

CS8601 -MOBILE COMPUTING

UNIT 1

INTRODUCTION

1.2. Generations of Mobile Communication Technologies:

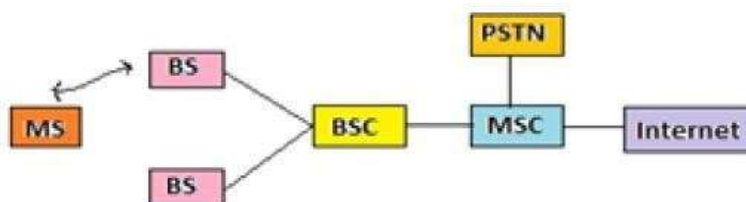
Mobile communication has become more popular in last few years due to fast reform **from 1G to 5G in mobile technology**. This reform is due to requirement of service compatible transmission technology and very high increase in telecoms customers. Generation refers change in nature of service compatible transmission technology and new frequency bands. In 1980 the mobile cellular era had started, and since then mobile communications have undergone considerable changes and experienced massive growth.

A. First Generation

- **1G** These phones were the first mobile phones to be used, which was introduced in **1982** and completed in early 1990.
- It was used for **voice services** and was based on technology called as **Advanced Mobile Phone System (AMPS)**. The AMPS system was frequency modulated and used **frequency division multiple access (FDMA)** with a channel capacity of 30 KHz and frequency band of 824- 894MHz. .

Its basic features are:

- It introduces mobile technologies such as **Mobile Telephone System (MTS), Advanced Mobile Telephone System (AMTS), Improved Mobile Telephone Service (IMTS), and Push to Talk (PTT)**.
- It has **low capacity, unreliable handoff, poor voice links, and no security** at all since voice calls were played back in radio towers, making these calls susceptible to unwanted eavesdropping by third parties.



Architecture of Advanced mobile phone system

B. Second Generation (2G)

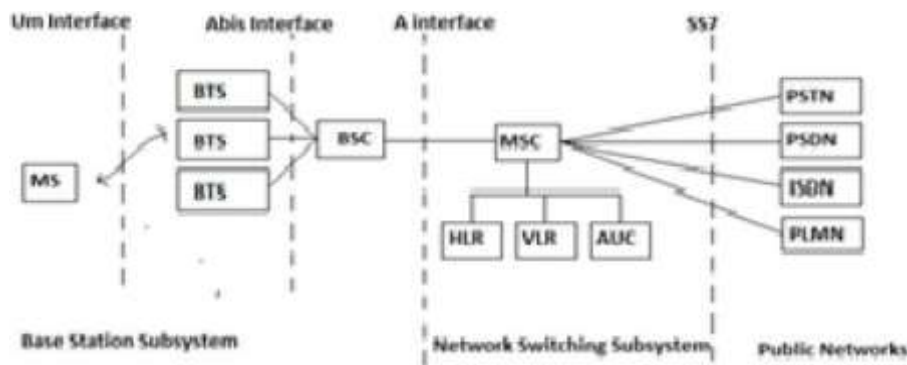
- 2G refers to the **second generation based on GSM** and was emerged in late
- **1980s.**
- It uses **digital signals for voice transmission**. Main focus of this technology was on digital signals and **provides services to deliver text and picture message at low speed (in kbps).**
- It use the **bandwidth of 30 to 200KHz.**
- Next to 2G, **2.5G system uses packet switched and circuit switched domain and provide data rate up to 144 kbps.**
e.g. **GPRS, CDMA and EDGE.**

The main features of 2G and 2.5G are :

- ✓ Data speed was upto 64kbps
- ✓ Use digital signals
- ✓ Enables services such as text messages, picture messages and MMS(Multimedia message)
- ✓ Provides better quality and capacity
- ✓ Unable to handle complex data such as videos.
- ✓ Required strong digital signals to help mobile phones work. If there is no network coverage in any specific area, digital signals would weak.

2.5 G :

- The GSM technology was continuously improved to provide better services which led to **development of advanced Technology between 2g and 3g**
- Provides phone calls
- Send/receive e-mail messages
- Web browsing
- Speed : 64-144 kbps
- Camera phones
- Take a time of 6-9 mins. to download a 3 mins. MP3 song.



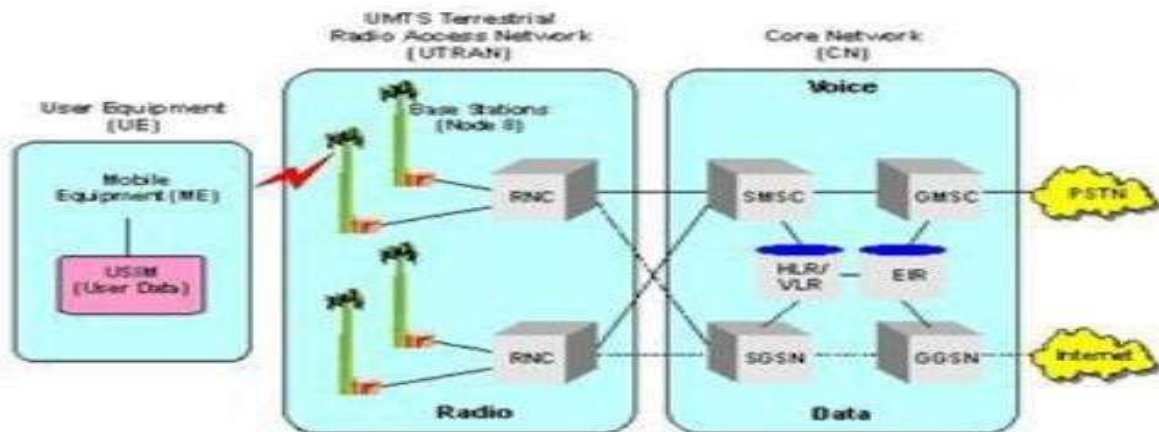
C. Third Generation (3G)

- 3G is **based on GSM and was launched in 2000**. The aim of this technology was to **offer high speed data**. The original technology was improved to **allow data up to 14 Mbps** and more using packet switching.
- It uses Wide Band Wireless Network with which clarity is increased. **It also offers data services, access to television/video, new services like Global Roaming.**
- It operates at a **range of 2100MHz and has a bandwidth of 15-20MHz** used for High-speed internet service, video chatting.

The main features of 3G are:

- ✓ Speed 2 Mbps
- ✓ Typically called smart phones
- ✓ Increased bandwidth and data transfer rates to accommodate web-based applications and audio and video files.
- ✓ Provides faster communication
- ✓ Send/receive large email messages
- ✓ High speed web/more security/video conferencing/3D gaming
- ✓ Large capacities and broadband capabilities
- ✓ TV streaming/mobile TV/Phone calls
- ✓ To download a 3 minute MP3 song only 11 sec-1.5 mins time required.
- ✓ Expensive fees for 3G licenses services
- ✓ It was challenge to build the infrastructure for 3G
- ✓ High bandwidth requirement
- ✓ Expensive 3G phones
- ✓ Large cell phones

3G mobile system was called as UMTS(Universal Mobile Telecommunication System) in Europe,while CDMA2000 is the name of American 3G variant. Also the IMT2000 has accepted a new 3G standard from China, i.e TD-SCDMA. WCDMA is the air- interface technology for UMTS.



D. Fourth Generation (4G)

4G offers a downloading speed of **100Mbps**.

4G provides same feature as 3G and additional services like **Multi-Media Newspapers, to watch T.V programs with more clarity and send Data much faster than previous generations** .

LTE (Long Term Evolution) is considered as 4G technology.

4G is being developed to accommodate **the QoS and rate requirements** set by forthcoming applications like wireless broadband access, **Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video**

4G is being developed to accommodate **the QoS and rate requirements** set by forthcoming applications like wireless broadband access, **Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video Broadcasting (DVB), minimal services like voice and data,** and other services that utilize bandwidth.

The main features of 4G are :

- Capable of provide 10Mbps-1Gbps speed
- High quality streaming video
- Combination of Wi-Fi and Wi-Max
- High security

- Provide any kind of service at any time as per user requirements anywhere
- Expanded multimedia services
- Low cost per-bit
- Battery use is more
- Hard to implement
- Need complicated hardware
- Expensive equipment required to implement next generation network

DF Fifth Generation (5G)

- 5G refer to Fifth Generation which was started from **late 2010s**.
- Facilities that might be seen with 5G technology includes far better levels of connectivity and coverage.
- The main focus of 5G will be **on world-Wireless World Wide Web (WWWW)**.
- It is a complete wireless communication with no limitations.

The main features of 5G are :

- It is highly supportable to WWWW (wireless World Wide Web)
- High speed, high capacity
- Provides large broadcasting of data in Gbps.
- Multi-media newspapers, watch TV programs with the clarity(HD Clarity)
- Faster data transmission that of the previous generation
- Large phone memory, dialing speed, clarity in audio/video
- Support interactive multimedia, voice, streaming video, internet and other
- More effective and attractive

Comparison of all generations of mobile Technologies:

Technology	1G	2G	3G	4G	5G
Start/Deployment	1970-80	1990-2004	2004-10	Now	Soon (probably by 2020)
Data Bandwidth	2Kbps	64 Kbps	2 Mbps	1 Gbps	Higher than 1 Gbps
Technology	Analog	Digital	CDMA 2000, UMTS,EDGE	Wi-Max, Wi-Fi, LTE	WWWW
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit,Packet	Packet	All Packet	All Packet
Primary Service	Analog Phone Calls	Digital Phone Calls and Messaging	Phone calls, Messaging, Data	All-IP Service (including Voice Messages)	High speed, High capacity and provide large broadcasting of data in Gbps
Key differentiator	Mobility	Secure, Mass adoption	Better Internet experience	Faster Broadband Internet, Lower Latency	Better coverage and no dropped calls, much lower latency, Better performance
Weakness	Poor spectral efficiency, major security issue	Limited data rates, difficult to support demand for internet and e-mail	Real performance fail to match type, failure of WAP for internet access	Battery use is more, Required complicated and expensive hardware	?

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CS8601 -MOBILE COMPUTING

UNIT 1

INTRODUCTION

1.1 Introduction to Mobile Computing and Applications of Mobile Computing:

The rapidly expanding technology of cellular communication, wireless LANs, and satellite services will make information accessible anywhere and at any time. Regardless of size, most mobile computers will be equipped with a wireless connection to the fixed part of the network, and, perhaps, to other mobile computers.

The resulting computing environment, which is often referred to as *mobile or nomadic computing*, no longer requires users to maintain a fixed and universally known position in the network and enables almost unrestricted mobility.

Mobile Computing is an umbrella term used to describe technologies that enable people to access network services anyplace, anytime, and anywhere

There are two different kinds of mobility: **user mobility and device portability**.

User mobility refers to a user who has access to the same or similar telecommunication services at different places, i.e., users communicate (wireless) “anytime, anywhere, with anyone”

With **device portability**, the communication device moves (with or without a user). Many mechanisms in the network and inside the device have to make sure that communication is still possible while the device is moving. devices can be connected anytime, anywhere to the network

A communication device can exhibit any one of the **following characteristics**:

- **Fixed and wired:** This configuration describes the typical desktop computer in an office. Neither weight nor power consumption of the devices allow for mobile usage. The devices use fixed networks for performance reasons.
- **Mobile and wired:** Many of today’s laptops fall into this category; users carry the

laptop from one hotel to the next, reconnecting to the company's network via the telephone network and a modem.

- **Fixed and wireless:** This mode is used for installing networks, e.g., in historical buildings to avoid damage by installing wires, or at trade shows to ensure fast network setup.
- **Mobile and wireless:** This is the most interesting case. No cable restricts the user, who can roam between different wireless networks. Most technologies discussed in this book deal with this type of device and the networks supporting them. Today's most successful example for this category is GSM with more than 800 million users.

