IMPROVING CHANNEL CAPACITY OF A CELLULAR SYSTEM USING CELL SPLITTING

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Abstract-As the number of users in a cellular system increases, the traffic per unit time also increases. The allocated spectrum becomes gradually congested and eventually becomes used up. Congestion of the spectrum means that the call blocking probability has increased and this is not desired in the system. This paper presents cell splitting as a technique of improving channel capacity in cellular communication system. It also went further to show that increase in channel capacity directly reduces call blocking probability and call delay probability. The results are simulated and shown using Matlab .

Key Words: *Frequency reuse, footprint, cell*

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1.0 Introduction

The developments in wireless communication networks over the past couple of decades have been enormous and have become ubiquitous in modern days.

It is commonly assumed that the next generation of wireless communication networks will be heterogeneous, with different types of wireless network and technologies co-existing [1].

There are currently many different types of wireless networks. Wireless local area networks and cellular networks are by far the most dominant wireless networks of our generation and have still sparked numerous research studies. [2]

The design objective of early mobile radio systems was to achieve a large coverage

area by using a single, high powered transmitter with an antenna mounted on a tall tower. While this approach achieved very good coverage, it also meant that it was impossible to reuse those same frequencies throughout the system, since any

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attempt to achieve frequency reuse would result in interference. For example, the Bell mobile system in New York City in the 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles. Faced with the fact that government regulatory agencies could not make spectrum allocations in proportion to the increasing demand for mobile services, it became imperative to re-structure the radio telephone system to achieve high capacity with limited radio spectrum while at the same time covering very large areas [3].

The idea of cellular network goes back as early as 1947, and it was thought that instead of using just one high-powered antenna to cover an entire metropolitan area, we should employ several lower powered antenna base stations scattered throughout the city, thereby breaking a macro-cell into several smaller micro-cells.

The spectrum is then divided such that the base stations of each of these micro-cells would be able to use a certain frequency band or channel without being affected too much by neighboring cells (i.e., to avoid inter-cell interference) [4].

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a cell. Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. The base station antennas are designed to achieve the desired coverage within the particular cell. By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits.

2.0 **Frequency Reuse concept in cellular Network**

The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning . Figure 1 illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the same group of channels. The hexagonal cell shape shown in Figure 1 is conceptual and is a simplistic model of the radio coverage for each base station, but it has been universally adopted since the hexagon permits easy and manageable analysis of a cellular system. The actual radio coverage of a cell is known as the footprint and is determined from field measurements or propagation prediction models.

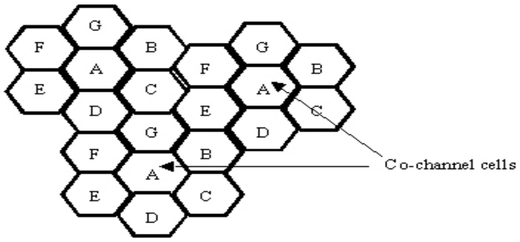

Fig1:Cellular Network with Frequency Re-use

When using hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell (center-excited cells) or on three of the six cell vertices (edge-excited cells). Normally, Omni directional antennas are used in center-excited cells and sectored directional antennas are used in corner-excited cells[5]. Practical considerations usually do not allow base stations to be placed exactly as they appear in the hexagonal layout. Most system designs permit a base station to be positioned up to one-fourth the cell radius away from the ideal location [6].

2.1 Improving Capacity in Cellular Network

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users. At this point, cellular design techniques are needed to provide more channels per unit coverage area. Techniques such as cell splitting, sectoring, and coverage zone approaches are used in practice to expand the capacity of cellular systems. Cell splitting allows an orderly growth of the cellular system. Sectoring uses directional antennas to further control the interference and frequency reuse of channels. The zone microcell concept distributes the coverage of a cell and extends the cell boundary to hard-to-reach places. While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station to oversee all handoff chores related to the microcells, thus reducing the computational load at the mobile switching centre (MSC) [7].

2.2. Cell Splitting

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. By defining new cells which have a smaller radius than the original cells and by installing these smaller cells (called microcells) between the existing cells, capacity increases due to the additional number of channels per unit area [8].

The consequence of the cell splitting is that the frequency assignment has to be done again, which affects the neighboring cells. It also increases the handoff rate because the cells are now smaller and a mobile is likely to cross cell boundaries more often compared with the case when the cells are big. Because of altered signaling conditions, this also affects the traffic in control channels [9].

