# Analysis of FFR & Performing Clustering to multi-operators in Cellular Networks for Spectrum Sharing

A project Report

*Submitted by*

**Shreya Raizada**

*In partial fulfillment of the requirements for the award of the degree of*

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# THESIS CERTIFICATE

This is to certify that the thesis titled **“Analysis of FFR & Performing Clustering to multi-operators in Cellular Networks for Spectrum Sharing”** submitted by **Shreya Raizada**, to the Indian Institute of Technology Madras, for the award of degree of **MASTER OF TECHNOLOGY** in Communication and Signal Processing is a bonafide record of the research work carried by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

**Prof. K. Giridhar**
Research Guide
Professor
Dept. of Electrical Engineering
IIT-Madras, 600 036

**Place:** Chennai
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And as always, I’m indebted to my parents for their unconditional love, patience, affection and support for everything I had attempted to do throughout my life.

# ABSTRACT

KEYWORDS: FFR, SFR, Frequency Allocation in FFR, Clustering, Inter site distance, Allocation of multi-operators.



A technique to manage interference is the fractional frequency reuse which is well-suited to OFDMA-based cellular networks wherein the bandwidth of the cells is partitioned into regions with different frequency reuse factors. Suppose there are multi-operators (four types of different operators) present in cells. These operators are uniformly spread in tier 0, tier 1 and tier 2. We consider only up to tier 2 for simplicity which can be extended on requirement. These operators are clustered into different groups with the help of clustering for satisfactory spectrum sharing. These clusters have to satisfy some constraints and some conditions to uniquely define clustering. Fractional frequency reuse offers a simpler alternative to the frequency reuse problem in multi-cell OFDMA networks. Fractional Frequency Reuse is applied to increase the spectral efficiency.

SFR is another deployment mode. In SFR, the cell center users are allowed to share sub-bands with edge users in other cells. However, we focus on only FFR and come with an astounding clustering mechanism to separate different multi-operators into groups for satisfactory spectrum sharing. The basic idea of FFR is to partition the cell's bandwidth so that (i) cell-edge users of adjacent cells do not interfere with each other and (ii) interference received by (and created by) cell interior users is reduced, while (iii) using more total spectrum than conventional frequency reuse. The idea of FFR is to apply a frequency reuse of one in the inner region and a higher reuse factor in cell edges (outer region).

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# ABBREVIATIONS

| | |
|---|---|
| **FFR** | Fractional Frequency Reuse |
| **SFR** | Soft Frequency Reuse |
| **CB** | Centre Band |
| **EB** | Edge Band |
| **ISD** | Inter Site Distance |
| **MIMO** | Multiple Input Multiple Output |
| **CCI** | Co-channel interference |

# CHAPTER 1

# INTRODUCTION

Broadband wireless networks use orthogonal frequency division multiple access (OFDMA) as the transmission scheme. Frequency reuse of unity is usually considered for such networks. Flexible frequency reuse methods namely, fractional frequency reuse (FFR) and soft frequency reuse (SFR) are suggested to improve the situation. In FFR and SFR, the total available bandwidth is divided into centre band (CB) and edge band (EB). The CB is used in the reuse factor of unity and EB is used in reuse factor greater than one in FFR. In SFR, EB uses a higher power than CB. The typical frequency allocation is shown in figure 1.1. The cell edge users as shown in figure 1.1 suffer from high outage probability due to heavy co-channel interference. Frequency spectrum is an expensive resources and its expensiveness is increasing day by day. The wireless network operators are often competing in acquiring licenses so that they can operate on frequencies of their choice. They can have other alternative also that is they can use free spectrum in license exempt band. In such cases, the operators have to find ways to manage interference from other networks sharing the same band.

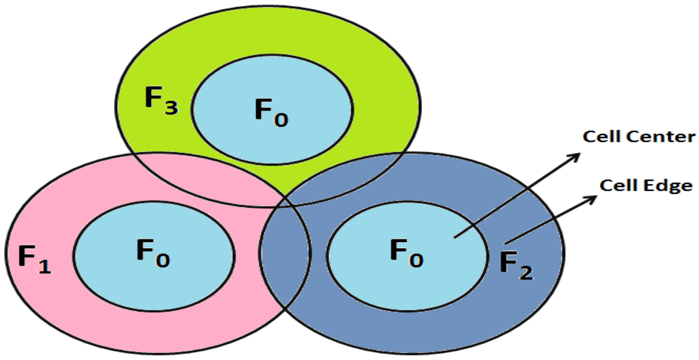


**Fig 1.1: Typical Frequency Allocation**
(Total spectrum= $F_0$+$F_1$+$F_2$+$F_3$)

Frequencies should be used in an efficient manner whether it is licensed or unlicensed spectrum. The process of using the same radio frequencies within a geographic area that are separated by enough distance to cause minimal interference with each other is termed as the frequency reuse. If frequency reuse of one is used in the cellular network, the cell edge users may not get proper signals due to interference from adjacent cells. The cell center is the area as shown in figure 1.1 and this is immune to co-channel interference (CCI). As cell edge users are only allowed to operate on a fraction of all available sub-channels, the allocation of this sub-channels fraction is done such that adjacent cells' edges will operate on different sets of available sub-channels (see picture above). This is called fractional frequency reuse. Fractional frequency reuse maximizes spectral efficiency for cell center users and improves signal strength and throughput for cell edge users.

## 1.1 Objective

The objective of this thesis is to examine fractional frequency reuse. Suppose there are multi-operators (four types of different operators) which are uniformly spread in cells. The goal of this thesis is to use some clustering mechanism so that different operators can be clustered in different groups so that spectrum sharing can be made possible. Here, the average ISD of operators A, B and C are same while operator D has smaller average ISD. The clustering is done such that there should not be same operators in a cluster. The preferable case is that there should be 4 different operators in a cluster. Also, the same operator should not be present in more than one cluster. However, as the multi-operators are uniformly distributed in cells, there would be the possibility that after clustering there would be two or three different operators in some clusters. Some constraints are used to get preferable case.

## 1.2 Thesis Outline

The thesis is organized as follows:

Chapter 2 deals with fractional frequency reuse. Here, various topics such as FFR deployment modes (Strict FFR and Soft Frequency Reuse (SFR)), Frequency allocation in FFR, clustering, cells layout formation, Minkowski metric etc. are explored. Some results for the analysis of FFR and getting proper layout for performing clustering to multi-operators so that spectrum sharing can be possible are also included in this chapter.

Chapter 3 contains simulation results which is obtained by varying the average inter site distance of one of the operator.

In chapter 4, conclusions and future scope are discussed.

Chapter 5 deals with Performance Analysis of CRC+2D Parity Check Code. Here, we tried to correct two bit errors by only using CRC and 2D Parity check code by arranging it in matrix form. This is separate topic and is not related to previous chapter.

# CHAPTER 2

# Analysis of FFR

Fractional frequency reuse (FFR) is an interference management technique which is well-suited to OFDMA-based cellular networks wherein the bandwidth of the cells is partitioned into regions with different frequency reuse factors. Fractional frequency reuse offers a simpler alternative to the frequency reuse problem in multi-cell OFDMA networks. The FFR scheme statically partitions the cell surface into two distinct geographical regions: the inner cell area and the outer cell area near the cell edge. The set of users present in the inner cell area is identified as the super group, whereas the set of users located in the outer cell area is called the regular group. The regular group users are further partitioned according to the cell sectors. The set of subcarriers to service these groups of users are also called super and regular group subcarriers, respectively. Fractional frequency reuse is suggested to improve the cell edge throughput over unity frequency reuse in orthogonal frequency division multiple access networks.

In wireless communications systems, important physical resources are spectrum, infrastructure and energy. In general, these resources are inadequate because of either natural limitations or costs. In wireless communications systems, radio spectrum is typically used such that interference is avoided or reduced by exclusive or careful allocation of frequency bands. Fractional Frequency Reuse (FFR) is applied to increase the spectral efficiency. Users close to the cell center are allowed to reuse frequency bands from neighbour sectors — frequency reuse one — whereas users close to the cell edge are assigned exclusive frequency bands.