1.1 Applications of Mobile Computing:

In many fields of work, the ability to keep on the move is vital in order to utilize time efficiently. The importance of Mobile Computers has been highlighted in many fields of which a few are described below:

a. Vehicles:

- ❖ Music, news, road conditions, weather reports, and other broadcast information are received **via digital audio broadcasting (DAB) with 1.5 Mbit/s**.
- ❖ For personal communication, **GSM, universal mobile telecommunications system (UMTS)** phone might be available offering voice and data connectivity with 384 kbit/s.
- ❖ The current position of the car is determined **via the global positioning system (GPS)**. Cars driving in the same area build a local ad-hoc network for the fast exchange of information in emergency situations or to help each other keep a safe distance. In case of an accident, not only will the airbag be triggered, but the police and ambulance service will be informed via an emergency call to a service provider.
- ❖ Buses, trucks, and trains are already transmitting maintenance and logistic information to their home base, which helps to improve organization (fleet management), and saves time and money.

b. Emergencies:

- An ambulance with a **high-quality wireless connection to a hospital can carry vital information** about injured persons to the hospital from the scene of the

accident.

- All the necessary steps for this particular **type of accident can be prepared** and specialists can **be consulted for an early diagnosis**.
- Wireless networks are the only means of communication in the case of natural disasters such as **hurricanes or earthquakes**. In the worst cases, only decentralized, wireless ad-hoc networks survive.

c. Business:

Managers can use mobile computers say, **critical presentations to major customers**. They can access the latest market **share information**. At a small recess, they can revise the presentation to take advantage of this information. **They can communicate with the office about possible new offers** and call meetings for discussing responds to the new proposals. Therefore, mobile computers can leverage competitive advantages.

A travelling salesman today needs instant access to the company's database: to ensure that files on his or her laptop reflect the current situation, to enable the company to keep track of all activities of their travelling employees, to keep databases consistent etc.

With wireless access, the laptop can be turned into a true mobile office, but efficient and powerful synchronization mechanisms are needed to ensure data consistency.

d. Credit Card Verification:

- ✓ At **Point of Sale (POS) terminals** in shops and supermarkets, when customers use **credit cards for transactions**, the intercommunication required between the bank central computer and the POS terminal, in order to effect verification of the card usage, can take place quickly and securely over cellular channels using a mobile computer unit.
- ✓ **This can speed up the transaction process and relieve congestion at the POS terminals.**

e. Replacement of Wired Networks:

- wireless networks can also be used to **replace wired networks, e.g., remote sensors, for tradeshows, or in historic buildings.**

- Due to economic reasons, **it is often impossible to wire remote sensors for weather forecasts, earthquake detection, or to provide environmental information.**
- **Wireless connections, e.g., via satellite, can help in this situation.**
Other examples for wireless networks are computers, sensors, or information displays in historical buildings, where excess cabling may destroy valuable walls or floors.

f. Infotainment:

- ❖ Wireless networks can **provide up-to-date information at any appropriate location.**
- ❖ The **travel guide** might tell you something about the history of a building (knowing via **GPS**, contact to a local base station, or triangulation where you are) downloading information about a concert in the building at the same evening via a local wireless network.
- ❖ Another growing field of wireless network applications lies in **entertainment and games** to enable, e.g., ad-hoc gaming networks as soon as people meet to play together.

g. Location dependent services

It is important for an application to ‘know’ something about the location or the user might need location information for further activities

- **Location aware services**
 - what services, e.g., printer, fax, phone, server etc. exist in the local environment
- **Follow-on services**
 - automatic call-forwarding, transmission of the actual workspace to the current location
- **Information services**
 - “push”: e.g., current special offers in the supermarket
 - “pull”: e.g., where is the Black Forrest Cheese Cake?

- **Support services**
 - caches, intermediate results, state information etc. “follow” the mobile device through the fixed network
- **Privacy**
 - who should gain knowledge about the location

1.2 Limitations of Mobile Computing

- Resource constraints: **Battery**
- **Interference:** Radio transmission cannot be protected against interference using shielding and result in higher loss rates for transmitted data or higher bit error rates respectively
- **Bandwidth:** Although they are continuously increasing, transmission rates are still very low for wireless devices compared to desktop systems. Researchers look for more efficient communication protocols with low overhead.
- **Dynamic changes in communication environment:** variations in signal power within a region, thus link delays and connection losses
- **Network Issues:** discovery of the connection-service to destination and connection stability
- **Interoperability issues:** the varying protocol standards
- **Security constraints:** Not only can portable devices be stolen more easily, but the radio interface is also prone to the dangers of eavesdropping. Wireless access must always include encryption, authentication, and other security mechanisms that must be efficient and simple to use.

Wireless networks in comparison to fixed networks

Higher loss-rates due to interference

- emissions of, e.g., engines, lightning

Restrictive regulations of frequencies

- frequencies have to be coordinated, useful frequencies are almost all occupied

Lower transmission rates

- local some Mbit/s, regional sometimes only, e.g., 53kbit/s with GSM/GPRS or about 150 kbit/s using EDGE – some Mbit/s with LTE

Higher delays, higher jitter

- connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems –in ms range with LTE

Lower security, simpler active attacking

- radio interface accessible for everyone, base station can be simulated, thus attracting calls from mobile phones

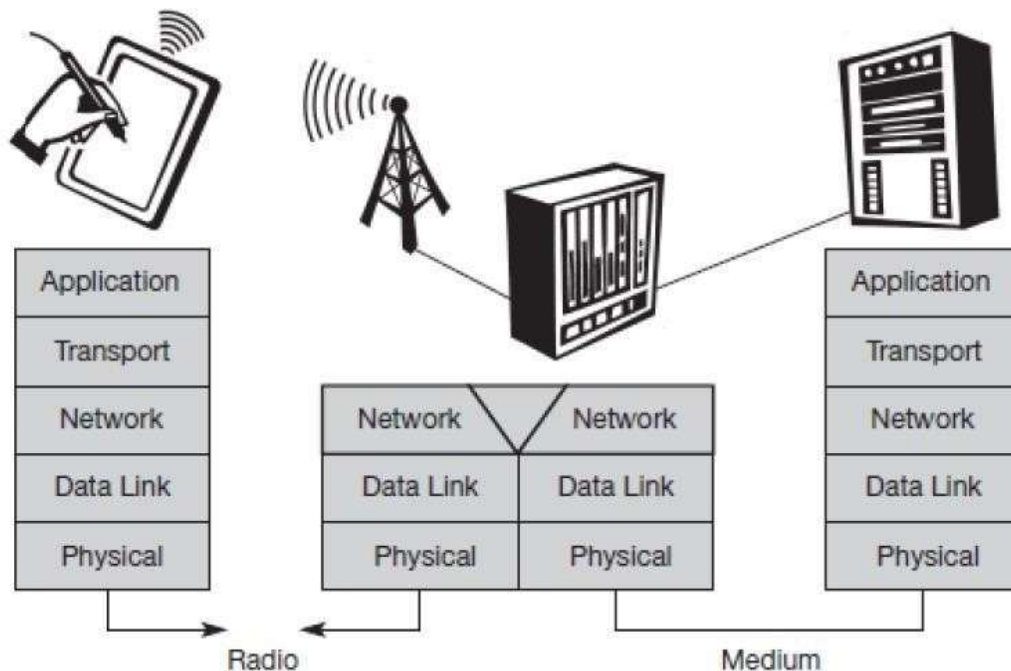
Always shared medium

- secure access mechanisms important

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A simplified reference model

The figure shows the **protocol stack** implemented in the system according to the reference model. **End-systems**, such as the PDA and computer in the example, need a full protocol stack comprising the application layer, transport layer, network layer, data link layer, and physical layer. Applications on the end-systems communicate with each other using the lower layer services. **Intermediate systems**, such as the interworking unit, do not necessarily need all of the layers.



A Simplified Reference Model

Physical layer: This is the lowest layer in a communication system and is responsible for the **conversion of a stream of bits into signals** that can be transmitted on the sender side. The physical layer of the receiver then transforms the signals back into a bit stream. For wireless communication, **the physical layer is responsible for frequency selection**, generation of the **carrier frequency**, **signal detection** (although heavy interference may disturb the signal), modulation of data onto a carrier frequency and (depending on the transmission scheme) encryption.

Data link layer: The main tasks of this layer include **accessing the medium, multiplexing of different data streams, correction of transmission errors, and synchronization** (i.e., detection of a data frame).

Altogether, the data link layer is responsible for a **reliable point-to-point connection** between two devices or a point-to-multipoint connection between one sender and several receivers.

Network layer: This third layer is responsible for **routing packets through a network** or establishing a connection between two entities over many other intermediate systems. Important functions are addressing, routing, device location, and handover between different networks.

Transport layer: This layer is used in the reference model to **establish an end-to-end connection**

Application layer: Finally, the applications (complemented by additional layers that can support applications) are situated on top of all transmission oriented layers. Functions are **service location, support for multimedia applications, adaptive applications** that can handle the large variations in transmission characteristics, and **wireless access to the world-wide web using a portable device.**

CS8601 -MOBILE COMPUTING

UNIT 1

INTRODUCTION

1.5. Medium access control(MAC)

The **Media Access Control (MAC)** data communication protocol sub-layer, also known as the Medium Access Control, is a sublayer of the Data Link Layer specified in the seven-layer OSI model (layer 2). The hardware that implements the MAC is referred to as a **Medium Access Controller**. The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sublayer and the network's physical layer. The MAC layer emulates a full-duplex logical communication channel in a multi-point network. This channel may provide unicast, multicast or broadcast communication service.

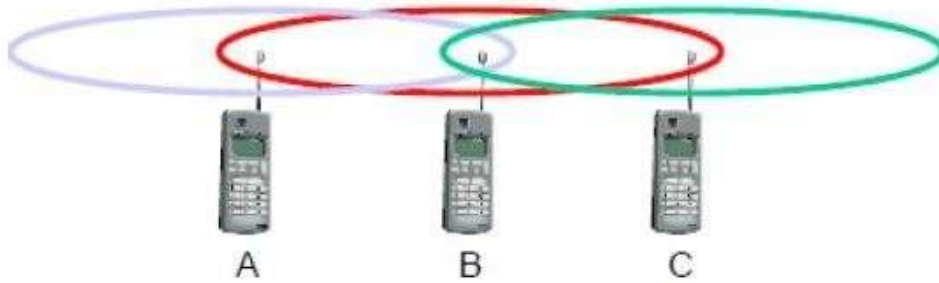
Motivation for a specialized MAC:

One of the most commonly used MAC schemes for wired networks is carrier sense multiple access with collision detection (CSMA/CD). In this scheme, a sender senses the medium (a wire or coaxial cable) to see if it is free. If the medium is busy, the sender waits until it is free. If the medium is free, the sender starts transmitting data and continues to listen into the medium. If the sender detects a collision while sending, it stops at once and sends a jamming signal. But this scheme does not work well with wireless networks. The problems are:

- a) Signal strength decreases proportional to the square of the distance
- b) The sender would apply CS and CD, but the collisions happen at the receiver
- c) It might be a case that a sender cannot “hear” the collision, i.e., CD does not work
- d) Furthermore, CS might not work, if for e.g., a terminal is “hidden”

Hidden and Exposed Terminals

Consider the scenario with three mobile phones as shown below. The transmission range of A reaches B, but not C (the detection range does not reach C either). The transmission range of C reaches B, but not A. Finally, the transmission range of B reaches A and C, i.e., A cannot detect C and vice versa.



Hidden terminals

- A sends to B, C cannot hear A
- C wants to send to B, C senses a “free” medium (CS fails) and starts transmitting
- Collision at B occurs, A cannot detect this collision (CD fails) and continues with its transmission to B
- A is “hidden” from C and vice versa

Exposed terminals

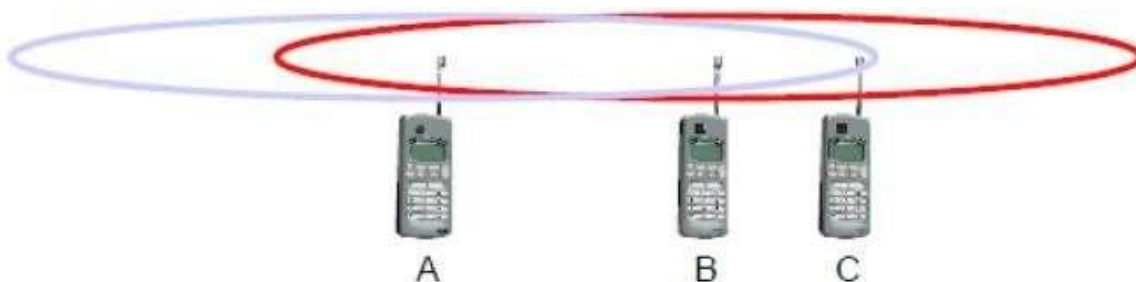
- B sends to A, C wants to send to another terminal (not A or B) outside the range
- C senses the carrier and detects that the carrier is busy.
- C postpones its transmission until it detects the medium as being idle again but A is outside radio range of C, waiting is **not** necessary
- C is “exposed” to B

Hidden terminals cause collisions, whereas Exposed terminals causes unnecessary delay.

