Wireless Communication

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Mid-Review	☐
Name	Lecture 2
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LECTURE 2 WIRELESS COMMUNICATION BASICS

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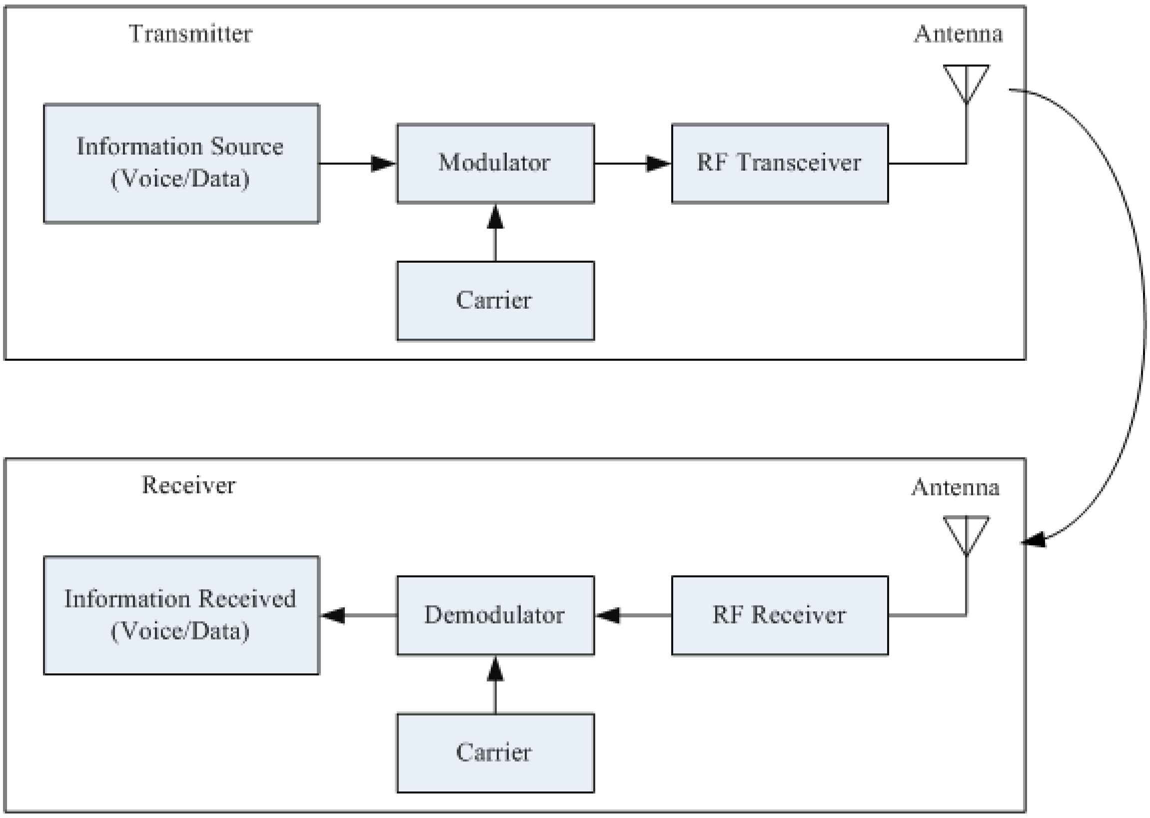
Basic concepts of wireless communications

▼ **Wireless comm.**

- EM wave: diff. freq. bands in EM spectrum
- Radio(omni-direction app.)
    - 30MHz - 1GHz
- Microwave(directional trans)
    - 1GHz to 40GHz(satellite/radar comm. / heating)
- Infrared(point-to-point/multipoint app.)
    - 300GHz to 200THz: remote control/optical networks

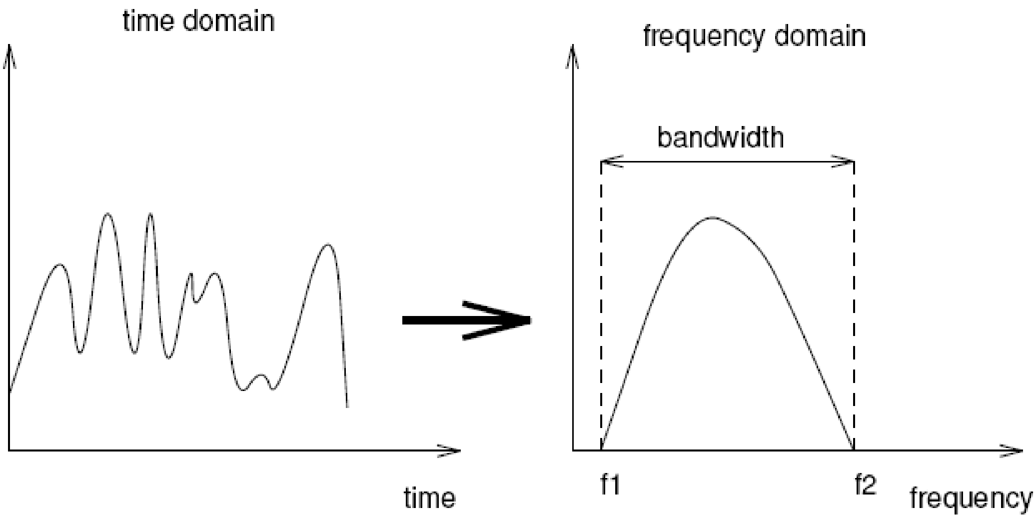
▼ **Simplified Wireless Communication System**



- Transmitter: data convey info; signal represent data; manipulate signal; transmitted to wireless medium via antenna
- Signal: propagated from transmitter's antenna to receiver's antenna over wireless medium
- Receiver: receive signal from wireless medium via antenna; convert signal to data; derive info