## 2.1 FFR deployment modes

There are two common FFR deployment modes which are Strict FFR and Soft Frequency Reuse (SFR). However, we only focused on strict FFR, but for informative purpose, a brief introduction to SFR is also mentioned below. It’ll give you an idea of spectrum sharing.

1) *Strict FFR:* Strict FFR is a modification of the traditional frequency reuse used substantially in multi-cell networks. Figure 2.2 illustrates Strict FFR for a hexagonal grid modeled deployment with a cell-edge reuse factor of RF=3. The cell center users of all cells are allocated a common sub-band of frequencies while cell-edge users are allocated

different sub-band of frequencies based on a reuse factor. As the cell center users do not share any spectrum with cell-edge users, it helps in reducing interference for both cell center users and cell-edge users.

2) *Soft Frequency Reuse (SFR):* SFR deployment with a reuse factor of RF= 3 on the cell-edge is shown in figure 2.1. SFR employs the same cell-edge bandwidth partitioning strategy as Strict FFR, but the cell center users are allowed to share sub-bands with edge users in other cells. As the cell center users share the bandwidth with neighboring cells, they typically transmit at lower power levels than the cell-edge users. While SFR is more bandwidth efficient than Strict FFR, it results in more interference to both cell center and edge users.

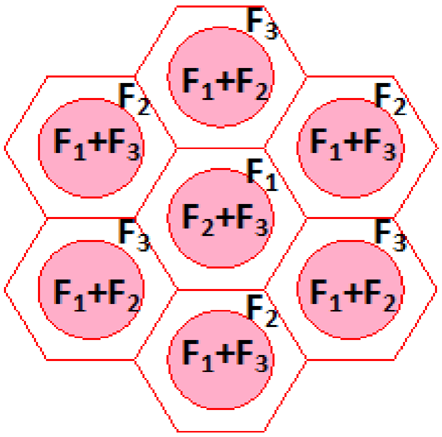


**Fig 2.1: Soft Frequency Reuse**
(Total spectrum= $F_1$+$F_2$+$F_3$)

## 2.2 Frequency Allocation in FFR

Frequency allocation in FFR for three neighbouring cells is shown below. The cell-centre users of all the cells rely on a common frequency band $F_0$, while the cell-edge users of the three cells occupy different frequency bands, namely $F_1$, $F_2$ and $F_3$.

The aim of FFR is to partition the cell's bandwidth in such a way that (i) cell-edge users of neighbouring cells do not interfere with each other and (ii) interference received by (and created by) cell center users is reduced, while (iii) using more total spectrum than conventional frequency reuse. The idea of FFR is to apply a frequency reuse of one in the inner region and a higher reuse factor in cell edges (outer region).

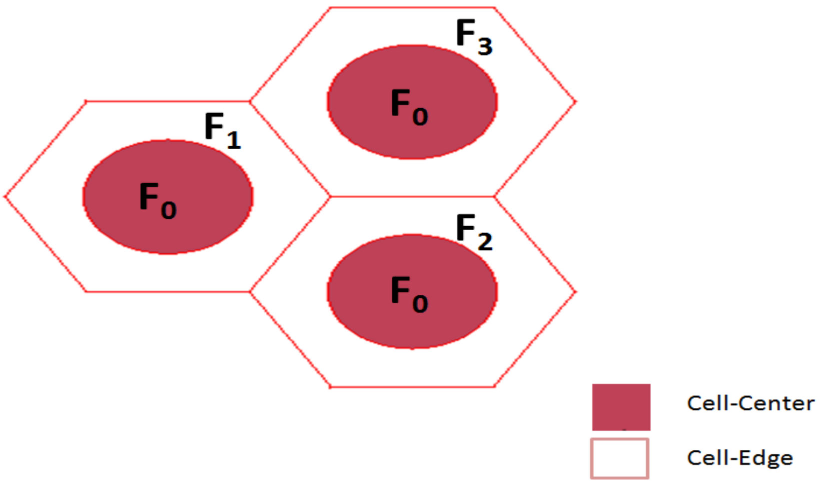


**Fig 2.2: Frequency allocation in FFR**

## 2.3 Cells Layout Design

Suppose there are multi-operators, namely A, B, C & D. We have to locate multi-operators in cells such that the average inter site distance (ISD) of operators A, B, C & D are 1 km, 1km, 1km and 600 m respectively. First, we have to form cells layout with radius R= 577.35 m. For simplicity, we have taken up to tier 2. The radius of inner circle is 350 m. The hexagonal cells layout is shown in figure 2.3.

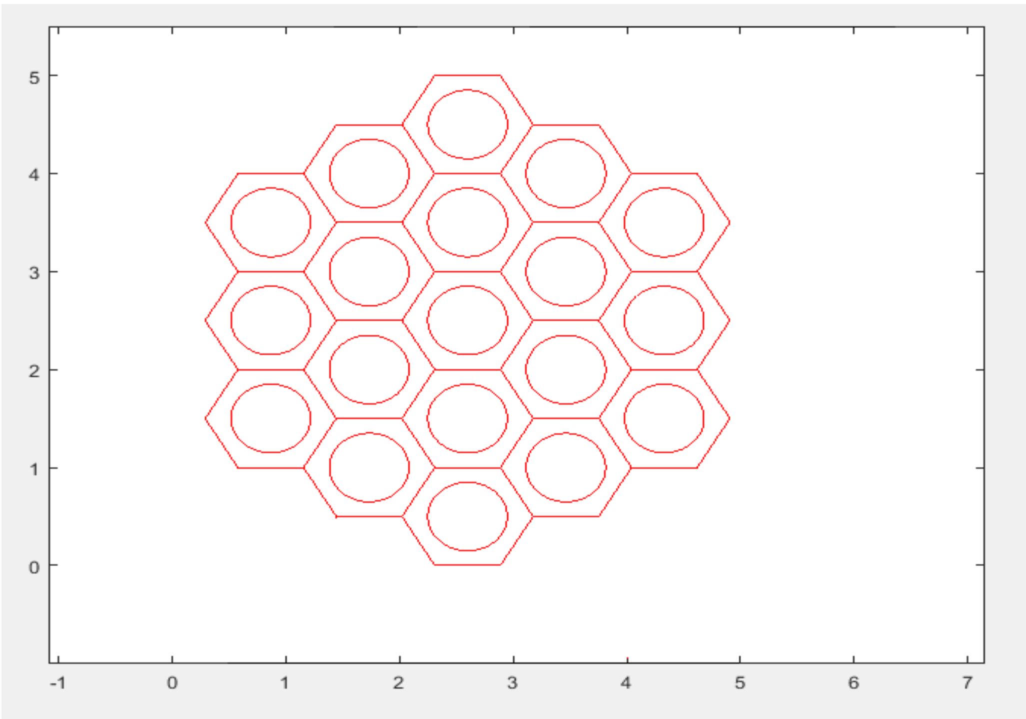

**Fig 2.3: Hexagonal Cells Layout**

Now, locate operator ‘A’, ‘B’, ‘C’ and ‘D’ with uniform average ISD. The geometry of multi-operators after locating them is given below:

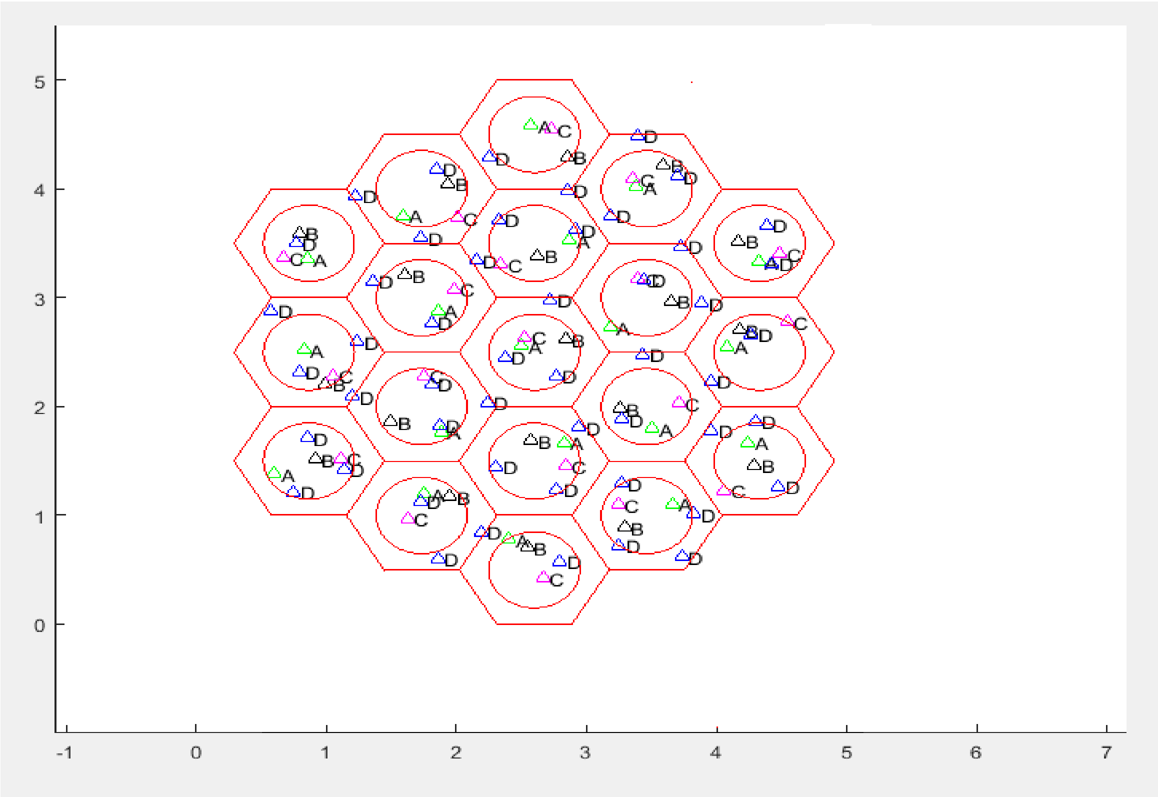


**Fig 2.4: Layout of Multi-operators A, B, C and D**

The next step is to form clusters such that interferences between operators in different clusters get minimized. For simplicity, we remove the hexagonal grid. The layout after removing hexagonal grid is shown in figure 2.5. The locations of all the operators are stored which would be used to form clusters. Before proceedings further, let us discuss about the clustering.

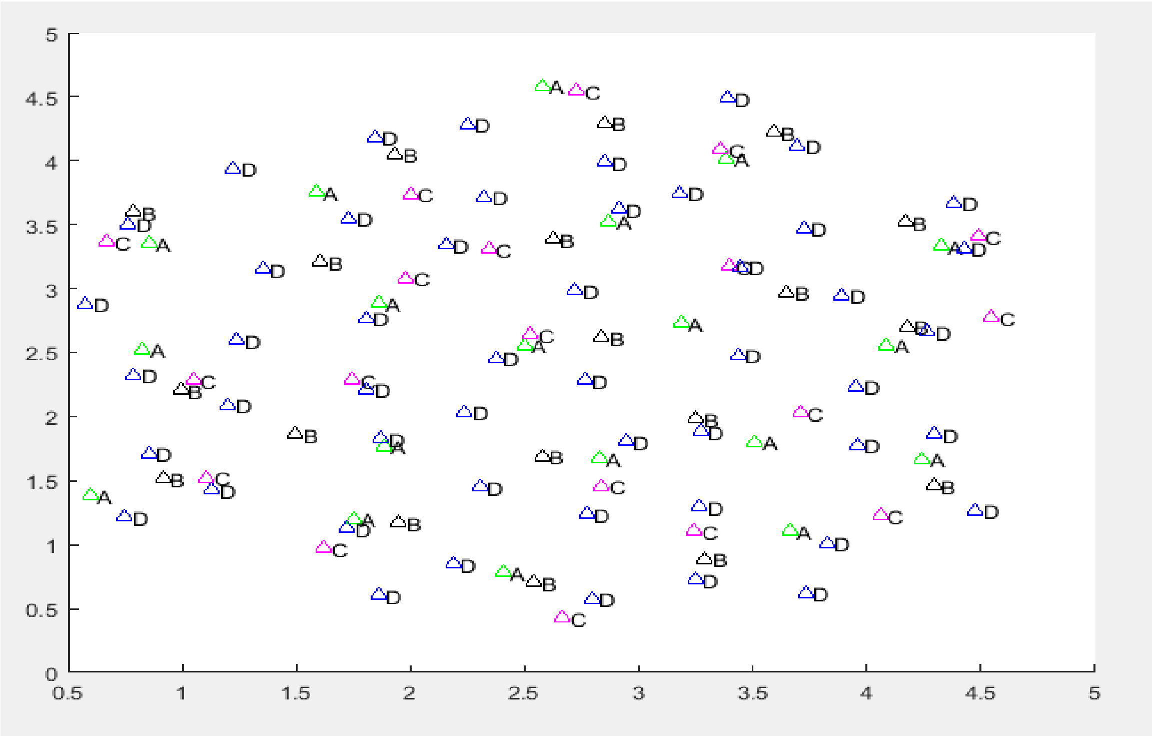


**Fig 2.5: Layout of Multi-operators A, B, C and D (without hexagonal grid)**

## 2.4 Clustering

We are about to perform clustering to the above layout. Before moving forwards, let us discuss some basic concepts of clustering.

Clustering is the way of dividing the data points into a number of groups such that data points in the same groups are more similar to other data points in the same group than those in other groups. We follow unique procedure to classify a given data set through a certain number of clusters. Here, we choose distance as the similarity criterion which is termed as distance based clustering. Two or more data points belong to the same cluster if they are near according to a given distance. But how to know which is a good clustering? Finally, it would be the users who should supply some criterion to suit the result of the clustering according to their needs. Scalability, discovering clusters with arbitrary shape etc. are the main requirements that a clustering algorithm should satisfy.

We can reform the zones for fractional reuse and propose a clustering based FFR, which offers higher flexibility in resource allocation. The final result after performing clustering to multi-operators in cellular networks can be visualized as mentioned in next chapter. In that layout, the average ISD of operator D is varied from 600m to 750m keeping average ISD of operator A, B and C fixed (1 km). As the average ISD of operator D is smaller, so we have more number of ‘D’ operators. The operator ‘D’ is taken as reference. The minimum distances between operator ‘D’ and other operators are calculated and some constraints are put so that if the minimum distance satisfies that constraints, the other operator with which minimum distance is calculated with respect to ‘D’ would get selected to form clusters.

### 2.4.1 Distance Measure

An important component of a clustering algorithm is the distance measure between the data points. Calculate the Euclidean distance between the data points and make groups of that data points which has minimum Euclidean distance. Figure 2.6 explains the formation of clusters.

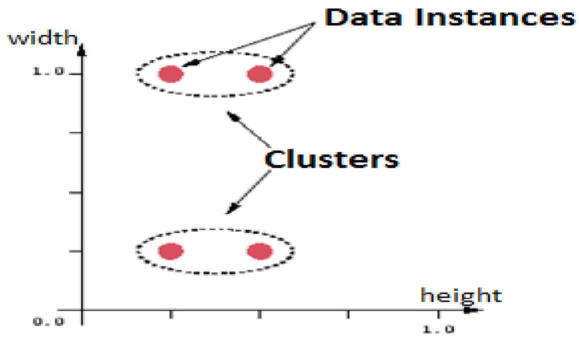


**Fig 2.6: Formation of Clusters**

### 2.4.2 Minkowski Metric

The Minkowski metric for higher dimensional data is given as

$$d_p(x_i, x_j) = \left( \sum_{k=1}^{d} |x_{i,k} - x_{j,k}|^p \right)^{\frac{1}{p}}$$

where d is the dimensionality of the data. The Euclidean distance is a special case obtained by putting p=2.

