UNIT 1

Introduction to Wireless Communication Systems

WEEK 1 : Introduction to wireless communication and mobile radio communication, Classification of wireless communications - simplex, half duplex, dull duplex, Paging and Cordless systems, Cellular telephone systems, Timing diagram - landline to mobile and mobile to mobile, Basic antenna parameters, Far field and near field

WEEK 2 : Frequency reuse, sectored and omni- directional antennas, Channel assignment strategies, Handoff and its types, Interference and system capacity

WEEK 3 : Trunking and Grade of Service, Cell splitting, Sectoring, Microcell zone concepts, Umbrella cells, Solving Problems

Text books, references:

1. Rappaport T.S, *"Wireless Communications: Principles and Practice",* Pearson education.
2. For antenna concepts - Constantine Balanis. A, *"Antenna Theory: Analysis and Design",* 3rd Edition, John Wiley, 2012.

WEEK 1 LECTURES

Overview - Evolution of wireless communication, mobile radio communication antenna basic and Cellular concepts

Syllabus Coverage :

Introduction to wireless communication and mobile radio communication, Classification of wireless communications - simplex, half duplex, dull duplex, Paging and Cordless systems, Cellular telephone systems, Timing diagram landline to mobile and mobile to mobile, Basic antenna parameters, Far field and near field

Courtesy:

1. Rappaport T.S, *"Wireless Communications: Principles and Practice",* Pearson education.

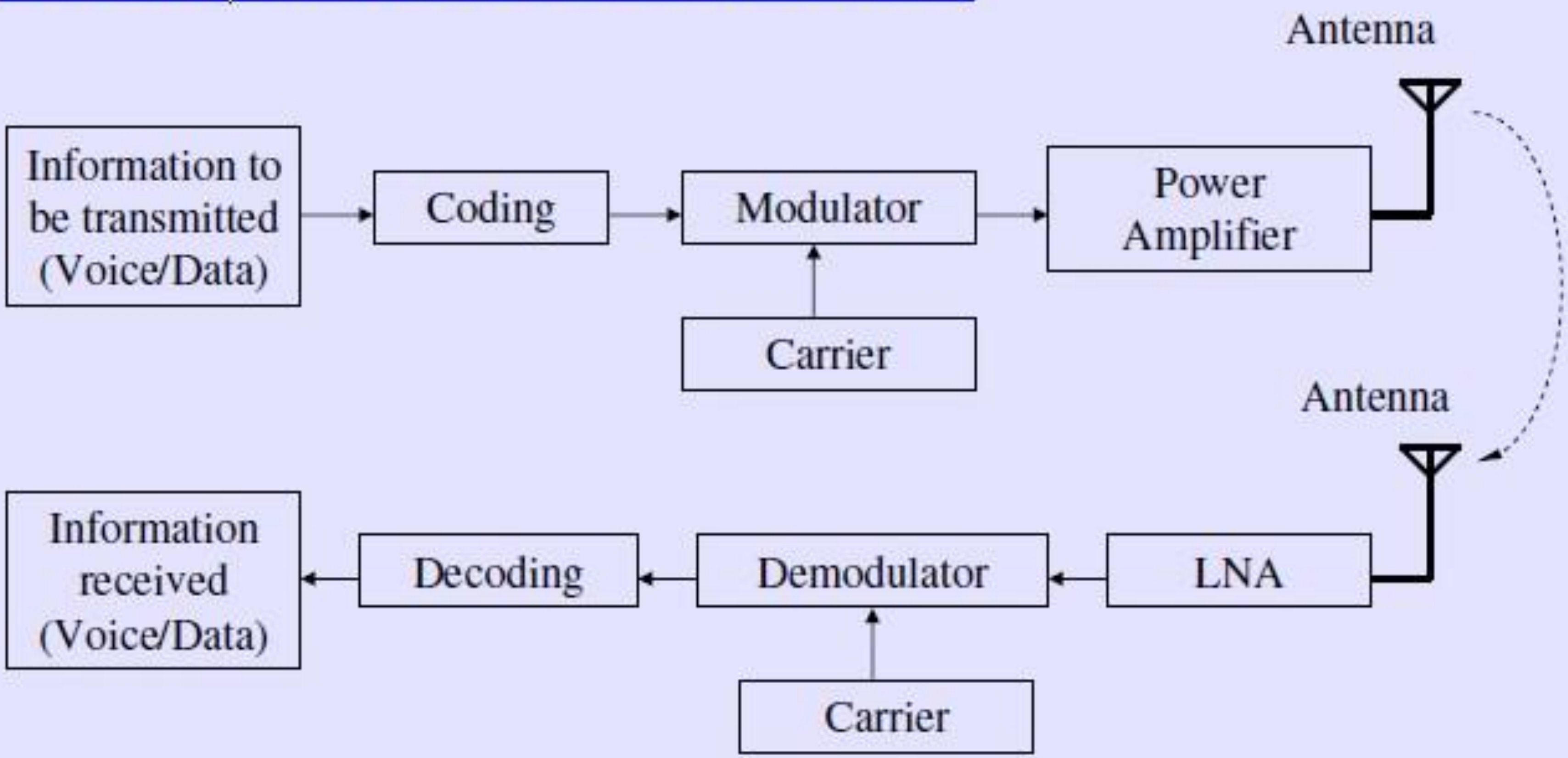
What is Wireless Communication?

- Transmitting/receiving voice and data using electromagnetic waves in free space.

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

The Structure of a wireless communication link involves several key components that work together and maintains the connection between the transmitter and the receiver. Every component plays an important role in the proper transmission of data from the transmitter to the receiver. The following block diagram demonstrates the complete structure of the wireless communication-link.

A Simplified Wireless Communication System Representation



Source : NPTEL Wireless lecture – Dr. Ranjan Bose (slide 28)

Transmitter Side

Information Source: It is a device that contains the information, or we can say it produces information and that information must be processed before transmitting through the propagation channel.

Source Encoder: It is a device that compresses the data provided by the information source in order to reduce the amount of data to be transmitted by removing the redundancies in the data.

Channel Coder: It is a device that is used to increase the reliability of the system by adding the redundant bit (parity bit) to the codded message to protect against errors that may occur during the transmission.

Modulator: It is a device that converts the codded message into a signal so that it can be transmitted through the communication channel. It converts digital data into analog signals.

Multiplexer: It is a device that allows multiple signals to share a single transmission line by combining them to a single composite signal.

Propagation Channel

It is a physical medium that carries the modulated signal. it is s the medium through which the signal travels. It can be air, water, or any other medium that allows the signal to propagate.

Receiver Side

Diversity Combiner: It is a device that combines multiple versions of the same signal that have been transmitted through different paths or channels. It Combines all the best-arising signals and by combining them produces the high power signal.

Equalizer: It is a device that compensates for the distortion introduced by the propagation channel by adjusting the amplitude and phase of the received signal.

Demodulator: A device that extracts the original codded message from the modulated signal received from the propagation channel. it is a device that converts the analog signal to digital data.

Channel Decoder: It is a device that corrects the errors in the codded message transmitted by the information source. It uses various techniques in order to correct the errors that occur due to noise and various other causes.

Source Decoder: It is a device that performs the opposite of the work performed by the source encoder, It decompresses the coded message back to its original format in order to recover the original data.

Characteristics:

Wireless communication links have several special characteristics that differentiate them from wired communication links. These characteristics include:

Mobility: Wireless communication links allow for mobile communication, where the user can move around freely while staying connected to the network. This is especially useful in situations where mobility is required, such as in a car or on a mobile device.

Flexibility: Wireless communication links are flexible and can be used in a variety of environments, including indoors and outdoors, in rural or urban areas, and in remote locations.

Scalability: Wireless communication links can be easily scaled up or down to accommodate changes in demand. This makes them ideal for situations where the demand for communication services may fluctuate over time.

Accessibility: Wireless communication links can provide access to communication services in areas where wired communication links are not available or feasible. This is particularly important in rural or remote areas, where wired infrastructure may be limited.

Interference: Wireless communication links are susceptible to interference from other wireless signals and noise, which can affect their performance. This requires careful management of the wireless spectrum to ensure that different wireless networks can coexist without interfering with each other.

Security: Wireless communication links require special security measures to protect against eavesdropping and other security threats. This includes encryption of data and authentication of users to prevent unauthorized access to the network.

An example (case study spectrum allocation) to Understand the Channel

- Assume a spectrum of 120 kHz is allocated over a base frequency for communication between stations A and B.

- Each channel occupies 40 kHz.

<table>
<tr><td rowspan="3">Station A</td><td>Channel 1 (b to b+40)</td><td rowspan="3">Station B</td></tr>
<tr><td>Channel 2 (b+40 to b+80)</td></tr>
<tr><td>Channel 3 (b+80 to b+120)</td></tr>
</table>

Can we allocate spectrum like that ? No, its Idealized; What can we do then? -Introduce Guard Bands; How do you determine the width of the Guard band?-Depends upon how sharp your receiver filter roll off factor is !

Types of Wireless Communication

• Mobile

Cellular Phones (GSM/ CDMA)

• Portable

IEEE 802.11b (Wi-Fi)

IEEE 802.15.3 (UWB)

• Fixed

IEEE 802.16 (Wireless MAN)

• FM Radio ~ 88 MHz • TV Broadcast ~ 200 MHz • GSM Phones ~ 900 MHz • GPS ~ 1.2 GHz • Bluetooth ~ 2.4 GHz • WiFi ~ 2.4 GHz

Why Wireless?

- Benefits
  - Mobility: Ability to communicate anywhere!!
  - Easier configuration, set up and lower installation cost

- Difficulties
  - Communication medium: Free space

- Noisy and unpredictable channel
- Broadcast channel, more user ->less BW per user
  - Higher equipment cost
  - Usually regulated spectrum and limited BW
    - Techno-politic
  - Need backbone systems in order to function properly

<u>Challenges :</u>

- Efficient Hardware
  - Low power transmitters, receivers
  - Low power signal processing tools
- Efficient use of finite radio spectrum
  - Cellular frequency reuse, medium access control protocols
- Integrated Services
  - Voice, data, multimedia over the same network
  - Service differentiation, priorities, resource sharing

• Network support for user mobility (mobile scenarios)

Maintaining quality of service over unreliable links.

Connectivity and coverage (internetworking)

Cost efficiency

• Fading
• Multipath
• Higher probability of data corruption

Hence, need for stronger channel codes

• Need for stronger security mechanisms – Privacy, Authentication.

Evolution of Mobile Radio Communications

Major Mobile Radio Systems

1934 - Police Radio uses conventional AM mobile communication system.

1935 - Edwin Armstrong demonstrate FM

1946 - First public mobile telephone service - push-to-talk

1960 - Improved Mobile Telephone Service, IMTS - full duplex

1960 - Bell Lab introduce the concept of Cellular mobile system 1968 - AT&T propose the concept of Cellular mobile system to FCC.

1976 - Bell Mobile Phone service, poor service due to call blocking

1983 - Advanced Mobile Phone System (AMPS), FDMA, FM

1991 - Global System for Mobile (GSM), TDMA, GMSK

1991 - U.S. Digital Cellular (USDC) IS-54, TDMA, DQPSK

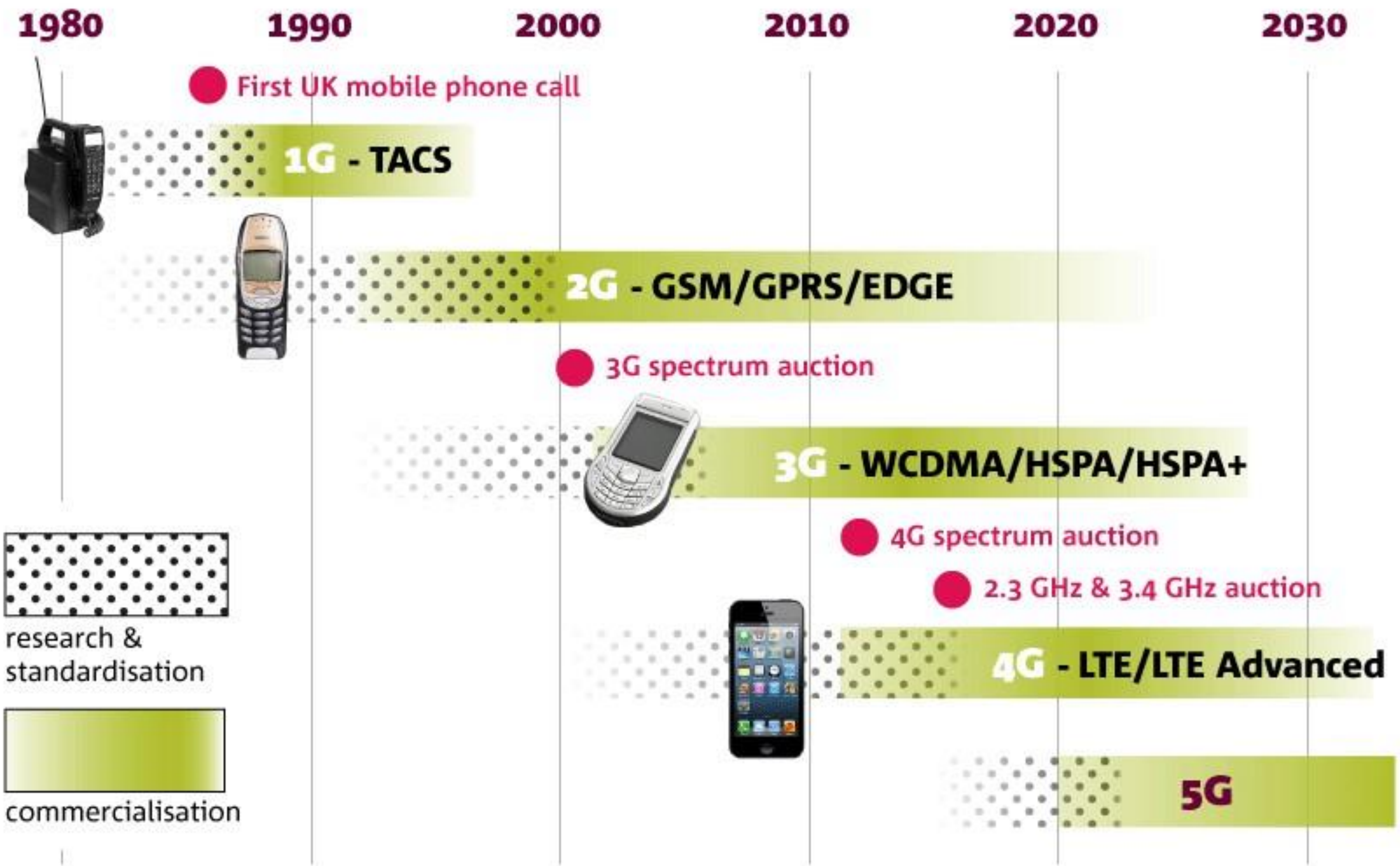
1993 - IS-95, CDMA, QPSK, BPSK

Example of Mobile Radio Systems

- Examples
  - Cordless phone
  - Remote controller
  - Hand-held walkie-talkies
  - Pagers
  - Cellular telephone
  - Wireless LAN
- Mobile - any radio terminal that could be moves during operation
- Portable - hand-held and used at walking speed
- Subscriber - mobile or portable user

In the older mobile radio systems, single high power transmitter was used to provide coverage in the entire area. Although this technique provided a good coverage, but it was virtually impossible in this technique to re-use the same radio channels in the system, and any effort to re-use the radio channels would result in interference. Therefore, in order to improve the performance of a wireless system with the rise in the demand for the services, a cellular concept was later proposed.

