Wireless Communication

Course Information

Recommended Textbooks

- Theodore Rappaport, **Wireless Communications: Principles and Practice**, Second Edition, Prentice Hall, December 2001.

Outline

- Introduction
  - What is wireless and mobile networking
  - History of Wireless
  - Challenges of Mobile and Wireless Communication
  - What is Personal Communications Systems
  - Overview of Wireless Technologies and Systems

Outline

- Cellular concepts
  - Frequency reuse,
  - Handoff
  - Interference and system capacity,
  - Sectoring
  - Cell splitting

Outline

- Wireless Link Characteristics
  - Radio Propagation
  - Short and Long wave properties
  - Attenuation
  - Interfence
  - Fading and Multi-path Fading
  - Transmit power and range
  - Bit Error Rate and Models

Outline

- Modulation Techniques
- Multiple Access (TDMA , FDMA and CDMA)
- GSM in detail

What is Wireless Communication

- Transmitting voice and data using electromagnetic waves in open space
- Electromagnetic waves
  - Travel at speed of light ($c = 3x10^8$ m/s)
  - Has a frequency (f) and wavelength (λ)
    - $c = f \times \lambda$
  - Higher frequency means higher energy photons
  - The higher the energy photon the more penetrating is the radiation

Why Wireless?

- Freedom from wires

  No cost of installing the wires, No bunches of wires running around e.g. Bluetooth , Wi-Fi

- Global coverage

  where wires communication is not feasible or costly

  e.g. rural areas, battle field and outer space.

- Stay Connected

  Any where any time

- Flexibility

  Connect to multiple devices simultaneously

Wireless History

- Ancient Systems: Smoke Signals, Carrier Pigeons…
- Using light and flags for wireless communication remained important for the navy until radio transmission was introduced. Even today a sailor has to know some codes represented by flags if all other means of wireless communication fail.
- James C Maxwell (1831- 1879) laying the theoretical foundation for EM fields with his famous equations
- Heinrich Hertz (1857- 1894) was the first to demonstrate the wave character of electrical transmission through space (1886).(Note Today the unit Hz reminds us of this discovery).

Wireless History cont…

- Radio invented in the 1880s by Marconi
- The first transatlantic transmission followed in 1901.
- WARC – World Administration Radio Conference took place ,coordinating world wide use of radio frequencies
- The 1st radio broadcast took place in 1906 when Reginald A Fessenden transmitted voice and music for Christmas.
- The invention of electronic vacuum tube in 1906 by Lee De Forest (1873- 1961) &Robert Von Lieben (1878 – 1913)Helped to reduce the size of sender and receiver .
- One of the 1st mobile transmitter was on board at Zeppelin in 1911

Wireless History cont…

- In 1915 , the first wireless voice transmission was set up between New York and San Francisco
- The 1st commercial radio station started in 1920
  - –Note Sender & Receiver still needed huge antennas High transmission power.
- In **1926**, the first telephone in a train was available on the Berlin – Hamburg line
- **1928** was the year of many field trials for TV broadcasting. John L Baird (1888 – 1946) transmitted TV across Atlantic and demonstrated color TV
- Until **1932** , all wireless communication used AM which offered relatively poor quality due to interference.

Wireless History cont …

- Invention of FM in 1933 by Edwin H Armstrong [1890 - 1954] .
- Both the modulation schemes are still used for todays radio broadcasting with FM having much better quality.
- 1946, Public Mobile in 25 US cities, high power transmitter on large tower. Covers distance of 50 Km. Push to talk, uses 120khz of RF bandwidth.1950 channels doubled and BW 60k, 1960 4times increase, BW 30khz
- After 2nd world war (in 1958) ,a network in Germany was build namely the analog A- Netz using a carrier frequency of 160 Mhz.
- Connection setup was only possible from the mobile station and no handover was possible

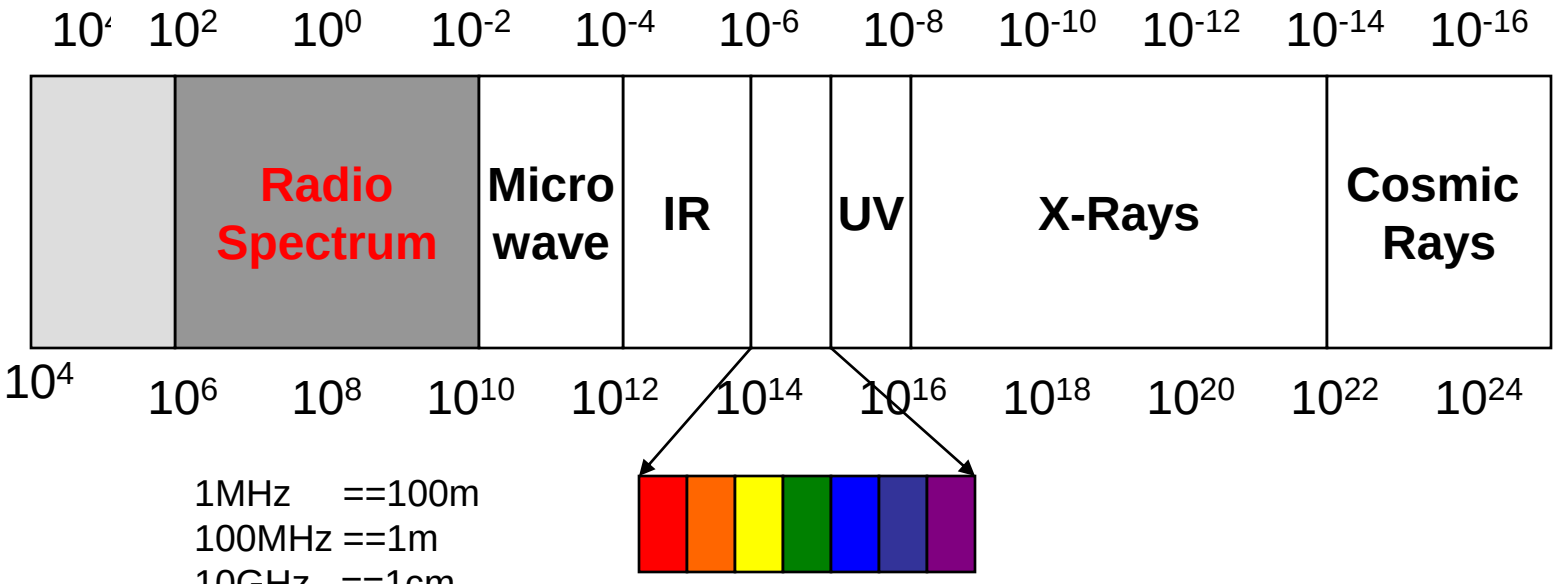
Wireless History cont …

- 1982: ***Groupe Spéciale Mobile*** was launched to develop standards for pan-European mobile network
- GSM now stands for ***Global System for Mobile Communications***
- 1992 Official commercial launch of GSM in Europe
- 1995 GSM specifications ported to PCS 1900
- 1997 - Wireless LANs
- 1998 - Specification for next generation CDMA starts Qualcomm starts work on wideband CDMA spec.
- 2000 - Bluetooth with 1Mbit/s specification, single cell Later work on 10Mbit/s spec with multi cell capability
- In 2002 Camera phones are first introduced in the U.S. market.

Wireless History cont …

- In 2005 mobile phone subscribers exceed fixed phone subscriber.
- iTunes Application Store (July) and Android Market (October) open in 2008
- In 2010 First 4G handset is introduced at International CTIA WIRELESS show.
- In 2010 Apple introduced the iPad, another revolution in portable “tablet” computing.
- In 2010 FCC proposes National Broadband Plan, recommending 500MHz of spectrum be allocated for commercial use by 2020.
- In 2012 the number of subscriber reaches 1 million.

