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ORIGINAL RESEARCH PAPER

Novel simple algorithm for frequency planning and optimization in cellular networks

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ABSTRACT

One of the most expensive components of constructing a cellular network is frequency planning. The cost of building and maintaining a network will be reduced if a set of base stations can be established with minimal service and preparation. Planning and optimization are carried out to guarantee that the scarce frequency is used to its maximum capability. The goal of this paper is to provide an autonomous method for planning and optimizing frequency in cellular networks. The method substitutes the inefficient, inaccurate, and time-consuming manual method. The automatic technique makes work easier for radio frequency (RF) engineers and lowers operating costs. Also, this article provides an autonomous planning and optimization technique that reduces intra-system interference levels to acceptable levels within the key performance indicators (KPIs) set for any suitable cellular network.

KEYWORDS

frequency planning, optimization algorithm, cellular networks

1. INTRODUCTION

Radio waves of a specific frequency are utilized to maintain a successful connection between users in the same or separate cellular networks. The nearest accessible base transceiver station receives and transmits the radio signals (BTS). In addition to communication in one direction, the BTS is also utilized for communication in the other direction. A BTS is made up of one or more transceivers known as TRXs, which are represented by carriers. A unique operational frequency is assigned to each TRX. The available radio frequency is divided into channels of uniformly sized slots. Every TRX in the BTS must be assigned a channel [1].

Interference is very likely to occur when two TRXs use nearby or the same channels. Adjacent-interference and co-channel interference are the two types of interference. The link's quality degrades as the level of interference rises. Every BTS (in a cluster) is given a different carrier frequency, and every cell is given a usable bandwidth for that carrier. The number of carrier frequencies available is limited since only a small portion of the radio spectrum is allotted to cellular radio. This means that the existing frequencies must be reused multiple times in order to supply enough channels to meet the demand. This presents the idea of frequency reuse, as well as the potential for interference between cells utilizing the same carrier frequencies, which will be reduced. The frequency reuse technique is widely used in cellular networks to mitigate the interference experienced by the users at the expense of lower spatial bandwidth efficiency [1–2].

The final step in the designing of global systems for mobile communication (GSM) networks is frequency planning in cellular networks. Prior to solving this issue, the network designer must handle other challenges such as where to place the BTSs and how to establish the antenna configuration parameters (tilt, azimuth, etc.). Once BTS sites have been determined for each sector, they must be fixed. The number of BTS sites depends on the traffic demand that the corresponding sector has to support. This procedure yields a certain number of TRXs per cell as a consequence. Every TRX must be assigned a channel, which is the algorithm's main goal [3–4].

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Over the last decade, cellular telephony has risen to prominence as the primary mode of wireless communication. The need to provide mobile telephony services drives the widespread development of cellular networks to enhance capacity in terms of user numbers. However, radio spectrum is a finite resource, preventing endless increases in user-based capacity [1]. As a consequence, radio frequencies must be efficiently utilized for thousands of transceivers by taking use of a fundamental aspect of radio wave propagation: signal strength decreases as distance rises. After a safe minimum distance has been reached, at which cells with the same frequency (co-channels) do not interfere, the cells are reused. Frequency reuse is the core concept of cellular mobile radio. Users in different geographical areas (in different cells) may simultaneously use the same frequency. Frequency reuse drastically increases user capacity and spectrum efficiency, and if generating a new frequency means that the standard of BTS infrastructure (GSM standard) must be changed with the frequency band, the communication channel is also limited by the frequency band standardization. And if every time a new frequency is generated, it means that it is not possible to provide a channel to a huge number of frequencies. This is the reason why it is better to reuse a frequency instead of generating a new one [1–3].

To avoid in-band interference, no two-neighbor cells/sites use neighboring frequencies. Frequency planning is essential to comply with the cellular frequency reuse principle. Manual frequency planning has become obsolete in this area due to its computational slowness and inability to address the conditional interdependencies of a large number of transmitter sites [1]. The paper proposes a novel strategy to minimize the deviation between the sites and the cells. This leads to making the parameter K (reuse pattern) very small. The size of the cells is kept small in the proposed paradigm, and then the capacity is increased.