# CHAPTER 3

# Simulation Results

This chapter contains the simulation results. MATLAB is used for simulating it.

## 3.1 Case I: Average ISD of operator D is 600m

Keep average ISD of operators A, B and C to be 1 km. As the average ISD of operator D is smaller, so we have more number of 'D' operators as clearly shown in figure 3.1.

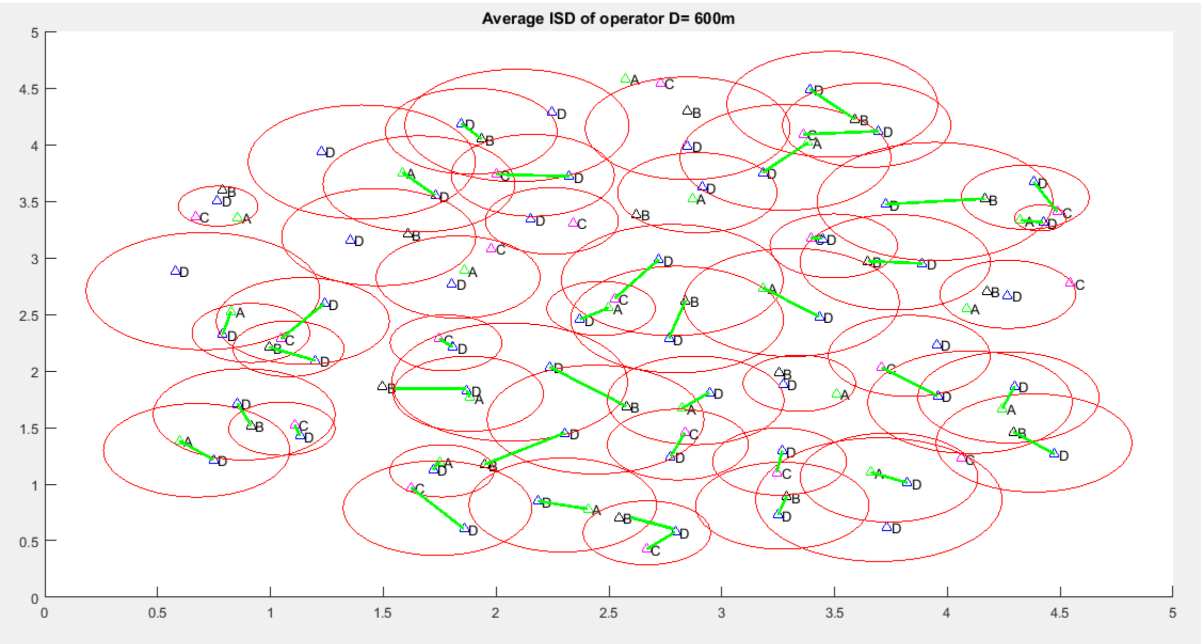


**Fig 3.1: Clustering of Multi-operators when average ISD of operator D= 600m**

Table 3.1 shows the locations of operators A, B, C and D. The column numbered '1' shows the x axis location and the column numbered '2' shows the y axis location for the respective operators. We'll keep the locations of operators A, B and C same in the remaining cases and only the location of operator D is varied. As the average ISD of operators A, B and C is 1 km each and up to tier 2 is considered, we can see that we have 19 operators each of A, B and C. The numbers of clusters with 1, 2, 3 and 4 different operators are 6, 37, 5 and 3 respectively as mentioned in table 3.2. We are getting some single operators which are not able to get clustered because we have more number of 'D' operators and such operators do not fulfil our objectives and in such cases, manually allocation of those operators can be done. Also, if we increase the number of cells (from tier 2 to tier 3), some of those single operators get clustered with operators present in tier 3. Figure 3.2 indicates relative strength of number of clusters for case I.

**Table 3.1: Locations of Multi-operators**

**Operator 'A'**

| | 1 | 2 |
|---|---|---|
| 1 | 1.7497 | 1.1980 |
| 2 | 1.8834 | 1.7659 |
| 3 | 1.8583 | 2.8871 |
| 4 | 1.5853 | 3.7532 |
| 5 | 3.6600 | 1.1061 |
| 6 | 3.5067 | 1.8019 |
| 7 | 3.1839 | 2.7323 |
| 8 | 3.3827 | 4.0194 |
| 9 | 0.5969 | 1.3826 |
| 10 | 0.8252 | 2.5256 |
| 11 | 0.8531 | 3.3541 |
| 12 | 2.4056 | 0.7814 |
| 13 | 2.8244 | 1.6709 |
| 14 | 2.4987 | 2.5580 |
| 15 | 2.8705 | 3.5257 |
| 16 | 4.2426 | 1.6683 |
| 17 | 4.0848 | 2.5564 |
| 18 | 4.3235 | 3.3322 |
| 19 | 2.5748 | 4.5836 |
| 20 | | |

**Operator 'B'**

| | 1 | 2 |
|---|---|---|
| 1 | 1.9473 | 1.1734 |
| 2 | 1.4979 | 1.8619 |
| 3 | 1.6069 | 3.2102 |
| 4 | 1.9350 | 4.0508 |
| 5 | 3.2887 | 0.8909 |
| 6 | 3.2527 | 1.9856 |
| 7 | 3.6471 | 2.9708 |
| 8 | 3.5911 | 4.2229 |
| 9 | 0.9141 | 1.5186 |
| 10 | 0.9935 | 2.2100 |
| 11 | 0.7875 | 3.5971 |
| 12 | 2.5425 | 0.7067 |
| 13 | 2.5770 | 1.6884 |
| 14 | 2.8393 | 2.6212 |
| 15 | 2.6221 | 3.3867 |
| 16 | 4.2921 | 1.4619 |
| 17 | 4.1748 | 2.7048 |
| 18 | 4.1659 | 3.5221 |
| 19 | 2.8485 | 4.2969 |
| 20 | | |

**Operator 'C'**

| | 1 | 2 |
|---|---|---|
| 1 | 1.6227 | 0.9713 |
| 2 | 1.7468 | 2.2836 |
| 3 | 1.9790 | 3.0836 |
| 4 | 2.0009 | 3.7366 |
| 5 | 3.2444 | 1.1029 |
| 6 | 3.7090 | 2.0313 |
| 7 | 3.3937 | 3.1738 |
| 8 | 3.3613 | 4.0901 |
| 9 | 1.1067 | 1.5243 |
| 10 | 1.0466 | 2.2855 |
| 11 | 0.6678 | 3.3673 |
| 12 | 2.6673 | 0.4260 |
| 13 | 2.8371 | 1.4575 |
| 14 | 2.5245 | 2.6410 |
| 15 | 2.3408 | 3.3092 |
| 16 | 4.0597 | 1.2298 |
| 17 | 4.5445 | 2.7782 |
| 18 | 4.4874 | 3.4085 |
| 19 | 2.7275 | 4.5466 |
| 20 | | |