Evolution of mobile phone communications



2G

- Frequency: 1.8GHz (900MHz), digital telecommunication
- Bandwidth: 900MHz (25MHz)
- Characteristic: Digital
- Technology: Digital cellular, GSM
- Capacity (data rate): 64kbps

- Why better than 1G?

- From 1991 to 2000
- Allows txt msg service
- Signal must be strong or else weak digital signal

- 2.5G
  - 2G cellular technc GPRS
  - E-Mails
  - Web browsing
  - Camera phones

3G

- Frequency: 1.6 – 2.0 GHz
- Bandwidth: 100MHz
- Characteristic: Digital broadband, increased speed
- Technology: CDMA, UMTS, EDGE
- Capacity (data rate): 144kbps – 2Mbps

- Why better than 2G?

- From 2000 to 2010
- Called smartphones
- Video calls
- Fast communication
- Mobil TV
- 3G phones rather expensive

4G

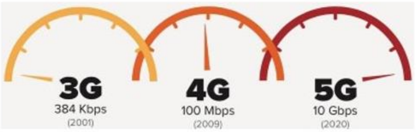
- Frequency: 2 – 8 GHz
- Bandwidth: 100MHz
- Characteristic: High speed, all IP
- Technology: LTE, WiFi
- Capacity (data rate): 100Mbps – 1Gbps

- Why better than 3G?

- From 2010 to today (2020?)
- MAGIC
  - Mobile multimedia
  - Anytime, anywhere
  - Global mobile support
  - Integrated wireless solutions
  - Customized personal service
- Good QoS + high security
- Bigger battery usage

5G

- https://5g.co.uk/guides/5g-frequencies-in-the-uk-what-you-need-to-know/
- Capacity (data rate): 1Gbps – UNLIMITED?



- From X (2020?) to Y (2030?)
- High speed and capacity
- Faster data trasmission than 4G
- Supports
  - Interactive multimedia
  - Voice streaming
  - Buckle up.. Internett
- More efficient

Cellular Technology: Evolution

- First generation:
  - Based on analog technology, uses a single base station to communicate with a single portable terminal.(e.g., Advance Mobile Phone Services - AMPS)
- Second generation:
  - Based on digital modulation and advanced call processing capabilities . (e.g., Global System for Mobile - GSM , IS-95 and Cordless Telephone - CT2).
- Third generation:
  - To provide a single set of standards that can meet a wide range of wireless applications (Multimedia) and provide universal access throughout the world.(e.g., WCDMA, CDMA-2000, etc.)
- Fourth generation:
  - To enable usage over IP platform – packet switching based (e.g., Long Term Evolution-Advanced (LTE-A), Mobile WiMAX)

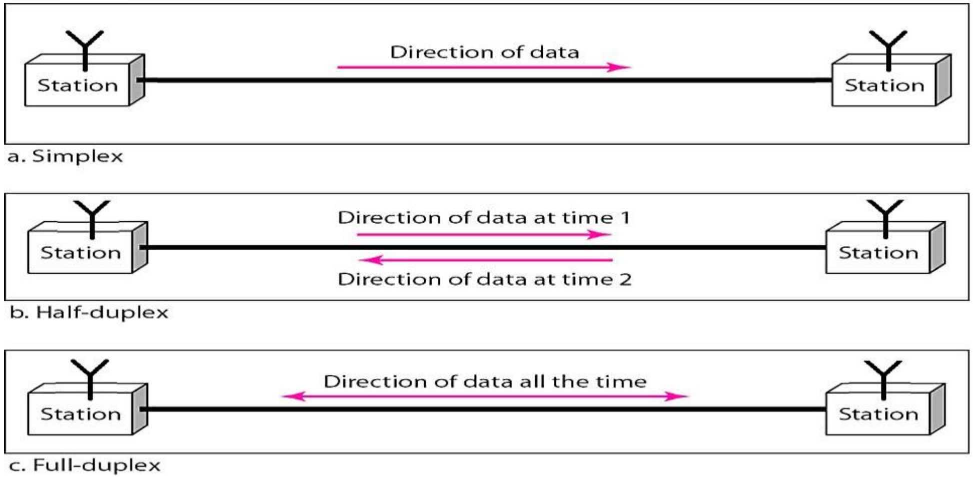
1G, 2G, 3G, 4G, 5G Comparison

	1G	2G	3G	4G	5G
Period	1980 – 1990	1990 – 2000	2000 – 2010	2010 – (2020)	(2020 - 2030)
Bandwidth	150/900MHz	900MHz	100MHz	100MHz	1000x BW pr unit area
Frequency	Analog signal (30 KHz)	1.8GHz (digital)	1.6 – 2.0 GHz	2 – 8 GHz	3 – 300 GHz
Data rate	2kbps	64kbps	144kbps – 2Mbps	100Mbps – 1Gbps	1Gbps <
Characteristic	First wireless communication	Digital	Digital broadband, increased speed	High speed, all IP	
Technology	Analog cellular	Digital cellular (GSM)	CDMA, UMTS, EDGE	LTE, WiFi	WWWW

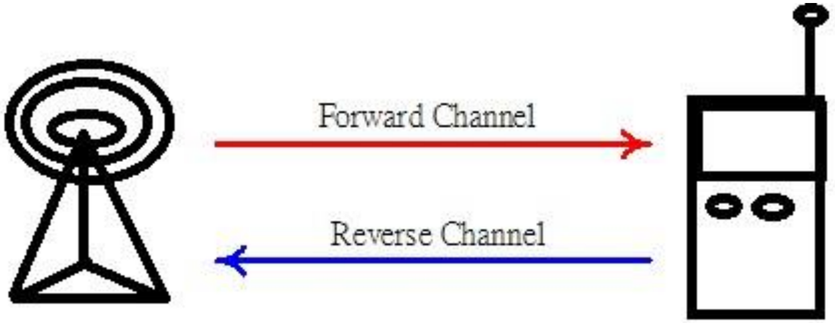
- https://www.linkedin.com/pulse/evolution-mobile-communication-from-1g-4g-5g-6g-7g-pmp-cfps

Classification of mobile radio transmission system

- Simplex: communication in only one direction
- Half-duplex: same radio channel for both transmission and reception (push-totalk)
- Full-duplex: simultaneous radio transmission and reception (FDD, TDD)



- Frequency division duplexing uses two radio channel
  - Forward channel: base station to mobile user
  - Reverse channel: mobile user to base station



- Time division duplexing shares a single radio channel in time.

Communication between two parties (a “link”), in general, can be one of the following:

• Simplex : Data/Voice is transferred in only one direction (e.g., paging). Not even an acknowledgement of receipt is returned.

• Half Duplex : Data/Voice is transferred in one direction at a time. One can’t talk and listen at the same time. One channel is required.

• Full Duplex : Data/Voice can be transferred in both directions between two parties at the same time. This requires two channels.

In a cellular system, there is full duplex communication, between a base station and a mobile. The two directions are called either uplink (from mobile to base station) or downlink (from BS to mobile). The downlink channel is synonymous with “forward channel”; the uplink channel is synonymous with the “reverse channel”.

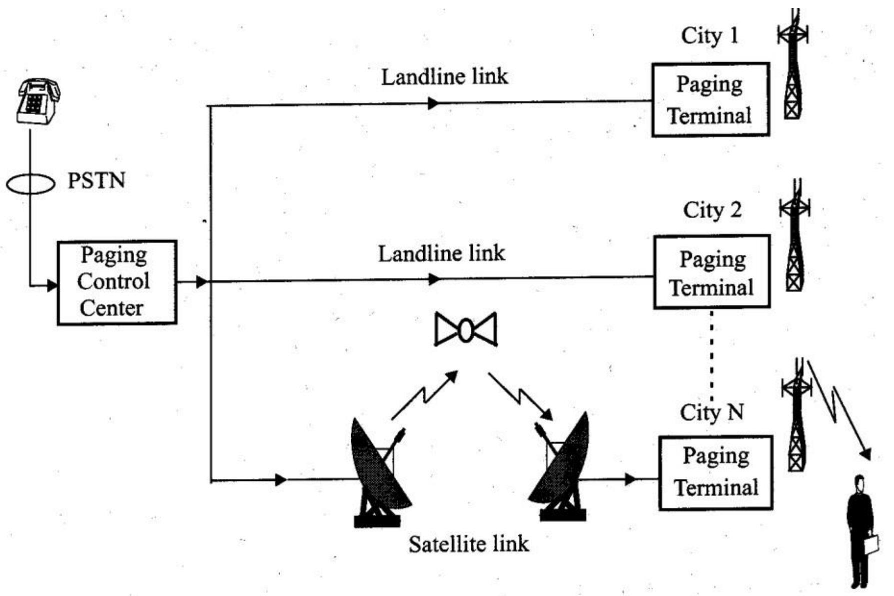
Simultaneous communication on the many channels needed for many users (radios) to communicate with a base station can be accomplished by one (or a combination) of the following multiple access methods.

• Frequency division multiple access (FDMA): Each channel occupies a different band of the frequency spectrum. Each signal can be upconverted to a frequency band by multiplying it by a sinusoid at the center frequency of that band, and then filtering out any out-of-band content.

- Time division multiple access (TDMA): Every period of time can be divided into short segments, and each channel can be carried only during its segment. This requires each device to be synchronized to have the same time clock.
- Code division multiple access (CDMA): Many channels occupies the same frequency band, at the same time. However, each channel occupies a different "code channel". Like sinusoids at different frequencies are orthogonal (non-interfering), sets of code signals can also be made so that all code signals are orthogonal to each other. One user's channel is multiplied by one code in the set, and at the receiver, can be separated from the other signals by filtering (like frequency bands can be filtered to remove out-of-band content).

Paging Systems

- Conventional paging system send brief messages to a subscriber. It is a form of simplex communication (only one way communication)
- Modern paging system: news headline, stock quotations, faxes, etc.
- Simultaneously broadcast paging message from each base station (simulcasting).
- Large transmission power to cover wide area. A Caller with the aid of PSTN sends a message, paging control center directs the messages

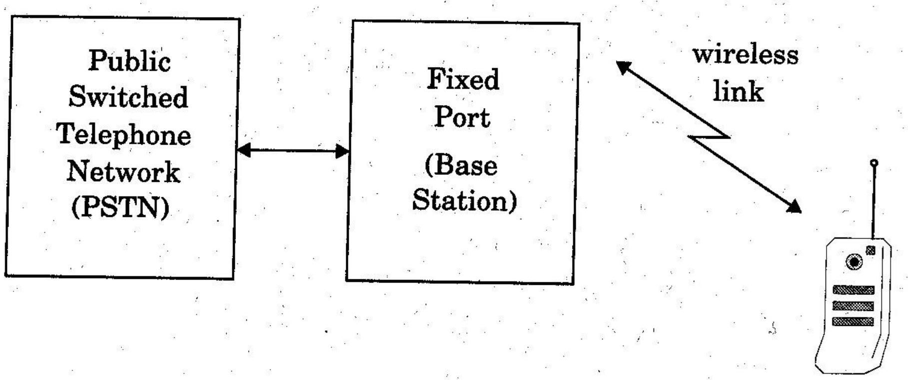


with the establishment of communication to the desired paging terminal or all the paging terminals (in case of broadcast) through landline or satellite link.

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp12.

Cordless Telephone System

- Cordless telephone systems are full duplex communication systems.
- First generation cordless phone
  - in-home use
  - communication to dedicated base unit
  - few tens of meters
- Second generation cordless phone
  - outdoor
  - combine with paging system
  - few hundred meters per station



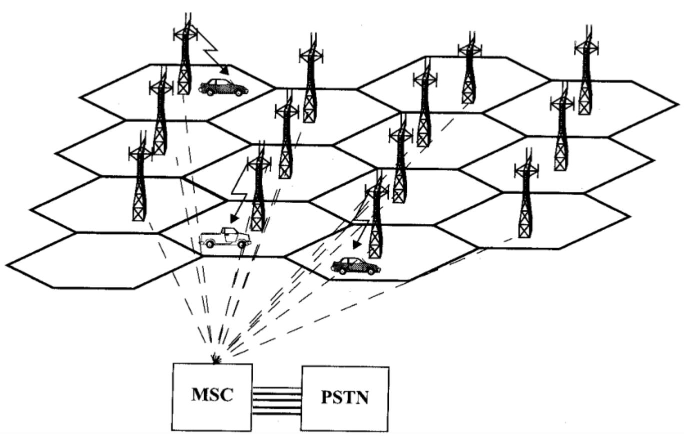
Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp13.

- **Uses radio to connect a portable hand set to a dedicated fixed base station**
- **The base station is then connected to a dedicated telephone line with a specific telephone number on the PSTN**

- **When a call is dialed or received, both fixed port and portable handset (depending upon the power backup) will be connected to the PSTN.**
- **Limited range and mobility**

Cellular Telephone Systems

- Provide connection to the PSTN for any user location within the radio range of the system.
- Characteristics
  - Large number of users
  - Large Geographic area
  - Limited frequency spectrum
- Reuse of the radio frequency by the concept of "cell".
- Basic cellular system: mobile stations, base stations, and mobile switching center.



Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp14.

- Communication between the base station and mobiles is defined by the standard common air interface (CAI)

  - forward voice channel (FVC): voice transmission from base station to mobile
  - reverse voice channel (RVC): voice transmission from mobile to base station
  - forward control channels (FCC): initiating mobile call from base station to mobile
  - reverse control channel (RCC): initiating mobile call from mobile to base station

Table 1.4 Wireless Communications System Definitions

Base Station	A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage region and consist of radio channels and transmitter and receiver antennas mounted on a tower.
Control Channel	Radio channel used for transmission of call setup, call request, call initiation, and other beacon or control purposes.
Forward Channel	Radio channel used for transmission of information from the base station to the mobile.
Full Duplex Systems	Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD) although new cordless/PCS systems are using TDD.
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 only either transmit or receive information.
Handoff	The process of transferring a mobile station from one channel or base station to another.
Mobile Station	A station in the cellular radio service intended for use while in motion at unspecified locations. Mobile stations may be hand-held personal units (portables) or installed in vehicles (mobiles).
Mobile Switching Center	Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connects the cellular base stations and the mobiles to the PSTN. An MSC is also called a mobile telephone switching office (MTSO).
Page	A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.
Reverse Channel	Radio channel used for transmission of information from the mobile to base station.
Roamer	A mobile station which operates in a service area (market) other than that from which service has been subscribed.
Simplex Systems	Communication systems which provide only one-way communication.
Subscriber	A user who pays subscription charges for using a mobile communications system.
Transceiver	A device capable of simultaneously transmitting and receiving radio signals.

When a cellular phone is turned ON, but not yet engaged in a call, it first scans the group of forward control channels to determine the one with the strongest signal, and then monitors that control channel until the signal level drops below a usable level.

