UNIT-5 MULTI-USER RADIO COMMUNICATION

Advanced Mobile Phone System (AMPS) - Global System for Mobile Communications (GSM) - Code division multiple access (CDMA) – Cellular Concept and Frequency Reuse - Channel Assignment and Handoff - Overview of Multiple Access Schemes - Satellite Communication - Bluetooth.

5.1 INTRODUCTION TO MULTI USER RADIO COMMUNICATION

Multiuser communications refer to the simultaneous use of a communication Channel by a number of users. Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner.

As the spectrum is limited, so the sharing is required to increase the capacity of cell or over a geographical area by allowing the available bandwidth to be used at the same time by different users. And this must be done in a way such that the quality of service doesn't degrade within the existing users.

Multiple access is a technique whereby many subscribers or local stations can share the use of a communication channel at the same time or nearly so, despite the fact that their individual transmissions may originate from widely different locations. Stated in another way, a multiple-access technique permits the communication resources of the channel to be shared by a large number of users seeking to communicate with each other.

There are subtle differences between multiple access and multiplexing that should be noted:

- Multiple access refers to the remote sharing of a communication channel such as a satellite or radio channel by users in highly dispersed locations. On the other hand, multiplexing refers to the sharing of a channel such as a telephone channel by users confined to a local site.
- In a multiplexed system, user requirements are ordinarily fixed. In contrast, in a multiple-access system user requirements can change dynamically with time, in which case provisions are necessary for dynamic channel allocation.

The main aim in Multi user communication system design is to be able to increase the capacity of the Channel in a given bandwidth with a sufficient level of quality of service. There are several different ways to allow access to the Channel. These include mainly the following:

1) Frequency division multiple-access (FDMA)
2) Time division multiple-access (TDMA)
3) Code division multiple-access (CDMA)
4) Space Division multiple access (SDMA)

FDMA, TDMA and CDMA are the three major multiple access techniques that are used to share the available bandwidth in a wireless communication system. Depending on how the available bandwidth is allocated to the users these techniques can be classified as narrowband and wideband systems.

5.1.1 NARROWBAND SYSTEMS

The term narrowband is used to relate the bandwidth of the single Channel to the expected coherence bandwidth of the Channel. The available spectrum is divided in to a large number of narrowband Channels. The Channels are operated using FDD.

Channel bandwidth < Coherence bandwidth

Coherence bandwidth:

It is the approximate maximum bandwidth or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading.

In narrow band FDMA, a user is assigned a particular Channel which is not shared by other users in the vicinity and if FDD is used then the system is called FDMA/FDD.

Narrow band TDMA allows users to use the same Channel but allocated a unique time slot to each user on the Channel, thus separating a small number of users in time on a single Channel. For narrow band TDMA, there generally are a large number of Channels allocated using FDD or TDD, each Channel is shared using TDMA. Such systems are called TDMA/FDD and TDMA/TDD access systems.

5.1.2 WIDEBAND SYSTEMS

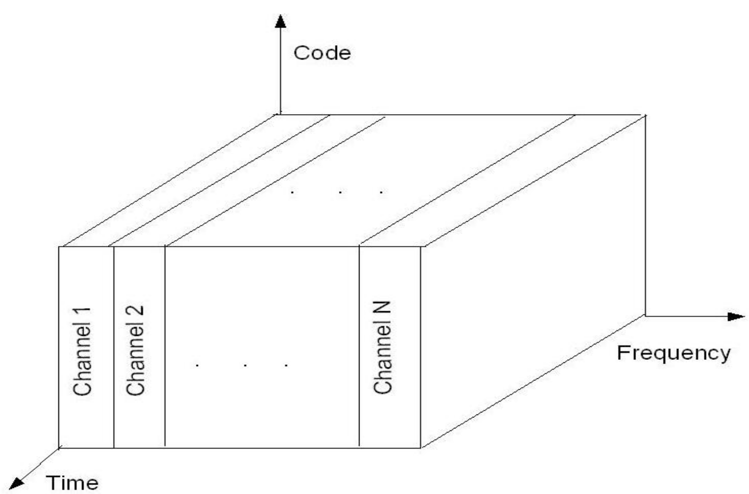
In wideband systems, the transmission bandwidth of a single Channel is much larger than the coherence bandwidth of the Channel. Thus, multipath fading does not greatly affect the received signal within a wideband Channel, and frequency selective fades occur only in a small fraction of the signal bandwidth.

Channel bandwidth > Coherence bandwidth

5.2 FREQUENCY DIVISION MULTIPLE ACCESS [FDMA]

This was the initial multiple-access technique for cellular systems in which each individual user is assigned a pair of frequencies while making or receiving a call as shown in Figure. One frequency is used for downlink and one pair for uplink.

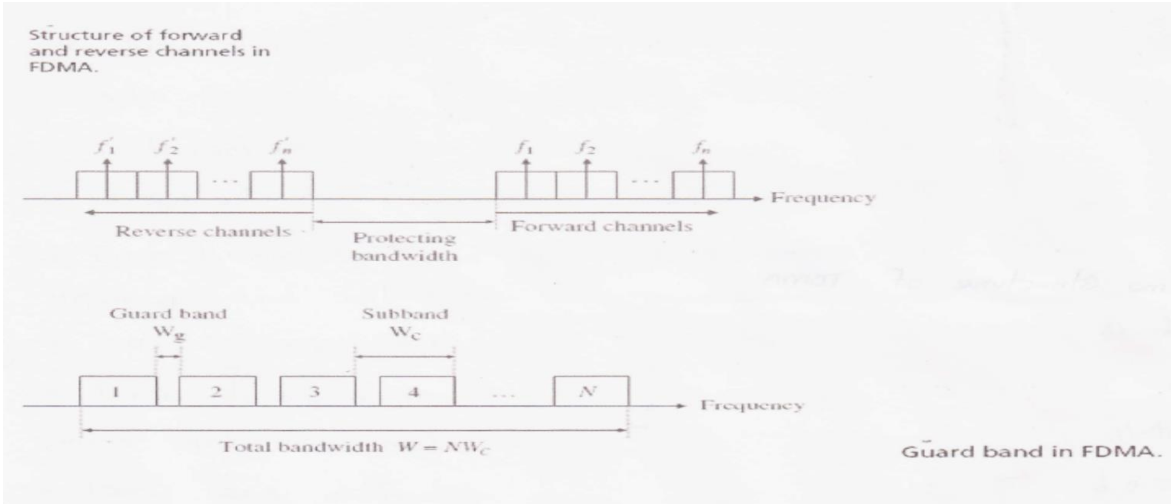
This is called frequency division duplexing (FDD). That allocated frequency pair is not used in the same cell or adjacent cells during the call so as to reduce the co Channel interference. Even though the user may not be talking, the spectrum cannot be reassigned as long as a call is in place. Different users can use the same frequency in the same cell except that they must transmit at different times.



5.2.1 FEATURES OF FDMA

The features of FDMA are as follows:

- The FDMA Channel can be used by only one user at a time. If an FDMA Channel is not in use, then it sits idle and it cannot be used by other users to increase share capacity.
- After the assignment of the Channel to a particular User, The user is allowed to transmit and receive simultaneously and continuously through the duplexed Channel.
- The bandwidths of FDMA systems are generally narrow.
- The symbol time is large compared to the average delay spread.
- The complexity of the FDMA mobile systems is lower than that of TDMA mobile systems.
- FDMA requires tight filtering to minimize the adjacent Channel interference.



A Guard band is an unused part of the radio spectrum between radio bands, for the purpose of preventing interference. It is a narrow frequency range used to separate two wider frequency ranges to ensure that both can transmit simultaneously without interfering with each other. A Guard band with BW f_g always present in between two FDMA Channels, for the purpose of preventing Interferences.

5.2.2 FDMA/FDD IN AMPS

The first U.S. analog cellular system, AMPS (Advanced Mobile Phone System) is based on FDMA/FDD. A single user occupies a single Channel while the call is in progress, and the single Channel is actually two simplex Channels which are frequency duplexed with a 45 MHz split.

When a call is completed or when a handoff occurs the Channel is vacated so that another mobile subscriber may use it. Multiple or simultaneous users are accommodated in AMPS by giving each user a unique signal. Voice signals are sent on the forward Channel from the base station to the mobile unit, and on the reverse Channel from the mobile unit to the base station. In AMPS, analog narrowband frequency modulation (NBFM) is used to modulate the carrier.

5.2.3 FDMA/TDD IN CT2

Using FDMA, CT2 system splits the available bandwidth into radio Channels in the assigned frequency domain. In the initial call setup, the handset scans the available Channels and locks on to an unoccupied Channel for the duration of the call. Using TDD (Time Division Duplexing), the call is split into time blocks that alternate between transmitting and receiving.

5.2.4 FDMA AND NEAR-FAR PROBLEM

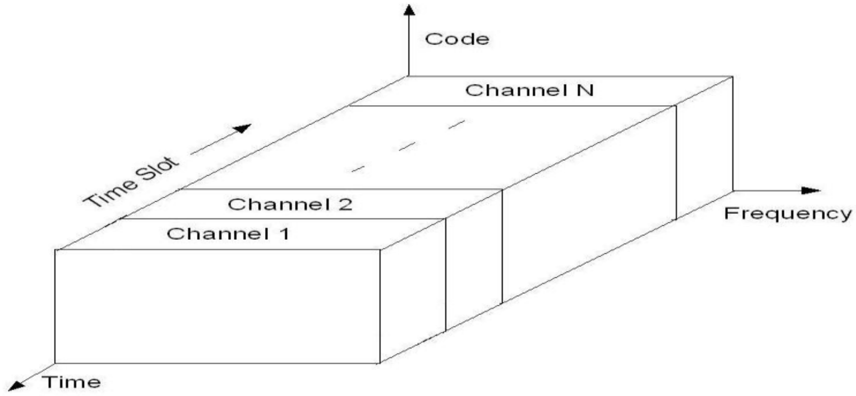
The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in CDMA systems where transmitters share transmission frequencies and transmission time.

In contrast, FDMA and TDMA systems are less vulnerable. FDMA systems offer different kinds of solutions to near-far challenge. Here, the worst case to consider is recovery of a weak signal in a frequency slot next to strong signal. Since both signals are present simultaneously as a composite at the input of a gain stage, the gain is set according to the level of the stronger signal; the weak signal could be lost in the noise floor. Even if subsequent stages have a low enough noise floor to provide.

5.3 TIME DIVISION MULTIPLE ACCESS [TDMA]

In digital systems, continuous transmission is not required because users do not use the allotted bandwidth all the time. In such cases, TDMA is a complimentary access technique to FDMA. Global Systems for Mobile communications (GSM) uses the TDMA technique.

