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Optimisation of Cellular Network System using Frequency-Reuse Technique

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Abstract
This paper presents a technique called "Channel Reuse" that can be employed by cellular network operators as an antidote to the challenges of limited channels in radio communication. This frequency reuse plays a key role in improving system capacity and spectral efficiency. In order to realise this, a simulated work has been carried out aimed at providing mobile telephone services to 32,000 subscribers within a landmass area of 4 Km^2 using only 500 channels. This has been implemented using winprop software. In addition, an analytical solution has equally been proffered to complement the simulated work. The overall results show that for efficient cellular radio communication system, a good engineering design work is necessary in order to guarantee good signal quality, wider coverage, stem dropped call and call failure rate.
Keywords: Frequency reuse, co-channel interference, cellular system, traffic

Introduction
Any cellular radio system mainly depends upon an intelligent assignment and reuse of channels (or frequency) throughout the coverage regions [5]. This reuse of frequency enables a cellular system to handle a huge number of channels. Frequency reuse is one of the fundamental concepts in which commercial wireless systems are based that involve the partitioning of an RF radiating area into cells [6]. Here, two or more cells can be adapted to use the same radio channels. Cells that use the same set of frequencies are referred to as co-channel cells. In doing this, careful planning is necessary in order to avoid performance degradation due to co-channel interference. As such, frequency isolation method is adopted i.e neighbouring cells are allocated channels which are completely different from that of co-channel cells. In the design of cellular systems, several shapes (i.e circle, square, hexagon) can be used to model cells. But a hexagon is considered the most ideal since it approximates circular coverage from a centrally located base station and it offers a wide range of cluster size determined by the relationship

$$N = i^2 + ij + j^2 \quad (1)$$

Where N is the cluster size, i and j are positive integers. For proper planning, it is also necessary to use a cluster size such that all the cells fit together to cover the desired service area without leaving any gaps. Figures 1a and 1b show the model for a hexagonal shaped cell and seven cell cluster.

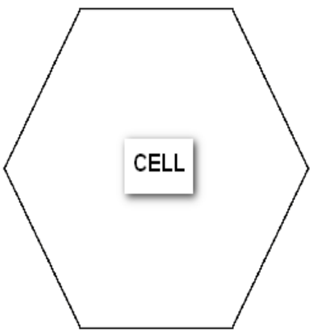

Figure 1a. Hexagonal shaped cell.

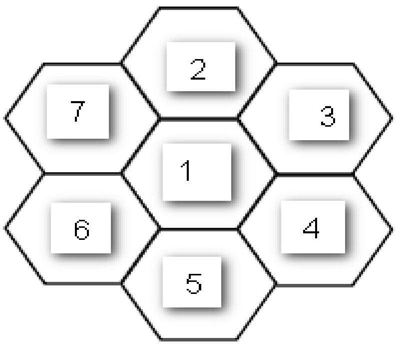

Figure 1b. seven-cell cluster

Considering Figure 1b and assuming that all the allocated channels have been used, the frequencies allotted to cell 1 can be repeated outside the cluster. This will definitely accommodate more users and invariably expand systems capacity. How far apart the two co-channel cells can be (reuse distance), is of major technical consideration to cellular operators. This (reuse distance) can be determined in terms of cell radius and is given by

$$D = \sqrt{3NR} \quad (2)$$

Where D is reuse distance, N is the number of cells in the cluster and R is the cell radius.

Design Analysis
The following parameters shown in Table 1.0 have been used in the design work.

Table 1.0 Design specification.

S/N	Parameters	values
1	Total no of channels	500
2	Number of users per Km^2	8,000
3	Landmass area	2 X 2 = 4 Km^2
4	Total no of users	32,000
5	Probability of blocking	0.02
5	Probability of network availability	0.98
6	Standard deviation of fading margin	8 dB
7	Transmission frequency	1800 MHz
8	Antenna type	Isotropic
9	Threshold power	-95 dBm

Design Consideration:- In the implementation of the above, it has been assumed that each user makes an average of two (2) calls per hour and each call lasts for four (4) minutes. This will provide useful information in the estimation of traffic intensity.

IMPLEMENTATION.

