Unit 1 Wireless Technology Fundamentals

Introduction to Mobile and Wireless Communication

The term wireless communication was introduced in the 19th century and wireless communication technology has developed over the subsequent years. It is one of the most important mediums of transmission of information from one device to other devices.

In this technology, the information can be transmitted through the air without requiring any cable or wires or other electronic conductors, by using electromagnetic waves like IR, RF, satellite, etc.

In the present days, the wireless communication technology refers to a variety of wireless communication devices and technologies ranging from smart phones to computers, tabs, laptops, Bluetooth Technology, printers.

Types of Wireless Communication

The different types of wireless communication mainly include, IR wireless communication, satellite communication, broadcast radio, Microwave radio, Bluetooth, Zigbee etc.

1. **Satellite Communication:** Satellite communication is one type of self-contained wireless communication technology, it is widely spread all over the world to allow users to stay connected almost anywhere on the earth. When the signal (a beam of modulated microwave) is sent near the satellite then, satellite amplifies the signal and sent it back to the antenna receiver which is located on the surface of the earth. Satellite communication contains two main components like the space segment and the ground segment. The ground segment consists of fixed or mobile transmission, reception and ancillary equipment and the space segment, which mainly is the satellite itself.

2. **Infrared Communication:** Infrared wireless communication communicates information in a device or systems through IR radiation. IR is electromagnetic energy at a wavelength that is longer than that of red light. It is used for security control, TV remote control and short range communications. In the electromagnetic spectrum, IR radiation lies between microwaves and visible light. So, they can be used as a source of communication

3. **Infrared Communication:** For a successful infrared communication, a photo LED transmitter and a photo diode receptor are required. The LED transmitter transmits the IR signal in the form of non-visible light that is captured and saved by the photoreceptor. So the information between the source and the target is transferred in this way. The source and destination can be mobile phones, TVs, security systems, laptops etc. supports wireless communication.

4. **Broadcast Radio:** The first wireless communication technology is the open radio communication to seek out widespread use, and it still serves a purpose nowadays. Handy multichannel radios permit a user to speak over short distances, whereas citizen's band and maritime radios offer communication services for sailors. Ham radio enthusiasts share data and function emergency communication aids throughout disasters with their

powerful broadcasting gear, and can even communicate digital information over the radio frequency spectrum.

5. **Microwave Communication:** Microwave wireless communication is an effective type of communication, mainly this transmission uses radio waves, and the wavelengths of radio waves are measured in centi-meters. In this communication, the data or information can be transfers using two methods. One is satellite method and another one is terrestrial method. The main disadvantage of microwave signals is, they can be affected by bad weather, especially rain.

6. **Wi-Fi:** Wi-Fi is a low power wireless communication that is used by various electronic devices like smart phones, laptops, etc.In this setup, a router works as a communication hub wirelessly. These networks allow users to connect only within close proximity to a router. Wi-Fi is very common in networking applications which affords portability wirelessly. These networks need to be protected with passwords for the purpose of security, otherwise it will access by others

Advantages of Wireless Communication

- Any data or information can be transmitted faster and with a high speed
- Maintenance and installation is less cost for these networks.
- The internet can be accessed from anywhere wirelessly
- It is very helpful for workers, doctors working in remote areas as they can be in touch with medical centers.

Disadvantages of Wireless Communication

- An unauthorized person can easily capture the wireless signals which spread through the air.
- It is very important to secure the wireless network so that the information cannot be misused by unauthorized users

Applications of Wireless Communication

Applications of wireless communication involve

- Security systems,
- Television remote control,
- Wi-Fi,
- Cell phones,
- Wireless power transfer,
- Computer interface devices and
- Various wireless communication based projects.

