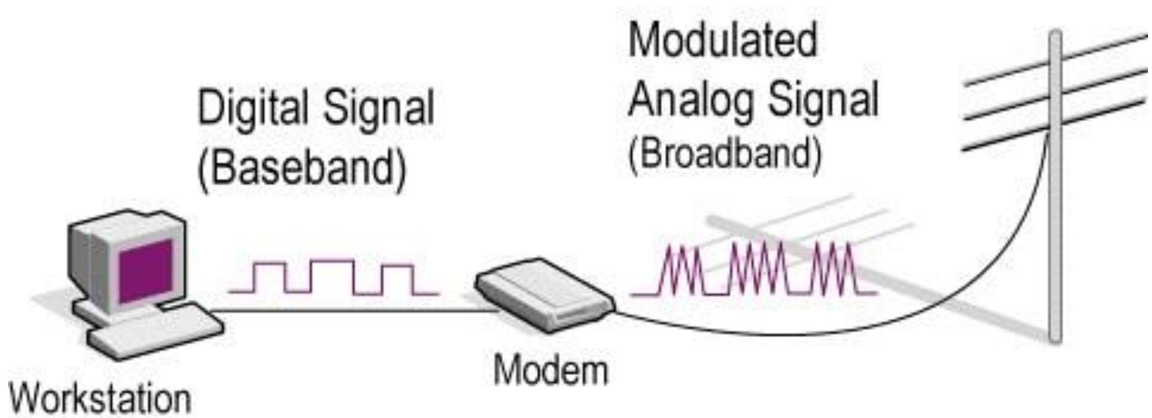
Signal Propagation Ranges

- 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

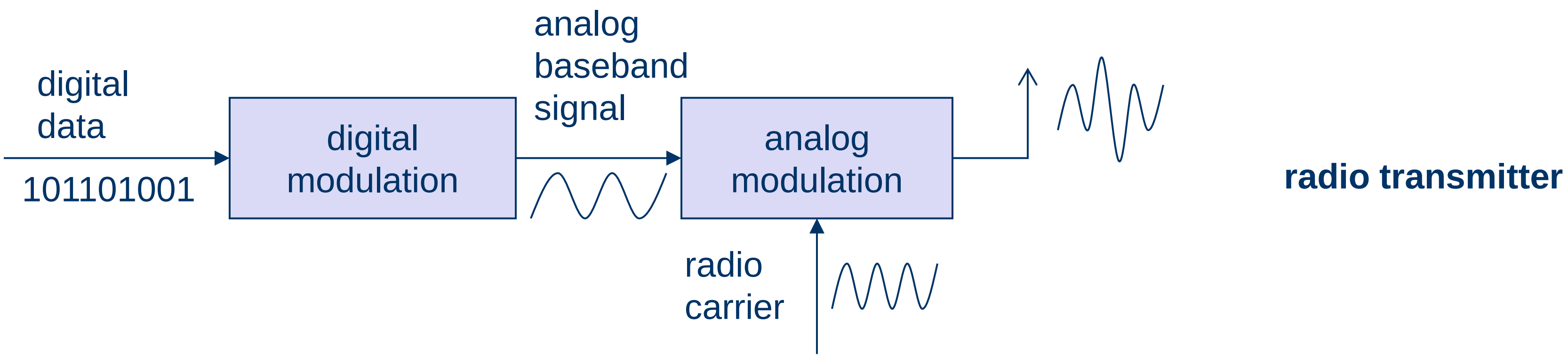


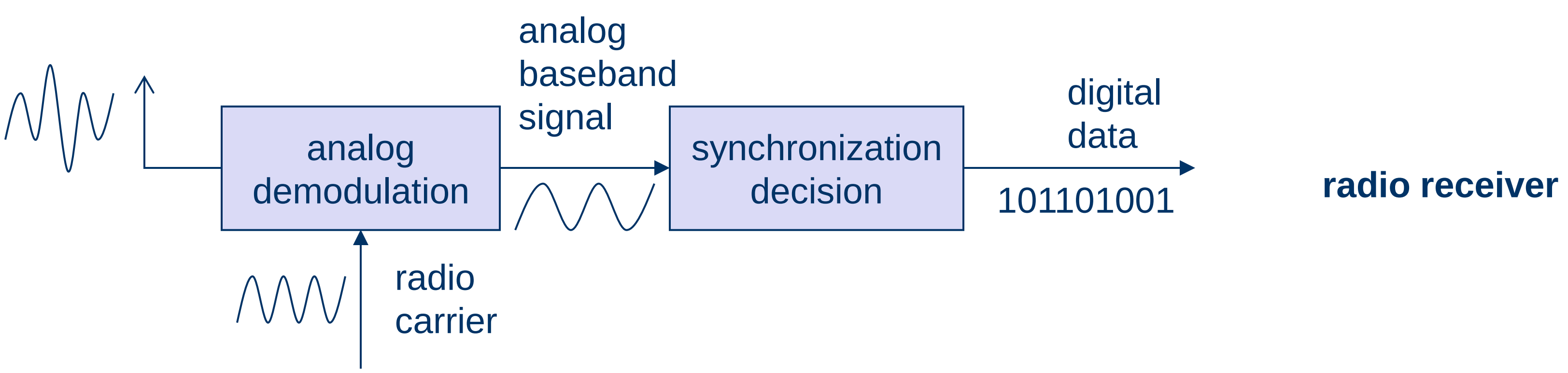
Baseband transmission





