Mobile Communications

EENG473

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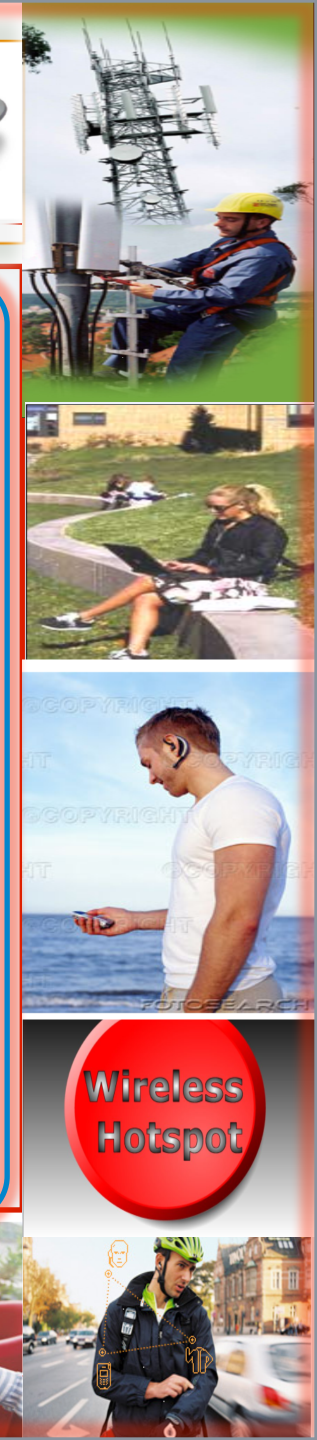


Outline

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

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: large-scale effects
- small-scale effects, propagation models.
- Mitigation Techniques: Equalization, diversity
- Multiple access techniques: FDMA, TDMA, CDMA.
- Wireless standards and systems GSM, UMTS, 5G

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

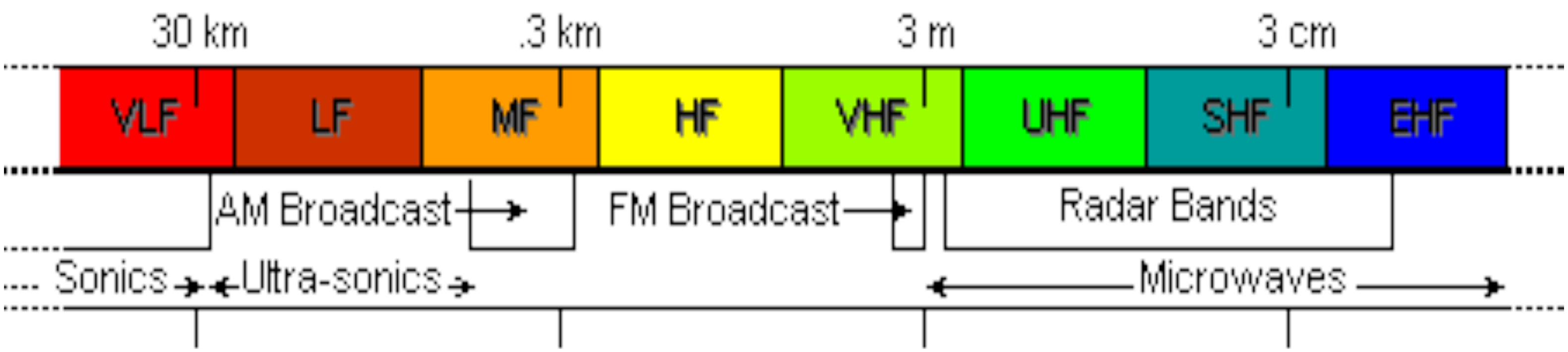
• late 1990's: Cellular has enjoyed exponential growth since 1988, with over 200 million users worldwide today**GSM Europe and IS-136 (TDMA) USA and CDMA(IS95) USA. (SIM, lightweight, low power, clarity of digital voice)**

•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.

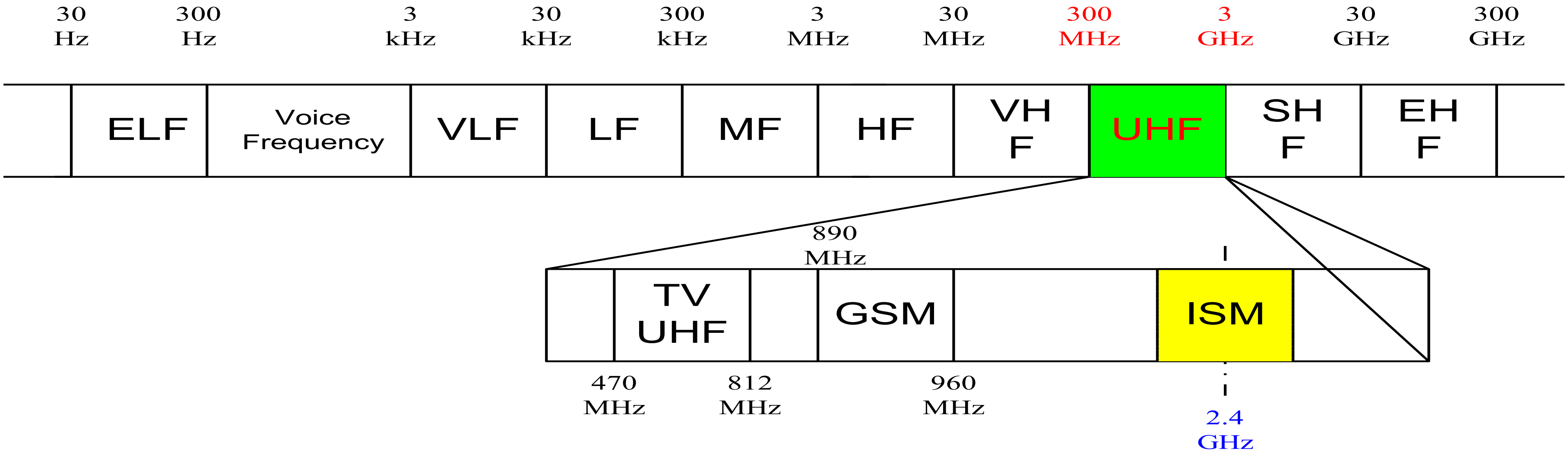
Background and Radio Frequency Spectrum Issues

Spectrum Regulations

- 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)



Spectrum Allocation



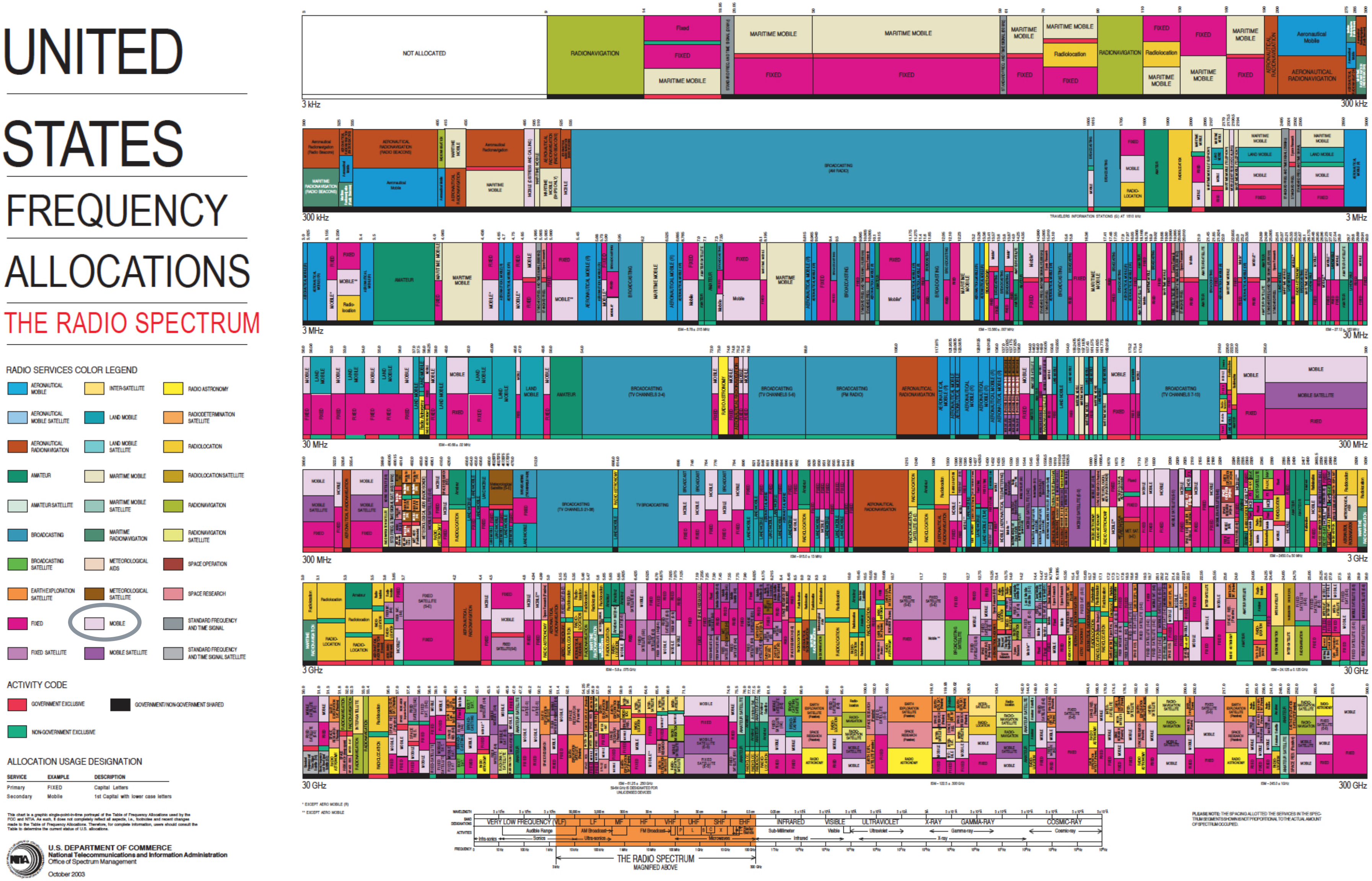
Note: The **Industrial, Scientific and Medical (ISM)** radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes.

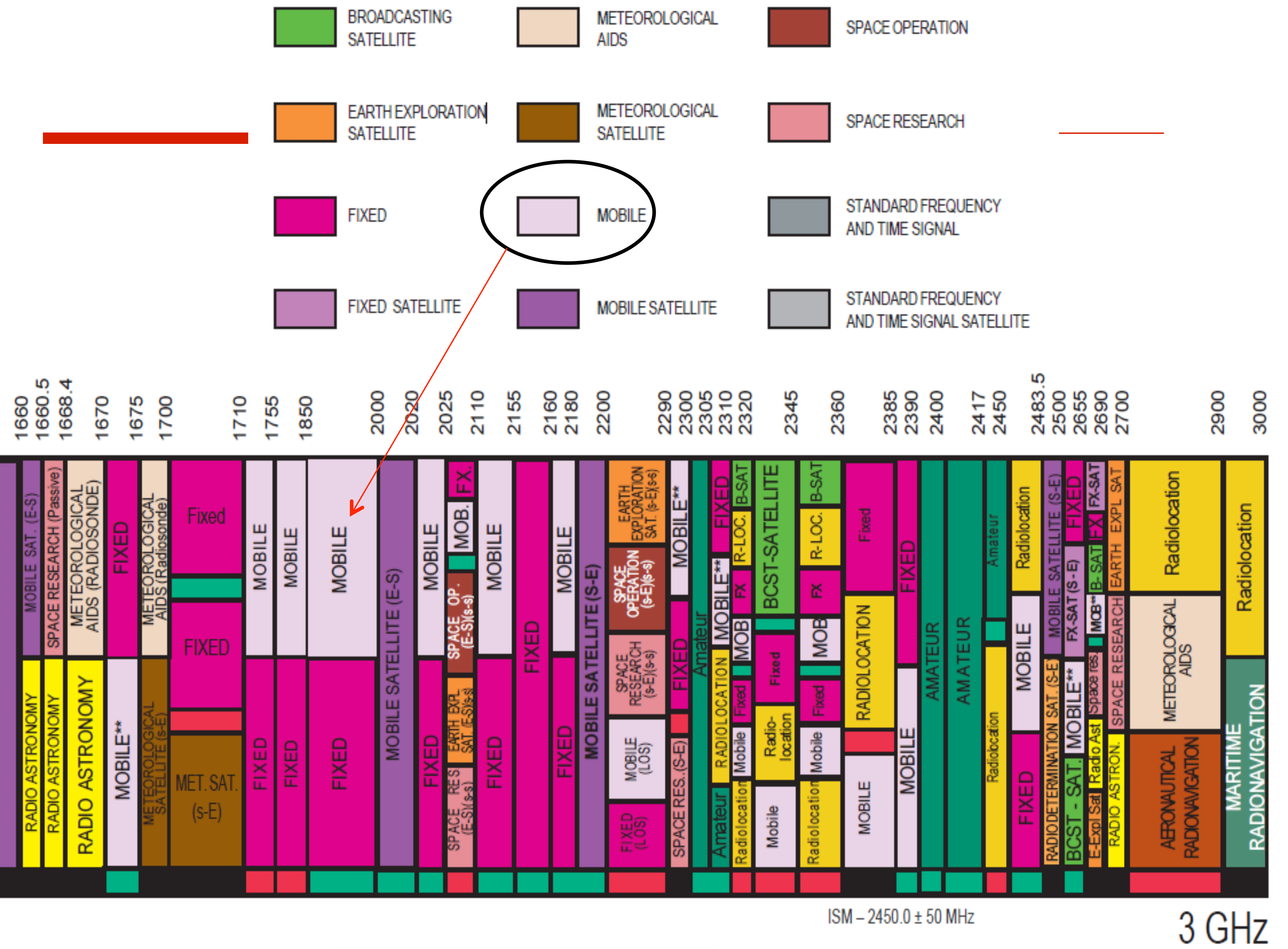
Bluetooth and IEEE 802.11b : 2.45 GHz band (wavelength =12.2 cm)

–Standard for **5.2 GHz** NII band (300 MHz)