Electromagnetic Spectrum

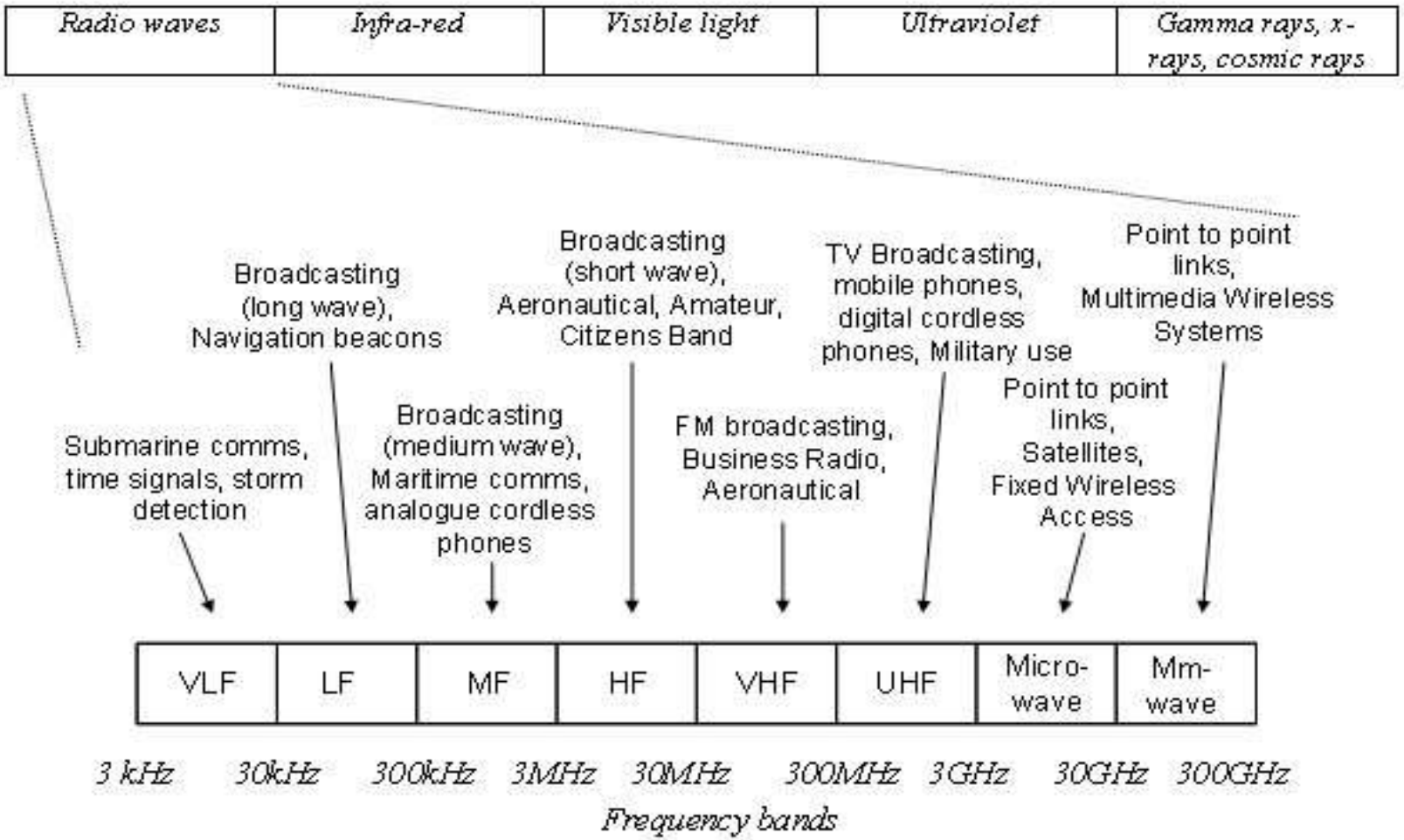


1MHz ==100m
100MHz ==1m
10GHz ==1cm

Visible light

< 30 KHz	VLF
30-300KHz	LF
300KHz – 3MHz	MF
3 MHz – 30MHz	HF
30MHz – 300MHz	VHF
300 MHz – 3GHz	UHF
3-30GHz	SHF
> 30 GHz	EHF

Electromagnetic Spectrum



Wavelength of Some Technologies

- GSM Phones:
  - frequency ~= 900 Mhz
  - wavelength ~= 33cm
- PCS Phones
  - frequency ~= 1.8 Ghz
  - wavelength ~= 17.5 cm
- Bluetooth:
  - frequency ~= 2.4Gz
  - wavelength ~= 12.5cm
  - Federal Communications Commission(FCC)
  - PTA

Frequency Carries/Channels

- The information from sender to receiver is carrier over a well defined frequency band.
  - This is called a channel
- Each channel has a fixed frequency bandwidth (in KHz) and Capacity (bit-rate)
- Different frequency bands (channels) can be used to transmit information in parallel and independently.

Wireless Com Sys Examples

- Cellular Telephony
- Wide Area Wireless Data Systems
- High Speed Local and Personal Area Networks
- Paging Messaging Systems
- Satellite Based Mobile System

Simplex Communication

- Normally, on a channel, a station can transmit only in one way.
  - This is called simplex transmision
- To enable two-way communication (called full-duplex communication)
  - We can use Frequency Division Multiplexing
  - We can use Time Division Multiplexing

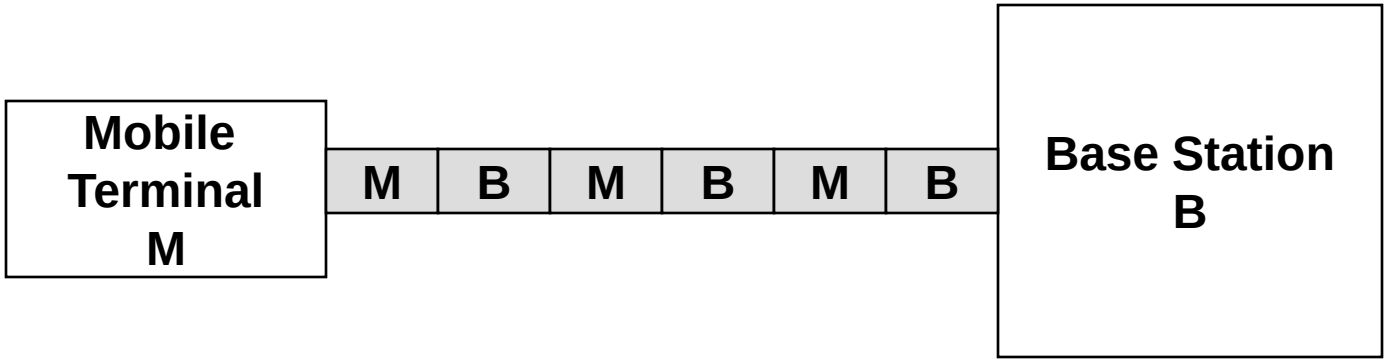
Duplex Communication - FDD

- FDD: Frequency Division Duplex

Forward Channel and Reverse Channel use different frequency bands

Duplex Communication - TDD

- TDD: Time Division Duplex



A singe frequency channel is used. The channel is divided into time slots. Mobile station and base station transmits on the time slots alternately.

Several PCS systems

- AMPS-USDC(NADC)IS-54 and 154
- IS-95 CDMA One System
  - CDMA based multiple access
- GSM: Global System for Mobile Communications
  - The mobile telephony system that we are using
- IS-136
  - USA digital cellular mobile telephony system
  - TDMA based multiple access
- Residential, business and public cordless access applications and systems

