CELLULAR AND MOBILE COMMUNICATIONS

TEXT BOOKS

- 1.Mobile and Cellular Telecommunications-W.C.Y.Lee
  Tata McGraw Hill, 2 nd Edition,2006.

2.Mobile Cellular Communication– Gottapu Sasibhushana Rao,, Pearson Education,1 stEdition, 2013.

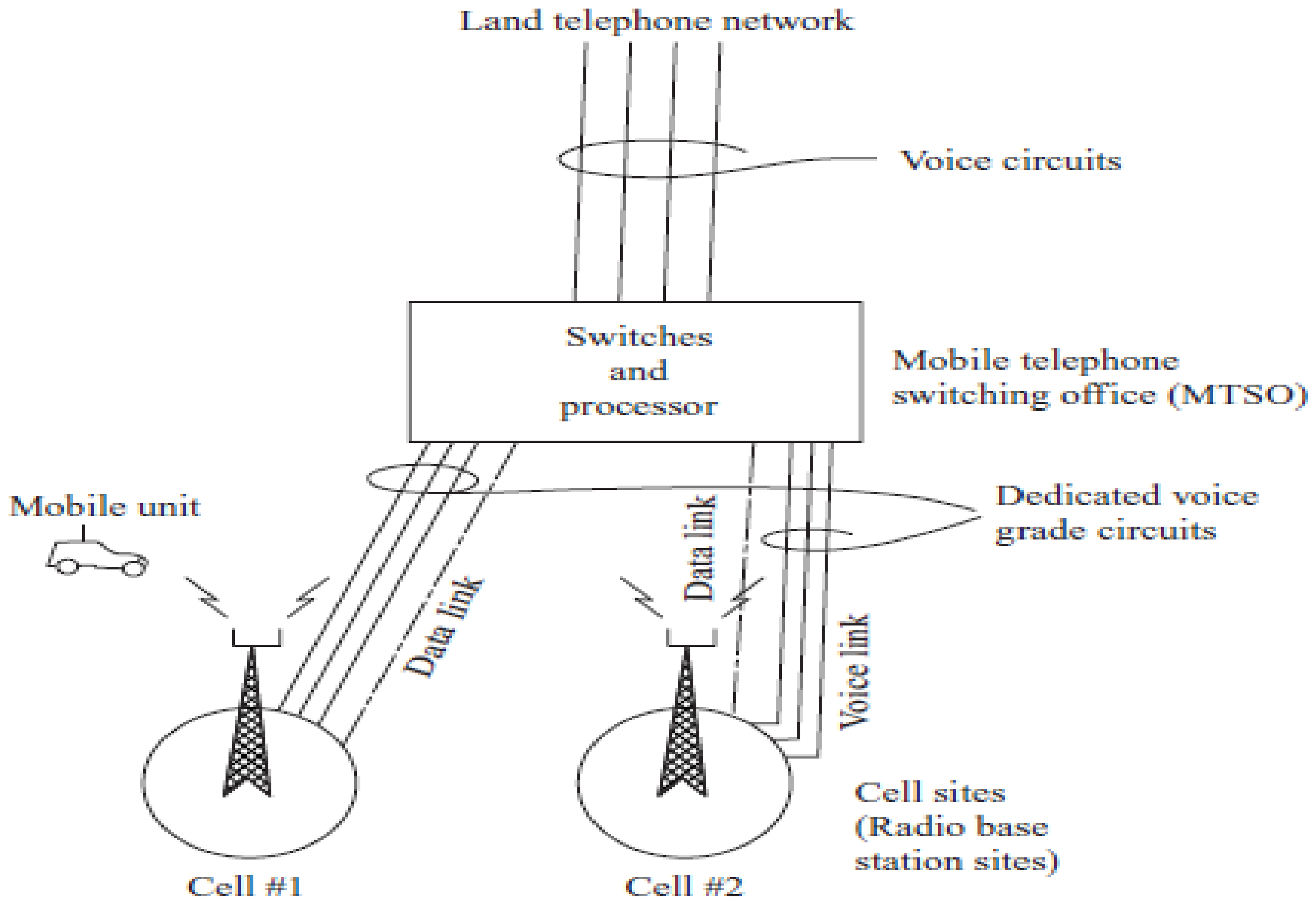
UNIT-I

- **INTRODUCTION TO CELLULAR MOBILE RADIO SYSTEMS:**
  - Basic Cellular System
  - operations of cellular systems
  - Call establishment
  - Operational channels
  - Performance criteria
  - concept of Digital cellular system
  - Hexagonal shaped cells, Frequency Reuse, Cell splitting
  - Sectoring, Microcell zone concept

Basic Cellular System

- A basic cellular system consists of three subsystems.
- A mobile unit,
- A cell site, and
- A mobile telephone switching office (MTSO)

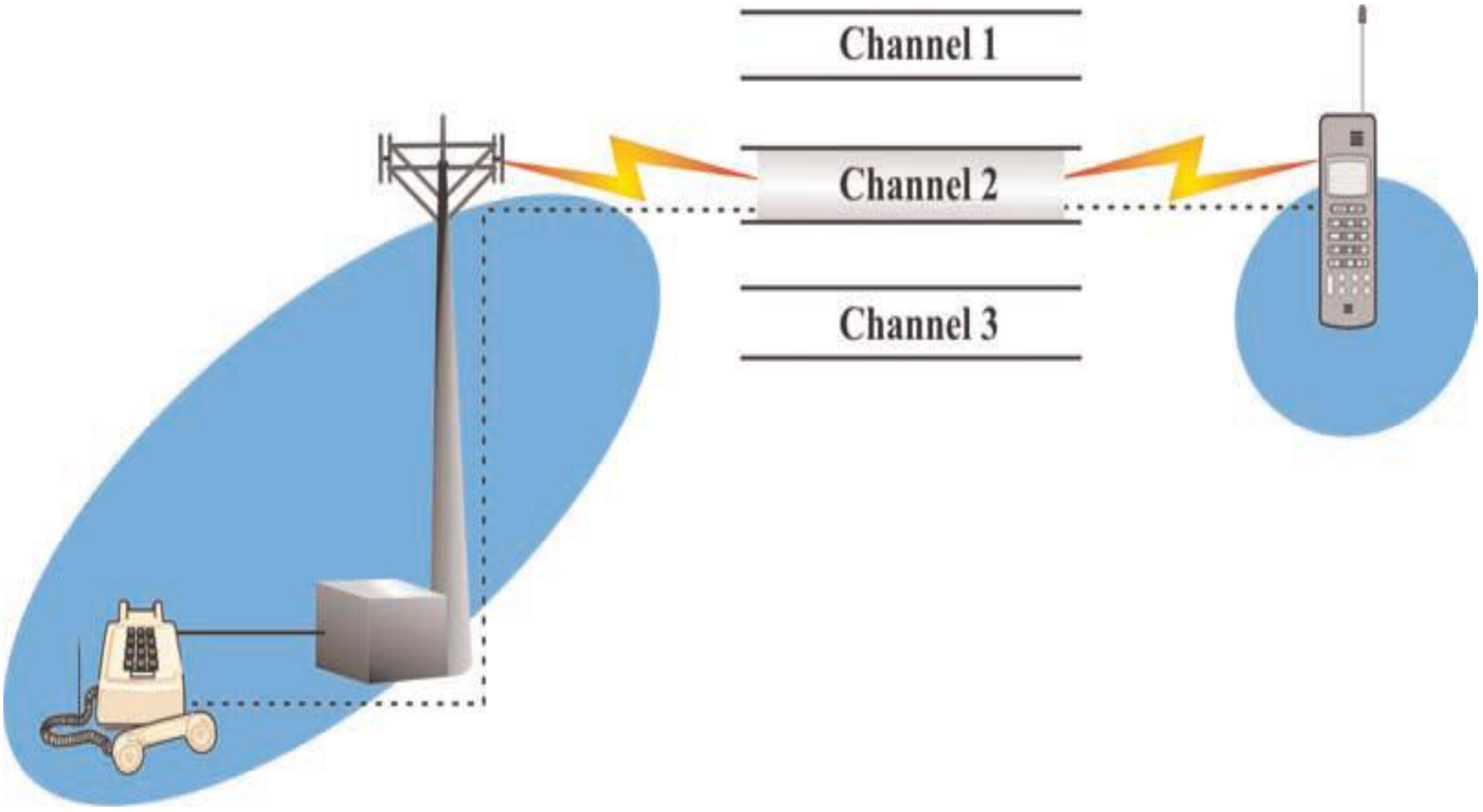
Basic Cellular System



- Mobile units:
  - A mobile telephone unit contains a control unit, a transceiver, and an antenna system.
- Cell site:
  - The cell site provides interface between the MTSO and the mobile units.
  - It has a control unit, radio cabinets, antennas, a power plant, and data terminals.

MTSO:

- The switching office, the central coordinating element for all cell sites,
- contains the cellular processor and cellular switch.
- It interfaces with telephone company zone offices, controls call processing, provides operation and maintenance, and handles billing activities.
- The cellular switch, switches calls to connect mobile subscribers to other mobile subscribers and to the nationwide telephone network.
- Its processor provides central coordination and cellular administration.


Channel 1
Channel 2
Channel 3

OPERATION OF CELLULAR SYSTEMS

Operations of Cellular Systems can be categorized as:

1.Operation Procedures

2. Maximum Number of Calls Per Hour Per Cell

3. Maximum Number of Frequency Channels Per Cell

Operation Procedures

The operation can be divided into four parts and a handoff procedure.

A. **Mobile unit initialization**

- When a user activates the receiver of the mobile unit, the receiver scans the set-up channels. It then selects the strongest and locks on for a certain time.
- This self-location scheme is used in the idle stage and is user-independent. It has a great advantage because it eliminates the load on the transmission at the cell site for locating the mobile unit.
- The disadvantage of the self-location scheme is that no location information of idle mobile units appears at each cell site.

Operation Procedures

B. Mobile Originated Call

- The user places the called number into an originating register in the mobile unit, and pushes the "send" button.
- A request for service is sent on a selected set-up channel obtained from a self-location scheme.
- The cell site receives it, and in directional cell sites (or sectors), selects the best directive antenna for the voice channel to use.
- At the same time, the cell site sends a request to the mobile telephone switching office (MTSO) via a high-speed data link.
- The MTSO selects an appropriate voice channel for the call, and the cell site acts on it through the best directive antenna to link the mobile unit.