**Operator 'D'**

| | 1 | 2 |
|---|---|---|
| 1 | 1.3268 | 1.3857 |
| 2 | 1.3440 | 1.9671 |
| 3 | 1.3107 | 2.7429 |
| 4 | 1.2462 | 3.1790 |
| 5 | 1.1514 | 3.7470 |
| 6 | 2.2274 | 0.7526 |
| 7 | 2.3736 | 1.4095 |
| 8 | 2.2848 | 2.0823 |
| 9 | 2.1645 | 2.6376 |
| 10 | 2.2325 | 3.1504 |
| 11 | 2.3008 | 3.9092 |
| 12 | 2.1880 | 4.4517 |
| 13 | 3.4382 | 0.7097 |
| 14 | 3.2572 | 1.3990 |
| 15 | 3.4347 | 2.0004 |
| 16 | 3.2508 | 2.6102 |
| 17 | 3.3400 | 3.1738 |
| 18 | 3.1721 | 3.8608 |
| 19 | 3.3197 | 4.3644 |
| 20 | 4.2772 | 1.3111 |
| 21 | 4.4511 | 1.9680 |
| 22 | 4.2230 | 2.5625 |
| 23 | 4.4394 | 3.0996 |
| 24 | 4.4806 | 3.7458 |
| 25 | 1.8616 | 4.1489 |
| 26 | 2.8929 | 4.1882 |
| 27 | 3.8280 | 4.0429 |
| 28 | 0.7955 | 1.0990 |
| 29 | 0.8292 | 1.5704 |
| 30 | 0.8602 | 2.1796 |
| 31 | 0.7337 | 2.8709 |
| 32 | 0.6017 | 3.5672 |
| 33 | 1.7788 | 0.5934 |
| 34 | 1.7819 | 1.2332 |
| 35 | 1.8703 | 1.7023 |
| 36 | 1.8455 | 2.2919 |
| 37 | 1.8575 | 2.8467 |
| 38 | 1.9017 | 3.4335 |
| 39 | 2.8974 | 0.6267 |
| 40 | 2.7462 | 1.1912 |
| 41 | 2.8096 | 1.6890 |
| 42 | 2.8943 | 2.4356 |
| 43 | 2.6710 | 2.9626 |
| 44 | 2.7186 | 3.4697 |
| 45 | 3.8985 | 1.2297 |
| 46 | 3.8936 | 1.7205 |
| 47 | 3.8016 | 2.3404 |
| 48 | 3.7963 | 2.8723 |
| 49 | 3.7979 | 3.4905 |
| 50 | 3.0055 | 3.0669 |

**Table 3.2: Percentage of clusters for case I**

| Number of different multi-operators per cluster | Number of clusters | Percentage of associated clusters |
|---|---|---|
| 1 | 6 | 11.7 |
| 2 | 37 | 72.5 |
| 3 | 5 | 9.8 |
| 4 | 3 | 5.8 |

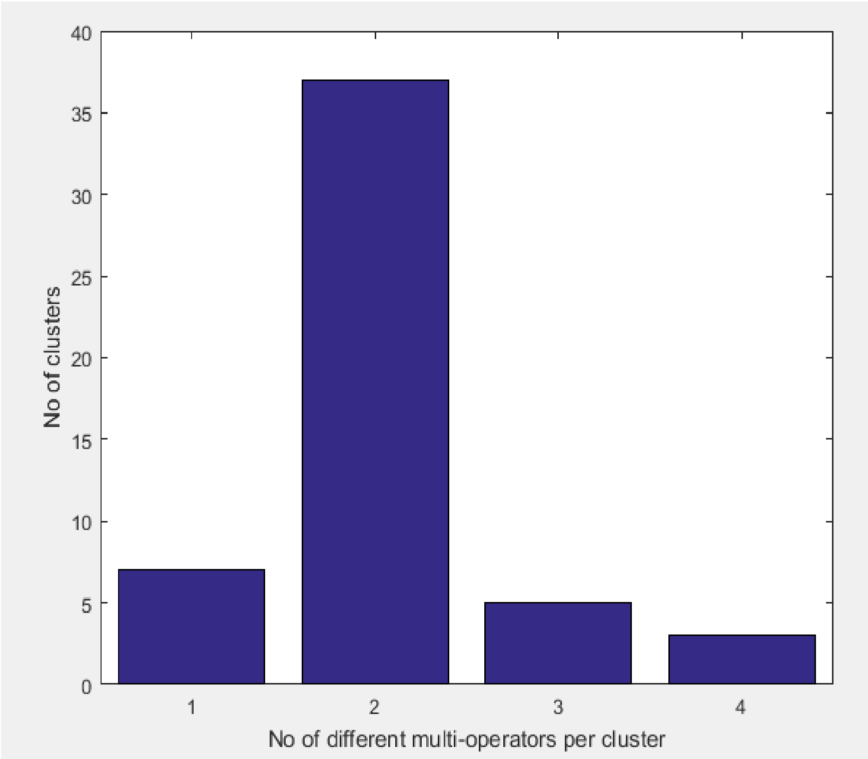


**Fig 3.2: Indication of relative strength of number of clusters for case I**

## 3.2 Case II: Average ISD of operator D is 650m

Keep locations of operators A, B and C unchanged. As the average ISD of operator D is smaller, so we have more number of 'D' operators as shown in figure 3.3. The numbers of clusters with 1, 2, 3 and 4 different operators are 2, 29, 9 and 3 respectively as mentioned in table 3.3. Figure 3.4 indicates relative strength of number of clusters for case II.

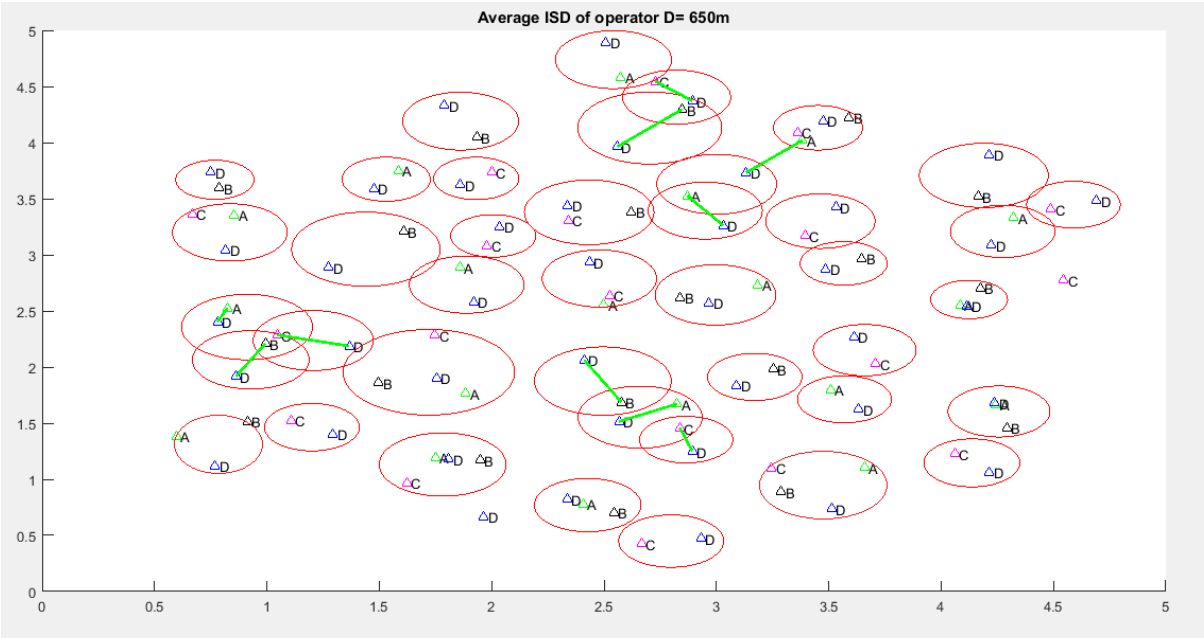


**Fig 3.3: Clustering of Multi-operators when average ISD of operator D= 650m**

**Table 3.3: Percentage of clusters for case II**

| Number of different multi-operators per cluster | Number of clusters | Percentage of associated clusters |
|---|---|---|
| 1 | 2 | 4.6 |
| 2 | 29 | 67.4 |
| 3 | 9 | 20.9 |
| 4 | 3 | 6.9 |

