Wireless Communications

Wireless communications refers to any communication system where a radio link connects the transmitter to the receiver. Thus wireless links can be fixed or mobile, terrestrial or satellite.

Fixed links: Refer to communication systems where the transmitter and receiver are stationary (fixed). For example:

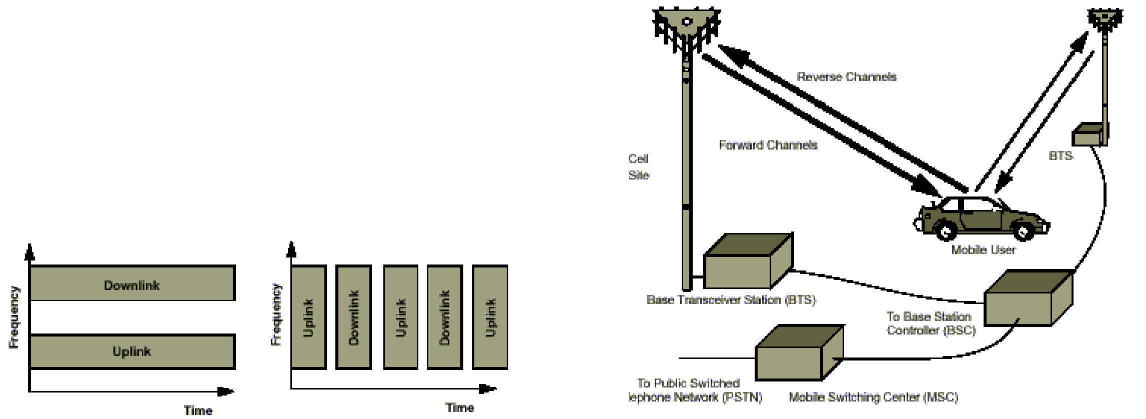
- Communication between fixed earth stations and geo-stationary satellites.
- Microwave links for broadband data, video and high speed internet access for fixed users.
- Home Television, repeater links, base station to base station, campus or neighbourhood area to stationary users.

Mobile links: Refer to communication systems where either the transmitter or receiver can move regardless of whether it is in motion or not. For example:

- Paging systems
- Wireless telephony
- Trunking systems
- Cellular telephony
- Satellite personal communications systems
- Wireless access to local area networks.

Communication can be one way only, known as *Simplex* or two-way communication known as *Duplex*. For example, in paging, where a signal is sent from the network to the user and received as a beep or a message is an example of a Simplex operation, whereas telephony provides two way communications. In order to enable duplex operation, the two links established between the user and the network need to use either different frequencies (frequency division duplex, FDD) or the same frequency but different time (time division duplex, TDD).

In wireless communication systems, the radio link from the network transmitter (known as the base station) to the user unit is called the *forward* link or *downlink*. The link in which the user unit is the transmitter and the base station is the receiver is called the *reverse* link or *uplink*. Figure 1 shows the concept of FDD and TDD in a duplex radio system.



FDD TDD Duplex communication (mobile and network).

(a) (b)

Figure 1. (a) Frequency versus time in FDD and TDD in duplex systems and (b) uplink/downlink in duplex operation

Multiple Access Techniques

A fundamental result from communications theory is that the signals from multiple users may share a transmission medium if their signals can be made orthogonal. This is usually achieved by separating them either in time or in frequency.

Note that Multiple access differs from the usual definition of multiplexing (such as frequency division multiplexing FDM or time division multiplexing TDM) in that the allocation of the particular resource to the user is made when the network is accessed and not on a permanent basis. For example in frequency division multiple access, the user can access the network using any one of the frequency bands allocated for the service in that area. The frequency band is allocated when the user requests access to the network. In a multiplexed system, user requirements are ordinarily fixed and the users are confined to a local site e.g. a fixed line telephone channel. Also, multiplexing can refer to one user sending data on more than one frequency, time, or antenna.

Multiple access techniques in mobile radio systems include:

1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)
4. Space division multiple access (SDMA)
5. Any combination of 1-4 above.

