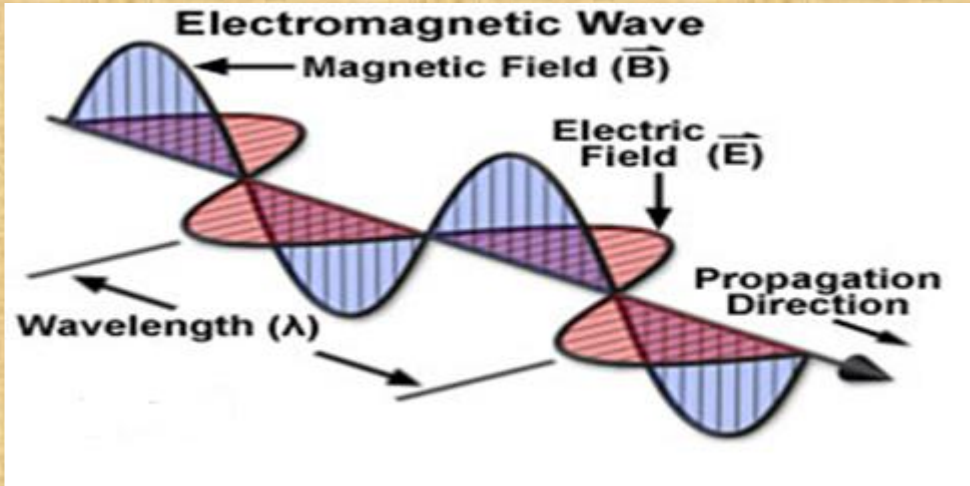
WIRELESS AND MOBILE COMMUNICATION

Wireless Communication

Wireless communication is transfer of information over a distance without using electrical conductors or wires.

Electromagnetic waves

The changing electric and magnetic fields propagate through space and form electromagnetic waves.



Cordless Telephone

It is a telephone with a wireless handset. It communicates via radio waves with a base station connected to fixed telephone line.

Cellular telephone system

Cellular telephone system provides a wireless connection to the PSTN.

Cell

High capacity is feasible by limiting the coverage area of each base station transmitter to a small geographical area called cell.

Cellular telephone system

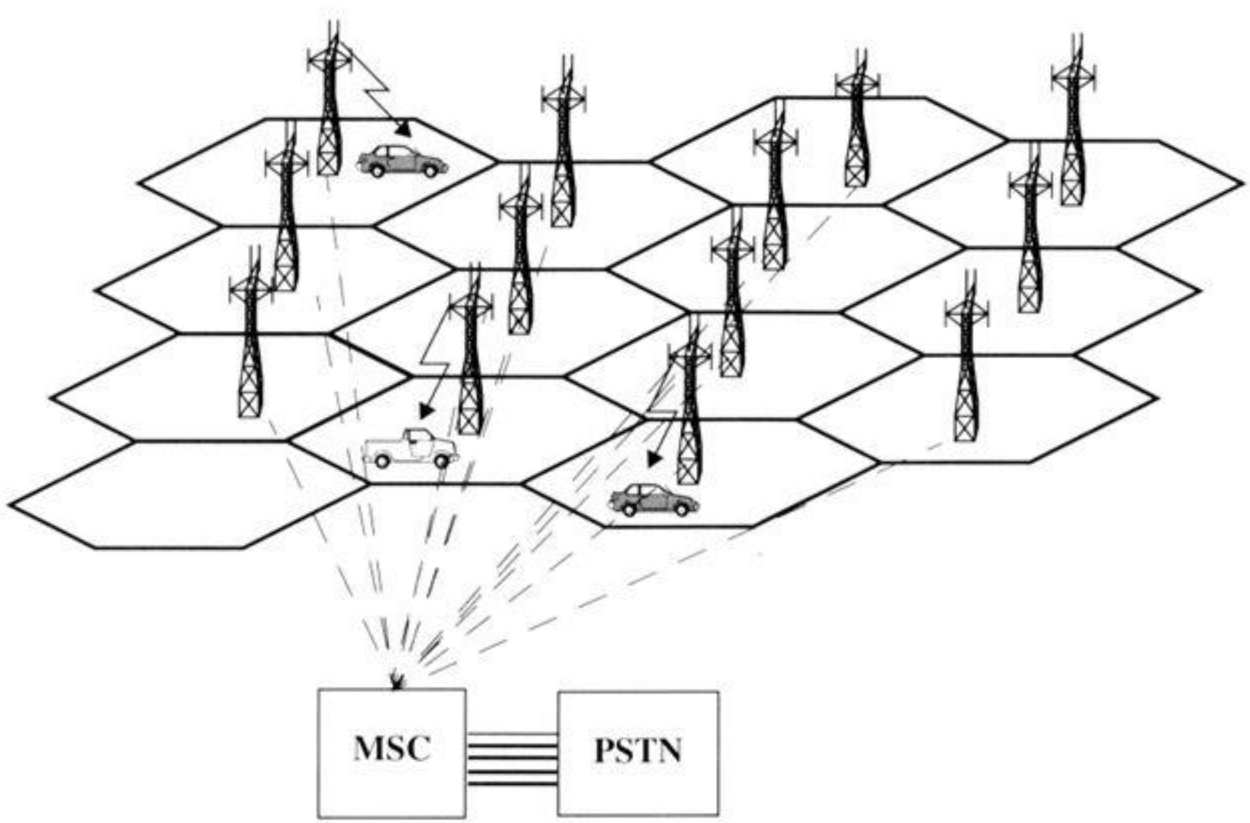


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

CELLULAR TELEPHONE SYSTEM

Cellular Telephone System

First generation cellular system:

First generation is generally written as 1G.

AMPS in America and Australia

Advance Mobile Phone System.

It uses 25MHz band in uplink transmission from 824 to 849MHz.

It uses 25 MHz band in downlink transmission from 869 to 894MHz.

ETACS

European Total Access Communication System

NTT

Nippon Telephone and Telegraph in Japan

1G analog Cellular System

region	America	Europe	Japan
parameter	AMPS	ETACS	NTT
Multiple access	FDMA	FDMA	FDMA
duplexing	FDD	FDD	FDD
Forward channel	869-894 MHz	935-960 MHz	870-885MHz
Reverse channel	824-849 MHz	890-915 MHz	925-940 MHz
Channel spacing	30 KHz	25 kHz	25 kHz
Data Rate	10 kbps	8 kbps	0.3 kbps
Spectral efficiency	0.33 bps/Hz	0.33 bps/Hz	0.012 bps/Hz
Capacity	832 channels	1000 channels	600 channels

Second Generation Cellular System

S. No.	Region parameter	US IS-54	Europe GSM	Japan PDC	US IS-95
1	Multiple Access	TDMA/ FDD	TDMA/ FDD	TDMA/ FDD	CDMA
2	Modulation	Pi/4 DQPSK	GMSK	Pi/4 DQPSK	QPSK/ OQPSK
3	Forward Channel	869-894 MHz	935-960 MHz	810-826 MHz	869-894 MHz
4	Reverse Channel	824-849 MHz	890-915 MHz	940-956 MHz	824-849MHz
5	Channel Spacing	30kHz	200kHz	25kHz	1.250 kHz
6	Data Chip Rate	48.6 kbps	270.833 kbps	42kbps	1.2288 Mbps
7	Speech Code Rate	7.95 kbps	13.4 kbps	6.7 kbps	1.2/2.4/ 4.8/9.6 kbps

3G wireless Communications

3G systems provide fast communication services.

3G wireless communications include multimedia entertainment, infotainment and location based services.

2.5G networks such as GPRS (Global Packet Radio Service) are already available in some parts of Europe.

It supports 144 kbps bandwidth with vehicles, 384kbps in campus and 2Mbps in stationary such as building.

3G supports the following:

PLMNs(Public land mobile networks.

Mobile IP(Mobile Internet Protocol)

WATM networks(Wireless Asynchronous transfer Mode)

LEO(Low Earth Orbit) satellite networks.

4G systems

In July 2003, ITU made a requirement for 4G system and 4G supports to:

At a standstill condition, the transmission rate should be 1 Gbps.

At a moving condition transmission rate should be 100 Mbps.

It includes the following:

(i)Interactive multimedia services such as teleconferencing, wireless internet etc.

(ii) Wider bandwidths, higher bit rates.

(iii) Global mobility and service portability.

(iv) Low Cost.

(v) Scalability of mobile networks.

4G uses OFDM (Orthogonal Frequency Division Multiplexing).

CELLULAR CONCEPT

Cellular Concept

The cellular concept is a major improvement in solving the problem of spectral accumulation or obstructions related to signals traffic.

It also solves the problem of user capacity.

Cell Area

A cellular network is a radio network distributed over land (geographical area) is known as cell and this area is known as cell area.

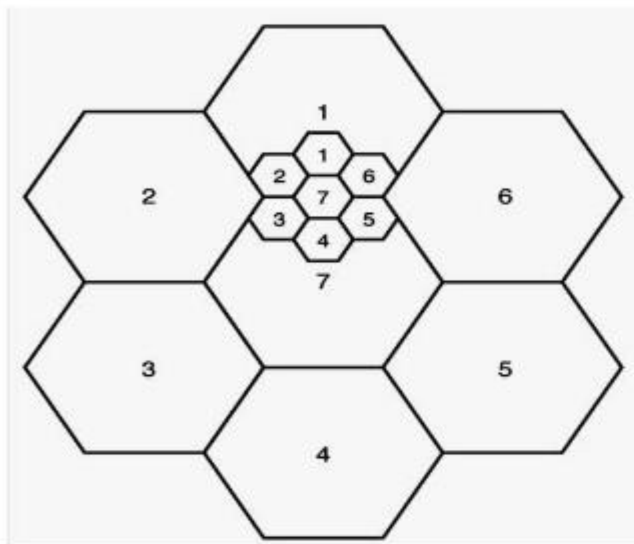
Each cell station is served by at least one fixed location transceiver and this location is known as cell site or base station.

Honeycomb cell pattern

Cellular Telephone Systems

Honeycomb – the pattern formed by the hexagonal- shaped cells.

Picocells – very small cells used indoor.



The hexagonal shape is chosen because it provides most effective transmission.

Hexagonal shaped cells are approximated to a circular shape and it eliminates inherently gaps present between adjacent cells.

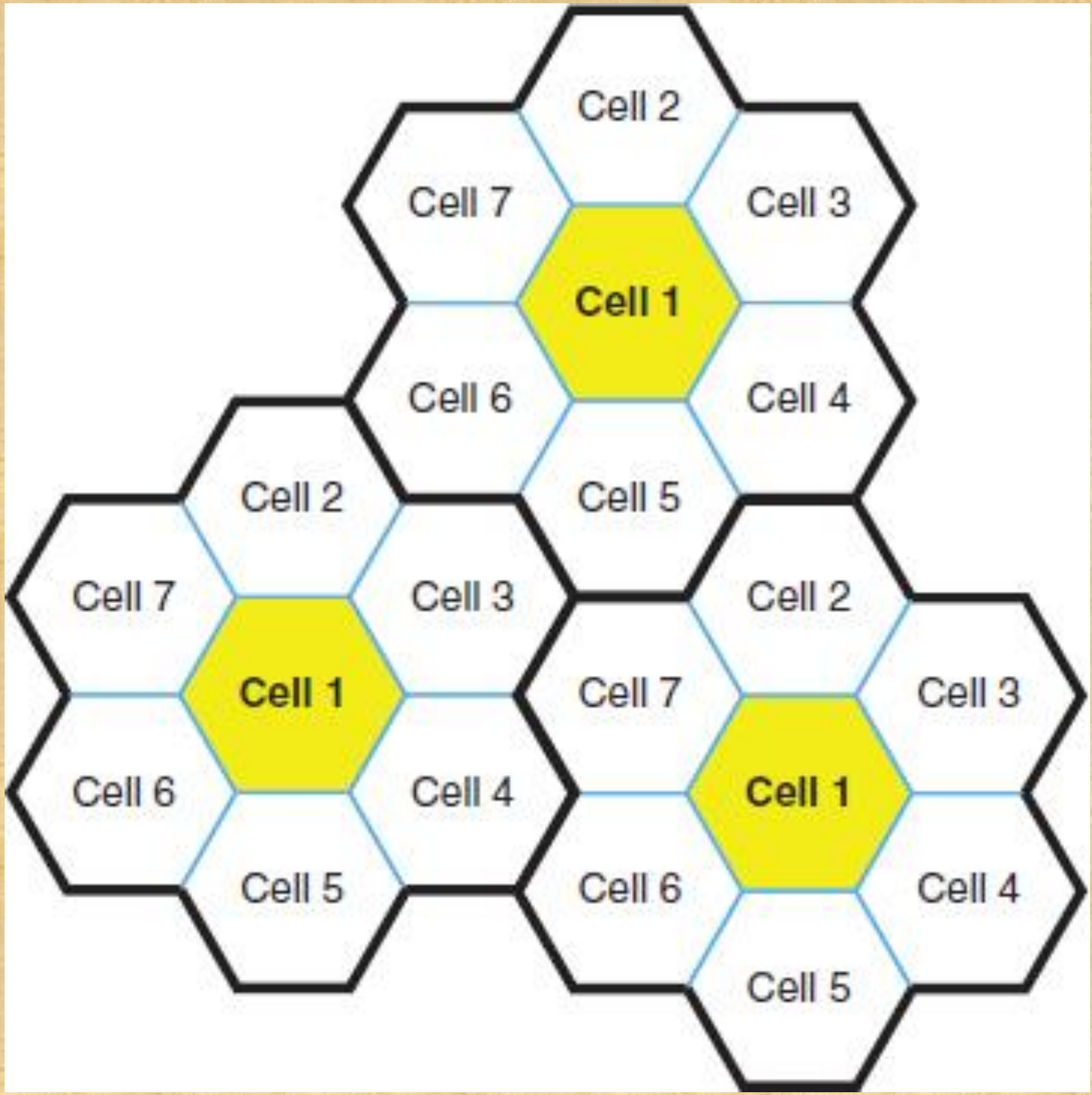
Macrocells

Radius between 1 mile and 15 miles.

Microcells

Radius upto 2 km.

Frequency Reuse



Frequency reuse is the process in which same set of frequencies can be allocated to more than one cell; provided cells are separated by sufficient distance.

The total no of channels available in a cluster can be expressed mathematically as

$$F=GN$$

F=no of full duplex cellular channels available in a cluster

G=no of channels in a cell

N=no of cells in a cluster

Mathematically, FRF is given as:

FRF=N/C

FRF=Frequency Reuse Factor

N=total no of full duplex channels in an area.

N=total no of full duplex channels in a cell.

FRF has no units

To connect cells without gap in between the geometry of hexagon is to satisfy the equation:

$N=i^2 + ij + j^2$

N = no of cells per cluster

i and j = non negative integer values

Interference

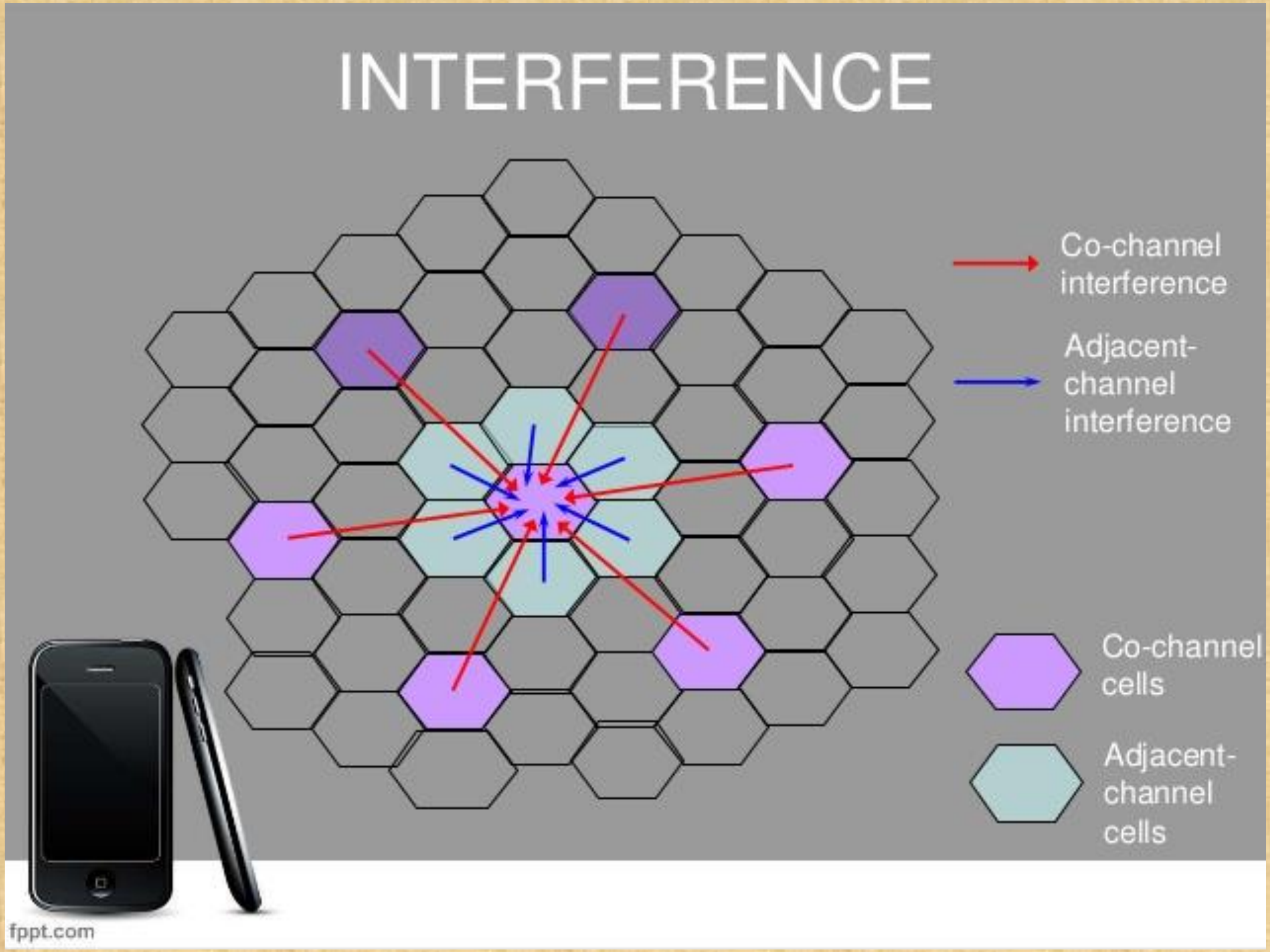
Interference is defined as a form of external noise.

There are two types of interferences produced within a cellular telephone system. These are:

(i) Co-channel Interference

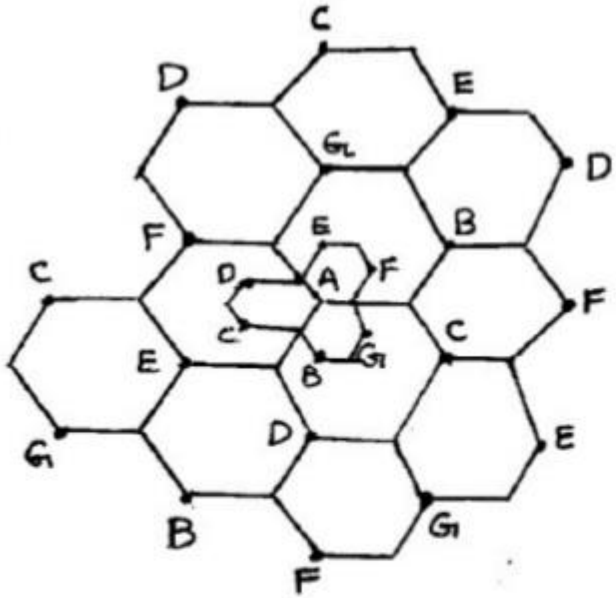
(ii) Adjacent channel interference.

