Wireless Communication and Mobile Computing

The Cellular Concept

Ref Book:
Chapter 2, Wireless Communications by Theodore S. Rappaport

Cellular Communication

- Each cellular service area is divided into small regions called cells.
- Each cell contains an antenna and is controlled by a small office called the cell office.
- Each cells office, in turn, is controlled by a switching office called a mobile telephone switching office (MTSO).
- The MTSO co-ordinates communication between all of the cell offices and the telephone control office.
- It is also responsible for connecting calls as well as recording call information and billing.

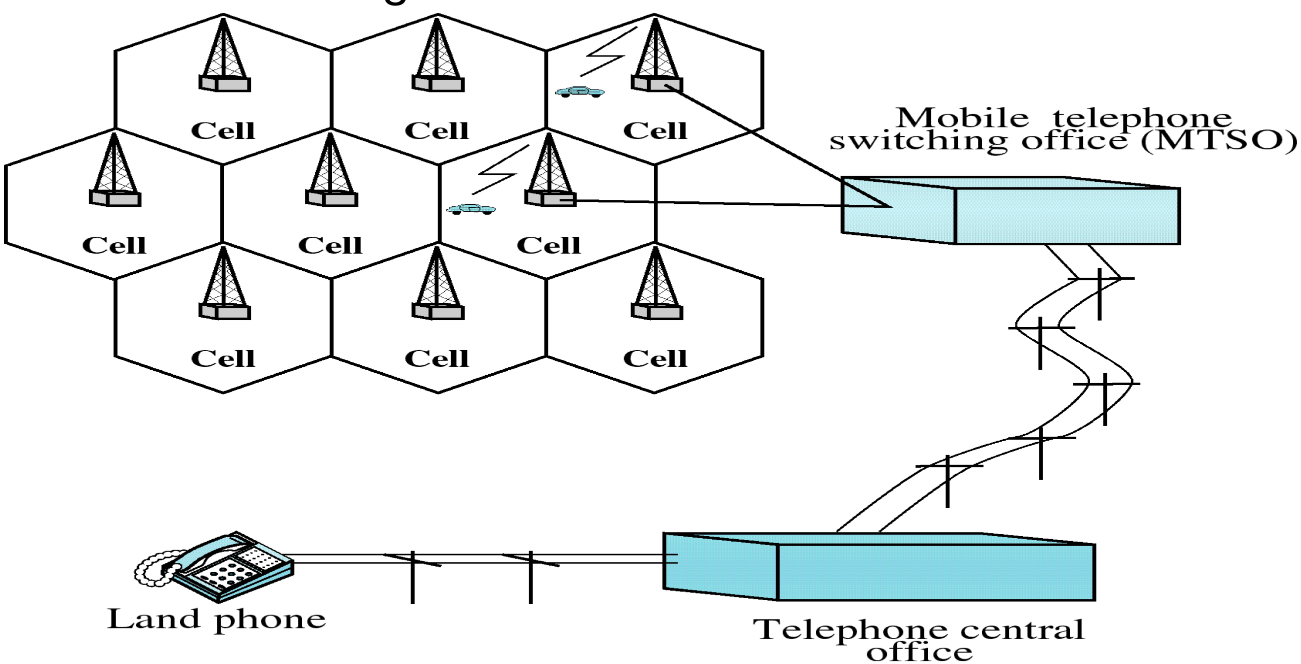


Table 1.4 Wireless Communications System Definitions

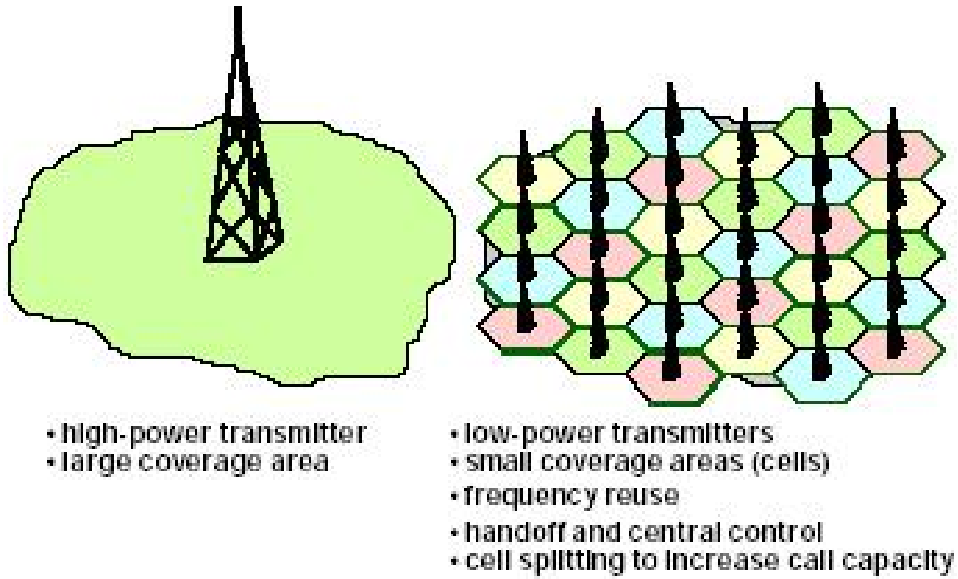
Base Station	A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage region and consist of radio channels and transmitter and receiver antennas mounted on a tower.
Control Channel	Radio channel used 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.

Cellular Concept

- The cellular concept is a system-level idea which calls for replacing a single, high power transmitter(large cell) with many low power transmitters(small cells).
- Each providing coverage to only a small portion of the service area.

- Each base station is allocated a portion of the total number of the channels available to the entire system, and nearby base stations are assigned different groups of channels.

- Neighboring base stations are assigned different groups of channels so that the interference between base stations is minimized.



What is Cell

- **Cell**

  - a small geographical area with a group of radio channels allocated to it.

  - served by a single base station or a cluster of base stations.

Areas divided into cells

- Each served by its own antenna
- Served by base station consisting of transmitter, receiver, and control unit
- Band of frequencies allocated
- Cells set up such that antennas of all neighbors are equidistant

Frequency Reuse

- **Cell Defination:** a small geographical area with a group of radio channels allocated to it. served by a single base station or a cluster of base stations.
- Each cellular base station is allocated a group of radio channels to be used within a small geographic area is called a cell.
- Base stations in adjacent cells are assigned channel groups which contain completely different channels that neighboring cells.
- The base stations antennas are designed to achieved the desired coverage within the cell.
- Limiting the coverage area to within the boundary of the cell, the same group of channels may be used to cover different cells that are separated from one another by distance large enough to keep interference levels within tolerable limits.
- The design process of selecting and allocating channel groups for all of the cellular base station within the system is called **frequency reuse**.

Frequency Reuse: Cell shape

- The hexagonal cell shape is conceptual and is a simplistic model of the radio coverage since the hexagon permits easy and manageable analysis of a cellular system.
- The actual coverage of the cell is known as the footprint and is determined by measurement or propagation prediction models.
- Choose a circle to represent the coverage are of the base station, adjacent circle cannot be overlaid upon a map without leaving gaps or creating overlapping region.
- Three choice of shape which cover an entire region and with equal area: a square, an equilateral triangle and a hexagon.
- A cell must be designed to serve the weakest mobile within the footprint and these are typically located at the edge of the cell.
- For a given distance between the center of the a polygon and its farthest perimeter points, the hexagon has the largest area of the three and closely approximately a circular radiation pattern.

