EXAMPLE 4.3 | Cell size and system capacity

(a) Assume a cellular system of 32 cells with a cell radius of 1.6 km, a total spectrum allocation that supports 336 traffic channels, and a reuse pattern of 7. Calculate the total service area covered with this configuration, the number of channels per cell, and a total system capacity. Assume regular hexagonal cellular topology.

(b) Let the cell size be reduced to the extent that the same area as covered in Part (a) with 128 cells. Find the radius of the new cell, and new system capacity.

Comment on the results obtained.

Solution

(a) *To calculate total service area, number of channels per cell, and system capacity*

Total number of cells in service area = 32 (given)

Radius of a cell, $R = 1.6$ km (given)

Step 1. *To calculate area of a regular hexagonal cell*

Area of a regular hexagonal cell, $A_{cell} = 3\sqrt{3}/2 \times R^2$

Therefore, $A_{cell} = 3\sqrt{3}/2 \times (1.6 \text{ km})^2 = 6.65 \text{ km}^2$

Step 2. *To calculate total service area*

Total service area covered = no. of cells in total area × Area of a cell

Hence, **total service area covered** = 32 × 6.65 = **213 km²**

Step 3. *To calculate number of channels per cell*

Total number of available traffic channels = 336 (given)

Frequency reuse pattern (cluster size) = 7 (given)

Hence, **number of channels per cell** = 336/7 = **48**

Step 4. *To calculate total system capacity*

Total system capacity = number of channels per cell × number of cells

Hence, **total system capacity** = 48 × 32 = **1536 channels**

(b) *Total number of available cells = 128 (given)*

Total service area = 213 km^2 (as calculated in Step 2)

Step 5. *To determine area of new regular hexagonal cell*

Area of a regular hexagonal cell = total service area / number of cells

= 213 km^2 / 128 = 1.66 km^2

Step 6. *To find radius of new smaller cell, R*

Area of a regular hexagonal cell = $3\sqrt{3}/2 \times R^2$

But, $3\sqrt{3}/2 \times R^2 = 1.66$ km^2 (as calculated in Step 5)

Or, $R = 0.8$ km

Hence, **radius of new smaller cell, *R* = 0.8 km**

Step 7. *To find new system capacity*

New system capacity = number of channels per cell × number of cells

New system capacity = 48 × 128

Hence, **new system capacity = 6144 channels**

Comment on the results It is observed that as the number of cells are increased from 32 to 128 to cover the same service area (213 km^2), the size of the cell (in terms of radius *R*) is decreased from 1.6 km to 0.8 km. Keeping the identical number of channels (48) per cell, total system capacity is significantly increased from 1536 channels to 6144 channels. Hence, cell size is one of the major factors to determine the system capacity for a given number of frequency channels allocated to serve the designated area.

EXAMPLE 4.5 | Frequency reuse and system capacity

A mobile communication system is allocated RF spectrum of 25 MHz and uses RF channel bandwidth of 25 kHz so that a total number of 1000 voice channels can be supported in the system.

(a) If the service area is divided into 20 cells with a frequency reuse factor of 4, compute the system capacity.

(b) The cell size is reduced to the extent that the service area is now covered with 100 cells. Compute the system capacity while keeping the frequency reuse factor as 4.

(c) Consider the cell size is further reduced so that the same service area is now covered with 700 cells with the frequency reuse factor of 7. Compute the system capacity.

Comment on the results obtained.

Solution

Number of available voice channels, $N = 1000$ (given)

Step 1. *To determine the cluster capacity*

We know that in a cellular system based on frequency-reuse concept, all the given available channels, that is, 1000, are allocated to each cluster uniformly.

Therefore, each cluster can serve 1000 active users simultaneously.

In other words, the capacity of a cluster = 1000

(a) *To compute the system capacity for given K*

Number of cells covering the area = 20 (given)

Frequency reuse factor or cluster size = 4 (given)

Step 2. *To determine number of clusters*

Number of clusters = number of cells/cluster size

Therefore, number of clusters = 20/4 = 5

Step 3. *To determine the system capacity*

The capacity of a cluster = 1000 (as calculated is Step 1)

Number of clusters = 5 (as calculated is Step 2)

Thus, number of channels in all 5 clusters = 1000 × 5 = 5000

Hence, **the system capacity = 5000 users**

(b) *To compute new system capacity for increased number of cells.*

Number of cells covering the area = 100 (given)