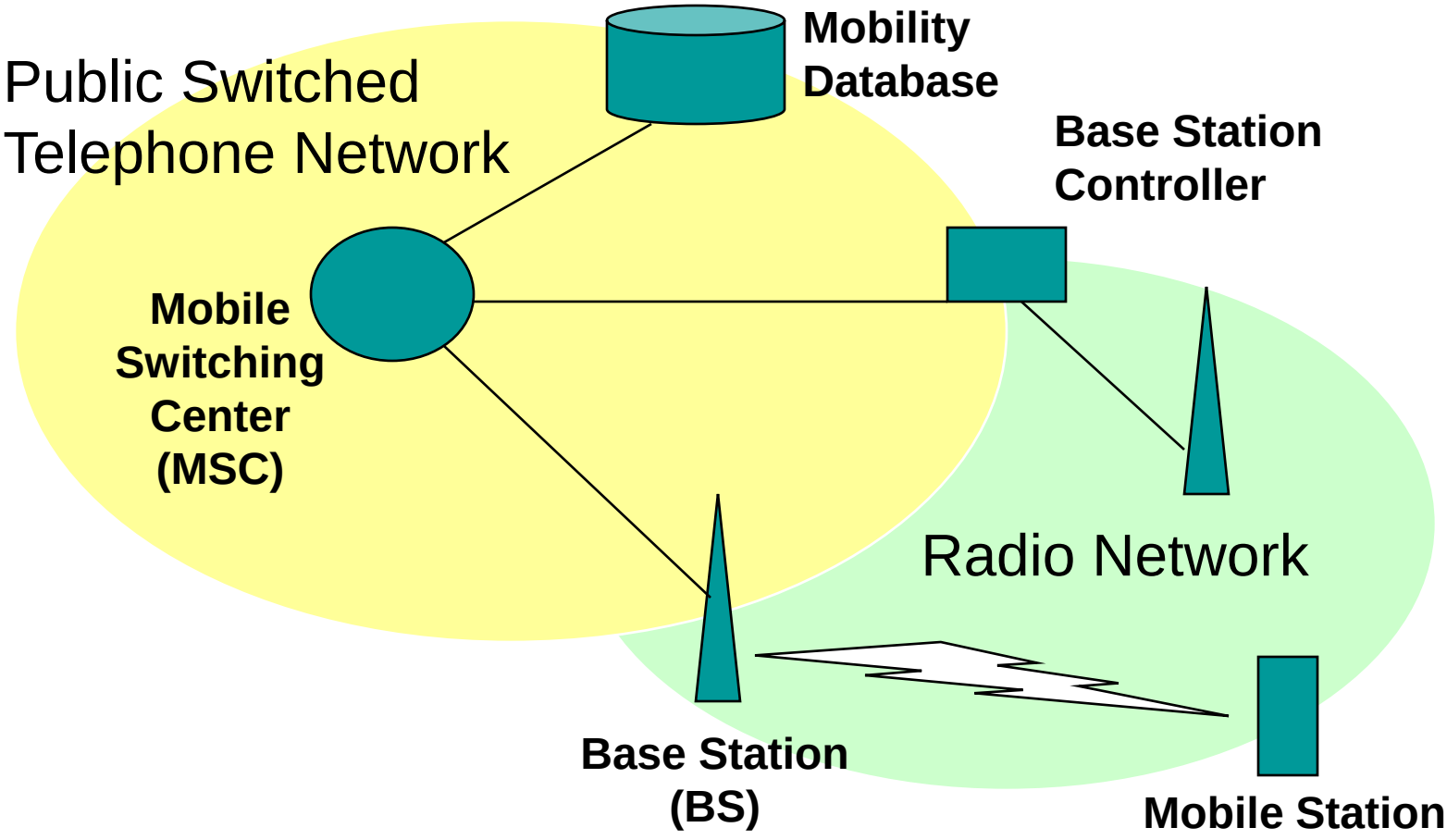
Several PCS systems

- Wideband wireless systems
  - For Internet access and multimedia transfer
    - Cdma2000
    - W-CDMA, proposed by Europe
    - SCDMA, proposed by China/Europe
- Other PCS Systems
  - Special data systems
    - CDPD: Cellular Digital Packet Data
  - Paging Systems
  - Mobile Satellite Systems
  - ISM band systems: Bluetooth, 802.11, etc

PCS Problems

- How to integrate mobile and wireless users to the Public Switched Telephone Network (PSTN) (Voice Network)
  - Cellular mobile telephony system
- How to integrate mobile and wireless users to the Internet (Data Network)
  - Mobile IP, DHCP.
- How to integrate all of them together and also add multimedia services (3G Systems)

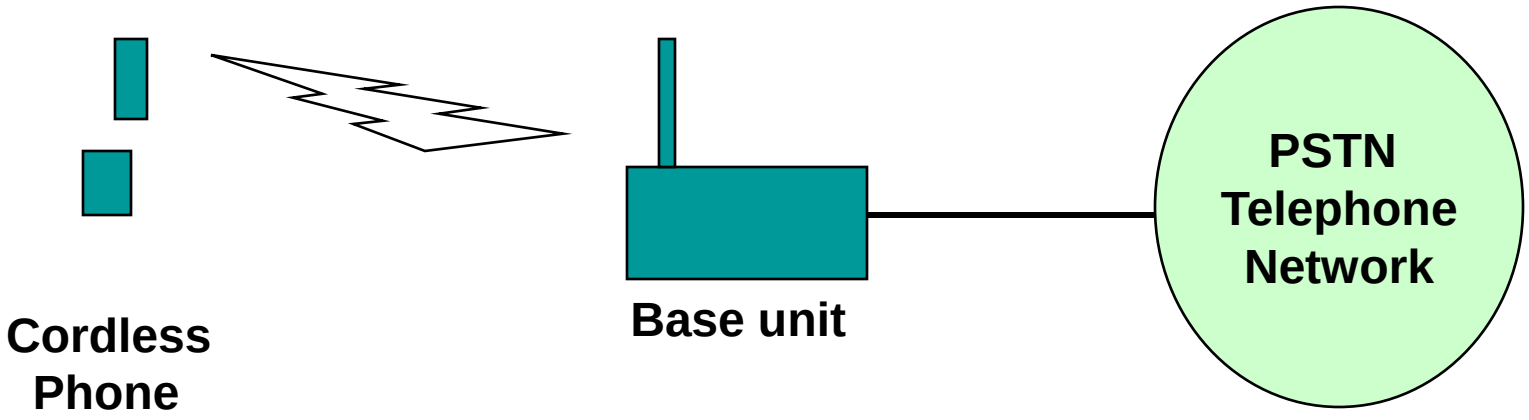
Very Basic Cellular/PCS Architecture



PCS Systems Classification

- Cordless Telephones
- Cellular Telephony
- Wide Area Wireless Data Systems
- High Speed Local and Personal Area Networks
- Paging Messaging Systems
- Satellite Based Mobile Systems
- 3G Systems

Cordless Telephones



Cordless Telephones

- Characterized by
  - Low mobility (in terms of range and speed)
  - Low power consumption
  - Two-way voice communication
  - High circuit quality
  - Low cost equipment, small form factor and long talk-time
  - No handoffs between base units
- Usage
  - At homes and at public places where cordless phone base units are available
- Design Choices
  - Few users per MHz
  - Few users per base unit

Cordless Phone

- Some more features
  - 32 Kb/s adaptive differential pulse code modulation (ADPCM) digital speech encoding
  - Tx power <= 10 mW
  - Low-complexity radio signal processing
    - No forward error correction (FEC) or whatsoever.
  - Low transmission delay < 50ms
  - Simple Frequency Shift Modulation (FSK)
  - Time Division Duplex (TDD)

Paging Systems

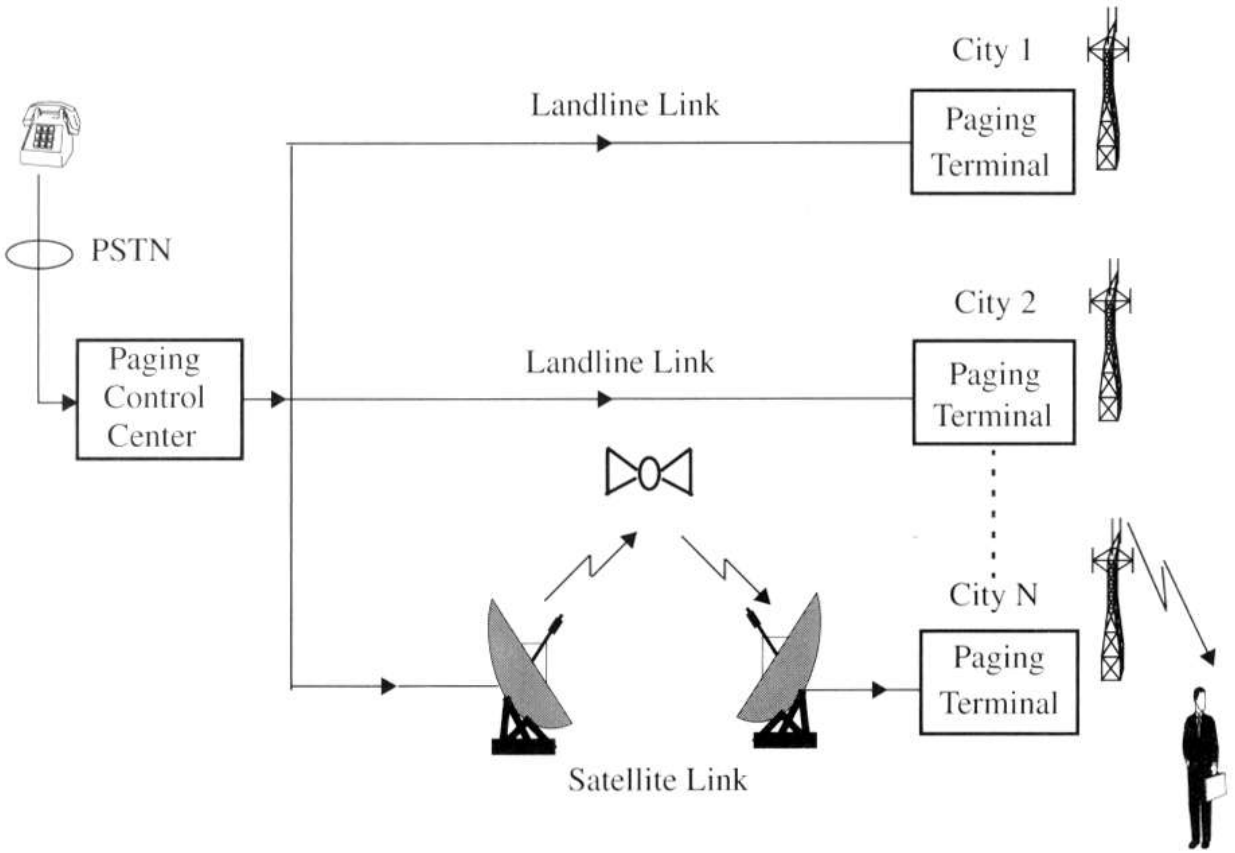
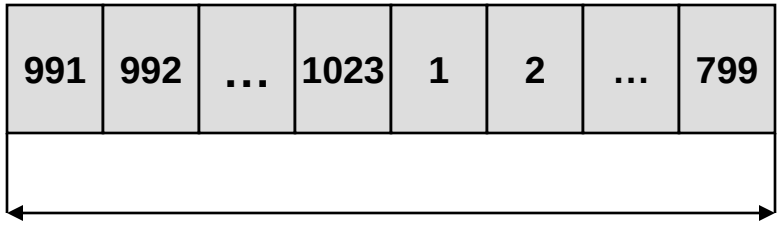