Radio Transmission Frequency

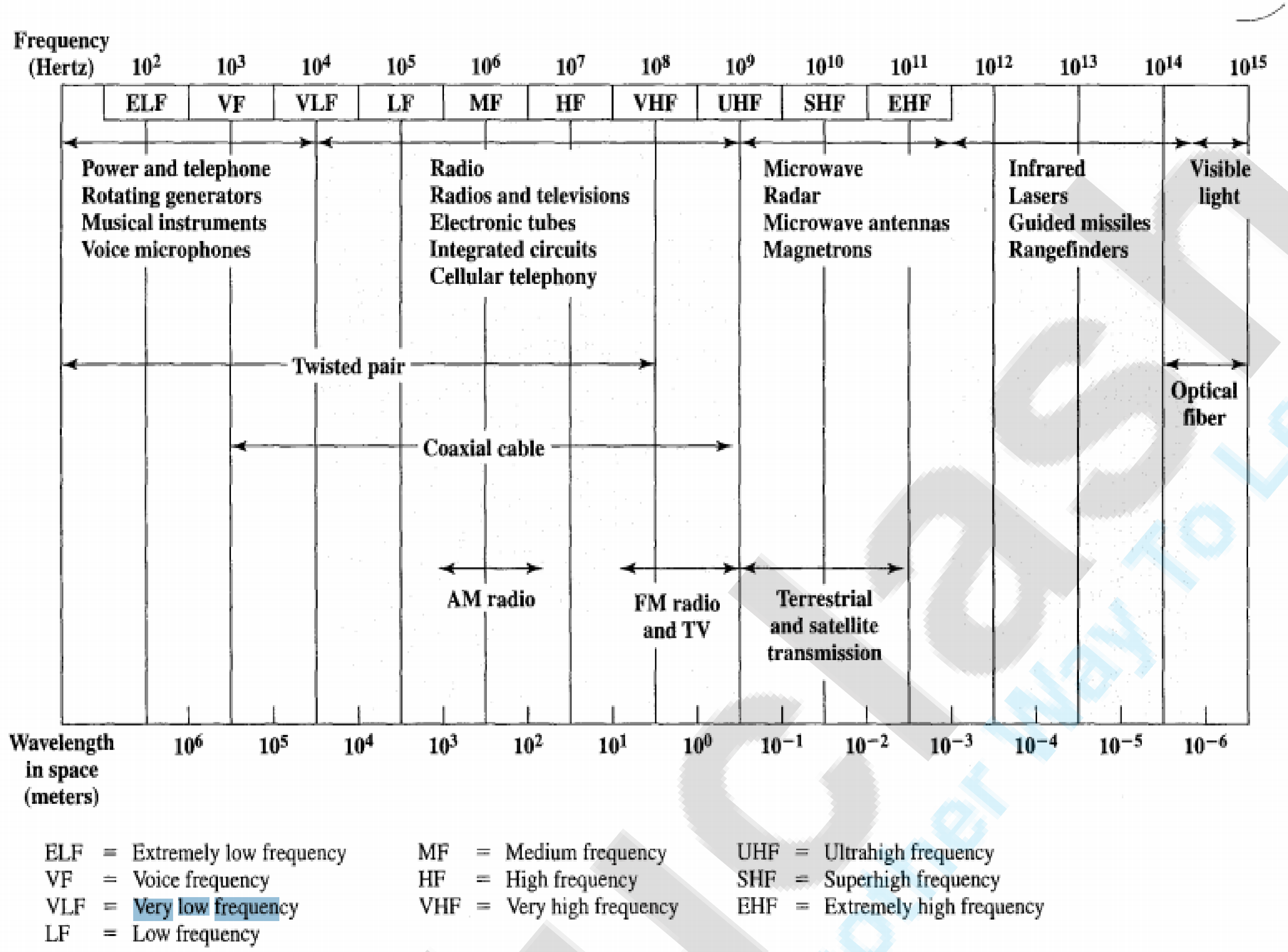


Figure 2.10 Electromagnetic Spectrum for Telecommunications

Radio transmission can take place using many different frequency bands. For traditional wired networks,

- Frequencies of up to several hundred kHz are used for distances up to some km with twisted pair copper wires,
- While frequencies of several hundred MHz are used with coaxial cable.
- Fiber optics are used for frequency ranges of several hundred THz.

Radio transmission starts at several kHz, the **very low frequency (VLF)** range. These are very long waves.

Waves in the **low frequency (LF)** range are used by submarines, because they can penetrate water and can follow the earth's surface.

Some radio stations still use these frequencies, e.g., between 148.5 kHz and 283.5 kHz in Germany.

The **medium frequency (MF)** and **high frequency (HF)** ranges are typical for transmission of hundreds of radio stations either

- as amplitude modulation (AM) between 520 kHz and 1605.5 kHz,
- as short wave (SW) between 5.9 MHz and 26.1 MHz, or
- as frequency modulation (FM) between 87.5 MHz and 108 MHz.

The frequencies limiting these ranges are typically fixed by national regulation and, vary from country to country.

Short waves are typically used for (amateur) radio transmission around the world, enabled by reflection at the ionosphere.

Transmit power is up to 500 kW – which is quite high compared to the 1 W of a mobile phone.

As we move to higher frequencies, the TV stations follow.

Conventional analog TV is transmitted in ranges of 174–230 MHz and 470–790 MHz using the **very high frequency (VHF)** and **Ultra high frequency (UHF)** bands.

In this range, digital audio broadcasting (DAB) takes place as well (223–230 MHz and 1452–1472 MHz) and digital TV is planned or currently being installed (470– 862 MHz), reusing some of the old frequencies for analog TV.

UHF is also used for mobile phones with analog technology (450– 465 MHz),

- The digital GSM (890–960 MHz, 1710–1880 MHz),
- Digital cordless telephones following the DECT standard (1880– 1900 MHz),
- 3G cellular systems following the UMTS standard (1900–1980 MHz, 2020–2025 MHz, 2110–2190 MHz) and many more

VHF and especially UHF allow for small antennas and relatively reliable connections for mobile telephony.

Super high frequencies (SHF) are typically used for directed microwave links (approx. 2–40 GHz) and fixed satellite services in the C-band (4 and 6 GHz), Ku-band (11 and 14 GHz), or Ka-band (19 and 29 GHz).

Some systems are planned in the **extremely high frequency (EHF)** range which comes close to infrared.

All radio frequencies are regulated to avoid interference, e.g., the German regulation covers 9 kHz–275 GHz.

The next step into higher frequencies involves optical transmission, which is not only used for fiber optical links but also for wireless communications.

Infrared (IR) transmission is used for directed links, e.g., to connect different buildings via laser links.

The most widespread IR technology, infra red data association (IrDA), uses wavelengths of approximately 850–900 nm to connect laptops, PDAs etc.

Finally, visible light has been used for wireless transmission for thousands of years.

While light is not very reliable due to interference, but it is nevertheless useful due to built-in human receivers.

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS, TDMA, CDMA** 824-849 MHz, 869-894 MHz; **TDMA, CDMA, GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910 MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz
	HiperLAN2, IEEE 802.11a 5150-5350 5470-5725	**HiperLAN2, IEEE 802.11a** 5150-5350 5725-5825	**HiperLAN2, IEEE 802.11a** 5150-5250

	Frequency	Common Uses
VLF	3-30 kHz	underwater communications
LF	30-300 kHz	AM radio
MF	300-3000 kHz	AM radio
HF	3-30 MHz	AM radio, long distance aviation communications
VHF	30-300 MHz	FM radio, television, short range avaiation communications, weather radio
UHF	300-3000 MHz	television, mobile phones, wireless networks, Bluetooth, satellite radio, GPS
SHF	3-30 GHz	satellite television and radio, radar systems, radio astronomy
EHF	30-300 GHz	radio astronomy, full body scanners

Regulations

- Radio frequencies are scarce resources. Many national (economic) interests make it hard to find common, worldwide regulations.
- The International Telecommunications Union (ITU) located in Geneva is responsible for worldwide coordination of telecommunication activities (wired and wireless).
- ITU is a sub-organization of the UN.
- The ITU Radio communication sector (ITU-R) handles standardization in the wireless sector, so it also handles frequency planning.

To have at least some success in worldwide coordination and to reflect national interests, the ITU-R has split the world into three regions:

- Region 1 covers Europe, the Middle East, countries of the former Soviet Union, and Africa.
- Region 2 includes Greenland, North and South America, and
- Region 3 comprises the Far East, Australia, and New Zealand.

Within these regions, national agencies are responsible for further regulations, e.g., the Federal Communications Commission (FCC) in the US.

Several nations have a common agency such as European Conference for Posts and Telecommunications (CEPT) in Europe.

To achieve at least some harmonization, the ITU-R holds, the World Radio Conference (WRC), to periodically discuss and decide frequency allocations for all three regions.

