Muhammad Ali Jinnah University, Islamabad Campus, Pakistan

Introduction to Wireless Communications

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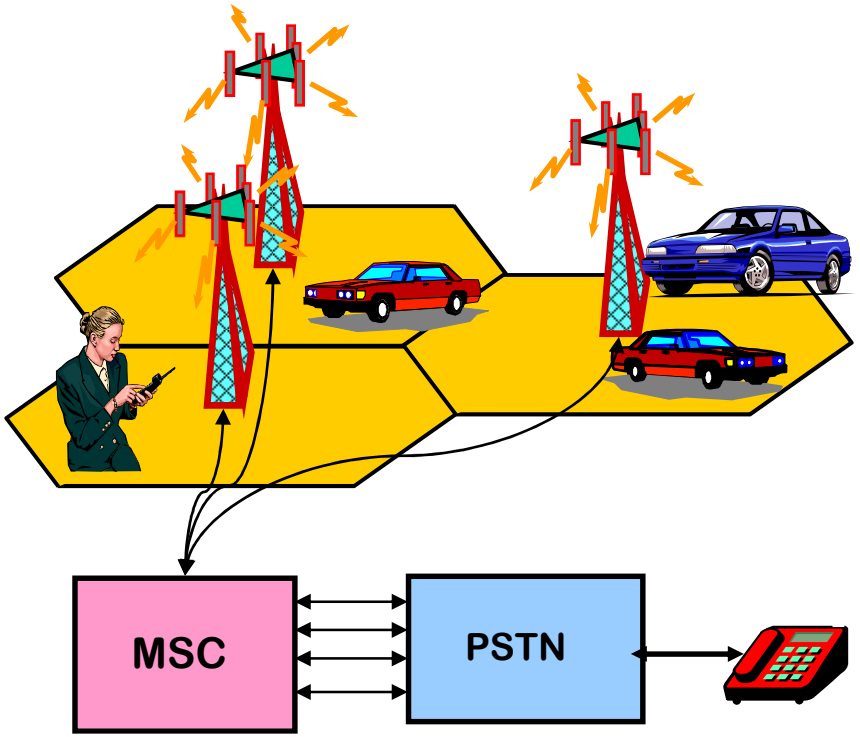

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Wireless Communications Research Lab, C-Block

Profiles:

- http://www.arwic.com/view-profile.php?id=194
- http://sc.hec.gov.pk/aphds/submit.asp?supid=2275

Research Interests

1. Wireless and Cellular Mobile Communication Systems
2. Fading Channel Modeling and Characterization
3. Smart Antennas and MIMO systems
4. Adaptive Signal Processing
5. Adaptive Multiuser Detection
6. CDMA Systems
7. Wireless Sensor Networks
8. Wireless LANs
9. Mobile Robot Navigation

Course Objectives

This course has been designed to provide a comprehensive approach towards the designing of cellular mobile communication systems. It begins with the basic cellular system modeling and then proceeds towards characterization and modeling of radio fading channels and other design aspects of a complete cellular system.

TEXT BOOK:

Theodore S. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, 1999
(Chapters 1-7, 9 and 11)

ADDITIONAL READINGS:

Lecture Slides
Class Handouts
Selected Research Papers

REFERENCE BOOKS:

A. Molisch, *Wireless Communications*, John Wiley & Sons, 2006
J. David Parsons, *Mobile Radio Propagation Channel*, John Wiley & Sons, 2000
IEEE Transactions/Letters on "Vehicular Technology, Communications, Wireless Communications, Antenna Propagation, Signal Processing"

Topical Course Outline

1. Introduction to Wireless Communication Systems
2. Modern Wireless Communication Systems
3. Cellular Concept and System Design Fundamentals
4. Handoff Management
5. Channel Assignment Management and Trunking Concept
6. Mobile Radio Propagation – Large Scale Fading
7. Mobile Radio Propagation – Small Scale Fading
8. Multiple Antenna Arrays
9. Smart Antennas and MIMO Communication Systems
10. Multiple Access Techniques for Wireless Communications
11. Introduction to Wireless Systems and Standards: GSM, IS-95B, WCDMA/CDMA2000
12. ITU Requirements and architecture of 4G Cellular Standard
13. 4G Cellular System: LTE-Advanced/ WiMAX-Advanced

MARKS DISTRIBUTION

No	Items	Percentage
1	Major Quiz-1	15%
2	Major Quiz-2	15%
3	Mid term exam	20%
4	Final term exam	40%
5	Class Conduct and In-Class Performance	10%
Total		100%

Contents

- Types of radio communication systems
  - Cellular systems
  - Cordless Systems
  - Paging Systems
  - Satellite Systems
  - Wireless LANs
  - Broadcast Systems
  - Bluetooth
- History of Cellular Mobile Comm. Systems
- Design challenges

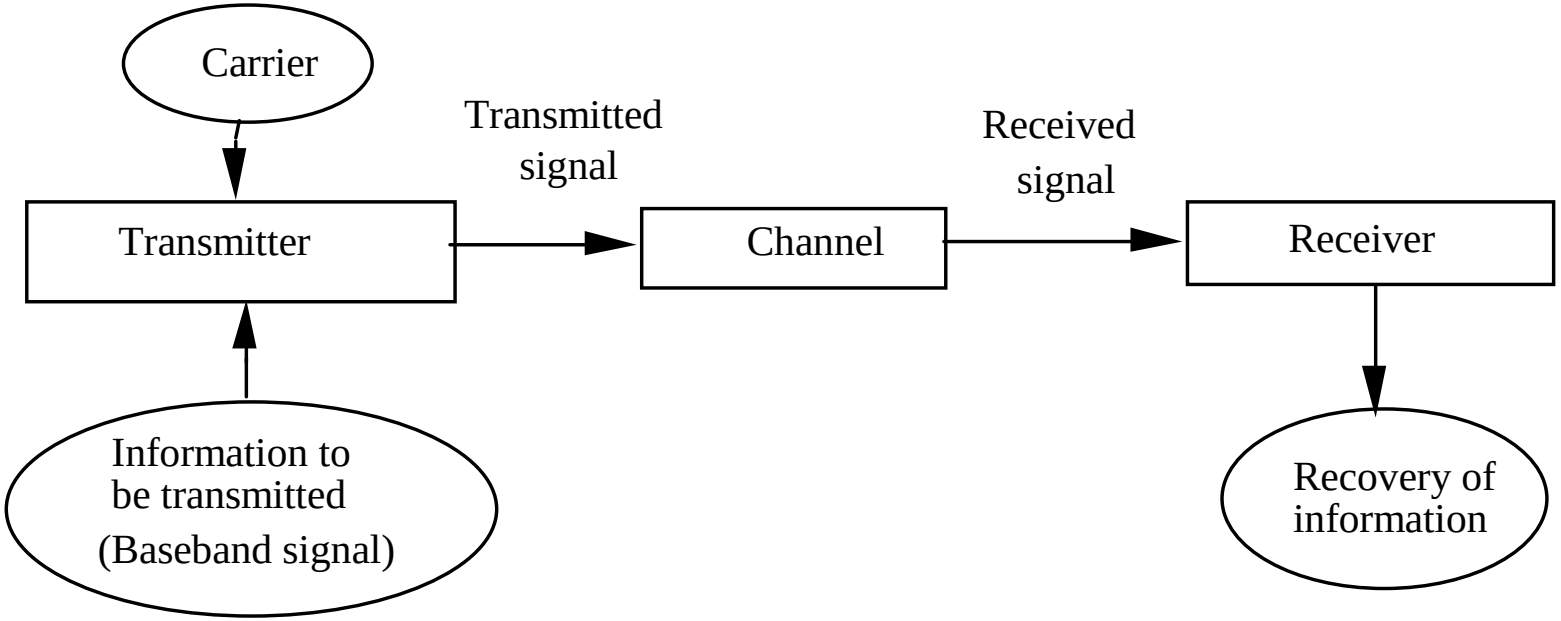
Contents (Contd.)

- Basic Concepts
- Terminology in Cellular Mobile Systems
  - Base station, Mobile station, Handoff
- Mobile Call Setup
- Roaming

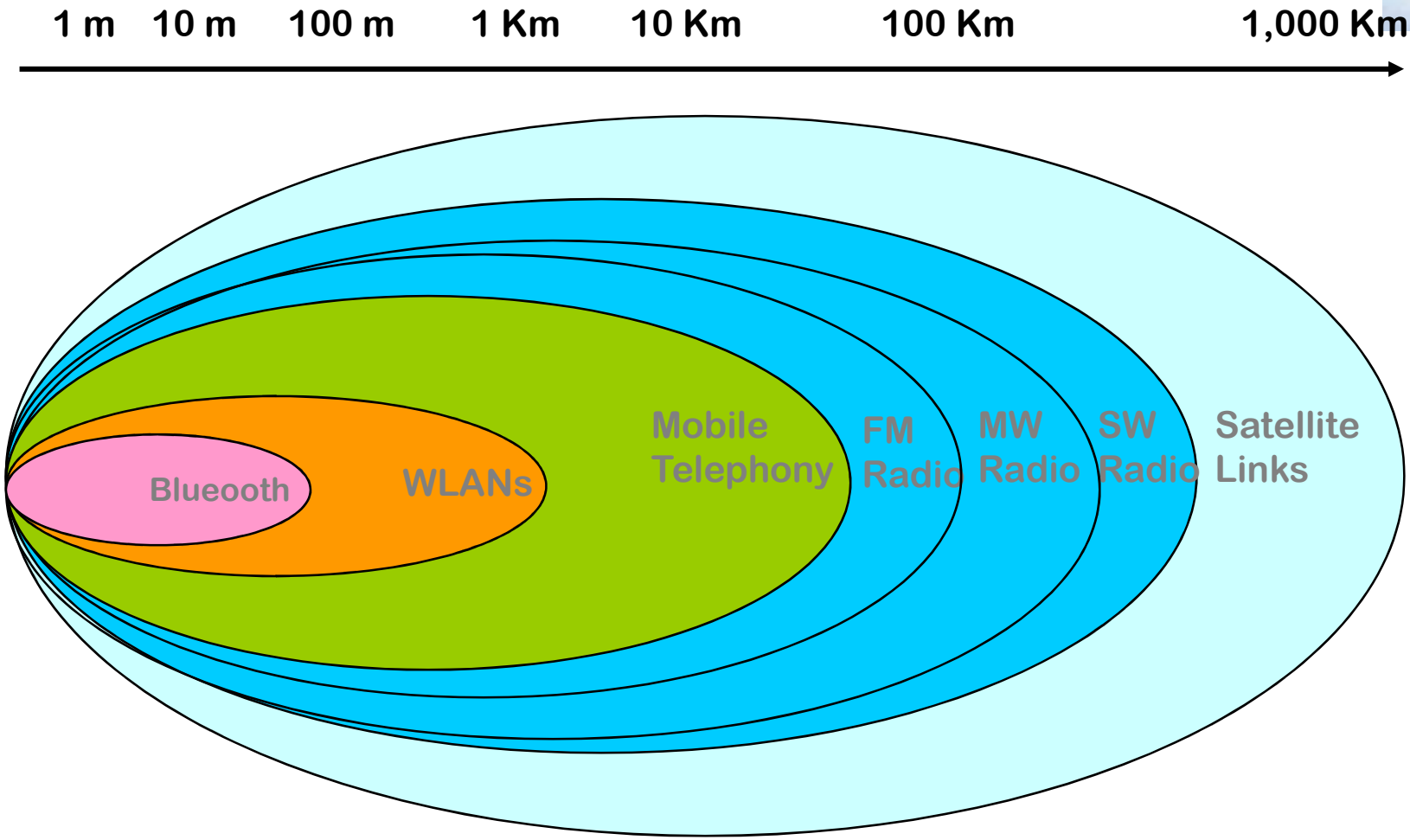
Wireless Communications

- **Information Communication at Any Time and Anywhere**
- **Brief history**
  - **Ancient Systems: Smoke Signals, Fire Signals, Carrier Pigeons**
  - **Radio invented in the 1880s by Marconi**
  - **Many sophisticated military radio systems were developed during and after WW2**
  - **Cellular has enjoyed exponential growth since 1988, with more than 3 billion users worldwide today**
  - **Ignited recent wireless revolution, 1980-2010**
  - **Growth rate tapering off (World wide) but may increase (in Pakistan)**
  - **Is there any future for wireless?**