Operation Procedures

C. Network Originated Call

- A land-line party dials a mobile unit number. The telephone company zone office recognizes that the number is mobile and forwards the call to the MTSO.
- The MTSO sends a paging message to certain cell sites based on the mobile unit number and the search algorithm.
- Each cell site transmits the page on its own set-up channel. If the mobile unit is registered, the registered site pages the mobile.
- The mobile unit recognizes its own identification on a strong set-up channel, locks onto it, and responds to the cell site.
- The mobile unit also follows the instruction to tune to an assigned voice channel and initiate user alert.

Operation Procedures

D. Call termination

- When the mobile user turns off the transmitter, a particular signal (signaling tone) transmits to the cell site, and both sides free the voice channel.
- The mobile unit resume monitoring pages through the strongest set-up channel.

Handoff procedure

Maximum Number of Frequency Channels Per Cell

EXAMPLE : Let the maximum calls per hour Qi in one cell be 3000 and an average calling time T be 1.76 min. The blocking probability B is 2 percent. Then we may use Q from Eq. 1 to find the offered load A.

$$A = \frac{3000 \times 1.76}{60} = 88$$

With the blocking probability B =2 percent, the maximum number of channels can be found from Appendix A as N = 100 .

2G Mobile Systems
(Digital Cellular Systems)

- Digital cellular technology
- Digital multiplexing-TDMA,CDMA
- Developed in Europe and the US
- Offer support for simple non-voice services like SMS (short messaging service)
- Speed up to 64kbps
- Systems using 2G
  - GSM,
  - TDMA(IS-136)
  - CDMA(IS-95)

2G Mobile Systems

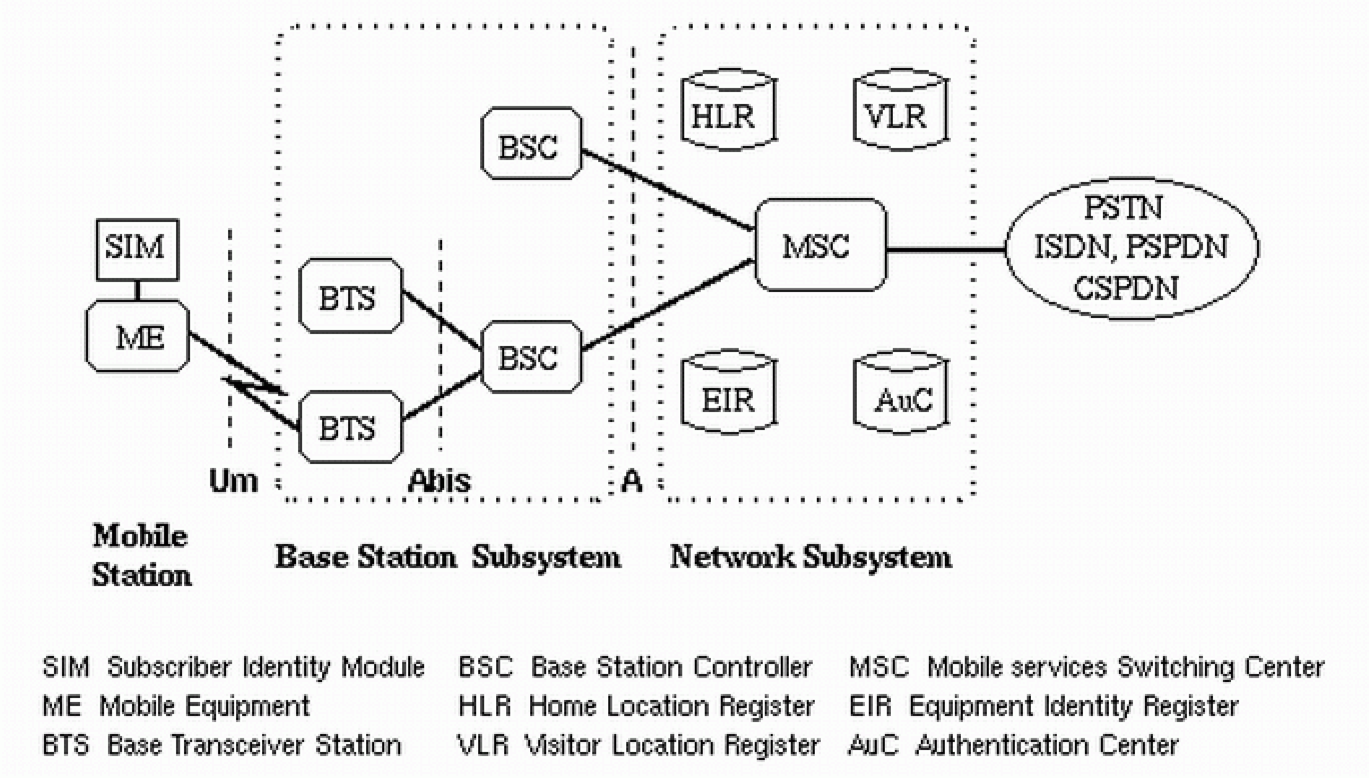
- Global System for Mobile Communications (GSM)
  - Time Division Multiple Access (TDMA).
  - 900 MHz, 1800 MHz and 1900 MHz
- (IS-136 TDMA)
  - Time Division Multiple Access (TDMA).
  - IS-136 referred to as Digital AMPS (DAMPS).
- CDMA(IS-95)
  - IS-95 is based on CDMA/DSSS and FDMA.
  - 800 MHz & 1900 MHz bands.

Features of 2G Mobile Technology

- Digital system,
- Better voice quality,
- Higher capacity,
- Lower power consumption.
- Short Messaging Service

Features of 2G Mobile Technology

Network Structure(Digital Cellular System)



BTS,BSC and MSC

- BTS & BSC: *Base Transceiver System and Base Station Controller*. Radio signal transceiver, a connection between handset and MSC
- MSC: *Mobile services Switching Center*, switching center of the GSM network, and connect to other networks

Databases

- HLR : Home Location Register, contains static information of subscribers and location update data
- VLR : Visitor Location Register, embedded in MSC to avoid delay, contains current location information of handsets.
- AUC : Authentication Center, stores secret keys for authentication and encryption of the radio channel
- EIR : Equipment Identity Register, contains a list of all valid mobile equipment in the network, by its International Mobile Equipment Identity (IMEI)

ANALOG VS DIGITAL CELLULAR SYSTEMS

FEATURE	ANALOG	DIGITAL
TRAFFIC CH	VOICE USE FM	VOICE ENCODED IN DIGITAL FORMAT
PROCESSING	MORE DIFFICULT	EASIER BY USING MODEM
ENCRYPTION	NO SECURITY	PROVIDES THIS CAPABILITY
NOISE	MORE NOISY	INHERENTLY LESS NOISY

ANALOG VS DIGITAL CELLULAR SYSTEMS (contd)

FEATURE	ANALOG	DIGITAL
ERROR DETECTION AND CORRECTION	NO SUCH FACILITY.SO VOICE WAS NOT CLEAR	SUCH CAPABILITY PROVIDED.SO VOICE IS CLEAR
CHANNEL ACCESS	ONE CH TO ONLY ONE USER.EACH CELL SUPPORTS A NO OF FIXED CH.	ONE CH SHARED BY NO OF USERS USING TDMA/CDMA
COMPATIBILITY	NOT COMPATIBLE WITH OTHER DEVICES	COMPATIBLE WITH COMPUTERS /COMPUTERS N/W WHICH USE DIGITAL FORMAT.

ANALOG CELLULAR SYSTEM

- 1 G / First Generation Cellular system.
- Evolved in early 80s.
- Called **AMPS – ADVANCED MOBILE PHONE SYSTEM**
- Released in 1983.
- Employed in North & South America, China, Australia etc.

General Specifications

• Base Stn Tx Band	869-894 M Hz
• M U Tx Band	824-849 M Hz
• Spacing between FCh & RCh	45 M Hz
• Channel Bandwidth	30 K Hz
• No of Full Duplex Ch	790
• No of Full Duplex Control Ch	42

1G Mobile Standards

- NMT (Nordic mobile Telephone)

Used in Nordic countries , Switzerland, Netherland, eastern Europe and Russia.

- AMPS(Advance Mobile Phone system)

Used in United State

- CDPD(total access communication system)

Used in United Kingdom.

Chronology of 1G wireless system

- 1970 : Developments of radio & computer technology for 800/900 MHZ mobile communication.
- 1976: WARC (world administrative Radio Conference) allocates spectrum for cellular radio.
- 1979: NTT (Nippon Telephone & Telegraph)introduces the first cellular system in Japan.
- 1981: NMT 900 system introduces by Ericsson Radio system AB & develop in scandinavia(region of Europe).

concept of Digital cellular system

DIGITAL CELLULAR SYSTEM –(GSM)