Signal

- Signals are the physical representation of data.
- Users of a communication system can only exchange data through the transmission of signals.
- Layer 1 of the ISO/OSI basic reference model is responsible for the conversion of data, i.e., bits, into signals and vice versa.
- Signals are functions of time and location.
- Signal parameters represent the data values.
- The most interesting types of signals for radio transmission are periodic signals, especially sine waves as carriers.
- The general function of a sine wave is,

$$g(t) = A_t \sin(2\pi f_t t + \varphi_t)$$

- Signal parameters are the amplitude A, the frequency f, and the phase shift ϕ.

- Sine waves are of special interest, as it is possible to construct every periodic signal g by using only sine and cosine functions according to a fundamental equation of Fourier :

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

In this equation the parameter c determines the Direct Current (DC) component of the signal. The coefficients an and bn are the amplitudes of the nth sine and cosine function.

- The equation shows that an infinite number of sine and cosine functions is needed to construct arbitrary periodic functions.
- The bandwidth of any medium, air, cable, transmitter etc. is limited and, there is an upper limit for the frequencies.

- A typical way to represent signals is the time domain.
- Here the amplitude A of a signal is shown versus time.
- Representations in the time domain are problematic if a signal consists of many different frequencies.

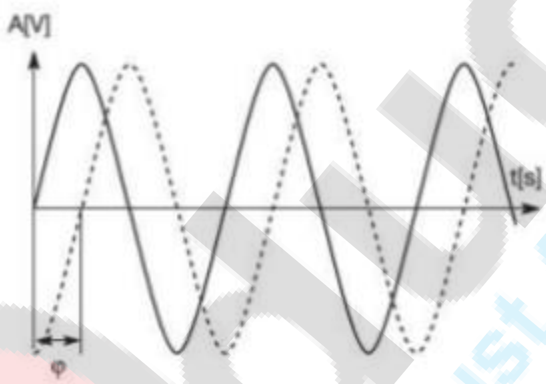


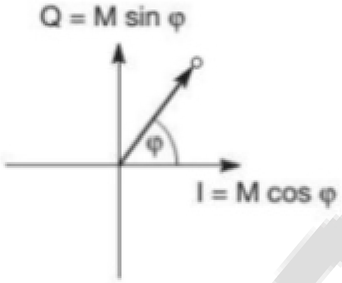
Figure 2.2 Time domain representation of a signal

- In this case, a better representation of a signal is the frequency domain.
- Here the amplitude of a certain frequency part of the signal is shown versus the frequency.
- Figure 2.3 only shows one peak and the signal consists only of a single frequency part (i.e., it is a single sine function).
- Arbitrary periodic functions would have many peaks, known as the frequency spectrum of a signal.
- A tool to display frequencies is a **spectrum analyzer.**

Figure 2.3 Frequency domain representation of a signal

- A third way to represent signals is the phase domain shown.
- This representation, also called phase state, shows the amplitude M of a signal and its phase ϕ in polar coordinates.
- The x-axis represents a phase of 0 and is also called In-Phase (I).
- A phase shift of 90° or π/2 would be a point on the y-axis, called Quadrature (Q).

Figure 2.4 Phase domain representation of a signal



Antenna:

- An antenna can be defined as an electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.
- For transmission of a signal, radio-frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment (atmosphere, space, water).
- For reception of a signal, electromagnetic energy impinging on the antenna is converted into radio-frequency electrical energy and fed into the receiver.
- In two-way communication, the same antenna can be and often is used for both transmission and reception.

Radiation Patterns

- An antenna will radiate power in all directions but, typically, does not perform equally well in all directions.
- The simplest pattern is produced by an idealized antenna known as the isotropic antenna.
- An isotropic antenna is a point in space that radiates power in all directions equally.
- The actual radiation pattern for the isotropic antenna is a sphere with the antenna at the center.
- However, radiation patterns are almost always depicted as a two-dimensional cross section of the three-dimensional pattern. The pattern for the isotropic antenna is shown in Figure 5.1a.

- The distance from the antenna to each point on the radiation pattern is proportional to the power radiated from the antenna in that direction.
- Figure 5.1b shows the radiation pattern of another idealized antenna. This is a directional antenna in which the preferred direction of radiation is along one axis.

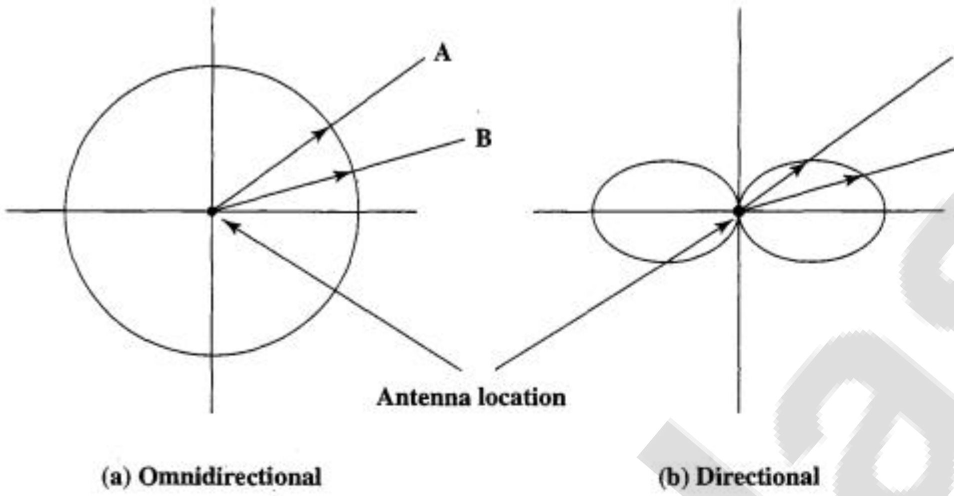


Figure 5.1 Idealized Radiation Patterns

Figure 5.1 shows a comparison of two transmission angles, A and B, drawn on the two radiation patterns. The isotropic antenna produces an omnidirectional radiation pattern of equal strength in all directions, so the A and B vectors are of equal length. For the antenna pattern of Figure 5.1b, the B vector is longer than the A vector, indicating that more power is radiated in the B direction than in the A direction, and the relative lengths of the two vectors are proportional to the amount of power radiated in the two directions.

