EEG453 Mobile Communications

Dr. Mohab A. Mangoud

د. مهاب عبد الحميد منجود

www.aast.edu/~mangoud

Outline

- Instructor
- Course Description
- Lecture Schedule
- Exams, Homework and Project
- Grading
- General Policies

Dr. Mohab A. Mangoud
www.aast.edu/~mangoud
Associate Professor
Department of electronics and Communications Engineering
Arab Academy for Science and Technology
B.O.Box 1029 Alexandria, Egypt
mangoud@aast.edu

Adjunct Professor
The Bradley Department of Electrical & Computer Engineering,
College of Engineering,
Virginia Polytechnic Institute and State University (Virginia Tech.)
302 Whittemore Hall
Blacksburg, Virginia, 24061-0111, USA
mohab@vt.edu

Now ….

Associate Professor

Department of Electrical and Electronics Engineering

College of Engineering

University of Bahrain

P.O.Box 32038- Kingdom of Bahrain

mangoud@eng.uob.bh

http://userspages.uob.edu.bh/mangoud

Administrative Issues

Room: **14-224**

💻mangoud@eng.uob.bh

Office hours:
- U T from 1 till 2 pm at my office
- or by appointment (please feel free to contact me)

Course Description

The cellular concept, Propagation modeling, frequency planning, Link control,Handoffs, Power Control, Traffic capacity, wireless networking, Examples of current mobile systems standards.

Course outline

- Overview
- Fundamentals of cellular systems: Basic building blocks, the cellular concept, handovers, power control, traffic engineering.
- Propagation aspects: Antennas, large-scale effects, small-scale effects, propagatiom models.
- Modulation Techniques: continuous phase modulation, MSK, pi/4 QPSK, SS modulation (PN sequences and FH).
- Mitigation Techniques: Equalization, diversity and channel coding
- Multiple access techniques: FDMA, TDMA, CDMA.
- Wireless standards and systems GSM, UMTS

Textbook

T. S. Rappaport, *Wireless Communications: Principles and Practice,* (Second Edition), Prentice Hall, 2002.

Is there a future for wireless?

Some history

- Ancient Systems: Smoke Signals, Carrier Pigeons, …
- 1861: Maxwell at king's college in London proposed mathematical theory of EM waves.
- 1887: Hertz demonstrated the existence of EM waves using standing waves.
- 1895-1898: Marconi u.o. Bologna built radio telegraph, his signal bridged the English channel 52km wide
- 1921: first analog land mobile by Detroit police department for police car dispatch. (two way radio voice, paging, dispatch).
- 1933: FM was invented which made possible high quality radio communications
- 1946: Bell systems began personal services operated at 150 MHz with speech channels 120 KHz apart.

•1947: IMTS improved mobile telephone service using FM was developed by AT&T. the first mobile system connected to PSTN Bell labs. (extending number of users in cellular concept, cellularization) during and after ww2

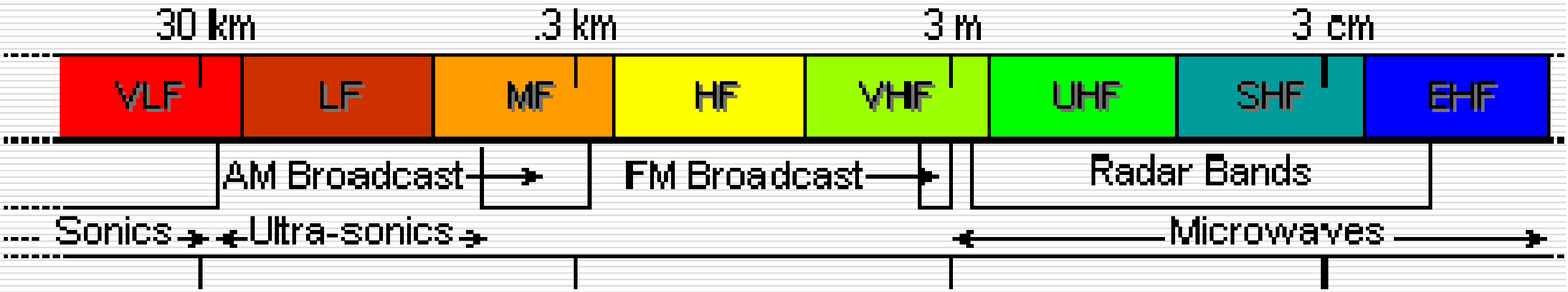
•1970's: AT&T proposed the first high capacity analog cellular telephone system called (AMPS) Advanced Mobile Phone Service. 1980's: the Total Access Communication System (TACS) in Europe, and the Japanese (JTACS) in Japan was developed

• late 1990's: Cellular has enjoyed exponential growth since 1988, with over 200 million users worldwide today**GSM Europe and IS-136 (TDMA) USA and CDMA(IS95) USA. (SIM, lightweight, low power, clarity of digital voice)**

•The demand for higher spectral efficiency and data rates has led to the development of the so called 3rd Generation wireless technology. 3G standardization failed o achieve single common world wide standard and now offers UTRA (WCDMA) and CDMA2000 as the primary standards.

Spectrum Regulation

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defense) In Europe, ETSI
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R (International Telecommunication Union Radio communication Sector)

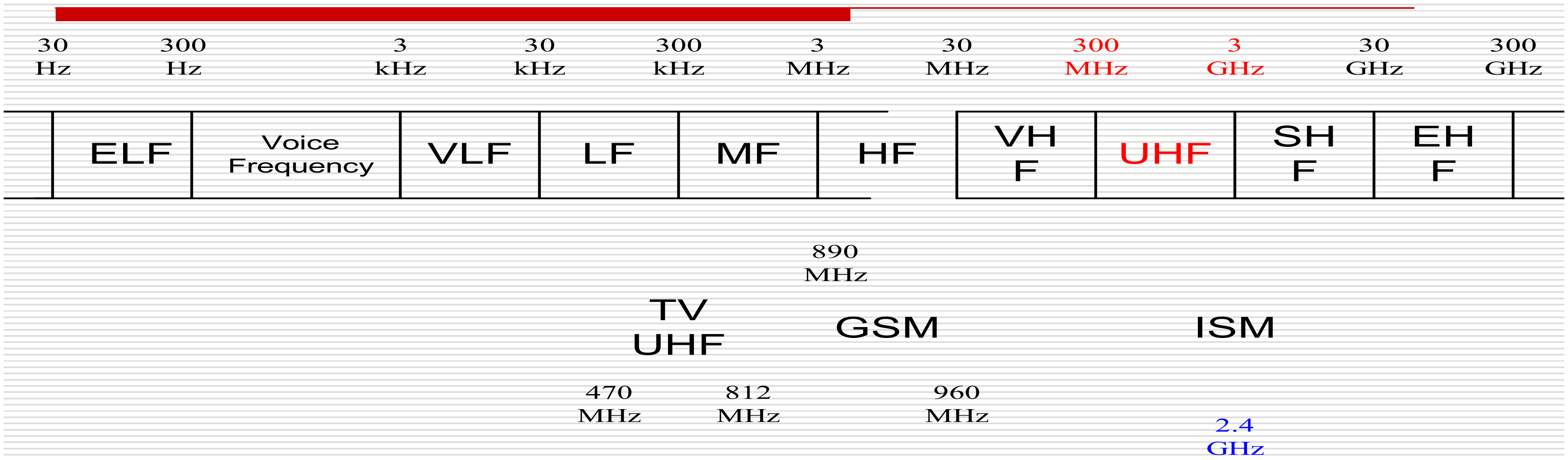


The Federal Communications Commission (FCC) is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions.

The Office of Spectrum Management (OSM) is responsible for managing the Federal Government's use of the radio frequency spectrum. http://www.ntia.doc.gov

ITU-R (International Telecommunication Union Radio communication Sector) http://www.itu.int

Frequency Allocation



Note: The **Industrial, Scientific and Medical (ISM)** radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes.

In recent years they have also been used for license-free error-tolerant communications applications such as Bluetooth and IEEE 802.11b 2.45 GHz band (12.2 cm)

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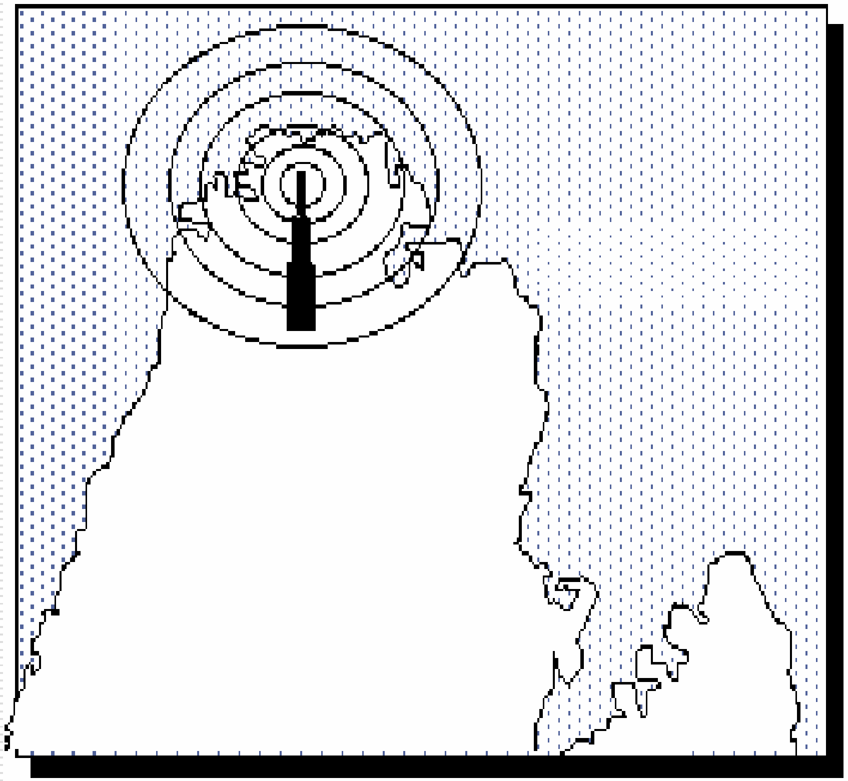
TABLE 1.1 Frequency Band Designations