Frequency reuse factor or cluster size = 4 (given)

Step 4. *To determine number of clusters*

Therefore, number of clusters = 100/4 = 25

Step 5. *To determine new system capacity*

Thus, number of channels in all 25 clusters = 1000 × 25 = 25000

Hence, **the new system capacity = 25000 users**

(c) *To compute new system capacity for increased number of cells and cluster size.*

Number of cells covering the area = 700 (given)

Frequency reuse factor or cluster size = 7 (given)

Step 6. *To determine number of clusters*

Therefore, number of clusters = 700/7 = 100

Step 7. *To determine new system capacity*

Thus, number of channels in 100 clusters = 1000 × 100 = 100,000

Hence, **the new system capacity = 100,000 users**

Comments on the results It is observed that as the number of cells covering a given service area is increased the number of clusters having all available number of channels increases. This results into significant increase in the number of active users in the system or the system capacity. Hence, it is concluded that frequency reuse enhances system capacity.

K will increase cochannel interference.

EXAMPLE 4.6 | **Cellular system capacity**

Consider that a geographical service area of a cellular system is 4200 km². A total of 1001 radio channels are available for handling traffic. Suppose the area of a cell is 12 km².

(a) How many times would the cluster of size 7 have to be replicated in order to cover the entire service area? Calculate the number of channels per cell and the system capacity.

(b) If the cluster size is decreased from 7 to 4, then does it result into increase in system capacity? Comment on the results obtained.

Solution

Service area of a cellular system, $A_{sys} = 4200 \text{ km}^2$ (given)

Coverage area of a cell, $A_{cell} = 12 \text{ km}^2$ (given)

Total number of available channels, $N = 1001$ (given)

(a) To calculate number of clusters, cell capacity, and system capacity

Cluster size, $K = 7$ (given)

Step 1. *To calculate the coverage area of a cluster*

The coverage area of a cluster, $A_{cluster} = K \times A_{cell}$

Therefore, $A_{cluster} = 7 \times 12 \text{ km}^2 = 84 \text{ km}^2$

Step 2. *To calculate the number of clusters*

The number of times that the cluster has to be replicated to cover the entire service area of cellular system $= A_{sys}/A_{cluster}$

Or, number of clusters, $M = 4200/84$

Hence, number of clusters, $M =$ **50 clusters**

Step 3. *To calculate cell capacity*

Since total number of available channels are allocated to one cluster, therefore, the number of channels per cell, $J = N/K$

Or, cell capacity, $J = 1001/7$

Hence, cell capacity, $J =$ **143 channels/cell**

Step 4. *To calculate system capacity*

The system capacity, $C = N \times M$

Or, system capacity, $C = 1001 \times 50$

Hence, the system capacity, $C =$ **50,050 channels**

(b) To calculate new system capacity for reduced K

New cluster size, $K = 4$ (given)

Step 5. *To calculate the coverage area of a new cluster*

The coverage area of a cluster, $A_{cluster} = K \times A_{cell}$

Therefore, $A_{cluster} = 4 \times 12 \text{ km}^2 = 48 \text{ km}^2$

Step 6. *To calculate increased number of clusters*

The number of times that the cluster has to be replicated to cover the entire service area of a cellular system $= A_{sys}/A_{cluster}$

Or, number of clusters, $M = 4200/48$

Hence, number of clusters, $M =$ **87 (approx.)**

Step 7. *To calculate new system capacity*

The system capacity, $C = N \times M$

Or, system capacity, $C = 1001 \times 87$

Hence, the system capacity, C = **87,000 channels**

Comments on the results From (a) and (b) above, it is seen that for decrease in cluster size from 7 to 4 results into an increase in number of clusters from 50 to 87 for a given service area. The system capacity is increased from 50,050 channels to 87,000 channels. Therefore, decreasing the cluster size does increase the system capacity. However, the average signal-to-cochannel interference also increases which has to be kept at an acceptable level in order to achieve desirable signal quality.

Assume that the cell size is kept constant and a fixed spectrum per cluster is allocated. Then more number of cells per cluster (that is, higher value of K) means

- Fewer channels per cell
- Less system capacity
- Less co-channel interference (cochannel cells farther apart)

And less number of cells per cluster (that is, lower value of K) means

- More channels per cell
- More system capacity
- More cochannel interference (cochannel cells closer together)

So it is desirable to choose reuse factor K to maximise capacity per area subject to interference limitations.