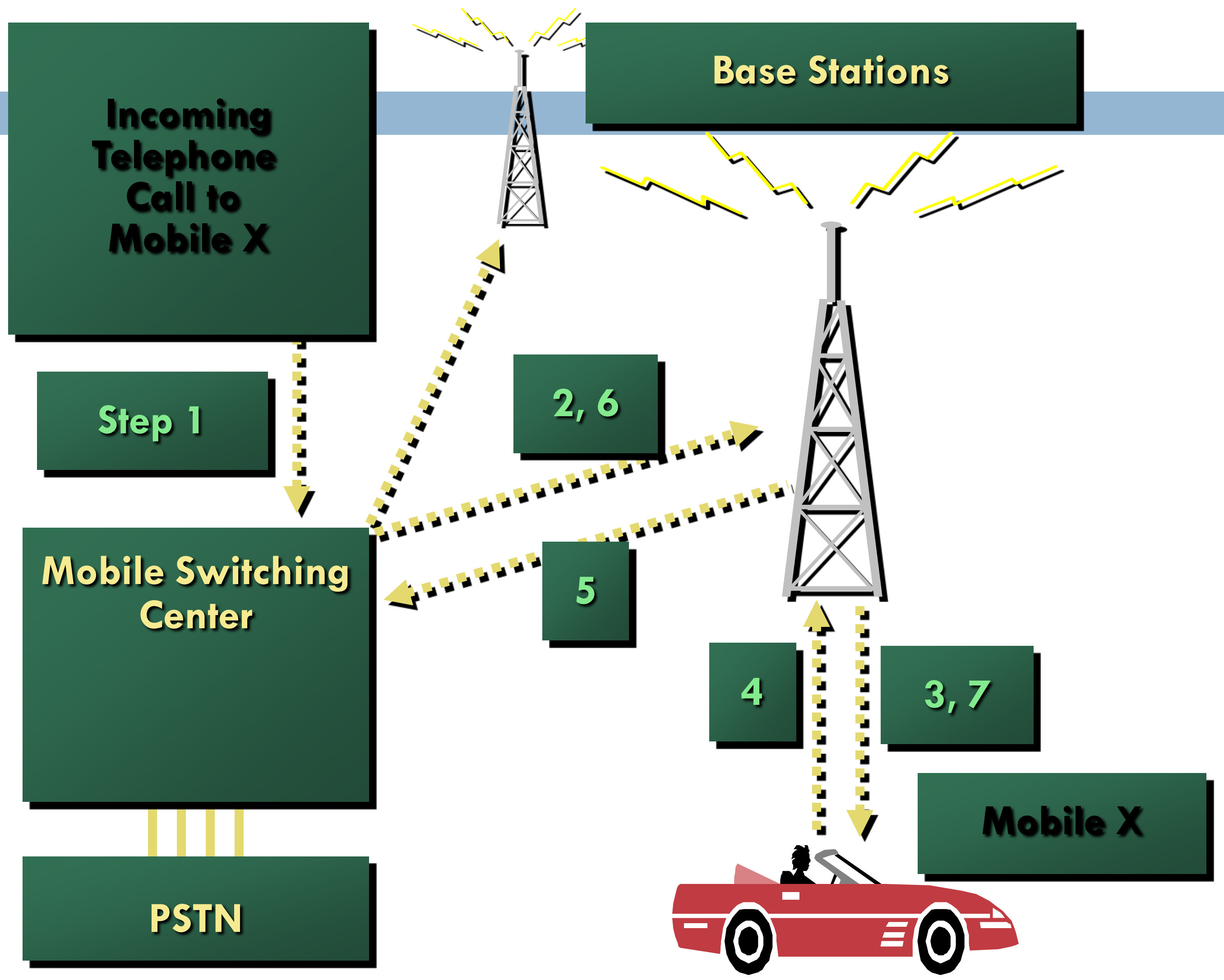
- GSM –GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS.

• YEAR INTRODUCED	1990
• ACCESS METHOD	TDMA
• BASE STN TX CH	935-960 M Hz
• M U TX CH	890-915 M Hz
• SPACING BETWEEN FWD AND REV CH	45 M Hz
• CH BANDWIDTH	200 K Hz
• NO OF DUPLEX CH	125
• MU MAX POWER	20 W
• USERS PER CH	8
• MODULATION	GMSK
• CARRIER BIT RATE	270.8
• SPEECH CODING BIT RATE	Kbps 13
• FRAME SIZE	Kbps
	4.6 ms

How does cellular system work?

- Base stations provide wireless connectivity to mobile users
- Each base station limits control to its small geographical area (2-3 sq. km) or *cell*.
- High capacity of cellular network is achieved:
  - by limiting the coverage to the cell
  - By using concept of *Frequency reuse*
  - However, frequencies are reused in cells quite far away to minimize interference

Steps in telephone call made to Mobile User



Cellular Process in call to Mobile User

Step 1 Incoming telephone call is received by MSC

Step 2 MSC dispatches request to all BSs

Step 3 BSs broadcast MIN over FCC

Step 4 Mobile acknowledges over RCC to local BS

Step 5 BS relays mobile reply to MSC

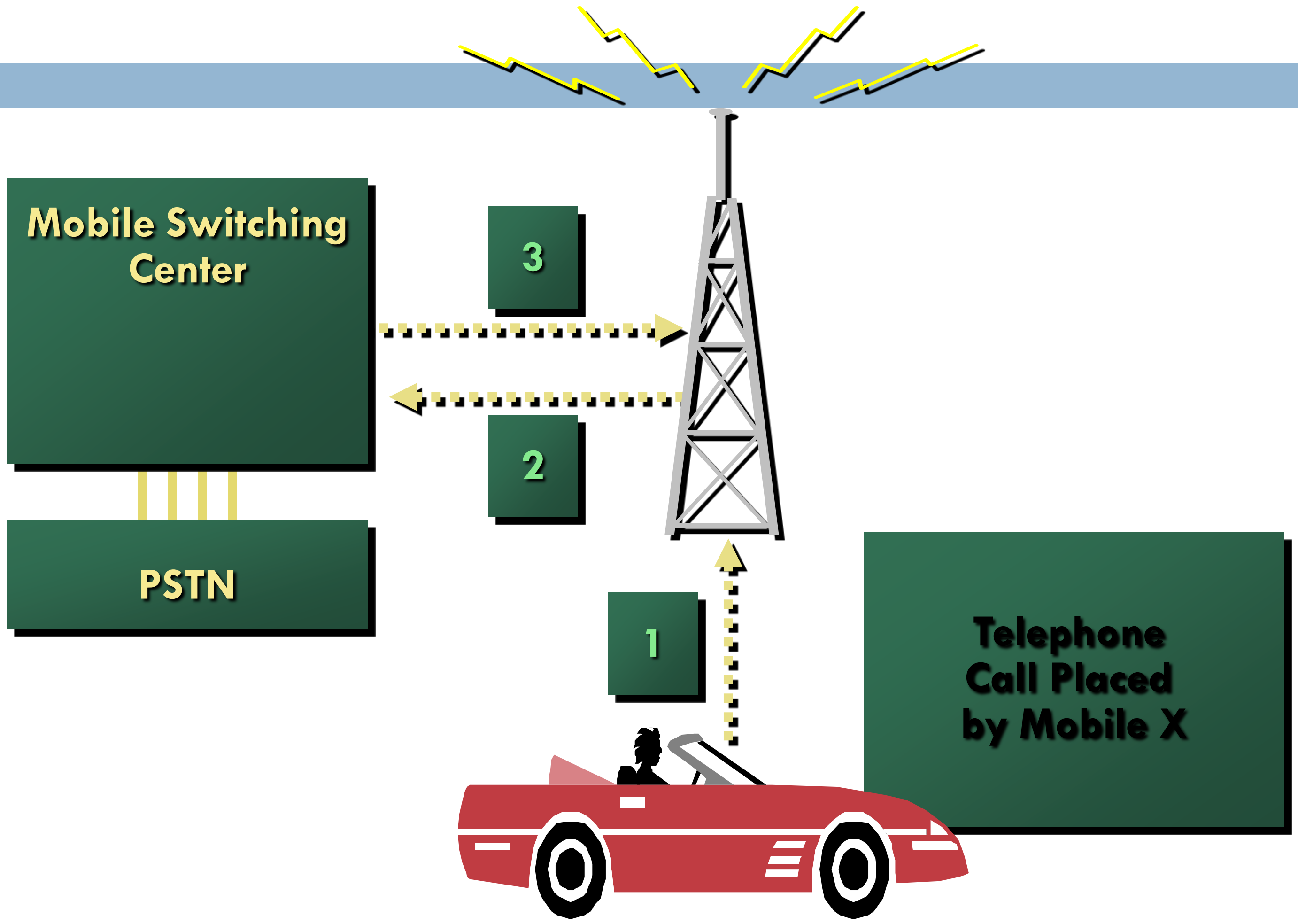
Step 6 MSC instructs local BS to initiate call

Step 7-1 BS signals mobile to use unused channel*

Step 7-2 Alert is transmitted over FVC to ring mobile*

* *Simultaneous process*

Steps in telephone call made from mobile user



Cellular Process in call from mobile user

Step 1-1 Mobile dials MIN of called party to BS

Step 1-2 Mobile transmits SCM* to show signal power

Step 2 BS receives data and sends it to MSC

Step 3-1 MSC validates request

Step 3-2 MSC connects to called party via PSTN

Step 4 MSC validates unused channel to mobile

* *Station class mark*

The SCM (Station Class Mark) is a 4 bit number which holds three different pieces of information. Your cellular telephone transmits this information (and more) to the cell tower. Bit 1 of the SCM tells the cell tower whether your cellphone uses the older 666 channel cellular system, or the newer 832 channel cellular system.

Performance Criteria

Voice Quality

a set value *x at which y percent of customers rate the system voice quality (from transmitter to receiver) as good or excellent, the top two circuit merits (CM) of the five listed below.*

Performance Criteria

CM	Score	Quality scale
CM5	5	Excellent (speech perfectly understandable)
CM4	4	Good (speech easily understandable, some noise)
CM3	3	Fair (speech understandable with a slight effort, occasional repetitions needed)
CM2	2	Poor (speech understandable only with considerable effort, frequent repetitions needed)
CM1	1	Unsatisfactory (speech not understandable)

Service Quality

The system should serve an area as large as possible.

The transmitted power would have to be very high to illuminate weak spots with sufficient reception, a significant added cost factor.

The higher the transmitted power, the harder it becomes to control interference

Number of dropped calls.
A high drop rate could be caused by either coverage problems or handoff problems related to inadequate channel availability.

Performance Criteria
Special Features
call forwarding,
call waiting,
voice stored (VSR) box,
automatic roaming, or navigation services
NO EXTRA COST

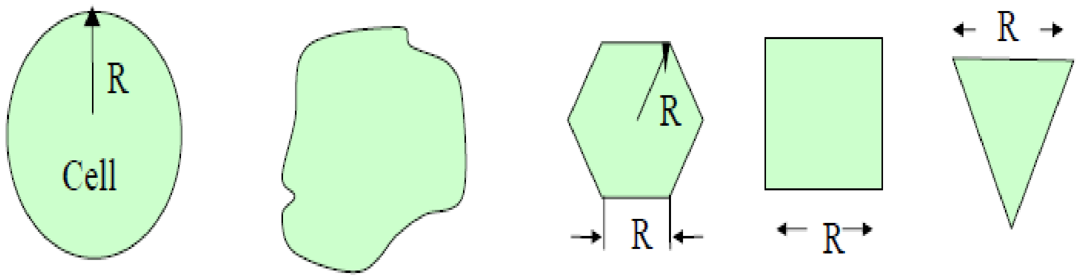
ELEMENTS OF CELLULAR SYSTEMS DESIGN

- The limitation in the cellular system is the frequency resource, the challenge is to serve the greatest number of customers with a specified system quality.
- Based on the concept of efficient spectrum utilization, the cellular mobile radio system design can be broken down into many elements, and each element can be analyzed and related to the others.