1. In FDMA, the available mobile bandwidth is divided into portions of non-overlapping frequency slots, which are assigned exclusively to individual users i.e. *single channel per user*. Examples of this technique are the analogue systems employed in the 1980's which include the American analogue system known as the Advanced Mobile Phone System (AMPS) cellular mobile systems, the Total Access Communications System (TACS) in Europe, and the Japanese TACS System (JTACS) in Japan.

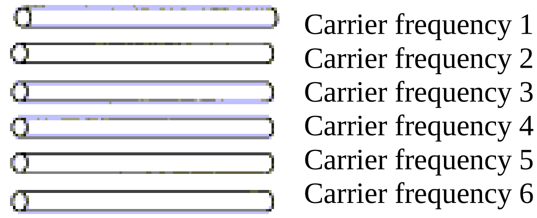
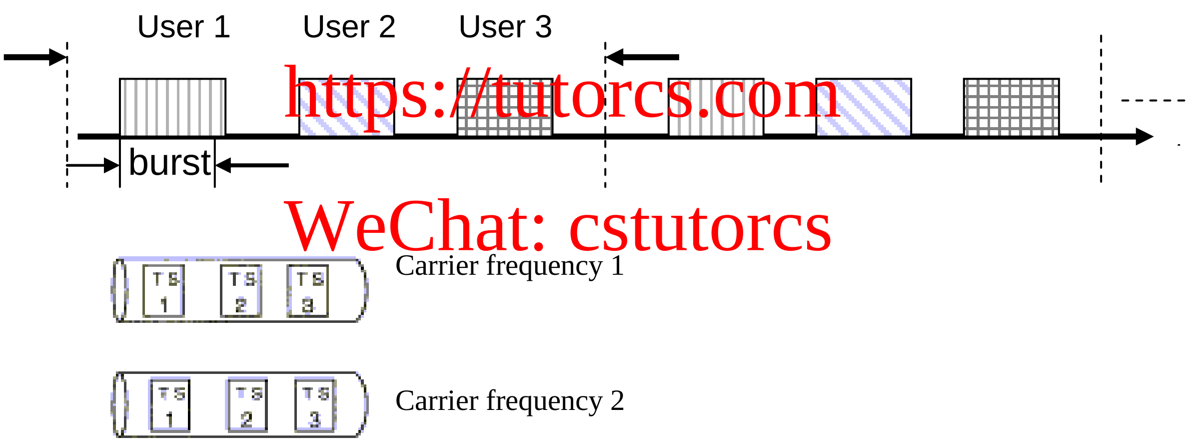


Figure 2. Frequency division multiple access

2. In TDMA, the transmission time is divided into portions of non-overlapping time slots, each assigned to each user in which they transmit. They have exclusive use of the entire bandwidth and communicate with each other by means of bursts of signals. These time slots are grouped into a periodic structure called frame. This enables a number of users to transmit over the same frequency band i.e. *multiple channels per carrier*. The users each transmit at a very high data rate during the brief time slot. For instance, if there are N time slots, each of which is T_s seconds long, then each user, producing data at some data rate R_d, must store data for NT_s seconds and transmit at a data rate NR_d during the T_s second time slot.



Time division multiple access

High data rate users may be accommodated by assigning more than one time slot to a user. For instance, if M time slots are assigned to a user, then they can produce data at a rate MR_d bits per second at the expense of allowing fewer users on the system.