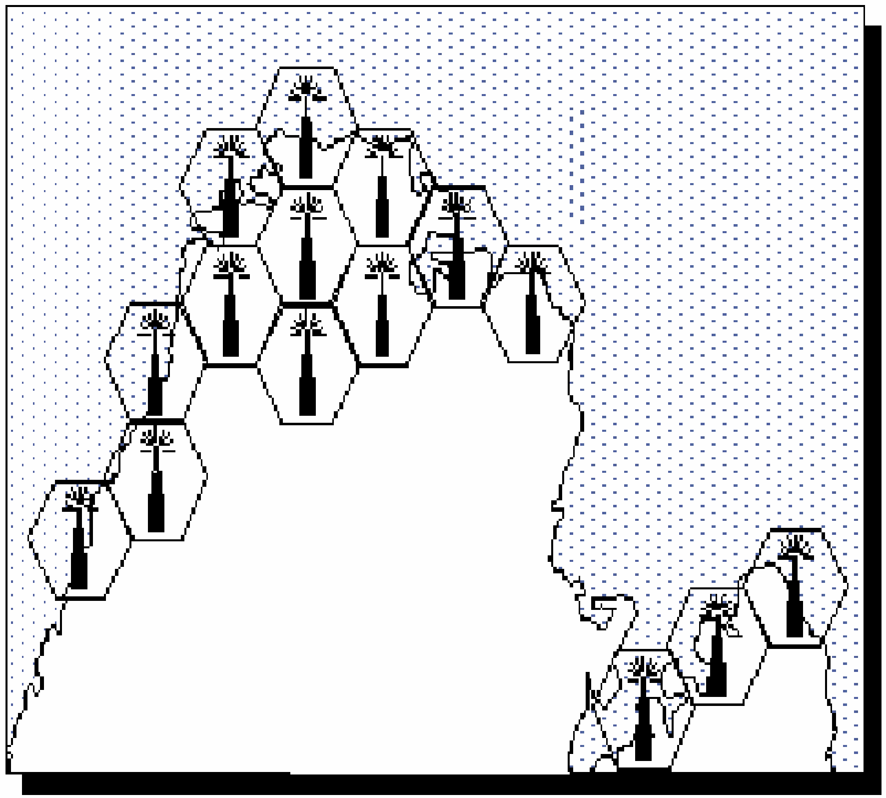
Frequency range, GHz	Band designati
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	μm

Cellular Telephone Systems

Early Mobile Telephone System Architecture

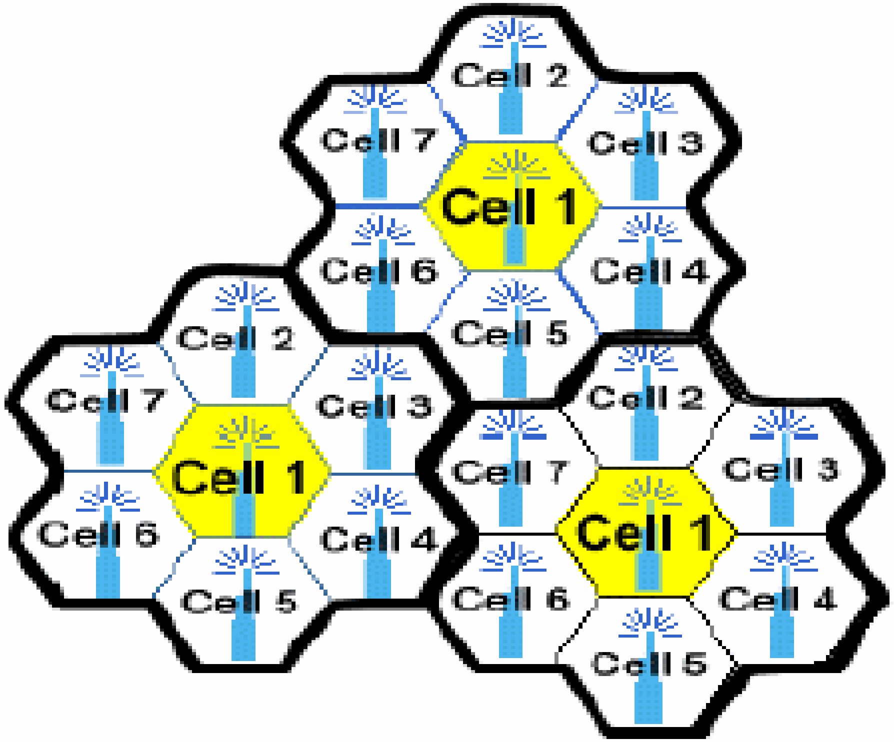
Mobile Telephone System Using Cellular Architecture





Frequency reuse, signal power falls off with distance to reuse the same frequency spectrum at spatially-separated locations.Specifically, the coverage area of a cellular system is divided into nonoverlapping cells where some set of channels is assigned to each cell. This same channel set is used in another cell some distance away.

Operation within a cell is controlled by a centralized base station, as described in more detail below. The interference caused by users in different cells operating on the same channel set is called intercell interference.In order to determine the best reuse distance and base station placement, an accurate characterization of signal propagation within the cells is needed.



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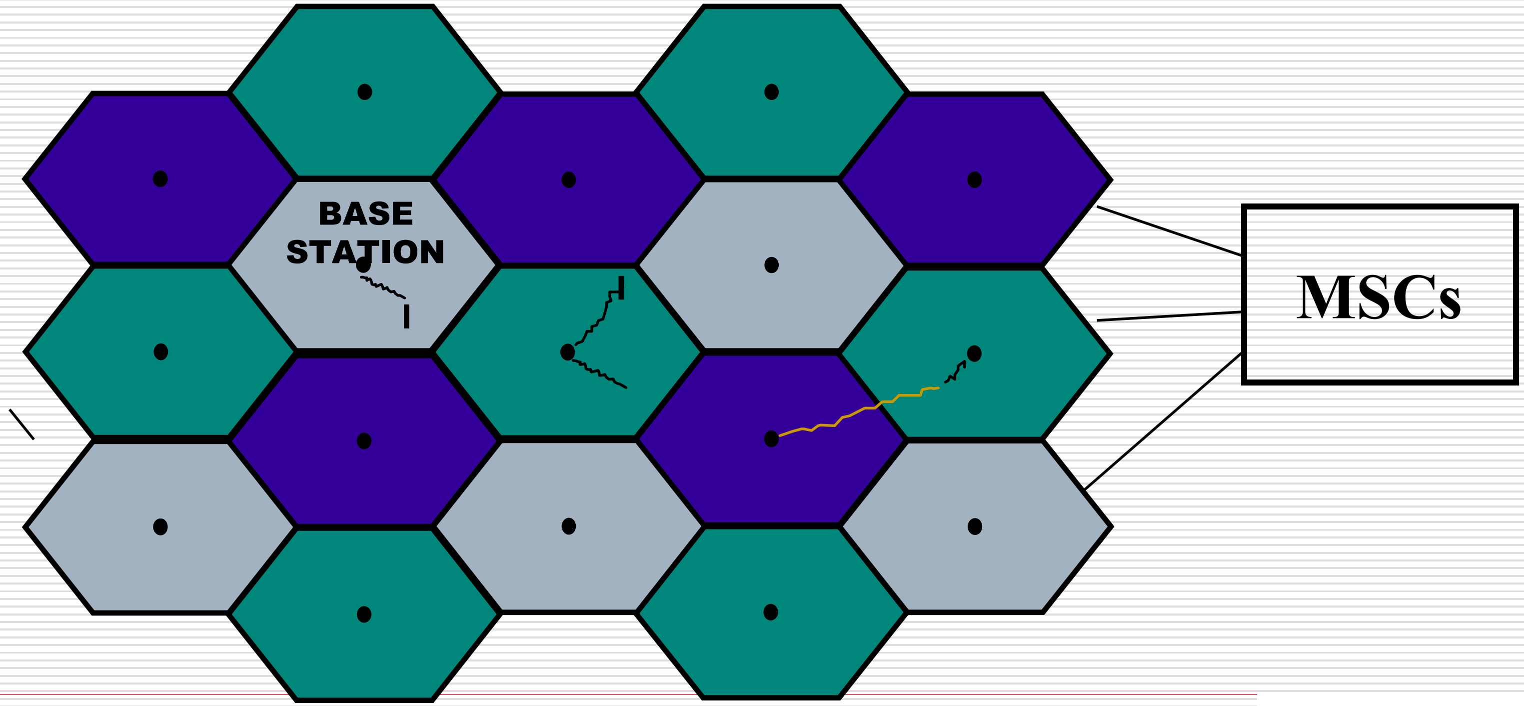
Cellular Systems:

- Reuse channels to maximize capacity
- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MSCs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