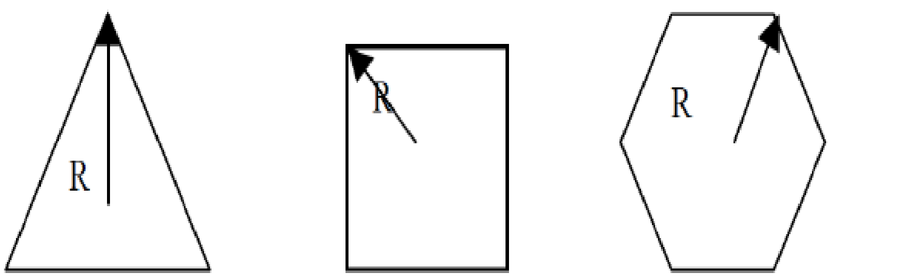
The major elements are

- The concept of frequency reuse channels
- The Co-channel Interference Reduction Factor
- The desired carrier to interference ratio
- The handoff mechanism, and
- Cell splitting

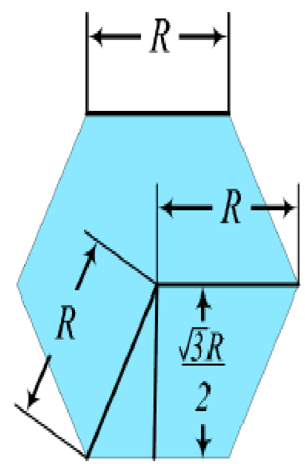
Cell Shape



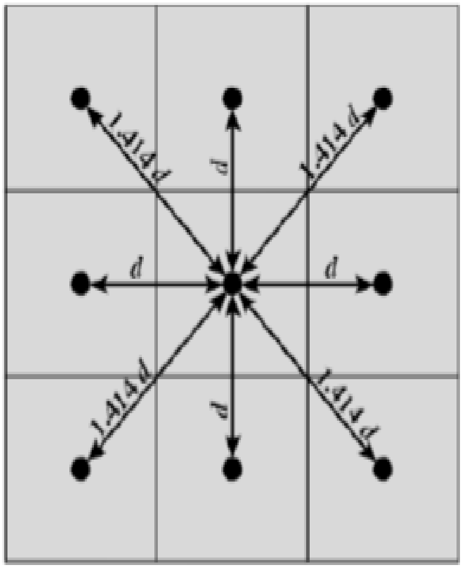
(a) Ideal cell (b) Actual cell (c) Different cell models



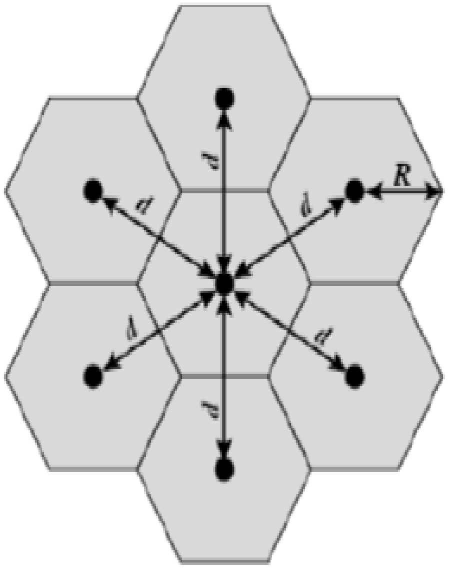
$A_{tri} = 1.3R^2$ $A_{sq} = 2.0R^2$ $A_{hex} = 2.6R^2$



- The most common model used for wireless networks is uniform hexagonal shape areas
  - A base station with omni-directional antenna is placed in the middle of the cell



(a) Square pattern



(b) Hexagonal pattern

$$d = \sqrt{3}R$$

Why hexagon for theoretical coverage?

For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three

Thus by using hexagon geometry, the fewest number of cells can cover a geographic region, and hexagon closely approximates a circular radiation pattern which would occur for an omnidirectional BS antenna and free space
propagation

When using hexagons to model a coverage areas, BS transmitters are depicted as either being in the center of the cell (center-excited cells) or on the three of the six cell vertices (edge-excited cells)

Normally omnidirectional antennas are used in center-excited cells and directional antennas are used in corner-excited cells

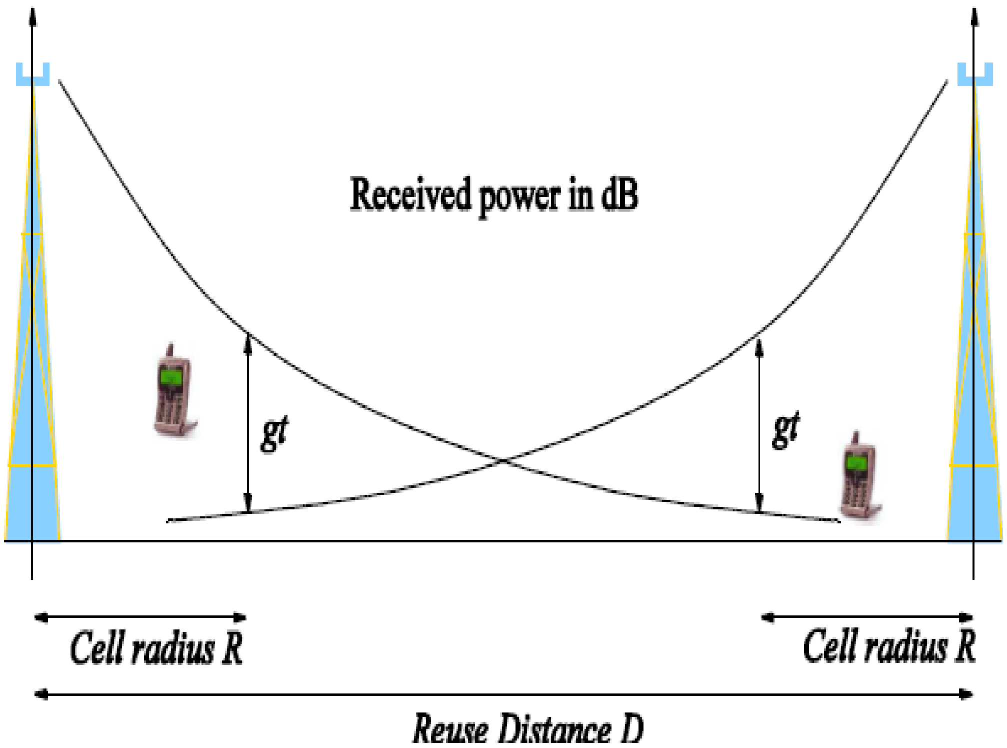
The area of an equilateral triangle to a circle approx = 17.77%
The area of a square to a circle approx = 63.7%
The area of a hexagon to a circle approx = **83%**

- ✓ It means hexagon has the highest coverage area after a circle.
- ✓ Thus hexagon satisfies all the conditions which is why the shape of a cell is hexagonal in cellular network.

Frequency Reuse

An efficient way of managing the radio spectrum is by reusing the same frequency, within the service area, as often as possible

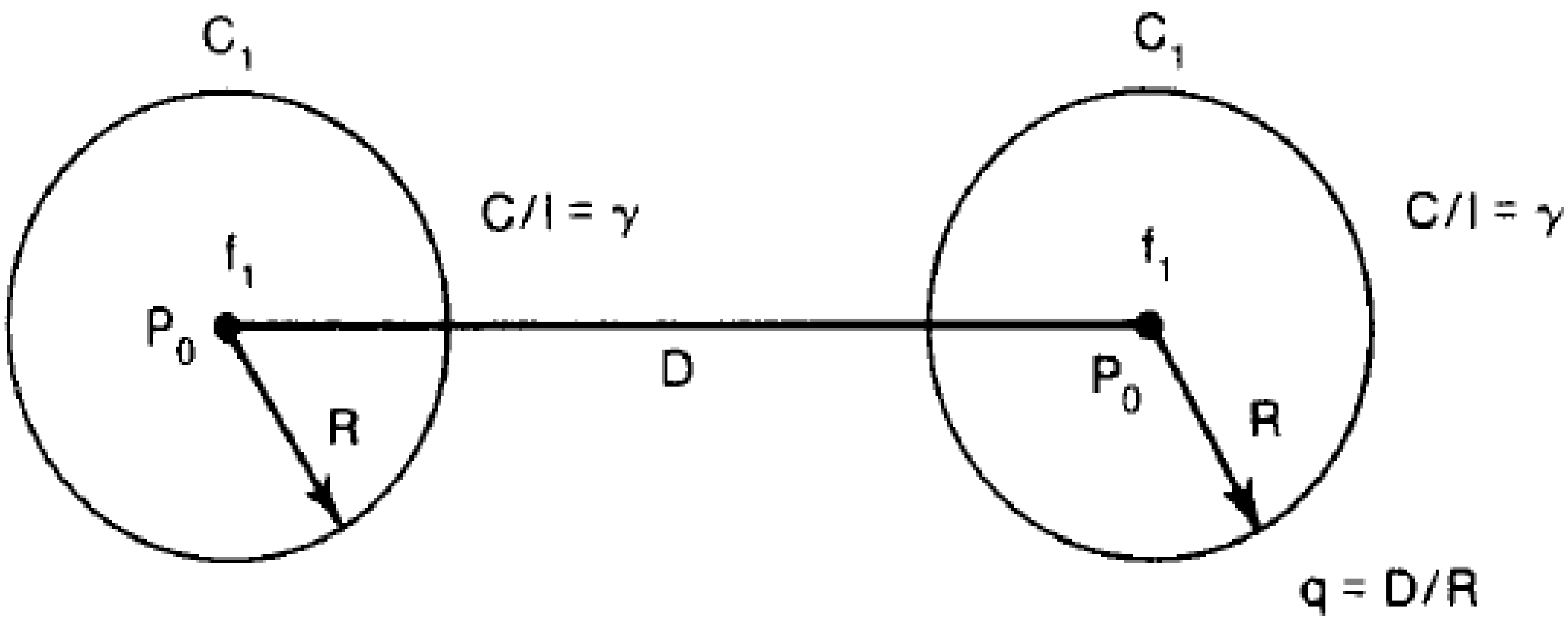
This frequency reuse is possible thanks to the propagation properties of radio waves



The concept of frequency reuse channels:

- A radio channel consists of a pair of frequencies, one for each direction of transmission that is used for full- duplex operation.
- A particular radio channel, say F1, used in one geographic zone as named it a cell, say C1, with a coverage radius R can be used in another cell with the same coverage radius at a distance D away.
- Frequency reuse is the core concept of the cellular mobile radio system.
- In this frequency reuse system, users in different geographic locations (different cells) may simultaneously use the same frequency channel.
- The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur.
- Interference due to the common use of the same channel is called co-channel interference and is our major concern in the concept of frequency reuse.

