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Analysis of Inter cell Interference Issues on Cellular Networks Using OFDMA

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Abstract: *In order to reduce interference and improve the capacity of the system the orthogonal frequency division multiplexing technique has been deployed in various cellular systems. But major problem in cellular systems is intercell interference especially at the cell edges. For reducing the impacts of ICI inter cell co-ordination techniques are investigated in this paper. The popular interference coordination technique is interference avoidance technique where the resources are divided between the users in all spatial, time, frequency domains to reduce the interference to some extent. This paper Provides comprehensive survey on the various ICIC avoidance schemes which consists of both static and dynamic schemes in OFDMA-based cellular networks.*

Keywords: *Avoidance, ICIC, ICI, OFDMA.*

I. Introduction

In present days speed of communicion and the data throughput is increasing day by day with high coverage area. But there are some major problems to increase the throughput i.e. bandwidth and power requirements. So to increase the throughput spread spectrum is required. As increasing bandwidth is very expensive and majority of the population can't afford that prices. So to reduce the cost effective utilization of the bandwidth is required. So frequency reuse mechanisms are deployed. However, as the frequency reuse increases[1], so does the interference caused by other users using the same channels. Therefore, interference becomes a decisive factor that limits the system capacity, and hence, the suppression of such interference becomes of a particular importance to the design of next generation cellular networks.

In cellular communication there are two types of interferences are present i.e. intracell interference and intercell interference[5]. Intracell interference is caused due to frequency channels in the same cell as well as due to the power leakages; Intercell interference is due to frequency channels of the adjacent cells.

To reduce the interference of cellular networks in the downlink we use WiMAx (Worldwide Interoperability for Microwave Access) LTE and LTE Advanced, Orthogonal Frequency Division Multiplexing (OFDM) or Orthogonal Frequency Division Multiple Access (OFDMA) was selected to reduce interference[1] and to efficiently meet their high performance requirements.

Orthogonal frequency-division multiplexing (OFDM) is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The technology was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency.

In some respects, OFDM is similar to conventional frequency-division multiplexing (FDM). The difference lies in the way in which the signals are modulated and demodulated. Priority[4] is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels.

OFDM is used in European digital audio broadcast services. The technology lends itself to digital television, and is being considered as a method of obtaining high-speed digital data transmission over conventional telephone lines. It is also used in wireless local area networks[3].

If we maintain even with less intracell or no interference, Intercell interference dominates the system performance and provides a great challenge to reduce it. To reduce interference [7]coordination techniques are classified as intercell mitigation and intercell avoidance techniques. Classification is shown in the fig.1.below.

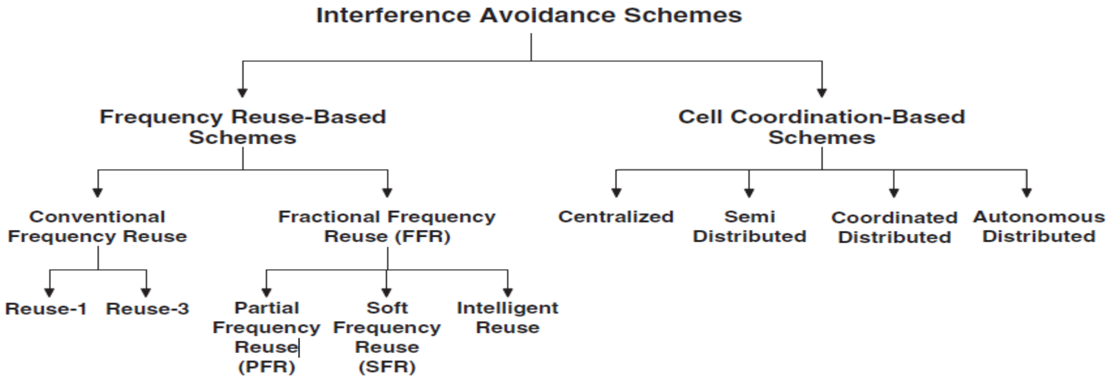


Fig.1. Classification of interference avoidance schemes

The interference *mitigation* is employed to reduce the impact of interference during the transmission or after the reception of the signal. In the literature[3] a wide range of techniques is presented in order to improve the throughput of the cell-edge users by reducing or suppressing the ICI. Interference mitigation techniques include

