WIRELESS NETWORKS

UNIT-1

WIRELESS TRANSMISSION

UNIT – I Syllabus

- **Introduction**: Applications, Short History of Wireless Communications, Simplified Reference Model.
- **Wireless Transmission**: Frequencies, Signals, Signal Propagation, Multiplexing, Modulation, Spread Spectrum, and Cellular Systems.
- **Medium Access Control**: Motivation for a Specialized MAC, SDMA, FDMA, TDMA, CDMA, and Comparison.

Introduction

Introduction

- Now a days, most of the computers will certainly be **portable.**
- How will users **access networks with the help of** computers or other communication devices?
- An ever-increasing number without any wires, i.e., **wireless. How will people spend much of their time at work, during** vacation?
- Many **people will be mobile**
- In this scenario, **a mobile network moving at high speed above ground with a wireless link** will be the only means of transporting data to and from passengers.
- **Think of cars with Internet access** and billions of embedded processors that have to communicate with, for instance, cameras, mobile phones, CD-players, headsets, keyboards, intelligent traffic signs and sensors.
- This plethora of devices and applications show the great importance of mobile communications today.

Introduction

- 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., the user can be mobile, and the services will follow him or her. Examples for mechanisms supporting user mobility are simple call-forwarding solutions known from the **telephone or computer desktops supporting roaming.**
- 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. A typical example for systems supporting device portability is the **mobile phone system**, where the system itself hands the device from one radio transmitter (also called a base station) to the next **if the signal becomes too weak.**

Wireless Networks

- A communication device can exhibit one of the following characteristics:
  - **Fixed and wired** *Ex: Desktop Computer*
  - **Mobile and wired** *Ex: Laptops*
  - **Fixed and wireless** *Ex: Buildings*
  - **Mobile and wireless** *Ex: GSM Mobiles*

Applications

- Vehicles
- Emergencies
- Business
- Replacement of wired networks
- Infotainment and more
- Location dependent services
- Mobile and wireless devices

Applications

- **Vehicles**-**DAB, UMTS, GPS, GSM**

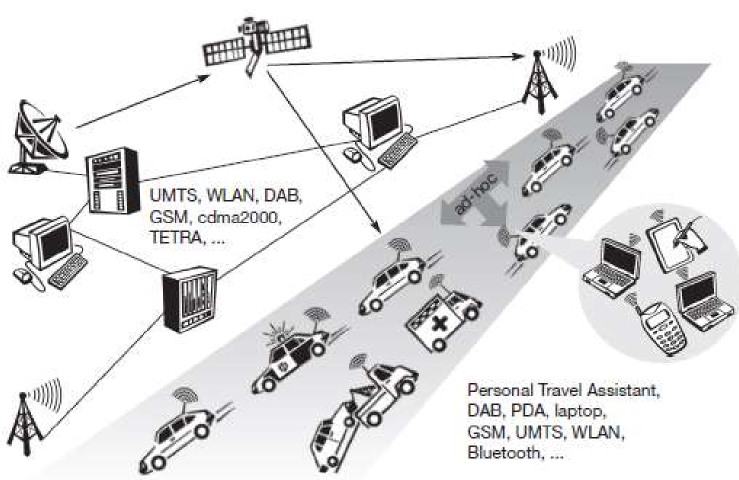


Figure 1.1 A typical application of mobile communications: road traffic

Applications

- **Emergencies** –

➢ **Ambulance** with a high-quality wireless connection to a hospital.

➢ Wireless networks are the only means of communication in the case of **natural disasters** such as **hurricanes or earthquakes.**

Applications

- **Business** - 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.

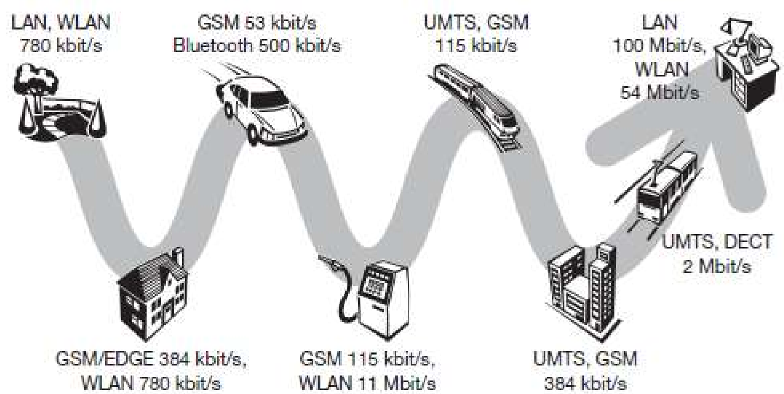


Figure 1.2 Mobile and wireless services – always best connected

Applications

- **Replacement of wired networks**

➢ In some cases, 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.

➢ **Tradeshows** need a highly dynamic infrastructure, but cabling takes a long time and frequently proves to be too inflexible.

Applications

- **Infotainment and more**

➢ **Imagine a travel guide** for a city. **Static information** might be loaded via CD-ROM, DVD, or even at home via the Internet.

➢ But 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.

➢ **You may choose a seat, pay via electronic cash**, and send this information to a service provider (Cheverst, 2000).

➢ 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.

Applications

- **Location dependent services**
  - **Follow-on services**
  - **Location aware services**
  - **Privacy**
  - **Information services**
  - **Support services**

Applications

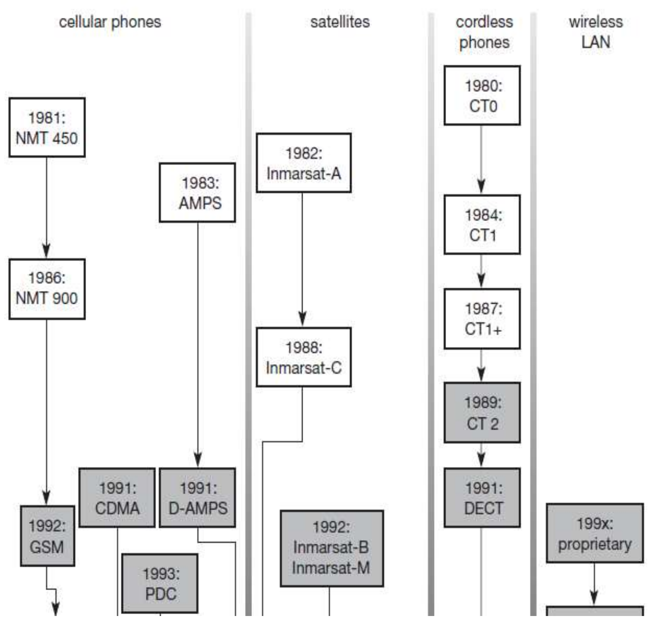
- **Mobile and Wireless devices**
  - **Sensor : Automatic Door Openers**
  - **Embedded Controllers : TV, Washing Machines**
  - **Pager: Displays short text message.**
  - **Mobile phones**
  - **Personal Digital Assistant**
  - **Pocket Computer**
  - **E-Notebook/Laptop**

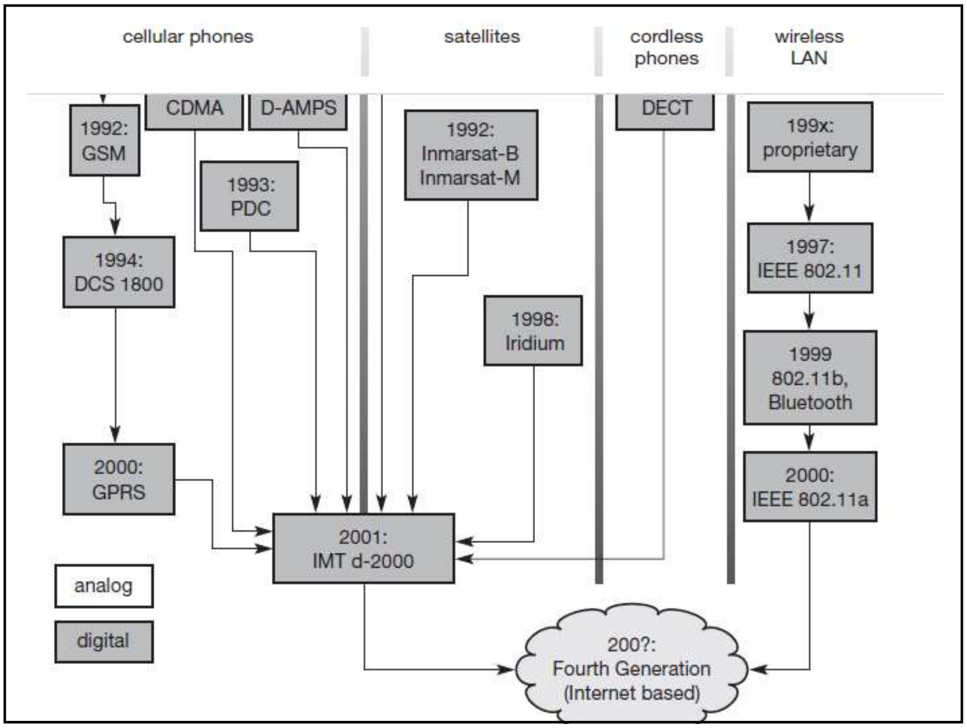
A Short history of Wireless Communication

- In ancient times, the **light** was either modulated' using mirrors to create a certain light on/light off pattern.
- The use of **smoke signals** for communication is mentioned by Polybius, Greece, as early as 150 BC. It is also reported from the early (or western) Han dynasty in ancient China (206 BC–24 AD) that light was used for signaling messages along a line of signal towers towards the capitol Chang'an.
- **Using light and flags** for wireless communication remained important for the **navy** until radio transmission was introduced.
- Wired communication started with **the first commercial telegraph line between Washington and Baltimore in 1843,** and **Alexander Graham Bell's** invention and marketing of the **telephone in 1876** (others tried marketing before but did not succeed.
- In Berlin**, a public telephone service** was available in **1881, the first regular** public **voice and video service (multimedia!)** was already available in **1936** between **Berlin and Leipzig.**

A Short history of Wireless Communication

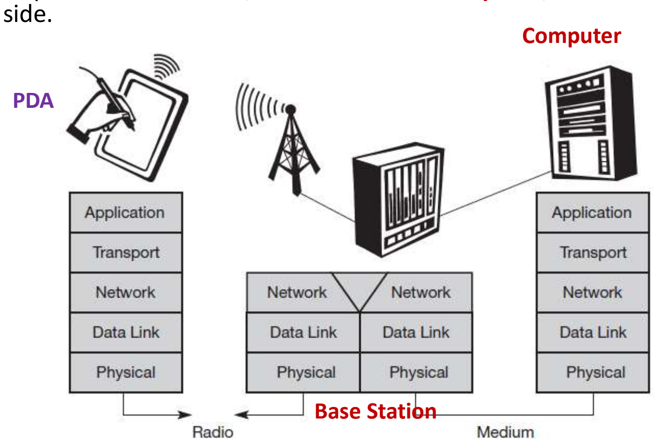
Figure 1.3
Overview of some wireless communication systems





A Simplified Reference Model

- Figure 1.6 shows a **Personal Digital Assistant (PDA)** which provides an example for a wireless and portable device.
- This PDA communicates with a base station in the middle of the picture. The **Base Station** consists of a radio transceiver (sender and receiver) and an interworking unit connecting the wireless link with the fixed link.
- The communication partner of the PDA, a conventional **Computer**, is shown on the right-hand side.



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**

❖ **modulation of data onto a carrier frequency**

❖ **and (depending on the transmission scheme) encryption.**

A Simplified Reference Model

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.

A Simplified Reference Model

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 topics are addressing, routing, device location,**
- **and handover between different networks.**

A Simplified Reference Model

Transport layer:

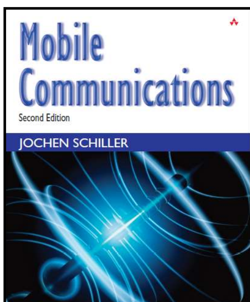
This layer is used in the reference model to establish an end-to-end connection.

- Topics like
- **Quality of Service,**
- **flow and congestion**
- **control are relevant,**
- especially if the transport protocols known from the Internet, **TCP and UDP**, are to be used over a wireless link.

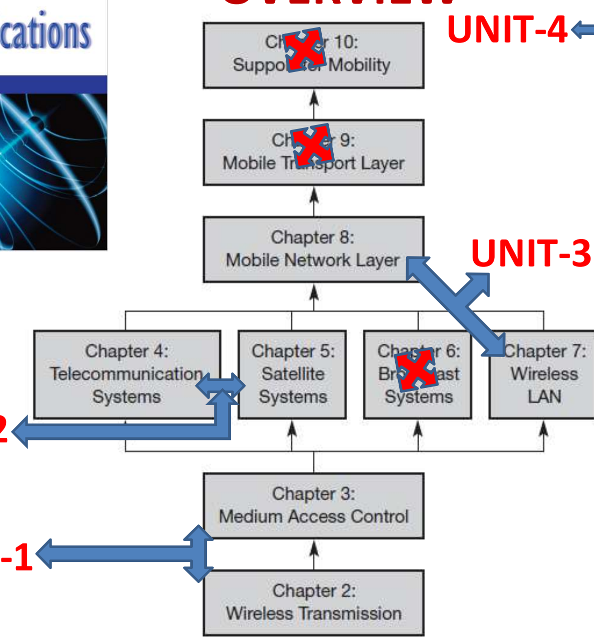
A Simplified Reference Model

Application layer:

- **Finally, the applications (complemented by additional** layers that can support applications) are situated on top of all transmission oriented layers.
- Topics of interest in this context 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.
- ➢ Very demanding applications are video (high data rate) and interactive gaming (low jitter, low latency).



OVERVIEW



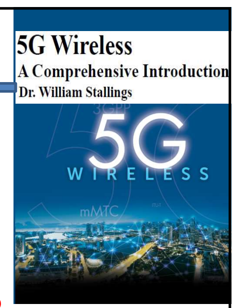


Figure 1.7 Overview of the book's structure

WIRELESS TRANSMISSION

WIRELESS TRANSMISSION

- **Frequencies,**
- **Signals,**
- **Antennas,**
- **Signal Propagation,**
- **Multiplexing,**
- **Modulation,**
- **Spread Spectrum,**
- **Cellular Systems: Frequency Management and Channel Assignment, types of hand-off and their characteristics.**

Frequencies

- Radio transmission can take place using many different frequency bands.
- Directly coupled to the frequency is the wavelength λ via the equation:

  $\lambda = c/f$, **where $c \cong 3X10^8$ m/s and f the frequency.**

- 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** (new coding schemes work with several hundred MHz even with twisted pair copper wires over distances of some 100 m).
- **Fiber optics are used for frequency ranges of several hundred THz**, but here one typically refers to the wavelength which is, e.g., 1500 nm, 1350 nm etc. (infra red).