–**Unlicensed National Information Infrastructure (U-NII) band , USA**

Very Crowded RF spectrum





BROADCASTING SATELLITE
METEOROLOGICAL AIDS
SPACE OPERATION
EARTH EXPLORATION SATELLITE
METEOROLOGICAL SATELLITE
SPACE RESEARCH
FIXED
MOBILE
STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE
MOBILE SATELLITE
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
1660
1660.5
1668.4
1670
1675
1700
1710
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1850
2000
2020
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2110
2155
2160
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2300
2305
2310
2320
2345
2360
2385
2390
2400
2417
2450
2483.5
2500
2655
2690
2700
2900
3000
MOBILE SAT. (E-S)
SPACE RESEARCH (Passive)
METEOROLOGICAL AIDS (RADIOSONDE)
FIXED
METEOROLOGICAL AIDS (Radiosonde)
Fixed
FIXED
MET. SAT. (s-E)
RADIO ASTRONOMY
RADIO ASTRONOMY
RADIO ASTRONOMY
MOBILE**
METEOROLOGICAL SATELLITE (s-E)
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SPACE OP. (E-S)(s-s)
EARTH EXPL. SAT. (E-S)(s-s)
SPACE RES. (E-S)(s-s)
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MOBILE SATELLITE (S-E)
EARTH EXPLORATION SAT. (s-E)(s-s)
SPACE OPERATION (s-E)(s-s)
SPACE RESEARCH (s-E)(s-s)
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RADIOLOCATION
Amateur
B-SAT
R-LOC.
FX
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Mobile
Radiolocation
BCST-SATELLITE
Fixed
Radio-location
Mobile
B-SAT
R-LOC.
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MOB
Fixed
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Radiolocation
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RADIOLOCATION
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AMATEUR
AMATEUR
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Radiolocation
Radiolocation
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MOBILE SATELLITE (S-E)
RADIODETERMINATION SAT. (S-E)
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FX-SAT (S-E)
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BCST - SAT.
FX-SAT
B-SAT
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EARTH EXPL SAT
SPACE RESEARCH
RADIO ASTRON.
Radiolocation
METEOROLOGICAL AIDS
AERONAUTICAL RADIONAVIGATION
Radiolocation
MARITIME RADIONAVIGATION
ISM – 2450.0 ± 50 MHz
3 GHz

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

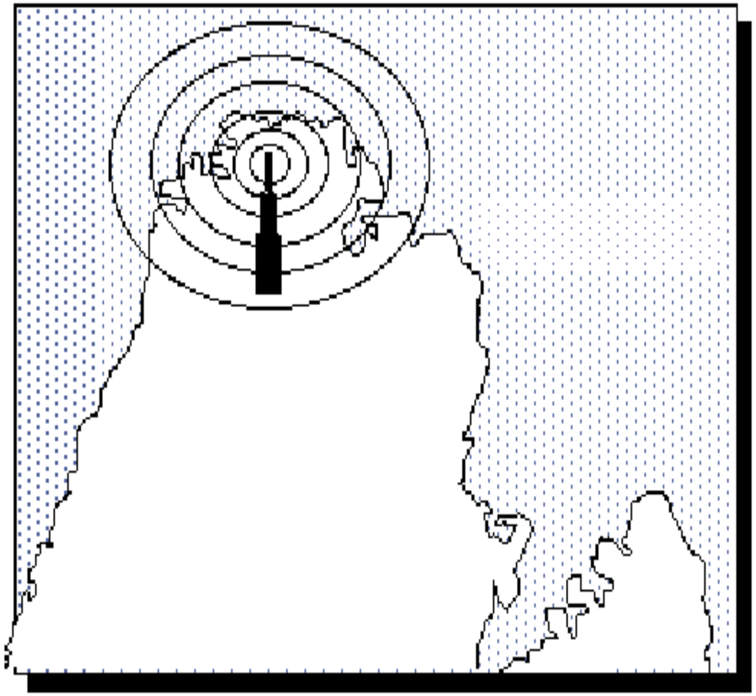
Cellular mobile phone networks basics

Cellular Network Fundamentals

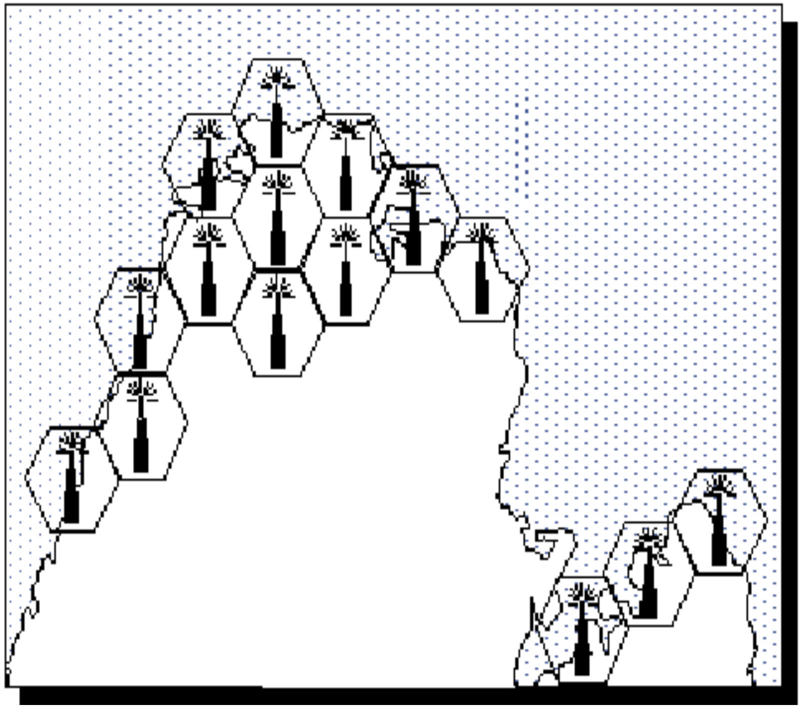
Rank	Country or region	Number of mobile phones	Population	% of population	Last updated date
	World	Over 6.6 billion	7,012,000,000[1]	79.86	2011[2]
1	China	1,010,000,000	1,341,000,000[3]	75.32	March 2012[4][5][6]
2	India	919,170,000	1,210,193,422[7]	76.00	Mar 2012 [8]
3	United States	327,577,529	310,866,000[9]	103.9	June 2011[10]
4	Brazil	250,800,000	192,379,287 [11]	130.36	April 2012[12]
5	Indonesia	250,100,000	237,556,363	105.28	May 2009[13]
6	Russia	224,260,000	142,905,200[14]	154.5	July 2011[15]
7	Japan	121,246,700	127,628,095	95.1	June 2011[16]
8	Pakistan	114,610,000	178,854,781[17]	66.5	Jan 2012[18] [19]
9	Germany	107,000,000	81,882,342	130.1	2009[20]
10	Nigeria	90,583,306	140,000,000	64.7	Feb. 2011[21]

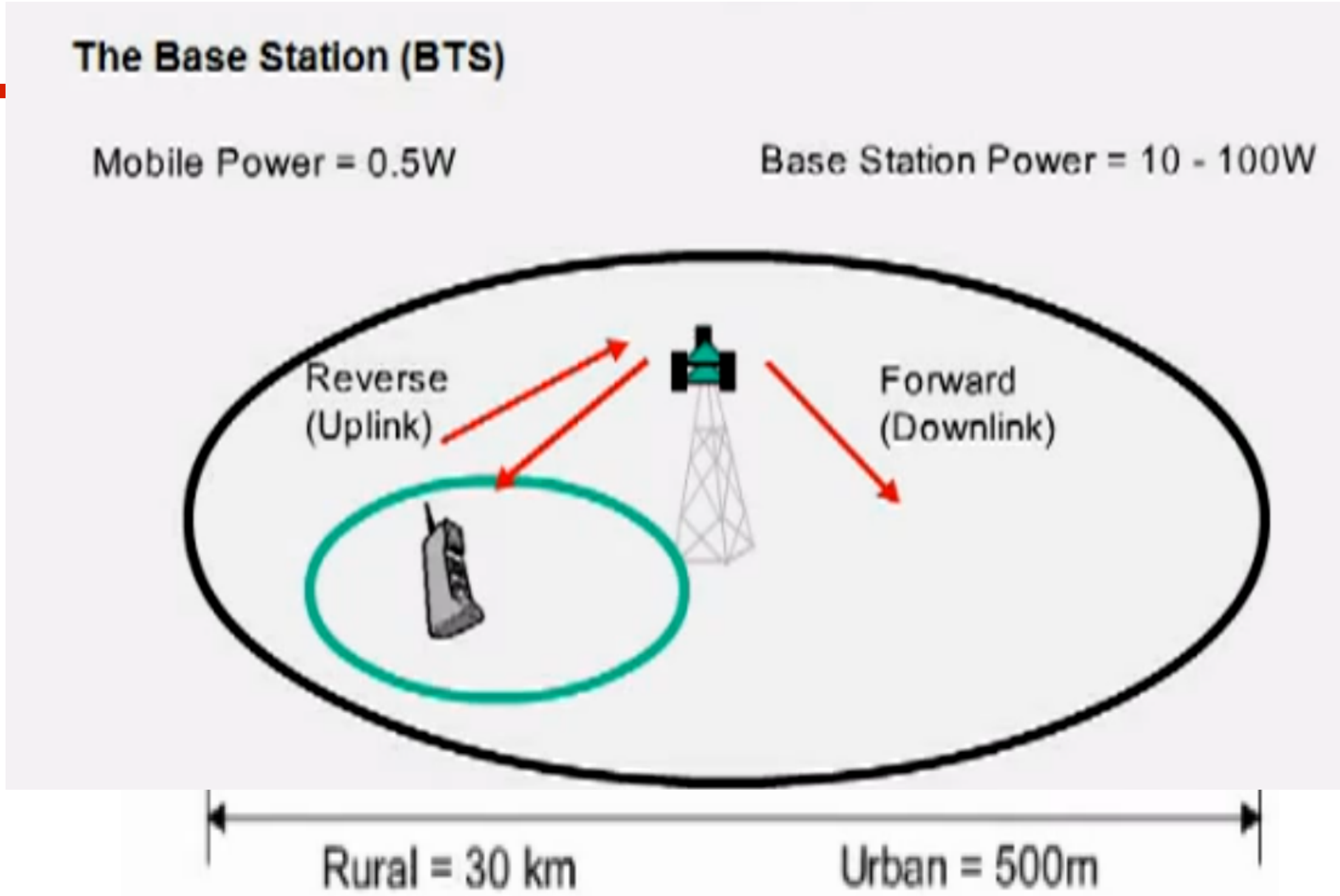
Cellular Telephone Systems

Early Mobile Telephone System Architecture



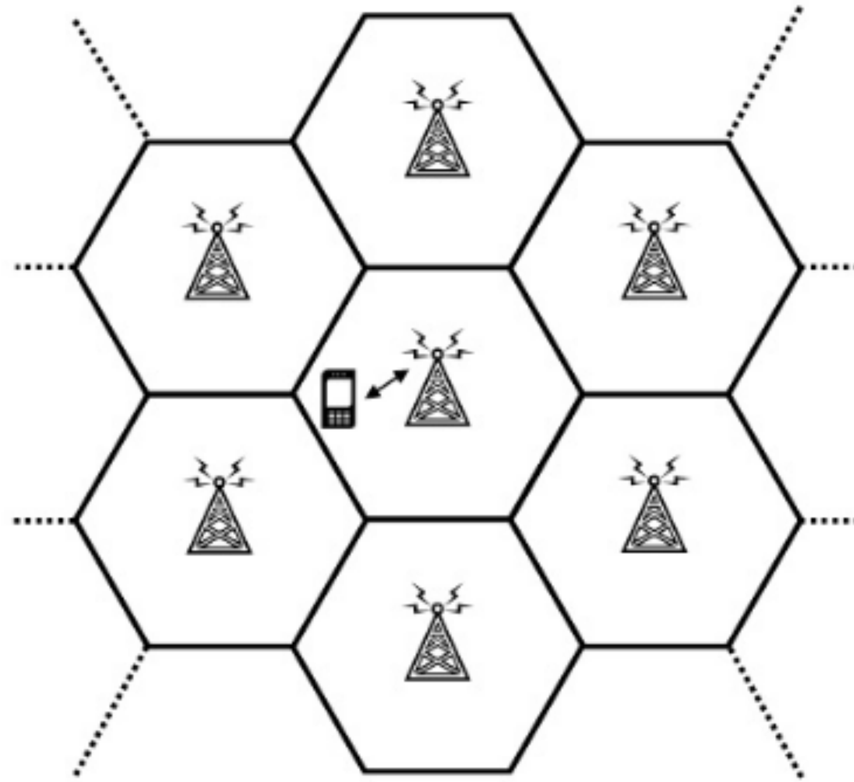
Mobile Telephone System Using Cellular Architecture

