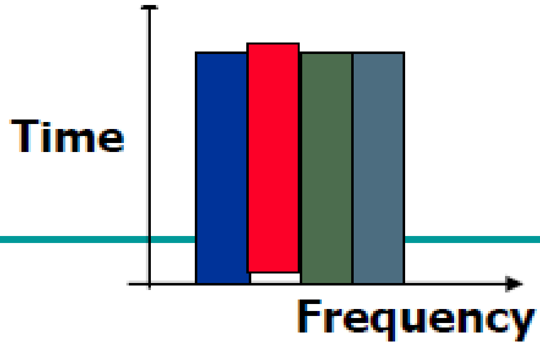
Wireless Communications

(Unit-5)

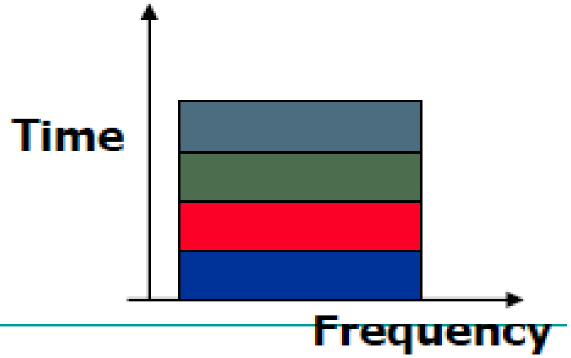
Multiple Access Techniques for Wireless Communications

- Introduction
- FDMA
- TDMA
- CDMA
- SS (Spread Spectrum)
  - FHSS
  - DSSS
  - Hybrid

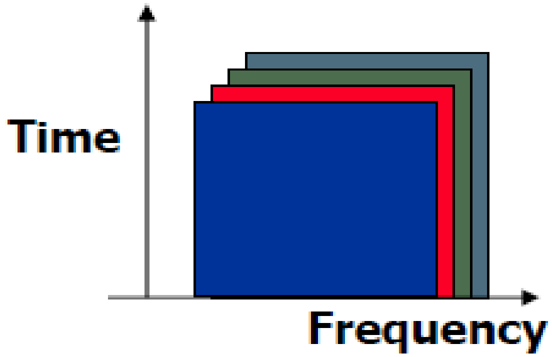
Multiple Access Techniques



FDMA



TDMA



CDMA

Question

- The EM spectrum is a limited resource

- How can we “share” it?
  - Time
  - Space
  - Frequency
  - Polarization
  - Spread Spectrum - use a wider bandwidth?

Multiple Access techniques

- Goal: allow many users to simultaneously share a communications resource

- Time Division Multiple Access (TDMA)
- Space Division Multiple Access (SDMA)
- Frequency Division Multiple Access (FDMA)
- Polarization Division Multiple Access (PDMA)
- Code Division Multiple Access (CDMA)
  - A Spread Spectrum form

Key Issue

- separate the signals at the receiver to extract *your* information

Two methods

- Do not mix the signals in the first place
  - can use space or time (SDMA or TDMA)
- Use distinctive properties of each signal as a means to identify
  - Frequency spectrum (FDMA)
  - Polarization of waves (PDMA)
  - code sequence attached to each message (CDMA)

Introduction

• **Multiple Access:**

The transmission from the BS in the downlink can be heard by each and every mobile user in the cell, and is referred as *broadcasting.*

Transmission from the mobile users in the uplink to the BS is many-to-one, and is referred to as multiple access.

Introduction

- Multiple Access:
  - Enable many mobile users to share simultaneously radio spectrum.
  - Provide for the sharing of channel capacity between a number of transmitters at different locations.
  - Aim to share a channel between two or more signals in such way that each signal can be received without interference from another.

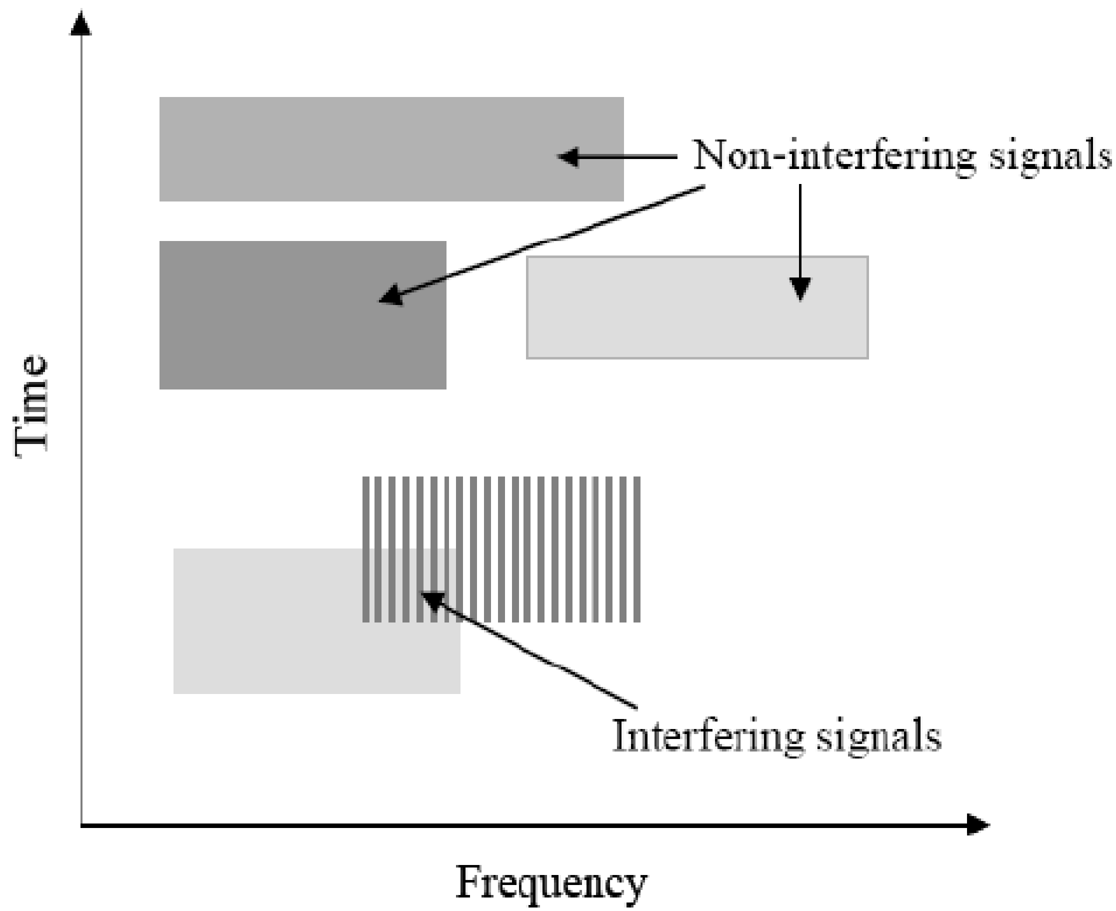
Introduction

- Multiple Access:

-Should not result in severe degradation in the performance of the system as compared to a single user scenario.

- Approaches can be broadly grouped into two categories: **narrowband and wideband**.

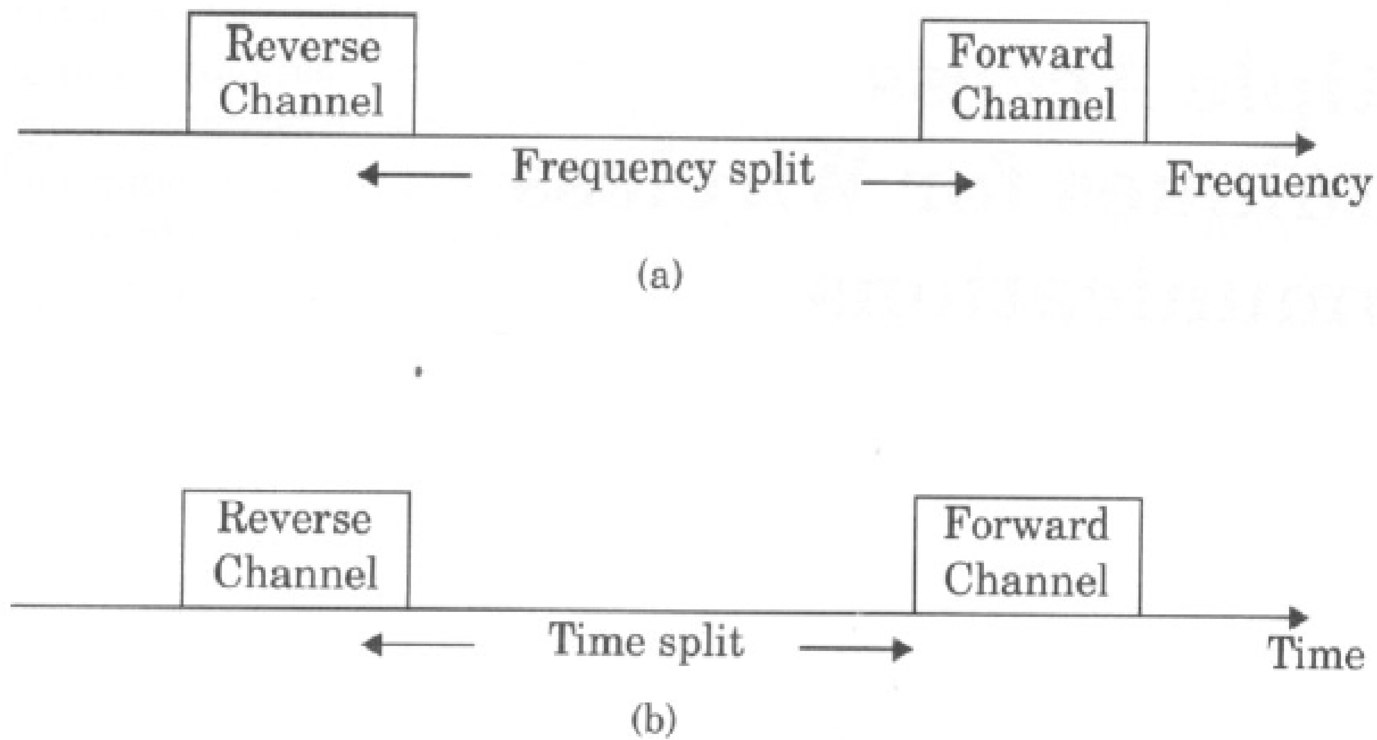
Introduction



Introduction

- In conventional telephone systems, it is possible to talk and listen simultaneously, called duplexing.
- Duplexing
  - Allow the possibility of talking and listening simultaneously.
  - Frequency Division Duplex (FDD)
    - Provides two distinct bands of frequencies for every user
  - Time Division Duplex (TDD)
    - Multiple users share a signal channel by taking turns in time domain
    - Each duplexing channel has both a forward time slot and a reverse time slot to facilitate bidirectional communication.