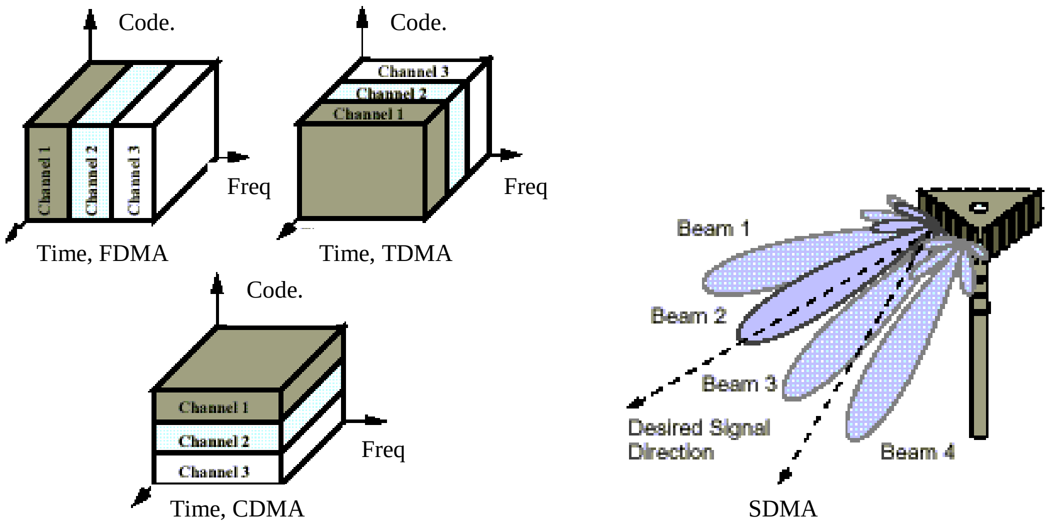
Examples of TDMA cellular systems are the Global System for Mobile Communications (GSM), Digital-AMPS (IS-136), the Personal Access Communications System (PACS), and the Personal Handyphone System (PHS).

3. CDMA: Code Division Multiple Access is a new wireless technology that allows multiple radio subscribers to share the same frequency band at the same time by assigning each user a unique code. The technology makes very efficient use of limited

spectral resources (multiple users per channel) and allows robust communication over time-varying radio channels. The bandwidth of the transmitted signal is much larger than the bandwidth of the data sequence, hence spread spectrum. Examples of these are the American IS-95, and third generation systems of W-CDMA and IMT 2000. Such systems suffer from the near far problem: this arises because mobile users near the base station will be received at a higher level than mobiles farther away. Hence, for CDMA systems to work successfully there is a need to use power control. Power control typically reduces the power transmitted by subscribers closest to the base station, while increasing the power of subscribers farthest away from the base station. There are two types of power control: open loop and closed loop. In open loop the mobile station adjusts its transmitted power depending on the received signal strength. In closed loop the base station monitors the received signal strength from the mobile and sends control words instructing the mobile to adjust its power. Closed loop power control is used in frequency division duplex (FDD) systems since due to the difference in frequency the signal strength received on one frequency band might be different from the other. Hence, when the mobile adjusts its own power it is using information based on the signal strength of the received carrier and not the transmitted carrier. Open loop control, however, has a smaller delay than the closed loop power control since it does not have to wait for feedback from the base station. This is particularly important over long links such as in satellite communications. In contrast, closed loop control can be operated on the signal to interference ratio instead of just the signal level and can instruct the mobile to increase its power to be received above the interference level if needed. However, this can suffer from positive feedback. When one mobile is instructed to raise its power level to combat interference from other users, this increases the interference from that mobile to the other users who in turn will be instructed to raise their own transmitted power. To overcome this problem, both signal strength and signal to interference estimates are used to control the power.

Power control can also be used in the downlink for example to enhance the signal level received by a mobile at the edge of the cell or to reduce interference to other cell users.

4. SDMA: this technology is being researched in particular for the mm wave band and it uses smart antennas to distinguish users in space by directing the antenna beam pattern to particular users.



Multiple access schemes: (a) FDMA, (b) TDMA, (c) CDMA, SDMA

Modulation schemes

The first mobile radio systems used analog services, which were widely deployed in the mid-1980s. The analog modulation scheme constrained capacity (number of users). To overcome the limitations of these analog systems, second generation systems, were developed using digital modulation. Digital systems offer many advantages over analog systems, including the ability to reliably recreate a virtually noise-free copy of the transmitted signal at the receiver provided that only a limited number of errors are made in receiving the digital signal. Advanced transmission and signal processing techniques can also be used with digital signals to combat the effects of noise and multipath encountered in mobile environments. Digital technologies also enable discontinuous transmission because users do not talk 100% of the time in both directions. These two features combine to provide higher capacity, better voice quality, and much longer battery life than was possible in analog systems. Second generation systems also incorporate integrated data transmission capabilities. Third generation systems add a range of broadband data capabilities and use spread spectrum modulation.