Wireless Communications



Wireless Systems: Range Comparison

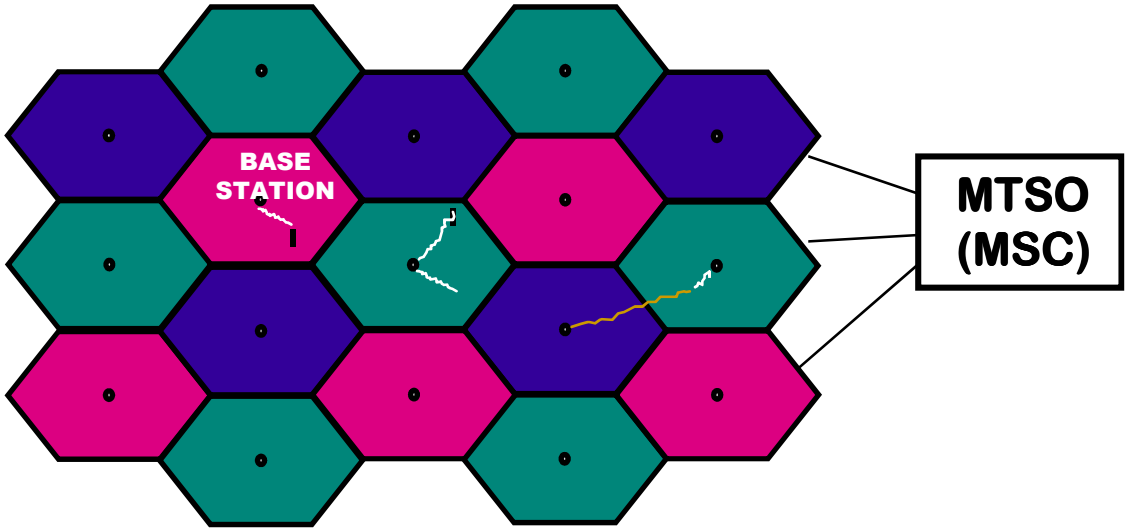


US Frequency Bands

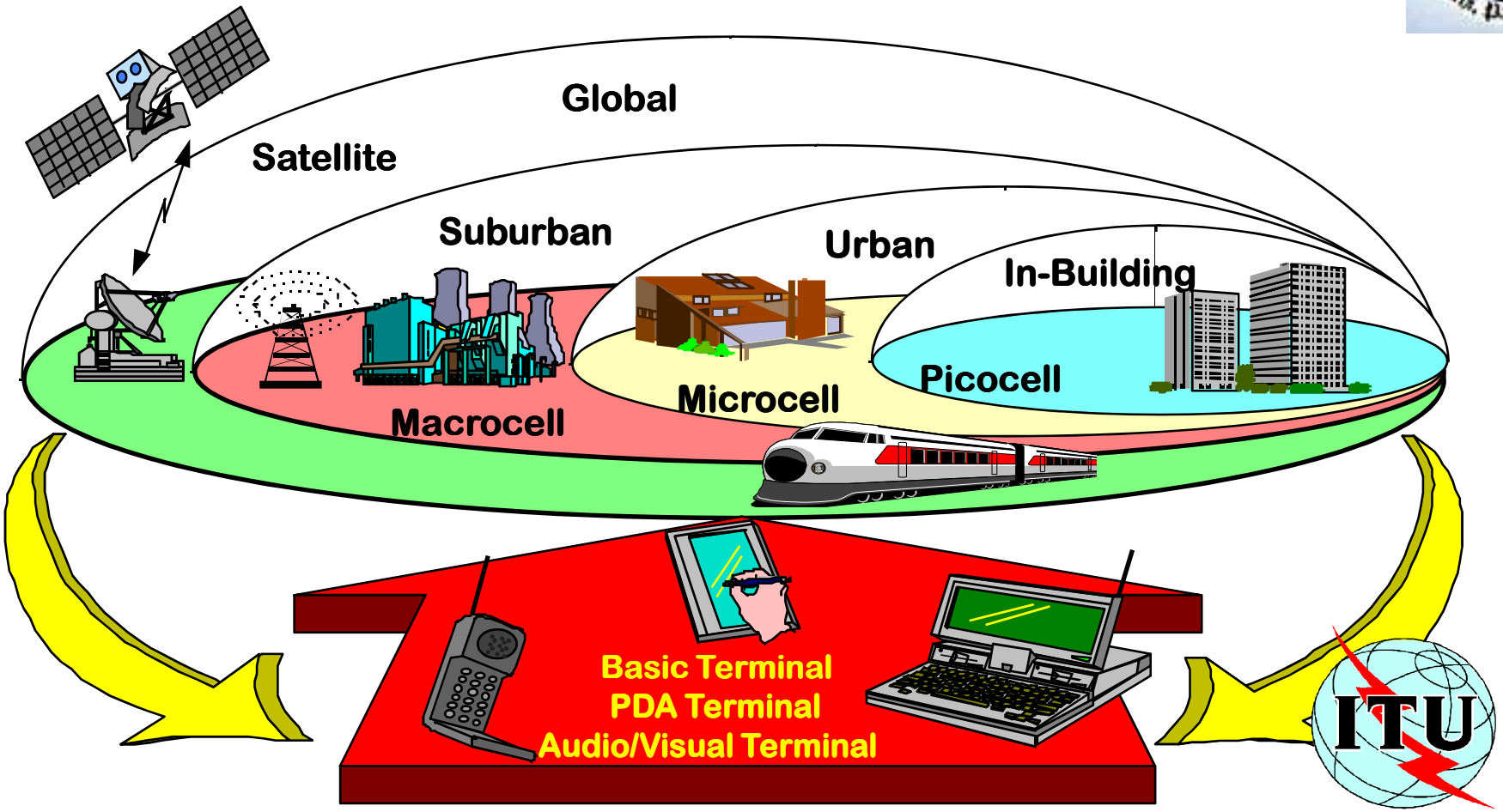
Band	Frequency range
UHF ISM	902-928 MHz
S-Band	2-4 GHz
S-Band ISM	2.4-2.5 GHz
C-Band	4-8 GHz
C-Band satellite downlink	3.7-4.2 GHz
C-Band Radar (weather)	5.25-5.925 GHz
C-Band ISM	5.725-5.875 GHz
C-Band satellite uplink	5.925-6.425 GHz
X-Band	8-12 GHz
X-Band Radar (police/weather)	8.5-10.55 GHz

Cellular Systems: Reuse channels to maximize capacity

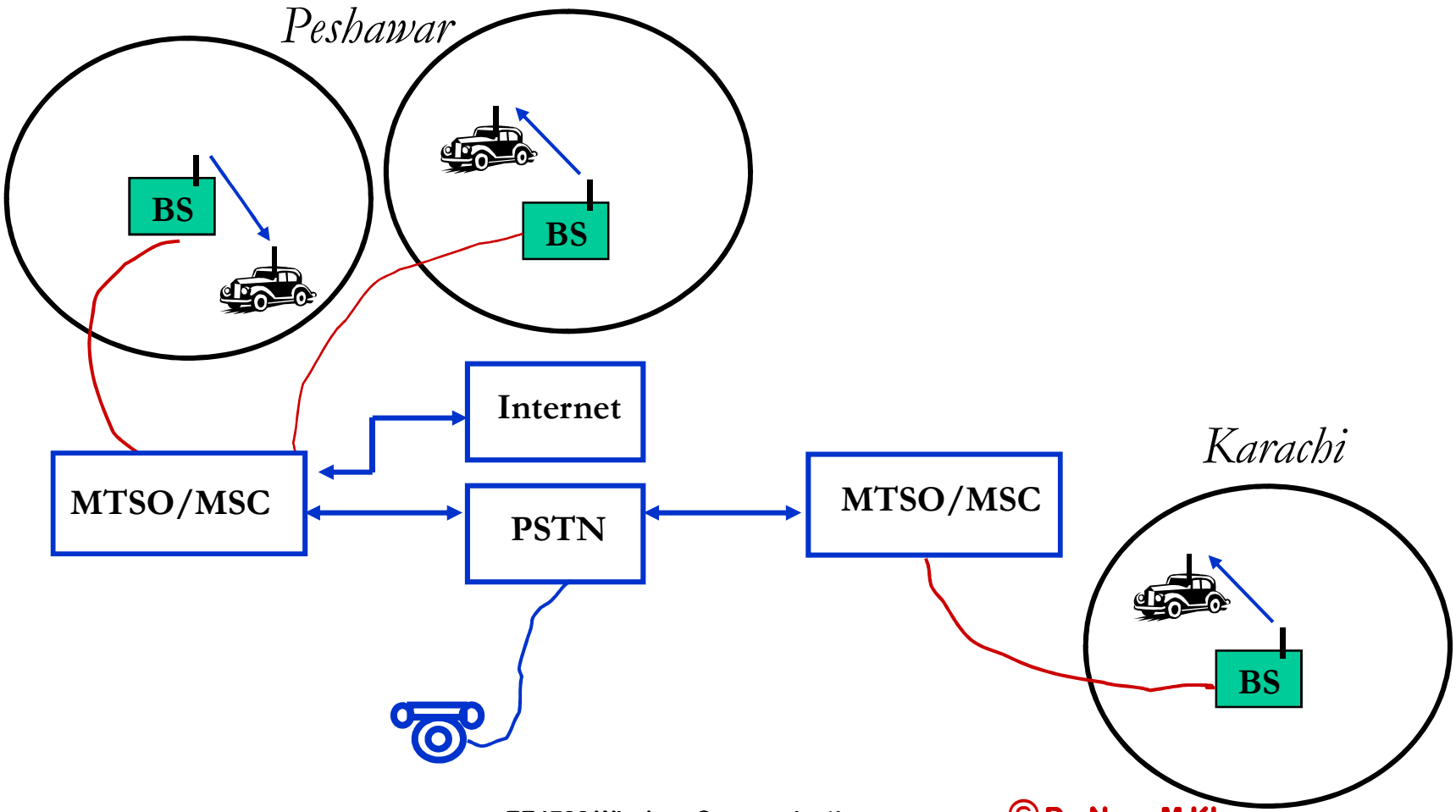
- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MTSOs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