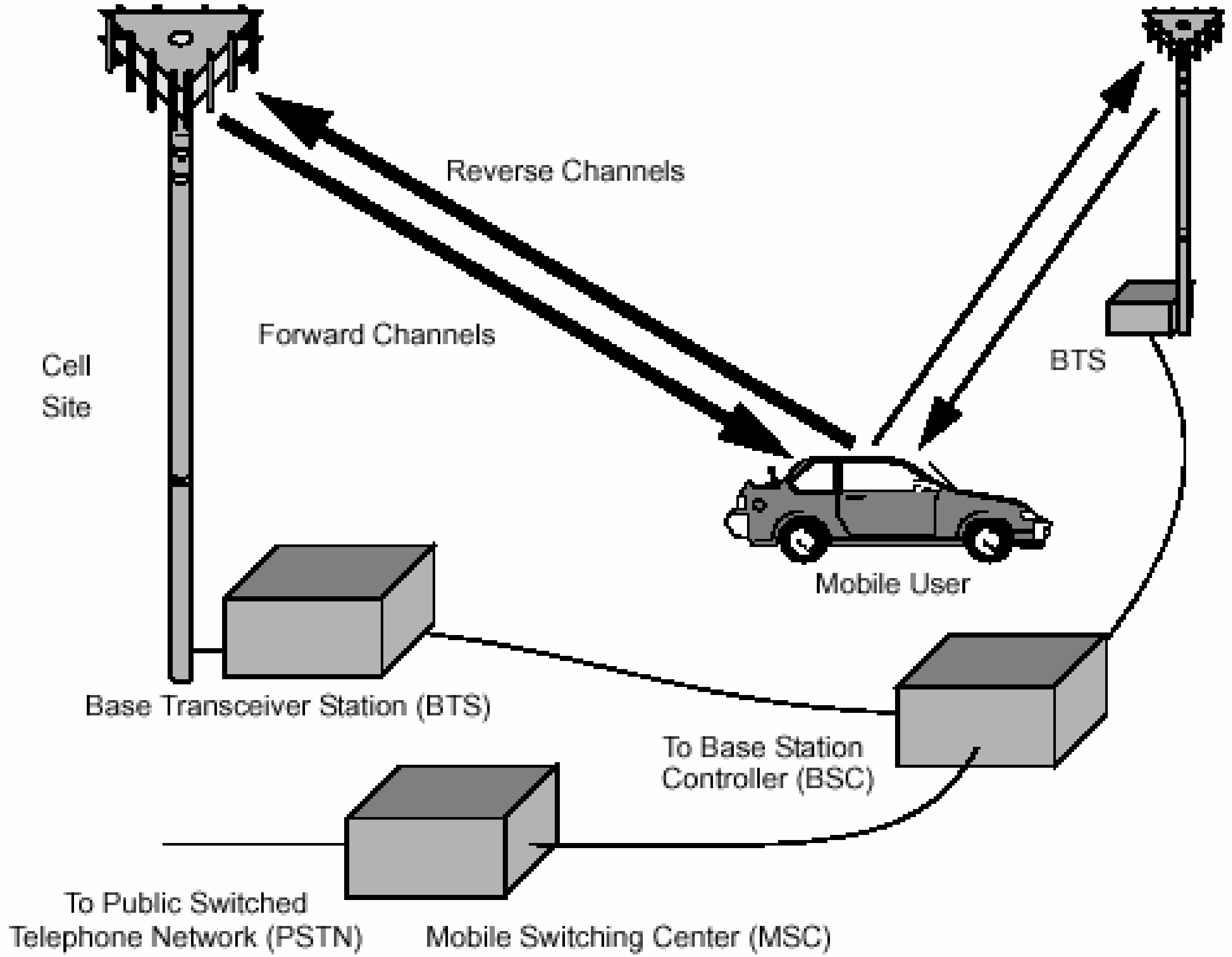


Figure 1–3 There are two main types of forward channels. Control and access channels are used to set up calls and provide security and management functions. Traffic channels are used to carry voice traffic. The reverse channels are also divided into access channels and traffic channels. In some systems, the Base Station Controller (BSC) may be integrated directly into the cell site. In other systems, as shown here, the Base Transceiver Stations (BTSs) are connected to a Base Station Controller.

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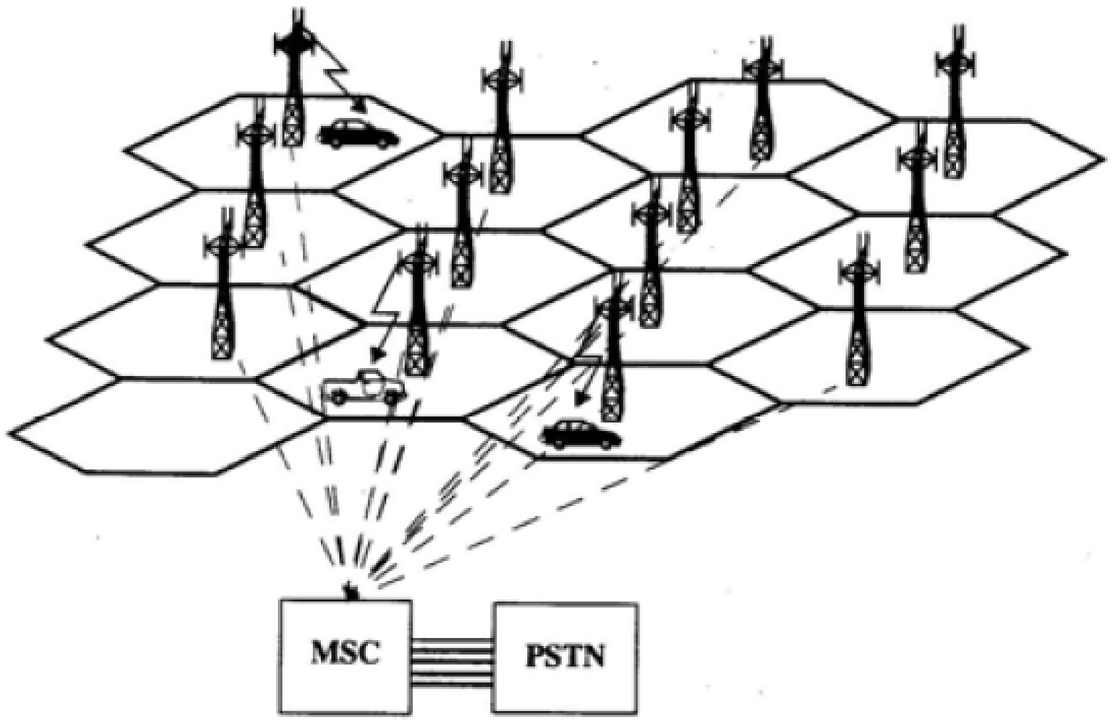
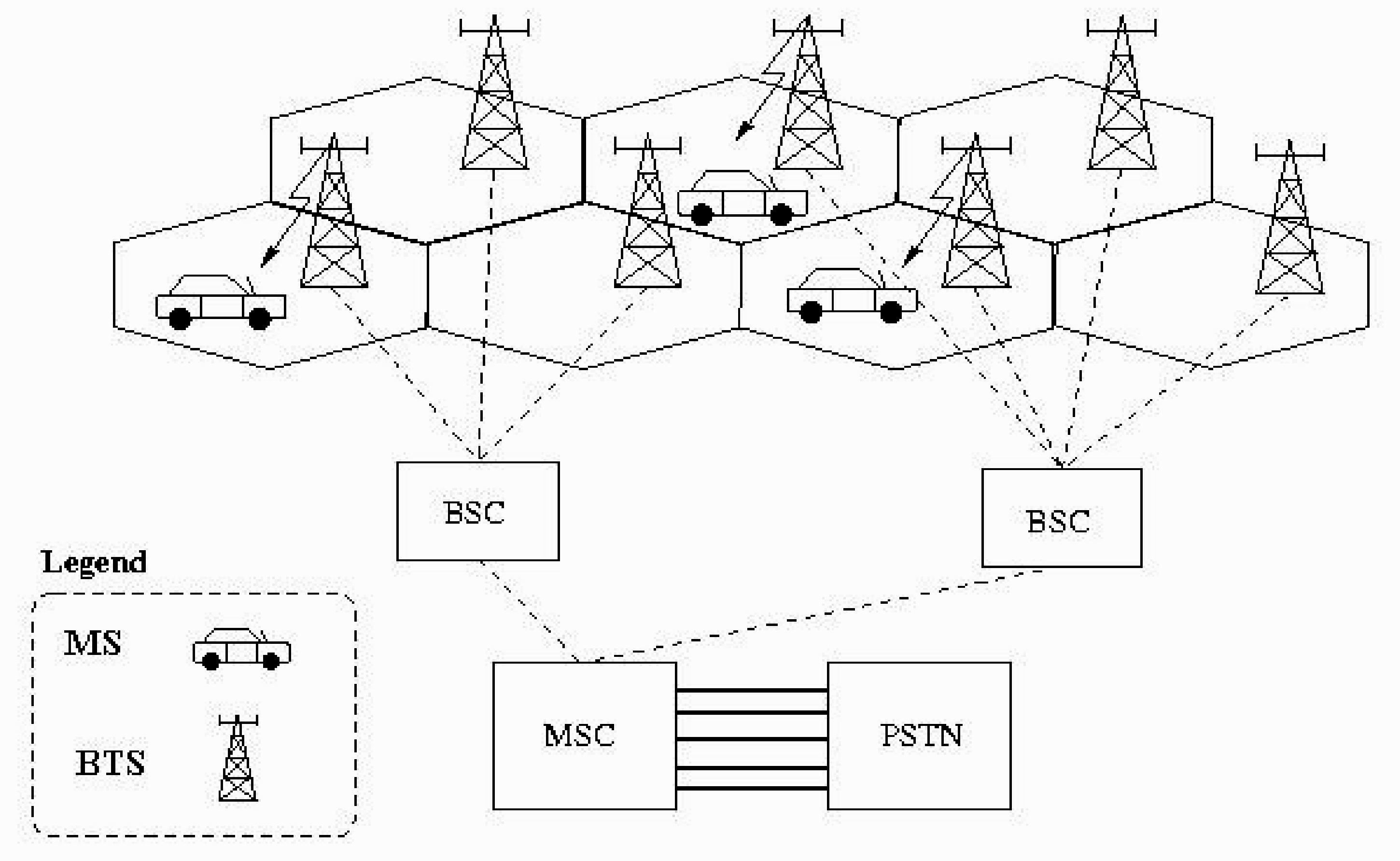