Introduction (4)



Classification

Multiple Accessing Techniques : with possible conflict and conflict- free

- Random access
- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)

-Spread spectrum multiple access (SSMA) :

- an example is Code division multiple access (CDMA)
- Space division multiple access (SDMA)

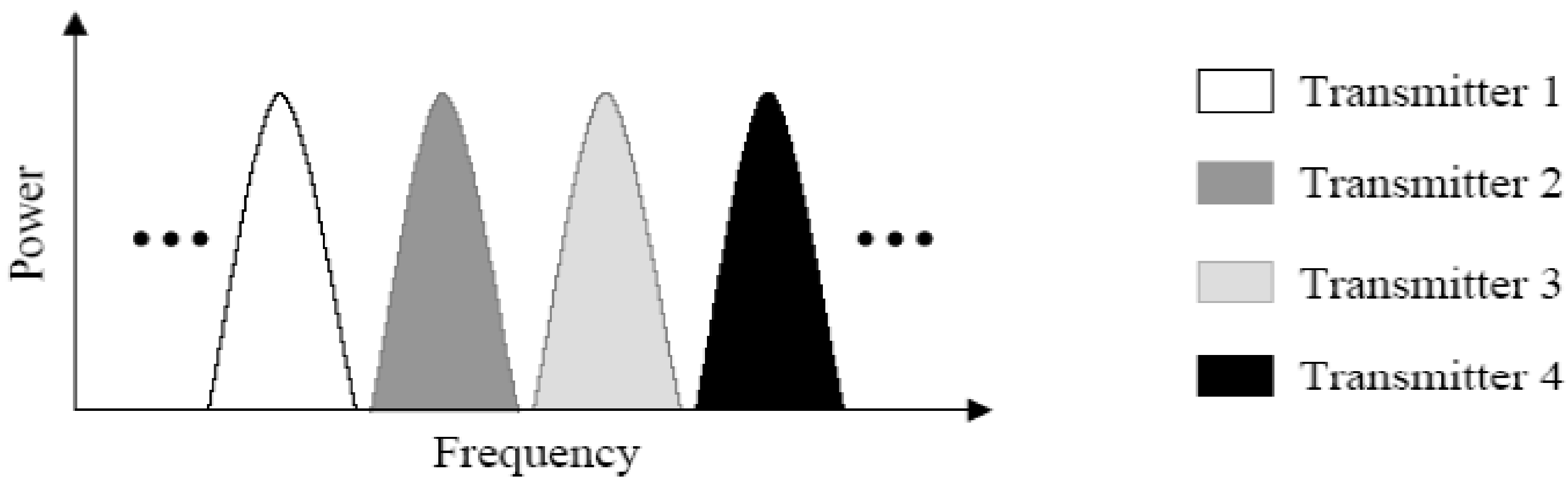
Frequency Division Multiple Access (FDMA)

-Provides two distinct bands of frequencies for every user, one for downlink and one for uplink.

- A large interval between these frequency bands must be allowed so that interference is minimized.
- Each transmitter is allocated a channel with a particular bandwidth.
- All transmitters are able to transmit simultaneously.
- During the period of the call, no other user can share the same frequency band.

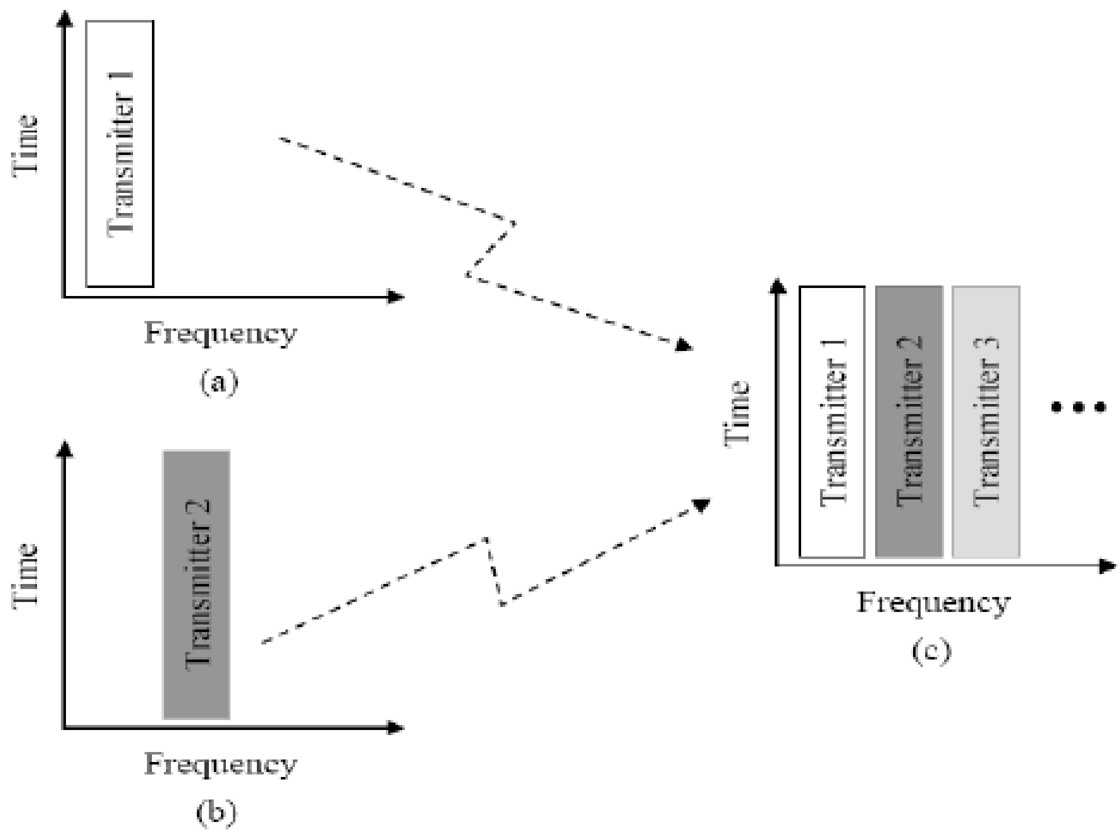
Frequency Division Multiple Access (FDMA)

- Allocation of separate channels to FDMA signals

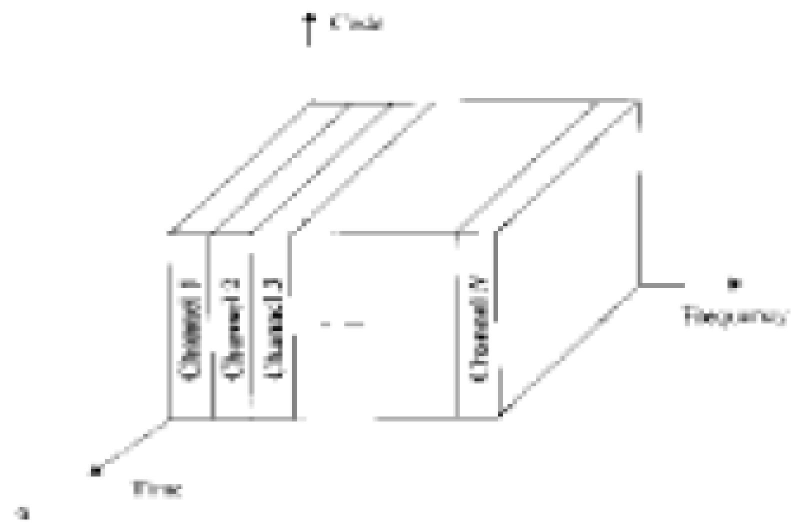


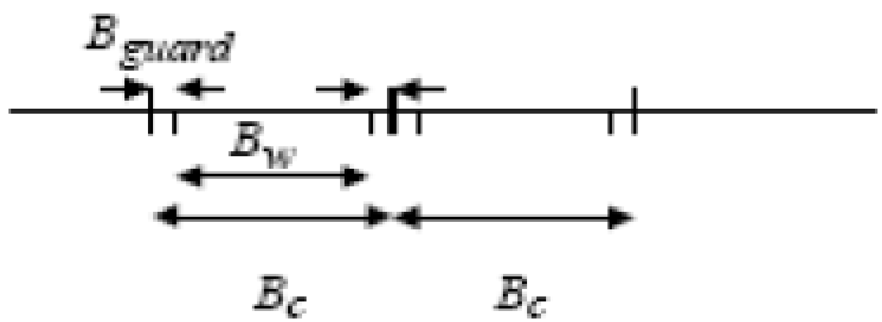
Frequency Division Multiple Access (FDMA)

- Time-frequency characteristic of FDMA



Frequency Division Multiple Access (FDMA)





Frequency Division Multiple Access (FDMA)

-All channels in a cell are available to all the mobiles.

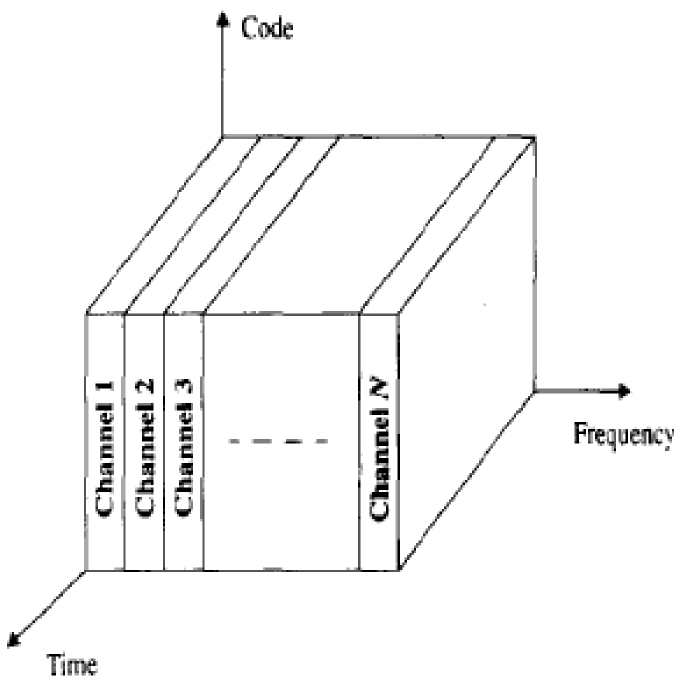
-Channel assignment is carried out on a first-come first-served basis.

The number of channels, given a frequency spectrum *BT , depends on the modulation technique (hence Bw* or *Bc) and the guard bands between the channels 2B guard .*

These guard bands allow for imperfect filters and oscillators and can be used to minimize adjacent channel interference.

Frequency Division Multiple Access (FDMA)

The number of channels that can be supported by FDMA Simultaneously is given by



$$N = \frac{B_t - 2B_{guard}}{B_c} \qquad (8.1)$$

where B_t is the total spectrum allocation, B_{guard} is the guard band allocated at the edge of the allocated spectrum, and B_c is the channel bandwidth.

Frequency Division Multiple Access (FDMA)

- Features of FDMA
- **Continuous transmission :** the channels, once assigned, are used on a non-time-sharing basis. This means that both subscriber and BS can use their corresponding allotted channels continuously and simultaneously.
  - If an FDMA channel is not in use , then it sits idle and can't be used by other users to increase the capacity.
  - Transmit simultaneously and continuously.
  - FDMA is usually implemented in narrowband systems.

Frequency Division Multiple Access (FDMA)

- Features of FDMA (Cont.)

Narrow bandwidth : Analog cellular systems use 25-30 kHz. Digital FDMA systems can make use of low bit rate speech coding techniques to reduce the channel band even more.

Low ISI : Symbol time is large compared to delay spread. No equaliser is required (Delay spread is generally less than a few µs – flat fading).

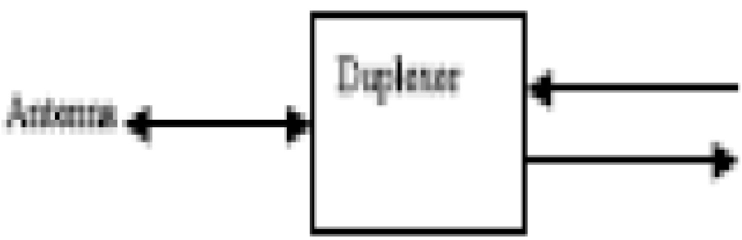
Simple hardware at mobile unit and BS :

(1) no digital processing needed to combat ISI

(2) ease of framing and synchronization.

Frequency Division Multiple Access (FDMA)

- Features of FDMA (Cont.)
  - FDMA uses duplexers since both TX and RX operate at the same time. This results in an increase in the cost of mobile and BSs.



- FDMA required tight RF filtering to minimize adjacent channel interference.

Frequency Division Multiple Access (FDMA)

- Features of FDMA (Cont.)
  - For continuous transmission, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.

Frequency Division Multiple Access (FDMA)

❑ Nonlinear effects in FDMA

-In a FDMA system, many channels share the same antenna at the BS. The power amplifiers or the power combiners, when operated at or near saturation are nonlinear.

- The nonlinearities generate intermodulation frequencies.

1. undesirable harmonics generated outside the mobile radio band cause interference to adjacent services.
2. undesirable harmonics present inside the band cause interference to other users in the mobile system.

Time Division Multiple Access (TDMA)

TDMA systems divide the channel time into frames. Each frame is further partitioned into time slots. In each slot only one user is allowed to either transmit or receive.