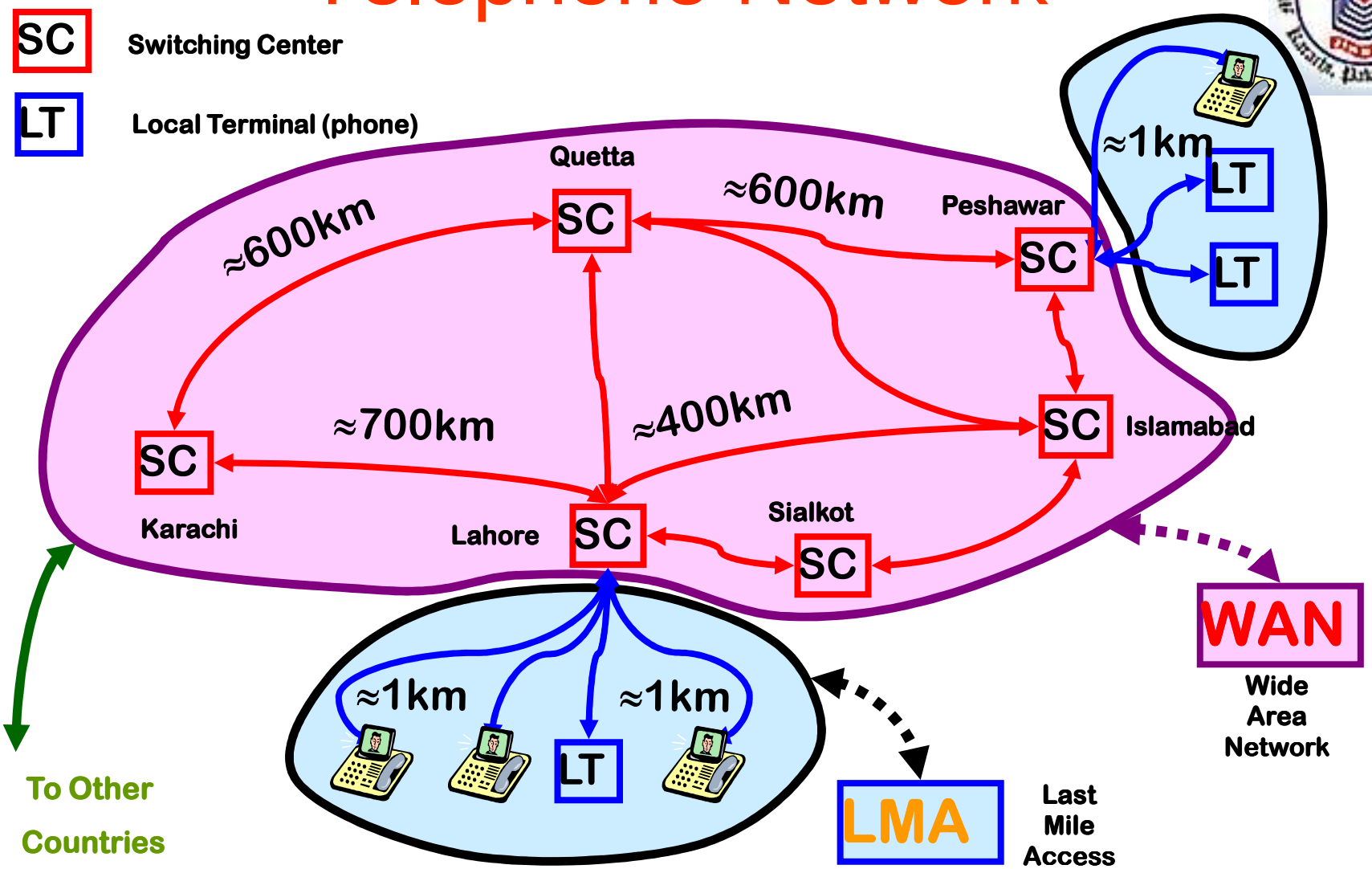
Cellular Systems



Cellular Networks



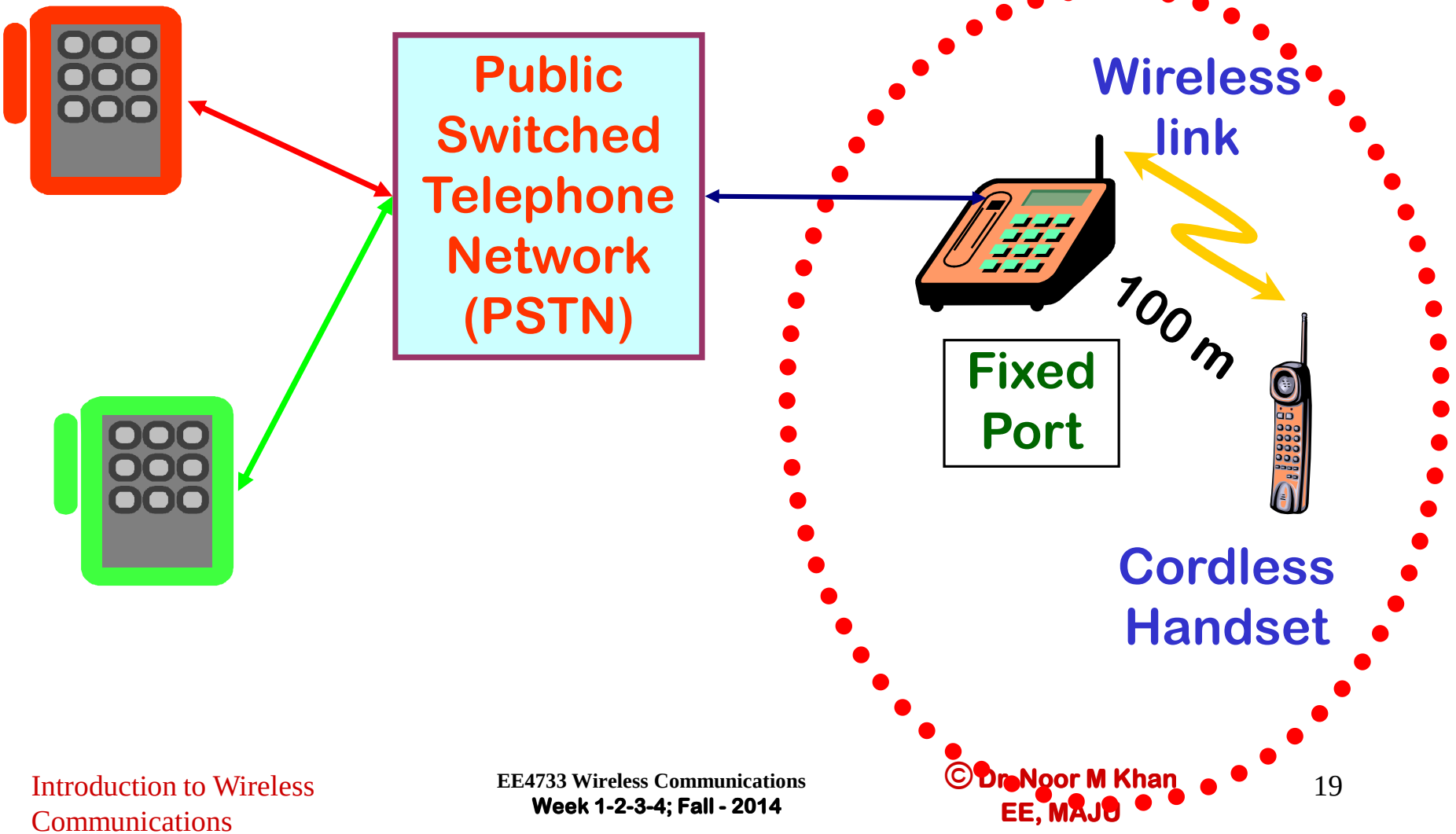
Telephone Network



Cordless System

- **Cordless telephone (CT)** is a communication system using radio waves to connect portable handset to a dedicated fixed port (base station) which is connected to PSTN as a normal telephone line (using ordinary telephone numbers)
- CT provides limited range and mobility in the vicinity of the base station (100 m)

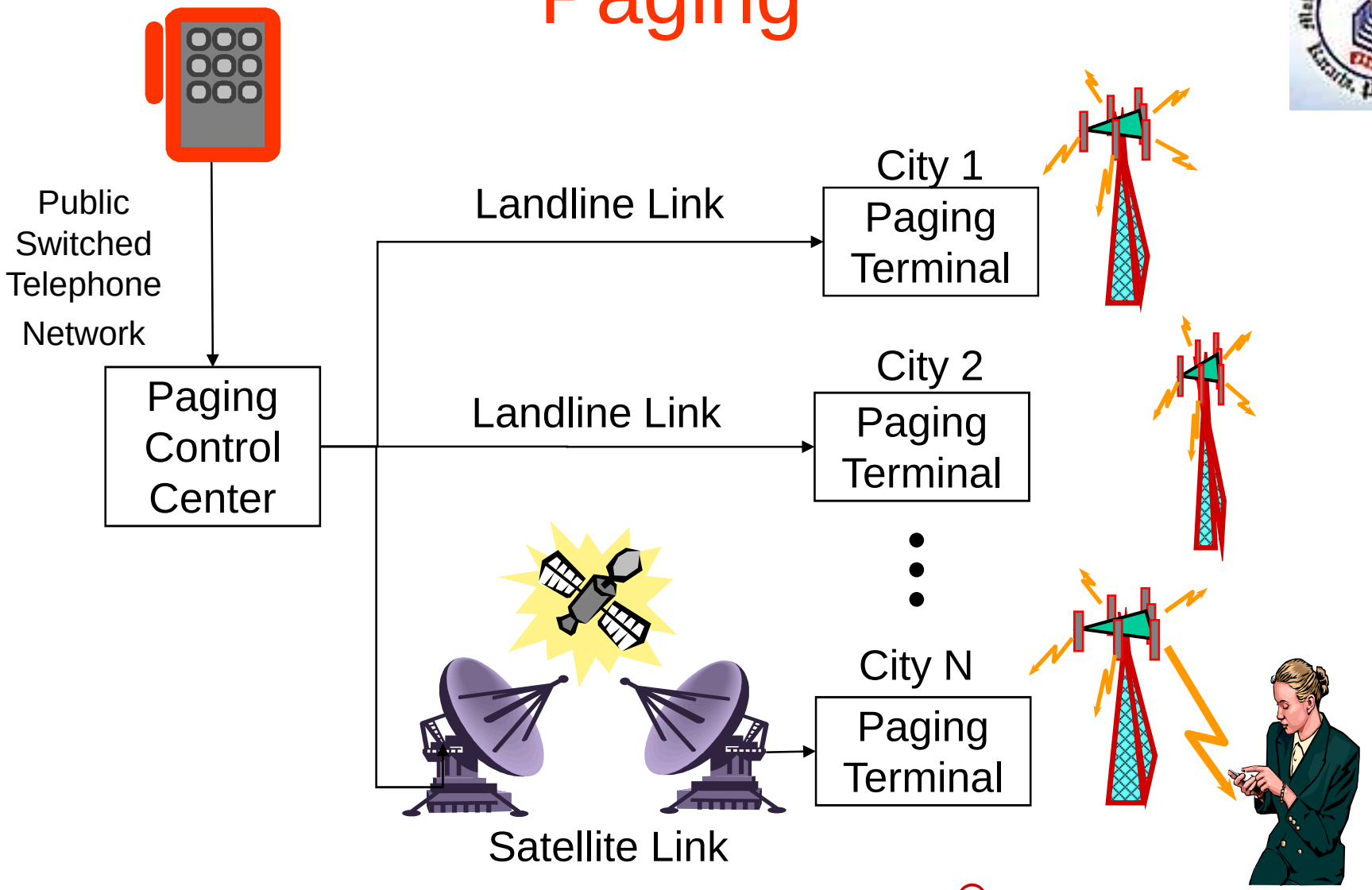
Cordless Telephone



Paging

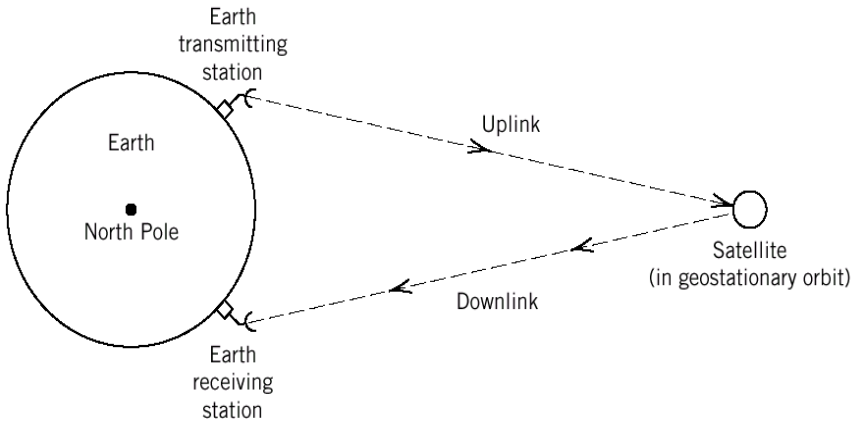
- **Paging systems** are wireless communication systems that send brief messages to a subscriber
- A message is sent to a paging subscriber via the paging system access number by a telephone keypad or modem
- The issued message is called a ***page***

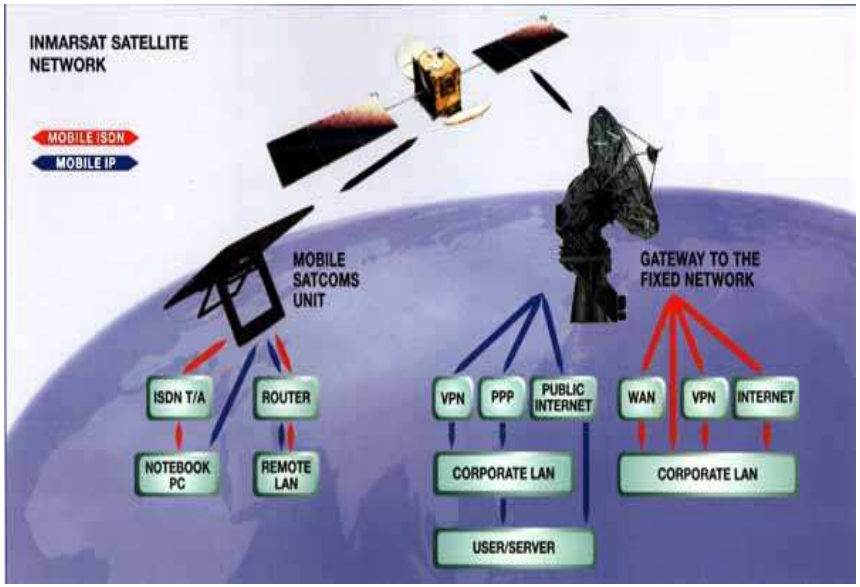
Paging


Public
Switched
Telephone
Network
Paging
Control
Center
Landline Link
Landline Link
Satellite Link
City 1
Paging
Terminal
City 2
Paging
Terminal
City N
Paging
Terminal

Satellite Communication System

- In a geostationary satellite system, a message signal is transmitted from an earth station via an ***uplink*** to a satellite, amplified in a ***transponder*** on board the satellite, and then retransmitted via ***downlink*** to another earth station.

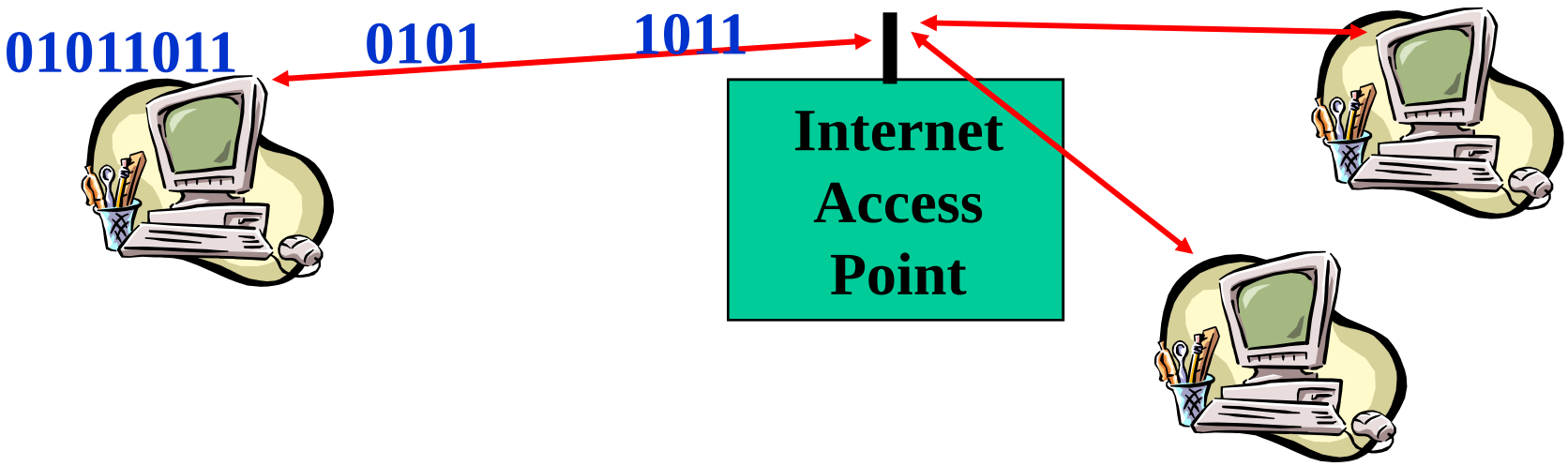




Satellite Communication System

- The most popular frequency band for satellite communications is 6GHz for the uplink and 4GHz for the downlink for the following reasons:
  - Relatively inexpensive microwave equipment
  - Low attenuation due to rainfall (primary cause of signal degradation)
  - Insignificant sky background noise (galactic, solar and terrestrial sources produce low noise in the region 1-10GHz)
- This (6/4GHz) band is used for terrestrial microwave links
- Second generation of satellites use 14/12 GHz band
- 14/12 GHz band requires smaller antennas than 6/4GHz band.

