1

Introduction

Goal:

To understand the key concepts of mobile communication networks and protocols, as the major pillar of the modern information technology.

1.1 Introduction - The fundamentals of wireless transmissions

In present and future the computers are portable. But the users need to access the networks. To do this the only choice is **wireless**. Mobile computing means communicating different things to different people. It is ubiquitous, wireless and remote computing .Wireless and mobile computing are not synonymous. Wireless is a transmission or information transport method that enables mobile computing.

Topics to be covered:

- Wireless transmission
- Frequencies for radio transmission
- Signals
- Antennas
- Signal Propagation
- Multiplexing
- Modulations
- Spread spectrum
- MAC – SDMA , FDMA , TDMA , CDMA
- Cellular Wireless Networks

1.1.1 Wireless

The way of accessing the network was by wire. The wires are replaced by electromagnetic waves through the air.

A communication device can have one of the following characteristics:

1. ***Fixed and Wired:*** (e.g.,) Desktop uses fixed Networks.
2. ***Mobile and Wired:*** (e.g.,) Laptop connected using Telephone and Modem.
3. ***Fixed a Wireless*****:** This mode is used for installing network in historical buildings to avoid damage caused due to wiring.
4. ***Mobile and Wireless*****:** No cable and the users can roam.

1.1.2 Wireless networks in comparison to fixed networks

- Higher loss-rates due to interference
- Restrictive regulations of frequencies
- Lower security, simpler active attacking
- Always shared medium

1.1.3 Mobile Communication: Development

Wireless communication systems offer data transport service to higher layers.

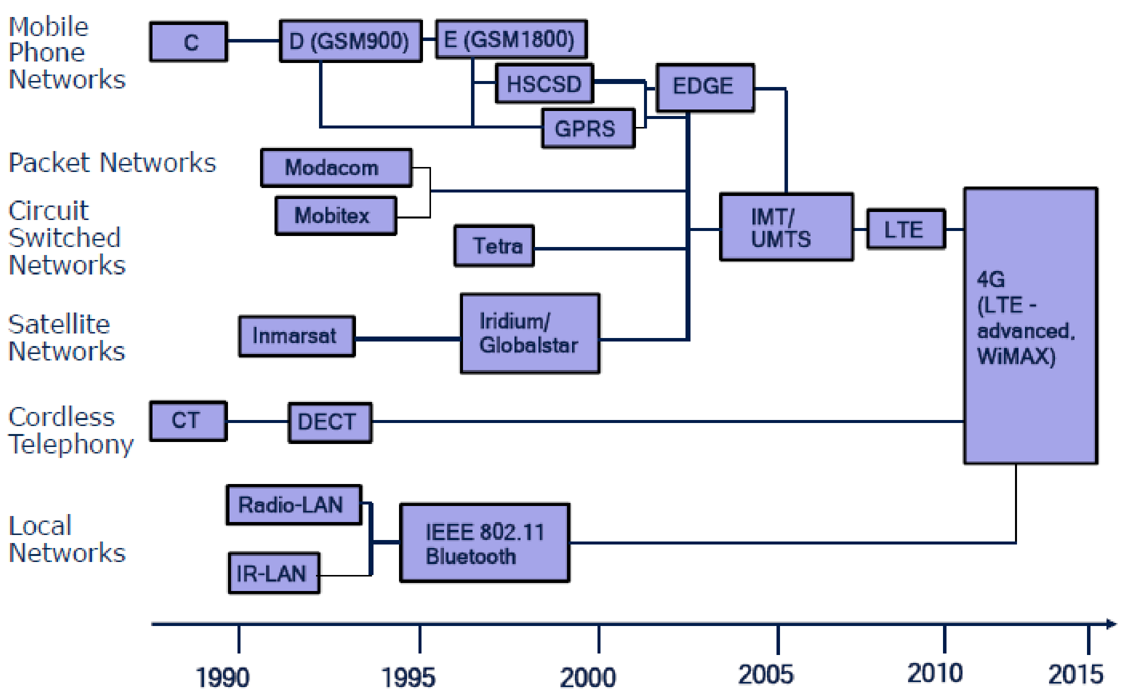

Fig 1.1 Mobile Communication Development

1.1.4 Principles of Mobile Communication

It is based on electro-magnetic radio transmission.

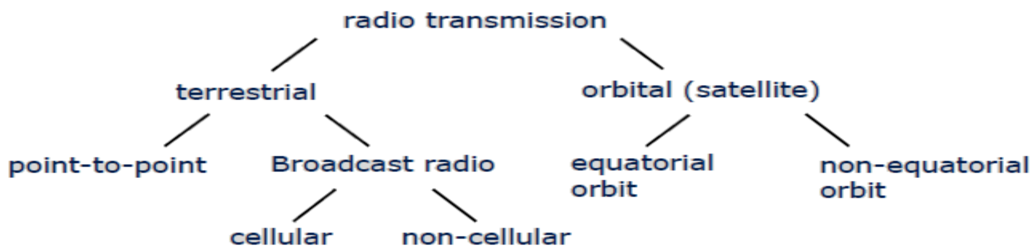

Fig 1.2 Principles of Mobile Communication

Principles:

- Propagation and reception of electro-magnetic waves
- Modulation and multiplex methods
- Focusing on cellular networks

1.1.5 An overview of Mobility and Portability:

Mobility:

There are two kinds of mobility

Aspects of mobility:

- **User mobility**: Refers to a user who has access to the same telecommunication services at different places. Users can communicate (wireless) “anytime, anywhere, with anyone”. Users are mobile and the services also follows (e.g.,) call forwarding in cellular phones.

- **Device portability**: Refers to the movement of communication devices. Devices can be connected anytime, anywhere to the network. (e.g.,) mobile phones.

Issues for Mobility:

- Bandwidth restrictions and variability
- Location-aware network operation
    - User may wake up in a new environment
    - Dynamic replication of data
- Querying wireless data & location-based responses
- Busty network activity during connections & handling disconnections
- Disconnection
    - OS and File System Issues - allow for disconnected operation
    - Database System Issues - when disconnected, based on local data

Issues for Portability:

- Battery power restrictions
- Risks to data
  - Physical damage, loss, theft
  - Unauthorized access
  - Encrypt data stored on mobiles
  - Backup critical data to fixed (reliable) hosts
- Small user interface
  - Small displays due to battery power and aspect ratio constraints
  - Cannot open too many windows
  - Difficult to click on miniature icons

Effects of device portability

1. Power consumption
   - Limited computing power, low quality displays, small disks due to limited battery capacity
   - CPU: power consumption ~ CV2f
     - C: internal capacity, reduced by integration
     - V: supply voltage, can be reduced to a certain limit
     - f: clock frequency, can be reduced temporally
2. Loss of data
   - Higher probability, has to be included in advance into the design (e.g., defects, theft)
3. Limited user interfaces
   - Compromise between size of fingers and portability
   - Integration of character/voice recognition, abstract symbols
4. Limited memory
   - Limited value of mass memories with moving parts
   - Flash-memory or? as alternative

1.1.6 Applications

1. Vehicles
   - Transmission of news, road condition, weather, music via DAB
   - Personal communication using GSM
   - Position via GPS
   - Local ad-hoc network with vehicles close-by to prevent accidents, guidance system, redundancy
   - Vehicle data (e.g., from busses, high-speed trains) can be transmitted in advance for maintenance

2. Emergencies
   - Early transmission of patient data to the hospital, current status, first diagnosis
   - Replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire etc.

3. Travelling salesmen
    - Direct access to customer files stored in a central location
    - Consistent databases for all agents
    - Mobile office

4. Replacement of fixed networks
    - Remote sensors, e.g., weather, earth activities
    - Flexibility for trade shows
    - LANs in historic buildings

5. Entertainment, education,
    - Outdoor Internet access
    - Intelligent travel guide with up-to-date location dependent information
    - Ad-hoc networks for multi user games

Location dependent services

1. Location aware services
    - Services exist in the local environment. e.g., printer, fax, phone, server etc.

2. Follow-on services
    - Automatic call-forwarding, transmission of the actual workspace to the current location

3. Information services
    - Push: e.g., current special offers in the supermarket
    - Pull: e.g., where is the Black Forrest Cherry Cake?

4. Support services
    - Caches, intermediate results, state information etc. „follow“ the mobile device through the fixed network Privacy
    - Who should gain knowledge about the location

1.1.7 Mobile and Wireless Devices Examples

1. Sensor: switch Sensing Office Door.
2. Embedded Controller: TV ,Washing Machine
3. Pager: Receiver, Displays short text message.
4. Mobile phones
5. PDA: Personal Digital Assistant,
6. Pocket Computer,
7. E-Notebook
8. Laptop

1.1.8 Reference Model

The reference model of wireless system is as follows,

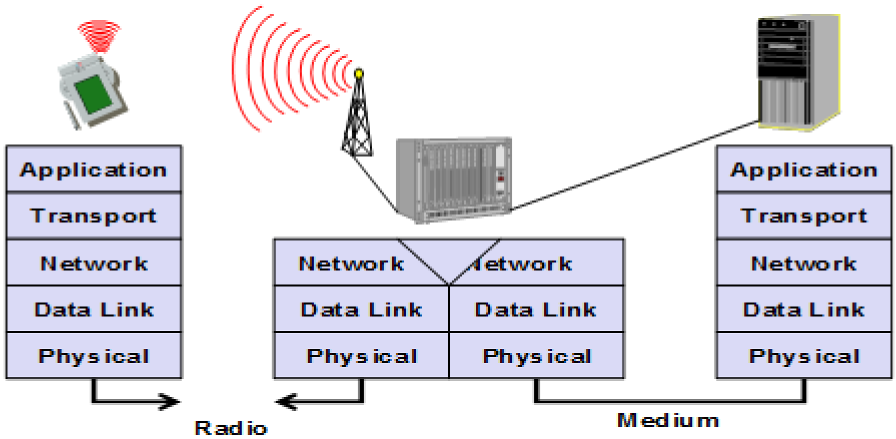

Fig 1.3: The reference model of wireless system

The description of the above figure is

- PDA is an example of wireless and portable device.
- The PDA communicates with the base station.
- The base station consists of a radio transceiver and an internetworking unit connecting the wireless link with the fixed link.
- The communication partners of the PDA are the conventional computer on the right hand side.
- The protocol stack is represented beneath the system.
- End systems such as PDA and computer need full protocol stack. Intermediate systems such as internetworking unit do not need all the layers.

1.1.9 Functions of the layers in Wireless and Mobile Environment

Wireless transmission Systems offers data transport services to higher layers.

1. **Physical Layer**

- The lowest layer in the communication system.
- This layer is responsible for conversion of bits into signals that can be transmitted in the sender side. The physical layer of the receiver then transforms the signals back into bit stream.
- This layer is responsible for frequency selection, generation of carrier frequency, signal detection, modulation and encryption.

2. Data Link layer

- The function is to access the medium ,multiplex the data streams;
- Correction of transmission errors and synchronization.
- It is responsible for reliable point to point connection between two devices or point to multipoint connection between one sender and many receivers.

3. Network Layer

- The function is routing of packets through network
- The other functions are addressing, device location and handover between different networks.

4. Transport layer

- This layer is used to establish an end to end connection
- The other functions are QoS, flow and congestion control.

5. Application layer

- The top most layers.
- The functions are service location, support for multimedia application, video sittler, latency.

1.2 Frequencies for Radio Transmission

The medium is wireless and the transmission is done via different radio frequency bands. The frequency and wavelength is related as follows,

$$\lambda = c/f$$

Where, c is the speed of light 3×10^8 m/s, f is the frequency.