- **Interference randomization**: where some cell-specific scrambling, interleaving, or frequency-hopping (spread spectrum).
- **Interference cancelation**: where the interference signals are detected and subtracted from the desired received signal, or if multiple antenna system is employed, the receiver can select the best quality signal among the various received signals.
- **Adaptive beam forming**: where the antenna can dynamically change its radiation pattern depending on the interference levels.

1.1. Scope of Paper

As the need for the high performance cellular networks have been increasing, in the last few years there has been many papers regarding the intercell interference avoidance schemes for OFDM networks[12]. The scope of our paper is to do comprehensive surveys that investigate a wide range of ICIC techniques. More over our aim is to reduce confusions in the terminology used by the different papers like partial frequency reuse (PFT) can termed in other papers as "Fractional Frequency Reuse with full isolation (FFR-FI)"[15].

More over there are many prospective proposed for dynamic avoidance schemes in different papers so in this paper [9]we have reduced the ambiguity or confusions regarding different views in the dynamic avoidance schemes. In the end we have proposed static and dynamic interference avoidance schemes for OFDM downlink

1.2. Paper Organization

The remainder of this paper is organized as follows. In Section 2, a classification of frequency reuse-based schemes is presented and various schemes are explained. Section 3 presents a classification for various coordination-based interference avoidance schemes and explains some of these schemes. A discussion on future research directions is presented in Section 4. Finally a summary is given in Section5[11].

II. Static ICIC: Frequency Reuse-Based Schemes

These are the schemes to reduce the Inter-cell Interference problem by having control over the usage of frequencies in various channels of the network[9]. Some of them are: Conventional frequency planning schemes, Fractional frequency reuse (FFR), Partial frequency reuse (PFR), and Soft frequency reuse (SFR).

These various schemes have to properly define some parameters like:-

- Sub-bands used in each sector (or) cell,
- Operating power at each channel,
- Cell region where set of channels are used.

To effectively explain these various schemes we use a classification model which is unified and will properly differentiate one scheme to the other scheme. We use some basic parameters in this classification model[17].

- A= {A1, A2, A3}; Sectors per cell
- B= {B1, B2, B3……………….Bk}; Bands of frequency spectrum in each cell
- C= {C1, C2, C3……….......... Ck}; Co-centric rings

- D= {D1, D2……………………Dn}; Power levels within Sub-bands of a cell

We get D= (Pi/Pmax), where
Pi is power level in a particular sub-band
Pmax is the maximum power level used in the system.
The frequency reused scheme can be defined by using the above described parameters as here:
A= {Bk (Dn, Ck): 1< k< B}.

2.1.Conventional Frequency Planning:

This technique consists of Frequency reuse factor (FRF) and we use reuse-1 scheme and reuse-3 scheme here. Reuse-1 scheme means using all the available frequencies in each sector with no restrictions on parameters like frequency resource usage or power allocation i.e., FRF=1[16]. This can be explained as follows: B = {B1}, R= {r1}, and A= {a1}. This can be written as
S1 = S2 = S3 = {B1 (a1, r1)}.
Advantages of reuse-1 scheme:

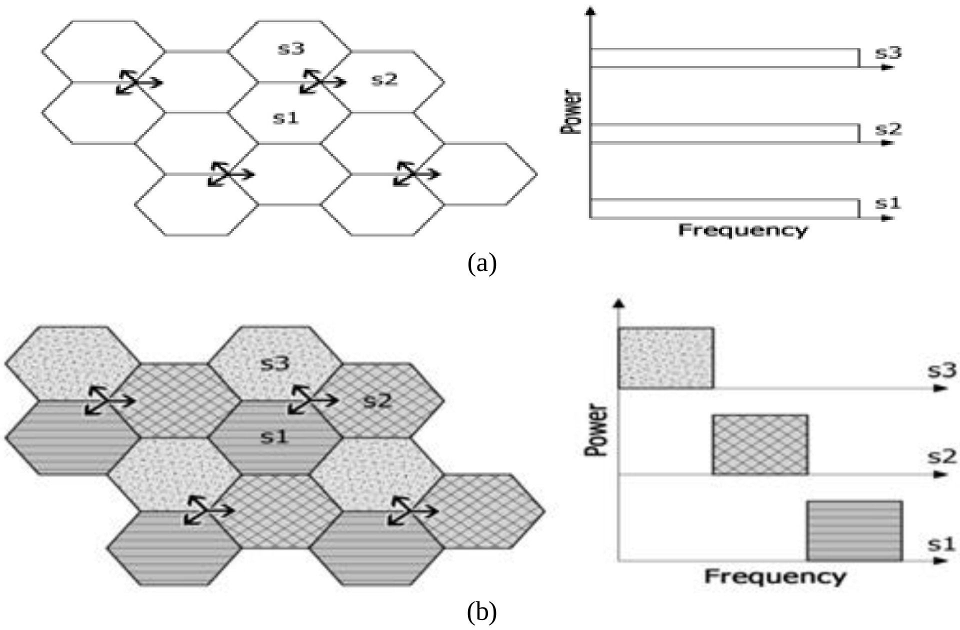
- High data rates can be achieved.

Disadvantages of reuse-1 scheme:

- Worst case inter-cell interference levels for cell edge users.
- Overall lower spectral efficiency.

In order to decrease the inter-cell interference levels we use another scheme called reuse-3 scheme where the frequency band is three equal sub bands which are orthogonal to each other. This can be described as follows: B = {B1, B2, B3}, R= {r1}, and A= {a1}. Now the expression of the three sectors is
S1 = {B1(0,0), B2(0,0), B3(a1,r1)}
S2 = {B1(0,0), B2(a1,r1), B3(0,0)}
S3 = {B1(a1,r1), B2(0,0), B3(0,0)}
Advantages of reuse-3 scheme:

- Improved inter-cell interference.
- Resource utilization in the network.
- Cost is reduced.



(b)

Fig**. 2.1.** Conventional Frequency Planning (a) Reuse-1 (b) Reuse-3.

2.2. Fractional frequency reuse (FFR):

This fractional frequency reuse scheme can be used for various FRF in between 1 and 3. This has two subsets – major group and minor group. Major group is used for the users at cell-edges whereas the minor group is used for users at cell-centers[2]. This FFR can be classified into three types. They are:

- Partial frequency reuse schemes (PFR)
- Soft frequency reuse schemes (SFR)
- Intelligent reuse schemes

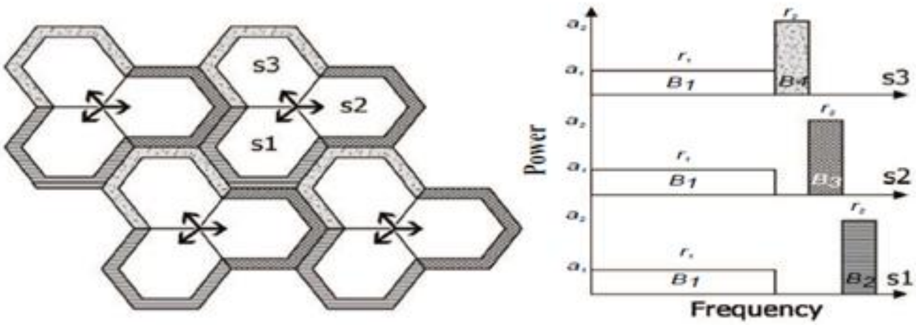


Fig. 2.2. Fractional Frequency Reuse with Full Isolation (FFR-FI).

There is a study which focuses on the FFR factor at the edges of the cell region where bandwidth is assigned to each region and all the subcarrier and power to all the users in a particular cell.