Near and far terminals

Consider the situation shown below. A and B are both sending with the same transmission power.

- Signal strength decreases proportional to the square of the distance
- So, B’s signal drowns out A’s signal making C unable to receive A’s transmission
- If C is an arbiter for sending rights, B drowns out A’s signal on the physical layer making C unable to hear out A.



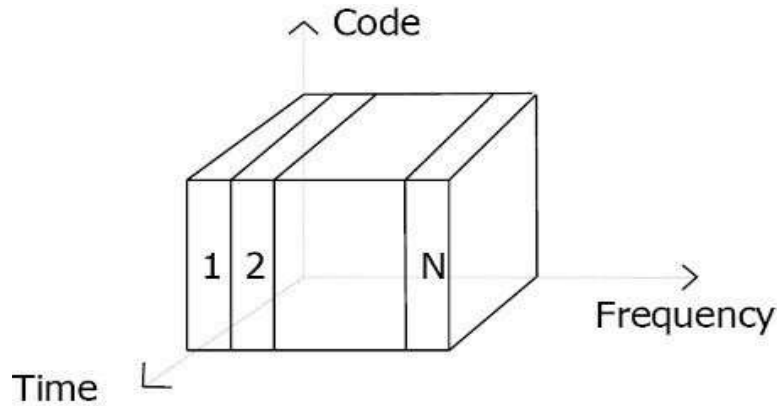
The **near/far effect** is a severe problem of wireless networks using CDM. All signals should arrive at the receiver with more or less the same strength for which Precise power control is to be implemented.

Space Division Multiple Access [SDMA]:

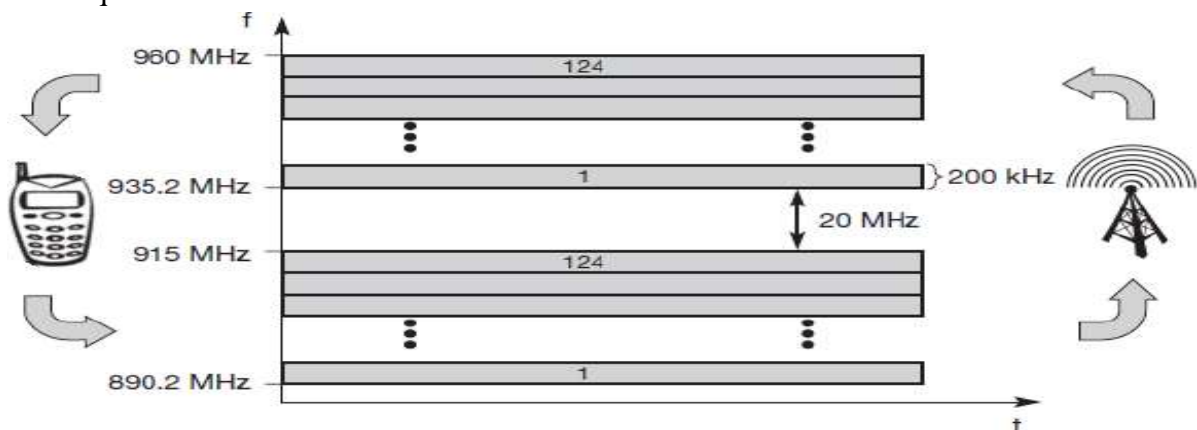
- ❖ **Space Division Multiple Access (SDMA)** is used for allocating a separated space to users in wireless networks.
- ❖ A typical application involves assigning an **optimal base station to a mobile phone user**. The mobile phone may receive several base stations with different quality.
- ❖ A MAC algorithm could **now decide which base station is best**, taking into account which frequencies (FDM), time slots (TDM) or code (CDM) are still available.
- ❖ The basis for the SDMA algorithm is **formed by cells and sectorized antennas** which constitute the infrastructure implementing **space division multiplexing (SDM)**.
- ❖ SDM has the unique advantage of not requiring any multiplexing equipment.
- ❖ **It is usually combined with other multiplexing techniques** to better utilize the individual physical channels.

Frequency Division Multiple Access [FDMA]:

Frequency division multiplexing (FDM) describes schemes to subdivide the frequency dimension into several non-overlapping frequency



Frequency Division Multiple Access is a method employed to permit several users to transmit simultaneously on one satellite transponder by assigning a specific frequency within the channel to each user. Each conversation gets its own, unique, radio channel. The channels are relatively narrow, usually 30 KHz or less and are defined as either transmit or receive channels. A full duplex conversation requires a transmit & receive channel pair. FDM is often used for simultaneous access to the medium by base station and mobile station in cellular networks establishing a duplex channel. A scheme called **frequency division duplexing (FDD)** in which the two directions, mobile station to base station and vice versa are now separated using different frequencies.



FDM for multiple access and duplex

The two frequencies are also known as **uplink**, i.e., from mobile station to base station or from ground control to satellite, and as **downlink**, i.e., from base station to mobile station or from satellite to ground control. The basic frequency allocation scheme for GSM is fixed and regulated by national authorities. All uplinks use the band between 890.2 and 915 MHz, all downlinks use

935.2 to 960 MHz. According to FDMA, the base station, shown on the right side, allocates a certain frequency for up- and downlink to establish a duplex channel with a mobile phone. Up- and downlink have a fixed relation. If the uplink frequency is $f_u = 890 \text{ MHz} + n \cdot 0.2 \text{ MHz}$, the downlink frequency is $f_d = f_u + 45 \text{ MHz}$, i.e., **$f_d = 935 \text{ MHz} + n \cdot 0.2 \text{ MHz}$** for a certain channel n . The base station selects the channel. Each channel (uplink and downlink) has a bandwidth of 200 kHz.

This scheme also has disadvantages. While radio stations broadcast 24 hours a day, mobile communication typically takes place for only a few minutes at a time. Assigning a separate frequency for each possible communication scenario would be a tremendous waste of (scarce) frequency resources. Additionally, the fixed assignment of a frequency to a sender makes the scheme very inflexible and limits the number of senders.

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UNIT 1

INTRODUCTION

1.3. Multiplexing:

- Multiplexing describes **how several users can share a medium with minimum or no interference**
 - It is concerned with **sharing the frequency range amongst the users**
 - **Bands are split into channels**
 - Four main ways of assigning channels
 - **Space Division Multiplexing (SDM)** : allocate according to location
 - **Time Division Multiplexing (TDM)**: allocate according to units of time
 - **Frequency Division Multiplexing (FDM)**: allocate according to the frequencies
 - **Code Division Multiplexing (CDM)** : allocate according to access codes
- Guard Space:** gaps between allocations

A. Space division multiplexing

- This is the basis of frequency reuse
- Each physical space is assigned channels
- Spaces that don't overlap can have the same channels assigned to them
- **Example: FM radio stations in different countries**

This multiplexing scheme is used, for example, at FM radio stations where the transmission range is limited to a certain region, many radio stations around the world can use the same frequency without interference

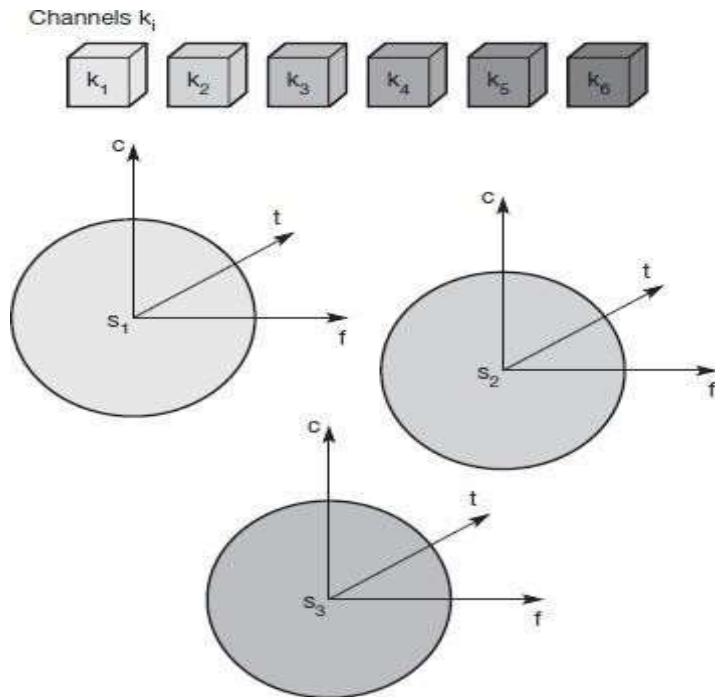
Below figure shows six channels k_i and introduces a three dimensional coordinate system. This system shows the dimensions of code c , time t and frequency f . For this first type of multiplexing, **space division multiplexing (SDM)**, the (three dimensional) space s_i is also shown. Here space is represented via circles indicating the interference range

For the remaining channels (k_4 to k_6) three additional spaces would be needed. In our highway example this would imply that each driver had his or her own lane.

Drawback

Although this procedure clearly represents a **waste of space**, this is exactly the principle used by the old analog telephone system: each subscriber is given a separate pair of

copper wires to the local exchange. In wireless transmission, **SDM implies a separate sender for each communication channel with a wide enough distance between senders.**



B. Frequency division multiplexing:

- Separation of the whole spectrum into smaller non overlapping frequency bands (guard spaces are needed)
- A channel gets a certain band of the spectrum for the whole time – receiver has to tune to the sender frequency

Again, **guard spaces** are needed to avoid frequency band overlapping (also called **adjacent channel interference**).

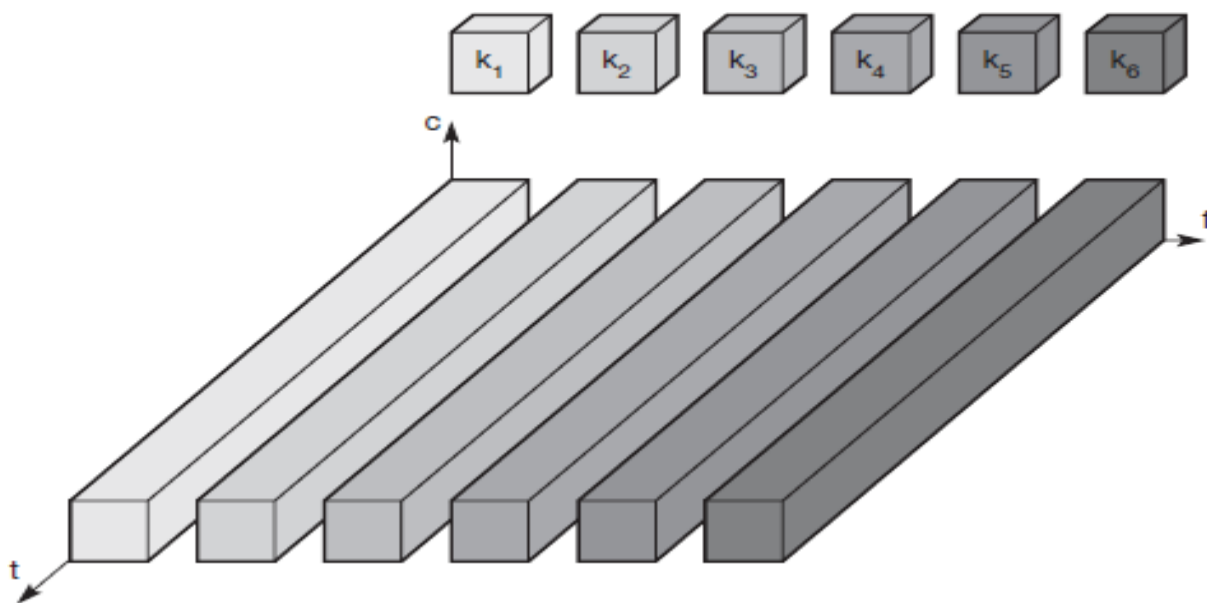
This scheme is used for **radio stations within the same region**, where each radio station has its own frequency. This very simple multiplexing scheme does not need complex coordination between sender and receiver: the receiver only has to tune in to the specific sender.

