Introduction to Wireless Networks

- To provide wireless communications within a particular geographic region (a city, for example), an integrated network of base stations must be deployed to provide sufficient radio coverage to all mobile users.
- The base stations, in turn, must be connected to a central hub called the mobile switching center (MSC).
- The MSC provides connectivity between the public switched telephone network (PSTN) and the numerous base stations, and ultimately between all of the wireless subscribers in a system.
- The PSTN forms the global telecommunications grid which connects conventional (landline) telephone switching centers (called central offices) with MSCs throughout the world.
- Radio links are established using a carefully defined communication protocol called common air interface also known as the handshake communication protocol.

Differences Between Wireless and Fixed Telephone Networks

- Transfer of information in the public switched telephone network (PSTN) takes place over landline trunked lines (called trunks) comprised of fiber optic cables, copper cables, microwave links, and satellite links.
- The network configurations in the PSTN are virtually static, since the network connections may only be changed when a subscriber changes residence and requires reprogramming at the local central office (CO) of the subscriber.
- Fixed networks are difficult to change.
- The available channel bandwidth for fixed networks can be increased by installing high capacity cables (fiber optic or coaxial cable).

- Transfer of information is by wireless radio links.
- Wireless networks, are highly dynamic, with the network configuration being rearranged every time a subscriber moves into the coverage region of a different base station or a new market.
- Wireless networks must reconfigure themselves for users within small intervals of time (on the order of seconds) to provide roaming and handoffs between calls as a mobile moves about.
- Wireless networks are constrained by the limited RF cellular bandwidth provided for each user.

Development of Wireless Networks

- First Generation Wireless Networks
- Second Generation Wireless Networks
- Third Generation Wireless Networks
- Fourth Generation Wireless Networks

Fixed Network Transmission Hierarchy

- Wireless networks rely heavily on landline connections. For example, the MSC connects to the PSTN and SS7 networks using fiber optic or copper cable or microwave links.
- Base stations within a cellular system are connected to the MSC using line-of-sight (LOS) microwave links, or copper or fiber optic cables.
- Standard digital signaling (DS) formats form a transmission hierarchy that allows high data rate transmission on digital networks by means of TDM (time division multiplexing).
- Most basic DS format is called DS-O, which represents one duplex voice channel which is digitized into a 64 kbps binary PCM format.
- Next DS format is DS-2, which represents twenty four full duplex DS-0 voice channels that are time division multiplexed into a 1.544 Mbps data stream.
- The T(N) designation is used to denote transmission line compatibility for a particular DS format. DS-1 signaling is used for a T1 trunk, which is a popular point-to-point network signaling format used to connect base stations to the MSC.
- Coaxial or fiber optic cable or wideband microwave links are used to transmit data rates in excess of 10 Mbps, whereas inexpensive wire (twisted pair) or coaxial cable may be used for slower data transfer.
- When connecting base stations to a MSC, or distributing trunked voice channels throughout a wireless network, T1 (DS1) or level 1 links are most commonly used and utilize common-twisted pair wiring.
- DS-3 and higher rate circuits are used to connect MSCs and COs to the PSTN.

Traffic Routing in Wireless Networks

- The amount of traffic capacity required in a wireless network depends upon the type of traffic carried.
- A subscriber's voice telephone call requires dedicated network access to provide real-time communications
- However, control and signaling traffic may be bursty in nature and may be able to share network resources with other bursty users.
- Some traffic may have an urgent delivery schedule while some may have no need to be sent in real-time.
- The type of traffic carried by a network determines the routing services, protocols, and call handling techniques which must be employed.
- Two general routing services are provided by networks. These are

❑ Connection- oriented services (virtual circuit routing), and

❑ Connectionless services (datagram services).

Comparison of Traffic services in Wireless Networks

- **Connection- oriented services (virtual circuit routing)**

- In connection-oriented routing, the communications path between the message source and destination is fixed for the entire duration of the message, and a call set-up procedure is required to dedicate network resources to both the called and calling parties.
- Since the path through the network is fixed, the traffic in connection-oriented routing arrives at the receiver in the exact order it was transmitted.
- A connection-oriented service relies heavily on error control coding to provide data protection in case the network connection becomes noisy.
- If coding is not sufficient to protect the traffic, the call is broken, and the entire message must be retransmitted from the beginning.
- Circuit switching is a connection-oriented service.

- **Connectionless services (datagram services).**

- Connectionless routing, does not establish a firm connection for the traffic, and instead relies on packet-based transmissions.
- Several packets form a message, and each individual packet in a connectionless service is routed separately. Successive packets within the same message might travel completely different routes and encounter widely varying delays throughout the network.
- Packets sent using connectionless routing do not necessarily arrive in the order of transmission and must to be reordered at the receiver. Because packets take different routes in a connectionless service, some packets may be lost due to network or link failure.
- Connectionless routing often avoids having to retransmit an entire message, but requires more overhead information for each packet like packet source address, the destination address, the routing information, and information needed to properly order packets at the receiver.
- In a connectionless service, a call set-up procedure is not required at the beginning of a call, and each message burst is treated independently by the network.
- Packet switching is the most common connectionless service

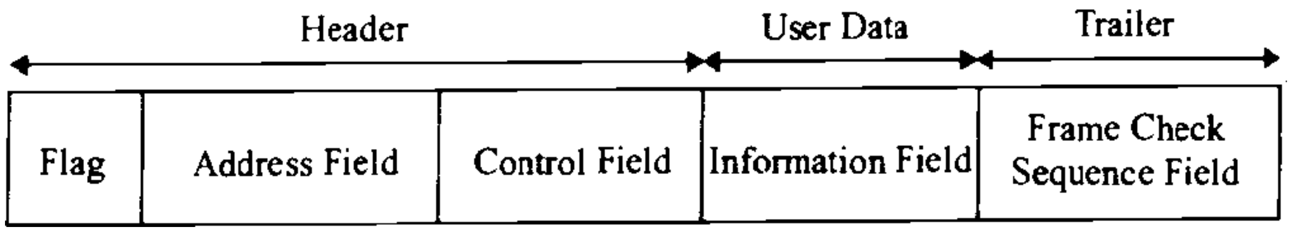
Comparison of Circuit switching and Packet switching

Circuit Switching

- First generation cellular systems provide connection-oriented services for each voice user by a technique called circuit switching.
- A physical radio channel is switched in to use for two-way traffic between the mobile user and the MSC, and the PSTN dedicates a voice circuit between the MSC and the end-user.
- Circuit switching establishes a dedicated connection between the base and mobile, and a dedicated frill duplex phone line between the MSC and the PSTN for the entire duration of a call.
- Wireless data networks are not well supported by circuit switching, due to their short, bursty transmissions which are often followed by periods of inactivity.
- Circuit switching is best suited for dedicated voice-only traffic, or for instances where data is continuously sent over long periods of time.