Ranges:

The radio frequency is a spectrum and it is divided into different frequency bands as follows,

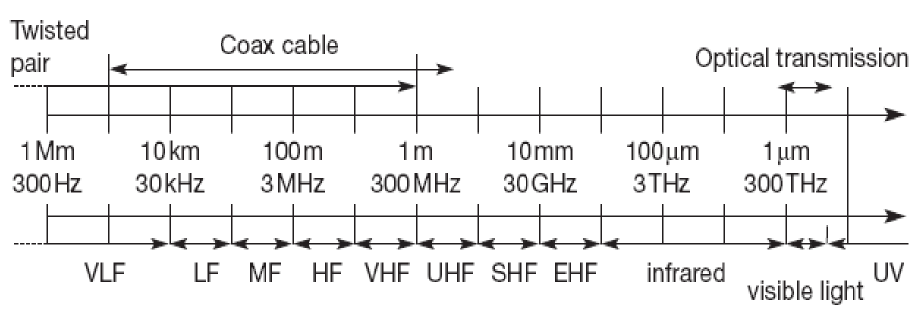

Fig 1.4: Frequency spectrum

Applications of different ranges:

1. VLF –Very Low Frequency.
2. LF-Low Frequency Range (30 kHz to 300 kHz)-used in submarines.
3. MF – Medium Frequency Range (300 kHz to 3 MHz)-used in Radio Stations..
4. HF – High Frequency Range (3 MHz to 30 MHz)-used in TV Stations.
5. VHF – Very high Frequency (30 MHz to 300 MHz)-used in DVB.
6. UH – Ultra High Frequency (300 MHz to 3 GHz) - Mobile.
7. MW – Micro Wave Frequency (>3 GHz).

Frequencies and regulations

ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS**, **TDMA**, **CDMA** 824-849 MHz, 869-894 MHz; **TDMA**, **CDMA**, **GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910 MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz

1.3 Signals

Signals are the physical representation of data. Data is converted into signals in physical layer. Communication between the systems can be done through transmission of signals. Signals are functions of time and location.

Classification of signals:

- Continuous time/discrete time
- Continuous values/discrete values
- Analog signal = continuous time and continuous values
- Digital signal = discrete time and discrete values

The signal for radio transmission is the periodic signal that too sine waves as carriers. Function of a sine wave is

$$\mathbf{g(t) = A_t \, sine\,(2\Pi f_1 + \Psi t)}$$

Parameters are

1. Amplitude A - Amplitute of the signal
2. Frequency f - Periodicity of signal.
3. Phase Shift - determines the shift of the signal relative to the same signal without a shift
4. t is time

Wave Form Representation: The signals are represented by waveforms as shown below.

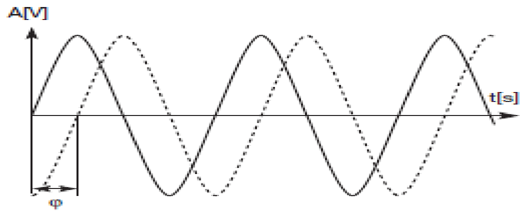

Fig 1.5: Time domain representation of signals

g (t) = instantaneous value of the sine wave signal.
A_t = maximum amplitude of the sing wave signal.
f_1 = Frequency f the periodic sine wave signal.
t = time
Ψ = phase shift.

In the above representation the problem is that if the signals contain many different frequencies.

Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

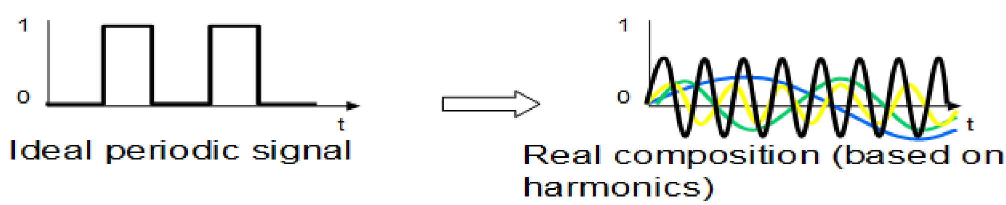

Fig 1.6: Fourier representation of periodic signals

The other ways to represent the signals are ,

1) Frequency domain,
2) Phase domain.

1. **Frequency domain:**

Fig 1.7: Frequency domain representation of the signal

2. **Phase Domain:**

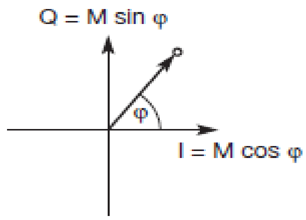

Fig 1.8: Phase domain representation of the signal

This representation is also called as phase state or signal constellation. X-axis is called in Phase 1 and Y –axis is called Quadrature. Y-axis is phase shift of 90^0.

1.4 Antennas

In wireless there are no wires and signals are transmitted through space. But the energy from the transmitter to the outside needs to be coupled. This is the function done by the antenna. Antenna couples the energy to and from spaces and to and from other conductor.

Types of Antenna

1. **Isotropic Radiation (Theoretical antenna):**

   The reference antenna model1 is isotropic radiator. The concept is that it radiates equal power in all direction.(i.e.,) radiation pattern is symmetric. This does not exist in reality.

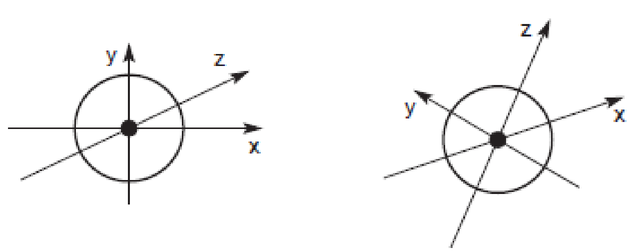

Fig 1.9: Isotropic Radiation (Theoretical antenna)

2. Dipole (Real antenna):

This is the real antenna. Which follows the directive effects (i.e.) intensity of radiation is not same in all directions. This is also called as Hertzian dipole.

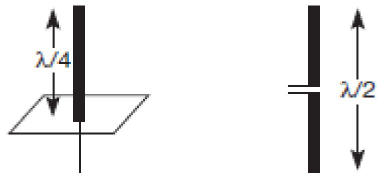

Fig 1.10: Simple Antenna

Construction of Dipole:

It has 2 collinear conductors of equal length, separated small gap. This gap is called as feeding gap. The length of the dipole is not arbitrary. The length of the dipoles is $\lambda/2$, where λ is wavelength of signal. $\lambda/2$ dipole has a uniform radiation in on plane which is Omni directional.

Radiation Pattern of Dipole:

It is used for the measurement of radiation around an antenna

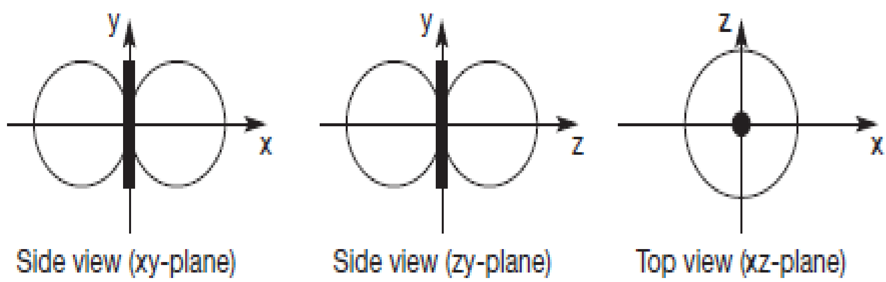

Fig 1.11: Radiation pattern of Dipole

Directed Antenna:

Directed antenna is combined to form sectorzed antenna. This helps in frequency reuse.
It is often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)

Antennas: diversity

- Grouping of 2 or more antennas- Multi-element antenna arrays
- Antenna diversity- Switched diversity, Selection diversity
  - Receiver chooses antenna with largest output diversity combining
  - Combine output power to produce gain
  - Cophasing needed to avoid cancellation

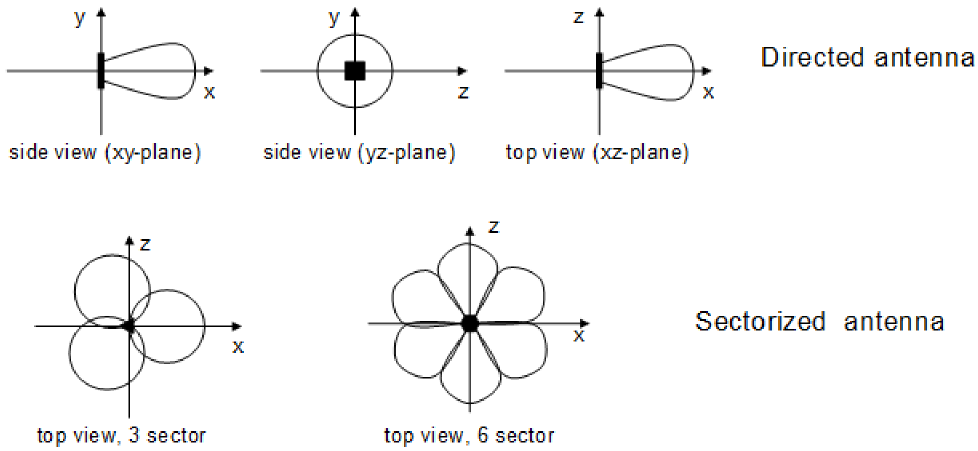

Fig 1.12: Directed and Sectorized antenna

1.5 Signal propagation

Wireless communication networks need senders and receivers of signals. As the wireless do not have wires hence direction of propagation is difficult to determine. The strength of signal is different at different point. The determination of the behavior of the signal is predictable only in vacuum

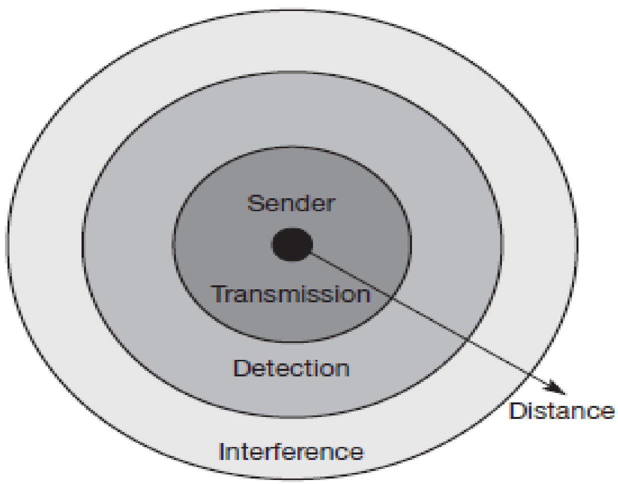

Fig 1.13: Range of transmission

The above figure shows that the strength of the signal depends upon other factors. Propagation in free space always like light (straight line).

Receiving power is proportional to $1/d^2$ (d = distance between sender and receiver)

Receiving power additionally influenced by

- Fading (frequency dependent)
- Shadowing
- Reflection at large obstacles
- Scattering at small obstacles
- Diffraction at edges

1. *Transmission Range*:

Within the certain radius of the sender the receiver can receive the signals with low error and the receiver can communicate back to the sender.

2. *Detection Range:*

Within the next radius, detection of the signal is possible. Because, the signal is transmitted with larger amount of power to distinguish it from back ground noise. The error rate is high so other side communication is not possible.

3. *Interference Region:*

Within the third radius the sender interferes with other transmission by adding noise. The receiver cannot detect the signals and the signals disturb other signals.

The Problems of Wireless Signals

a) Path loss of radio signals
b) Propagation effects on signals
c) multipath propagation

a) Path loss of Radio Signals

In free space the radio signals propagate as light and follow a straight line. When the straight line exists between sender and receiver it is called as line of sight (LOS). Even in vacuum the signal suffers from free space loss. The received power in vacuum depends on,

- Distance between the sender and receiver , $p\alpha\ (1/d^2)$.
- Wavelength and gain of receiver and transmitter antennas.