2. LITERATURE REVIEW

Although frequency planning in cellular networks is a hard problem, the fact is that cellular systems operate 24 h a day, seven days a week, and hence cannot afford extended wait times for better plans because their business is at risk [2]. As a consequence, automation of frequency planning is unavoidable. Frequency channels should be employed in a manner that the requirements for maximum coverage and capacity are satisfied with the least amount of intra-system interference as possible for a benign frequency plan. This involves frequency plan optimization through the use of a range of dynamic parameters that control cell coverage profiles and traffic capacity distributions [3]. To account for variations in the terrain and traffic profile on the ground, as well as the influence these changes have on the received power levels of any random user in one cell in relation to interference from another cell, the frequency plan must be adaptive. The Inter Cell Dependency Matrix (ICDM), which may be utilized as an input to the frequency planning and optimization algorithm and is representative of real-time network conditions [4], well represents the interference correlation between cells. The authors of [5] proposed a novel method for automatic frequency planning in both new and existing networks. The new method replaces the time-consuming and inexact manual process, simplifies planning, and lowers operational costs. Furthermore, sophisticated EA (evolutionary algorithms) techniques are used in this process, which can yield a near-optimal solution.

The article [6] suggested an innovative technique for automatic frequency plan development and optimization, with the goal of keeping intra-system interference levels within the allowed limits of the key performance indicators (KPIs) set for every real-time cellular network. The idea of an Inter-Cell Dependency Matrix (ICDM) was used for autonomous frequency planning and optimization, which comprises cell correlations in terms of the effect one cell has on the other, especially in terms of co-channel interference.

In article [7] an automatic frequency planning (AFP) is implemented in the real cellular networks of different major cities in Pakistan using the Automatic Frequency Optimization System (AFOS) tool. The call drop rate was reduced by 14–35 percent after implementing the frequency plan from the AFOS tool using the base-band frequency hopping technique.

The authors introduced a method in [8] that optimizes a nonlinear, multivariate, and multi-criterion interference function in order to offer a very effective frequency planning solution in a reasonable time. However, it has been demonstrated that the proposed algorithm is sophisticated.

3. DESIGN PROCEDURE

3.1. Frequency planning and optimization in GSM (global system mobile communications) 900 system

The scheme for allocating and reusing channels over a coverage region is known as frequency reuse. Each cellular base station is given a set of radio channels or frequency sub-bands to utilize within a cell, which is a limited geographic area. The cell is hexagonal in form. Frequency reuse, also known as frequency planning, is the process of selecting and distributing frequency sub-bands for all of a system's cellular base stations.

The distance between base stations using the same frequency, D, and the cell (hexagon) radius, R, are two factors to take into consideration in frequency reuse patterns. For the hexagonal model, cells of similar size, and frequency reuse patterns that repeat the frequencies in the same sequence, the reuse distance is explicit. The distance D between two hexagons and the hexagon radius R with paths i and j are non-negative integers. The cluster size (K) is equal to $i^2 + ij + j^2$ and the area of hexagon is equal to $2.61\ R^2$ [1].

3.1.1. Frequency reuse pattern. The pattern is 3/9 frequency reuse. Three sites, each serving three cells, are used to form a cluster of nine cells. The frequency reuse rate is a metric for how effective a frequency plan is. The frequency plan's effectiveness is improved by multiple reuse rates.

3.1.2. Carrier to channel interference ratio (C/I) in 3/9 cell repeat pattern. The pattern should result in a C/I of greater than 9 dB in principle. To decrease the impact of interference, additional steps are required. Frequency hopping and dynamic power control are effective strategies.

3.1.3. Capacity per area (C/A) in 3/9 repeat pattern. A1 and C3 are geographically nearby cells that use adjacent ratio carriers. This means that Mobile Stations (MSs) operating on the border of adjacent cells A1 and C3 have a C/A of 0 dB. This design, as shown in Fig. 1, is far superior to the GSM configuration.