Coverage Patterns

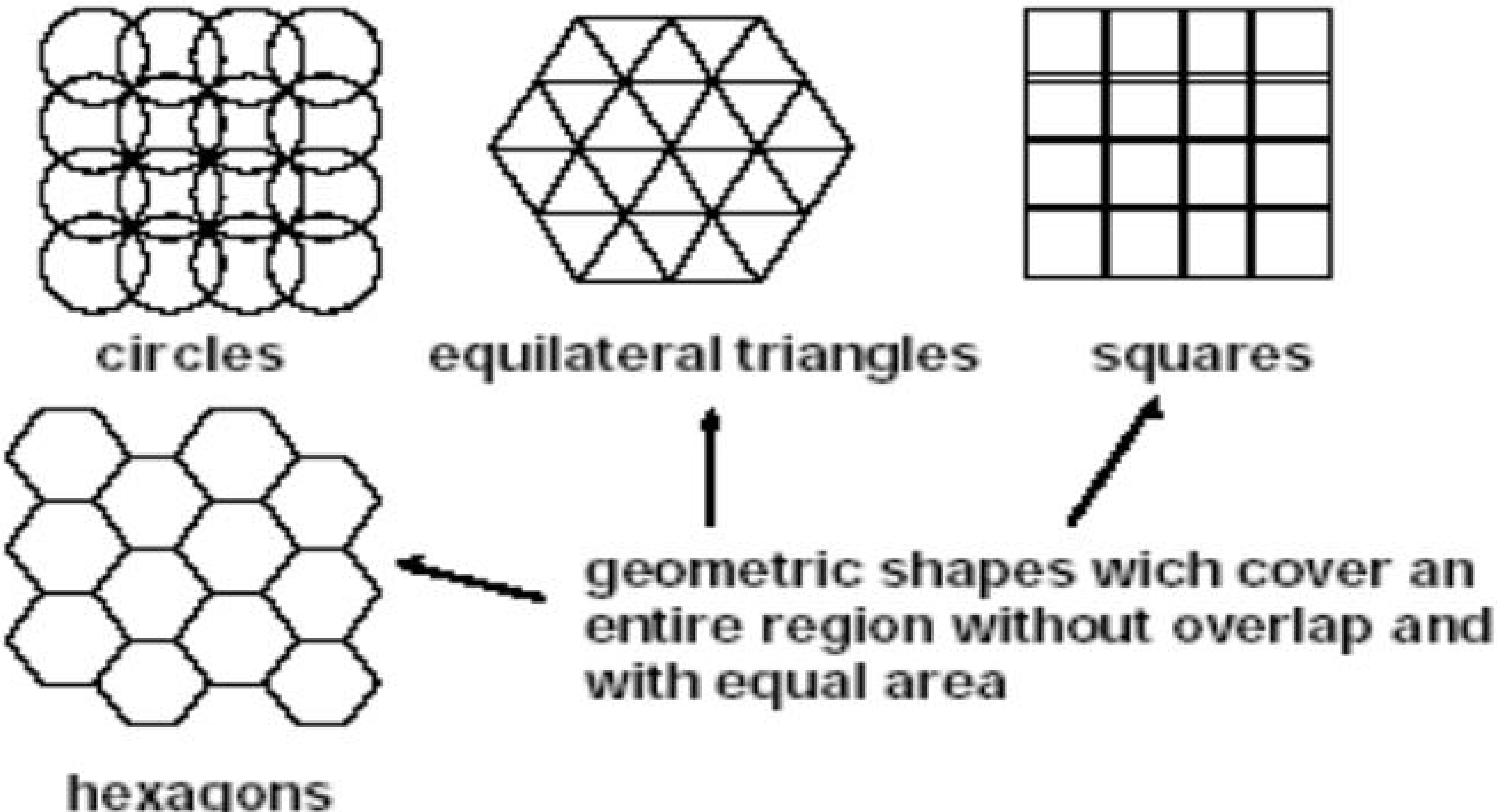


Illustration of the concept of cellular frequency reuse

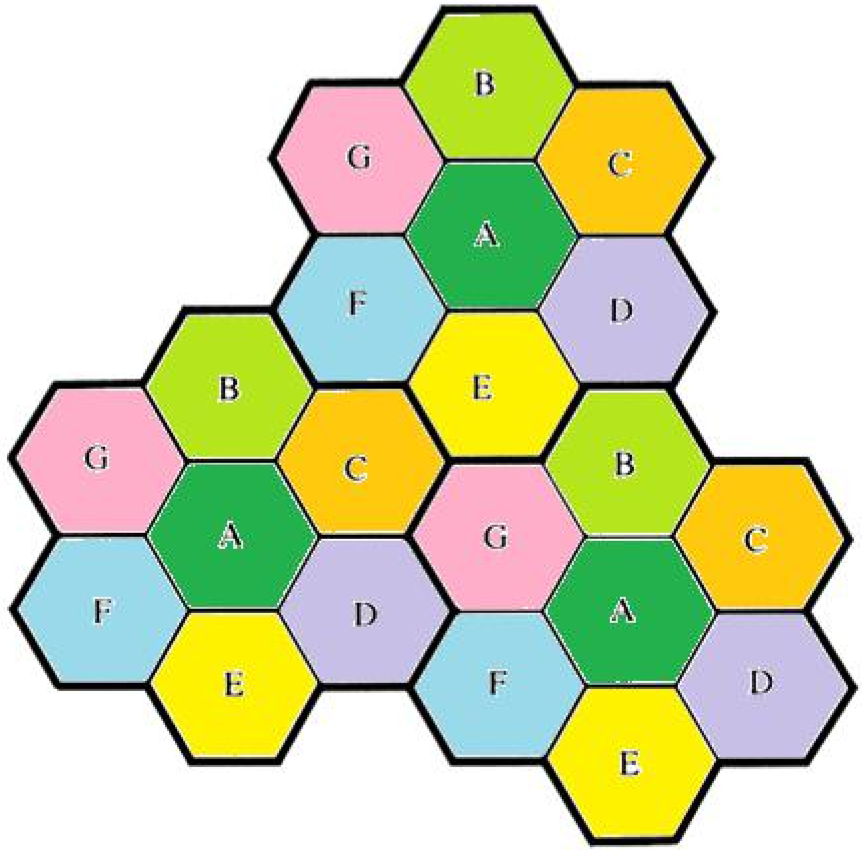


Figure Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, *N*, is equal to seven, and the frequency reuse factor is 1/7 since each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

Frequency Reuse: mathematical

- Consider a cellular system which has a total of **S** duplex channels available for use.
- If each cell is allocated a group of **k** channels **(k<S)** and if the **S** channels are divided among **N** cells into unique and disjoint channel groups which each have the same number of channels.
- The total number of the available radio channels can be expressed as

$$\mathbf{S = kN}$$

Frequency Reuse: mathematical

- The N cells which collectively use the complete set of the available frequencies is called **cluster.**
- If the cluster is replicated M times, the total number of duplex channels, C can be used as a measure of capacity as

$$C = MkN = MS$$

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

Frequency Reuse: mathematical

- The factor N is called cluster size and typically equal to **4, 7 and 12.**
- If the cluster size N is reduced while the cell size is kept constant, more clusters are required to cover a given area. Hence more capacity is achieved.
- Large cluster size indicate that the ratio between the cell radius and distance between co-channels is small.
- Conversely, small cluster size indicates that co-channel cells are located much closer together.
- **The value of N is a function of how much interference a mobile or base station can tolerate.**
- The small possible value of N desirable in order to maximize capacity over a given area.
- The frequency reuse factor is given by 1/N since each cell within a cluster is only assigned 1/N of the total available channels.

Method of locating co-channel cells in a cellular system

- In order to tessellate – to connect without gaps between adjacent cells – the geometry of hexagon is such that the number of cells per cluster, N can only have values which satisfy equation:

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

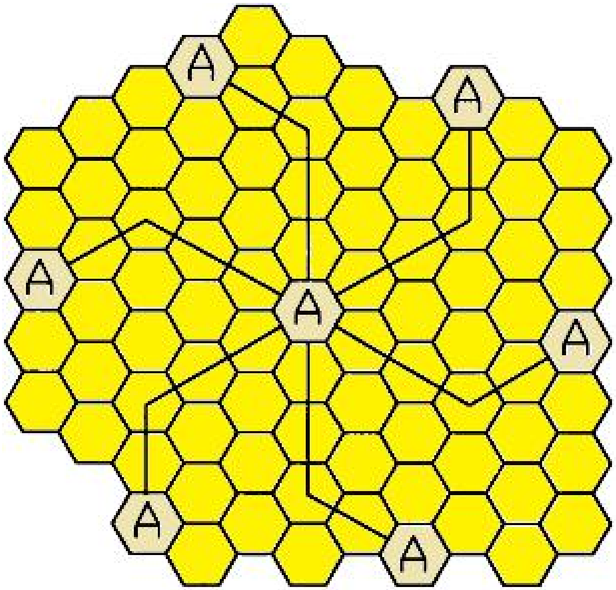
Where i and j are non-negative integers.

19-cell reuse example (N=19, i=3, j =2)

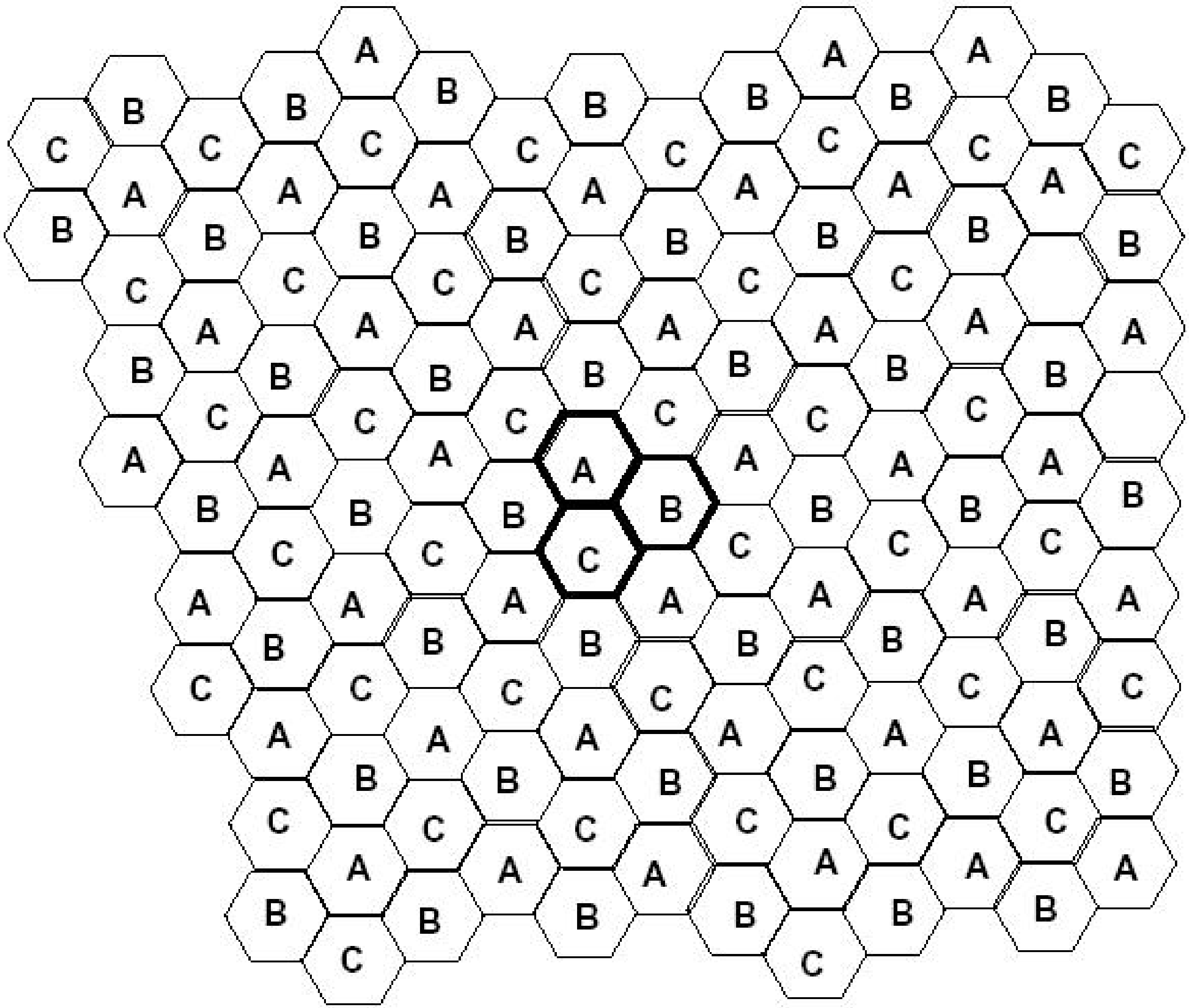
- To find the nearest co-channel neighboring of a particular cell, on must do the following:

(1)Move i cells along any chain of hexagon and then

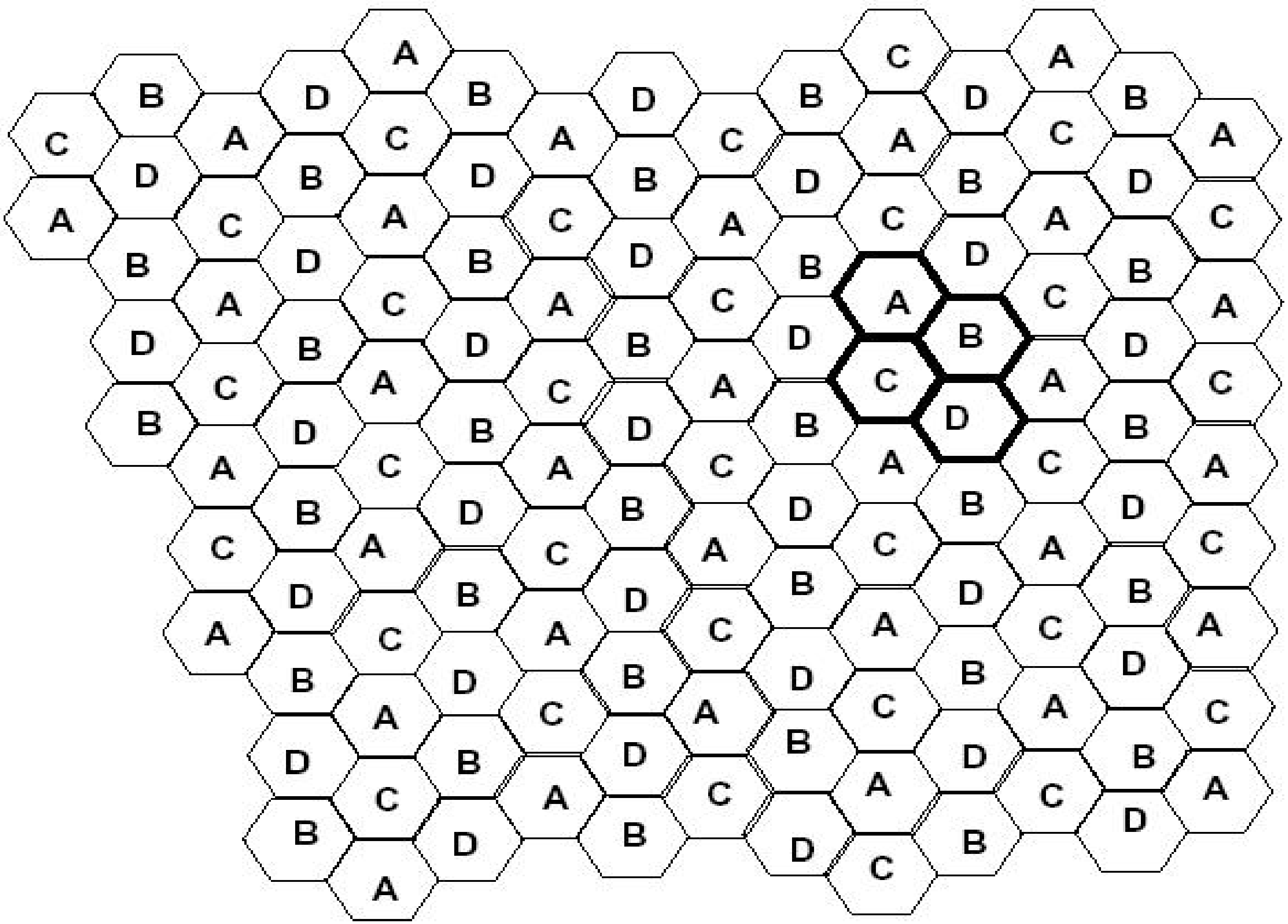
(2) turn 60 degree counter-closewise and move j cells.



3-cell reuse pattern (i=1,j=1)



4-cell reuse pattern (i=2,j=0)



7-cell reuse pattern (i=2,j=1)

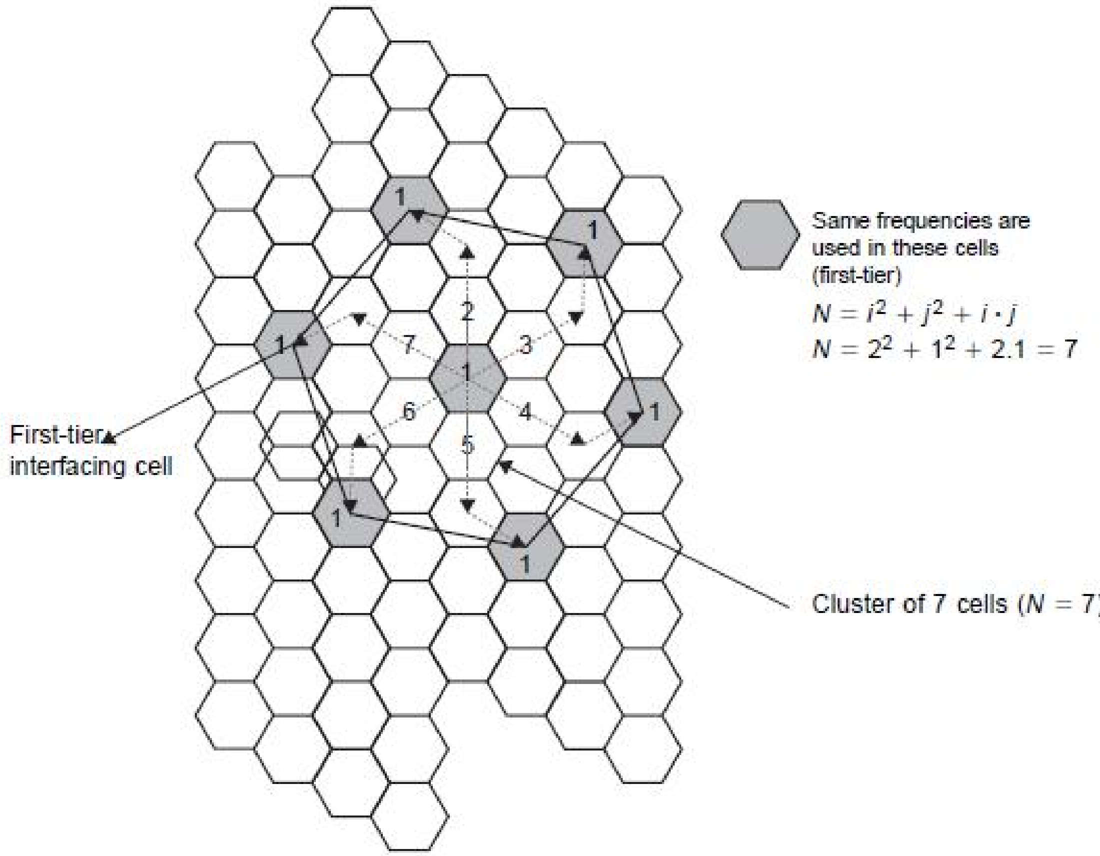
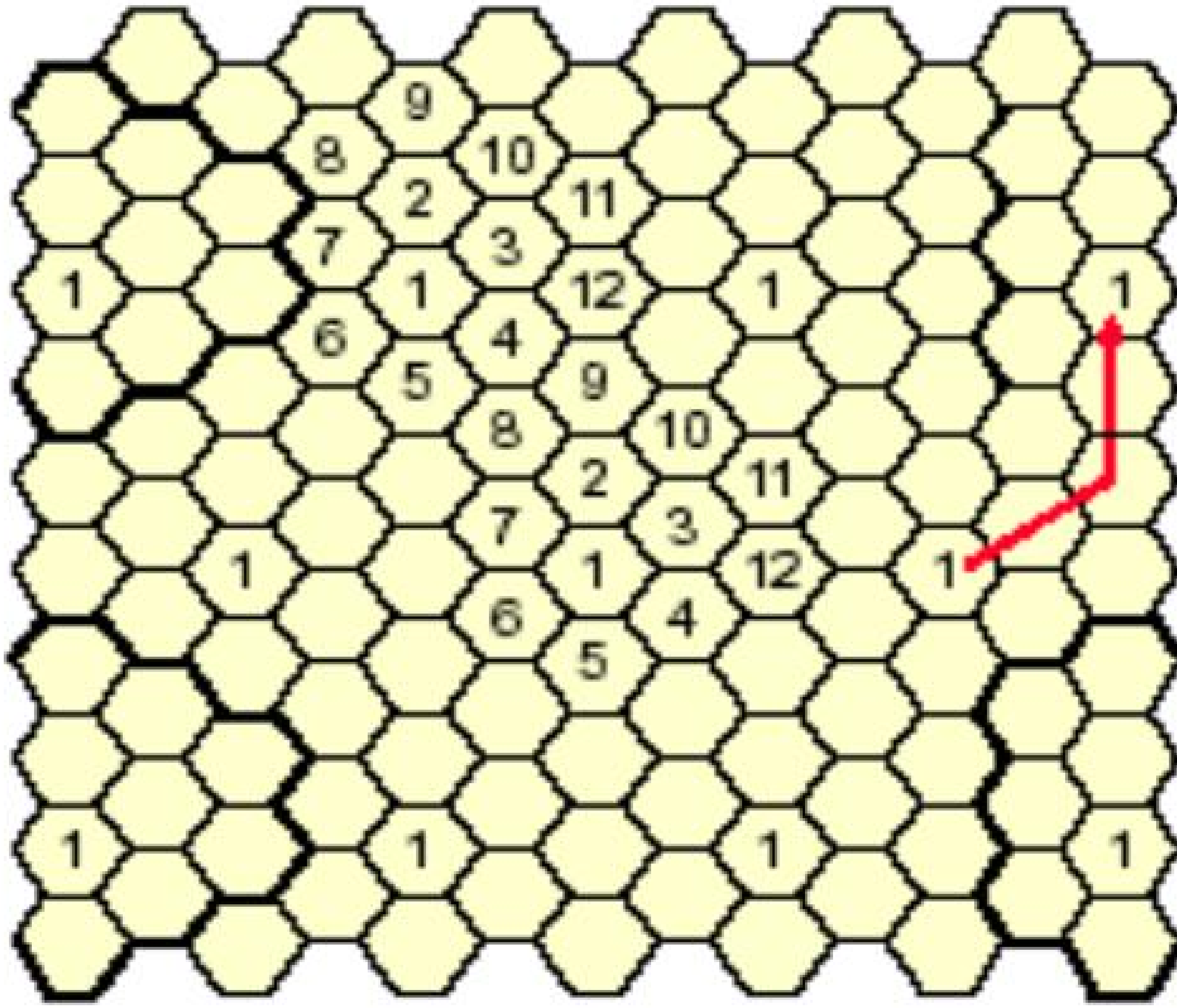
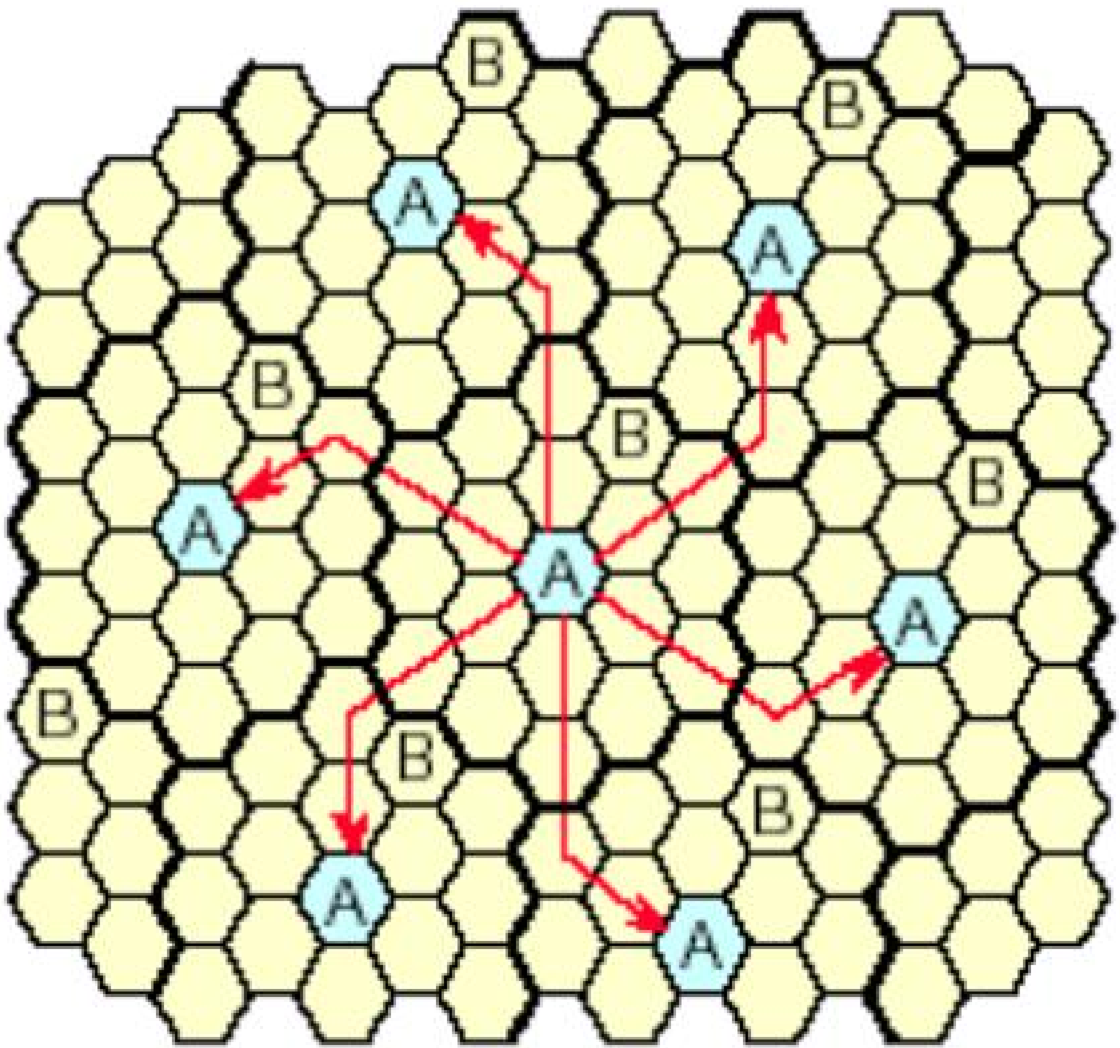