Interference



Improving coverage and capacity in a cellular system

Cell splitting



- The process of subdividing a congested cell into smaller cell.
- Each with its own base station and a corresponding reduction in antenna height.
- leads to increase in capacity

Cell Sectoring

Sectoring methods

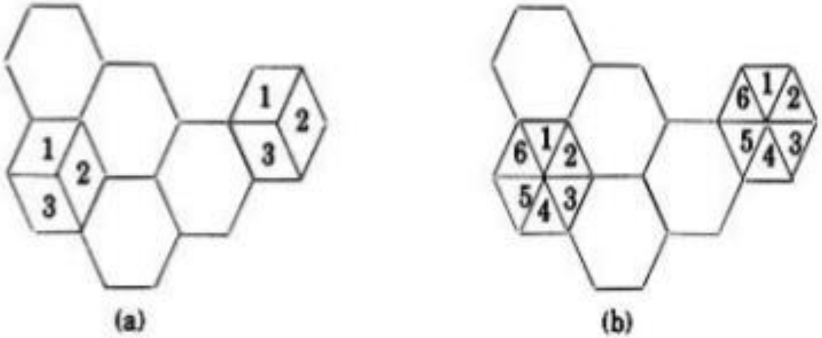
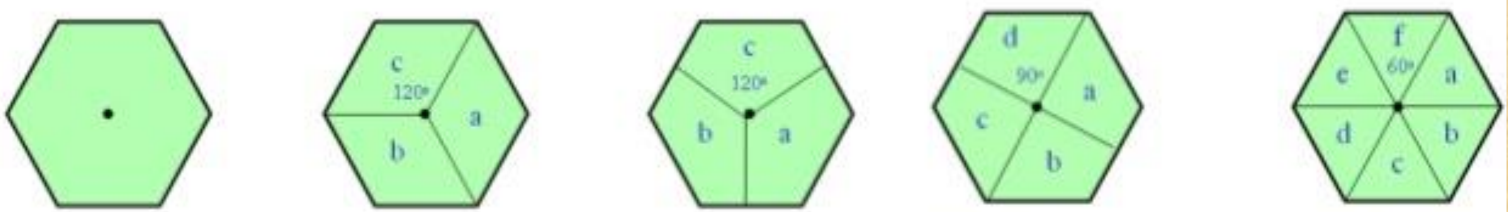


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Cell sectoring

Improving Capacity in Cellular Systems

- Aim: To provide more channels per unit coverage area
- Techniques: Three techniques are used to improve capacity
- SECTORING:
  - Use directional antennas to further control the interference and frequency reuse of channels.
  - Examples: Omni, 120^0, 60^0 and 90^0



(a). Omni (b). 120° sector (c). 120° sector (alternate) (d). 90° sector (e). 60° sector

Repeater for range extension

It is a must for a wireless operator to provide coverage for “hard to reach areas”.

Hard to reach areas are such as buildings, valleys, or tunnels.

To provide effective services in cellular communication, Radio re transmitters known as repeaters are used.

Repeater amplifies the signal received from base station and radiates it further to the specific coverage region.

6^{th} Semester

Wireless & Mobile Communication

Lincoln Hadda
ECE Department
GP Sonipat

Outline

- Course Info
- Introduction
  - What is Wireless
  - What is PCS
- History of Wireless
- Some Mobile Statistics

Recommended Textbooks

- Theodore Rappaport, **Wireless Communications: Principles and Practice**, Second Edition, Prentice Hall, December 2001.
- Yi-Bing Lin, Imrich Chlamtac, **Wireless and Mobile Network Architectures**, John Wiles & Sohns, 1st edition, 2000.
  - You don’t have to buy these books. But I recommend buying them if you have the opportunity!

Reading List

- You will read a lot of papers in this course
- The papers are on the course web page
  - You can download them from there.
  - If a paper is not there, let me know.
  - I will put the paper on my door if there is no online copy of the paper
- The paper-list size on the webpage will be reduced, so that you don't spend all of your time only on this course.

Grading

- There will be one midterm and one final exam
- There may be projects. I did not determine them yet.
  - Simulation or implementation projects
  - No idea how hard they will be!
  - No idea which language(s) they will be implemented on!
- Attendance is important!

Why projects are important?

- I hear and I forget, I see and I remember, I do and I understand

  Confucius

Outline

- Introduction
  - What is wireless and mobile networking
  - History of Wireless
  - Challenges of Mobile and Wireless Communication and Networking
  - What is Personal Communications Systems
    - Why there is demand on that
    - What is ubiquitous computing.
  - Overview of Wireless Technologies and Systems

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

- Wireless Media Access
  - What is different in Wireless Media than Wireline Media
    - Why CSMA/CD does not work
    - MACA and MACAW protocols
  - TDMA and FDMA
  - CDMA

Outline

- Handoff
  - More from telecom point view
  - How handoffs are triggered
  - How handoffs are managed
- Routing
  - more from data networking point of view
  - How mobility affect routing for mobile hosts
  - Mobile IP

Outline

- Transport Protocols over Wireless and Mobile Networks
  - How does wireless links and mobile hosts affect the performance and operation of transport protocols
  - Look specifically to TCP
  - There are many proposals to improve the performance of TCP over wireless links and for mobile hosts

Outline

- Ad-Hoc Mobile Networks
  - What if the mobile hosts are not roaming around an infrastructure-based network
  - Ad-hoc networks are established spontaneounly
    - There is no infrastructure that you can rely on
    - A mobile terminal may also act as an network router
  - Routing protocols for ad-hoc networks
    - Network connectivity graph is not fixed; dynamically changes over time
    - The network elements are small-capacity, battery-powered devices

Outline

- Looking closely to the wireless systems
  - Wireless Local Area Networks
    - 802.11 and HiperLAN Standards
  - Wireless Personal Area Networks and Home Networking
    - Bluetooth and HomeRF
  - Wide-Area Wireless Cellular Networks
    - GSM
    - CDMA
    - GPRS
    - 3G Networks

Outline

- Wireless and Mobile Applications
  - Wireless Application Protocol
  - Mobile Applications
    - Mobile Databases
- Quality of Service in Mobile/Wireless Networks
    - What are the challenges for providing QoS in mobile and wireless environments

Outline

- Service and Device Discover in Mobile Networks
  - How can you discover the resources around you
  - Service Location Protocol
  - Jini
- Power Management
  - How low-power objective affect the design of wireless systems and network protocols
  - Issues and solutions

Outline

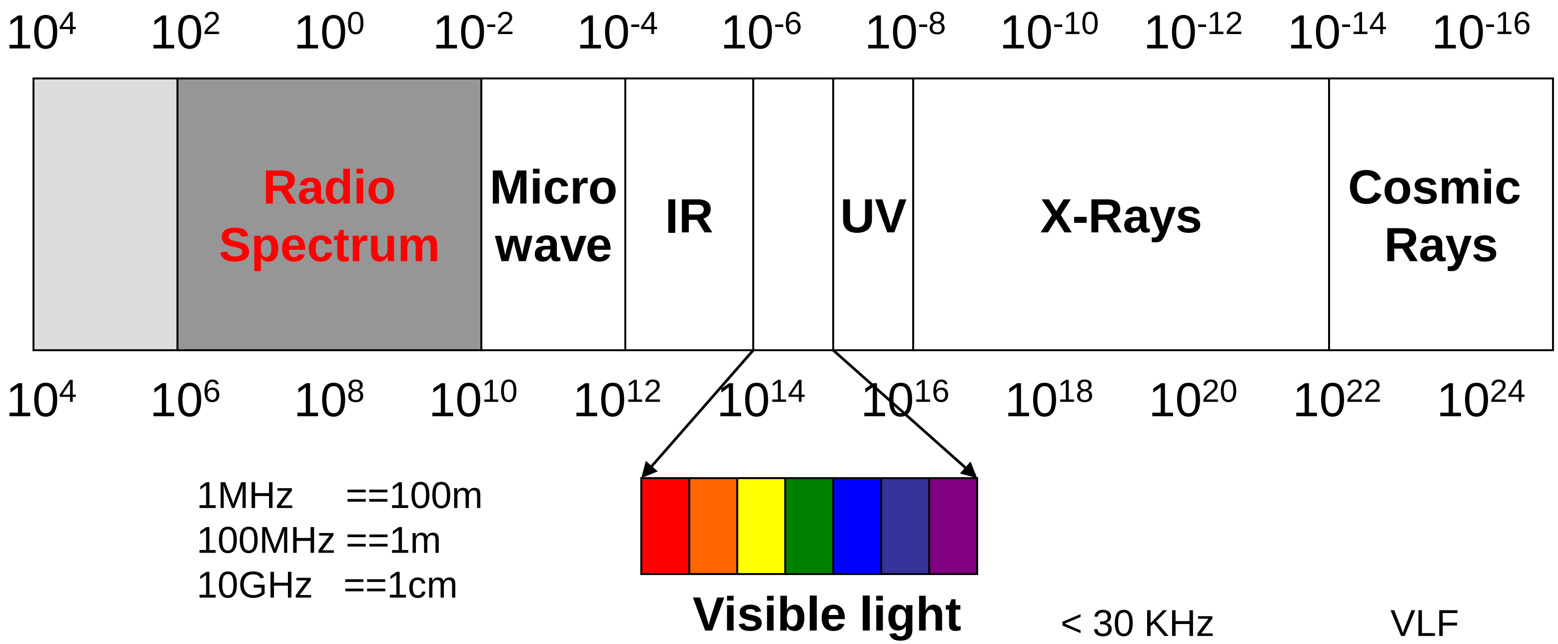
- Introduction to Peer2peer networking
  - What is peer2peer networking
  - Why client-server computing is not enough always
  - Centralized, distributed and hybrid peer2peer systems
- Wrap up and Conclusions

What is Wireless and Mobile Communication?

Wireless Communication

- Transmitting voice and data using electromagnetic waves in open space
- Electromagnetic waves
  - Travel at speed of light ($c = 3 \times 10^8$ 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

Electromagnetic Spectrum



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

< 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

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

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.

Example

- Assume a spectrum of 90KHz is allocated over a base frequency b for communication between stations A and B
- Assume each channel occupies 30KHz.
- There are 3 channels
- Each channel is simplex (Transmission occurs in one way)
- For full duplex communication:
  - Use two different channels (front and reverse channels)
  - Use time division in a channel

Station A	**Channel 1 (b - b+30)**	**Station B**
	Channel 2 (b+30 - b+60)	
	Channel 3 (b+60 - b+90)	

Homework 1

- Read and digest the following papers!
  - M. Weiser, **The Computer for the Twenty-First Century**, *Scientific American*, Vol. 265, No. 3, (September 1991), pp. 94-104.
  - D. Cox, **Wireless Personal Communications: What is It?**, *IEEE Personal Communications Magazine*, (April 1995), pp. 20-35.

- These papers are on the course webpage!

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

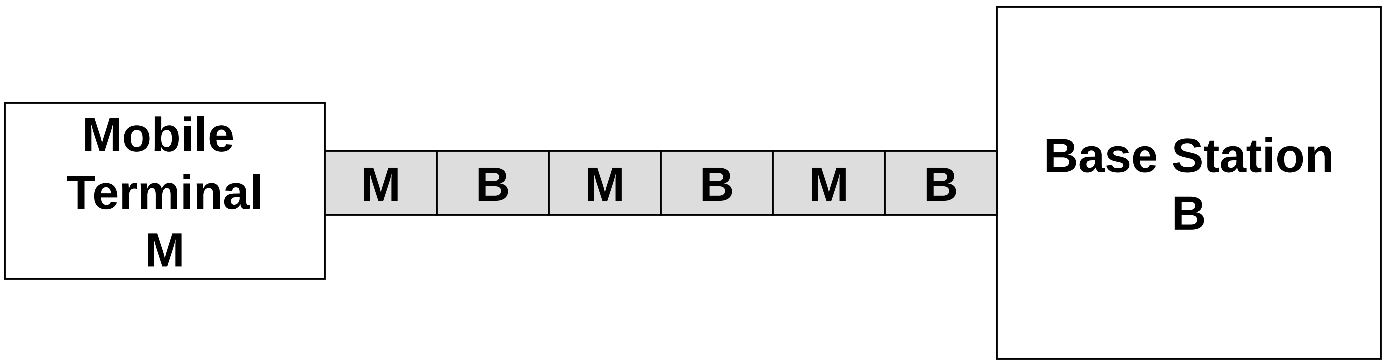
Duplex Communication - FDD

- FDD: Frequency Division Duplex

Forward Channel and Reverse Channel use different frequency bands

Duplex Communication - TDD

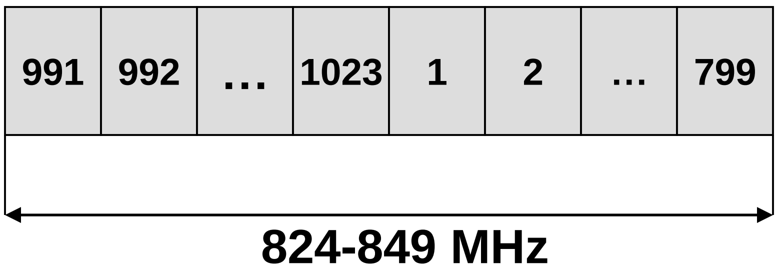
- TDD: Time Division Duplex



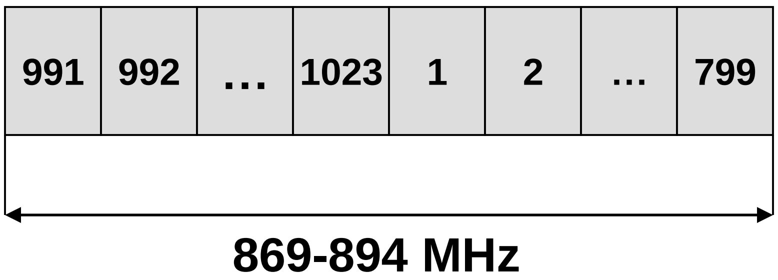
A singe frequency channel is used. The channel is divided into time slots. Mobile station and base station transmits on the time slots alternately.

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)

Channel bandwidth is 45 MHz

What is Mobility

- Initially Internet and Telephone Networks is designed assuming the user terminals are static
  - No change of location during a call/connection
  - A user terminals accesses the network always from a fixed location
- Mobility and portability
  - Portability means changing point of attachment to the network offline
  - Mobility means changing point of attachment to the network online

Degrees of Mobility

- Walking Users
  - Low speed
  - Small roaming area
  - Usually uses high-bandwith/low-latency access
- Vehicles
  - High speeds
  - Large roaming area
  - Usually uses low-bandwidth/high-latency access
  - Uses sophisticated terminal equipment (cell phones)

The Need for Wireless/Mobile Networking

- Demand for Ubiquitous Computing
  - Anywhere, anytime computing and communication
    - You don’t have to go to the lab to check your email
  - Pushing the computers more into background
    - Focus on the task and life, not on the computer
    - Use computers seamlessly to help you and to make your life more easier.
  - Computers should be location aware
    - Adapt to the current location, discover services

Some Example Applications of Ubiquitous Computing

- You walk into your office and your computer automatically authenticates you through your active badge and logs you into the Unix system
- You go to a foreign building and your PDA automatically discovers the closest public printer where you can print your schedule and give to your friend

More Examples

- You walk into a Conference room or a shopping Mall with your PDA and your PDA is smart enough to collect and filter the public profiles of other people that are passing nearby
  - Of course other people should also have smart PDAs.
- The cows in a village are equipped with GPS and GPRS devices and they are monitored from a central location on a digital map.
  - No need for a person to guide and feed them
- You can find countless examples

How to realize Ubiquitous Computing

- Small and different size computing and communication devices
  - Tabs, pads, boards
  - PDAs, Handhelds, Laptops, Cell-phones
- A communication network to support this
  - Anywhere, anytime access
  - Seamless, wireless and mobile access
  - Need for Personal Communication Services (PCS)
- Ubiquitous Applications
  - New software

What is PCS
Personal Communication Services

What is PCS

- Personal Communication Services
  - A wide variety of network services that includes wireless access and personal mobility services
  - Provided through a small terminal
  - Enables communication at any time, at any place, and in any form.
- The market for such services is tremendously big
  - Think of cell-phone market

Several PCS systems

- High-tier Systems
  - 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
  - Personal Digital Cellular
  - IS-95 cdmaOne System
    - CDMA based multiple access

Several PCS systems

- Low-tier systems
  - Residential, business and public cordless access applications and systems
    - Cordless Telephone 2 (CT2)
    - Digital Enhanced Cordless Telephone (DECT)
    - Personal Access Communication Systems (PACS)
    - Personal Handy Telephone System (PHS)

Several PCS systems

- Wideband wireless systems
  - For Internet access and multimedia transfer
    - Cdma2000
    - W-CDMA, proposed by Europe
    - SCDMA, proposed by Chine/Europe

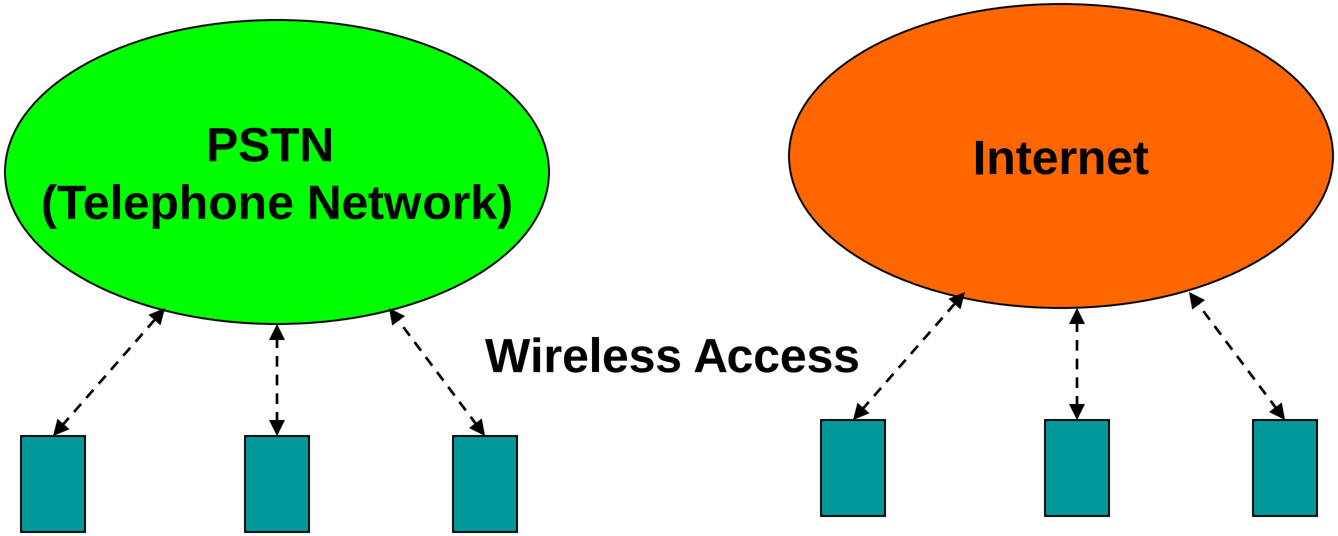
Several PCS systems

- Other PCS Systems
  - Special data systems
    - CDPD: Cellular Digital Packet Data
    - RAM Mobile Data
    - Advanced Radio Data Information System (ARDIS)
  - Paging Systems
  - Mobile Satellite Systems
    - LEO, MEO, HEO satellites for data/voice
  - 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, Cellular IP
- How to integrate all of them together and also add multimedia services (3G Systems)