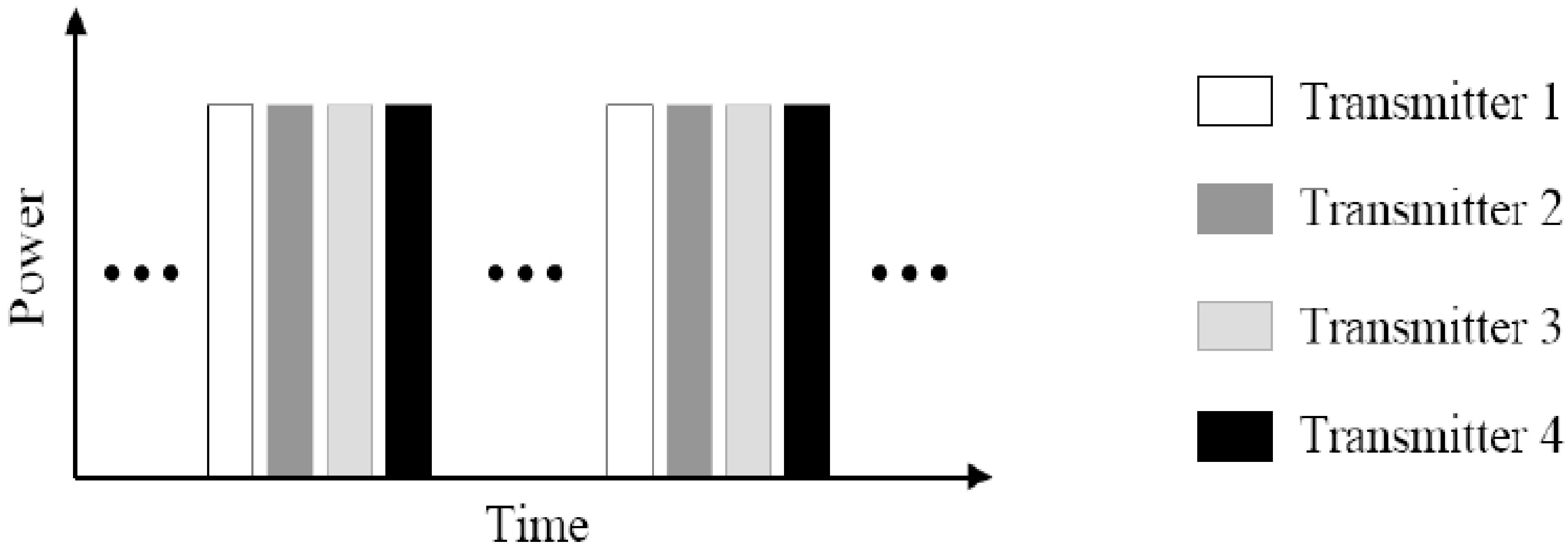
Unlike FDMA, only digital data and digital modulation must be used.

Time Division Multiple Access (TDMA)

- Transmitters share a common channel.
- Only one transmitter is allowed to transmit at a time.
  - Synchronous TDMA: access to the channel is restricted to regular.
  - Asynchronous TDMA: a station may transmit at any time that the channel is free.

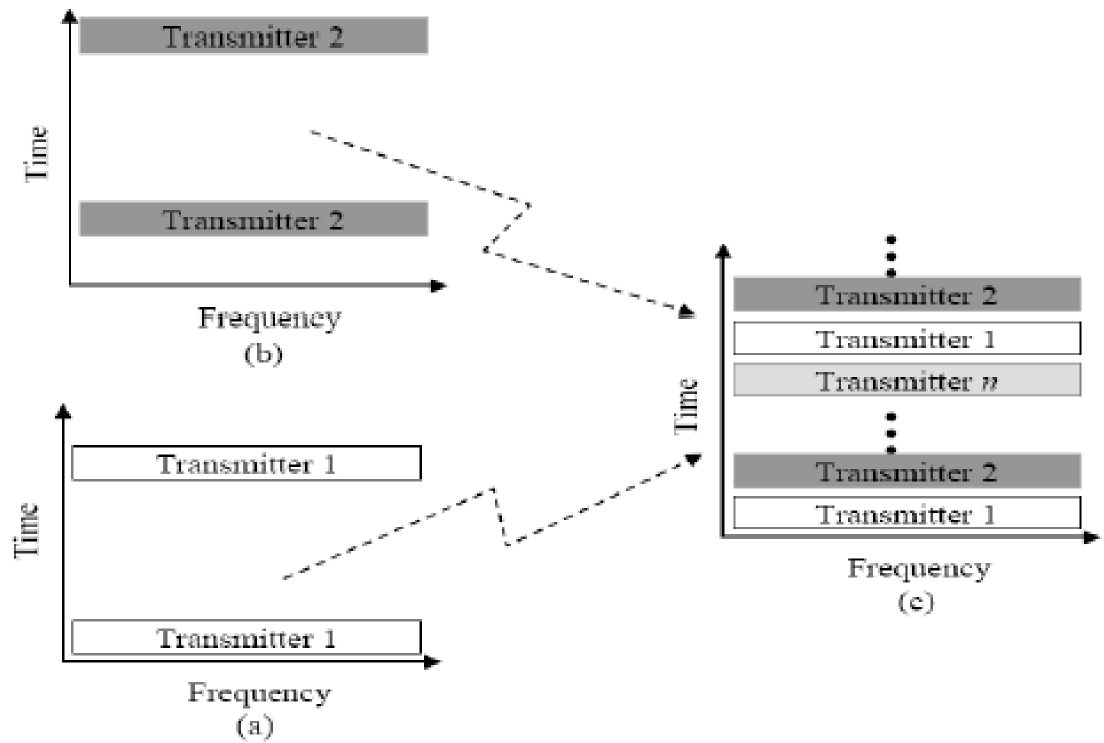
Time Division Multiple Access (TDMA)

- Allocation of time slot in TDMA



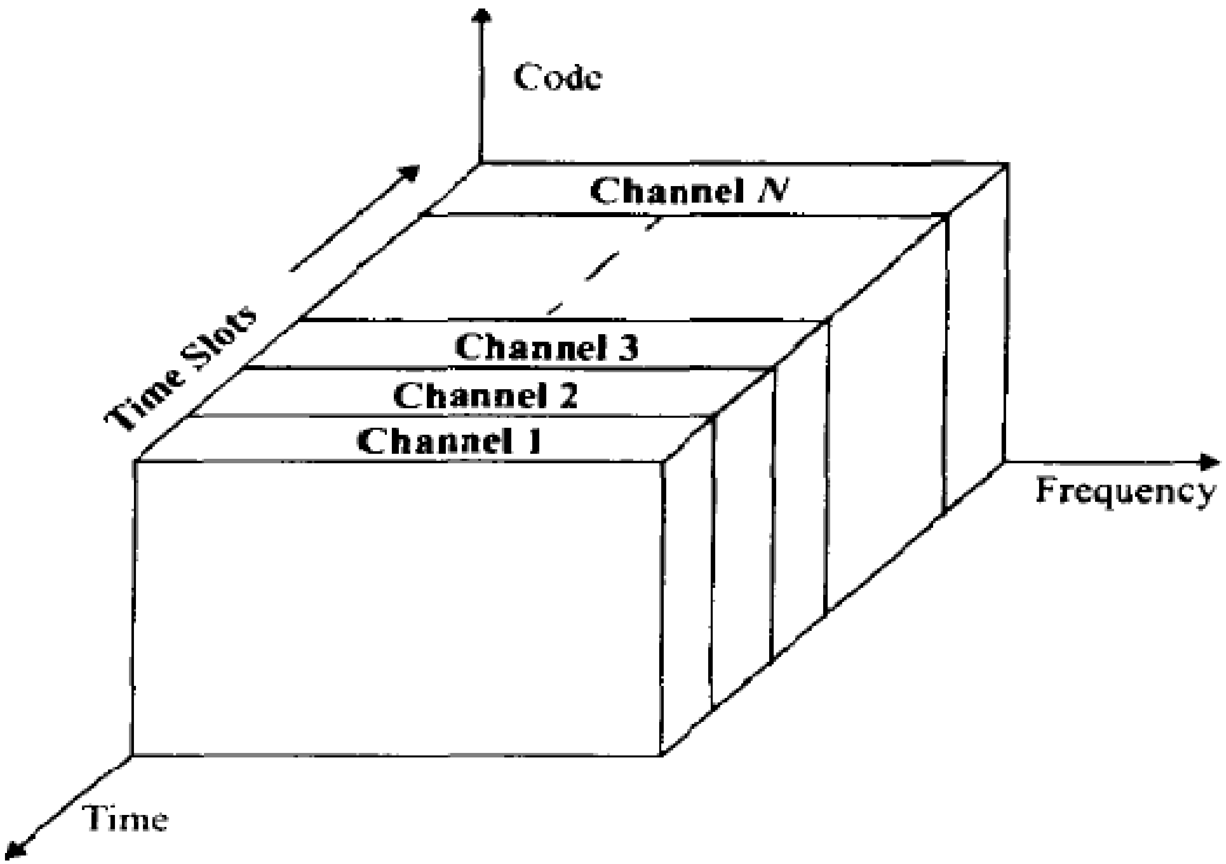
Time Division Multiple Access (TDMA)

- Time-frequency characteristic of synchronous TDMA



Time Division Multiple Access (TDMA)

- Allocation of time slot in TDMA



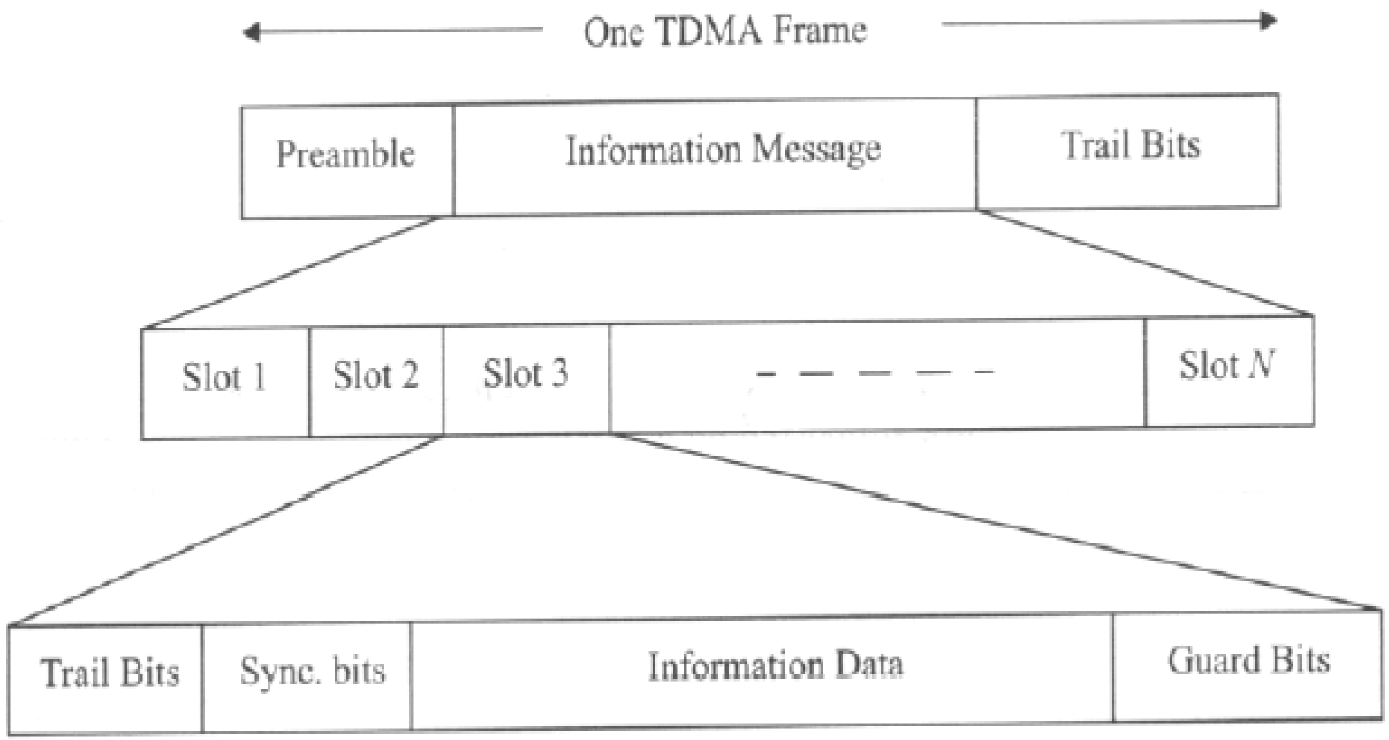
Time Division Multiple Access (TDMA)

- Features of TDMA
  - TDMA systems divide the radio spectrum into time slots.
  - Each user occupies a cyclically repeating time slot.