Figure 1 Cell arrangement with reuse factor.

12-cell reuse pattern (i=2,j=2)

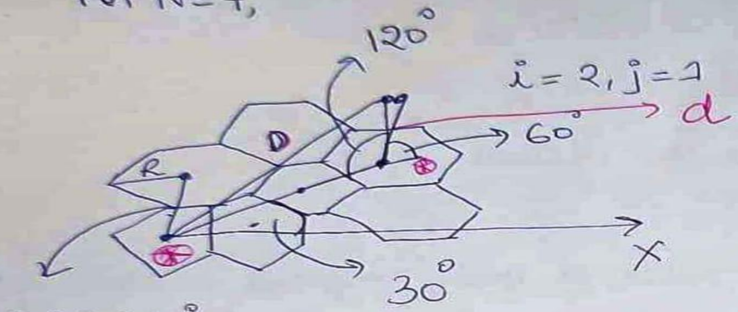


19-cell reuse pattern (i=3,j=2)

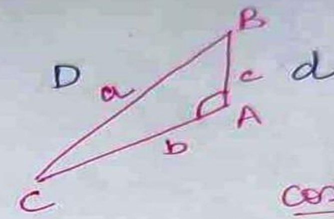


Proof of co-channel frequency Reuse Ratio:

For $N=7$,



$2R\cos 30°$



Cosine Rule

$$a^2 = b^2 + c^2 - 2bc\cos(A)$$

$$A = 120°$$

$$d = 2R\cos 30° = 2R\frac{\sqrt{3}}{2} = \sqrt{3}R.$$

$$D^2 = (i\times d)^2 + (j\times d)^2 - 2(i\times d)(j\times d)\cos 120°$$

$$= i^2d^2 + j^2d^2 - 2id\times jd\cos 120°$$

$$= d^2(i^2 + j^2 - \cancel{2}ij \times (\tfrac{-1}{\cancel{2}}))$$

$$= d^2(i^2 + j + ij)$$

$$D^2 = 3R^2N \quad \Big| \quad \boxed{D = \sqrt{3N}\,R}$$

Therefore, frequency reuse factor,

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

You can also refer: https://www.youtube.com/watch?v=GrUqu7ryRr4
Time: 3:06

Geometry of Hexagons (Cont’d)

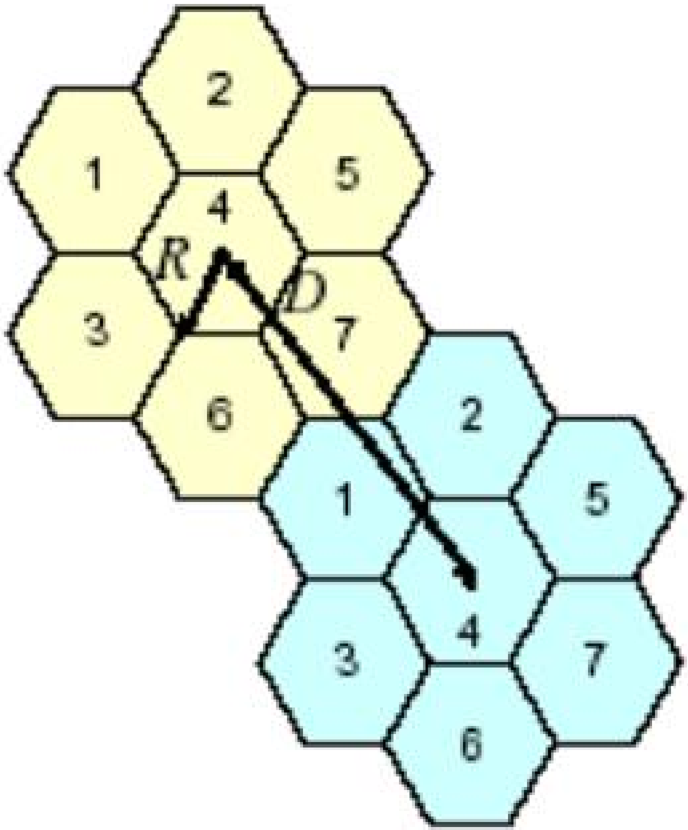
- D = minimum distance between centers of cells that use the same band of frequencies (called co-channels)
- R = radius of a cell

  d = distance between centers of adjacent cells ($d = R\sqrt{3}$)
- N = number of cells in repetitious pattern (Cluster) Reuse factor
- Each cell in pattern uses unique band of frequencies

Hexagon Reuse Clusters

- For uniform hexagonal cells, a tesselating reuse cluster of size N can be constructed if
$$N = i^2 + ij + j^2,$$
where i and j are non-negative integers such that $i \geq 1$; $i \geq j$.
- So $N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 27, \ldots$ are allowable cluster sizes.
- Note that N can be thought of as the reuse factor in the 2-D system.
- Hence, if there are K cells and a total of M channels with a reuse factor of N, the total channel capacity C in the system is
$$C = \lfloor \frac{M}{N} \rfloor K$$