Frequencies

- Figure 2.1 gives a rough overview of the frequency spectrum that can be used for data transmission. The figure shows frequencies starting at 300 Hz and going up to over 300 THz.

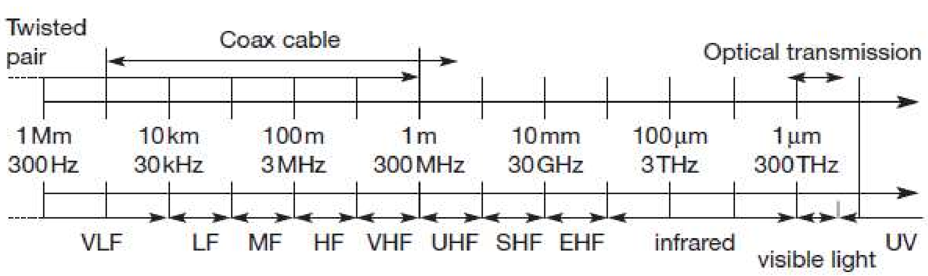


Figure 2.1 Frequency spectrum

Frequencies

- **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**.

Frequencies

- **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.

Frequencies

- **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 **infra red**.
- 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.
- **Infra Red (IR) transmission** is used for **directed links,** e.g., **to connect different buildings via laser links.**

Frequencies

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 (formerly known as Consultative Committee for International Radio communication, CCIR).
- 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.

Frequencies

Regulations

- 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.**
- While **CEPT is still responsible for the general planning**, many tasks have been transferred to other agencies (confusing anybody following the regulation process).
- For example, **the European Telecommunications Standards Institute (ETSI)** is responsible for standardization and consists of national standardization bodies, public providers, manufacturers, user groups, and research institutes.

Frequencies

Table 2.1 Example systems and their frequency allocations (all values in MHz)

	Europe	US	Japan
Mobile phones	**NMT** 453–457 463–467	**AMPS, TDMA, CDMA** 824–849 869–894	**PDC** 810–826 940–956 1429–1465 1477–1513
	GSM 890–915 935–960 1710–1785 1805–1880	**GSM, TDMA, CDMA** 1850–1910 1930–1990	
	UMTS (FDD)/ W–CDMA 1920–1980 2110–2190		**FOMA/ W–CDMA** 1920–1980 2110–2170

Frequencies

Table 2.1 Example systems and their frequency allocations (all values in MHz)

	UMTS (TDD) 1900–1920 2020–2025		
Cordless telephones	**CT1+** 885–887 930–932	**PACS** 1850–1910 1930–1990	**PHS** 1895–1918
	CT2 864–868	**PACS–UB** 1910–1930	**JCT** 254–380
	DECT 1880–1900		
Wireless LANs	**IEEE 802.11** 2400–2483	**IEEE 802.11** 902–928 2400–2483	**IEEE 802.11** 2400–2497
	HiperLAN2, IEEE 802.11a 5150–5350 5470–5725	**HiperLAN2, IEEE 802.11a** 5150–5350 5725–5825	**HiperLAN2, IEEE 802.11a** 5150–5250
Others	**RF-Control** 27, 128, 418, 433, 868	**RF-Control** 315, 915	**RF-Control** 426, 868
	Satellite (e.g., Iridium, Globalstar) 1610–1626, 2483–2500		

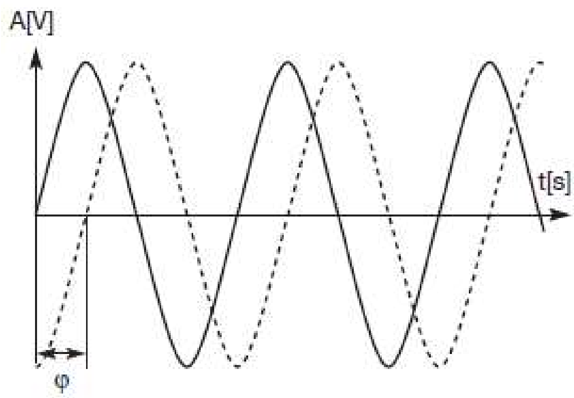
Signals

- **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.

Signals



Signals

- 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 a_n and b_n 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.

•However, the frequencies of these functions (the so-called **harmonics)** increase with a growing parameter n and are a multiple of the **fundamental frequency f.**

Signals

Representation of Signals

- **Time Domain –** Having One frequency**,** This is also the typical representation known from an **oscilloscope.**
- **Frequency Domain-** if a signal consists of many different frequencies, Here the amplitude of a certain frequency part of the signal is shown versus the frequency. A tool to display frequencies is a **spectrum analyzer**
- **Phase Domain-**This representation, also called phase state or signal **constellation diagram**, shows the amplitude M of a signal and its phase *φ in polar* coordinates. (The length of the vector represents the amplitude, the angle the phase shift.)
- 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).***

Signals

Representation of Signals

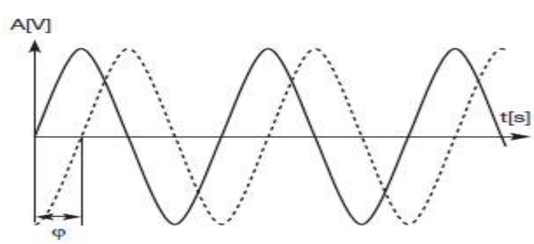


Figure 2.2 Time domain representation of a signal

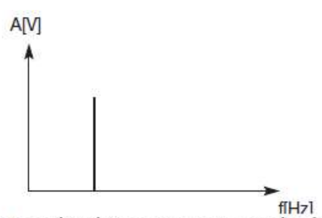


Figure 2.3 Frequency domain representation of a signal

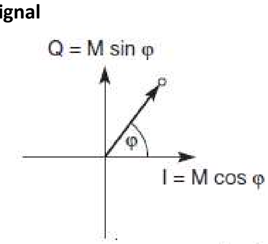


Figure 2.4 Phase domain representation of a signal

Antennas

- **Antennas couple the energy from the transmitter** to the outside world and, in reverse, from the **outside world to the receiver.**
- Antennas **couple electromagnetic energy to and from space to and from a wire or coaxial cable** (or any other appropriate conductor).
- A theoretical reference antenna is the **isotropic radiator, a point in space** radiating equal power in all directions, i.e., all points with equal power are located on a sphere with the antenna as its center.
- The **radiation pattern is symmetric** in all directions (see Figure 2.5, a two dimensional cross-section of the real three-dimensional pattern).

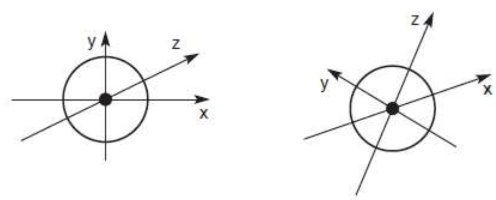


Figure 2.5 Radiation pattern of an isotropic radiator

Antennas

- However, **such an antenna does not exist in reality.**
- **Real antennas all exhibit directive effects, i.e., the intensity of radiation is not the same in all** directions from the antenna.
- The simplest real antenna is a thin, **center-fed dipole, also called Hertzian dipole, as shown in Figure 2.6 (right-hand side). The** dipole consists of two collinear conductors of equal length, separated by a small feeding gap.
- The length of the dipole is not arbitrary, but, for example, half the wavelength λ *of the signal* to transmit results in a very efficient radiation of the energy.
- If **mounted on the roof of a car**, the length of ***λ/4*** *is efficient. This is also known as* **Marconi antenna.**
- A ***λ/2 dipole*** *has a uniform or* ***omni-directional radiation pattern in one plane*** and a figure eight pattern in the other two planes as shown in Figure 2.7.
- This type of antenna can only overcome environmental challenges by boosting the power level of the signal. Challenges could be mountains, valleys, buildings etc.

Antennas

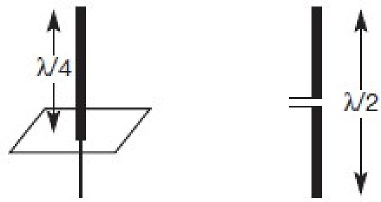


Figure 2.6 Simple Antennas

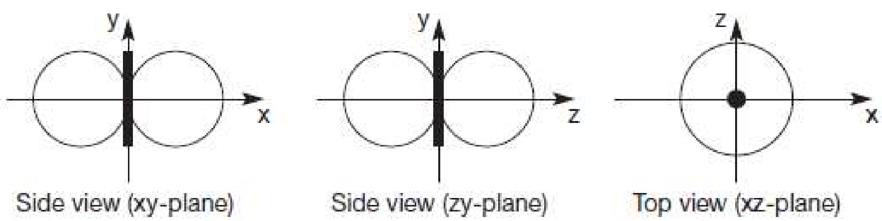


Figure 2.7 Radiation pattern of a simple dipole

Antennas

- **If an antenna is positioned, e.g., in a valley or between buildings, an omnidirectional radiation pattern is not very useful.**
- In this case, **Directional antennas with certain fixed preferential transmission and reception directions** can be used.
- Figure 2.8 shows the radiation pattern of a directional antenna with the main lobe in the direction of the x-axis.
- A special example of directional antennas is constituted by **satellite dishes.**

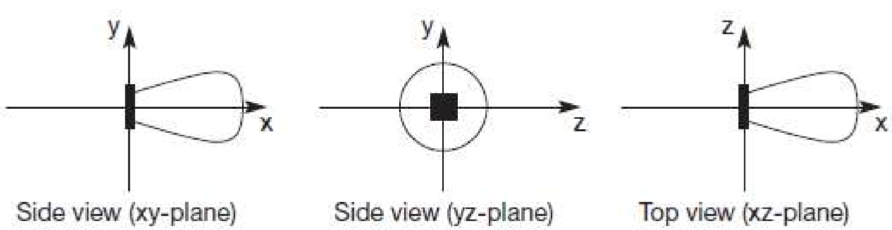


Figure 2.8 Radiation pattern of a directed antenna

Antennas

- Several directed antennas can be combined on a single pole to construct a **Sectorized antenna.**
- **A cell can be Sectorized** into, for example, **three or six sectors**, thus enabling frequency reuse.
- Figure 2.9 shows the radiation patterns of these **Sectorized antennas.**

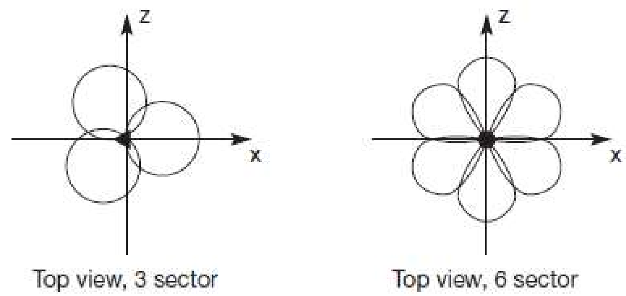


Figure 2.9 Radiation patterns of Sectorized Antennas

Antennas

- **Two or more antennas can also be combined** to improve reception by counteracting **the negative effects of multi-path propagation.**
- These antennas, also called **multi-element antenna arrays**, allow **different diversity schemes.**
- One such scheme is **switched diversity or selection diversity,** where the receiver always uses the antenna element with the largest output.
- **Diversity combining constitutes a combination of the power of all signals** to produce gain.
- The phase is first corrected (cophasing) to avoid cancellation.

Antennas

- As shown in Figure 2.10, different schemes are possible.
- On the left, two **λ/4 antennas** are combined with a distance of λ/2 between them on top of a ground plane.
- On the right, three standard **λ/2 dipoles** are combined with a distance of λ/2 between them.
- Spacing could also be in multiples of λ/2.

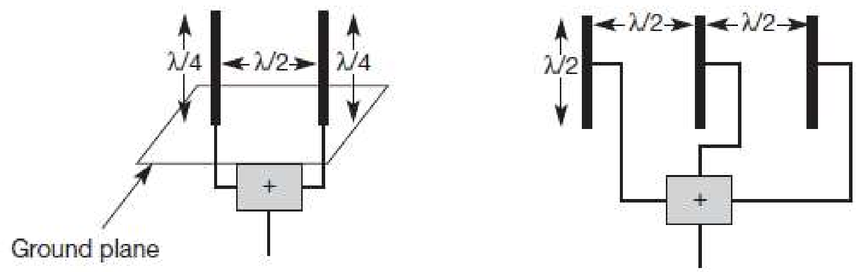


Figure 2.10 Diversity antenna systems

Antennas

- A more advanced solution is provided by **Smart Antennas which combine multiple antenna elements** (also called **antenna array**) with signal processing to optimize the radiation/reception pattern in response to the signal environment.
- **These antennas can adapt to changes in reception power**, transmission conditions and many signal propagation effects.
- **Antenna arrays can also be used for beam forming**. This would be an extreme case of a directed antenna which can follow a single user thus using **Space Division Multiplexing** .
- It would not just be base stations that could follow users with an individual beam.
- Wireless devices, too, could direct their electromagnetic radiation, e.g., away from the human body towards a base station. This would help in reducing the absorbed radiation.
- Today's **handset antennas are omni-directional as the integration of smart antennas into mobiles is difficult and has not yet been realized.**

Signal Propagation

- In wireless networks, the **signal has no wire to determine the direction of propagation**, whereas signals in wired networks only travel along the wire .
- . One can precisely determine the behavior of a **signal travelling along this wire, e.g., received power depending on the length.**
- **For wireless transmission**, this predictable behavior is only **valid in a vacuum**, **i.e., without matter between the sender and the receiver.**
- However, **real life does not happen in a vacuum**, **radio transmission has to contend with our atmosphere, mountains, buildings, moving senders and receivers etc.**
- In reality, the three circles referred to above will be bizarrely-shaped polygons with their shape being time and **frequency dependent.**

Signal Propagation

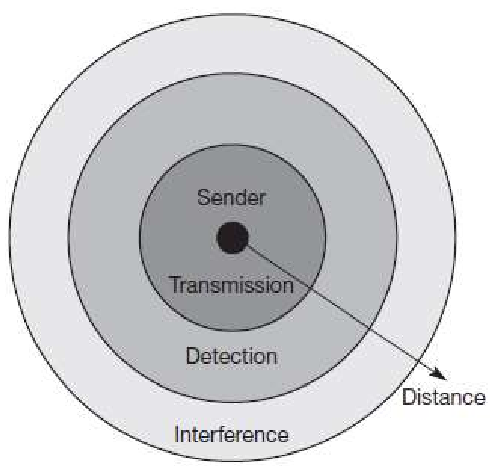


Figure 2.11 Ranges for transmission, detection, and interference of signals

Signal Propagation

- **Transmission range: Within a certain radius of the sender transmission is possible**, i.e., a receiver receives the signals with an **error rate low** enough to be able to communicate and can also act as sender.
- **Detection range: Within a second radius, detection of the transmission is** possible, i.e., **the transmitted power is large enough to differ from background noise**. However, the error rate is too high to establish communication.
- **Interference range: Within a third even larger radius, the sender may interfere with other transmission by adding to the background noise. A receiver will not be able to detect the signals, but the signals may disturb other signals.**

Signal Propagation

Path loss of Radio Signals

- In free space radio signals propagate as light does (independently of their frequency), i.e., they follow a straight line (besides gravitational effects). If such a straight line exists between a sender and a receiver it is called **Line-Of-Sight (LOS).**
- **Even if no matter exists** between the sender and the receiver (i.e., if there is a vacuum), the **signal still experiences the free space loss. The received power** ***P_r is proportional to $1/d^2$ with d being the distance between sender and receiver*** **(inverse square law).**
- While the **path loss or attenuation does not cause** too much **trouble for short distances, e.g., for LANs** , the atmosphere heavily influences transmission over long distances, e.g., satellite.
- Even mobile phone systems are influenced by weather conditions such as heavy rain. **Rain can absorb much of the radiated energy of the antenna.**
- **Depending on the frequency, radio waves can also penetrate objects.**
- Generally **the lower the frequency, the better the penetration**. Long waves can be transmitted through the oceans to a **submarine** while high frequencies can be blocked by a tree.