Looking to PCS from different Angles



Mobile Users
-Cell phone users
-Cordless phone users

Mobile Users
-Laptop users
-Pocket PC users
-Mobile IP, DHCP enabled computers

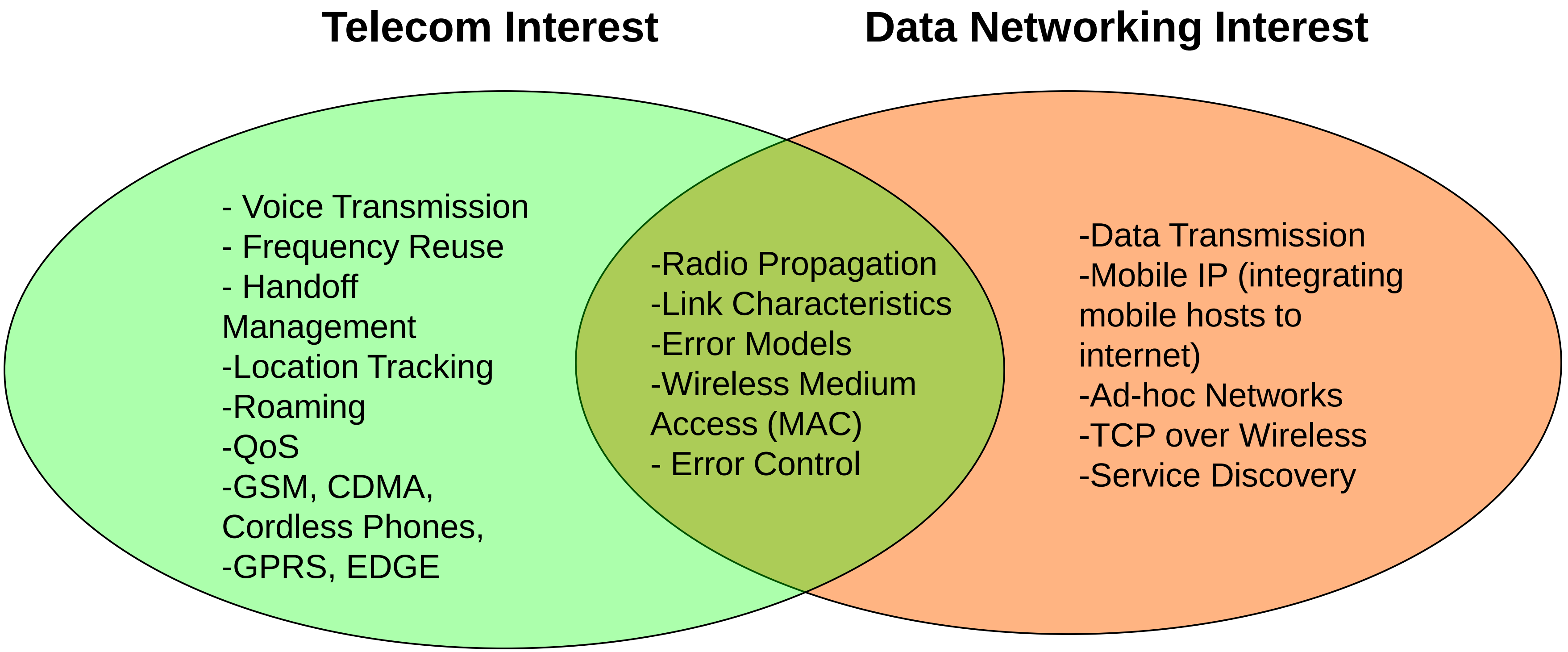
Telecom People View

Data Networking People View

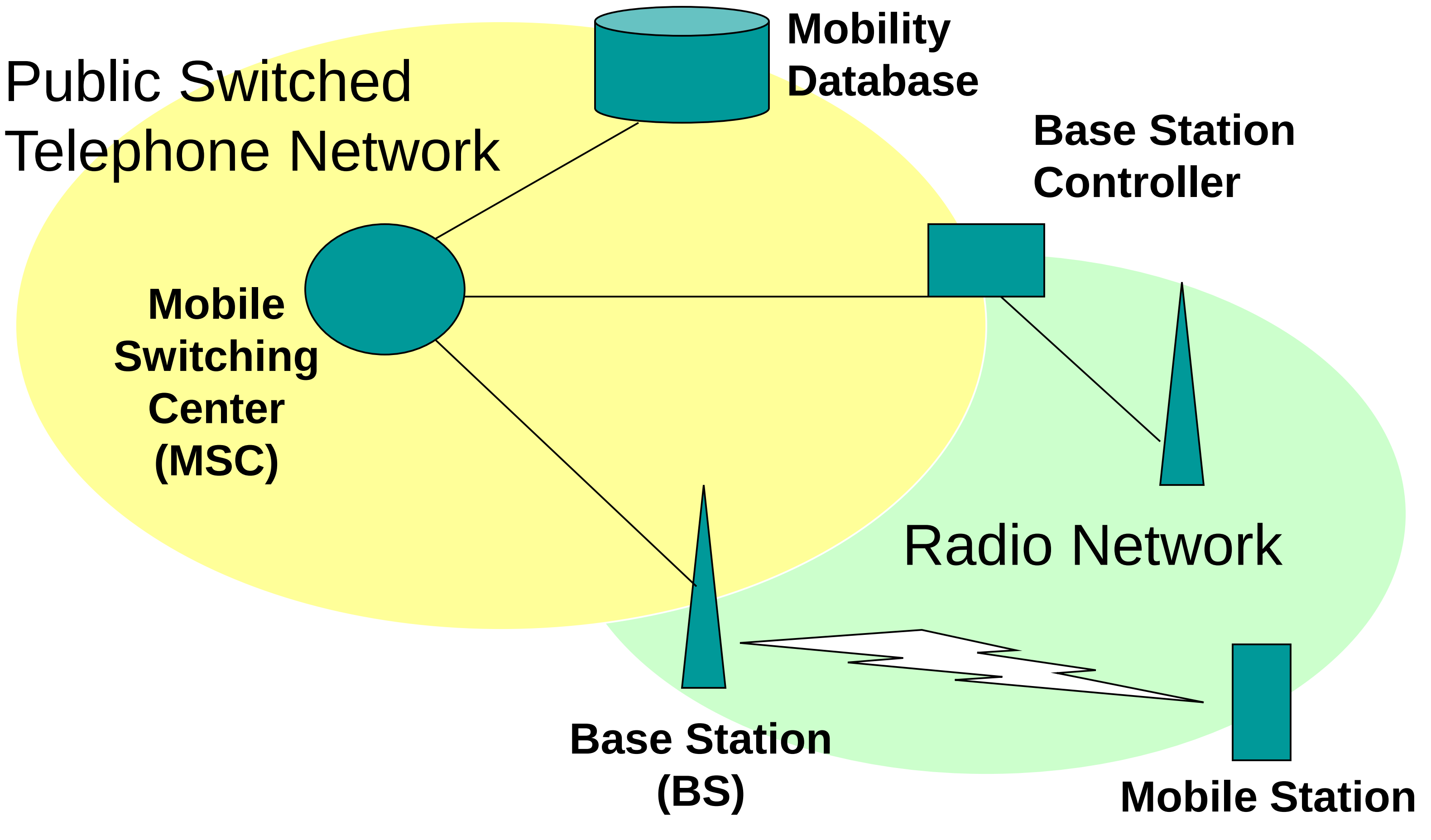
What does this course cover?

- This course will cover the problems/solutions in the telecommunication domain and also in the data networking domain
  - Mobile IP (data)
  - TCP over Wireless (data)
  - GSM, GPRS, CDMA (telecom)
- We will also cover some fundamental problems/solutions for wireless access
  - Wireless channel characteristics
  - Recovering from errors
  - Wireless media access

Telecom and Data Networking



Very Basic Cellular/PCS Architecture



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) or installed on 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
- 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.
- 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.

PCS Systems Classification

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

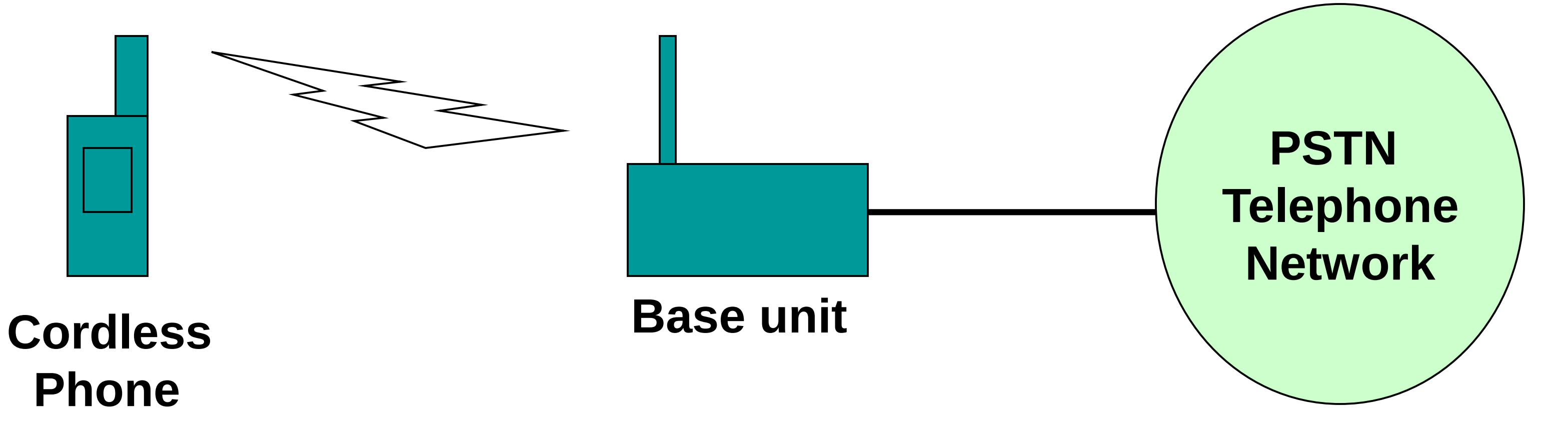
Major Mobile Radio Standards USA

Standard	Type	Year Intro	Multiple Access	Frequency Band (MHz)	Modulation	Channel BW (KHz)
AMPS	Cellular	1983	FDMA	824-894	FM	30
USDC	Cellular	1991	TDMA	824-894	DQPSK	30
CDPD	Cellular	1993	FH/Packet	824-894	GMSK	30
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-900	Cellular	1986	FDMA	890-960	FM	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

Cordless Telephones



Cordless Telephones

- Characterized by
  - Low mobility (in terms of range and speed)
  - Low power consumption
  - Two-way tetherless (wireless) voice communication
  - High circuit quality
  - Low cost equipment, small form factor and long talk-time
  - No handoffs between base units
- Appeared as analog devices
- Digital devices appeared later with CT2, DECT standards in Europe and ISM band technologies in USA

Cordless Telephones

- Usage
  - At homes
  - At public places where cordless phone base units are available
- Design Choices
  - Few users per MHz
  - Few users per base unit
    - Many base units are connected to only one handset
  - Large number of base units per usage area
  - Short transmission range

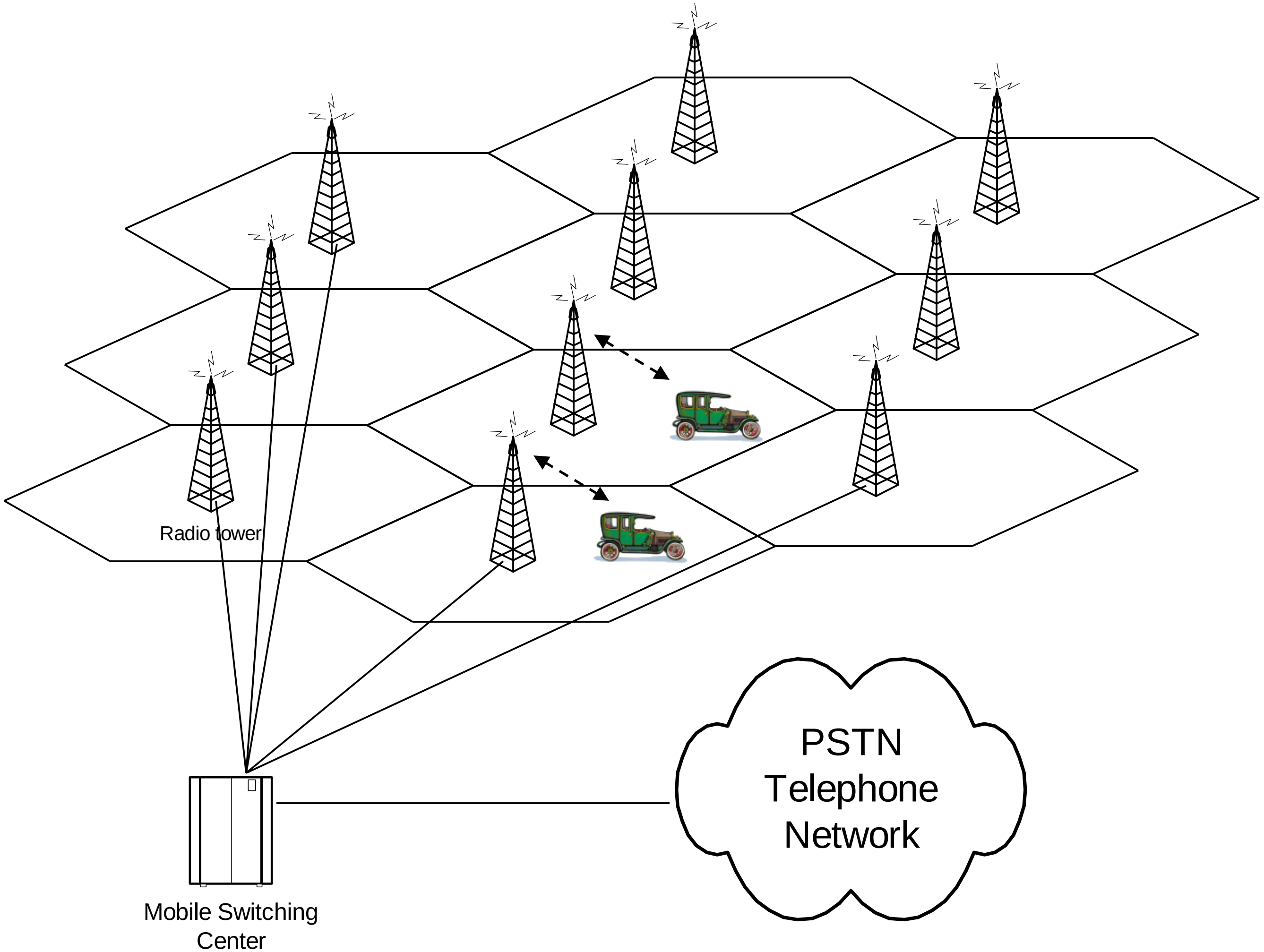
Cordless Phone

- 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)

Cellular Telephony

- Characterized by
  - High mobility provision
  - Wide-range
  - Two-way tetherless voice communication
  - Handoff and roaming support
  - Integrated with sophisticated public switched telephone network (PSTN)
  - High transmit power requires at the handsets (~2W)

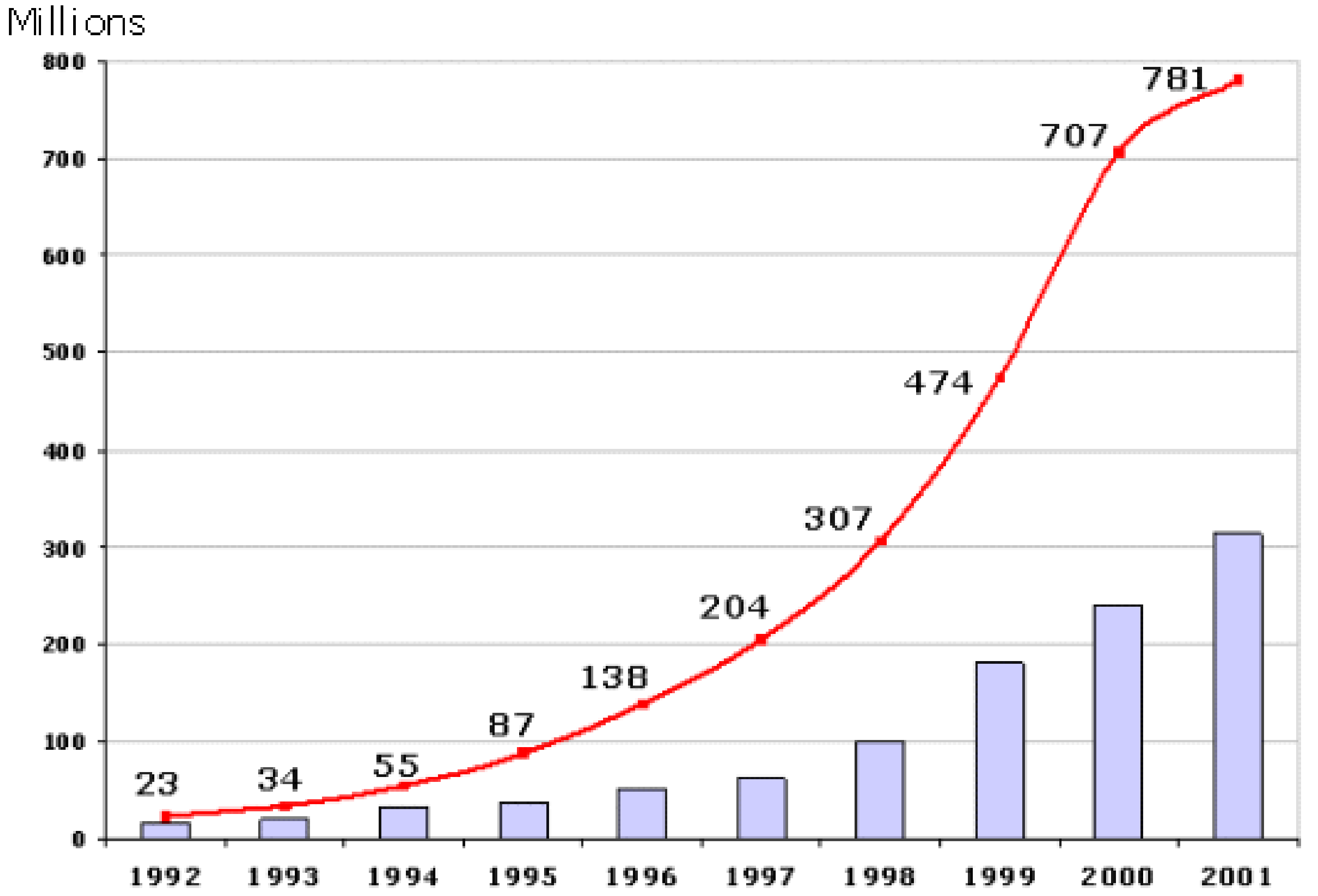
Cellular Telephony - Architecture



Cellular Telephony Systems

- Mobile users and handsets
  - Very complex circuitry and design
- Base stations
  - Provides gateway functionality between wireless and wireline links
  - ~1 million dollar
- Mobile switching centers
  - Connect cellular system to the terrestrial telephone network

World Cellular Subscriber Growth



Mobile Systems Market

- Ericsson sells half of the mobile base stations
  - 1 base station ~ 100 thousand - 1 million dollar
- Nokia has the biggest market in cell-phones
  - 1 cell-phone ~ 100 dollar

- Nokia has to sell 10,000 cell-phones to match the revenue Ericsson obtains from selling just one base-station!