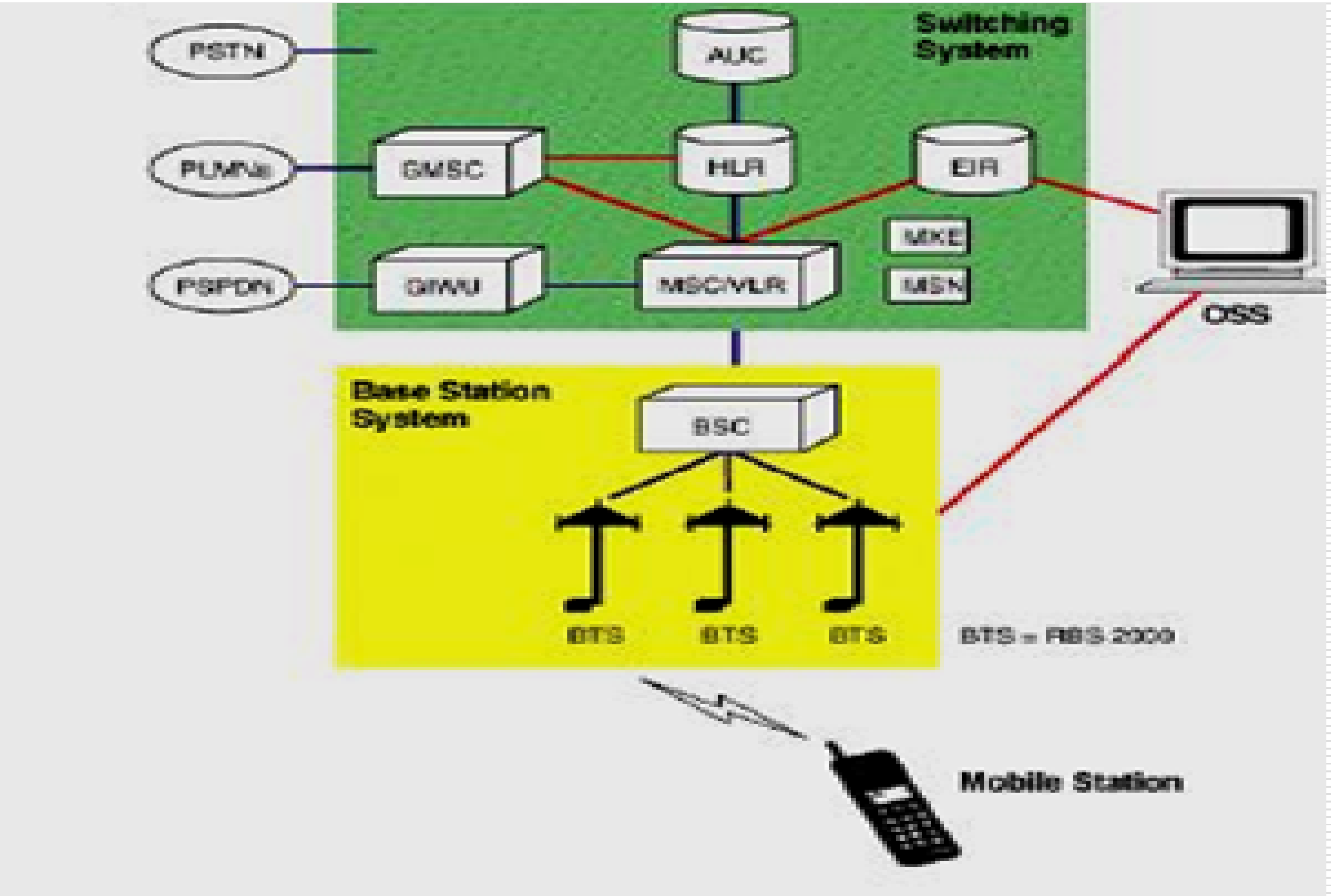
Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

BASE STATION SYSTEM



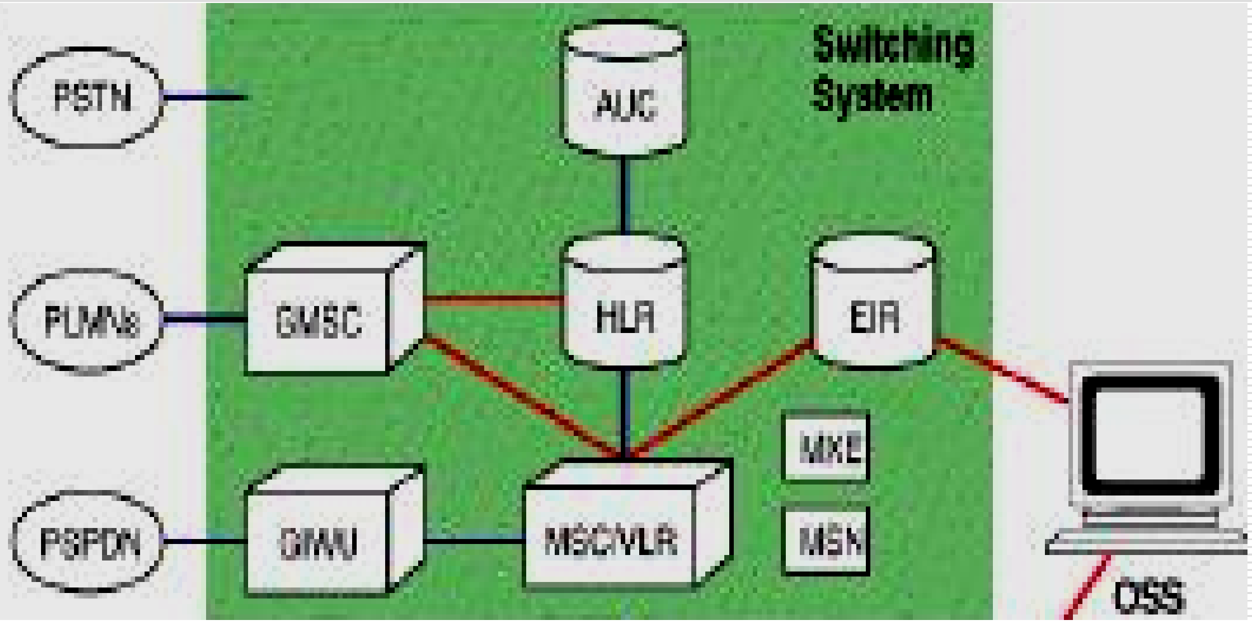
- It consists of:
  - Base Station Controller (BSC)
  - Base Transceiver Stations (BTS)

CELLULAR NETWORK COMPONENTS



1. Mobile station (MS)
2. Base Transceiver Station (BTS)
3. Mobile Services Switching Center
4. Base Station Controller (BSC)
5. Public Switched Telephone Network (PSTN)

SWITCHING SYSTEM (SS)



- Responsible for performing call processing and subscriber-related functions.

Consists of:

- Mobile Services Switching Center (MSC)
- Visitor Location Register (VLR)
- Home Location Register (HLR)
- Authentication Center (AUC)
- Equipment Identity Register (EIR)

The First Generation (1G)

1G cellular systems in the U.S., called the Advance Mobile Phone Service (AMPS), used FDMA with 30 KHz FM-modulated voice channels. The FCC initially allocated 40 MHz of spectrum to this system, which was increased to 50 MHz shortly after service introduction to support more users. This total bandwidth was divided into two 25 MHz bands, one for mobile-to-base station channels and the other for base station-to-mobile channels. The FCC divided these channels into two sets that were assigned to two different service providers in each city to encourage competition. A similar system, the European Total Access Communication System (ETACS), emerged in Europe. AMPS was deployed worldwide in the 1980's and remains the only cellular service in some of these areas, including some rural parts of the U.S. Many of the first generation cellular systems in Europe were incompatible, and the Europeans quickly converged on a uniform standard for second generation (2G) digital systems called GSM. (Groupe Sp´eciale Mobile) (changed to Global Systems for Mobile Communications.)

The Second Generation (2G)

In USA two standards in the 900 MHz cellular frequency band:
IS-54, which uses a combination of TDMA and FDMA and phase-shift keyed modulation, IS-95, which uses direct-sequence CDMA with binary modulation and coding.

The spectrum for digital cellular in the 2 GHz PCS frequency band, The end result has been three different digital cellular standards for this frequency band: IS-136 (which is basically the same as IS-54 at a higher frequency), IS-95, and the European GSM standard.

The digital cellular standard **in Japan** is similar to IS-54 and IS-136 but in a different frequency band, and **the GSM system in Europe is at a different frequency than the GSM systems in the U.S.** This proliferation of incompatible standards in the U.S. and internationally makes it impossible to roam between systems nationwide or globally without a multi-mode phone and/or multiple phones (and phone numbers). All of the second generation digital cellular standards have been enhanced to support high rate packet data services [15]. GSM systems provide data rates of up to 100 Kbps by aggregating all timeslots together for a single user.