Relationship between Q and N



Q = co-channel reuse ratio
D = frequency reuse distance
R = cell radius
N = # cells per cluster
$1/N$ = frequency reuse factor

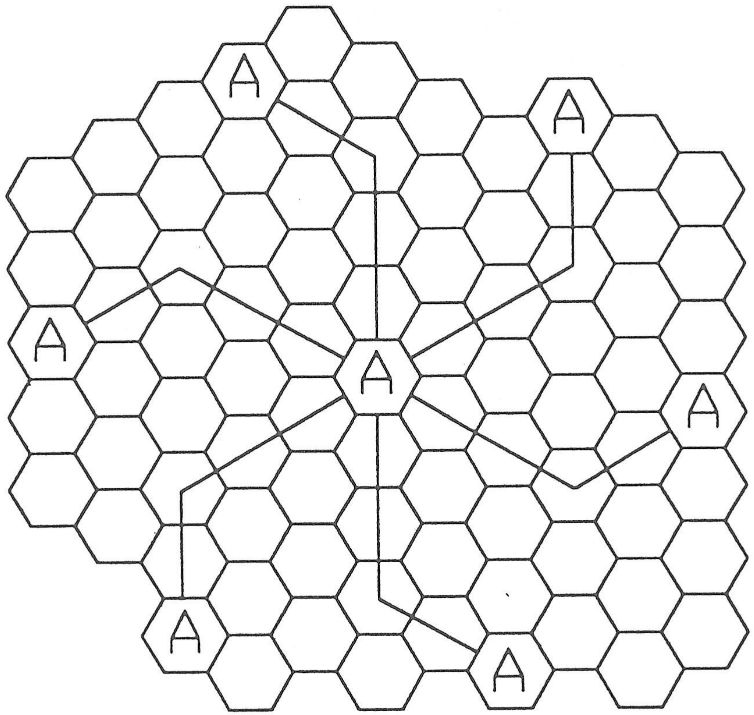
$$Q = \frac{D}{R} = \sqrt{3N}$$

Cell Clusters

Reuse coordinates		Number of cells in re-use pattern	Normalised reuse distance
i	*j*	N	SQRT(N)
1	0	1	1
1	1	3	1.732
1	2	7	2.646
2	2	12	3.464
1	3	13	3.606
2	3	19	4.359
1	4	21	4.583

since D = SQRT(N)

Co–channel Cell Location



- Method of locating co–channel cells
- Example for N=19, i=3, j=2

If a total of 33 MHz of bandwidth is allocated to a particular FDD(Frequency Division Duplex) cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses
(a) 4-cell reuse (b) 7-cell reuse and (c) 12-cell reuse.

Total bandwidth = 33 MHz

Channel bandwidth = 25 kHz * 2 simplex channels = 50 kHz / duplex channel

Total available channels = 33,000/50 = 660 channels

(a) For N=4

total number of channel per cell = 660/4 ≈ 165 channels.

(b) For N=7

total number of channel per cell = 660/7 ≈ 95 channels.

(c) For N=12

total number of channel per cell = 660/12 ≈ 55 channels.

If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channel and voice channels in each cell for each of the three system

Total no. of control channels (from 1 MHz spectrum) = 1000/50 = 20 control channels out of the 660 channels.

The 660 channels must be evenly distributed to each cell within the cluster. In practice, only the 640 voice channels would be allocated, since the control channels are allocated separately as 1 per cell.

(a) N = 4, we can use 5 control channels and 160 voice channels per cell. But in practice, each cell needs 1 control channel, so 1 control channel and 160 voice channel per cell.

(b) N = 7, 4-cells with 3 control channel and 92 voice channels, 2-cells with 3 control channels and 90 voice channel and 1-cell with 2 control channel and 92 voice channel, how ever in practice, each cell would have 1-control channel, so 2-cells would have 91 voice channel and 3-cells would have 92 voice channels.

(c) N = 12, we can have 8-cells with 2 control channel and 53 voice channel and 4-cells with 1 control channel and 54 voice channels. how ever in practice, each cell would have 1-control channel, so 8-cells with 53 voice channels and 4-cells with 54 voice channels.

Channel Assignment

- The objectives of increasing capacity and minimizing interference
- Two type of channel assignment schemes :

Fixed channel assignment

- Each cell is allocated a predetermined set of voice channels.
- Any call attempt within the cell can only be served by the unused channels in that particular cell.
- If all channels in that cell are occupied, the call is blocked.
- In Borrowing scheme, a cell is allowed to borrow channel from neighboring cell. The mobile switching center(MSC) supervise such borrowing procedures.

Channel Assignment

Dynamic channel assignment

- Voice channel are not allocated to different cells permanently.
- Each time a call request is made, the serving base station requests a channel from the MSC.
- The MSC then allocates a channel to the requested cell following an algorithm that takes into account
  - the likelihood of future blocking within the cell,
  - the frequency of the use(the reuse distance of the channel) etc.

- The MSC allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse.

Channel Assignment

<u>Dynamic channel assignment</u>

- It requires MSC to collect real-time data on channel occupancy, traffic distribution and RSSI of all channels.
    - This increases storage and computaional load on the system
    - However, it provides increase channel utilization and decreased call blocking.

Handoff Strategies

- **Defination:** A mobile user moves to a different cell while conversation is in progress, MSC transfers the call to a new BS.
  - Identify new BS
  - New Voice and control channels to be allocated
  - Hand-off Procedure Animation

- Handoff must be performed:
    - Successfully
    - Infrequently
- To achieve this, designers must specify optimum signal level at which handoff initiates.

•Once a signal level is specified as minimum usable for acceptable voice quality, handoff is done.

Handoff Strategies

- In practice, a slightly stronger signal level is used as a threshold.
- Normally taken between -90 dBm and -100 dBm.
- The margin $\Delta = P_{r(handoff\_threshold)} - P_{r\,min}$ can not be too large or too small.
- If Δ is too large, unnecessary handoff, burden on MSC.
- If Δ is too small, insuffiecient time to complete a handoff before a call is lost due to weak signal.
- Δ should be chosen carefully to meet conflicting requirements.

Handoff Strategies

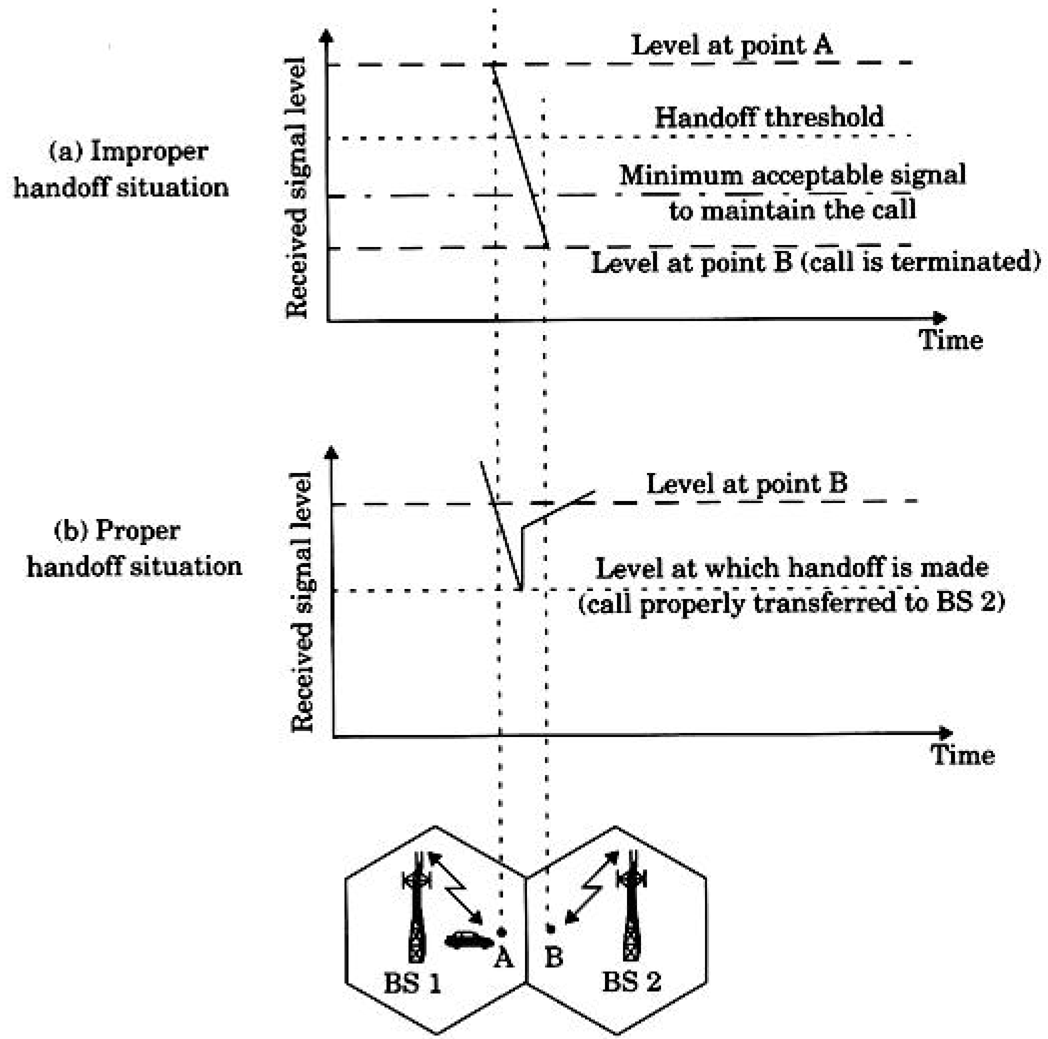


Illustration of a handoff scenario at cell boundary.