By utilizing 5 MHz of bandwidth in GSM 900, the design intends to extend coverage to a new location (Nominal Channel Band Spacing). The Traffic Channel (TCH) frequency plan is made as per specifications (Signal to Noise Ratio (SINR) >9 dB), with a 6 dB marginal for Broadcast Control Channel (BCCH) SINR, utilizing the available bandwidth. The system is interference restricted when the propagation exponent is equal to 4.

In such severe instances, cluster sizes of up to $K = 12$ or even more are utilized. Because cluster sizes tend to reduce as traffic grows, network re-planning and optimization must be a continuous process. The cluster sizes of BCCH and TCH may differ. BCCH is necessary for connectivity due to having a higher cluster size.

The positions of nine cell sites are within ($x = 5$ km, $y = 5$ km) coordinates. A 3/9 frequency reuse pattern is required for frequency planning to avoid interference. Nine cells are supported by three three-sector sites, with three cells per cell site, in a 3/9 reuse pattern. The number of frequencies in the 3/9 cell scheme is equal to 27 per channel [1].

Traditionally, the desired coverage area is divided into multiple smaller portions (cells) that create clusters. A cluster is a group of cells in which each conceivable carrier has been employed just once. When carriers are utilized in cells from surrounding clusters, interference arises. To reduce interference, the frequency reuse distance (the distance between two stations using the same carrier) must be as large as possible.

3.2. Optimization requirements

Network optimization is a technique for enhancing network performance in a specific setting. The optimization requirements require at least: hypotheses, constants, variables, constraints, and objective function [1].

- Hypotheses

With a 3/9 reuse pattern, each three-sector site has three cells, and each cluster has three three-sector sites, for a total of nine cells. There are three cell sites in the cluster. The cells A1, B1, and C1 are found in cell site 1, the cells A2, B2, and C2 are found in cell site 2, and the cells A3, B3, and C3 are found in cell site 3. Because a total of 27 cells were needed for full coverage, the total number of cell sites is 9. Each cell site has the same geographical coverage area. Each cell's RF channels with a 5 MHz carrier frequency are assigned based on traffic demand with the C/I ≥ 9 being used for 3/9 (frequency hopping).