    So a channel may be thought of as a particular time slot of every frame, where *N time slots comprise a frame.*
- Transmit data in a buffer-and-burst method, thus the transmission for any user is not continuous. Transmitter can be turned off during idle periods.
  - TDMA has TDD and FDD modes.

Time Division Multiple Access (TDMA)

- TDMA Frame Structure



Time Division Multiple Access (TDMA)

- TDMA Frame Structure (Cont.)
  - In TDMA, the preamble contains the address and synchronization information that both the base station and the mobiles use to identify each other.
  - Different TDMA standards have different TDMA frame structures.

Number of channels in TDMA system – The number of TDMA channel slots that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m(B_{tot} - 2B_{guard})}{B_c} \tag{8.5}$$

where m is the maximum number of TDMA users supported on each radio channel. Note that two guard bands, one at the low end of the allocated frequency band and one at the high end, are required to ensure that users at the edge of the band do not "bleed over" into an adjacent radio service.

Time Division Multiple Access (TDMA)

- Features of TDMA (Cont.)

  Multiple channels per carrier or RF channels.

  Share a single carrier frequency with several users.

  Narrow or wide bandwidth – depends on factors such as modulation scheme, number of voice channels per carrier channel.

  High ISI – Higher transmission symbol rate, hence resulting in high ISI. Adaptive equaliser required.

  - **High framing overhead –** A reasonable amount of the total transmitted bits must be dedicated to synchronization purposes, channel identification. Also guard slots are necessary to separate users.

Time Division Multiple Access (TDMA)

- Features of TDMA (Cont.)

- The use of digital technology permits the inclusion of several facilities in the mobile unit, increasing its complexity. One example is the use of slow frequency hopping to counteract multipath fading.
- - Flexible data rates by assigning multiple time slots to different users based on their demand.
  - No duplexers is required since users employ different time slots for transmission and reception.
  - TDMA can allocate different numbers of time slots per frame to different users, allowing bandwidth be supplied on demand to different users.

Time Division Multiple Access (TDMA)

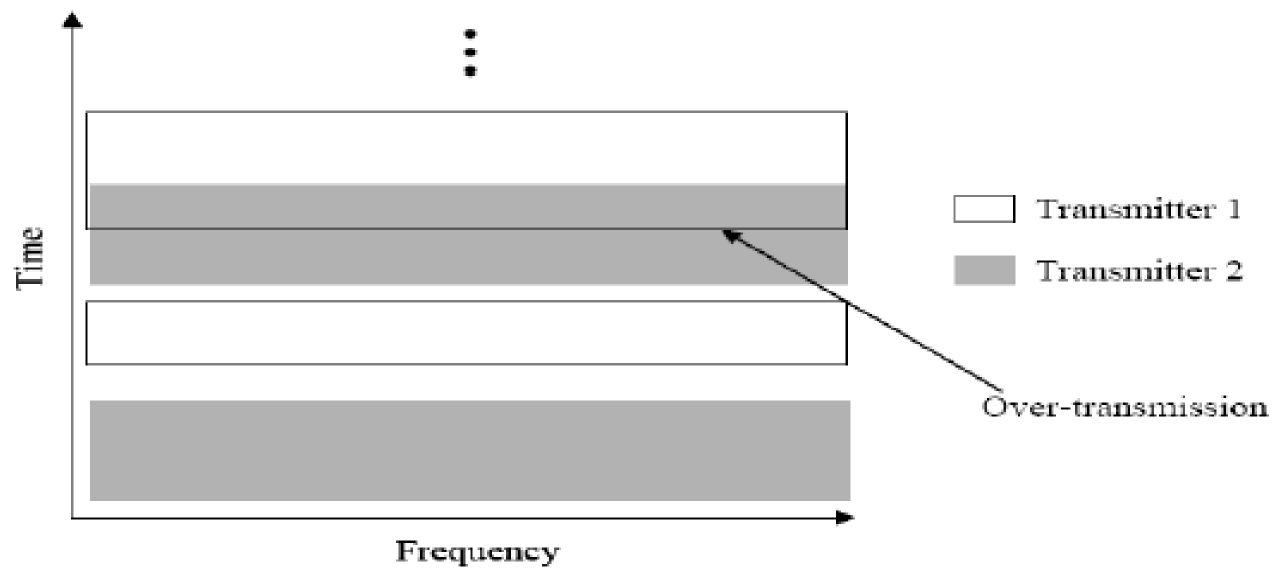
- Features of TDMA (Cont.)
- **Efficiency of TDMA, η $_f$** *: is a measure of the percentage* of bits per frame which contain transmitted data. The transmitted data include source and channel coding bits.

$$\eta_f = \frac{b_T - b_{OH}}{b_T} \cdot 100\%$$

b_{OH} includes all overhead bits such as preamble, guard bits, etc.

Time Division Multiple Access (TDMA)

- Asynchronous TDMA: Carrier-Sense Multiple Access (CSMA)
  - Allows a transmitter to access the channel at any time that is not being used by another transmitter.



TDMA Pros and Cons

Advantages

- flexible bit rate
  - channels may have varying data rates
- efficient use of channels

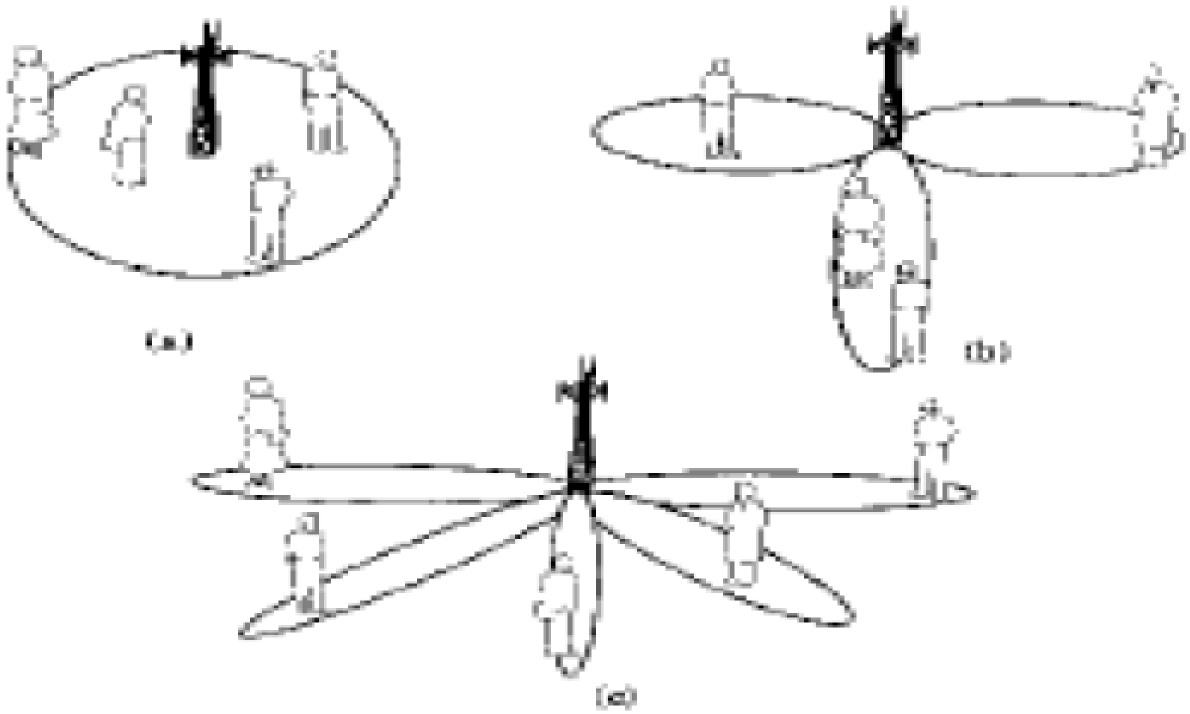
Disadvantages

- Synchronization
  - must lock on to your time slot (signal processing)
- Overhead
  - processing required for buffering...

SDMA Space Division Multiple Access

- SDMA controls the radiated energy for each user in space. It serves different users by using spot beam antennas.
- These different areas covered by the antenna beam may be served by the same frequency (in TDMA or CDMA) or different frequencies (in FDMA system).
- Sectorized antennas (b) may be thought of as a primitive application of SDMA.
- - An ideal adaptive antenna (c) is able to form a beam for each user in the cell of interest, and the base station tracks each user in the cell as it moves.

SDMA Space Division Multiple Access



SDMA

- **Features**

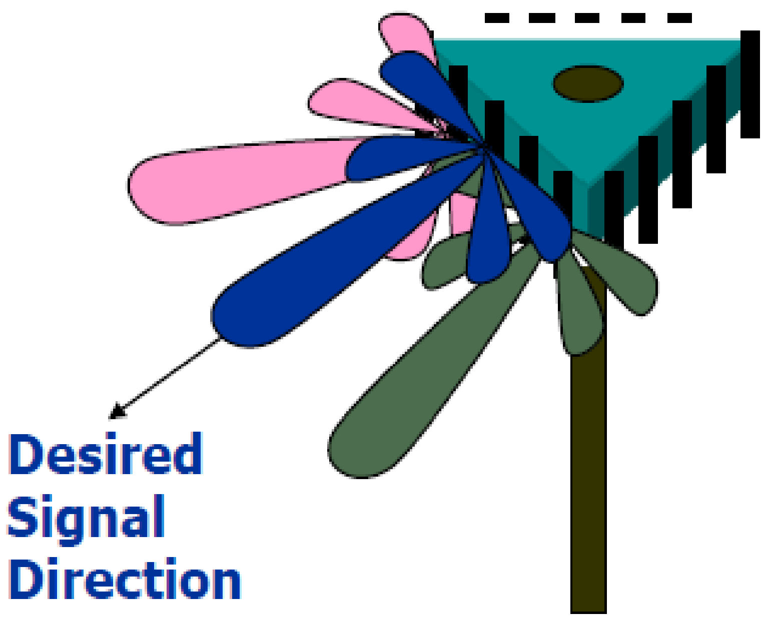
- A large number of independently steered high-gain beams can be formed without any resulting degradation in SNR ratio.

- Beams can be assigned to individual users, thereby assuring that all links operate with maximum gain.

- Adaptive beamforming can be easily implemented to improve the system capacity by suppressing cochannel interference.

SDMA Space Division Multiple Access

- Use highly directional Antenna
  - The receiver selects the beam that provides the greatest signal enhancement and interference reduction
  - Smart antenna systems can adjust their antenna pattern to enhance the desired signal, null or reduce interference.



SDMA Pros and Cons

Advantages

- BW increases with km^2
- Simple system

Disadvantages

- Restricted Geometry
  - terminals in same direction cannot share
- May have unused BW
  - if no terminals in given zone, bw not used

Spread Spectrum Multiple Access

Spread spectrum systems

The desired signal is transmitted over a bandwidth which is much larger than the Nyquist bandwidth.