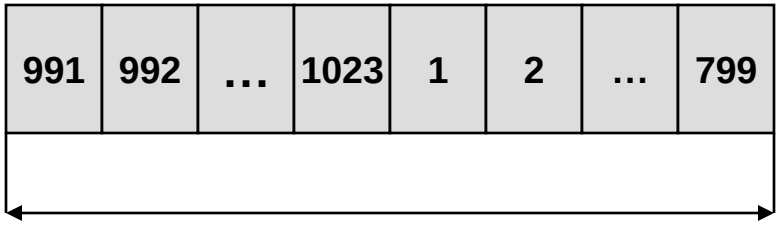
Figure 1.3 A wide area paging system. The paging control center dispatches pages received from the PSTN throughout several cities at the same time.

Example - Frequency Spectrum Allocation in U.S. Cellular Radio Service

Reverse Channel



Forward Channel



Channel Number	Center Frequency (MHz)
Reverse Channel 1 <=N <= 799	0.030N + 825.0
991 <= N <= 1023	0.030(N-1023) + 825.0
Forward Channel 1 <=N <= 799	0.030N + 870.0
991 <= N <= 1023	0.030(N-1023) + 870.0

(Channels 800-990 are unused)

Fwd & Rev Channel in each duplex pair is 45 MHz apart

Major Mobile Radio Standards

Standard	Type	Year Intro	Multiple Access	Frequency Band (MHz)	Modulation	Channel BW (KHz)
AMPS	Cellular	1983	FDMA	824-894	FM	30
USDC IS- 54 IS-136	Cellular	1991	TDMA	824-894	DQPSK	30 3 users in 30 and 6
IS-95	Cellular/PCS	1993	CDMA	824-894 1800-2000	QPSK/BPSK	1250
FLEX	Paging	1993	Simplex	Several	4-FSK	15
DCS-1900 (GSM)	PCS	1994	TDMA	1850-1990	GMSK	200
PACS	Cordless/PCS	1994	TDMA/FDMA	1850-1990	DQPSK	300

Major Mobile Radio Standards - Europe

Standard	Type	Year Intro	Multiple Access	Frequency Band (MHz)	Modulation	Channel BW (KHz)
ETACS	Cellular	1985	FDMA	900	FM	25
NMT-450/900	Cellular	1981/ 1986	FDMA	450-470 890-960	FM FM	25 12.5
GSM	Cellular/PCS	1990	TDMA	890-960	GMSK	200KHz
C-450	Cellular	1985	FDMA	450-465	FM	20-10
ERMES	Paging	1993	FDMA4	Several	4-FSK	25
CT2	Cordless	1989	FDMA	864-868	GFSK	100
DECT	Cordless	1993	TDMA	1880-1900	GFSK	1728
DCS-1800	Cordless/PCS	1993	TDMA	1710-1880	GMSK	200

Wireless System Definitions

- Mobile Station
  - A station in the cellular radio service intended for use while in motion at unspecified locations. They can be either hand-held personal units (portables e.g. a walkie-talkie or cordless) or cell phone in fast moving vehicles (mobiles)
- Base station
  - A fixed station in a mobile radio system used for radio communication with the mobile stations. Base stations are located at the center or edge of a coverage region. They consists of radio channels and transmitter and receiver antennas mounted on top of a tower.

Wireless System Definitions

- Mobile Switching Center
  - Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connections the cellular base stations and the mobiles to the PSTN (telephone network). It is also called Mobile Telephone Switching Office (MTSO)
- Subscriber
  - A user who pays subscription charges for using a mobile communication system
- Transceiver
  - A device capable of simultaneously transmitting and receiving radio signals

Wireless System Definitions

- Control Channel
  - Radio channel used for transmission of call setup, call request, call initiation and other beacon and control purposes.
- Forward Channel
  - Radio channel used for transmission of information from the base station to the mobile
- Reverse Channel
  - Radio channel used for transmission of information from mobile to base station

Wireless System Definitions

- Simplex Systems
  - Communication systems which provide only one-way communication
  - Pagers
- Half Duplex Systems
  - Communication Systems which allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can either transmit or receive information.
  - Push-to-talk and release-to-listen systems
- Full Duplex Systems
  - Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD).