The Second and half Generation (2.5 G)

This enhancement is called **GPRS.** A more fundamental enhancement, **Enhanced Data Services for GSM Evolution (EDGE),** further increases data rates using a high-level modulation format combined with FEC coding.

This modulation is more sensitive to fading effects, and EDGE uses adaptive techniques to mitigate this problem. Specifically, EDGE defines six different modulation and coding combinations, each optimized to a different value of received SNR.

The received SNR is measured at the receiver and fed back to the transmitter, and the best modulation and coding combination for this SNR value is used. The IS-54 and IS-136 systems currently provide data rates of **40-60 Kbps** by aggregating time slots and using high-level modulation. This evolution of the IS-136 standard is called IS-136HS (high-speed). The IS-95 systems support higher data using a time-division technique called high data rate (HDR)[16].

The 3G story ? (1)

• 3G will add broadband data to support video, internet access and other high speed data services for mobile devices.

• 1992 the world administrative radio commission (WARC) of the ITU formulated a plan to implement a global frequency band in the 2 GHZ range that would be common to all countries for universal wireless comm. Systems.

•1995: this visionary concept is known as Future Public Land Mobile Telephone System (FPLMTS), was renamed International Mobile Telecommunication 2000 (IMT-2000).

• IMT-2000 vision of commonality is not tenable due to the leading TDMA-GSM in Europe and CDMA-IS95 in USA. Thus the ITU in recent years expressed a desire to determine a family of standards that would be implemented in a common frequency band over the globe.

The 3G story ? (2)

• In June 1998, ITU received 15 IMT2000 proposals from leading Governments and industrial bodies over the world. Includes CDMA in air interface 1920-1980 uplink and 2110-2170 downlink with TDD.

• Soon the ITU is scheduled to select the winning world standards. The leading U.S proposal, (cdma2000), will backward-compatible with IS-95 systems but will support chip rates up to 12 times the 1.2288 Mchip/sec rate used in current system. Also support smart antennas.It is likely that cdma2000 will be developed for US market regardless of ITU action.

• the European Telecommunications Standards Institute (ETSI) has developed the Universal Telecommunications System (UMTS) as an evolutionary path for GSM. The UMTS Terrestrial Radio Access (UTRA) standard is a Wideband CDMA (W-CDMA) technology.

The 3G story ? (3)

• the UTRA proposal shares a number of features including direct sequence spreading rates, frame rate, and slot structure with other proposals from North America (W-CDMA/NA) and Asia (W-CDMA/Japan and CDMA-II Korea).

•The UWC-136 proposal is designed to provide an upgrade path for both the North America TDMA (IS-136) and GSM. It also suport Frequency Hopping technique (FH).

•Thus, FH and CDMA spread spectrum techniques will be our focus in this course.

The Third Generation (3G)

The third generation (3G) cellular systems are based on a wideband CDMA standard developed within the auspices of the International Telecommunications Union (ITU) [15]. The standard, initially called International Mobile Telecommunications 2000 (IMT-2000), provides different data rates depending on mobility and location, from **384 Kbps** for pedestrian use to **144 Kbps** for vehicular use to **2 Mbps** for indoor office use.

The 3G standard is incompatible with 2G systems, so service providers must invest in a new infrastructure before they can provide 3G service. The first 3G systems were deployed in Japan.

One reason that 3G services came out first in Japan is the process of 3G spectrum allocation, which in Japan was awarded without much up-front cost.The 3G spectrum in both Europe and the U.S. is allocated based on auctioning, thereby requiring a huge initial investment for any company wishing to provide 3G service.

The Third Generation (3G)

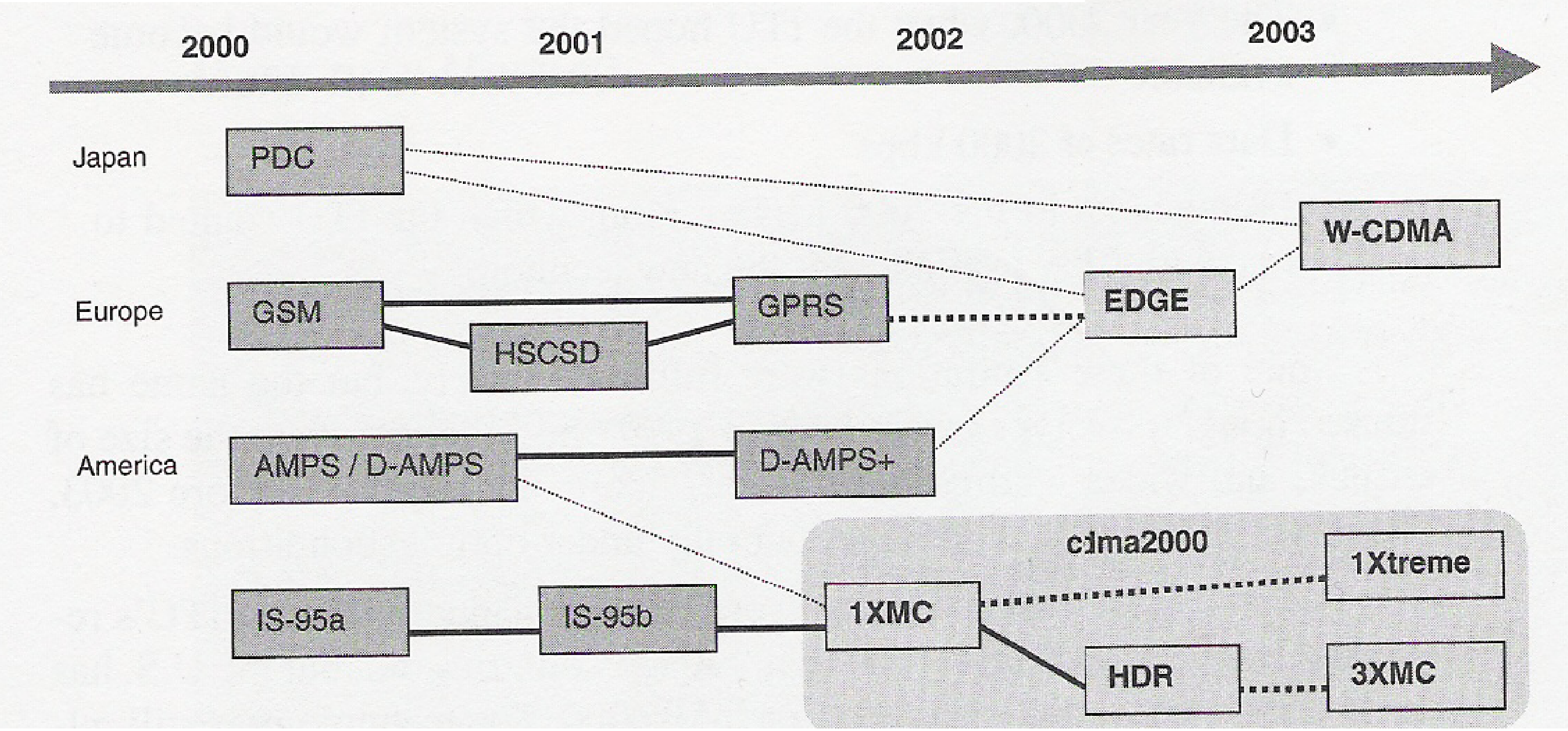
European companies collectively paid over 100 billion dollars in their 3G spectrum auctions. There has been much controversy over the 3G auction process in Europe, with companies charging that the nature of the auctions caused enormous overbidding and that it will be very difficult if not impossible to reap a profit on this spectrum. A few of the companies have already decided to write off their investment in 3G spectrum and not pursue system buildout. In fact 3G systems have not grown as anticipated in Europe, and it appears that data enhancements to 2G systems may suffice to satisfy user demands. However, the 2G spectrum in Europe is severely overcrowded, so users will either eventually migrate to 3G or regulations will change so that 3G bandwidth can be used for 2G services (which is not currently allowed in Europe).

3G development in the U.S. has lagged far behind that of Europe. The available 3G spectrum in the U.S. is only about half that available in Europe. Due to wrangling about which parts of the spectrum will be used, the 3G spectral auctions in the U.S. have not yet taken place. However, the U.S. does allow the 1G and 2G spectrum to be used for 3G, and this flexibility may allow a more gradual rollout and investment than the more restrictive 3G requirements in Europe. It appears that delaying 3G in the U.S. will allow U.S. service providers to learn from the mistakes and successes in Europe and Japan.

International Mobile Telecommunications-2000 (IMT-2000) is the global standard for third generation (3G) wireless communications, defined by a set of interdependent ITU Recommendations. IMT-2000 provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and/or satellite based networks. It will exploit the potential synergy between digital mobile telecommunications technologies and systems for fixed and mobile wireless access systems.

ITU activities on IMT-2000 comprise international standardization, including frequency spectrum and technical specifications for radio and network components, tariffs and billing, technical assistance and studies on regulatory and policy aspects.

Upgrade path to 3G



Evolution of Mobile Networks

	First Generation Systems	Second Generation Systems	Third Generation Systems
Time Frame	1984-1996	1996-2000	2000-2010
Services	Analog Mobile Telephony Voice Band Data	Digital voice, messaging	High speed data Broadband video Multimedia
Architecture	Macrocellular	Microcellular, Picocellular Wireless Local Loop	
Radio Technology	Analog FM, FDD-FDMA	Digital modulation, CDMA, TDMA using TDD and FDD	CDMA, possibly combined with TDMA, with TDD and FDD variants
Frequency Band	800 MHz	800+1900 MHz	2 GHz+
Examples	AMPS TACS ETACS NMT450/900 NTT JTACS/NTACS	cdmaOne (IS-95) GSM/DCS-1900 US TDMA IS-136 PACS PHS	cdma2000 WCDMA

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	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	$\pi/4$ DQPSK	$\pi/4$ 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	3	8 (16 with 16 kbps vocoder)
Speech Coding	Code Excited Linear Prediction (CELP) @ 13 kbps, Enhanced Variable Rate Codec (EVRC) @ 8 kbps	Residual Pulse Excited-Long Term Prediction (RPE-LTP) @ 13 kbps	Vector Sum Excited Linear Predictive Coder (VSELP) @ 7.95 kbps	Adaptive Differential Pulse Code Modulation (ADPCM) @ 32 kbps

Table 1–4 Ten IMT-2000 candidate standards proposed to ITU in 1998 [ITU98].