Call initiation by a landline (PSTN) subscriber to mobile user:

The mobile switching centre (MSC) dispatches the request to all base station in a cellular system. The Mobile Identification Number (MIN) which is subscriber telephone number is then broadcast as a paging message over all of the forward control channels throughout the cellular system. The mobile receives the paging message sent by BS which s monitors, and responds by identifying itself over the RCC. The BS relays the acknowledgement sent by the mobile and informs the MSC of handshake. The MSC instructs the BS to move the call to an unused voice channel pair within the cell. The BS signals the mobile to change frequencies to an unused forward and reverse voice channel pair. Another data message is transmitted on forward channel to instruct the mobile telephone to ring and mobile user to answer the phone. Figures in the next page shows sequence of events involved in call connection.

Call initiation by a mobile user:

Once a call is in progress, the MSC adjusts the transmitted power of the mobile and changes the channel of the mobile unit and base stations in order to maintain call quality as the subscriber moves in and out of range of each base station. This is called a handoff. Special control signaling is applied to the voice channels so that the mobile unit may be controlled by the base station and the MSC while a call is in progress. When a mobile originates a call, a call initiation request is sent on the reverse control channel. With this request the mobile unit transmits its telephone number (MIN), electronic serial number (ESN), and the telephone number of the called party. The mobile also transmits a station class mark (SCM) which indicates what the maximum transmitter power level is for the particular user. The cell base station receives this data and sends it to the MSC. The MSC validates the request, makes connection to the called party through the PSTN, and instructs the base station and mobile user to move to an unused forward and reverse voice channel pair to allow the conversation to begin. Figure shows the sequence of events involved with connecting a call which is initiated by a mobile user in a cellular system.

A call initiation request is sent on the reverse control channel (RCC).Mobile unit transmits its telephone number (MIN), Electronic Serial Number (ESN), Station Class Mark (SCM) which indicates power level and telephone number of called party. The cell BS receives this information and sends it to MSC. The MSC validates the request, makes connection to called party through the PSTN.MSC instructs BS and mobile user to move to an unused voice channel pair to allow the conversation to begin

Timing diagram illustrating how a call to a mobile user initiated by a landline subscriber is established.

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp16.

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

time →

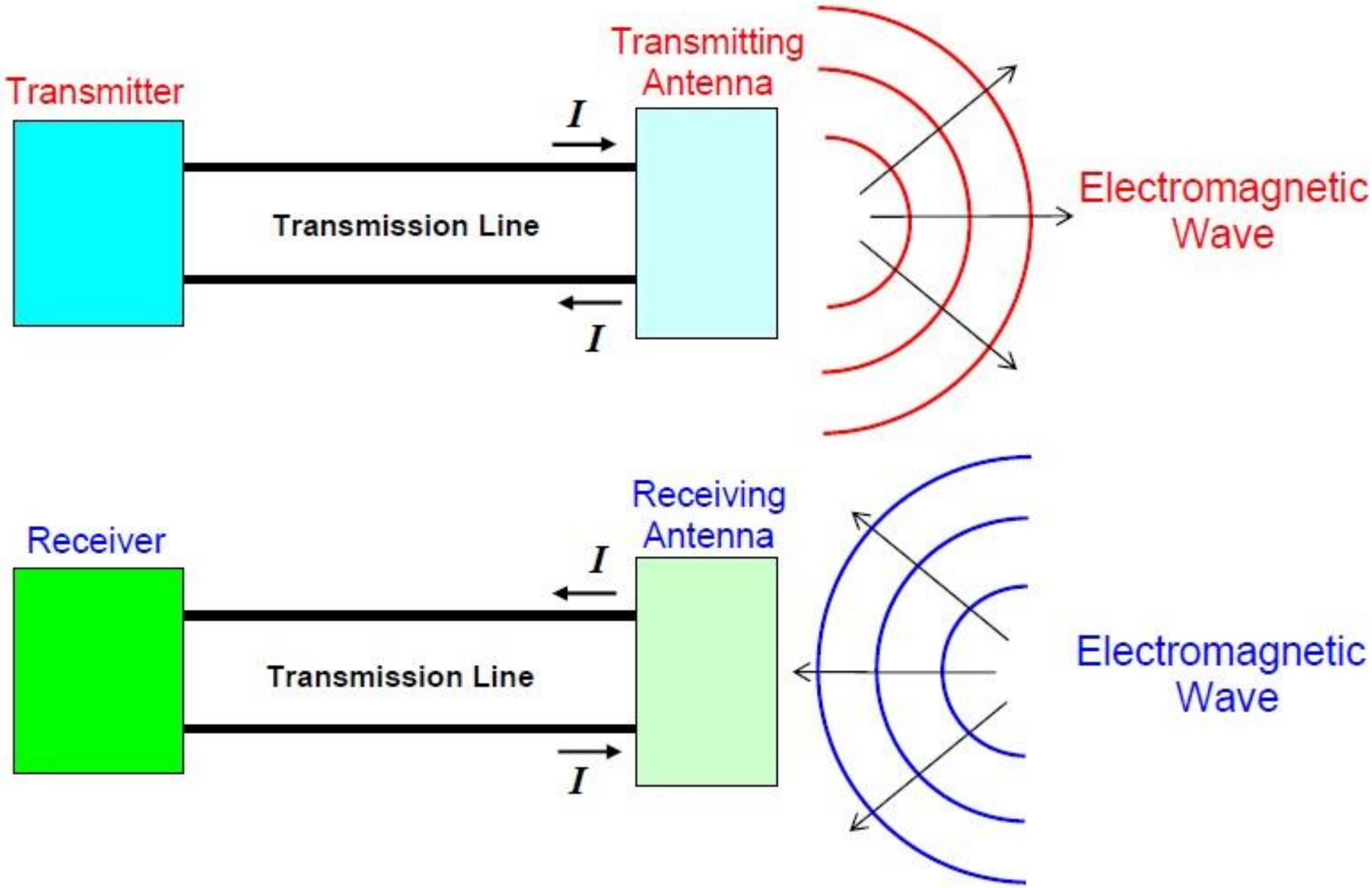
Timing diagram illustrating how a call initiated by a mobile is established

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp17.

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

time →

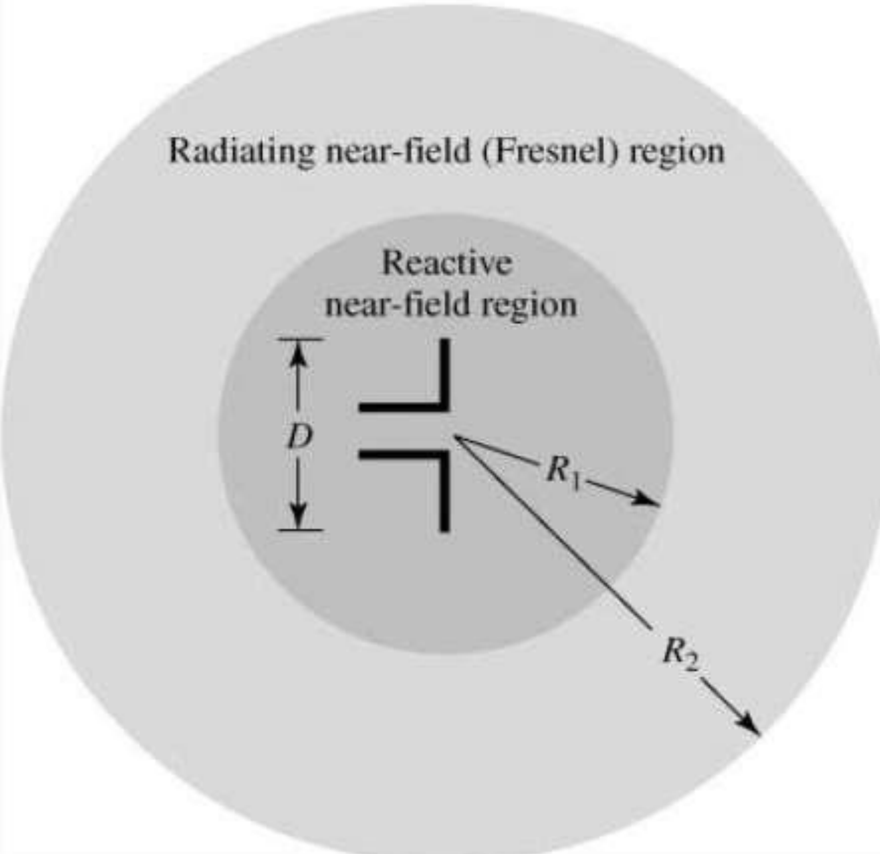
Antennas



Antennas are <u>transducers</u> that transfer electromagnetic energy between a transmission line and free space.

Field Regions

Far-field (Fraunhofer) region

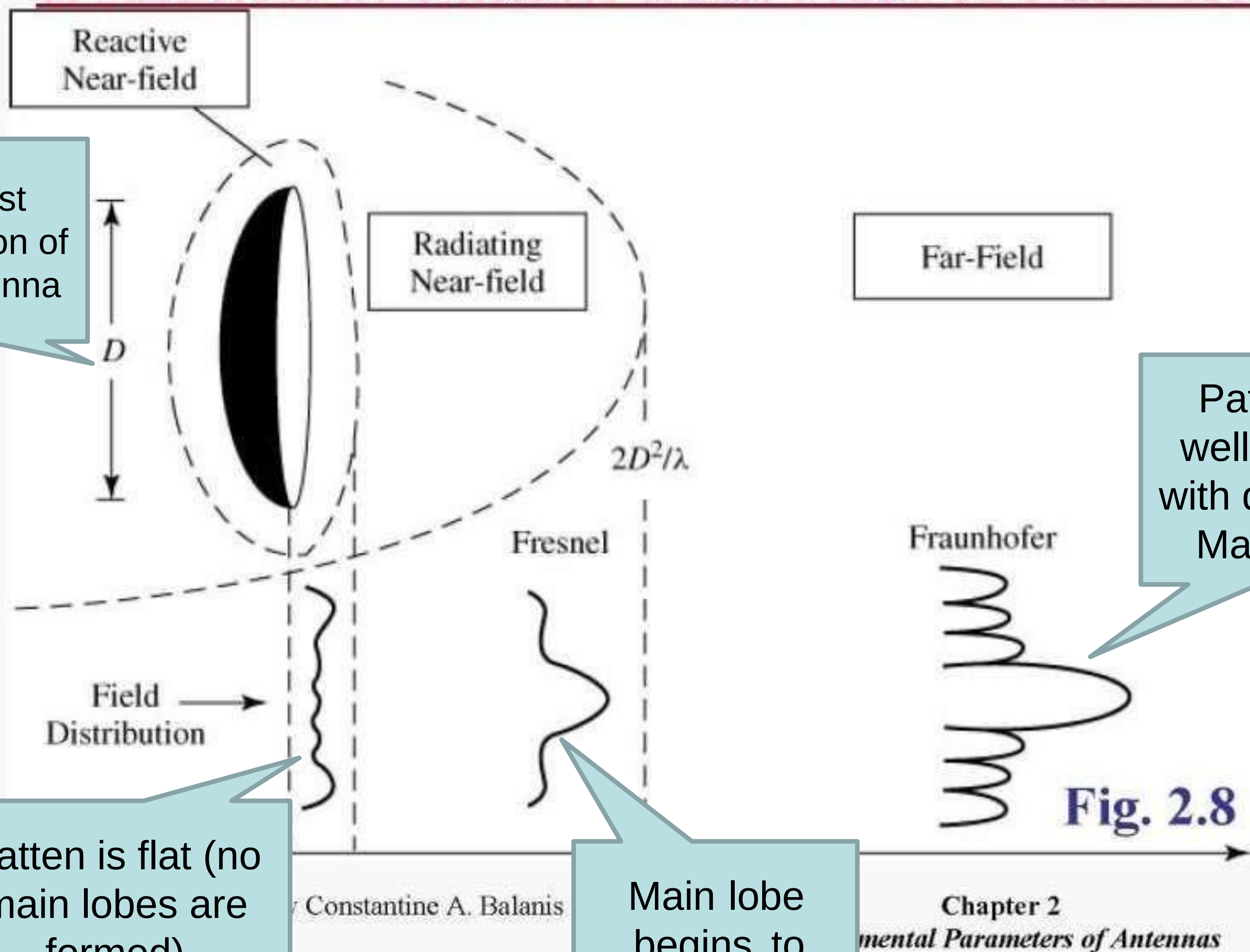


$R_1 = 0.62\sqrt{D^3/\lambda}$

$R_2 = 2D^2/\lambda$

Fig. 2.7

Evolution of Pattern from Near to Far Field



Largest dimension of the antenna

Pattern is well formed with dominant Main lobe

Patten is flat (no main lobes are formed)

Main lobe begins to develop

I. Reactive Near-Field

A. Phases of electric & magnetic fields are often near quadrature; thus

1. Highly reactive wave impedance
2. High content of non-propagating stored energy near the antenna

II. Radiating Near-Field

A. Fields are predominantly in phase

B. Fields do not yet display a spherical wavefront; thus pattern varies with distance

C. Region where near-field measurements are made

III. Far-Field

A. Fields exhibit spherical wavefront

$2D^2/\lambda$ thus the pattern, ideally, does not vary with distance

B. Electric & magnetic fields are in-phase

C. Wave impedance is, ideally, real

D. Power predominantly real; propagating energy

The *beamwidth of a pattern is defined as the angular separation between two identical* points on opposite side of the pattern maximum.

Half-Power Beamwidth (HPBW) is defined as: "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam."

The angular separation between the first nulls of the pattern is referred to as the *First-Null Beamwidth (FNBW)*

*Radiation intensity (*W/unit solid angle*) in a given direction is defined as "the power radiated from an* antenna per unit solid angle." Obtained by multiplying radiation density (in W/m^2) with square of distance r.

Directivity of an antenna defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

The total antenna efficiency e_0 *is used to take into account losses at* the input terminals and within the structure of the antenna.

1. reflections because of the mismatch between the transmission line and the antenna (reflection) – results in reflection coefficient Γ_{in}
2. *I^2R losses (conduction and dielectric – ic and id)*

- Gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities.
- Directivity is a measure that describes only the directional properties of the antenna, and it is therefore controlled only by the pattern.

The dipole and monopole are two of the most widely used antennas for wireless mobile communication systems. An array of dipole elements is extensively used as an antenna at the base station. The monopole, because of its broadband characteristics and simple construction, is perhaps to most common antenna element for portable equipment, such as cellular telephones, cordless telephones, automobiles, trains, etc. An alternative to the monopole for the handheld unit is the loop. Other elements include the inverted F, planar inverted F antenna (PIFA), microstrip (patch), spiral.

In cell phone devices – PIFA antennas are used in recent days and before 2G and LTE systems, Monopole antennas were used

Examples of stationary, retractable/telescopic and embedded/hidden antennas used in commercial cellular and cordless telephones, walkie-talkies, and CB radios.

Triangular array of dipoles used as a sectoral base-station antenna for mobile Communication.