Wireless Local Area Networks (WLANs)



- WLANs connect "local" computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
- Poor performance in some apps (e.g. video)

Wireless LAN Standards

- 802.11b (Earlier Generation)
  - Standard for 2.4GHz ISM band (80 MHz)
  - Frequency hopped spread spectrum
  - 1.6-10 Mbps, 500 ft range
- 802.11a (Emerging Generation)
  - Standard for 5GHz band (300 MHz)
  - OFDM with time division
  - 20-70 Mbps, variable range
- 802.11g (Current Generation)
  - Standard in 2.4 GHz and 5 GHz bands
  - OFDM
  - Speeds up to 54 Mbps

Now, almost all available WLAN Cards have all 3 standards

Wireless LAN Standards

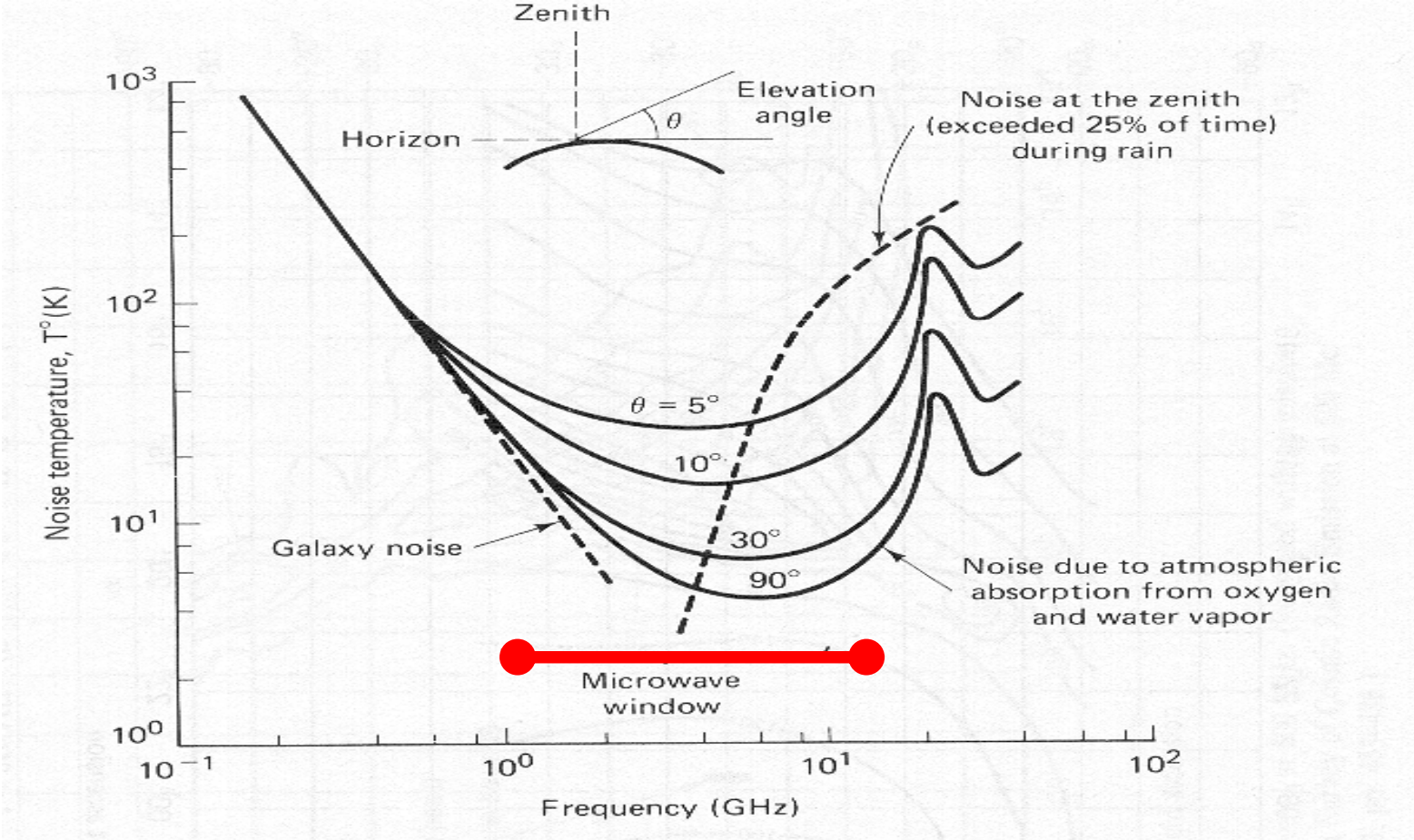
- 802.11n, ac (Next Generations)
  - Standard in 2.4 GHz and 5 GHz bands with 20/40MHz
  - MIMO-OFDM
  - Speeds up to 600 Mbps

WiFi Standards Comparison Table

	802.11b	802.11g	802.11a	802.11n	
IEEE Ratified	1999	2001	1999	2008	
Frequency	2.4GHz	2.4GHz	5GHz	2.4GHz	5GHz
Non-overlapping Channels	3	3	12	3	12
Baseline Bandwidth Per Channel	11Mbps	54Mbps	54Mbps	65Mbps	65Mbps
Number of Spatial Streams	1	1	1	2, 3* or 4*	2, 3* or 4*
Channel Bonding	No	No	No	No	Yes
Max Bandwidth Per Channel	11Mbps	54Mbps	54Mbps	130Mbps	270Mbps

Ref: Wireless Standards Comparison Table, Available Online at http://www.air-stream.org.au/wireless_standards

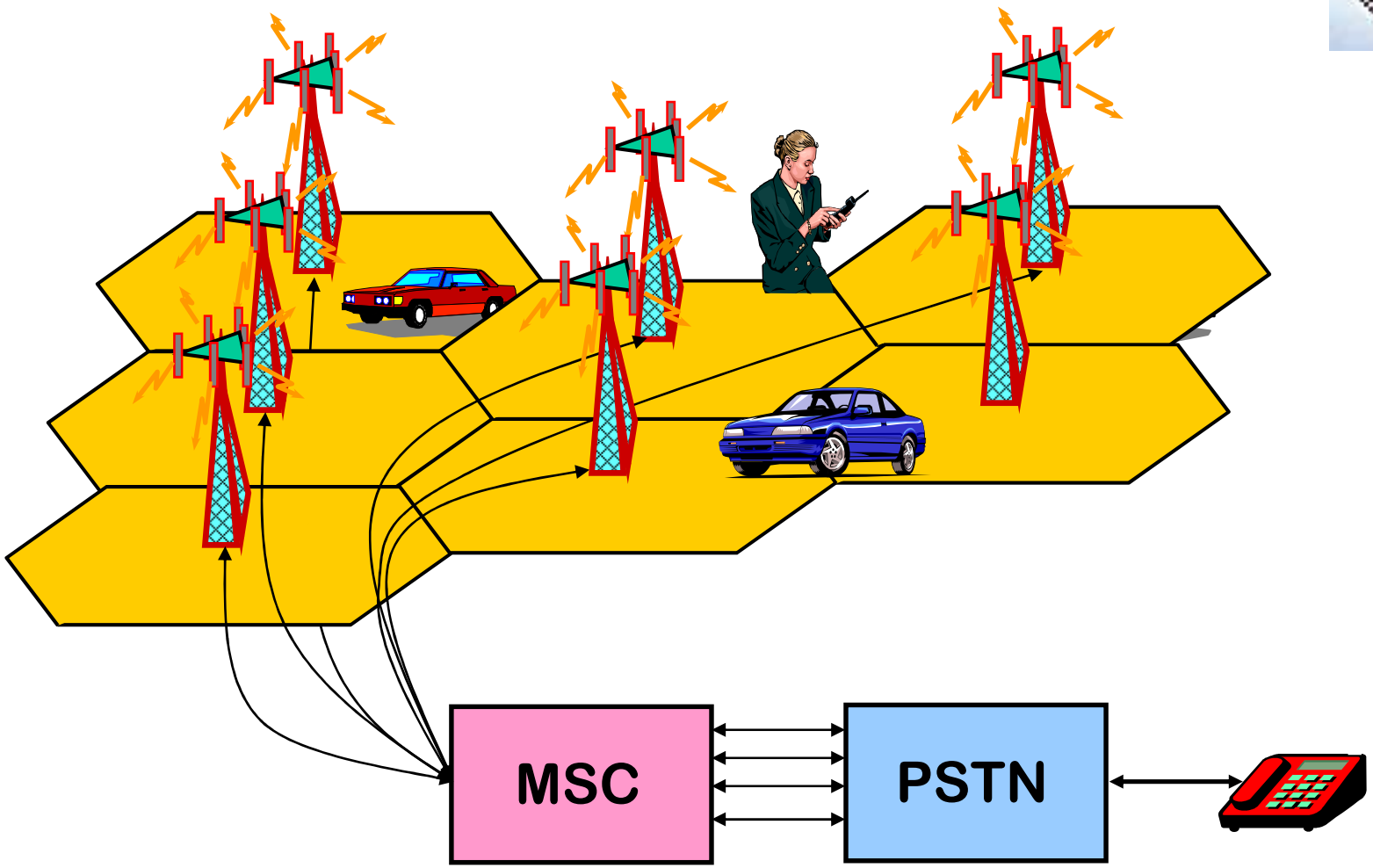
Satellite Systems Noise Level



Cellular Communication System

- Cellular telephones are personally portable devices that may be used in motor vehicles or by pedestrians.
- Communicating by radio-wave in the 800-900-megahertz band, they permit a significant degree of mobility within a defined serving region that may be hundreds of square kilometers in area.

Cellular System



Cellular Coverage

- The geographic area served by a cellular radio system is broken up into smaller geographic areas, or cells.
- Uniform hexagons most frequently are employed to represent these cells on maps and diagrams;
- in practice, though, radio-waves do not confine themselves to hexagonal areas, so that the actual cells have irregular shapes.
- All communication with a mobile or portable instrument within a given cell is made to the base station that serves the cell.

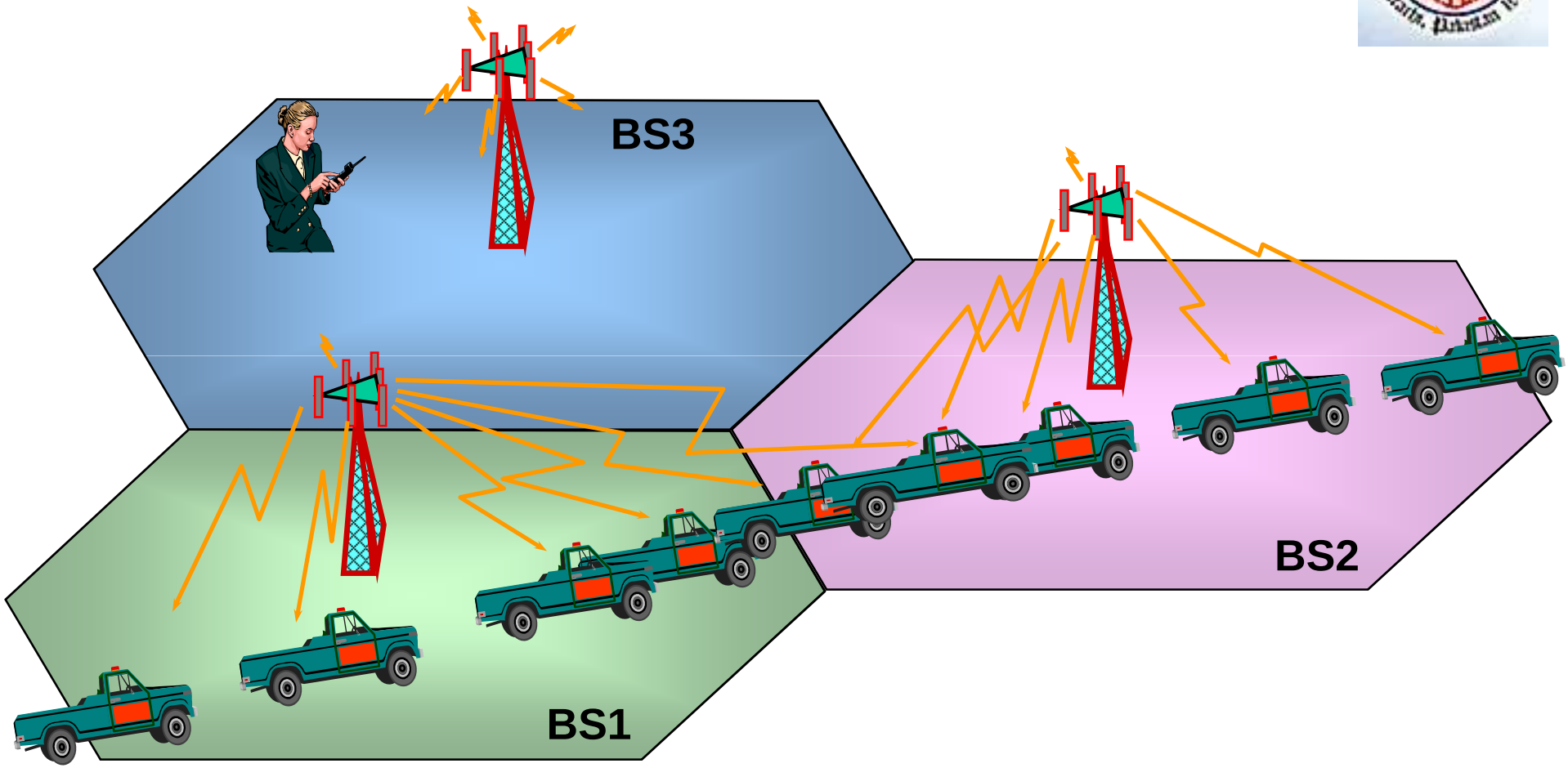
Frequency Reuse

- The transmitting power of battery-operated portable units is relatively low and the attenuation of the propagating radio waves is relatively high.
- That gives us the opportunity for the sending and the receiving frequencies assigned to a cell to be reused in other (more distant) cells within the larger geographic area.
- Thus, the spectral efficiency of a cellular system is increased by a factor equal to the number of times a frequency may be reused within its service area.

Handoff (Handover)

- Usually a mobile unit proceeds from one cell to another during the course of a call,
- A central controller (mobile telephone switching office (MTSO)) automatically reroutes the call from the old cell to the new cell without a noticeable interruption in the signal reception.
- This process is known as handoff.
- MTSO acts as an intelligent central office switch that keeps track of the movement of the mobile subscriber.