Air Interface	Mode of Operation	Duplexing Method	Key Features and Support of Smart Antenna Technology
cdma2000 US TIA TR45.5	Multi-Carrier and Direct Spreading DS-CDMA at $N = 1.2288$ Mcps with N=1,3,6,9,12	FDD and TDD Modes	• Backward compatibility with IS-95A and IS-95B. Downlink can be implemented using either Multi-Carrier or Direct Spreading. Uplink can support a simultaneous combination of Multi-Carrier and Direct Spreading. • *Auxiliary carriers to help with downlink channel estimation in forward link beamforming.*
UTRA (UMTS Terrestrial Radio Access) ETSI SMG2 ***W-CDMA/NA*** (Wideband CDMA/ North America) USA T1P1-ATIS ***W-CDMA/Japan*** (Wideband CDMA) Japan ARIB	DS-CDMA at Rates of $N \times 1.024$ Mcps with N=4,8,16	FDD and TDD Modes	• Wideband DS-CDMA System. Backward compatibility with GSM/DCS-1900. Up to 2.048 Mbps on Downlink in FDD Mode. • The collection of proposed standards represented here each exhibit unique features, but support a common set of chip rates, 10 ms frame structure, with 16 slots per frame. • *Connection-dedicated pilot bits assist in downlink beamforming.*

Japan ARIB			*downlink beamforming.*
CDMA II South Korea TTA			
WIMS/W-CDMA USA TIA TR46.1			
CDMA I South Korea TTA	DS-CDMA at $N \times 0.9216$ Mcps with N=1,4,16	FDD and TDD Modes	• Up to 512 kbps per spreading code, code aggregation up to 2.048 Mbps.
UWC-136 (Universal Wireless Communications Consortium) USA TIA TR45.3	TDMA - Up to 722.2 kbps (Outdoor/Vehicular), Up to 5.2 Mbps (indoor office)	FDD (Outdoor/ Vehicular) TDD (Indoor Office)	• Backward compatibility and upgrade path for both IS-136 and GSM. • Fits into existing IS-136 RF frequency plan. • *Explicit plans to support adaptive antenna technology.*
TD-SCDMA China Academy of Telecommunication Technology (CATT)	DS-CDMA 1.1136 Mcps	TDD	• RF channel bit rate up to 2.227 Mbps • *Use of smart antenna technology is fundamental (but not strictly required) in TD-SCDMA*
DECT ETSI Project (EP) DECT	1150-3456 kbps TDMA	TDD	• Enhanced version of 2G DECT technology.

Cellular System	Year of Introduction	Transmission Type	Multiple Access Technique	Channel Bandwidth	System Generation
Advanced Mobile Phone System (AMPS)	1983	Analog	FDMA	30kHz	First
Narrowband AMPS (NAMPS)	1992	Analog	FDMA	10kHz	First
U.S. Digital Cellular (USDC)	1991	Digital	TDMA	30kHz	Second
U.S Narrowband Spread Spectrum(IS-95)	1993	Digital	CDMA	1.25MHz	Second
Wideband cdmaOne	2000	Digital	CDMA	-	Third

Table 1 Major Mobile Standards in North America [6]

Cellular System	Year of Introduction	Transmission Type	Multiple Access Technique	Channel Bandwidth	System Generation
E-TACS	1985	Analog	FDMA	25kHz	First
NMT-900	1986	Analog	FDMA	12.5kHz	First
Global System for Mobile (GSM)	1990	Digital	TDMA	200kHz	Second
Universal Mobile Tele-communications System (UMTS)	>2000	Digital	CDMA/ TDMA	-	Third

Table 2 Major Mobile Standards in Europe [6]

	Pico-cell	Micro-cell
Cell radius	<100m	<1000m
Antenna	Ceiling/wall mounted	Below roof top height
Max. multipath delay spread	1 μsec	5 μsec
Applications and environments	Indoor/Outdoor Within buildings City centres Local high bit rate	High density outdoor Business (indoor) Fixed (Outdoor) Inner city areas
Services and data rate supported	All services (up to 2Mbps)	Up to 384kbps

Table 5 Cell Types used in UTMS

Data rates and Access techniques

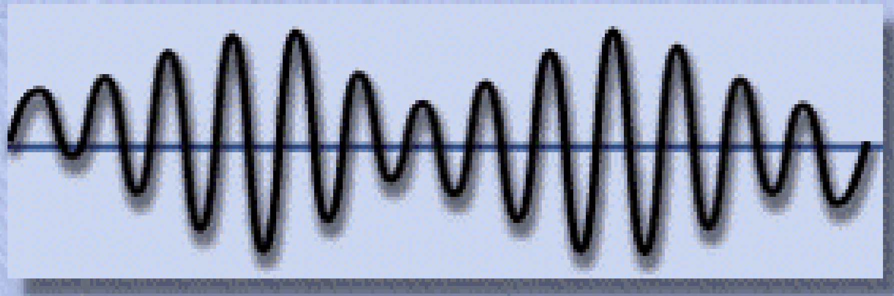
In the unlicensed 2.4GHz ISM band, the FCC dictates the use of either frequency-hopping spread spectrum (FHSS) or direct-sequence spread spectrum (DSSS) technology.

- **FHSS** systems are targeted at low-cost low-power low-range low-data-rate applications, and include **Bluetooth, HomeRF (SWAP), 2.4GHz DECT (digital European cordless telephone), and FHSS IEEE802.11.**

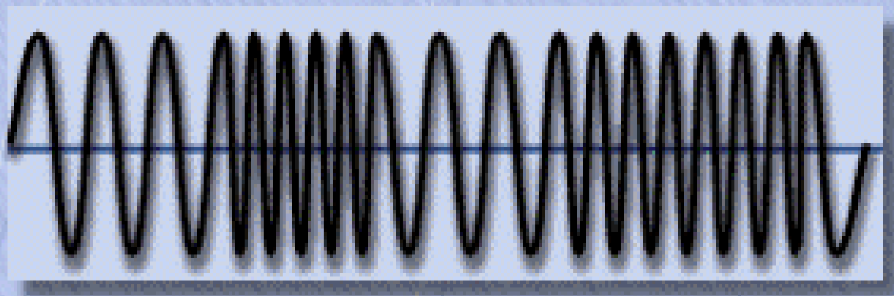
- ❖ The **DSSS IEEE802.11b systems** are intended for higher-data-rate and higher-range applications, and typically cost more and consume more power.
- ❖ Bluetooth systems are directed at data transfer, such as transferring an e-mail message from a cell phone to a PDA, and support data rates up to **721kbps.**
- ❖ HomeRF supports both data and voice transmission, and allows data rates up to **1.6Mbps**.
- ❖ Carrying over from its past incarnation at 1.9GHz, 2.4GHz DECT is intended for 2.4GHz cordless phones with a data rate of **552kbps**.
- ❖ **DSSS IEEE802.11b** systems currently support data rates up to **11Mbps**

- PSK requires too wide a bandwidth

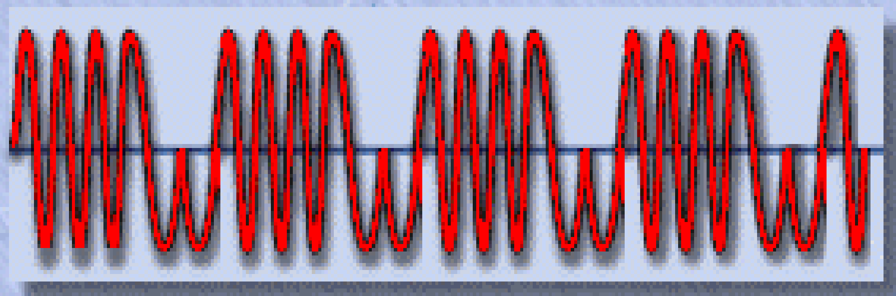
- Gaussian Minimum Shift Keying (GMSK) is actually used on the GSM air interface



AMPLITUDE MODULATION



FREQUENCY MODULATION



PHASE SHIFT KEYING (PSK)