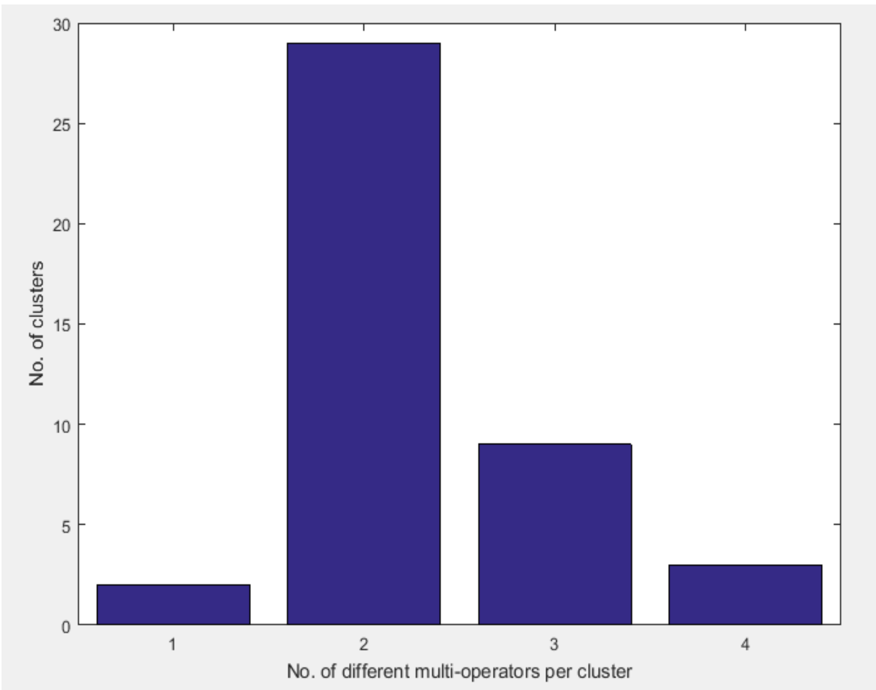


**Fig 3.4: Indication of relative strength of number of clusters for case II**

## 3.3 Case III: Average ISD of operator D is 700m

Keep locations of operators A, B and C unchanged. As the average ISD of operator D is smaller, so we have more number of 'D' operators as shown in figure 3.5. The numbers of clusters with 1, 2, 3 and 4 different operators are 1, 20, 8 and 7 respectively as mentioned in table 3.4. Figure 3.6 indicates relative strength of number of clusters for case III.

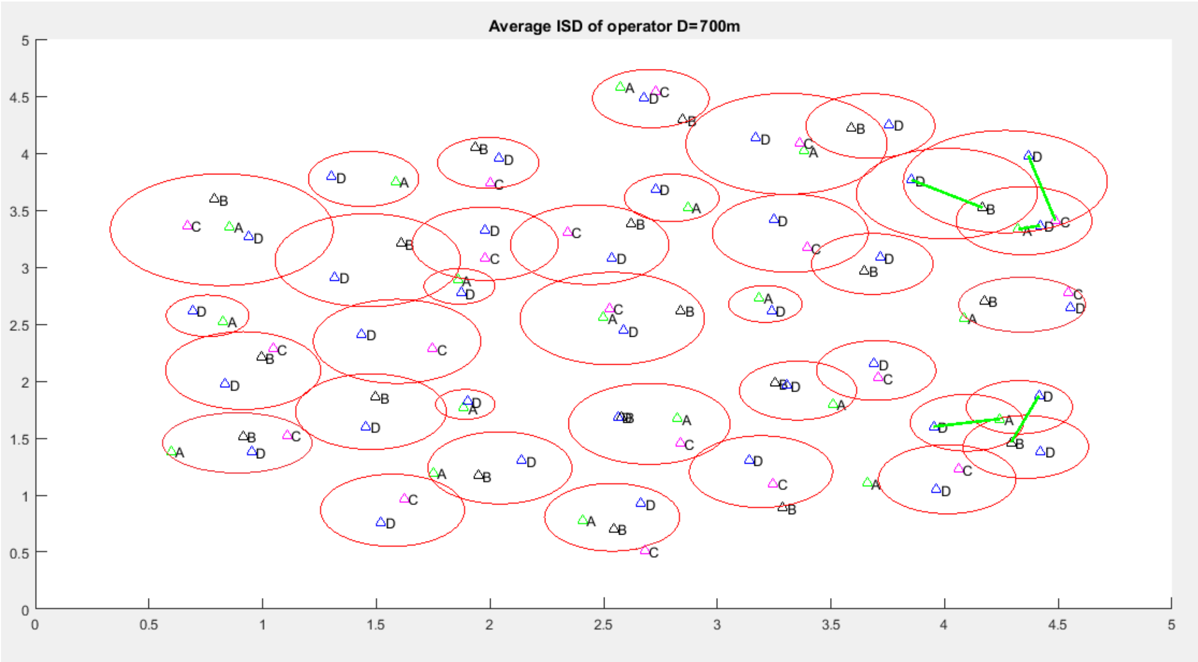


**Fig 3.5: Clustering of Multi-operators when average ISD of operator D= 700m**

**Table 3.4: Percentage of clusters for case III**

| **Number of different multi-operators per cluster** | **Number of clusters** | **Percentage of associated clusters** |
|---|---|---|
| 1 | 1 | 2.7 |
| 2 | 20 | 55.5 |
| 3 | 8 | 22.2 |
| 4 | 7 | 19.4 |

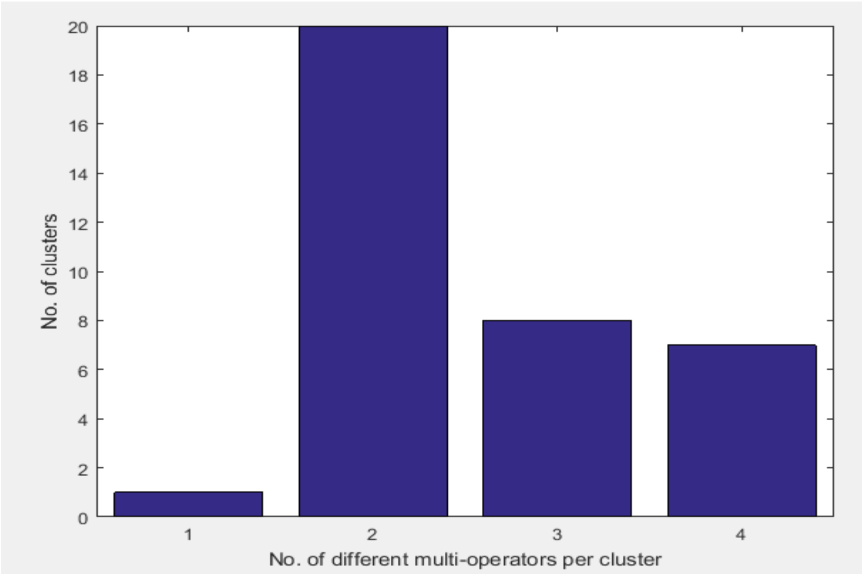


**Fig 3.6: Indication of relative strength of number of clusters for case III**

## 3.4 Case IV: Average ISD of operator D is 750m

Keep locations of operators A, B and C unchanged. As the average ISD of operator D is smaller, so we have more number of ‘D’ operators as shown in figure 3.7. The numbers of clusters with 1, 2, 3 and 4 different operators are 0, 18, 9 and 7 respectively as mentioned in table 3.5. Figure 3.8 indicates relative strength of number of clusters for case IV.