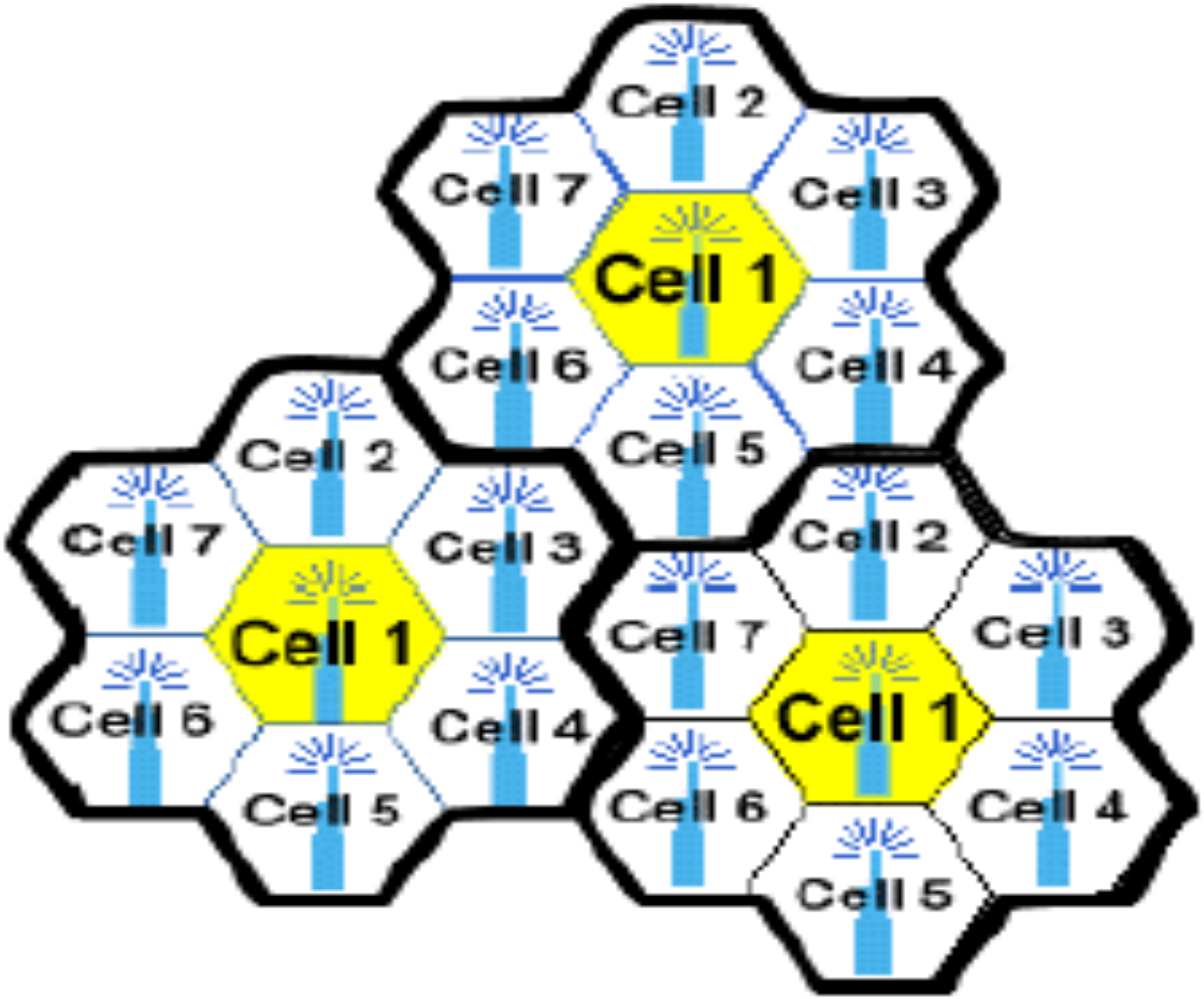



The Base Station (BTS)
Mobile Power = 0.5W
Base Station Power = 10 - 100W
Reverse
(Uplink)
Forward
(Downlink)
Rural = 30 km
Urban = 500m

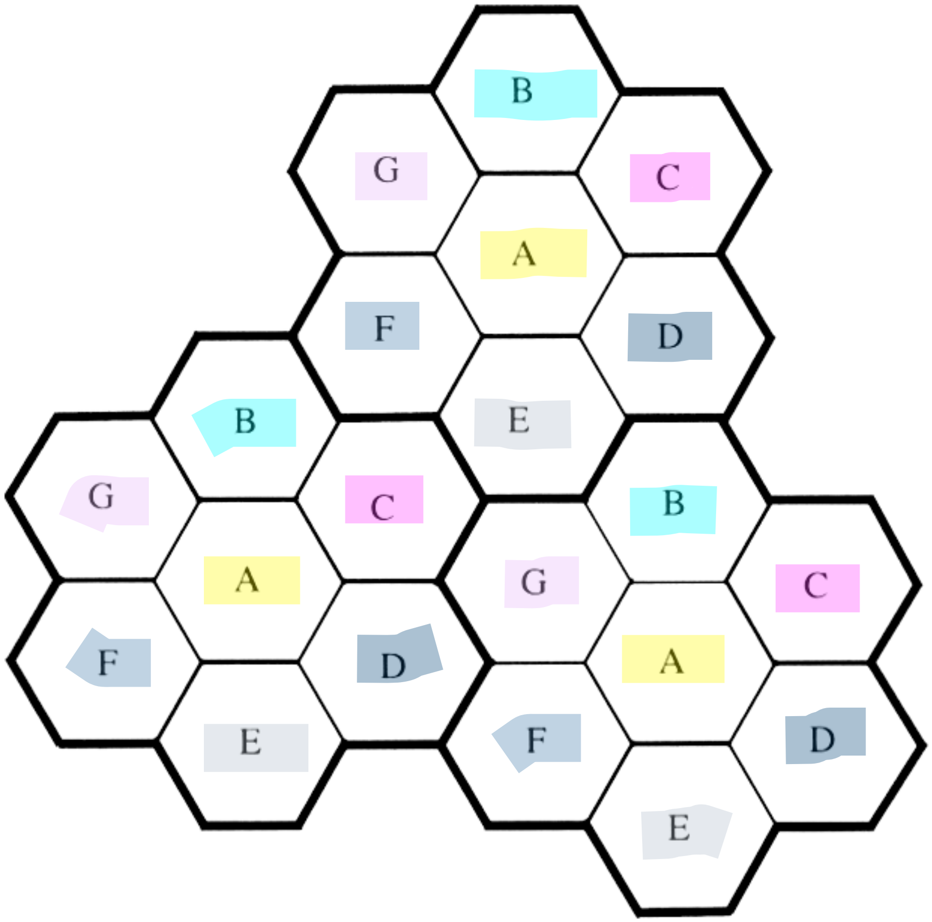
Cellular Wireless System

- A large geographical region is segmented into smaller "cell"s.
  - Transmit power limitation
  - Facilitates frequency spectrum re-use
- Cellular network design issues
  - Inter-cell synchronization
  - Handoff mechanism
  - Frequency planning

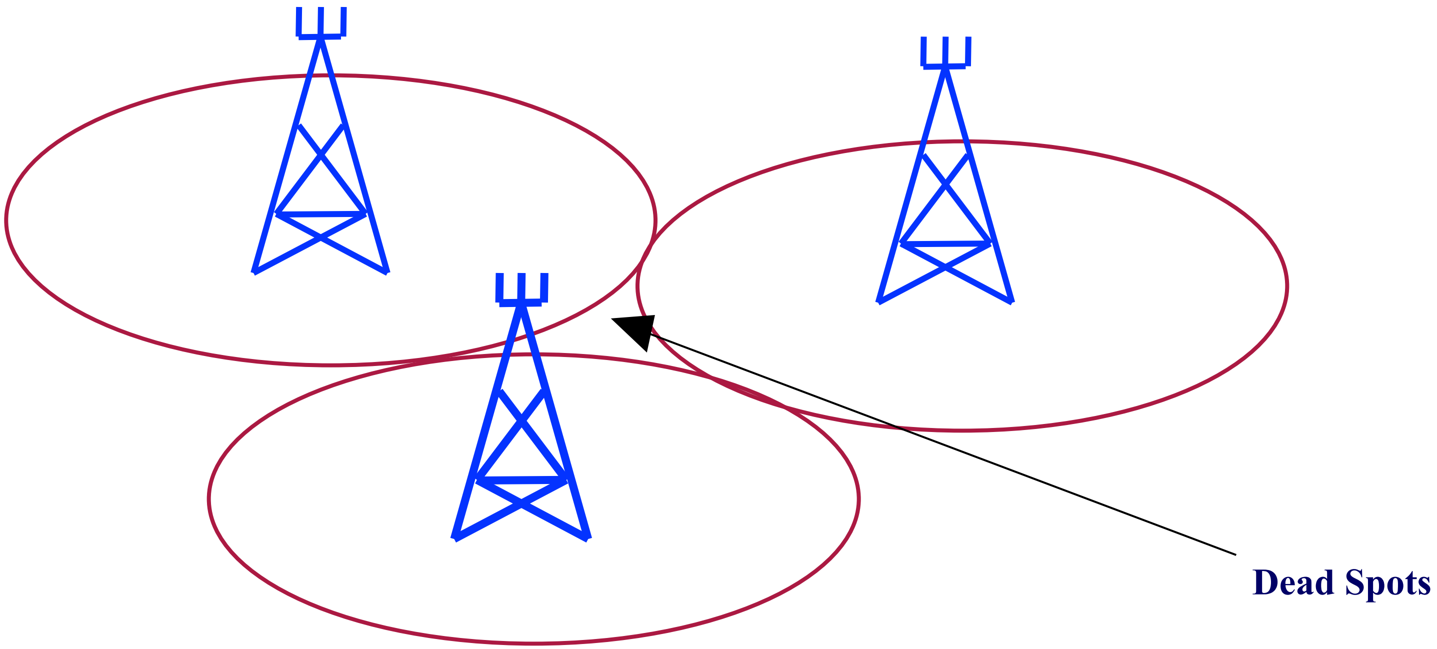



Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5

The Cellular Concept



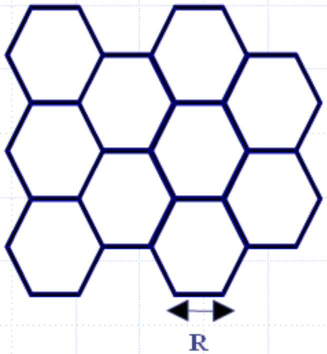
Cell Geometry, Radio Coverage

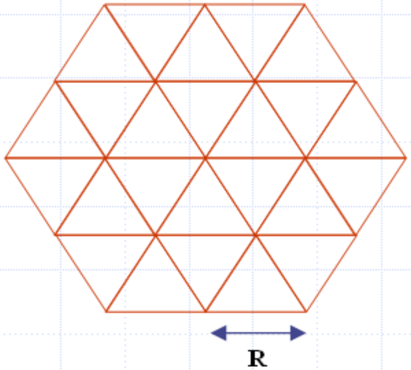


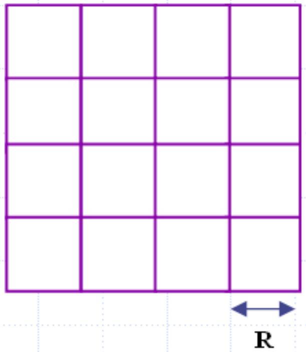
Problem of omni directional antennas

Cell Geometrical Shape

To solve the dead spot problem



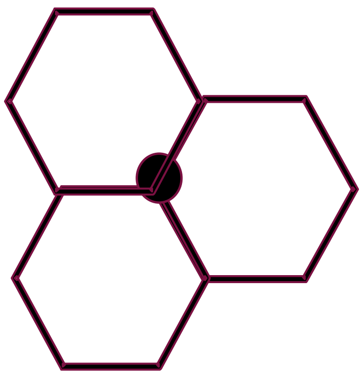




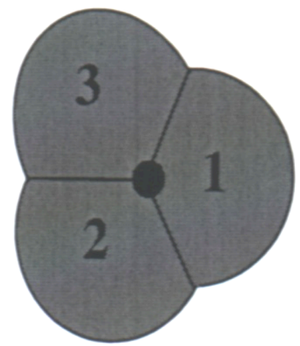
Tradeoffs

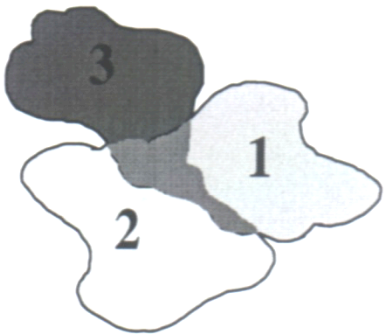
- The number of cells required to cover a given area.
- The cell transceiver power.

Sectorial Antenna



Sectorial Antenna

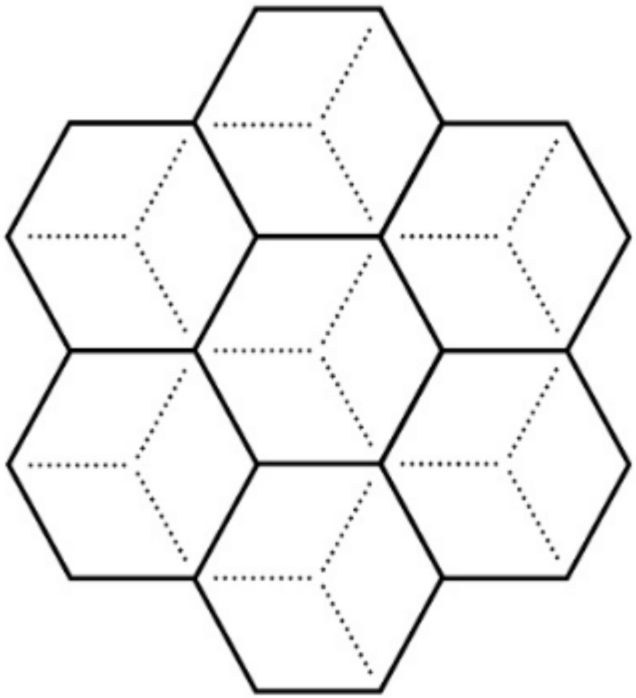




The cells will take the form of overlapping circles.

Due to the obstacles in the coverage area the actual shape of the cells would be Random.