In TDMA, the entire bandwidth is available to the user but only for a finite period of time. In most cases the available bandwidth is divided into fewer Channels compared to FDMA and the users are allotted time slots during which they have the entire Channel bandwidth at their disposal, as shown in Figure.

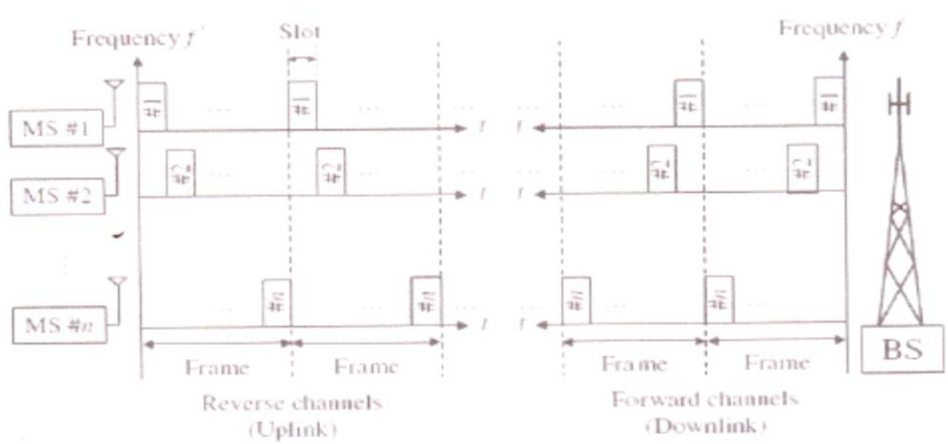


TDMA requires careful time synchronization since users share the bandwidth in the frequency domain. The number of Channels is less, inter Channel interference is almost negligible. TDMA uses different time slots for transmission and reception.

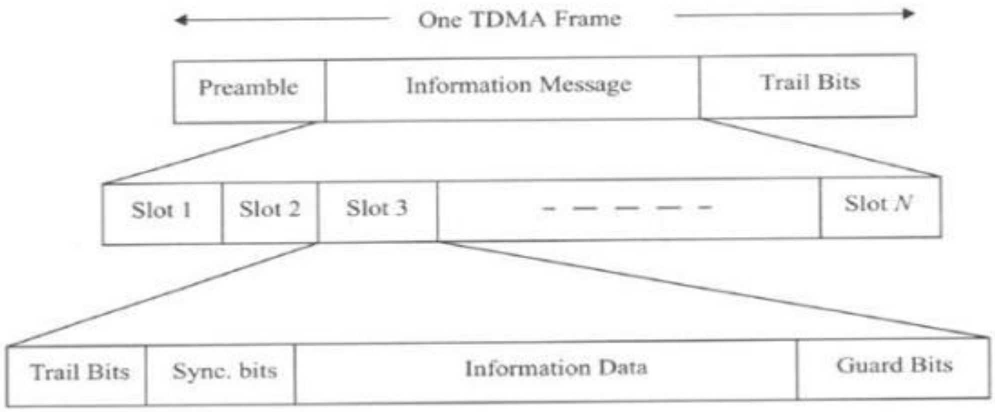
This type of duplexing is referred to as Time division duplexing (TDD).The features of TDMA include the following:

1. TDMA shares a single carrier frequency with several users where each user makes use of non-overlapping time slots.
2. The number of time slots per frame depends on several factors such as modulation technique, available bandwidth etc.
3. Data transmission in TDMA is not continuous but occurs in bursts. This results in low battery consumption since the subscriber transmitter can be turned OFF when not in use.
4. Because of a discontinuous transmission in TDMA the handoff process is much simpler for a subscriber unit, since it is able to listen to other base stations during idle time slots.
5. TDMA uses different time slots for transmission and reception thus duplexers are not required.
6. TDMA has an advantage that is possible to allocate different numbers of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by concatenating or reassigning time slot based on priority.

Basic Structure of a TDMA System



5.3.1 TDMA FRAME STRUCTURE



In TDMA, the preamble contains the address and synchronization information that both the base station and the mobiles use to identify each other. Trail bits signify the end of TDMA frame. Synchronization with receiver clock is ensured by synchronization bits.

Since there are significant delays between users, each user receives the reference burst with a different phase, and its traffic burst is transmitted with a correspondingly different phase within the time slot. There is a guard interval at the end of each time slot. As the transmission moves into the guard period, the mobile network adjusts the timing advance to synchronize the transmission.

There is therefore a need for guard times to take account of this uncertainty. Each Time Slot is therefore longer than the period needed for the actual traffic burst, thereby avoiding the overlap of traffic burst even in the presence of these propagation delays.

Efficiency of TDMA

* The efficiency of a TDMA System is a measure of the Percentage of transmitted data that Contains information as opposed to providing overhead for the access Scheme.

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where

b_{OH} -> no overhead bits per frame

b_r -> no. of overhead bits

b_p -> no of overhead bits per preamble in each slot

b_g -> no equivalent bits in each guard time interval

N_r -> reference bursts per frame,

N_t -> traffic bursts per frame.

* Then the frame efficiency is

$$\eta_f = \left[1 - \frac{b_{OH}}{b_T} \right] \times 100\%.$$

5.3.2TDMA/FDD IN GSM

As discussed earlier, GSM is widely used in Europe and other parts of the world.GSM uses a variation of TDMA along with FDD. GSM digitizes and compresses data, then sends it down a Channel with two other streams of user data, each in its own time slot.

It operates at either the 900 MHz or 1800 MHz frequency band. Since many GSM network operators have roaming agreements with foreign operators, users can often continue to use their mobile phones when they travel to other countries.

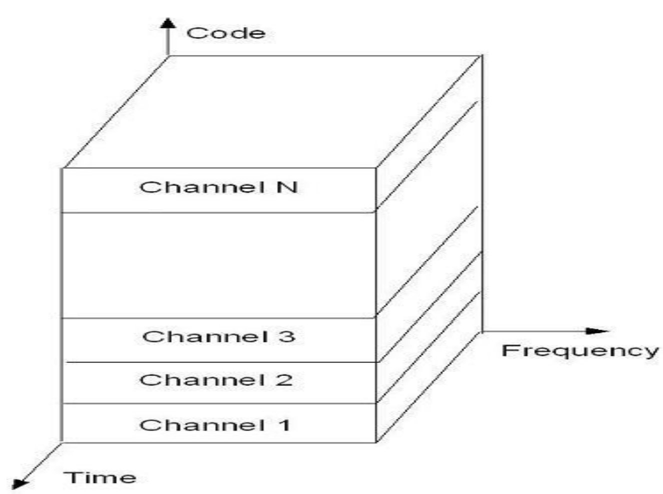
5.3.3 TDMA/TDD IN DECT

DECT is a pan European standard for the digitally enhanced cordless telephony using TDMA/TDD. DECT provides 10 FDM Channels in the band 1880-1990 MHz each Channel supports 12 users through TDMA for a total system load of 120 users.

DECT supports Hand-Over. Users can roam over from cell to cell as long as they remain within the range of the system. DECT antenna can be equipped with optional spatial diversity to deal with multipath fading.

5.4 SPREAD SPECTRUM MULTIPLE ACCESS [SSMA]

Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth whose magnitude is greater than the minimum required RF bandwidth. A pseudo noise (PN) sequence converts a narrowband signal to a wideband noise like signal before transmission. SSMA is not very bandwidth efficient when used by a single user. However since many users can share the same spread spectrum bandwidth without interfering with one another, spread spectrum systems become bandwidth efficient in a multiple user environment.



There are two main types of spread spectrum multiple access techniques:

1. Frequency Hopped Multiple Access (FHMA)
2. Direct sequence multiple access (DSMA) or Code division multiple access (CDMA).

5.4.1 FREQUENCY HOPPED MULTIPLE ACCESS (FHMA)

This is a digital multiple access system in which the carrier frequencies of the individual users are varied in a pseudo random fashion within a wideband Channel. The digital data is broken into uniform sized bursts which are then transmitted on different carrier frequencies.

5.4.2 CODE DIVISION MULTIPLE ACCESS

In CDMA, the same bandwidth is occupied by all the users, however they are all assigned separate codes, which differentiates them from each other (shown in Figure). CDMA utilize a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrowband message signal.

Direct Sequence Spread Spectrum (DS-SS)

This is the most commonly used technology for CDMA. In DS-SS, the message signal is multiplied by a Pseudo Random Noise Code.

Each user is given his own code-word which is orthogonal to the codes of other users and in order to detect the user, the receiver must know the codeword used by the transmitter. There are, however, two problems in such systems which are discussed below.

5.4.3 CDMA/FDD IN IS-95

In this standard, the frequency range is: 869-894 MHz (for Rx) and 824-849 MHz (for Tx). In such a system, there are a total of 20 Channels and 798 users per Channel. For each Channel, the bit rate is 1.2288 Mbps. For orthogonality, it usually combines64 Walsh-Hadamard codes and an m-sequence.

5.4.3 SELF-INTERFERENCE PROBLEM OR SELF JAMMING

In CDMA, self-interference arises from the presence of delayed replicas of signal due to multipath. The delays cause the spreading sequences of the different users to lose their orthogonality, as by design they are orthogonal only at zero phase offset. Hence in dispreading a given user's waveform, nonzero contributions to that user's signal arise from the transmissions of the other users in the network. This is distinct from both TDMA and FDMA, wherein for reasonable time or frequency guard-bands, respectively, orthogonality of the received signals can be preserved.

5.4.4 NEAR-FAR PROBLEM

The near-far problem is a serious one in CDMA. This problem arises from the fact that signals closer to the receiver of interest are received with smaller attenuation than are signals located further away. Therefore the strong signal from the nearby transmitter will mask the weak signal from the remote transmitter.

In TDMA and FDMA, this is not a problem since mutual interference can be filtered. In CDMA, however, the near-far effect combined with imperfect orthogonality between codes(e.g. due to different time sifts), leads to substantial interference. Accurate and fast power control appears essential to ensure reliable operation of multiuser DS-CDMA systems.

5.5 SPACE DIVISION MULTIPLE ACCESS [SDMA]

SDMA utilizes the spatial separation of the users in order to optimize the use of the frequency spectrum. A primitive form of SDMA is when the same frequency is reused in different cells in a cellular wireless network. The radiated power of each user is controlled by Space division multiple access. SDMA serves different users by using spot beam antenna.

These areas may be served by the same frequency or different frequencies. However for limited co-Channel interference it is required that the cells are sufficiently separated. This limits the number of cells a region can be divided into and hence limits the frequency re-use factor.

A more advanced approach can further increase the capacity of the network. This technique would enable frequency re-use within the cell. In a practical cellular environment it is improbable to have just one transmitter fall within the receiver beam width.