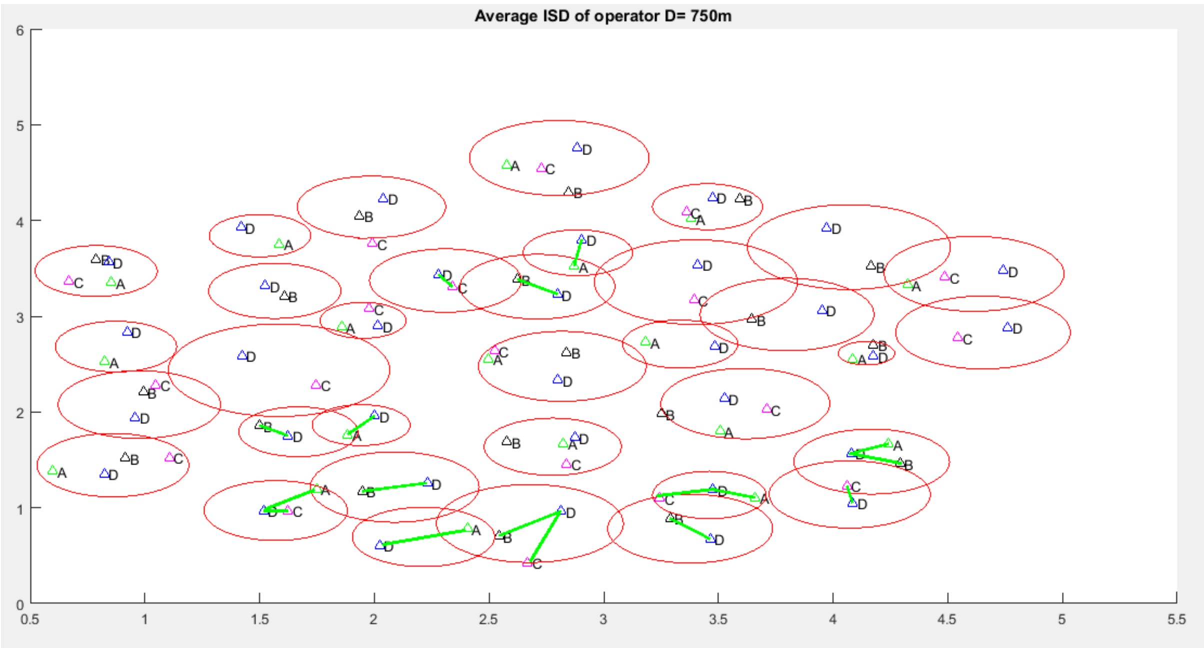


**Fig 3.7: Clustering of Multi-operators when average ISD of operator D= 750m**

**Table 3.5: Percentage of clusters for case IV**

| **Number of different multi-operators per cluster** | **Number of clusters** | **Percentage of associated clusters** |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 18 | 52.9 |
| 3 | 9 | 26.5 |
| 4 | 7 | 20.5 |

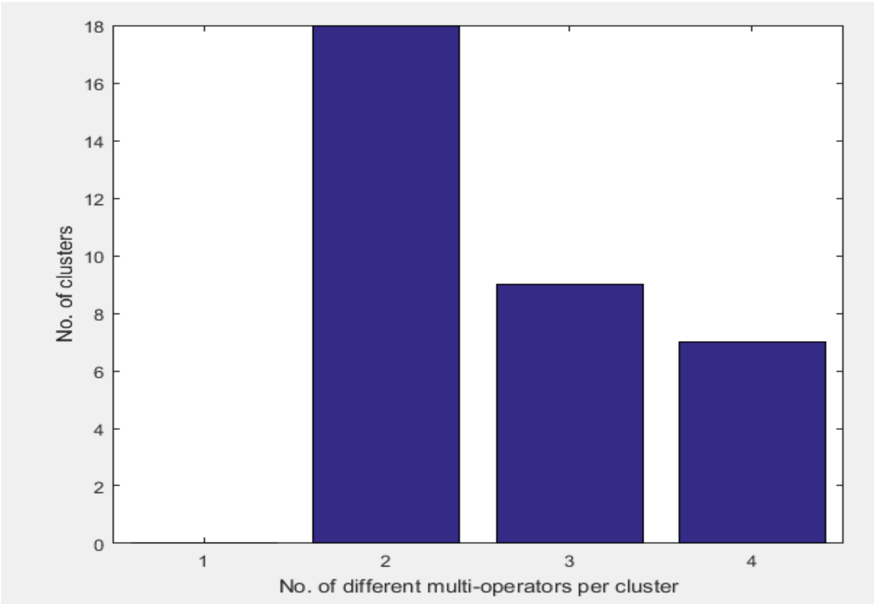


**Fig 3.8: Indication of relative strength of number of clusters for case IV**

### 3.5 Comparison of Case I, Case II, Case III and Case IV

Figure 3.9 compares all the cases. It can be seen that when the average ISD of operator 'D' is 600m (Case I), there would be more number of clusters having one (more clearly, one operator means it is not clustered with any other operators) or two different operators with respect to other cases. While it is lower for case II, case III and case IV which is considerable according to the requirement. In case IV, in every cluster, there are at least two operators. Also, the numbers of clusters having three or four (preferable case) different operators are more for case III and case IV as compared to case I and case II. The more inferences are given in the next chapter.

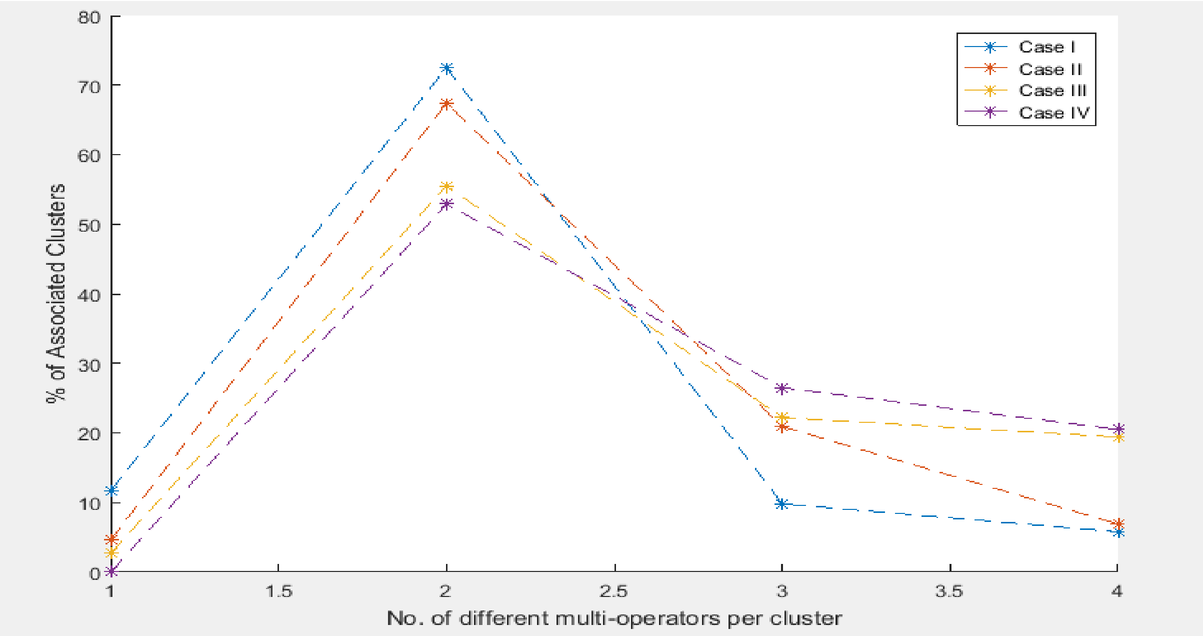


**Fig 3.9: Comparison of all the four Cases**

# CHAPTER 4

# CONCLUSIONS AND FUTURE SCOPE

## 4.1 Conclusions

In this project, FFR is analysed and clustering is applied to multi-operators to separate them into different groups for competent spectrum sharing. We can extend the number of cells and clustering can be used effectively. During clustering, there might be the possibility that same operator is shared by more than one cluster or more than one operator of the same type is present in the same cluster. In such cases, clusters have to be redesigned by using some different approach. Suppose there is an operator which is shared by two clusters such that in one cluster, there are 4 operators and in other cluster, there are two operators as shown in figure 4.1 (Total number of operators in these two clusters is 5). So, in this case, the clusters have to be redesigned. One approach is to take operators from that clusters which has lesser number of operators and form one new cluster. So, after clustering, this new cluster has two operators and now forms clustering with the remaining three operators. So, using this approach, there won't be any operators which are shared. This is one particular case and there would be other cases also for which clustering has to be done intuitively.