OPTION A (3-cell cluster without channel reuse)

- $Total\ no\ of\ channels\ per\ cell = \frac{500}{3} = 166$
- $Offered\ traffic\ at\ 2\%\ grade\ of\ service = 152.55$Erlang/Cell (from Erlang B traffic Table)
- $Carried\ traffic = 152.55\ X\ 0.98 = 149.499$ Erlang/Cell.
- $Total\ traffic\ to\ be\ carried = 149.499\ X\ 3 = 448.497\ Erl.$
- $Traffic\ intensity = 2\ \times \frac{4}{60} = 0.133$
- $Total\ no\ of\ users = \frac{total\ carried\ traffic}{traffic\ intensity} = \frac{448.497}{0.133} = 3{,}372\ Users.$

Going by the result shown above, only 3,372 users could be accommodated on the network. This is just a fraction (10.5%) of the entire population which clearly indicates that a 3-cell cluster will not yield the desired result. The next line of thought will be consideration of channel reuse.

OPTION B (3-cell cluster with channel reuse)

When opting for channel reuse, one of the most likely problems to be encountered is the co-channel interference. Since it is a 3-cell reuse, the reuse distance (D) would be small and this can give rise to a high co-channel interference. A possible way out is to reduce the transmitter power at the base station and this was actually implemented in the simulation work. Also, a sectorised antenna can be used. With this 3-cell reuse, a total number of 28 cells have been suggested with likelihood of an effective coverage.

- $Carried\ traffic\ per\ single\ cell = 149.499\ Erl.$
- $Suggested\ no\ of\ cells = 28$
- $Total\ traffic\ to\ be\ carried\ by\ 28\ cells = 149.499\ \times\ 28 = 4185.972\ Erl$
- $Total\ no\ of\ users = \frac{total\ carried\ traffic}{traffic\ intensity} = \frac{4185.972}{0.133} = 31{,}473\ Users.$

This value 31,473 corresponds to 98.4% of the total intended users (32,000) to be served. This is still within acceptable limit of the given specification. It therefore implies that 28 cells of 3-cell cluster reuse would meet the demand in this area.

OPTION C (Alternative option) 7-cell cluster with channel reuse.

Apart from a 3-cell cluster reuse, a 7-cell cluster reuse could also be deployed. This will use a total number of seventy one (71) cells. The design analysis is as presented below.

- $Total\ no\ of\ channels\ per\ cell = \frac{500}{7} = 71$
- $Offered\ traffic\ at\ 2\%\ grade\ of\ service = 60.08$ Erlang/Cell.
- $Carried\ traffic = 60.08\ X\ 0.98 = 58.88$ Erlang/Cell.
- $suggested\ no\ of\ cells\ to\ be\ reused\ = 71\ cells$
- $Total\ traffic\ to\ be\ carried = 58.88\ X\ 71 = 4180.48\ Erl.$
- $Total\ no\ of\ users = \frac{total\ carried\ traffic}{traffic\ intensity} = \frac{4180.48}{0.133} = 31{,}432\ Users.$

This value (31432) equally covers about 98% of the intended users and is considered acceptable. Option B (3-cell reuse) uses a total number of 28 cells in its implementation while option C (7-cell reuse) makes use of 71 cells. A 3-cell reuse has therefore been considered more appropriate over 7-cell. To this end, the former (option B) has been adopted in our implementation. This is because implementation of 7-cell reuse is more expensive than the 3-cell reuse. For example, every cell site (base station) requires huge investment in terms of tower, R-F transmission equipment, power generators and fuelling, personnel cost on security guard etc. These operational costs will lead to high service charges by the operator, a situation that will be unbearable to subscribers. Therefore, proper network planning is essential in order to achieve operational efficiency and good service delivery.

Our implementation is as shown (diagrammatically) in Figures 2a and 2b and followed by the simulation work.