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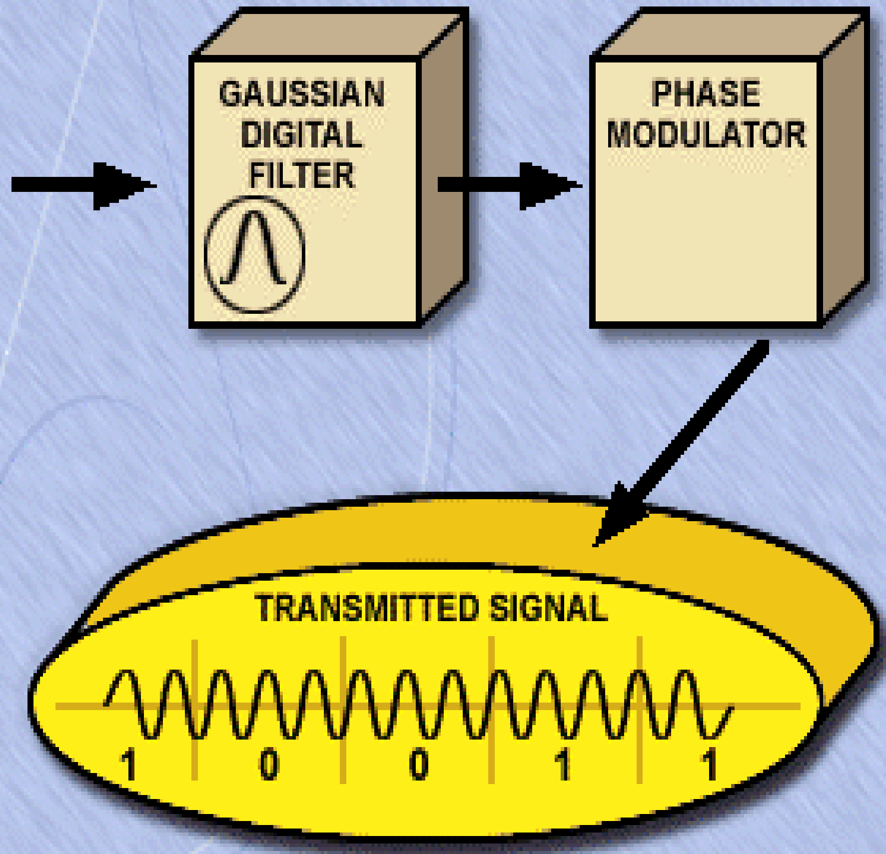
Gaussian Minimum Shift Keying:

- Digital signal filtered through a Gaussian Filter
- Filtering distorts the signal, rounding off the corners and removing abrupt phase changes
- Distorted signal is used to phase shift the carrier signal
- Phase change occurs over a period of time
- Frequency components are lowered, reducing the bandwidth requirement



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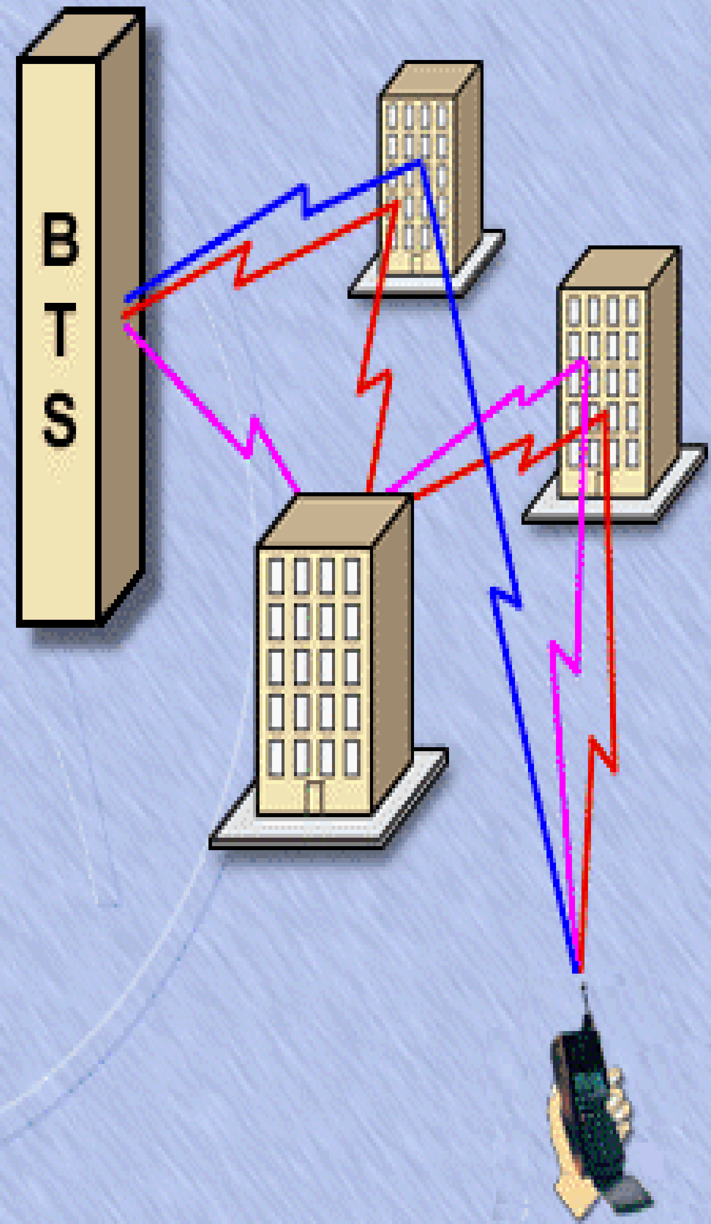
MULTIPATH FADING

- Signals travel from transmitter to receiver by different routes and experience time dispersion
- Signals combine again at receiver, constructively or destructively
- Combined signal strength also changes when receiver moving



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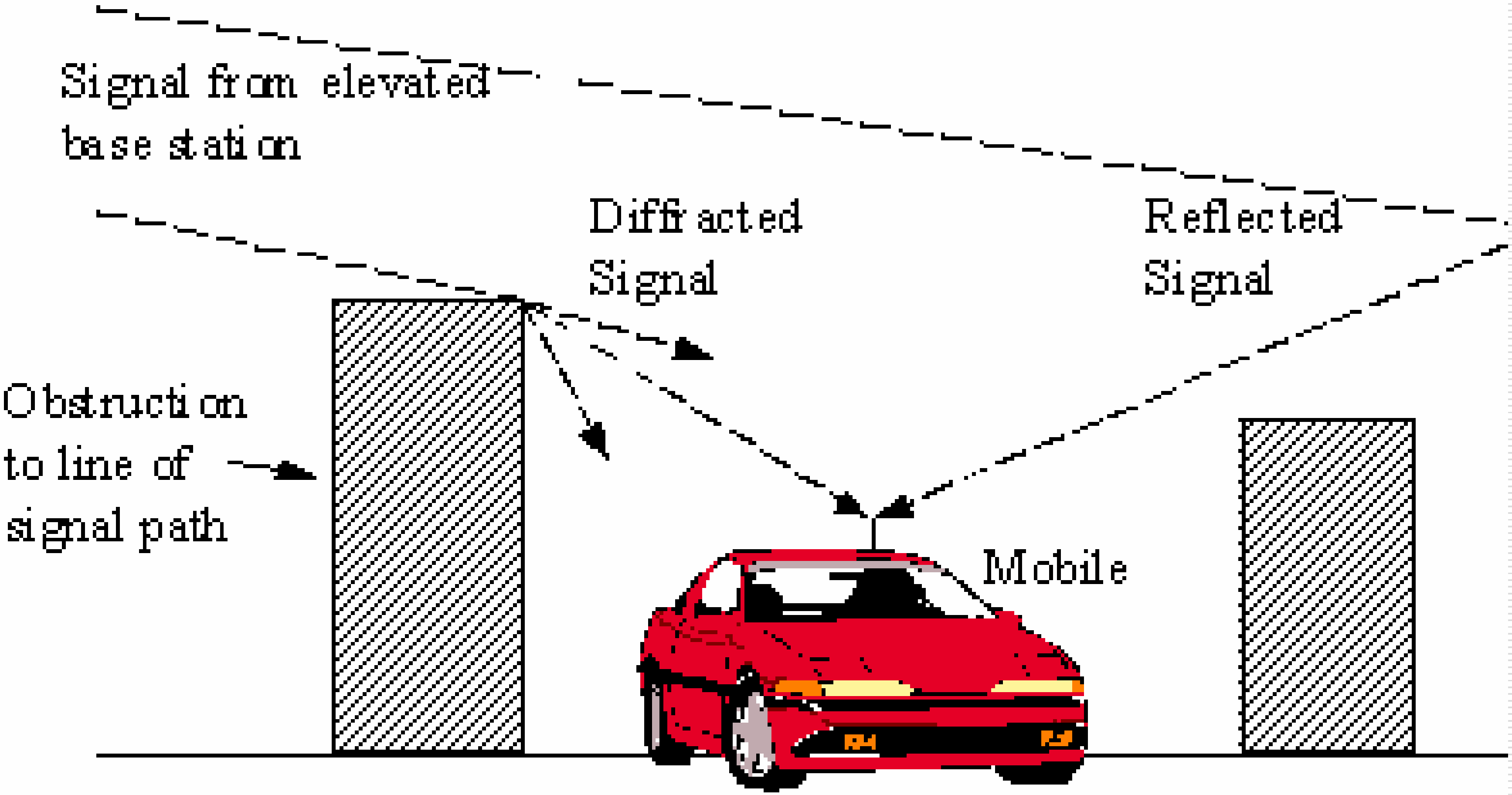
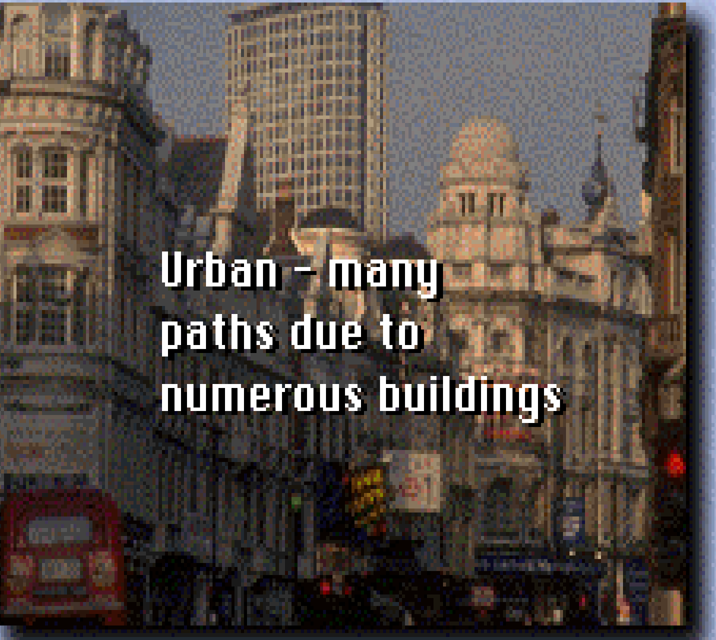
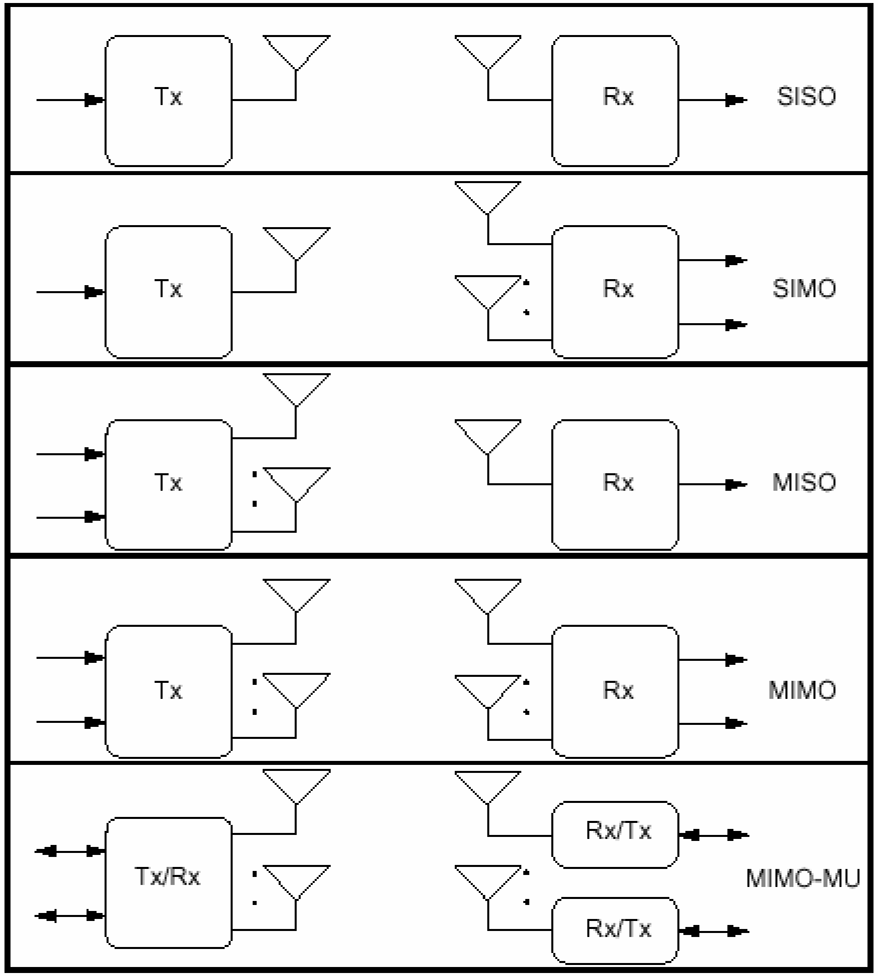