Therefore it becomes imperative to use other multiple access techniques in conjunction with SDMA. When different areas are covered by the antenna beam, frequency can be re-used, in which case. TDMA or CDMA is employed, for different frequencies FDMA can be used.

5.6 COMPARISON OF VARIOUS MULTIPLE DIVISION TECHNIQUES

Technique	FDMA	TDMA	CDMA	SDMA
Concept	Divide the frequency band into disjoint subbands	Divide the time into non-overlapping time slots	Spread the signal with orthogonal codes	Divide the space into sectors
Active terminals	All terminals active on their specified frequencies	Terminals are active in their specified slot on same frequency	All terminals active on same frequency	Number of terminals per beam depends on FDMA/TDMA/CDMA
Signal separation	Filtering in frequency	Synchronization in time	Code separation	Spatial separation using smart antennas
Handoff	Hard handoff	Hard handoff	Soft handoff	Hard and soft handoffs
Advantages	Simple and robust	Flexible	Flexible	Very simple, increases system capacity
Disadvantages	Inflexible, available frequencies are fixed, requires guard bands	Requires guard space, synchronization problem	Complex receivers, requires power control to avoid near-far problem	Inflexible, requires network monitoring to avoid intracell handoffs
Current applications	Radio, TV, and analog cellular	GSM and PDC	2.5G and 3G	Satellite systems, others being explored

5.7 ADVANCED MOBILE PHONE STANDARD [AMPS]

Advanced Mobile Phone System (AMPS) was an analog mobile phone system standard developed by Bell Labs, and officially introduced in the Americas in 1983.It was the primary analog mobile phone system in North America (and other locales) through the 1980s and into the 2000s. Later this technology is succeeded by Digital AMPS.

While Motorola was developing a cellular phone, from 1968-1983 Bell Labs worked out a system called Advanced Mobile Phone System (AMPS), which became the first cellular network standard in the U.S. Motorola and others designed and built the cellular phones for this and other cellular systems. AMPS is a first-generation cellular technology that uses separate frequencies, or "Channels", for each conversation (Frequency-division multiple access (FDMA)). It therefore required considerable bandwidth for a large number of users.

In general terms, AMPS was very similar to the older "0G" Improved Mobile Telephone Service, but used considerably more computing power in order to select frequencies, hand off conversations to PSTN lines, and handle billing and call setup.

"Back end" call setup functionality is a special feature of AMPS when compared to older generation systems. In AMPS, the cell centers could flexibly assign Channels to handsets based on signal strength, allowing the same frequency to be re-used in various locations without interference. This allowed a larger number of phones to be supported over a geographical area. AMPS pioneers coined the term "cellular" because of its use of small hexagonal "cells" within a system.

AMPS suffered from many weaknesses compared to digital technologies. As an analog standard, it was susceptible to static and noise, and there was no protection from 'eavesdropping' using a scanner. AMPS cellular service operated in the 850 MHz Cellular band. D-AMPS was a digital, 2G standard used mainly by AT&T Mobility and U.S. Cellular in the United States, succeeded and replaced the analog AMPS.

Parameters	Specifications
Uplink frequencies	824-849 MHz
Downlink frequencies	869- 894 MHz
Channel spacing	30 MHz
Modulation	Frequency modulation
No .of Channels	832
Multiple Access	FDMA

5.8 GSM – GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS

5.8.1 Historical Overview

The Global System for Mobile communications (GSM) is by far the most successful mobile Communication system worldwide. Its development started in 1982. The European Conference of Postal and Telecommunications Administrations (CEPT), predecessor of the European Telecommunication Standards Institute (ETSI), founded the Groupe Speciale Mobile, with the mandate to develop proposals for a pan-European digital mobile communication system. Two goals were supposed to be achieved:

- First, a better and more efficient technical solution for wireless communications – it had become evident at that time that digital systems would be superior in respect to user capacity, ease of use, and number of possible additional services compared with the then-prevalent analog systems.
- Second, a single standard was to be realized all over Europe, enabling roaming across borders. This was not possible before, as incompatible analog systems were employed in different countries.

In the following years, several companies developed proposals for such a system. These proposals covered almost all possible technical approaches in different technical areas. For multiple access, Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA) were suggested. The proposed modulation techniques were Gaussian Minimum Shift Keying (GMSK), 4-Frequency Shift Keying (4-FSK), Quadrature Amplitude Modulation (QAM), and Adaptive Differential Pulse Modulation (ADPM). Transmission rates varied from 20 kbit/s to 8Mbit/s.

In the early 1990s, it was realized that GSM should have functionalities that had not been included in the original standard. Therefore, the so-called phase-2 specifications, which included these functions, were developed until 1995. Further enhancements, which include packet radio - General Packet Radio Service (GPRS), and the more efficient modulation of Enhanced Data rates for GSM Evolution (EDGE), have been introduced since then. Because of these extensions GSM is often referred to as the 2.5th generation system, as its functionalities are beyond those of a second-generation system, but do not enable all third-generation functionalities.

The success of GSM exceeded all expectations. Though it was originally developed as a European system, it has spread all over the world in the meantime. Australia was the first non-European country that signed the basic agreement (Memorandum of Understanding (MoU)). Since then, GSM has become the worldwide mobile communication standard,1 with a number of subscribers that approached 3.5 billon in 2009. A few exceptions remain in Japan and Korea, where GSM was never implemented. In the U.S.A., GSM was competing with the CDMA-based Interim Standard-95 (IS-95) system. In contrast to most countries where spectral licenses were provided on condition that the network operator would use GSM, the licenses in the U.S.A. were sold without requiring companies to implement a specific system. In 2009, there were two major operators offering GSM based services, while another two were using rival technologies.

There are three versions of GSM, each using different carrier frequencies. The original GSM system uses carrier frequencies around 900 MHz. GSM1800, which is also called Digital Cellular System at the 1800-MHz band (DCS1800), was added later to support the increasing numbers of subscribers. Its carrier frequencies are around 1,800 MHz, the total available bandwidth is roughly three times larger than the one around 900 MHz, and the maximal transmission power of MSs is reduced. Apart from this, GSM1800 is identical to the original GSM. Thus, signal processing, switching technology, etc. can be reused without changes. The higher carrier frequency, which implies a smaller path gain, and reduced transmission power reduce the sizes of the cells significantly.

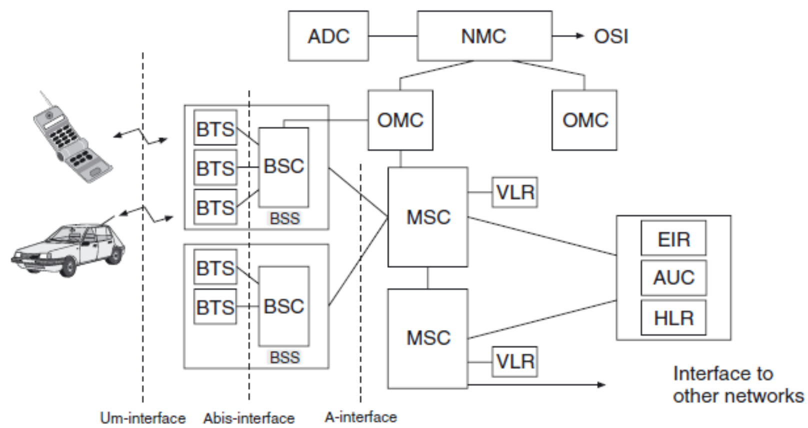
5.8.2 SYSTEM OVERVIEW

A GSM system consists essentially of three parts – namely, the Base Station Subsystem (BSS), the Network and Switching Subsystem (NSS), and the Operation Support System (OSS).

5.8.2.1 BASE STATION SUBSYSTEM

The BSS consists of Base Transceiver Stations (BTSs) and the Base Station Controllers (BSCs). The BTS establishes and maintains the connection to the MSs within its cell. The interface between the MS and the BTS is the air interface, called the Um-interface in the GSM context. The BTS hosts, at a minimum, the antennas and the Radio

Frequency (RF) hardware of a BS, as well as the software for multiple access. Several – or, rarely, one – BTSs are connected to one BSC; they are either collocated, or connected via landline, directional microwave radio links, or similar connections. The BSC has control functionality. It is, among other things, responsible for HandOver HO) between two BTSs that are connected to the same BSC. The interface between BTS and BSC is called the Abis-interface. In contrast to the other interfaces, this interface is not completely specified in the standard.2 Distribution of the functionalities between BTS and BSC may differ depending on the manufacturer. In most cases, one BSC is connected to several BTSs. Therefore, it is possible to increase the efficiency of implementation by shifting as much functionality as possible to the BSC. However, this implies increased signaling traffic on the link between the BTS and the BSC, which might be undesirable (remember that these links are often rented landline connections). In general, the BSS covers a large set of functionalities. It is responsible for Channel assignment, maintenance of link quality and handover, power control, coding, and encryption.



5.8.2.2 NETWORK AND SWITCHING SUBSYSTEM

The main component of the NSS is the Mobile-services Switching Center (MSC), which controls the traffic between different BSCs. One function of the MSC is mobility management, which comprises all the functions that are necessary to enable true mobility for subscribers. To give but one example, one function of the MSC is the management of HOs that occur when an MS is leaving the area of one BSC and moving into the area covered by another BSC. Other functions are the so-called paging and location update. All interactions with other networks – especially the landline Public Switched Telephone Network (PSTN) – are also performed by the MSC.

The NSS includes some databases, too. The Home Location Register (HLR) contains all the numbers of the mobile subscribers associated with one MSC and information about the location of each of these subscribers. In the event of an incoming call, the location of the desired subscriber is looked up in the HLR and the call is forwarded to this location. Therefore, we can conclude that from time to time a traveling MS has to send updates of its location to its HLR.

The Visitor Location Register (VLR) of one MSC contains all the information about mobile subscribers from other HLRs that are in the area of this MSC and are allowed to roam in the network of this MSC. Furthermore, a temporary number will be assigned to the MS to enable the "host" MSC to establish a connection to the visiting MS. The Authentication Center (AUC) verifies the identity of each MS requesting a connection. The Equipment Identity Register (EIR) contains centralized information about stolen or misused devices.

5.8.2.3 OPERATING SUPPORT SYSTEM

The OSS is responsible for organization of the network and operational maintenance. More specifically, the OSS mainly covers the following functions:

1. Accounting: how much does a specific call cost for a certain subscriber? There are also plenty of different services and features, from which each subscriber may choose an individual selection included in a specific plan. While this rich choice of services and prices is vital in the marketplace, the administrative support of this individualism is rather complicated.