Packet Switching

- Packet switching (also called virtual switching) is the most common technique used to implement connectionless services
- It allows a large number of data users to remain virtually connected to the same physical channel in the network.
- Call set-up procedures are not needed to dedicate specific circuits when a particular user needs to send data.
- Packet switching breaks each message into smaller units for transmission and recovery and adds a certain amount of control information to each packet (fig below).
- It provides excellent channel efficiency for bursty data transmissions of short length.
- The channel is utilized only when sending or receiving bursts of information which is useful in cases of limited bandwidth.
- Packet switching supports intelligent protocols for data flow control and retransmission.



GSM Services and Features

- GSM services follow ISDN guidelines and are classified as either teleservices or data services. Teleservices include standard mobile telephony and mobile-originated or base-originated traffic. Data services include computer-to computer communication and packet-switched traffic.
- User services may be divided into three major categories:
- Telephone services including emergency calling, facsimile, Videotex and Teletex
- Bearer services or data services which are limited to layers 1, 2, and 3 of the open system interconnection (OSI) reference model
- Supplementary ISDN services are digital in nature, and include call diversion, closed user groups, and caller identification. Supplementary services also include the short messaging service (SMS) which allows GSM subscribers and base stations to transmit alphanumeric pages of limited length.

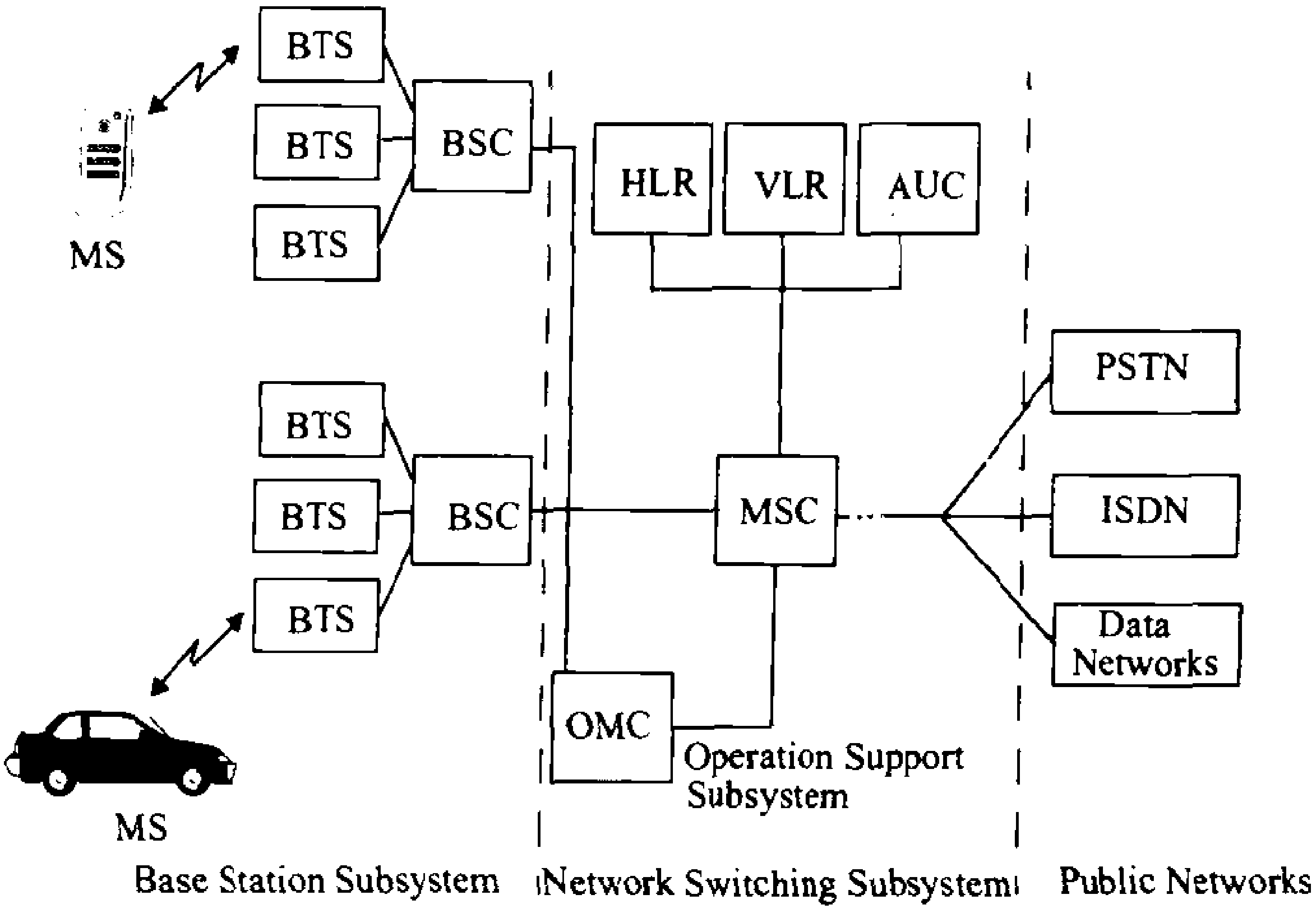
Global System for Mobile (GSM)

- Global System for Mobile (GSM) is a second generation cellular system standard that was developed to solve the fragmentation problems of the first cellular systems in Europe.
- GSM was originally developed to serve as the pan-European cellular service and promised a wide range of network services through the use of ISDN.
- GSM is the world's first cellular system to specify digital modulation and network level architectures and services.
- It is now the world's most popular standard for new cellular radio and personal communications equipment throughout the world.
- Two remarkable features of the GSM are the Subscriber Identity Module (SIM) and the on-the-air privacy feature provided by the system.
- Subscriber Identity Module (SIM), which is a memory device that stores information such as the subscriber's identification number, the networks and countries where the subscriber is entitled to service, privacy keys, and other user-specific information. A subscriber uses the SIM with a 4-digit personal ID number to activate service from any GSM phone.
- On-the-air privacy is ensured because its is virtually impossible to eavesdrop on a GSM radio transmission. The privacy is made possible by encrypting the digital bit stream sent by a GSM transmitter.