It is first developed for military applications for

1. Security
2. Undetectability: minimum probability of being detected
3. Robust against intentional jammers

Spread Spectrum Multiple Access

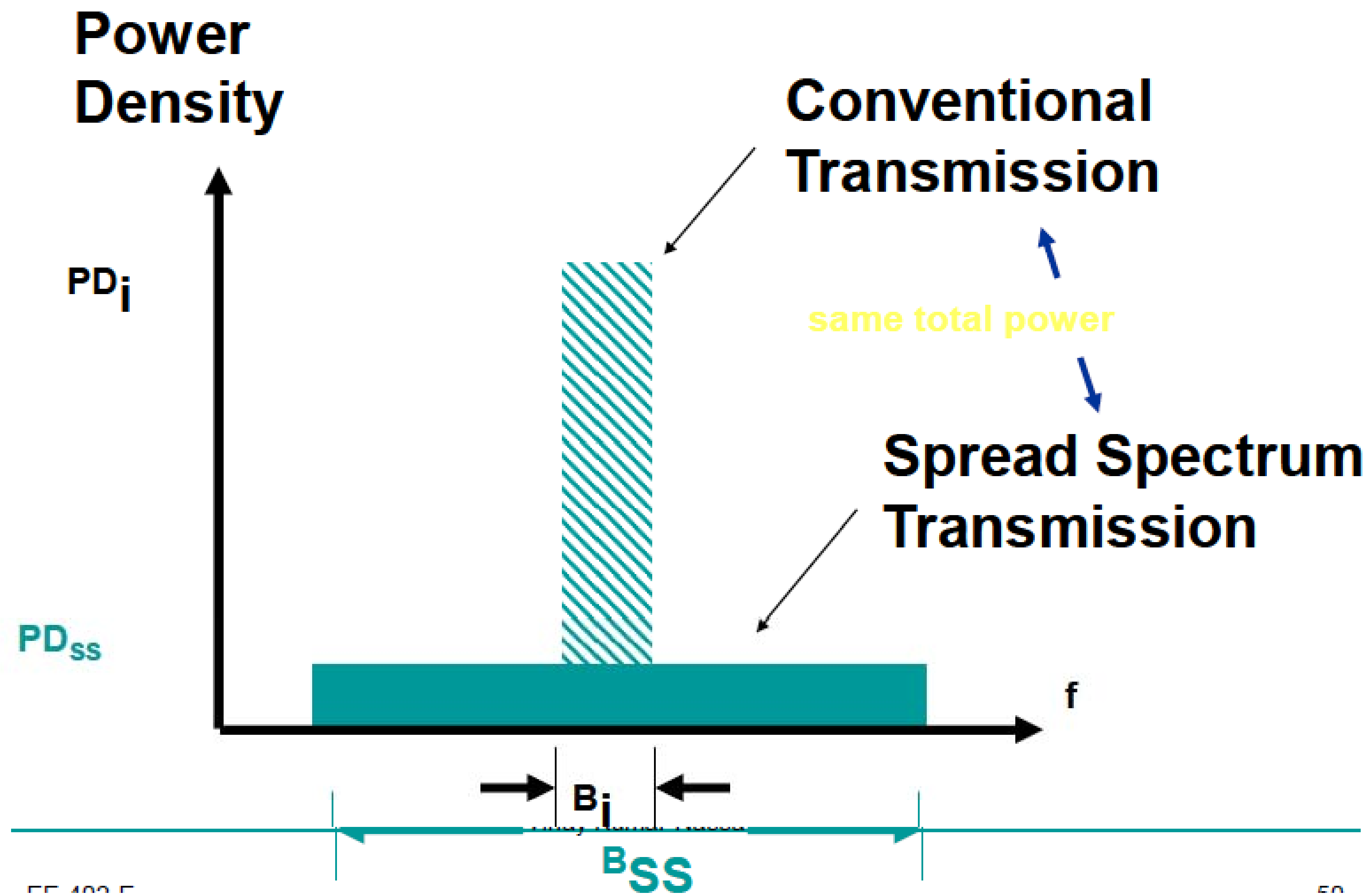
Applications

- Security
- Robust against unintentional interference
- It is not bandwidth efficient when used by a single user but has the capability to overcome narrowband jamming signals (cannot overcome AWGN or wideband jamming signal) and multipath.
- Providing multiple access
- If many users can share the same spread spectrum bandwidth without interfering with one another, bandwidth efficient improved but will affect the capability to overcome jamming.

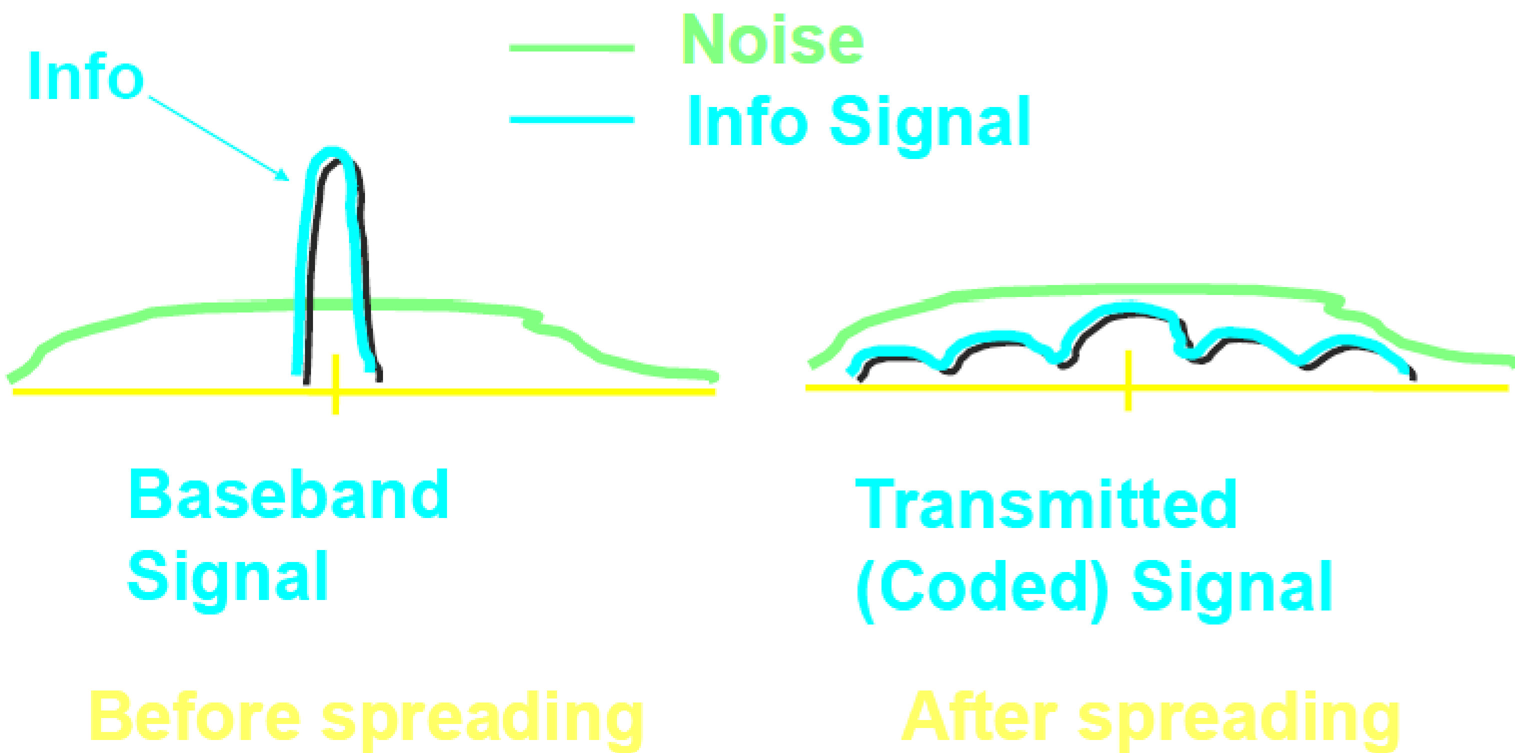
Spread Spectrum Multiple Access

- A transmission technique in which a PN(Pseudo Noise) code, independent of information data, is employed as a modulation waveform to "spread" the signal energy over a bandwidth much greater than the signal information bandwidth.
- At the receiver the signal is "despread"(Correlate) using a synchronized replica of the PN code.
- Direct Sequence Spread Spectrum (DSSS)
- Frequency Hopping Spread Spectrum (FHSS)

Spread Spectrum - illustrated



Spreading Process

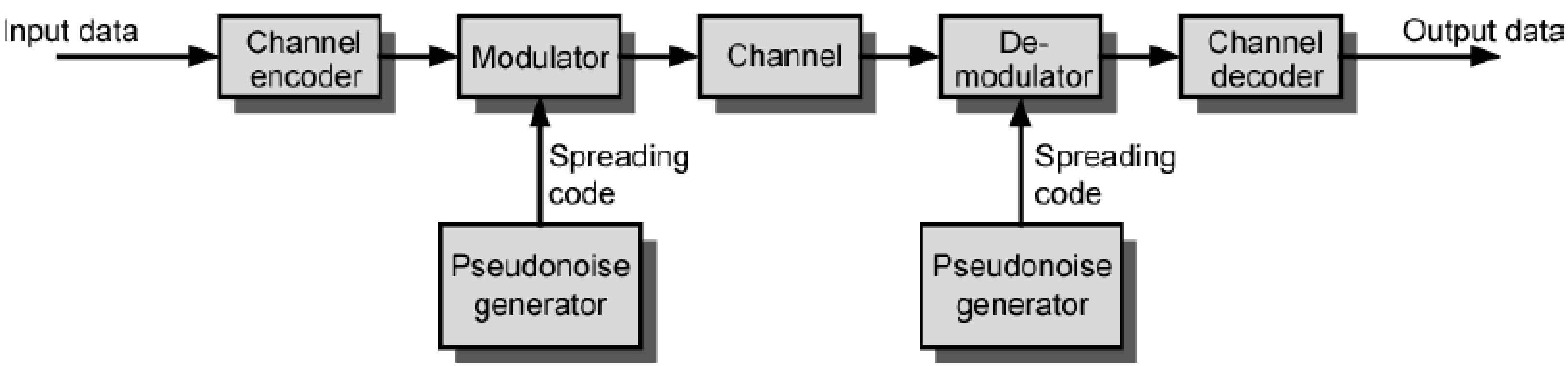


How can you recover signal < noise

Spread Spectrum Concept

- Input fed into channel encoder
  - Produces narrow bandwidth analog signal around central frequency
- Signal modulated using sequence of digits
  - Spreading code/sequence
  - Typically generated by pseudonoise/pseudorandom number generator
- Increases bandwidth significantly
  - Spreads spectrum
- Receiver uses same sequence to demodulate signal
- Demodulated signal fed into channel decoder

General Model of Spread Spectrum System



Gains

- Immunity from various noise and multipath distortion
  - Including jamming
- Can hide/encrypt signals
  - Only receiver who knows spreading code can retrieve signal
- Several users can share same higher bandwidth with little interference
  - Cellular telephones
  - Code division multiplexing (CDM)
  - Code division multiple access (CDMA)

Pseudorandom Numbers

- Generated by algorithm using initial seed
- Deterministic algorithm
  - Not actually random
  - If algorithm good, results pass reasonable tests of randomness
- Need to know algorithm and seed to predict sequence

PN Sequence Generator

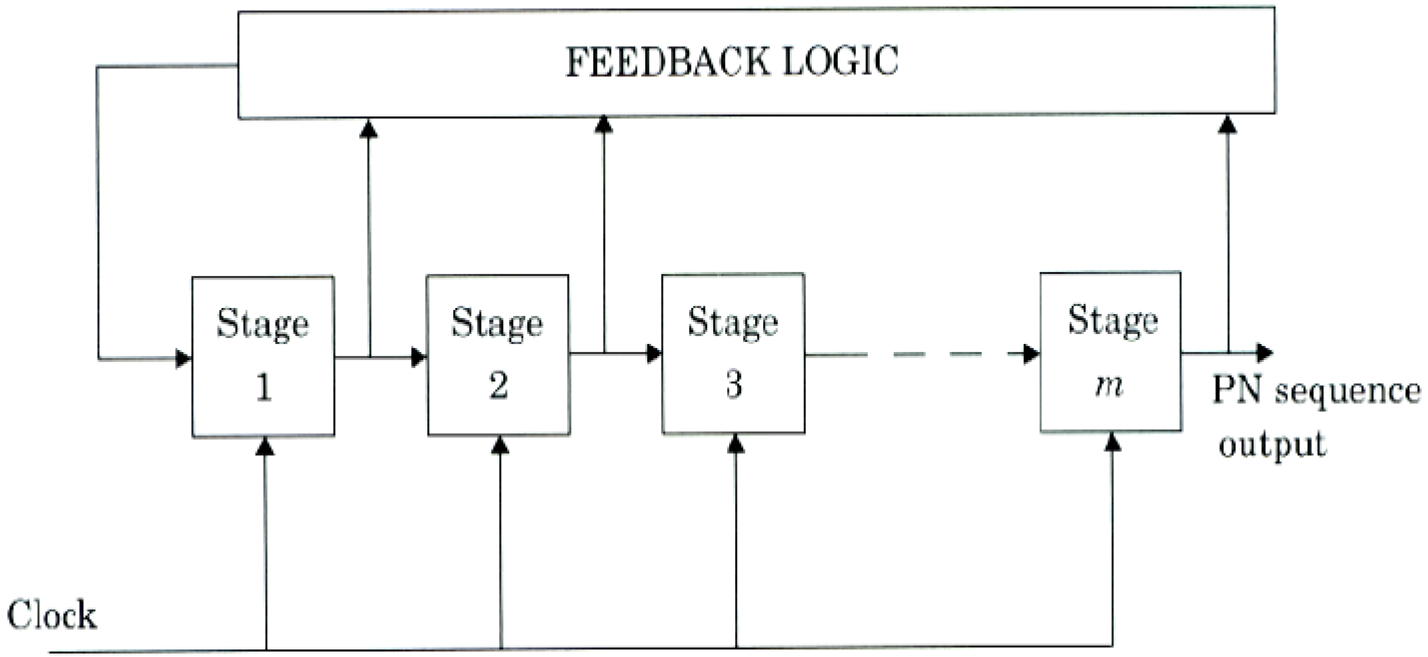


Figure 6.48 Block diagram of a generalized feedback shift register with *m* stages.