Modulation and Demodulation





Signal Modulation

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

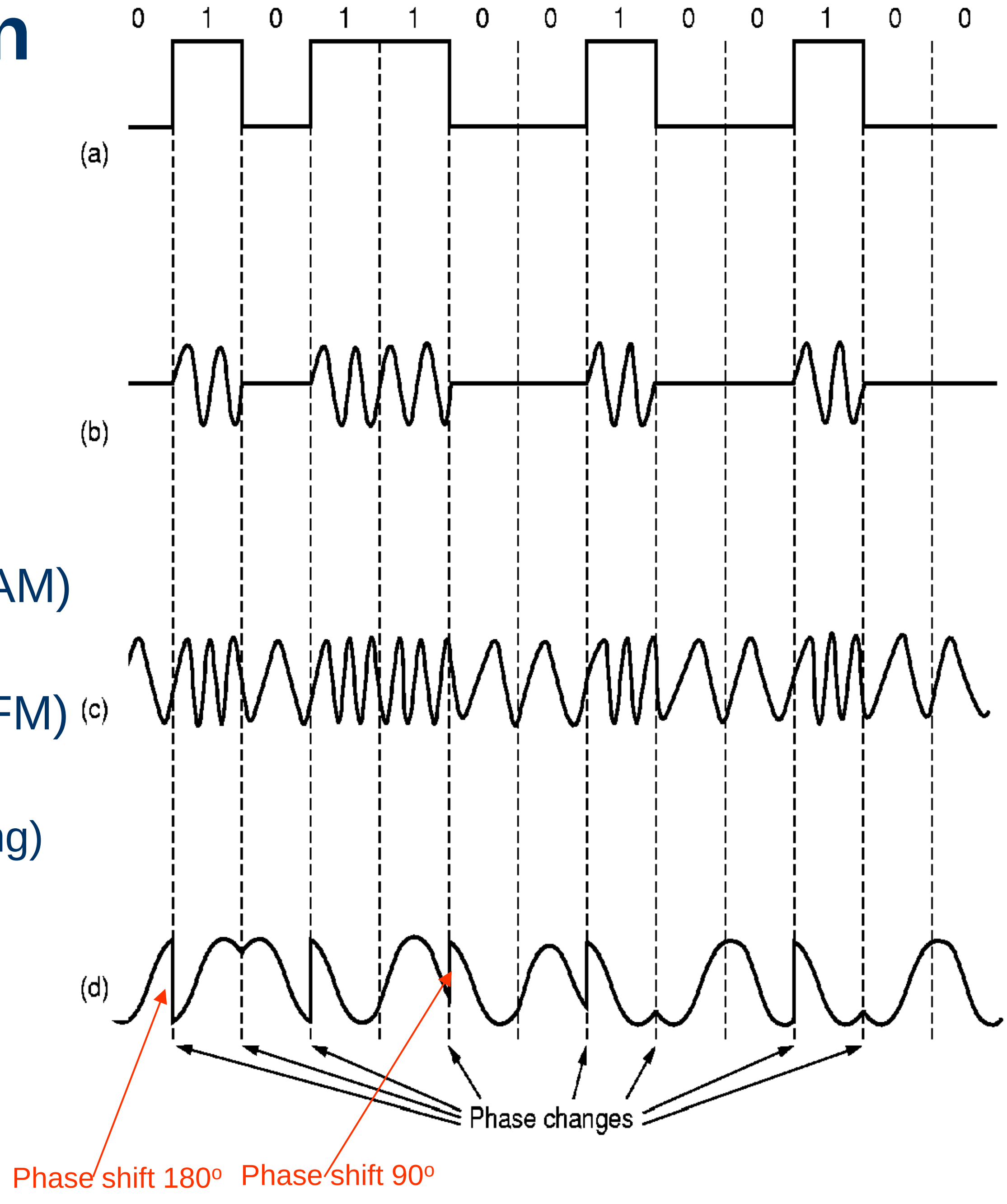
- (a) unmodulated (digital) signal
- (b) amplitude modulation (AM)