In real scenario the power depends upon the atmospheric conditions. When the distance is short then the path loss (or) attenuation is negligible. The propagation behavior of the radio waves is,

1. **Ground wave:** (<2 MHz) these are the waves with
   a) Low frequency
   b) Follow the earth surface
   c) Can travel long distances.

2. **Sky Wave:** (2-30MHz)
   a) The waves are reflected at ionosphere.
   b) The waves bounce to and from the ionosphere and earth.
   c) Travels around world.

3. **Line of signal:** (>30MHz)
   a) The waves follow a line of sight.
   b) Hence there can be a direct communication with satellites.
   c) In the atmosphere they suffer from refraction.

b) Propagation Effects on Signals

As there is the atmosphere between the sender and the receiver the radio waves do not follow line of sight. The effects caused due to the distance between the sender and receiver on the radio signals are,

1.Blocking (or) Shadowing:

- This is the extreme form of attenuation.
- Even small obstacles block the signal.

2.Reflection of Signals:

- When the object is large, when compared to the wavelength of the signal, the signal is reflected.
- The strength of the signal decreases.

3. Refraction:

- The velocity of the electromagnetic waves depends upon the density of the medium.

4.Scattering:

- If the size of the obstacle is lesser than the wavelength the waves are scattered.

5.Diffraction:

- Diffraction is similar to to scattering. The radio waves will be deflected at an edge and propagate in different directions.

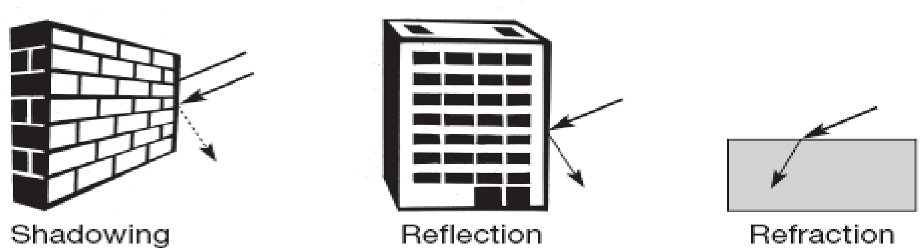

Fig 1.14: Diffraction

c) Multipath Propagation

The propagation effects leads to channel impairment called multipath propagation. In the above figure the sender is at left and receiver is in the car and 3 paths the signal takes.

- Radio waves emitted by the sender can travel along a straight line or reflected or scattered.
- The real situation is that the signals can take many paths.
- At the receiver, due to the different paths with different length the signals reach the destination at different times. This is called as **delay spread.**

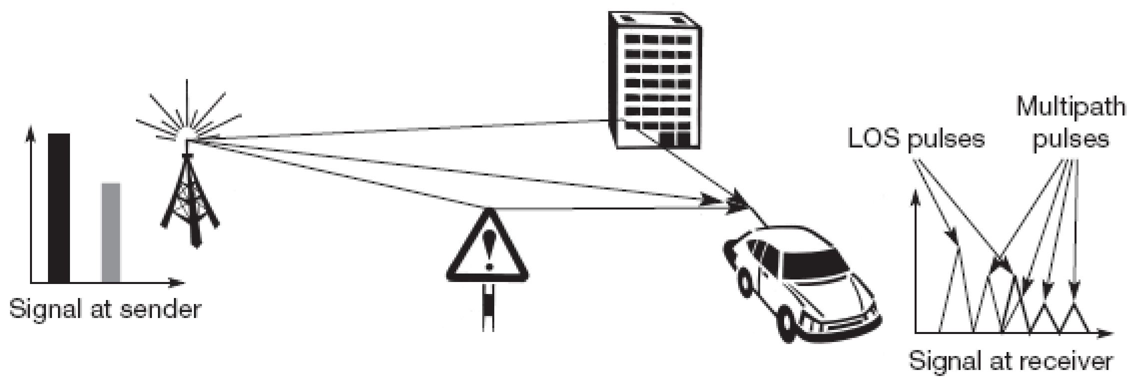

Fig 1.15: Multipath Propagation

The original signal is spread due to different delay on the parts of signals.

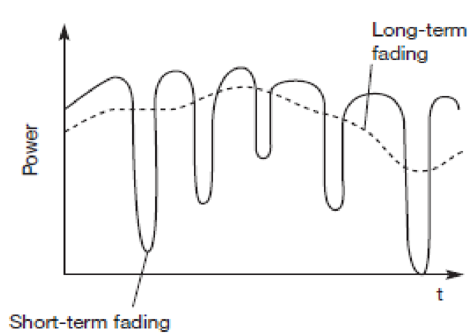

Fig 1.16: Original signal propogation

Effects of Delay Spread:

1.The short impulse will be smeared on to a broader impulse (or) to weaker impulse. Consider the above figure.

- There are 3 possible paths; hence the receiver receives 3 smaller impulses.
- Each path has a different attenuation and pulse have different power.
- Some of the pulses will be very weak to be detected. Consider the second impulse on the sender.

They are separated from each other. Consider the second impulse on the receivers.

- The shaded part represent that the signals are overlapped.
- As we know the impulse represents a symbol which in turn represent a bit.
- The energy intended for one symbol spills over to the adjacent symbol leading to an effect called inter symbol interference (ISI) (i.e.) the overlapping area.
- This overlapping leads to misinterpretation of symbols, hence causing transmission errors.

2.To avoid this overlapping the receiver should know the channel characteristics.

- To enable this sender sends training sequence known by the receiver.
- The receiver compares the received signals and the training signal. Followed by equalizer to compensate for distortion.
- As the senders and receivers are mobile the channel characteristics change overtime and the path they travel also vary. Hence the receiver needs to adapt to the varying channel characteristic.
- The power of the signal also changes overtime. The change in the received power is called as **short term fading.**
- As the receiver cannot adapt quickly to the changes the error rate increases.

1.6 Multiplexing

Multiplexing tells how users may be able to share the medium with minimum or no interference. For wireless multiplexing can be done in 4 dimensions to the communication channel.

1) Space
2) Frequency
3) Time
4) Code.

The communication channel is the association of senders and receivers.

1.Space Division Multiplexing

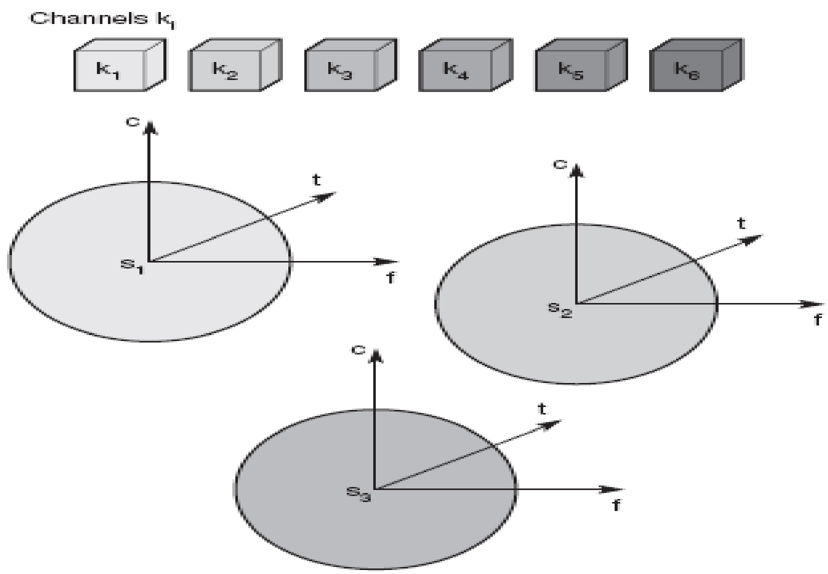

Fig 1.17: Space Division Multiplexing

The above figure represents six channels k_1 to k_6. The space are reprinted in 3D system the dimensions having C-code, t-time, f-frequency. The space is represented by circles. The three channels k1 to k3can be mapped onto 3 space S1, S2, S3, which are separate and hence no interference. The space between the interference regions is called guard space. For the three remaining channels additional spaces cannot be provided. Hence they need to share the existing spaces.

2.Frequency Division Multiplexing

The oldest used technique used for multiplexing. Possible when the useful bandwidth of the medium exceeds that of the signals it has to carry. Each signal is modulated on a different carrier frequency. This results in shifting the spectrum of the signal around the carrier frequency. Sufficient guard-band is given so those neighboring signals do not overlap in the frequency domain.

At the receiving end each signal is extracted by first passing it through a band-pass filter and then demodulating with the same carrier frequency that was used to modulate the signal. The signals carried using FDM may be analog signals or may be analog signals representing digital data. However FDM is mostly a technique from the era of analog communications. In FDM a device uses some of the channel all of the time. FDM is used in radio and television broadcasting. FDM is also used in high capacity long distance links in the telephone network.

Frequency division multiplexing (FDM) achieves multiplexing by using different carrier frequencies .Receiver can "tune" to specific frequency and extract modulation for that one channel .Frequencies must be separated to avoid interference - “Wastes” potential signal bandwidth for guard channels.Only useful in media that can carry multiple signals with different frequencies - high-bandwidth required .
FDM is used as follows,

- The standard of the analog telephone network
- The standard in radio broadcasting
- The standard for video
    1. Broadcast
    2. Cable
    3. Satellite

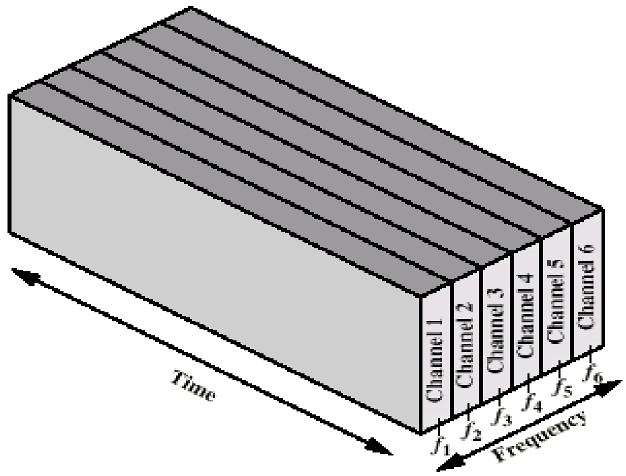

Fig 1.18: Frequency Division Multiplexing Diagram

This method subdivides the frequency into many non-overlapping frequency bands. Each channel is allotted to an own frequency band. Guard spaces are needed to avoid overlapping. This overlapping is called adjacent channel interference. (e.g.) Radio stations.

Advantages:

- Simple mechanism.
- No need of co-ordination.

Disadvantages:

- Wastage of channel as the mobile device will be used for few minutes
- Frequency resource is scarce.
- Limits the number of senders and is in inflexible

3.Time Division Multiplexing

Time division multiplexing is more suitable for digital data. TDM can be used when the data rate available on a communication link exceeds the data rate required by any one of the sources. In TDM each source that is to use the link fills up a buffer with data. A TDM multiplexer scans the buffers in some predetermined order and transmits bits from each source one after the other.

- Requires digital signaling & transmission
- Requires data rate = sum of inputs + framing
- Data rate much higher than equivalent analog bandwidth uses

- Separates data streams in time not frequency
- The standard of the modern digital telephone system

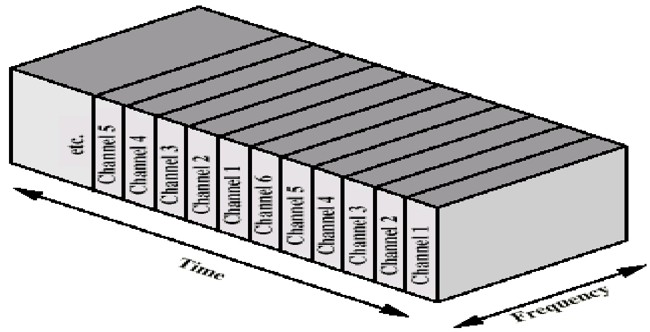

Fig 1.19: Time Division Multiplexing

Here the time is shared which is more flexible. The channel is given the whole bandwidth for a certain amount of time. Guard spaces separate the different time periods. When the two transmissions overlap in time this is called as co-channels interference. Synchronization between the senders is needed. FDM and TDM can be combined and used in GSM.