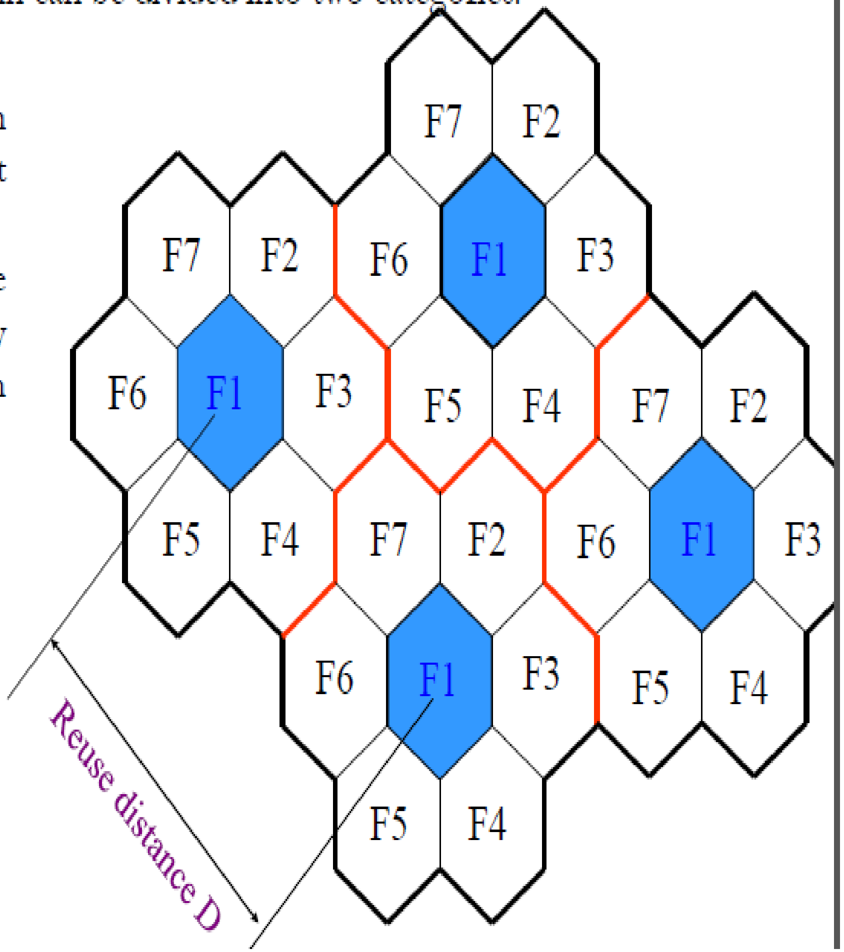
Frequency Reuse Concept



Frequency Reuse

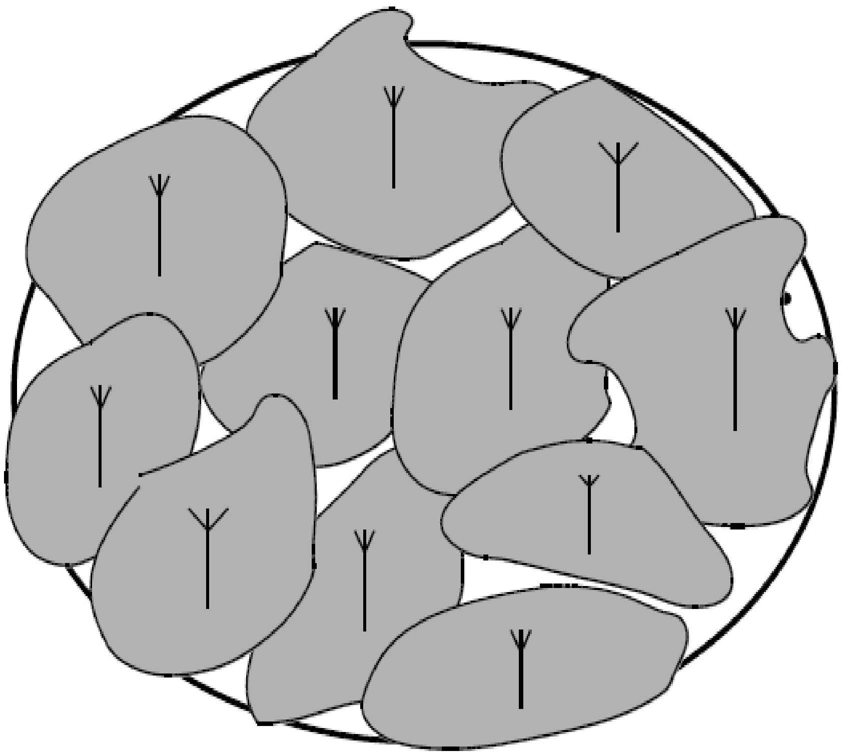
The frequency reuse concept can be used in the time domain and the space domain. Frequency reuse in the time domain results in the occupation of the same frequency in different time slots. It is called time-division multiplexing (TDM). Frequency reuse in the space domain can be divided into two categories.

1. Same frequency assigned in two different geographic areas, such as AM or FM radio stations using the same frequency in different cities.
2. Same frequency repeatedly used in a same general area in one system2—the scheme is used in cellular systems. There are many cochannel cells in the system. The total frequency spectrum allocation is divided into K frequency reuse patterns, as illustrated in Fig. for K = 4, 7, 12, and 19.

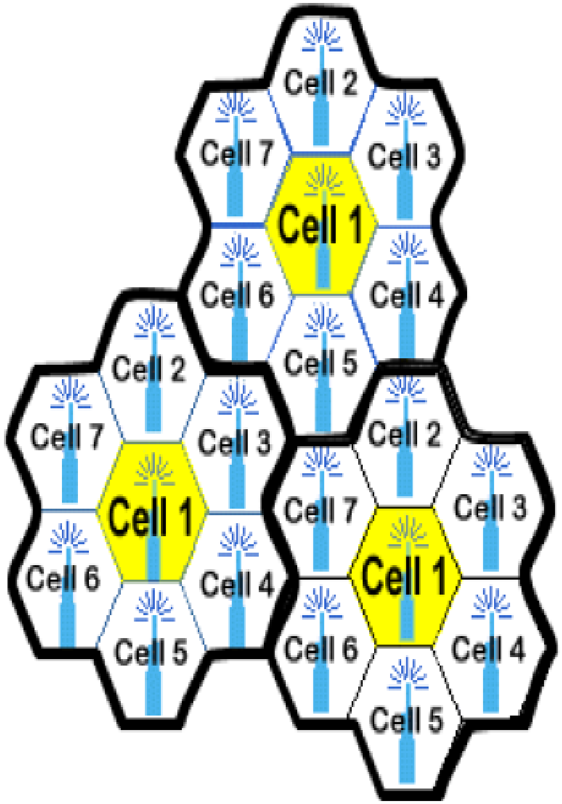


How Often Are Frequencies Reused (Frequency Reuse Factor)?

Cells with the same number have the same set of frequencies



Frequency Reuse



Frequency Allocation Concepts

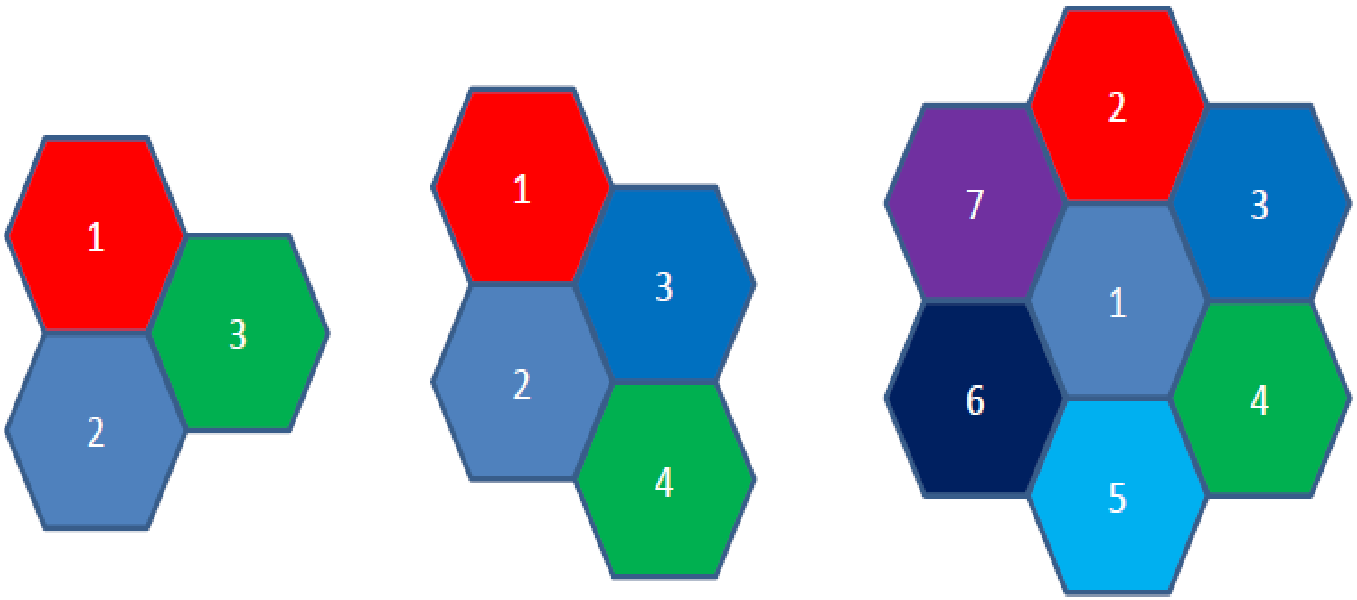
- Consider a cellular system which has a total of ***S*** duplex channels.
- Each cell is allocated a group of ***k*** channels, $k < S$.
- The ***S*** channels are divided among ***N*** cells.
- The total number of available radio channels $S = kN$
- The ***N*** cells which use the complete set of channels is called ***cluster***.
- The cluster can be repeated ***M*** times within the system. The total number of channels, ***C***, is used as a measure of capacity

$$C = MkN = MS$$

- The capacity is directly proportional to the number of replication ***M***.
- The cluster size, ***N***, is typically equal to 4, 7, or 12.
- Small N is desirable to maximize capacity.
- The frequency reuse factor is given by $1/N$