2. Maintenance: the full functionality of each component of the GSM network has to be maintained all the time. Malfunctions may either occur in the hardware or in the software components of the system. Hardware malfunctions are more costly, as they require a technician to drive to the location of the malfunction. In contrast, software is nowadays administrated from a central location. For example, new versions of switching software can be installed in the complete BSS from a central location, and activated all over the network at a specific time. Revision and maintenance software often constitutes a considerable part of the overall complexity of GSM control software.

3. MS management: even though all MSs have to pass a type approval, it may happen that "bad apple" devices, which cause system wide interference, are operating in the network. These devices have to be identified and their further activities have to be blocked.

4. Data collection: the OSS collects data about the amount of traffic, as well as the quality of the links.

5.8.3 THE AIR INTERFACE

GSM employs a combined FDMA/TDMA approach which further combines with Frequency Domain Duplexing (FDD)

FDD

In the first GSM version, frequencies from 890 to 915MHz and from 935 to 960MHz were available. The lower band is used for the uplink (connection from the MS to the BS). The upper band is used for the downlink. The frequency spacing between the uplink and downlink for any given connection is 45MHz. Therefore, relatively cheap duplex filters are sufficient for achieving very good separation between the uplink and downlink. For GSM1800, the frequency ranges are 1,710–1,785MHz for the uplink, and 1,805–1,880MHz for the downlink. In North America, 1,850–1,910MHz is used for the uplink and 1,930–1,990MHz for the downlink.

FDMA

Both uplink and downlink frequency bands are partitioned into a 200-kHz grid. The outer 100 kHz of each 25-MHz band are not used, as they are guard bands to limit interference in the adjoined spectrum, which is used by other systems. The remaining 124 200-kHz subbands are numbered consecutively by the so-called Absolute Radio Frequency Channel Numbers (ARFCNs).

TDMA

Due to the very-bandwidth-efficient modulation technique (GMSK, see below), each 200-kHz subband supports a data rate of 271 kbit/s. Each subband is shared by eight users. The time axis is partitioned into timeslots, which are periodically available to each of the possible eight users. Each timeslot is 576.92 µs long, which is equivalent to 156.25 bits. A set of eight timeslots is called a frame; it has duration of 4.615 ms. Within each frame, the timeslots are numbered from 0 to 7. Each subscriber periodically accesses one specific timeslot in every frame on one frequency subband. The combination of timeslot number and frequency band is called the physical Channel. The kind of data that are transmitted over one such physical Channel depends on the logical Channel.

5.8.4 LOGICAL AND PHYSICAL CHANNELS

In addition to the actual payload data, GSM also needs to transmit a large amount of signaling information. These different types of data are transmitted via several logical Channels. The name stems from the fact that each of the data types is transmitted on specific timeslots that are parts of physical Channels. The first part of this section discusses the kind of data that is transmitted via logical Channels. The second part describes the mapping of logical Channels to physical Channels.

Logical Channels

Traffic Channels (TCHs)

Payload data are transmitted via the TCHs. The payload might consist of encoded voice data or "pure" data. There is a certain flexibility regarding the data rate: Full-rate Traffic Channels (TCH/F) and Half-rate Traffic Channels (TCH/H). Two half-rate Channels are mapped to the same timeslot, but in alternating frames.

Full-Rate Traffic Channels

• Full-rate voice Channels: the output data rate of the voice encoder is 13 kbit/s.Channel coding increases the effective transmission rate to 22.8 kbit/s.

· Full-rate data Channels: the payload data with data rates of 9.6, 4.8, or 2.4 kbit/s are encoded with Forward Error Correction (FEC) codes and transmitted with an effective data rate of 22.8 kbit/s.

Half-Rate Traffic Channels

• Half-rate voice Channels: voice encoding with a data rate as low as 6.5 kbit/s is feasible. Channel coding increases the transmitted data rate to 11.4 kbit/s.

Broadcast Channels (BCHs)

BCHs are only found in the downlink. They serve as beacon signals. They provide the MS with the initial information that is necessary to start the establishment of any kind of connection. The MS uses signals from these Channels to establish a synchronization in both time and frequency. Furthermore, these Channels contain data regarding, e.g., cell identity. As the BSs are not synchronized with respect to each other, the MS has to track these Channels not only before a connection is established, but all the time, in order to provide information about possible HOs.

Frequency Correction Channels (FCCHs)

The carrier frequencies of the BSs are usually very precise and do not vary in time, as they are based on rubidium clocks. However, dimension considerations and price considerations make it impossible to implement such good frequency generators in MSs. Therefore, the BS provides the MS with a frequency reference (an unmodulated carrier with a fixed offset from the nominal carrier frequency) via the FCCH. The MS tunes its carrier frequency to this reference; this ensures that both the MS and the BS use the same carrier frequency.

Synchronization Channel (SCH*)*

In order to transmit and receive bursts appropriately, an MS not only has to be aware of the carrier frequencies used by the BS but also of its frame timing on the selected carrier. This is achieved with the SCH, which informs the MS about the frame number and the Base Station Identity Code (BSIC). Decoding of the BSIC ensures that the MS only joins admissible GSM cells and does not attempt to synchronize to signals emitted by other systems in the same band.

Broadcast Control Channel (BCCH)

Cell-specific information is transmitted via the BCCH. This includes, e.g., Location Area Identity (LAI),7 maximum permitted signal power of the MS, actual available TCH, frequencies of the BCCH of neighboring BSs that are permanently observed by the MS to prepare for a handover, etc.

Common Control Channels (CCCHs)

Before a BS can establish a connection to a certain MS, it has to send some signaling information to all MSs in an area, even though only one MS is the desired receiver. This is necessary because in the initial setup stage, there is no dedicated Channel established between the BS and a MS. CCCHs are intended for transmission of information to all MSs.

Paging Channel (PCH)

When a request – e.g., from a landline – arrives at the BS to establish a connection to a specific MS, the BSs within a location area send a signal to all MSs within their range. This signal contains either the permanent International Mobile Subscriber Identity (IMSI) or the Temporary Mobile Subscriber Identity (TMSI) of the desired MS. The desired MS continues the process of establishing the connection by requesting (via a Random Access Channel (RACH)) a TCH. The PCH may also be used to broadcast local messages like street traffic information or commercials to all subscribers within a cell. Evidently, the PCH is only found in the downlink.

Random Access Channel (RACH*)*

A mobile subscriber requests a connection. This might have two reasons. Either the subscriber wants to initiate a connection, or the MS was informed about an incoming connection request via the PCH. The RACH can only be found in the uplink.

Access Grant Channel (AGCH)

Upon the arrival of a connection request via the RACH, the first thing that is established is a Dedicated Control Channel (DCCH) for this connection. This Channel is called the Standalone Dedicated Control Channel (SDCCH). This Channel is assigned to the MS via the AGCH, which can only be found in the downlink.

Dedicated Control Channels (DCCHs)

Similar to the TCHs, the DCCHs are bidirectional – i.e., they can be found in the uplink and downlink. They transmit the signaling information that is necessary during a connection. As the name implies, DCCHs are dedicated to one specific connection.

Standalone Dedicated Control Channel (SDCCH)

After acceptance of a connection request, the SDCCH is responsible for further establishing this connection. The SDCCH ensures that the MS and the BS stay connected during the authentification process. After this process has been finished, a TCH is finally assigned for this connection via the SDCCH.

Slow Associated Control Channel (SACCH)

Information regarding the properties of the radio link is transmitted via the SACCH. This information need not be transmitted very often, and therefore the Channel is called slow. The MS informs the BS about the strength and quality of the signal received from serving BSs and neighboring BSs. The BS sends data about the power control and runtime of the signal from the MS to the BS.

Fast Associated Control Channel (FACCH)

The FACCH is used for HOs that are necessary for a short period of time; therefore, the Channel has to be able to transmit at a higher rate than the SACCH. Transmitted information is similar to that sent by the SDCCH. The SACCH is associated with either a TCH or a SDCCH; the FACCH is associated with a TCH.

5.9 CELLULAR CONCEPTS

Radio telephone system should be structured to achieve high capacity with limited radio spectrum while at the same time covering very large areas.

Older System:

- Achieve a large coverage area by using a simple, high powered transmitter.
- Put BS on top of mountains or tall towers, so that it could provide coverage for a large area.
- The next BS was so far away that interference was not an issue.
- Severely limit the number of users that could communicate simultaneously.
- Noise-limited system with few users.
- The Bell mobile system in New York City in the 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles.

The number of simultaneous calls a mobile wireless system can accommodate is essentially determined by the total spectral allocation for that system and the bandwidth required for transmitting signals used in handling a call.

Example- Using a typical analog system, each channel needs to have a bandwidth of around 25 kHz to enable sufficient audio quality to be carried, as well as allowing for a guard band between adjacent signals to ensure there are no undue levels of interference. Using this concept, it is possible to accommodate only forty users in a frequency band 1-MHz wide. Even if 100 MHz were allocated to the system, this would enable only 4000 users to have access to the system. Today cellular systems have millions of subscribers, and therefore a far more efficient method of using the available spectrum is needed.

- Cellular systems accommodate a large number of users over a large geographic area, within a limited frequency spectrum.
- High capacity is achieved by limiting the coverage of each base station transmitter to a small geographic area called a cell so that the same radio channels may be reused by another base station located some distance away.
- The coverage area is divided into many cells.

- Replace a single, high power transmitter (large cell) with many low power transmitters (small cells) each providing coverage to only one cell area (a small portion of the service area).
- A sophisticated switching technique called a handoff enables a call to proceed un-interrupted when the user moves from one cell to another.

The concept of cells was first proposed as early as 1947 by Bell Laboratories in the US, with a detailed proposal for a High-Capacity Mobile Telephone System incorporating the cellular concept submitted by Bell Laboratories to the FCC in 1971. The first AMPS system was deployed in Chicago in 1983.

Basic cellular system

- Consist of mobile stations, base stations, and a mobile switching center (MSC).
- Mobile switching center (MSC)
- Sometimes called a mobile telephone switching office (MTSO)
- Coordinates the activities of all of the base stations
- Connect the entire cellular system to the PSTN.
- Accommodates all billing and system maintenance functions
- Each mobile communicates via radio with one of the base stations and may be handed-off to any number of base stations throughout the duration of a call.
- Mobile station
- Contains a transceiver, an antenna, and control circuitry.
- Base stations
- Serve as a bridge between all mobile users in the cell and connects the simultaneous mobile calls via telephone lines or microwave links to the MSC.
- Consist of several transmitters and receivers which simultaneously handle full duplex communications
- Generally have towers which support several transmitting and receiving antennas.

Communication between the base station and the mobiles is defined by a standard common air interface (CAI) that specifies four different channels.