Advantages:

- Flexible
- Time can be adjusted based upon the load.

Disadvantage:

- Synchronization needed.

4.Code division Multiplexing

Each channel has a unique code. All channels use the same spectrum at the same time.

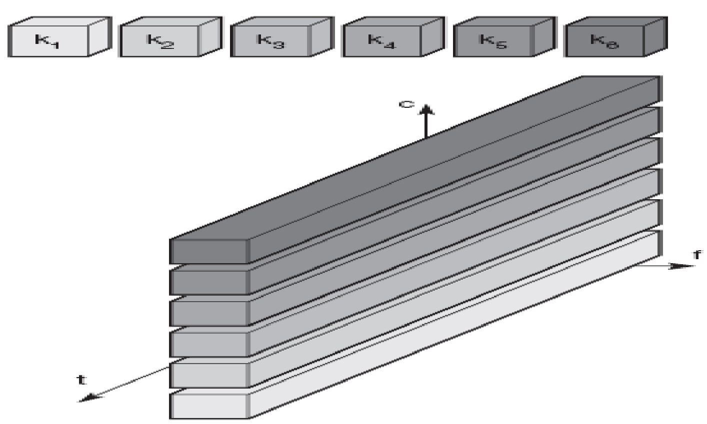

Fig 1.20: Code division Multiplexing

This is a new scheme in communication. All the channels use the same frequency at the same time for transmission via a code. Separation is needed and done by the own code called guard spaces. Analogy can be had as in a party people taking in their own language which is unknown to many. The language is the code here.

Advantages:

- Protection against interference and tapping.
- Code space is huge.

Disadvantages:

- High complexity at the receiver.
- The receiver needs to know the code and should separate the data from the noise.
- The receiver must be synchronized with the sender.
- Power control is needed.

1.7 Modulation

In the digital modulation the digital data is translated into an analog signal for the machine which supports analog signals. In wireless network the digital transmission cannot be used. Hence the digital data is to be translated to analog signals.

Methods for translation are,

(1) Amplitude shift keying – ASK
(2) Frequency shift keying – FSK
(3) Phase shift keying – PSK

The wireless transmission needs analog modulation. The function of analog modulation is to shift the center frequency of the baseband signal generated by the digital modulation up to the radio carrier.The analog modulation is needed because baseband signals cannot be directly transmitted via wireless systems due to

i) Antenna:

The height of the antenna depends upon magnitude of the signals wavelength for 1 MHz signal the antenna height should e 100 m.

ii) Frequency Division Multiplexing:

For base band transmission FDM cannot be used. The higher the carrier frequency the more bandwidth is available for base band signals.

iii) Medium Characteristics:

- Path loss, Reflection, Refraction etc.depends upon the wavelength of the signal.
- The carrier frequency needs to be chosen based upon the application.

Methods for Analog Modulation

1. Amplitude
2. Frequency
3. Phase

1.7.1 Procedure for Modulation in Transmitter and Receiver

In Transmitter

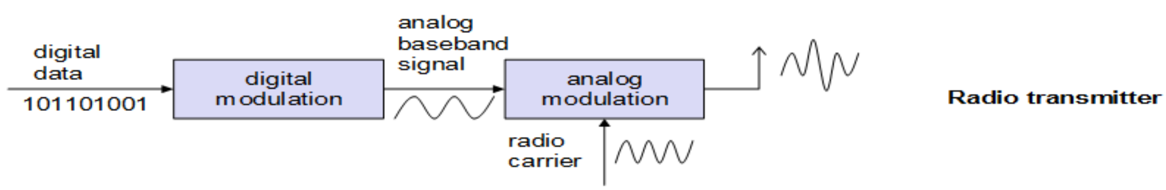

Fig 1.21: Radio Transmitter

- The digital data is converted into analog base band signal.
- The analog modulation shifts the center frequency of the analog signal up to the radio carrier. The signal is transmitted via antenna.

In Receiver

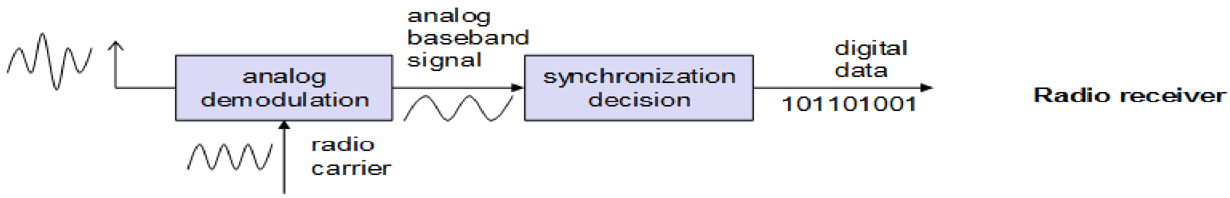

Fig 1.22: Radio Receiver

The receiver receives the analog radio signal. The demodulation takes place into analog base band signal with the help of carrier. Bits or frames have to be detected and the receiver must synchronize with the sender, Finally the receiver has to decide if the signal represents 1 or 0. Modulation of digital signals known as Shift Keying

Problems faced by digital modulation

1. Spectral Efficiency
2. Power Efficiency
3. Robustness

1.7.2 Method of the conversion of digital data into analog base band signals

1. Amplitude Shift Keying
2. Frequency Shift Keying
3. Phase Shift Keying
4. Advanced Frequency Shift Keying
5. Advanced Phase Shift Keying

Amplitude Shift Keying

- Simplest digital modulation scheme
- The two binary values 1 and 0 are represented by two different amplitude
- Requires low bandwidth, susceptible to interferences
- In wireless constant amplitude cannot be guaranteed hence unfit for wireless.

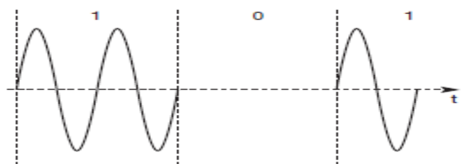

Fig 1.23: Amplitude shift keying (ASK)

Frequency Shift Keying

- This scheme is used with wireless transmission
- Simplest form of FSK is binary FSK.
- Assign one frequency f1 to 1 and another frequency f2 to 0.
- To implement is to switch between 2 oscillators. To avoid sudden changes special frequency modulation with continuous phase modulation.
- FSK needs a larger bandwidth.

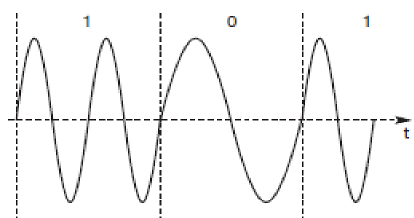

Fig 1.24: Frequency shift keying (FSK)

Phase Shift Keying

- This scheme uses shifts in the phase of a signal to represent data.
- The figure represents a phase shift of 180^0
- This is called as binary PSK because shifts y 280^0 for change in bit.
- To receive the signal the receiver must synchronize frequency and phase with the transmitter.
- The synchronization can be done with phase lock loop(PLL)
- PSK is more resistance to interference
  - Transmitter and receiver are more complex.

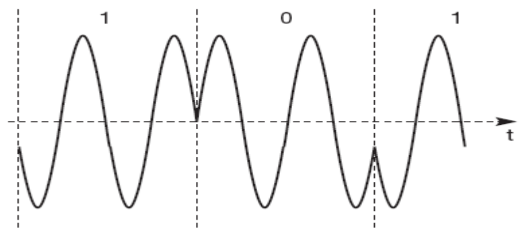

Fig1.25: Phase shift keying (PSK)

Advanced Frequency Shift Keying

- FSK scheme used in wireless is minimum shift keying (MSK)
- MSK is BFSK without abrupt changes.

Implementation of FSK

1. The data nits are separated into odd bits and even bits.
2. The duration of each bit is doubled.
3. The scheme uses two frequencies f_1 and $f_2 = 2f_1$

The frequency is chosen based on the following.

1. Even bit and odd bit are 0 , f_2 is inverted with a phase shift of 180^0
2. Even bit 1, odd bit in 0 the is inverted.
3. Even bit 0 and odd bit in 1, f_1 is taken as such.
4. if both are 1 then f_2 is taken

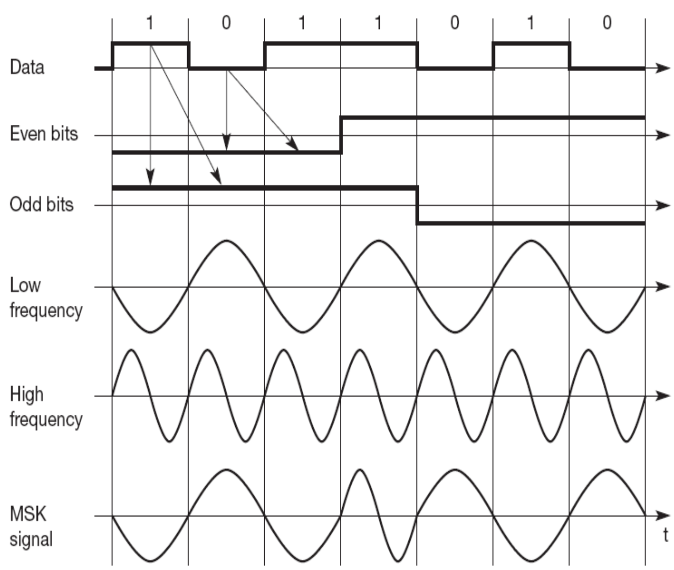

Fig 1.26: Advanced Frequency Shift Keying

Advanced phase shift keying

The basic BPSK uses one shift in phase. This figure in BPSK phase domain

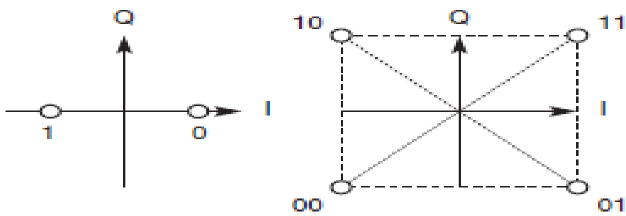

Fig 1.27: Advanced phase shift keying

This figure shows quadrature PSK higher bit rates can be achieved by coding two bits into one phase shift.

QPSK in Time Domain

QPSK is implemented in 2 variants

- The phase shift is relative to a reference signal.
- If this scheme is used a phase shift of 0 mean the signal in phase with reference to this signal

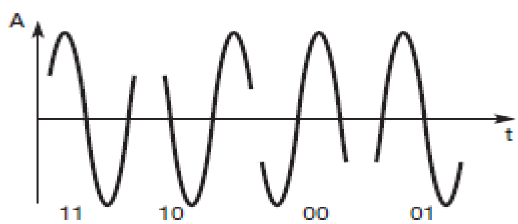

Fig 1.28: QPSK in Time Domain

A QPSK signal will exhibit a phase shift of

- 45^0 for 11
- 135^0 for 00
- 2250^0 for 00
- 315^0 for o1

- The transmitter selects the signals and concatenates.
- Transmitter and receiver have to be synchronized.

1.8 Spread spectrum

The term “spread spectrum” refers to the expansion of signal bandwidth, by several orders of magnitude.**Spread-spectrum** techniques are methods by which energy generated in a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference and jamming, and to prevent detection.Different SS techniques are available, but all have one idea in common, the key (also called code or sequence) attached to the communication channel. The manner of inserting this code defines precisely the SS technique in question.