- **Advantages**

- **No dynamic coordination necessary**
- **Works also for analog signal**

Disadvantages:

- ✓ While radio stations broadcast 24 hours a day, mobile communication typically takes place for only a few minutes at a time. Assigning a separate frequency for each possible communication scenario would be a **tremendous waste of (scarce) frequency resources**.
- ✓ Additionally, **the fixed assignment of a frequency to a sender makes the scheme very inflexible and limits the number of senders.**



C. Time division multiplexing:

Here a channel k_i is given the **whole bandwidth for a certain amount of time**, i.e., all senders use the same frequency but at different points in time.

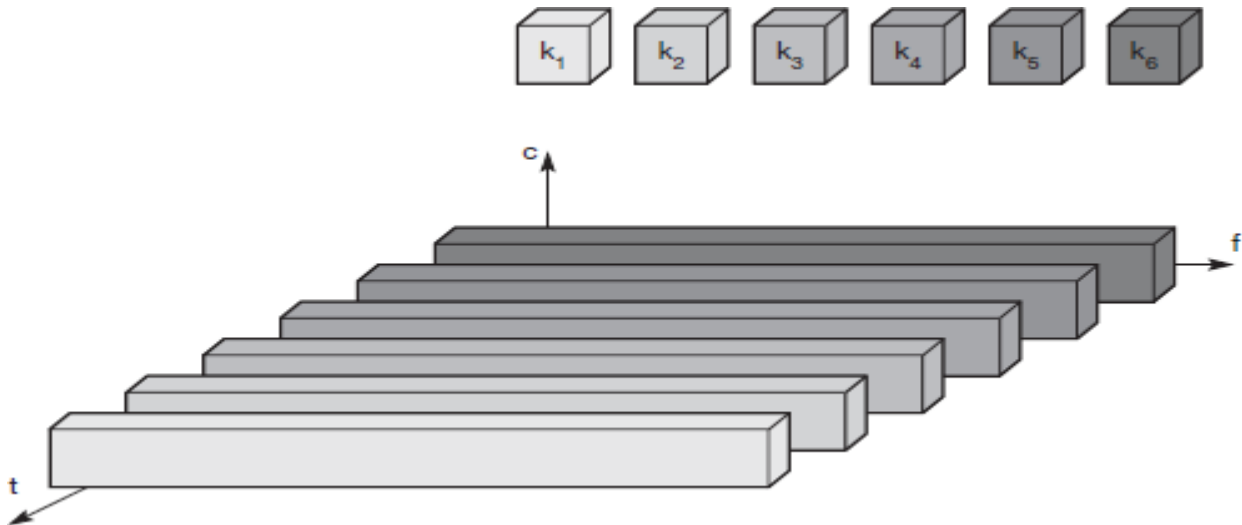
Again, **guard spaces**, which now represent time gaps, have to separate the different periods when the senders use the medium. In our highway example, this would refer to the gap between two cars.

If two transmissions overlap in time, this is called **co-channel interference**. (In the highway example, interference between two cars results in an accident.)

To avoid this type of interference, **precise synchronization between different senders** is necessary.

Advantages:

- Only one carrier in the medium at any time
- Throughput high even for many users
- **Disadvantages**
- Precise clock synchronization necessary



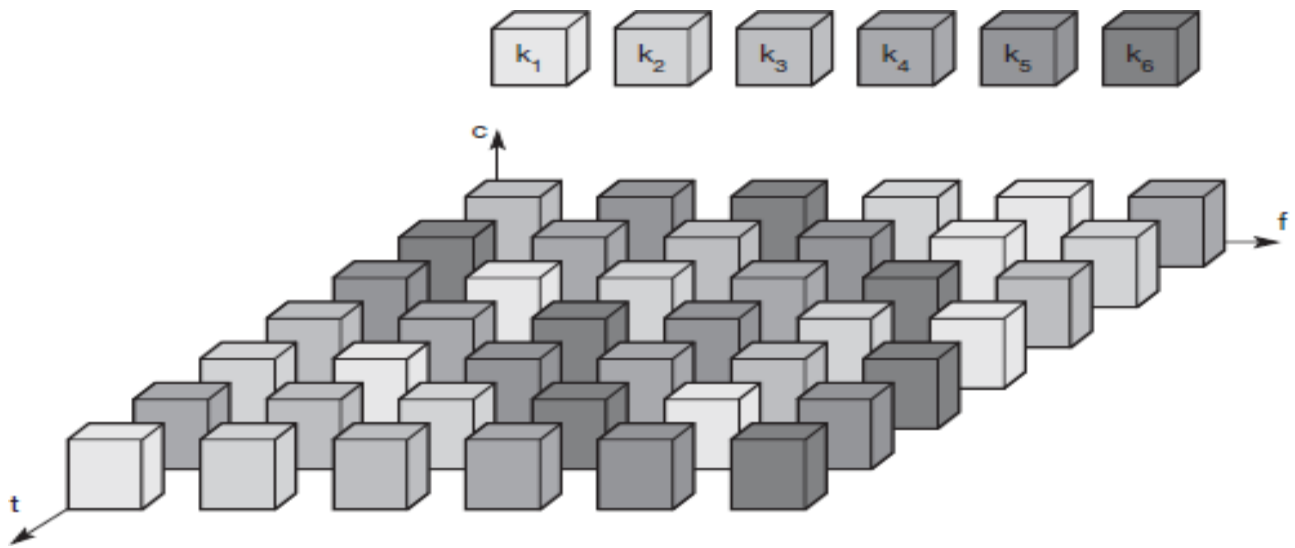
Frequency and time division multiplexing

Frequency and time division multiplexing can be combined, i.e., a channel

- A channel gets a certain frequency band for a certain amount of time
- Now **guard spaces are needed both in the time and in the frequency dimension.**
- Example: **GSM**
- **Advantages**
 - Better protection against tapping
 - Protection against frequency selective interference

Disadvantages

Precise clock synchronization necessary



D. Code division multiplexing:

- Below figure shows how all channels k_i use the same frequency at the same time for transmission.

- **Separation is now achieved by assigning each channel its own 'code',**
- **Guard spaces are realized by using codes with the necessary 'distance' in code space, e.g., orthogonal codes.**

- **Implemented using spread spectrum technology**

- The typical everyday example of CDM is a party with many participants from different countries around the world who establish communication channels, i.e., they talk to each other, using the same frequency range (approx. 300–6000 Hz depending on a person's voice) at the same time. If everybody speaks the same language, SDM is needed to be able to communicate (i.e., standing in groups, talking with limited transmit power).

- But as soon as another code, i.e., another language, is used, one can tune in to this language and clearly separate communication in this language from all the other languages. (The other languages appear as background noise.)

- This explains why CDM has **built-in security**: if the language is unknown, the

signals can still be received, but they are useless. By using a secret code (or language), a secure channel can be established in a 'hostile' environment. (At parties this may cause some confusion.). Guard spaces are also of importance in this illustrative example. Using, e.g., Swedish and Norwegian does not really work; the languages are too close. But Swedish and Finnish are 'orthogonal' enough to separate the communication channels.

Advantages

- Bandwidth efficient
- No coordination and synchronization necessary
- Good protection against interference and tapping

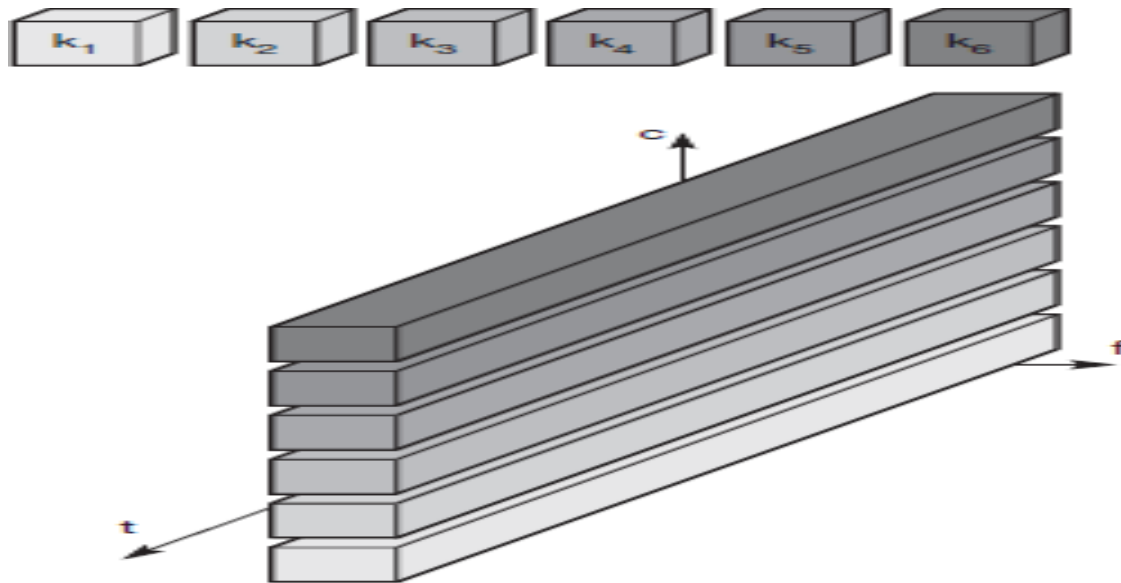
Disadvantages

Precise power control

required More

complex signal

regeneration



CS8601 -MOBILE COMPUTING

UNIT 1

INTRODUCTION

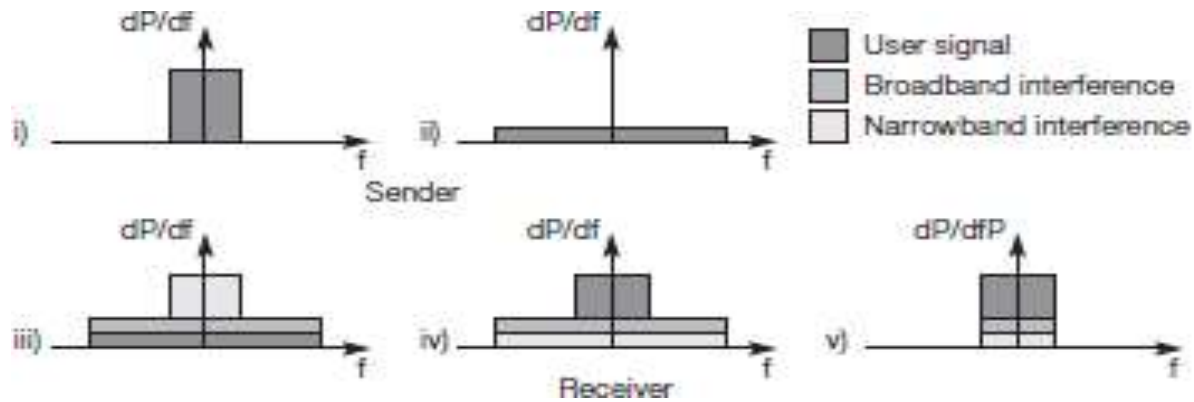
1.4. Spread spectrum

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- **Solution: spread the narrow band signal into a broad band signal using a special code**
- **protection against narrow band interference**
- Figure shows i) shows an idealized narrowband signal from a sender of user data (here power density dP/df versus frequency f).

The sender now spreads the signal in step ii), i.e., **converts the narrowband signal into a broadband signal**. The energy needed to transmit the signal (the area shown in the diagram) is the same, but it is now spread over a larger frequency range. **The power level of the spread signal can be much lower than that of the original narrowband signal without losing data.**

During transmission, narrowband and broadband interference add to the signal. The sum of interference and user signal is received. The receiver now knows how to despread the signal, converting the spread user signal into a narrowband signal again, while spreading the narrowband interference and leaving the broadband interference.

In step v) the receiver applies a bandpass filter to cut off frequencies left and right of the narrowband signal. Finally, the receiver can reconstruct the original data because the power level of the user signal is high enough, i.e., the signal is much stronger than the remaining interference.



Drawbacks:

- (i) **Increased complexity** of receivers that have to despread a signal.
- (ii) **Large frequency band** that is needed due to the spreading of the signal.

Although spread signals appear more like noise, they still raise the background noise level and may interfere with other transmissions if no special precautions are taken.