- Sectorized cells



Cellular system

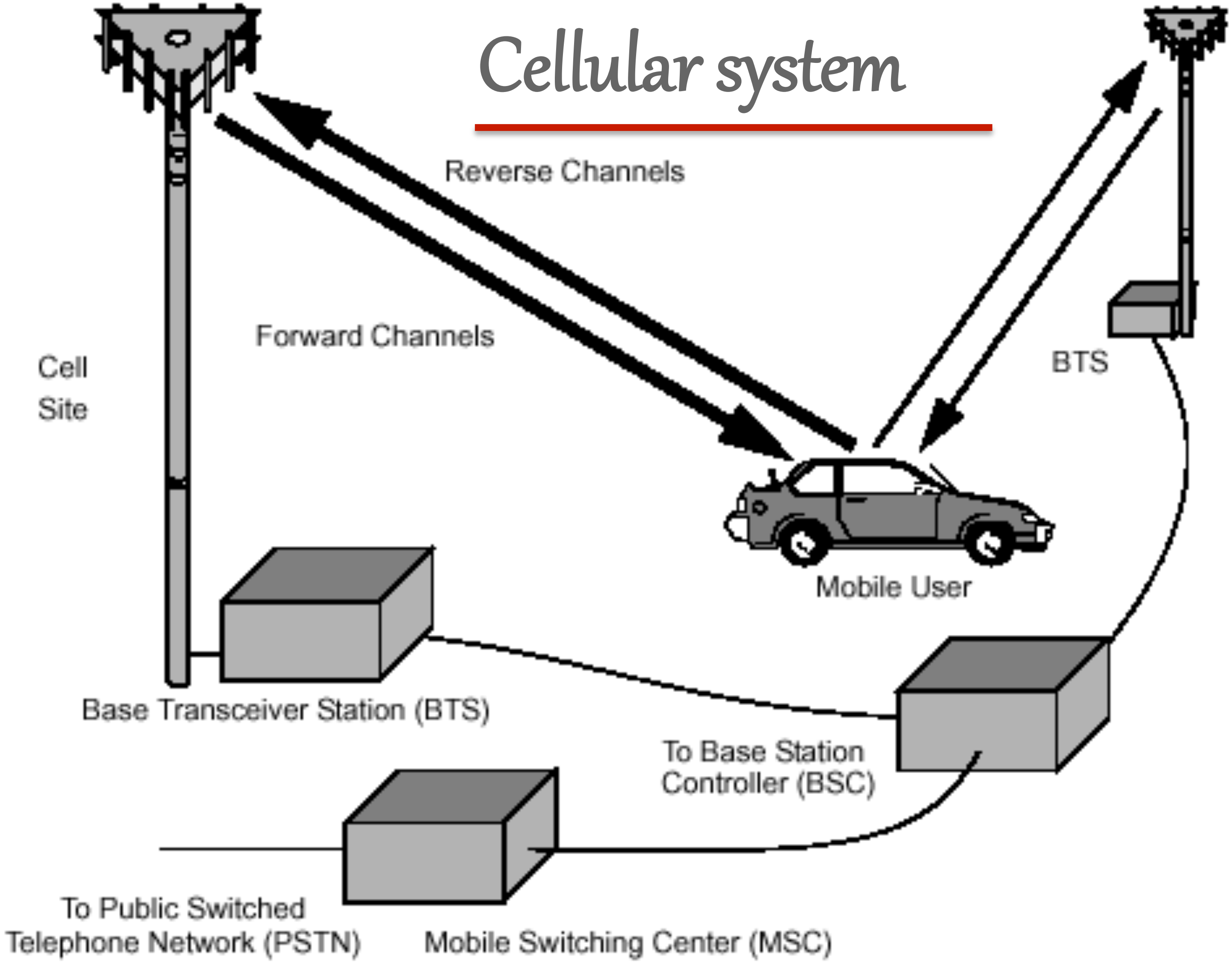


Figure 1–3 There are two main types of forward channels. Control and access channels are used to set up calls and provide security and management functions. Traffic channels are used to carry voice traffic. The reverse channels are also divided into access channels and traffic channels. In some systems, 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.

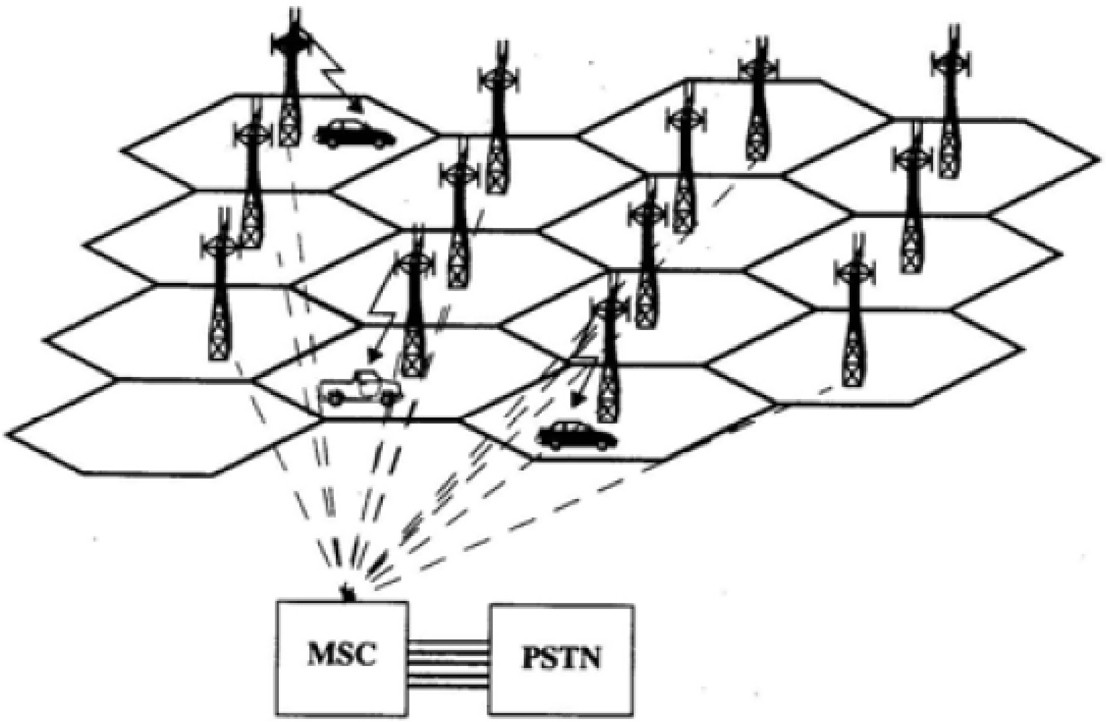
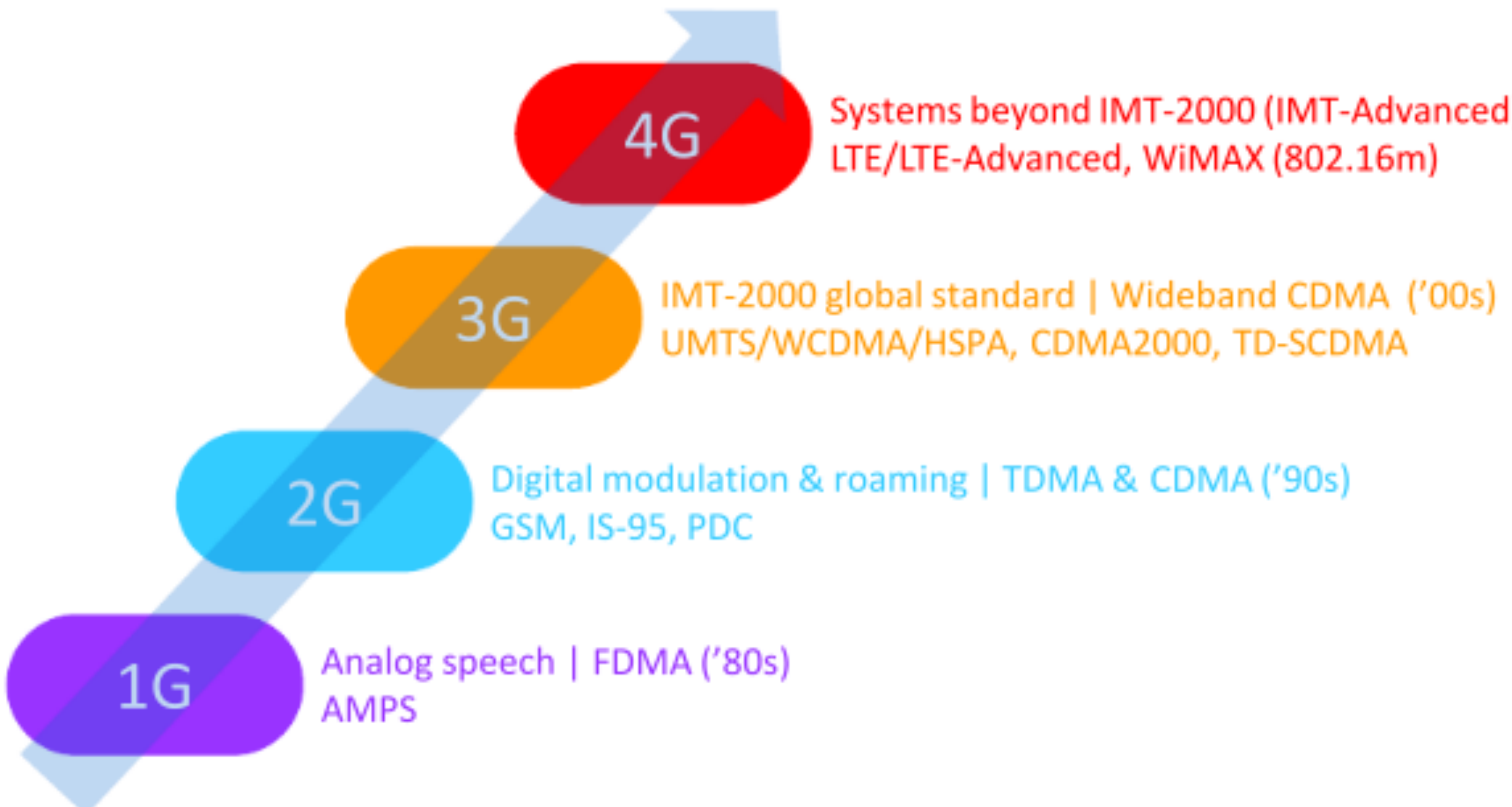


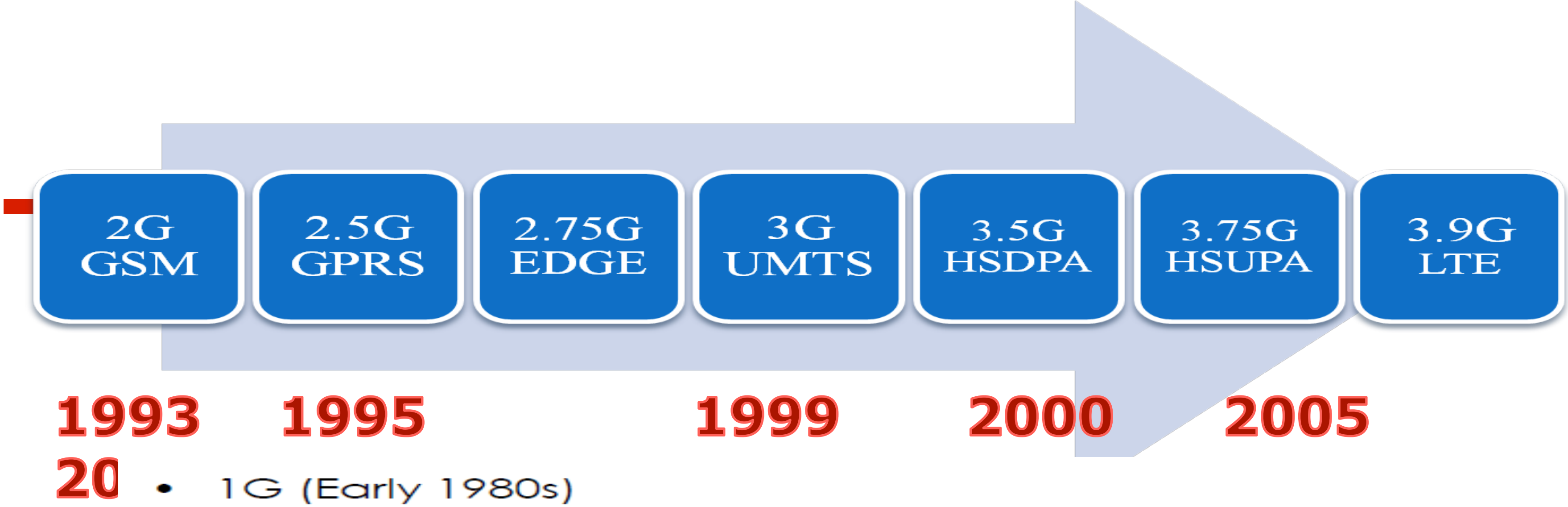
Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

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

Cellular system Evolution



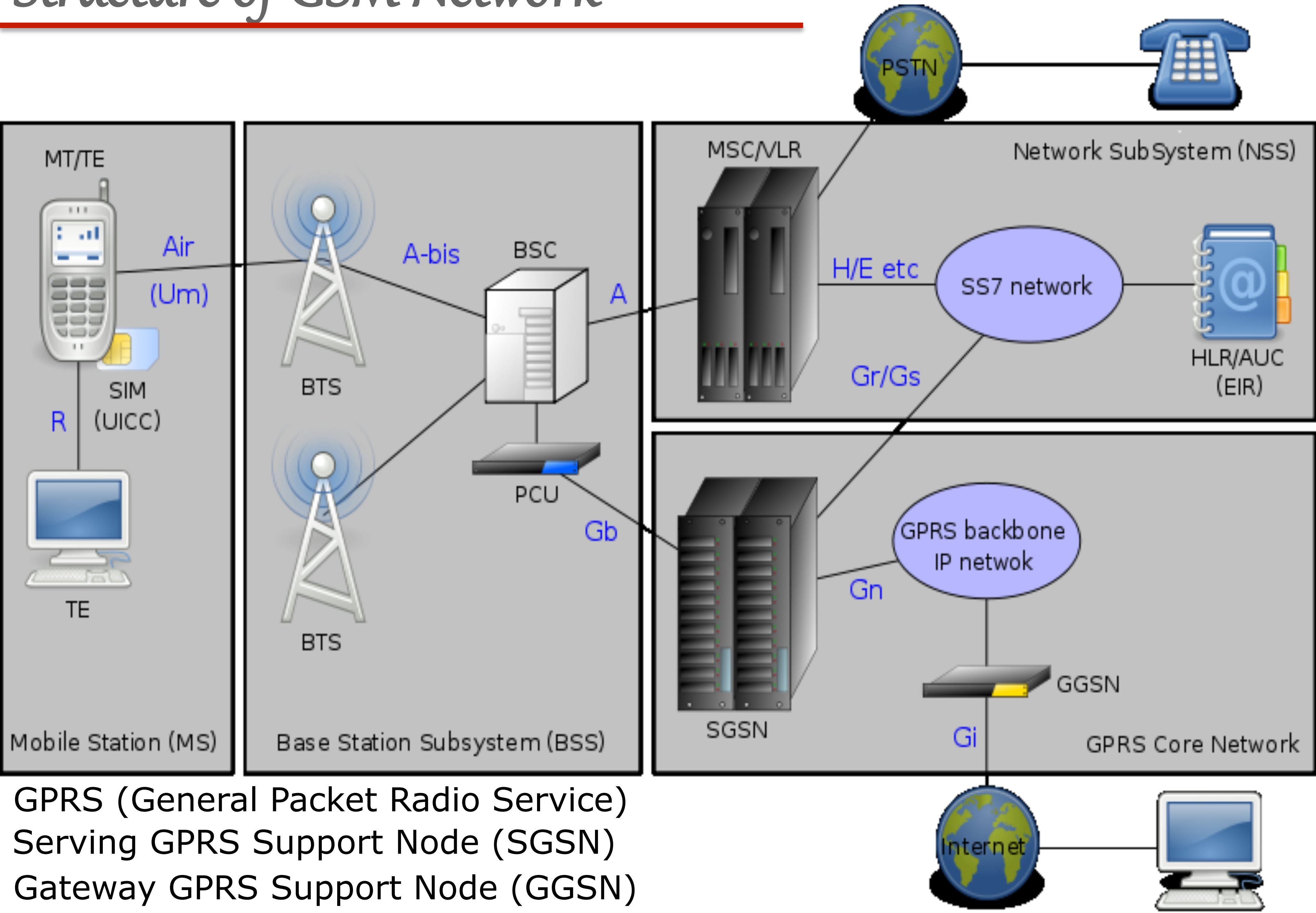


- 1G (Early 1980s)
  - Analog speech communications.
  - Analog FDMA.
  - Ex: AMPS
- 2G (Early 1990s)
  - Digital modulation of speech communications.
  - Advanced security and roaming.
  - TDMA and narrowband CDMA.
  - Ex: GSM, IS-95 (cdmaOne), and PDC
- 3G (Late 1990s)
  - Global harmonization and roaming.
  - Wideband CDMA
  - Ex: UMTS, cdma2000, and TD-SCDMA