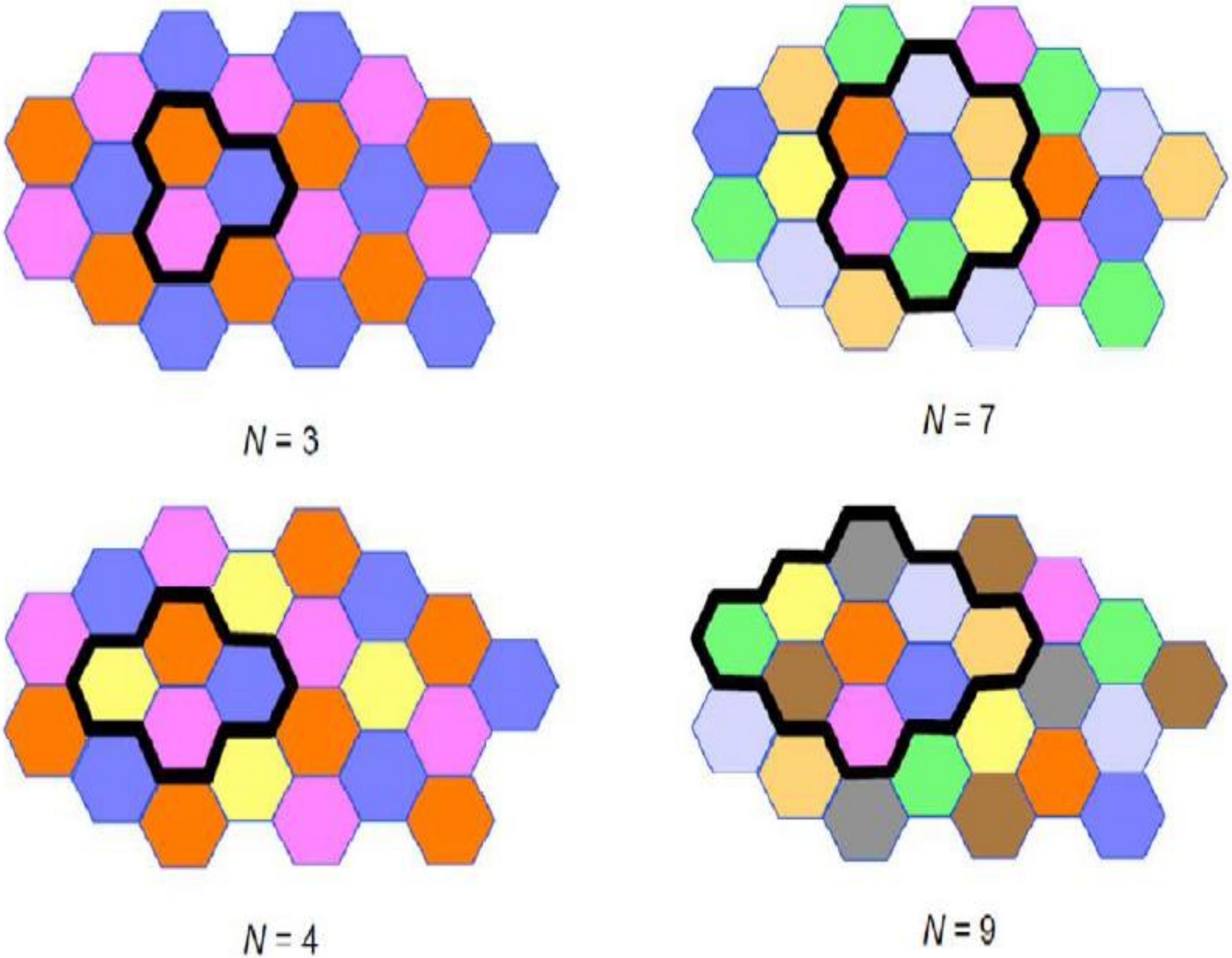
Cluster:

- A cluster is a group of adjacent cells.
- No frequency reuse is done within a cluster.
- Number of cells in cluster $N=i^2+ij+j^2$



3-cell cluster　　4-cell cluster　　7-cell cluster

Different Cluster Sizes



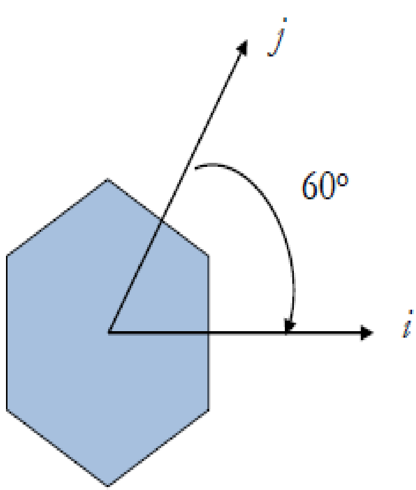
- Hexagonal geometry has
  - exactly six equidistance neighbors
  - the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees.
- Only certain cluster sizes and cell layout are possible.
- The number of cells per cluster, N, can only have values which satisfy

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

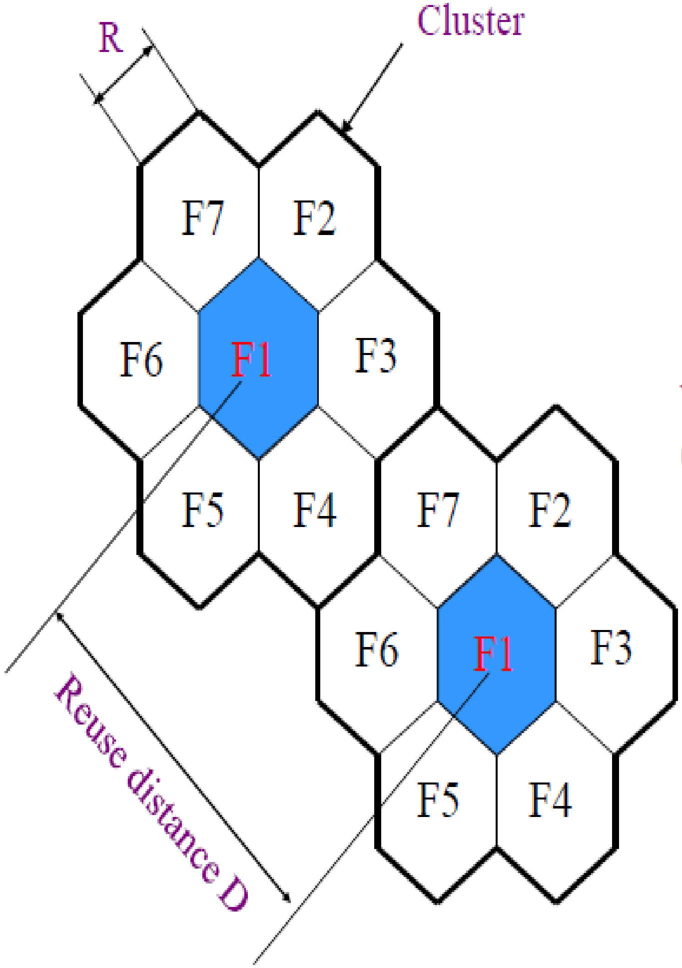
where i and j are integers.

  - N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, …, etc.

  The popular value of N being 4 and 7.



Reuse Distance



- For hexagonal cells, the reuse distance is given by

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

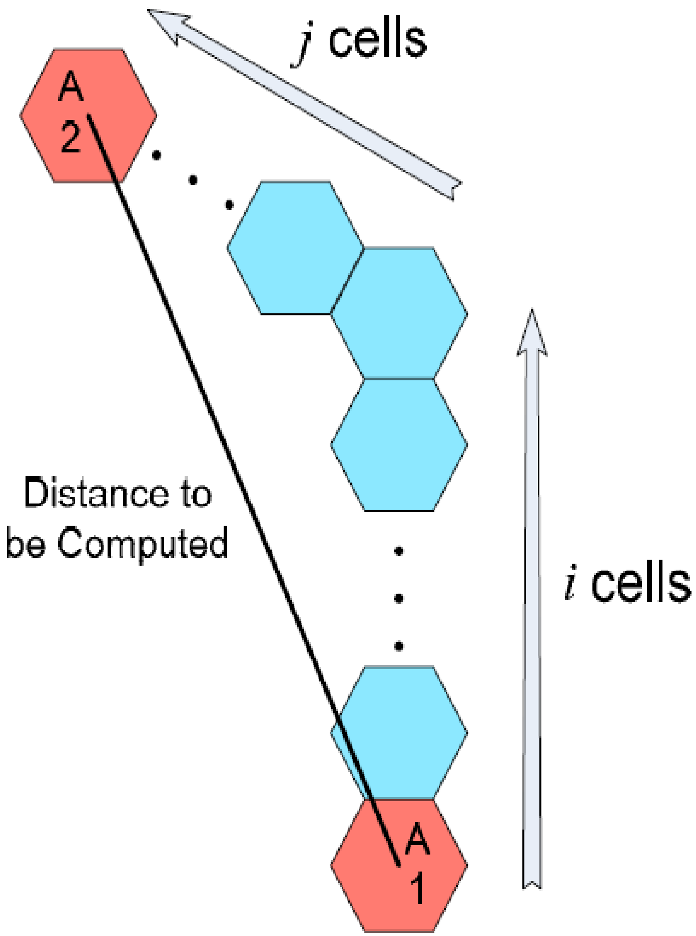
where R is cell radius and N is the reuse pattern (the cluster size or the number of cells per cluster).