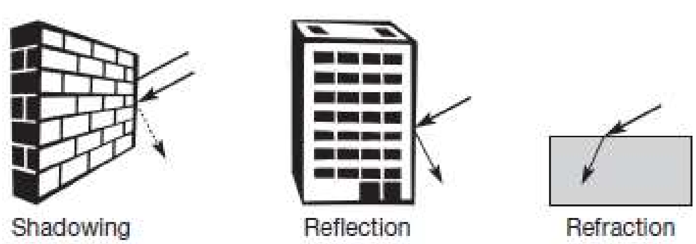
Signal Propagation

Radio waves can exhibit **three Fundamental Propagation behaviors** depending on their frequency:

- **Ground wave (<2 MHz): Waves with low frequencies follow the earth's surface** and can propagate long distances. These waves are used for, e.g., **Submarine communication or AM radio.**
- **Sky wave (2–30 MHz): Many international broadcasts and amateur radio use these short waves** that are **reflected at the ionosphere.** This way the waves can bounce back and forth between the ionosphere and the earth's surface, travelling around the world.
- **Line-of-sight (>30 MHz): Mobile phone systems, satellite systems, cordless telephones etc.** use even higher frequencies. The emitted waves follow a (more or less) straight line of sight. This enables direct communication with satellites (**no reflection at the ionosphere**) or microwave links on the ground.

Signal Propagation

- **Additional signal propagation effects**



Signal Propagation

Additional Signal Propagation effects

- An extreme form of attenuation is **blocking or shadowing of radio signals** due to large obstacles (see Figure 2.12, left side). The higher the frequency of a signal, the more it behaves like light. **Even small obstacles like a simple wall, a truck on the street, or trees in an alley may block the signal.**
- Another effect is the **reflection of signals as shown in the middle of Figure 2.12. If an object is large compared to the wavelength of the signal**, e.g., huge buildings, mountains, or the surface of the earth, the signal is reflected.
- The reflected signal is not as strong as the original, as objects can absorb some of the signal's power.
- **The refraction effect** occurs because the velocity of the electromagnetic waves depends on the **density of the medium through which it travels.** Only in vacuum does it equal *c.*
- *As* the figure shows, **waves that travel into a denser medium are bent towards the medium.** This is the reason for LOS radio waves being bent towards the earth: the density of the atmosphere is higher closer to the ground.

Signal Propagation

Additional Signal Propagation effects

- If the size of an obstacle is in the order of the wavelength or less, then waves can be **scattered . An incoming signal is scattered into several weaker outgoing signals.**
- Another effect is **diffraction of waves. This effect is** very similar to scattering.
- Radio waves will be deflected at an edge and propagate in different directions. The result of scattering and diffraction are patterns with varying signal strengths depending on the location of the receiver.
- Effects like **attenuation, scattering, diffraction, and refraction all happen simultaneously and are frequency and time dependent.**

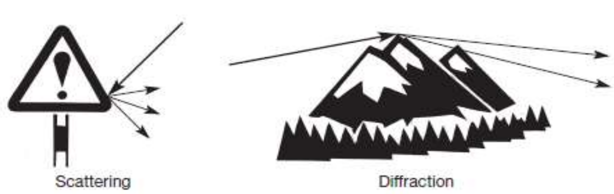
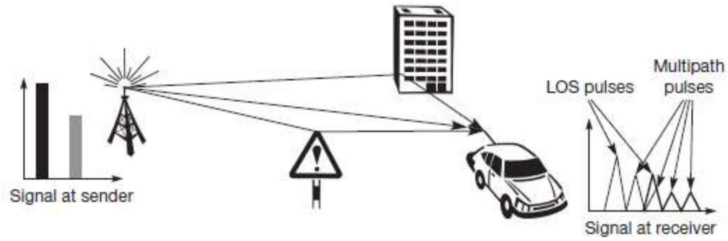


Figure 2.13
Scattering and diffraction of waves

Signal Propagation

- **Multi-Path Propagation**



Radio waves emitted by the sender can either travel along a straight line, or they may be reflected at a large building, or scattered at smaller obstacles.
Due to the finite speed of light, signals travelling along different paths with different lengths arrive at the receiver at different times. This effect (caused by multi-path propagation) is called **delay spread: the original signal is spread due** to different delays of parts of the signal. This delay spread is a typical effect of radio transmission. Typical values for **delay spread are approximately 3 *μs in cities, up to 12 μs can be observed*.** ***GSM, for example, can*** **tolerate up to 16** ***μs of delay spread, i.e., almost a 5 km path difference.***

Signal Propagation

Multi-Path Propagation

- **Now consider that each impulse should represent a symbol**, and that one or several symbols could represent a bit. The energy intended for one symbol now spills over to the adjacent symbol, an effect which is called **Inter symbol interference (ISI).**
- **The higher the symbol rate to be transmitted,** the worse the effects of ISI will be, as the original symbols are moved closer and closer to each other.
- **Due to this interference, the signals of different symbols can cancel each other out leading to misinterpretations at the receiver and causing transmission errors.**
- If the receiver knows the delays of the different paths (or at least the main paths the signal takes), it can compensate for the distortion caused by the channel.
- The sender may first transmit a **training sequence known by the receiver.** The receiver then compares the received signal to the original training sequence and programs an **equalizer that compensates for the distortion.**

Signal Propagation

Multi-Path Propagation

- While ISI and delay spread already occur in the case of fixed radio transmitters and receivers, the situation is even worse if receivers, or senders, or both, move.
- Then the **channel characteristics change over time, and the paths a signal can travel along vary.** This effect is well known (and audible) **with analog radios while driving**. The power of the received signal changes considerably over time. These **quick changes in the received power are also called Short-term Fading.**
- **Long-term Fading**, shown here as the average power over time, is caused by, for example, **varying distance to the sender** or more remote obstacles.
- Typically, **senders can compensate for long-term fading by increasing/ decreasing sending power** so that the received signal always stays within certain limits.
- **Doppler shift caused by a moving** sender or receiver.

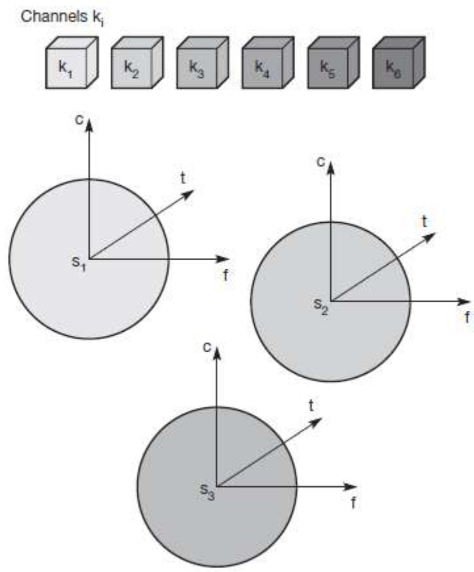
Multiplexing

- **Multiplexing describes how several users can share a medium with minimum or no interference**.
- One example, is **highways with several lanes**. Many users (car drivers) use the same medium (the highways) with hopefully no interference (i.e., accidents). This is possible due to the provision of several lanes (space division multiplexing) separating the traffic.
- In addition, different cars use the same medium (i.e., the same lane) at different points in time (time division multiplexing).
- For wireless communication, multiplexing can be carried out in four dimensions: **space, time, frequency, and code.**
- Depending on this there are four types of Multiplexing

✓ **Space Division Multiplexing**
✓ **Frequency Division multiplexing**
✓ **Time Division Multiplexing**
✓ **Code Division Multiplexing**

Multiplexing

- **Space Division Multiplexing**



Multiplexing

Space Division Multiplexing

- 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.
- How is the separation of the different channels achieved? The channels k_1 to k_3 can be mapped onto the three 'spaces' s_1 to s_3 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 (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.

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 k_i is now allotted its own frequency band as indicated.

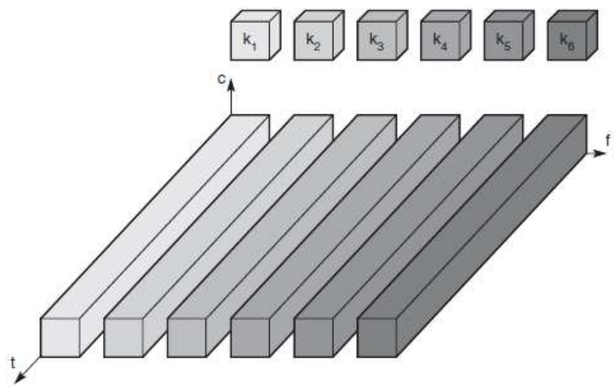


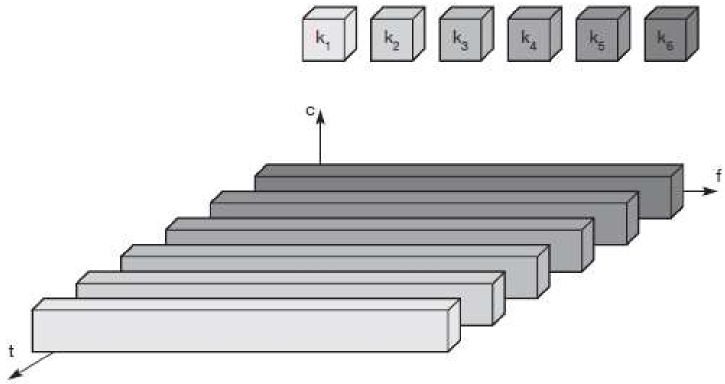
Figure 2.17 Frequency Division Multiplexing (FDM)

Multiplexing

- 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.**

Multiplexing

- **Time Division Multiplexing**

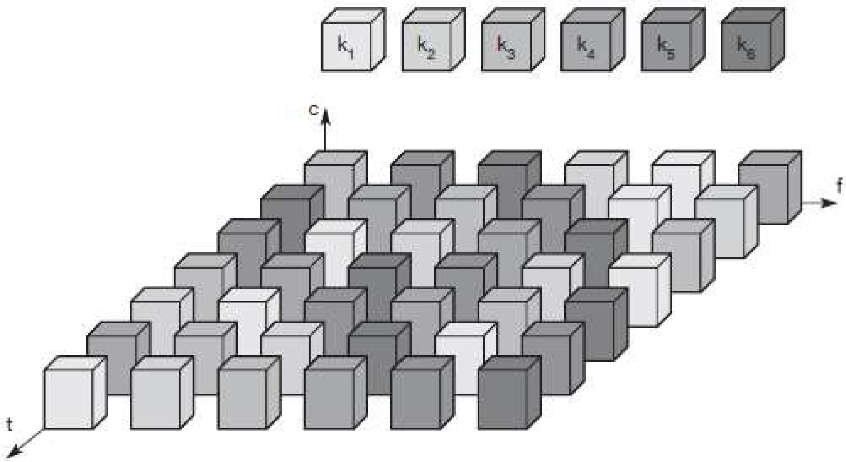


Multiplexing

- 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.

Multiplexing

- **Frequency and time division multiplexing can be combined**



Multiplexing

Code Division Multiplexing

- 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. CDM is Viterbi**

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.

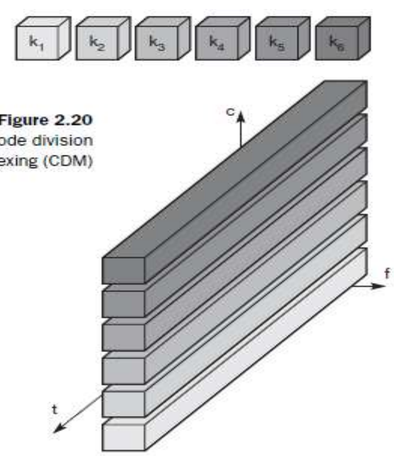


Figure 2.20 Code division multiplexing (CDM)

Multiplexing

- 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.**
- **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.**

Modulation

- **For wired networks** is the old analog telephone system – to connect a computer to this system a modem is needed.
- **The modem then performs the translation of digital data into analog signals and vice versa**.
- Digital transmission is used, for example, in wired local area networks or within a Computer.
- **In wireless networks**, however, digital transmission cannot be used. Here, the **binary bit-stream has to be translated into an analog signal first**. The three basic methods for this translation are

❑ **Amplitude shift keying (ASK),**
❑ **Frequency shift keying (FSK), and**
❑ **Phase shift keying (PSK).**

Modulation

- Apart from the translation of digital data into analog signals, wireless transmission requires an additional modulation, an **analog modulation that shifts the center frequency of the baseband signal generated by the digital modulation up to the radio carrier.**
- For example, digital modulation translates a 1 Mbit/s bit-stream into a baseband signal with a bandwidth of 1 MHz.