A typical example of cell splitting is shown in Figure 2. Here, it is assumed that the cell cluster is congested and as a result, the call blocking probability has risen above an acceptable level. Imagine if every cell in the cluster was reduced in such a way that the radius, R of every cell was cut in half, (R/2). In order to cover the entire service area with smaller cells, approximately four times as many cells would be required. The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and thus capacity, in the coverage area. In the example shown in Figure 2, the smaller cells were added in such a way as to preserve the frequency reuse plan of the system. In this case, the radius of each new microcell is half that of the original cell.

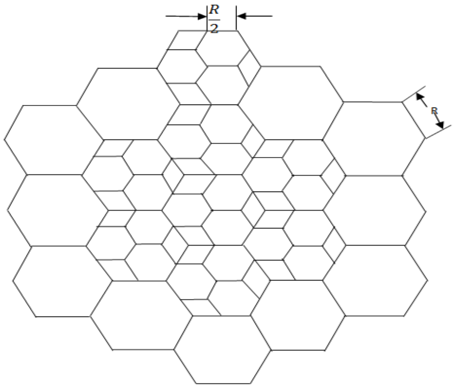

Fig 2 : Each cell in a cluster is split into approximately four smaller cells by reducing R by half.

For the new cells to be smaller in size, the transmit power of these cells must be reduced. The transmit power of the new cells with radius half that of the original cells can be found by examining the received power ,$P_{r,}$ at the new and old cell boundaries and setting them equal to each other. This is necessary to ensure that the frequency reuse plan for the new microcells behaves exactly as for the original cells. For Figure 2,

$$P_r[\text{old cell}] \propto Pt_1 R^{-n} \qquad (1)$$

and

$$P[\text{new cell}] \propto Pt_2 \left(\frac{R}{2}\right)^{-n} \qquad (2)$$

where Pt_1 and Pt_2 are the transmit powers of the larger and smaller cell base stations, respectively, and n is the path loss exponent. If we take $n = 4$ and set the received powers equal (that is, assume perfect power control) to each other, then

$$Pt_2 = Pt_1/16 \qquad (3)$$

In other words, the transmit power must be reduced by 12 dB in order to fill in the original coverage area with microcells, while maintaining the *S*/*I* requirement [2].

3.0 Result and Analysis

In this paper we considered a cellular system shown in Figure 3, where the original cells have radius R which equal to 2 km. The cellular system covers an area of 6 km x 6 km whose call blocking probability Pr[blocking] and call queuing (delay) Pr[delay] has risen beyond an acceptable level. These cells need be split into smaller cells and must have equal number of channels no matter how small it becomes after splitting

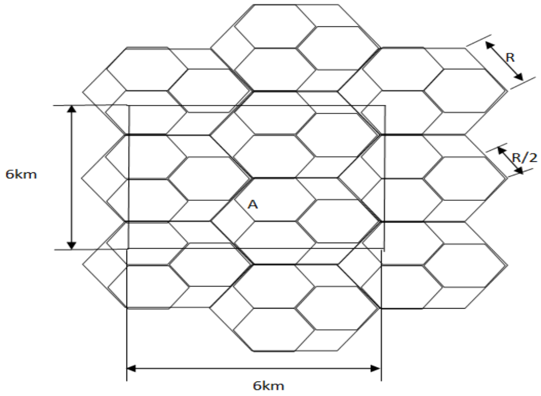

Fig 3: System Under Consideration

3.1 System Parameters

The various parameters which are directly related to models under consideration in this work are described in table 1 below. These parameters are constant which have been assumed to enable us successfully analyze the various mathematical models used in this paper.

Table 1: Numerical Parameters and their Values

S/No	Parameters	value
1	capacity (C)	229
2	cluster (K)	7
3	total offered traffic (A)	500
4	signal-to-interference ratio (S/I)	18.999 dB
5	desired signal power (S)	(64-74) dB
6	summation of interfering power	(3.4-3.9)dB

The probability that a new call is blocked given by the Erlang B formula [9] was evaluated for different value of channels in ascending order using Matlab. The corresponding values of call blocking probabilities are tabulated against the number of channels as shown below in table 2

Table 2: Blocking probabilities and number of channels

S/No	Pr[blocking]	number of channels
1	0.8902	100
2	0.8422	200
3	0.8276	300
4	0.8081	1000
5	0.8054	1500

3.2 Impact of Increase in Capacity on Call Delay Probability (Pr[delay]).

The probability that a call is delayed or queued given by the Erlang [10] was evaluated for different value of channels in ascending order using Matlab. The corresponding values of call delay probabilities are tabulated against the number of channels as shown below in table 3.