To apply an SS technique, simply inject the corresponding SS code somewhere in the transmitting chain before the antenna.(That injection is called the spreading operation).the effect is to diffuse the information in a larger bandwidth. Conversely, you can remove the SS code (dispreading operation) at a point in the receive chain before data retrieval. The effect of a dispreading operation is to reconstitute the information in the original bandwidth. Obviously, the same code must be known in advance at both ends of the transmission channel. (In some circumstances, it should be known only by those two parties.)

At this point, we know that the main SS characteristic is the presence of a code or key, which must be known in advance by the transmitter and receiver(s). Communications, the codes are digital sequences that must be as long and as random as possible to appear as “noise-like” as possible. But in any case, they must remain reproducible; otherwise, the receiver will be unable to extract the message that has been sent. Thus, the sequence is “nearly random” such a code is called a pseudo-random number (PRN) or sequence. The method most frequently used to generate pseudo-random codes is based on a feedback shift register. The more popular PRN sequences have names: Barker, M-Sequence, Gold, and Hadamard-Walsh. Different SS techniques are distinguished according to the point in the system at which a pseudo-random code (PRN) is inserted in the communication channel.

Effects of spreading and interference

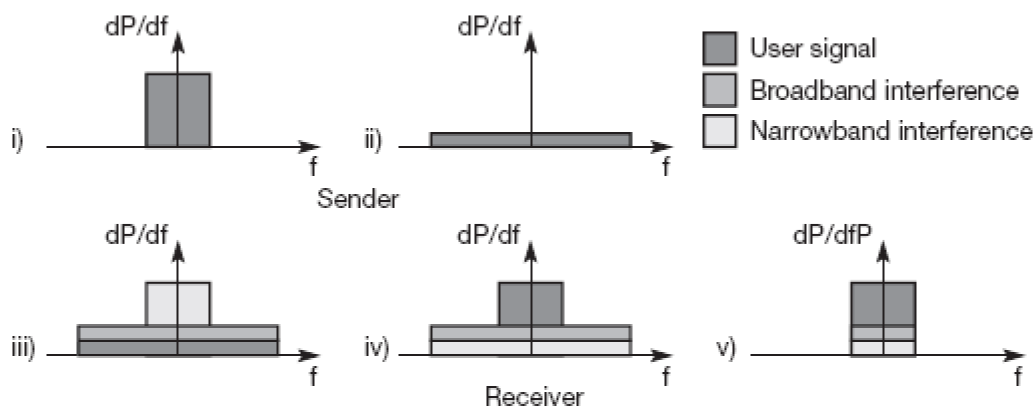

Fig 1.29: Effects of spreading and interference

If the PRN is inserted at the data level, we have the direct sequence from of spread spectrum (DSSS). If the PRN acts at the carrier-frequency level, we have the frequency hopping from of spread spectrum (FHSS).Frequency hopping is one of two basic modulation techniques used in spread spectrum signal transmission. It is the repeated switching of frequencies during radio transmission, often to minimize the effectiveness of “electronic warfare” – that is, the unauthorized interception or jamming of telecommunication. It also is known as frequency, hopping code division multiple access.

Direct sequence spread spectrum, also known as direct sequence code division multiple access (DS-CDMA), and is one of two approaches to spread spectrum modulation for digital signal transmission over the airwaves. In direct sequence spread spectrum, the stream of information to be transmitted is divided into small pieces, each of which is allocated across to a frequency channel across the spectrum. A data signal at the point of transmission is combined with a higher data _ rate bit sequence (also known as a chipping code) that divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission.

1.8.1 Direct Sequence Spread Spectrum (DSSS)

Process 1 – Spreading code modulation

For the duration of every message bit, the carrier is modulated (PSK) following a specific sequence of bits (known as chips). The process is known as “chipping” and results in the substitution of every message bit by (same) sequence of chips. In DSSS systems, the **spreading code** is the chip sequence used to represent message bits,

Process 2- Message modulation

For message bits “0”, the sequence of chips used to represent the bit remains as dictated by process 1 above, is inverted. In this way message bits”0” and ‘1” are represented (over the air) by different chip sequences (once being the inverted version of the other one).-Redundancy is achieved by the presence of the message it on each chip of the spreading code. Even if some of the chips of the spreading code are affected by noise, the receiver may recognize the sequence and take a correct decision regarding the received message bit.

- **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.

Direct Sequence Spread Spectrum Transmitter

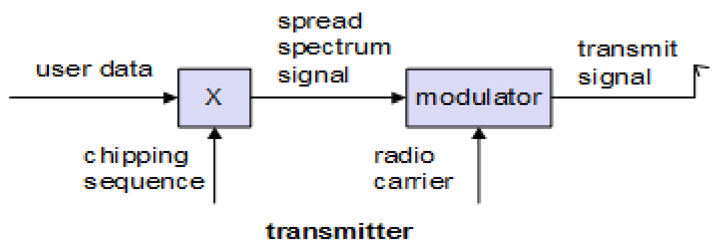

Fig 1.30: DSSS Transmitter

DSSS Receiver

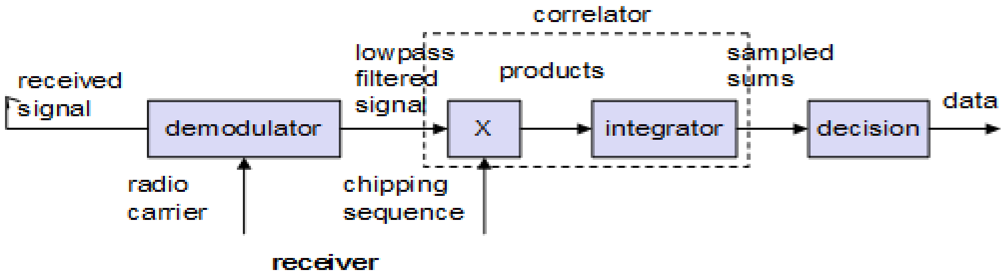

Fig 1.31: DSSS receiver

Advantages

- Reduces frequency selective fading
- In cellular networks
  - Base station scan use the same frequency range several base stations can detect and recover the signal
  - Soft handover

Disadvantages

- Precise power control necessary

1.8.2 FHSS (Frequency Hopping Spread Spectrum)

Process 1 – Spreading Code Modulation

The frequency of the carrier is periodically modified(hopped) following a specific sequence of frequencies, in FHSS systems, the **spreading code** is this list of frequencies to be used for the carrier signal, a.k.a the “hopping sequence” The amount of time spent on each hop is known as dwell time and is typically in the range of 100 ms.

Process 2- Message Modulation

The message modulates the (hopping) carrier (FSK), thus generating a narrow band signal for the duration of each dwell, but generating a wide band signal, if the process is regarded over periods of time in the range of seconds. Redundancy is achieved through the possibility to execute re-transmissions on different carrier frequencies (hops).

Basic Operation of FHSS

- Typically 2k carriers frequencies forming 2k 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

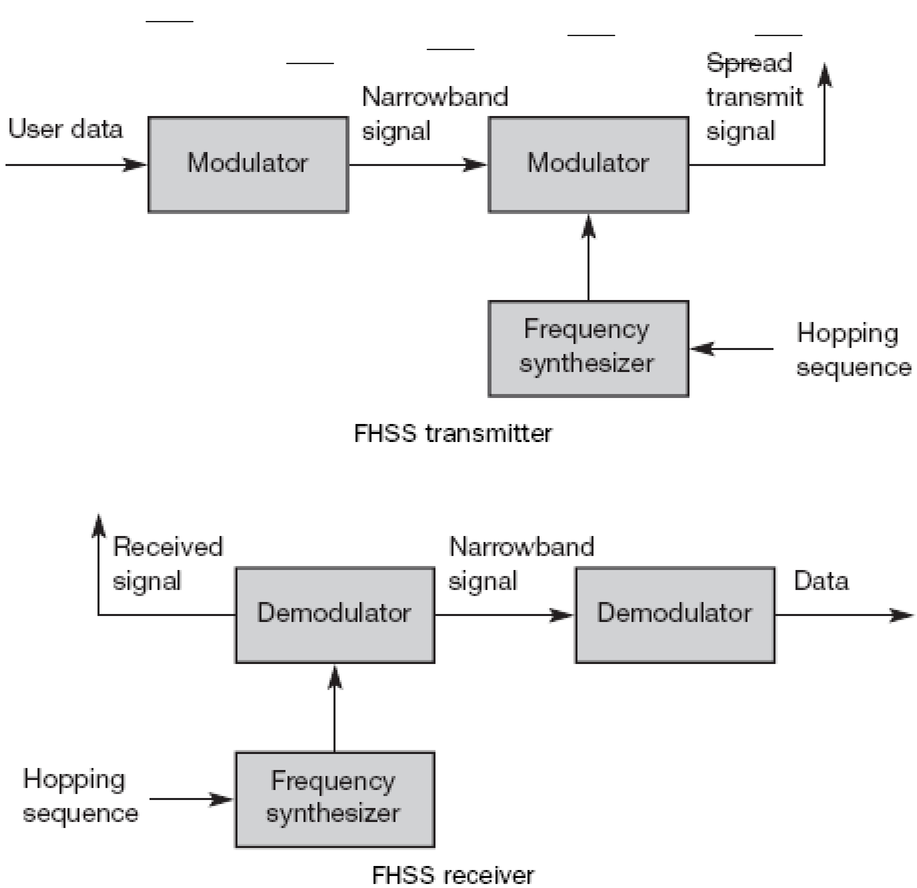

Fig 1.32: Basic Operation of FHSS

Discrete changes of carrier frequency

- Sequence of frequency changes determined via pseudo random number sequence

Two versions

- Fast Hopping: Several frequencies per user bit
- Slow Hopping: Several user bits per frequency

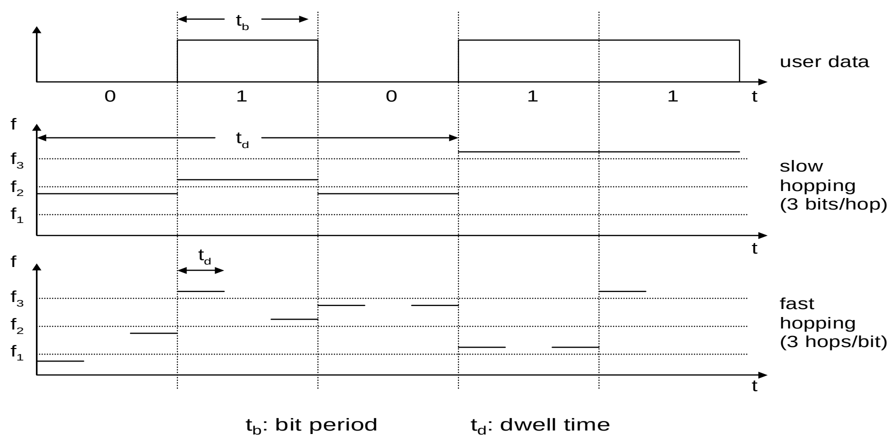

Fig 1.33: Discrete changes of carrier frequency

Advantages

- Frequency selective fading and interference limited to short period
- Simple implementation
- Uses only small portion of spectrum at any time

Disadvantages

- Not as robust as DSSS
- Simpler to detect

1.9 Medium Access Control (MAC)

Overview:

MAC comprises all the mechanisms that regulate user access to medium using SDM, TDM, FDM, and CDM. Special MAC is needed in wireless because of hidden and exposed terminals or near and far terminals. One scheme is not purely used in a system but mix of schemes is used in reality.