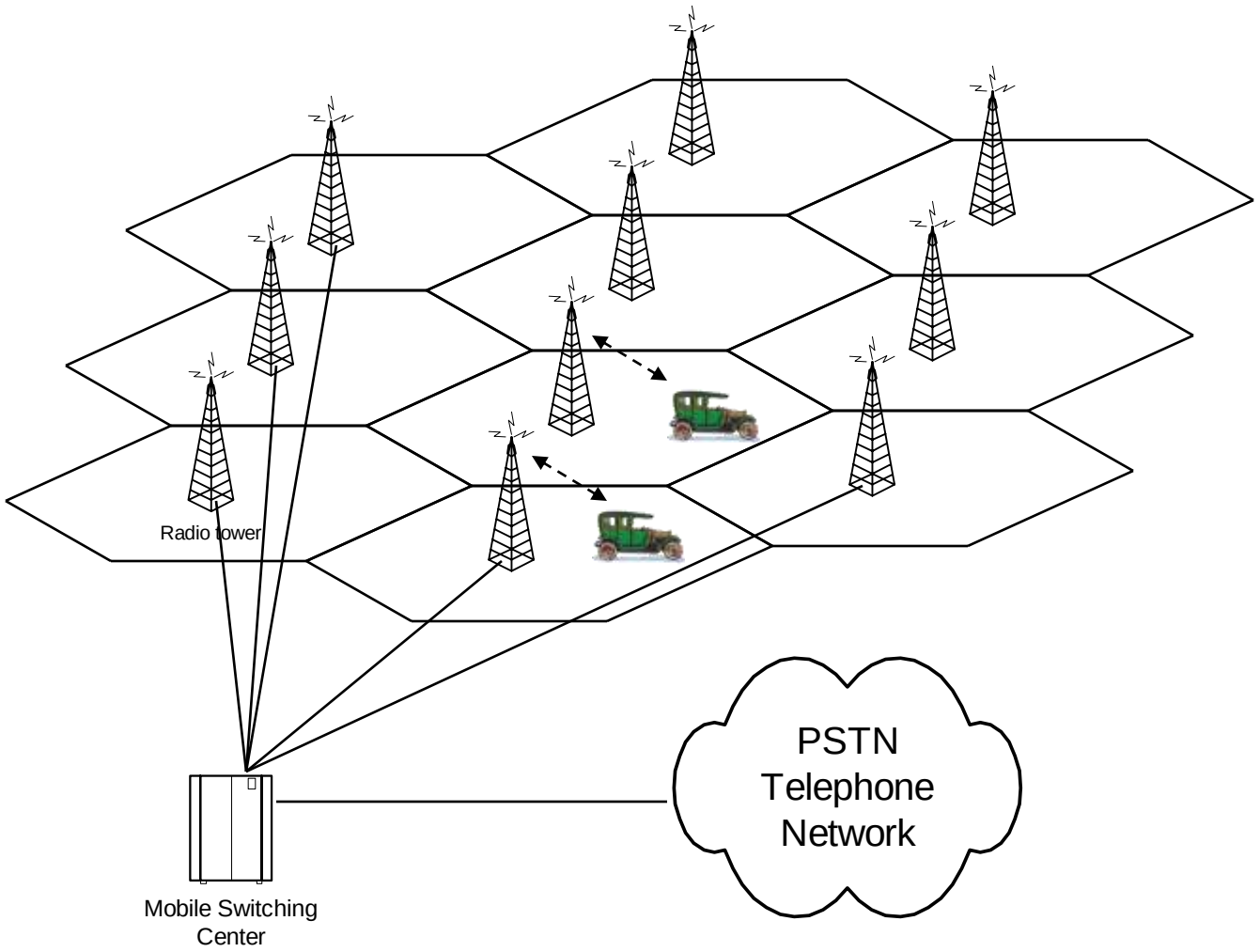
Wireless System Definitions

- Handoff
  - The process of transferring a mobile station from one channel or base station to an other.
- Roamer
  - A mobile station which operates in a service area (market) other than that from which service has been subscribed.
- Page
  - A brief message which is broadcast over the entire service area, usually in simulcast fashion by many base stations at the same time.

Cellular Telephony

- Characterized by
  - High mobility provision
  - Wide-range
  - Two-way voice communication
  - Handoff and roaming support
  - Integrated with sophisticated public switched telephone network (PSTN)
  - When mobile is turned on and not engaged in a call monitors the control channel for strongest BS.

Cellular Telephony - Architecture



Cellular Telephony Systems

- Mobile users and handsets
  - Very complex circuitry and design
- Base stations
  - Provides gateway functionality between wireless and wire line links
- Mobile switching centers
  - Connect cellular system to the terrestrial telephone network

Call to Mobile Initiated by PSTN

MSC		Receives call from PSTN. Sends the requested MIN to all base station.			Verifies that the mobile has a vaild MIN, ESN pair.	Requests BS to move mobile to unused voice channel pair.		Connects the mobile with the calling party on the PSTN.
Base Station	FCC		Transmits page (MIN) for specified user.				Transmits data message for mobile to move to specific voice channel.	
	RCC			Receives MIN, ESN, Station Class Mark and passes to MSC.				
	FVC							Begin voice transmission.
	RVC							Begin voice reception.
Mobile	FCC		Receives page and matches the MIN with its own MIN.				Receives data messages to move to specified voice channel.	
	RCC			Acknowledges receipt of MIN and sends ESN and Station Class Mark.				
	FVC							Begin voice reception.
	RVC							Begin voice transmission.

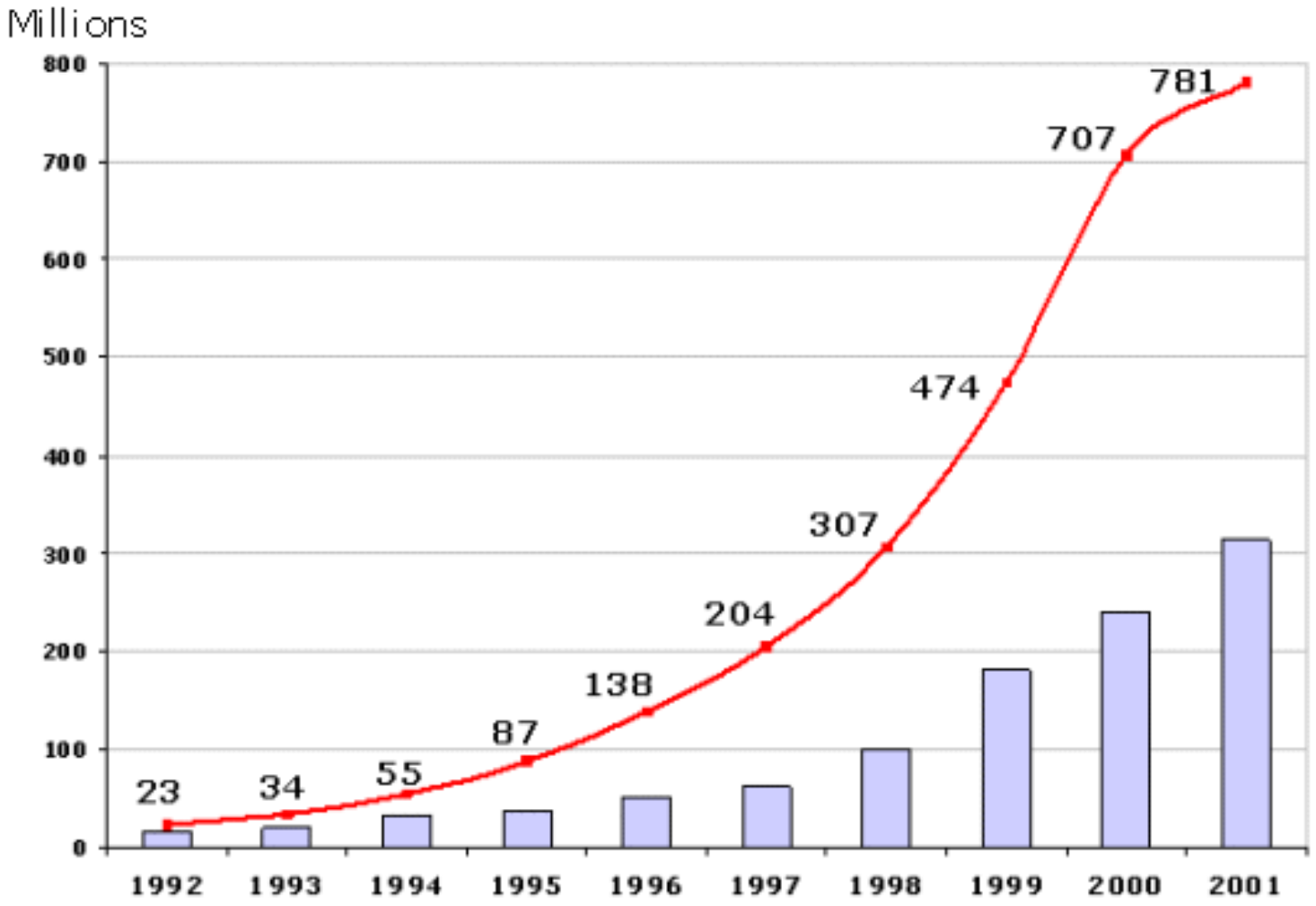
time →

Mobile initiated Call

MSC			Receives call initiation request from base station and verifies that the mobile has a vaild MIN, ESN pair.	Instructs FCC of originating base station to move mobile to a pair of voice channels.		Connects the mobile with the called party on the PSTN.	
Base Station	FCC				Page for called mobile, instructing the mobile to move to voice channel.		
	RCC	Receives call initiation request. and MIN, ESN, Station Class Mark.					
	FVC						Begin voice transmission.
	RVC						Begin voice reception.
Mobile	FCC				Receives page and matches the MIN with its own MIN. Receives instruction to move to voice channel.		
	RCC	Sends a call initiation request along with subscriber MIN and number of called party.					
	FVC						Begin voice reception.
	RVC						Begin voice transmission.

time →

World Cellular Subscriber Growth



Cellular Networks

- First Generation
  - Analog Systems
  - Analog Modulation, mostly FM
  - AMPS
  - Voice Traffic
  - FDMA/FDD multiple access
- Second Generation (2G)
  - Digital Systems
  - Digital Modulation
  - Voice Traffic
  - TDMA/FDD and CDMA/FDD multiple access
- 2.5G
  - Digital Systems
  - Voice + Low-datarate Data
- Third Generation
  - Digital
  - Voice + High data rate DATA
  - Multimedia Transmission also

2nd Generation Cellular Networks

- 2 G networks include 3 TDMA and 1 CDMA based standards.
- GSM:
  - 8 time slotted users for each 200kHz channel
  - Deployed in cellular and PCS bands(Europe, Asia, Australia and South America)
- IS-136(USDC/NADC):
  - Supports 3 time slotted users in each 30 kHz channel
  - Deployed in cellular and PCS bands(North and South America and Australia)
- PDC: Japanese digital standard similar to IS136
- IS-95(cdma One):
  - Supports 64 orthogonally coded users on 1.25MHz channel

2nd Generation Cellular Networks

- 2G standards were first to rely on digital modulation on air interface and sophisticated DSP both in handsets and BS.
- 2G networks were deployed for conventional mobile telephony.
- In 2001 major carriers decided in favor of 3G systems based on TDMA based GSM platform instead of IS136 and PDC.