Handoff Strategies

- Call Drops
  - Excessive delay by MSC due to high load
  - Δ is set too small for handoff time
  - No channels are available on any of nearby BS.
- When to handoff:
  - Mobile is actually moving away from serving BS.
  - To ensure this:
    - BS monitors the signal level for certain period of time.
    - The period depend depends on the vehicle speed.
      - ➢ If pedesrian, then monitoring for long time.
      - ➢ If vehicle, then monitoring for short time.
  - If slope of average received signal level is steep, handoff is made quickly.

Handoff Strategies

- In the generation of analog cellular system (1G): signal strength measurements are made by the base stations and supervised by the MSC.
- Each BS constantly monitors the signal strength of all its reverse channels to determine relative location of each mobile user.
- The locator receiver is used to scan and determine signal strengths of mobile users which are in neighboring cells which appears to in need of handoff and reports all RSSI values to the MSC.
- Based on the locator receiver signal strength information from each base station, the MSC decides if a handoff is necessary or not.

Mobile Assisted Handoff

- In second generation system (2G), handoff decisions are mobile assisted.
  - every mobile station measures the received power from surrounding base stations.
  - reports the results of these measurement to the serving base station.
  - handoff initiated when the received power from the base station of the neighboring cell begin exceed the power received from the current base station by a certain level or for a certain period of time.

- The MAHO method enables the call to be handled over between base stations at a much faster rate than in first generation analog system since handoff are made by each mobile.
- MSC no longer constantly monitors RSSI.
- More suitable for microcellular where HO is frequent.

Intersystem handoff

- If a mobile moves from one cellular system to a differenat system controlled by a differeant MSC,
- Issues to be addressed:
  - A local call becomes a long distance call(Roaming)
  - Compatiblity between two MSCs must be determined
  - different systems have different policies and methods for managing handoff requests.

Prioritizing handoff

- Call termination in middle of conversation is more annpying than being blocked on a new call attempt.
- Two methods of handoff prioritizing:
  - Guard Channel Cocept
  - Queueing of handoff requests

Guard Channel Concept:

- A fraction of available channels is reserved exclusively for handoff requests.
- **disadvantage:** total carried traffic is reduced.

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Queueing of handoff requests:

- Possible due to time interval elapsed when the signal level drops below to threshold untill minimum signal level.
- Decrease probablity of forced termination due to lack of available channels.
- Tradeoff between decrease in probablity of forced termination and total traffic.
- The delay time and queue size is determined from traffic pattern.
- Queueing does not guarntee zero probablity of call termination since large delay will cause signal level to drop.

Δ $\quad P_{threshold} - P_{min}$

$\Delta =$

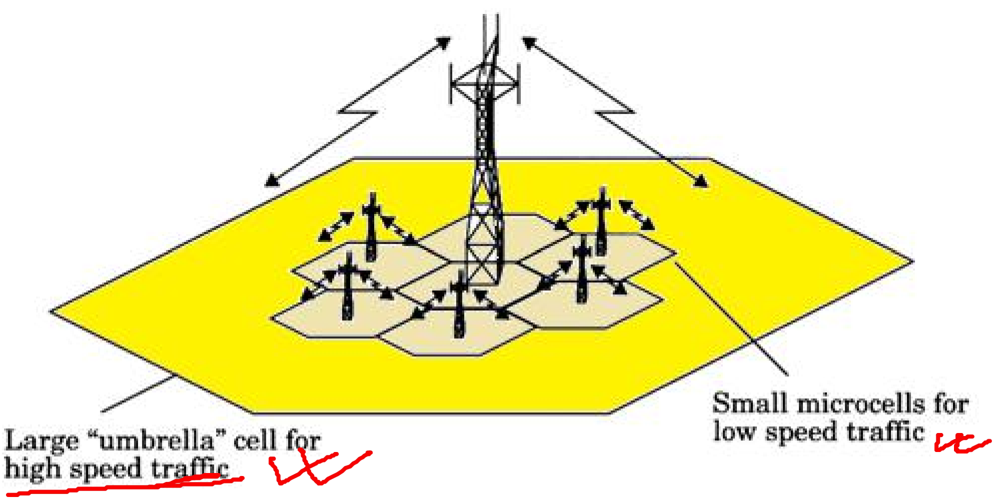
Practical Handoff considerations

- Several problems arise to design a system for wide range of mobile velocities.
  - High speed vehicles pass through a cell in a matter of seconds.
  - With micro cells additions, the MSC can quickly become burdened.
  - Pedestrian users may never need a handoff during a call.

- Issues:
  - Schemes to handle high high speed and low speed users simultaneously.
  - Ability to obtain new cells
  - Additional capacity is provided through addition of new cell sites.
  - Difficult to obtain new cell sites.
  - Install additional channel and BS at same location of an existing cell (umbrella cell)

The umbrella Cell Approach

- It is possible to provide large and small cells which are co-located at a single location by using different antenna heights and different power levels.
- This technique is called the umbrella cell approach and is used to provide large area coverage to high speed users while providing small area coverage to users travelling at low speeds.

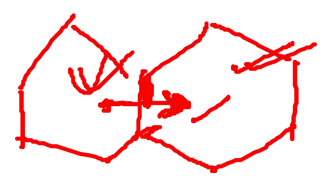


The umbrella cell approach.

Cell Dragging Problem

- Problem in micro-cell due to high signal strength of pedestrian users.
- Occurs in urban areas where there is a LOS path.

- Average signal strength does not decay rapidly even if a user travels well beyond the range of cell.
- The RSSI may be above the handoff threshold and thus handoff is not made.
- This creates potential interference since a user has travelled deeo within a neighbouring cell.
- This problem can solve by adjusting handoff threshold and radio coverage parameters carefully.



Cell Dragging Problem

- In 1G,
  - time to make handoff when signal drops below threshold is 10 sec.
  - this requires that the value of Δ be on the order of 6 dB to 12 dB.
- In 2G such as GSM,
  - MAHO determines the best handoff candiddate and requires only 1 or 2 seconds.
  - Δ is ususlly between 0 dB and 6 dB.
  - Provdes MSC substanial time to rescue a call.

Situations for triggering Handoff

- If a subscriber who is in a call or a data session moves out of coverage of one cell and enters coverage area of another cell, a handoff is triggered for a continuum of service. The tasks that were being performed by the first cell are delineating to the latter cell.
- Each cell has a pre-defined capacity, i.e. it can handle only a specific number of subscribers. If the number of users using a particular cell reaches its maximum capacity, then a handoff occurs. Some of the calls are transferred to adjoining cells, provided that the subscriber is in the overlapping coverage area of both the cells.
- Cells are often sub-divided into microcells. A handoff may occur when there is a transfer of duties from the large cell to the smaller cell and vice versa. For example, there is a traveling user moving within the jurisdiction of a large cell. If the traveler stops, then the jurisdiction is transferred to a microcell to relieve the load on the large cell.
- Handoffs may also occur when there is an interference of calls using the same frequency for communication.

Trunking and Grade of Service

- Trunking allows a large number of users to share the relatively small numbers of channels in a cell by providing access to each user, on demand from the pool of available channels.

- Relies on statstical behaviour of users so that a fixed number of channels may accomdate a large random user community.

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

Grade of service is a measure of the ability of a user to access a trunked system during the busiest hour.

Interference

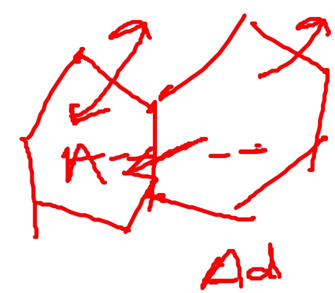
ACI

- A mobile received unwanted signal from another mobile in the same cell, a call in progress in a neighboring cell, others base station operating in the same frequency band.

Co-channels

- Interference is more serve in urban area, due to the greater RF noise floor, and large number of base stations and mobiles.

- Two type of interference
- Co-channel interference
- Adjacent channel interference.



Co-channel Interference

- The cells that use the same set of frequencies in a given coverage area is called co-channel cells.

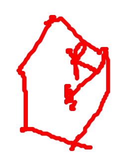
- The interference between signals from co-channels cells is called co-channel interference.

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

Co-channel Interference and system capacity

- Assume cell size are same and stations transmit same power.
- The co-channel interference ratio is independent of the transmitted power.
- it is a function of the radius of the cell(R) and the distance between centers of the nearest co-channel (D).
- We have seen by using hexagonal geometry, The co-channel reuse ratio Q is related to cluster size N as

$$Q = \frac{D}{R} = \sqrt{3N} \qquad (1)$$



- Small vale of Q provide larger capacity since the cluster size is small where as large value of Q improves the transmission quality due to a smaller level of co-channel interference.

Co-channel Interference and system capacity

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

$\sqrt{3N}$

Co-channel Interference and system capacity

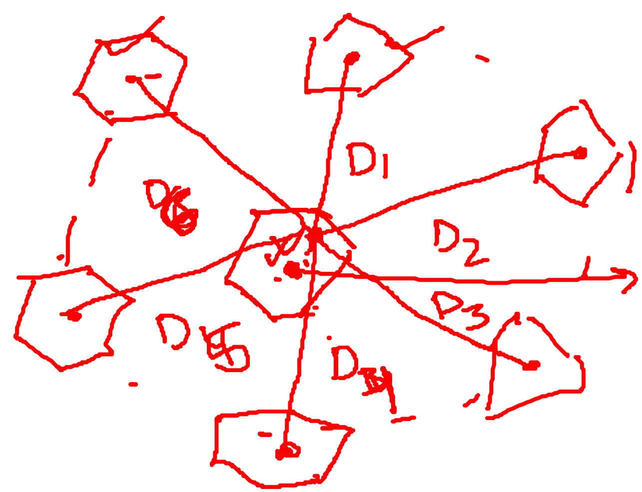
- Let i_0 be the number of co-channel interfering cells. The signal-to-interference ratio (S/I) for a mobile receiver which monitor the forward channel can expressed as

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i} \quad (2)$$

$i_0 = 6$

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{6} I_i}$$

- Where S is the desired signal power from the base station and I_i is the interference power caused by the ith interfering co-channel cell base station.