There are several reasons why this baseband signal cannot be directly transmitted in a wireless system:

- **Antennas: As shown, an antenna must be the order of magnitude** of the signal's wavelength in size to be effective. For the 1 MHz signal in the example this would result in an antenna some hundred meters high, which is obviously not very practical for handheld devices. With 1 GHz, antennas a few centimeters in length can be used.

Modulation

- **Frequency division multiplexing: Using only baseband transmission, FDM** could not be applied. Analog modulation shifts the baseband signals to different carrier frequencies as required. The higher the carrier frequency, the more bandwidth that is available for many baseband signals.
- **Medium characteristics: Path-loss, penetration of obstacles, reflection,** scattering, and diffraction – all the **effects depend heavily on the wavelength of the signal**.
- **Depending on the application**, the right carrier frequency with the desired characteristics has to be chosen: **long waves for submarines**, **short waves for handheld devices**, **very short waves for directed microwave transmission** etc.

Modulation

- Figure 2.21 shows a (simplified) block diagram of a radio transmitter for digital data.
- The **first step is the digital modulation of data** into the analog baseband signal according to one of the schemes .
- The **analog modulation** then shifts the center frequency of the analog signal up to the radio carrier. This signal is then transmitted via the antenna.

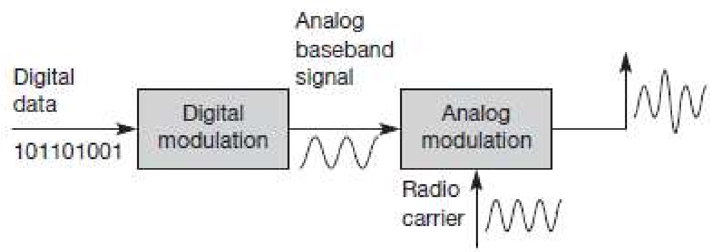


Figure 2.21 Modulation in a Transmitter

Modulation

- The receiver (see Figure 2.22) receives the analog radio signal via its antenna and **demodulates the signal into the analog baseband signal with the help of the known carrier.**
- **For digital data, another step is needed. Bits or frames have to be detected, i.e., the receiver must synchronize with the sender.**
- How synchronization is achieved, depends on the digital modulation scheme. **After synchronization, the receiver has to decide if the signal represents a digital 1 or a 0, reconstructing the original data.**

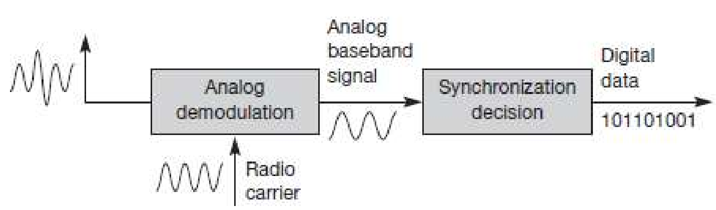


Figure 2.22 Demodulation and data reconstruction in a receiver

Modulation

- The **digital modulation schemes** presented in the following sections **differ in many issues**, such as
  - **spectral efficiency (i.e., how efficiently the modulation** scheme utilizes the **available frequency spectrum**),
  - **power efficiency (i.e., how** much power is needed to transfer bits – which is **very important for portable devices that are battery dependent**), and
  - **robustness to multi-path propagation,** noise, and interference

Modulation

- **Amplitude Shift Keying**

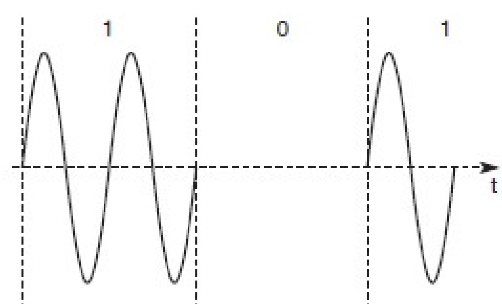


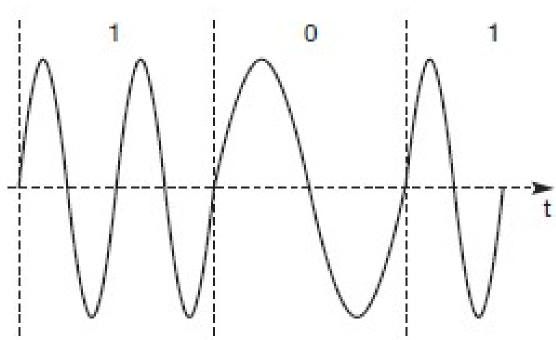
Figure 2.23 Amplitude shift keying (ASK)

Modulation-Amplitude Shift Keying

- The two binary values, 1 and 0, are represented by two different amplitudes.
- In the example, one of the amplitudes is 0 (representing the binary 0).
- This simple scheme only **requires low bandwidth**, but is very **susceptible to interference.**
- Effects like **multi-path propagation, noise, or path loss heavily influence the amplitude.**
- In a wireless environment, a constant amplitude cannot be guaranteed, so **ASK is typically not used for wireless radio transmission.**
- However, the wired transmission scheme with the highest performance, namely **optical transmission, uses ASK**.
- Here, **a light pulse may represent a 1**, while the **absence of light represents a 0**. The carrier frequency in optical systems is some hundred THz.
- ASK can also be applied to wireless infra red transmission, using a directed beam or diffuse light.

Modulation

Frequency Shift Keying



Modulation-Frequency shift keying

- A modulation scheme often used for wireless transmission is **frequency shift keying (FSK). The simplest form of FSK, also called binary FSK (BFSK), assigns one frequency f_1 to the binary 1 and another frequency f_2 to the** binary 0.
- A very simple way to implement FSK is to **switch between two oscillators**, one with the frequency f1 and the other with f2, depending on the input.
- To avoid sudden changes in phase, special frequency modulators with **continuous phase modulation, (CPM)** can be used.
- **Sudden changes in phase cause high frequencies, which is an undesired side-effect.**
- **A simple way to implement demodulation** is by using two bandpass filters, one for f_1 the other for f_2.
- **A comparator** can then compare the signal levels of the filter outputs to decide which of them is stronger.
- FSK needs a larger bandwidth compared to ASK but is much less susceptible to errors.

Modulation

- **Phase shift keying**

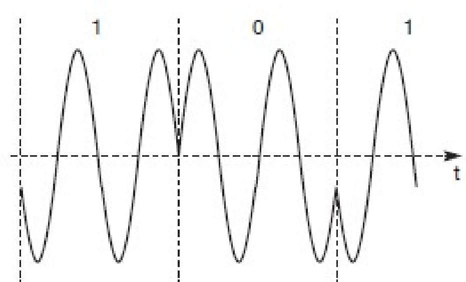


Figure 2.25 Phase shift keying (PSK)

Modulation-Phase Shift Keying

- Finally, **phase shift keying (PSK)** uses shifts in the phase of a signal to represent data. Figure 2.25 shows **a phase shift of 180° or *π as the 0 follows* the 1** (the same happens as the 1 follows the 0).
- This simple scheme, shifting the phase by 180° each time the value of data changes, is also called **binary PSK (BPSK).**
- A simple implementation of a **BPSK modulator could multiply a frequency f with +1 if the binary data is 1 and with –1 if the binary data is 0.**
- To receive the signal correctly, the receiver must synchronize in frequency and phase with the transmitter. This can be done using a **phase lock loop (PLL).**
- Compared to FSK, PSK is more resistant to interference, but receiver and transmitter are also more complex.

Modulation

- **Advanced frequency shift keying**

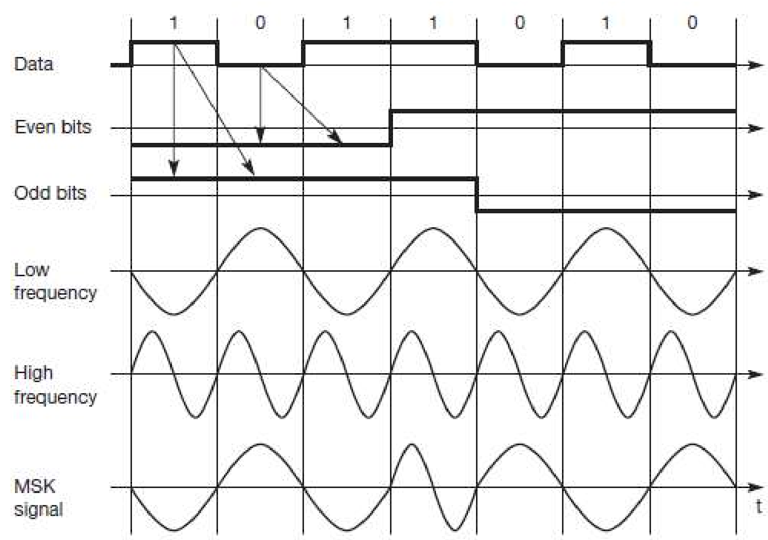


Figure 2.26 Minimum shift keying (MSK)

Modulation-Advanced Frequency Shift Keying

- A famous FSK scheme used in many wireless systems is **Minimum Shift Keying (MSK).**
- **MSK is basically BFSK without abrupt phase changes, i.e., it belongs to** CPM schemes.
- **In a first step**, data bits are separated into **even and odd bits**, the duration of each bit being doubled.
- The scheme also uses two frequencies: **f_1, the lower frequency**, and **f_2, the higher frequency, with $f_2 = 2f_1$.**

Modulation-Advanced Frequency Shift Keying

- According to the following scheme, the lower or higher frequency is chosen (either inverted or non-inverted) to generate the MSK signal:
  - **if the even and the odd bit are both 0, then the higher frequency f_2 is inverted (i.e., f_2 is used with a phase shift of 180°);**
  - **if the even bit is 1, the odd bit 0, then the lower frequency f_1 is inverted. This is the case, e.g., in the fifth to seventh columns of Figure 2.26,**
  - **if the even bit is 0 and the odd bit is 1, as in columns 1 to 3, f_1 is taken without changing the phase,**
  - **if both bits are 1 then the original f_2 is taken.**
- A high frequency is always chosen if even and odd bits are equal.
- The signal is inverted if the odd bit equals 0. This scheme avoids all phase shifts in the resulting MSK signal.
- Adding a so-called **Gaussian low pass filter** to the MSK scheme results in **Gaussian MSK (GMSK), which is the digital modulation scheme for many** European wireless standards GSM, DECT).
- The filter reduces the large spectrum needed by MSK.

Modulation

- **Advanced phase shift keying**

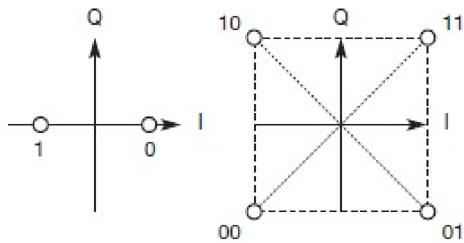


Figure 2.27 BPSK and QPSK in the phase domain

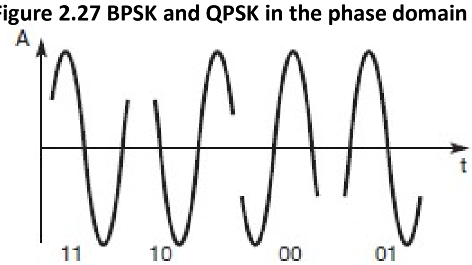


Figure 2.28 QPSK in the time domain

Modulation-Advanced Phase Shift Keying

- The basic BPSK scheme only uses one possible phase shift of 180°.
- The left side of Figure 2.27 shows BPSK in the phase domain (which is typically the better representation compared to the time domain in Figure 2.25).
- The right side of Figure 2.27 shows **Quadrature PSK (QPSK), one of the most common PSK schemes (sometimes also called Quaternary PSK**).
- Here, higher bit rates can be achieved for the same bandwidth by coding two bits into one phase shift.
- Alternatively, one can reduce the bandwidth and still achieve the same bit rates as for BPSK.

Modulation-Advanced Phase Shift Keying

- QPSK (and other PSK schemes) can be realized in two variants.
- The phase shift can always be relative to a **reference signal (with the same** frequency).
- If this scheme is used, a phase shift of **0 means that the signal is in phase with the reference signal.**
- **A QPSK signal will then exhibit a phase shift of 45° for the data 11, 135° for 10, 225° for 00, and 315° for 01 – with all phase shifts being relative to the reference signal.**
- The transmitter 'selects' parts of the signal as shown in Figure 2.28 and concatenates them.
- To reconstruct data, the receiver has to compare the incoming signal with the reference signal.

Modulation-Advanced Phase Shift Keying

- One problem of **this scheme involves producing a reference signal at the receiver.**
- Transmitter and receiver **have to be synchronized very often**, e.g., by using special synchronization patterns before user data arrives or via a pilot frequency as reference.
- One way to avoid this problem is to use **differential QPSK (DQPSK).**
- **Here the phase shift is not relative to a reference signal but to the phase of the previous two bits.**
- In this case, the **receiver does not need the reference signal** but only compares two signals to reconstruct data.
- DQPSK is used in US wireless technologies IS-136 and PACS and in Japanese PHS.

Modulation-Advanced Phase Shift Keying

- One could now think of **extending the scheme to more and more angles for shifting the phase.**
- For instance, one can think of coding 3 bits per phase shift using 8 angles.
- Additionally, the **PSK scheme could be combined with ASK** as is done for example in **Quadrature Amplitude Modulation (QAM)** for standard 9,600 bit/s modems (left side of Figure 2.29).
- Here, **three different amplitudes and 12 angles** are combined **coding 4 bits per phase/amplitude change.**
- Problems occur for wireless communication in case of noise or ISI. The more 'points' used in the phase domain, the harder it is to separate them.
- **DQPSK has been proven as one of the most efficient schemes** under these considerations (Wesel, 1998).