EXAMPLE 4.7 | Cluster and system capacity

A cellular communication service area is covered with 12 clusters having 7 cells in each cluster and 16 channels assigned in each cell. Show that

(a) the number of channels per cluster are 112

(b) the system capacity is 1344

Solution

Number of clusters in the service area = 12 (given)

Number of cells in a cluster = 7 (given)

Number of channels in a cell = 16 (given)

(a) *To determine the number of channels per cluster*

Number of channels in a cluster is given by the number of cells in a cluster multiplied by the number of channels in a cell, that is,

Number of channels in a cluster $= 7 \times 16$

Hence, **number of channels per cluster = 112 channels/cluster**

(b) *To determine the system capacity*

The system capacity is given by the number of clusters in a given area multiplied by the number of channels in a cluster, that is,

Number of channels in the system $= 112 \times 12$

Hence, **the system capacity = 1344 channels/system**

Important Equations

- $K = i^2 + j^2 + i \times j$ (4.13)
- $q = D/R$ (4.14)
- $q = D/R = \sqrt{3K}$ (4.15)

Short-Answer Type Questions with Answers

A4.1 Why can the actual shape of the cell may not be either a circle or a regular geometrical shape?
The actual shape of the cell is determined by the desired received signal level by the mobile subscribers from its cell-site transmitter in its service area. The received signal is affected by many factors including reflections, refractions, and contour of the terrain as well as multipath propagation due to presence of natural and man-made structures. Therefore, the actual shape of the cell may not be either a circle or a regular geometrical shape but may be a zigzag shape which indicates a true radio coverage area. However, for proper planning and analysis of a cellular system, an appropriate model of a regular geometry shape is needed for the cell.

A4.2 Why can the cellular topology not be formed by using ideal circular shape?
The cellular topology formed by using ideal circular shape results into overlaps or gaps between them which is not desirable in cellular communications which has to be essentially continuous. It is highly desirable to construct the cellular system architecture such that the cells do not overlap, and are tightly packed without any dead signal spots. This form of cellular configuration requires the use of regular geometrical topologies (say, a regular hexagonal pattern) instead of a circular shape.

A4.3 Distinguish between a cell and a cell-site.
A cell is a wide geographical service area which is served by the base-station radio equipment and their antennas mounted on tall towers located at the centre of the cell. A cell-site is a location or a point at the centre of the cell which provides radio signal coverage to a cell.

A4.4 What is the significance of cell size?
Each cell size varies depending on the landscape. Typical size of a cell may vary from a few 100 metres in urban areas to several kilometres in the rural areas. Smaller cells are used when there is a requirement to support a large number of mobile subscribers in a small service area or when a low transmission power may be required to reduce the effects of interference. Large cells are employed in remote areas, coastal regions, and areas with few mobile subscribers.

A4.5 Mention the major limitations of conventional radio communication systems.
The inefficient spectrum utilisation, limited service area capability, inadequate system capacity, and lower grade of service. The conventional radio communication systems are usually designed for providing service in an autonomous geographic zone and by selecting RF channels from a specified allocated frequency band.

A4.6 What is the core concept of the cellular communications?
Frequency reuse is the core concept of the cellular communications. The plan of dividing the large geographic service area into many small contiguous cells and using a low-power transmitter with low antenna at base station in each cell is referred to as cellular communications. The design process of selecting and allocating channel groups for all the cellular base stations within a system is called frequency reuse planning.

A4.7 List few typical technical issues for proper design and planning of a cellular network.
The technical issues for proper design and planning of a cellular network include selection of a suitable frequency reuse pattern, physical deployment

and radio coverage modeling, plans to account for the expansion of the cellular network, analysis of the relationship between the capacity, cell size, and the cost of the infrastructure.

A4.8 What complications arise due to usage of smaller cells?
Smaller cells are needed in areas of the higher traffic demand. As cells become smaller, more cell-sites are needed and hand-off occurs more frequently. This requires more computing power and faster response both at the system level and in the individual mobile phone. Typically, once the radius drops below about 0.5 km the hand-offs occur so frequently that it is difficult to cope with a mobile moving at high speed.

A4.9 Assume that the allocated number of channels in a cluster are fixed and the size of each cell is kept constant. How will the system design be affected by choosing higher value of cluster size?
More number of cells per cluster (that is, higher value of cluster size) would mean less number of available channels per cell, less system capacity per cell, and lower cochannel interference because cochannel cells will be located farther apart with higher value of cluster size.