N=7
first tier
co channel
cells

Serving
base station

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{6} \left(\frac{D_i}{R}\right)^{-n}}$$

D_i is same for all the six interfering cells,

then $D_i = D$

$$\frac{S}{I} = \frac{1}{6\left(\frac{D}{R}\right)^{-n}} \qquad Q = \frac{D}{R}$$

$$\frac{S}{I} = \frac{1}{6(Q)^{-n}} \Rightarrow \boxed{\frac{S}{I} = \frac{Q^n}{6}}$$

$$Q = \left[6\left(\frac{S}{I}\right)\right]^{1/n}$$

Co-channel Interference and system capacity

- The average received power P_r at distance d from the transmitting antenna is given by

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n} \rightarrow \text{path loss exponent} \quad (3)$$

Or

$$P_r(dBm) = P_{0(dBm)} - 10n \log_{10}\left(\frac{d}{d_0}\right) \quad (4)$$

- Where P_0 is the received power at reference distance d_0 and n is the path loss exponent.

- If D_i is the distance of the ith interferer from mobile then the received power is at a given mobile due to ith interfering cell will be proportional to $(Di)^{-n}$

Co-channel Interference and system capacity

- From equation (2) and (3) , the S/I for mobile can be written as

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0}(D_i)^{-n}} \tag{5}$$

if all the interfering base stations are equidistance from the desired base station and distance is D then

$$\frac{S}{I} = \frac{\left(\frac{D}{R}\right)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0} \tag{6}$$

S/I is related of cluster size.

Co-channel Interference and system capacity

- Using the cell geometry layout for seven cell cluster with a mobile at the cell boundary, the mobile is a distance D-R from the two nearest co-channel interfering cells and D and D+R from the others interfering cells, and n=4 then

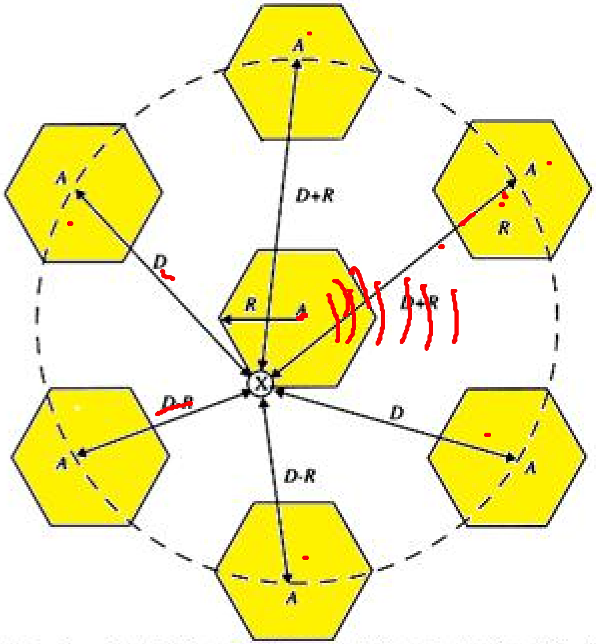
path loss exponent

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

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4}+2(D+R)^{-4}+2(D)^{-4}} \qquad (7)$$

It can be rewritten as

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4}+2(Q+1)^{-4}+2(Q)^{-4}} \qquad (8$$

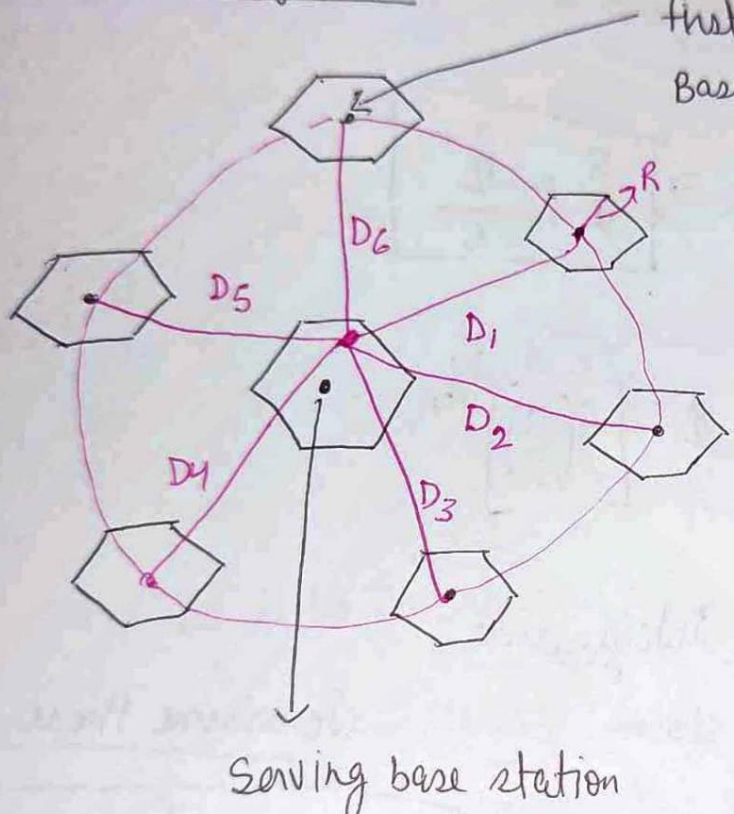


6→2

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

Co-Channel Interferance Derivation (Hand-written)

Co-channel Interference



base transmitters are omnidirectional antenna.

- Co channel Interferance ratio is given by

$$\frac{S}{I} = \frac{\text{Signal}}{\text{Interference}} = \frac{S}{\sum_{k=1}^{M} I_k}$$

Here I is the Co-channel Intefrence,

M → maximum number of co-channel Interferring cell.

When M=6, S/I is given by

$$\frac{S}{I} = \frac{S}{\sum_{K=1}^{6} \left(\frac{D_K}{R}\right)^{-\gamma}}$$

$\gamma \rightarrow$ pathloss exponent

γ depends on environment

So, If we assume D_K is same for the six interferring cells,

then $D_K = D$.

$$\frac{S}{I} = \frac{1}{6\left(\frac{D}{R}\right)^{-\gamma}}$$

Since $q = \frac{D}{R}$

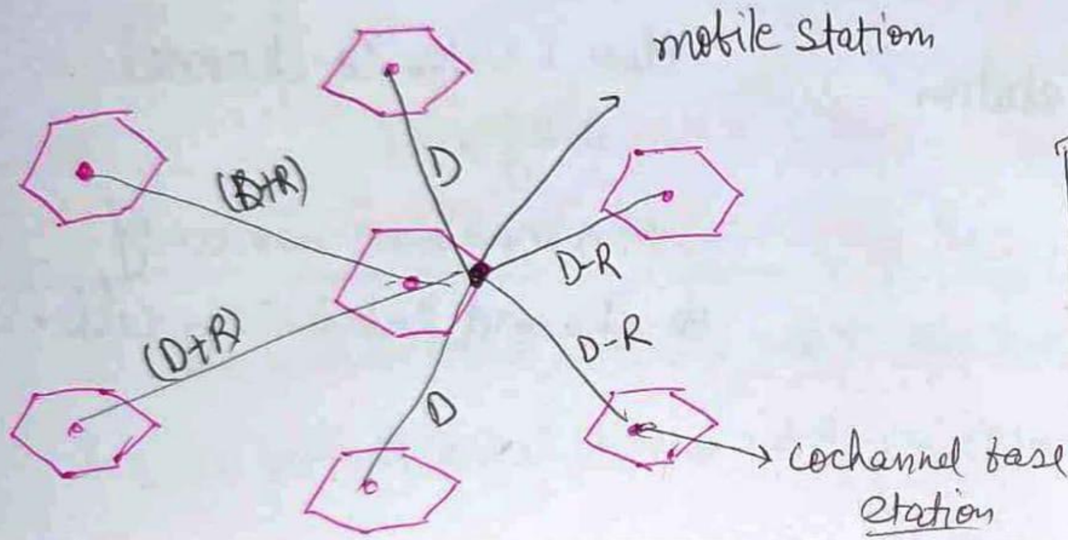
So, $\frac{S}{I} = \frac{1}{6(q)^{-\gamma}} \Rightarrow \boxed{\frac{S}{I} = \frac{q^{\gamma}}{6}}$

$$\frac{S}{I} = \frac{1}{6(q)^{-\gamma}} \Rightarrow \boxed{\frac{S}{I} = \frac{q^{\gamma}}{6}}$$

or

$$q = \left[6\left(\frac{S}{I}\right)\right]^{1/\gamma}$$

Worst Case of Cochannel Interferrence



We assume these distanc

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

or

$$\frac{S}{I} = \frac{1}{2(q-1)^{-\gamma} + 2(q)^{-\gamma} + 2(q+1)^{-\gamma}}$$

Co-channel Interference and system capacity

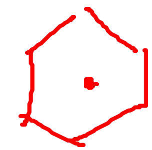
- For N=7, the co-channel reuse ratio Q is 4.6 and the worst case S/I is approximated as 49.56 (17 dB) using equation (8) where as exact solution by equation (5) is 17.8.
- Hence for 7-cell cluster, the S/I ratio slightly less than 18 dB for the worst case.

- To design a cellular system for proper performance in the worst case, it would be necessary to increase the next largest size that is 12 (i=i=2).

Q

If a signal-to-interference ratio of 15dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster (N) size that should be used for maximum capacity if the path loss exponent is (a) n = 4, (b) n=3 ? Assume that there are six co-channel cells in the fist tier, and all of them are at the same distance from the mobile. Use suitable approximations.