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-datarate Data
  - Multimedia Transmission also

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
Speech Coding	CELP at 13Kbps EVRC at 8Kbps	RPE-LTP at 13 Kbps	VSELP at 7.95 Kbps

2G and Data

- 2G is developed for voice communications
- You can send data over 2G channels by using modem
- Provides adat rates in the order of ~9.6 Kbps
- Increased data rates are requires for internet application
- This requires evolution towards new systems: 2.5 G

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

3G Systems

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

3G Systems

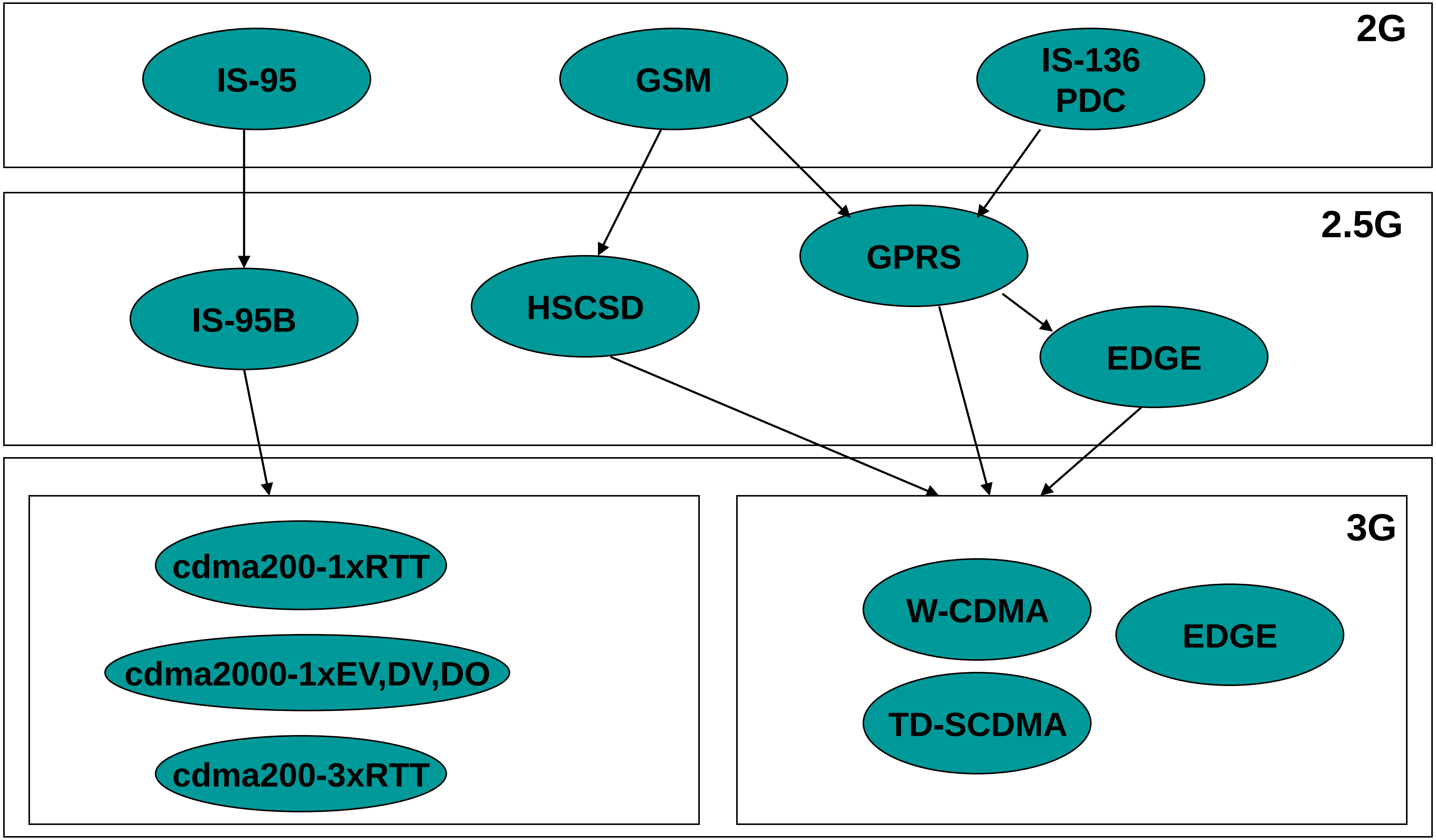
- Evolution of Systems
  - CDMA sysystem evaolved to CDMA2000
    - CDMA2000-1xRTT: Upto 307 Kbps
    - CDMA2000-1xEV:
    - CDMA2000-1xEVDO: upto 2.4 Mbps
    - CDMA2000-1xEVDV: 144 Kbps datarate
  - GSM, IS-136 and PDC evolved to W-CDMA (Wideband CDMA) (also called UMTS)
    - Up to 2.048 Mbps data-rates
    - Future systems 8Mbps
    - Expected to be fully deployed by 2010-2015
  - New spectrum is allocated for these technologies

Interest to 3G Applications

	Western Europe	Eastern Europe	USA
Emails	4.5	4.7	4.3
City maps/directions	4.3	4.2	4.2
Latest news	4.0	4.4	4.0
Authorize/enable payment	3.4	3.8	3.0
Banking/trading online	3.5	3.4	3.2
Downloading music	3.1	3.4	3.2
Shopping/reservation	3.0	3.1	2.9
Animated images	2.4	2.7	2.6
Chat rooms, forums	2.3	2.9	2.2
Interactive games	2.0	2.2	2.4
Games for money	1.8	1.8	1.8

(Means based upon a six-point interest scale, where 6 indicates high interest and 1 indicates low interest.)

Upgrade Paths for 2G Technologies



INTRODUCTION

Mobile communication is an important aspect in communication technology and mobile phone has become the most common tool of communication over the recent years.

**Several innovative improvements regarding mobile communication technologies have been made by developing various multiple-access schemes used for wireless
communication (such as TDMA, FDMA, CDMA, WCDMA, etc).**

The big challenge is to select the right technology for the applications and systematically identify the factors that influence the overall performance

Mobility is one of the most invigorating features, having an enormous impact on how communication is evolving into the future.

Mobility in 4G networks requires new level of mobility support as compared to traditional mobility.

This presentation brings about the different generations of mobile technology and identifies the different issues and challenges related to mobility management in 4G networks.

0TH GENERATION

Pre-cell phone mobile telephony technology, such as radio telephones that some had in cars before the arrival of cell phones.

Communication was possible through voice only.

These mobile telephones were usually mounted in cars or trucks.

Technologies :

PTT(Push to Talk)
MTS (Mobile Telephone System)
IMTS (Improved MTS)

First Mobile Radio Telephone-1924

1st GENERATION

Analog cell phones.
A voice call gets modulated to a higher frequency of about 150 and it is transmitted between radio towers. This is done using a technique called Frequency-Division Multiple Access (FDMA).

Technologies:

- **FDMA (Frequency Division Multiple Access)**
- **NMT (Nordic Mobile Telephone)**
- **AMPS (Advanced Mobile Phone System)**

Problems :

- **No security**
- **Prone to distortions**

2nd GENERATION

Digital cell phones
Speed: 10kbits/sec
Time to download a 3min MP3 song:
31-41 min
Different Services :

- digital voice calling
- short message service (SMS)

Standards:

- GSM
- CDMA
- TDMA

Benefits:

- consume less battery power
- improves the voice clarity
- reduces noise in the line
- secrecy and safety to the data and voice


NOKIA
PACIFIC BELL
LG
verizon


NOKIA

3rd GENERATION

2G networks were built mainly for voice data and slow transmission. Due to rapid changes in user expectation, they do not meet today's wireless needs.

3G networks provide the ability to transfer voice data and non-voice data over the same network simultaneously.

Applications :

Internet, e-mail, fax, e-commerce, music, video clips, and videoconferencing

The aim of the 3G is to allow for more coverage and growth with minimum investment.

Combines a mobile phone, laptop PC and TV

Features includes:

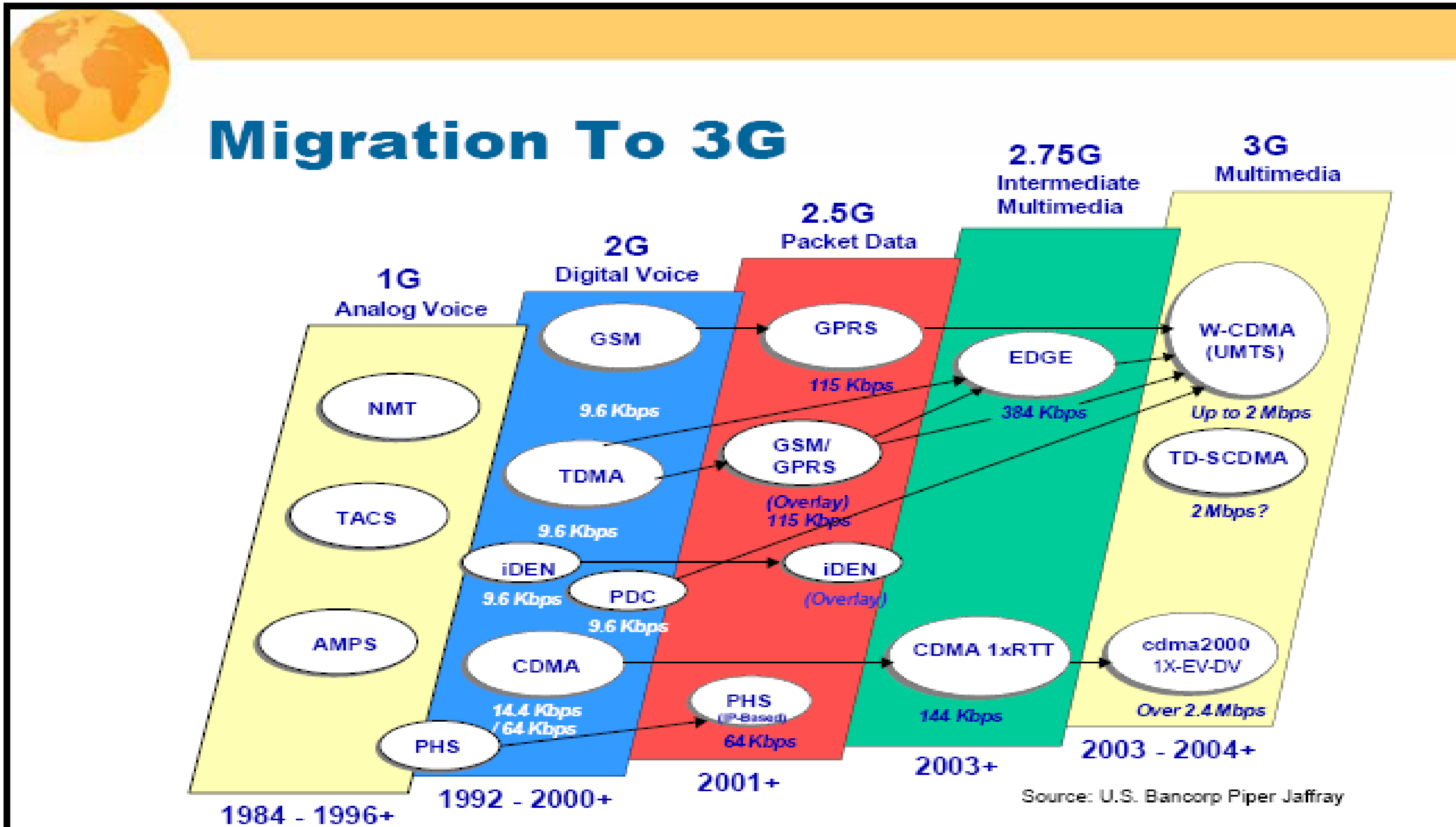
- Phone calls
- Global roaming
- Send/receive large email messages
- High-speed Web
- Navigation/maps
- Videoconferencing
- TV streaming
- Electronic agenda meeting reminder
-GPS

Speed: 144kb/sec-3mb/sec i.e. 1 million bits, or 125,000 bytes, of data are being transferred per second

Time to download a 3min MP3 song: 11sec-1.5min

3G has the following enhancements over 2.5G and previous networks:

- **Enhanced audio and video streaming**
- **Several Times higher data speed**
- **Video-conferencing support**
- **Web and WAP browsing at higher speeds**
- **IPTV (TV through the Internet) support**



Migration To 3G
1G
Analog Voice
NMT
TACS
AMPS
1984 - 1996+
2G
Digital Voice
GSM
9.6 Kbps
TDMA
9.6 Kbps
iDEN
9.6 Kbps
PDC
9.6 Kbps
CDMA
14.4 Kbps / 64 Kbps
PHS
1992 - 2000+
2.5G
Packet Data
GPRS
115 Kbps
GSM/ GPRS
(Overlay) 115 Kbps
iDEN
(Overlay)
PHS
(IP-Based)
64 Kbps
2001+
2.75G
Intermediate Multimedia
EDGE
384 Kbps
CDMA 1xRTT
144 Kbps
2003+
3G
Multimedia
W-CDMA (UMTS)
Up to 2 Mbps
TD-SCDMA
2 Mbps?
cdma2000 1X-EV-DV
Over 2.4 Mbps
2003 - 2004+
Source: U.S. Bancorp Piper Jaffray

DRAWBACKS BY GENERATION

1G	**Poor voice quality, Poor battery life, Large phone size, No security, frequent call drops, Limited capacity and poor handoff reliability.**
2G	**The GSM is a circuit switched, connection oriented technology, where the end systems are dedicated for the entire call session. This causes inefficiency in usage of bandwidth and resources. They are unable to handle complex data such as video.**
3G	**1.High bandwidth requirement. 2. High spectrum licensing fees. 3.Huge capital.**


NOKIA
Sony Ericsson
Cyber-shot
Menu
Options
Sony Ericsson
My Music
Online Store
Now Playing
Artists
Albums
Tracks
Playlists
Open
More


Start
htc
Phil
Claire
Jim
Victor
Dana
Conference Room
6 Connected 07:38
Email
Note
Speaker
Mute
End Conf Call
Add Call
Menu

4th GENERATION

4G development focuses around achieving ultra-broadband speeds, competing with and in some cases outstripping the speeds provided by your home internet connection.

4G average speeds are targeted to be in the 100Mbps to 1Gbps range, roughly 10 to 100 times (dependent on location) faster than 3G networks. At that rate, that 4-minute MP3 download would take you mere seconds.

A 4G phone can run on a 3G network just fine, and it'll be ready for the 4G revolution when the time comes.

There are two major systems in U.S, which are using the 4G mobile technology – WiMax, backed by Clearwire and Long Term Evolution or LTE.

WiMax's majority owner is Sprint Nextel. Sprint currently has two mobile phones, the HTC Evo and the Samsung Epic, which achieve speeds 10 times faster than 3G; coverage is still limited to major metropolitan cities. Outside of these areas, data speeds revert to 3G.

Long Term Evolution is backed by Verizon. According to cnet, Verizon has completed initial 4G wireless test, but not available for widespread use until end of 2012.

The word "MAGIC" also refers to 4G wireless technology which stands for Mobile multimedia, Any-where, Global mobility solutions over, Integrated wireless and Customized services.

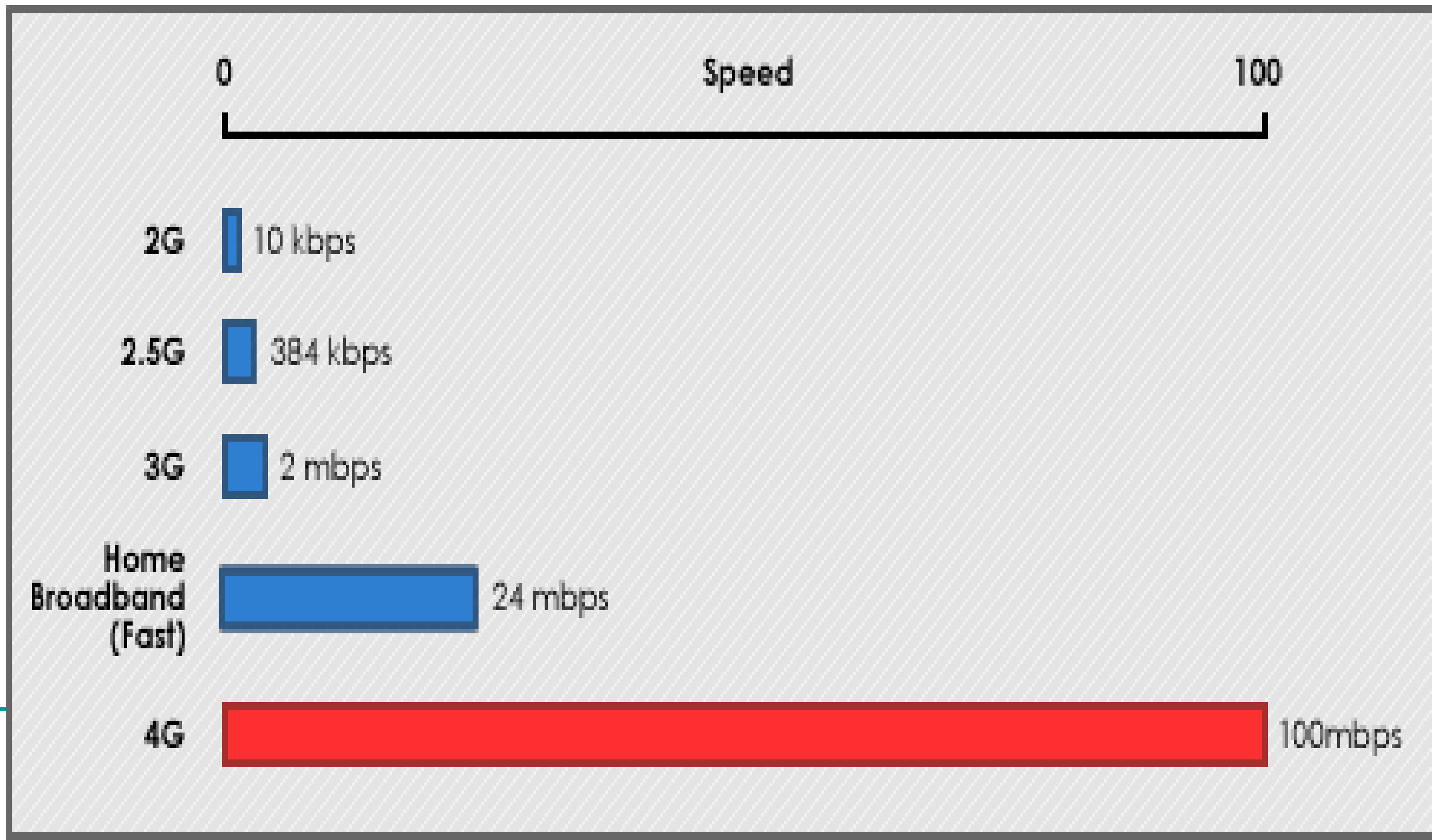
Features include:

- A spectrally efficient system
- High network capacity
- Huge data rate
- Perfect connectivity & global roaming
- High quality of service
- Security & Privacy

Speed:

The data transfer is 100 Mbps for outdoor and 1Gbps for indoor.

The design is that 4G will be based on OFDM (Orthogonal Frequency Division Multiplexing), which is the key enabler of 4G technology. Other technological aspects of 4G are adaptive processing and smart antennas, both of which will be used in 3G networks and enhance rates when used in with OFDM




THE 4G
FUTURE


htc MAX 4G
htc
smart mobility
Yota

Applications :

Games

Games will be a major application segment in 4G.

Electronic Agents

There will be e-assistance, e-secretaries, e-advisors, e-administrators etc. This kind of control is what home automation applications anticipate.

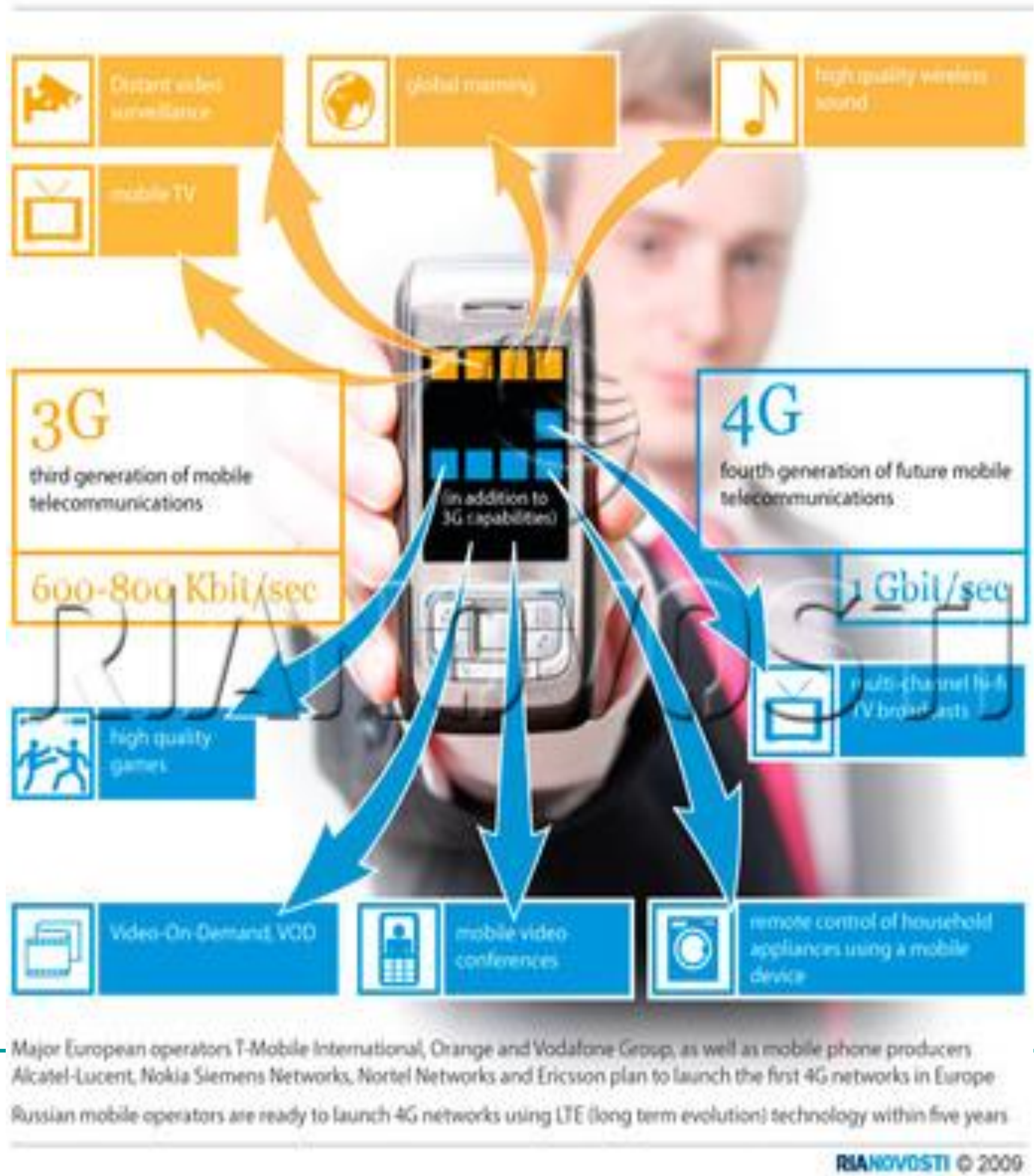
Broadband Access in Remote Locations

4G networks will provide a wireless alternative for broadband access to residential and business customers. In addition, 4G will provide the first opportunity for broadband access in remote locations without an infrastructure to support cable or DSL access.