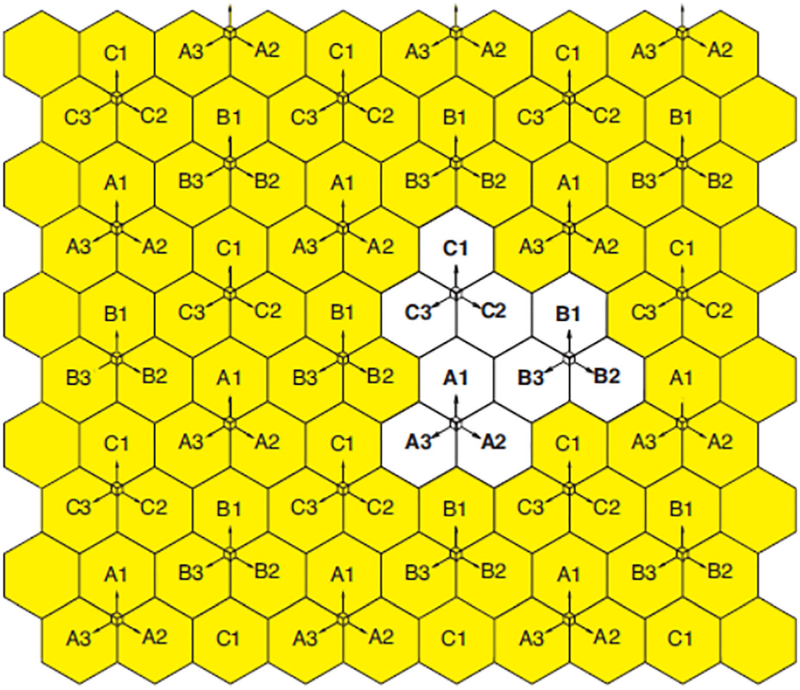

Fig. 1. Adjacent cells in geographical area

- Constants and variables

The distance (d) between j and k is constant and equal to the distance between location j and location k, where j and k are equal to (1–9). And the variables are: The xij ≥0 is the cell site placed at location j, where j is equal to (1–9), the distance (i) that is equal to the total distance between the site's three locations i, where i is equal to (1–3). The parameters hi and li are the deviation up distance and deviation down distance for site i, respectively. Both parameters, hi and li, are ≥0.

- Constraints

Let us reuse factor in (i in j) will be equal to the sum (j in J) x (i, j) = 3, each location has only one cell site (j in J) and will be equal to the sum (i in I) x (i, j) = 1, each site's total distance (i) will be equal to the sum of (j in J, k in K) x (i, j) * d (j, k). The uniform distance1 will be distance (1) – distance (2) – h1 + l1 = 0, the same thing for distance 2 and distance 3, which will be distance (2) – distance (3) – h2 + l2 = 0 and distance (1) – distance (3) – h3 + l3 = 0, respectively.

- Objective function

In a mathematical optimization problem, the objective function is a real-valued function whose value is to be minimized or maximized over a collection of possible options. Let us abbreviate "minimize deviation" to Min_Dev.

$$\text{Min\_Dev.}: \ l1 + l2 + l3 + h1 + h2 + h3 \tag{1}$$

All the constraints mentioned above are subject to Min_Dev. to minimize the deviation between the sites and the cells.

As illustrated in Fig. 2 below, the coverage area is split into clusters made up of several smaller locations. A cluster is a collection of cells in which all of the possible carriers have only been used once. To avoid interference, the frequency reuse distance between two sites should be as large as possible.

The interference level is still significant, even with the cells mapped as described above, deviation (upper and lower deviation) decreased, and the distance between the sites established. To overcome this issue, a reuse pattern utilizing three cells is proposed.

3.3. Proposed frequency reuse pattern

Each of the three cells makes use of a different subset of the available channels. Co-channel interference is weaker than the signal coming from the cell, thus cells that utilize the same frequency are positioned as far apart as possible. From hexagon geometry cells [1], the reuse distance (*D*) is given by Eq. (2):

$$D = (\sqrt{3K}).\ R \tag{2}$$

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

Because the cell is hexagonal in this situation, the most substantial interference occurs from the 6 nearest co-channel cells, as shown in Eq. (3) below:

$$C/I = (1/6)\ (D/R)^{\gamma} \tag{3}$$

Path loss (γ) = 2 in free space, although it usually varies from 3 to 4 in most instances.

For $K = 3$ and $\gamma = 3.7$, we have

$$C/I = (1/6)(3R/R)^{3.7} = 9.7095 = 9.872\text{dB} \tag{4}$$

The *C/I* value estimated above is 9 dB, which is the cited GSM value. As the number of interferers increases, the overall interference tends to a Gaussian distribution and therefore likes Additive White Gaussian Noise (AWGN), according to the central limit theorem. The following Eq. (5)