2G Technologies

	cdmaOne (IS-95)	GSM, DCS-1900	IS-54/IS-136 PDC
Uplink Frequencies (MHz)	824-849 (Cellular) 1850-1910 (US PCS)	890-915 MHz (Eurpe) 1850-1910 (US PCS)	800 MHz, 1500 Mhz (Japan) 1850-1910 (US PCS)
Downlink Frequencies	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)	935-960 (Europa) 1930-1990 (US PCS)	869-894 MHz (Cellular) 1930-1990 (US PCS) 800 MHz, 1500 MHz (Japan)
Deplexing	FDD	FDD	FDD
Multiple Access	CDMA	TDMA	TDMA
Modulation	BPSK with Quadrature Spreading	GMSK with BT=0.3	$\pi/4$ DQPSK
Carrier Seperation	1.25 MHz	200 KHz	30 KHz (IS-136) (25 KHz PDC)
Channel Data Rate	1.2288 Mchips/sec	270.833 Kbps	48.6 Kbps (IS-136) 42 Kbps (PDC)
Voice Channels per carrier	64	8	3

2G and Data

- 2G is developed for voice communications
- Data sent using Circuit switching
- Provides data rates in the order of ~9.6 Kbps
- Increased data rates are required for internet application
- This requires evolution towards new systems: 2.5 G

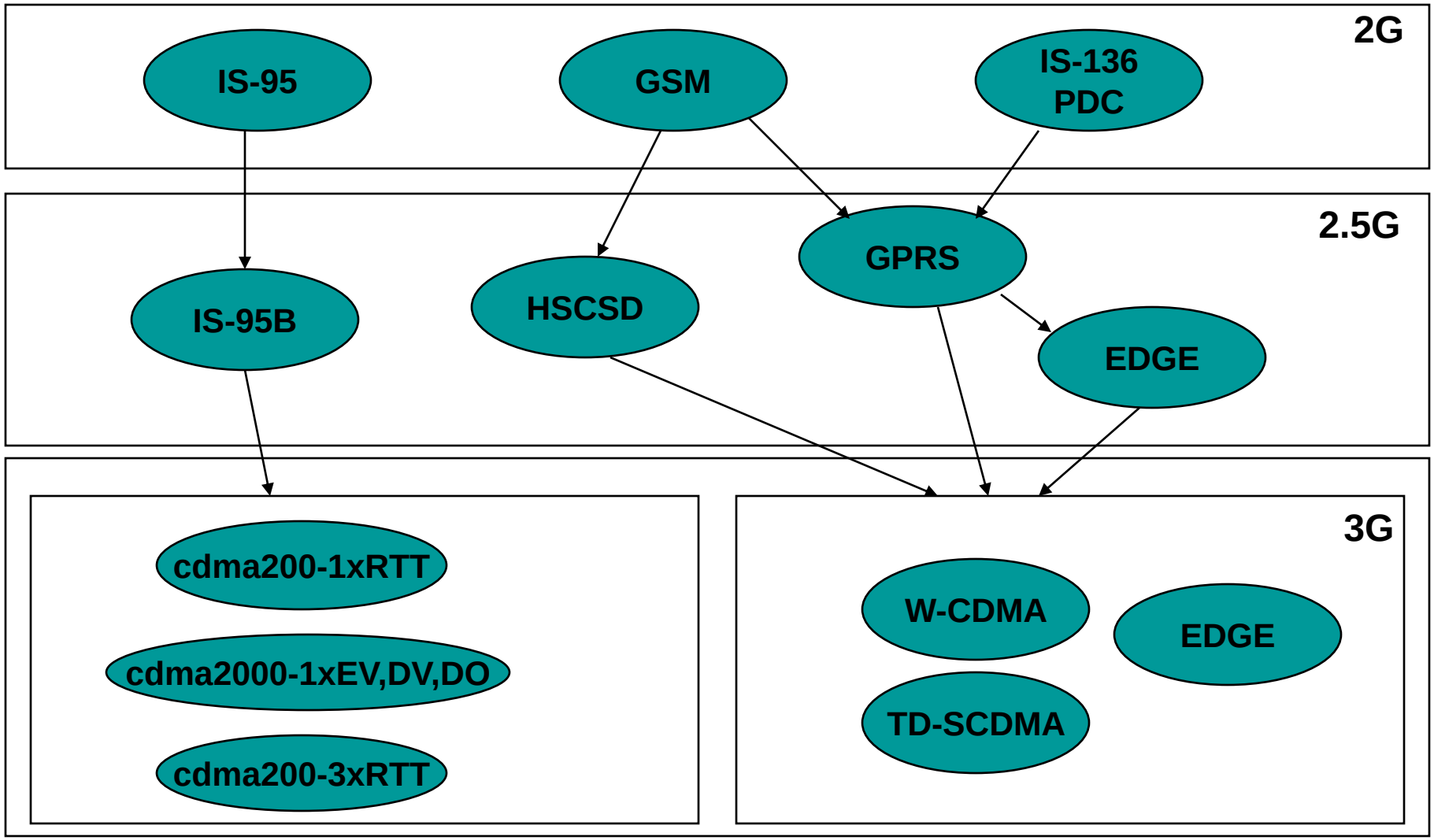
Evolution to 2.5G Mobile Networks

- The 2G deployed before the widespread use of Internet.
- limited Internet browsing and short messaging capability using CS approach.
- In effort to provide increased data-rates, new data centric standards have been developed and overlaid over existing 2G equipments.
- Existing systems were supplemented with hardware and software upgrade to support high data rates for web browsing, email, m-commerce and LBS.

2.5 Technologies

- Evolution of TDMA Systems
  - HSCSD for 2.5G GSM
    - Up to 57.6 Kbps data-rate
  - GPRS for GSM and IS-136
    - Up to 171.2 Kbps data-rate
  - EDGE for 2.5G GSM and IS-136
    - Up to 384 Kbps data-rate
- Evolution of CDMA Systems
  - IS-95B
    - Up to 64 Kbps

Upgrade Paths for 2G Technologies



2.5 Technologies

- HSCSD for 2.5G GSM
  - Allows a user to use consecutive time slots(TS) in GSM to obtain high data-rates.
  - Relaxes error control algorithms and increases data rate to 14.4kbps as compared to 9.6kbps for GSM.
  - Using 4 consecutive TS, HSCSD provides a raw tx-ion rate of 57.6kbps.
  - Requires a software upgrade at the GSM BS.
- GPRS for GSM and IS-136
  - General Packet Radio System is Packet based data networks.
  - Well suited for internet usage.
  - Supports multi-user network sharing of individual radio channel and time slot