2.3. Partial frequency reuse schemes (PFR)

The main theme of the PFR is to limit the resource portion such that some frequencies are not used in few sectors. PFR is also called as FFR with full isolation because it takes care of cell-edge users from adjacent cell interference.

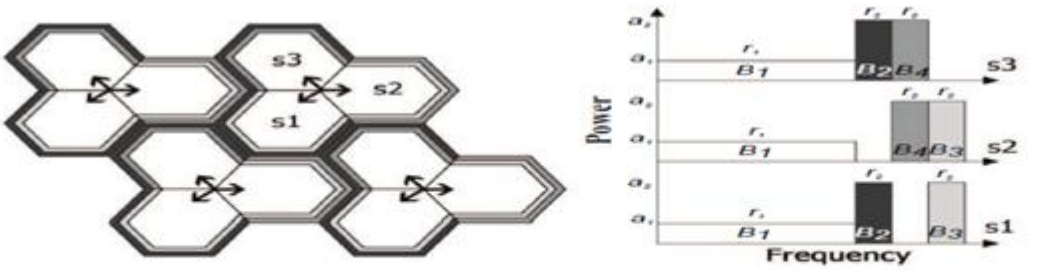
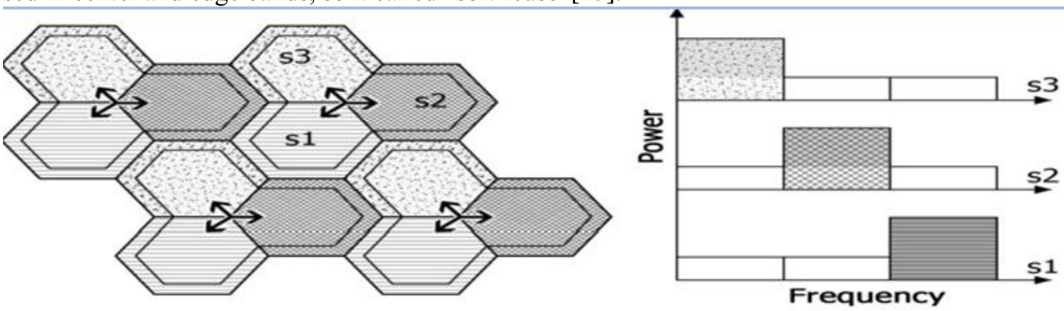


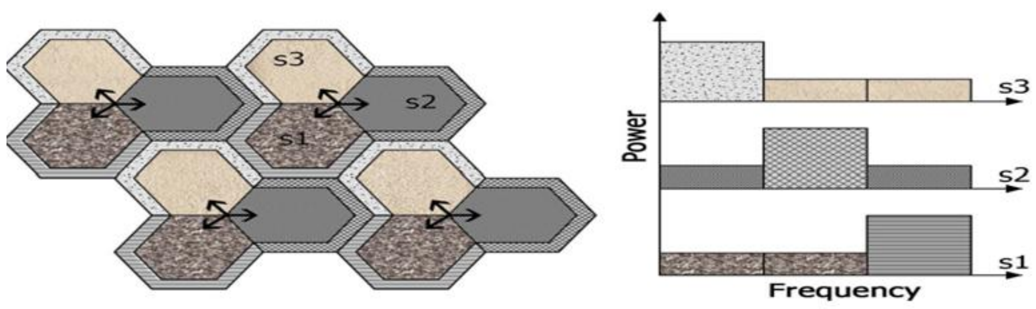
Fig. 2.3. PFR with only one interference in the worst case.

2.4. Soft frequency reuse (SFR):

Unlike the PRF scheme where there is no-sharing policy resulting in lower utilization of the frequency resources, SFR schemes have balance between the FRF and PFR schemes and powers can be properly adjusted and used in center and edge bands, so it called “soft reuse”[19].