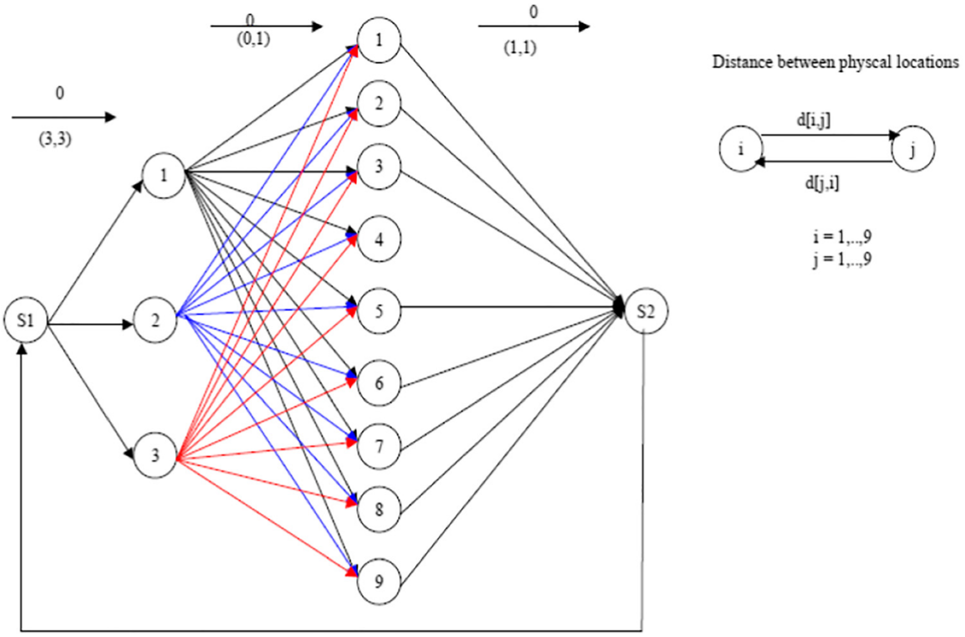

Fig. 2. Network diagram

from the Shannon Theorem [9] is a rough estimate of capacity based on this:

$$C = B_T log_2[1 + SINR] \tag{5}$$

where B_T is the bandwidth of the communication channel and $SINR$ (Signal to Noise Ratio) ≈ C/I.

The capacity per area for a single frequency band that is utilized through an area (A) is calculated as in Eq. (6) [10]:

$$C/A = B_T log_2[1 + SINR]/K\pi R^2 \tag{6}$$

where $\pi = 3.14$ and A is a given area

To ensure good performance and maximum capacity, the minimal K that gives an acceptable $SINR$ is utilized. Reduce the value of R to improve the system's capacity per unit area. This is an excellent strategy, but it is uneconomical since it necessitates the construction of extra base stations, which is costly.

Since the path loss exponent is distance dependent, systems with lesser cells incur larger amounts of interference. When the cell radius, R, is reduced, the value reaches 2. This is due to the fact that unobstructed line of sight propagation is more likely in less or fewer cells in this case. If the reuse factor, K, is constant, it can be shown that it reduces C/I and $SINR$. When the cell radius is reduced, K must be raised in order to maintain a suitable interference level.

3.4. System paradigm

Consider the geographical region depicted in Fig. 3, where every cell has a radius of R. The distribution of channels among cells is considered to be based on a resource planning model with a cluster size of three. The Dmin (minimum reuse distance) is $3R$. In other words, the number of adjacent cells in interference is 6. For example, our reference cell is B3, and interference from the following 6 adjacent cells will be regarded as: A3, C3, A5, C4, A2, and C1.

If a cell utilizes a channel, none of the other six interference adjacent cells do as well. When an MS initiates a call, a request message is sent to the nearest BTS, which picks a free primary channel and guarantees that there is no co-channel interference, hence optimizing channel use. To improve channel reuse, several of the channel selection systems include a resource planning model. The allocation of a defined set of resources to cells is done in static resource planning. With the rise in traffic variety, however, a few cells are starved of spectrum while others go underutilized.

When cells are starved, there is a good risk that calls will be dropped owing to a lack of resources. Static resource planning becomes wasteful in a changing traffic environment. To transact with the unbalanced resource distribution, greater flexibility in planning is necessary, with resources dynamically varying in response to traffic. In Orthogonal Frequency Division Multiple Access (OFDMA), resource allocation guarantees that no two users in a cell are allotted the same resource at the same time. This removes the intracell interference because of the transmission in the cell.