The need of Special MAC

Consider the wired CSMA/CD scheme

- A sender senses the medium to see if it is free
- If the medium is busy the sender waits until the medium is free
- If found free starts transmitting he data and continues to listen the medium
- If the sender detects and collision, it stops transmission immediately and sends jamming sequence.
- This scheme does not work in wireless because CSMA/CD does not consider the collisions in the sender side but only at the receiver end.
- This is not a problem with wired because the same signal strength is assumed to be present all over the wire.
- If collisions occur in the wire, it can be noticed by all.

(1) Problem when used in wireless

- This will not work in the wireless because" Signal strength decreases to the square of the distance of the sender"
- The sender senses the medium and finds it to be free, the sender starts sending the message but a collision occurs at the receiver due to second sender.
- This problem is called as hidden terminal problem.

(2) The sender detects no collision and assumes that the data has been transmitted without errors, but collision might have occurred. Collision detection is very difficult in wireless. So wired MAC cannot be used for wireless.

More details on why MAC of fired networks fail in wireless scenario

The fixed MAC when used on wireless faces the following

(1) Hidden and exposed terminals,
(2) Near and far terminals.

1.Hidden and Exposed Terminals

Hidden Terminal

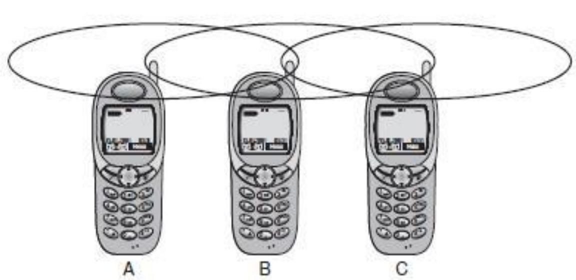

Fig 1.34: Hidden and Exposed Terminals

Consider 3 mobile phases as in the figure in next page.

- The transmission range of ‘A’ reaches ‘B’ but not ‘C’
- The transmission range of ‘C’ reaches ‘B’ but not ‘A’
- Transmission range of ‘B’ reaches ’A’ and ‘C’
- ‘A’ starts sending to ‘B’,’C’ does not receive this transmission.
- ‘C’ also wants to send to ‘B’ ,and senses the medium is free ‘C’ also starts sending message to ‘B’ hence resulting in a collision at ‘B’.
- ‘A’ cannot detect the collision at ‘B’ and still continues to send message.
- ‘A’ is hidden for ‘C’.

Exposed Terminal:

- Consider the scenario that ‘B’ to sends a message to A, ‘C’ wants to send a message to some other mobile which is outside the reference of A and B.
- ‘C’ senses that the medium is busy hence it postpones the transmission uinti,. It detects the medium is idle.
- In this scenario ‘C’s waiting is unneeded.
- Causing a collision at ‘B’ does not matter because the collision in too weak to propagates to A, C is exposed to B.

2.Near and Far Terminals

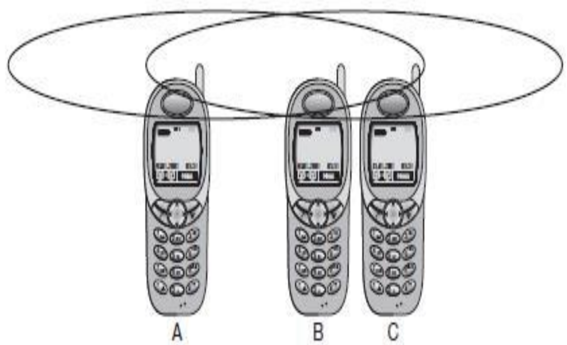

Fig 1.35: Near and Far Terminals

- A and B are sending with same transmission power to c.
- The signal strength decreases to the square of the distance.
- Due to the above B’s signal drowns out A’s signal as result ‘C’ cannot receive A’s information.
- The near/far effect is a severe problem of a wireless using CDM.
- All signals should arrive at the receiver with the almost same strength.
- If not the one’s which is closer will have higher strength than the one which is farther away.
- So if separated by code, the closest one would drown the others.

Mechanisms to access the medium

1. SDMA
2. FDMA
3. TDMA
4. CDMA

1.9.1 SDMA

- SDMA stands for Space ‘division Multiple Access.
- SDMA is used for allocating separated space to users of wireless network.
- Application is assigning an optimal as e station to a m bile phone.
- MAC algorithm decides which base station is best taking into consideration, TDM, CDM.
- SDMA is never used in isolation but used with one or more schemes.
- The SDMA algorithm works on cells and sectorized antenna which form the infrastructure.

1.9.2 FDMA

- FDMA stands for frequency division multiple accesses.
- Contain algorithm allocating frequencies to transmission channels according to FDM,
- Allocation can be fixed or dynamic.
- Channels can be assigned to the write Fixed /Dynamic frequency at tall times(i.e.) Pure FDMA or FDMA with TDMA is the fixed allocation. The vice versa is dynamic
- Sender and receiver need to agree on a hoping pattern otherwise receive could not tune to the right frequency.
- Hopping patters are fixed at least for a longer period.
- FDM is used for simultaneous access to the medium by base station and mobile station cellular networks.
- The two partners establish a duplex channel (i.e.) a channel that allows transmission in both directions.
- The tow direction, mobile station to base station and vie versa are separated using different frequencies
- This scheme is called frequency division duplex.
- The both partners need to have to know the frequencies in advance.
- The two frequencies are also known as uplink and downlink.
- The uplink is from mobile station to base station or ground control to satellite
- The downlink is from base station to mobile station or from satellite to ground control.

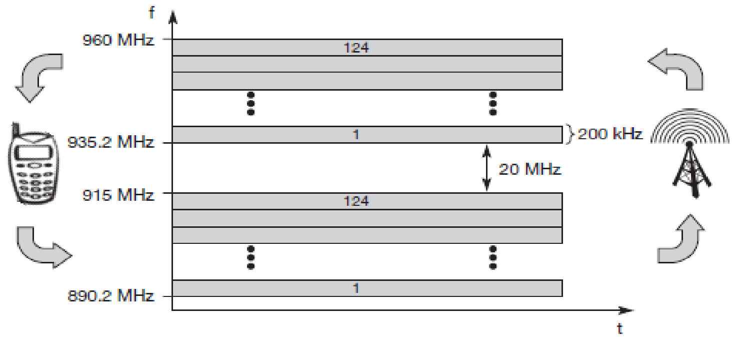

Fig 1.36: Frequency Division Multiplexing for Multiple Access and Duplex (FDMA)

1.9.3 TDMA

- TDMA stands for time division multiple access.
- TDMA offers flexible scheme, allocates time slots for communication which is controlled by TDM.
- The receiver need not tune the frequency; can stay at the same frequency.
- Uses only one frequency, many algorithms exist to control the medium access
- Here the system listens to many channels separated in time at the same frequency
- Synchronization between the sender and receiver needs to be achieved.
- To do the synchronization the channel is allocated a fixed time slot (or) by using dynamic allocation scheme.
- For dynamic allocation identification of each transmission is necessary.
- MAC addresses ifs used as identification.
- This Identification makes the receiver identify when any message is intended for it.
- Fixed schemes do not need an identifications, but inflexible.

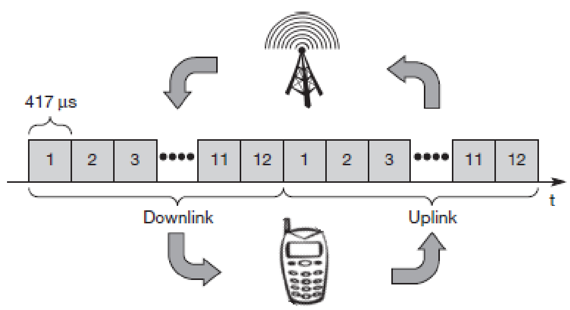

Fig 1.37: Time Division Multiplexing for Multiple Access and Duplex

Type of TDM

(a) Fixed TDMA
(b) Demand Oriented TDMA

Fixed TDM

- This is the simplest algorithm for using TDM

- Here time slots are allocated for channels in the fixed pattern.
- Hence the result is fixed bandwidth.
- Now external synchronization needed.
- Each mobile must know its turn, hence no inference will occur.
- The pattern is to be assigned by the base stations.
- This environment suits well
    - When the bandwidth is fixed.
    - When the system needs fixed delay.
    - Constant data rate.
- The frequency is same.
- Assigning the different slots for uplink and downlink with the same frequency is called as Time Division Multiplex.

In the above figure 12 slots are used for uplink and 12 slots (different) for downlink.

Advantages:

- Bandwidth is fixed
- Delay is fixed
- Constant data rate

Disadvantages:

- Wastage of bandwidth when the system has no data to transmit
- Inflexible
- Not suitable for burst data

Demand oriented TDMA

The demand oriented TDMA methods are

1. Classical Aloha
2. Slotted Aloha
3. CSMA
4. DAMA
5. PRMA
6. Reservation TDMA
7. MACA
8. Polling
9. ISMA

Classical Aloha

- Here the TDMA is applied without controlling the access
- Each station can access the medium without a central arbiter controlling the access and without co-ordination

- If two or more stations access the medium at the same time collision occurs and the data transmitted is too destroyed
- Aloha is neither co-coordinated nor resolves contention.
- Can be used under light load.

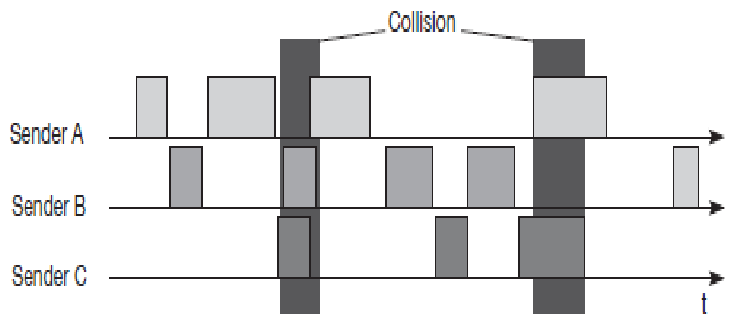

Fig 1.38: Classical Aloha

Slotted Aloha

- In slotted Aloha the time is divided into slots.
- All the senders need to be synchronized.
- When the sender wants to transmit attempts at the beginning of time slot.
- Synchronization is done at the beginning of the of time slot.

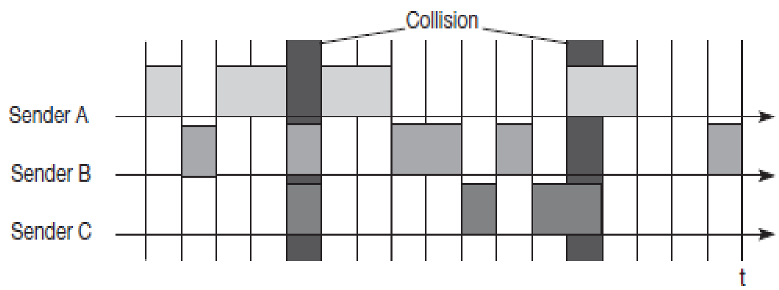

Fig 1.39: Slotted Aloha Multiple Access

- Systems are not co-ordinated.
- Through put is doubled from classical Aloha to slotted Aloha.
- Well suited for light load.
- Guarantees for maximum delay and throughput in not given.

CSMA

- Carrier senses multiple accesses.
- The medium is sensed before the access. Hence the name CSMA/
- The concept of sensing and accessing the medium decreases the probability of collision.
- Hidden terminals cannot be detected.

- Hence collision can occur at the receiver.
- Types of CSMA.

(i) **Non-Persistent CSMA:**

- Station sense the medium and start sending immediately if the medium is free.
- If the medium is busy the stations waits for a random amount of time and the once again senses the medium. Repeats the above if the medium is found busy.

(ii) P-Persistent CSMA:

- The nodes the sense the medium.
- Transmit with a probability P, when the medium is free and postponing to the next slot with the probability 1-P.