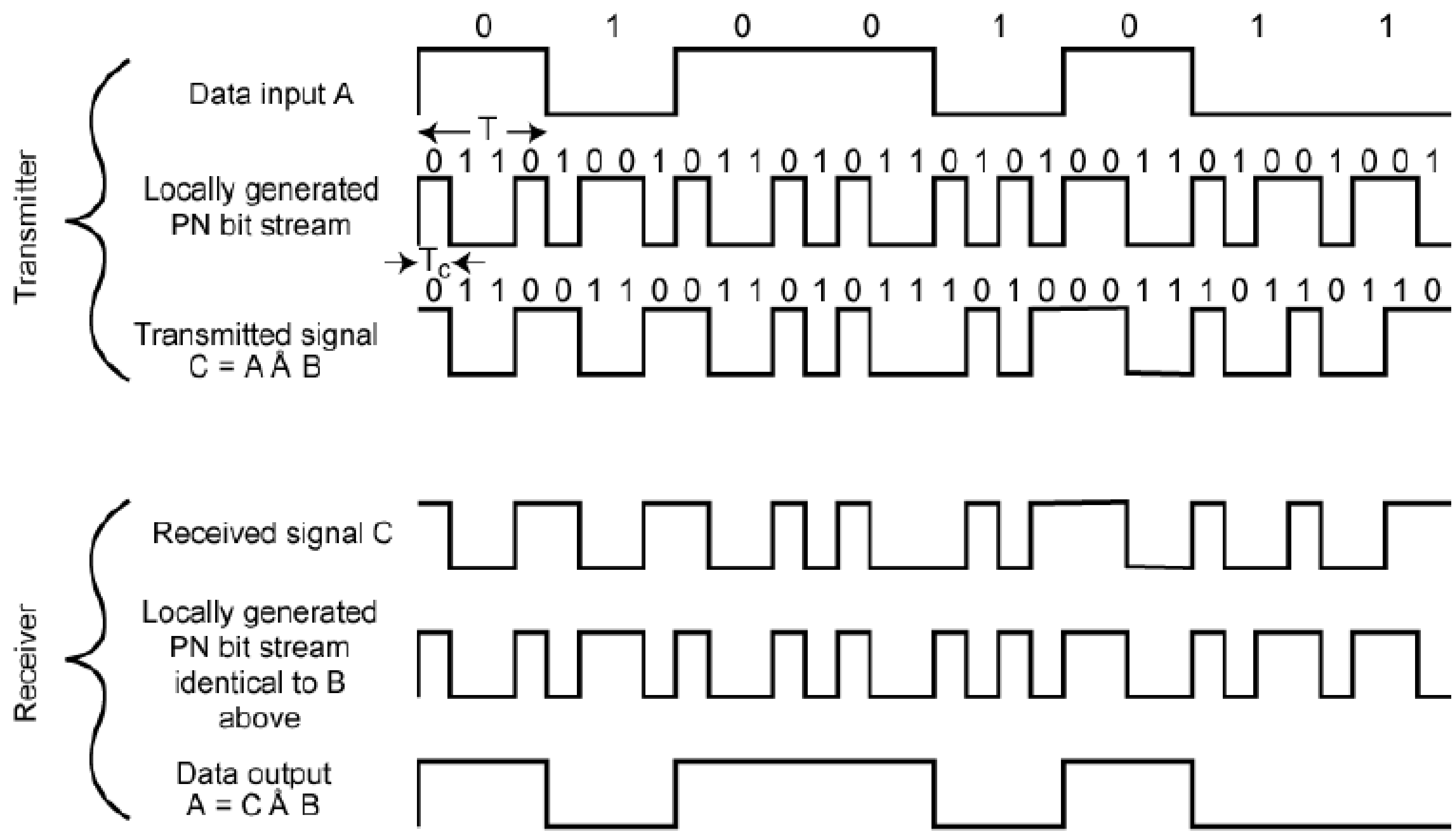
Spread Spectrum Multiple Access

- Direct Sequence Spread Spectrum (DSSS)
  - A carrier is modulated by a digital code in which the code bit rate is much larger than the information signal bit rate. These systems are also called pseudo-noise systems.
  - Also called code division multiple access (CDMA)
  - A short code system uses a PN code length equal to a data symbol.
  - A long system uses a PN code length that is much longer than a data symbol.

Direct Sequence Spread Spectrum (DSSS)

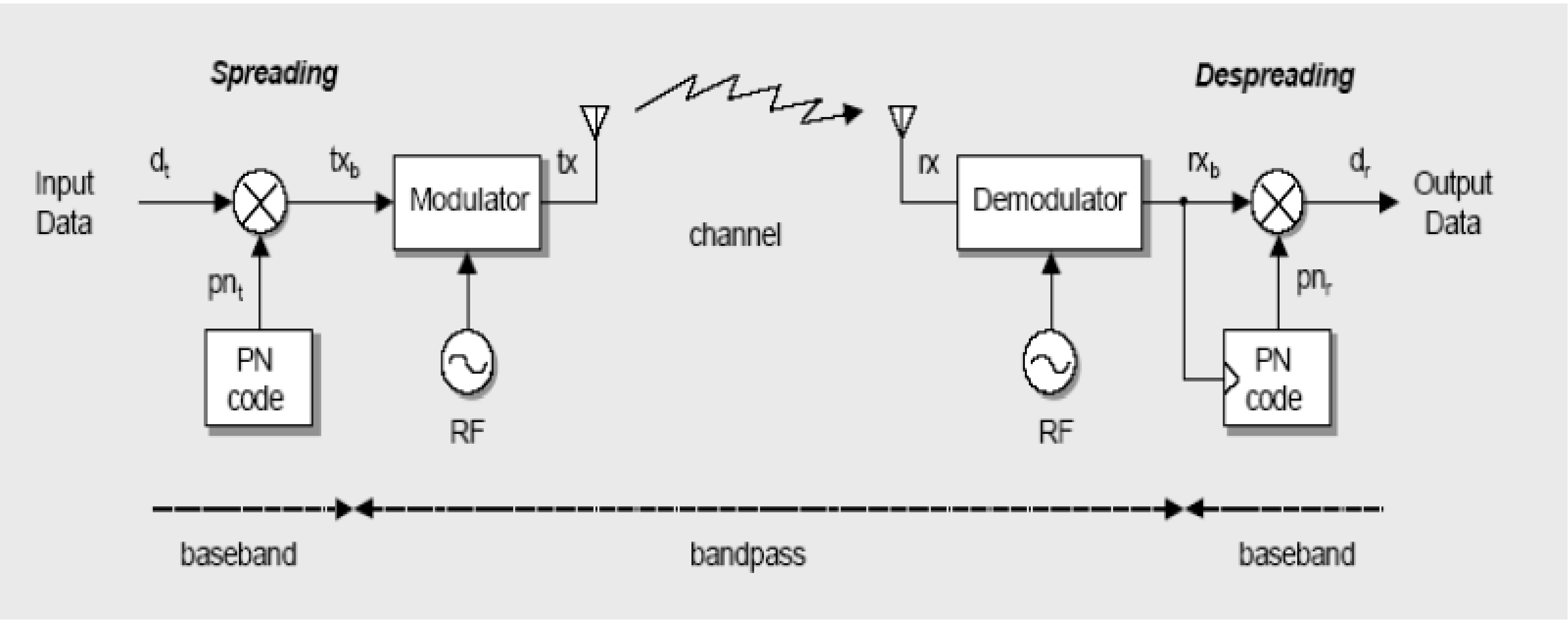
- Each bit represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
  - In proportion to number of bits used
  - 10 bit spreading code spreads signal across 10 times bandwidth of 1 bit code
- One method:
  - Combine input with spreading code using XOR
  - Input bit 1 inverts spreading code bit
  - Input zero bit doesn't alter spreading code bit
  - Data rate equal to original spreading code
- Performance similar to FHSS

Direct Sequence Spread Spectrum Example

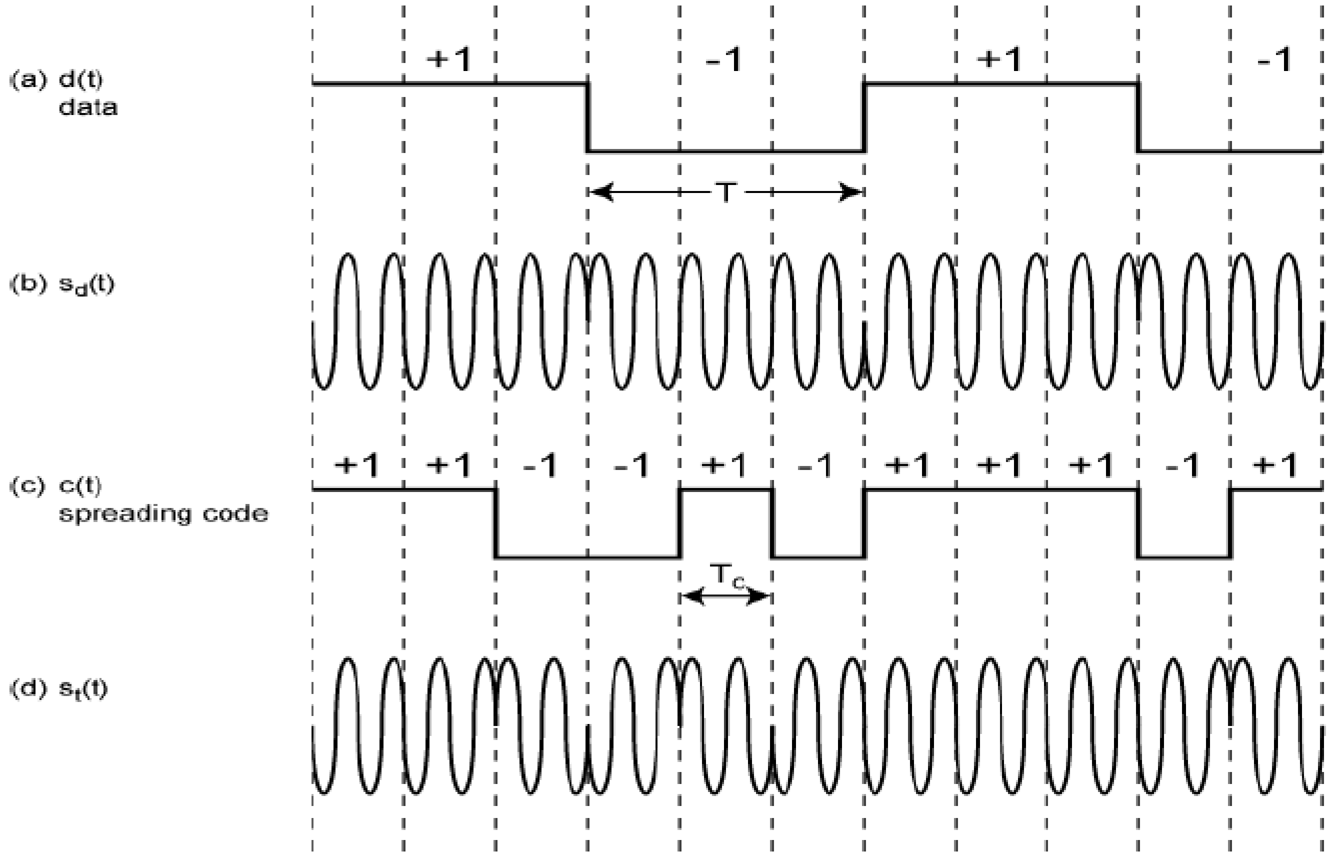


Spread Spectrum Multiple Access

- Basic principle of DSSS
  - For BPSK modulation



Direct Sequence Spread Spectrum Using BPSK Example



Frequency Hopping

- Frequency hopping is a form of FDMA
- Each transmitter is allocated a group of channels, known as *hop set* .
- The transmitter transmits data in short bursts, choosing one of these channels on which to transmit each burst.