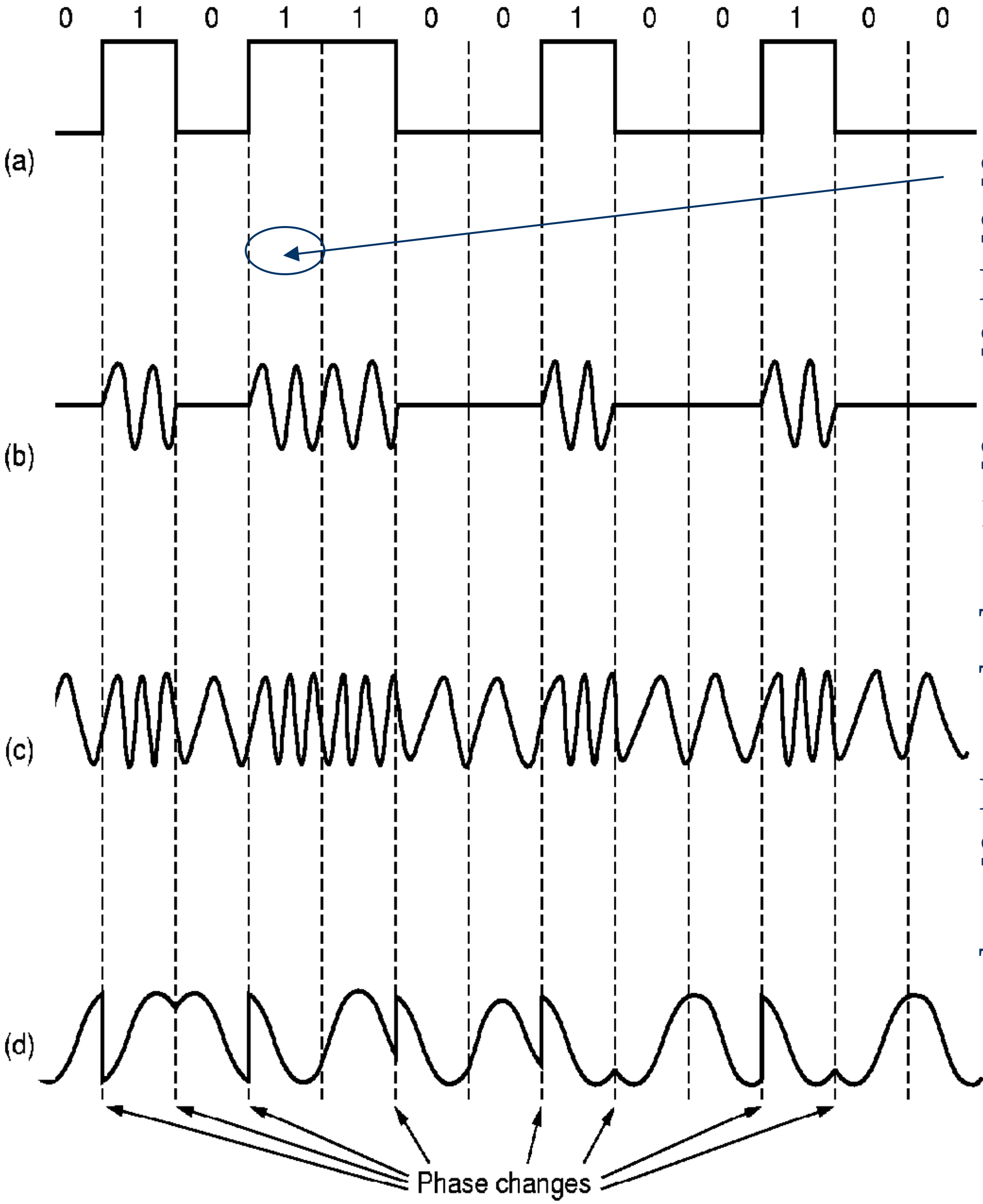
  $s(t) = A(t) \cos(f\, t + \phi)$
- (c) frequency modulation (FM)

  $s(t) = A \cos(f(t)\, t + \phi)$
  - 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 **<u>"symbol"</u>** is sent

Symbol=piece of information=level of voltage

Simpler :