(a) Forward voice channels (FVC): voice transmission from the base station to mobiles

(b) Reverse voice channels (RVC): voice transmission from mobiles to the base station

(c) Forward control channels (FCC) and reverse control channels (RCC)

- Often called setup channels
- Involve in setting up a call and moving it to an unused voice channel.
- Initiate mobile calls
- Transmit and receive data messages that carry call initiation and service requests, and are monitored by mobiles when they do not have a call in progress.
- FCCs also serve as beacons which continually broadcast all of the traffic requests for all mobiles in the system.
- Supervisory and data messages are sent in a number of ways to facilitate automatic channel changes and handoff instructions for the mobiles before and during a call.

5.10 FREQUENCY REUSE

Frequency reuse refers to the use of radio channels on the same carrier frequency to cover different areas which are separated from one another by sufficient distances so that co-channel interference is not objectionable. Frequency reuse is employed not only in mobile-telephone service but also in entertainment broadcasting and most other radio services. Most modern wireless systems are organized into geographic cells, each controlled by a base station. Exceptions: Small-area systems such as local-area wireless networks and personal-area networks, Ad hoc and wireless sensor networks.

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a cell.

Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. The base station antennas are designed to achieve the desired coverage within the particular cell.

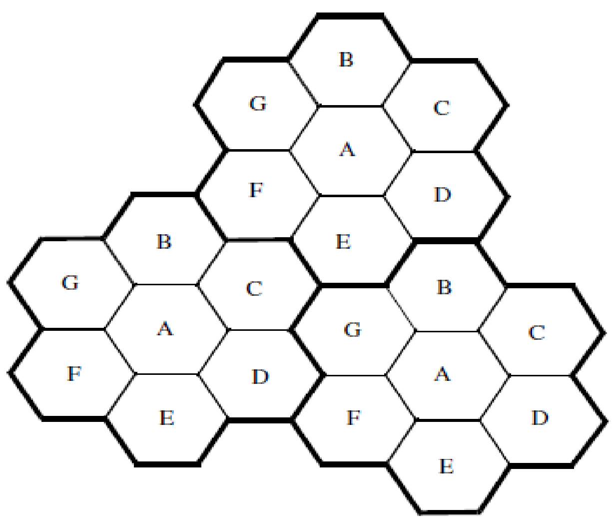
By limiting the coverage area within the boundaries of a cell, the same group of channel may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits.

The distance between two cells that an use the same frequency channels is called the reuse distance. This reuse distance can be computed from link budgets. Why can't we use each frequency in each cell? Same reason as why we separate the BSs of the older system far away from one another.

Suppose user A is at the boundary of its assigned cell, so that distances from the useful BS and from a neighboring BS are the same. If the neighboring BS transmits in the same frequency channel (in order to communicate with user B in its own cell), then the signal-to-interference ratio (SIR) seen by user A is 0 dB. So, reuse a frequency not in every cell, but only in cells that have a certain minimum distance from each other. Using different allocated frequency bands, adjacent cells can overlap without causing interference.

We use hexagonal cell shape as a simplistic model of the radio coverage for each base station. Universally adopted since the hexagon permits easy and manageable analysis of a cellular system. The actual radio coverage of a cell is known as the footprint and is determined from field measurements or propagation prediction models.

In reality, it is not possible to define exactly the edge of a cell. The signal strength gradually reduces, and towards the edge of the cell performance falls. As the mobiles themselves also have different levels of sensitivity, this adds a further greying of the edge of the cell. It is therefore impossible to have a sharp cut-off between cells. In some areas they may overlap, whereas in others there will be a hole in coverage. Although the real footprint is amorphous in nature, a regular cell shape is needed for systematic system design and adaptation for future growth. Why hexagon? Adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions. When considering geometric shapes which cover an entire region without overlap and with equal area, there are three sensible choices: a square, an equilateral triangle, and a hexagon. A cell must be designed to serve the weakest mobiles within the footprint, and these are typically located at the edge of the cell. For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three. By using the hexagon geometry, the fewest number of cells can cover a geographic region. Closely approximate a circular radiation pattern which would occur for an omnidirectional base station antenna and free space propagation. Permit easy and manageable analysis of a cellular system.



The above figure illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the same group of channels. The frequency reuse plan is overlaid upon a map to indicate where different frequency channels are used.

Cluster

- The total coverage area is divided into clusters.

- There can be no co-channel interference within a cluster.
- The number of cells in a cluster is called the cluster size. This number is denoted by N.
- The N cells collectively use the complete set of available frequencies.

Capacity

Let S = the total number of available duplex radio channels for the system

k = the number of channels allocated to each cell (k < S)

N = cluster size

(a) If the S channels are divided among N cells into unique and disjoint channel groups which each have the same number of channels,

$$S = kN$$

(b) If a cluster is replicated M times within the system, the total number of duplex channels, C, is given by

$$C = MS = MkN$$

(c) For a fixed total coverage area A_{total} and the coverage area A_{cell} of each cell, the number of cells in the system is

$$M \; X \; N = \frac{A_{TOTAL}}{A_{CELL}}$$

In which case,

$$C = \frac{A_{TOTAL}}{A_{CELL}} \text{x} \frac{S}{N}$$

5.11 CHANNEL ASSIGNMENT

For efficient utilization of radio spectrum a frequency reuse scheme with increasing capacity and minimizing interference is required. For this channel assignment is used

Types : Fixed channel assignment, dynamic channel assignment.

5.11.1 FIXED CHANNEL ASSIGNMENT

If the channels in each cell is allocated to the users within the cell, it will be called as fixed channel assignment. If all channels are occupied, the call Will be blocked.

5.11.2 DYNAMIC CHANNEL ASSIGNMENT

If the voice channels are not allocated permanently in a cell, it will be called as dynamic channel assignment. In this assignment, channels are dynamically allocated to users by the MSC.

5.12 HANDOFF

When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station. This handoff operation not only involves identifying a new base station, but also requires that the voice and control signals be allocated to channels associated with the new base station.

Processing handoffs is an important task in any cellular radio system. Many handoff strategies prioritize handoff requests over call initiation requests when allocating unused channels in a cell site. Handoffs must be performed successfully and as infrequently as possible, and be imperceptible to the users. In order to meet these requirements, system designers must specify an optimum signal level at which to initiate a handoff. Once a particular signal level is specified as the minimum usable signal for acceptable voice quality at the base station receiver (normally taken as between –90 dBm and –100 dBm), a slightly stronger signal level is used as a threshold at which a handoff is made. This margin, given by Δ = Pr handoff – Pr minimum usable, cannot be too large or too small. If Δ is too large, unnecessary handoffs which burden the MSC may occur, and if Δ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions. Therefore, Δ is chosen carefully to meet these conflicting requirements.

Dropped call event can happen when there is an excessive delay by the MSC in assigning a handoff or when the threshold Δ is set too small for the handoff time in the system. Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact that no channels are available on any of the nearby base stations (thus forcing the MSC to wait until a channel in a nearby cell becomes free).

Hand off

* Process of transferring a moving active user from one base station to another without disrupting the call.

Hand off strategies

1. Ist generation hand off
2. MAHO [mobile Assisted Hand off]
3. Inter System hand off
4. Guard channel Concept
5. Queuing
6. Umbrella approach
7. Soft and hard hand off
8. cell dragging

→ Ist generation hand off -

* In this almost all the work were carried out by msc with the help of base station.
* Using the locator receiver the msc will measure the signal strength of the moving mobile
* If the level decreases it will perform handoff by its own.

→ MAHO [mobile Assisted Hand off]:

* In this every mobile station measures the received power from surrounding base stations and continually reports the results of these measurements to the serving base station.

* when the power received from the base station of a neighboring cell begins to exceed the power received from the current base station by a certain level or for a certain period of time a handoff is initiated.

* Since all the measurements were done by the mobile, the load of the msc is reduced considerably.

→ Inter System handoff – occurs if a mobile moves from one cellular system to a different ~~MSC~~ cellular system controlled by a different MSC [service provider] or while roaming.

→ Guard channel Concept – In this some channels are reserved only for hand off.

→ Queuing :- If more number of users request handoff the they will be placed in queue before alloting channels.

→ Umbrella approach :-

(i) Speed of the user is a main factor in deciding a successful hand off.

(ii) In urban areas the cell size will be very small and high speed users will cross quickly.

(iii) To perform handoff on these high speed users we use micro and macro cells concurrently.

→ Cell dragging.

(i) Cell dragging occurs in an urban environment when there is a line-of-sight [LOS] radio path between the pedestrian subscriber and the base station.

(ii) Even after the user has traveled well beyond the designed range of the cell, the received signal at the base station does not decay rapidly resulting in cell dragging.

→ Soft and hard hand off

(i) Hard hand-off → when the user moves to a new cell, he will be assigned with a new set of channels.

(ii) Soft hand-off → when the user moves to a new cell, the channel itself will be switched to the new base station. CDMA uses Soft Hand off.

5.13 BLUETOOTH

Bluetooth is a standard used in links of radio of short scope, destined to replace wired connections between electronic devices like cellular telephones, Personal Digital Assistants (PDA), computers, and many other devices. Bluetooth technology can be used at home, in the office, in the car, etc. This technology allows to the users instantaneous connections of voice and information between several devices in real time. The way of transmission used assures protection against interferences and safety in the sending of information. Between the principal characteristics, must be named the hardiness, low complexity, low consume and low cost. The Bluetooth is a small microchip that operates in a band of available frequency throughout the world. Communications can realize point to point and point multipoint.

How it works?

Every device will have to be equipped with a microchip (transceiver) that transmits and receives in the frequency of 2.4 GHz that is available in the whole world (with some variations of bandwidth in different countries). Besides the information, there are three channels of voice available.

The information can be exchanged to speeds of up to 1 megabit for second (2 megabits for second in the Second Generation of this Technology). A scheme of “frequency hop” (jumps of frequency) allows to the devices to communicate inclusive in areas where a great electromagnetic interference exists. Besides that is provided with schemes of encryptation and check.

Frequency Bands

The standard Bluetooth operates in the band of 2,4 GHz. Though worldwide, this band is available, the width of the band can differ in different countries. This is the frequency of band of the scientific and medical industries 2.45 GHz (ISM*). The ranges of the bandwidth in The United States and Europe are between 2.400 to 2.483,5 MHz and it covers part of France and Spain. The ranges of the bandwidth in Japan are between 2.471 to 2.497 MHz. So the system can be used worldwide due to that the transmitters of radio covers 2.400 and 2.500 MHz and it is possible to select the appropriate frequency. This ISM is opened for any system of radio and must take care of the interferences of monitors for baby, the controls for doors of garages, the wireless telephones and the microwave ovens (the source with higher interference).