Mobile radio systems

Paging Systems:

- The ITU-R Recommendation No. 539 and 584 define a paging system as a unidirectional broadcasting radio system (*simplex*), which is used to transmit alerting signals (a beep), a short numeric message (usually a telephone number), or an alphanumeric message (e.g. stock market bulletins), excluding voice messages. Some pagers send short voice messages, which are converted to digital signals and transmitted at a low rate. For example the European paging system (ERMES) has 8 different alerting tones, a maximum length of 16000 digit numeric message and a maximum of 9000 alphanumeric characters.

Classical paging systems have the following properties:

- They use a narrowband in the frequency range of a few hundred MHz or the VHF band (30-300 MHz) in the radio broadcasting range.
- Small size of mobile receivers
- Lack of confirmation that the message has been received (recent systems permit acknowledgement message)

In a paging system all receivers listen to the broadcast signals, detecting only the message addressed to them. The message is sent to a call center either by the sender directly calling the center or via a modem link or the internet.

Paging networks can be private or public.

- Private networks are installed and operated within an institution or a company and their coverage is restricted to the area of the company. These usually consist of a call center, a base station and pagers (mobile users).
- Public networks are used by private users and can be either local networks, limited to one city or its vicinity or national networks operating in the whole country.

There are several protocols used in paging systems, such as the ITU protocol known as POCSAG (Post Office Code Synchronisation Advisory Group) protocol. Another is the Swedish Search protocol, which sends the paging message using existing FM radio by adding the paging signal at 57 kHz above the spectrum of the stereo signal. At the receiver, the pager extracts the paging signal by filtering it, converts it to baseband and detects the binary stream containing the message.

Wireless Telephony

Wireless telephony refers to the cordless telephone used in the home or in the work environment. The base station in this case is the part connected to the PSTN (Public Switched Telephone Network) and the mobile is the handset. First cordless telephones used analogue modulation whereas later systems use digital modulation.

For the second generation, the coverage area was expanded where for example CT-2 base stations were installed in high-density areas such as train stations or shopping malls. This service was called *Telepoint.* Users who are registered with Telepoint services could initiate a call but could not receive it. The system was not popular in the UK where it was proposed but was successful in Hong Kong and Singapore.
Another EU standard was developed called DECT (Digital Enhanced Cordless Telecommunications). This is intended mainly for indoor communication. DECT base stations are through a controller, which permits the user to move between base stations

without being disconnected. It also enables the user to be called from any base station in whose range it is located. Table 1 gives an overview of cordless telephone standards.

Feature	*CT2*	*CT2+*	*DECT*	*PHS*
Frequency Band (MHz)	864-868	944-948	1880-1900	1895-1918
Multiple Access	FDMA	F/TDMA	F/TDMA	F/TDMA
Duplexing	TDD	TDD	TDD	TDD
Carrier Spacing (kHz)	100	100	1728	300
Modulation	GFSK	GSFK	GFSK	$\pi/4$-DQPSK
Number of Carriers	40	40	10	77
Channels/Carrier	1	1	12	4
Bit Rate (kb/s)	72	72	1152	384
Speech Coding	ADPCM 32 kb/s	ADPCM 32 kb/s	ADPCM 32 kb/s	ADPCM 32 kb/s
Frame Size (ms)	2	2	10	5
Mean TX Power (mW)	5	5	10	10
Peak TX Power (mW)	10	10	250	80

Table 1 Cordless telephone standards

Trunking Systems

Trunking systems are mobile communication systems specializing in communications within an enterprise, which manage resources dispersed in space, such as a fleet of trucks or service vehicle. They are also useful for special services such as the police, emergency services, gas and power suppliers, etc. Their characteristic feature is the existence of a dispatch and control center, which manages the calls. They provide connections which are not normally available from a regular telephone network. For example, a call can be dispatched to all mobile stations or to a group of mobile stations. Trunking systems originally had a single base station and a common radio channel over which all mobile stations could listen to the signal sent to any of them. The latest system is digital and is known as TETRA which is able to transmit voice and data signals.

Personal Satellite Communication Systems

Example is the INMARSAT family of satellites, specialised in maritime communications. They provide voice or data communication at a limited quality in a very large area. The communications is either uni-directional or bi-directional. Access is difficult inside buildings. Recently a number of low to medium orbit satellite systems have been proposed including Iridium, Globalstar and intermediate circular orbit (ICO). For low orbit, the number of satellites is large and the area that is covered by each is smaller than those in higher orbits; hence providing higher capacity since the same set of frequencies can be reused. The power and the cost of each satellite are low. Also, the delay is smaller than for higher orbit satellite, which ensures a higher level of comfort. A compromise between low orbit and high orbit is the ICO system.