A4.10 How will the system design be affected by choosing a smaller value of cluster size?
Assuming that the allocated spectrum and the cell size is fixed, less number of cells per cluster (that is, smaller value of cluster size) would mean more number of available channels per cell, higher system capacity per cell, but increase in cochannel interference due to reduced distance between cochannel cells.

A4.11 List the factors to determine the minimum distance between cochannel cells.
The minimum distance between cochannel cells, which allows the same frequency to be reused in these cells, depends on many factors such as the number of cochannel cells in the vicinity of the centre cell, the type of geographic terrain contour, the cell-site antenna height and the transmitted power at each cell-site. Usually, the size of all the cells is approximately same and fixed. Then the cochannel interference is independent of transmitter power of each cell.

A4.12 What are the important parameters of the wireless communication network designed on cellular approach?
The three important design parameters in cellular architecture are frequency reuse pattern (K), frequency reuse distance (D), and frequency reuse factor (q). These are related to one another by the expression $q = D/R$. The frequency reuse factor determines the minimum distance between nearest cochannel cells for repeating a set of frequency channels.

A4.13 Can the value of cluster size be increased more than 7 to minimise the effect of cochannel interference?
In most mobile radio environments, use of cluster size $K = 7$ is not sufficient to avoid interference. But increasing the value of K more than 7 would reduce the number of channels per cell, assuming the available spectrum fixed in the system. This would result in reduction in the cell capacity and hence the spectrum efficiency. Therefore, there is trade-off among various system performance parameters such as system capacity, spectrum efficiency and signal quality so as to determine the optimum value of cluster size.

A4.14 How is signal quality affected by employing frequency reuse concept in cellular communication systems?
The frequency reuse method is useful for increasing the efficiency of spectrum usage but results in cochannel interference which degrades the received signal quality. Cochannel interference occurs equally in all available channels in a given area assuming non-selective fading channel environment. Since the cochannel interfering signals are amplified, processed and detected in the same manner as the desired signal, the receiver is particularly vulnerable to these emissions. Thus, cochannel interference may either desensitise the receiver or override or mask the desired signal. It may also combine with the desired signal to cause serious distortions in the detected output.

A4.15 What could be the possible sources of interference which may limit the performance of cellular communication systems?
Interference is the major limiting factor in the performance of cellular communication systems.

Short-Answer Type Questions with Answers

A6.1 What is meant by frequency management?
Frequency management refers to dividing the allocated radio spectrum into the total number of available channels depending on the channel bandwidth of a given cellular system. It includes the functions such as designating the set-up or control and signaling channels, designating and grouping the voice or traffic channels into subsets, and numbering the channels for frequency-planning purpose.

A6.2 Distinguish between uplink and downlink.
Each communication link involves a pair of frequency channels that allows for full duplex operation. In an uplink, the signal transmission takes place from the mobile subscriber transmitter to the cell-site receiver. Uplink is also referred to as reverse channel link. In downlink, the signal transmission takes place from the cell-site transmitter to the mobile subscriber receiver. Downlink is also referred to as forward channel link. The uplink and downlink are always separated in frequency by a specific value termed as duplex separation.

A6.3 Why is it necessary to form frequency channel groups?
The frequency planning of the cellular network is required to meet specific objectives which include avoiding the assignment of adjacent channels in the same cell, keeping the desired channel separation within each cell, use of combiner–tuner network device to allow a single antenna to transmit signals from multiple cells/sectors, and making cluster designing easier. The process of forming the frequency channel groups out of available channels is necessary to meet these requirements of the frequency planning in the cellular network.

A6.4 State the reason for assigning 21 set-up channels each from channel numbers 313–333 in Block A and 334–354 in Block B in US-AMPS analog cellular system.
A total of 42 set-up channels (21 channels each in Block A and Block B) are numbered in the middle of all the assigned channels, that is, channel numbers 313–333 in Block A and 334–354 in Block B. This is deliberately done in order to facilitate scanning of all these set-up channels continuously by a frequency synthesizer in the mobile receivers which can be same equipment operating either in Block A or Block B.

A6.5 What is the need of set-up channels? Classify them.
Set-up channels are control channels, which are primarily used to set up the calls. All set-up channels carry signaling data information only. Each cell or sector of a cell requires at least one set-up channel. According to the nature of their usage, set-up channels can be classified as access channels and paging channels. An access channel is used by the mobile subscribers to access the system for the mobile-originating calls and paging channels are used by the base stations for mobile-terminating calls.