GSM System Architecture

- The GSM system architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The subsystems are the
- Base Station Subsystem (BSS),
- Network and Switching Subsystem (NSS), and the
- Operation Support Subsystem (OSS).
- The Mobile Station (MS) is also a subsystem, but is usually considered to be part of the BSS for architecture purposes.
- The BSS, also known as the radio subsystem, provides and manages radio transmission paths between the mobile stations and the Mobile Switching Center (MSC). The BSS also manages the radio interface between the mobile stations and all other subsystems of GSM.
- The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the PSTN and ISDN.
- The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose, and troubleshoot all aspects of the GSM system. This subsystem also interacts with the other GSM subsystems.

GSM System Architecture



GSM System Architecture

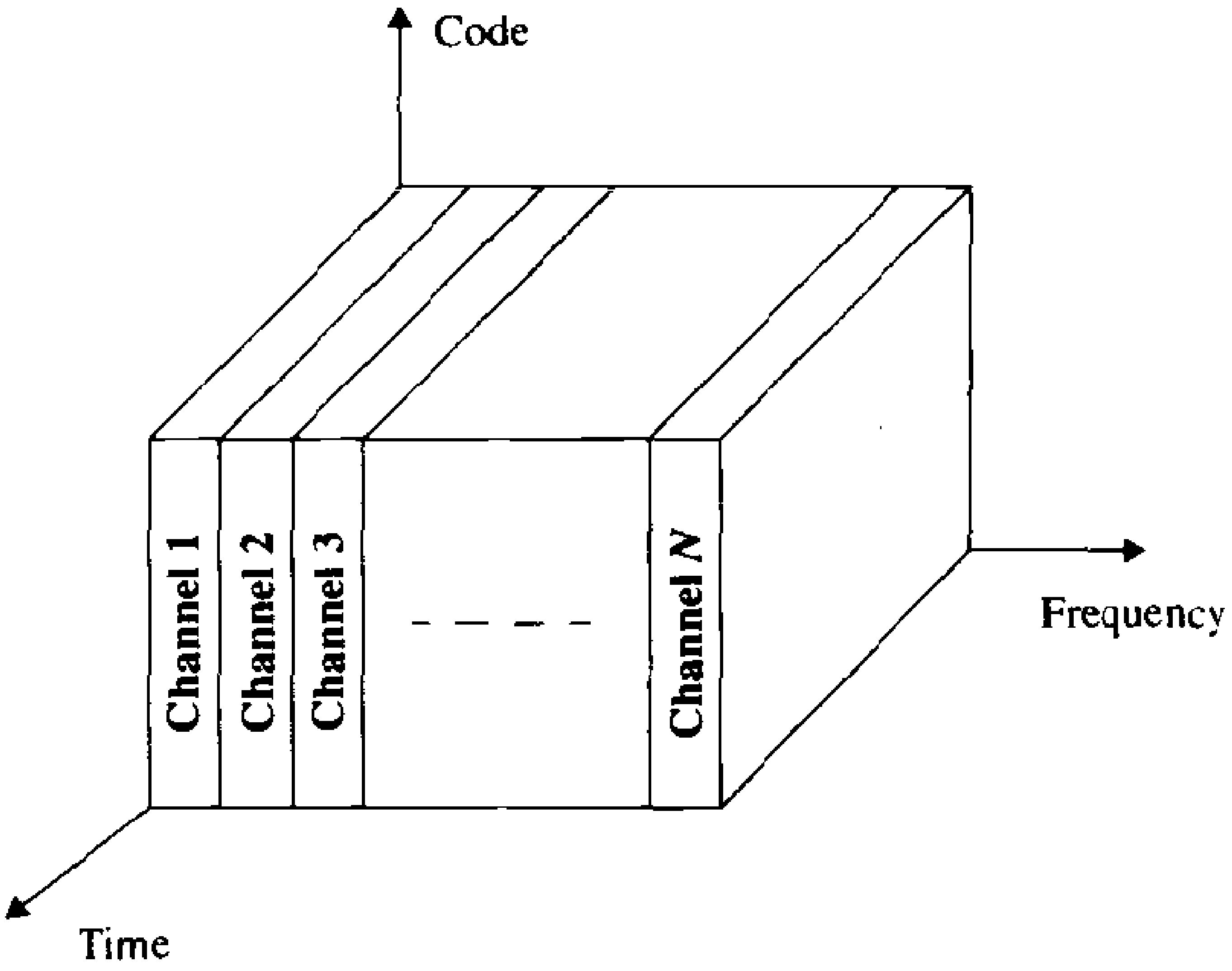
- Figure shows the block diagram of the GSM system architecture. The Mobile Stations (MS) communicate with the Base Station Subsystem (BSS) over the radio air interface. The BSS consists of many Base station Controllers (BSCs) which connect to a single MSC, and each BSC typically controls up to several hundred Base Transceiver Stations (BTSs). Some of the BTSs maybe co-located at the BSC, and others may be remotely distributed and physically connected to the BSC by microwave link or dedicated leased lines. Mobile handoffs (HO) between two BTSs under the control of the same BSC are handled by the BSC, and not the MSC. This greatly reduces the switching burden of the MSC.
- The NSS handles the switching of GSM calls between external networks and the BSCs in the radio subsystem and is also responsible for managing and providing external access to several customer databases. In the NSS, there are three different databases called the Home Location Register (HLR), Visitor Location Register (VLR), and the Authentication Center (AUC).
- The OSS supports one or several Operation Maintenance Centers (OMC) which are used to monitor and maintain the performance of each MS, BS, BSC, and MSC within a GSM system. The OSS has three main functions, which are 1) to maintain all telecommunications hardware and network operations with a particular market, 2) manage all charging and billing procedures, and 3) manage all mobile equipment in the system.