- E-commerce
- Business/Work
- Private Life
- Vehicular
- Public Place
- Entertainment
- Education

Technology	3G	4G
Frequency band	1.8 - 2.5GHz	2 - 8GHz
Bandwidth	5-20MHz	15-200MHz
Data rate	Up to 2Mbps	100Mbps moving - 1Gbps stationary
Switching	Circuit/Packet	Packet

3G and 4G capabilities and features



Technology	1G	2G	2.5G	3G	4G
Design Began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2010?
Service	Analog voice, synchronous data to 9.6 kbps	Digital voice, short messages	Higher capacity, packetized data	Higher capacity, broadband data up to 2 Mbps	Higher capacity, completely IP-oriented, multimedia, data to hundreds of megabits
Standards	AMPS, TACS, NMT, etc.	TDMA, CDMA, GSM, PDC	GPRS, EDGE, 1xRTT	WCDMA, CDMA2000	Single standard
Data Bandwidth	1.9 kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	CDMA?
Core Network	PSTN	PSTN	PSTN, packet network	Packet network	Internet

5th GENERATION

5G is a is a technology used in research papers and projects to denote the next major phase of mobile telecommunication standards.It is a Real wireless world that is a complete WWWW: World Wide Wireless Web. 5G technology has changed the means to use cell phones within very high bandwidth. A user would never have experienced such a high value technology.

5G technology is going to be a new mobile revolution in mobile market.5G technology has extraordinary data capabilities and has ability to tie together unrestricted call volumes and infinite data broadcast within latest mobile operating system.

CONCLUSION

We have seen how the technology has progressed through the years.

4G mobile technologies will stimulate subscriber interest in broadband wireless applications because of its ability and flexibility towards the world of wireless mobile communications. 4G just right started from 2002 and there are many standards and technologies, which are still in developing process. Therefore, no one can really sure what the future 4G will look like and what services it will offer to people.

4G is the evolution based on 3G's limitation and it will fulfill the idea of WWWW(5G), World Wide Wireless Web, offering more services and smooth global roaming with inexpensive cost

Since 3G mobile is still in the market, 4G reduces the market competition in the mobile industry

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❖Generations of Mobile Wireless Technology: A Survey
By Mudit Ratana Bhalla & Anand Vardhan Bhalla
International Journal of Computer Applications (0975 – 8887)
Volume 5– No.4, August 2010

❖Evolution and Development Towards 4th Generation (4G) Mobile Communication Systems
By M. Junaid Arshad, Amjad Farooq, Abad Shah
Journal of American Science

The Cellular Concept

Cellular Systems-Basic Concepts

- Cellular system solves the problem of spectral congestion.
- Offers high capacity in limited spectrum.
- High capacity is achieved by limiting the coverage area of each BS to a small geographical area called cell.
- Replaces high powered transmitter with several low power transmitters.
- Each BS is allocated a portion of total channels and nearby cells are allocated completely different channels.
- All available channels are allocated to small no of neighboring BS.
- Interference between neighboring BSs is minimized by allocating different channels.

Cellular Systems-Basic Concepts

- Same frequencies are reused by spatially separated BSs.
- Interference between co-channels stations is kept below acceptable level.
- Additional radio capacity is achieved.
- Frequency Reuse-Fix no of channels serve an arbitrarily large no of subscribers

Cellular Systems-Basic Concepts

- Same frequencies are reused by spatially separated BSs.
- Interference between co-channels stations is kept below acceptable level.
- Additional radio capacity is achieved.
- Frequency Reuse-Fix no of channels serve an arbitrarily large no of subscribers

Frequency Reuse

- used by service providers to improve the efficiency of a cellular network and to serve millions of subscribers using a **limited radio spectrum**
- After covering a certain distance a radio wave gets attenuated and the signal falls below a point where it can no longer be used or cause any interference
- A transmitter transmitting in a specific frequency range will have only a limited coverage area
- Beyond this coverage area, that frequency can be reused by another transmitter.
- The entire network coverage area is divided into cells based on the principle of frequency reuse

Frequency Reuse

- A cell = basic geographical unit of a cellular network; is the area around an antenna where a specific frequency range is used.
- when a subscriber moves to another cell, the antenna of the new cell takes over the signal transmission
- a cluster is a group of adjacent cells, usually 7 cells; no frequency reuse is done within a cluster
- the frequency spectrum is divided into sub-bands and each sub-band is used within one cell of the cluster
- in heavy traffic zones cells are smaller, while in isolated zones cells are larger

Frequency Reuse

- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning.
- Cell labeled with same letter use the same set of frequencies.
- Cell Shapes:
- Circle, Square, Triangle and Hexagon.
- Hexagonal cell shape is conceptual , in reality it is irregular in shape

Frequency Reuse

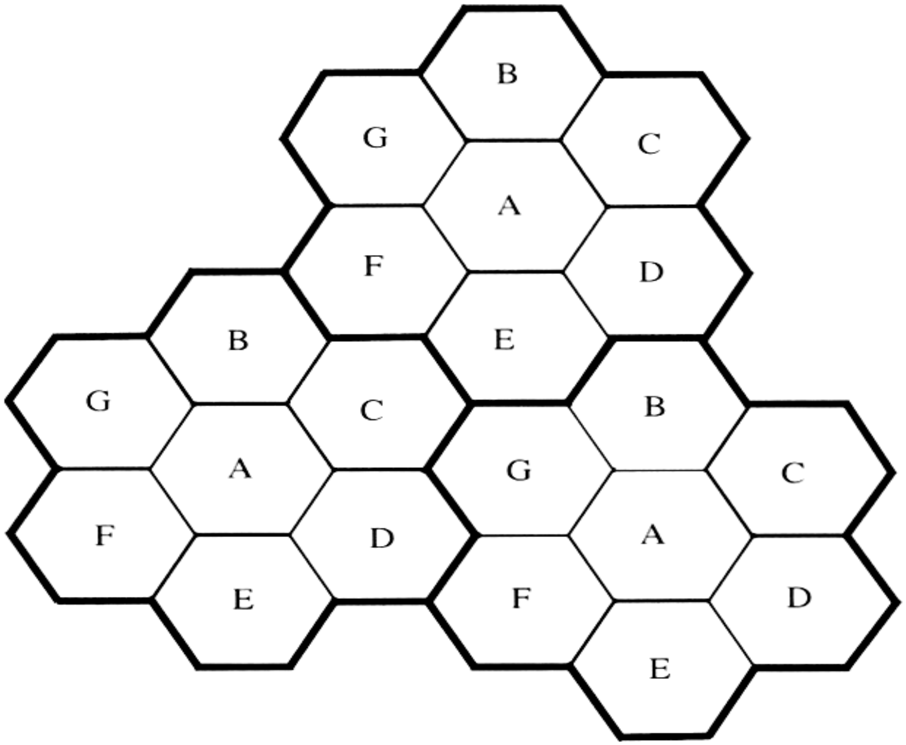


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, *N*, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

Frequency Reuse

- In hexagonal cell model, BS transmitter can be in centre of cell or on its 3 vertices.
- Centered excited cells use omni directional whereas edge excited cells use directional antennas.
- A cellular system having ‘S’ duplex channels, each cell is allocated ‘k’ channels(k<S).
- If S channels are allocated to N cells into unique and disjoint channels, the total no of available channel is S=kN.

Frequency Reuse

- N cells collectively using all the channels is called a cluster, is a group of adjacent cells.
- If cluster if repeated M times, the capacity C of system is given as

$$C=MkN=MS$$

- Capacity of system is directly proportional to the no of times cluster is repeated.
- Reducing the cluster size N while keeping the cell size constant, more clusters are required to cover the given area and hence more capacity.
- Co-channel interference is dependent on cluster size, large cluster size less interference and vice versa.

Frequency Reuse

- The Frequency Reuse factor is given as 1/N, each cell is assigned 1/N of total channels.
- Lines joining a cell and each of its neighbor are separated by multiple of 60^0,certain cluster sizes and cell layout possible
- Geometery of hexagon is such that no of cells per cluster i.e N, can only have values which satisfy the equation

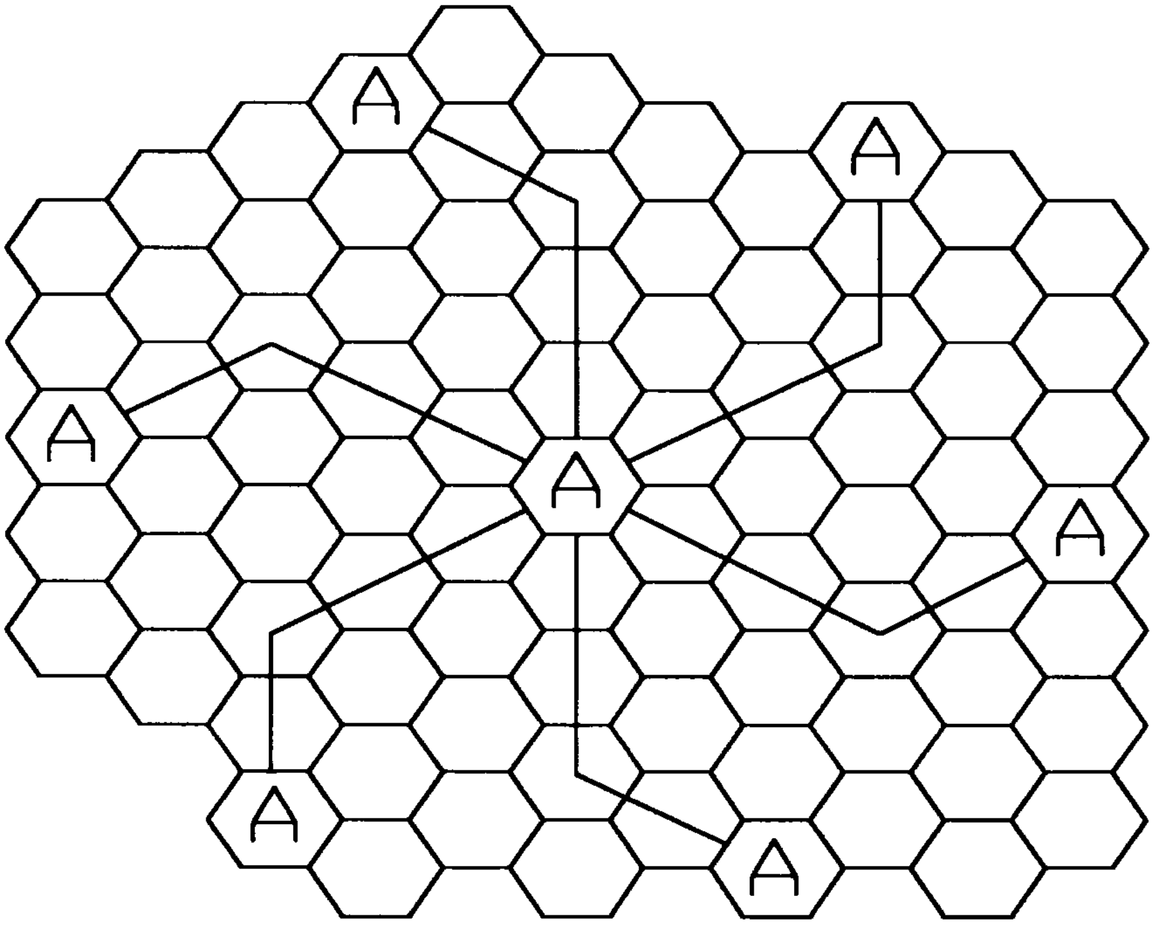
$$N=i^2+ij+j^2$$

N, the cluster size is typically 4, 7 or 12.

In GSM normally N =7 is used.

- i and j are integers, for i=3 and j=2 N=19.
- Example from Book

Locating co-channel Cell



Channel Assignment Strategies

- A scheme for increasing capacity and minimizing interference is required.
- CAS can be classified as either fixed or dynamic
- Choice of CAS impacts the performance of system.
- In Fixed CA each cell is assigned a *predetermined* set of voice channels
- Any call attempt within the cell can only be served by the *unused* channel in that particular cell
- If all the channels in the cell are occupied, the call is *blocked*. The user does not get service.
- In variation of FCA, a cell can *borrow channels* from its neighboring cell if its own channels are full.

Dynamic Channel Assignment

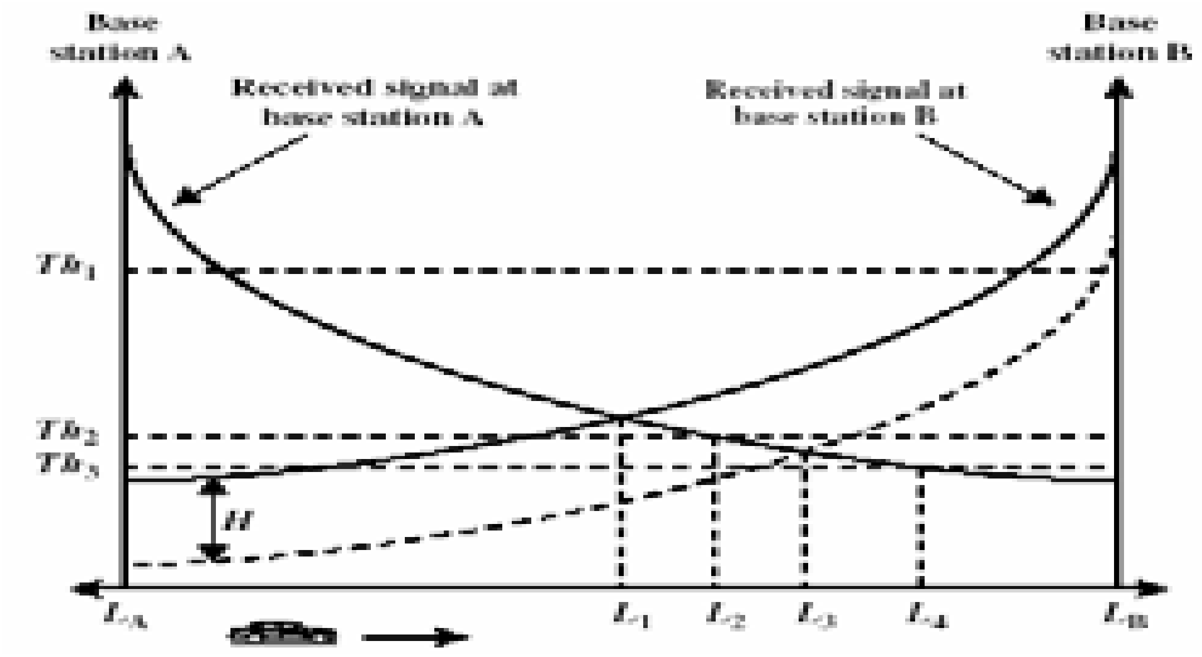
- Voice channels are not allocated to different cells *permanently*.
- Each time a call request is made, the *BS request* a channel from the MSC.
- MSC allocates a channel to the requesting cell using an algorithm that takes into account
  - likelihood of future blocking
  - The reuse distance of the channel (should not cause interference)
  - Other parameters like cost
- To ensure min QoS, MSC only allocates a given frequency if that frequency is not currently in use in the cell or any other cell which falls within the *limiting reuse distance.*
- DCA reduce the likelihood of blocking and increases capacity
- Requires the MSC to collect realtime data on channel occupancy and traffic distribution on continous basis.

Hand-off

- Mobile *moves into a different cell during* a conversation, MSC transfers the call to new channel belonging to new BS
- Handoff operation involves *identifying the new BS* and *allocation of voice and control signal* to channels associated with new BS
- Must be performed *successfully, infrequently* and *impercitble* to user
- To meet these requirements an *optimum signal level* must be defined to initiate a handoff.
- Min usuable signal for acceptable voice qualtiy -90 to -100 dBm
- A slight higher value is used as *threshold*

Handoff

By looking at the variations of signal strength from either BS it is possible to decide on the optimum area where handoff can take place



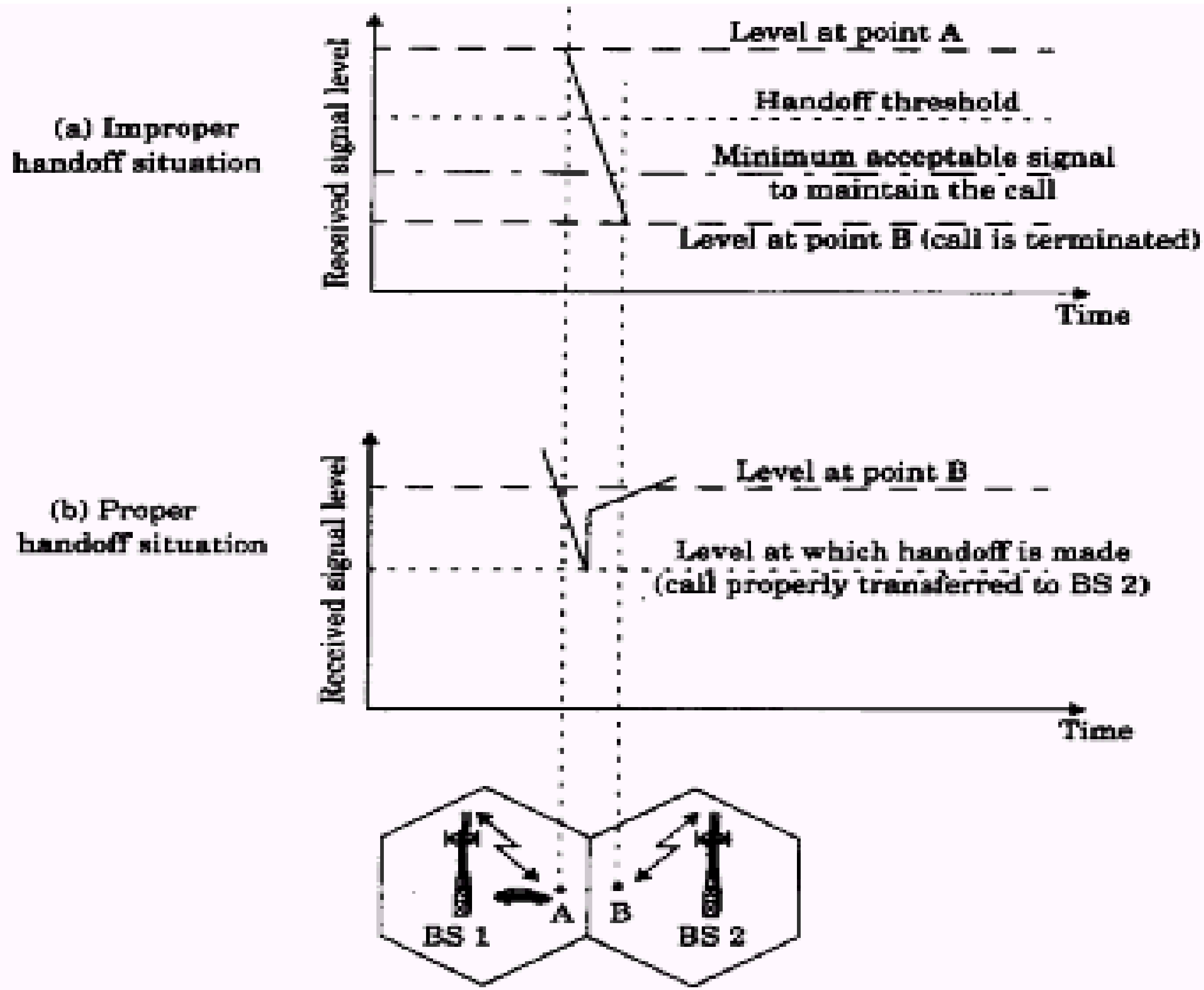


Figure 2.3
Illustration of a handoff scenario at cell boundary.