- Spreading the spectrum can be achieved in two different ways as shown in the following two sections

1. **Direct sequence spread spectrum**
2. **Frequency hopping spread spectrum**

Direct sequence spread spectrum:

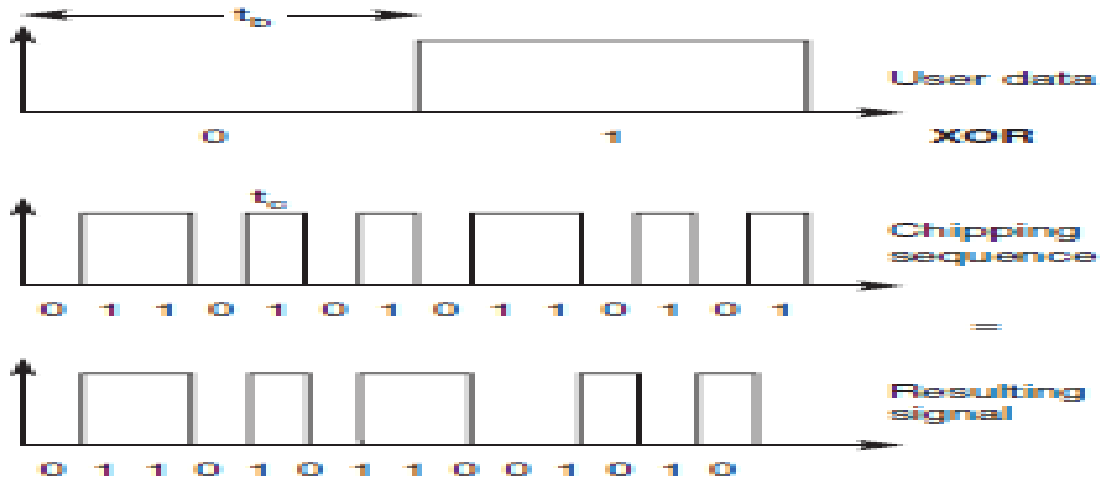
Direct sequence spread spectrum (DSSS) systems take a user bit stream and perform an (XOR) with a so-called chipping sequence as shown in below figure.

The example shows that the result is either the sequence 0110101 (if the user bit equals 0) or its complement 1001010 (if the user bit equals 1). While each user bit has a duration t_b , the chipping sequence consists of smaller pulses, called chips, with a duration t_c .

If the chipping sequence is generated properly it appears as random noise:

this sequence is also sometimes called **pseudo-noise** sequence.

The **spreading factor** $s = t_b/t_c$ determines the bandwidth of the resulting signal. If the original signal needs a bandwidth w , the resulting signal needs $s \cdot w$ after spreading

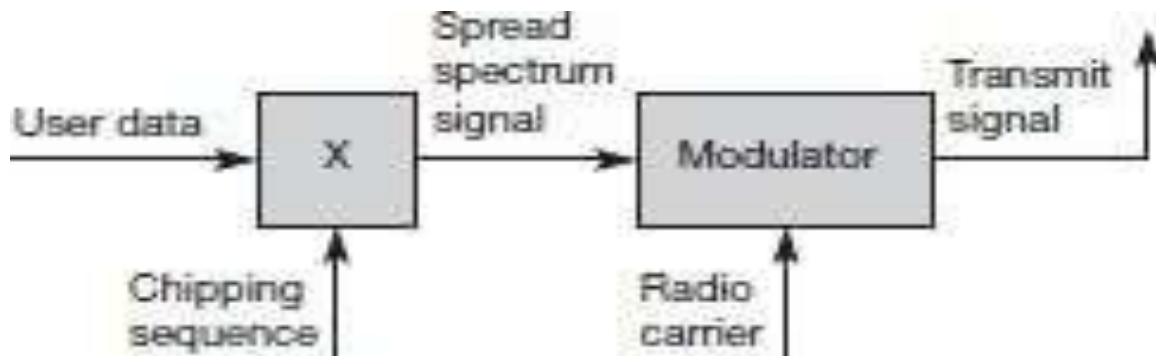


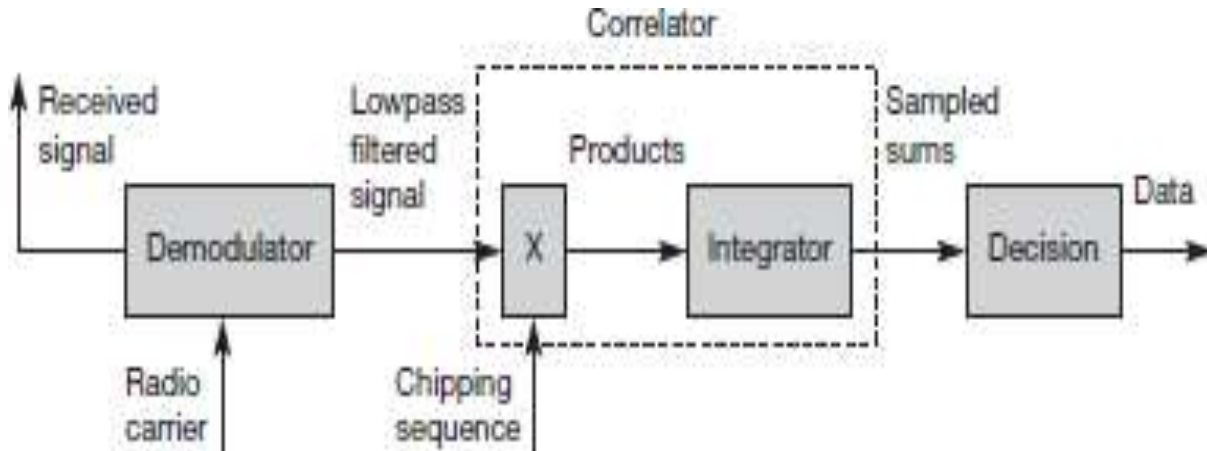
DSSS need additional components as shown in the simplified block diagrams in below figure

The first step in a DSSS transmitter, the spreading of the user data with the chipping sequence (digital modulation).

Assuming for example a user signal with a bandwidth of 1 MHz. Spreading with the above 11-chip Barker code would result in a signal with 11 MHz bandwidth. The radio carrier then shifts this signal to the carrier frequency (e.g., 2.4 GHz in the ISMband).

This signal is then transmitted as





The DSSS receiver is more complex than the transmitter. The receiver only has to perform the inverse functions of the two transmitter modulation steps. However, noise and multi-path propagation require additional mechanisms to reconstruct the original data.

The first step in the receiver involves demodulating the received signal. This is achieved using the same carrier as the transmitter reversing the modulation and results in a signal with approximately the same bandwidth as the original spread spectrum signal. **Additional filtering can be applied to generate this signal.**

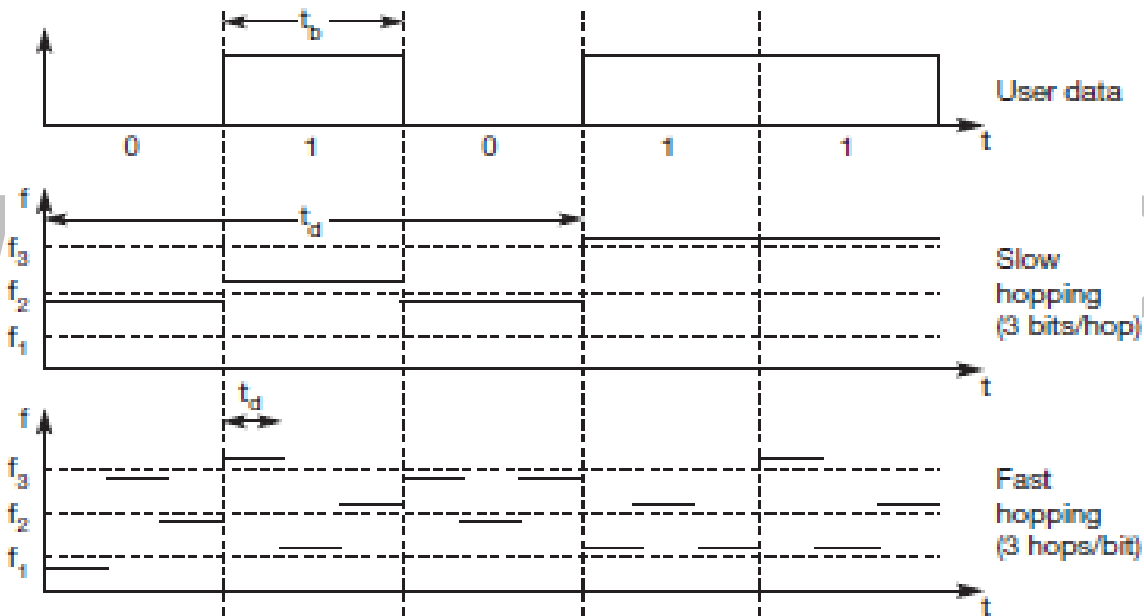
If transmitter and receiver are perfectly synchronized and the signal is not too distorted by noise or multi-path propagation, DSSS works perfectly well according to the simple scheme shown. Sending the user data 01 and applying the 11-chip Barker code 10110111000 results in the spread 'signal' 1011011100001001000111. On the receiver side, this 'signal' is XORed bit-wise after demodulation with the same Barker code as chipping sequence. This results in the sum of products equal to 0 for the first bit and to 11 for the second bit. The decision unit can now map the first sum (=0) to a binary 0, the second sum (=11) to a binary 1 – this constitutes the original user data.

Frequency hopping spread spectrum:

For **frequency hopping spread spectrum (FHSS)** systems, the total available **bandwidth is split into many channels of smaller bandwidth plus guard spaces between the channels.**

Transmitter and receiver stay on one of these channels for a certain time and then hop to another channel. **This system implements FDM and TDM.**

The pattern of channel usage is called the **hopping sequence**, the time spend on a channel with a certain frequency is called the **dwell time**. FHSS comes in two variants, **slow and fast hopping**



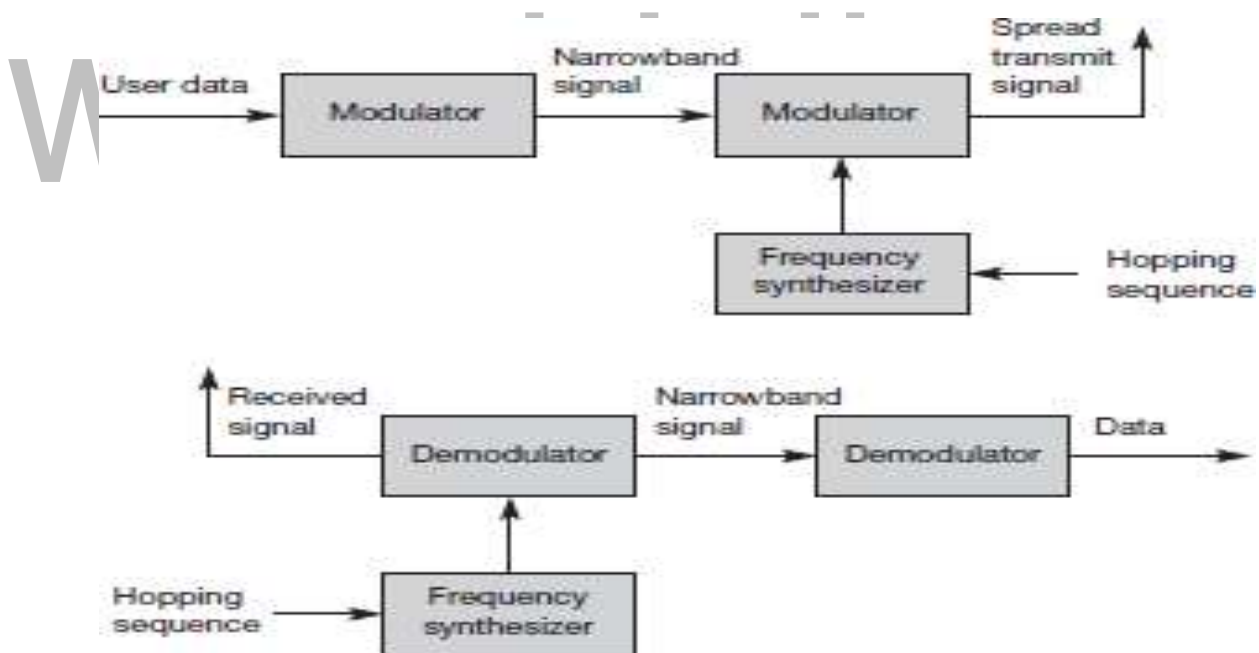
In **slow hopping**, the transmitter uses one frequency for several bit periods. Above figure shows five user bits with a bit period t_b . Performing slow hopping, the transmitter uses the frequency f_2 for transmitting the first three bits during the dwell time t_d . Then, the transmitter hops to the next frequency f_3 . Slow hopping systems are typically cheaper and have relaxed tolerances, but they are not as immune to narrowband interference as fast hopping systems.