Introduction to Multiple Access

- Cellular systems divide a geographic region into cells where a mobile phone in each cell communicates with a base station. The main objective of a cellular system design is to handle as many calls as possible within the given bandwidth with maximum reliability.
- The techniques that have been developed to allow many users to simultaneously share the finite amount of resources or radio spectrum in a most efficient way are known as multiple access techniques. As a result, high capacity is achieved by simultaneously allocating the available bandwidth to multiple users.
- The possible multiple access methods are
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)
- Space Division Multiple Access (SDMA)

Frequency Division Multiple Access (FDMA)

- **Frequency division multiple access (FDMA) assigns individual channels to individual users. Each user is allocated a unique frequency band or channel. These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same frequency band. In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel.**
- **The first U.S. analog cellular system, the Advanced Mobile Phone System (AMPS), is based on FDMA/FDD.**



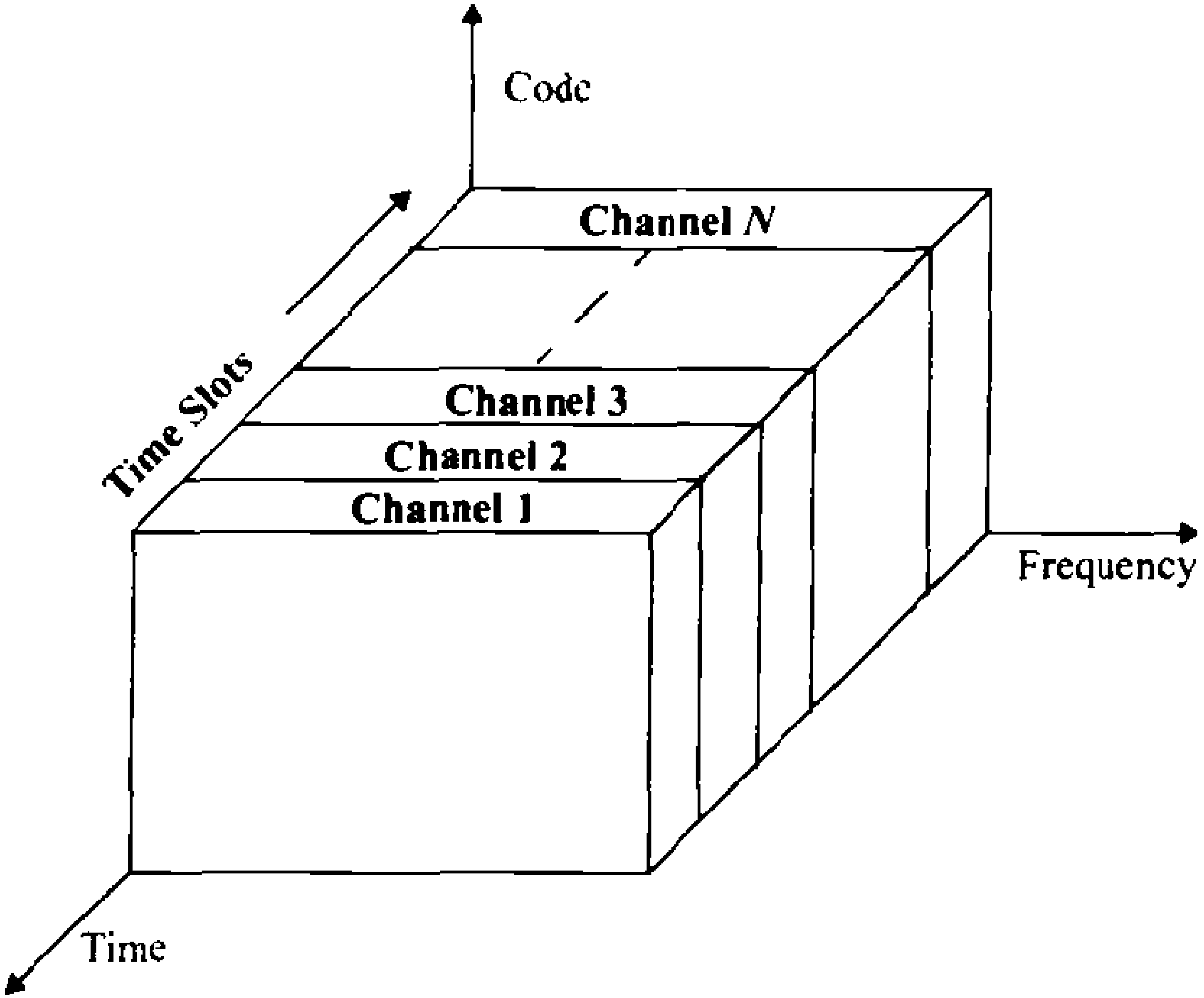
Frequency Division Multiple Access (FDMA)

Features of FDMA

- FDMA channel carries only one phone circuit at a time.
- If an FDMA channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity.
- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.
- FDMA is a narrowband system.
- The symbol time is large as compared to the average delay spread which means that the amount of intersymbol interference is low.
- Less complex when compared to TDMA.
- Fewer overhead bits are needed as compared to TDMA.
- FDMA systems have higher cell site system costs as compared to TDMA because of the single channel per carrier design.
- More expensive due to the use of duplexer in the mobile unit.
- FDMA requires tight RF filtering to minimize adjacent channel interference