Modulation-Advanced Phase Shift Keying

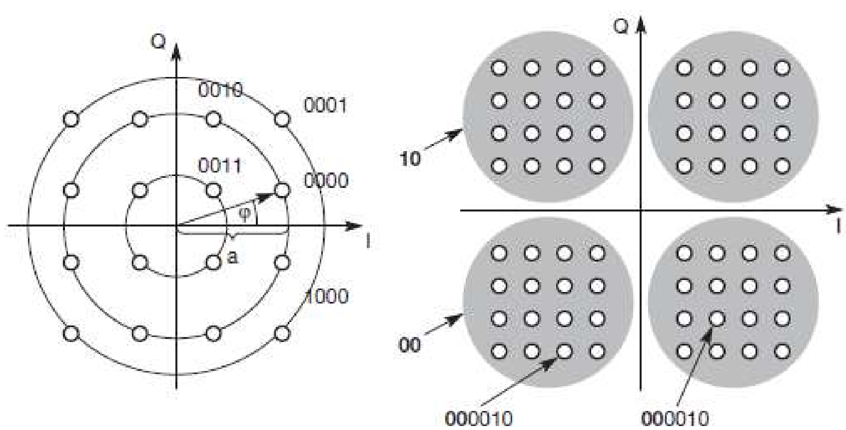


Figure 2.29 16 Quadrature Amplitude Modulation and hierarchical 64 QAM

Modulation-Advanced Phase Shift Keying

- A more advanced scheme is a hierarchical modulation as used in the **digital TV standard DVB-T.**
- The right side of Figure 2.29 shows a **64 QAM that contains a QPSK modulation. A 64 QAM can code 6 bit per symbol. Here the two most significant bits are used for the QPSK signal embedded in the QAM signal.**
- If the reception of the signal is good the entire QAM constellation can be resolved.
- Under poor reception conditions, e.g., with moving receivers, only the QPSK portion can be resolved.
- A high priority data stream in DVB-T is coded with QPSK using the two most significant bits. The remaining 4 bits represent low priority data.
- For TV this could mean that the standard resolution data stream is coded with high priority, the high resolution information with low priority.
- If the signal is distorted, at least the standard TV resolution can be received.

Modulation

Multi-Carrier Modulation

- Apart from the others, **multi-carrier modulation (MCM), orthogonal frequency division multiplexing (OFDM) or coded OFDM (COFDM) that are used in the context of the** European digital radio system DAB and the WLAN standards IEEE 802.11a and HiperLAN2.
- The main attraction of MCM is its good ISI mitigation property.
- Here higher bit rates are more vulnerable to ISI.
- **MCM splits the high bit rate stream into many lower bit rate streams, each stream being sent using an independent carrier frequency.**
- If, for example, n symbols/s have to be transmitted, each subcarrier transmits n/c symbols/s with c being the number of subcarriers.
- One symbol could, for example represent 2 bit as in QPSK. DAB, for example, uses between 192 and 1,536 of these subcarriers. The physical layer of HiperLAN2 and IEEE 802.11a uses 48 subcarriers for data.

Modulation- Multi-Carrier Modulation

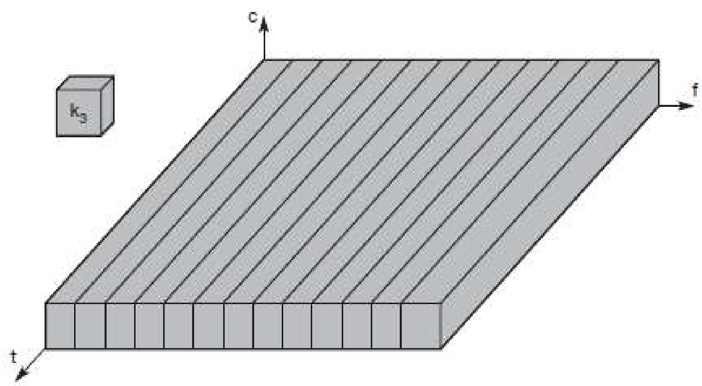


Figure 2.30 Parallel data transmission on several subcarriers with lower rate

Modulation- Multi-Carrier Modulation

- Figure 2.31 shows the superposition of orthogonal frequencies. The maximum of one subcarrier frequency appears exactly at a frequency where all other subcarriers equal zero.
- Using this scheme, frequency selective fading only influences some subcarriers, and not the whole signal – an additional benefit of MCM.
- **OFDM** is a special method of implementing MCM using orthogonal carriers. Computationally, this is a very efficient algorithm based on fast Fourier transform (FFT) for modulation/demodulation.
- If additional error-control coding across the symbols in different subcarriers is applied, the system is referred to as **COFDM**.

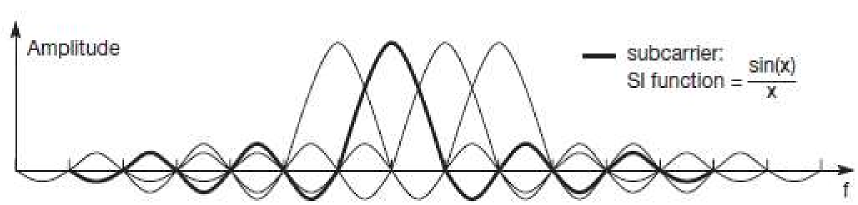


Figure 2.31 Superposition of orthogonal frequencies

Spread Spectrum

- As the name implies, **spread spectrum techniques involve spreading the bandwidth** needed to transmit data – which does not make sense at first sight.
- Spreading the bandwidth has several advantages. **The main advantage is the resistance to narrowband interference.**
- In Figure 2.32, diagram **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.**
- Depending on the generation and reception of the spread signal, the power level of the user signal can even be as low as the background noise.
- This makes it difficult to distinguish the user signal from the background noise and thus hard to detect.

Spread Spectrum

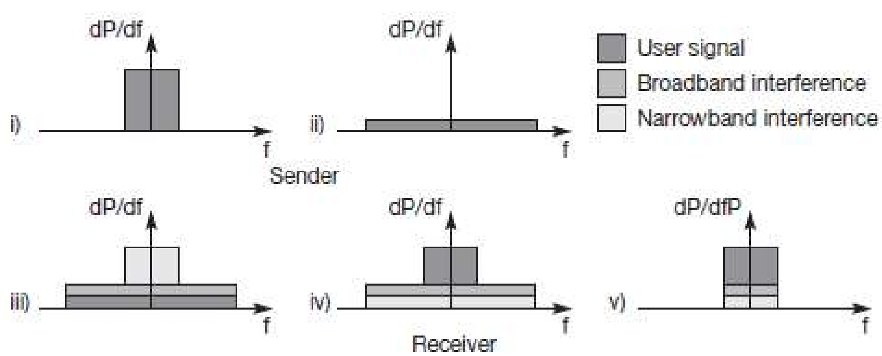


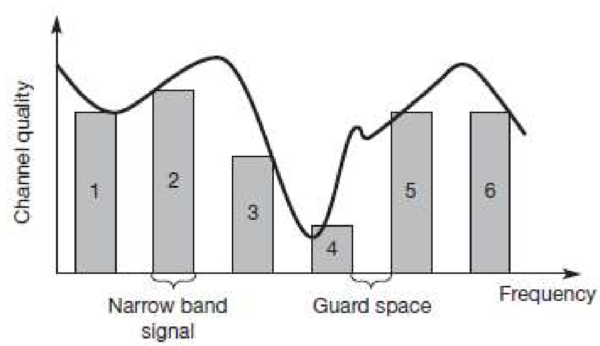
Figure 2.32 Spread spectrum: spreading and despreading

Spread Spectrum

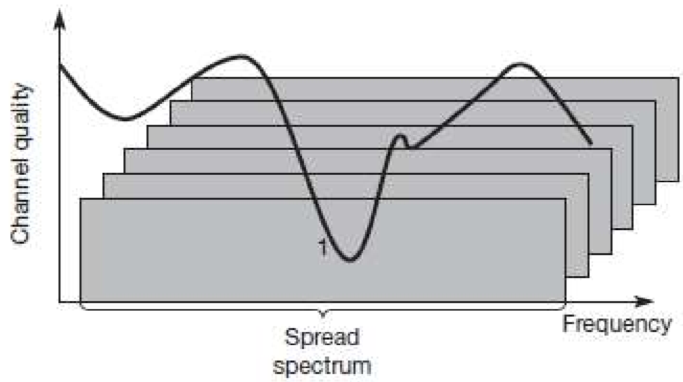
- During transmission, narrowband and broadband interference add to the signal in **step iii).**
- The sum of interference and user signal is received.
- The receiver now knows how to despread the signal **iv)** , converting the spread user signal into a narrowband signal again, while spreading the narrowband 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.

Spread Spectrum

• Six different channels use **FDM** for multiplexing, which means that each channel has its own narrow frequency band for transmission. Between each frequency band a guard space is needed to avoid adjacent channel interference.
• This is frequency dependent and is a measure for interference at this frequency.
• Depending on receiver characteristics, channels 1, 2, 5, and 6 could be received while the quality of channels 3 and 4 is too bad to reconstruct transmitted data. Narrowband interference destroys the transmission of channels 3 and 4.



Spread Spectrum



Spread Spectrum

- Spread spectrum is now applied to all narrowband signals. To separate different channels, **CDM is now used** instead of FDM.
- **Each channel is allotted its own code**, which the receivers have to apply to recover the signal.
- This is the security effect of spread spectrum if a secret code is used for spreading used **for Military Applications.**
- Spread spectrum now allows an overlay of new transmission technology at exactly the same frequency at which current narrowband systems are already operating. This is used by **US mobile phone systems**.
- Spread spectrum technologies also exhibit **drawbacks.**
- ➢ **1.The increased complexity of receivers that have to de-spread a signal.**
- ➢ **2.**Another problem is **the background noise level and may interfere with other transmissions if no special precautions are taken.**

Spread Spectrum

- Spreading the spectrum can be achieved in two different ways

1. Direct Sequence Spread Spectrum(DSSS)

2. Frequency Hopping Spread Spectrum(FHSS)

Spread Spectrum-
Direct Sequence Spread Spectrum

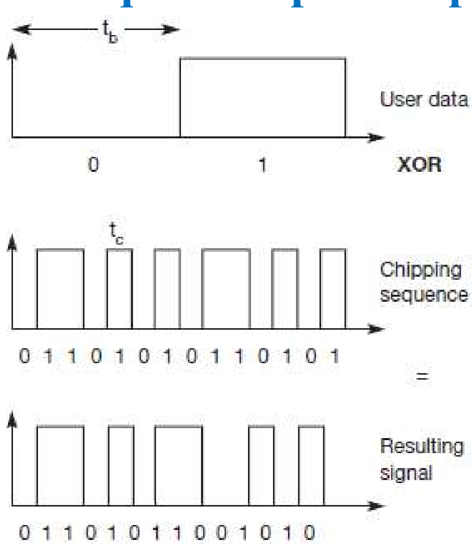


Figure 2.35 Spreading with DSSS

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 Figure 2.35.**
- 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 $\mathbf{t_c}$.
- 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·w** after spreading.

Spread Spectrum-

Direct Sequence Spread Spectrum

- While the **spreading factor** of the very simple example is only 7 (and the chipping sequence 0110101 is not very random), civil applications use spreading factors between 10 and 100, **military applications use factors of up to 10,000.**
- **Wireless LANs complying with the standard IEEE 802.11** use, for example, the sequence **10110111000**, a so-called **Barker code**, if implemented using DSSS.
- Barker codes exhibit a good robustness against interference and insensitivity to multi-path propagation.
- Other known Barker codes are 11, 110, 1110, 11101, 1110010, and 1111100110101.

Spread Spectrum-
Direct Sequence Spread Spectrum

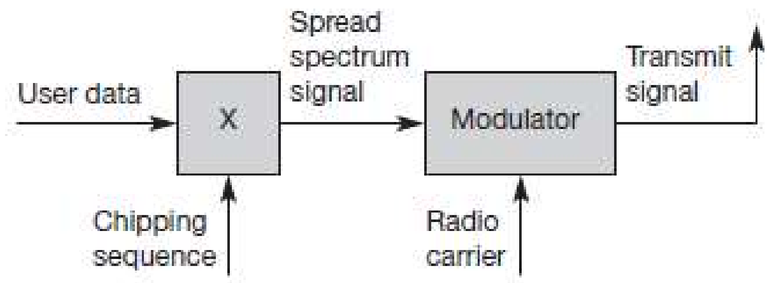


Figure 2.36 DSSS Transmitter

Spread Spectrum-
Direct Sequence Spread Spectrum

At Transmitter

- The first step in a DSSS transmitter, Figure 2.36 is the spreading of the user data with the chipping sequence (digital modulation). The spread signal is then modulated with a radio carrier.
- 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 ISM band). This signal is then transmitted.

Spread Spectrum-
Direct Sequence Spread Spectrum

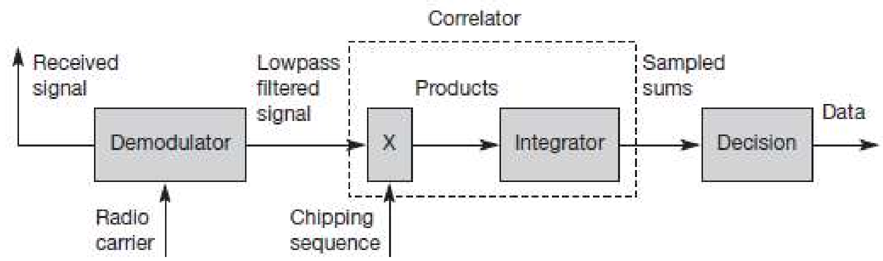


Figure 2.37 DSSS Receiver

Spread Spectrum-
Direct Sequence Spread Spectrum

- 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.**
- **The next steps** constitute a real challenge for DSSS receivers, contributing to the complexity of the system. **The receiver has to know the original chipping sequence, i.e., the receiver basically generates the same pseudo random sequence as the transmitter.**
- **Sequences at the sender and receiver have to be precisely synchronized** because the receiver calculates the product of a chip with the incoming signal.

Spread Spectrum-

Direct Sequence Spread Spectrum

- During a bit period, which also has to be derived via synchronization, an **integrator adds** all these products.
- Calculating the products of chips and signal, and adding the products in an **integrator is also called correlation, the device a correlator.**
- Finally, in each bit period a **decision unit samples the sums generated by the integrator and decides if this sum represents a binary 1 or a 0.**

Spread Spectrum-

Direct Sequence Spread Spectrum

- **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.