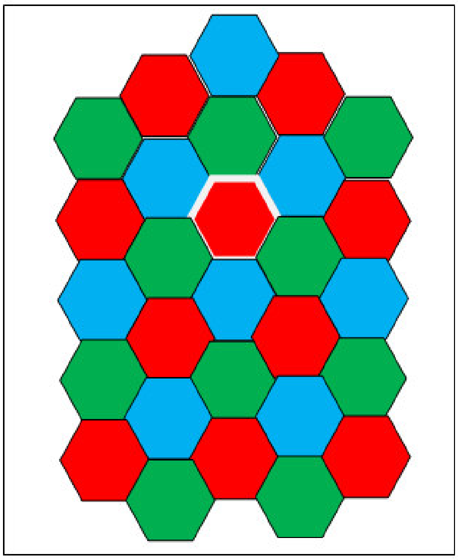

Fig. 2a. 28 cells arranged with reused channels

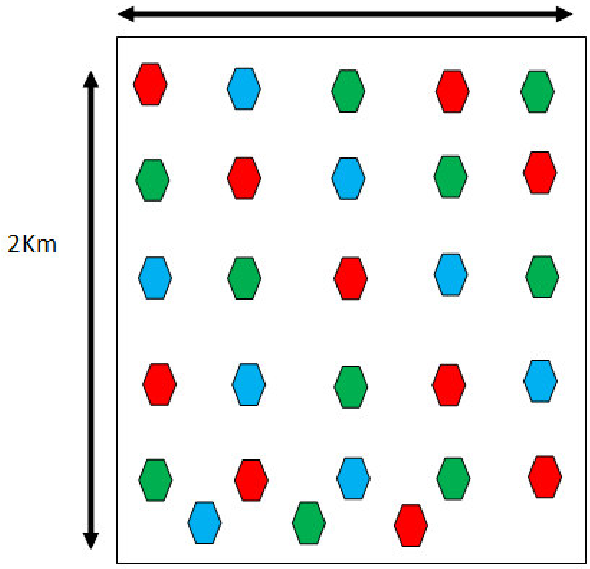

Fig.2b arrangement of the cells within the 2X2 landmass

Arrangement of the 28 cells are as shown in Figure 2a with adjacent cells having different channels. The reused channels are alternated to minimise co-channel interference. Figure 2b shows the placement arrangement of the cells within the given landmass area of 4 Km^2. An assumption has been made here that the terrain is very flat. But in the real life situation, antenna heights would vary depending on the topological nature of the area. This, actually reflected in the implemented work whereby several portions of the landmass have different altitudes due to the building heights. Since the antennas were mounted on top of the buildings, different heights were realised.

SIMULATION

The above has been simulated using Winprop software. The 2 X 2 Km^2 area was realised on the map by selecting points 514000 to 516000 along X axis and 5034000 to 5036000 along Y axis. The building height feature on the winprop was enabled in order to reveal relative building heights within the area map. Following these, the antennas were carefully placed on some selected buildings at a maximum height each of 4m above the buildings. It is necessary to mention here that the buildings have varying heights and this in turn implies that all the antennas acquired different heights. The first feature that was examined is the power profile and the result obtained is as shown in Figures 3a and 3b.