WEEK 2 LECTURES

Overview - Cellular concepts - Frequency reuse, Channel assignment- Hand off, Interference and system capacity

Syllabus Coverage:

Frequency reuse, sectored and omni- directional antennas, Channel assignment strategies, Handoff and its types, Interference and system capacity

Courtesy:

1. Rappaport T.S, *"Wireless Communications: Principles and Practice",* Pearson education.

Cellular Concept

The design aim of early mobile wireless communication systems was to get a huge coverage area with a single, high-power transmitter and an antenna installed on a giant tower, transmitting a data on a single frequency. Although this method accomplished a good coverage, but it also means that it was practically not possible to reuse the same frequency all over the system, because any effort to reuse the same frequency would result in interference.

The cellular concept was a major breakthrough in order to solve the problems of limited user capacity and spectral congestion. Cellular system provides high capacity with a limited frequency spectrum without making any major technological changes. It is a system level idea in which a single high-power transmitter is replaced with multiple low- power transmitters, and small segment of the service area is being covered by each transmitter, which is referred to as a cell. Each base station (transmitter) is allocated a part of the total number of channels present in the whole system, and different groups of radio channels are allocated to the neighboring base stations so that all the channels present in the system are allocated to a moderately small number of neighboring base stations.

The mobile transceivers (also called mobile phones, handsets, mobile terminals or mobile stations) exchange radio signals with any number of base stations. Mobile phones are not linked to a specific base station, but can utilize any one of the base stations put up by the company. Multiple base stations covers the entire region in such a way that the user can move around and phone call can be carried on without interruption, possibly using more than one base station. The procedure of changing a base station at cell boundaries is called handover. Communication from the Mobile Station (MS) or mobile phones to the Base Station (BS) happens on an uplink channel also called reverse link, and downlink channel or forward link is used for communication from BS to MS. To maintain a bidirectional communication between a MS and BS, transmission resources must be offered in both the uplink and downlink directions. This can take place either using Frequency-Division Duplex (FDD), in which separate frequencies are used for both uplink and downlink channels, or through Time-Division Duplex (TDD), where uplink and downlink communications take place on the same frequency, but vary in time.

FDD is the most efficient technique if traffic is symmetric, and FDD has also made the task of radio planning more efficient and easier, because no interference takes place between base stations as they transmit and receive data on different frequencies. In case of an asymmetry in the uplink and downlink data speed, the TDD performs better than FDD. As the uplink data rate increases, extra bandwidth is dynamically allocated to that, and as the data rate decreases, the allotted bandwidth is taken away. Some of the important cellular concepts are:

- Frequency reuse
- Channel Allocation
- Handoff
- Interference and system capacity
- Trunking and grade of service
- Improving coverage and capacity

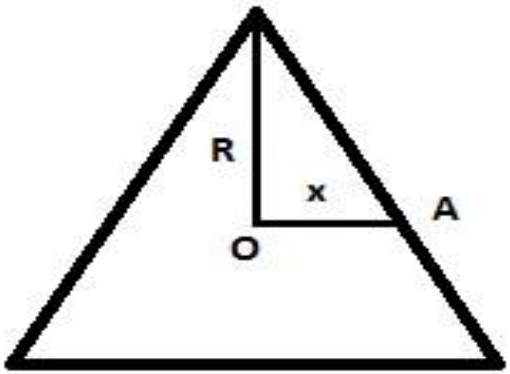
Cellular Systems-Basic Concepts

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. 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

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

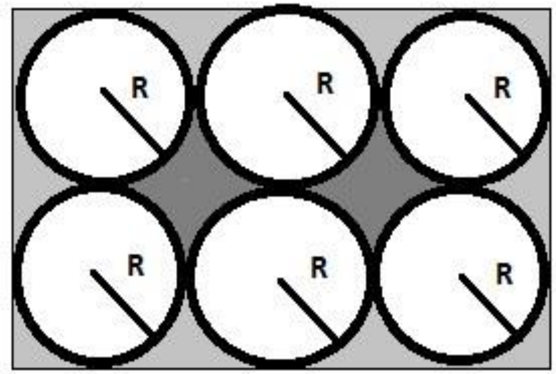
The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning. Cell labeled with same letter use the same set of frequencies. Cell Shapes: Circle, Square, Triangle and Hexagon. Hexagonal cell shape is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



Triangular Cell

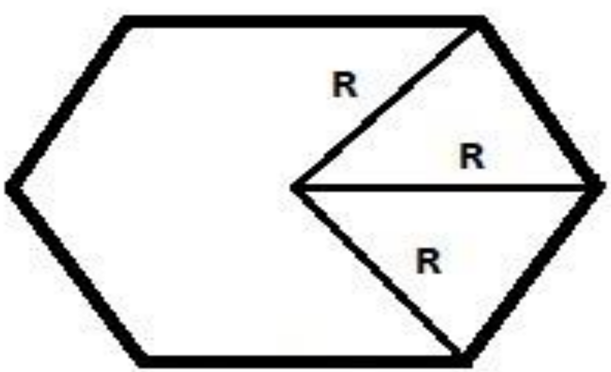
x < R (Non-Uniform Distribution)

$A_{triangle} = 1.3R^2$



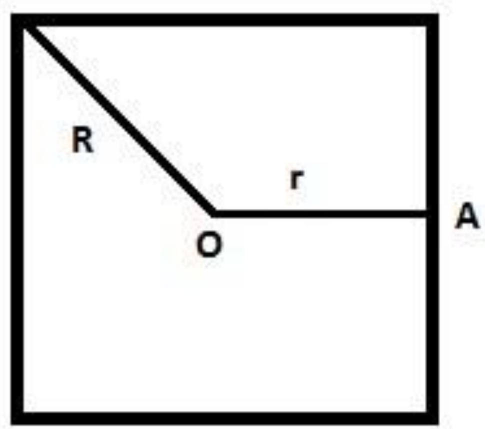
Circular Cell

--> Missed Area



Hexagonal cell
(Uniform Distribution without overlap & witout gap area)

$A_{Hex} = 2.6R^2$

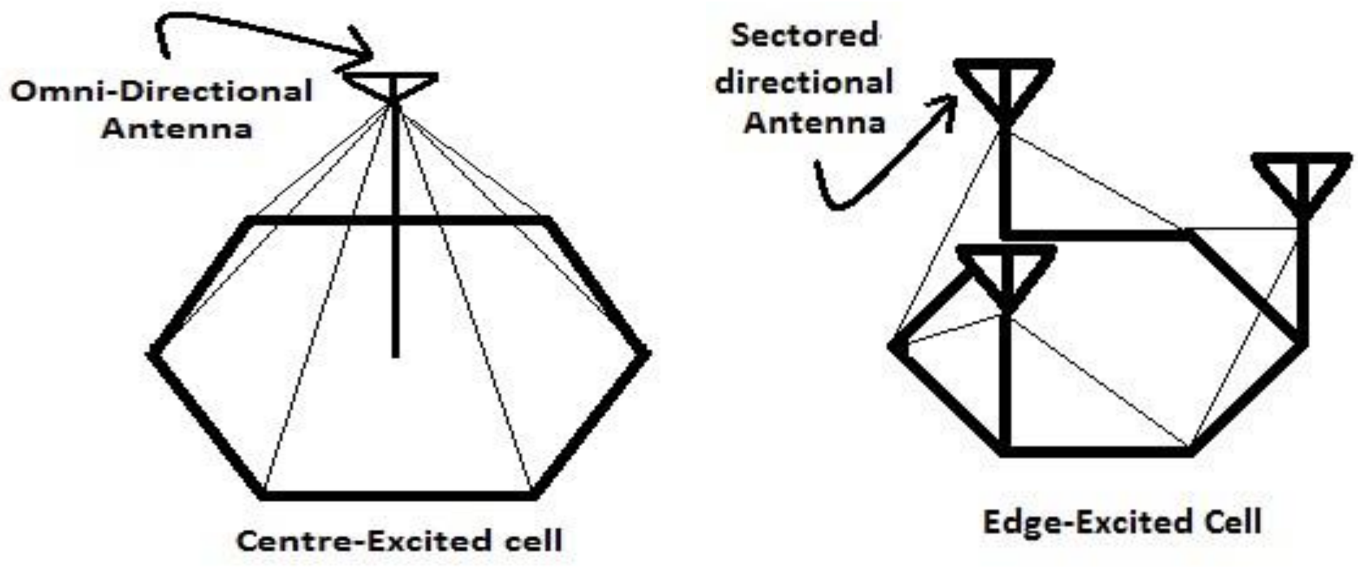


Square cell

< R (Non-Uniform Distribution)

$A_{Square} = 2.0R^2$

Hexagonal cell shape is conceptual & is a simplistic model of radio coverage for each base station. As the radiation from antenna is circular, thus there is fading on the edges of triangle & Square. But in Hexagon shape, there is **lesser fading** on the edges. When using hexagonal shaped cell, base station areas are depicted as either being in centre of cell i.e. **Central Excited Cell** or on the 3 edges of the 6 cell vertices i.e. **Edge Excited Cell.** For Central Excited Cell, **Omni-directional** antennas are used. For Edge Excited Cell, **Sectored-directional** antennas are used.



The design process of selecting & allocating channel groups for all the cellular base stations with in a system is called **Frequency Reuse** or **Frequency Planning.**

Frequency Reuse Distance : Minimum distance b/w co-channel cells required to keep co-channel interference below certain threshold.

Each cellular base station is allocated a group of radio channels to be used within a small geographic area called **Cell.**

Base station of adjacent cells are assigned channel group which contains completely **different channels** than neighboring cells.

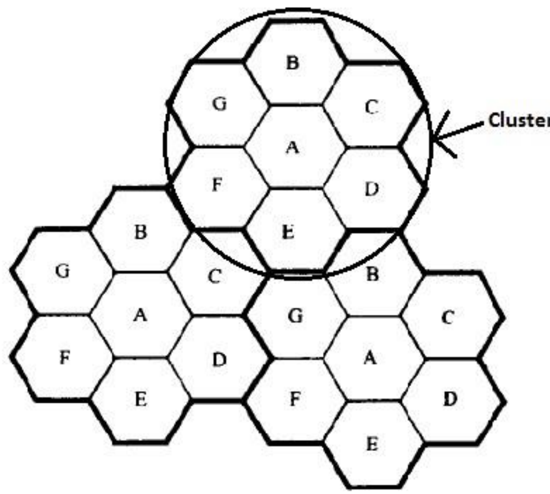


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, N, is equal to seven, and the frequency reuse factor is 1/7 since each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

If N cells which collectively use the complete set of available frequencies is called a **cluster**. The base station antennas are designed to achieve the **desired coverage** within the particular cell. By limiting the coverage of a cell, the **same group of channels** may be used to cover different cells that are separated from one- another by large distances enough to keep interference level within tolerable limit. After how many cells two cells assigned the **same frequency** to use, **frequency Reuse concepts** is used.

Consider a cellular system which has a total of **‘S’** duplex channels (total no. of channels in a cluster). If each cell is allocated a group of **‘K’** channels & if S channels are divided among N cells into unique & disjoint channel groups.

Total number of available radio channels **in a cluster** can be given as:

S = KN

If a cluster is replicated **M** times within a system, total number of duplex channel **‘C’** can be used as a measure of capacity & is given as: C = MS

C= MKN

Capacity of a cellular system is directly proportional to number of times a cluster is replicated in a fixed service area.

Factor ‘N’ is called cluster size.

let total number of channel allocated for a cluster is **M = 395.**

Let **N = 7** (N= number of cells in a cluster), it means 395/7 = 57 frequencies is possible an average per cell to characterizing the frequency reuse.

Frequency Reuse factor of a cellular system is = 1/N (since each cell within a cluster is only assigned 1/N of total available channels in the system); N = Cluster size is given by : **N = $i^2 + j^2 +$ i.j** (i & j are integers); For **i=1, j=1**, then **N = 3**. i.e. one cluster has 3 cells.

N may be = 1, 3, 4, 7, 9, 12, 13, 16, 19 etc.

d = distance b/w centre of two adjacent cells, R = Radius of cell

D = Minimum distance b/w centre of cells that use same channels or frequency band (co-channels)

Frequency reuse distance: $D^2 = 3R^2 (i^2 + j^2 + i.j)$

$$D^2 = 3R^2 .N$$

$$D = (3N)^{1/2}. R \quad \text{or } D/R = (3N)^{1/2}$$

As $d = 3^{1/2} .R$ $\qquad$ $D/d = (N)^{1/2}$

Locating co-channel Cell

To find the nearest co-channel neighbors of a particular cell, one must do the following:

a) Move i cells along any chain of hexagon.

b) Turn 60^{o} counter clockwise & move j cells.

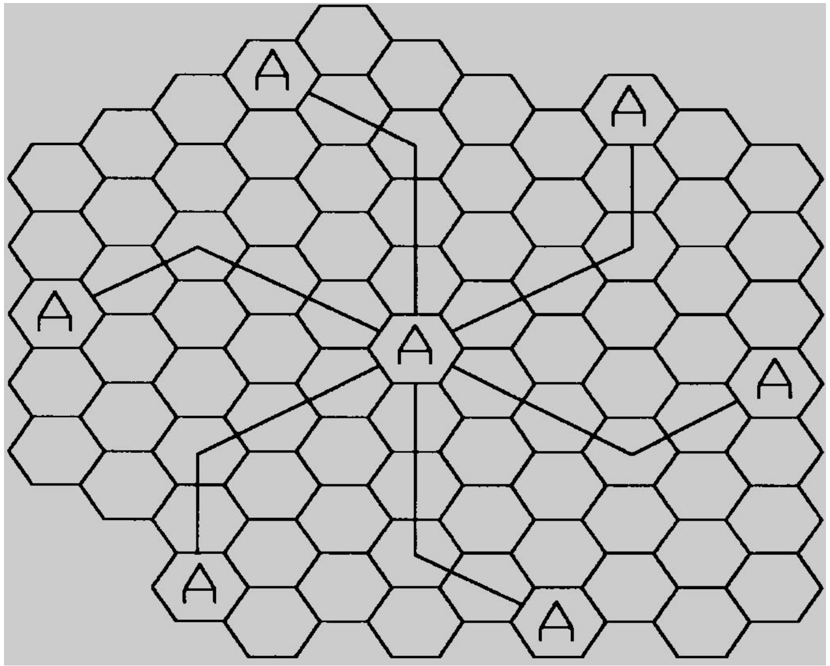


Figure 3.2 Method of locating co-channel cells in a cellular system.

In this example, N = 19 (i.e., i = 3, j = 2). (Adapted from [Oet83] © IEEE.) Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 60.