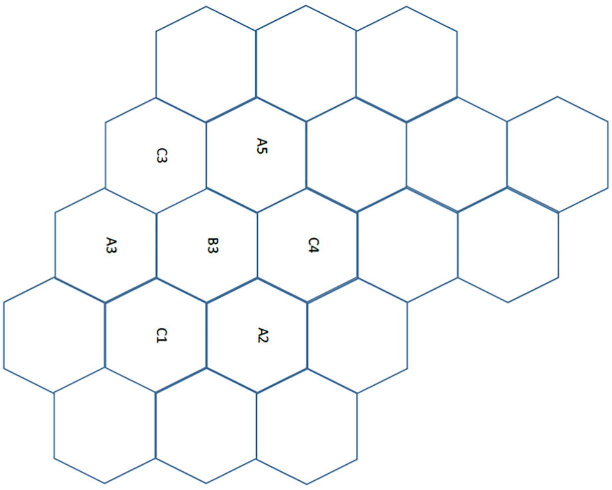

Fig. 3. System paradigm

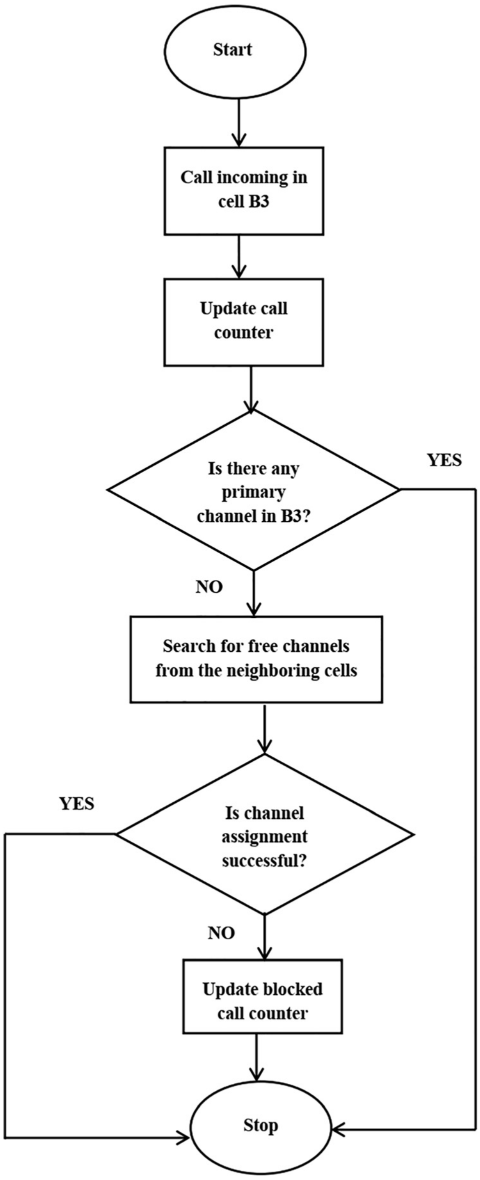

Fig. 4. Flowchart of proposed algorithm

The following are the steps for utilizing resource planning models:

- When all the primary channels have been used up, the cell will request the secondary channels.
- The set of cells is split into a number of disjoint subsets, each with at least a minimum reuse distance between any two cells in the same subset. The set of channels is also subdivided into disjointed subsets that are equivalent.
- In disjoint subsets, the channels are primary channels for cells in one subset and secondary channels for cells in another subset.

3.5. The proposed algorithm and its work

The proposed algorithm flowchart of frequency planning and optimization for the system paradigm is shown in Fig. 4. The cells are split into three disjointed linear subsets. A, B, and C are the three options. To avoid neighboring channel interference, these subsets are disjointed. Every one of the three cells utilizes a different subset of the available channel. Each cell is surrounded by six other cells. Consider the following scenario: There are a total of 21 channels, each with seven primary channels.