Antenna Types

Dipoles

- Two of the simplest and most basic antennas are the half-wave dipole, or Hertz, antenna (Figure 5.2a) and the quarter-wave vertical, or Marconi, antenna (Figure 5.2b).
- The half-wave dipole consists of two straight collinear conductors of equal length, separated by a small gap. The length of the antenna is one-half the wavelength of the signal that can be transmitted most efficiently.
- A vertical quarter-wave antenna is the type commonly used for automobile radios and portable radios.
- A half-wave dipole has a uniform or omnidirectional radiation pattern in one dimension and a figure eight pattern in the other two dimensions (Figure 5.3a). More complex antenna configurations can be used to produce a directional beam.

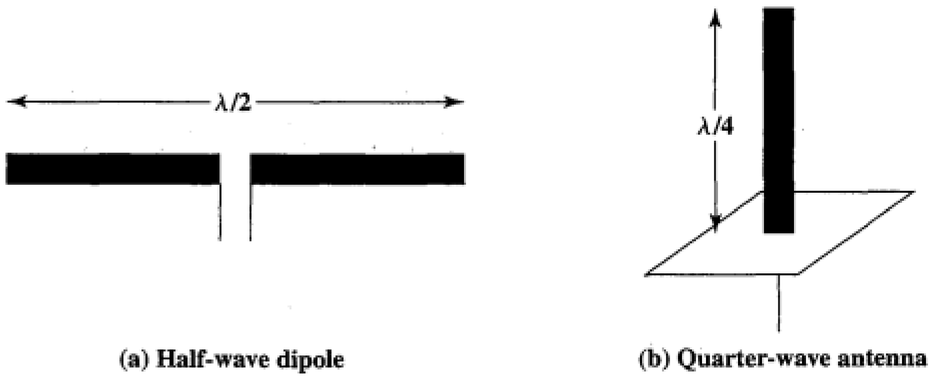


Figure 5.2 Simple Antennas

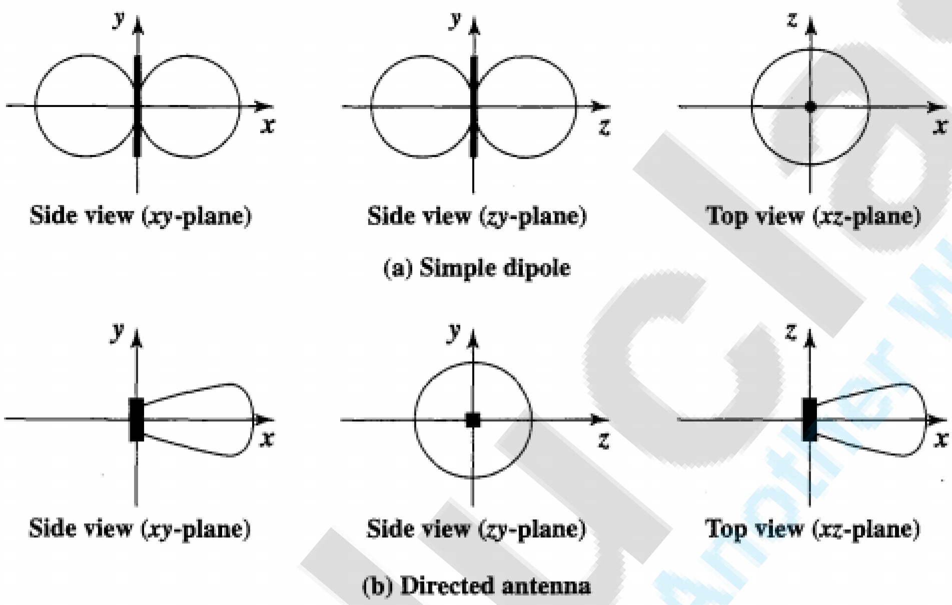


Figure 5.3 Radiation Patterns in Three Dimensions [SCHI00]

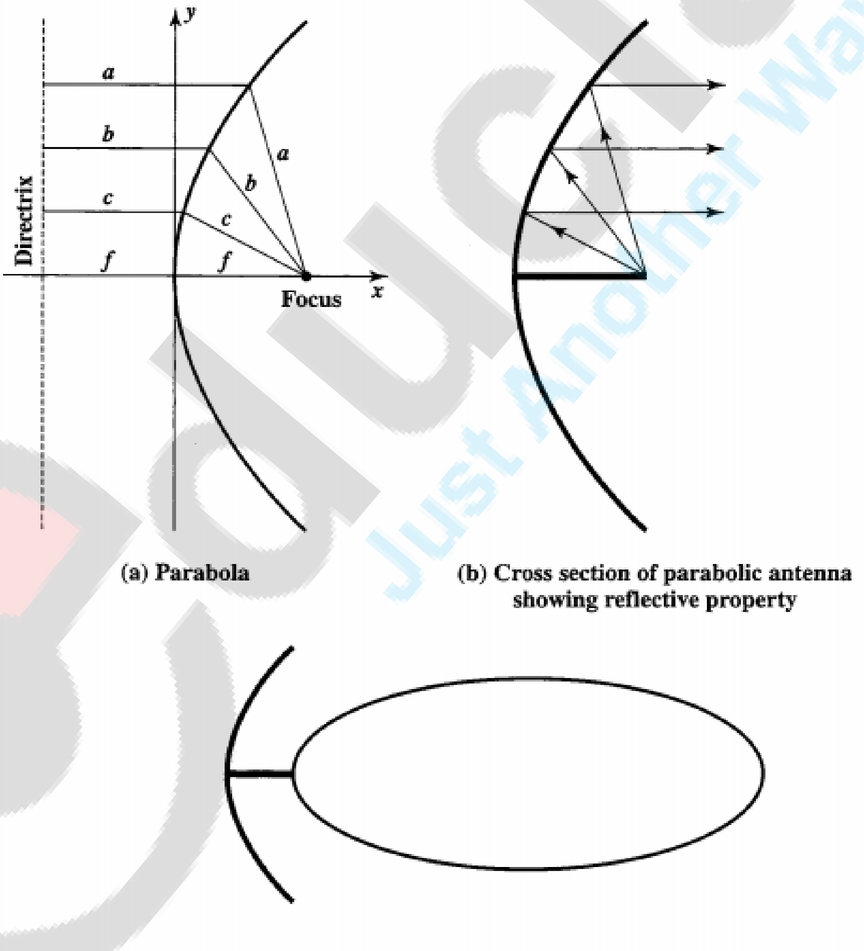
- A typical directional radiation pattern is shown in Figure 5.3b. In this case the main strength of the antenna is in the x-direction.