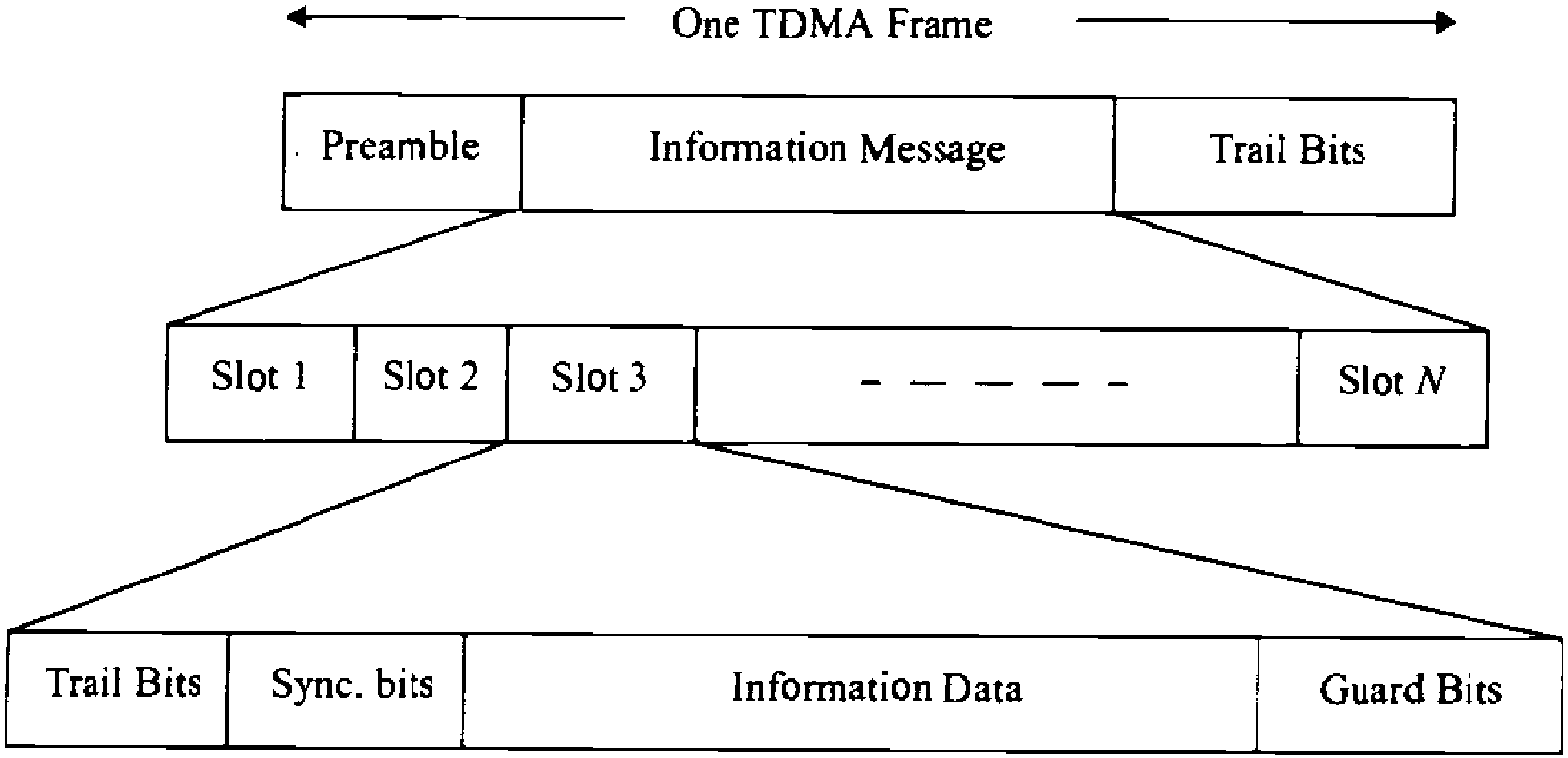
Time Division Multiple Access(TDMA)

- Time Division Multiple Access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. Each user occupies a cyclically repeating time slot, so a channel may be thought of as particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is noncontinuous. This implies that digital data and digital modulation must be used with TDMA.
- The transmission from various users is interlaced into a repeating frame structure.
- A frame consists of a number of slots. Each frame is made up of a preamble, an information message, and trail bits.



Time Division Multiple Access(TDMA)

- **TDMA frame structure is shown below.**



Time Division Multiple Access (TDMA)

Features of TDMA

- TDMA shares a single carrier frequency with several users, where each user makes use of nonoverlappin time slots
- Data transmission is in discrete bursts which gives extended battery life.
- Handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations durin idle time slots.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required.
- Adaptive equalization is usually necessary in TDMA systems.
- The transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized.
- High synchronization overhead is required in TDMA systems because of burst transmissions.
- It is possible to allocate different numbers of time slots per frame to different users.
- More efficient use of spectrum.

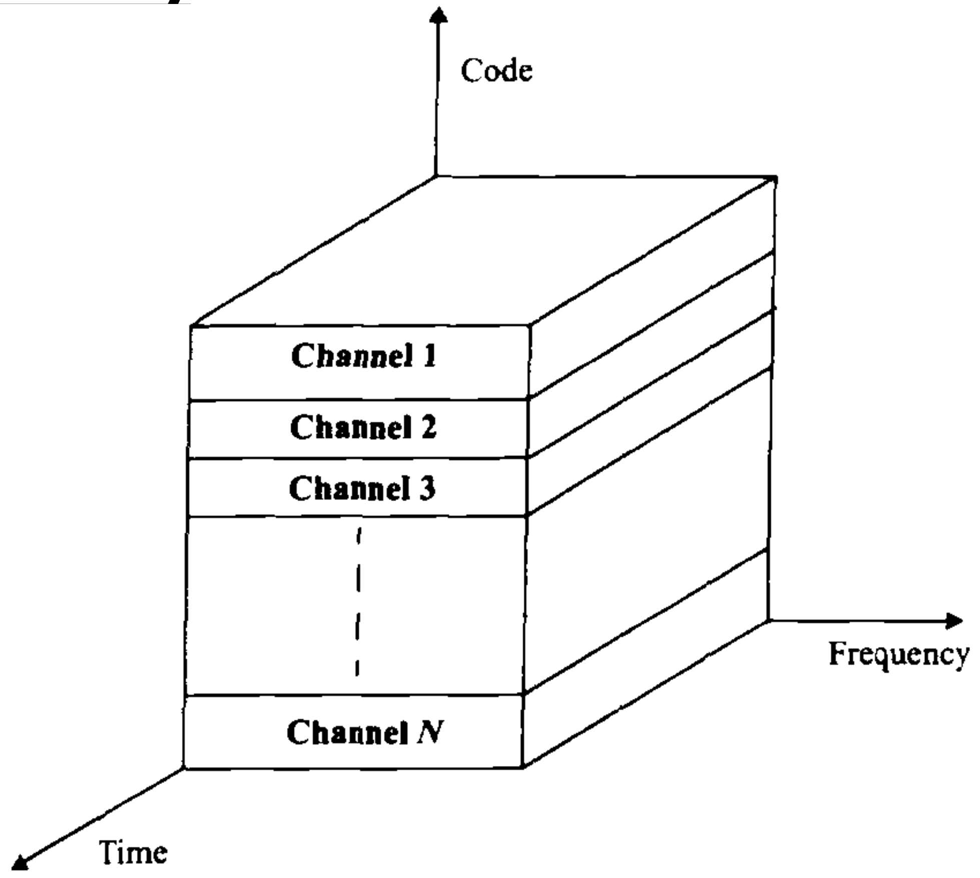
Code division multiple access (CDMA).