(a)



(b)

Fig.2.4. Soft frequency reuse: (a) reuse-1 in cell-center, (b) Partial frequency reuse in cell-center

The enhanced version of SFR scheme is **Soft fractional frequency reuse (SFFR)** where there is improvement in the overall cell throughput of FFR. SFFR uses the common sub-band types which gives throughput to inner users.

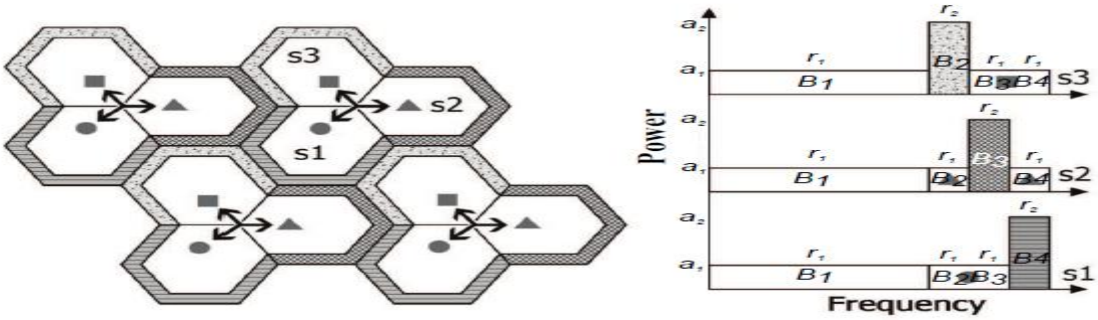


Fig.2.5. Soft fractional frequency reuse (SFFR)

2.5. Intelligent reuse scheme

It is also called as Incremental frequency reuse (IFR) scheme. This scheme is introduced to solve problems in SFR scheme like low spectrum efficiency and co-channel interference issues and to properly maintain the overall system capacity by controlling[20] the ICI effectively. This scheme consists of a tri-sector cell where there are 3 types of cells. In this scheme different sub-channels are assigned directly from adjoining cells.

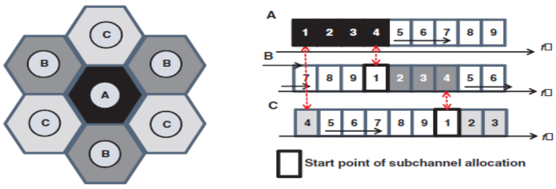


Fig.2.5.IFR scheme in a tri-sector cell system

2.6. Enhanced fractional frequency reuse (EFFR)

This scheme is introduced in order to improve the IFR and SFR schemes by overcoming their limitations and enhancing the system capacity even under overload situations[15]. This scheme consists of 3 cell-types for neighboring cells in a system. This scheme consists of primary segment which is orthogonal and secondary segment.

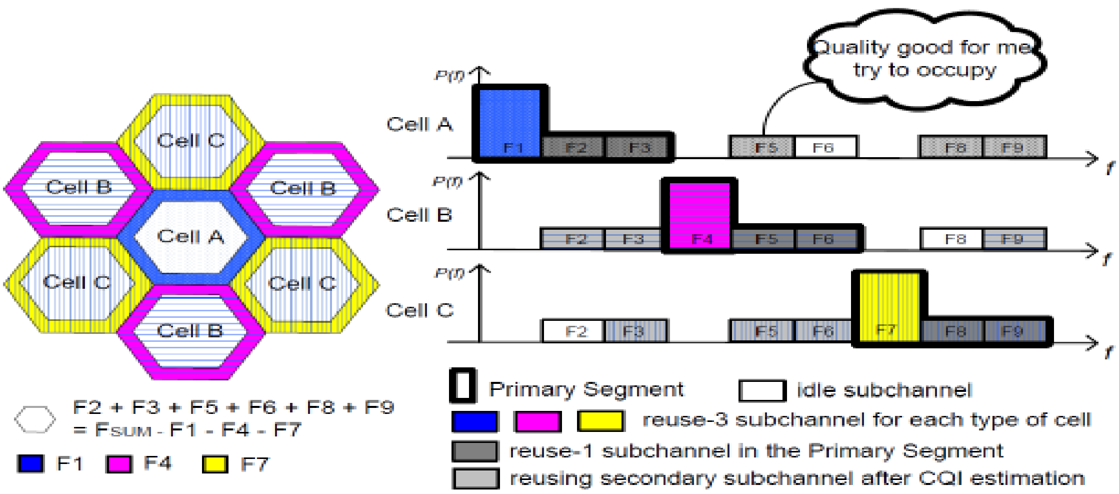


Fig.2.6. Enhanced fractional frequency reuse (EFFR)