(iii) 1-Persistent CSMA:

- All the nodes wishing g to transmit data, senses the medium and transmits the data as soon as the medium is idle with probability
- Results in collision if many want to transmit data.
- This method is unfair; hence to introduce fairness the stations waiting for a longer time will be given the chance.

(iv) CSMA/CA (Collision Avoidance):

The medium is sensed and if found busy waiting time follows the back off scheme. Thus avoids the occurrence of collision.

DAMA

Demand Assigned Multiple Access (or) Reservation Aloha

- This method uses the concept of Reservation and Fixed TDMA.
- Here there is a fixed reservation period followed and fixed TDMA.
- During the reservation periods the stations can reserve future slots in the transmission period.
- Collisions can occur during the reservation period only.
- This method has two phases.
    - Contention phase
    - Transmission phase.

Contention Phase:

This is the reservation phase
- This phase follows the slotted aloha scheme.
- During this phase all the stations reverse the future slot.

- Collision occurs during this phase.
- If successful time slot for the future is reserved no other station is allowed to transmit during this slot.
- The stations need to be synchronized.
- This is an explicit reservation scheme.

Transmission Phase:

The reserved senders transmit the data during this phase.

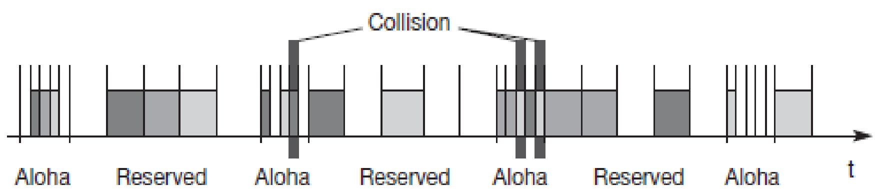

Fig 1.40: Transmission Phase

Packet Reservation Multiple Access (PRMA)

- PRMA is an implicit reservation scheme.
- The slots are reserved according to the scheme described below.

Scheme:

- Frame is divided into slots.
- The frame is repeated in time with fixed TDM.
- The base station broadcasts the status of each slot to the mobile stations.
- All the stations receive this broadcast and determine which slot is free and which slot is occupied.
- The station's name is indicated in the slot which is reserved for that station.
- For example of frame 1 it reads as ACDABA-F. this indicates that the 7th slot is free
- The stations wanting the slot compete in an Aloha scheme.
- If more stations compete collision occurs then the base stati8on returns the reservation status of frame 1 as ACDABA-F.
- Again the stations can compete for the 7th slot.

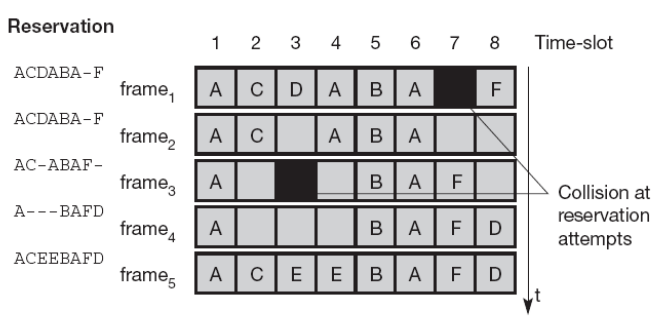

Fig 1.41: Packet Reservation Multiple Access

Reservation TDMA

- This method allows randomness and freedom
- The frame has reservation phase followed y transmission phase.
- The reservation has fixed TDM scheme of N mini slots.

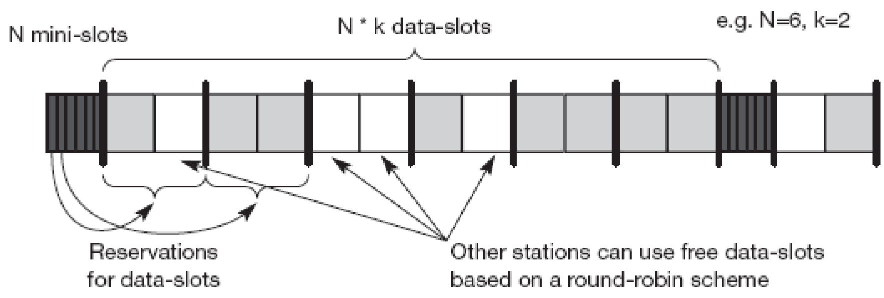

Fig 1.42: Reservation TDMA access scheme

- The transmission phase has N.K data slots for the frame where K is the data slot for 1 mini slot.
- Guarantees bandwidth and fixed delay.
- Other stations can send in unused slots only.
- The free slots usage can be via round robin or aloha.

Multiple Access with Collision Avoidance

- The previous access mechanisms do not handle the problem of hidden terminal.
- MACA has a simple scheme which solves a hidden terminal problem does not need a base station. Follows random access, with dynamic reservation.

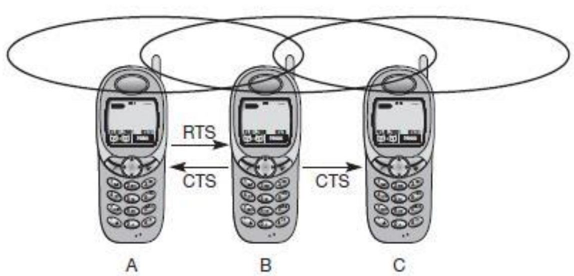

Fig 1.43: MACA can avoid hidden terminals

- The sender A sends a RTS (Request to send signal to the receiver ‘B’).
- The content of RTS is name of the sender, receiver and duration of transmission.
- RTS is not heard by ‘C’. B when free sends CTS (clear to send) signal to A.
- Contents of CTS are the name of the sender same of the receive, and the duration.
- CTS is heard by ‘A’ and ’C’ discards because it is neither the sender nor receiver.
- This CTS indicates that ‘B’ is involved in transmission and hence ’C’ cannot send any message to ‘B’.

- Hence collision is avoided at ‘B’ thus solving the hidden terminal problem.
- When A and ‘C’ sends RTS at the same time to ‘B’ collision occurs resolve the contention by sending acknowledgement CTS to one station.

Exposed Node Problem Solution:

- B sends RTS to A
- ‘C’ does not react to this message
- ‘A’ acknowledges and sends CTS to B.

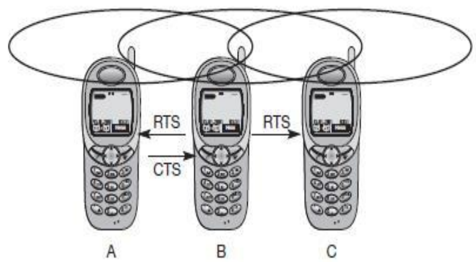

Fig 1.44: MACA can avoid exposed terminals

- CTS from A to ‘B’ are not heard by ‘C’.
- Hence ‘C’ can start transmission to a different uses, thus avoiding exposed node problem.

Problem faced:

- Overheads in sending RTS and CTS.
- Unsuitable for time critical data packets which is to be transmitted in short duration
- State diagram for the sender and receiver.

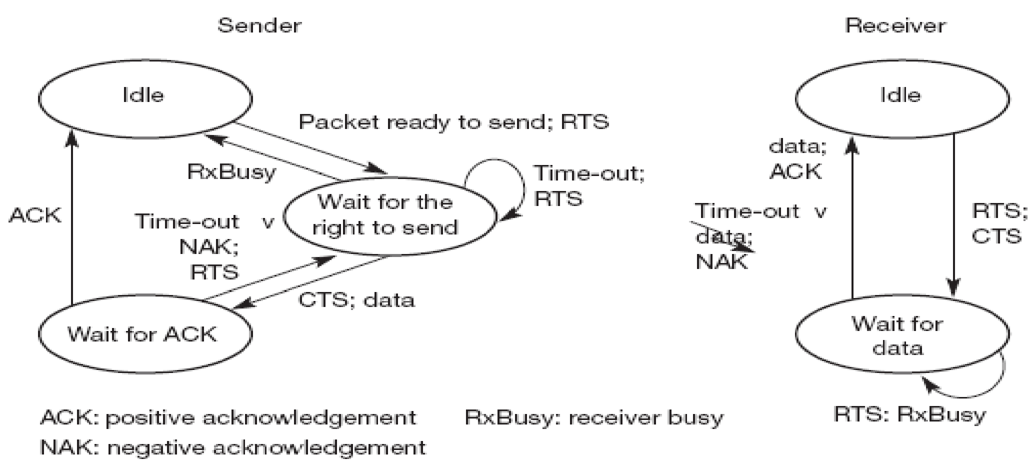

Fig 1.45: State diagram for sender and receiver

- The sender is on the idle state until a user requests for transmission of data
- The sender issues an RTS and waits for CTS.

- If the receiver gets the RTS and if free sends CTS and waits for data.
- The sender receiver CTS and sends data.
- If the sender didn't receive CTS, the sender world sends RTS after time out.
- If it has received sends the data and waits for acknowledgement and returns to waiting state.
- If the receiver sends positive acknowledgement the sender and receiver moves to idle state.
- If the sender receives a negative acknowledgement the sends RTS once again.
- The receiver can indicate that it is busy via R_x busy message.

Polling

- This scheme is a centralized scheme.
- In this scheme there is one master and many slave stations.
- The master polls the slaves according to any one of the schemes like that of round robin.
- There is contention phase and transmission phase. In the contention phase the master can poll the slaves to reserve the transmission phase
- In the contention phase the master can poll the slave's transmission phase.
- The transmission is done according

ISMA-Inhibit Sense Multiple Access:

- The medium is detected by inhibition.
- The base station signals a medium busy via busy tone on the down link
- When the medium is free the busy tone stops.
- The uplink is not co-ordinated.
- The base station acknowledges is the successful transmission.
  - In case when the acknowledge is missed the mobile devices can conclude a collision.

1.9.4 CDMA

- CDMA stands for code division multiple accesses.
- CDMA uses the technique of code division multiplexing.
- CDMA uses the codes to separate the users in code space thus helping the medium to be shared without interference.

Spread Aloha multiple Access:

Here the CDMA and Aloha are combined to from SAMA.

Working principle

- Users use the same spreading code.

- Sender A and B access the medium at the same time in their narrow band spectrum resulting in collision.
- The same data can be sent with higher power for shorter period 1 the spread spectrum is used to spread the signal to increase the bandwidth.

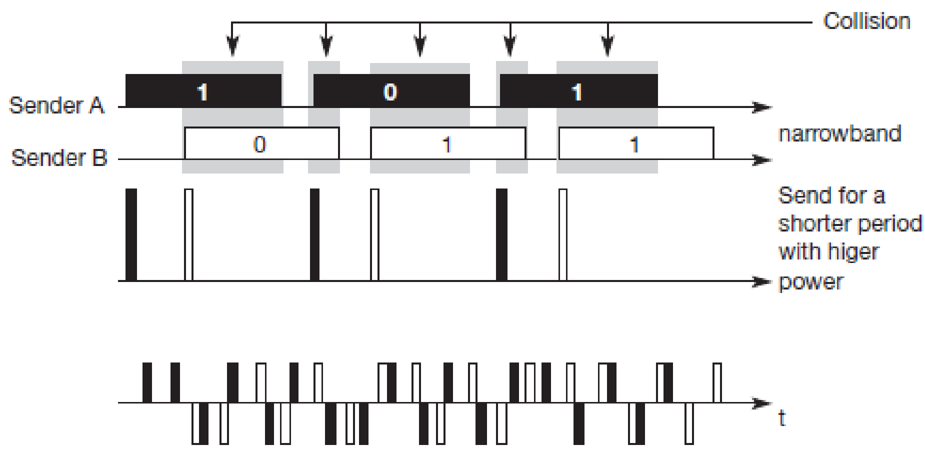

Fig 1.46: Spread Aloha Multiple Access

Advantages:

1. Collision is low.
2. Spread spectrum a result in robustness against narrow band interference. 3. Coexistence with other systems n same frequency band.