Spread Spectrum-
Direct Sequence Spread Spectrum

- **But what happens in case of multi-path propagation?** Then several paths with different delays exist between a transmitter and a receiver.
- In this case, using so-called Rake Receivers provides a possible solution.
- A **Rake Receiver uses** n correlators for the n strongest paths.
- **Each correlator is synchronized to the transmitter** plus the delay on that specific path.
- **As soon as the receiver detects a new path which is stronger than the currently weakest path, it assigns this new path to the correlator with the weakest path.**
- The **output of the correlators are then combined and fed into the decision unit.**

Spread Spectrum-
Frequency Hopping Spread Spectrum (FHSS)

- 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.**

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

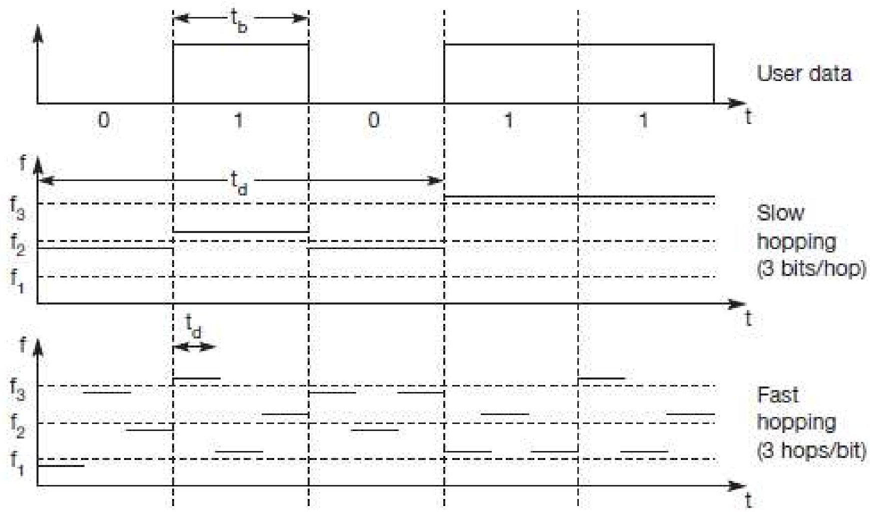


Figure 2.38 Slow and Fast Frequency Hopping

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

Slow Hopping

- **In slow hopping, the transmitter uses one frequency for several bit periods.**
- Figure 2.38 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.
- **Slow frequency hopping is an option for GSM**

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

Fast Hopping

- For **fast hopping systems, the transmitter changes the frequency several** times during the transmission of a single bit. In the example of Figure 2.38, **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.
- Another example of an FHSS system is **Bluetooth, performs 1,600 hops per second and uses 79 hop carriers equally spaced with 1 MHz in the 2.4 GHz ISM band.**

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

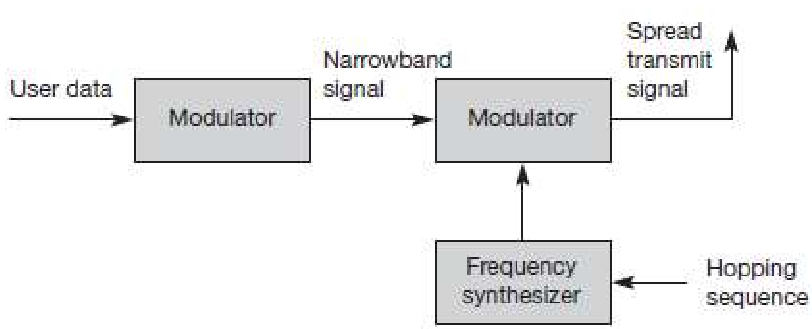


Figure 2.39 FHSS Transmitter

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

- **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 fi at the same time, then these two transmissions do not interfere.
- This requires the coordination of all transmitters and their hopping sequences

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

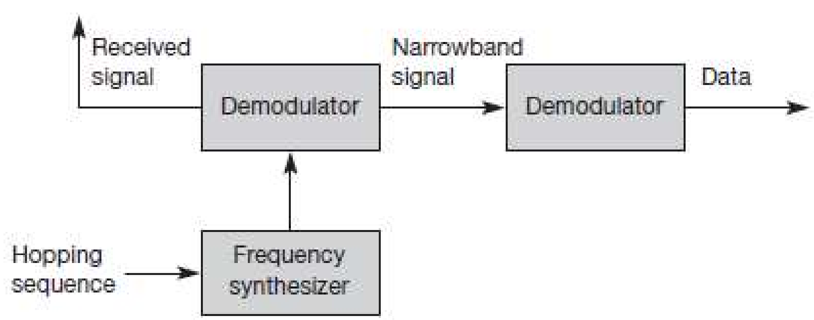


Figure 2.40 FHSS Receiver

Spread Spectrum-

Frequency Hopping Spread Spectrum (FHSS)

- 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.

Cellular Systems

Advantages of cellular systems with small cells are the following:

- Higher capacity
- Less transmission power
- Local interference only
- Robustness

Small cells also have some Disadvantages:

- Infrastructure needed
- Handover needed
- Frequency planning

Cellular Systems

- Cellular systems for mobile communications implement SDM.
- Each transmitter, typically called a **base station, covers a certain area, a cell.**
- **Cell radii can vary from tens of meters in buildings**, and **hundreds of meters in cities**, **up to tens of kilometers in the countryside**.
- **The shape of cells are never perfect circles or hexagons, but depend on the environment (buildings, mountains, valleys etc.), on weather conditions, and sometimes even on system load.**
- **To avoid interference, different transmitters within each other's interference range use FDM. If FDM is combined with TDM the hopping pattern has to be coordinated.**
- **The general goal is never to use the same frequency at the same time within the interference range**

Cellular Systems

Frequency Management and Channel Assignment

CELLULAR MODELS

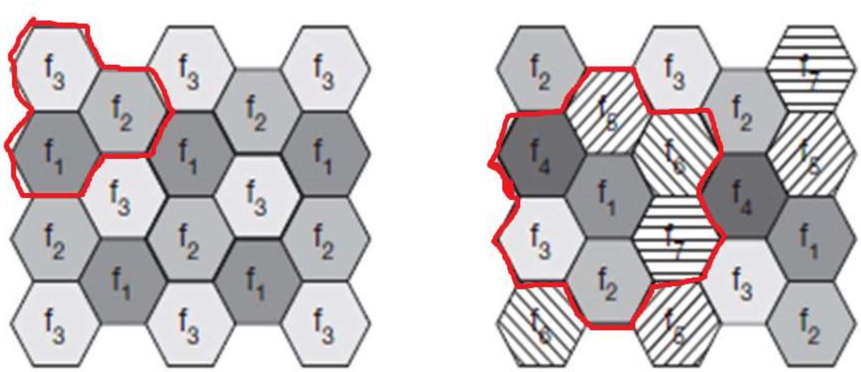


Figure 2.41 : Cellular system with three and seven cell clusters

Cellular Systems

Frequency Management and Channel Assignment

CELLULAR MODELS

- Two possible models to create cell patterns with minimal interference are shown in Figure 2.41.
- Cells are combined in **clusters – on the left side three cells form a cluster**, on the right side **seven cells form a cluster**.
- **All cells within a cluster use disjointed sets of frequencies.**
- On the left side, one cell in the cluster uses set f_1, another cell f_2, and the third cell f_3.
- In real-life transmission, the pattern will look somewhat different.
- **The hexagonal pattern is chosen** as a simple way of illustrating the model. This pattern also shows the repetition of the same frequency sets.
- The transmission power of a sender has to be limited to avoid interference with the next cell using the same frequencies.

Cellular Systems

Frequency Management and Channel Assignment

- **To reduce interference** even further (and under certain traffic conditions, i.e., number of users per km) **sectorized antennas can be used.**
- **Figure 2.42** shows the **use of three sectors per cell in a cluster with three cells.** Typically, it makes sense to use sectorized antennas instead of omni-directional antennas for larger cell radii.

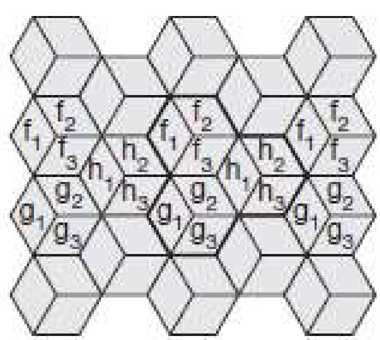


Figure 2.42 Cellular system with three cell clusters and three sectors per cell

Cellular Systems

Frequency Management and Channel Assignment

- The fixed assignment of frequencies to cell clusters and cells respectively, is not very efficient if traffic load varies. For instance, in the case of a heavy load in one cell and a light load in a neighboring cell, it could make sense to 'borrow' frequencies. Cells with more traffic are dynamically allotted more frequencies. This scheme is known as **borrowing channel allocation (BCA), while the first fixed scheme** is called **fixed channel allocation (FCA).**
- **FCA is used in the GSM system as it is** much simpler to use, but it requires careful traffic analysis before installation.
- A **dynamic channel allocation (DCA) scheme has been implemented in** DECT. In this scheme, frequencies can only be borrowed, but it is also possible to freely assign frequencies to cells.
- With dynamic assignment of frequencies to cells, the danger of interference with cells using the same frequency exists. The 'borrowed' frequency can be blocked in the surrounding cells.

Cellular Systems

Cell Breathing

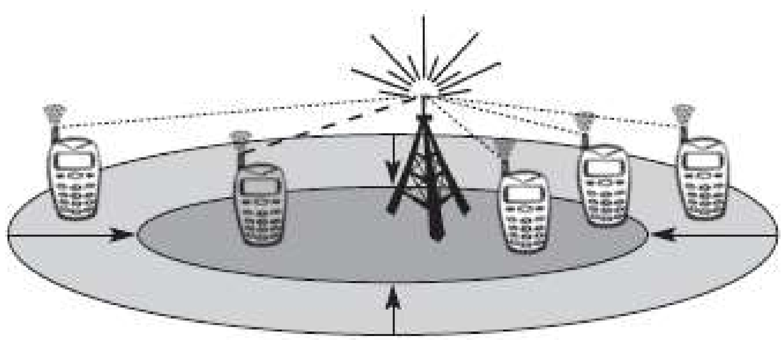


Figure 2.43 Cell breathing depending on the current load

Figure 2.43 illustrates this phenomenon with a user transmitting a high bit rate stream within a CDM cell. This additional user lets the cell shrink with the result that two users drop out of the cell.

Cellular Systems

Cell Breathing

- **Cellular systems using CDM instead of FDM** do not need such elaborate channel allocation schemes and complex frequency planning.
- **Here, users are separated through the code they use, not through the frequency.**
- Cell planning faces another problem – the cell size depends on the current load.
- Accordingly, **CDM cells are commonly said to 'breathe'. While a cell can cover a larger area under a light load, it shrinks if the load increases.** The reason for this is the **growing noise level if more users are in a cell.**
- The higher the noise, the higher the path loss and the higher the transmission errors.
- **Finally, mobile stations further away from the base station drop out of the cell.**

Cellular Systems

Types of Hand-off and their Characteristics

- In cellular telecommunications, the terms **handover or handoff** refers to the **process of transferring an ongoing call or data connectivity from one Base Station to another Base Station.**
- When a mobile moves into a different cell while the conversation is in progress then the MSC (Mobile Switching Center) transfers the call to a new channel belonging to the new Base Station.
- When a mobile user A moves from one cell to another cell then BSC 1 signal strength loses for the mobile User A and the signal strength of BSC 2 increases and thus ongoing calls or data connectivity for mobile users goes on without interrupting.

Cellular Systems

Types of Hand-off and their Characteristics

Types of Handoff

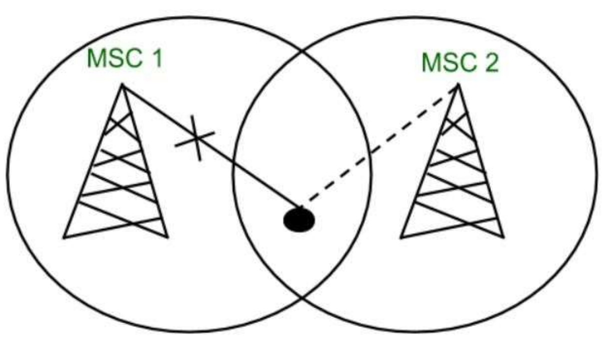
- **Hard Handoff**
- **Soft Handoff**
- **Delayed Handoff**
- **Mobile-Assisted Handoff**

Cellular Systems

Types of Hand-off and their Characteristics

Hard Handoff

- When there is an actual break in the connectivity while switching from one Base Station to another Base Station. There is no burden on the Base Station and MSC because the switching takes place so quickly that it can hardly be noticed by the users.

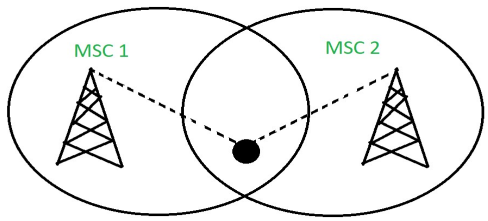


Cellular Systems

Types of Hand-off and their Characteristics

Soft Handoff

- Soft Handoff is a mechanism in which the device gets connected with two or more base stations at the same time. At least one of the links is kept when radio signals are added or removed to the Base Station. Soft Handoff adopted the 'make before break' policy. If a channel is in power loss then another channel will always be on standby mode so this makes it best in terms of quality as compared to Hard handoff. Soft handoffs are used in devices supporting CDMA/WDMA networks



Cellular Systems

Types of Hand-off and their Characteristics

Delayed Handoff

- Delayed handoff occurs when no base station is available for accepting the transfer. The call continues until the signal strength reaches a threshold, and after that, the call is dropped. Generally, it happens when the user is out of the network coverage area, or at some dead spots where network reach is very low.

Mobile-Assisted Handoff

- Mobile-Assisted handoff is generally used when a mobile phone helps a base station to transfer the call to another base station with better-improvised connectivity and more signal strength. This handoff is used in TDMA technique-based GSM devices.

MEDIUM ACCES CONTROL(MAC)

MEDIUM ACCES CONTROL(MAC)

- MAC – Motivation
- SDMA
- FDMA
- TDMA
- CDMA
- Comparison

MAC

- Medium Access Control(MAC) comprises all mechanisms **that regulate user access to a medium using SDM, TDM, FDM, or CDM.**
- MAC is thus **similar to traffic regulations** in the highway/multiplexing.
- The fact that several vehicles use the same street crossing in TDM, for example**, requires rules to avoid collisions**; one mechanism to enforce these rules is traffic lights.
- **MAC belongs to layer 2**, the **data link control layer (DLC). Layer 2 is subdivided into the logical link control (LLC),** layer 2b, and the MAC, layer 2a.
- The task of DLC is **to establish a reliable point to point or point to multi-point connection between different devices over a wired or wireless medium**.

Motivation

- Let us consider **carrier sense multiple access with collision detection, (CSMA/CD) which works as follows.**
- **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.**
- In case of Wireless networks, **the sender may now apply carrier sense and detect an idle medium.** The sender starts sending – but a collision happens at the receiver due to a second sender at **hidden terminal.**

Motivation

- The same can happen to the collision detection.
- The sender detects no collision and assumes that the data has been transmitted without errors, but a **collision might actually have destroyed the data at the receiver.**
- **Collision detection** is very difficult in wireless scenarios as the transmission power in the area of the transmitting antenna is several magnitudes higher than the receiving power.
- So, this very common MAC scheme from wired network fails in a wireless scenario.