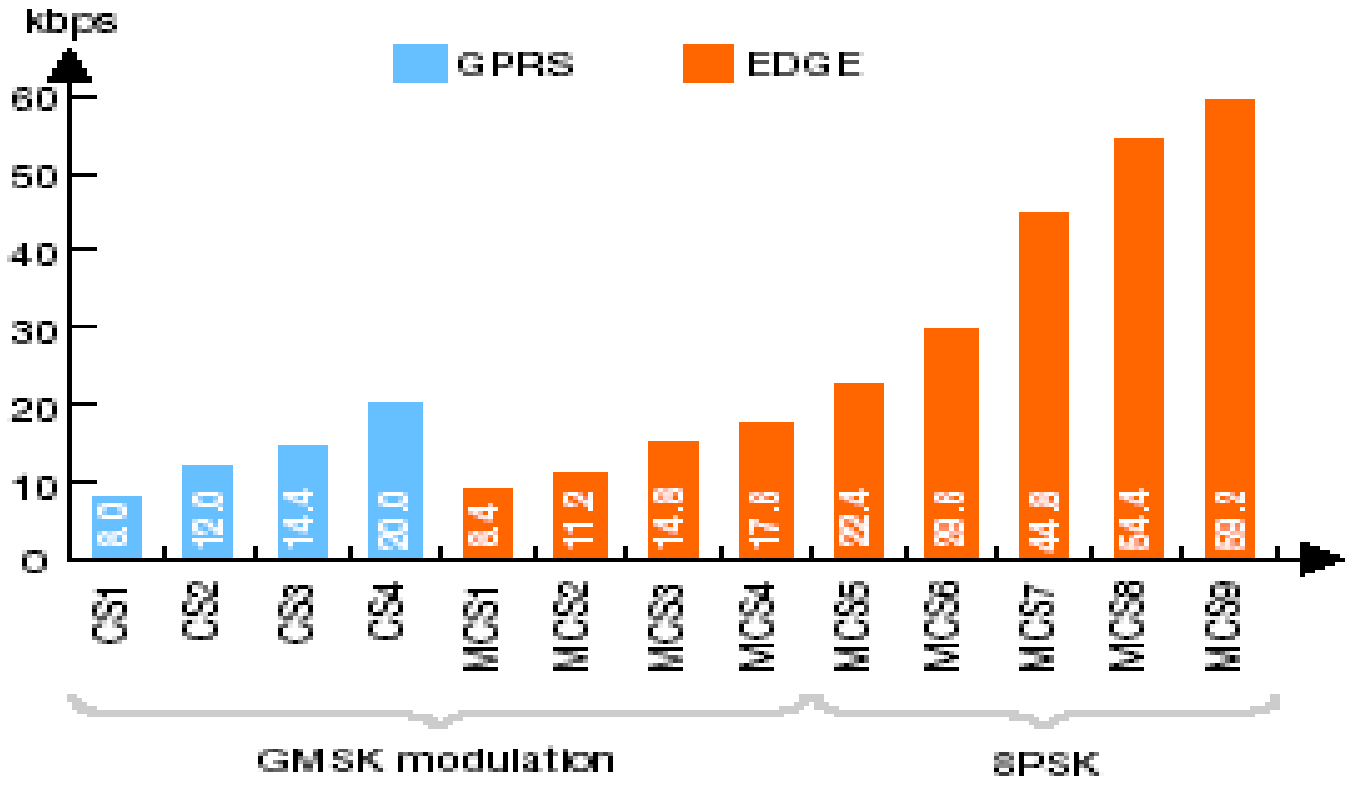
2.5 Technologies

- GPRS for GSM and IS-136
  - Retains the modulation format specified in 2G standard, but uses completely redefined air interface
  - With all the time slots dedicated for a GPRS user its able to achieve data rate of 171.2 kbps(where each slot provides 21.4 kbps raw un-coded date)
  - Applications are required to provide there own error correction schemes.
  - Merely requires new routers and internet gateways at the BS, and software upgrade to redefine BS air interface.

2.5 Technologies

- EDGE for 2.5G GSM and IS-136
  - Enhanced Data rate for GSM evolution.
  - Requires new hardware and software upgrade at BSs.
  - Uses 8PSK digital Modulation in addition to GMSK used for GSM
  - 9 different autonomously selectable air interface format, Multiple Modulation and Coding Schemes(MCS), with varying degree off error control protections.
  - Each MCS state may use GMSK or 8 PSK for network access, depending on instantaneous demand of network and operating conditions.
  - ***User connection may adaptively determine best MCS settings for particular radio propagation conditions, selecting best air interface is called incremental redundancy.***
    - Radio data rate per time slot – 69.2kbps *8=547.2 per channel

2.5 Technologies



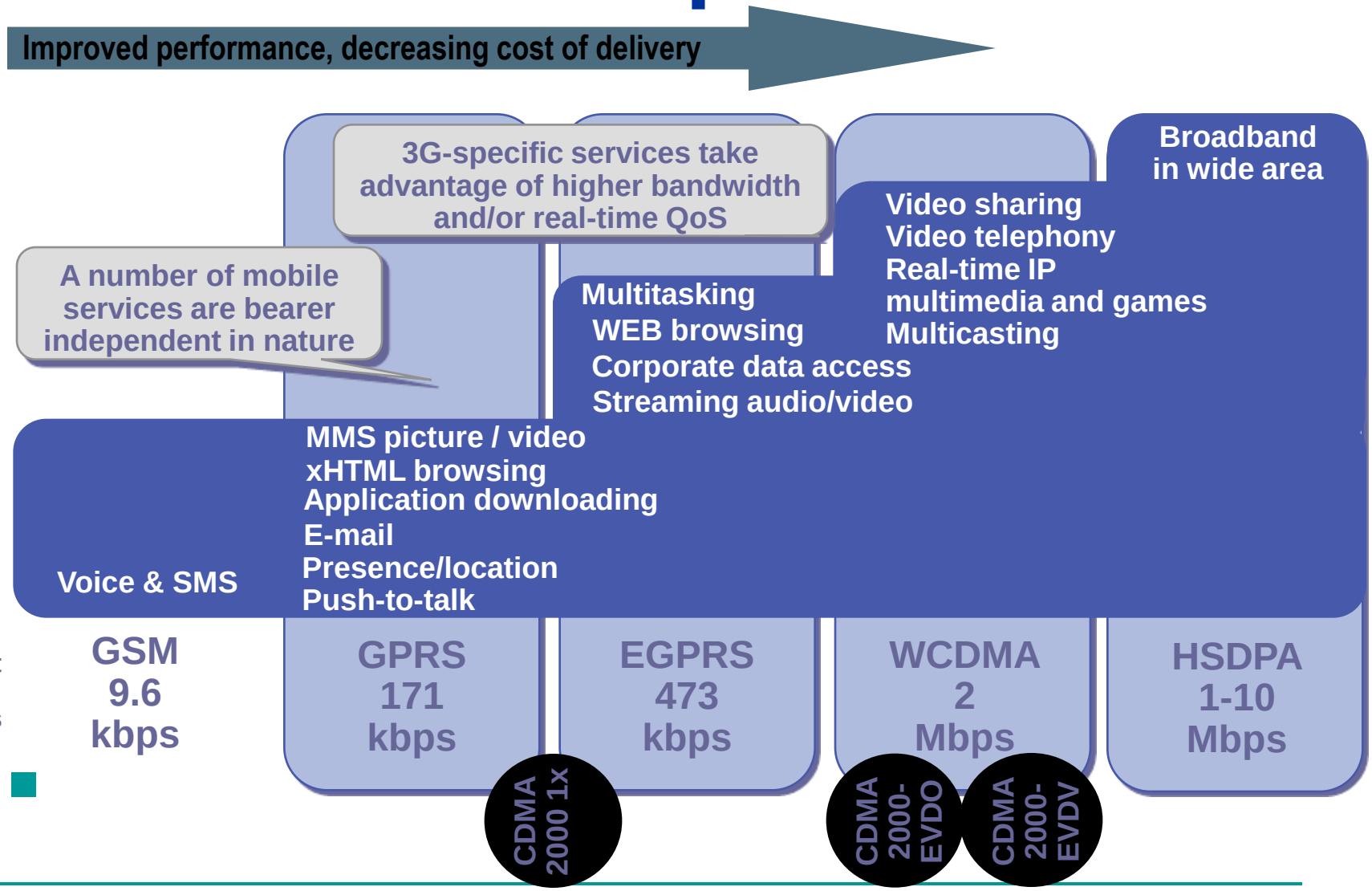
2.5 Technologies

- Evolution of CDMA Systems
  - IS-95B
    - Support *medium data rate(MDR)* service by allowing user to command 8 Walsh codes simultaneously to provide data rate of 115.2kbps (8*14.4kbps)
    - In reality only 64kbps is available to a user due to slotting techniques of the air interface.