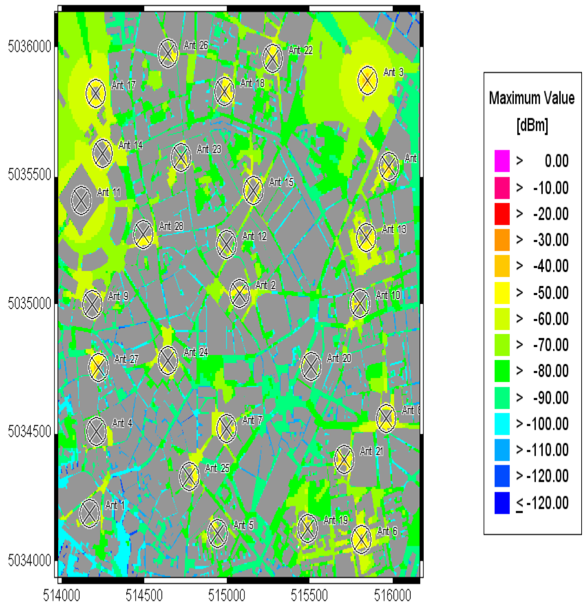

Figure 3a. power profile plot using 0.1Watt at each base station

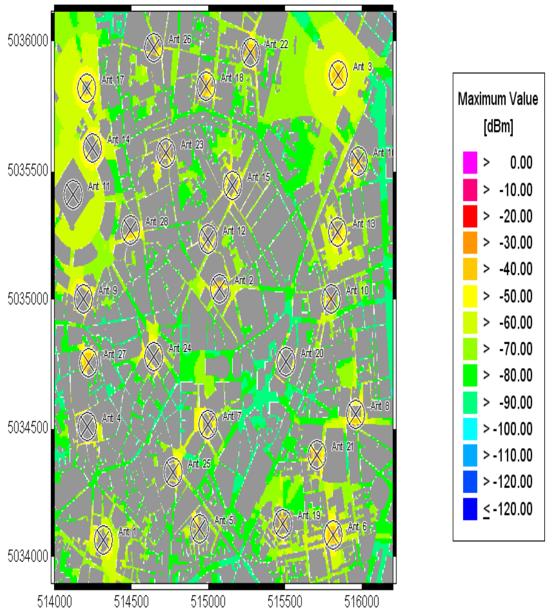

Figure 3b. plot showing base station power at 1Watt

Presented above are power profile plots at two different power levels (0.1W and 1W). Figure 3b gave a much better result than Figure 3a. For example, in the neighbourhood of base stations 1, 3, 4 and 9, little traces of shadow zones exist (Figure 3a) where the power level falls within -120 dBm which is far below the threshold level. By implication, it means that mobile communications within such areas would be marred by call failure and dropped calls. A little improvement in this is seen in Figure 3b when the transmitter power was increased to 1Watt. Another observation in Figure 3a is that the antenna (antenna 1) was placed on top of a 14m - high building and having a nearby building which is 55m high thereby causing signal blockage. This antenna was subsequently removed and placed on the 55m high building (Figure 3b) which is the tallest around. The result gave a much better improvement in signal level as shown in Figure 3b.

Further to this, the signal-to-co-channel interference was investigated and the result is as presented in Figure 4.

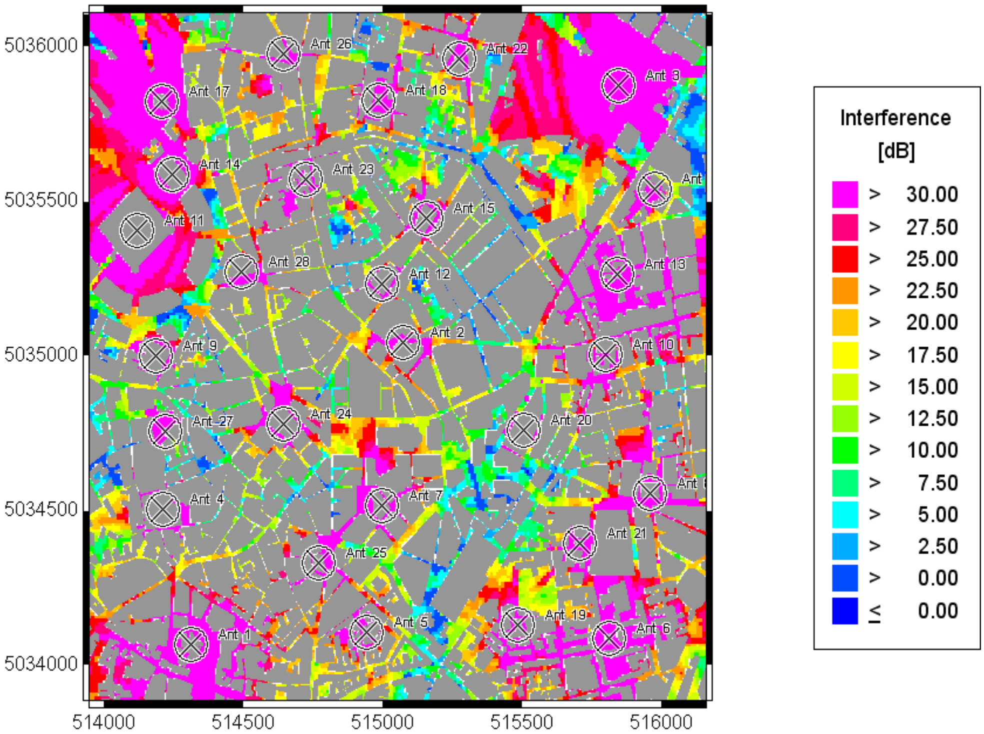

Figure 4. Co-channel interference plot.