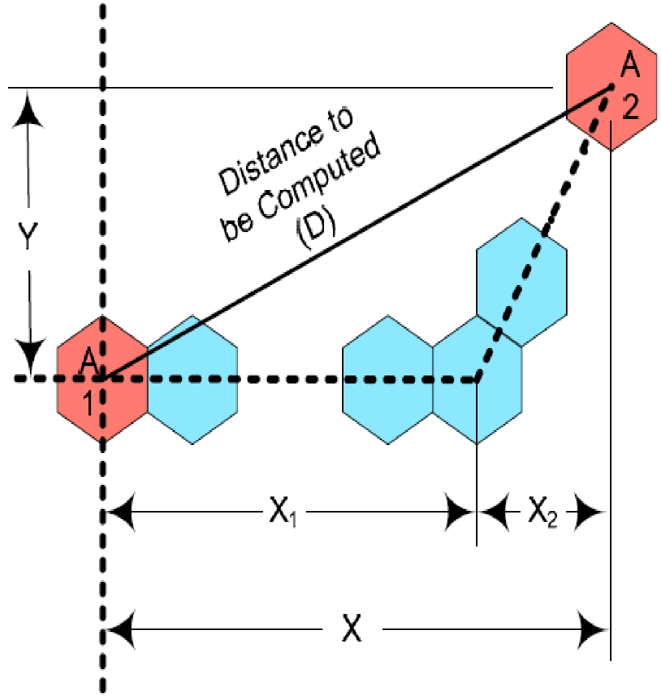
- Reuse factor is

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

Distance between Co-Channel Cell Centers

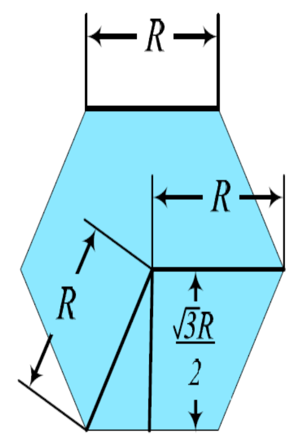
Knowing the relation between i, j, and N, we can easily find distance between the center points of two co-channel cells (cells with the same frequency band) in terms of i and j. Consider any two co-channel cells. We will take for simplicity a cell and its co-channel cell that is located to its top-left location as shown in the below figure.





To compute the distance D, we need to compute X and Y, or simply X_1, X_2, and Y showr
figure. Once these are found, the distance is computed easily using Pythagoras Theorem.

Let us define the cell radius R to be the distance from the center point of the cell to any of
shown in the figure below. Note that the edge length of the cell is equal to cell radius b
hexagonal shape, while the line from the center to mid point of any edge is equal to $\frac{\sqrt{3}R}{2}$.



Clearly,

$$X_1 = 2i\left(\frac{\sqrt{3}R}{2}\right) = iR\sqrt{3} \quad (1)$$

$$X_2 = 2j\left(\frac{\sqrt{3}R}{2}\right)\cos\left(60^\circ\right) = \frac{jR\sqrt{3}}{2} \tag{2}$$

Therefore,

$$\begin{aligned} X &= X_1 + X_2 \\ &= R\sqrt{3}\left(i + \frac{j}{2}\right) \end{aligned} \tag{3}$$

and *Y* is

$$Y = 2j\left(\frac{\sqrt{3}R}{2}\right)\sin\left(60^\circ\right) = \frac{3jR}{2} \tag{4}$$

So, the distance *D* becomes

$$\begin{aligned} D &= \sqrt{3R^2\left(i + \frac{j}{2}\right)^2 + \frac{9j^2R^2}{4}} \\ &= \sqrt{3i^2R^2 + 3ijR^2 + \frac{3j^2R^2}{4} + \frac{9j^2R^2}{4}} \\ &= \sqrt{3i^2R^2 + 3ijR^2 + 3j^2R^2} \\ &= R\sqrt{3\left(i^2 + ij + j^2\right)} \end{aligned} \tag{5}$$

We notice that the part in the parentheses in the last form of *D* is nothing but *N*, which means we can rewrite it as

$$D = R\sqrt{3N} \tag{6}$$

The quantity

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

(7)

is called the channel reuse ratio is an indication of how often frequencies are being reused.

Table 3.1 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

Possible Cluster Sizes

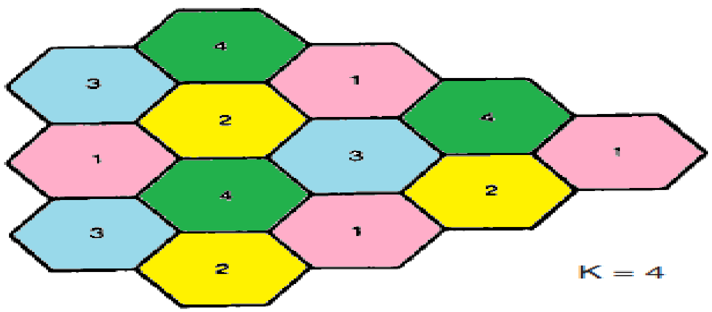
Is any cluster size possible? The answer is NO. There are some cluster sizes that if repeated they will be able to cover the complete region (try for example 8). In fact, there following formula give the cluster sizes N that are possible:

$$N = i^2 + ij + j^2 \qquad (5)$$

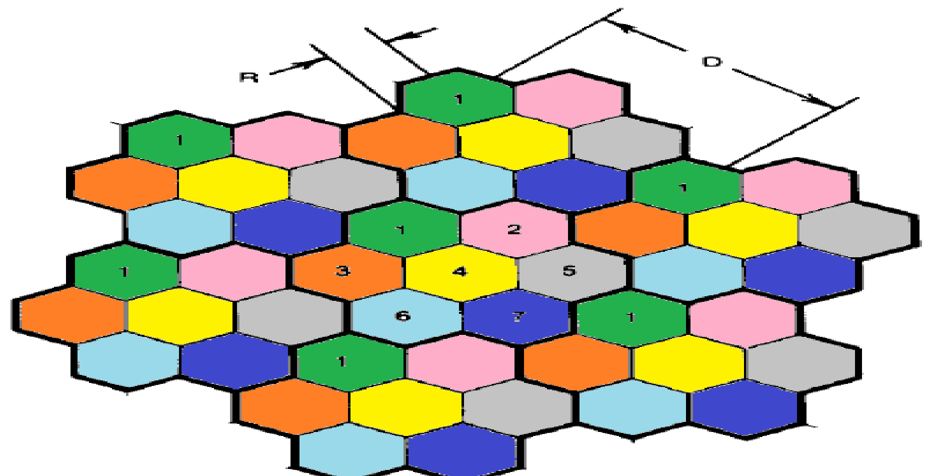
Where $i \geq 0$ and $j \leq i$. Applying this equation for all possible values of $0 \leq i \leq 12$ and all possible values of $i \leq j \leq 12$ gives the table below

N		i												
		0	1	2	3	4	5	6	7	8	9	10	11	12
j	0	0	1	4	9	16	25	36	49	64	81	100	121	144
	1		3	7	13	21	31	43	57	73	91	111	133	157
	2			12	19	28	39	52	67	84	103	124	147	172
	3				27	37	49	63	79	97	117	139	163	189
	4					48	61	76	93	112	133	156	181	208
	5						75	91	109	129	151	175	201	229
	6							108	127	148	171	196	223	252
	7								147	169	193	219	247	277
	8									192	217	244	273	304
	9										243	271	301	333
	10											300	331	364
	11												363	397
	12													432

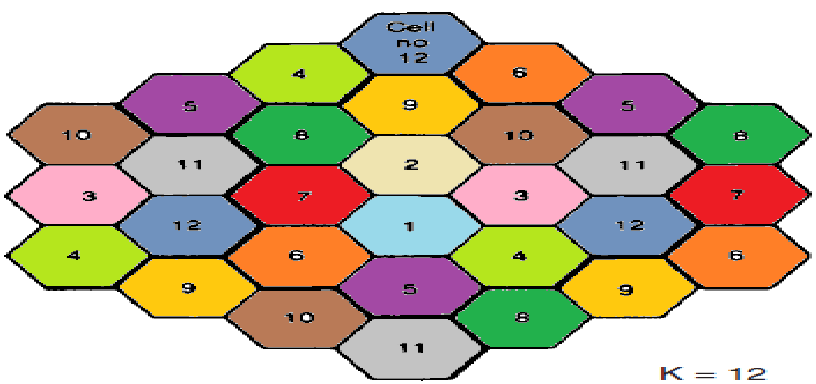
The concept of frequency reuse channels : N-cell reuse Pattern