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

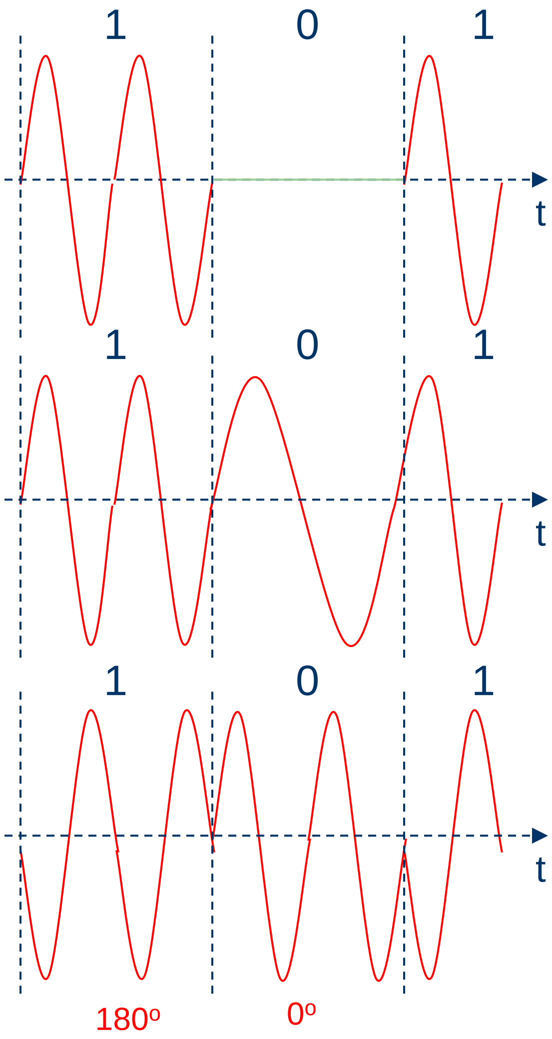
To increase the data rate we cannot reduce
The sample duration indefinitely

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

This is usually combined with PSK

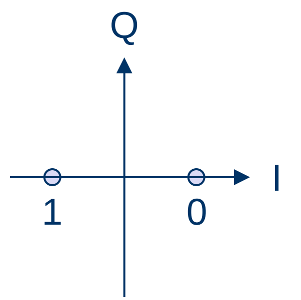
Digital Modulation

- 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

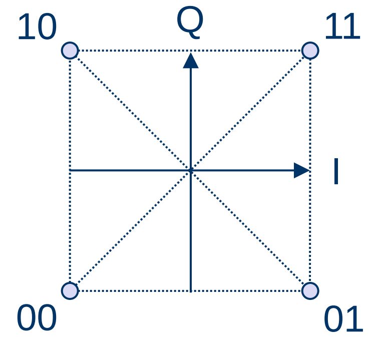


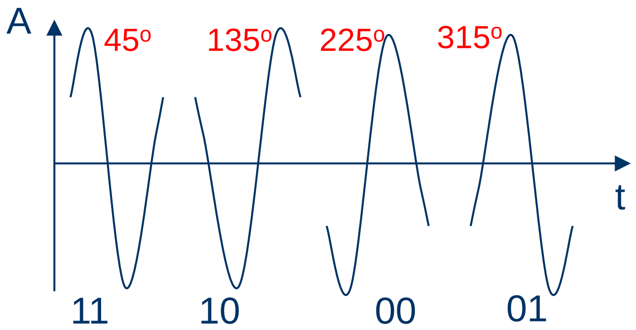
Advanced Phase Shift Keying

- 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

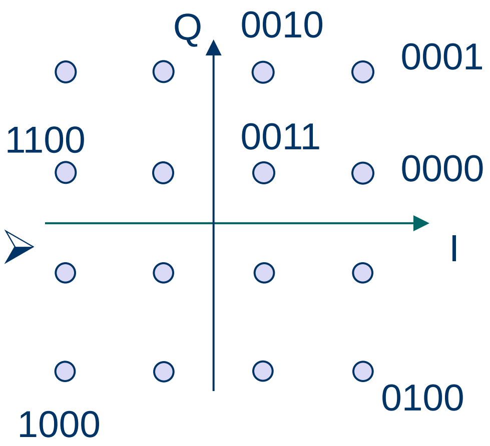


- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - more complex
  - better spectral efficiency