Motivation- Hidden and exposed terminals

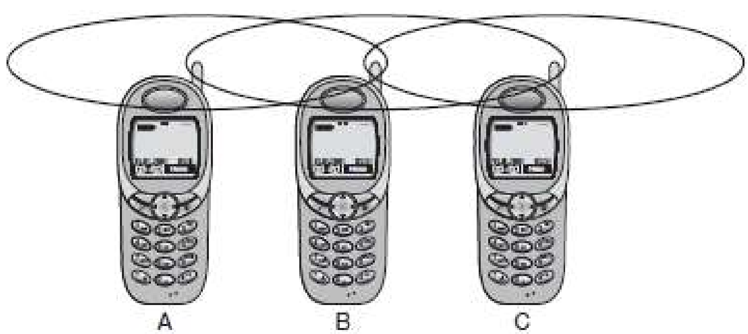


Figure 3.1 Hidden and Exposed Terminals

Motivation- Hidden and Exposed Terminals

- Consider the scenario with three mobile phones as shown in Figure 3.1.
- 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.
- **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.

Motivation- Hidden and Exposed Terminals

- While hidden terminals may cause collisions, the next effect only causes unnecessary delay.
- Now consider the situation that **B sends something to A** and **C wants to transmit data to some other mobile phone outside the interference ranges of A and B.**
- **C senses the carrier and detects that the carrier is busy (B's signal). C postpones its transmission until it detects the medium as being idle again.**
- **But as A is outside the interference range of C, waiting is not necessary.**
- **Causing a 'collision' at B does not matter because the collision is too weak to propagate to A.** In this situation, **C is exposed to B.**

Motivation-Near and Far terminals

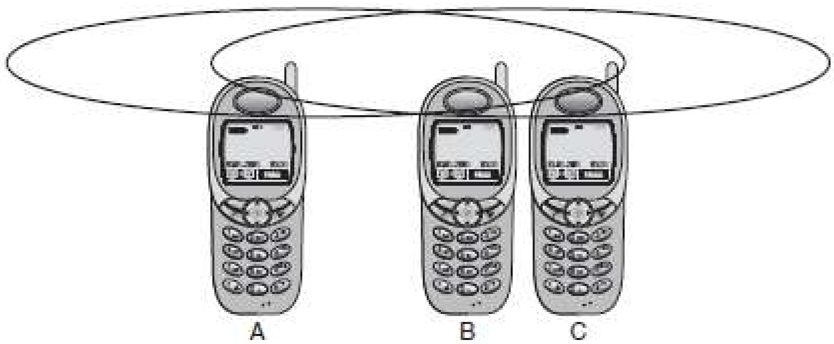


Figure 3.2 Near and Far terminals

Motivation- Near and Far terminals

- Consider the situation as shown in Figure 3.2.
- **A and B are both sending with the same transmission power.**
- **As the signal strength decreases proportionally to the square of the distance**, **B's signal drowns out A's signal**. **As a result, C cannot receive A's transmission.**
- Now think of C as being an arbiter for sending rights (e.g., C acts as a base station coordinating media access). In this case, terminal B would already drown out terminal A on the physical layer.
- C in return would have no chance of applying a fair scheme as it would only hear B.
- 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.
- Otherwise a person standing closer to somebody could always speak louder than a person further away.

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 (depending on the technology).
- Typically, **SDMA is never used in isolation** but always in combination with one or more other schemes.
- The basis for the **SDMA algorithm is formed by cells and sectorized antennas which constitute the infrastructure implementing space division multiplexing (SDM).**

FDMA

- **Frequency division multiple access (FDMA) comprises all algorithms allocating frequencies to transmission channels according to** the **frequency division multiplexing (FDM) scheme.**
- Allocation can either be **fixed or dynamic.**
- **Channels can be assigned to the same frequency at all times**, i.e., pure FDMA, or **change frequencies according to a certain pattern, i.e., FDMA combined with TDMA.**
- Furthermore, **FDM is often used for simultaneous access to the medium by base station and mobile station in cellular networks**. Here the two partners typically establish a **duplex channel, i.e., a channel that allows for simultaneous** transmission in both directions.
- The two directions, mobile station to base station and vice versa are now separated using different frequencies. This scheme is then called **frequency division duplex (FDD).**

FDMA

- Again, both partners have to know the frequencies in advance; they cannot just listen into the medium.
- 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.

FDMA

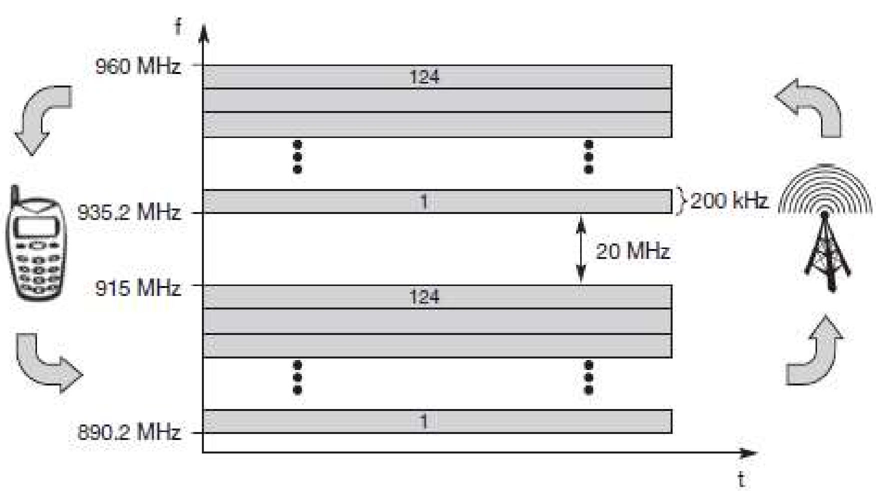


Figure 3.3 Frequency division multiplexing for multiple access and duplex

FDMA

- 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 fu = 890 MHz + n·0.2 MHz, the downlink frequency is fd = fu + 45 MHz, i.e., fd = 935 MHz + n·0.2 MHz for **a certain channel,n**.
- The base station selects the channel. **Each channel (uplink and downlink) has a bandwidth of 200 kHz.**
- This illustrates the use of FDM for multiple access (**124 channels per direction are available at 900 MHz**) and duplex according to a predetermined scheme.

TDMA

- 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**, i.e., controlling **TDM.**
- Now **tuning in to a certain frequency is not necessary, i.e., the receiver can stay at the same frequency the whole time.**
- **Using only one frequency, and thus very simple receivers and transmitters, many different algorithms exist to control medium access.**
- **Almost all MAC schemes for wired networks work according to this principle**, e.g., **Ethernet, Token Ring, ATM etc.**

TDMA

- **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**.
- **Dynamic allocation schemes** require an identification for each transmission as this is the case for typical wired MAC schemes (e.g., **sender address**) or the transmission has to be announced beforehand.
- **MAC addresses are quite often used as identification.** This enables a receiver in a broadcast medium to recognize if it really is the intended receiver of a message.
- **Fixed schemes do not need an identification, but are not as flexible considering varying bandwidth requirements.**

TDMA

- **Fixed TDM**
- **Classical Aloha**
- **Slotted Aloha**
- **Carrier sense multiple access**
- **Demand assigned multiple access**
- **PRMA packet reservation multiple access**
- **Reservation TDMA**
- **Multiple access with collision avoidance**
- **Polling**
- **Inhibit sense multiple access**

TDMA- 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.
- Fixed access patterns (at least fixed for some period in time) fit perfectly well for connections with a fixed bandwidth. Furthermore, these patterns guarantee a fixed delay – **one can transmit, e.g., every 10 ms as this is the case for standard DECT systems.**
- TDMA schemes with fixed access patterns are used for many digital mobile phone systems like IS-54, IS-136, GSM, DECT, PHS, and PACS.

TDMA- Fixed TDM

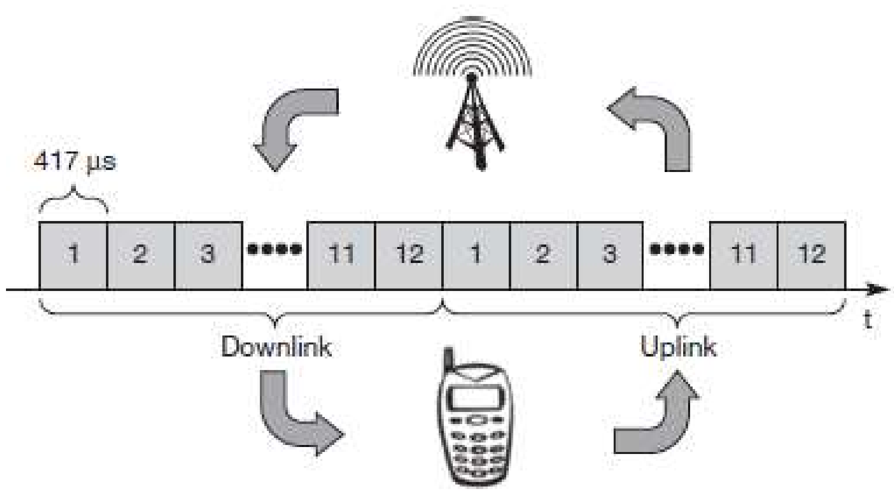


Figure 3.4 Time division multiplexing for multiple access and duplex

TDMA- Fixed TDM

- Figure 3.4 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.
- In the example below, which is the standard case for the DECT cordless phone system, **the pattern is repeated every 10 ms, i.e., each slot has a duration of 417 μs.** *This repetition guarantees access to the medium every* 10 ms, independent of any other connections.

TDMA- Classical Aloha

- As mentioned above, TDMA comprises all mechanisms controlling medium access according to TDM. **But what happens if TDM is applied without controlling access?**
- This is exactly what the classical Aloha scheme does, a scheme which was invented at the of several stations.
- Aloha neither **University of Hawaii and was used in the ALOHANET for wireless connection** coordinates medium access nor does it resolve contention on the MAC layer.
- Instead, each station can access the medium at any time as shown in Figure 3.5.
- **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).

TDMA- Classical Aloha

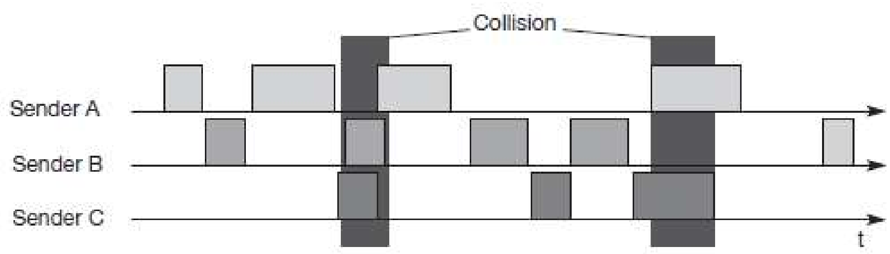


Figure 3.5 Classical Aloha multiple access

TDMA- Slotted Aloha

- The first refinement of the classical Aloha scheme is provided by the introduction of time slots (**slotted Aloha).**
- **In this case, all senders have to be synchronized, transmission can only start at the beginning of a time slot as** shown in Figure 3.6.
- Still, access is not coordinated. Under the assumption stated above, the introduction of slots raises the throughput from 18 per cent to 36 per cent, i.e., slotting doubles the throughput.

TDMA- Slotted Aloha

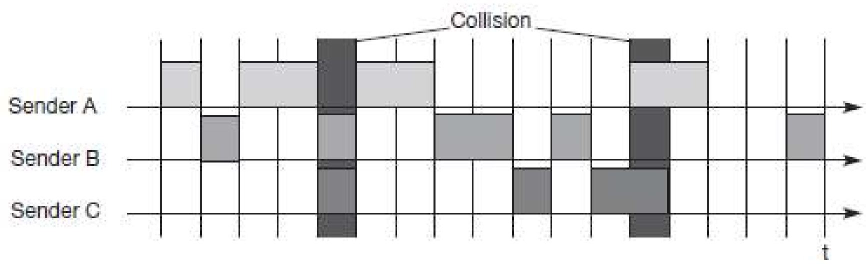


Figure 3.6 Slotted Aloha multiple access

TDMA- Carrier sense multiple access

- 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

TDMA- Carrier Sense Multiple Access

- Several versions of CSMA exist.
- In **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.
- In **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.
- In **1-persistent CSMA systems, all stations wishing to transmit access the medium at the** same time, as soon as it becomes idle. This will cause many collisions if many stations wish to send and block each other. To create some fairness for stations waiting for a longer time, back-off algorithms can be introduced, which are sensitive to waiting time as this is done for standard Ethernet (Halsall, 1996).

TDMA- Carrier Sense Multiple Access

- 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.
- Another, very elaborate scheme **is elimination yield – non-preemptive multiple access (EY-NMPA) used in the** HIPERLAN 1 specification. Here several phases of sensing the medium and accessing the medium for contention resolution are interleaved before one “winner” can finally access the medium for data transmission. Here, priority schemes can be included to assure preference of certain stations with more important data.

TDMA- Demand assigned multiple access

- A general improvement of Aloha access systems can also be achieved by **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.
- Alternatively, the transmission period can be split into periods with and without collision.
- In general, these schemes cause a higher delay under a light load (first the reservation has to take place), but allow higher throughput due to less collisions.

TDMA- Demand assigned multiple access

- One basic scheme is **demand assigned multiple access (DAMA) also called reservation Aloha, a scheme typical for satellite systems. DAMA, as shown in** Figure 3.7 has two modes.
- During a **contention phase** following the **slotted Aloha scheme**, all stations can try to reserve future slots. For example, different stations on earth try to reserve access time for satellite transmission.
- 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.

TDMA- Demand assigned multiple access

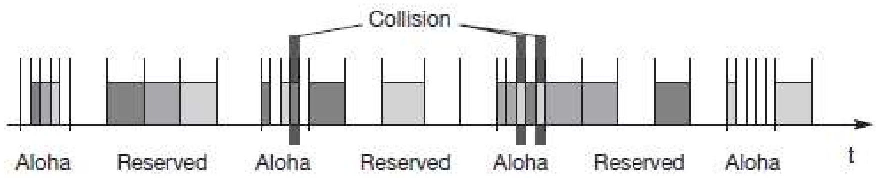


Figure 3.7 Demand assignment multiple access with explicit reservation

TDMA- PRMA(Packet Reservation Multiple Access)

- An example for an implicit reservation scheme is **packet reservation multiple access (PRMA).**
- Here, slots can be reserved implicitly according to the following scheme. **A certain number of slots forms a frame (Figure 3.8 shows eight slots in a frame).**
- The frame is repeated in time (forming frames one to five in the example), i.e., a fixed TDM pattern is applied.