2.5 Technologies

Wireless Data Tech	Channel BW	Duplex	Infrastructure Change	Requires New Spectrum	Requires New Handsets
HSCSD	200KHz	FDD	Requires Software Upgrade at base station	No	Yes, New HSCSD handsets provide 57.6Kbps on HSCSD n/w and 9.6 Kbps on GSM n/w with dual mode phones. GSM only phones will not work in HSCSD N/w.
GPRS	200KHz	FDD	Requires new packet overlay including routers and gateways	No	Yes, New GPRS handsets work on GPRS n/w at 171.2Kbps, 9.6 Kbps on GSM n/w with dual mode phones. GSM only phones will not work in GPRS n/w.
EDGE	200KHz	FDD	Requires new transceivers at base station. Also, software upgrade to the BSC & BTS	No	Yes, New handsets work on EDGE n/w at 384Kbps, GPRS n/w at 144Kbps, and GSM n/w at 9.6 Kbps with tri-mode phones. GSM and GPRS-only phones will not work in EDGE n/w.
W-CDMA	5MHz	FDD	Requires completely new base stations	Yes	Yes, New W-CDMA handsets will work on W-CDMA at 2Mbps, EDGE n/w at 384 Kbps, GPRS n/w at 144 Kbps. GSM n/w at 9.9 Kbps. Older handsets will not work in W-CDMA.

Services roadmap

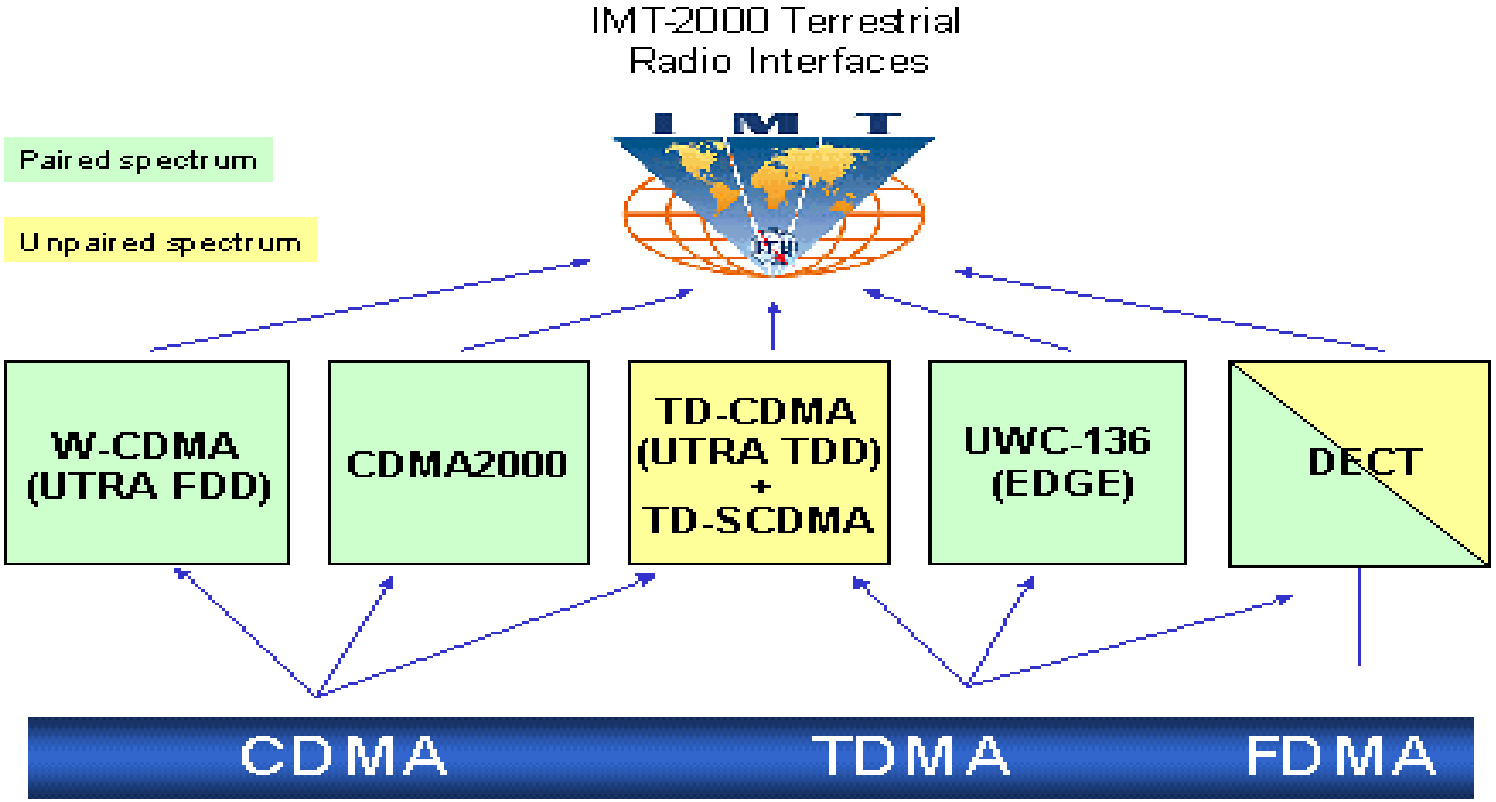


3G Systems

- Goals
  - Voice and Data Transmission
    - Simultanous voice and data access
  - Multi-megabit Internet access
    - Interactive web sessions
    - Communication using VoIP
  - Multimedia Content
    - Live music

3G Standards

- 3G Standard is created by ITU-T and is called as **IMT-2000.**
- The aim of IMT-2000 is to harmonize worldwide 3G systems to provide **Global Roaming.**



3G Systems

- Evolution of CDMA Systems
  - CDMA system evolved to CDMA2000
    - CDMA2000-1xRTT: Upto 307 Kbps
    - CDMA2000-1xEV: Evolutionary(Proprietary high data rate)
    - CDMA2000-1xEVDO: upto 2.4 Mbps(radio channels with data only)
    - CDMA2000-1xEVDV: 144 Kbps datarate (radio channels with data and voice)
  - GSM, IS-136 and PDC evolved to W-CDMA (Wideband CDMA) (also called UMTS)
    - Up to 2.048 Mbps data-rates
    - Future systems 8Mbps
    - Expected to be fully deployed by 2010-2015

3G W-CDMA(UMTS)

- UMTS is the European vision of 3G.
- UMTS is an upgrade from GSM via GPRS or EDGE.
- The standardization work for UMTS is carried out by Third Generation Partnership Project (3GPP).
- Data rates of UMTS are:
  - 144 kbps for rural
  - 384 kbps for urban outdoor
  - 2048 kbps for indoor and low range outdoor
- Virtual Home Environment (VHE)
- Wide band CDMA technology is selected for UTRAN air interface.
- New spectrum is allocated for these technologies i.e. 2500 to 2690, 1710-1885 and 806-960 MHz both for CDMA and UMTS standards.

3G CDMA 2000

- Seamless and evolutionary high data rate for 2G and 2.5 G CDMA, around 1.25 MHz radio channel.
- The standardization work for 3G CDMA 2000 is carried out by Third Generation Partnership Project 2(3GPP2).
- First air interface **CDMA 2000 1X RTT** (1X, 1 time original CDMA channel bandwidth, RTT, Radio Transmission Technology)
- Supports data rate up-to 307kbps
- CDMA2000-3xRTT
  - 3 adjacent (single 3.75 MHz)radio channels used together to provide data throughput in excess of 2 Mbps, ***Requires new RF HW at BS***
  - 3 non adjacent channels may be operated as simultaneously in parallel as 1.25 MHz each
- 3G TD-SCDMA (Radio Channel 1.6MHz)
  - Chinese's standard for 3G, evolution o GSM, adds high data rate equipment at BS, data only overlay on GSM using TDMA and TDD

3G CDMA 2000

Wireless Data Tech.	Channel BW	Duplex	Infrastructure Change	Requires New Spectrum	Requires New Handsets
IS-95B	1.25MHz	FDD	Requires new software in BSC	No	Yes, New handsets will work on IS-95B at 64 Kbps and IS-95A at 14.4 Kbps. Cdma One phones can work in IS-95B at 14.4 Kbps
Cdma2000 1xRTT	1.25MHz	FDD	Requires new s/w in backbone and new channel cards at base stations. Also need to build a new packet service node.	No	Yes, New handsets will work on 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xRTT but at lower speeds.
Cdma2000 1xEV (DO & DV)	1.25MHz	FDD	Requires s/w and digital card upgrade on 1xRTT networks	No	Yes,New handsets can work on 1xEV at 2.4 Mbps, 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xEV but at lower speeds.
Cdma2000 3xRTT	3.75MHz	FDD	Requires backbone modifications and new channel cards at base stations.	Maybe	Yes, New handsets will work on 95A at 14.4 Kbps, 95B at 64 Kbps, 1xRTT at 144 Kbps, 3xRTT at 2 Mbps. Older handsets can work in 3X but at lower speeds.