For **fast hopping** systems, the transmitter changes the frequency several

times during the transmission of a single bit. In the above figure, the transmitter hops three times during a bit period. Fast hopping systems are more complex to implement because the transmitter and receiver have to stay synchronized within smaller tolerances to perform hopping at more or less the same points in time. However, these systems are much better at overcoming the effects of narrowband interference and frequency selective fading as they only stick to one frequency for a very short time.

The below Figures show simplified block diagrams of FHSS transmitters and receivers respectively.

The first step in an FHSS transmitter is the modulation of user data according to one of the digital-to analog modulation schemes, e.g., FSK or BPSK. This results in a narrowband signal, if FSK is used with a frequency f_0 for a binary 0 and f_1 for a binary



1. In the next step, frequency hopping is performed, based on a hopping sequence.

The hopping sequence is **fed into a frequency synthesizer generating the carrier frequencies f_i .**

A second modulation uses the modulated narrowband signal and the carrier

frequency to generate a new spread signal with frequency of f_i+f_0 for a 0 and f_i+f_1 for a 1 respectively. If different FHSS transmitters use hopping sequences that never overlap, i.e., if two transmitters never use the same frequency f_i at the same time, then these two transmissions do not interfere.

This requires the coordination of all transmitters and their hopping sequences. As for DSSS systems, pseudo-random hopping sequences can also be used without coordination.

The receiver of an FHSS system has to know the hopping sequence and must stay synchronized. It then performs the inverse operations of the modulation to reconstruct user data. Several filters are also needed .

Compared to DSSS, spreading is simpler using FHSS systems. FHSS systems only use a portion of the total band at any time, while DSSS systems always use the total bandwidth available. DSSS systems on the other hand are more resistant to fading and multi-path effects. DSSS signals are much harder to detect – without knowing the spreading code, detection is virtually impossible. If each sender has its own pseudo-random number sequence for spreading the signal (DSSS or FHSS), the system implements CDM.

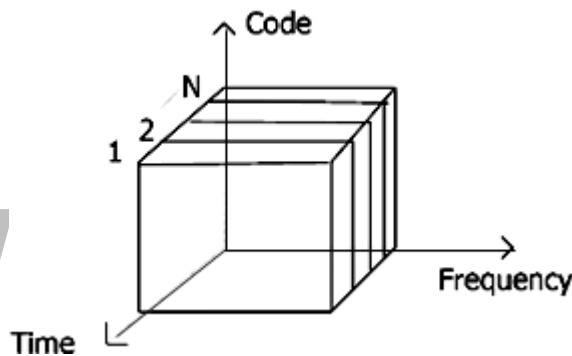
CS8601 -MOBILE COMPUTING

UNIT 1

INTRODUCTION

1.6. Time Division Multiple Access [TDMA]:

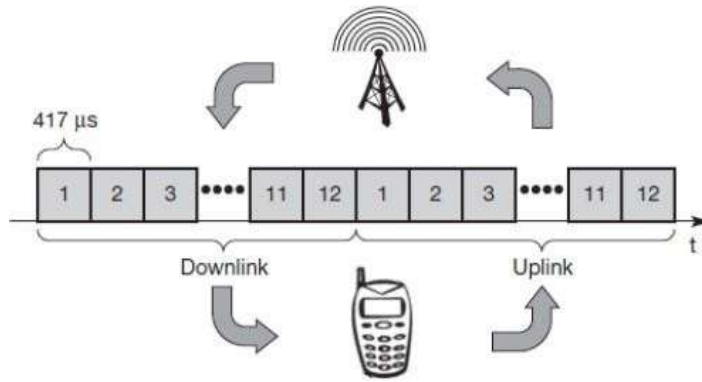
A more flexible multiplexing scheme for typical mobile communications is time division multiplexing (TDM). Compared to FDMA, time division multiple access (TDMA) offers a much more flexible scheme, which comprises all technologies that allocate certain time slots for communication. Now synchronization between sender and receiver has to be achieved in the time domain. Again this can be done by using a fixed pattern similar to FDMA techniques, i.e., allocating a certain time slot for a channel, or by using a dynamic allocation scheme.



Listening to different frequencies at the same time is quite difficult, but listening to many channels separated in time at the same frequency is simple. Fixed schemes do not need identification, but are not as flexible considering varying bandwidth requirements.

Fixed TDM

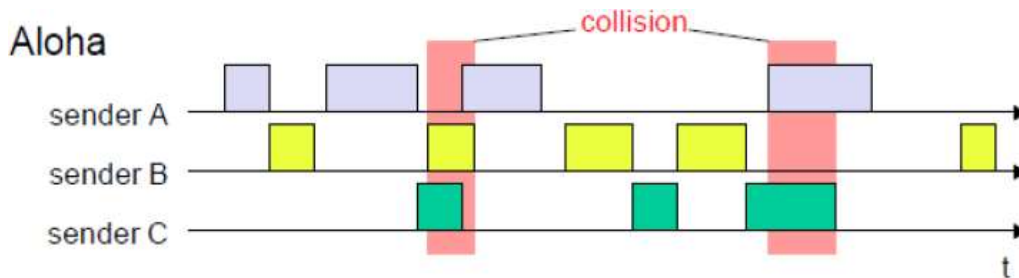
The simplest algorithm for using TDM is allocating time slots for channels in a fixed pattern. This results in a fixed bandwidth and is the typical solution for wireless phone systems. MAC is quite simple, as the only crucial factor is accessing the reserved time slot at the right moment. If this synchronization is assured, each mobile station knows its turn and no interference will happen. The fixed pattern can be assigned by the base station, where competition between different mobile stations that want to access the medium is solved.



The above figure shows how these fixed TDM patterns are used to implement multiple access and a duplex channel between a base station and mobile station. Assigning different slots for uplink and downlink using the same frequency is called **time division duplex (TDD)**. As shown in the figure, the base station uses one out of 12 slots for the downlink, whereas the mobile station uses one out of 12 different slots for the uplink. Uplink and downlink are separated in time. Up to 12 different mobile stations can use the same frequency without interference using this scheme. Each connection is allotted its own up- and downlink pair. This general scheme still wastes a lot of bandwidth. It is too static, too inflexible for data communication. In this case, connectionless, demand-oriented TDMA schemes can be used.

Classical Aloha

In this scheme, TDM is applied without controlling medium access. Here each station can access the medium at any time as shown below:

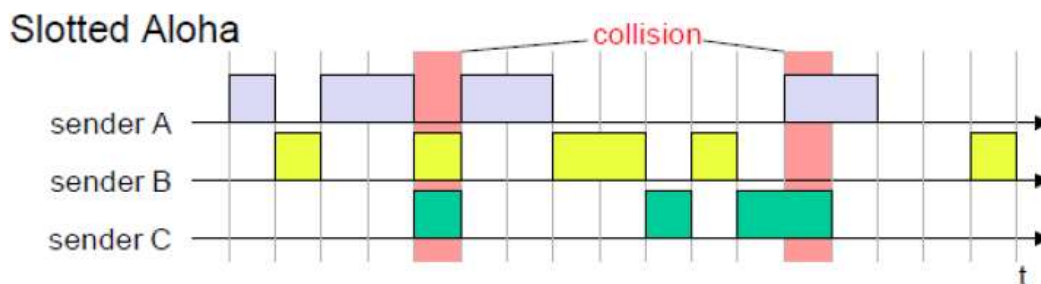


This is a random access scheme, without a central arbiter controlling access and without coordination among the stations. If two or more stations access the medium at the same time, a **collision** occurs and the transmitted data is destroyed. Resolving this problem is left to higher layers (e.g., retransmission of data). The simple Aloha works fine for a light load and does not require any complicated access mechanisms.

Slotted Aloha

The first refinement of the classical Aloha scheme is provided by the introduction of

timeslots (**slotted Aloha**). In this case, all senders have to be **synchronized**, transmission can only start at the beginning of a **time slot** as shown below.



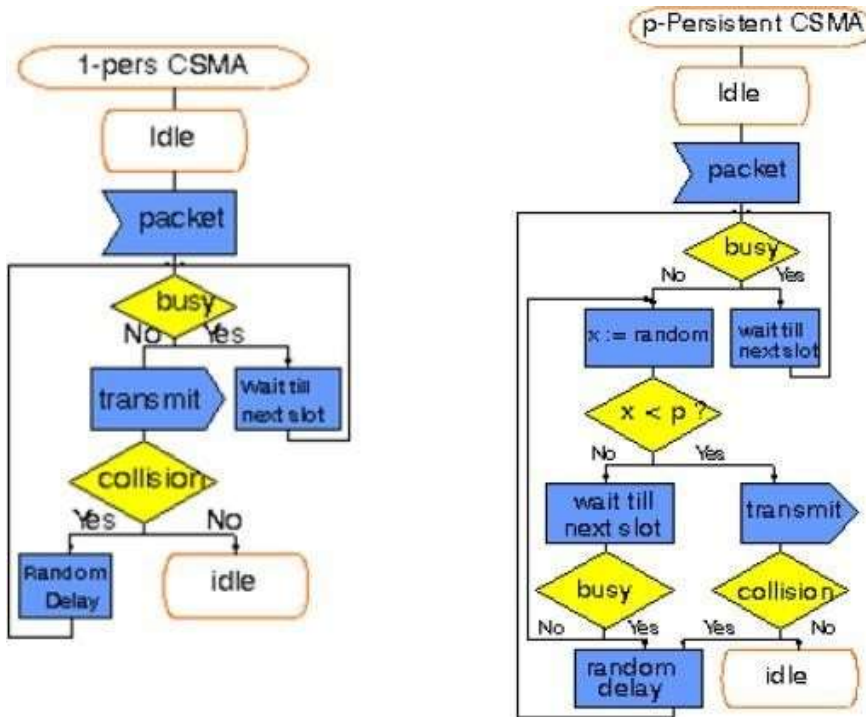
The introduction of slots raises the throughput from 18 per cent to 36 per cent, i.e., slotting doubles the throughput. Both basic Aloha principles occur in many systems that implement distributed access to a medium. Aloha systems work perfectly well under a light load, but they cannot give any hard transmission guarantees, such as maximum delay before accessing the medium or minimum throughput.

Carrier sense multiple access[CSMA]

One improvement to the basic Aloha is sensing the carrier before accessing the medium. Sensing the carrier and accessing the medium only if the carrier is idle decreases the probability of a collision. But, as already mentioned in the introduction, hidden terminals cannot be detected, so, if a hidden terminal transmits at the same time as another sender, a collision might occur at the receiver. This basic scheme is still used in most wireless LANs. The different versions of CSMA are:

- 1-persistent CSMA:** Stations sense the channel and listen if it's busy and transmit immediately, when the channel becomes idle. It's called 1-persistent CSMA because the host transmits with a probability of 1 whenever it finds the channel idle.
- non-persistent CSMA:** stations sense the carrier and start sending immediately if the medium is idle. If the medium is busy, the station pauses a random amount of time before sensing the medium again and repeating this pattern.
- p-persistent CSMA:** systems nodes also sense the medium, but only transmit with a probability of p , with the station deferring to the next slot with the probability $1-p$, i.e., access is slotted in addition

CSMA with collision avoidance (**CSMA/CA**) is one of the access schemes used in wireless LANs following the standard IEEE 802.11. Here sensing the carrier is combined with a back-off scheme in case of a busy medium to achieve some fairness among competing stations.