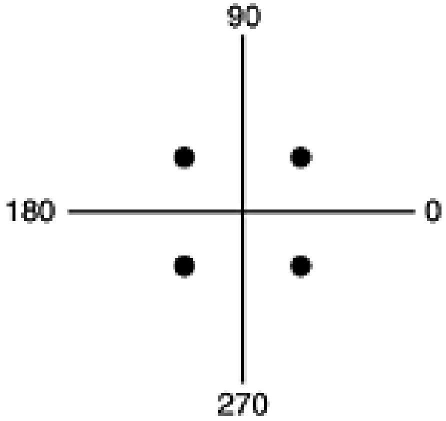


Quadrature Amplitude Modulation

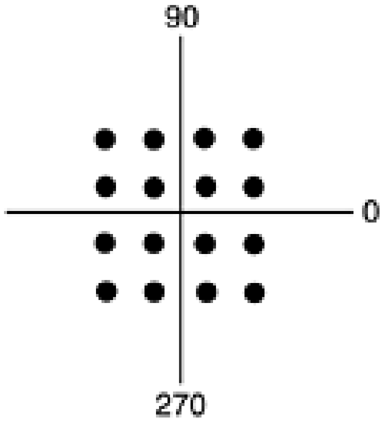
- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes
- 

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

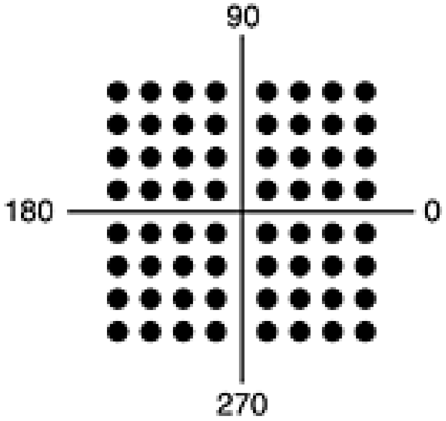
- BPSK (Binary Phase Shift Keying) = 2 phase shifts, 1 amplitude level, 1 bit/symbol
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