Wireless Access to the Local Area Networks (WLAN)

These systems provide wireless access to computer networks. For these systems, user range and mobility are very limited. Power of mobile is very low due to proximity to the base station. Several frequency bands are used in WLANs. Some systems use the ISM (Industrial Scientific and Medical) band at 2.45 GHz, others use the spectrum around 5 GHz.

WLAN systems either communicate with a base station with a master controller or *ad hoc* networks where, the mobile stations can communicate with each other.

Cellular Telephony

Land mobile radio was introduced as early as the 1920s to provide two-way communications to automobiles. In the 1970s Bell Labs invented the concept of cellular radio to provide communication to a large number of users. The first cellular system was implemented by NTT (Nipon Telephone and Telegraph) in 1979. In 1981 Ericsson Radio Systems AB fielded the Nordic Mobile Telephone (NMT) 900, and in 1983 AT&T fielded AMPS (Advanced Mobile Phone Service). These early systems known as first generation used analogue modulation, FDMA and FDD channels (see Table 2). In NMT, NTT, and AMPS, the FDD channels were separated by 45 MHz. Since these systems had a single channel per carrier they had limited capacity. Hence, these analogue systems were soon to be replaced by digital systems.

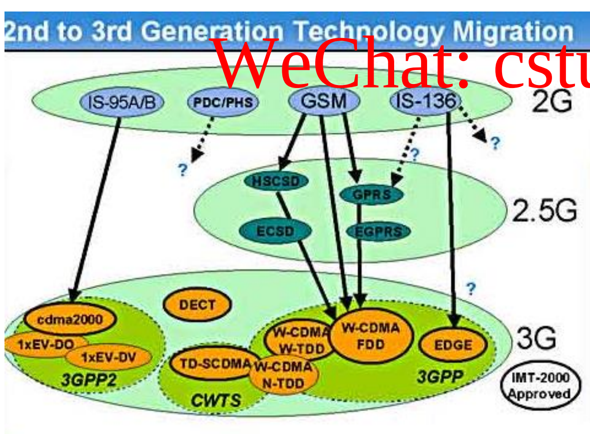
In Europe the different standards did not enable roaming (using the mobile phone between countries) and there was a need to enable data transmission. To this end the *Groupe Speciale Mobile* (GSM) was set up to establish a common standard in Europe. This became known as the GSM digital system, which first operated in the 900 MHz band and was deployed in 1992 as *the first world's digital system.*

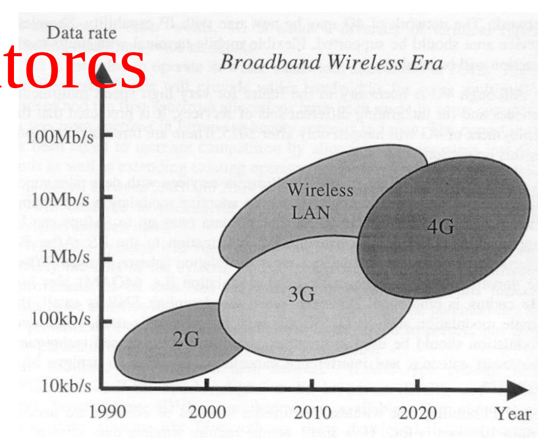
The American 2G system was developed to enhance capacity but it was also required to be backward compatible with AMPS. This resulted in two systems: CDMA IS-95 proposed by Qualcomm and TDMA systems: IS-54 and IS-36. Capacity enhancement is 6-10 times that of AMPS.

Still further need for higher data rates pushed for the development of the third generation cellular network which use CDMA and provide for variable rate of data transmission and multi-media services as shown in Table 2. Table 3 lists the attributes of second generation wireless systems deployed in various parts of the world.