▼ Data vs. Signal

- data: convey meaning/info; analog data / digital data
- Signal: representation of data; analog/digital data



- view as function of time/freq
  - time-domain representation

    - Sinusoidal wave $s(t) = A\sin(2\pi ft + \phi)$ is a periodic signal (most basic one)
      - Amplitude (A): maximum strength of the signal over time (measured in volts)
      - Frequency (f): rate at which the signal repeats, measured by cycles per second (called Hertz (Hz))
      - Period (T): amount of time it takes for one repetition of the signal
        - Relation: $T = 1/f$
      - Phase (ϕ): the relative position to the origin within a single cycle of a signal
      - Wavelength (λ): distance occupied by a single cycle of the signal (the distance between two points of corresponding phase of two consecutive cycles)
        - Relation: $\lambda = cT = c/f$, $c \cong 3\times10^8$m/s (speed of light)

  - freq-domain representation
    - $S(t)= \sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)$
- Bandwidth of signals
  - spectrum - range of freq. that a signal contains
  - bandwidth - width of spectrum of signal(diff. b/t highest & lowest freq.

▼ Analog vs. Digital

- Analog signal: data→ signal easily; transmission media only propagate analog signal
- Digital signal: robust to noise interference; suffer more from attenuation(衰減) —— need repeater to retransmit for long distance

▼ Channel Capacity

- channel - single path provided by transmission medium via physical separation / logical separation(freq./time division multiplexing)
- upper limit for signal transmission(capacity)
  - analog - bandwidth; digital - data rate

Signal Propagation

▼ Antennas

- EM signal are produced, transmitted and received via antennas
  - transmitting antenna: transmitter deliver radiates into surrounding in form of radio/microwave signals
  - receiving antenna: convert signals from the environment into alternating current and deliver it to the receiver
- Isotropic radiator(all direction)
- real antenna: quarter wave(λ/4) Marconi antenna on car roof/ half wave dipole

▼ Signal Propagation

- signal propagation in free space is a straight light(line of sight)

$$\boxed{P_r = G_r G_t \left(\frac{\lambda}{4\pi d}\right)^2 P_t}$$

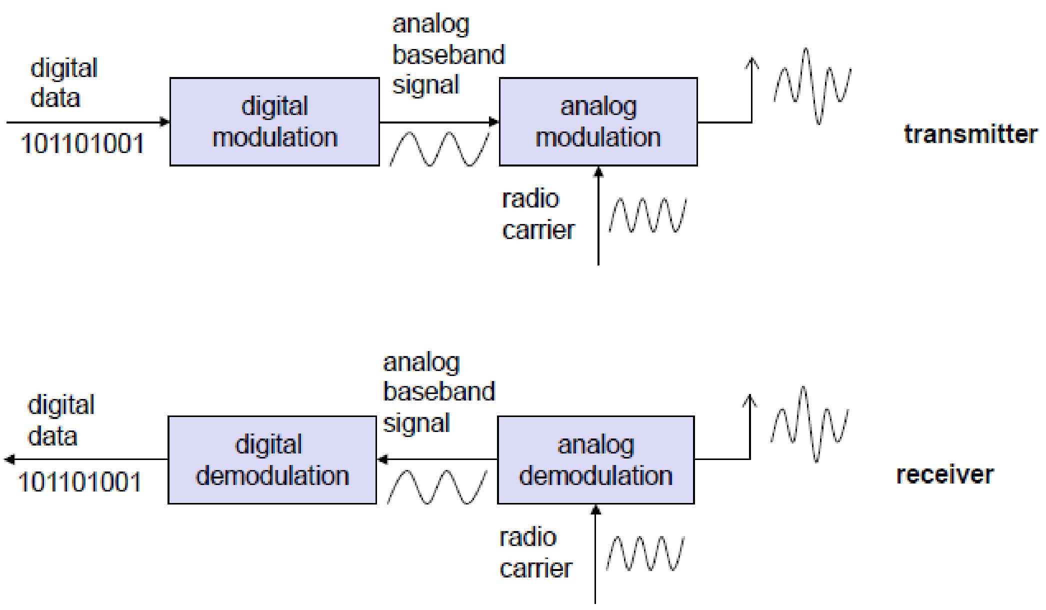
- free space propagation model
  - Pr: received power
    Pt: transmitted power
    Gr, Gt: receiver and transmitter antenna gains
    λ=c/f: wavelength
- Signal propagation range
  - transmission range: comm. is possible, low error rate
  - interference range: comm. impossible; signal interferes other transmission

- Signal Propagation influence by: shadowing / reflection / scattering / diffraction

- ▼ Multipath Propagation
  - take different path from sender to receiver; different time; different phase
- ▼ Fading Effect
  - Channel chara. changes over time/location due to
    - signal path change / different delay variation / different phase of different path
    - rapid fluctuation in power received(fast fading)
  - other change: surrounding obstacles
    - slow change on average received(short fading) — more smooth

Modulation techniques P23

- ▼ Modulation and Demodulation



  - ▼ Modulation
    - The process how carrier signal is manipulated to carry data info.
      - info signal - typically a low freq. signal(baseband signal)
      - carrier signal - high freq. sinusoid, no info. carry

- modulated signal - parameter in carrier need to be varied over time to represent baseband signal