Figure 2 Radio Propagation Effects

- GSM combats multipath fading with:
  - Equalisation
  - Diversity
  - Frequency Hopping
  - Interleaving
  - Channel Coding





SISO: Single input Single output
SIMO: Single input Multiple output
MISO: Multiple input Single output
MIMO: Multiple input Multiple output
MIMO-MU: Multiple input Multiple output (multiuse

Smart antennas

What are Smart Antennas?

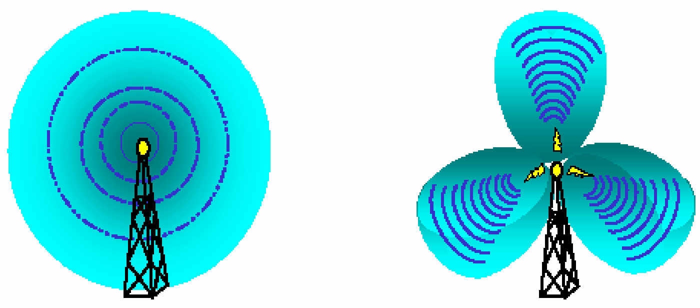
- Traditional cellular systems
- Idea of smart antenna

It consists of

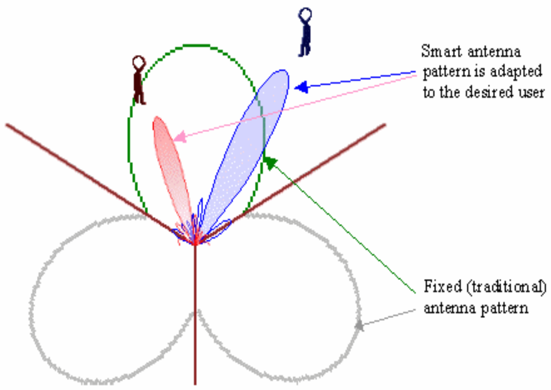
a number of radiating elements (antenna array)

a combining/dividing network (Beamforming unit)

control unit, realized using DSP

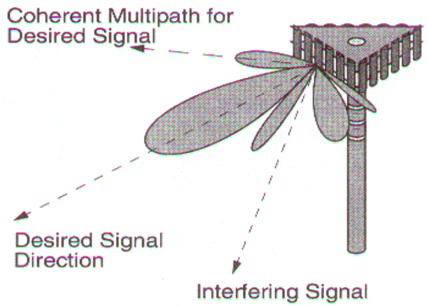


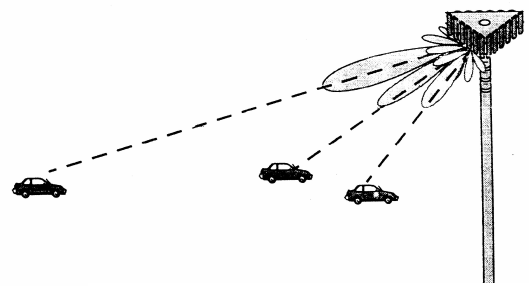
Omnidirectional antenna   Multibeam antenna array



Why Smart Antennas?

- to increase the system capacity and to increase the signal quality (system performance
- to avoid problems associated with multipath





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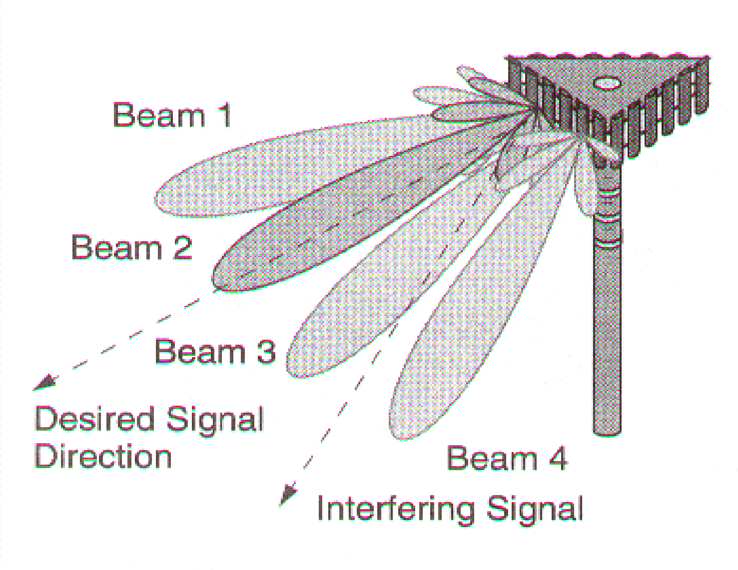
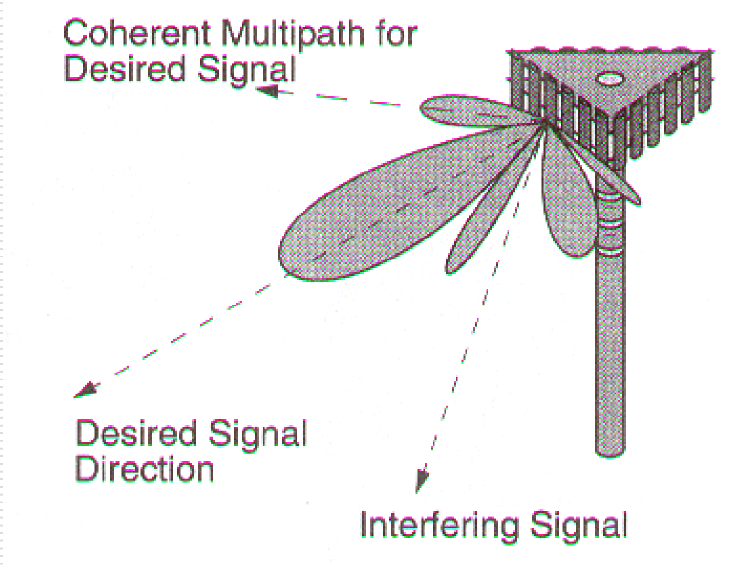
Types of Smart Antennas

- Switched-Beam Antennas
- Adaptive-Array Antennas





•Disadvantages:

Signal strength degradation

The desired signal and interfering signals can not be distinguished (Reduced S/N)

•A direction of arrival (DOA) algorithm for determining signal direction & interference sources is needed.

•The beam pattern is adapted (steered) based on changed in both the desired and interfering signal locations.

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