- Code division multiple access (CDMA) is one type of Spread Spectrum Multiple Access Technique . It uses the spread spectrum techniques to increase spectrum efficiency over current TDMA and FDMA systems.
- Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth that is several orders of magnitude greater than the minimum required RF bandwidth.
- There are two main types of spread spectrum multiple access techniques;
- Frequency hopped multiple access (FH) and
- Direct sequence multiple access (DS).
- Direct sequence multiple access is also called code division multiple access (CDMA).
- CDMA uses unique spreading codes to spread the baseband data before transmission.
- CDMA assigns a unique code sequence to each user that is used to code data before transmission. If the receiver knows the code sequence related to a user, it is able to decode the received data. The codes are called Pseudo-noise (PN) sequences.
- The narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal which is the pseudo-noise code sequence.

Code division multiple access (CDMA)

Features of CDMA

- All users in a CDMA system, use the same carrier frequency and may transmit simultaneously. Each user has its own pseudorandom code word which is approximately orthogonal to all other code words.
- The receiver performs a time correlation operation to detect only the specific desired code word. All other code words appear as noise due to decorrelation. For detection of the message signal, the receiver needs to know the code word used by the transmitter. Each user operates independently with no knowledge of the other users.
- CDMA has a soft capacity limit. Increasing the number of users in a CDMA system raises the noise added to the system.
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum.
- Channel data rates are very high in CDMA systems.
- Self-jamming is a problem in CDMA system.

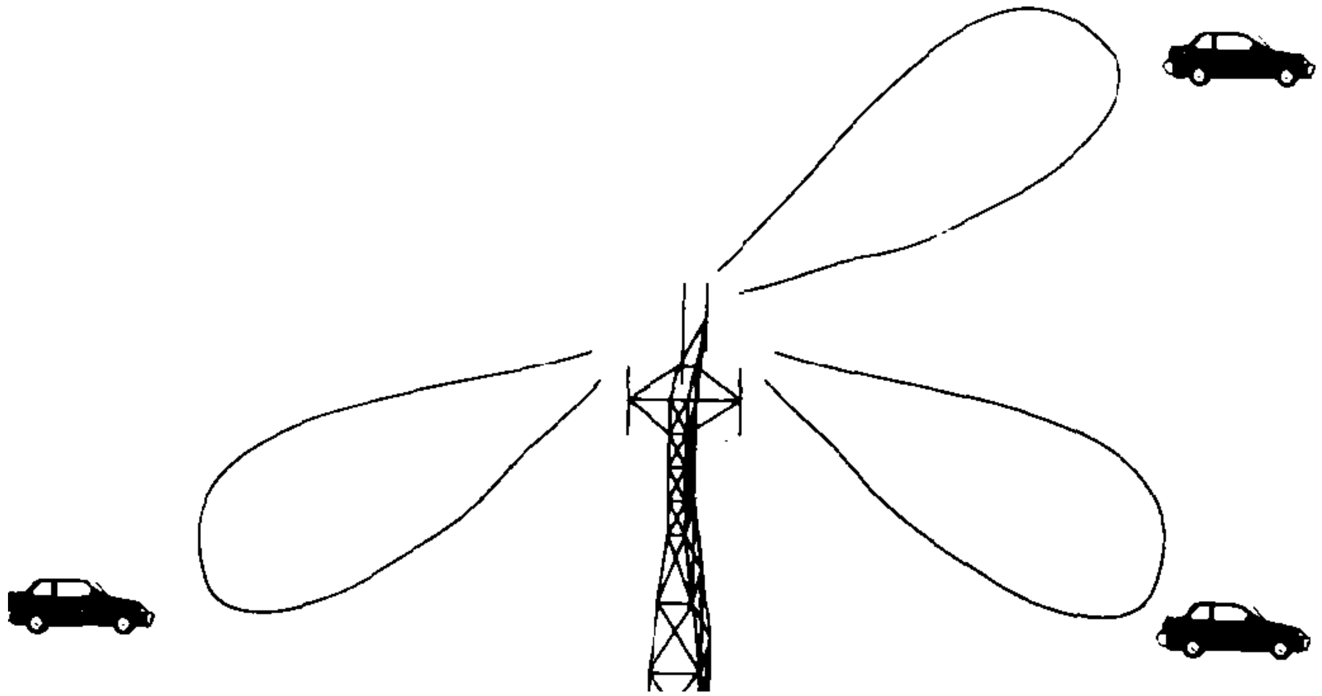


Frequency Hopped Multiple Access (FHMA)

- Frequency Hopped Multiple Access also known as Frequency Hopped Spread Spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudo random sequence known to both transmitter and receiver. The carrier frequencies of the individual users are varied in a pseudorandom fashion within a wideband channel.
- The digital data is broken into uniform sized bursts which are transmitted on different carrier frequencies. The instantaneous bandwidth of any one transmission burst is much smaller than the total spread bandwidth.
- In the FH receiver, a locally generated PN code is used to synchronize the receivers instantaneous frequency with that of the transmitter.
- At any given point in time, a frequency hopped signal only occupies a single, relatively narrow channel.
- A frequency hopped system provides a level of security, especially when a large number of channels are used, since an unintended (or an intercepting) receiver that does not know the pseudorandom sequence of frequency slots must retune rapidly to search for the signal it wishes to intercept.
- The FH signal is somewhat immune to fading, since error control coding and interleaving can be used to protect the frequency hopped signal against deep fades.
- Bluetooth uses FHSS technique.

Space Division Multiple Access (SDMA)

- Space division multiple access (SDMA) uses the spatial dimension for multiplexing of different data streams by transmitting the data streams over different non-overlapping transmission channels. SDMA enables users to share simultaneously the same bandwidth in different geographical locations.
- Space division multiple access (SDMA) controls the radiated energy for each user in space. SDMA serves different users by using spot beam antennas. These different areas covered by the antenna beam may be served a TDMA or CDMA system at same frequency or by different frequencies in an FDMA system.
- Sectorized antennas are an application of SDMA. Adaptive antennas can be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures.