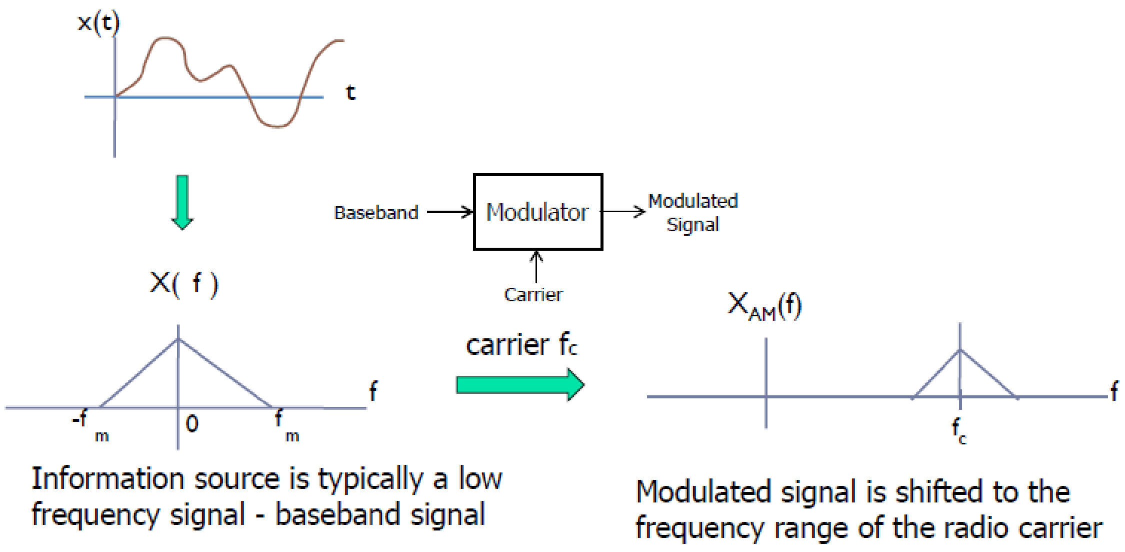
▼ Demodulation

Reserve process of modulation: extract data info from received signal

antenna is too large → no send baseband signal directly

▼ Analog Modulation

- shift center freq. of baseband signal up to freq. range of radio carrier



- why
  - reduce size of antenna(size ∝wavelength)
  - provide freq. division multiplexing by shifting baseband signal to high freq. band
  - avoid signal distortion due to wireless medium chara.
- Basic scheme
  - amplitude modulation(AM): $s(t) = A(t) \sin(2\pi ft)$
  - freq. modulation(FM): $s(t) = A \sin(2\pi f(t)t)$
  - phase modulation(PM): $s(t) = A \sin(2\pi ft+ \varphi(t))$

▼ Digital Modulation

- Digital data is translated into analog signal(baseband)
  - shit keying, wireless medium only allows analog signal transmission

- Basic Scheme
    - amplitude shift keying(ASK), freq. shit keying(FSK), phase shift keying(PSK)
    - difference in spectral effi, power effi, robustness…

Multiplexing techniques

▼ Multiplexing

- multiplexing allows multiple users' signal to be carried on a single medium
- use the transmission medium more efficient
- ensure low interference: divide medium into several channel that can be used independently without interferences

▼ 4 ways

▼ (SDM)Space-division multiplexing

- separate whole space into cells
- cell use certain band of spectrum for signal transmission
- advantage: simple, increase capacity by reusing freq. in different cell
- disadvantage: inflexible, need handoff

▼ (FDM)Frequency-division multiplexing

- separate whole spectrum into smaller freq. bands
- a channel get certain band of spectrum for whole time
- advantage: no dynamic coordination needed, work for analog signal
- disadvantage: waste of bandwidth if the traffic is distributed unevenly; inflexible; need guard space

▼ (TDM)Time-division multiplexing

- a channel get whole spectrum for certain amount of time
- advantage: 1 carrier in medium at any time; high throughput even for many users
- disadvantage: need precise time synchronization

▼ (CDM)Code-division multiplexing

- all channel use the same spectrum at the same time

- each channel has a unique code
- the channels are separated by assigning them their unique code
- advantage: bandwidth efficient; no coordination and synchronization necessary; good protection against interference
- disadvantage: lower user data rates; more complex signal regeneration

▼ Time and freq. division multiplexing

- Combination of both methods
- advantages: protection against frequency selective interference; higher data rate compared to code …
- disadvantage: precise coordination required

▼ Orthogonal Frequency Division Multiplexing

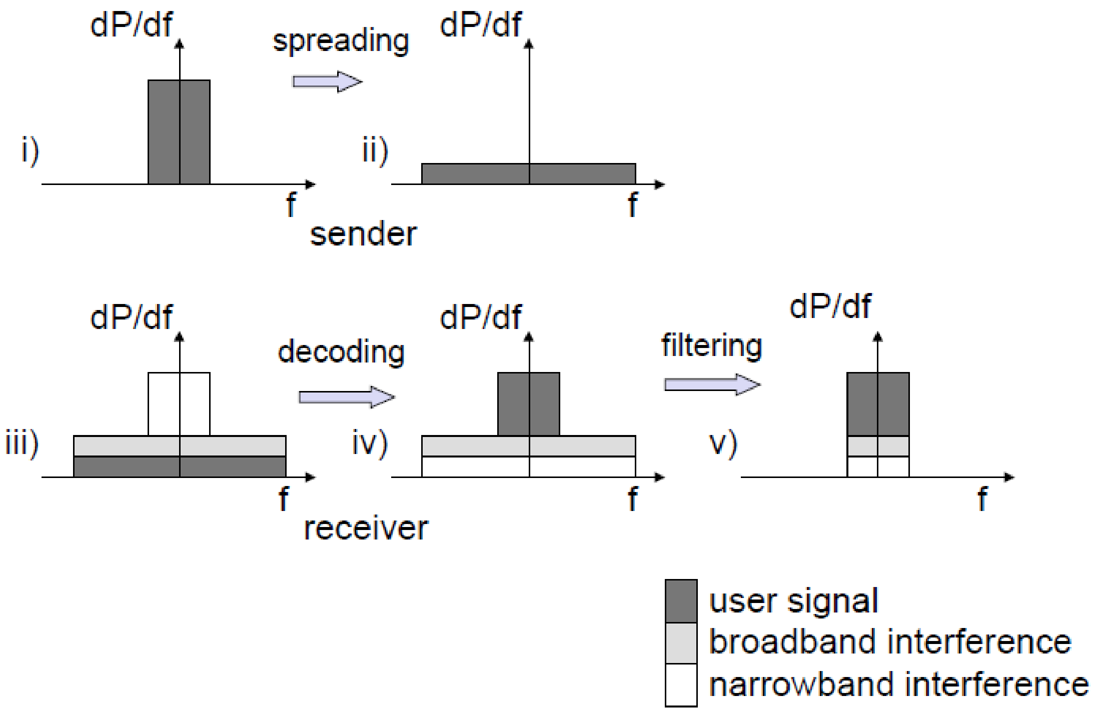
- Multiple channels overlapped to save bandwidth
- signals at diff. channels not interference at certain freq.
- advantages: overlapped freq. channels save bandwidth; support higher data rates compared to FDM; solve multipath propagation problem
- disadvantage: precise time synchronization required