Hand-off strategies

- Handoff is made when received signal at the BS *falls below* a certain threshold
- During handoff: to avoid call termination, *safety margin should exist* and should not be too large or small

$$\Delta = Power\_{handoff} - Power\_{min\ usable}$$

- Large Δ results in unecesarry handoff and for small Δ unsufficient time to complete handoff, so carefully chosen to meet the requirements.
- Fig a, handoff not made and signal falls below min acceptable level to keep the channel active.
- Can happen due to excessive delay by MSC in assigning handoff, or when threshold Δ is set to small.
- Excessive delay may occur during high traffic conditions due to computional loading or non avialablilty of channels in nearby cells

Hand-off

- In deciding when to handoff , it is important to ensure that the drop in signal level is not due to momentary fading.

- In order to ensure this the BS monitors the signal for a certain period of time before initiating a handoff

- The length of time needed to decide if handoff is necessary depends on the speed at which the mobile is moving

Hand-off strategies

- In 1st generation analog cellular systems, the signal strength measurements are made by the BS and are supervised by the MSC.
- A spare Rx in base station (locator Rx) monitors RSS of RVC's in neighboring cells
  - Tells Mobile Switching Center about these mobiles and their channels
  - Locator Rx can see if signal to this base station is significantly better than to the host base station
- MSC monitors RSS from all base stations & decides on handoff

Hand-off strategies

- In 2^{nd} generation systems Mobile Assisted Handoffs (MAHO)are used
- In MAHO, every MS measures the received power from the surrounding BS and continually reports these values to the corresponding BS.
- Handoff is initiated if the signal strength of a neighboring BS exceeds that of current BS
- MSC no longer monitors RSS of all channels
  - reduces computational load considerably
  - enables much more rapid and efficient handoffs
  - imperceptible to user

Soft Handoff

- CDMA spread spectrum cellular systems provides a unique handoff capability
- Unlike channelized wireless systems that assigns different radio channel during handoff (called hard handoff), the spread spectrum MS share the same channel in every cell
- The term handoff here implies that a different BS handles the radio communication task
- The ability to select between the instantaneous received signals from different BSs is called soft handoff

Inter system Handoff

- If a mobile moves from one cellular system to a different system controlled by a different MSC, an inter-system handoff is necessary
- MSC engages in intersystem handoff when signal becomes weak in a given cell and MSC cannot find another cell within its system to transfer the on-going call
- Many issues must be resolved
  - Local call may become long distance call
  - Compatibility between the two MSCs

Prioritizing Handoffs

- Issue: Perceived Grade of Service (GOS) – service quality as viewed by users
  - "quality" in terms of dropped or blocked calls (not voice quality)
  - assign higher priority to handoff vs. new call request
  - a dropped call is more aggravating than an occasional blocked call
- Guard Channels
  - % of total available **cell** channels exclusively set aside for handoff requests
  - makes fewer channels available for new call requests
  - a good strategy is dynamic channel allocation (not fixed)
    - adjust number of guard channels as needed by demand
    - so channels are not wasted in cells with low traffic

Prioritizing Handoffs

- *Queuing* of Handoff Requests
  - use time delay between handoff threshold and minimum useable signal level to place a blocked handoff request in queue
  - a handoff request can "*keep trying"* during that time period, instead of having a single block/no block decision
  - prioritize requests (based on mobile speed) and handoff as needed
  - calls will still be dropped if time period expires

Practical Handoff Considerations

- Problems occur because of a *large range of mobile velocities*
  - pedestrian vs. vehicle user
- Small cell sizes and/or micro-cells → *larger # handoffs*
- MSC load is *heavy* when high speed users are passed between very small cells
- **Umbrella Cells**
  - use *different antenna heights* and *Tx power levels* to provide large **and** small cell coverage
  - multiple antennas & Tx can be co-located at single location if necessary (saves on obtaining new tower licenses)
  - large cell → high speed traffic → fewer handoffs
  - small cell → low speed traffic
  - example areas: interstate highway passing through urban center, office park, or nearby shopping mall

Umbrella Cells

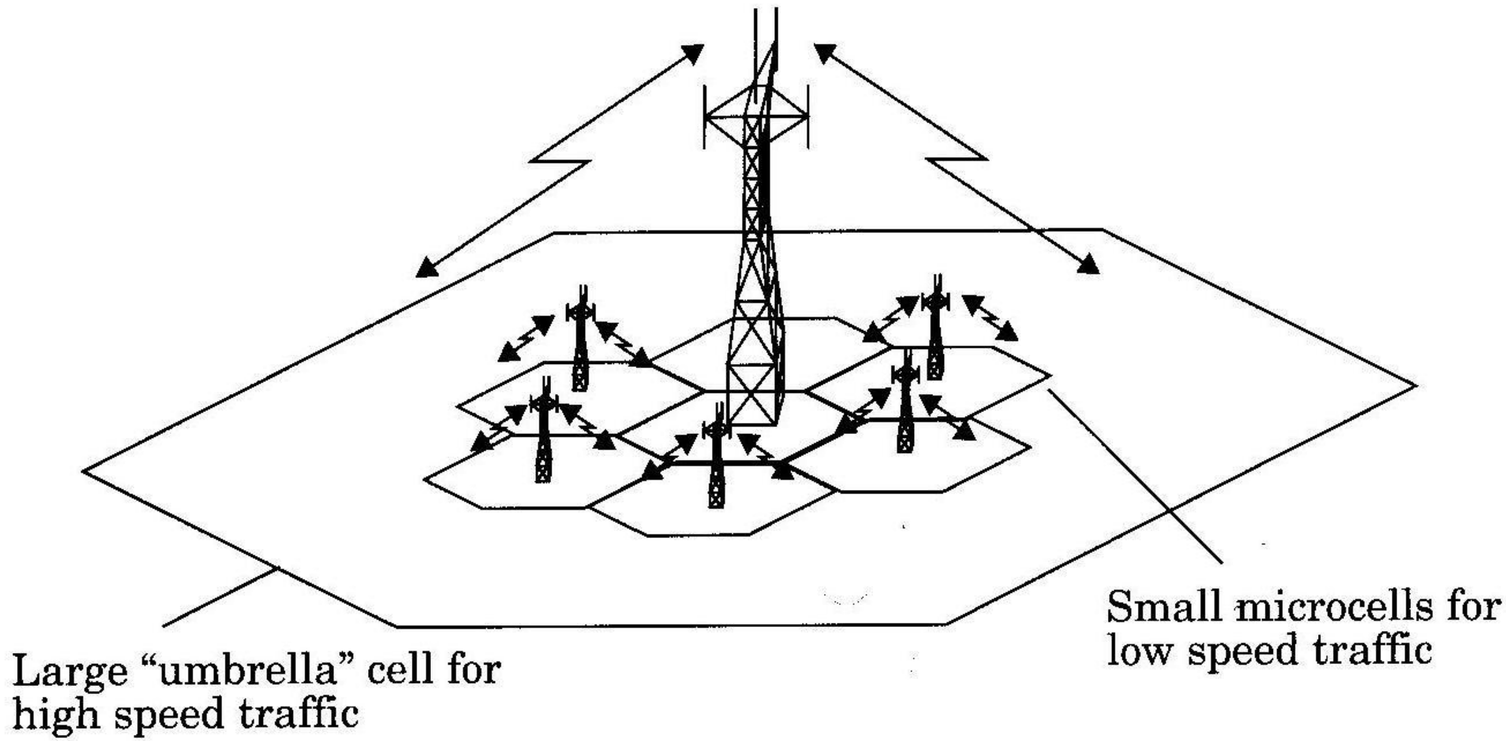


Figure 3.4 The umbrella cell approach.

Typical handoff parameters

- Analog cellular (1st generation)
  - threshold margin △ ≈ 6 to 12 dB
  - total time to complete handoff ≈ 8 to 10 sec
- Digital cellular (2nd generation)
  - total time to complete handoff ≈ 1 to 2 sec
  - lower necessary threshold margin △ ≈ 0 to 6 dB
  - enabled by mobile assisted handoff

Reuse Ratio:

- For hexagonal cell reuse distance is given by
  $D=R(\sqrt{3N})$
- Where R is cell size or cell radius and N is cluster size
- D increases as we increase N
- Reuse factor is given by $Q=D/R=(\sqrt{3N})$

Interference

- Goals for this section
  - Co-Channel
  - Adjacent Channel
- How to calculate signal to interference ratio

Interference

- Interference is major limiting factor in the performance of cellular radio. It limits the capacity and increases the no of dropped calls.
- Sources of interference include
  - Another mobile in same cell
  - A call in progress in a neighboring cell
  - Other BSs operating in the same frequency band

Effects of Interference

- Interference in voice channels causes
  - Crosstalk
  - Noise in background
- Interference in control channels causes
  - Error in digital signaling, which causes
    - Missed calls
    - Blocked calls
    - Dropped calls

Interference

- Two major types of Interferences
  - Co-channel Interference (CCI)
  - Adjacent channel Interference (ACI)
- CCI is caused due to the cells that reuse the same frequency set. These cells using the same frequency set are called Co-channel cells
- ACI is caused due to the signals that are adjacent in frequency

Co-channel Interference

- Increase base station Tx power to improve radio signal reception?
  - will also increase interference into other co-channel cells by the same amount
  - no net improvement
- Separate co-channel cells by some minimum distance to provide sufficient isolation from propagation of radio signals?
  - if all cell sizes, transmit powers, and coverage patterns ≈ same → co-channel interference is independent of Tx power

Co-channel Interference

- co-channel interference depends on:
  - *R* : cell radius
  - *D* : distance to base station of nearest co-channel cell where $D=R(\sqrt{3N})$
- if *D/R* ↑ then spatial separation relative to cell coverage area ↑
  - improved isolation from co-channel RF energy
- *Q* = *D* / *R* : co-channel reuse ratio
  - hexagonal cells → $Q = D/R = \sqrt{3N}$
- Smaller value of Q provides larger capacity, but higher CCI
- Hence there is tradeoff between capacity and interference.
  - small Q → small cluster size → more frequency reuse → larger system capacity
  - small Q → small cell separation → increased CCI

Signal to Interference ratio S/I

- The Signal-to-Interference (S/I) for a mobile is

$$\text{Eq. (3.5)}: \quad \frac{S}{I} = \frac{S}{\sum_{i=1}^{i_o} I_i} \quad \text{where}$$

  - S is desired signal power ,I_i : interference power from i^{th} co-channel cell
- The average received power at distance d is

$$P_r = Po\ (d/d_o)^{-n}$$

- The RSS decays as a power law of the distance of separation between transmitter and receiver
- Where P_o is received power at reference distance d_o and n is the path loss exponent and ranges between 2-4
- If D_i is the distance of i^{th} interferer, the received power is proportional to $(D_i)^{-n}$

Signal to Interference ratio S/I

- The S/I for mobile is given by

$$\frac{S}{I} = \frac{\text{signal from intended base station when at edge of cell (R away)}}{\text{signals from other base stations (D away)}}$$

$$= \frac{R^{-n}}{\sum_{i=1}^{i_o} (D_i{}^{-n})}$$

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0=6} (D_i)^{-n}} = \frac{(D/R)^n}{6} = \frac{(\sqrt{3N})^n}{6} = \frac{Q^4}{6}$$

- With only the first tier(layer of) equidistant interferers.
- For a hexagonal cluster size, which always have 6 CC cell in first tier

Signal to Interference ratio S/I

- The MS is at cell boundary

The aproximate S/I is given by, both in terms of R and D, along with channel reuse ratio Q

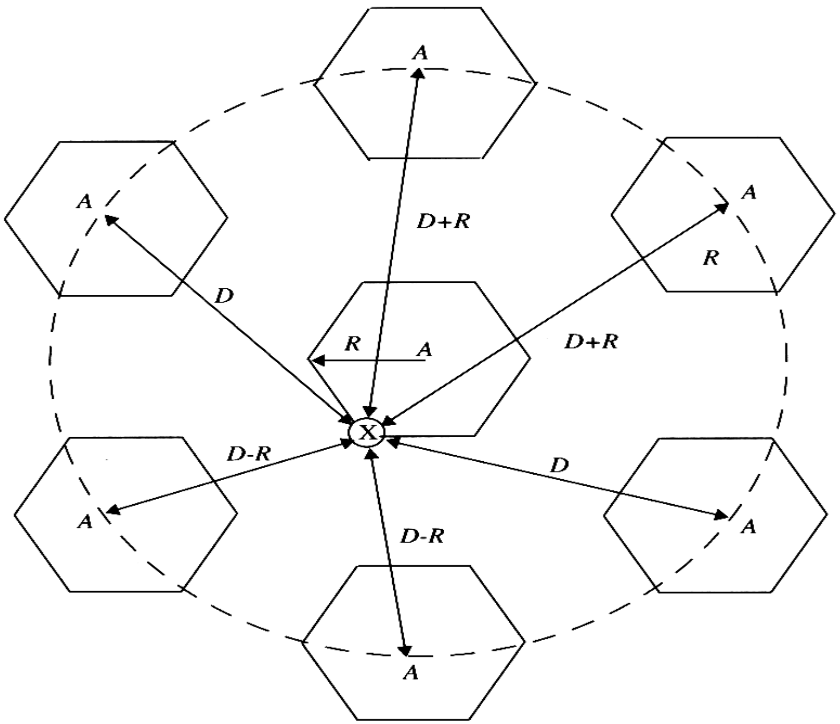


Figure 3.5 Illustration of the first tier of co-channel cells for a cluster size of $N = 7$. An approximation of the exact geometry is shown here, whereas the exact geometry is given in [Lee86]. When the mobile is at the cell boundary (point X), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D+R)^{-4} + 2D^{-4}} \qquad \frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}$$

Example S/I

- Examples for Problem 2.3
- TDMA can tolerate S/I = 15 dB
- What is the optimal value of N for omni-directional antennas? Path loss = 4. **Co-channel Interference**

- cluster size N =7 (choices 4,7,12)
- path loss exponent (means)n=4
- co-channel reuse ratio Q=sqrt(3N)=4.582576
- Ratio of distance to radius Q=D/R=4.582576
- number of neighboring cells i_o=6 # of sides of hexagon
- signal to interference ratio S/I= $(D/R)^{\wedge n} / i_o$ =73.5
- convert to dB, S/I=10log(S/I) =18.66287dB

- S/I is greater than required, it will work.

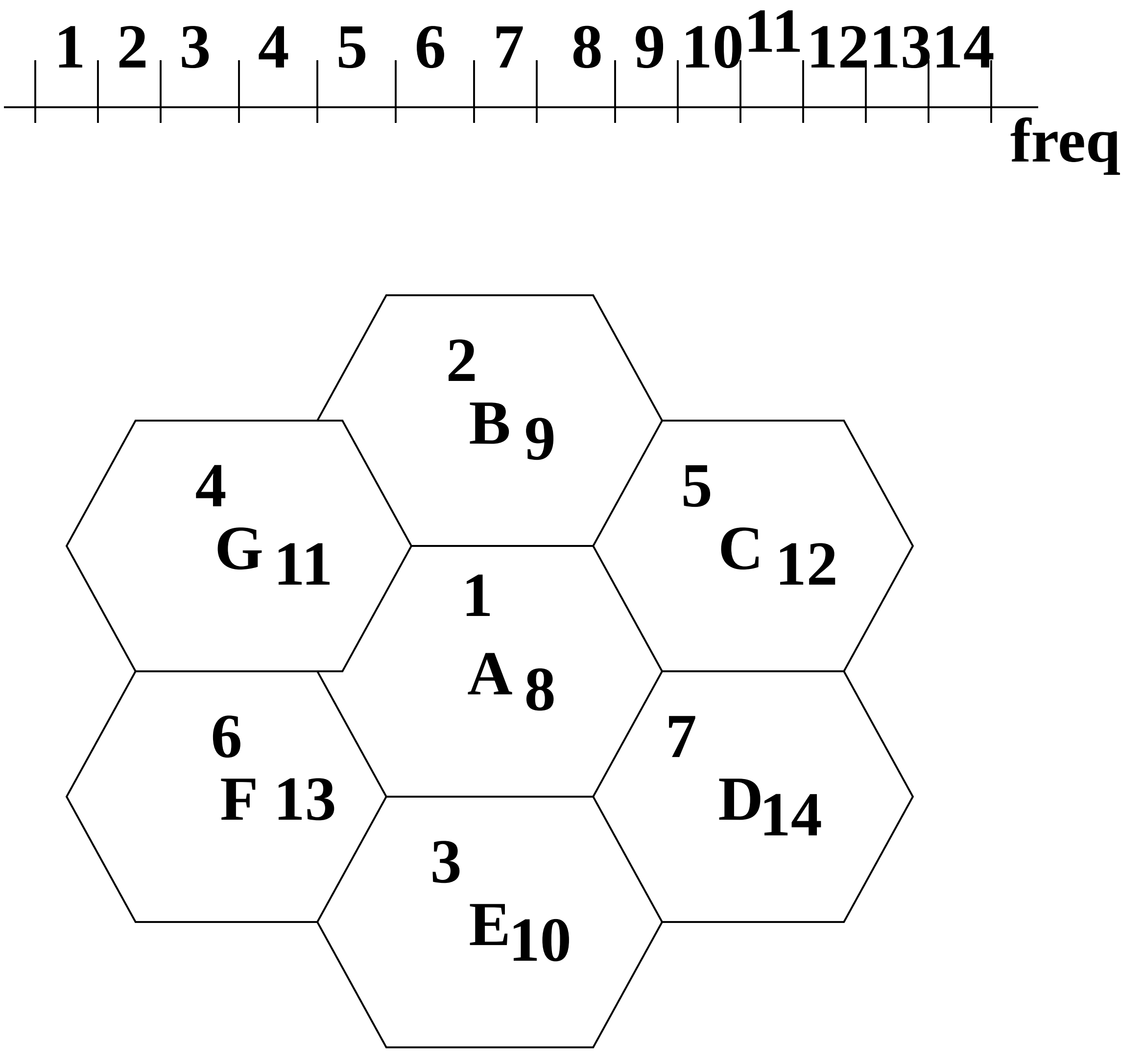
Example S/I

- cluster size N=4 (choices 4,7,12)
- path loss exponent (means) n=4
- co-channel reuse ratio Q= sqrt(3N)=3.464102
- Ratio of distance to radius Q=D/R=3.464102
- number of neighboring cells io=6 ,# of sides of hexagon
- signal to interference ratio S/I= $(D/R)^{\wedge n} / i_o$ =24
- convert to dB, S/I= 10log(S/I)=13.80211dB
- S/I is less than required, it will not work!

- cluster size N=7
- path loss exponent n=3
- Q=sqrt(3N)=4.582576
- number of neighboring cells io= 6, # of sides of hexagon
- signal to interference ratio=S/I= $(D/R)^{\wedge n} / i_o$ =16.03901
- convert to dB, S/I=10log(S/I)=12.05178dB
- S/I is less than required, it will not work!