Handoff (Handover)



Development of Mobile Telephone Systems.

- In the United States, interconnection of mobile radio transmitters and receivers (transceivers) with the PSTN began in 1946, with the introduction of mobile telephone service (MTS) by AT&T.
- The MTS system employed frequencies in either the 35-megahertz band or the 150-megahertz band.
- A mobile user who wished to place a call from a radiotelephone had to search manually for an unused channel before placing the call.

Mobile Telephone Service (MTS) by AT&T

- In MTS the user spoke with a mobile operator, who actually dialed the call over the PSTN.
- The radio connection was simplex--i.e., only one party could speak at a time
- The call direction was controlled by a push-to-talk switch in the mobile handset.

IMTS by AT&T

- In 1964 AT&T introduced a second generation of mobile telephony, known as improved mobile telephone service (IMTS).
- IMTS provided:
  - 11channels in the 152-158-MHz band,
  - full-duplex operation,
  - automatic dialing, and
  - automatic channel searching.
- 1969 an additional 12 channels were added in the 454-459-MHz band.

Success of IMTS by AT&T

- Only 11 (or 12) channels were available for all users of the system within a given geographic area (such as the metropolitan area around a large city)
- Each frequency was used only once in that area.
- The IMTS system faced a high demand for a very limited channel resource.
- Example: in New York City during 1976, the IMTS system served 545 customers.
- 3,700 customers were on a waiting list for the service.

Drawbacks of IMTS

- In IMTS each base-station antenna was located on a tall structure and transmitted at high power in an attempt to provide coverage throughout the entire service area.
- Because of these high power requirements, all subscriber mobile units in the IMTS system were instruments that carried large batteries.

Start of AMPS

- During this time the American cellular radio system, known as the advanced mobile phone system, or AMPS, was developed primarily by AT&T and Motorola, Inc.
- AMPS was based on 666 paired voice channels, spaced every 30 kilohertz in the 800-megahertz region.
- AMPS system employed an analog-frequency modulation, and was designed to support both mobile and portable subscriber units.

Success of AMPS.

- AMPS was publicly introduced in Chicago in 1983 and was a success from the beginning.
- At the end of the first year of service, there were a total of 200,000 AMPS subscribers throughout the United States;
- 1988 there were more than 2,000,000. In response to this growth, an additional 166 voice channels were allocated to cellular carriers in each market.
- Still, the cellular system soon experienced capacity shortages.

AMPS Improvements

- The American cellular industry responded with several proposals for increasing capacity without requiring additional spectrum allocations.
- One analog FM approach, proposed by Motorola in 1991, was known as narrowband AMPS, or NAMPS.
- In NAMPS systems each existing 30-kilohertz voice channel is split into three 10-kilohertz channels.

NAMPS and IS-54

- In place of the 832 channels available in AMPS the NAMPS system offered 2,496 channels.
- A second approach named IS-54 (IS-136), developed by Telecommunications Industry Association (TIA) in 1988, employed
  - digital modulation
  - digital voice compression and
  - time-division multiple access (TDMA) method;
- IS-54 permitted also three new voice channels in place of one AMPS channel

IS-95

- In 1994 appeared a third approach, developed originally by Qualcomm, Inc., but also adopted as a standard IS-95 by the TIA.
- This third approach used a form of spread spectrum multiple access known as code-division multiple access (CDMA)--a technique that combined digital voice compression with digital modulation.
- The CDMA system offered 10 to 20 times the capacity of existing AMPS cellular techniques.

Developments Outside US

- All of these improved capacity cellular systems are deployed in the United States.
- In Oct. 2000 Telstra, Australia replaced its analog AMPS network with CDMA IS-95 network.
- AMPS was the first cellular system developed, yet the first cellular system actually to be deployed was a Japanese system deployed in 1979.
- Japanese system was followed by the Nordic mobile telephone (NMT) system, deployed in 1981 in Denmark, Finland, Norway, and Sweden.

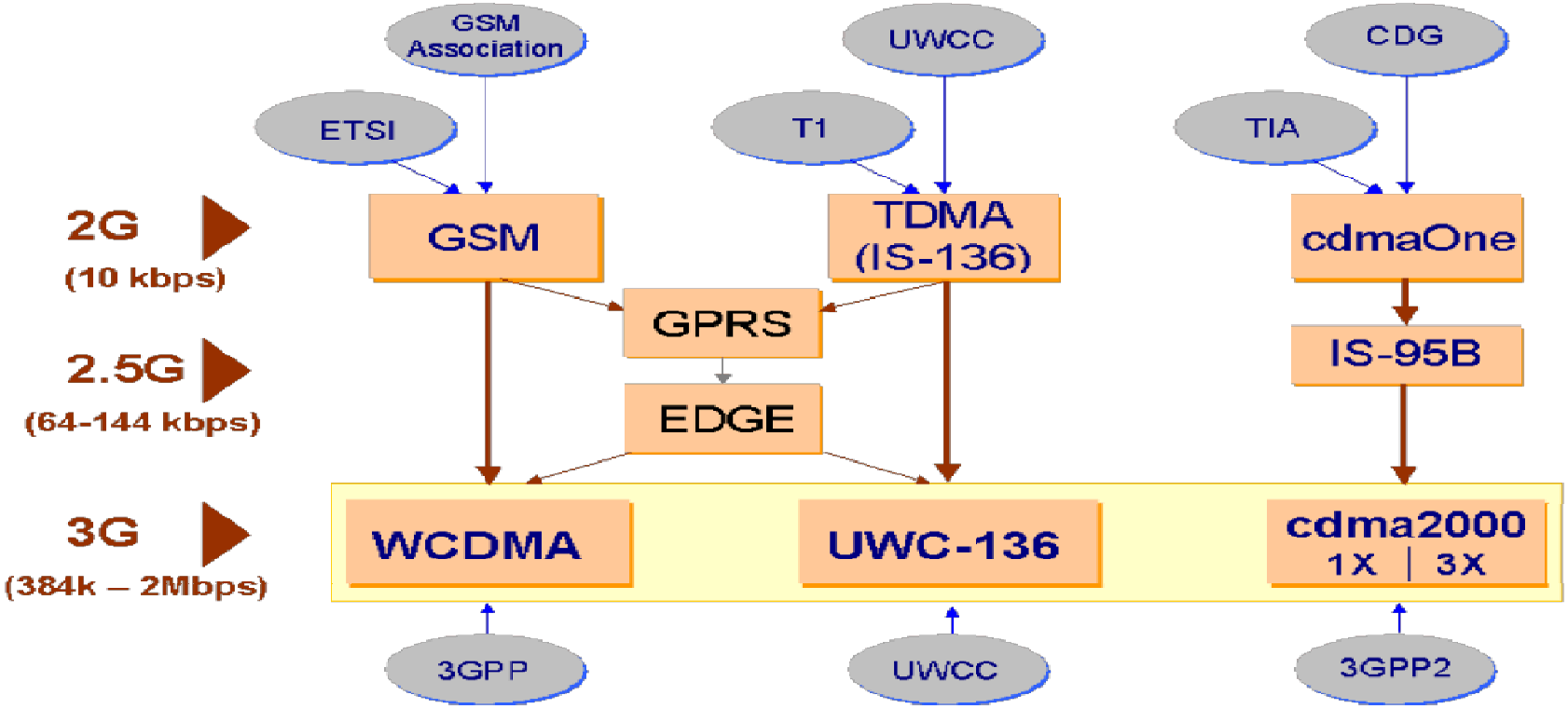
Need for GSM

- Total access communication system (TACS), was deployed in the United Kingdom in 1983.
- A number of other cellular systems were developed and deployed in many more countries in the 80s and 90's. All of them were incompatible with one another.
- In 1988 a group of government-owned public telephone bodies within the European Community announced the digital global system for mobile (GSM) communications,
- GSM was the first system that would permit a cellular user in one European country to operate in another European country with the same equipment.

Convergence of Applications

- **Old but Still Existing Services**:
  - Radio, TV, Telephone, VCR, CD, 1G/2G Cellular;
  - Very LIMITED choice, Capacity Req: << 1 Mbps/user
  - Dedicated Hardware.
- **Current Services**:
  - CD/DVD, WiFi, cable TV, Satellite Phone, 3G Cellular, Wireless Broadband Internet Access, Personal Video;
  - Large but still LIMITED choice, Capacity Req: = 1 Mbps/user
  - Somewhat converged but still Dedicated Hardware.
- **Future Services**:
  - Wireless Broadband, Games, IP Library, IPTV , Personal Video, 4G
  - Unlimited choice Capacity Req: >> 1 Mbps/user
  - Internet **software** terminal, Software Defined Radio (SDR)

Path from 2G to 3G Mobile Communication Systems



Migration Path to 4G Mobile Comm. Systems

- **First Major Migration Path (Europe…)**
  - **I Gen, 80's, ETACS (C-450,NMT-450..),(FDMA), Analog**
  - **II Gen, 90's, GSM, GPRS, EDGE, (TDMA) Digital**
  - **III Gen, 00's, W-CDMA , (CDMA), All Digital**
- **Second Major Migration Path (USA)**
  - **I Gen, 80's, AMPS, (FDMA), Analog**
  - **II Gen, 90's, IS-54 (TDMA), IS-95 (CDMA), Digital**
  - **III Gen, 00's, CDMA2000 (CDMA), All Digital**
- **Universal 3GPP Migration Path (USA, Europe and Asia)**
  - **III-IV Gen, 10's, HSPA+-A, EVDO-A (CDMA), All Digital**
  - **IV Gen, 10's, LTE-A, WiMAX-MAN (OFDM), All Digital**

3G Cellular Systems

- Currently, 3G cellular systems are being deployed worldwide.
- The 3G standards were developed by ITU (International Telecommunication Union) under the name of IMT-2000 (International Mobile Telecommunications 2000) or UMTS (Universal Mobile Telecommunications System).
- It demands a data rate of 2Mbits/s at stationary mobiles, 384 k-bits/s for a user at pedestrian speed, and 144 k-bits/s in a moving vehicle.

- In June 1998, ITU-R (ITU's Radio-communication Sector) received 11 competing proposals for terrestrial mobile systems, and approved five. Two main-stream 3G standards are WCDMA and CDMA2000, which are administered by two bodies in ITU, 3GPP (Third-Generation Partnership Project) and 3GPP2 (Third-Generation Partnership Project 2), respectively.
- In October 2007, ITU decided to include WiMAX (802.16e) in the IMT2000 suite of wire less standards. WiMAX now is a strong contender to WCDMA and CDMA2000.

WCDMA/UTRA

- WCDMA (Wideband CDMA), also known as UTRA (UMTS Terrestrial Radio Access), was jointly developed by ARIB (*Association of Radio Industries and Businesses*), Japan and ETSI (*European Telecommunications Standards Institute*) in 1998-1999.
- Bandwidth of 5MHz and a chip rate of 3.84 M chips/s.
- Provided flexibility to conform with the spectrum spacing of GSM.
- WCDMA employs CDMA/FDD with QPSK/BPSK
- WCDMA supports user data rates up to 2.3 M bits/s both in the uplink and the downlink

HSDPA/HSUPA/HSPA+

- The HSDPA (High-Speed Downlink Packet Access) and HSUPA (High-Speed Uplink Packet Access) standards evolved as a consequence of 3GPP to high-speed data services. They together are known as HSPA (High Speed Packet Access)
- HSDPA employs orthogonal frequency division multiplexing (OFDM) technology for transmission. HSDPA supports 16QAM (quadrature amplitude modulation), achieving a data rate of up to 14.4Mbits/s. HSUPA uses QPSK modulation only, and has a speed of upto 5.76Mbits/s. HSDPA and HSUPA are both treated as 3.5G systems, and they have both FDD and TDD modes
- They both evolved to HSPA+ (3.9G), specified in 3GPP Release7 in 2008.
- Downlink MIMO (multiple input multiple output) is supported in HSPA+

CDMA2000

- CDMA2000, also known as IS2000, was proposed by TIA/EIA. It is a narrow band multicarrier solution, with a carrier width of 1.25MHz and a chip rate of 1.2288 M chips/s, achieving a maximum data rate of 2.457 M bits/s in the downlink.
- CDMA 2000 supports the legacy IS-95 at the air interface.
- It adopts CDMA/FDD in the FDD mode and TDMA/CDMA/TDD in the TDD mode. The modulation schemes are BPSK, QPSK, 8PSK and 16QAM.