A6.6 How are voice channels assigned for establishment of voice calls?
The assignment of certain sets of voice channels in each cell is based on causing minimum cochannel and adjacent channel interference. For mobile-originating calls, the mobile unit selects a cell-site based on its received signal-strength indicator (RSSI) value on a set-up channel. The call request from a mobile unit is received by the cell-site on the reverse set-up channel (access channel). The cell-site scans the RSSI of incoming signals and determines which sector out of three sectors of a cell has the maximum RSSI value. The MTSO then assigns a suitable voice channel from the available voice channels in that sector.

A6.7 Define channel assignment. Differentiate between static and dynamic channel assignment.
Channel assignment refers to the allocation of specific channels to cell-sites on long-term basis, and to mobile units on a short-term basis during a call. In static channel assignment, the available channels are divided into number of groups of fixed channels each cell is assigned to one of these groups of channels. In dynamic channel assignment, the central pool of channels keeps all the available channels. Channels are assigned dynamically as new requests for radio resource (for a new originating call or hand-off of existing call) arrive in the system.

A6.8 Under what circumstances, is static channel assignment normally used?

The static channel assignment procedure is acceptable as far as the cellular system has uniform distribution of mobile subscribers in a given service area and fully meets the capacity requirement within the available radio resources.

A6.9 List few advantages and disadvantages of fixed channel-assignment scheme.

There are certain advantages of fixed channel-assignment scheme such as fixed characteristics (power, frequency) for transceivers, reasonably acceptable performance under uniform and/or high traffic loads, and non-requirement of run-time coordination as cells independently decide their channel-assignment decisions. The disadvantages of fixed channel-assignment scheme, the problem of hot spots or localised traffic congestion which necessitates the channel borrowing from neighbouring cells.

A6.10 Assuming constant traffic density in all the cells, how the channels are assigned to each cell using fixed channel-assignment scheme?

The channel-assignment algorithm in fixed channel assignment (FCA) scheme is very straightforward. The total numbers of available channels are simply divided by the cluster size of the system and assign this number of channels to each cell. The FCA strategy is simple to implement, and it remains unchanged with time.

A6.11 Fixed channel-assignment scheme does not utilise the available spectrum efficiently. Justify this statement.

In practice, traffic in each cell is not constant and it changes with time due to the movement of mobile subscribers from one cell to another. This results in higher probabilities of call blocking in some cells due to non-availability of voice channels and lower probabilities of call blocking in other cells. This results in poor utilisation of the available spectrum.

A6.12 Suggest some means to equalize the poor utilisation of channels in all cells under fixed channel-assignment scheme in practical cellular systems.

The simplest solution is that the cells with higher traffic density should somehow use the free channels available in low traffic density cells. This is possible by a nonuniform assignment of channels to cells. With a nonuniform fixed channel-assignment technique, the channel-assignment algorithm takes into consideration the expected traffic and the call-blockage probability in each cell. Other means to improve the channel utilisation includes channel sharing and channel borrowing strategies with the assistance of neighbouring cells.

A6.13 List few channel-sharing algorithms in fixed channel-assignment scheme.

The most popular channel-sharing algorithms include ordered channel assignment scheme with rearrangement, channel assignment with sharing and reassignment, and temporary channel borrowing. There are relative advantages and disadvantages of different channel-sharing algorithms in terms of total channel utilisation, total carried traffic, and assignment complexity. Implementation of a particular scheme is based on the traffic behaviour and system parameters.

A6.14 Which channel-assignment approach can be effectively deployed to handle increased traffic situation?

One approach to address increased traffic of either originating calls or hand-off calls in a cell is to borrow free available channels from neighbouring cells. Only those channels should be borrowed which do not cause any interference with cells within reuse distance associated with these clusters. Alternatively, a larger cell is to split it into a number of smaller cells inside a cell in an overlapped cells-based system with different channels assigned to them.

A6.15 What are different ways to implement borrowing channel-assignment scheme?

One way could be to use fixed channel assignment in the beginning. When all the fixed channels are occupied, then the cell borrows channels from the neighboring cells. Another way could be to divide the available channels per cell into two groups, one group assigned to each cell permanently and the second group kept reserved for borrowing by its neighbouring cells. Another way could be borrowing with channel ordering in which priorities to all channels of each cell are assigned, and then used in a sequential priority order.