Spread spectrum techniques

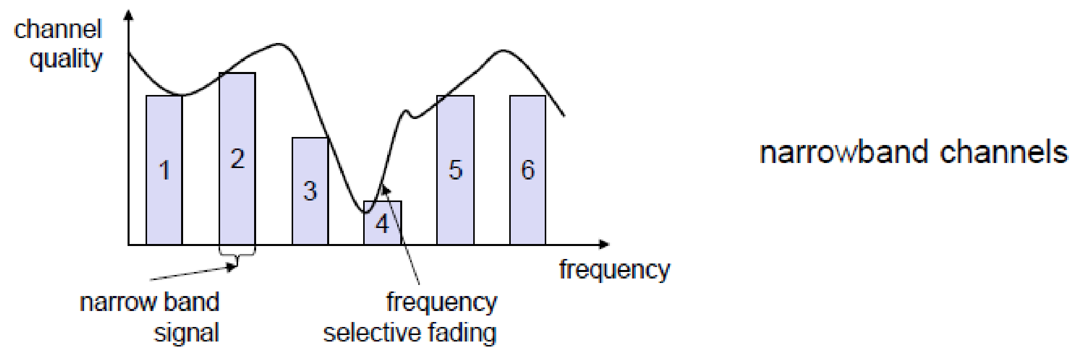
▼ Spread Spectrum Techniques

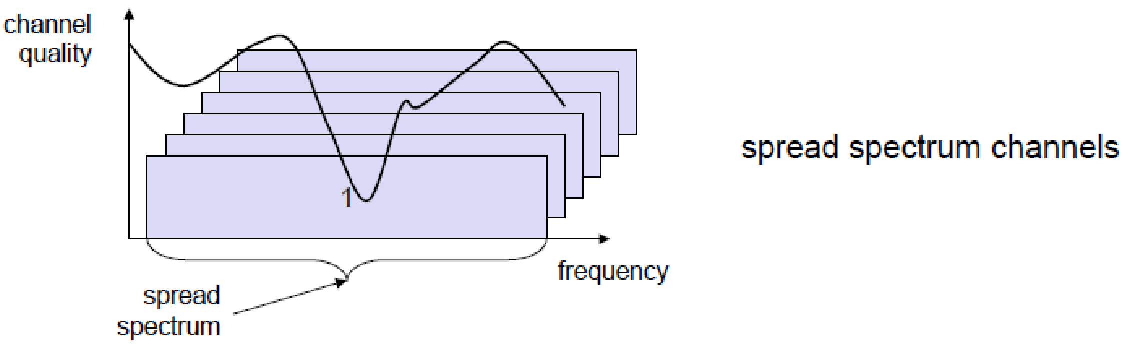
- use wide range of freq. to transmit a narrowband signal to defend against interferences
    - problem of radio transmission: narrow band signals can be wiped out for duration of the interference
    - Solution: spread the narrow band signal into a broad band signal using special code to protect against narrow band interference