Parabolic Reflective Antenna

- An important type of antenna is the **parabolic reflective antenna**, which is used in terrestrial microwave and satellite applications.
- A parabola is the locus of all points equidistant from a fixed line and a fixed point not on the line. The fixed point is called the focus and the fixed line is called the directrix (Figure 5.4a).
- If a parabola is revolved about its axis, the surface generated is called a paraboloid.
- A cross section through the paraboloid parallel to its axis forms a parabola and a cross section perpendicular to the axis forms a circle. Such surfaces are used in automobile

headlights, optical and radio telescopes, and microwave antennas because of the following property: If a source of electromagnetic energy (or sound) is placed at the focus of the paraboloid, and if the paraboloid is a reflecting surface, then the wave will bounce back in lines parallel to the axis of the paraboloid; Figure 5.4b shows this effect in cross section.

- In theory, this effect creates a parallel beam without dispersion. In practice, there will be some dispersion, because the source of energy must occupy more than one point. The converse is also true.
- If incoming waves are parallel to the axis of the reflecting paraboloid, the resulting signal will be concentrated at the focus.
- Figure 5.4c shows a typical radiation pattern for the parabolic reflective antenna, and Table 5.1 lists beam widths for antennas of various sizes at a frequency of 12 GHz. Note that the larger the diameter of the antenna, the more tightly directional is the beam.



(a) Parabola

(b) Cross section of parabolic antenna showing reflective property

(c) Cross section of parabolic antenna showing radiation pattern

Figure 5.4 Parabolic Reflective Antenna

Table 5.1 Antenna Beamwidths for Various Diameter Parabolic Reflective Antennas at $f = 12$ GHz [FREE97]

Antenna Diameter (m)	Beam Width (degrees)
0.5	3.5
0.75	2.33
1.0	1.75
1.5	1.166
2.0	0.875
2.5	0.7
5.0	0.35

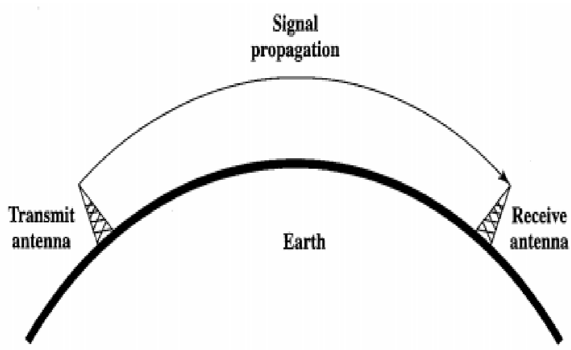
Signal Propagation/Propagation modes:

A signal radiated from an antenna travels along one of three routes:

1. Ground wave,
2. Sky wave, or
3. Line of sight (LOS).

Ground Wave Propagation

- Ground wave propagation (Figure 5.5a) more or less follows the contour of the earth and can propagate considerable distances, well over the visual horizon.
- This effect is found in frequencies up to about 2 MHz
- Several factors account for the tendency of electromagnetic wave in this frequency band to follow the earth's curvature.
- One factor is that the electromagnetic wave induces a current in the earth's surface, the result of which is to slow the wave front near the earth, causing the wave front to tilt downward and hence follow the earth's curvature.
- Another factor is diffraction, which is a phenomenon having to do with the behaviour of electromagnetic waves in the presence of obstacles.

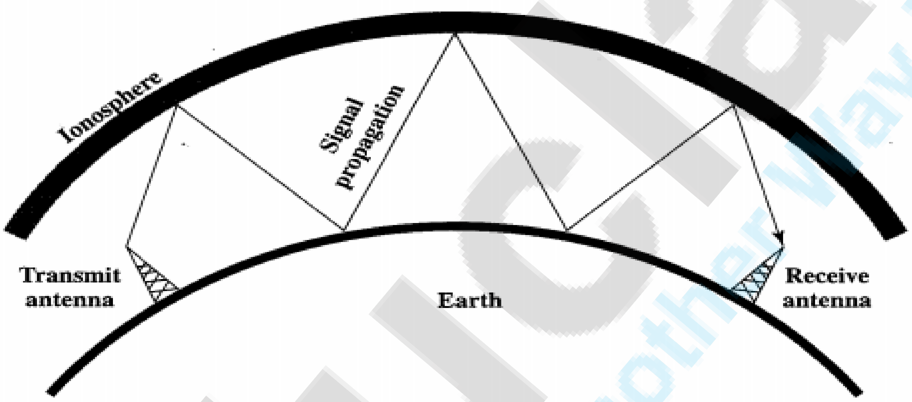


(a) Ground wave propagation (below 2 MHz)

- Electromagnetic waves in this frequency range are scattered by the atmosphere in such a way that they do not penetrate the upper atmosphere. The best-known example of ground wave communication is AM radio

Sky Wave Propagation

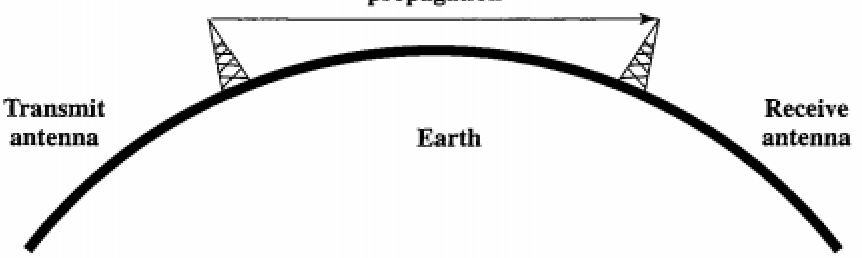
- Sky wave propagation is used for amateur radio, CB radio, and international broadcasts such as BBC and Voice of America.
- With sky wave propagation, a signal from an earth-based antenna is reflected from the ionized layer of the upper atmosphere (ionosphere) back down to earth.
- Although it appears the wave is reflected from the ionosphere as if the ionosphere were a hard reflecting surface, the effect is in fact caused by refraction. Refraction is described subsequently.
- A sky wave signal can travel through a number of hops, bouncing back and forth between the ionosphere and the earth's surface (Figure 5.5b).
- With this propagation mode, a signal can be picked up thousands of kilometers from the transmitter.