Effect of cluster size N

Channels unique in same cluster, repeated over clusters; Keep cell size same

- large N : weaker interference, but lower capacity

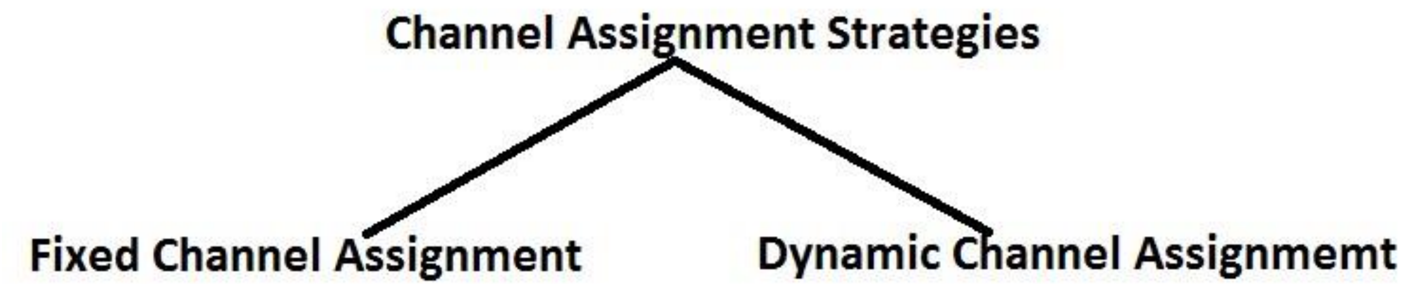
- small N: higher capacity, more interference ,need to maintain certain S/I level

Frequency reuse factor: 1/N

Each cell within a cluster assigned 1/N of the total available channels. In most of the upcoming networks, frequency reuse factor is 1.

<u>Channel Assignment Strategies (CAS)</u>

Frequency reuse scheme increases capacity and minimizes interference



- Fixed channel assignment

Each cell is allocated a predetermined set of voice channel; any new call attempt can only be served by the unused channels; the call will be *blocked* if all channels in that cell are occupied

- Dynamic channel assignment

  Channels are not allocated to cells permanently; allocate channels based on request; reduce the likelihood of blocking, increase capacity.

Fixed Channel Assignment Strategy (FCAS)

In FCAS 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 Strategy (DCAS)

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). 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. DCA is more complex (real time), but reduces likelihood of blocking.

Handoff

When a mobile moves into a different cell while conversation is in progress, the MSC automatically transfers the call to a new channel belonging to new base station is known as **Handoff.** Handoff operation not only involves **identifying a new base station**, but also requires that the **voice & control signals** be allocated to channels with the new base station.

Handoff must be **performed successfully** & as **infrequently** as possible. For this system designer must specify an **optimum signal level** at which to **initiate** a handoff. Once a particular signal level is specified as the **minimum usable signal** for acceptable voice quality at the base station receiver, a slightly stronger signal level is used as a **threshold** at which a handoff is made.

This margin (Threshold) is given by:

$$\Delta = P_r(\text{HANDOFF}) - P_r(\text{MIN. USABLE})$$

- Δ can't be too large or too small.

Case 1: if Δ is **too large**, unnecessary handoffs are there, which burden the MSC.

Case 2: if Δ is **too small**, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions.

- Call Drop event can happen:

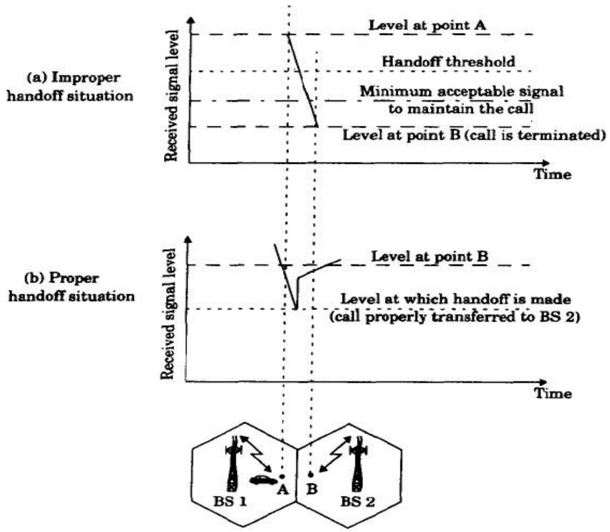
Case 1: When there is an excessive delay by the MSC in assigning a handoff.

Excessive delay may occur during:

1) High traffic density, due to computational loading at the MSC
2) Due to the fact that no channels are available on any of the nearby base stations.

Case 2: When the threshold Δ is set too small for the handoff time in the system.

Dwell Time : The time over which a call be maintained within a cell without handoff is called **"Dwell Time".** (after the handoff threshold)

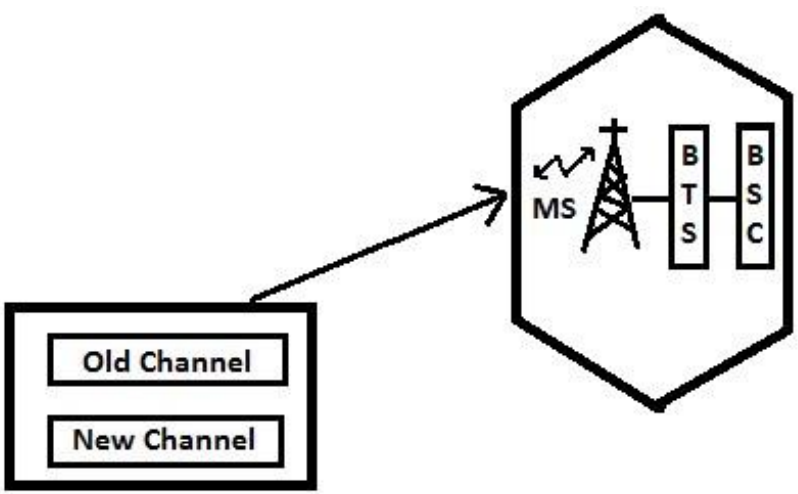


Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 63.

Types of Handoff

1) **Intra-cell-Intra BSC Handover**
2) **Inter-cell-Intra BSC Handover**
3) **Inter-cell-Inter BSC Handover**
4) **Inter MSC Handover**

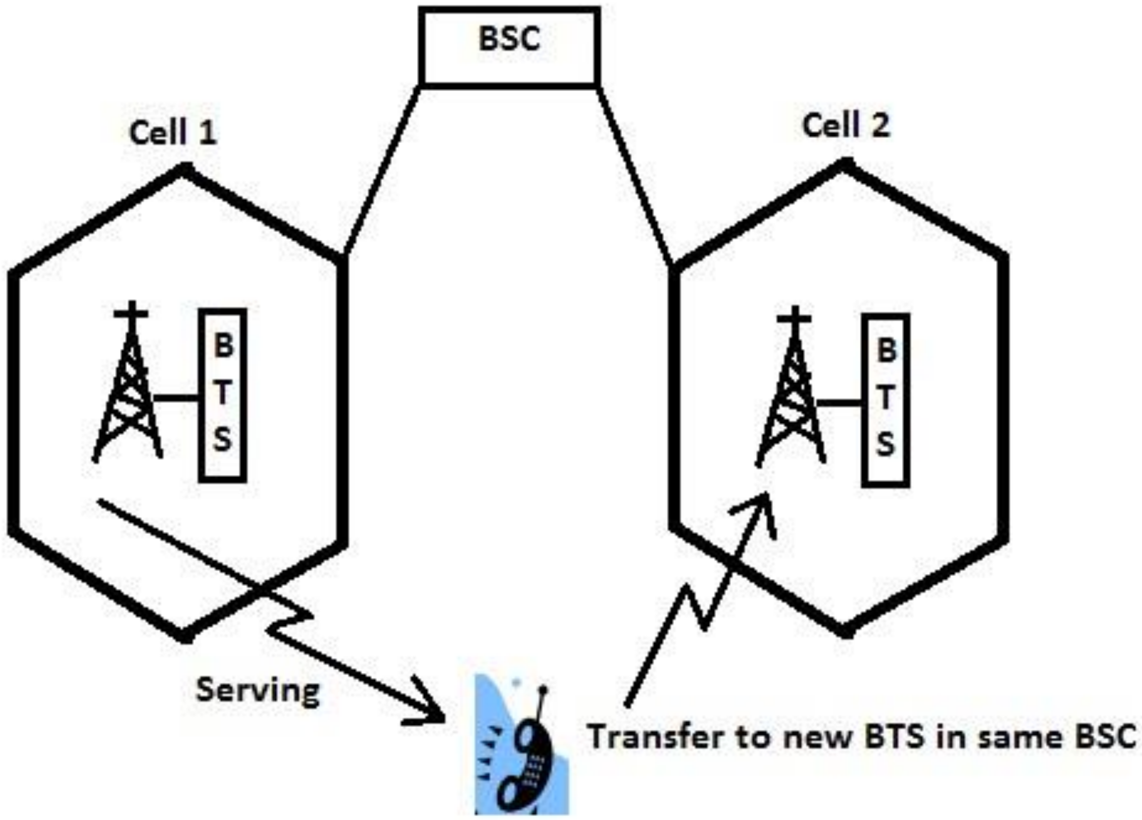
1) Intra-cell-Intra BSC Handover : Smallest of the Handover is the intra-cell handover where the subscriber is handed over to another traffic channel (generally in another frequency) with in same cell.



- In this case, BSC controlling the cell makes the decision to perform handover.

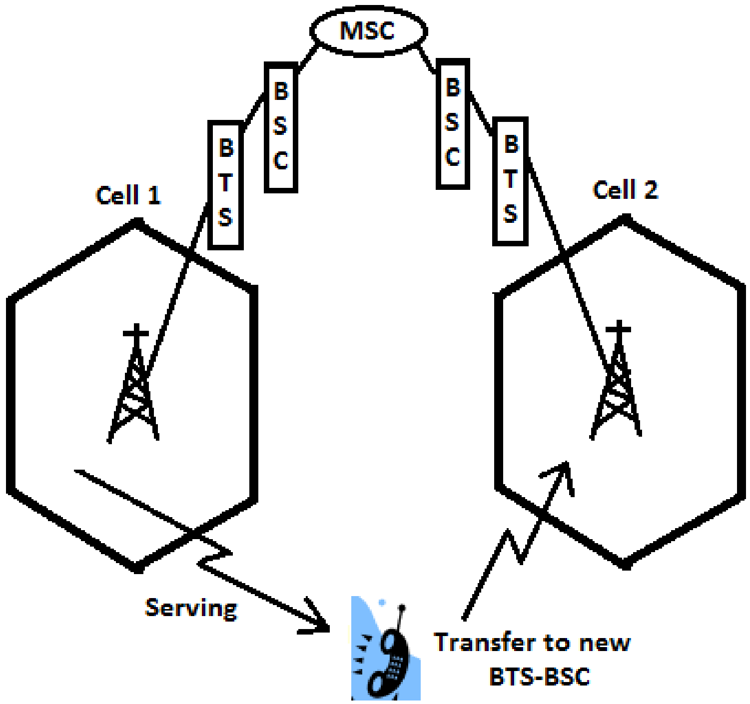
2) Inter-cell-Intra BSC Handover :

The subscriber moves from cell1 to cell 2 but within BSC. In this case, the handover process is carried out by the BSC. Traffic connection with cell 1 is released when the connection with cell 2 is setup successfully.



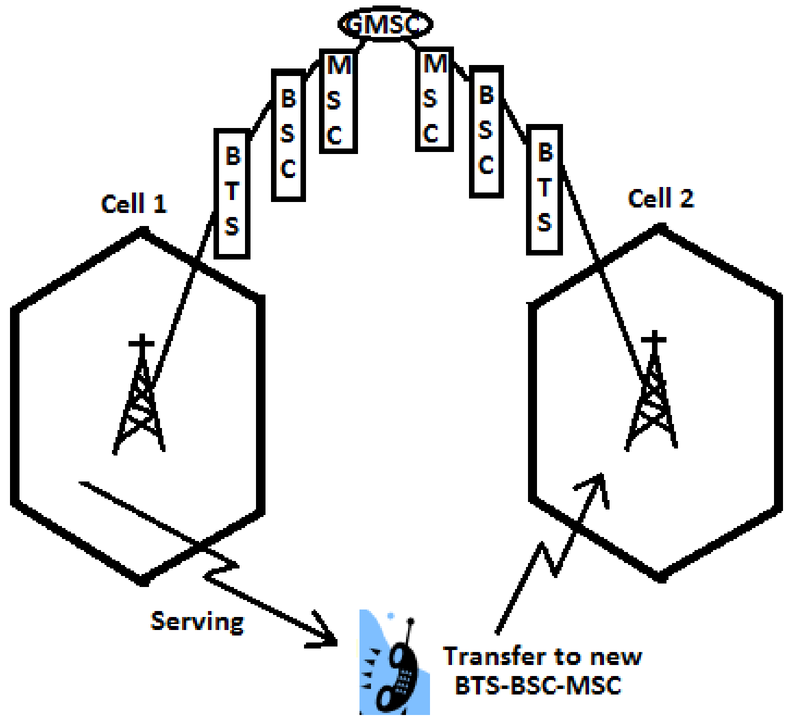
3) Inter-cell-Inter BSC Handover :

The subscriber moves from cell1 to cell 2 which is served by another BSC. In this case, handover process is carried out by the MSC, but the decision to make the handover is still done by the first BSC. Traffic connection with the first BSC & BTS is released when the connection with the new BSC & BTS is setup successfully.



4) Inter MSC Handover :

The subscriber moves from cell1 to cell 2 which is served by another MSC. In this case, handover process is carried out by the GMSC. Traffic connection with the first BTS-BSC-MSC is released when the connection with the new BTS-BSC-MSC is setup successfully.

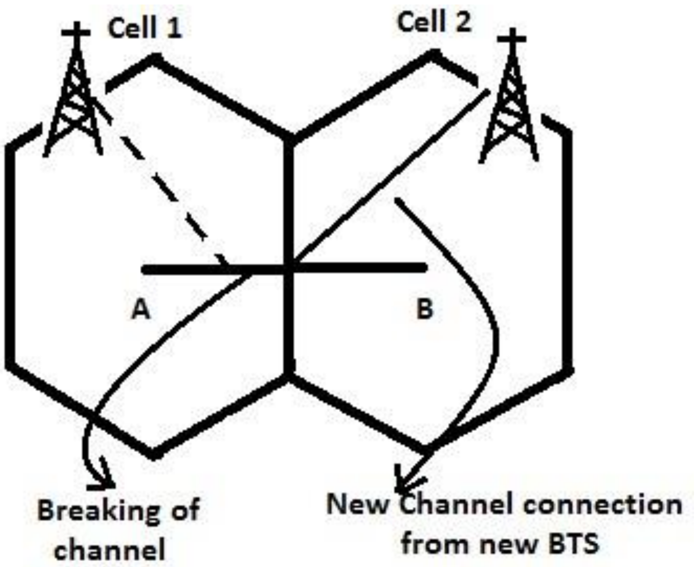


Classification of Handoff

Handoff can be classified as:

1) Hard Handoff
2) Soft Handoff

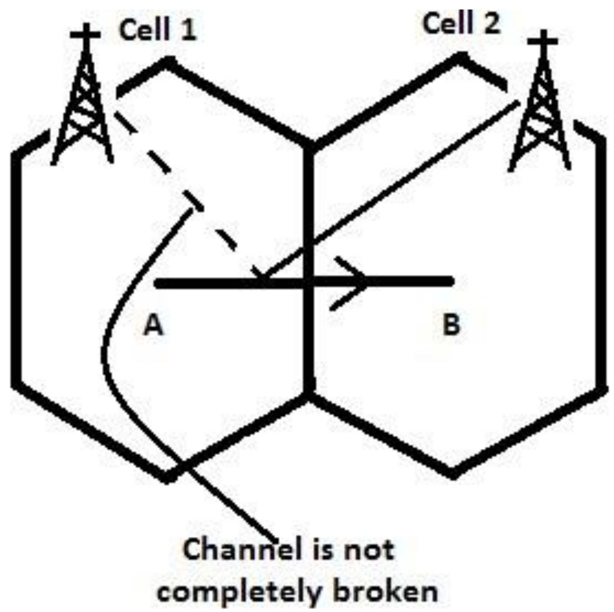
1) Hard Handoff :



Also known as **Break Before Make.** It is one in which the channel in the source cell is released & only then the channel in the target cell is engaged. Thus the connection to the source is broken before the connection to the target is made. Hard handoffs are intended to be **instantaneous** in order to minimize the disruption to the call. It is not necessary that there is always a connection b/w base station & mobile station.