▼ Interferences

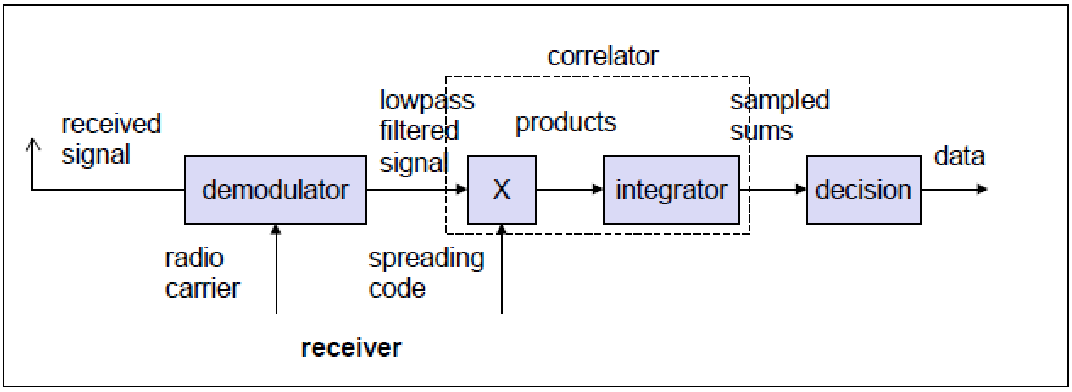


- ▼ Spreading & Freq selective fading

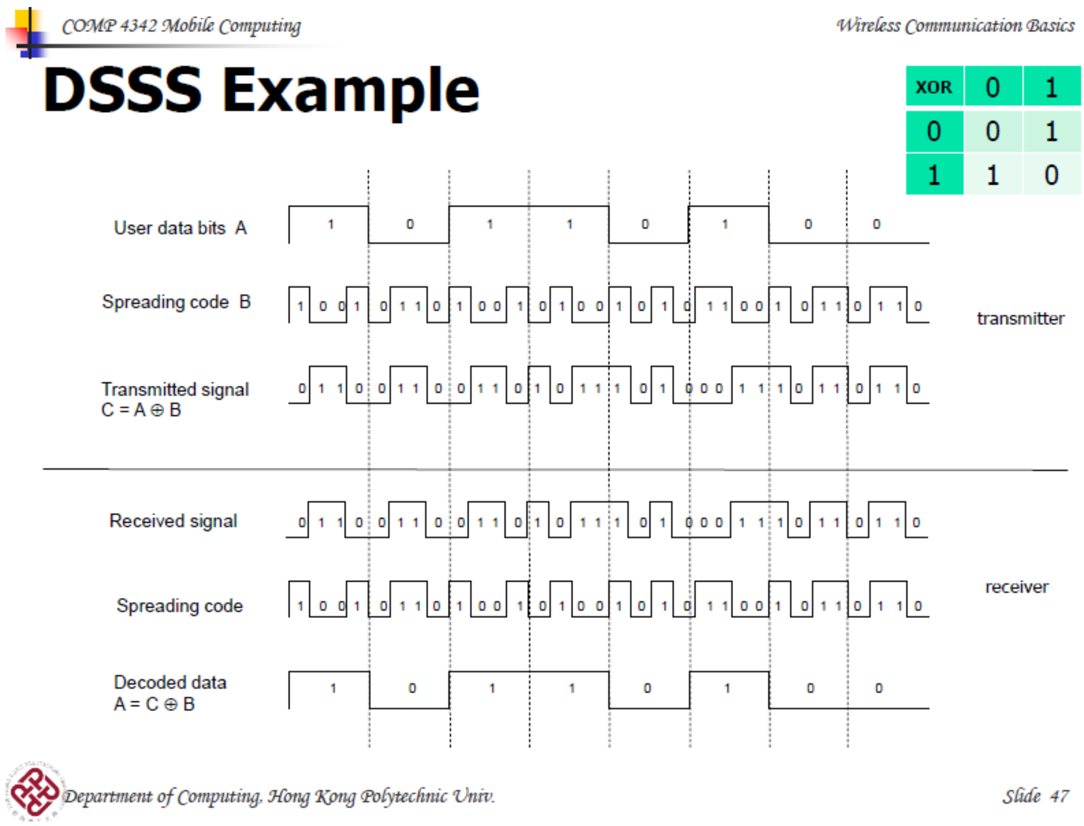




- ▼ Techniques
  - ▼ DSSS(direct sequence spread spectrum)



- Transmitter
  - before msg is transmitted, each msg data stream is mixed with spreading code
    - spread code: m-bit chipping seq.
    - effect is spreading signal spectrum across a wider frequency band
    - 1 technique is using exclusive-OR to mix msg data stream with spreading code
  - spread spectrum signal modulated with carrier for transmission
- Receiver
  - received signal is first demodulated to baseband signal
  - the same spreading code is used to decode the baseband signal to the msg data stream via correlator



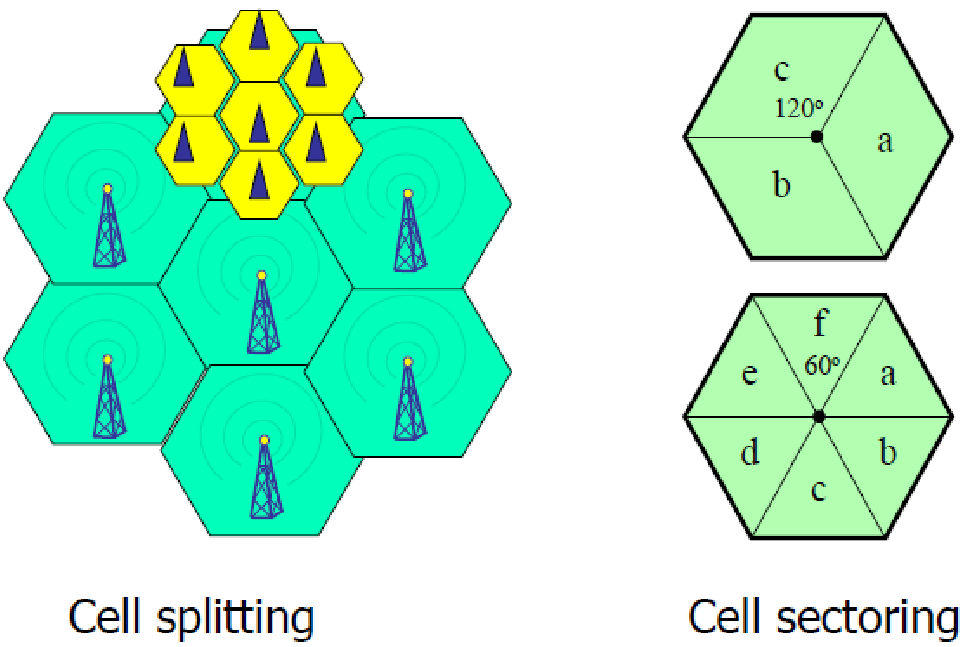
- ▼ FHSS(frequency hopping spread spectrum)
    - transmitter
        - choose same carrier frequency sequences and synchronize with transmitter in freq. to receive the signal
    - receiver
        - choose the same carrier freq. seq. and synchronize w/ transmitter in freq. to receive signal
            - receiver use selected carrier to demodulate the received signal to the band signal
            - baseband signal can further be demodulated to the data stream