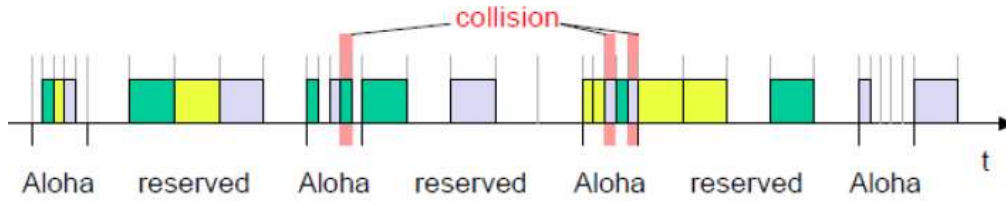


Demand assigned multiple access[DAMA]

Channel efficiency for Aloha is 18% and for slotted Aloha is 36%. It can be increased to 80% by implementing reservation mechanisms and combinations with some (fixed) TDM patterns. These schemes typically have a reservation period followed by a transmission period. During the reservation period, stations can reserve future slots in the transmission period. While, depending on the scheme, collisions may occur during the reservation period, the transmission period can then be accessed without collision.

One basic scheme is **demand assigned multiple access (DAMA)** also called **reservation Aloha**, a scheme typical for satellite systems. It increases the amount of users in a pool of satellite channels that are available for use by any station in a network. It is assumed that not all users will need simultaneous access to the same communication channels. So that a call can be established, DAMA assigns a pair of available channels based on requests issued from a user. Once the call is completed, the channels are returned to the pool for an assignment to another call. Since the resources of the satellite are being used only in proportion to the occupied channels for the time in which they are being held, it is a perfect environment for voice traffic and data traffic in batch mode.

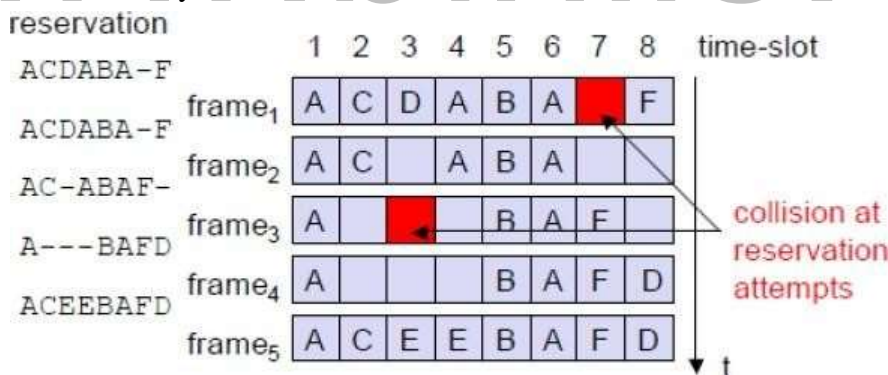
It has two modes as shown below.



During a contention phase following the slotted Aloha scheme; all stations can try to reserve future slots. Collisions during the reservation phase do not destroy data transmission, but only the short requests for data transmission. If successful, a time slot in the future is reserved, and no other station is allowed to transmit during this slot. Therefore, the satellite collects all successful requests (the others are destroyed) and sends back a reservation list indicating access rights for future slots. All ground stations have to obey this list. To maintain the fixed TDM pattern of reservation and transmission, the stations have to be synchronized from time to time. DAMA is an **explicit reservation** scheme. Each transmission slot has to be reserved explicitly.

PRMA packet reservation multiple access

It is a kind of implicit reservation scheme where, slots can be reserved implicitly. A certain number of slots form a frame. The frame is repeated in time i.e., a fixed TDM pattern is applied. A base station, which could be a satellite, now broadcasts the status of each slot to all mobile stations. All stations receiving this vector will then know which slot is occupied and which slot is currently free.



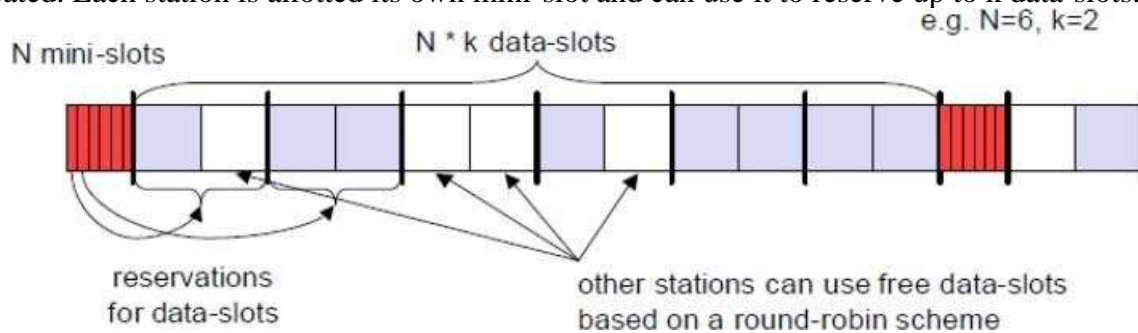
The base station broadcasts the reservation status 'ACDABA-F' to all stations, here A to F. This means that slots one to six and eight are occupied, but slot seven is free in the following transmission. All stations wishing to transmit can now compete for this free slot in Aloha fashion. The already occupied slots are not touched. In the example shown, more than one station wants to access this slot, so a collision occurs. The base station returns the reservation status 'ACDABA-F', indicating that the reservation of slot seven failed (still indicated as free) and that nothing has changed for the other slots. Again, stations can compete for this slot. Additionally, station D has stopped sending in slot three and station F in slot eight. This is noticed by the base station after the second frame. Before the third frame starts, the base station indicates

that slots three and eight are now idle. Station F has succeeded in reserving slot seven as also indicated by the base station.

As soon as a station has succeeded with a reservation, all future slots are implicitly reserved for this station. This ensures transmission with a guaranteed data rate. The slotted aloha scheme is used for idle slots only; data transmission is not destroyed by collision.

Reservation TDMA

In a fixed TDM scheme N mini-slots followed by $N \cdot k$ data-slots form a frame that is repeated. Each station is allotted its own mini-slot and can use it to reserve up to k data-slots.



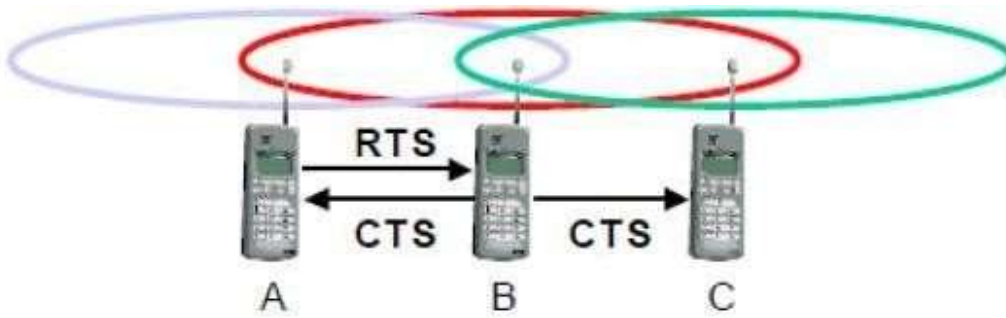
This guarantees each station a certain bandwidth and a fixed delay. Other stations can now send data in unused data-slots as shown. Using these free slots can be based on a simple round-robin scheme or can be uncoordinated using an Aloha scheme. This scheme allows for the combination of, e.g., isochronous traffic with fixed bitrates and best-effort traffic without any guarantees.

Multiple access with collision avoidance [MACA]

Multiple access with collision avoidance (MACA) presents a simple scheme that solves the hidden terminal problem, does not need a base station, and is still a random access Aloha scheme – but with dynamic reservation. Consider the hidden terminal problem scenario.

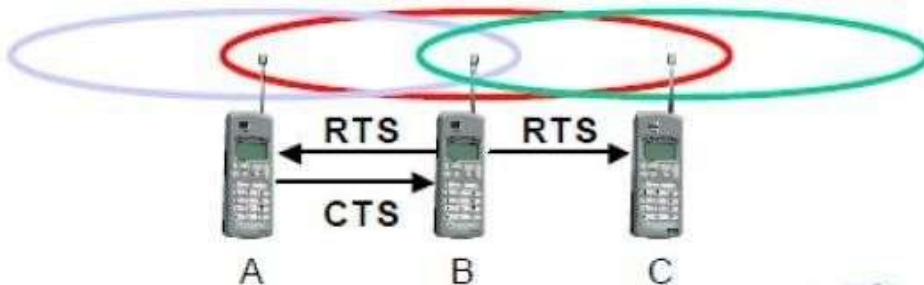
A starts sending to B, C does not receive this transmission. C also wants to send something to B and senses the medium. The medium appears to be free, the carrier sense fails. C also starts sending causing a collision at B. But A cannot detect this collision at B and continues with its transmission. A is **hidden** for C and vice versa.

With MACA, A does not start its transmission at once, but sends a **request to send (RTS)** first. B receives the RTS that contains the name of sender and receiver, as well as the length of the future transmission. This RTS is not heard by C, but triggers an acknowledgement from B, called **clear to send (CTS)**. The CTS again contains the names of sender (A) and receiver (B) of the user data, and the length of the future transmission.



This CTS is now heard by C and the medium for future use by A is now reserved for the duration of the transmission. After receiving a CTS, C is not allowed to send anything for the duration indicated in the CTS toward B. A collision cannot occur at B during data transmission, and the hidden terminal problem is solved. Still collisions might occur when A and C transmits a RTS at the same time. B resolves this contention and acknowledges only one station in the CTS. No transmission is allowed without an appropriate CTS.

Now MACA tries to avoid the **exposed terminals** in the following way:



With MACA, B has to transmit an RTS first containing the name of the receiver (A) and the sender (B). C does not react to this message as it is not the receiver, but A acknowledges using a CTS which identifies B as the sender and A as the receiver of the following data transmission. C does not receive this CTS and concludes that A is outside the detection range. C can start its transmission assuming it will not cause a collision at A. The problem with exposed terminals is solved without fixed access patterns or a base station.

Polling

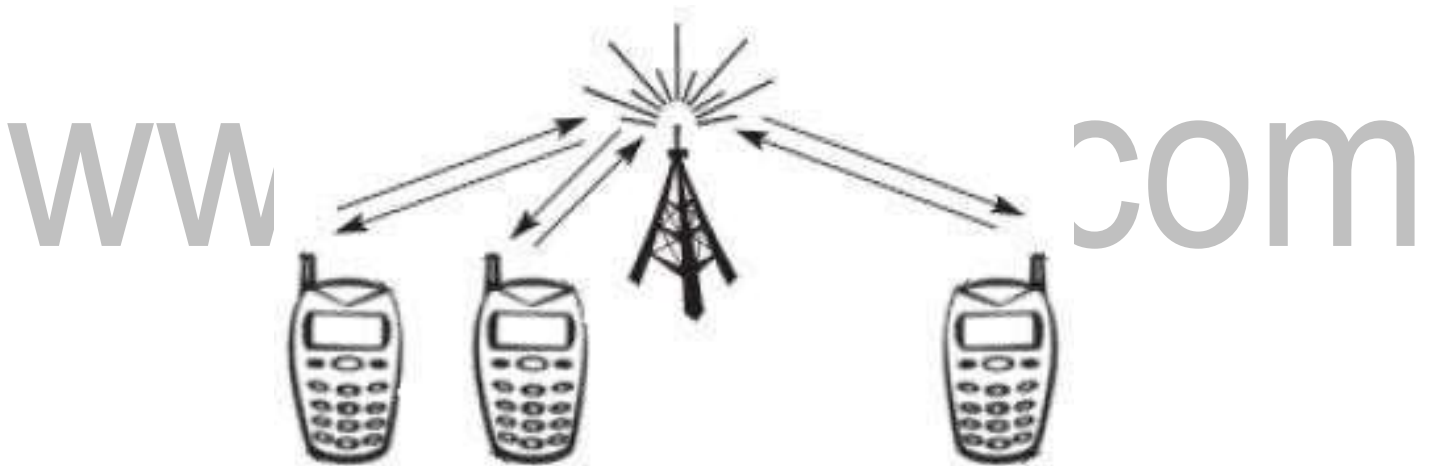
Polling schemes are used when one station wants to be heard by others. Polling is a strictly centralized scheme with one master station and several slave stations. The master can poll the slaves according to many schemes: round robin (only efficient if traffic patterns are similar over all stations), randomly, according to reservations (the classroom example with polite students) etc. The master could also establish a list of stations wishing to transmit during a contention phase. After this phase, the station polls each station on the list.