2) Soft Handoff :

Also known as **Make Before Break.** It is one in which the channel in the source cell is retained & used for a while in parallel with the channel in target cell. Thus the connection to the target is established before the connection to the source is broken. In this kind of handoff, there is always a connection b/w base station & mobile station.



Prioritizing Handoff / Guard Channel Concept

Here some of the channels of total available channels is **reserved** for handoff request from on-going calls which may be handed-off into the cell. Guard channels however offer **efficient spectrum utilization** when dynamic channel assignment strategies, which minimize the number of required guard channels by efficient demand-based allocation are used.

Queuing of handoff request :

It is another method to **decrease** the probability of **forced termination of calls** due to lack of available channels. Queuing of handoffs is possible due to the fact there is a finite time interval b/w the time the received signal level drops below the handoff threshold & the time the call is terminated due to insufficient signal level.

Practical Handoff Considerations

- Problems occur because of a *large range of mobile velocities*
  - pedestrian vs. vehicle user
  - A pedestrian never requires handoff during the call, but if high speed user passes constantly b/w very small cells, MSC gets burdened quickly.
- 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

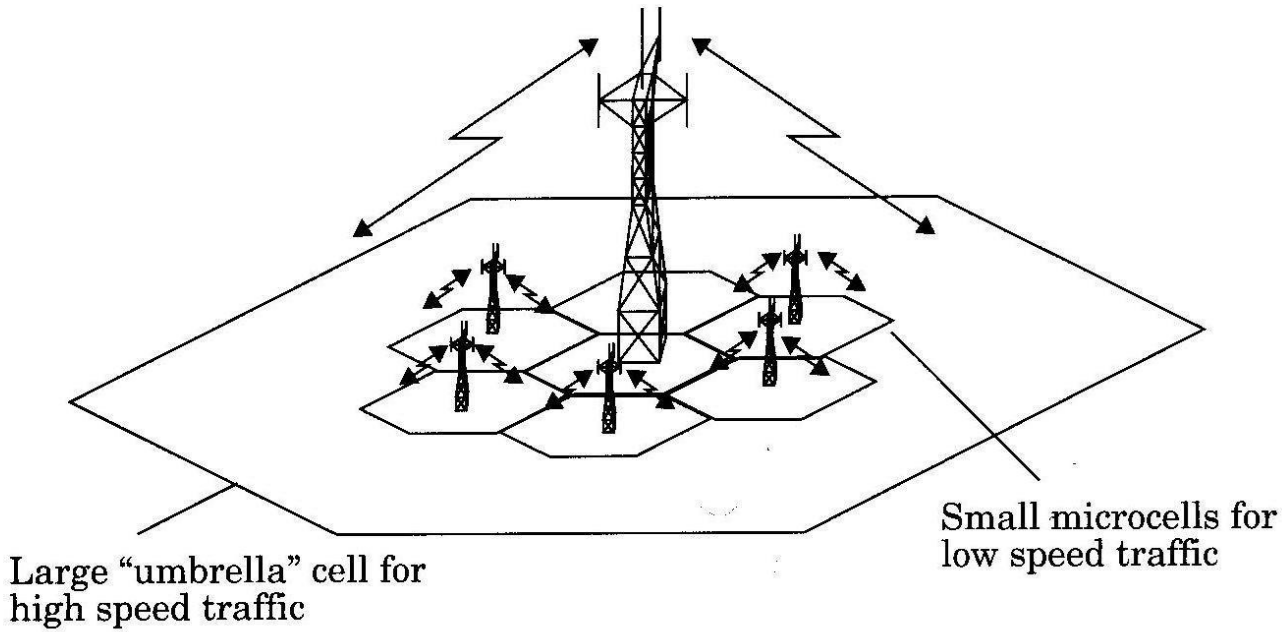


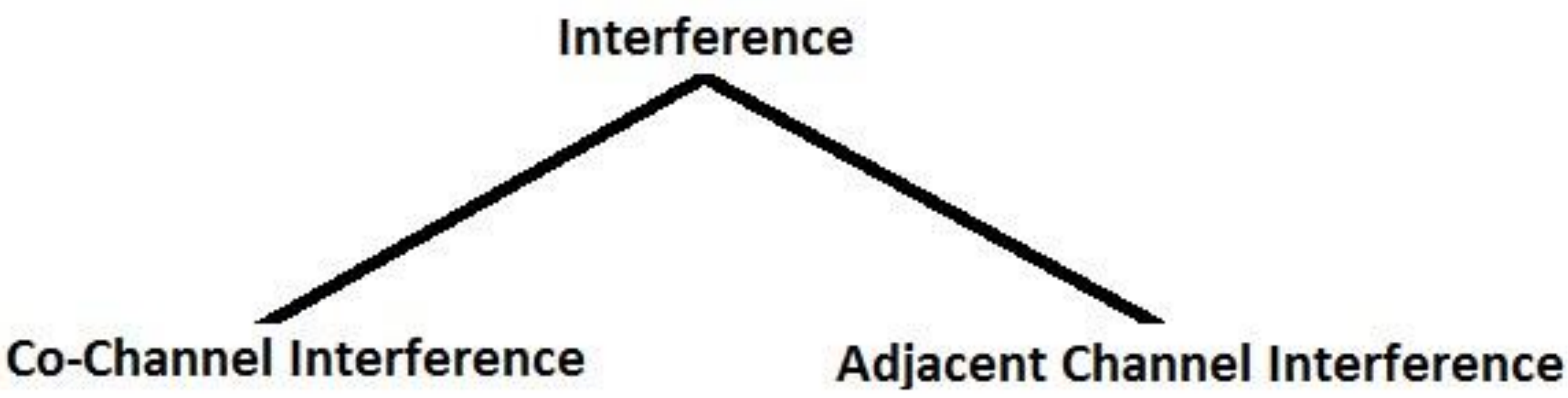
Figure 3.4 The umbrella cell approach.

For Analog cellular (1st generation) the threshold margin $\triangle \approx 6$ to 12 dB; total time to complete handoff $\approx$ 8 to 10 sec. For Digital cellular (2nd generation) total time to complete handoff ≈ 1 to 2 sec, lower necessary threshold margin △ ≈ 0 to 6 dB and enabled by mobile assisted handoff.

<u>Interference & System Capacity</u>

Source of interference :

- Another mobile in the same cell.
- A call in progress in a neighboring cell.
- Other base stations operating in the same frequency band.
- Any non-cellular system which inadvertently leaks energy into cellular frequency band.



Effects of Interference

– Interference in voice channels causes Crosstalk and Noise in background

– Interference in control channels causes error in digital signaling, which causes Missed calls, Blocked calls and Dropped calls

Co-Channel Interference & System Capacity

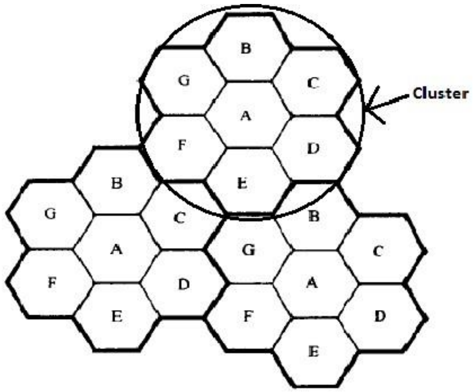
Frequency reuse implies that in a given coverage area there are several cells that use the same set of frequencies. These cells are called **Co-Channel cells** & interference b/w signals from these cells is called **Co-Channel Interference.**

Unlike, **thermal noise** which can be overcome by increasing the SNR (signal to-noise ratio), Co-Channel interference can not be combated by simply increasing the carrier power of a transmitter, because an **increase in carrier transmit power** increases the **interference to neighboring co-channel cells**.

To reduce co-channel interference, co-channel cells must be physically separated by a **minimum distance** to provide sufficient isolation due to propagation.

R is the Radius of a cell

D is the distance b/w centers of the nearest co-channel cells.



Therefore by **increasing the ratio D/R**, separation b/w co-channel cells relative to the coverage distance of a cell is increased. Thus **interference is reduced**.

Q - Co-Channel Reuse ratio, is related to cluster size shown in table. For Hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N}$$

Table Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp

Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

A **small value of Q** provides **larger capacity,** Since the cluster size N is small. A **large value of Q** improves the **Transmission Quality,** Due to smaller level of co-channel interference. Therefore a **Trade-off** must be made b/w these two objectives in actual cellular design.

Let i_o be the number of co-channel interfering cells.

Then, the signal-to-interference ratio (S/I or SIR) for a mobile receiver which monitors a forward channel can be expressed as:

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

where S is the desired signal power from the desired base station & I is the interference power caused by the i^{th} interfering co-channel cell base station.

Average Power Received P_r at a distance d from the transmitting antenna is approximated by:

$$P_r = P_0\left(\frac{d}{d_0}\right)^{-n}$$

$$P_r\,(\text{dBm}) = P_0\,(\text{dBm}) - 10n\log\left(\frac{d}{d_0}\right)$$

where $\mathbf{P_o}$ is the power received at a close-in reference point in the far field region of the antenna at a small distance $\mathbf{d_o}$ from the transmitting antenna & **n** is the path loss exponent.

Now consider the **forward link** where the desired signal is the serving base station & where the interference is due to co-channel base station.

If D_i is the distance of the $_i{}^{th}$ interfere from the mobile, the received power at a given mobile due to the i^{th}interfering cell will be proportional to

$(Di)^{-n}$.

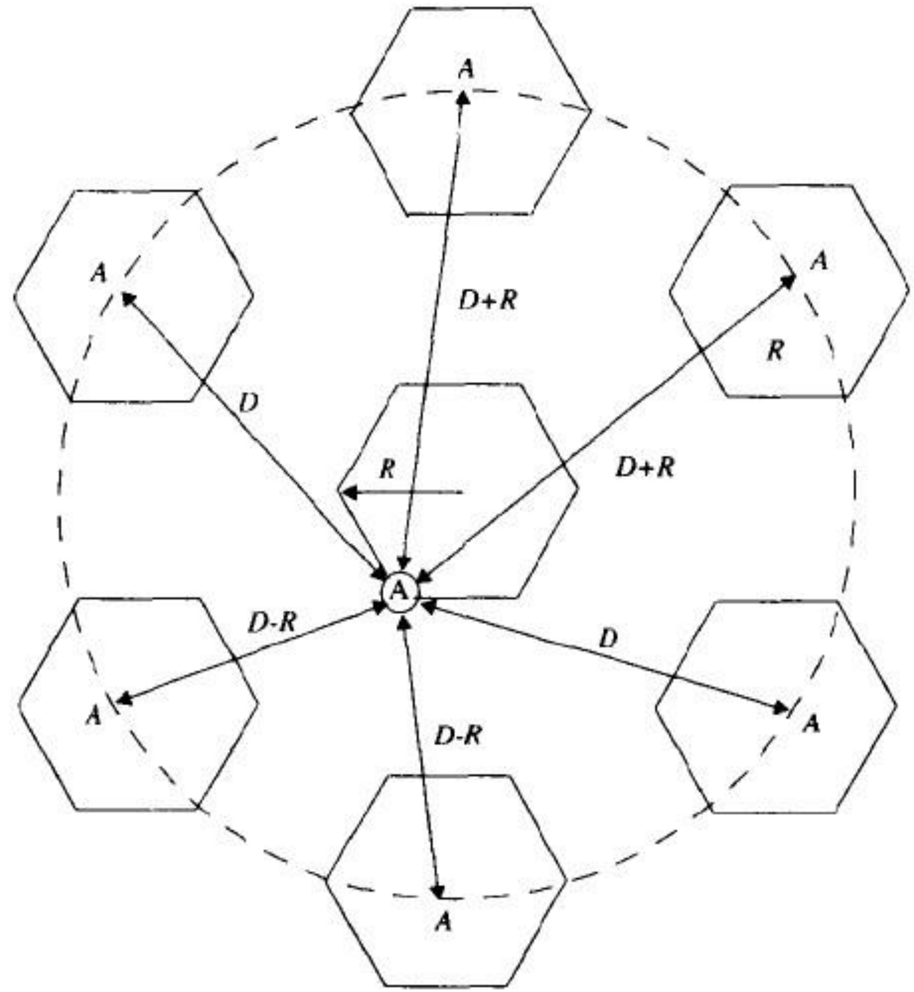
When transmit power of each base station is equal & the path Loss exponent is the same throughout the coverage area,

S/I for a mobile can be approximated as:

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

---------(A)

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 71.



If the interfering base stations are equidistant from the desired base station & if this distance is equal to the distance **D** b/w cell centers, then

$$\frac{S}{I} = \frac{(D/R)}{i_0}$$

S/I relates to the cluster size N, which in turns determine the capacity of the system. From equation C= M.K.N.

▪ For US, AMPS cellular system which uses FM & 30 kHz channels, subjective tests indicate that sufficient voice quality is provided when S/I is greater than or equal to 18dB.

▪ In order to meet this requirement, the cluster size N should be at least 6.49 (=7), assuming path loss exponent n=4.

▪ For a **seven cell** cluster, with the mobile unit at the cell boundary, the mobile is a distance **D-R** from the two nearest co-channel interfering cell & is exactly **D+R/2**, **D**, **D-R/2** and **D+R** from the other interfering cells in the first tier.

▪ **S/I** ratio for the worst case can be closely approximated as (n=4)

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

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

▪This equation can be rewritten in terms of the co-channel reuse ratio Q, as

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}$$ ***-------(B)***

▪ For N=7, the co-channel reuse ratio Q is 4.6 and the worst case S/I is approximated as 49.56 (17dB) using equation **(B),** where as an exact solution using equation **(A)** yields 17.8dB. Hence for a seven-cell cluster, the S/I ratio is slightly less than 18dB for the worst case.

Numericals

Example 3.2

For given path loss exponent (a) $n = 4$ and (b) $n = 3$, find the frequency reuse factor and the cluster size that should be used for maximum capacity. The signal to interference ratio of 15 dB is minimum required for satisfactory forward channel performance of a cellular system. There are six co-channel cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

Solution

(a) $n = 4$

First, let us consider a seven-cell reuse pattern.

Using Equation (3.4), Frequency reuse factor, $Q = D/R = \sqrt{3N} = \sqrt{21} = 4.583$

Using Equation (3.9), the signal-to-noise interference ratio is given by

$$S/I = (1/6) \times (4.583)^4 = 75.3 = 18.66 \text{ dB}$$

Since this is greater than the minimum required S/I, $N = 7$ can be used.