- ▼ Features of spread spectrum
    - allow multiple users to use the same freq. band
        - to dedicate receiver that knows patterns of the transmitting signal, spread-spectrum signal is easily detected; for other, spread-spectrum signal like background noise
    - higher reliability and security
        - resist to frequency selective fading and interference

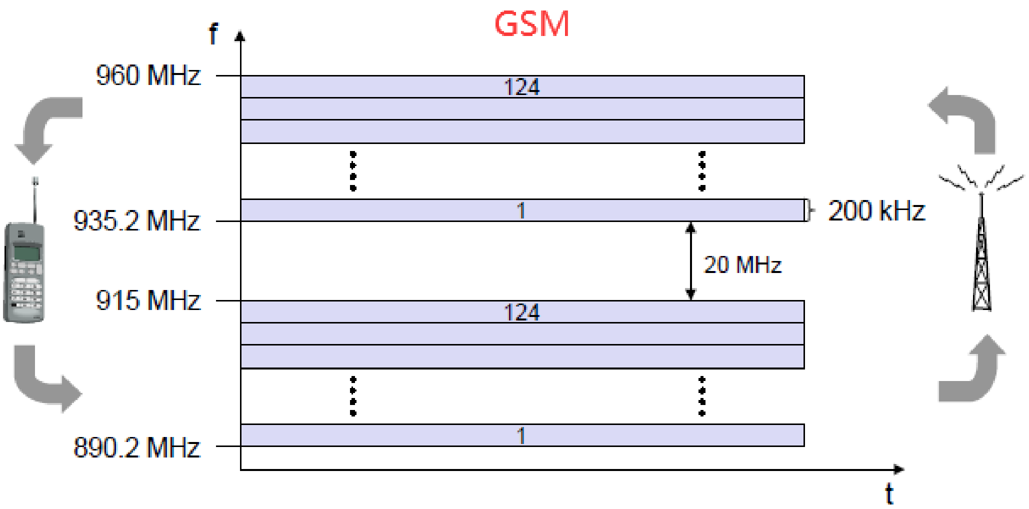
- provide secure communication and resist to eavesdropping

Media access control(MAC) methods

- ▼ MAC Method
    - Regulate multiple terminals to access the shared medium
        - how to allocate medium resource(freq. time slot, spreading codes) to terminal that share the medium
    - Approach: channel based methods / packet-based methods
- Channel-based Methods
    - assign each terminal its separated channel in medium for transmission
    - provide collision-free multiple access to the medium
    - more suitable to carry voice
    - ▼ SDMA(Space division Multiple Access)

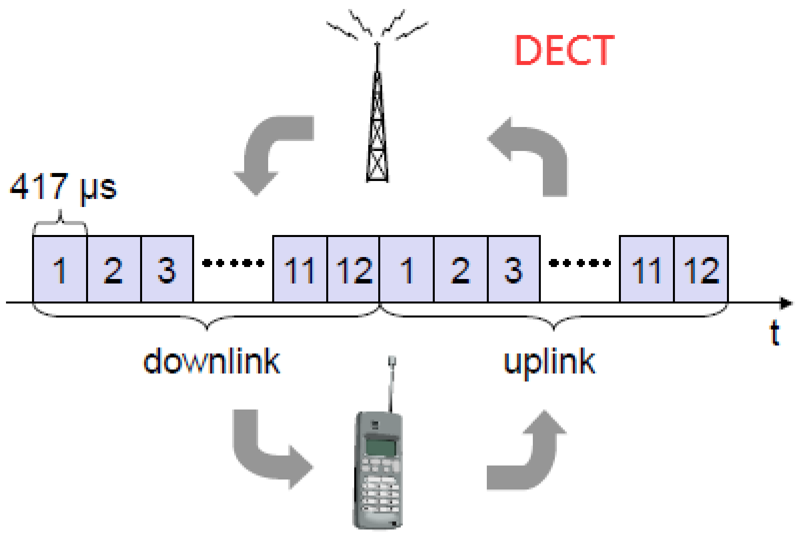


        - based on SDM, Segment space into cells
        - e.g. cell structure in cellular networks
    - ▼ FDMA(Frequency Division Multiple Access)



- Based on FDM; Allocate freq. to channels / define a freq. hopping pattern
- E.g., 1G system, FH for 2G system

▼ TDMA (Time Division Multiple Access)



- Based on TDM; Allocate time slots to channels in a fixed pattern
- Time can be allocated on demand and in a distributed fashion
- E.g., 2G system

▼ CDMA (Code Division Multiple Access)

- **Sender A**
  - sends A_d = 1, key A_k = 010011 (assign: "0"= -1, "1"= +1)
    $A_d = +1 \quad A_k = (-1, +1, -1, -1, +1, +1)$
  - sending signal
    $A_s = A_d * A_k = (+1) * (-1, +1, -1, -1, +1, +1)$
    $= (-1, +1, -1, -1, +1, +1)$
- **Sender B**
  - sends B_d = 0, key B_k = 110101 (assign: "0"= -1, "1"= +1)
    $B_d = -1 \quad B_k = (+1, +1, -1, +1, -1, +1)$
  - sending signal
    $B_s = B_d * B_k = (-1) * (+1, +1, -1, +1, -1, +1)$
    $= (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $S = A_s + B_s = (-1, +1, -1, -1, +1, +1) + (-1, -1, +1, -1, +1, -1)$
    $= (-2, 0, 0, -2, +2, 0)$