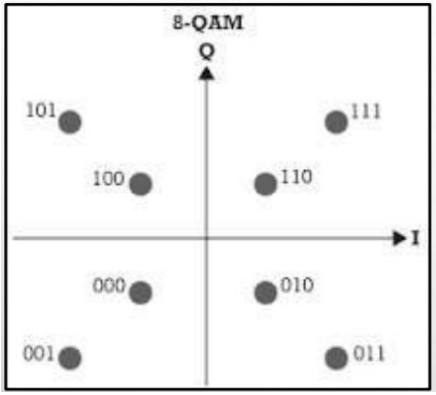
QPSK

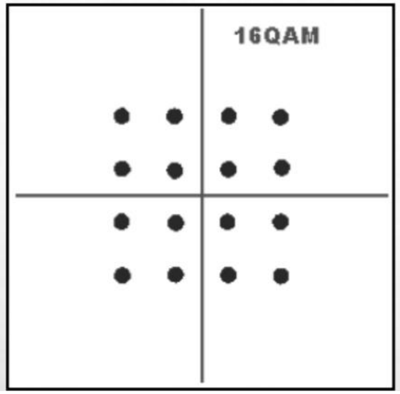


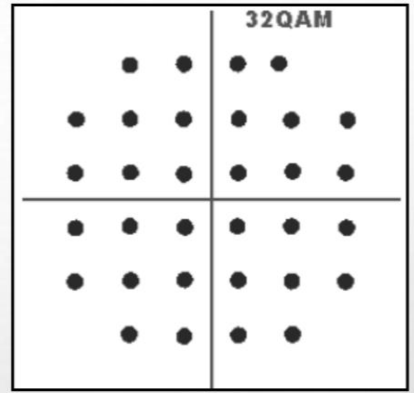
QAM-16

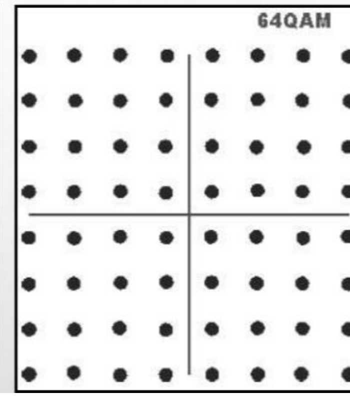


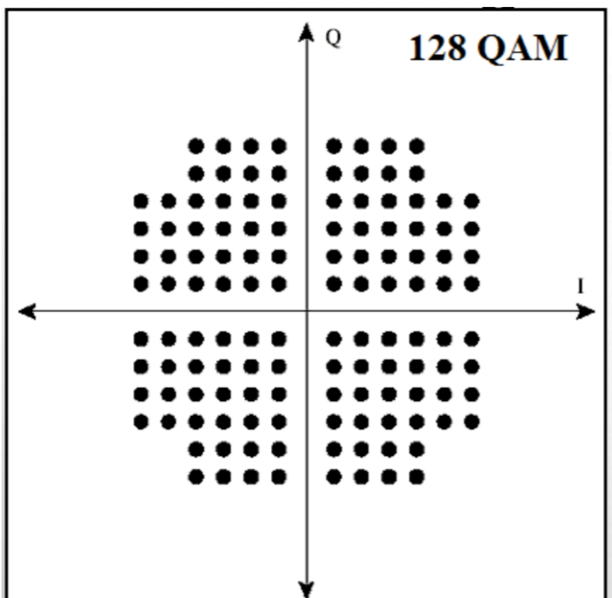
QAM-64

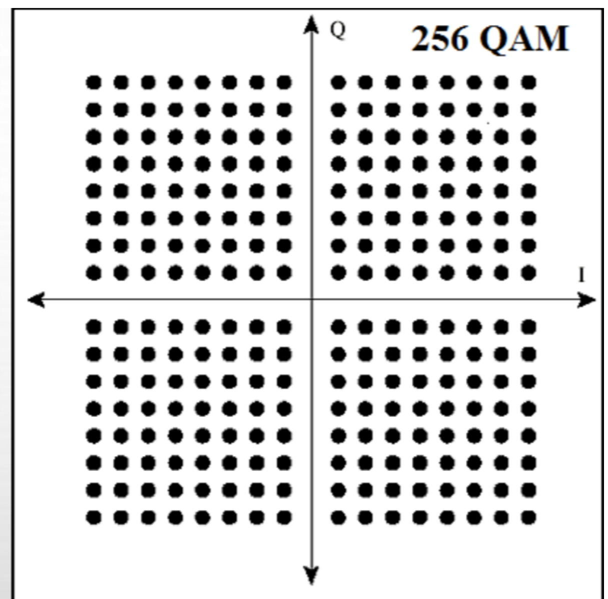

8-QAM
Q
I
101
111
100
110
000
010
001
011


16QAM