Space Division Multiple Access (SDMA)

- **By using adaptive antenna arrays also called smart antennas in mobile radio systems, signals can be received and sent only from and into a limited angular range, following the directional nature of multipath This improves coverage in noise limited situations and enhances capacity in interference-limited situations.**

Advantages of SDMA

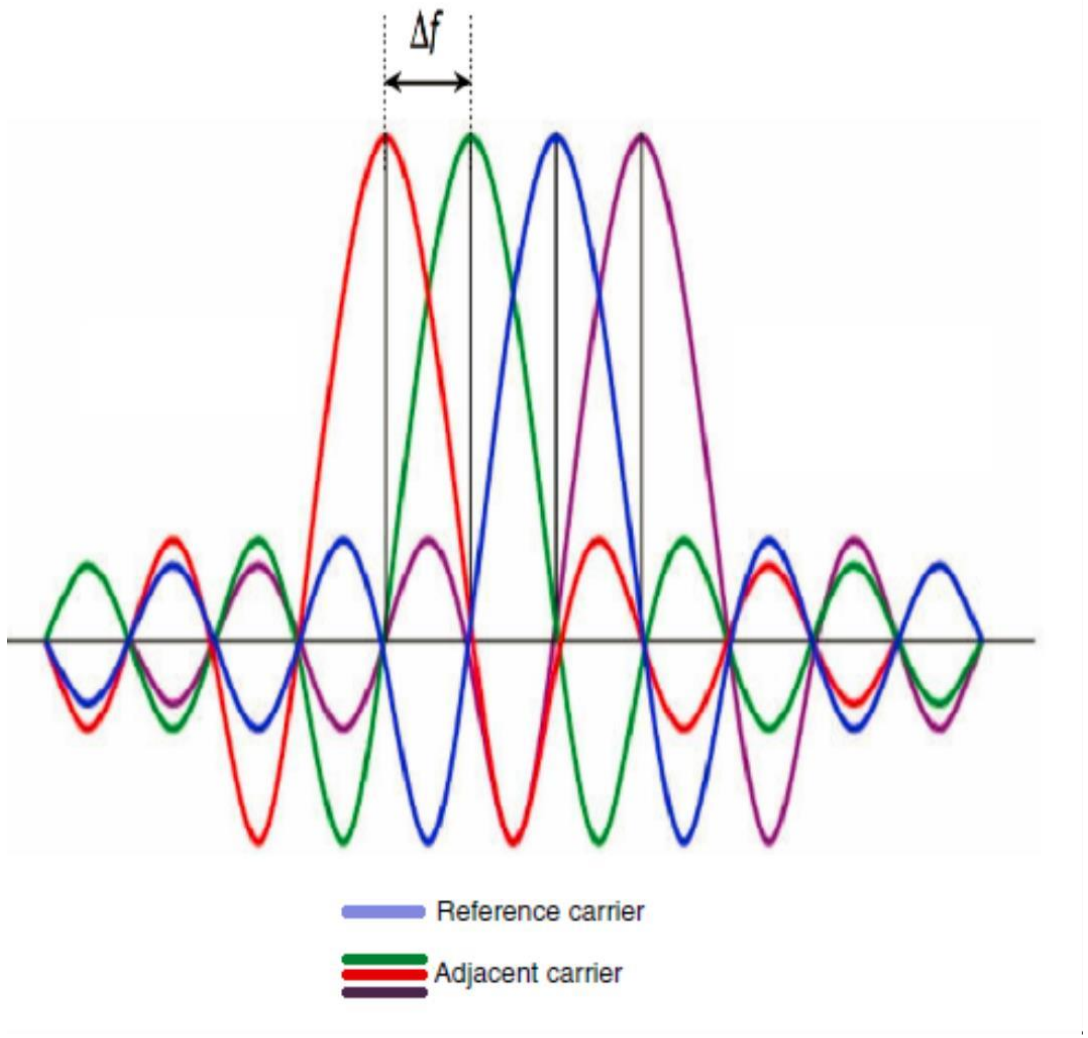
- **Range extension: The coverage area of the antenna array is greater than that of a single element.**
- **Interference Suppression: In noisy areas where the range is limited by interference, spatially selective transmission and reception result in range extension.**
- **Multipath effect elimination**
- **Capacity increase**
- **Compatibility with most of the existing modulation schemes**

Comparison of FDMA,TDMA,CDMA.SDMA

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 the 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 as scarce resource	Complex receivers, needs more complicated power control for senders
Comment	Only 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

Orthogonal Frequency Division Multiplexing (OFDM)