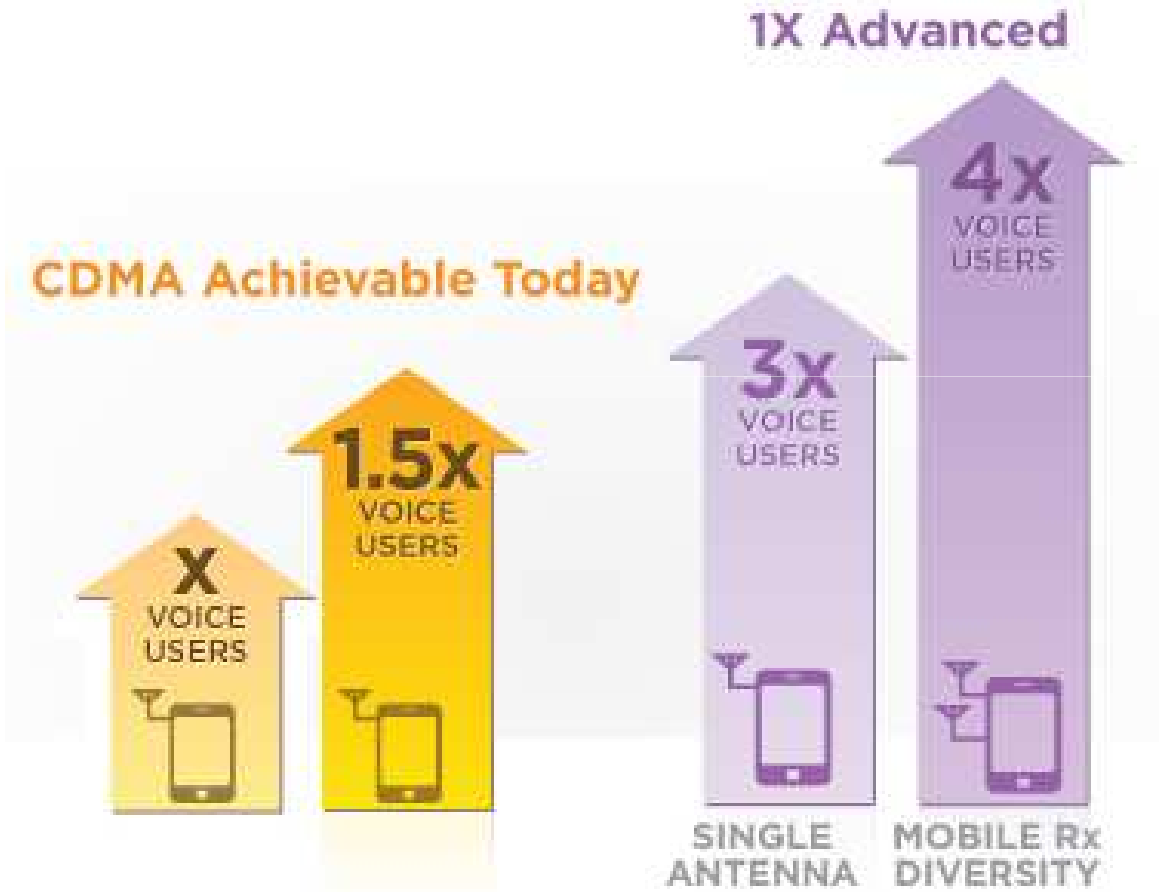
CDMA 2000 1x

- The CDMA 2000 family includes 1x(Phase1), 1xEV-DO (Evolution, Data Optimized), and 1xEV-DV (Evolution, Data and Voice) standards. 1xEV-DO and 1xEV-DV, together are known as IS-856 of TIA/EIA.
- CDMA 2000 1x was first deployed in Korea in October 2000.
- CDMA 2000 1x is four times more efficient than TDMA networks, and has a voice capacity that is twice that of IS-95. It delivers a peak data rate of 144 k bits/s in loaded network, and delivers a peak packet data rate of 307 k bits/s in mobile environments.

1xAdvanced/ 1xEV-Do/ 1xEV-DV

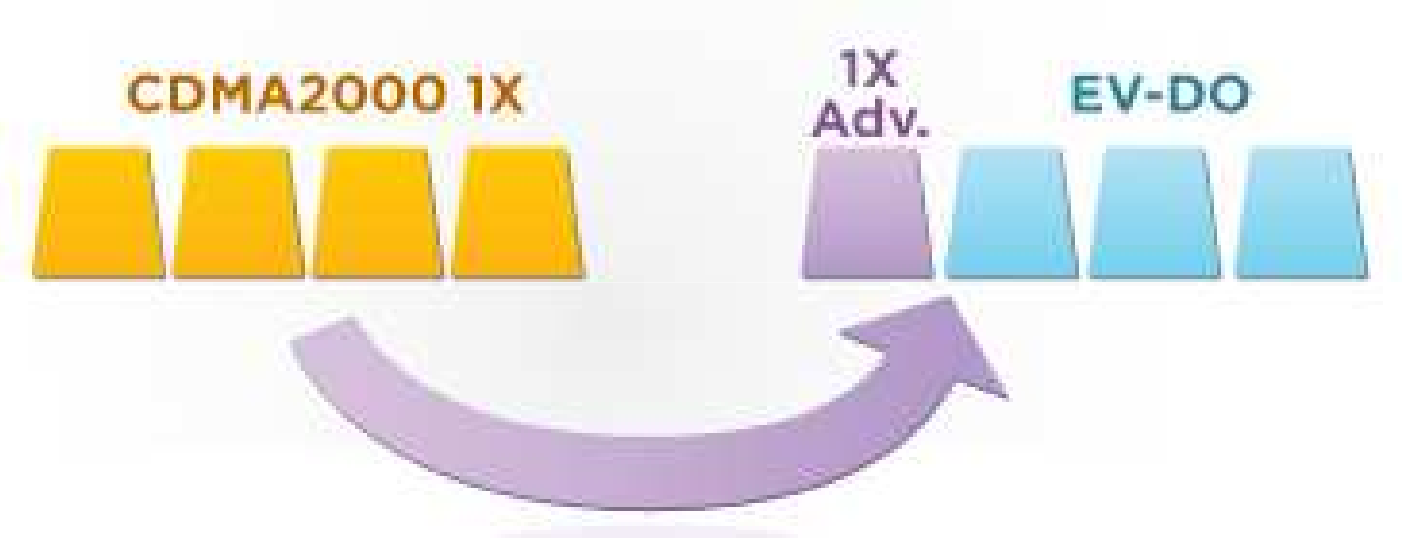
- 3GPP2 published 1xAdvanced in August 2009 for upgrading the 1x platform. By taking advantage of several interference cancellation and radio link enhancements, 1xAdvanced can theoretically quadruple the voice capacity of 1x systems in the same 1.25MHz of spectrum.
- 1xEV-Do provided peak forward data rates of up to2.4 M bits/s in a 1.25 MHz channel, and achieves an average throughput of over 700 k bits/s, equivalent to cable modem speeds. The data rate on the reverse link is up to 153.6 k bits/s. 1xEV-DO offers multicast services, which enable multimedia services, such as real time TV broad cast and movies, to an un limited number of users.
- 1xEV-DV supports a peak data rate of 3.09 M bits/s in the forward link and 1.8456 M bits/s in the reverse link (3.5G)

1x Advanced Main Features



Ref: Qualcomm

1x Advanced Main Features



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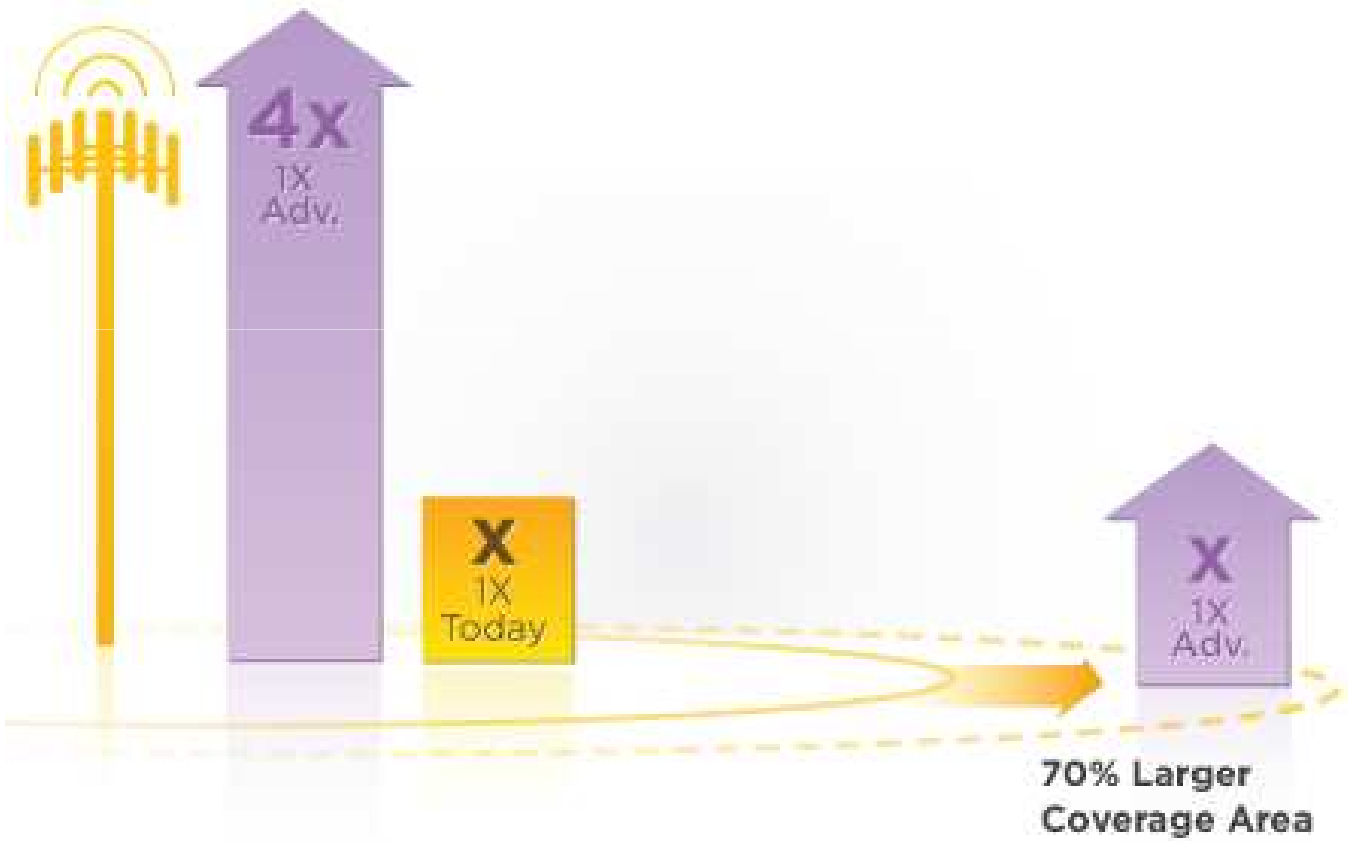
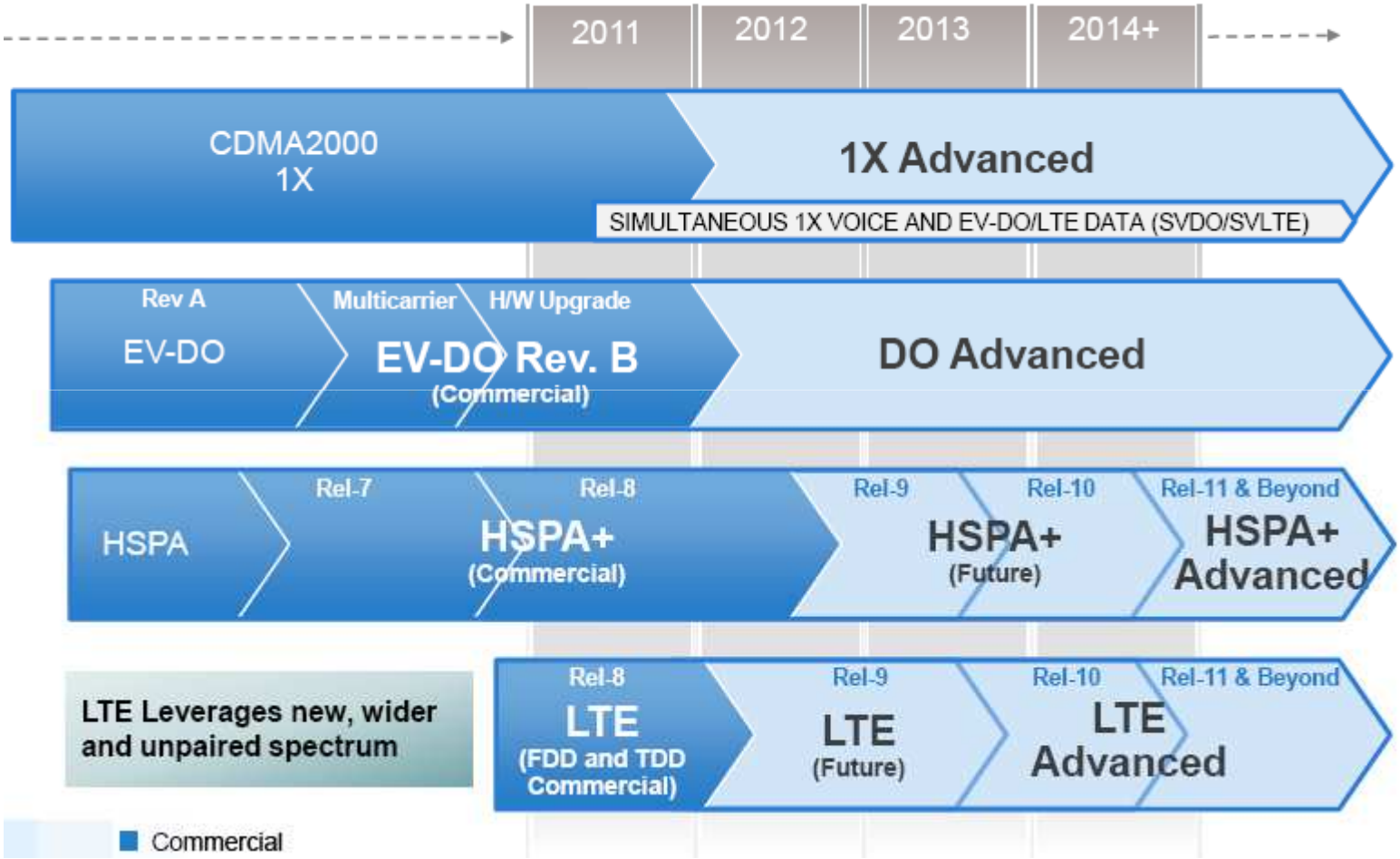
1x Advanced Main Features



Ref: Qualcomm

Qualcomm is a Leader in 3G and 4G



N x EV-DO

- NxEV-DO or EV-DO Multicarrier was published in 2006. It provides a peak forward link data rate of N×4.9 M bits/s, and a peak reverse link data rate of N×1.8 M bits/s.
- It is capable of delivering a peak data rate of 73.5 M bits/s in the forward link and 27 M bits/s in the reverse link by using 15 carriers.
- This can be treated a 3.9G technology.