Figure 4 shows the result for signal to co-channel interference. Generally, most parts of the area map have good signal level of above 17.5 dB which is an indication of low co-channel interference. In the design work, 18.66 dB has been obtained as our co-channel interference estimated value. This value represents a region of good signal quality with less CCI. Though, little interference is observed at some points within the area map especially where the signal power falls below 2.5 dB. This is due to different cells having same channels. The most practical way of minimising this is to increase the effective distance between the co-channel cells. This will subsequently improve transmission quality. Also, a sectorised antenna may be used at some points.

In addition, the possible number of channels that can be received at any point within the area map was investigated and the result is as shown in Figure 5.

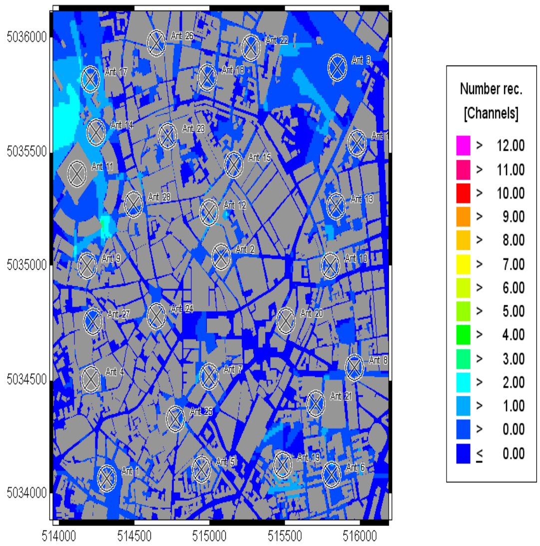

Figure 5a. Plot for 0.1Watt

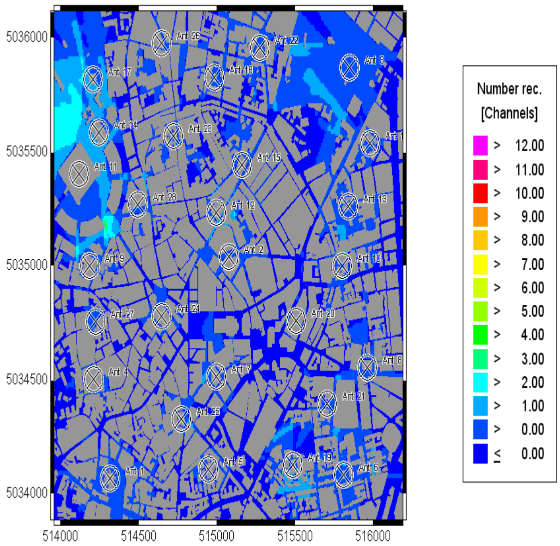

Figure 5b. Plot for 1Watt.

Presented above (Figures 5a & 5b) is the plot for possible number of channels to be received by prospective users at any location within the area map. It clearly shows that in most locations, users can receive only one channel while at few locations there are possibilities of receiving up to three channels. This can be seen around base stations 1, 3, 9, 11, 14, 17 and 19. But it desirable that only one channel be received at any point for better efficiency. Also, there is no clear difference between the plot for 0.1Watt power and 1Watt. It can therefore be suggested that Figure 5a is preferable due to its power budget.

Conclusion

This paper has demonstrated that the concept of frequency reuse is fundamental to cellular system. The concept allows repeated use of available limited resources so as to enhance system capacity. Also, it was shown that for efficient cellular communication that guarantees wider coverage, low interference and increased capacity, a good engineering design work coupled with proper planning and management of network resources is essential. Other area that may be explored to further enhance service delivery is to adopt an efficient channel assignment strategy. This will ensure effective utilisation of limited radio spectrum with reduced call blocking.

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