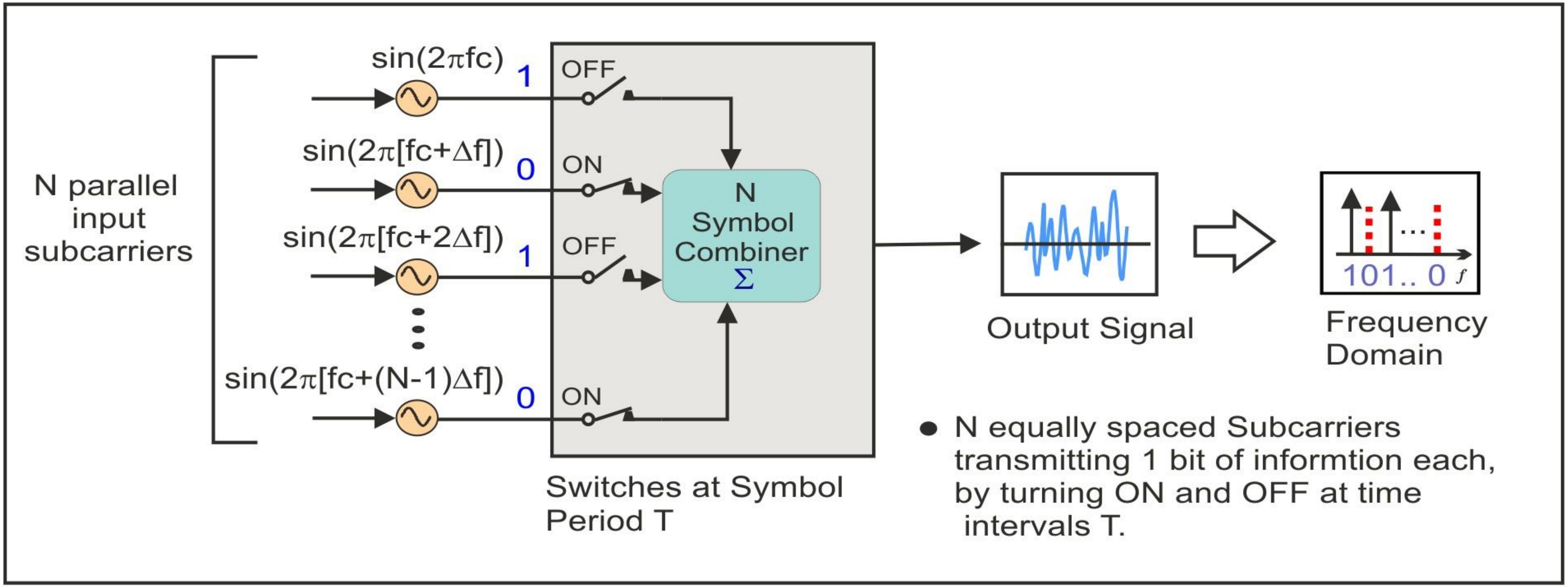
- OFDM is an important technology for all 4G systems where it offers robust performance over multipath fading channels and has the ability to achieve high spectral efficiency.
- OFDM is a form of multi carrier modulation where high rate data stream is split into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers.
- An OFDM signal consists of a sum of subcarriers that are modulated using PSK or QAM.
- The signal can be represented as sum of real and imaginary parts which correspond to the in-phase and quadrature components.
- The advantage of OFDM is the mutual orthogonality of its carriers which provides high spectral efficiency.



Subcarrier frequency spectra in OFDM is shown in the figure.

Orthogonal Frequency Division Multiplexing (OFDM)

- **Block diagram of OFDM is shown below.**



Simple OFDM Generation

EDGE

- Formerly, EDGE was the abbreviation for Enhanced Data Rates for GSM Evolution

- With EDGE being adopted by the North American market, EDGE is the acronym for Enhanced Data Rate for Global Evolution

- EDGE introduces a new modulation scheme which is an 8-PSK in addition to GMSK in the case of GSM

- GPRS and HSCSD works with the normal GSM modulation scheme which is GMSK.GMSK has lots of advantages, the most important of which being that it does not contain any amplitude modulation.Its low speed is one disadvantage.In GMSK, only 1 bit can be transmitted per symbol, as opposed to 8-PSK where 3 bits are transmitted per symbolThis makes 8-PSK three times faster than GMSK

EDGE

EDGE is mainly concerned with the modulation scheme on the Air-interface. Adding 8-PSK as a new modulation scheme requires all base stations to receive hardware upgrades of their RF-parts to support the EDGE technology.This is a major undertaking which is risky, and most importantly, costly to the operator.

EDGE

- Require h/w and s/w upgrade of both BS and MS

- Used 8-PSK in addition to GMSK

- Uses 9 air interface formats, known a multiple Modulation and Coding Schemes (MCS) autonomously and rapidly selectable for each time slot or user. Controlled by a feedback loop for maximum throughput with an acceptable outage performance

- Using all 8 slots, can reach a max of 547 Kbps per user, practically 384Kbps per user per carrier.

UWB

UWB, ultra wide band technology, is a form of transmission that occupies a very wide bandwidth. Typically this will be many Gigahertz, and it is this aspect that enables it to carry data rates of Gigabits per second.

The fact that UWB transmissions have such a wide bandwidth means that they will cross the boundaries of many of the currently licensed carrier based transmissions. As such one of the fears is that UWB transmission may cause interference. However the very high bandwidth used also allows the power spectral density to be very low, and the power limits on UWB are being strictly limited by the regulatory bodies. In many instances they are lower than the spurious emissions from electronic apparatus that has been certified. In view of this it is anticipated that they will cause no noticeable interference to other carrier based licensed users.

Ultra-Wideband (UWB) provides an interesting new technology for shortrange ultra-high speed communications in the frequency band 3.1 GHz to 10.6 GHz. It supports a bit rate greater than 100 Mbps within a 10-meter radius for wireless personal area communications.

The advantages of UWB include low-power transmission, robustness for multi-path fading and low power dissipation. The low power transmission of the UWB is the key characteristic that might allow it to coexist with other wireless networking standards such as 802.11 LAN, 802.16 MAN and WAN. 2

Since the capacity of a communications channel in a non-fading environment is expressed as:

C = B * log2 (1+S/N)

$$C = B \cdot \log_2 (1 + S/N)$$

where C = channel capacity (bit/s)
B = channel bandwidth ‘BW’ (Hz) S = signal power (watts)
N = noise power (watts)

According to above equation, the capacity can be increased by either increasing B or S/N. It is obvious that the capacity can be increased more by increasing B rather than S/N.

The main types of UWB systems are: (i) Imaging systems that include ground penetration radars (GPR), wall and through wall imaging, medical imaging, and surveillance systems; (ii) Vehicular radar systems; and (iii) Communications and measurements systems.

These systems operate in the following frequency bands:

Imaging systems operate below 960 MHz or in the 3.1 GHz to 10.6 GHz frequency band. Typical applications are use by rescue organizations, law enforcement, mining companies and construction companies. They are also used to detect the location of objects through a wall and to detect movements of people or objects located behind walls. In medical fields , they are used for health applications research.Communications and measurement systems operate in the 3.1 GHz to 10.6 GHz frequency band. Vehicular radar systems operate in the 22 GHz to 29 GHz frequency band. They are used for near collision avoidance.

Despite the single named used for the ultra wideband (UWB) transmissions, there are two very different technologies being developed.

- **Carrier free direct sequence ultra wideband technology: This form of ultra-wideband technology transmits a series of impulses. In view of the very short duration of the pulses, the spectrum of the signal occupies a very wide bandwidth.**

- **MBOFDM, Multi-Band OFDM ultra wideband technology: This form of ultra wideband technology uses a wide band or multiband orthogonal frequency division multiplex (MBOFDM) signal that is effectively a 500 MHz wide OFDM signal. This is 500 MHz signal is then hopped in frequency to enable it to occupy a sufficiently high bandwidth.**