UTRA-TDD and TD-SCDMA

- 3GPP also has two TDD modes: UTRA-TDD and TD-SCDMA (Time Division-Synchronous Code Division Multiple Access).
- UTRA-TDD, developed by ETSI, is the TDD mode of UMTS.
- UTRA-TDD employs TDMA/CDMA/TDD with QPSK modulation. It uses the same bandwidth (5MHz) and chip rate (3.84 M chips/s) as UTRA-FDD.
- Like UTRA-FDD, UTRA-TDD supports the legacy GSM at the network level.
- The frame of 10ms length is divided into 16 slots, and each slot allows up to 8 CDMA channels.

Cont…

- TD-SCDMA was proposed in China in 1998. It is similar to UTRA-TDD in many aspects, but uses a bandwidth of 1.6 MHz and a chip rate of 1.28 M chips/s.
- The maximum data rate is 2 M bits/s.
- TD-SCDMA is almost twice that of UTRA-TDD. TD-SCDMA provides a cost effective way to up grade existing GSM networks to 3G core networks.
- TD-SCDMA was first deployed in China on April 1,2008.

UWC-136/EDGE

- ITU also approved UWC-136 (Universal Wireless Communication 136)/EDGE as a candidate for IMT-2000 3G standards. UWC-136/EDGE was developed by TIA/EIA to maximize commonality between IS-136 and GPRS, and to meet the ITU-R requirements for IMT-2000.
- UWC-136 provides backward compatibility with IS-136 and IS-136+.
- UWC-136 increases the voice and data capacity of the 30kHz channels by using enhanced modulations ($\pi/4$-DQPSK and 8PSK) with the existing 30kHz IS-136+.
- A complementary wideband TDMA is defined to provide high data rate. By adding a 200kHz carrier component to provide a data rate of 384 k bits/s, compatibility with GPRS and EDGE is possible.
- For transmission at a data rate of 2 M bits/s, a carrier component of 1.6 MHz is added. EDGE also evolved to EDGE Evolution(3.5G).

DECT

- DECT was also approved by ITU as a PCS solution for the IMT-2000 standard.
- DECT employs FDMA/TDMA/TDD.
- In order to increase the data rate to meet IMT-2000 requirements, in addition to its original GMSK modulation, other modulation schemes such as π/2-DBPSK, π/4-DQPSK, andπ/8-D8PSK are also used.

Mobile WiMAX

- Mobile WiMAX, developed on the basis of IEEE 802.16e, is a wireless metropolitan area network (MAN) technology.
- IEEE802.16e was completed in December 2005.
- IEEE 802.16e is based on OFDM technology.
- It allows OFDMA with both FDD and TDD operations.
- MIMO technology is supported in WiMAX.
- It can deliver a maximum of 75Mbits/s and cover a range of 70 miles.
- Mobile WiMAX can be treated as 3.9G.
- Mobile WiMAX is deployed in the 2 to 6 GHz licensed bands.
- The first commercial mobile WiMAX network was launched in Korea in June 2006.

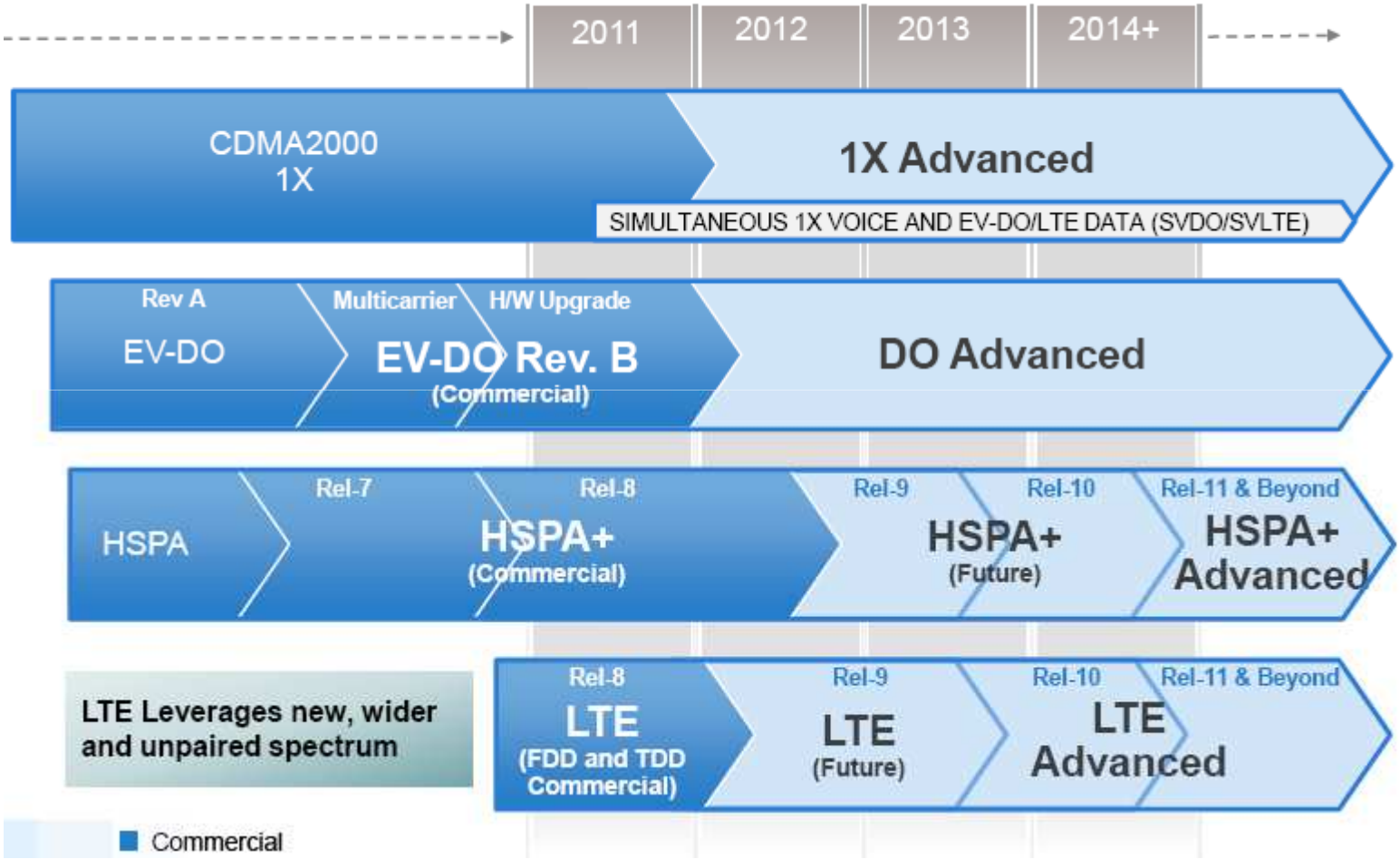
3GPP LTE

- 3GPP LTE (Long-Term Evolution), also referred to as E-UTRA (Evolved UTRA) or E-UTRAN (Evolved UTRA Network), is the project name for the evolution of UMTS, which was started in 2005.
- LTE, publicized in 3GPP Release 8, was finalized in December 2008.
- LTE was first launched by TeliaSonera in Sweden in 2012. It was installed by Ericsson.
- LTE uses a number of bandwidths scalable from 1.25 MHz to 20MHz, and both FDD and TDD can be used
- Both OFDM and MIMO technologies are employed to enhance the data rate to 172.8 M bits/s for the down link and 86.4 M bits/s for the uplink.

Cont…

- LTE uses OFDM in the downlink, while in the uplink a single carrier (SC) FDMA is used. The bandwidth of LTE is more than twice that of HSDPA.
- LTE has a 2 to 6 dB peak-to-average power ratio (PAPR) advantage over the OFMDA method used in mobile WiMAX.
- For a 5 MHz band, HSPA+ achieves 42 M bits/s downlink and 10Mbits/s uplink, while LTE achieves 43.2 M bits/s downlink and 21.6Mbits/s uplink. But HSPA+ does not support over 5 MHz band, while LTE supports up to 20 MHz band.
- The modulations used in LTE are QPSK, 16QAM, or 64QAM.
- LTE can be treated as 3.9G.

Qualcomm is a Leader in 3G and 4G



ITU-R Requirements for 4G IMT-Advanced

- Worldwide functionality & roaming
- Compatibility of services
- Interworking with other radio access systems
- Enhanced peak data rates
  - ❖ 100 Mbit/s for high
  - ❖ 1 Gbit/s for low mobility

Data Rate Requirements for 4G

Data rate requirements set by ITU-R (Approved in 2003, Released in 2008) for IMT-Advanced (International Mobile Telecommunications-Advanced) 4G standards are:

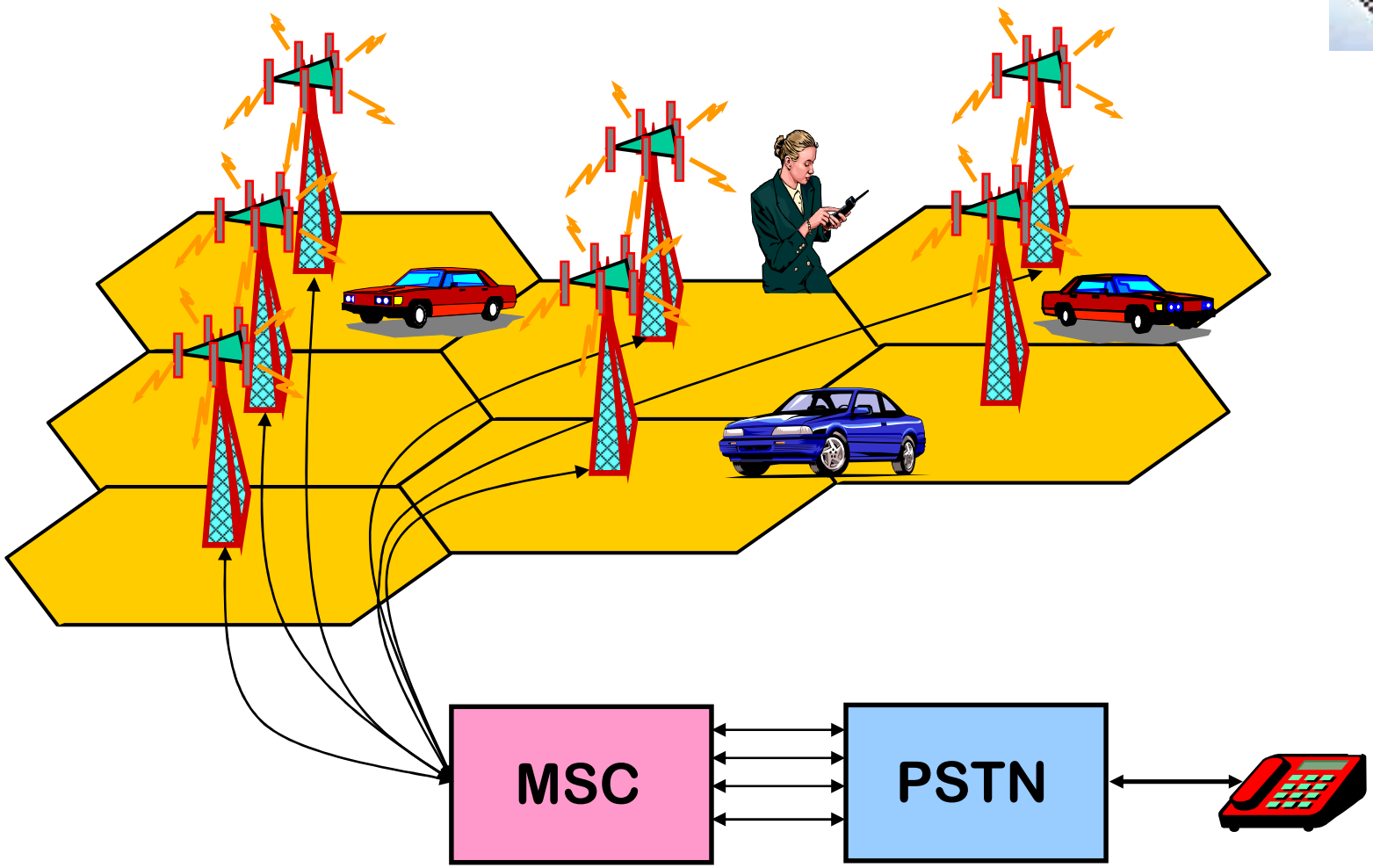
- **100 Mbps, for high mobility communication (from Trains/Cars)**
- **1 Gbps, for low mobility communication (from pedestrians)**

Or in terms of Peak Link Spectral Efficiency:

- **15 b/s/Hz in the downlink**
- **6.75 b/s/Hz in the uplink**

Ref: http://www.itu.int/rec/R-REC-M.1645/en
http://www.techspot.com/guides/272-everything-about-4g/