32QAM


64QAM

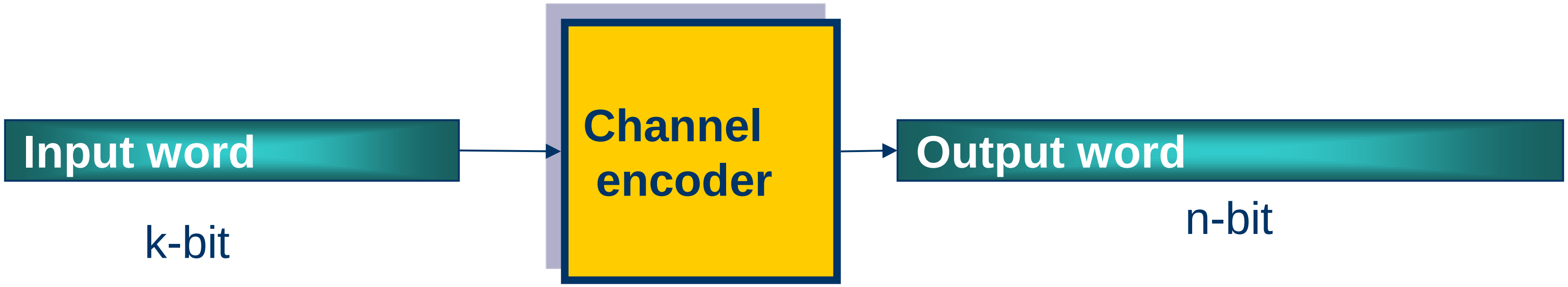

Q
128 QAM
I


Q
256 QAM
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

Channel coding



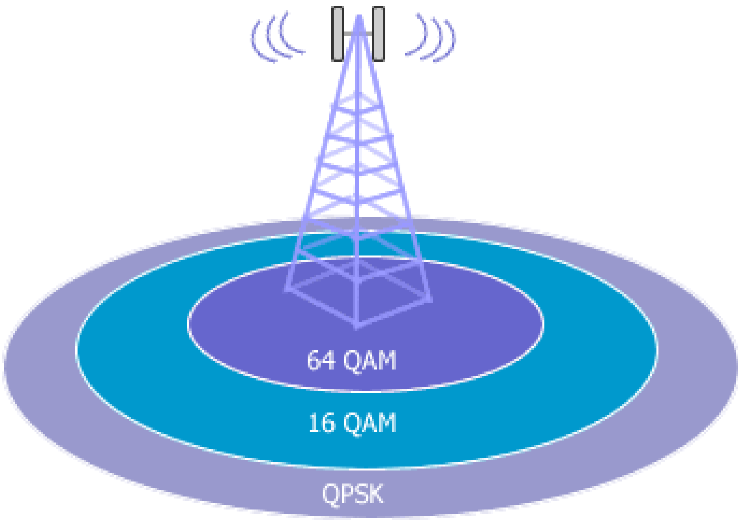
codeword

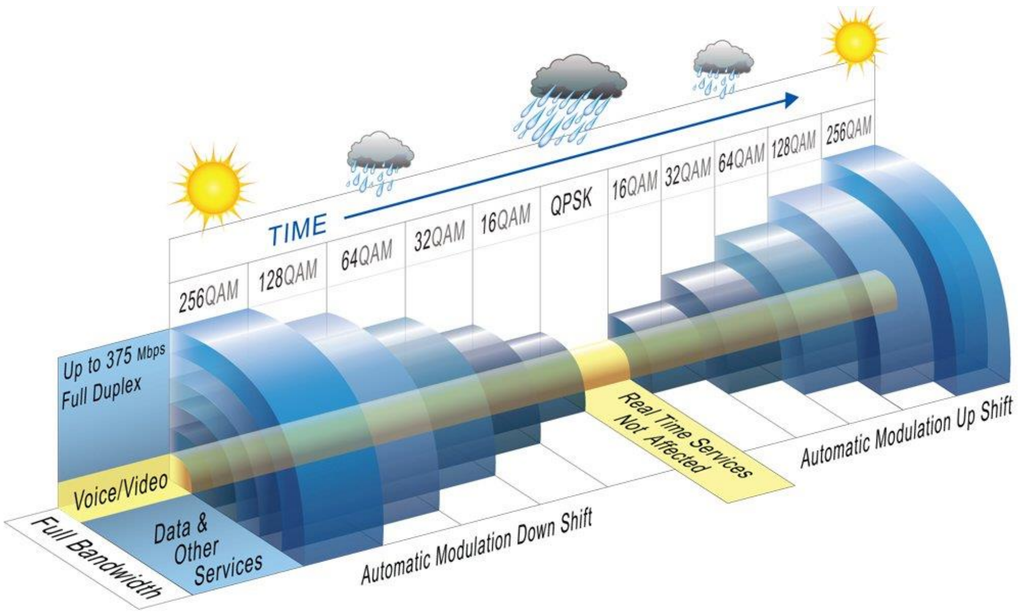
Code sequence

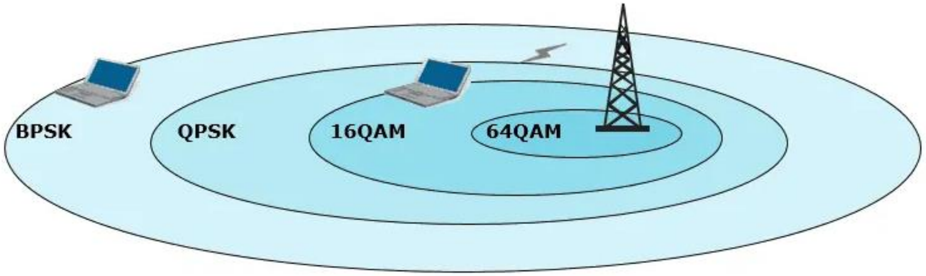
Redundancy = (n-k)