- **2.5G – GPRS (General Packet Radio Service)**
- 2.75G- Enhanced Data Rates for GSM Evolution (EDGE)
- 3.5G- High Speed Downlink Packet Access (HSDPA)
- 3.75G- High Speed Uplink Packet Access (HSUPA)
- 3.9G- Evolved High Speed Packet Access (HSPA+)

Generation	Frequency	Definition	throughput	Technology
1G (1981-1996)	800-900 MHz (BW = 30 kHz)	Analog (FM) Voice	14.4 Kbps (peak)	AMPS, NMT, TACS ETACS
2G (1996-2000)	900/1800 MHz 850/1900 MHz (BW = 200KH)	Digital Narrowband Circuit Switching Data Voice Messaging (SMS)	9.6 / 14 Kbps	GSM/DCS - 1900 TDMA(IS-136) CDMA (IS95- CDMA-one)
2.5G, 2.75G		Packet Switching Data WAP +MMS	56 kbit/s up to 115 kbit/s	GPRS, EDGE
3G (2001-2010) (wideband-Global)	2GHz + 1920 -2170MHz (BW=5MHz)	Digital Broadband Packet Switching Data (High speed data Multimedia)	3.1 Mbps (Peak) 500-700 Kbps	CDMA2000 (Verizon, Sprint) UMTS, WCDMA (AT&T, T-Mobile+ Europe)
3.5G 3.75G		>2 Mbps	14.4 Mbps (peak) 1-3 Mbps 42 Mbps (peak)& 28 Mbps → 2x2 MIMO 672 Mbps	HSPA: HSDPA, HSUPA HSPA+
4G (2012+) (Broadband) 5G=Gigabit	LTE (3GPP) LTE-A (3GPP2)	Digital Broadband All IP (voice +data) Very High	100-300 Mbps (peak) 100 -1000 Mbps (peak) 3-5 Mbps	LTE (WCDMA) Mobile WIMAX, IEEE802.16 (d,e,m) UBM (IP networks)

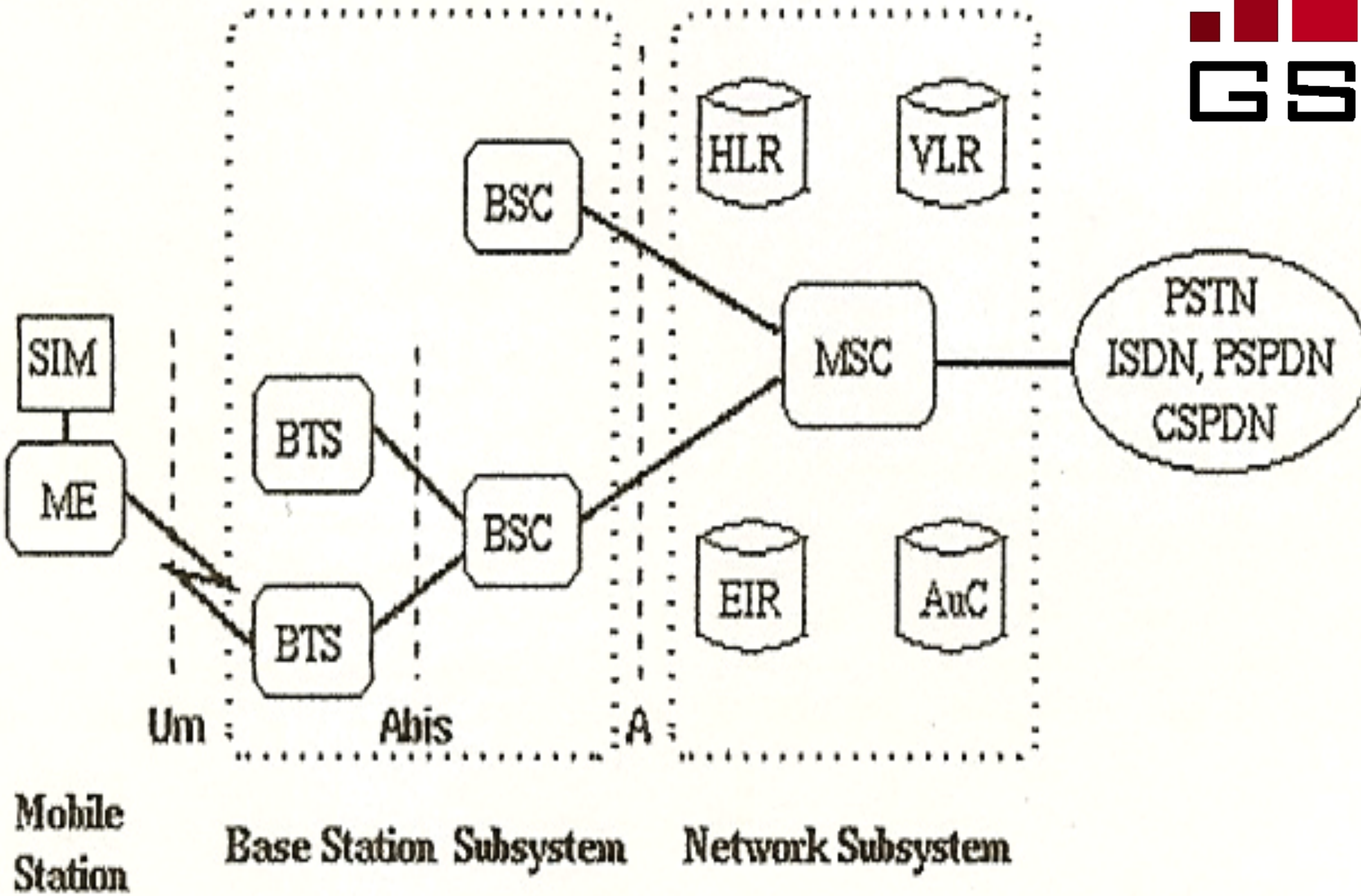
Structure of GSM Network



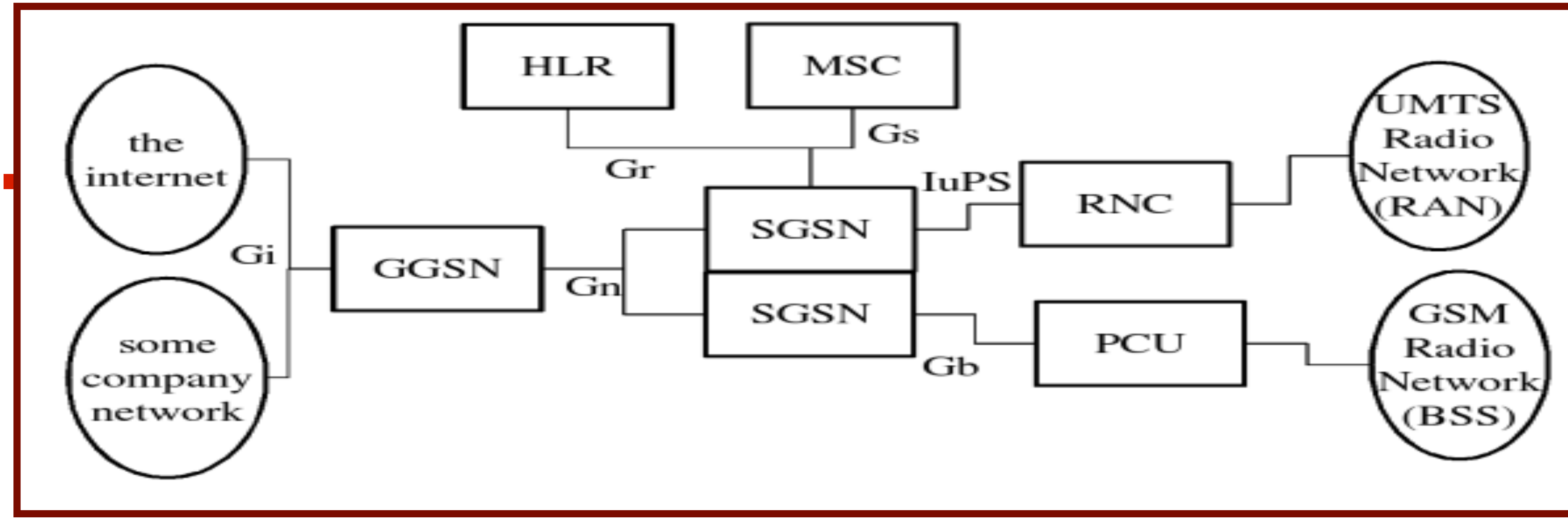
GPRS (General Packet Radio Service)
Serving GPRS Support Node (SGSN)
Gateway GPRS Support Node (GGSN)

System Architecture

- Mobile Station (MS)
  - Mobile Equipment (ME)
  - Subscriber Identity Module (SIM)
- Base Station Subsystem (BBS)
  - Base Transceiver Station (BTS)
  - Base Station Controller (BSC)
- Network Subsystem
  - Mobile Switching Center (MSC)
  - Home Location Register (HLR)
  - Visitor Location Register (VLR)
  - Authentication Center (AUC)
  - Equipment Identity Register (EIR)



SIM Subscriber Identity Module
ME Mobile Equipment
BTS Base Transceiver Station
BSC Base Station Controller
HLR Home Location Register
VLR Visitor Location Register
MSC Mobile services Switching Center
EIR Equipment Identity Register
AuC Authentication Center



The GPRS core network is the central part which allows 2G, 3G and WCDMA mobile networks to transmit IP packets to external networks such as the Internet provides mobility management, session management and transport for Internet Protocol packet services in GSM and WCDMA networks.

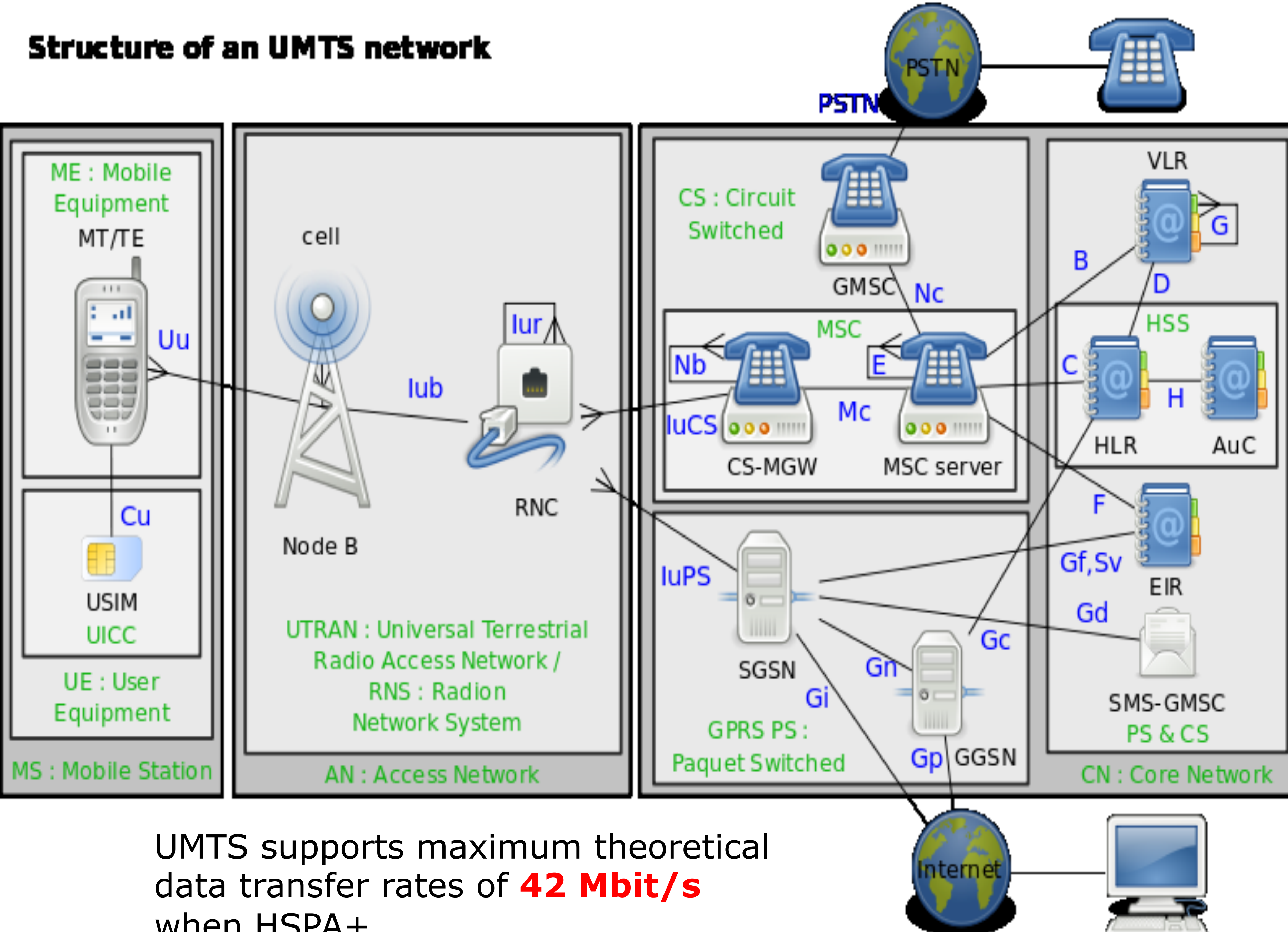
Gateway GPRS Support Node (GGSN): is responsible for the interworking between the GPRS network and external packet switched networks

Serving GPRS Support Node (SGSN): is responsible for the delivery of data packets from and to the mobile stations within its geographical service area.