Subset A: 1, 4, 7, 10, 13, 16, 19
Subset B: 2, 5, 8, 11, 14, 17, 20
Subset C: 3, 6, 9, 12, 15, 18, 21

Assumptions are made as follows:

- Each cell's neighbors are well specified. B3 is the central cell, while A3, C3, A5, C4, A2, and C1 are its neighbors.
- Because the terrain in the regarded geographical region is flat, the algorithm does not account for channel fading.
- All BTSs in the cell transmit at the same power and are in the same location.
- Directional antennas are utilized in sectorized cells, where every cell has three sectors, each of which is given two channels, resulting in the installation of two TRXs.

Once cell B3 receives a call request, it examines the availability of primary channels and connects the call if there are any empty primary channels. If no primary channels are accessible, it launches seek for free primary cells in nearby cells (A3, C3, A5, C4, A2 and C1). When it receives a confirmation message from nearby cells, it chooses a channel at random from the first one received. The call is linked, ensuring that the call's quality is preserved.

B3 confirms the selected channel and designates it as an interference channel. The borrower must return the channel before it may be utilized again. The method is mainly based on channel assignment in such a way that channel usage is maximized while voice quality is maintained. The algorithm guarantees that channels are reused as much as possible.

Information on free channels is gathered during channel acquisition to ensure that two cells within a minimal reuse distance do not share the same channels. The search and update stages of the distributed Dynamic Channel Allocation (DCA) mechanism make up the acquisition phase.

When cell B3 demands a free channel, the channel selection technique is utilized to pick one available channel and validate whether it may use the selection channel with its interfering adjacent cells. After that, whenever a cell obtains or releases a channel, it notifies its interference neighbors, ensuring that each cell in the system paradigm is constantly aware of its interference's available channels.

4. RESULTS AND DISCUSSION

The cells are placed geographically in such a manner that interference is kept to a minimum. Co-channel interference

Table 1. Deviations results for each cell site

Deviations									
Cell site	1	2	3	4	5	6	7	8	9
1	0	1	0.25	0	0.5	0	1	0	0.75
2	0.75	0	0	1	0.25	1	0	1	1
3	0.25	1	0.25	0	0	0	1	0.5	0.25