Power

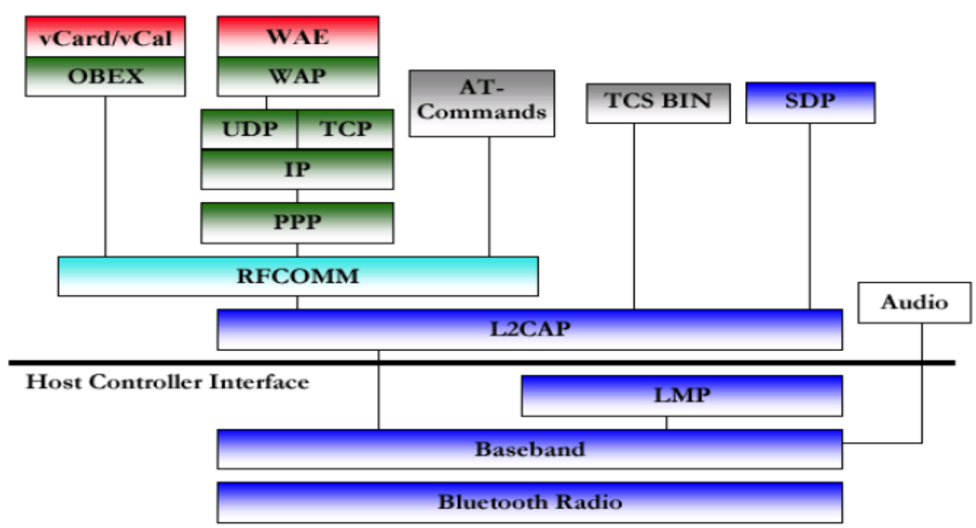
The equipments of transmission are qualified in 3 groups according to the level of power of emission, as we can see below. The recipient equipment must possess a sensibility of at least 70 dBm, and the rate of admissible mistake must be a minor or equal to 0,1 %.

Device Power Class	Maximum Permitted Power mW(dBm)	Range (approximate)
Class 1	100 mW (20 dBm)	~100 meters
Class 2	2.5 mW (4 dBm)	~10 meters
Class 3	1 mW (0 dBm)	~1 meter

The chip is going to be incorporated in portable devices and powered by batteries, that´s why it must has a very limited consumption of power (up to 97 % less than a mobile telephone). If the Bluetooth devices do not exchange information, then they establish the way of "wait" to save energy, staying to the scout of messages. The power of transmission that is used as specification is of 1 mW for a scope of 10 m, 100 mW for a scope of up to 100 m.

Protocols

Different applications can operate under different sets of protocols; nevertheless, all of them have a link of information and a physical cap common Bluetooth. The figure below shows the set of protocols:



MAIN APPLICATIONS

Bluetooth's applications are very varied and allow changing radically the form that the users interact with the mobile telephones and other devices. Inside the field of the technology, the application is immediate because it allows an easy, instantaneous communication, in any place and low cost. We cannot forget the impact in the way of realizing the processes, on having replaced the conventional means and having made new business and applications possible.

More prevalent applications of Bluetooth:

- Wireless control of and communication between a mobile phone and a hands-free headset. This was one of the earliest applications to become popular.

- Wireless networking between PCs in a confined space and where little bandwidth is required.
- Wireless communications with PC input and output devices, the most common being the mouse, keyboard and printer.
- Transfer of files between devices with OBEX (a kind of communications protocol).
- Replacement of traditional wired serial communications in test equipment, GPS receivers, medical equipment, bar code scanners, and traffic control devices.
- For controls where infrared was traditionally used.
- Sending small advertisements from Bluetooth enabled advertising hoardings to other, discoverable, Bluetooth devices.
- Two seventh-generation game consoles, Nintendo's Wii and Sony's PlayStation 3 use
- Bluetooth for their respective wireless controllers.
- Dial-up internet access on personal computer or PDA using a data-capable mobile
- phone as a modem.

5.14 CODE DIVISION MULTIPLE ACCESS

Spread-spectrum telecommunications is a technique in which a telecommunication signal is transmitted on a bandwidth considerably larger than the frequency content of the original information. Frequency hopping is a basic modulation technique used in spread spectrum signal transmission.

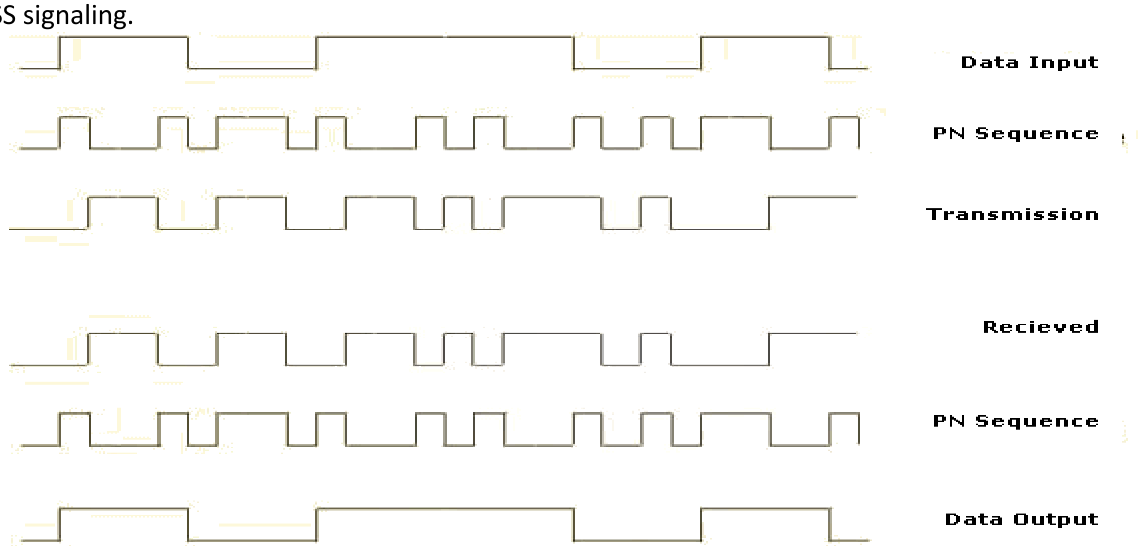
In telecommunication and radio communication, spread-spectrum techniques are methods by which a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise and jamming, to prevent detection, and to limit power flux density (e.g. in satellite downlinks).

Spread-spectrum telecommunications is a signal structuring technique that employs direct sequence, frequency hopping, or a hybrid of these, which can be used for multiple access and/or multiple functions. This technique decreases the potential interference to other receivers while achieving privacy. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wideband (radio) band of frequencies. The receiver correlates the received signals to retrieve the original information signal. Originally there were two motivations: either to resist enemy efforts to jam the communications (anti-jam, or AJ), or to hide the fact that communication was even taking place, sometimes called low probability of intercept (LPI).

Frequency-hopping spread spectrum (FHSS), direct-sequence spread spectrum (DSSS), time-hopping spread spectrum (THSS), chirp spread spectrum (CSS), and combinations of these techniques are forms of spread spectrum. Each of these techniques employs pseudorandom number sequences — created using pseudorandom number generators— to determine and control the spreading pattern of the signal across the allocated bandwidth.

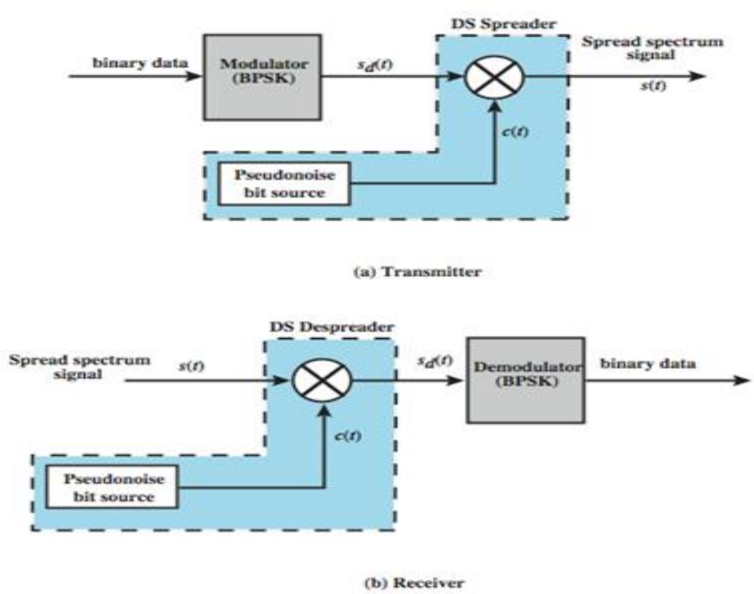
Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is used as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme.

In telecommunications, direct-sequence spread spectrum (DSSS) is a modulation technique. As with other spread spectrum technologies, the transmitted signal takes up more bandwidth than the information signal that modulates the carrier or broadcast frequency. The name 'spread spectrum' comes from the fact that the carrier signals occur over the full bandwidth (spectrum) of a device's transmitting frequency. Certain IEEE 802.11 standards use DSSS signaling.



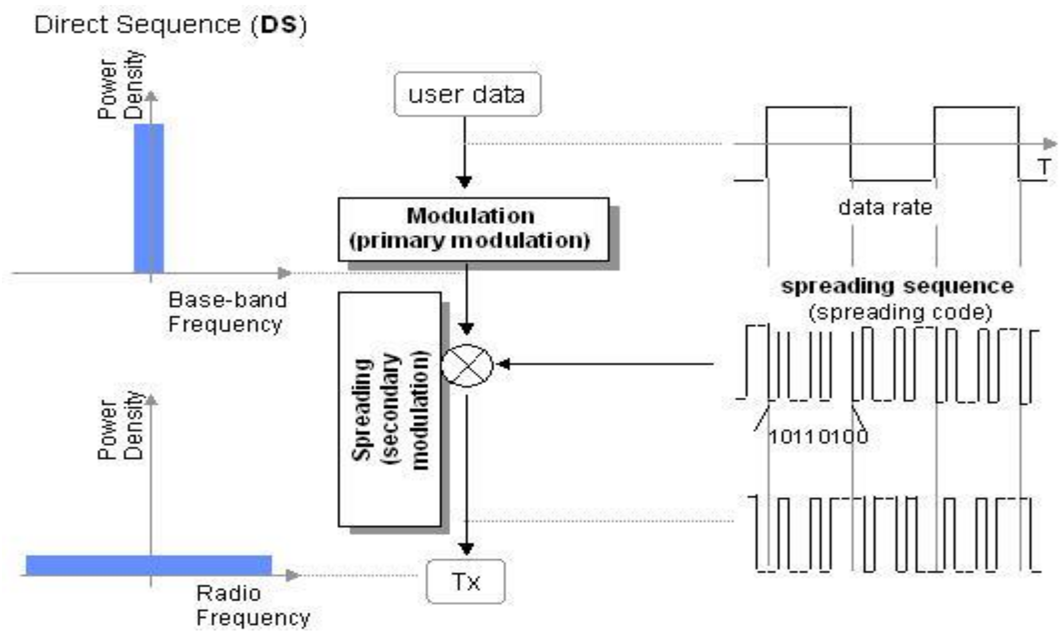
5.14.1 DIRECT SEQUENCE SPREAD SPECTRUM

Using CDMA the spread spectrum signal is obtained by modulating initial signal s(t) using specially formed sequence of positive and negative pulses— pseudo-noise (PN). Such method is called direct spreading.