Packet control unit: The allocation of channels between voice and data is controlled by the base station, but once a channel is allocated to the PCU, the PCU takes full control over that channel.

The Radio Network Controller (or RNC): is a governing element in the UMTS radio access network (UTRAN) and is responsible for controlling the Node Bs that are connected to it..

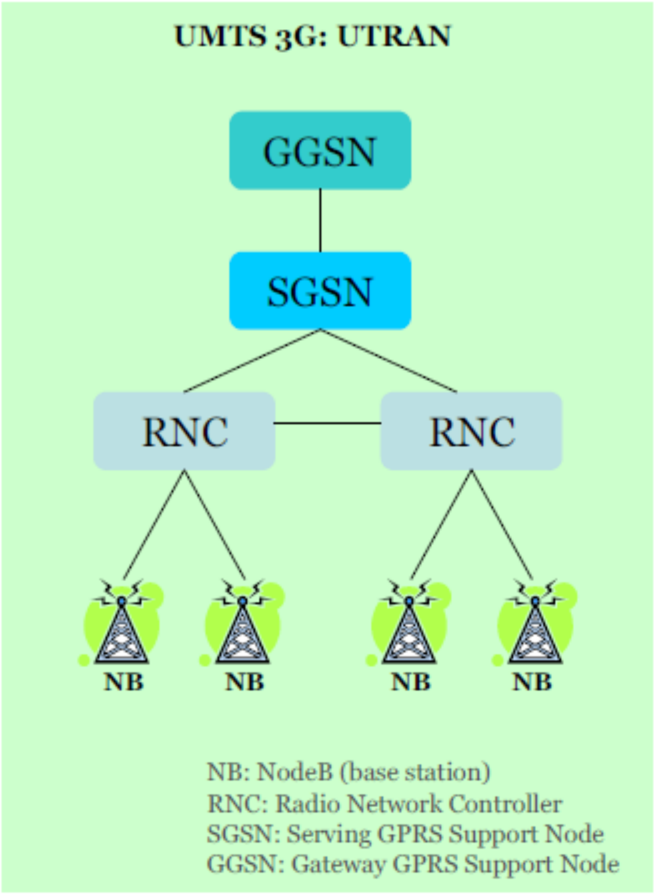
Structure of an UMTS network

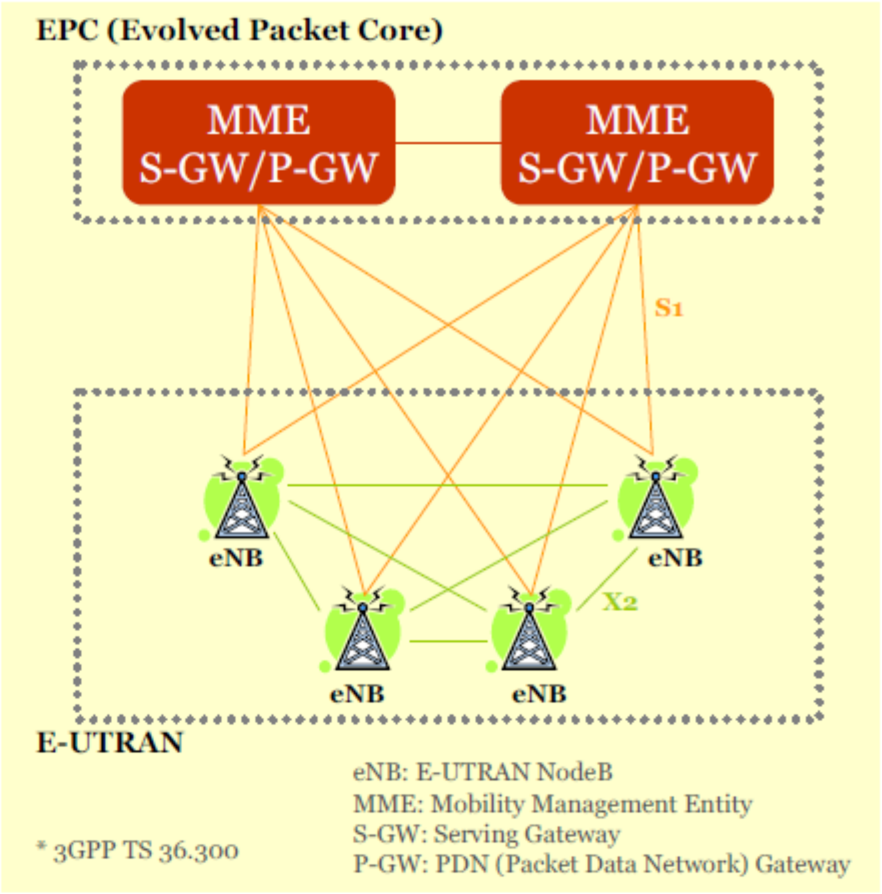


UMTS supports maximum theoretical data transfer rates of **42 Mbit/s** when HSPA+

LTE Network Architecture

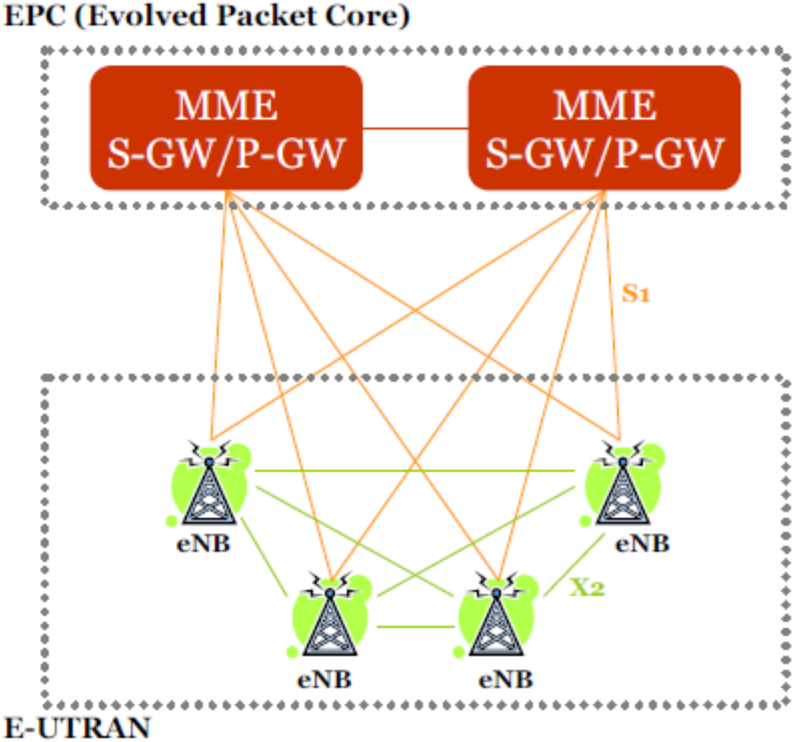
- E-UTRAN (Evolved Universal Terrestrial Radio Access Network)





LTE Network Architecture

- eNB
  - All radio interface-related functions
- MME
  - Manages mobility, UE identity, and security parameters.
- S-GW
  - Node that terminates the interface towards E-UTRAN.
- P-GW
  - Node that terminates the interface towards PDN.



* 3GPP TS 36.300

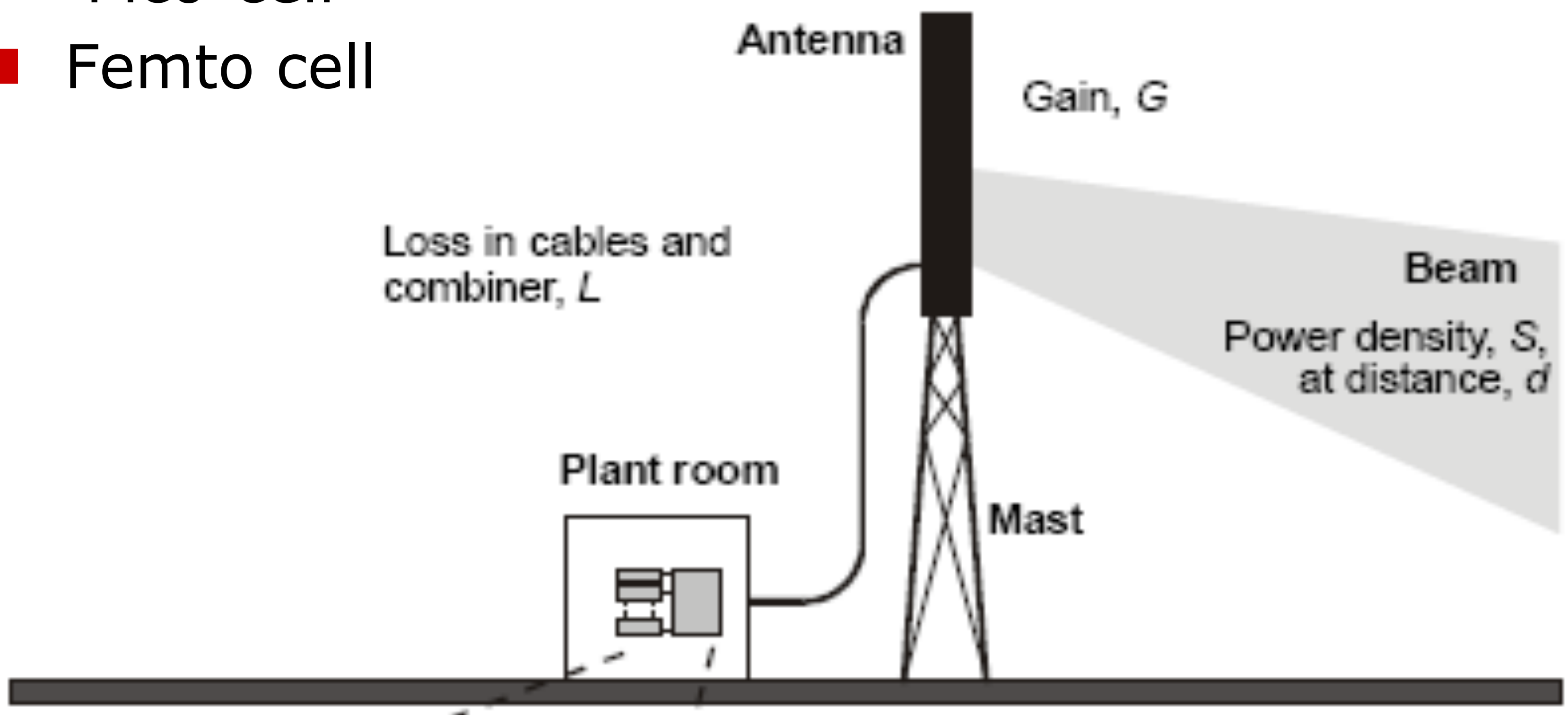
eNB: E-UTRAN NodeB
MME: Mobility Management Entity
S-GW: Serving Gateway
P-GW: PDN (Packet Data Network) Gateway

Types and Structure of Base Station

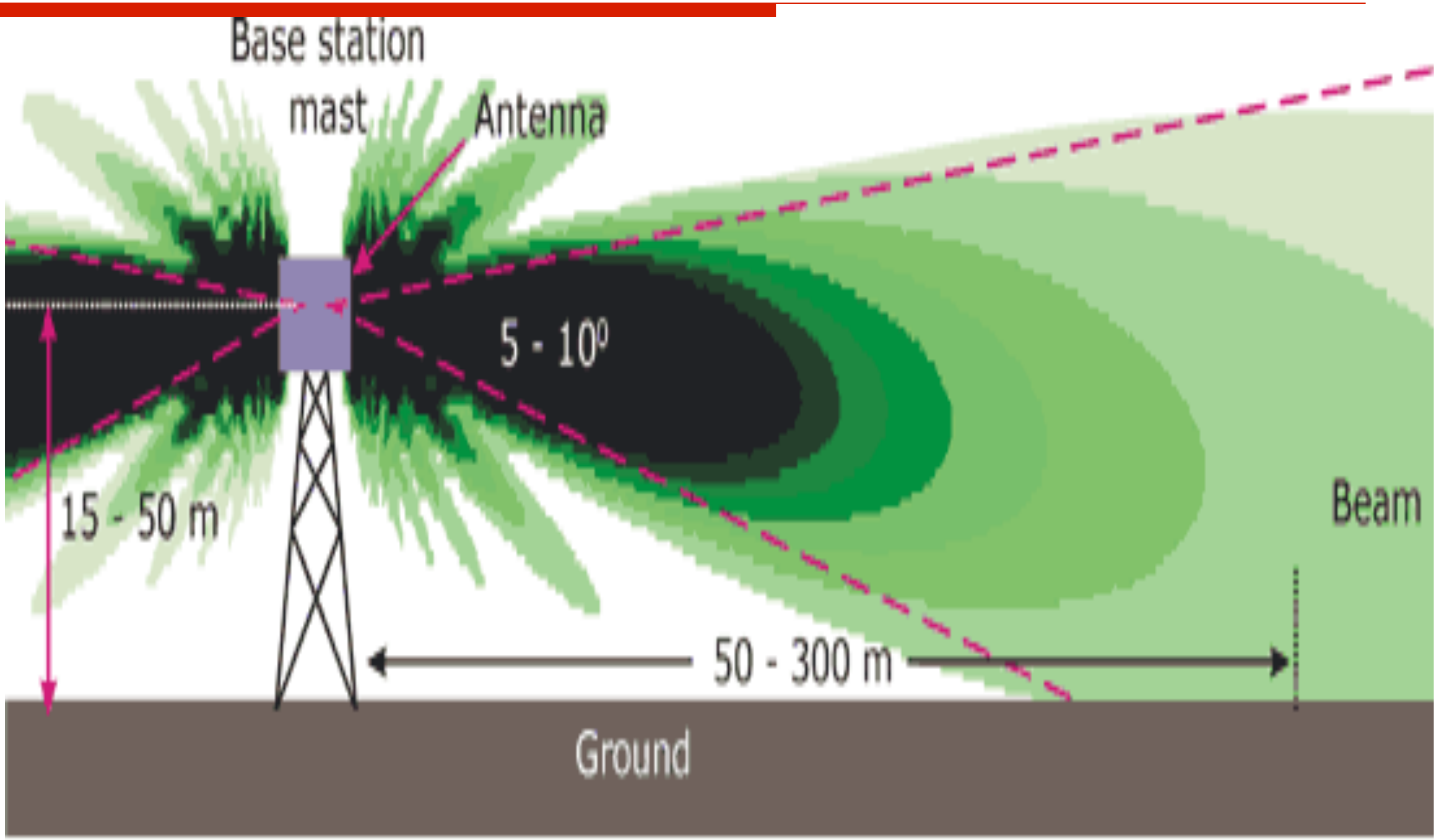
types of Base stations:

- Macro-cell
- Micro-cells
- Pico-cell
- Femto cell

The base station consists of : **plants room, mast, Antenna and cables.**



RF Beamfrom the Base Station



Base Station Antenna 1800 MHz PCS & GSM (Sectored cells)

Frequency Range	1710-1990 MHz
Bandwidth	170 MHz
Gain	12.5 dBi
VSWR	≤ 1.5
Nominal Impedance	50 ohm
Polarization	Vertical
Maximum Power	100 W
Connector	N Female
3dB Beamwidth Horizontal Plane	120°
3dB Beamwidth Vertical Plane	16°
F/B	> 25 dB
Dimension	600 × 100 × 80 mm
Weight	6 kg / 13.23 lb

Main characteristics of a GSM hand-held terminal transmitter

	GSM 900	DCS 1800
Frequency band	890 – 915 MHz	1710 – 1785 MHz
Channel width	200 kHz	200 kHz
Peak radiated power	2 W	1 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK
Maximum average radiated power	250 mW	125 mW

Main characteristics of a GSM base-station transmitter

	GSM 900	DCS 1800
Frequency band	935 – 960 MHz	1805 – 1880 MHz
Channel width	200 kHz	200 kHz
Peak radiated power (typical)	30 W	30 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK


base station antenna in Mexico City, Mexico. There are three antennas: each serves a 120-degree segment of the horizon. The microwave dish links the site with the telephone


492 F High Point Road in Gaffney, South Carolina.


Two GSM base stations disguised as trees in Dublin, Ireland.


Cell tower disguised as a palm tree in Tucson, Arizona






The Beginning

Dyna-Tac

New Take-Along Telephones Give You Pushbutton Calling to Any Number

This amazing phone system could handle thousands of calls simultaneously, patching yours directly into a phone exchange

By JOHN R. FREE

Handsets Evolution (from the brick to the slick)

1983: Motorola DynaTAC 8000X

Analog voice

World's first handheld cellular phone call in public

On April 3, 1973, Motorola installed a base station to handle the first public demonstration of a phone call over the cellular network

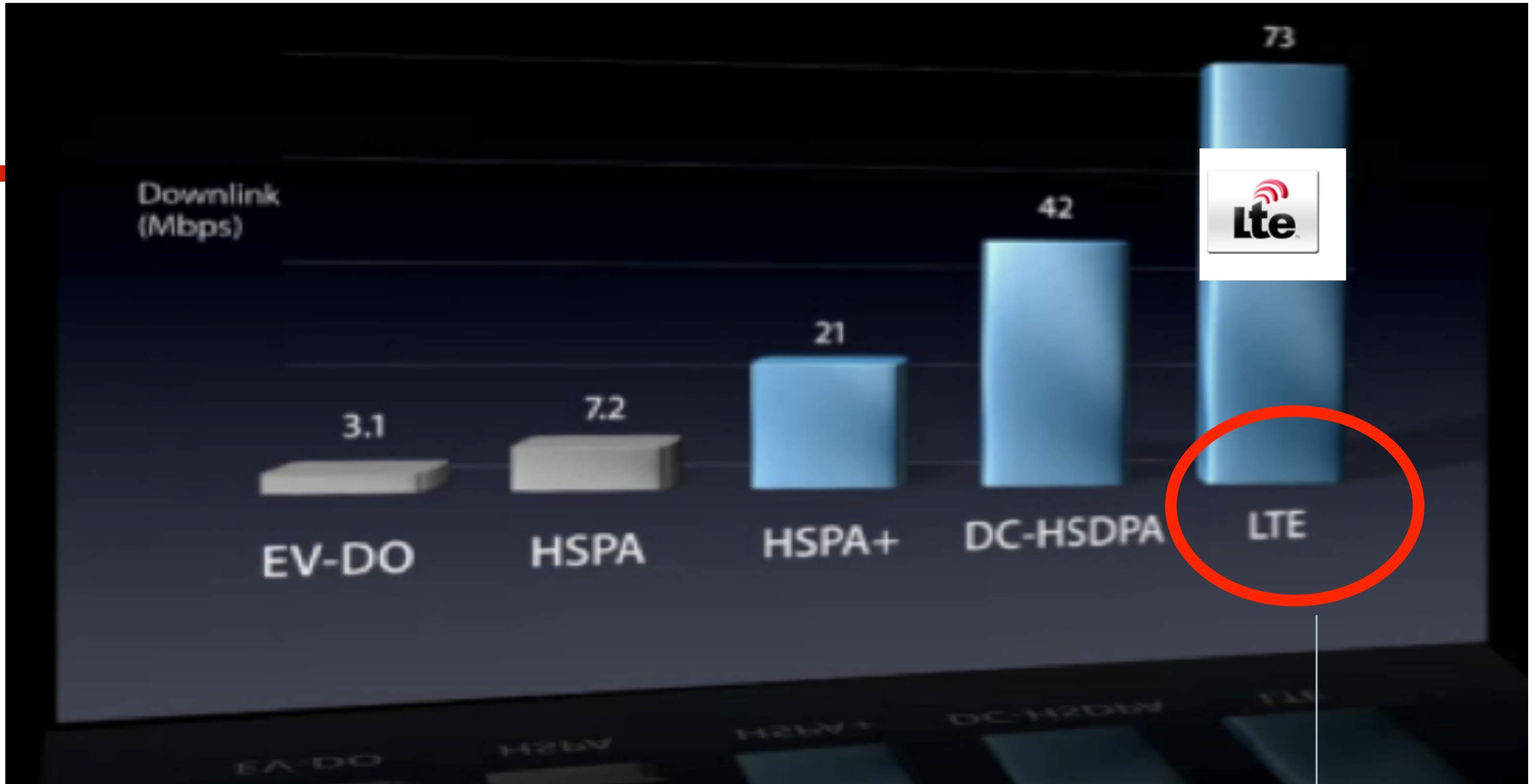
weighed about 2.5 lb (1.1 kg).

Cooper and Motorola took the cellular phone technology to **New York** to demonstrate it to reporters and the public, standing on **Sixth Avenue** in New York City near the New York Hilton hotel, Cooper made a phone call from a prototype **Dyna-Tac** handheld cellular phone before going to a press conference upstairs in the

Mobile phone systems Evolution (the road to 4Gand What is LTE?)

2012: The year LTE becomes a standard, not a luxury

4G LTE. The fastest cellular network.



[What is LTE?]

Wifi+ 4G

Fundamental Constraints

- Shannon's capacity upper bound
  - Achievable data rate is fundamentally limited by bandwidth and signal -to-noise ratio (SNR).

Signal power

$$C = BW \cdot \log_2\left(1 + \frac{S}{N}\right) \text{ [bits per second]}$$

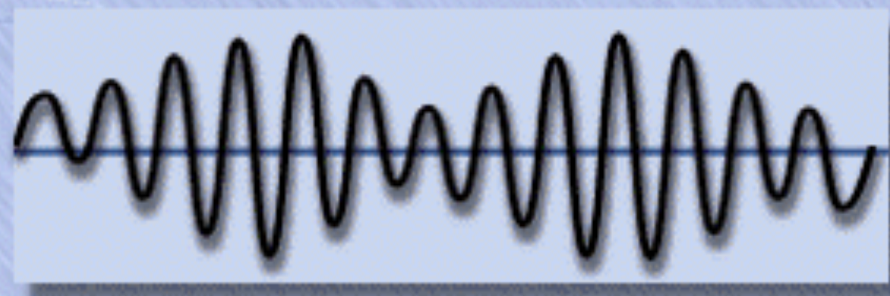
Channel bandwidth

Noise power

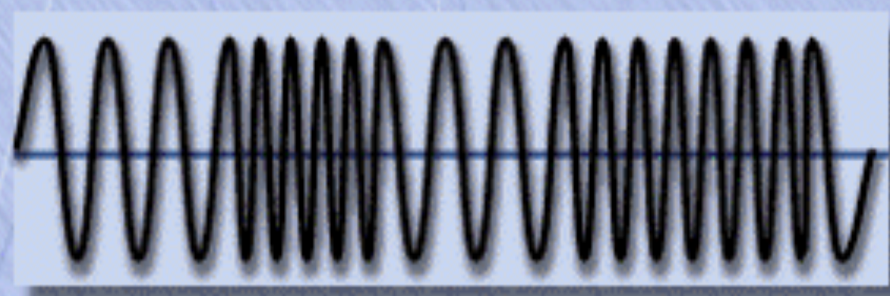
$$\eta = \frac{\text{Transmission Rate}}{\text{Channel Bandwidth } W} \; [\text{bits}/s/Hz].$$

- PSK requires too wide a bandwidth

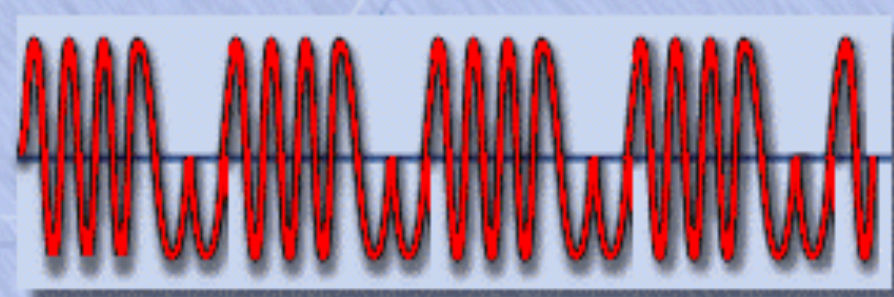
- Gaussian Minimum Shift Keying (GMSK) is actually used on the GSM air interface



AMPLITUDE MODULATION



FREQUENCY MODULATION

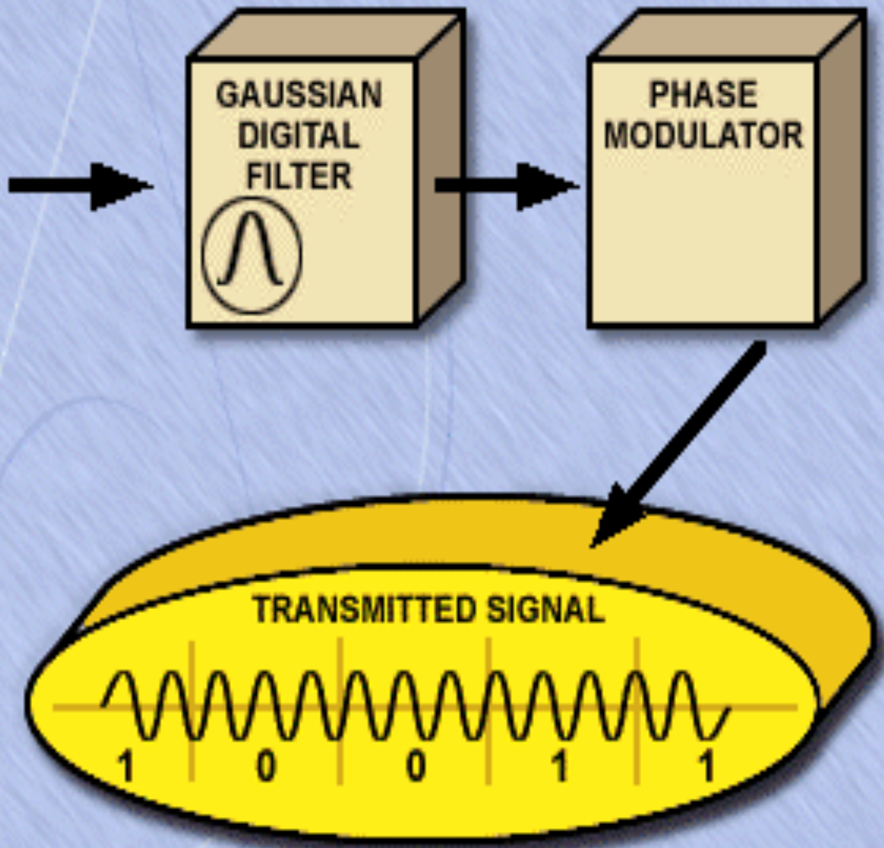


PHASE SHIFT KEYING (PSK)