Cellular System

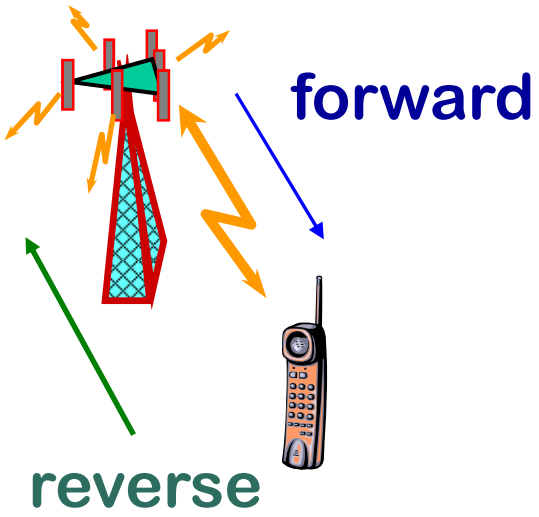


Cellular Telephone System Structure

- A cellular telephone system consists of:
  - Mobile stations (MS)
    - Handheld or vehicular
  - Base stations (BS)
    - Towers supporting several transceivers
  - Mobile switching center (MSC) or mobile telephone switching office (MTSO)
    - Activity control of all BS, connects to PSTN

Cellular System Radio Interface

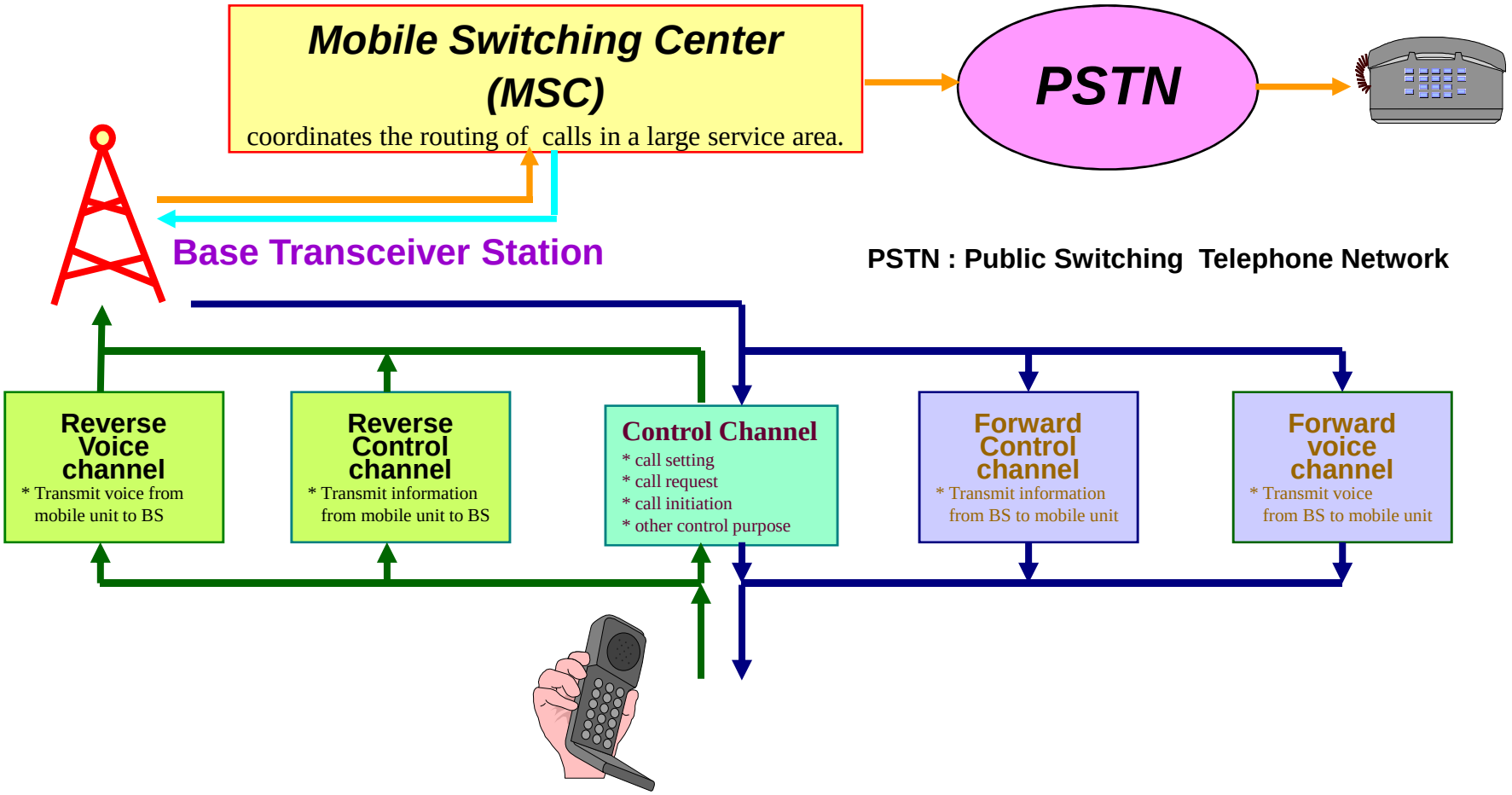
- The ***common air interface*** **(CAI)** defines communication between BS and MS
- Types of channels used in a mobile system:
  - Forward voice channel (FVC)
  - Forward control channel (FCC)
  - Reverse voice channel (RVC)
  - Reverse control channel (RCC)



Cellular Telephone System

- Forward voice channel (FVC)
  - BS to MS voice transmission
- Reverse voice channel (RVC)
  - MS to BS voice transmission
- Forward control channel (FCC) and Reverse control channel (RCC)
  - Setting up mobile call and moving it to voice channel

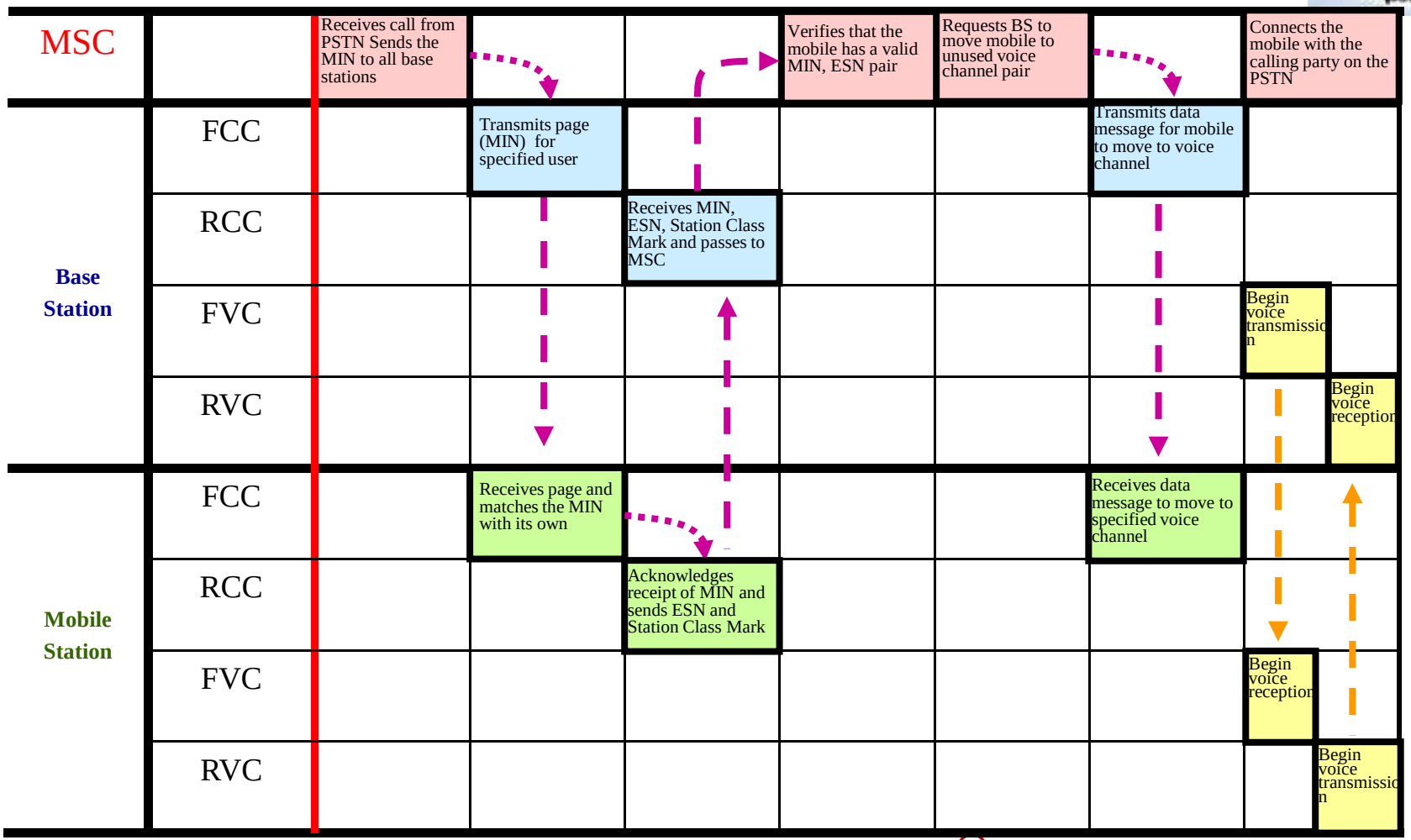
Cellular Telephone System



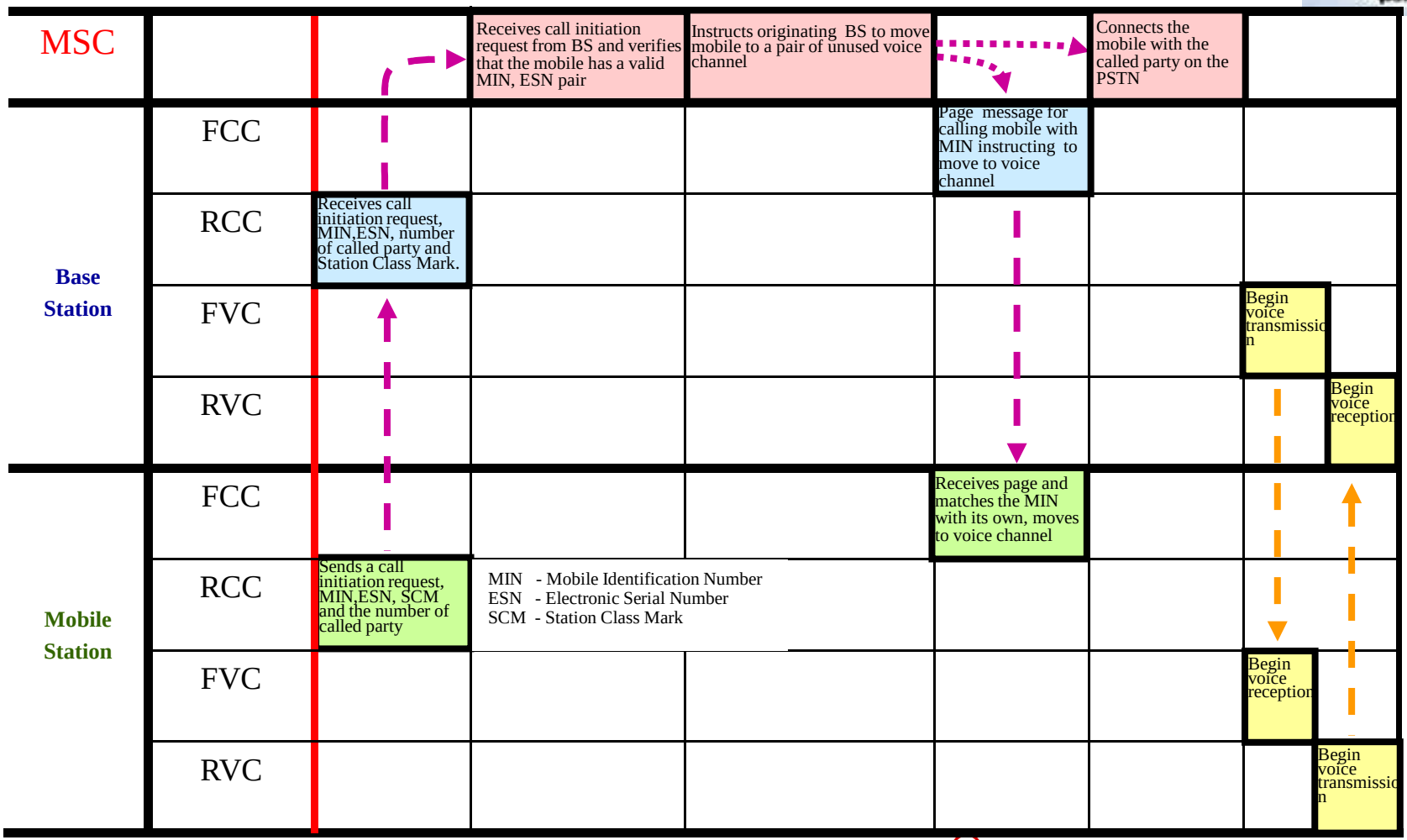
Cellular Telephone Call

- Mobile station (phone) turned on
  - it scans for the group of forward control channels(FCC) to find the one with the strongest signal
  - Monitors that control channel until the signal drops below usable level
  - Again scans for the strongest control channel
- The control channels are defined and standardized over the entire area

Call **to** a Mobile Phone



Call from a Mobile Phone



Roaming(1)

- **Roaming** allows subscribers to operate in mobile phone service areas other then the service area where the service is subscribed
- When a mobile enters area outside the home service area it is registered as roamer in the new service area
- Since FCC are everywhere the same, roamer is receiving information from FCC

Roaming(2)

- Every several minutes MSC issues command over each FCC to all mobiles previously unregistered to report their MIN and ESN over the RCC
- Unregistered mobiles periodically report back subscriber information upon receiving the registration request
- The MSC uses MIN/ESN data to request billing status from the home location register (HLR)
- If the mobile has roaming authorization at home, MSC registers the subscriber in a visiting location register (VLR) as a valid roamer
- Once registered roaming mobiles are allowed to receive and place calls from the new service area
- Billing is routed automatically to the subscribers home service provider (HLR)