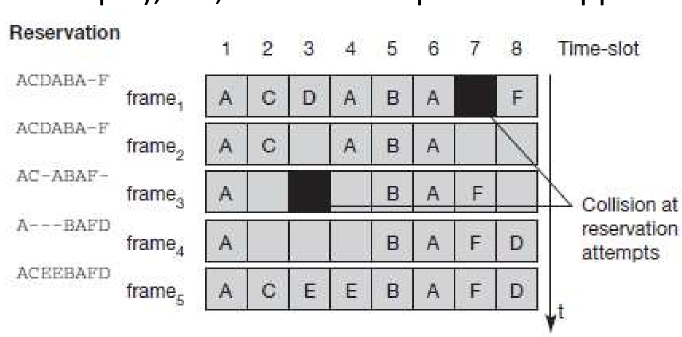


Figure 3.8 Demand assignment multiple access with implicit reservation

TDMA- Reservation TDMA

- An even more fixed pattern that still allows some random access is exhibited by **reservation TDMA (see Figure 3.9).**
- **In a fixed TDM scheme N mini-slots followed by N·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.

TDMA- Reservation TDMA

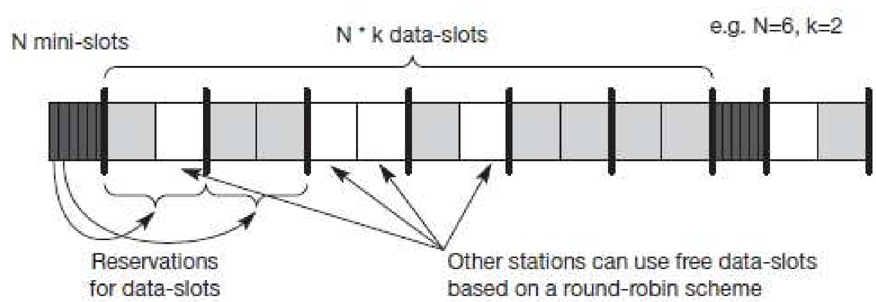


Figure 3.9 Reservation TDMA access scheme

TDMA- Multiple access with collision avoidance

- **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.
- Figure 3.10 shows the same scenario as Figure 3.1 with the hidden terminals.
- Remember, A and C both want to send to B. A has already started the transmission, but is hidden for C, C also starts with its transmission, thereby causing a collision at B.

TDMA- Multiple access with collision avoidance

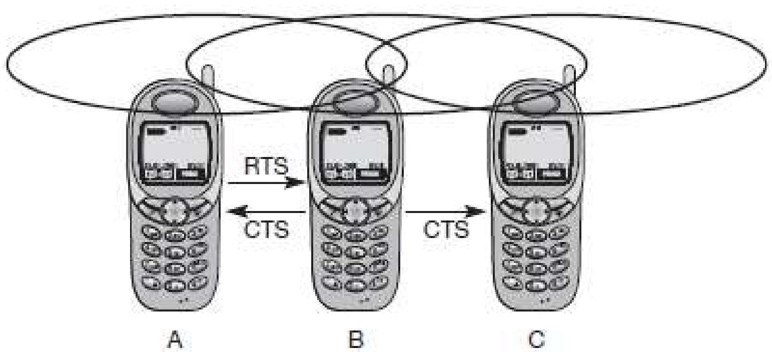


Figure 3.10 MACA can avoid hidden terminals

TDMA- Multiple access with collision avoidance

- 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 – provided that the transmission conditions remain the same.

TDMA- Multiple access with collision avoidance

- Still, collisions can occur during the sending of an RTS.
- Both A and C could send an RTS that collides at B.
- RTS is very small compared to the data transmission, so the probability of a collision is much lower.
- B resolves this contention and acknowledges only one station in the CTS (if it was able to recover the RTS at all).
- No transmission is allowed without an appropriate CTS.
- This is one of the medium access schemes that is optionally **used in the standard IEEE 802.11**

TDMA- Multiple access with collision avoidance

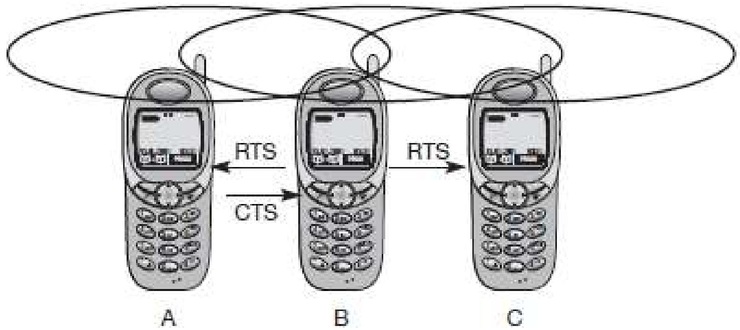


Figure 3.11 MACA can avoid exposed terminals

TDMA- Multiple access with collision avoidance

- Remember, **B wants to send data to A**, **C to someone else.** But C is polite enough to sense the medium before transmitting, sensing a busy medium caused by the transmission from B. C defers, although C could never cause a collision at A.
- With MACA, **B has to transmit an RTS first** (as shown in Figure 3.11) 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. One problem of MACA is clearly the overheads associated with the RTS and CTS transmissions – for short and time-critical data packets, this is not negligible.
- MACA also assumes symmetrical transmission and reception conditions. Otherwise, a strong sender, directed antennas etc. could counteract the above scheme.

TDMA- Multiple access with collision avoidance

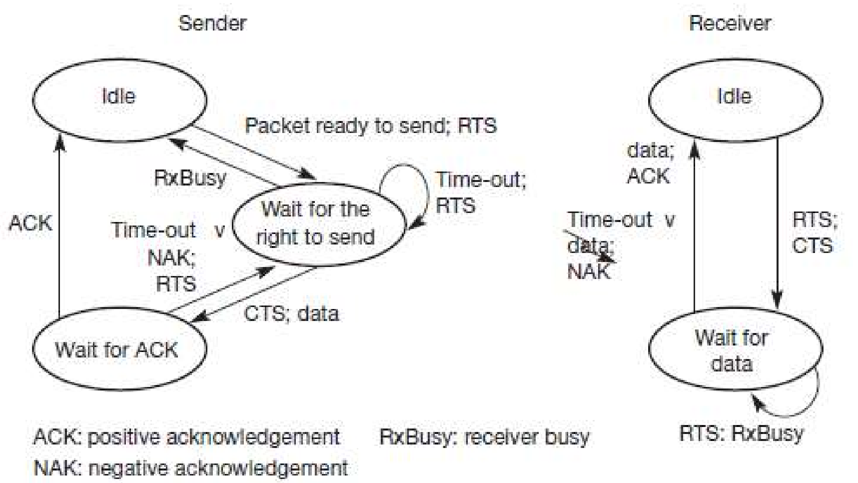


Figure 3.12 Protocol machines for multiple access with collision avoidance

TDMA- Multiple access with collision avoidance

- Figure 3.12 shows **simplified state machines** for a sender and receiver.
- The sender is idle until a user requests the transmission of a data packet.
- The sender then issues an RTS and waits for the right to send.
- **If the receiver gets an RTS and is in an idle state, it sends back a CTS and waits for data.**
- The sender receives the CTS and sends the data.
- **Otherwise, the sender would send an RTS again after a time-out** (e.g., the RTS could be lost or collided).
- After transmission of the data, the sender waits for a positive acknowledgement to return into an idle state.
- The receiver sends back a positive acknowledgement if the received data was correct. If not, or if the waiting time for data is too long, the receiver returns into idle state.
- If the sender does not receive any acknowledgement or a negative acknowledgement, it sends an RTS and again waits for the right to send.
- Alternatively, a receiver could indicate that it is currently busy via a separate RxBusy.
- Real implementations have to add more states and transitions, e.g., to limit the number of retries.

TDMA- Polling

- **Where one station is to be heard by all others** (e.g., the base station of a mobile phone network or any other dedicated station), **polling schemes (known from** the mainframe/terminal world) can be applied.
- 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.**
- Similar schemes are used, e.g., in the Bluetooth wireless LAN and as one possible access function in IEEE 802.11 systems

TDMA- Inhibit sense multiple access

- Another combination of different schemes is represented by **inhibit sense multiple access (ISMA).**
- **This scheme, which is used for the packet data transmission service** Cellular Digital Packet Data (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 (see Figure 3.13).
- **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.** (Salkintzis, 1999)

TDMA- Inhibit sense multiple access

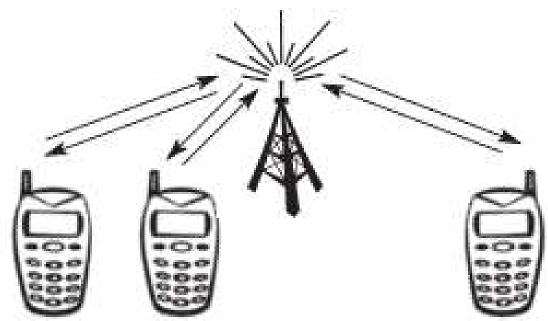


Figure 3.13 Inhibit sense multiple access using a busy tone

CDMA

- Finally, **codes with certain characteristics can be applied to the transmission to enable the use of code division multiplexing (CDM).**
- **Code division multiple access (CDMA) systems use exactly these codes to separate different users in** code space and **to enable access to a shared medium without interference.**
- **The main problem is how to find "good" codes and how to separate the signal from noise generated by other signals and the environment.**
- A code for a certain user should have a good auto correlation and should be orthogonal to other codes.
- **Orthogonal in code space has the same meaning as in standard space (i.e., the three dimensional space).**

CDMA-Spread Aloha Multiple Access

- Spread Aloha Multiple access (SAMA) is a **combination of CDMA and TDMA.**
- SAMA works as follows: **each sender uses the same spreading code** (in the example shown in Figure 3.19 this is the code 110101).
- The standard case for Aloha access is shown in the upper part of the figure.
- Sender A and sender B access the medium at the same time in their narrowband spectrum, so that all three bits shown cause a collision.

CDMA-Spread Aloha Multiple Access(SAMA)

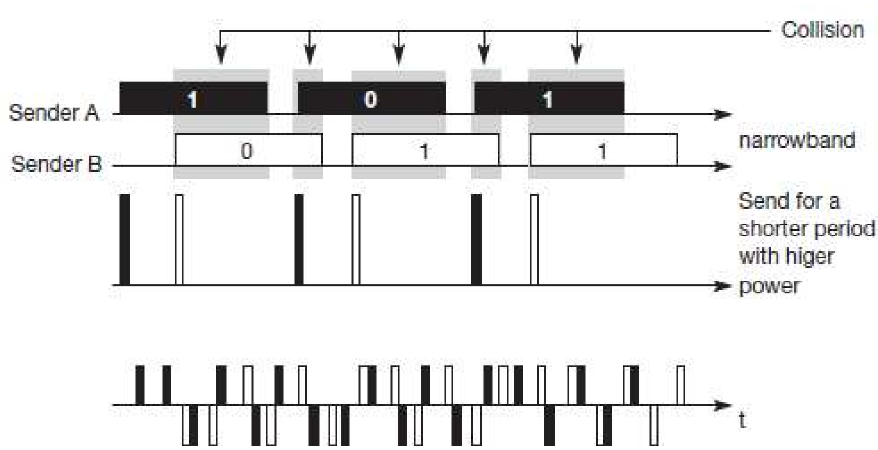


Figure 3.19 Spread Aloha multiple access(SAMA)

CDMA-Spread Aloha Multiple Access(SAMA)

- The same data could also be sent with higher power for a shorter period as shown in the middle, but now spread spectrum is used to spread the shorter signals, i.e., to increase the bandwidth (spreading factor s = 6 in the example).
- Both signals are spread, but the chipping phase differs slightly. Separation of the two signals is still possible if one receiver is synchronized to sender A and another one to sender B.
- The signal of an unsynchronized sender appears as noise.
- The probability of a 'collision' is quite low if the number of simultaneous transmitters stays below 0.1–0.2s (Abramson, 1996). This also depends on the noise level of the environment.

CDMA-Spread Aloha Multiple Access(SAMA)

- The **main problem** in using this approach is finding good chipping sequences.
- Clearly, the code is not orthogonal to itself – it should have a good autocorrelation but, at the same time, correlation should be low if the phase differs slightly.
- The maximum throughput is about 18 per cent, which is very similar to Aloha.
- **benefits** from the advantages of spread spectrum techniques: robustness against narrowband interference and simple coexistence with other systems in the same frequency bands.

Comparison of SDMA, TDMA, FDMA, and CDMA Mechanisms

Approach	SDMA	TDMA	FDMA	CDMA
Idea	Segment space into cells/sectors	Segment sending time into disjoint time-slots, demand driven or fixed patterns	Segment the frequency band into disjoint sub-bands	Spread the spectrum using orthogonal codes
Terminals	Only one terminal can be active in one cell/one sector	All terminals are active for short periods of time on the same frequency	Every terminal has its own frequency, uninterrupted	All terminals can be active at the same place at the same moment, uninterrupted
Signal separation	Cell structure directed antennas	Synchronization in the time domain	Filtering in the frequency domain	Code plus special receivers
Advantages	Very simple, increases capacity per km^2	Established, fully digital, very flexible	Simple, established, robust	Flexible, less planning needed, soft handover

Comparison of SDMA, TDMA, FDMA, and CDMA Mechanisms

Approach	SDMA	TDMA	FDMA	CDMA
Disadvantages	Inflexible, antennas typically fixed	Guard space needed (multi-path propagation), synchronization difficult	Inflexible, frequencies are a scarce resource	Complex receivers, needs more complicated power control for senders
Comment	Only in combination with TDMA, FDMA or CDMA useful	Standard in fixed networks, together with FDMA/SDMA used in many mobile networks	Typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	Used in many 3G systems, higher complexity, lowered expectations; integrated with TDMA/FDMA

REVIEW

- **Introduction:** Applications, Short History of Wireless Communications, Simplified Reference Model**.**
- **Wireless Transmission:** Frequencies, Signals, Signal Propagation, Multiplexing, Modulation, Spread Spectrum, and Cellular Systems.
- **Medium Access Control:** Motivation for a Specialized MAC, SDMA, FDMA, TDMA, CDMA, and Comparison.

UNIT-1 ENDS

THANK YOU