(b) Sky wave propagation (2 to 30 MHz)

Line-of-Sight Propagation

- Above 30 MHz, neither ground wave nor sky wave propagation modes operate, and communication must be by line of sight (Figure 5.5c).
- For satellite communication, a signal above 30 MHz is not reflected by the ionosphere and therefore can be transmitted between an earth station and a satellite overhead that is not beyond the horizon.
- For ground-based communication, the transmitting and receiving antennas must be within an effective line of sight of each other. The term effective is used because microwaves are bent or refracted by the atmosphere. The amount and even the direction of the bend depends on conditions, but generally microwaves are bent with the curvature of the earth and will therefore propagate farther than the optical line of sight.



(c) Line-of-sight (LOS) propagation (above 30 MHz)

Multiplexing:

In both local and wide area communications, it is almost always the case that the capacity of the transmission medium exceeds the capacity required for the transmission of a single signal. To make efficient use of the transmission system, it is desirable to carry multiple signals on a single medium. This is referred to as multiplexing.

Figure depicts the multiplexing function in its simplest form. There are n inputs to a multiplexer. The multiplexer is connected by a single data link to a demultiplexer. The link is able to carry n separate channels of data. The multiplexer combines (multiplexes) data from the n input lines and transmits over a higher capacity data link. The demultiplexer accepts the multiplexed data stream, separates (demultiplexes) the data according to channel, and delivers them to the appropriate output lines.

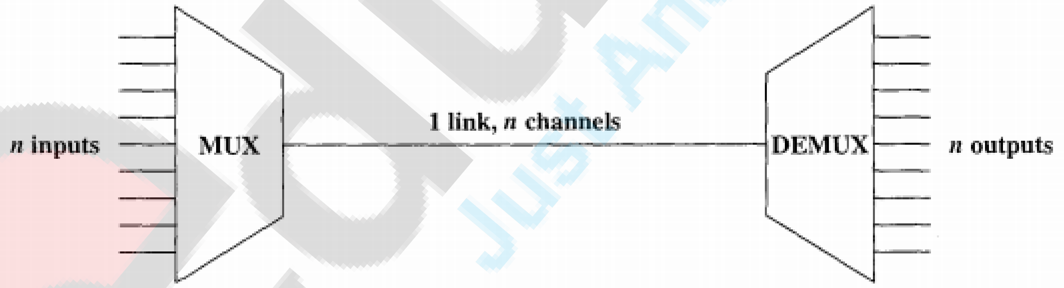
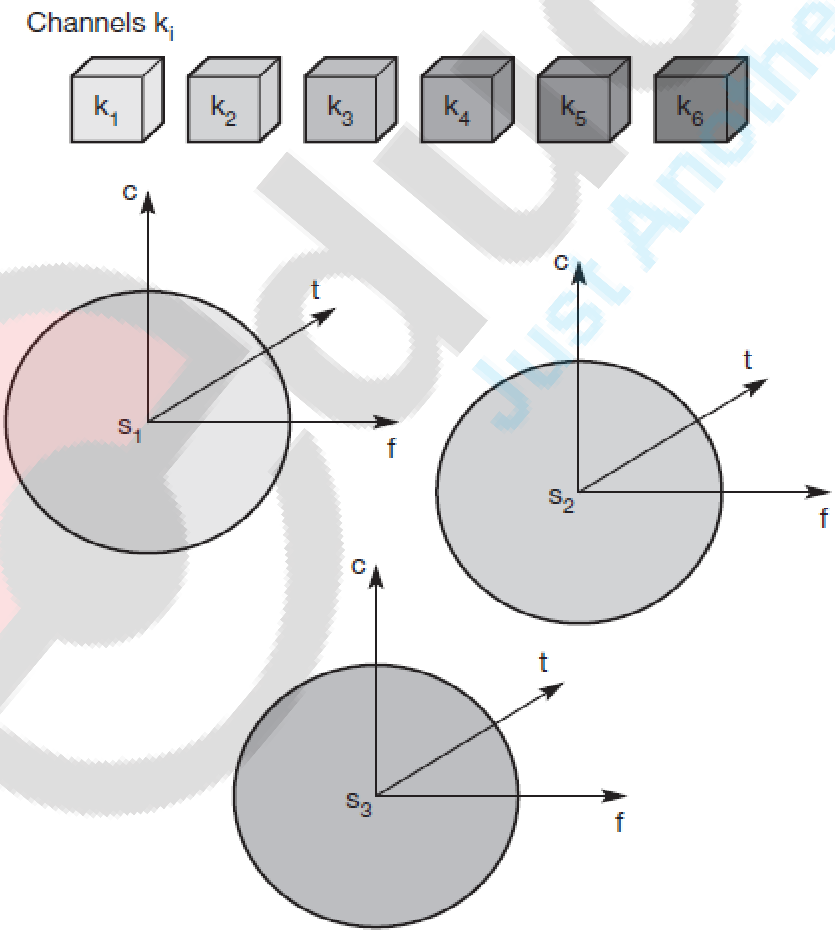


Figure 2.11 Multiplexing

Two techniques for multiplexing in telecommunications networks are in common use: frequency division multiplexing (FDM) and time division multiplexing (TDM).