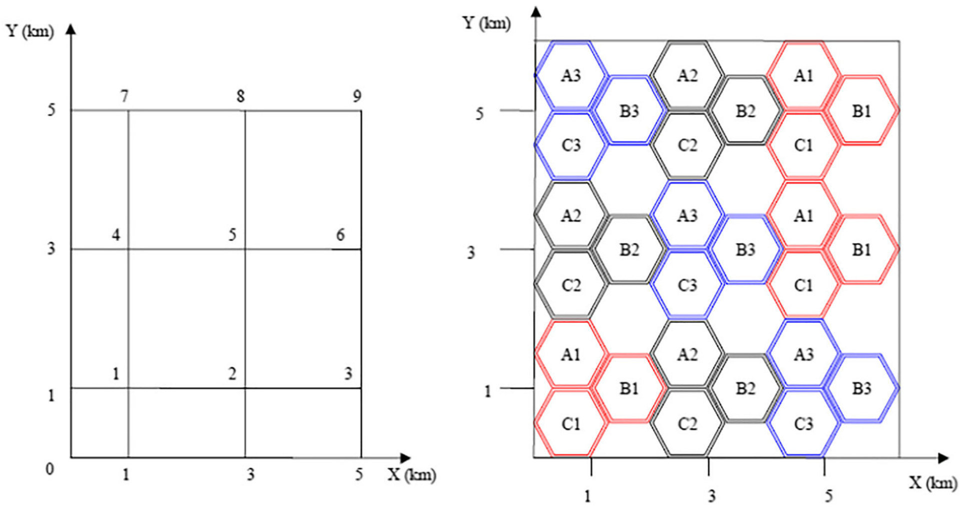

Fig. 5. Geographical mapping of cells

Table 2. Simulation results

Calls incoming in cell B3	Sum of borrowed channels	Sum of blocked calls in DCA	Sum of blocked calls in FCA	Probability of call block in DCA	Probability of call block in FCA
811	5	22	285	0.0271	0.351
751	5	12	260	0.0159	0.346
754	1	16	311	0.0212	0.412
734	6	32	272	0.0435	0.370
774	3	19	250	0.0245	0.322
738	6	18	246	0.0243	0.333
721	5	13	274	0.0180	0.380
704	5	14	225	0.0198	0.319
817	5	22	313	0.0269	0.383
697	2	16	302	0.0229	0.433
776	5	0	289	0	0.372
825	4	12	229	0.0145	0.277
784	3	16	223	0.0204	0.284
824	5	13	306	0.0157	0.371
683	2	12	289	0.0175	0.423
793	9	46	281	0.0580	0.354
712	5	11	264	0.0154	0.370

is lower than the signal coming from the cells, thus cells utilizing the same frequency are separated by a large distance.

As shown in Fig. 5, the deviation (upper and lower deviation) is reduced with the cells mapped, and the distance between each cell site is found to be 50 km using the A Mathematical Programming Language (AMPL). As seen in Table 1, and as mentioned in Section 3.2, all the constraints are subject to Min_Dev. to minimize the deviation between the sites and the cells.

To test the proposed technique for incoming calls in cell B3 with 9 allocated channels, first we put incoming calls in cell B3, calls blocked in the Dynamic Channel Allocation (DCA) mechanism, and blocked calls in the Fixed Channel Allocation mechanism to equal zero. Then we define the number of iterations from 1 to 100 and generate a random number of calls with a frequency range of 600–900 MHz that is stored in a database in MATLAB 2021b with 9 allocated channels. We define the 6 neighbors of cell B3 and generate a random number of calls in the neighbors of cell B3 that are: A3, C3, A5, C4, A2, and C1. Then we put the condition in the Dynamic Channel Allocation mechanism to be met for a call to be supported using primary channels, incoming calls B3 $\leq$ 6. In the Fixed Channel Allocation (FCA) mechanism, the same procedure is used, but the condition is that incoming calls from B3 > 6.

Table 2 shows the incoming calls in cell B3, borrowed channels sum, calls being blocked sum in the DCA, calls being blocked sum in the FCA, as well as the probability of them.

Dynamic Channel Allocation (DCA) mechanism is not constantly assigned to different cells; rather BS assigns channels to incoming calls dynamically. When compared to the Fixed Channel Allocation mechanism, call blocking is negligible under the Dynamic Channel Allocation (DCA) mechanism. The Dynamic Channel Allocation (DCA) mechanism decreases call blockage by a substantial amount. This is related to channel borrowing and the resource planning model's decrease of cluster size. Radio resource reuse is dynamic, resulting in increased trucking efficiency. Fixed Channel Allocation mechanism is a traditional method in which every cell is assigned to a set of channels. The frequency plan determines how the channels are assigned. Channels cannot be transferred from one cell to another. The probability of a call being blocked is calculated as follows:

$$P = (Calls\ blocked)/\ (Calls\ incoming\ in\ cell\ B3) \tag{7}$$

$$P\ (DCA) = (Calls\ blocked\ in\ DCA)/\ (Calls\ incoming\ in\ cell\ B3) \tag{8}$$

$$P\ (FCA) = (Calls\ blocked\ in\ FCA)/\ (Calls\ incoming\ in\ cell\ B3) \tag{9}$$

5. CONCLUSION

The sources of RF interference, the kinds of RF interference, the factors that influence RF interference and the permissible amount of RF interference were all covered in this paper. The allotment of radio frequencies to all of the BTSs in the network is the most essential duty for RF engineers when building a cellular system. Frequency reuse is required due to the scarcity and high cost of frequency bands. The study in this paper discussed frequency reuse patterns and went on to demonstrate how successful they are when applied in a network. The proposed algorithm employs a resource planning model to ensure effective channel reuse while reducing cluster size. The simulation results demonstrate that the suggested Dynamic Channel Allocation (DCA) mechanism has a considerably lower blocking probability than the Fixed Channel Allocation mechanism.

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