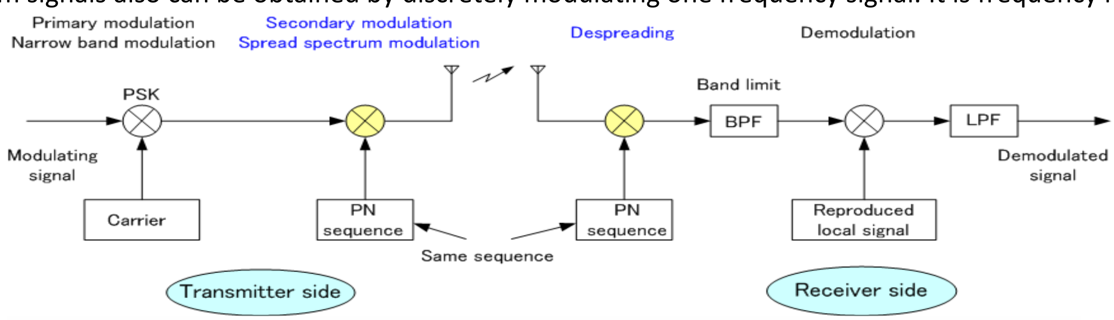
(a) Transmitter

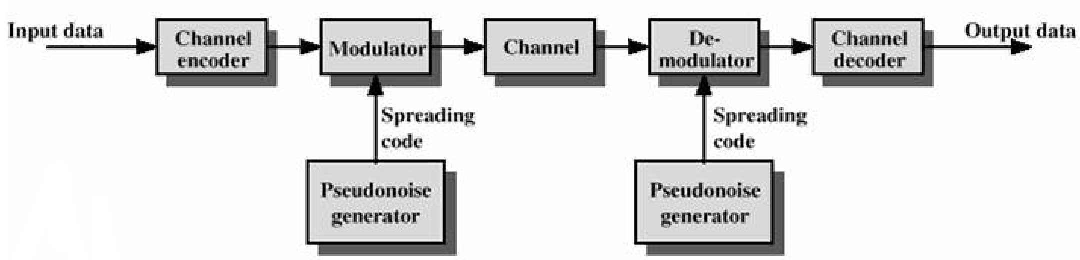
(b) Receiver

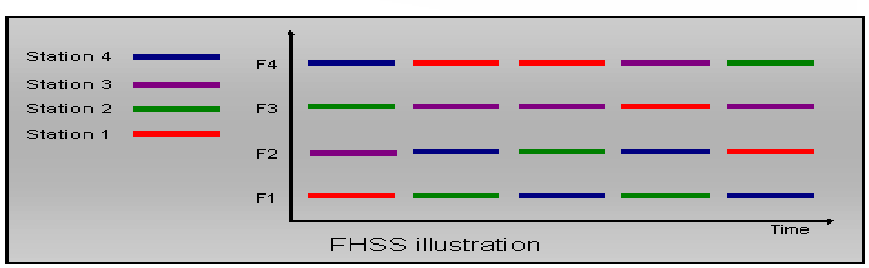


5.14.2 FREQUENCY HOPING SPREAD SPECTRUM

For a long time spread spectrum signals were obtained by modulating radio oscillation frequency using saw form signal. Using such modulation frequency of modulated signal is periodically changed. Spread spectrum signals also can be obtained by discretely modulating one frequency signal. It is frequency hopping method.







5.15 SATELLITE COMMUNICATION

A satellite is an artificial object which has been intentionally placed into orbit. Such objects are sometimes called artificial satellites to distinguish them from natural satellites such as the Moon. Satellites are used for a large number of purposes. Common types include military and civilian Earth observation satellites, communications satellites, navigation satellites, weather satellites, and research satellites. Satellites that are used for transmitting or broadcasting useful information for long ranges are known as communication satellites. A communications satellite or comsat is an artificial satellite sent to space for the purpose of telecommunications.

For fixed (point-to-point) services, communications satellites provide a microwave radio relay technology complementary to that of communication cables. They are also used for mobile applications such as communications to ships, vehicles, planes and hand-held terminals, and for TV and radio broadcasting.

Satellites are usually semi-independent computer-controlled systems. Satellite subsystems attend many tasks, such as power generation, thermal control, telemetry, attitude control and orbit control.

5.15.1 SATELLITE ORBITS

Satellite orbits vary greatly, depending on the purpose of the satellite, and are classified in a number of ways. Well-known (overlapping) classes include

- Low Earth orbit
- polar orbit, and
- geostationary orbit.

Modern communications satellites use a variety of orbits including geostationary orbits, Molniya orbits, elliptical orbits and low (polar and non-polar) Earth orbits.

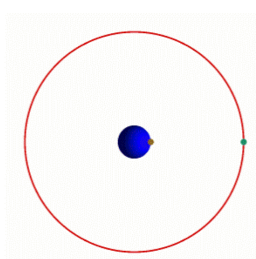
5.15.2 GEOSTATIONARY ORBITS

A geosynchronous orbit (sometimes abbreviated GSO) is an orbit around the Earth with an orbital period of one side real day (approximately 23 hours 56 minutes and 4 seconds), matching the Earth's sidereal rotation period. The synchronization of rotation and orbital period means that, for an observer on the surface of the Earth, an object in geosynchronous orbit returns to exactly the same position in the sky after a period of one sidereal day.

A special case of geosynchronous orbit is the geostationary orbit, which is a circular geosynchronous orbit at zero inclination (that is, directly above the equator). A satellite in a geostationary orbit appears stationary, always at the same point in the sky, to ground observers. Popularly or loosely, the term "geosynchronous" may be used to mean geostationary. Specifically, geosynchronous Earth orbit (GEO) may be a synonym for geosynchronous equatorial orbit, or geostationary earth orbit. Communications satellites are often given geostationary orbits, or close to geostationary, so that the satellite antennas that communicate with them do not have to move, but can be pointed permanently at the fixed location in the sky where the satellite appears.

A geostationary orbit (GEO) is a circular geosynchronous orbit in the plane of the Earth's equator with a radius of approximately 42,164 km (26,199 mi). A satellite in such an orbit is at an altitude of approximately 35,786 km (22,236 mi) above mean sea level. It maintains the same position relative to the Earth's surface.

To an observer on the earth, a satellite in a geostationary orbit appears motionless, in a fixed position in the sky. This is because it revolves around the earth at the earth's own angular velocity. A geostationary orbit is useful for communications because ground antennas can be aimed at the satellite without their having to track the satellite's motion. This is relatively inexpensive.



5.15.3 LOW EARTH ORBIT

A low Earth orbit (LEO) is an orbit around Earth with an altitude between 160 kilometers (99 mi), with an orbital period of about 88 minutes, and 2,000 kilometers (1,200 mi), with an orbital period of about 127 minutes. Objects below approximately 160 kilometers (99 mi) will experience very rapid orbital decay and altitude loss. With the exception of the manned lunar flights of the Apollo program, all human spaceflights have taken place in LEO (or were suborbital).

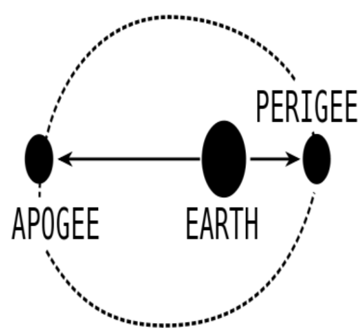
Objects in LEO encounter atmospheric drag in the form of gases in the thermosphere (approximately 80–500 km up) or exosphere (approximately 500 km and up), depending on orbit height. Objects in LEO orbit Earth between the atmosphere and below the inner Van Allen radiation belt. The altitude is usually not less than 300 km for satellites, as that would be impractical due to atmospheric drag.

The orbital velocity needed to maintain a stable low earth orbit is about 7.8 km/s, but reduces with increased orbital altitude. Although the Earth's pull due to gravity in LEO is not much less than on the surface of the Earth, people and objects in orbit experience weightlessness because they are in free fall. A low earth orbit is simplest and most cost effective for a satellite placement and provides high bandwidth and low communication latency.

5.15.4 APSIS- APOGEE AND PERIGEE

Apogee and Perigee refer to the moon and its relation to the earth. The moon's orbit is not circular, but elliptical and when the moon is at its closest point to earth, it is said to be at its perigee and when it's at its furthest point it is said to be at its apogee.

Apogee and perigee are terms which indicate the distance between the earth and the moon. Apogee is when the moon is furthest from the earth, and perigee is when it is the closest.

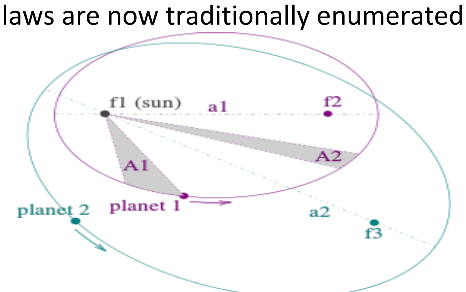


5.15.5 KEPLER'S LAWS OF PLANETARY MOTION

Johannes Kepler, developed three laws which described the motion of the planets across the sky.

- **The Law of Orbits:** All planets move in elliptical orbits, with the sun at one focus.
- **The Law of Areas:** A line that connects a planet to the sun sweeps out equal areas in equal times.
- **The Law of Periods:** The Square of the period of any planet is proportional to the cube of the semi major axis of its orbit.

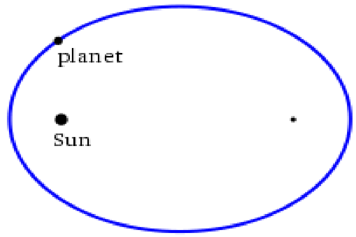
In astronomy, Kepler's laws of planetary motion are three scientific laws describing the motion of planets around the Sun. Kepler's laws are now traditionally enumerated in this way:



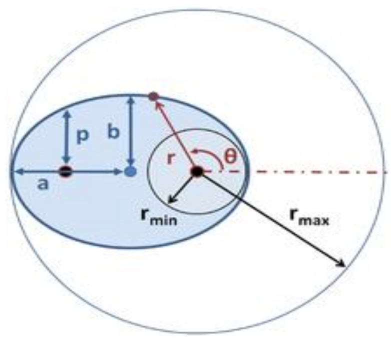
- The orbits are ellipses, with focal points ƒ1 and ƒ2for the first planet and ƒ1 and ƒ3 for the second planet. The Sun is placed in focal point ƒ1.
- The two shaded sectors A1 and A2 have the same surface area and the time for planet 1 to cover segment A1 is equal to the time to cover segment A2.
- The total orbit times for planet 1 and planet 2 have a ratio a13/2: a23/2.