- **Receivers** receive the combined signal **S = (-2, 0, 0, -2, +2, 0)**
- **Receiver A**
  - apply key A_k to inner product the signal **S**
    - $A_e = S \bullet A_k = (-2, 0, 0, -2, +2, 0) \bullet (-1, +1, -1, -1, +1, +1)$
      $= (-2)*(-1)+0*(+1)+0*(-1)+(-2)*(-1)+(+2)*(+1)+0*(+1)$
      $= 2 + 0 + 0 + 2 + 2 + 0 = 6$
  - decision: result $A_e > 0$ => original bit was "1"

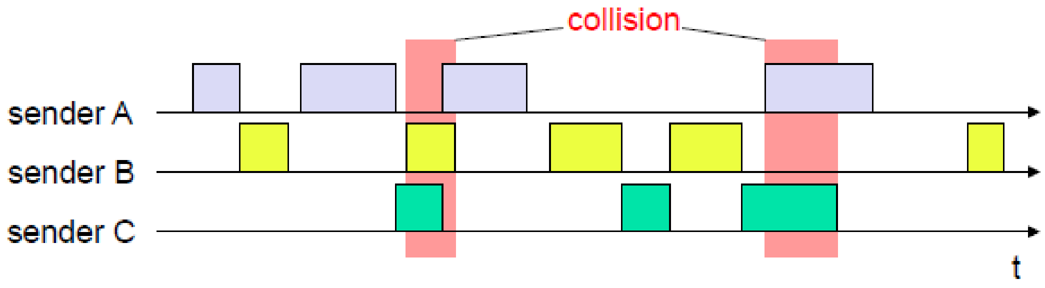
- **Receiver B**
  - apply key B_k to inner product the signal **S**
    - $B_e = S \bullet B_k = (-2, 0, 0, -2, +2, 0) \bullet (+1, +1, -1, +1, -1, +1)$
      $= (-2)*(+1)+0*(+1)+0*(-1)+(-2)*(+1)+(+2)*(-1)+0*(+1)$
      $= -2 + 0 + 0 - 2 - 2 + 0 = -6$
  - decision: result $B_e < 0$ => original bit was "0"

- Based on CDM –Assign codes to separate different users in code space
- E.g., 3G system

- Packet-based methods
  - access by terminals on demand
  - no dedicated channel for each terminal
  - terminal compete for use of channel to send packet
  - collision may occurs

- protocol regulate multiple terminal to randomly access shared medium
- need to resolve transmission collision
- suitable for wireless networks that are designed to send data packets

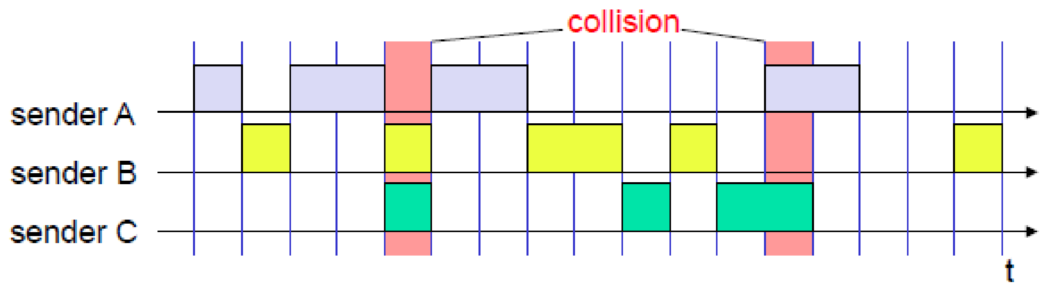
▼ Aloha (grandmother of all random access protocols)



- stations access channel at will and may cause collision

▼ Slotted Aloha

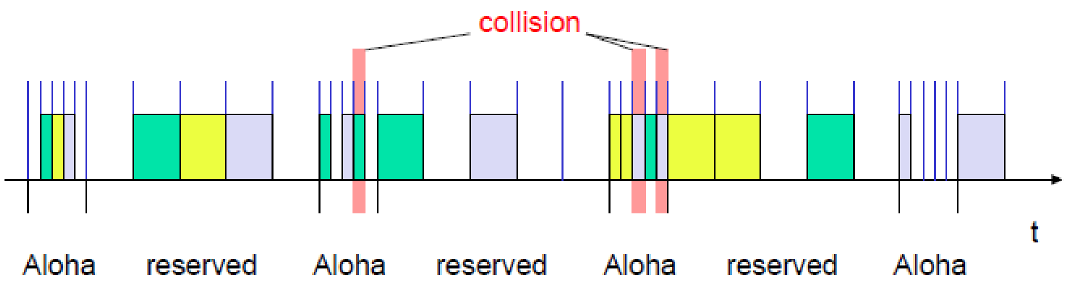
- channel time is divided into slots
- stations access channel at beginning of each slot
- frame transmission occupies the entire slot
- frame is wiped out by collision if one or more other stations also access the same slot



▼ DAMA

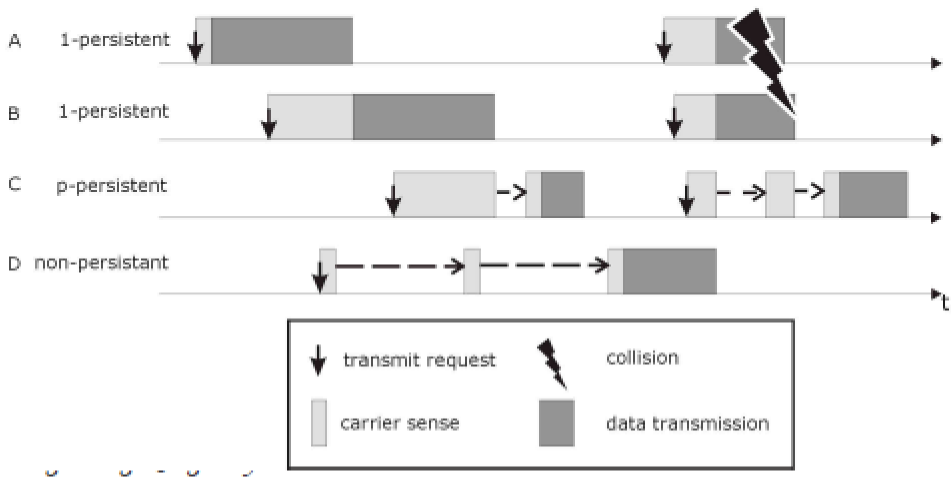
- channel throughput for Aloha is low
  18% for Aloha, 36% for slotted Aloha
- DAMA increases throughput to 80%
  - Aloha mode for reservation - sender compete with others to reserve future time slot, collision possible