	First Generation	Second Generation	Third eneration
Time Frame	1984-1996	1996-2000	2000-2010
Services	Analogue mobile telephony Voice band data	Digital voice, Messaging For example GSM data services: 2.4, 4.8, 9.6 kb/s	High speed data 9.6 kb/s for satellite users 144 kb/s for vehicular users 384 kb/s for pedestrian users 2.048 Mb/s for indoor office environment Broadband video Multimedia
Radio Technology	Analogue FM, FDD-FDMA	Digital modulation CDMA, TDMA using TDD and FDD	CDMA, possibly combined with TDMA, TDD and FDD variants
Frequency band	800/900 MHz	800+1900 MHz	2 GHz
Examples, carrier spacing and number of channels	AMPS (30 kHz, with 832) TACS ETACS NMT450/900 (12.5 kHz with 1999). NTT (25/6.25 kHz with 600/2400), (6.25 kHz with 560), (6.25 kHz with 280) JTACS/NTACS	US: cdmaOne (IS-95) IS-54, IS-36 Europe: GSM/DCS-1800/PCS1900 Japan: PDC (Personal Digital Cellular)	cdma2000 WCDMA

Table 2. Cellular radio systems.

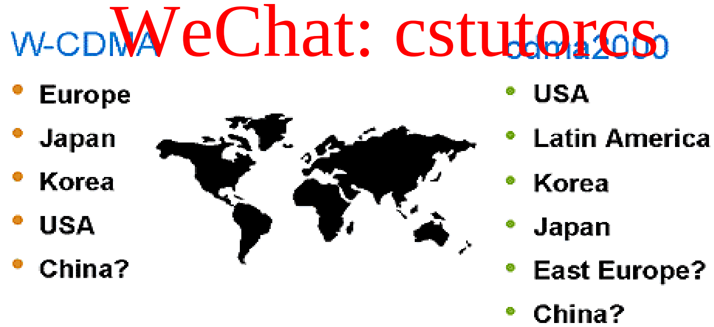




Data rate for different generations

	CdmaOne, IS95, ANSI J-STD-008	GSM, DCS-1900, ANSI J-STD-007	NADC, IS-54/IS-136, ANSI J-STD-011	PACS, ANSI J-STD-014
Uplink Frequencies	824-849 MHz (US Cellular) 1850-1910 MHz (US PCS)	890-915 MHz (Europe) 1850-1910 MHz (US PCS)	824-849 MHz (US Cellular) 1850-1910 MHz (US PCS)	1850-1910 MHz (US PCS)
Downlink Frequencies	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)	935-960 MHz (Europe) 1930-1990 MHz (US PCS)	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)	1930-1990 MHz (US PCS)
Duplexing	FDD	FDD	FDD	FDD
Multiple Access Technology	CDMA	TDMA	TDMA	TDMA
Modulation	BPSK with Quadrature Spreading	GMSK with BT=0.3	π/4 DQPSK	π/4 DQPSK
Carrier Separation	1.25 MHz	200 kHz	30 kHz	300 kHz
Channel Data Rate	1.2288 Mchips/sec	270.833 kbps	48.6 kbps	384 kbps
Voice and Control Channels per Carrier	64	8 full rate and 16 half rate	3	8 (16 with 16 kbps)

Table 3. Second generation cellular radio systems



Third Generation systems

Feature	W-CDMA	cdma2000
Multiple Access	FDD: DS/CDMA TDD: T/CDMA	FDD: DS-CDMA TDD: T/CDMA
Chip Rate (Mcps)	FDD: 1.024/4.096 8.192/16.384 TDD: 4.096	1.2288/3.6864 7.3728/11.0593/ 14.7456
Carrier Spacing (MHz)	(1.25),5,10,20	1.25,5,10,15,20
Frame Length (ms)	10	20
Modulation	FDD: FL: QPSK RL: dual-channel QPSK TDD: FL&RL: QPSK	FL: QPSK RL: BPSK
Coding	rate-1/2, 1/3 $K = 9$ CC optional RS outer code	rate-1/2, 1/3, 1/4 $K = 9$ CC rate-1/2, 1/3, 1/4, $K = 4$ TC
Interleaving	inter/intraframe	intraframe
Spreading	FDD: FL: BPSK RL: QPSK TDD: FL,RL: QPSK	QPSK
Inter BS synchronization	asynchronous	synchronous

Parameters for W-CDMA and cdma2000