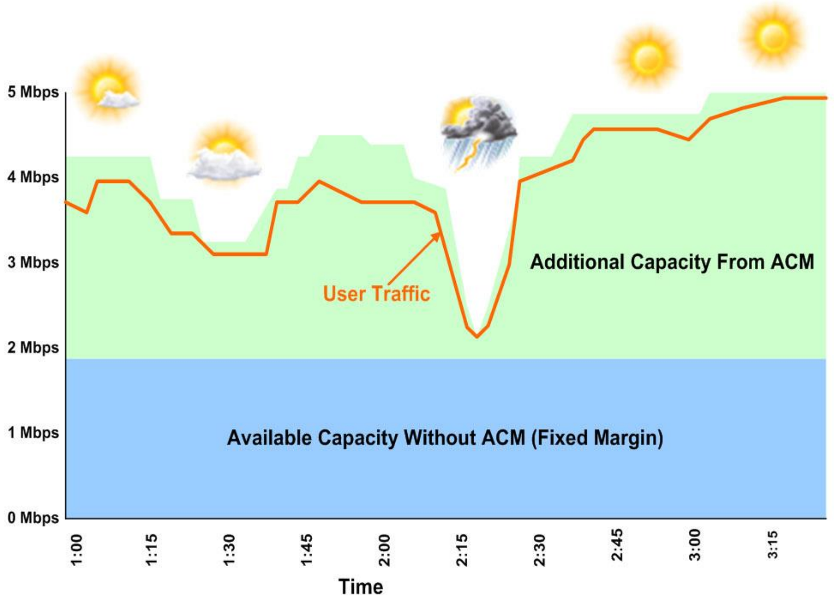
Code rate = k/n

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

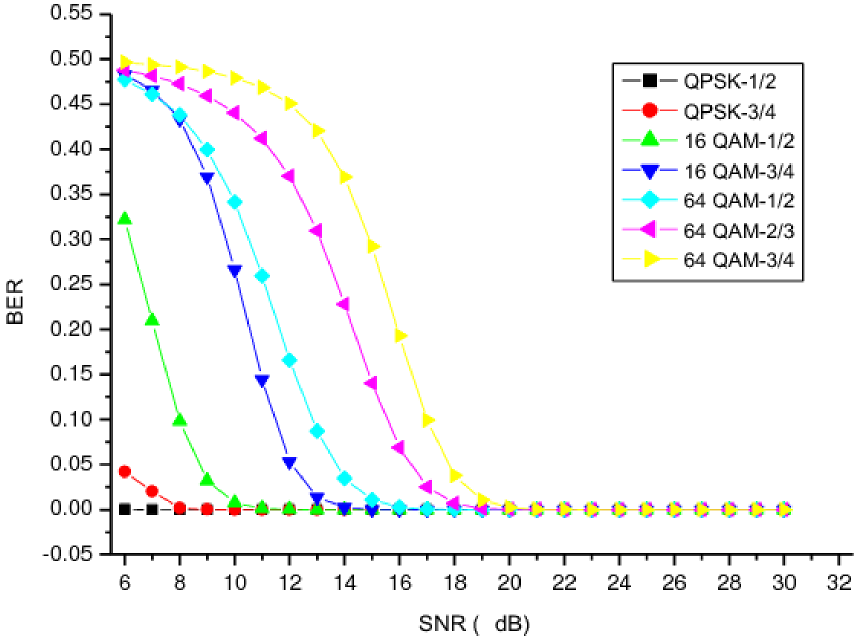
- Two Categories of Channel Fading Impairments
  - Fast Channel Fading (ex: Multi-Path)
  - Slow Channel Fading (ex: Shadow Fading)
- Goal is to adjust SNR update rates so that:
  - SNR updates slow enough to average fast fading effects
  - SNR updates fast enough to track slow fading effects

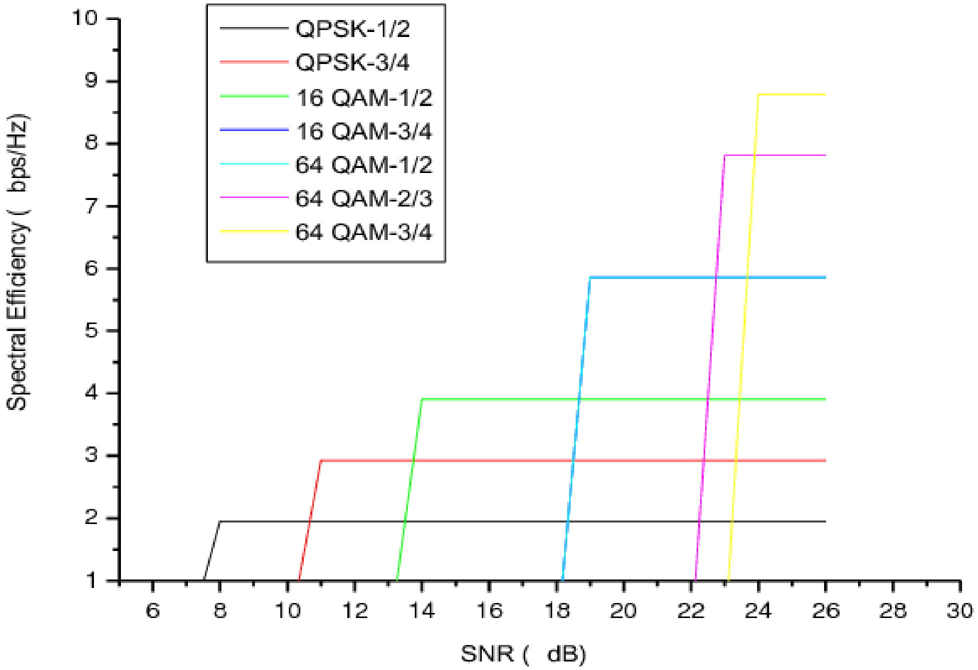
ACM schemes in LTE (4G)

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





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