(b) $n = 3$

First, let us consider a seven-cell reuse pattern.

Using Equation (3.9), the signal-to-interference ratio is given by

$$S/I = (1/6) \times (4.583)^3 = 16.04 = 12.05 \text{ dB}$$

Since this is less than the minimum required S/I, we need to use a larger N.

Using Equation (3.3), the next possible value of N is 12, $(i = j = 2)$.

The corresponding co-channel ratio is given by Equation (3.4) as

$$D/R = 6.0$$

Using Equation (3.3), the signal-to-interference ratio is given by

$$S/I = (1/6) \times (6)^3 = 36 = 15.56 \text{ dB}$$

Since this is greater than the minimum required S/I, $N = 12$ is used.

Interference & System Capacity

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.

It is the interference caused to the signal which is adjacent in frequency to the desired signal. Imperfect receiver side filters allow the neighboring signal to mix with the actual pass band. If adjacent channel signal strength becomes strong, it will be difficult for Base Station to differentiate the actual mobile signal from the strong mobile signal. ACI occurs when transmissions are sent on an adjacent or partially overlapping channel. The channel bleeds over on an overlapping channel, which adds noise and interference. This is worst than co-channel because it is received and looks like noise.

The reasons behind adjacent channel interference - Due to multiple channels close to each other communicating using similar frequencies. Irrelevant power emission from an adjacent channel.

Factors for reducing Adjacent Channel Interference -Proper filtering, Careful Channel Assignments by managing the space between two adjacent cells which should remain constant.

WEEK 3 LECTURES

Overview - Trunking and erlang, Capacity calculation- Improving coverage and capacity

Syllabus Coverage:

Trunking and Grade of Service, Cell splitting, Sectoring, Microcell zone concepts, Umbrella cells (already covered in week 2), Solving Problems

Courtesy:

1. Rappaport T.S, *"Wireless Communications: Principles and Practice",* Pearson education.

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.

- 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)
- 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:

  Traffic = number of calls x duration

  Traffic = 30 x 5 = 150

  Traffic (per 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=λ*H(Erlangs)***

Total Offered Traffic Intensity for a system of U users (A): **A =U*Au(Erlangs)**

Traffic Intensity per channel, in a C channel trunked system **Ac=U*Au/C(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)''.**

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

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

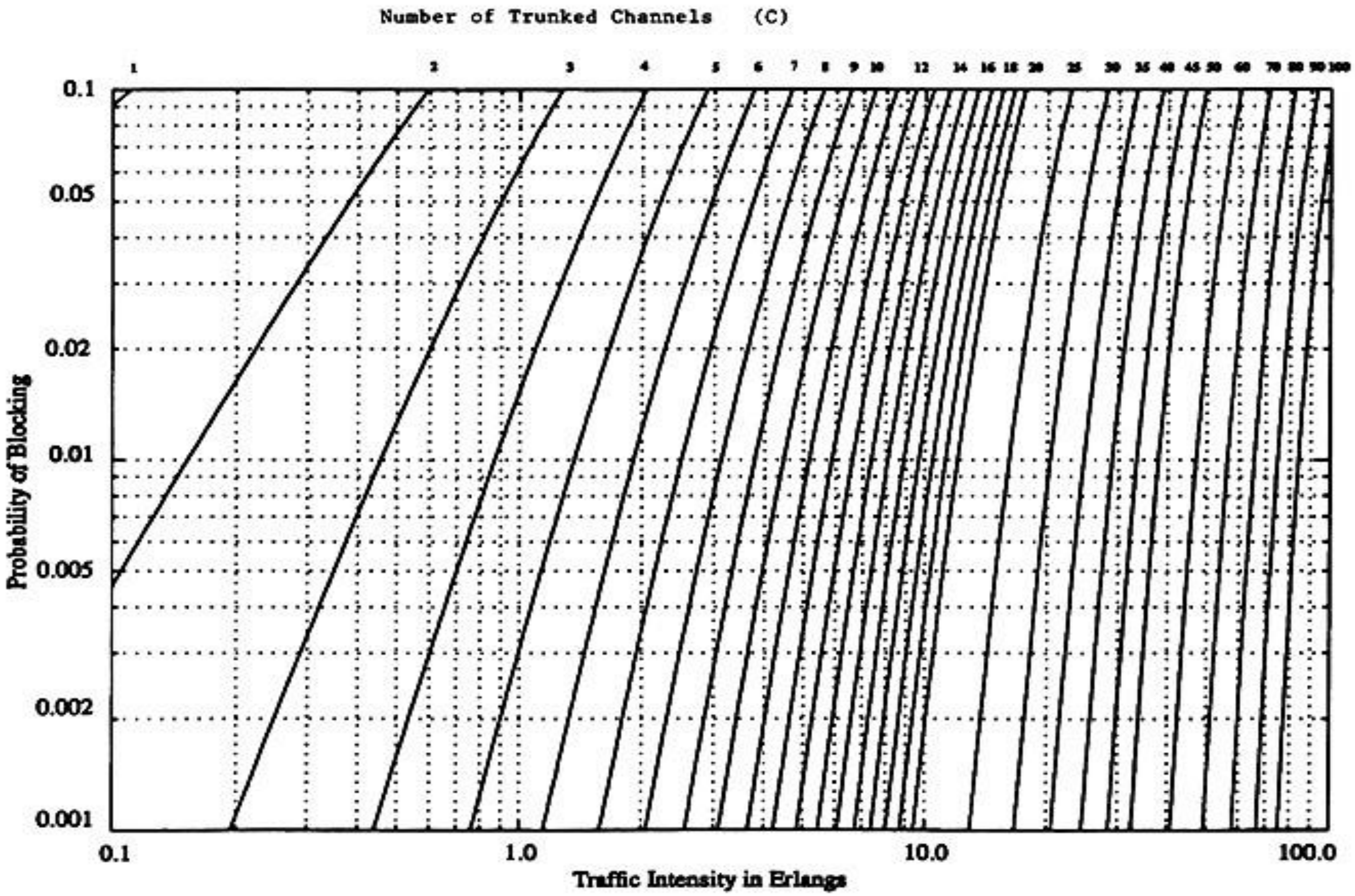


Figure 3.6 The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

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

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 79.

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)

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

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*

Erlang C

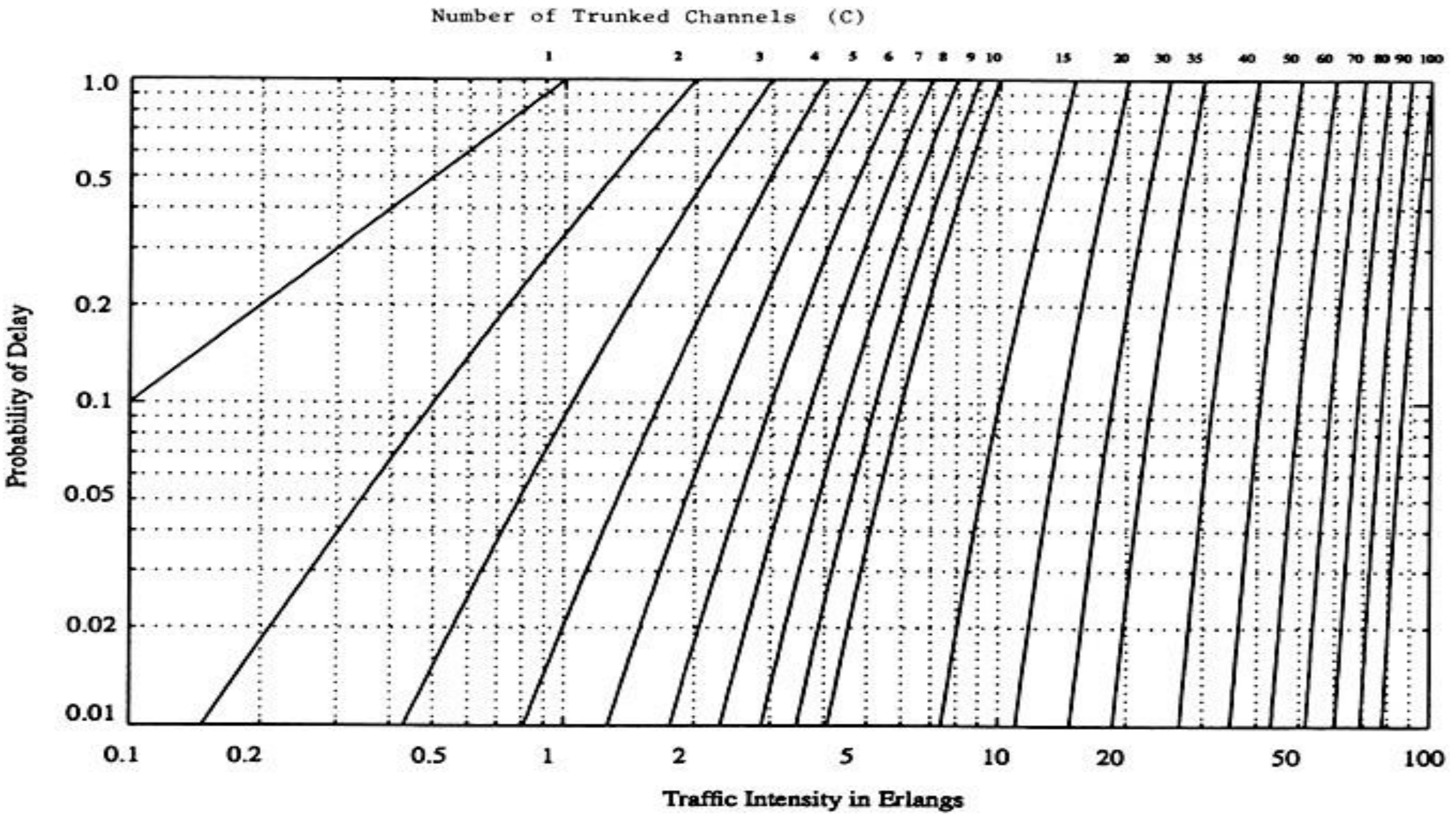


Figure 3.7 The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 82.

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

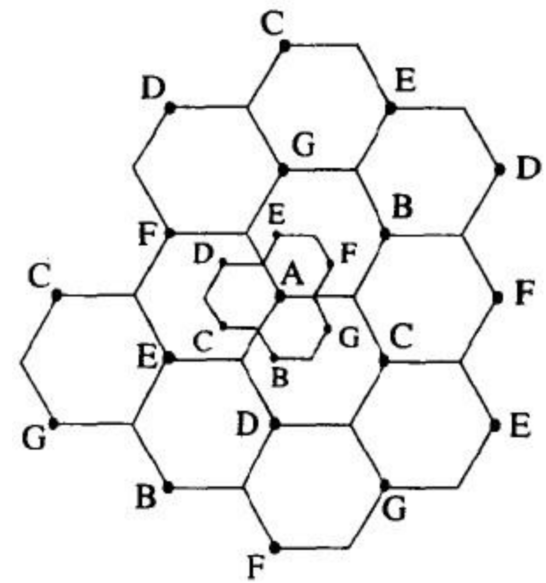
10 trunked channels can offer 60% more traffic at a specific GOS than two 5 channel trunks. Therefore, if in a certain situation we sub-divide the total channels in a cell into smaller channel groups then the total carried traffic will reduce with increasing number of groups

Improving Coverage & Capacity in Cellular system

As number of users increases, number of channel assigned to a cell become insufficient to support large number of users. Therefore Cellular design techniques are required.

- The cellular design techniques which are required to provide more channels per unit coverage area are:

    1) **Cell Splitting**
    2) **Sectoring**
    3) **Microcell Zone Concept**



1) Cell Splitting :

The process of subdividing a congested cell into smaller cells, each with its own base station & a corresponding reduction in antenna height & transmitted power. Cell splitting Reduces the transmitted power. The original base station A is surrounded by 6 new microcell. The smallest cells are added as to preserve the frequency reuse plan. Now G is placed halfway b/w the 2 larger stations utilizing same channel set G.

Cell splitting increases the capacity of a cellular system:

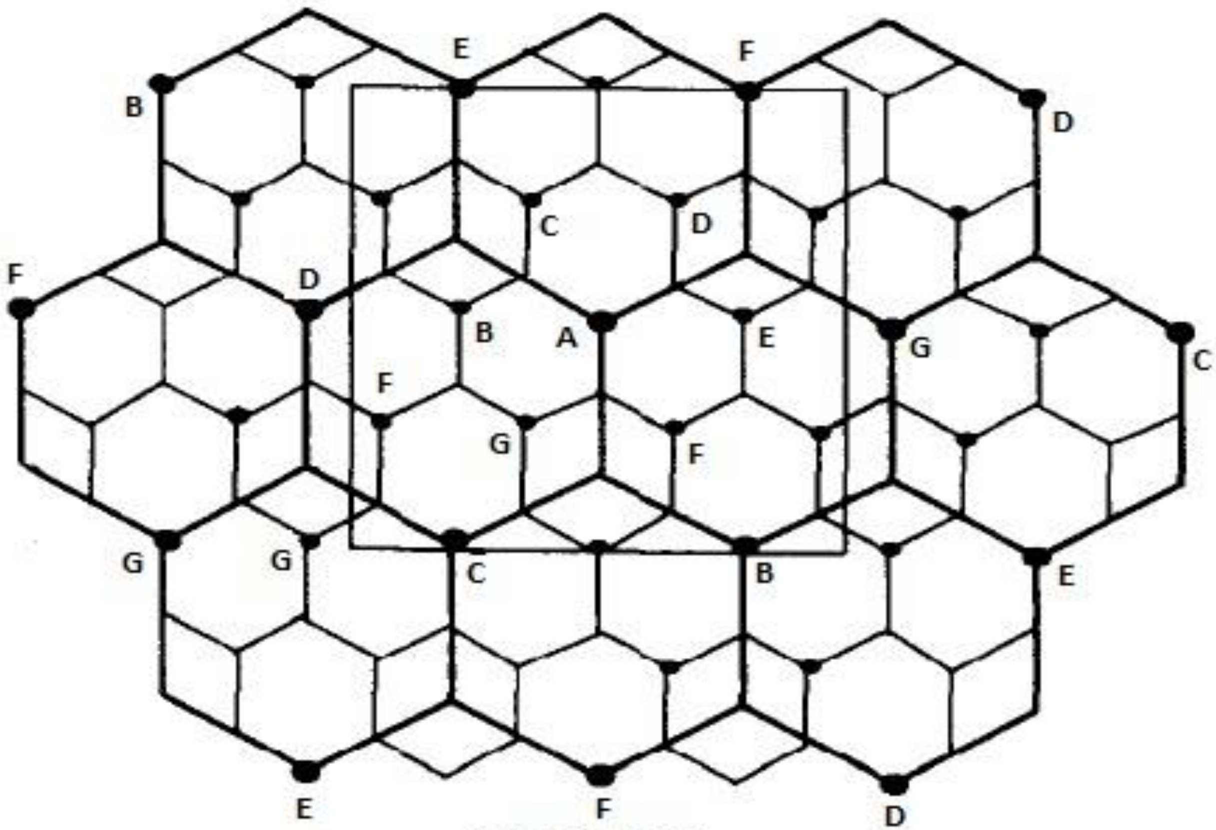
It increases the number of times that channel are reused. By defining new cells which have a smaller radius than original cells & by installing smaller cell. Due to additional number of channels per unit area.