Adjacent Channel Interference

- Results from imperfect receiver filters, allowing nearby frequencies to leak into pass-band.
- Can be minimized by careful filtering and channel assignments.
- Channels are assigned such that frequency separations between channels are maximized.
- For example, by sequentially assigning adjacent bands to different cells
- Total 832 channels, divided into two groups with 416 channels each.
- Out of 416, 395 are voice and 21 are control channels.
- 395 channels are divided into 21 subsets, each containing almost 19 channels, with closet channel 21 channels away
- If N=7 is used, each cell uses 3 subsets, assigned in such a way that each channel in a cell is 7 channels away.



Frequency Planning/Channel Assignment

Table 3.2 AMPS Channel Allocation for A and B Side Carriers

1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	
85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	
127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	
148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	
169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	
190	191	192	193	194	195	196	197	198	199	20	201	202	203	204	205	206	207	208	209	210	
211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	A SIDE
232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	
253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	
295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	-	-	-	
313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	667	668	669	
670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	
691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	
712	713	714	715	716	-	-	-	-	991	992	993	994	995	996	997	998	999	1000	1001	1002	
1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	
334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	
355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	
376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	
397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	
418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	
439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	
460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	
481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	
502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	
523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	
544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	B SIDE
565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	
607	608	609	610	611	6612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	
628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	
649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	-	-	-	
-	-	-	-	-	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	
733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	
754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	
775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	
796	797	798	799																		

Learning Objectives

- Concept of Trunking
- Key definitions in Trunking /Traffic Theory
- Erlang-(unit of traffic)
- Grade of Service
- Two Types of Trunked Systems
- Trunking Efficiency

Trunking & Grade of Service

- Cellular radio systems rely on *trunking to accommodate a large number of users in a limited radio spectrum.*

- Trunking allows a large no of users to share a relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channels.

- In a trunked radio system (TRS) each user is allocated a channel on a per call basis, upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

Key Definitions

- Setup Time: Time required to allocate a radio channel to a requesting user
- Blocked Call: Call which cannot be completed at the time of request, due to congestion(*lost call)*
- Holding Time: Average duration of a typical call. Denoted by *H(in seconds)*
- Request Rate: The average number of calls requests per unit time(λ)
- Traffic Intensity: Measure of channel time utilization or the average channel occupancy measured in Erlangs. Dimensionless quantity. Denoted by A
- Load: Traffic intensity across the entire TRS (Erlangs)

Erlang-a unit of traffic

- The fundamentals of trunking theory were developed by Erlang, a Danish mathematician, the unit bears his name.
- An Erlang is a unit of telecommunications traffic measurement.
- Erlang represents the continuous use of one voice path.
- It is used to describe the total traffic volume of one hour
- A channel kept busy for one hour is defined as having a load of one Erlang
- For example, a radio channel that is occupied for thirty minutes during an hour carries 0.5 Erlangs of traffic
- For 1 channel
  - Min load=0 Erlang (0% time utilization)
  - Max load=1 Erlang (100% time utilization)

Erlang-a unit of traffic

- For example, if a group of 100 users made 30 calls in one hour, and each call had an average call duration(holding time) of 5 minutes, then the number of Erlangs this represents is worked out as follows:

- Minutes of traffic in the hour = number of calls x duration
- Minutes of traffic in the hour = 30 x 5 = 150
- Hours of traffic in the hour = 150 / 60 = 2.5
- **Traffic Intensity= 2.5 Erlangs**

Traffic Concepts

- Traffic Intensity offered by each user(Au): Equals average call arrival rate multiplied by the holding time(service time)

  $$Au = \lambda H \text{(Erlangs)}$$

- Total Offered Traffic Intensity for a system of U users (A):

  $$A = U * Au \text{(Erlangs)}$$

- Traffic Intensity per channel, in a C channel trunked system

  $$Ac = U * Au / C \text{(Erlangs)}$$

Trunking & Grade of Service

- In a TRS, when a particular user requests service and all the available radio channels are already in use , the user is *blocked or denied access to the system. In some systems a queue may be used to hold the requesting users until a channel becomes available.*
- Trunking systems must be designed carefully in order to ensure that there is a low likelihood that a user will be blocked or denied access.
- The likelihood that a call is blocked, or the likelihood that a call experiences a delay greater than a certain queuing time is called "**Grade of Service" (GOS)''.**

Trunking & Grade of Service

- **Grade of Service (GOS): Measure of ability of a user to access a trunked system during the busiest hour. Measure of the congestion which is specified as a probability.**

- The probability of a call being blocked
- **Blocked calls cleared(BCC) or Lost Call Cleared(LCC) or Erlang B systems**

- The probability of a call being delayed beyond a certain amount of time before being granted access
- **Blocked call delayed or Lost Call Delayed(LCD) or Erlang C systems**

Blocked Call Cleared Systems

- When a user requests service, there is a minimal call set-up time and the user is given immediate access to a channel if one is available
- If channels are already in use and no new channels are available, call is blocked without access to the system
- The user does not receive service, but is free to try again later
- All blocked calls are instantly returned to the user pool

Modeling of BCC Systems

- The Erlang B model is based on following assumptions :
  - Calls are assumed to arrive with a Poisson distribution
  - There are nearly an infinite number of users
  - Call requests are memory less ,implying that all users, including blocked users, may request a channel at any time
  - All free channels are fully available for servicing calls until all channels are occupied
  - The probability of a user occupying a channel(called service time) is exponentially distributed. Longer calls are less likely to happen
  - There are a finite number of channels available in the trunking pool.
  - Inter-arrival times of call requests are independent of each other

Modeling of BCC Systems

- **Erlang B formula is given by**

$$\Pr[\text{blocking}] = \frac{A^C / C!}{\sum_{k=0}^{C} \frac{A^k}{k!}}$$

- where ***C*** *is the number of trunked channels offered by a trunked radio system and* ***A*** *is the total offered traffic.*

Erlang B

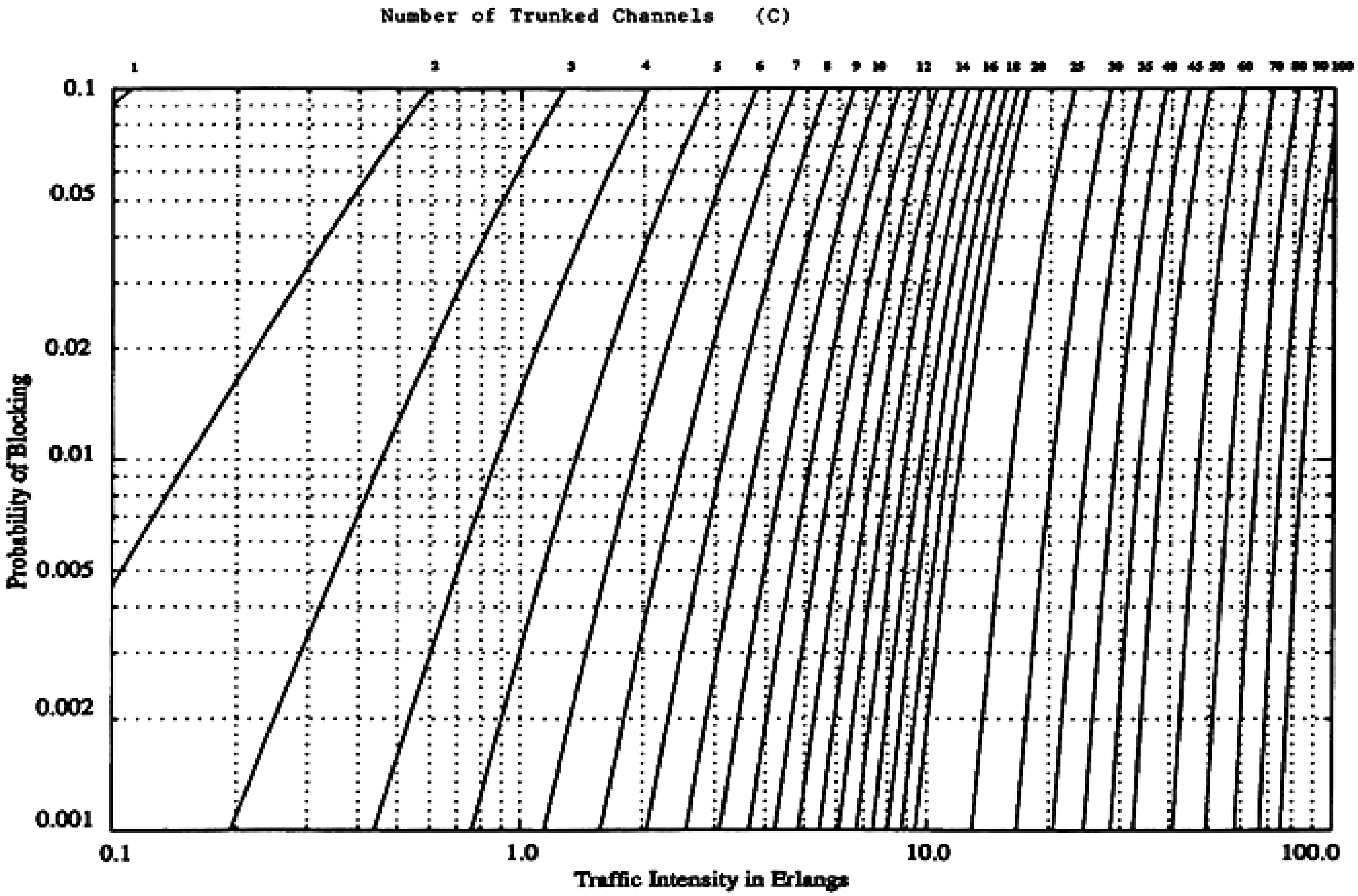


Figure 3.6 The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

Example 3.4

- How many users can be supported for 0.5% blocking probability for the following number of trunked channels in a BCC system? (a) 5, (b) 10,(c)=20. Assumed that each user generates 0.1 Erlangs of traffic.
- Solution
- Given C=5, GOS=0.005, Au=0.1,
- From graph/Table using C=5 and GOS=0.005,A=1.13
- Total Number of users U=A/Au=1.13/0.1=11 users
- Given C=10, GOS=0.005, Au=0.1,
- From graph/Table using C=5 and GOS=0.005,A=3.96
- Total Number of users U=A/Au=3.96/0.1=39 users
- Given C=20, GOS=0.005, Au=0.1,
- From graph/Table using C=20 and GOS=0.005,A=11.10
- Total Number of users U=A/Au=11.10/0.1=110 users

Erlang B Trunking GOS

Table 3.4 Capacity of an Erlang B System

Number of Channels *C*	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

BCC System Example

- Assuming that each user in a system generates a traffic intensity of 0.2 Erlangs, how many users can be supported for 0.1% probability of blocking in an Erlang B system for a number of trunked channels equal to 60.
- **Solution 1:**
- System is an Erlang B
- *Au* = 0.2 Erlangs
- Pr [Blocking] = 0.001
- *C = 60 Channels*
- From the Erlang B figure, we see that
- *A ≈ 40 Erlangs*
- *Therefore U=A/Au=40/0.02=2000users.*

Blocked Call Delayed(BCD) Systems

- Queues are used to hold call requests that are initially blocked
- When a user attempts a call and a channel is not immediately available, the call request may be delayed until a channel becomes available
- Mathematical modeling of such systems is done by Erlang C formula
- The Erlang C model is based on following assumptions :
- Similar to those of Erlang B
- Additionally, if offered call cannot be assigned a channel, it is placed in a queue of infinite length
- Each call is then serviced in the order of its arrival

Blocked Call Delayed Systems

- Erlang C formula which gives likelihood of a call not having immediate access to a channel (all channels are already in use)

$$\Pr(delay > 0) = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1}\frac{A^k}{k!}}$$

Erlang C

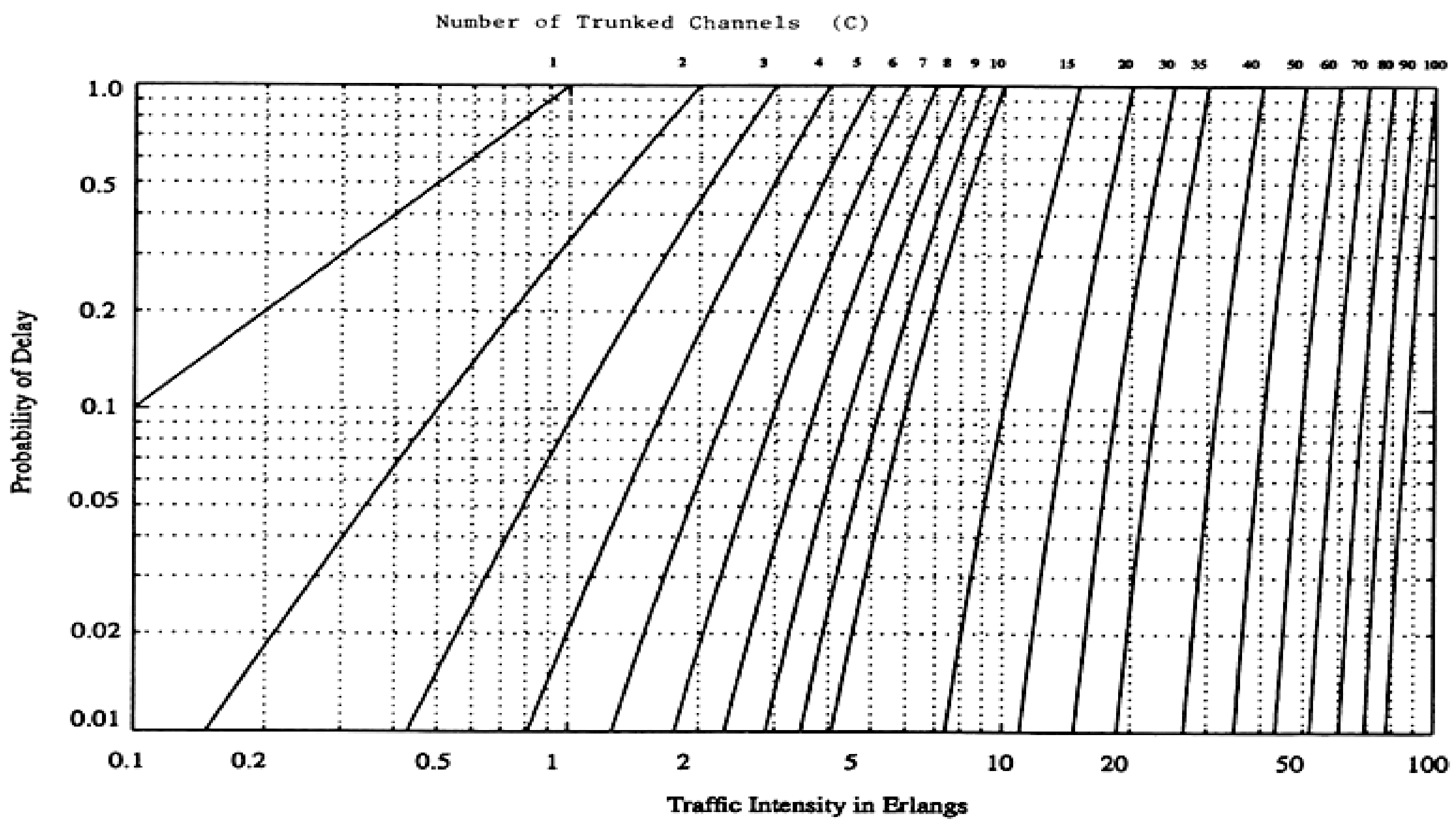


Figure 3.7 The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Modeling of BCD Systems

- Probability that any caller is delayed in queue for a wait time greater than **t seconds is given as GOS of a BCD System**
- The probability of a call getting delayed for any period of time greater than zero is

  P[delayed call is forced to wait > t sec]=P[delayed] x Conditional P[delay is >t sec]

- Mathematically;

  Pr[delay>t] = Pr [delay>0] Pr [delay>t| delay>0]

- Where P[delay>t| delay>0]= $e^{(-(C-A)t/H)}$

  Pr[delay>t] = Pr [delay>0] e(-(C-A)t/H)

  - where C = total number of channels, *t =delay time of interest, H=average duration of call*

Trunking Efficiency

- Trunking efficiency is a measure of the number of users which can be offered a particular GOS with a particular configuration of fixed channels.
- The way in which channels are grouped can substantially alter the number of users handled by a trunked system.
- **Example:**
- 10 trunked channels at a GOS of 0.01 can support 4.46 Erlangs, where as two groups of 5 trunked channels can support 2x1.36=2.72 Erlangs of traffic
- 10 trunked channels can offer 60% more traffic at a specific GOS than two 5 channel trunks.
- Therefore, if in a certain situation we sub-divide the total channels in a cell into smaller channel groups then the total carried traffic will reduce with increasing number of groups

Erlang B Trunking GOS

Table 3.4 Capacity of an Erlang B System

Number of Channels *C*	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
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20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

Improving Capacity

- As demand for service increases, system designers have to provide more channel per unit coverage area

- Common Techniques are: Cell Splitting, Sectoring and Microcell Zoning

- Cell Splitting increases the number of BS deployed and allows an orderly growth of the cellular system

- Sectoring uses directional antennas to further control interference

- Micro cell Zoning distributes the coverage of cell and extends the cell boundary to hard-to-reach areas

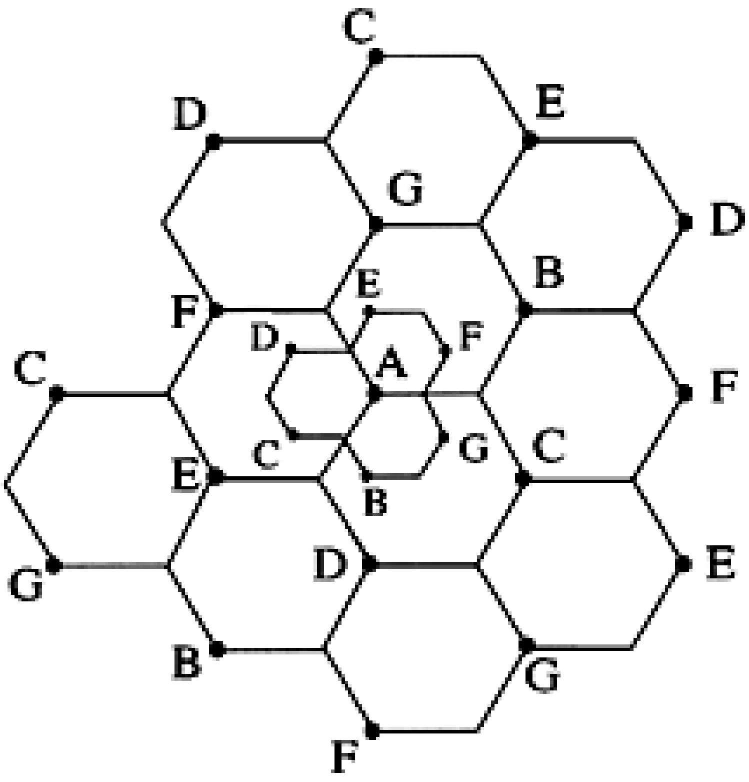
Cell Splitting

- Cell splitting is the process of subdividing a congested cell into smaller cells with
  - their own BS
  - a corresponding reduction in antenna height
  - a corresponding reduction in transmit power

- Splitting the cell reduces the cell size and thus more number of cells have to be used
- For the new cells to be smaller in size the transmit power of these cells must be reduced.
- Idea is to keep Q=D/R constant while decreasing R

- More number of cells ► more number of clusters ► more channels ►high capacity

Cells are split to add channels with no new spectrum usage



Example S/I

- cluster size N=4 (choices 4,7,12)
- path loss exponent (means) n=4
- co-channel reuse ratio Q= sqrt(3N)=3.464102
- Ratio of distance to radius Q=D/R=3.464102
- number of neighboring cells io=6 ,# of sides of hexagon
- signal to interference ratio S/I= $(D/R)^{\wedge n}$ / i_o =24
- convert to dB, S/I= 10log(S/I)=13.80211dB
- S/I is less than required, it will not work!

- cluster size N=7
- path loss exponent n=3
- Q=sqrt(3N)=4.582576
- number of neighboring cells io= 6, # of sides of hexagon
- signal to interference ratio=S/I= $(D/R)^{\wedge n}$ / i_o =73.334
- convert to dB, S/I=10log(S/I)=18.65dB
- S/I is less than required, it will work!

Cell Splitting-Power Issues

- Suppose the cell radius of new cells is reduced by half
- What is the required transmit power for these new cells??