K = 4

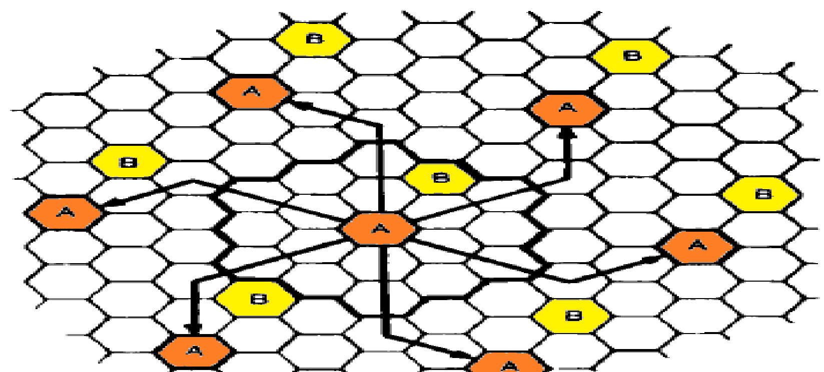


K = 7



K = 12

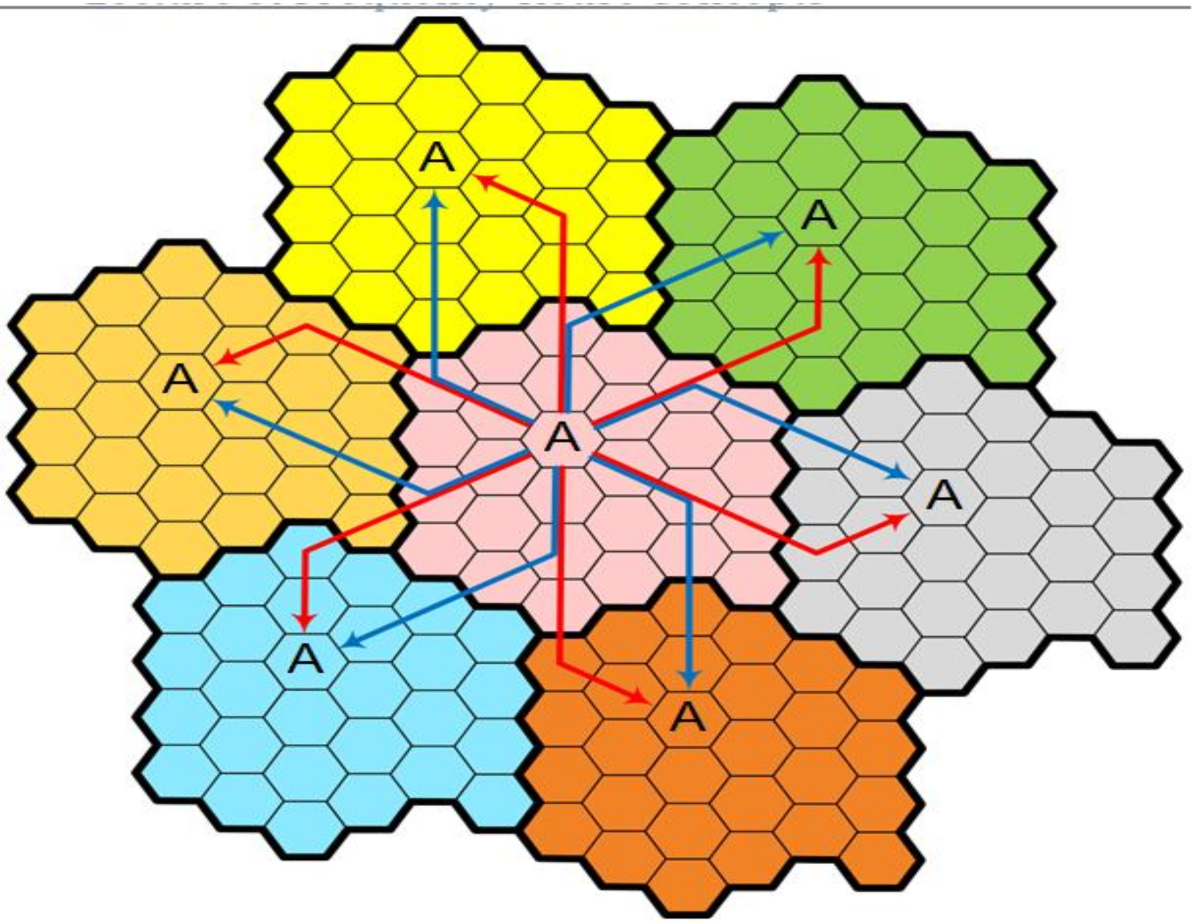
12 Cell reuse pattern to start-up configuration



$K = i^2 + ij + j^2 = 19$

Relation Between i, j, and N

To illustrate the relation between i, j, and N, let us consider the cluster size N = 28. This cluster size is obtained by having i = 4 and j = 2. Also, assume that in this cluster, one of the cells has been allocated a channel group A.

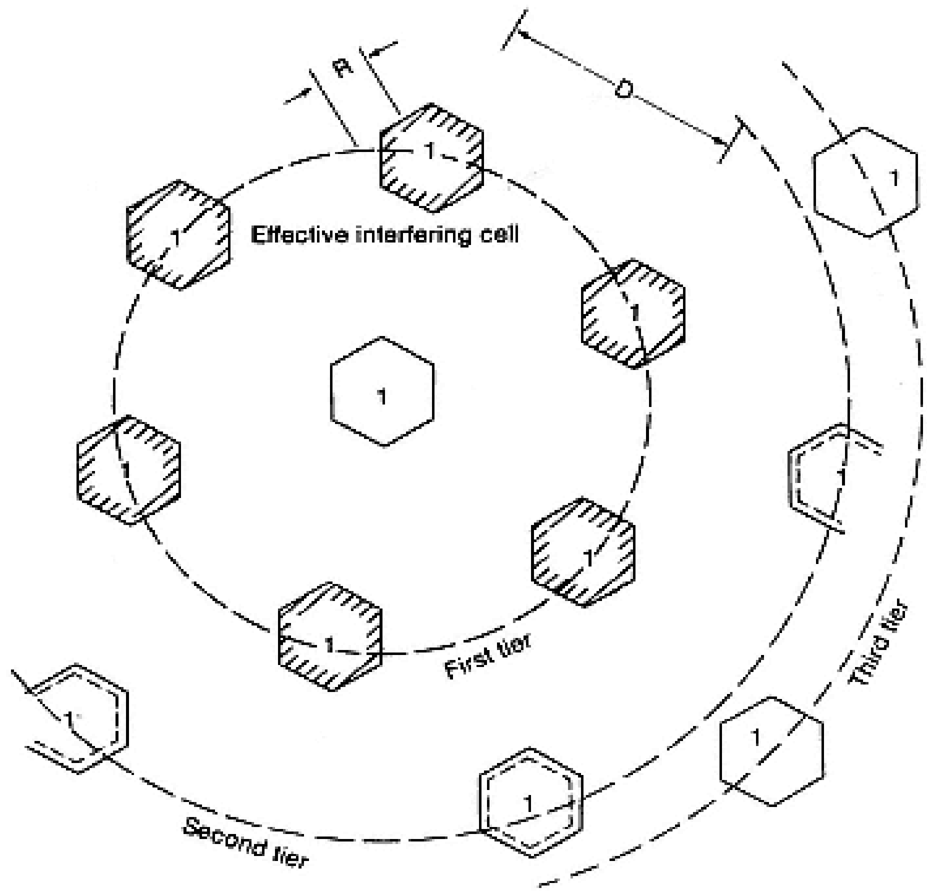


Cochannel Interference Reduction Factor

- q= D/R
- D = f(KI, C/I)
- where K_I is the number of cochannel interfering cells in the first tier and
- *C/I* is the received carrier-to-interference ratio at the desired mobile receiver

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^{K_I} I_k} \qquad (2.3\text{-}3)$$

The maximum number of K_I in the first tier can be shown as six (i.e., 2piD/D » 6).



$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}} \qquad (2.3\text{-}4)$$

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{K_I} \left(\frac{D_k}{R}\right)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K_I} (q_k)^{-\gamma}} \qquad (2.3\text{-}5)$$

$$q_k = \frac{D_k}{R} \qquad (2.3\text{-}6)$$

where q_k is the cochannel interference reduction factor with kth cochannel interfering cell

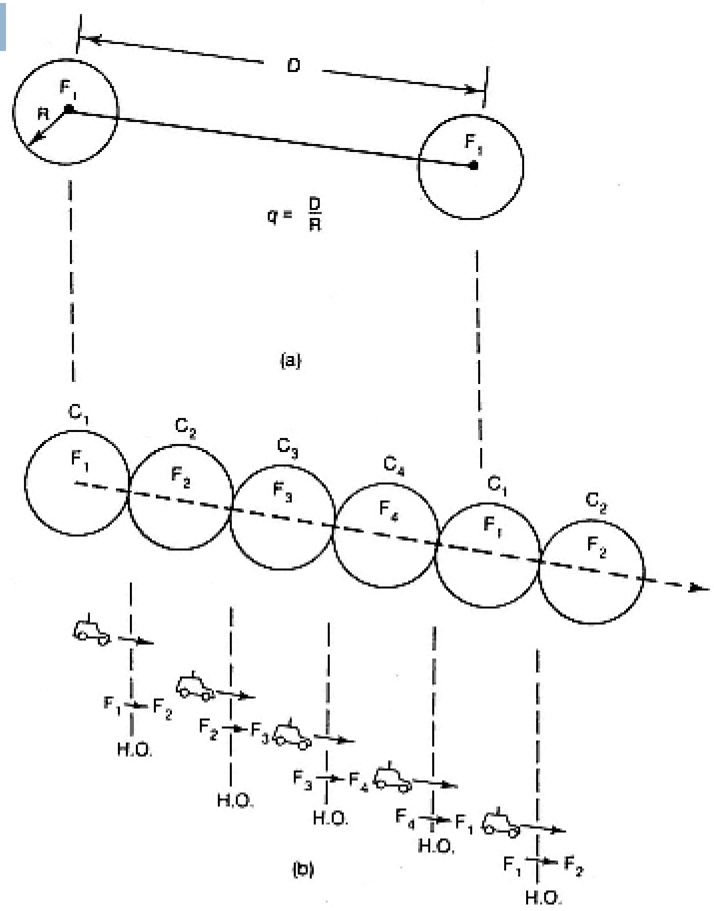
$$\frac{C}{I} = \frac{R^{-\gamma}}{6D^{-\gamma}} = \frac{q^{\gamma}}{6} \qquad (2.4\text{-}1)$$

Thus

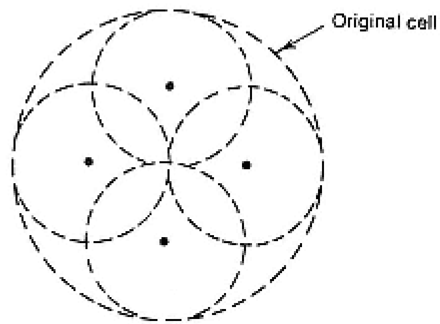
$$q^{\gamma} = 6\,\frac{C}{I} \qquad (2.4\text{-}2)$$

- The propagation path loss is 40dB/dec
- Hence,
- q = (6* C/I) ^1/r
- = (6 * 63.1) ^ 1/6 = 4.41
- C/I = 18dB is measured by the acceptance of voice quality from the present receivers.

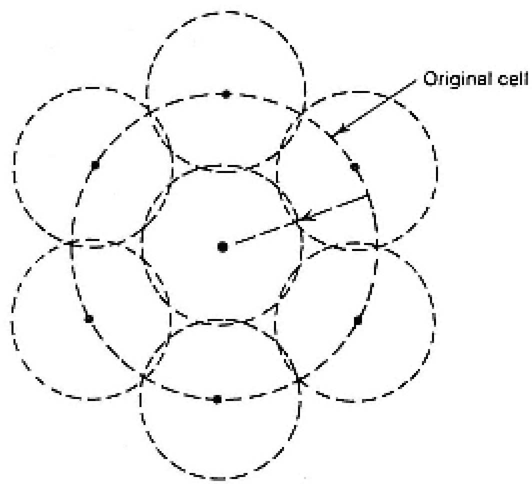
Handoff mechanism



Cell splitting



(a)



(b)

Cell Splitting

Cell splitting is the process of subdividing a congested **cell** into smaller **cells** such that each smaller **cell** has its own base station with Reduced antenna height and Reduced transmitter power. It increases the capacity of a **cellular** system since number of times channels are reused increases.

Cell splitting is a method in which congested (heavy traffic) cell is subdivided into smaller cells, and each smaller cell is having its own base station with reduction in antenna height and transmitter power. The original congested bigger cell is called macrocell and the smaller cells are called microcells. Capacity of cellular network can be
increased by creating micro-cells within the original cells which are having smaller radius
than macro-cells, therefore, the capacity of a system increases because more channels per
unit area are now available in a network

Cell Splitting

- Cell splitting is a technique to divide a cell (congested) into smaller cells to increase capacity
- Cell splitting allows channels to be reused
- Cell splitting also requires adjustment to the antenna transmission power