- Reserve mode for data transmission - reserve slot success → sender can send data without collision



CSMA

- sender will sense the carrier before sending a packet



- persistent CSMA
    - when medium is busy a station can persistently wait for medium to become idle, then transmit with probability p
- Non-persistent CSMA
    - when medium is busy, station does not monitor wireless medium all the time, but listens to the medium again at predefined time

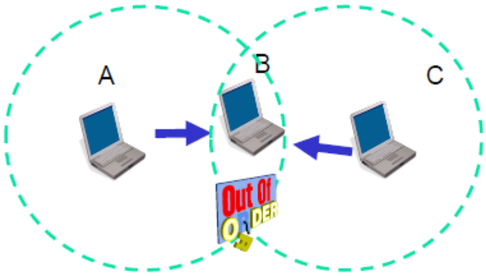
CSMA/CD

- CD(collision detection): Sender terminates transmission as soon as a collision is detected
- well for wired networks
    - CS mechanism to detect if medium occupied

- CD mechanism to detect if the signal is collided

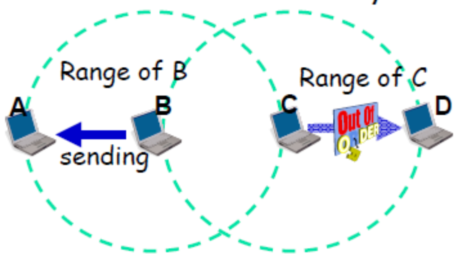
- not for wireless network
    - CS no work if sending terminal is out of transmission range of sender(hidden terminal)
        - hidden terminal problem

◆ A sends to B, C cannot receive A
◆ C wants to send to B, C senses a "free" medium (CS fails)
◆ Collision at B, A cannot detect the collision (CD fails)
◆ A is "hidden" for C -> cause collisions



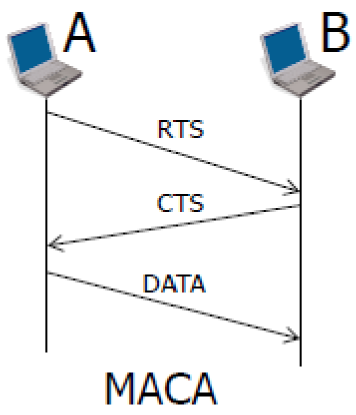
        - Exposed terminal problem

◆ B sends to A
◆ C wants to send to D, CS signals a medium in use, C has to wait
◆ Since A is outside radio range of C, waiting is not necessary
◆ B is "exposed" to C –> unnecessary blocking



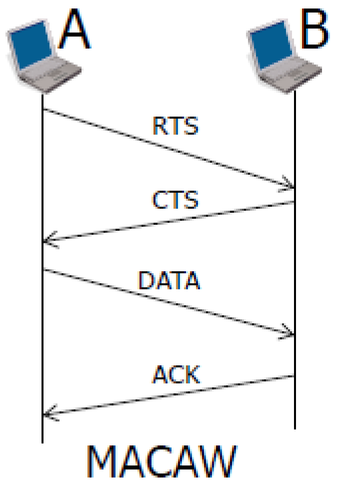
    - CD does not work since collision that happens at receiver cannot be detected by the sender

▼ MACA(Multiple Access with Collision Avoidance)



- use short signaling packet(RTS/CTS) for collision avoidance
  - RTS- request to send
    If the sender wants to send a data packet, it first broadcasts short RTS packet to receiver to request
  - CTS-clear to send
    The receiver grants the right by broadcasting CTS packet when ready to receive
  - DATA
    when sender receives CTS, it sends data too receiver

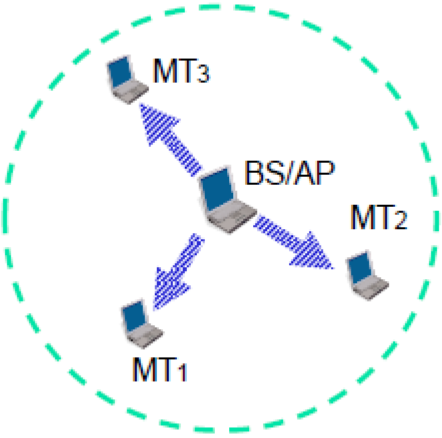
▼ MACAW(Multiple Access with Collision Avoidance for Wireless)



- enhance MACA by requiring receiver send ACK after each successful data transmission
- Error can be quickly recovered in MAC layer than upper network layer

- MACAW can solve hidden terminal problem, but generally do not solve the exposed terminal problem

▼ Polling



- 1 central terminal (base station / access point that can be heard by all others) can poll all other terminals according to a certain schedule
- Example

Example: Randomly Addressed Polling

- Base station (BS) broadcasts readiness signal to all mobile terminals (MTs)
- MTs ready to send can transmit a random number to BS without collision (random number used as the dynamic address of MT)
- BS randomly chooses one address from the list of all random numbers for polling the MT
  - Collision occurs if two MTs choose the same address
- BS acknowledges correct packets from that MT and continues polling next MT
- This cycle repeats after all MTs of the list are polled