Pr[at old cell boundary]=Pt1R^{-n}

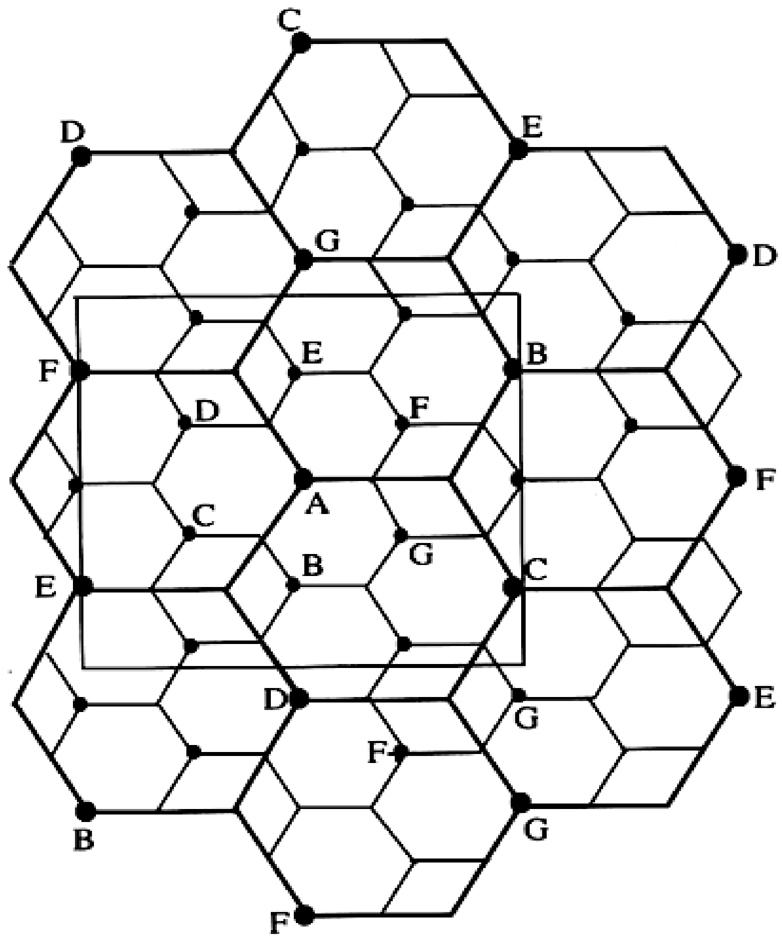
Pr[at new cell boundary]= Pt2(R/2) $^{-n}$

- where Pt1and Pt2are the transmit powers of the larger and smaller cell base stations respectively, and n is the path loss exponent.
- So**,** **Pt2= Pt1/2^{n}**
- If we take *n=3 and the received powers equal to each other, then*

Pt2=Pt1/8

- In other words, the transmit power must be reduced by 9dB in order to fill in the original coverage area while maintaining the S/I requirement

Illustration of cell splitting in 3x3 square centered around base station A



Cell Splitting

- In practice not all the cells are split at the same time hence different size cells will exist simultaneously.

- In such situations, special care needs to be taken to keep the distance between co-channel cells at the required minimum, and hence channel assignments become more complicated.

- To overcome handoff problem:
  - Channels in the old cell must be broken down into two channel groups, one for smaller cell and other for larger cell
  - The larger cell is usually dedicated to high speed traffic so that handoffs occur less frequently
  - At start small power group has less channels and large power group has large no of channels, at maturity of the system large power group does not have any channel

Umbrella Cells

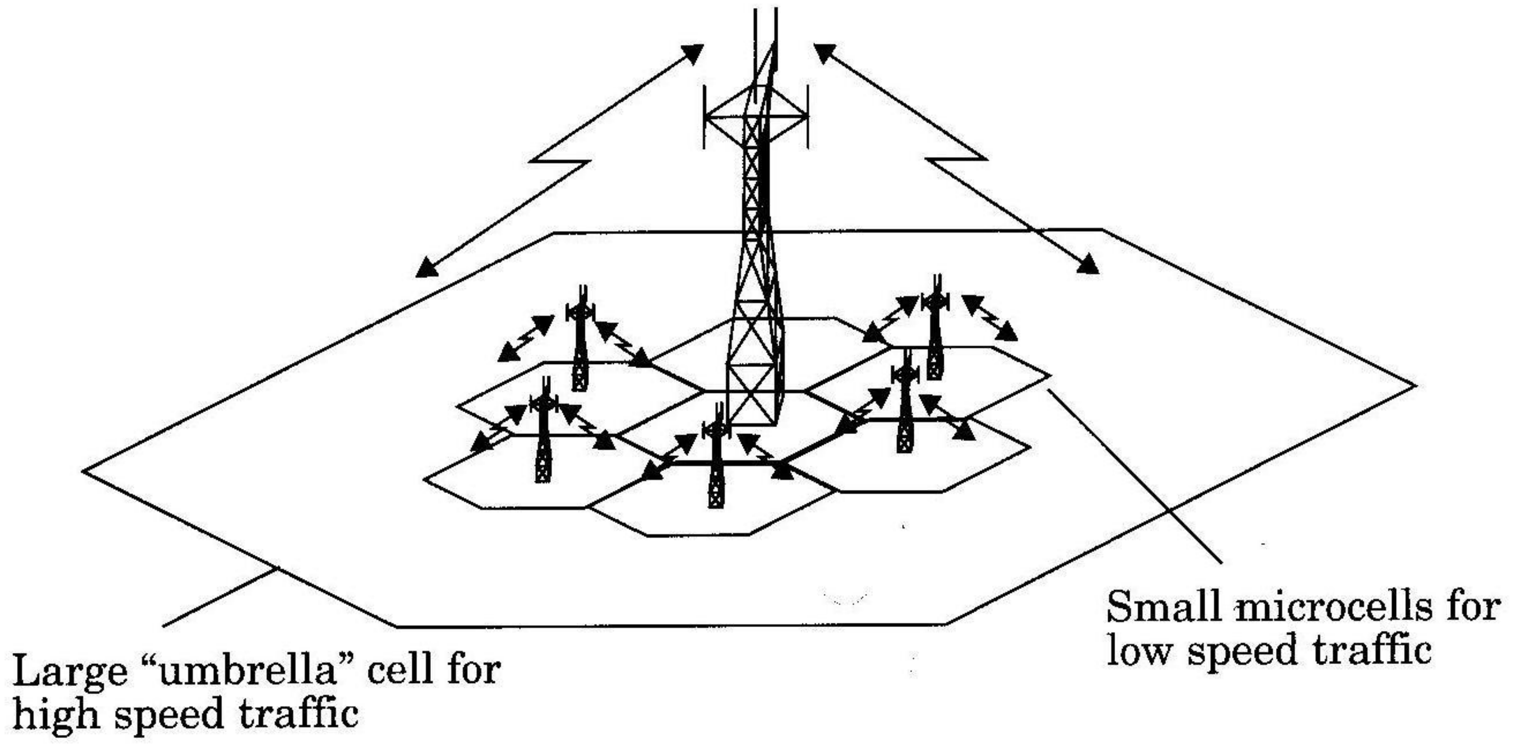
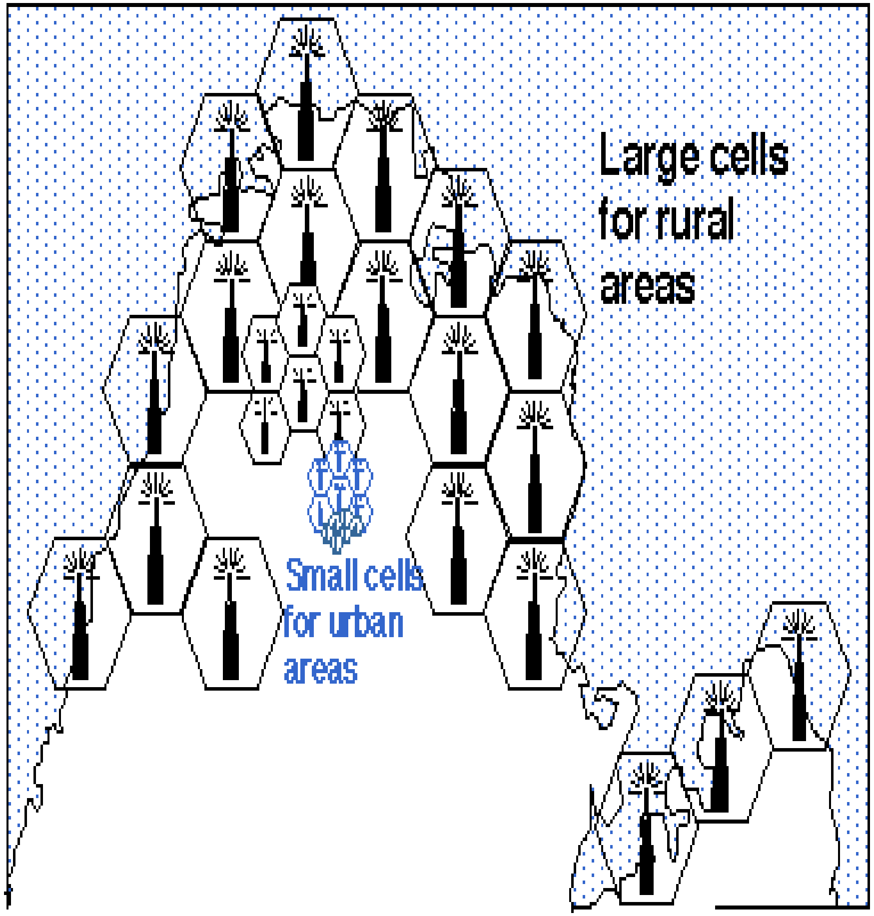
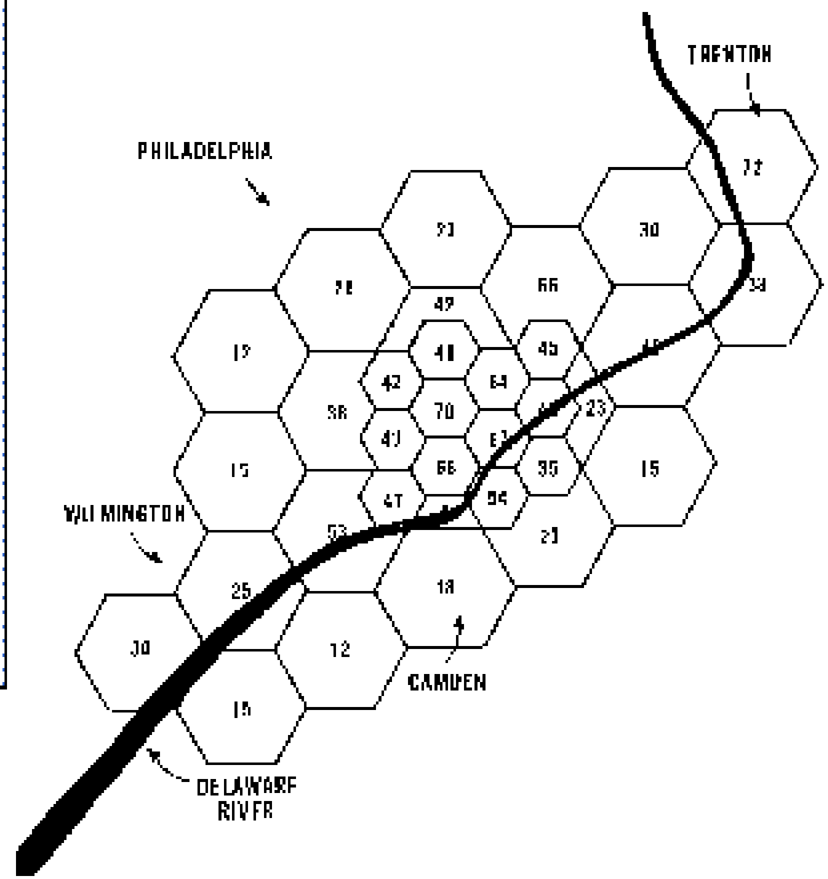


Figure 3.4 The umbrella cell approach.


Large cells
for rural
areas
Small cells
for urban
areas


TRENTON
PHILADELPHIA
WILMINGTON
CAMDEN
DELAWARE
RIVER

Sectoring

- In this approach
  - first SIR is improved using directional antennas,
  - capacity improvement is achieved by reducing the number of cells in a cluster thus increasing frequency reuse

- The CCI decreased by replacing the single omni-directional antenna by several directional antennas, each radiating within a specified sector

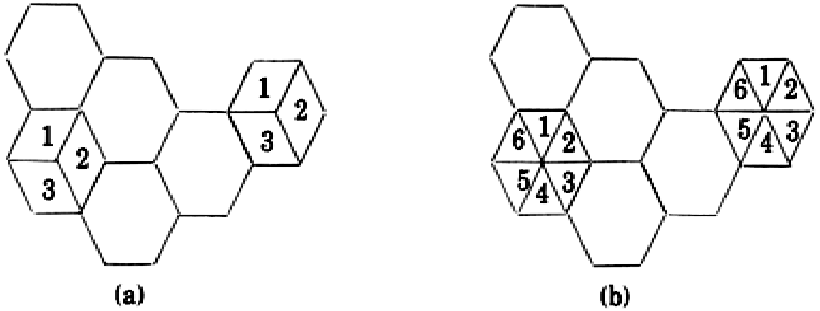


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Sectoring

A directional antenna transmits to and receives from only a fraction of total of the co-channel cells. Thus CCI is reduced

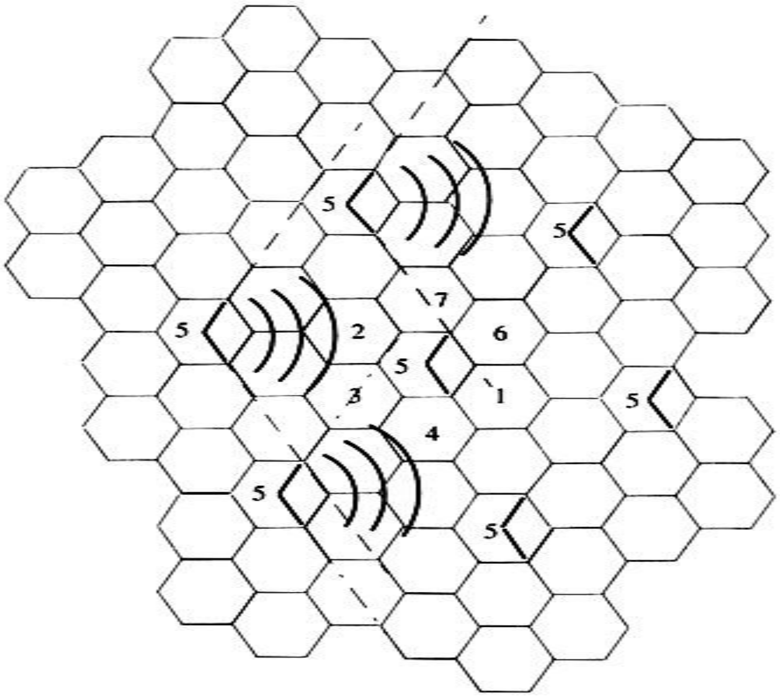


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

Problems with Sectoring

- Increases the number of antennas at each BS
- Decrease in trunking efficiency due to sectoring(dividing the bigger pool of channels into smaller groups)
- Increase number of handoffs(sector-to sector)
- Good news:Many modern BS support sectoring and related handoff without help of MSC

Microcell Zone Concept

- The Problems of sectoring can be addressed by Microcell Zone Concept
- A cell is conceptually divided into microcells or zones
- Each microcell(zone) is connected to the same base station(fiber/microwave link)
- Doing something in middle of cell splitting and sectoring by extracting good points of both
- Each zone uses a directional antenna
- Each zone radiates power into the cell.
- MS is served by strongest zone
- As mobile travels from one zone to another, it retains the same channel, i.e. no hand off
- The BS simply switches the channel to the next zone site

Micro Zone Cell Concept

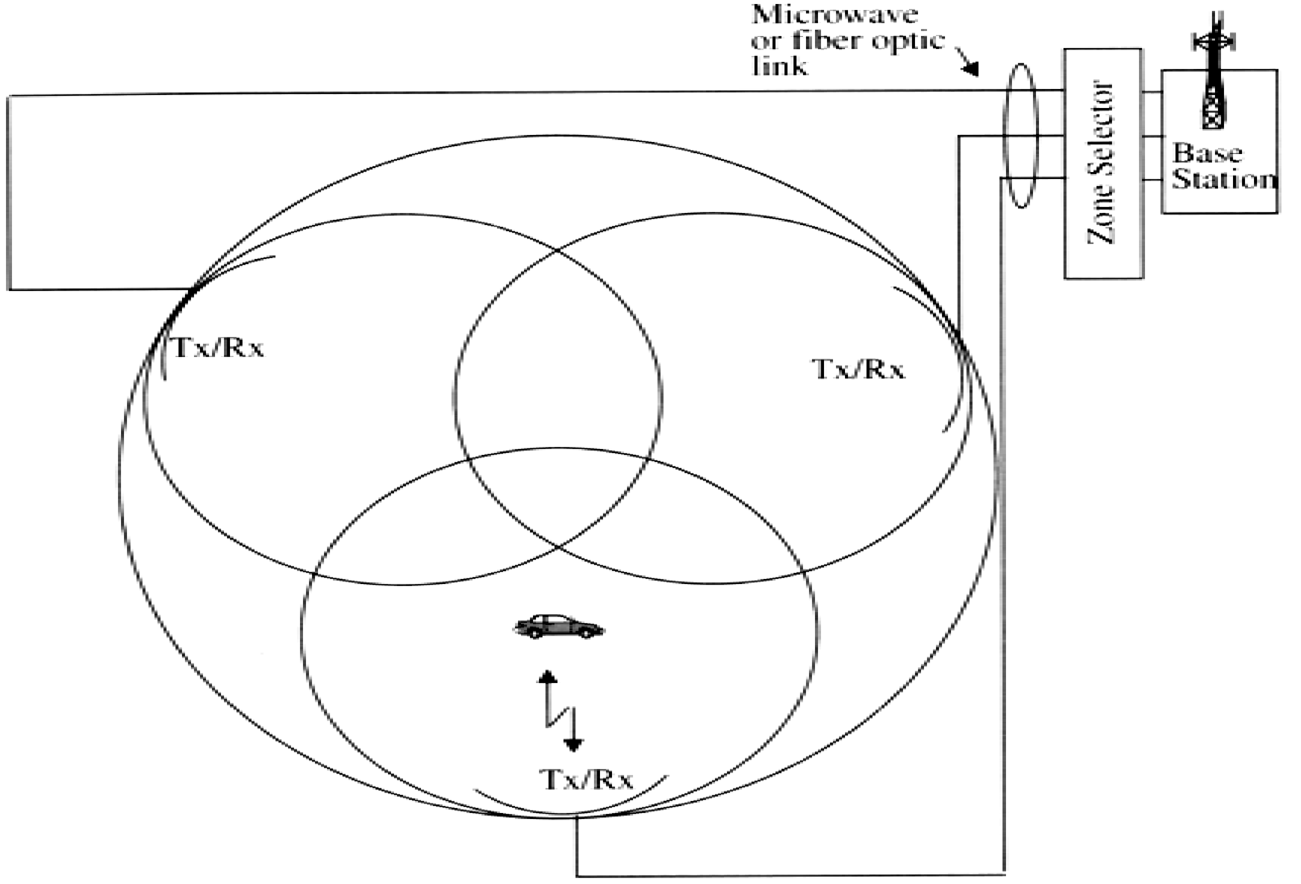


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

Microcell Zone Concept

- Reduced Interference (Zone radius is small so small and directional antennas are used).
- Decrease in CCI improves the signal quality and capacity.
- No loss in trunking efficiency (all channels are used by all cells).
- No extra handoffs.
- Increase in capacity (since smaller cluster size can be used).

Repeaters for Range Extension

- Useful for hard to reach areas
  - Buildings
  - Tunnels
  - Valleys

- Radio transmitters called Repeaters can be used to provide coverage in these area
- Repeaters are **bi-directional**
- Rx signals from BS
- Amplify the signals
- Re-radiate the signals
- Received noise and interference is also re-radiated