Table 3: Call probabilities evaluated from channel capacity

s/no	Pr[delay]	number of channels
1	0.5954	12
2	0.0460	18
3	0.0013	21

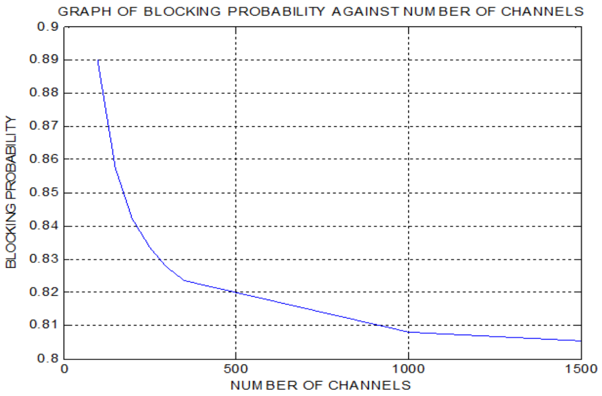

Fig 4: Graph of blocking probability against number of channels

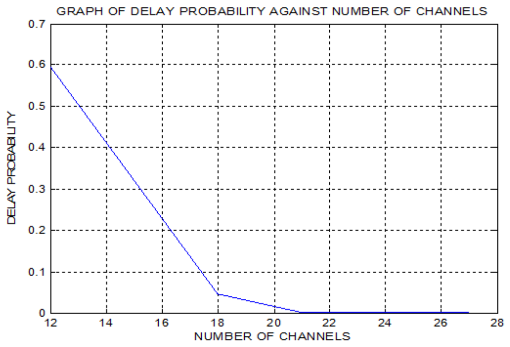

Fig 5: Graph of delay probability against number of channels

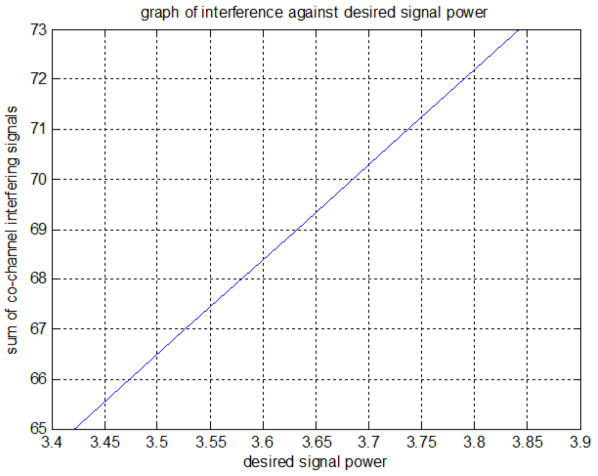

Fig 6: Graph of interference against desired signal power

4.0 Summary of Results

The probability that a new call is blocked represented as Pr[blocked] is plotted against channel capacity in Figure 4. The result shows that as the channel capacity increases, the call blocking probability Pr[blocked] reduces until a point when it becomes constant. Figure 4 proves that more calls is allowed in the system as the channel capacity increases.

The probability that a new call is queued or delayed Pr[delayed] is plotted against channel capacity in Figure 5. The graph shows that as the channel capacity increases, the call delay probability decreases until it becomes constant as it tends to zero (0). From the graph, it could be seen that the number of calls delayed in the system is reduced as the channel capacity increases.

The sum of all co-channel interfering signals is plotted against the desired signal power in Figure 6. The result shows a linear relationship between the desired signal power and the sum of co-channel interfering signals. Therefore, to ensure that the system function properly, the power of the desired signal must chosen such that the resultant co-channel interference is manageable.

5.0 Conclusion

In conclusion, the capacity of a cellular communication system can be increased using cell splitting. The extent to which the capacity increment can be achieved is dependent on signal-to-interference ratio of the system after the cell splitting. The increment in channel capacity after cell splitting helps to reduce the call blocking probability and call delay or queuing probability. The results show that when properly and orderly carried out, the cell splitting technique has the capability of increasing the capacity of a congested cellular system.

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