Disadvantages:

1. Finding the good chipping sequence is difficult. 2. Code is not orthogonal to itself.

Comparison of the medium access mechanism

Approach	SDMA	TDMA	FDMA	CDMA
Idea	Segment space into cells/sectors	Segment sending time into disjoint time-slots, demand driven or fixed patterns	Segment the frequency band into disjoint sub-bands	Spread the spectrum using orthogonal codes
Terminals	Only one terminal can be active in one cell/one sector	All terminals are active for short periods of time on the same frequency	Every terminal has its own frequency, uninterrupted	All terminals can be active at the same place at the same moment, uninterrupted
Signal separation	Cell structure directed antennas	Synchronization in the time domain	Filtering in the frequency domain	Code plus special receivers
Advantages	Very simple, increases capacity per km^2	Established, fully digital, very flexible	Simple, established, robust	Flexible, less planning needed, soft handover
Disadvantages	Inflexible, antennas typically fixed	Guard space needed (multi-path propagation), synchronization difficult	Inflexible, frequencies are a scarce resource	Complex receivers, needs more complicated power control for senders
Comment	Only in combination with TDMA, FDMA or CDMA useful	Standard in fixed networks, together with FDMA/SDMA used in many mobile networks	Typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	Used in many 3G systems, higher complexity, lowered expectations; integrated with TDMA/FDMA

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1.10 Introduction to cellular system

General Concept

The following concept holds when cell system follows SDM. For mobile communication transmitter is needed. The transmitter is called as base station. The base station covers certain area called cell. The radius of the cell can be from meters, tens of meters, kilometers. The shape of the cells is assumed to be circle or hexagon. The real shape depends upon environment, weather and load. Because of this reason of coverage there are thousands of base stations throughout. The drawback is in eh interference. Hence never use the same frequency at the same time within the Interference Range.

Cell : Why Hexagon?

- In reality the cell is an irregular shaped circle, for design convenience and as a first order approximation, it is assumed to be regular polygons
- The hexagon is used for two reasons:
  - A hexagonal layout requires fewer cells, therefore, fewer transmission site
  - Less expensive compared to square and triangular cells
- Irregular cell shape leads to inefficient use of the spectrum because of inability to reuse frequency on account of co channel interference uneconomical deployment of equipment, requiring relocation from one cell site to another.

Advantages of cell structures:

- Higher capacity, higher number of users
- Less transmission power needed
- More robust, decentralized
- Base station deals with interference, transmission area etc. locally

Problems:

- Fixed network needed for the base stations
- Handover (changing from one cell to another) necessary
- Interference with other cells

Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies

1.10.1 Methods to create cell patterns

Clusters:

Cells are combined to form clusters.

Types:

1. Three cell forming a cluster.
2. Seven cells forming a cluster.

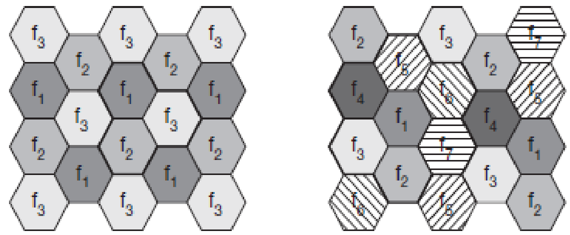

Fig 1.47: Three cells forming a cluster

All the cells within a cluster use a different set of frequencies. Moreover still l to avoid interference sectorized antenna can be used.

Assignment of frequency to cells

1. Fixed
2. Dynamic

Fixed:

Here the frequencies are assigned in advance to the cell cluster and cell respectively. This method is called as FCA used in GSM.

Disadvantage: Not efficient in different traffic load condition.

Dynamic:

Here the frequency can be borrowed and the frequency can be freely assigned to cells used in DECT.

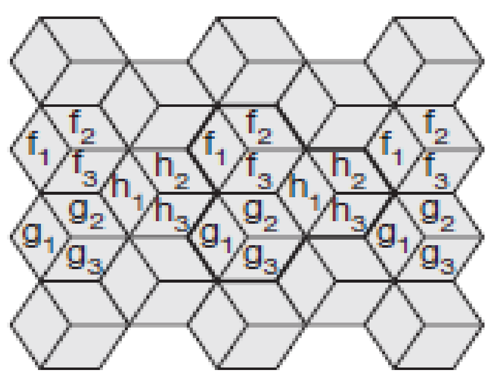

Fig 1.48: Cells using sectorized antenna

As the frequencies are repeated, the transmission power has to be limited to avoid interference. Another method to reduce the interference it's to use sectorized antenna.

Borrow of Frequency

Here when a cell has heavy traffic and its neighbor has light load, the frequency can be borrowed. This scheme is called as borrowing channel allocation (BCL).

Breathe:

When cellular systems use CDM m the cell planning faces a problem of cell size depending upon the load, under that scenario the cells are said to breathe.

The concept of breathe is that the cells can cover a large area under light load and size shrinks under heavy load.

Advantages of Cellular System with Small Cells

(1) Higher Capacity:

- With SDM the frequency can be reused.
- Frequency reuse is feasible if the two transmitters are far away.
- Small cells allow more users.

(2) Less Transmission Power:

- Power is problematic for the mobile/hand held devices.
- The devices which are closer to the base station needs less transmission power.

(3) Local Interference:

- In small cells the mobile and base station need to cater only the local interference.
- In this case of large cells they have to cater more interference problems

(4) Robustness:

- Cellular systems are decentralized.
- If one antenna fails it affects only small area.

Disadvantages:

(1) Infrastructure:

- Cellular systems need complex infrastructure to connect all base stations.
- (e.g.) Antenna, Location registers, switches are needed, which makes the system costly.

(2) Handover:

- As the cell size is small more number of handover is needed.
- Handover means, when quality is low, the mobile needs to be handed over from one transmitter to another.

(3) Frequency:

- As the frequency is reused between transmitters, to avoid the interference the frequency has to be distributed carefully.
- More over only limited number of frequencies are available.

1.10.2 Cellular Wireless Networks

Cellular network organization

- Use multiple low –power transmitters(100 W or less)
- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver and control unit
  - Band of frequencies allocated
  - Cells setup such that antennas of all neighbors are equidistant(hexagonal pattern)

Frequency Reuse

- Adjacent cells assigned different frequencies to avoid interference or crosstalk.
- Objective is to reuse frequency in nearby cells.
  - 10 to 50 frequencies assigned to each cell.
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells.
  - The issue is to determine how cells may must intervene between two cells using the same frequency.

Approaches to cope with Increasing Capacity

- Adding new channels.
  - **Frequency borrowing :**Frequencies are taken from adjacent cells by congested cells.
  - **Cell splitting:** Cells in areas of high usage can be split into smaller cells.
  - **Cell sectoring** : Cells are divided into a number of wedge-shaped sectors, each with their own set of channels.
  - **Micro cells** : Antennas move to buildings, hills and lamp posts.

Cellular System Terms

- Base Station (BS)-includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO)-connects calls between mobile units.
- Two types of channels available between mobile unit and BS.
  - **Control channels:** used to exchange information having to do with setting up and maintaining calls.
  - **Traffic channels:** carry voice or data connection between users.

Steps in a n MTSO Controlled Call between Mobile Users

- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff

Additional functions in an MTSO Controlled Call

- Call blocking
- Call termination
- Call drop
- Calls to /from fixed and remote mobile subscriber.

Mobile Radio Propagation Effects

- Signal strength
  - Must be strong enough between base station and mobile unit to maintain signal quality at the receiver.
  - Must not be so strong as to create too much co channel interference with channels in another cell using the same frequency band.
- Fading
  - Signal propagation effects may disrupt the signal and cause errors.

Handoff Performance Metrics

- **Cell blocking probability:** Probability of a new call being blocked.
- **Call dropping probability :** Probability that a call is terminated due to a handoff
- **Call completion probability :** Probability that an admitted call is not dropped before it terminates.
- **Probability of unsuccessful handoff:** Probability that a handoff is executed while the reception conditions are inadequate.
- **Handoff blocking probability:** Probability that a hand off cannot be successfully completed.
- **Handoff probability :** Probability that a handoff in which a mobile is not connected to either base station.
- **Handoff delay:** Distance the mobile moves from the point at which the handoff should occur to the point at which it does occur.

Handoff Strategies used to Determine Instant of Handoff

- Relative signal strength
- Relative signal strength with threshold
- Relative signal strength with hysteretic

- Relative signal strength with hysteretic and threshold
- Prediction techniques

Power Control

- Design making it desirable to include dynamic power control in a cellular system
    - Received power must be sufficiently above the background Boise for effective communication
    - Desirable to minimize power in the transmitted signal from the mobile.
    - Reduce co channel interference, alleviate health concerns, save battery power
    - In SS systems using CDMA, it's desirable to equalize the received power level from all mobile units at the BS.

Types of Power Control

- **Open :** Loop power control
    - Depends solely on mobile unit
    - No feedback from BS
    - Not as accurate as closed – loop, but can react quicker to fluctuations in signal strength.
- **Closed:** Loop power control
    - Adjusts signal strength in reverse channel based on metric of performance
    - BS makes power adjustment decision and communicates to mobile on control channel.

Traffic Engineering

- Ideally available channels would equal number of subscribers active at one time
- In practice, not feasible to have capacity handle all possible load.
- For N simultaneous user capacity and L subscribers.
    - $L<N$ –nonblocking system
    - $L>N$ –blocking system.

Blocking System Performance Questions

- Probability that call request is blocked?
- What capacity is needed to achieve a certain upper bound on probability of blocking?
- What is the average delay?
- What capacity is needed to achieve a certain average delay?

Traffic Intensity

- Load presented to a system:

  $$A=\lambda \hat{h}$$

  - **λ** =mean rate of calls attempted per unit time
  - h=mean holding time per successful call
  - A=average number of calls arriving during average holding period for normalized l

Factors that determine the Nature of the Traffic Model

- Manner in which blocked calls are handled.
  - Lost calls delayed (LCD)-blocked calls put in a queue awaiting a free channel
  - blocked calls rejected and dropped
  - Lost calls cleared(LCC)-user waits before another attempt
  - Lost calls held(LCH)-user reputedly attempts calling
- Number of traffic sources
  - Whether number of users is assumed to be finite or infinite

First Generation Analog

- Advanced Mobile Phone Service(AMPS)
- In North America, two 25-MHz bands allocated to AMPS
  - One for transmission from base to mobile unit
  - One for transmission from mobile unit to base
- Each band split in two to encourage competition
- Frequency reuse exploited

AMPS Operation

- Subscriber initiates call by keying in phone number and presses send key
- MTSO verifies number and authorizes user
- MTSO issues message to user's cell phone indicating send and receive traffic channels
- MTSO sends ringing signal to called party
- Party answers; MTSO establishes circuit and initiates billing information
- Either party hangs up; MTSO releases circuit, frees channels, completes billing.

Differences between First and Second Generation Systems

- **Digital traffic channels:**First-generation systems are almost purely analog; second-generation systems are digital
- **Encryption :**A second generation systems provide encryption to prevent eavesdropping
- **Error detection and correction:** Second-generation digital traffic allows for detection and correction, giving clear voice reception
- **Channel access:** Second –Generation systems allow channels to be dynamically shared by a number of users.

Mobile Wireless TDMA Design Considerations

- **Number of logical channels(number of time slots in TDMA frame):**8
- **Maximum cell radius(R):**35km
- **Frequency :** Region around 900 MHz
- **Maximum vehicle speed(V_m):** 250km/hr
- **Maximum coding delay:** Approx.20ms
- **Maximum delay spread(D_m):**10 ms
- **Bandwidth:** Not to exceed 200 kHz(25 kHz per channel)