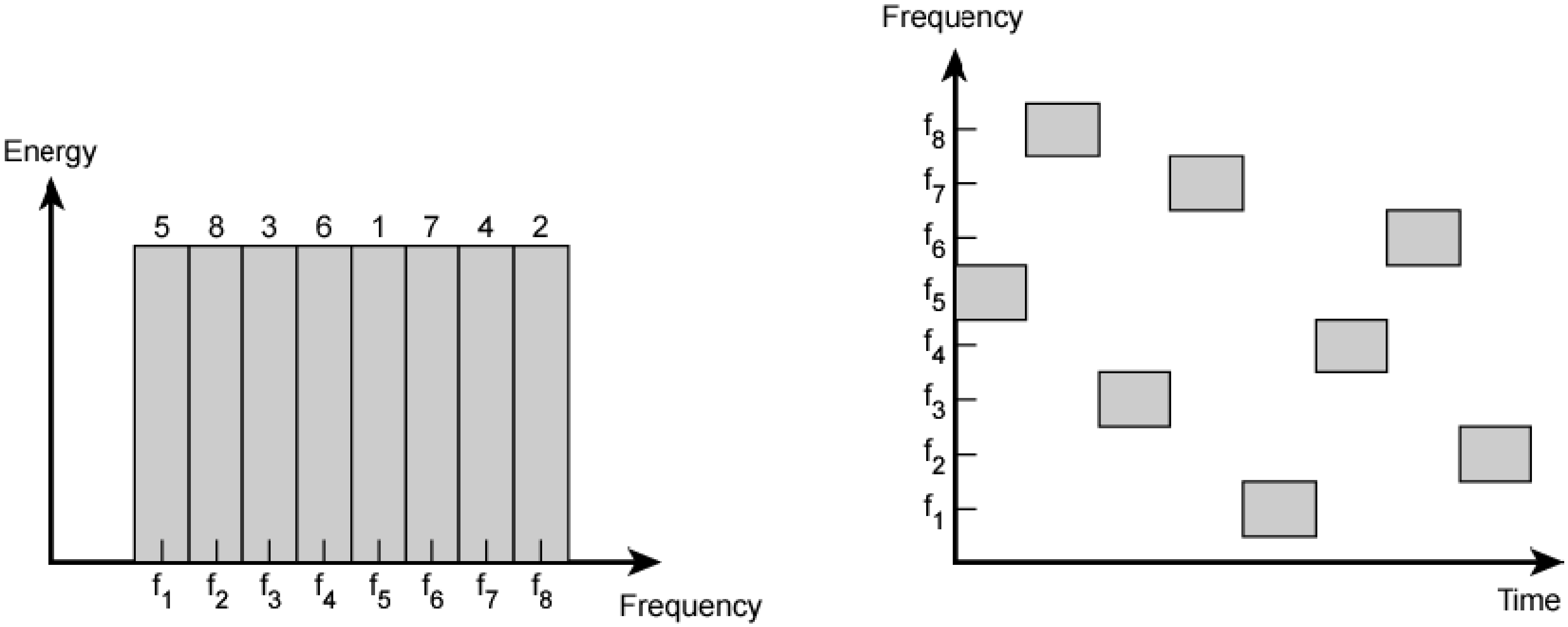
Frequency Hopping Spread Spectrum (FHSS)

- Signal broadcast over seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Jamming on one frequency affects only a few bits

Basic Operation

- Typically 2^k carriers frequencies forming 2^k channels
- Channel spacing corresponds with bandwidth of input
- Each channel used for fixed interval
  - 300 ms in IEEE 802.11
  - Some number of bits transmitted using some encoding scheme
    - May be fractions of bit (see later)
  - Sequence dictated by spreading code

Frequency Hopping Example

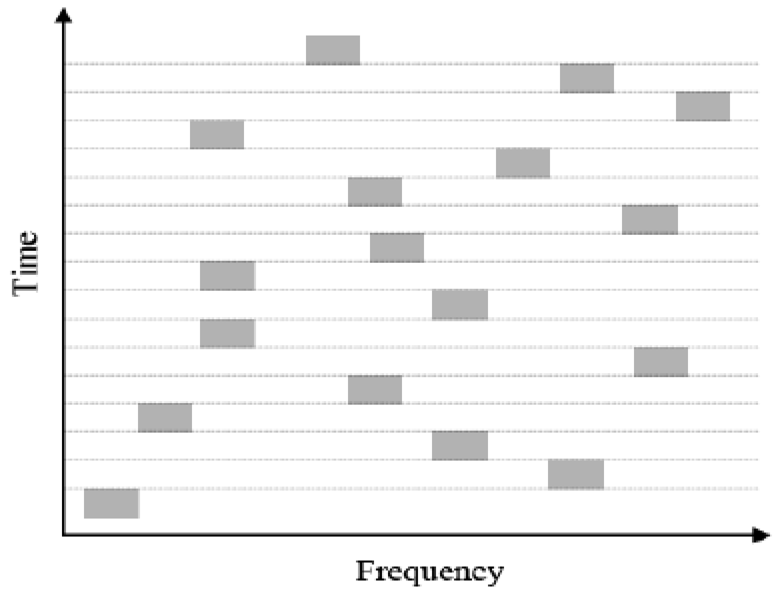


(a) Channel assignment

(b) Channel use

Frequency Hopping

- Time-frequency characteristic of a single transmitter.



Spread Spectrum Multiple Access

- Frequency Hopping Spread Spectrum (FHSS)
  - It divides available bandwidth into N channels and hops between these channels according to the PN sequence.
  - Fast hopping
  - Slow hopping

Slow and Fast FHSS

- Frequency shifted every T_c seconds
- Duration of signal element is T_s seconds
- Slow FHSS has $T_c \geq T_s$
- Fast FHSS has $T_c < T_s$
- Generally fast FHSS gives improved performance in noise (or jamming)

FHSS Performance Considerations

- Typically large number of frequencies used
  - Improved resistance to jamming

Comparison SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time slots, demanc driven or fixed patterns	segment the frequency band into disjoint subbands	spread the spectrum using orthogonal codes
Terminals	onlyone terminal car be active in one cell/one sector	all terminals are active for short periods of time on the same frequenc	every terminal has i own frequency, uninterrupted	all terminals can be acti e at the same place at the same moment, uninterrupted
Signal separation	cell structure, directe antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantage	very simple, increase capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantage	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers needs more complicated powe control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, togethei with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problem s, higher complexity, lowered expectations; w ll be integrated with TDMA/FDMA

Packet Radio

- In packet radio (PR) access techniques, many subscribers attempt to access a single channel in an uncoordinated (or minimally coordinated manner.
- Collision from the simultaneous transmissions of multiple transmitters are detected at the BS, in which case an ACK or NACK signal is broadcast by the BS to alert the desired user of received transmission.
- PR multiple access is very easy to implement but has low spectral efficiency and may include delays.
- The subscribers use a contention technique to transmit on a common channel.

Packet Radio

- ALOHA protocols, developed for early satellite systems, allow each subscriber to transmit whenever they have data to sent.

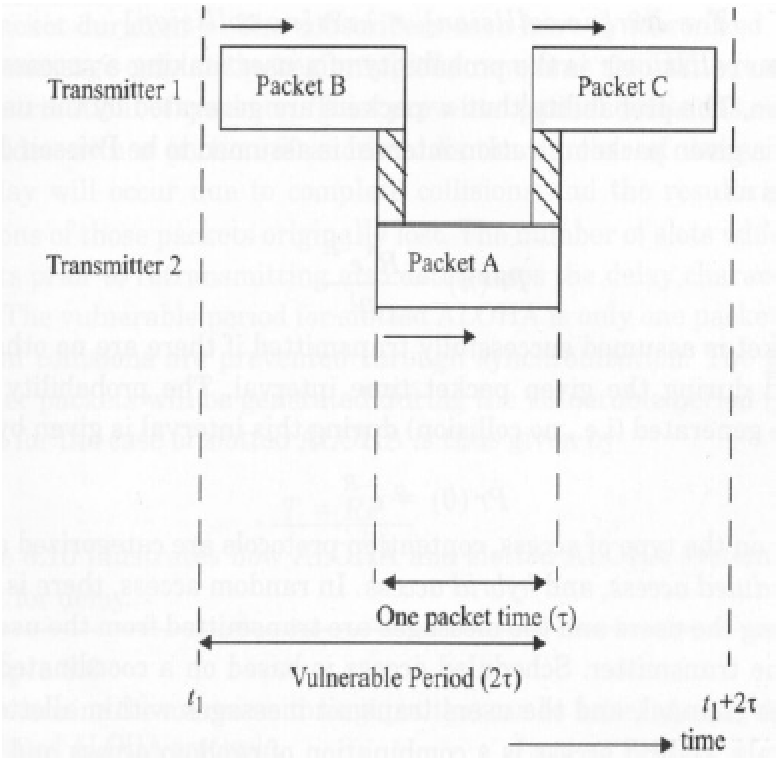
- The transmitting subscribers listen to the acknowledgement feedback to determine if transmission has been successful or not.

- If a collision occurs, the subscriber waits a random amount of time, and then transmits the packet.

- The performance of contention techniques can be evaluated by throughput (T), which is defined as the average number of message successfully transmitted per unit time, and the average delay (D) experienced by a typical message burst.

Packet Radio

- **Packet Radio Protocols**
  - V_p, vulnerable period is defined as the time interval during which the packets are susceptible to collisions with transmission form other user.
  - Packet A suffer a collision if other terminals transmit packets during the period t_1 to $t_1 +$



Packet Radio

- Type of Access
  - Contention protocols are categorized as:
    - Random Access: there is no coordination among that users and the messages are transmitted from the users as they arrive at the transmitter.
    - Scheduled Access: based on a coordinated access of users on the channel and the users transmit messages within allotted slots or time intervals.
    - Hybird Access: a combination of random access and scheduled.

Packet Radio

- Pure ALOHA
  - The pure ALOHA protocol is random access protocol used for data transfer and a user accesses a channel as soon as a message is ready to be transmitted.
  - After a transmission, the user waits for an acknowledgment on either the same channel or a separate feedback channel.
  - In case of collisions, the terminal waits for a random period of time and retransmits the message.
  - For pure ALOHA, the vulnerable period is double the packet duration: ,

$$\Pr(n) = \frac{(2R)^n e^{-2R}}{n!} \qquad \Pr(0) = e^{-2R}$$

$$T = R\, e^{-2R}$$

Packet Radio

- Slotted ALOHA
  - In slotted ALOHA, time is divided into equal time slots of length greater than the packet duration .
  - The subscribers each have synchronized clocks and transmit a message only at the beginning of a new time τ slot.
  - The vulnerable period of slotted ALOHA is only one packet duration, since partial collisions are prevented through synchronization.
  - The probability that no other packets will be generated during the vulnerable period is e^{-} .
  - The throughput for the case of slotted ALOHA is thus given by $T =$.