2.7.Combined partial reuse and Soft handover:

To eliminate the complexity of geometry and the need for extra signaling a new ICIC scheme is introduced which has both Partial frequency reuse (PFR) and Soft handover (SH). This ICIC scheme will properly distinguish the cell interior users (CIUs) and cell edge users (CEUs)[16].

This scheme depends on the readily available information from handover algorithm and provides cell edge throughput gain and a low soft handover overhead

III. Dynamic ICIC: Cell Coordination-based Schemes

A general optimization framework for a sum-utility optimization formulation for dynamic interference coordination problem and its sub-optimal solutions are described briefly[18] in this Paper. These sub-optimal approaches are based on different assumptions representing different system configurations, complexities, and interference avoidance gains, which emerge from the common optimization framework.

3.1. Sub-optimal solutions

Solving the optimization problem globally offers a number of challenges- 1) a centralized approach is necessary 2) complete system knowledge at the central controller is required, 3) The resulting combinatorial integer linear problem is similar to a 3-dimensional assignment problem which is NP-complete for a fairly sized problem. In this thesis, [11]different sub-optimal solutions are explored in order to mitigate above difficulties. The fact which is used in the proposed solutions is that only the dominant interferers affect the signal quality. As a result, optimization can be applied within a group of neighboring transmitters forming a cluster and this reduces the size of the combinatorial problem significantly. However, in a real network,[13] the relation of interference and its interdependency propagates throughout the whole network.

To illustrate with an example[17], let us consider four sectors A, B, C, and D; here, let us assume that the transmit antennas belonging to sectors C and D are dominant interferers to UEs in sector A, and antennas in sectors A and C are dominant to those in sector B. If two clusters are formed as {A,C,D} and {A,B,C}, it would be observed that sectors A and C are common in both clusters. Hence,[14] optimizing each cluster independently may reduce the overall problem size (compared to optimizing {A,B,C,D}in a single shot) but it may provide misleading results unless inter-relation among the clusters are captured in the optimization problem.

In the solutions, the concept of interferer group to form a cluster is used. Algorithm aims to maximize sum-utility within a cluster honoring the inter-cluster dependencies. In particular, three different approaches have been investigated as follows.

3.1.1. A Two-Level Algorithm with Partial Central Processing

The functionalities of this algorithm reside at two different levels- sector and central. In essence, the 3-dimensional (3-D) assignment problem

Each sector forms a cluster taking all first-tier sectors as potential dominant interferers. The sector-level algorithm finds a set of resource[12] units for each of its first-tier sectors that are to be restricted from its perspective that heuristically maximizes it's the sum-utility in a 2-dimensional sense. However, these clusters are very dependent on each other as a particular sector is a member of different clusters. Therefore, the results from cluster-wise heuristic optimization should be processed in a centralized manner. However, the heuristic optimization (somewhat in a selfish manner) reduces the problem size significantly as it uses 2-dimensional assignment problem at the sector-level algorithm[5].

The Hungarian (also known as Khun-Munkres) algorithm is used at the sector-level in an iterative manner. The Hungarian algorithm is a one-to-one optimal solution for an assignment problem,[4] which is polynomial time solvable. However,[20] as this algorithm is used in an iterative manner, the overall assignment becomes rather a good sub-optimal solution. The sector-level algorithm prepares resource restrictions as a form of requests from its perspective. To that end, a central controller is used to process these restriction requests in an optimal manner (the 3rd dimension is handled here) and produces a final set of resource restrictions for all sectors[12]. Note that the problem size at the central controller is very tractable as it only works on restriction requests rather than looking into a large combinatorial optimization space.