$\boxed{D_K = D}$



- (a) n = 4
- First let us consider a seven-cell reuse pattern (N=7), by using $Q = \frac{D}{R} = \sqrt{3N}$ the co-channel reuse ratio Q=D/R = 4.583.

by using $\frac{S}{I} = \frac{\left(\frac{D}{R}\right)^n}{i_0} = \frac{(4.583)^4}{6} =$ 75.3 = 18.66 dB

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

N=7

(b) n =3, let us consider a seven cell reuse pattern, by using S/I = $\frac{\left(\frac{D}{R}\right)^n}{i_0} = \frac{(4.583)^3}{6}$ = 16.04 = 12.05 dB

This less than the minimum required S/I, we need to use a larger N. The next possible value of N is 12 (i=j=2)

So D/R = 6.0

S/I = 1/6 * 6^3 = 36 = 15.56 dB

$\boxed{N=12,\ n=3}$

It is greater than the minimum required S/I, N=12 is used.

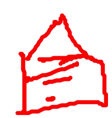
Adjacent Channel Interference

- Interference resulting from signal which are adjacent in frequency to the desired signal is called adjacent channel interference.
- It is results from imperfect receiver filter which allow nearby frequency to leak into the passband.

- By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference can be reduce.

- If the frequency reuse factor is large, the separation between channel at the base station may not be sufficient to keep the adjacent channel interference level within tolerable limits.

$\boxed{Q=\sqrt{3N}}$



Cell Splitting

Improving capacity in Cellular System.

- Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power.

- Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused.

- Cell splitting allows a system to grow by replacing large cells with smaller cells, while not upsetting the channel allocation scheme required to maintain the minimum co-channel reuse ratio Q between co-channel cells.

- New G base station was placed half ways between two larger stations G utilizing same set of channel to preserve frequency reuse plan

R/2

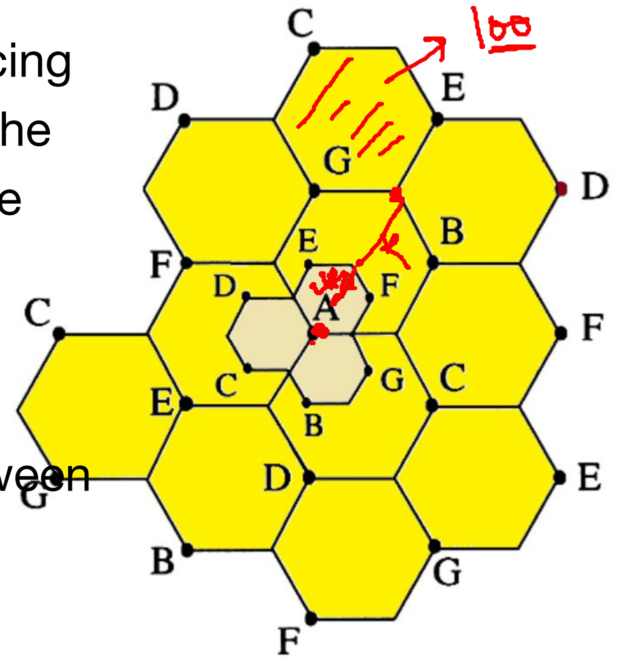


Illustration of cell splitting.

Cell Splitting

- If the radius of new cells are R/2, R is the radius of the original cells.
- The transmit power of the new cells can be reduce to preserve the frequency reuse plan can be calculated as

- P_r is the receive power at the cell boundary.

$P_{t_1} \to$ original power

$P_{t_2} \to$ new cell

$$P_r[\text{at old cell boundary}] \propto P_{t1} R^{-n}$$

and

$n = 2$ (for rural Area)

$$P_r[\text{at new cell boundary}] \propto P_{t2} (R/2)^{-n}$$

Where P_{t1} and P_{t2} are the transmit powers of larger and smaller cell stations and n is the pathloss exponent. If n=4

$P_{t_2} = \frac{P_{t_1}}{2^2} = \frac{P_{t_1}}{4}$

$\boxed{2^4 = 16}$

$R/2$

$$P_{t2} = P_{t1} / 16$$

The transmit power must be reduced by 12 dB = 10 log(16) in order to fill in the original coverage area with microcells, while maintaining the S/I requirements

$n = 4$

$R = R/2$, $P_{t_2} = \frac{P_{t_1}}{16}$

$P_{t_1} R^{-n} = P_{t_2} R_2^{-n} \Rightarrow \boxed{P_{T_2} = \frac{P_{T_1}}{2^n}}$

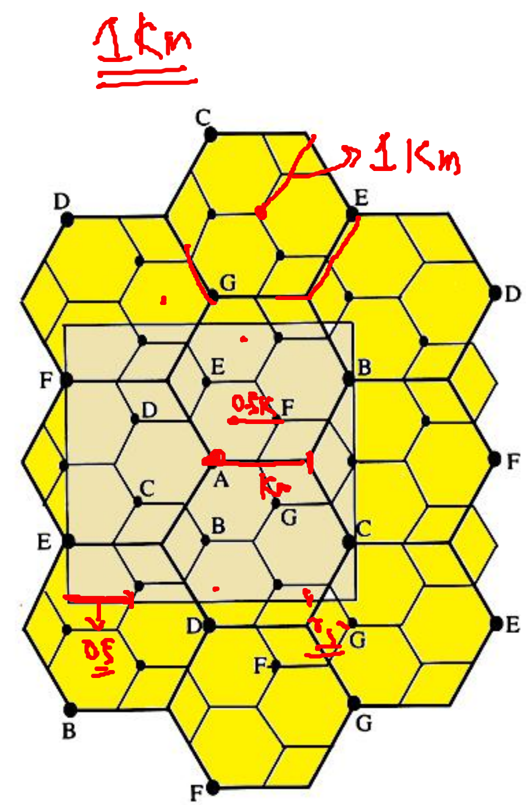
In the figure, Assume each base station uses 60 channels, regardless of cell size. If each original cell has a radius of 1 km and each microcells has a radius of 0.5 km. finds the number of channels contained in a 3 km by 3 km square centered around base station A under the following conditions:
(a) without use of microcells (b) the lettered microcells as shown figure are used (c) if all the original base stations are replaced by microcells. Assume cells on the edge of the square to be contained within the square.

(a) 5 base stations are covered in 3 km by 3 km area. Since radius of cell is 1 km. We need to cover 1.5 km towards the right, left, top and bottom of A. so the total number of channel = 5 x 60 = 300 channels.

(b) base station A is surrounded by six microcells . Therefore total no of base stations in the square area under study equal to 5 + 6 = 11. so total no of channels = 11 x 60 = 660 channels.

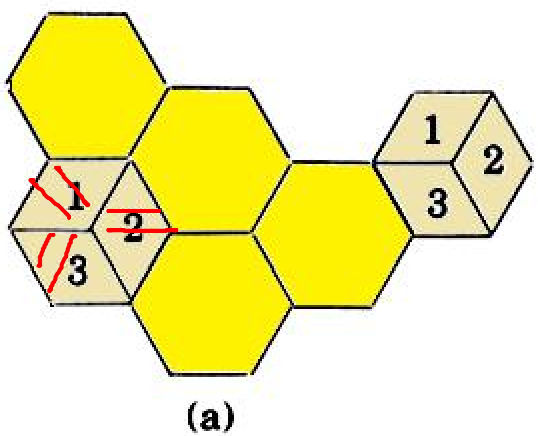
(c) There are total 17 base stations. Total no of channels = 17 x 60 = 1020 channel.

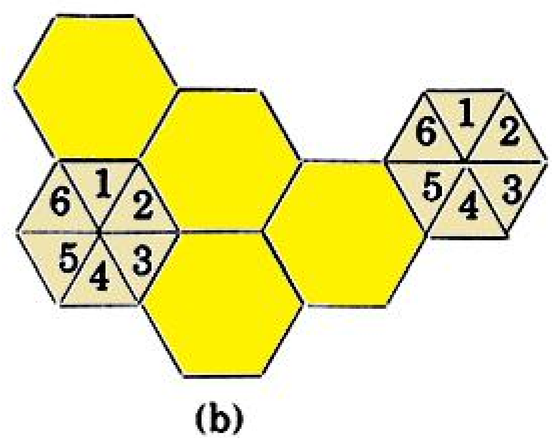
There is 3.4 times increase in capacity compared to case (a).



Sectoring

- The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called sectoring.
- By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells.
- A cell normally portioned into three 120 degree sectors or 60 degree sectors.





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

Sectoring

- Assuming 7-cells reuse, for 120°, the number of interferers in the first tire is reduced from 6 to 2. this is because only 2 of the 6 co-channels cells receive interference with a particular sectored channel group.
- Sectoring improves S/I.
- It increases the number of handoffs.

• more no. of antennas are required

• decreased trunking efficiency.

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

• Micro Cell Zoning.

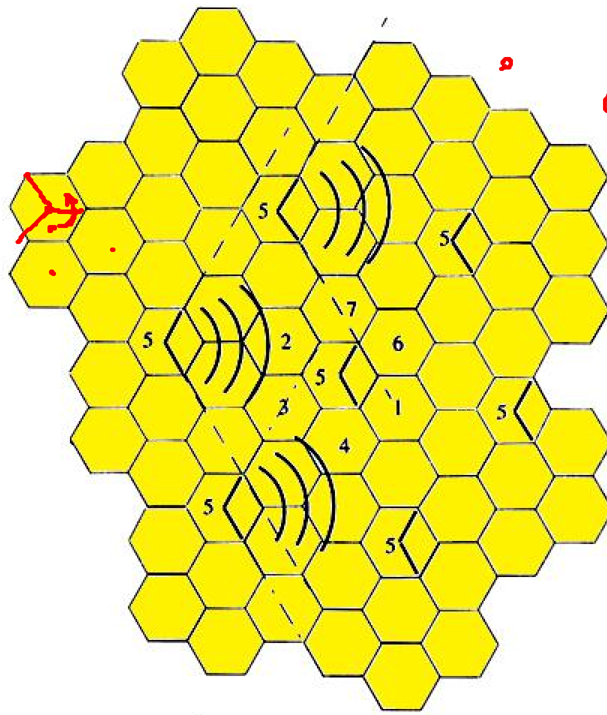


Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.