FIRST LAW:

"The orbit of every planet is an ellipse with the Sun at one of the two foci."



Kepler's first law placing the Sun at the focus of an elliptical orbit



Heliocentric coordinate system (r, θ) for ellipse. Also shown are: semi-major axis a, semi-minor axis b and semi-latus rectum p; center of ellipse and its two foci marked by large dots. For θ = 0°, r = rmin and for θ = 180°, r = rmax.

Mathematically, an ellipse can be represented by the formula:

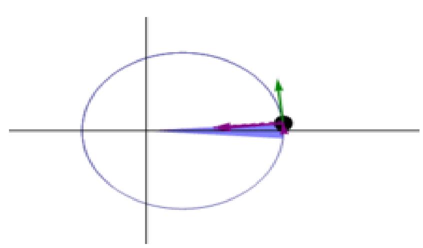
$$r = \frac{\varepsilon\,|d|}{1+\varepsilon\,\cos\theta},$$

where (r, θ) are polar coordinates, d is the focal parameter, and ε is the eccentricityof the ellipse.

Note that 0 < ε < 1 for an ellipse; in the limiting case ε = 0, the orbit is a circle with the sun at the centre

SECOND LAW:

"A line joining a planet and the Sun sweeps out equal areas during equal intervals of time."



The same blue area is swept out in a given time. The green arrow is velocity. The purple arrow directed towards the Sun is the acceleration. The other two purple arrows are acceleration components parallel and perpendicular to the velocity.

This law relates radial distance and angular velocity in elliptical orbits. That is, in a perfectly circular orbit, the orbital radius of the satellite would be constant and therefore so would be its observed angular velocity. In elliptical orbits, the orbital radius of the satellite will vary and therefore so will its angular velocity. This is shown in the above animation where the satellite travels "faster" (greater angular velocity) when closer to the parent object, then "slower" (less angular velocity) at a more distant radius. The result is that the blue sectors are shorter but wider when close to the body, then longer but narrower at a greater distance. Kepler's 2nd law states that for a given elliptical orbit, any two sectors of equal time duration will have the same area. This implies that radial distance and angular velocity have an inversely proportional relationship in a given orbit; angular velocity is minimum at apoapsis and maximum at periapsis. The constant of proportionality is the rate at which area in the ellipse is covered.

In a small time dt the planet sweeps out a small triangle (or, more precisely, a sector) having base line r and height $r d\theta$ and area $dA = \frac{1}{2} \cdot r \cdot r d\theta$ and so the constant areal velocity is

$$\frac{dA}{dt} = \tfrac{1}{2} r^2 \frac{d\theta}{dt}.$$

The planet moves faster when it is closer to the Sun.

The area enclosed by the elliptical orbit is πab. so the period P satisfies

$$P \cdot \tfrac{1}{2} r^2 \frac{d\theta}{dt} = \pi ab$$

and the mean motion of the planet around the Sun $n = 2\pi/P$ satisfies

$$r^2 d\theta = abn dt.$$

THIRD LAW:

The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit. The third law captures the relationship between the distance of planets from the Sun, and their orbital periods. Kepler’s enunciated this third law in a laborious attempt to determine what he viewed as the "music of the spheres" according to precise laws, and express it in terms of musical notation. So it used to be known as the harmonic law.

Mathematically, the law says that the expression P^2/a^3 has the same value for all the planets in the solar system. The modern formulation with the constant evaluated reads:

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

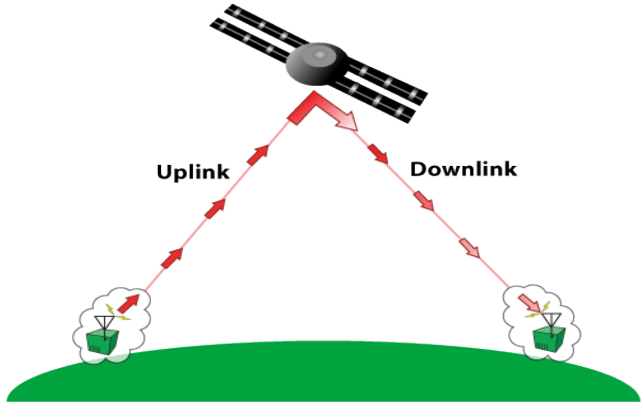
with

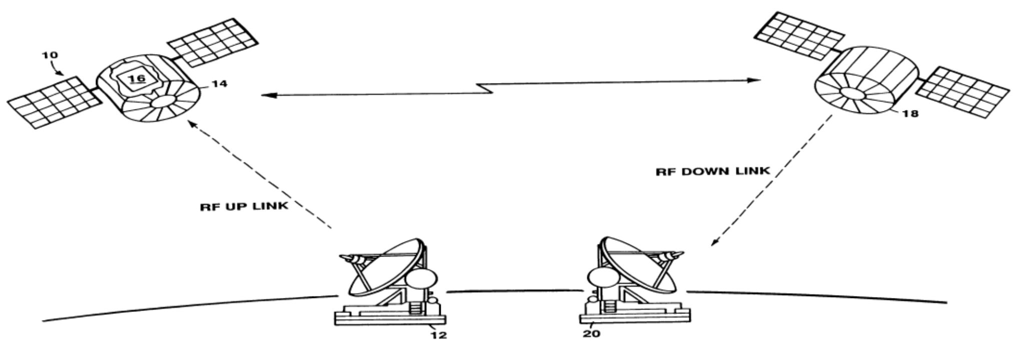
T the orbital period of the orbiting body,
M the mass of the star,
G the universal gravitational constant and
r the radius, the semi-major axis of the ellipse.

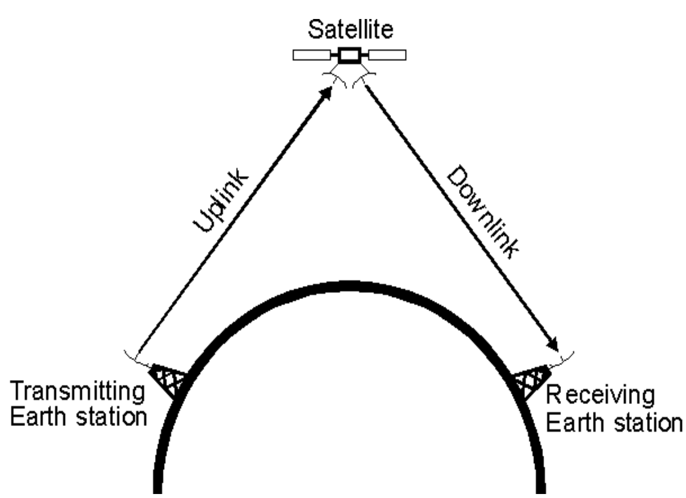
5.15.6 SATELLITE LINKS:

The communication going from a satellite to ground is called downlink, and when it is going from ground to a satellite it is called uplink. When an uplink is being received by the spacecraft at the same time a downlink is being received by Earth, the communication is called two-way. If there is only an uplink happening, this communication is called upload. If there is only a downlink happening, the communication is called one-way.

The communication happening between two satellites is characterized by a Cross link.







5.15.7 TRANSPONDER:

In telecommunication, a **transponder** is one of two types of devices. In air navigation or radio frequency identification, a flight transponder is a device that emits an identifying signal in response to an interrogating received signal. In a communications satellite, a transponder gathers signals over a range of uplink frequencies and re-transmits them on a different set of downlink frequencies to receivers on Earth, often without changing the content of the received signal or signals.

The term is a portmanteau for *Trans*mitter-res*ponder*. It is variously abbreviated as XPDR, XPNDR, TPDR or TP. A communications satellite's channels are called transponders, because each is a separate transceiver or repeater. With digital video data compression and multiplexing, several video and audio channels may travel through a single transponder on a single wideband carrier. Original analog video only has one channel per transponder, with subcarriers for audio and automatic transmission identification service (ATIS). Non-multiplexed radio stations can also travel in single channel per carrier (SCPC) mode, with multiple carriers (analog or digital) per transponder. This allows each station to transmit directly to the satellite, rather than paying for a whole transponder, or using landlines to send it to an earth station for multiplexing with other stations.

5.15.8 LINK BUDGET

A link budget is the accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feed line and miscellaneous losses. Randomly varying channel gains such as fading are taken into account by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced by the use of mitigating techniques such as antenna diversity or frequency hopping.

A simple link budget equation looks like this:

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB)

A link budget equation including all these effects, expressed logarithmically, might look like this:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

where:

P_{RX} = received power (dBm)
P_{TX} = transmitter output power (dBm)
G_{TX} = transmitter antenna gain (dBi)
L_{TX} = transmitter losses (coax, connectors...) (dB)
L_{FS} = free space loss or path loss (dB)
L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)
G_{RX} = receiver antenna gain (dBi)
L_{RX} = receiver losses (coax, connectors...) (dB)

The loss due to propagation between the transmitting and receiving antennas, often called the path loss, can be written in dimensionless form by normalizing the distance to the wavelength:

L_{FS} (dB) = 20×log[4×π×distance/wavelength] (where distance and wavelength are in the same units)

When substituted into the link budget equation above, the result is the logarithmic form of the Friis transmission equation.

In some cases it is convenient to consider the loss due to distance and wavelength separately, but in that case it is important to keep track of which units are being used, as each choice involves a differing constant offset. Some examples are provided below.

L_{FS} (dB) = 32.45 dB + 20×log[frequency(MHz)] + 20×log[distance(km)] [1]

L_{FS} (dB) = - 27.55 dB + 20×log[frequency(MHz)] + 20×log[distance(m)]

L_{FS} (dB) = 36.6 dB + 20×log[frequency(MHz)] + 20×log[distance(miles)]

These alternative forms can be derived by substituting wavelength with the ratio of propagation velocity (c, approximately 3×10^8 m/s) divided by frequency, and by inserting the proper conversion factors between km or miles and meters, and between MHz and (1/sec).

5.15.9 FOOT PRINTS OF A SATELLITE

The footprint of a communications satellite is the ground area that its transponders offer coverage, and determines the satellite dish diameter required to receive each transponder's signal. There is usually a different map for each transponder (or group of transponders) as each may be aimed to cover different areas of the ground.

Footprint maps usually show either the estimated minimum satellite dish diameter required or the signal strength in each area measured in dBW.