Example: Randomly Addressed Polling

- base station signals readiness to all mobile terminals
- terminals ready to send transmit random number without collision using CDMA or FDMA
- the base station chooses one address for polling from list of all random numbers (collision if two terminals choose the same address)
- the base station acknowledges correct packets and continues polling the next terminal
- this cycle starts again after polling all terminals of the list

Inhibit sense multiple access

This scheme, which is used for the packet data transmission service Cellular Digital PacketData (CDPD) in the AMPS mobile phone system, is also known as **digital sense multiple access (DSMA)**. Here, the base station only signals a busy medium via a busy tone (called BUSY/IDLE indicator) on the downlink.



After the busy tone stops, accessing the uplink is not coordinated any further. The base station acknowledges successful transmissions; a mobile station detects a collision only via the missing positive acknowledgement. In case of collisions, additional back-off and retransmission mechanisms are implemented.

CODE DIVISION MULTIPLE ACCESS [CDMA]

Code division multiple access systems apply codes with certain characteristics to the transmission to separate different users in code space and to enable access to a shared medium without interference.

All terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel. Each sender has a unique random number, the sender XORs the signal with this random number. The receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function

Disadvantages:

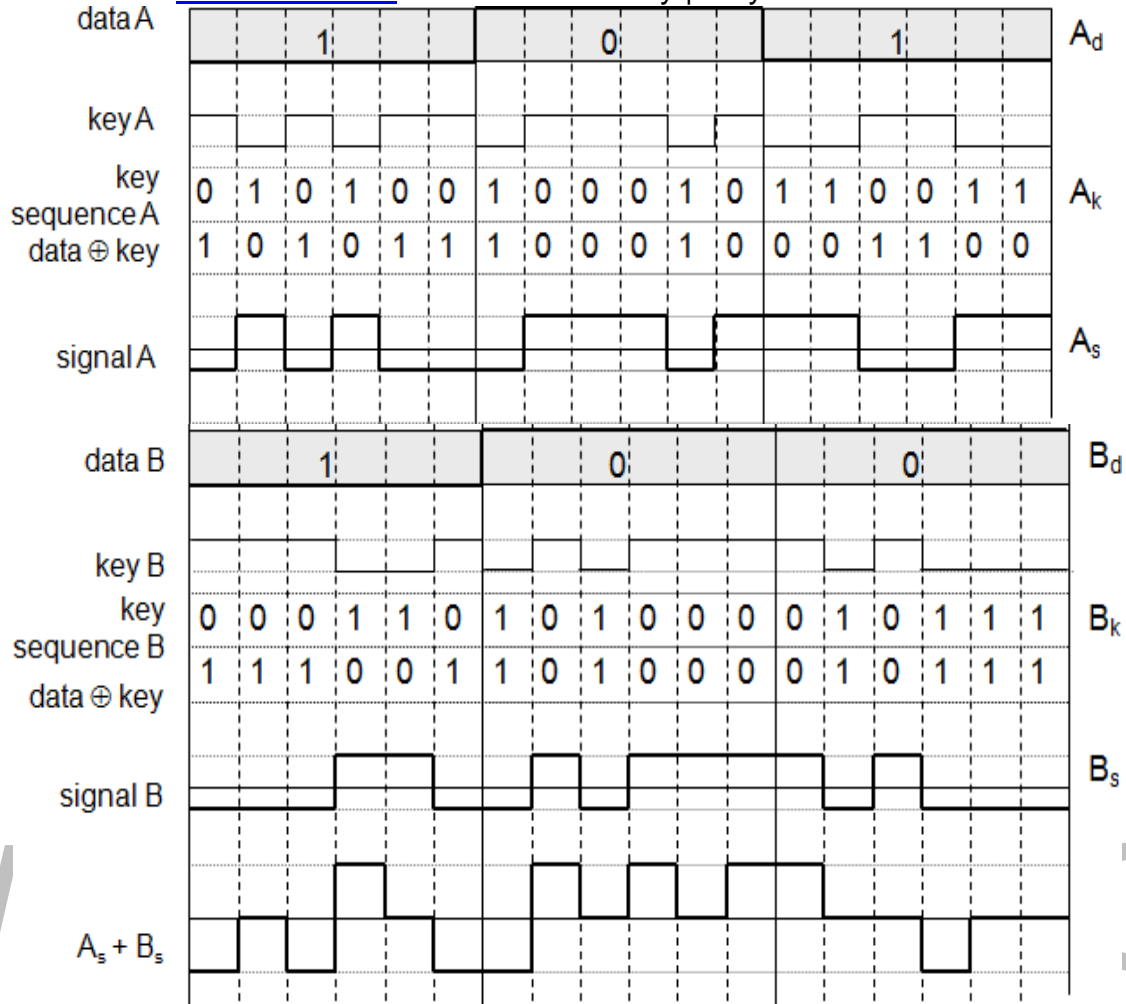
1. higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
2. all signals should have the same strength at a receiver

Advantages:

1. all terminals can use the same frequency, no planning needed
2. huge code space (e.g. 232) compared to frequency space
3. interferences (e.g. white noise) is not coded
4. forward error correction and encryption can be easily integrated

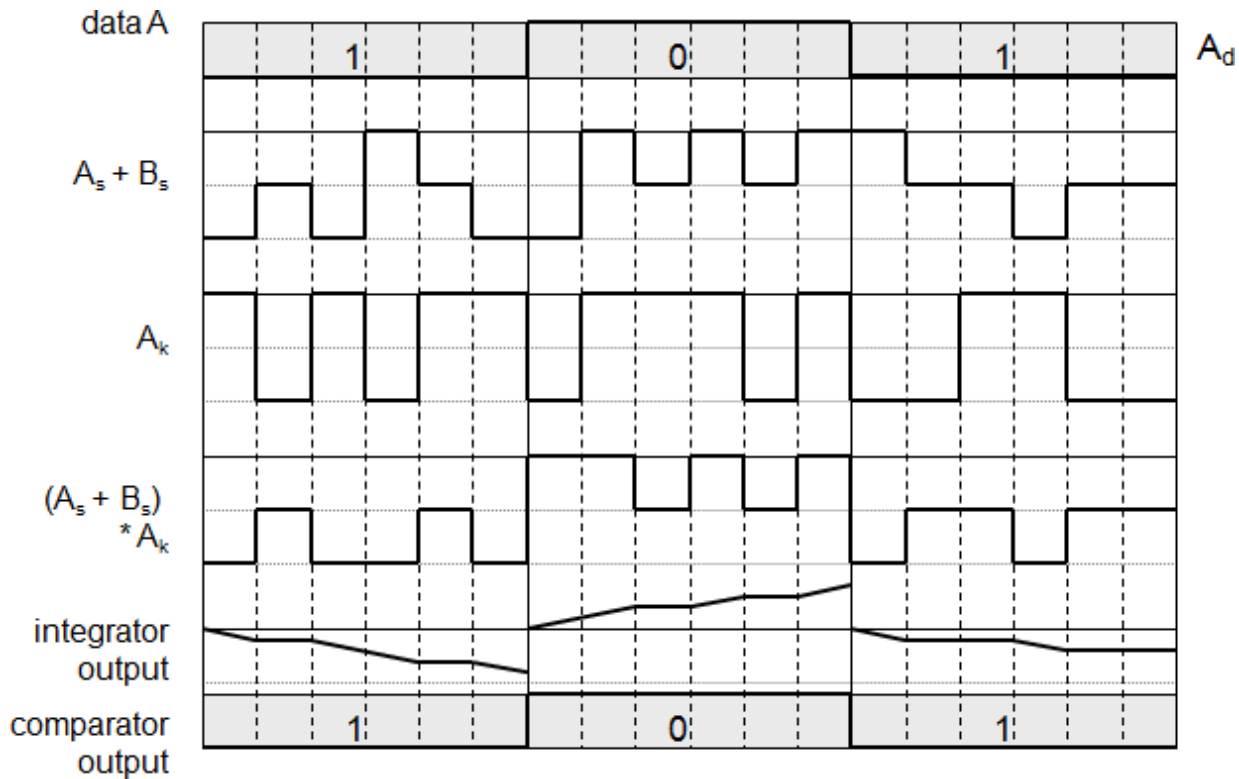
- Sender A
 - sends $A_d = 1$, key $A_k = 010011$ (assign: “0” = -1, “1” = +1)
 - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
 - sends $B_d = 0$, key $B_k = 110101$ (assign: “0” = -1, “1” = +1)
 - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
 - interference neglected (noise etc.)
 - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
 - apply key A_k bitwise (inner product)
 - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
 - result greater than 0, therefore, original bit was “1”
 - receiving B
 - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. “0”

The following figure shows a sender A that wants to transmit the bits 101. The key of A is shown as signal and binary sequence A_k . The binary “0” is assigned a positive signal value, the binary “1” a negative signal value. After spreading, i.e., XORing A_d and A_k , the resulting signal is A_s .



Coding and spreading of data from sender A and sender B

The same happens with data from sender B with bits 100. The result is B_s . A_s and B_s now superimpose during transmission. The resulting signal is simply the sum $A_s + B_s$ as shown above. A now tries to reconstruct the original data from A_d . The receiver applies A's key, A_k , to the received signal and feeds the result into an integrator. The integrator adds the products, a comparator then has to decide if the result is a 0 or a 1 as shown below. As clearly seen, although the original signal form is distorted by B's signal, the result is quite clear. The same happens if a receiver wants to receive B's data.



Reconstruction of A's data

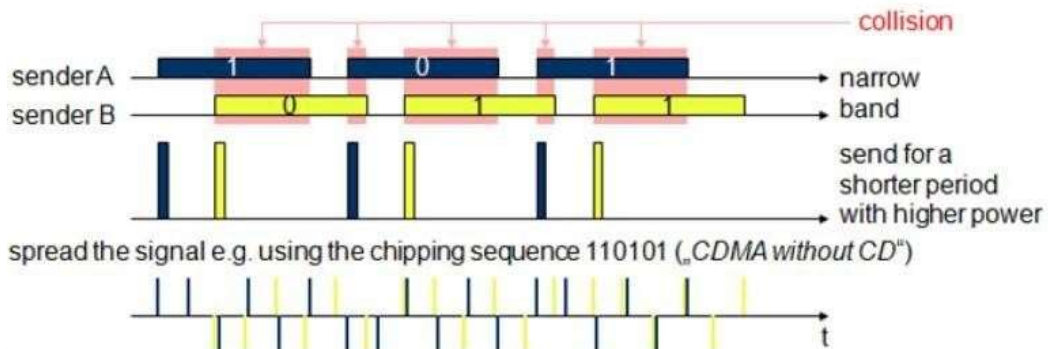
Soft handover or **soft handoff** refers to a feature used by the CDMA and WCDMA standards, where a cell phone is simultaneously connected to two or more cells (or cell sectors) during a call. If the sectors are from the same physical cell site (a sectorised site), it is referred to as **softer handoff**. This technique is a form of mobile-assisted handover, for IS-95/CDMA2000 CDMA cell phones continuously make power measurements of a list of neighboring cell sites, and determine whether or not to request or end soft handover with the cell sectors on the list.

Soft handoff is different from the traditional hard-handoff process. With hard handoff, a definite decision is made on whether to hand off or not. The handoff is initiated and executed without the user attempting to have simultaneous traffic channel communications with the two base stations. With soft handoff, a *conditional* decision is made on whether to hand off. Depending on the changes in pilot signal strength from the two or more base stations involved, a hard decision will eventually be made to communicate with only one. This normally happens after it is evident that the signal from one base station is considerably stronger than those from the others. In the interim period, the user has simultaneous traffic channel communication with all candidate base stations. It is desirable to implement soft handoff in power-controlled CDMA systems because implementing hard handoff is potentially difficult in such systems.

Spread Aloha multiple access (SAMA)

CDMA senders and receivers are not really simple devices. Communicating with n devices requires programming of the receiver to be able to decode n different codes. Aloha was a very simple scheme, but could only provide a relatively low bandwidth due to collisions. SAMA uses spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha.

In SAMA, each sender uses the same spreading code, for ex 110101 as shown below. Sender A and B access the medium at the same time in their narrowband spectrum, so that the three bits shown causes collisions. The same data could also be sent with higher power for shorter periods as show.



The main problem in using this approach is finding good chipping sequences. The maximum throughput is about 18 per cent, which is very similar to Aloha, but the approach benefits from the advantages of spread spectrum techniques: robustness against narrowband interference and simple coexistence with other systems in the same frequency bands.

Comparison SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km ²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

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