Packet Radio

- Carrier Sense Multiple Access (CSMA)
  - CSMA protocols are based on the fact that each terminal on the network is able to monitor the status of the channel before transmitting information.
  - In CSMA, detection delay and propagation delay are two important parameters.
    - Detection delay is a function of he receiver hardware and is the time required for a terminal to sense whether or not the channel is idle.
    - Propagation delay is a relative measure of how fast it takes for a packet to travel from a BS to a MS.

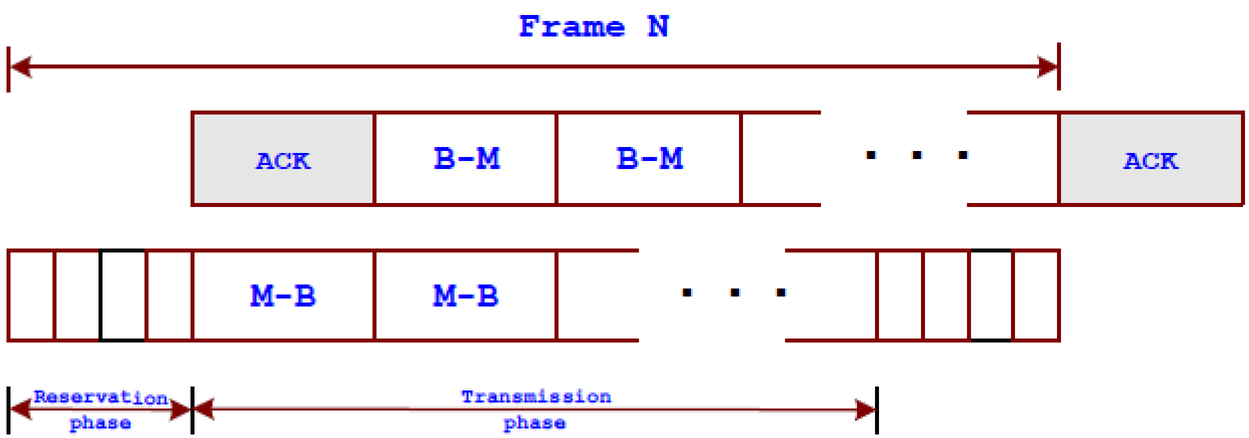
Packet Radio

- Several variations of the CSMA strategy
  - 1-persistent CSMA
  - Non-persistent CSMA
  - *p*-persistent CSMA
  - CSMA/CD
  - Data sense multiple access(DSMA)

Packet Radio

Reservation Protocols

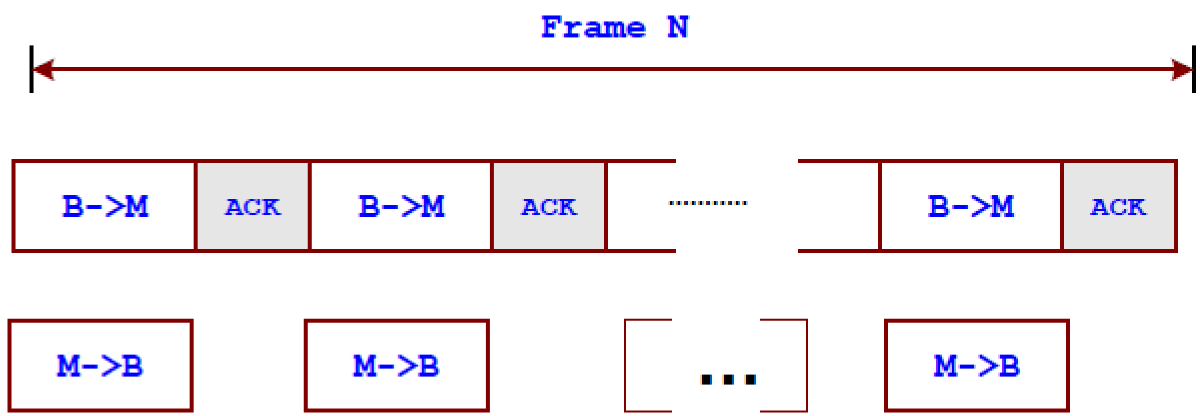
- Reservation ALOHA (R-ALOHA)
  - R-ALOHA is a packet scheme based on time division multiplexing.
  - Two phase: contention phase and transmission phase
  - Mobiles contend the channel in reservation phase (slotted-ALOHA)
  - Mobiles that succeed in making reservation can transmit without interference



Packet Radio

- PRMA (Packet Reservation Multiple Access)
  - A combination of TDMA and reservation ALOHA
  - Ask channel resource in the talkspurt
  - Release channel resource in the silent gap
  - Permission probability

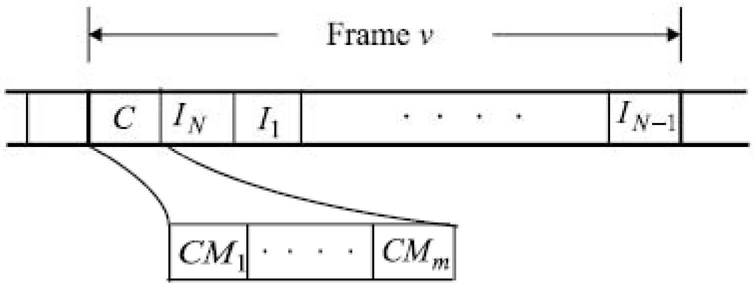
Effect of voice activity detector



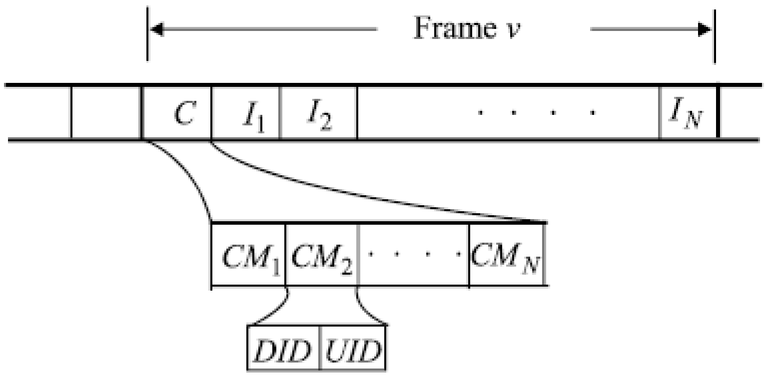
Packet Radio

- NC-PRMA (Non-Collision Packet Reservation Multiple Access)
  - The existing users inform the BS about their demands in a non-collision manner *(time-frequency signaling scheme)*

I_i : Information slot
CM_i : Control minislot
C : Control slot
UID : Uplink user identifier
DID : Downlink user identifier



(a) Uplink structure



(b) Downlink structure

CAPACITY OF CELLULAR SYSTEMS

- **Channel Capacity** for a "radio system can be defined as the maximum number of channels or users that can be provided in a fixed frequency band."

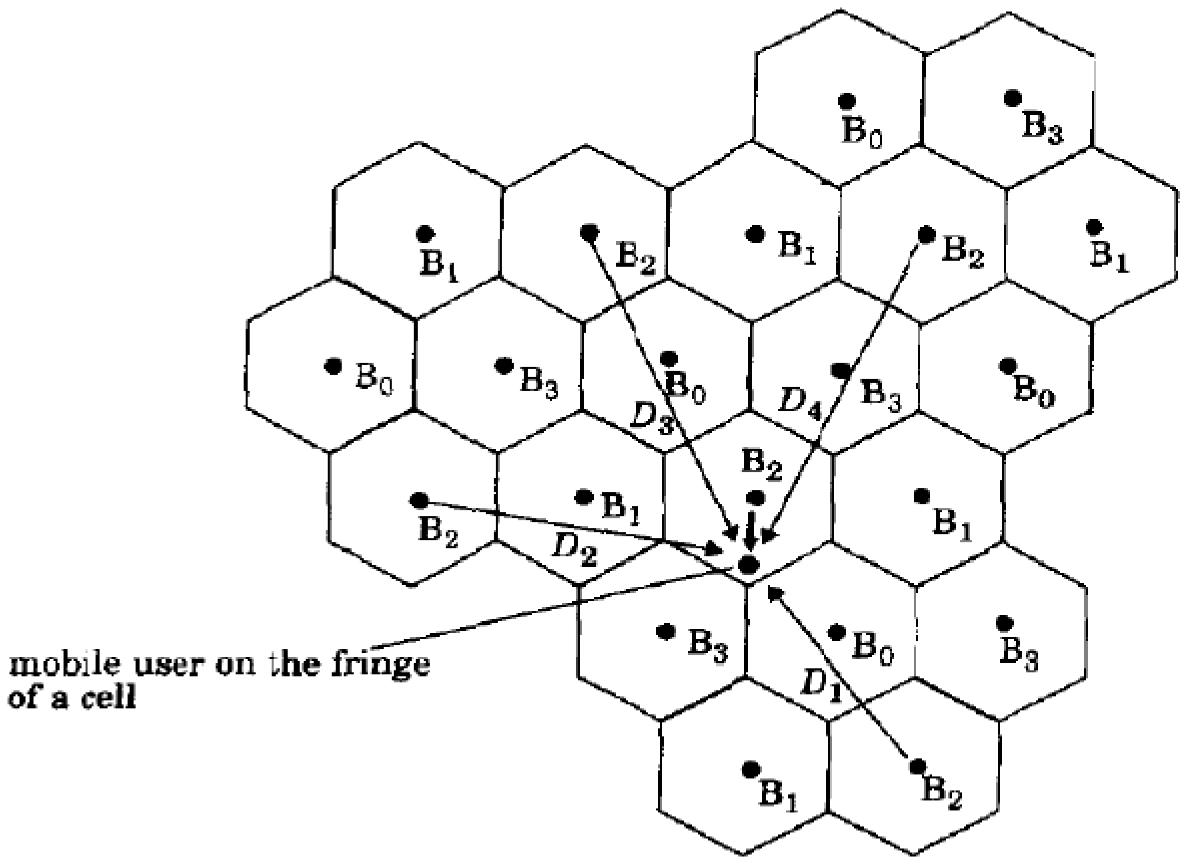
- **Reverse Channel Interference**: Interference at a base station receiver coming from subscriber units in the surrounding cells.

- **Forward Channel Interference:** Interference at subscriber unit coming from surrounding co-channel base stations .

CAPACITY OF CELLULAR SYSTEMS

- Radio capacity is a parameter which measures spectrum efficiency of a Wireless system.
- This parameter is determined by the required carrier to interference ratio(C/I) and the channel bandwidth B_c.

CAPACITY OF CELLULAR SYSTEMS



CAPACITY OF CELLULAR SYSTEMS

- Co-Channel reuse ratio is given by

$$Q=D/R$$

- Considering M closest co-channel cells as first order interference C/I is given as

$$\frac{C}{I} = \frac{D_0^{-n_o}}{\sum_{k=1}^{M} D_k^{-n_k}}$$

CAPACITY OF CELLULAR SYSTEMS

Where,

n_0=>Path loss exponent in the desired cell

D_k=>Distance of the K_{th} cell from the mobile

D_0=> Distance from the desired base station to the mobile

n_k =>Path loss exponent in the K_{th} interfering base station

CAPACITY OF CELLULAR SYSTEMS

- If M=6 and assume all of them are at a same distance D and have same path loss exponents equal to the desired cell then

$$\frac{C}{I} = \frac{D_0^{-n}}{6D^{-n}}$$

- Assuming maximum interference occurs when mobile is at the cell edge D_0= R and if minimum carrier to interference ratio for acceptable signal quality at the receiver is denoted as $(C/I)_{min}$
- For acceptable performance following equation must hold good

$$\frac{1}{6}\left(\frac{R}{D}\right)^{-n} \geq \left(\frac{C}{I}\right)_{min}$$

CAPACITY OF CELLULAR SYSTEMS

- Therefore replacing D/R by co-channel reuse factor i.e. Q

$$Q = \left(6\left(\frac{C}{I}\right)_{min}\right)^{1/n}$$