Area of bigger cell = $A_o = \pi R^2$

Area of smaller cell = $A_N = \pi (R/2)^2 = \pi R^2/4$

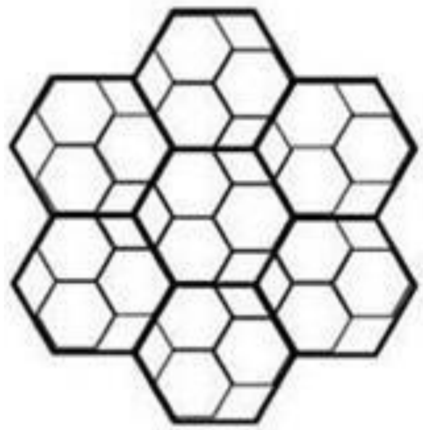
$4 A_N = A_o$ or $A_N = A_o/4$

Therefore New Area is ¼ of the older area.



Cell Splitting

As New Area is ¼ of the older area (now one bigger cell include approximately 4 smaller cell), therefore the capacity of system is increased by 4 times.



Before Cell splitting :

Total BW available = 25MHz

Each user Required = 25kHz

Therefore

1 Antenna can serve = 25MHz / 25kHz = 1000 user.

After Cell Splitting :

As older area is 4 times the newer area. i.e. we have now

4 new area = 1 older area

For one new area,

Total BW available = 25MHz

Each user Required = 25kHz

Therefore 1 Area can serve = 25MHz / 25kHz = 1000 user.

Therefore 4 Area can serve = 1000 * 4 = 4000 user.

i.e. Capacity is increased by 4 times, due to cell splitting.

Let P_{t1} (Transmit Power at old cell boundaries)

Let P_{t2} (Transmit Power at new cell boundaries) let P_{r1} (Required Power at old cell boundaries) let P_{r2} (Required Power at new cell boundaries) and **n** is the path loss exponent.

$$Pr1 = Pt1\,(R)^{-n}$$

$$Pr2 = Pt2\,(R/2)^{-n}$$

As frequency reuse plan for new microcells behave exactly as the original cells.

Therefore $$P_{r1} = P_{r2}$$

Therefore $$P_{t1}\,(R)^{-n} = P_{t2}\,(R/2)^{-n}$$

$$Pt1 / Pt2 = (1/2)^{-n}$$

Taking log both side

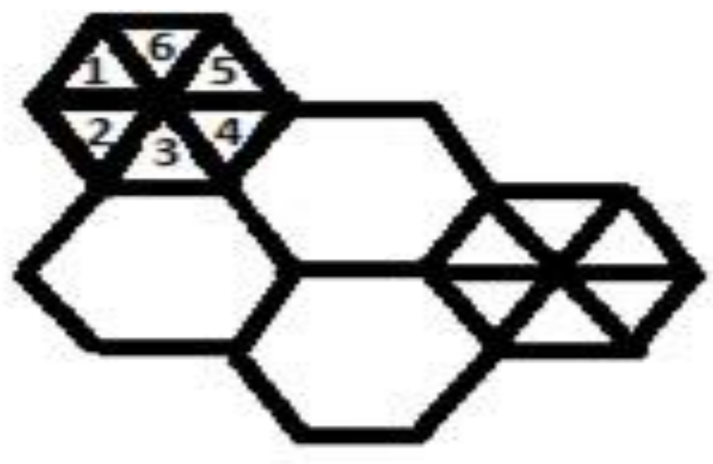
$$10 \log_{10} (P_{t1} / P_{t2}) = n10 \log_{10}(2) = 3n$$

For **n = 4,** $P_{t1} / P_{t2} = 12$ dB

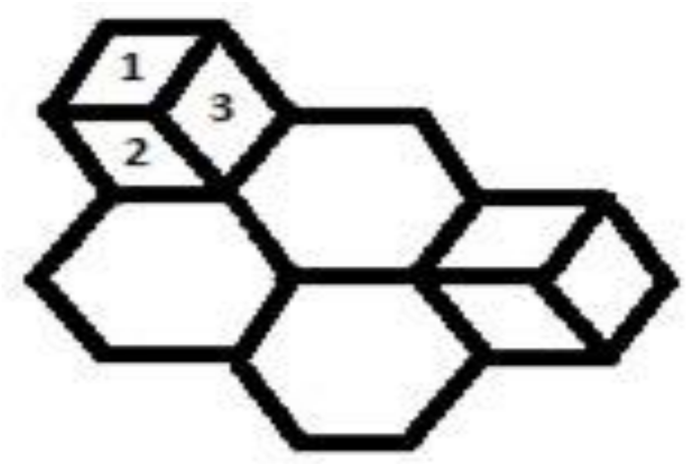
i.e. **Transmitted Power is reduced by 12 dB with newer cell.**

2) Sectoring :

The technique for decreasing the co-channel interference & thus increasing the system performance by using directional antenna is known as Sectoring **.** Sectoring Can be done at 60^{o} & 120^{0} .



Sectoring- 60^{o}



Sectoring- 120^{o}

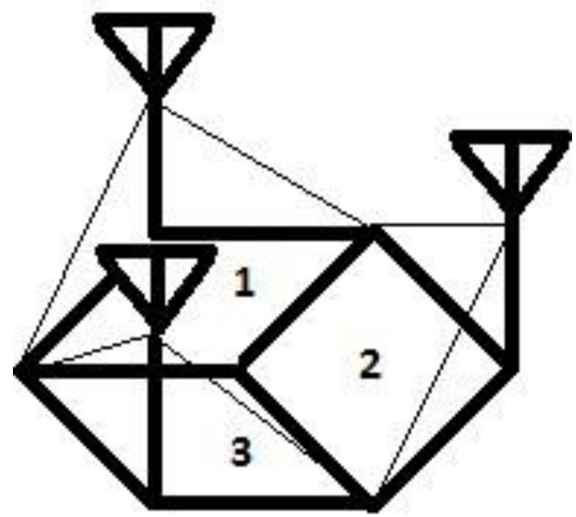
Source : Wireless Communications: Principles and Practice, Theodore S. Rappaport, pp 90.

Co-channel Interference in a cellular system may be decreased by replacing a single Omni directional antenna at the base station by several directional antenna, each radiating with in a specific sector. Antenna changed from Omni directional to **Directional**. Antenna are **not placed near** to each other, otherwise adjacent channel interference get increased.

By cell splitting,:

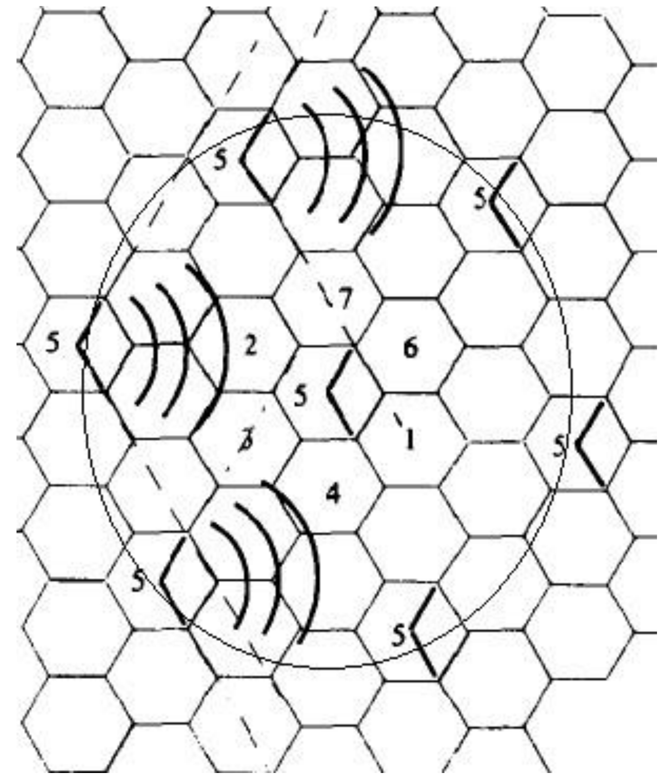
it increase the number of channels & this is achieved by **decreasing** the cell radius **R** & keeping Co-channel reuse ratio **D/R constant**, it increases the number of channels & this is achieved by keeping **R constant & D/R decreased**.

Sectoring **increases** the **S/I** (signal to interference) ratio by



using direction antenna so that cluster size may be reduced.

Capacity improvement is achieved by reducing the number of cells in a cluster, thus increase the **frequency reuse**. To do all this, we have to reduce interference without decreasing the transmit power.



When sectoring is employed, the channels used in a particular Cell are broken down into sectored groups & are used only with in a Particular sector.

Assuming N=7 for the case 120^o Sector. The number of interference In the first tier is reduced from 6 to 2. This is because only 2 of 6 co-channel Cells receive interference with a Particular sectored group as shown. Out of 6 co-channel cells, 3 are on Right & 3 are on Left of middle cell. With Omni directional antenna due to Presence of 6 cells, they can interfere (in tier) with middle 5^{th} block. Now, only 2 antenna will interfere with the middle one, so the number is reduced to 2 from 6.

3) Microcell Zone Concept :

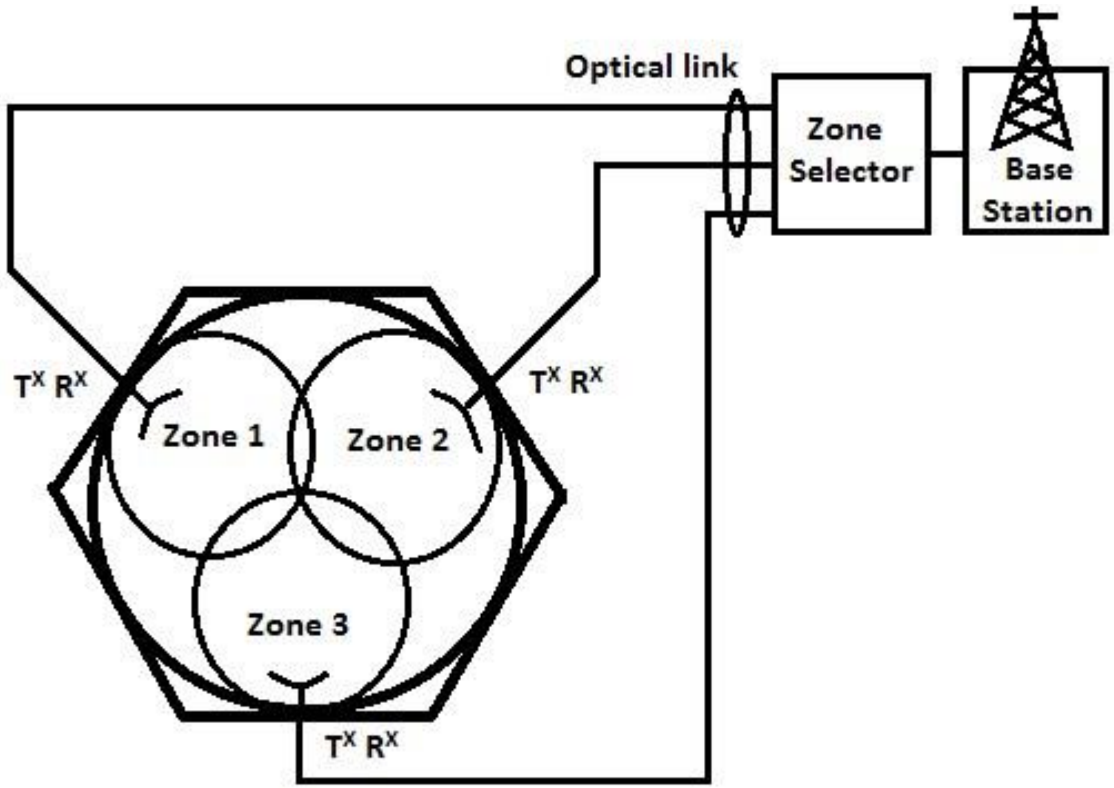
Problem with sectoring

Even inside a cell, handoff is required. Load on the MSC is increased and To overcome this problem, we divide the cell into further 2-3 zones. This technique is known as Microcell Zone Concept. This concept is introduced by **LEE.**

Construction : Each of 3 or more zone sites are connected to a **single base station** & share the **same radio equipment** (Base Station)as shown in figure. Zones are connected by **coaxial cable, fiber optic cable** or **microwave link** to the base station.

Multiple zones & a single base station Make up a cell.

Operation : A mobile with in a cell, is served by the zone with the strongest signal. ▪ This approach is superior to



Microcell Zone Concept

sectoring since antennas are placed on the edges of the cell & any BS Channel may be assigned to any zone by the base station. As mobile travels from one zone to another within the cell, it retains the same channel. Unlike in sectoring, handoff is not required at the MSC when the mobile travels b/w zones within the cell.

The micro-cell zone concept is associated with sharing the same radio equipment by different micro-cells. It results in decreasing of cluster size and, therefore, increase in system capacity. The micro-cell zone concept is used in practice to improve the capacity of cellular systems. To improve both capacity and signal quality of a cellular system, cell sectoring depends upon correct setting up of directional antennas at the cell-site. But it also gives rise to increase in the number of handoffs and trunking inefficiencies. In a 3-sector or 6-sector cellular system, each sector acts like a new cell with a different shape and cell. Channels allocated to the un-sectored cell are divided between the different sectors present in a cell, thereby decreasing number of channels available in each sector. Furthermore, handoff takes place every time a mobile user moves from one sector to another sector of the same cell. This results in significant increase of network load on BSC and MSC of the cellular system. The problem of channel partitioning and increase in network load become very hard if all the 3 or 6-sectored directional antennas are placed at the centre of the cell. All the three zone-sites also behave as receivers, which also receive signals transmitted by a mobile user present anywhere in the cell. All the three zone-sites are linked to one common base station. This arrangement is known as Lee's micro-cell zone concept. In order to avoid delay, these zone-sites are connected through a high-speed fiber link to the base station. The base station first finds out, which of the three zone-sites has the better received signal strength from the mobile user and then that particular zone-site is used to transmit the signal to the mobile user. Therefore, only one zone-site is active at a time for communicating with the user and it also minimizes the co-channel interference experienced by the mobile user. Therefore, micro-cell zone architecture minimizes the co-channel interference, improves system capacity, demands less handoffs, and the system is easy to implement. The system capacity for a system with cluster size k=3 is 2.33 times greater than the present analog cellular system with k=7 for the C/I requirement of 18 dB. This micro-cell system gives improved voice quality than the AMPS cellular system at 850 MHz. The micro-cell zone concept can be used with both digital communication systems and personal communication systems, and is best suited for indoor applications. It is also very useful to provide services along highways or in crowded urban areas.

Advantages of micro zone concept:

1. When the mobile user moves from one zone to another within the same cell, the mobile user can keep the same channel for the call progress.

2. The effect of interference is very low due to the installation of low power transmitters.

3. Better signal quality is possible.

4. Fewer handoffs when a call is in progress.