By: Dr.Mohab Mangoud

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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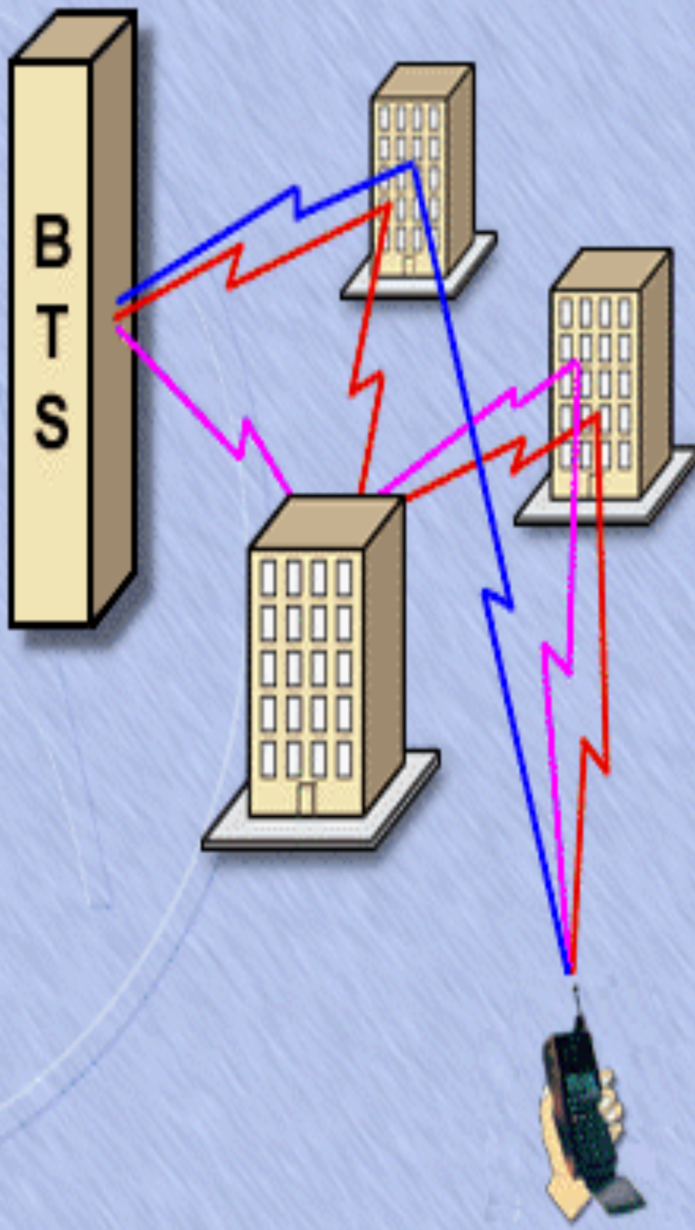
MULTIPATH FADING

- 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



By: Dr.Mohab Mangoud

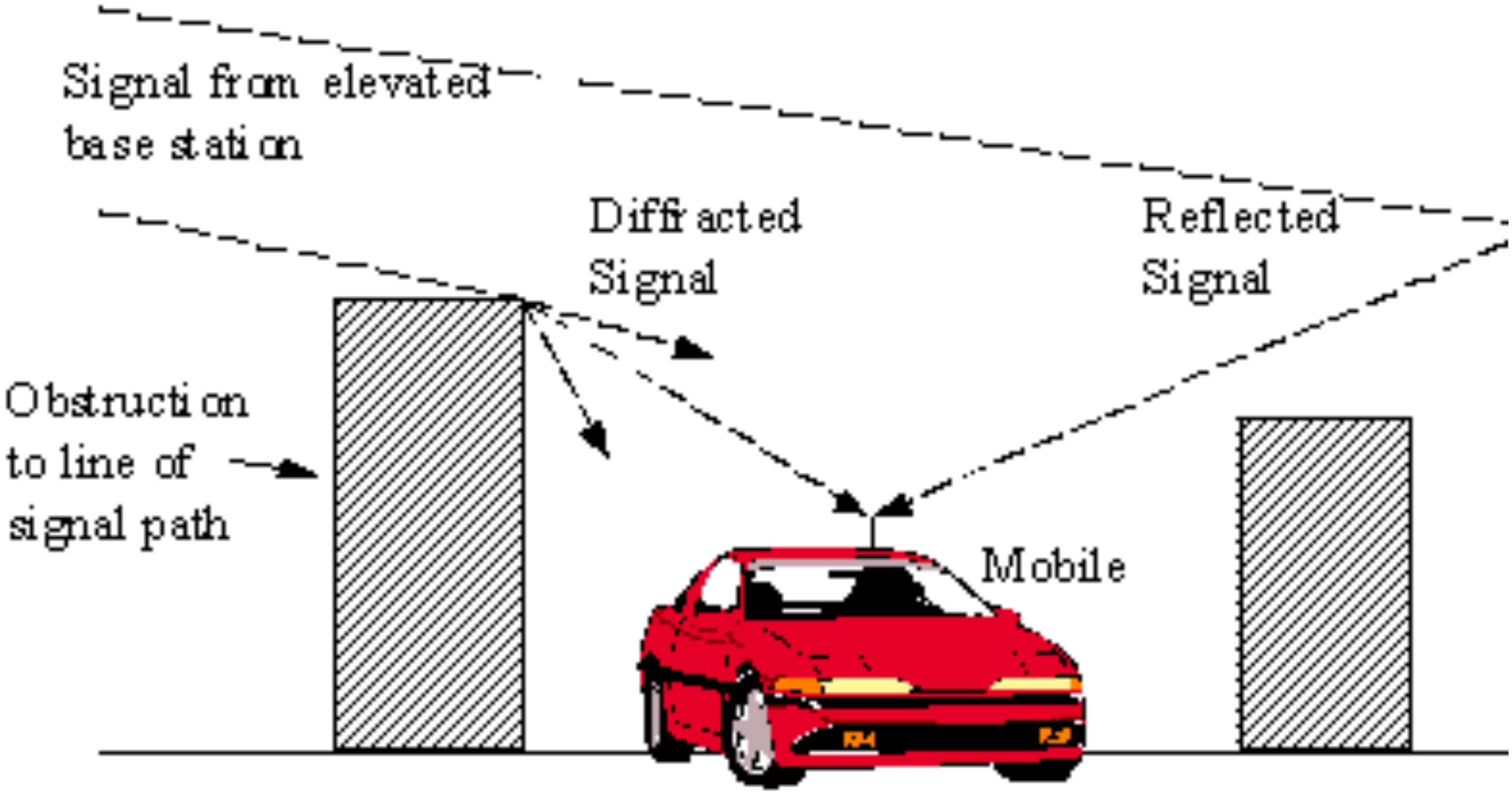
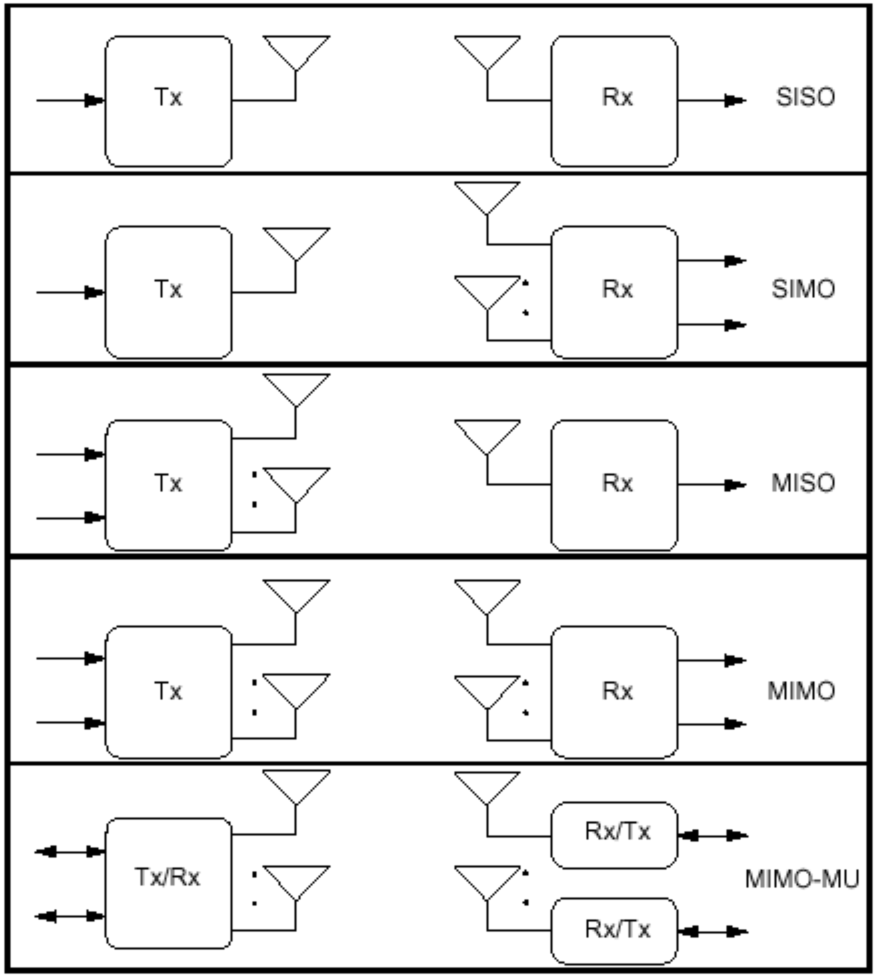


Figure 2 Radio Propagation Effects

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

By: Dr.Mohab Mangoud



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 & Beamforming

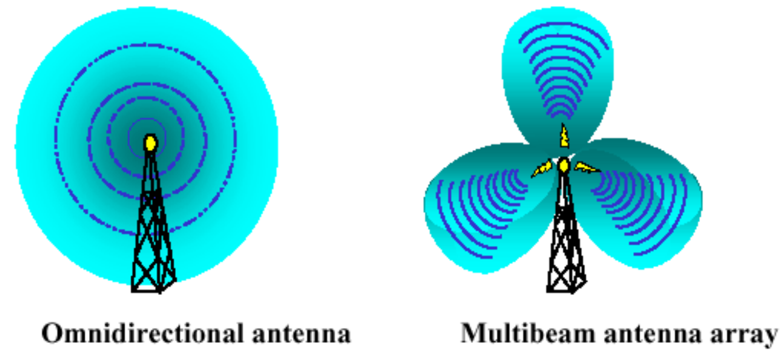
- Traditional cellular systems
- Idea of smart antenna

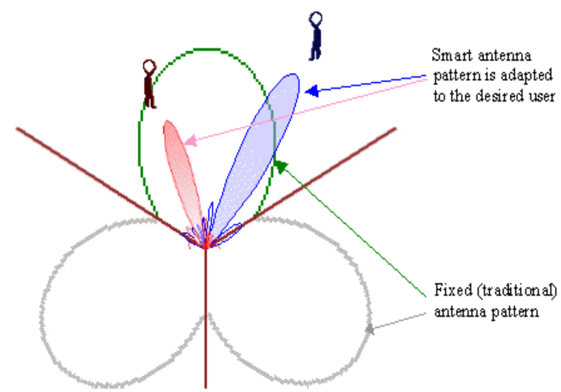
It consists of

a number of radiating elements (antenna array)

a combining/dividing network (Beamforming unit)

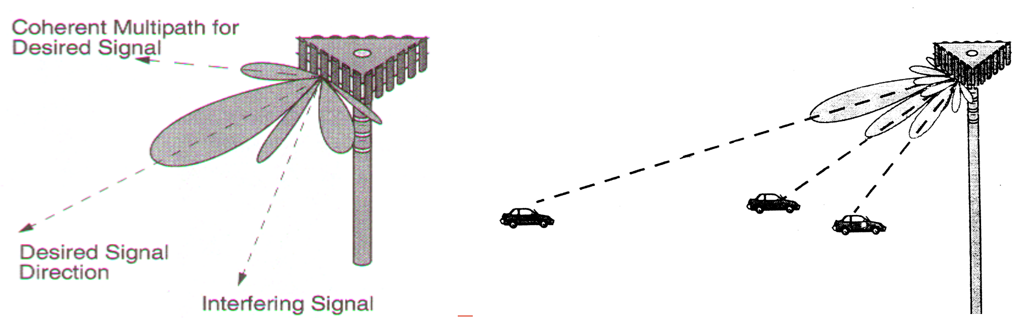
control unit, realized using DSP





Beamforming

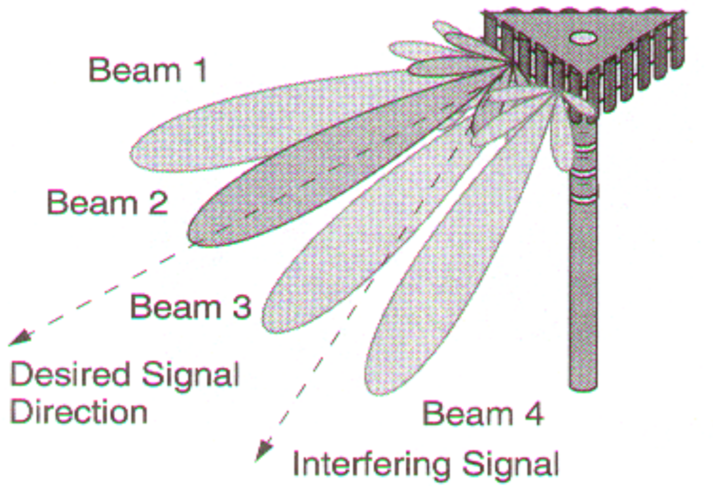
- to increase the system capacity and to increase the signal quality (system performance
- to avoid problems associated with multipath



By: Dr.Mohab Mangoud

Types of Smart Antennas

- Switched-Beam Antennas

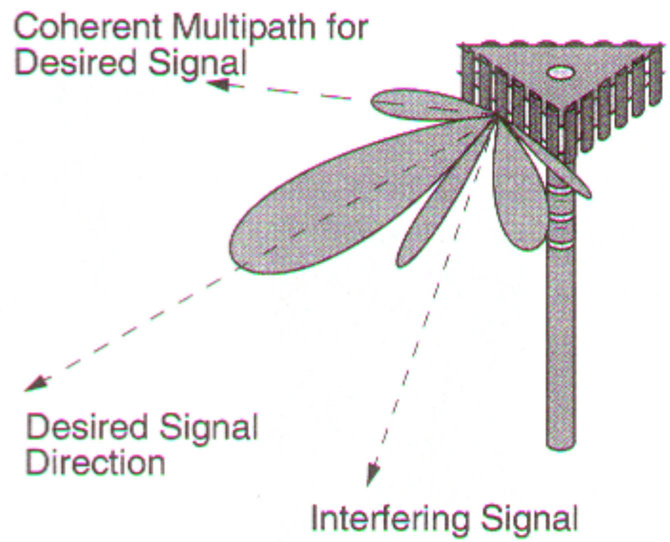


•Disadvantages:

Signal strength degradation

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

- Adaptive-Array Antennas



•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.