Space division multiplexing

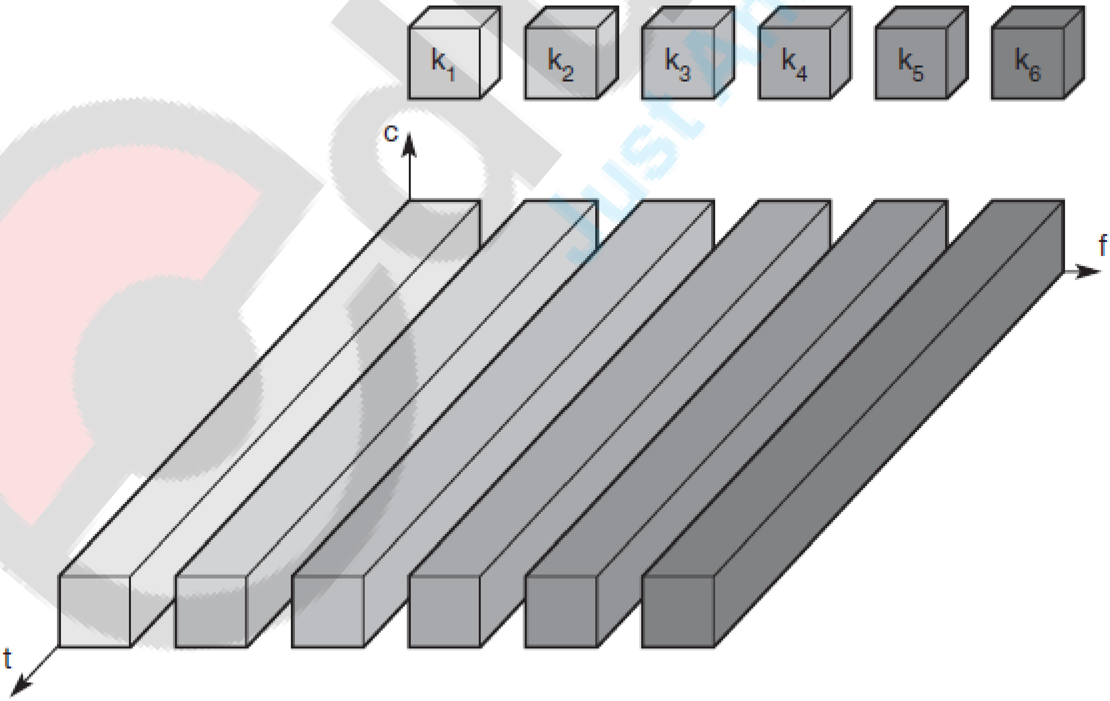
- For wireless communication, multiplexing can be carried out in four dimensions:
    1. space,
    2. time,
    3. frequency, and
    4. code.
- In this field, the task of multiplexing is to assign space, time, frequency, and code to each communication channel with a minimum of interference and a maximum of medium utilization.
- The term communication channel here only refers to an association of sender(s) and receiver(s) who want to exchange data.
- Figure shows six channels ki 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 si is also shown.
- Here space is represented via circles indicating the interference range as introduced in Figure 2.11.
- The channels k1 to k3 can be mapped onto the three 'spaces' s1 to s3 which clearly separate the channels and prevent the interference ranges from overlapping.
- The space between the interference ranges is sometimes called guard space. Such a guard space is needed in all four multiplexing schemes presented.



- For the remaining channels (k4 to k6) three additional spaces would be needed.
- In our highway example this would imply that each driver had his or her own lane.
- 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. 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.
- Using SDM, obvious problems arise if two or more channels were established within the same space, for example, if several radio stations want to broadcast in the same city.
- Then, one of the following multiplexing schemes must be used (frequency, time, or code division multiplexing).

Frequency division multiplexing

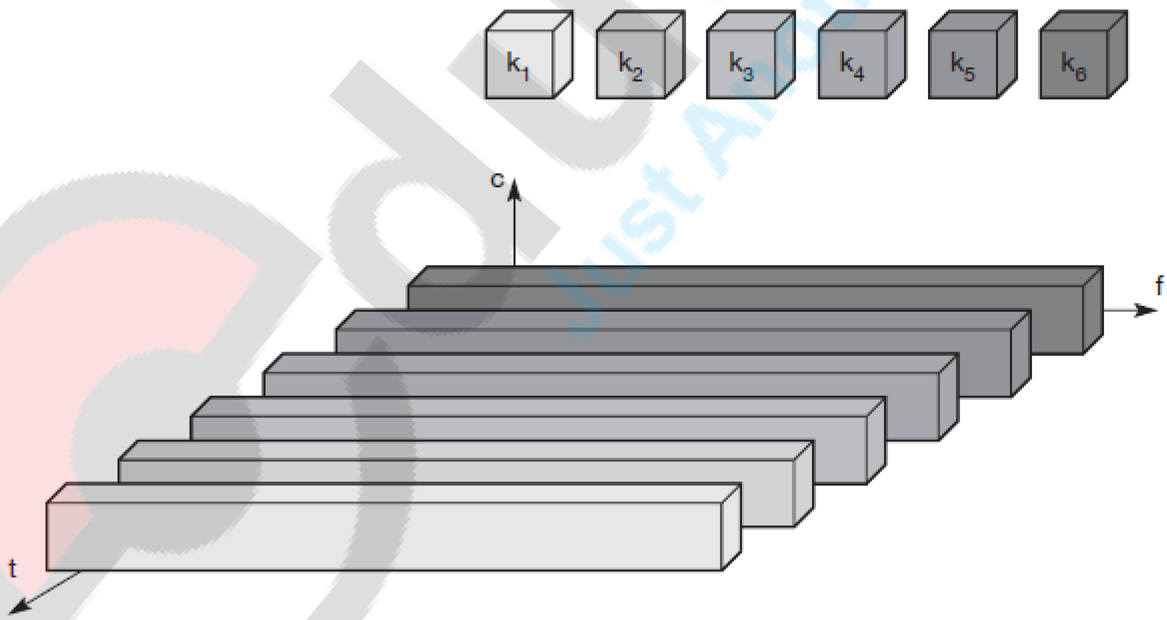
- Frequency division multiplexing (FDM) describes schemes to subdivide the frequency dimension into several non-overlapping frequency bands as shown in Figure 2.17.
- Each channel ki is now allotted its own frequency band as indicated. Senders using a certain frequency band can use this band continuously.
- 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.



- However, 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.