3.1.2. A Distributed Algorithm with Neighboring Cell Coordination

This is a distributed algorithm where each sector finds a set of restrictions for each of its neighboring dominant sectors as in the previous approach. However, these resource restrictions are negotiated by inter-BS communications. This scheme was developed to study interference coordination problem in LTE,[14] where central processing of RRM functionalities is not encouraged due to at network architecture. In LTE, neighboring BSs (eNBs) communicate with each other using X2 interface. Furthermore, inter-cell interference as intra-eNB and inter-eNB interference are treated differently[9], as eNB-eNB communication is not required for intra-eNB interference. The Hungarian algorithm is used for intra- and inter-eNB interference avoidance.

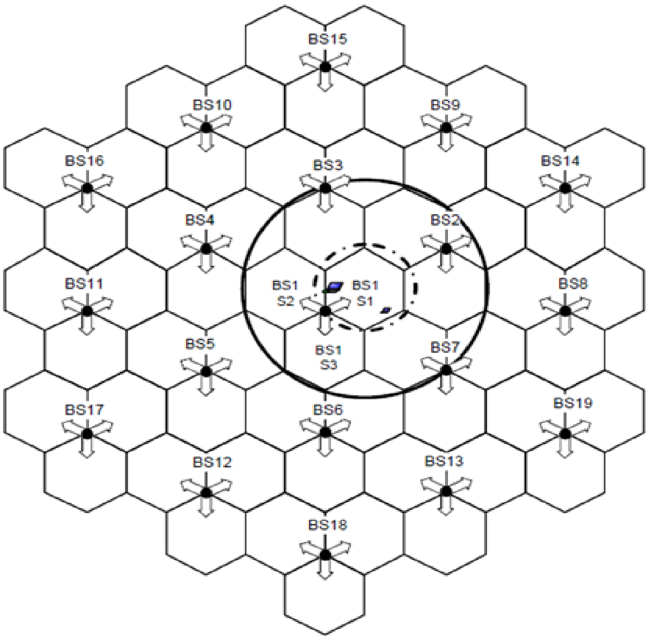


Fig.3.1 Network layout consisting of 3-sector cell sites

3.1.3. A Centralized Approach with Clusters

Compared to the above two, this approach involves more centralized processing. In this scheme, each user in every sector ends two most dominant interferers from the neighboring first-tier sectors with which it forms an interferer group (i.e., clusters). The ILP formulation takes dependencies among clusters into consideration by appropriate linear constraints. The problem size is further reduced by assigning a subset of resource units at a time. In summary,[19] a 3-dimensional assignment problem is solved in this scheme, however, with reduced size. A fast commercial solver is used to evaluate the performance of this approach.

IV. Future Research Directions

- *Wireless Network Cloud (WNC)*: Recently, with the emergence related to wireless infrastructure including software radio technology and remote radio head technology,[16]*Wireless Network Cloud (WNC)* with *Base Station Pooling (BSP)* is becoming an interesting alternative network architecture where all eNBs computational resources (enabled by Software Radio) are pooled in a central location and connected via fiber to simple radio-front ends (Remote Radio heads) mounted on remote cell-towers. WNC provides all the necessary transmission and processing resources for a wireless access network to operate in a central fashion . A promising research direction is to re-think the way ICIC centralized schemes are structured by exploiting the transmission and processing resources of the WNC[2].

V. Summary

The common theme of ICIC avoidance schemes is to apply restrictions to the usage of downlink resources such time/frequency and/or transmit power resources. Such coordination of restrictions will provide an opportunity to limit the interference generation in the area of the cellular network. Accordingly, Signal to Interference and Noise Ratio (SINR) can be improved at the receivers in the coverage area, which will provide potential for increased (cell-edge) data-rates over the coverage area, or increased coverage for given data-rates.

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