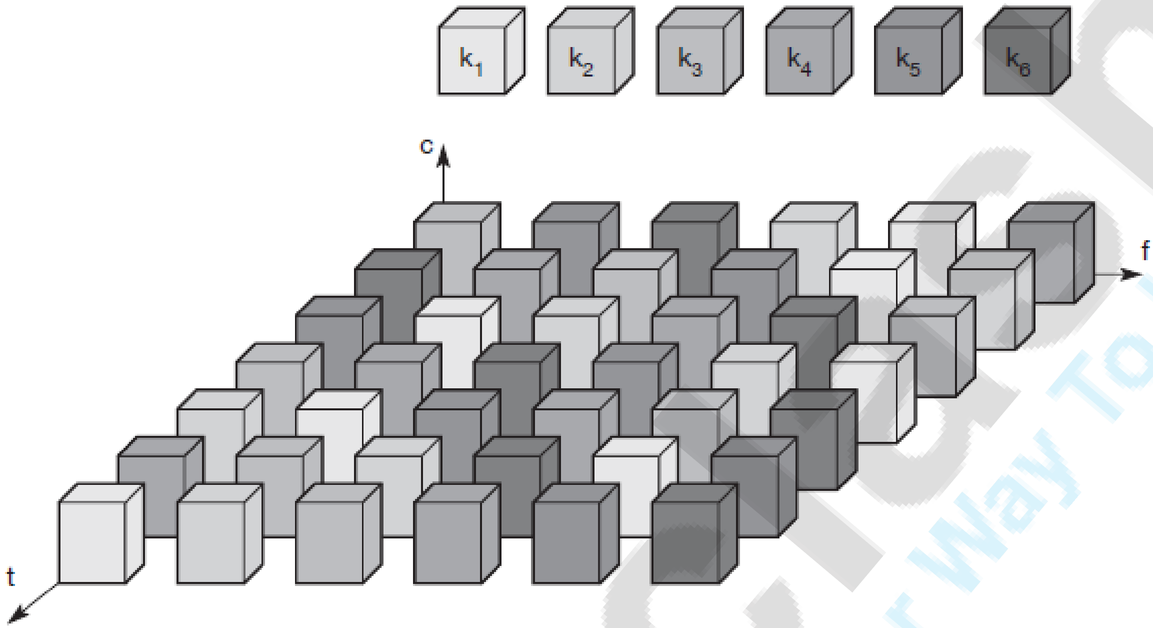
Time division multiplexing

- A more flexible multiplexing scheme for typical mobile communications is time division multiplexing (TDM).
- Here a channel ki 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 (see Figure 2.18).
- 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. This is clearly a disadvantage, as all senders need precise clocks or, alternatively, a way has to be found to distribute a synchronization signal to all senders.
- For a receiver tuning in to a sender this does not just involve adjusting the frequency, but involves listening at exactly the right point in time. However, this scheme is quite flexible as one can assign more sending time to senders with a heavy load and less to those with a light load.



- Frequency and time division multiplexing can be combined, i.e., a channel ki can use a certain frequency band for a certain amount of time as shown in Figure 2.19.
- Now guard spaces are needed both in the time and in the frequency dimension. This scheme is more robust against frequency selective interference, i.e., interference in a certain small frequency band.

- A channel may use this band only for a short period of time. Additionally, this scheme provides some (weak) protection against tapping, as in this case the sequence of frequencies a sender uses has to be known to listen in to a channel.
- The mobile phone standard GSM uses this combination of frequency and time division multiplexing for transmission between a mobile phone and a so-called base station (see section 4.1).

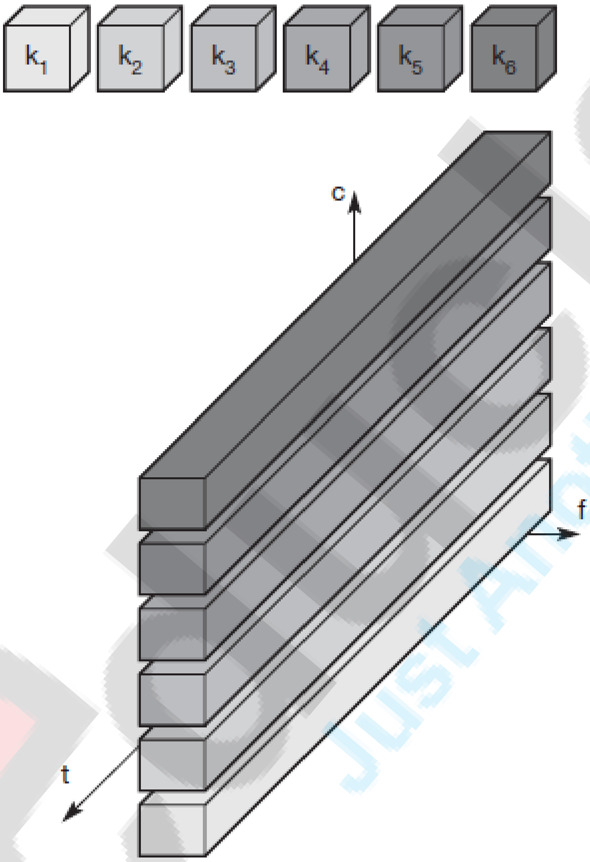


- A disadvantage of this scheme is again the necessary coordination between different senders.
- One has to control the sequence of frequencies and the time of changing to another frequency.
- Two senders will interfere as soon as they select the same frequency at the same time. However, if the frequency change (also called frequency hopping) is fast enough, the periods of interference may be so small that, depending on the coding of data into signals, a receiver can still recover the original data. (This technique is discussed in section 2.7.2.)

Code division multiplexing

- While SDM and FDM are well known from the early days of radio transmission and TDM is used in connection with many applications, code division multiplexing (CDM) is a relatively new scheme in commercial communication systems.
- First used in military applications due to its inherent security features (together with spread spectrum techniques, see section 2.7), it now features in many civil wireless transmission scenarios thanks to the availability of cheap processing power (explained in more detail in section 3.5).
- Figure 2.20 shows how all channels ki 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.

- The technical realization of CDM is discussed in section 2.7 and chapter 3 together with the medium access mechanisms. An excellent book dealing with all aspects of CDM is Viterbi (1995).
- 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.)



- The main advantage of CDM for wireless transmission is that it gives good protection against interference and tapping.
- Different codes have to be assigned, but code space is huge compared to the frequency space.
- Assigning individual codes to each sender does not usually cause problems.
- The main disadvantage of this scheme is the relatively high complexity of the receiver (see section 3.5).
- A receiver has to know the code and must separate the channel with user data from the background noise composed of other signals and environmental noise.

- Additionally, a receiver must be precisely synchronized with the transmitter to apply the decoding correctly. The voice example also gives a hint to another problem of CDM receivers.
- All signals should reach a receiver with almost equal strength, otherwise some signals could drain others.
- If some people close to a receiver talk very loudly the language does not matter. The receiver cannot listen to any other person. To apply CDM, precise power control is required.