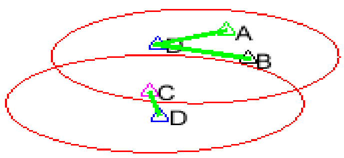


**Fig 4.1: Redesigning of Clusters**

It is also concluded that the average ISD of operator 'D' (the operator having the smallest ISD) should not be taken too small. In case I, where the average ISD of operator 'D' is 600m, it can be seen that there are more number of operators which are single (not clustered) i.e. 11.7% (see table 3.2). Also, the percentages of clusters with 2, 3 and 4 different operators are 72.5%, 9.8% and 5.8% respectively. In case II, the percentages of clusters with 1, 2, 3 and 4 different operators are 4.6%, 67.4%, 20.9% and 6.9% respectively (see table 3.3). In case III, the percentages of clusters with 1, 2, 3 and 4 different operators are 2.7%, 55.5%, 22.2% and 19.4% respectively (see table 3.4). The percentages of clusters with 1, 2, 3 and 4 different operators in case IV are 0%, 52.9%, 26.5% and 20.5% respectively (see table 3.5). It is observed that as we increase the average ISD of operator ‘D’ from 600m to 750m, the percentages of clusters with 1 and 2 different operators decreases. For only single operator case (where operator is not clustered), it decreases from 11.7% to 0%. The percentage of clusters with 2 different operators decreases from 72.5% to 52.9%. However, the percentages of clusters with 3 and 4 different operators increase which is as expected because if the average ISD of operator ‘D’ is also 1km (i.e. same as other operators), then it could be easily concluded that there would be more clusters with 4 different operators. The percentage of clusters with 3 different operators increases from 9.8% to 26.5% and for 4 different operators, it increases from 5.8% to 20.5%.

## 4.2 Future Scope

The concept of clustering can be extended beyond tier 2 which helps in allocating multi-operators across large geographical region effectively and efficiently and helps in minimizing interference and spectrum sharing. The other scope is to study the MU-MIMO and SIMO system which is aided by fractional frequency reuse in the context of the cellular uplink.

# CHAPTER 5

# Performance Analysis of CRC+2D Parity Check Code (Other Work)

Data block size of 56 bits are used for BER performance analysis for CRC+2D parity check code over AWGN channel with Rayleigh fading. Suppose we have data block of size 56 bits. We wish to transmit this data such that one bit and two bit errors can be corrected at the receiver side using CRC and 2D Parity Check Code. This is the other work that is done successfully and is not related to any of the previous chapter.

## 5.1 Input Data+CRC+2D Parity Check Code in Matrix Form

Suppose we have randomly generated input data bits as shown in figure 5.1. Arrange this input data bits in 7x8 matrix form. The input data as shown in figure 5.1 is treated as a polynomial and CRC is calculated by dividing the input data polynomial by CRC generator polynomial. This CRC generator polynomial is known at both transmission and reception side. CRC8 (0x97) is used. After calculating CRC, append these 8 bits CRC to the previous input data matrix so we get 8x8 matrix. A 2D parity check is used to calculate parity bits of each row and each column. Input data along with CRC is arranged in matrix form and the parity bits are calculated and appended to form 9x9 matrix. The final matrix construction after merging input data, CRC and parity bits are shown in figure 5.2.

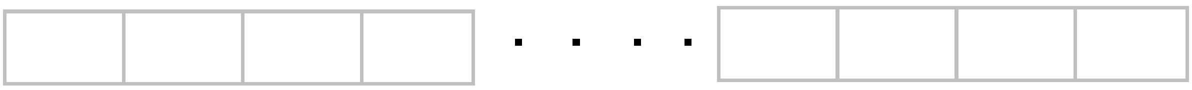

**Fig 5.1: 56 bits Input Data**

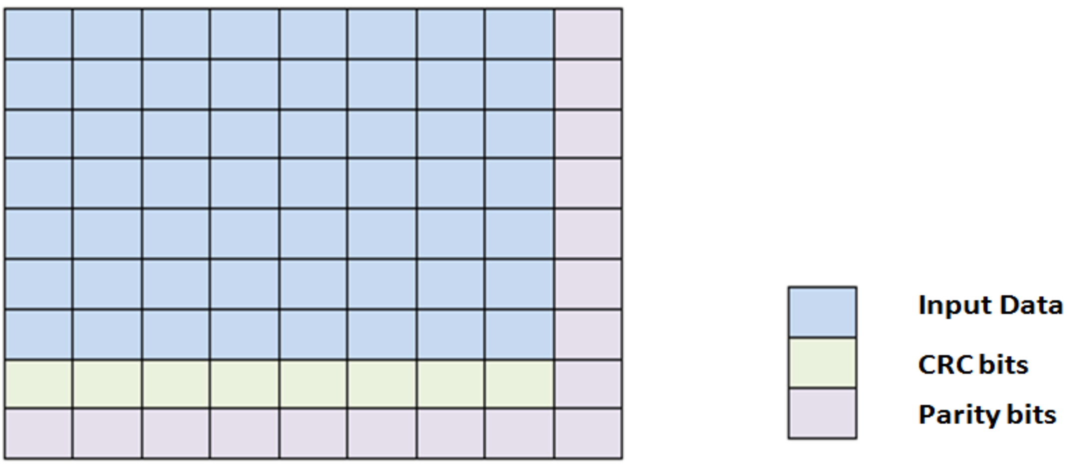


**Fig 5.2: Input Data+CRC+2D Parity Check Code in Matrix Form**

## 5.2 Error Correction at the Receiver

At the receiver side, data is divided by the same CRC polynomial. A zero syndrome indicates that the received data is error free or CRC polynomial is unable to detect the error. The CRC polynomial should be selected properly for various data lengths. Parity check is done again to detect and correct error. An unmatched parity bit means there is an error which is pointed by the parity bit.

### 5.2.1 Single Bit Correction

1. Calculate CRC syndrome for the received data block excluding CRC bits and Parity bits. We termed it as new CRC.
2. Calculate parity bits- row wise and column wise for the received data block including CRC bits. We termed these as new row and column wise parity bits respectively.
3. Suppose there is single bit error in the received data block as shown in figure 5.3. Compare new row and column wise parity bits with the received row and column wise parity bits and we get parity check results. If it indicates single bit error, perform correction (by flipping that bit) only if the new CRC matches with the reference syndrome. The location of reference syndrome which is stored in the lookup table is pointed by the parity check results.

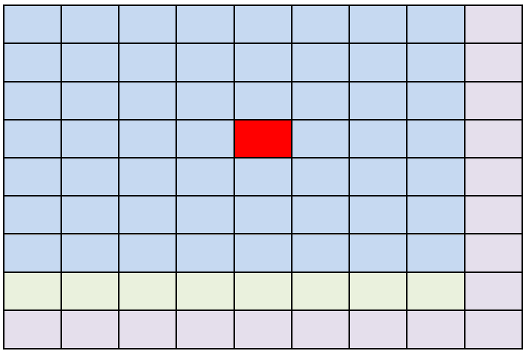

**Fig 5.3: Single bit error in the Received Block**

### 5.2.2 Two Bit Correction

1. Repeat above step 1 and step 2.
2. There are some different types of two bit errors that occur in the received data. The parity check results calculated in previous step uniquely define each type. The parity check results point to the possible location of reference syndrome and the CRC syndrome matching as in step 3 above confirms the correction and that would be

corrected by flipping the bits in the received data block pointed by the parity check results.

## 5.3 Result

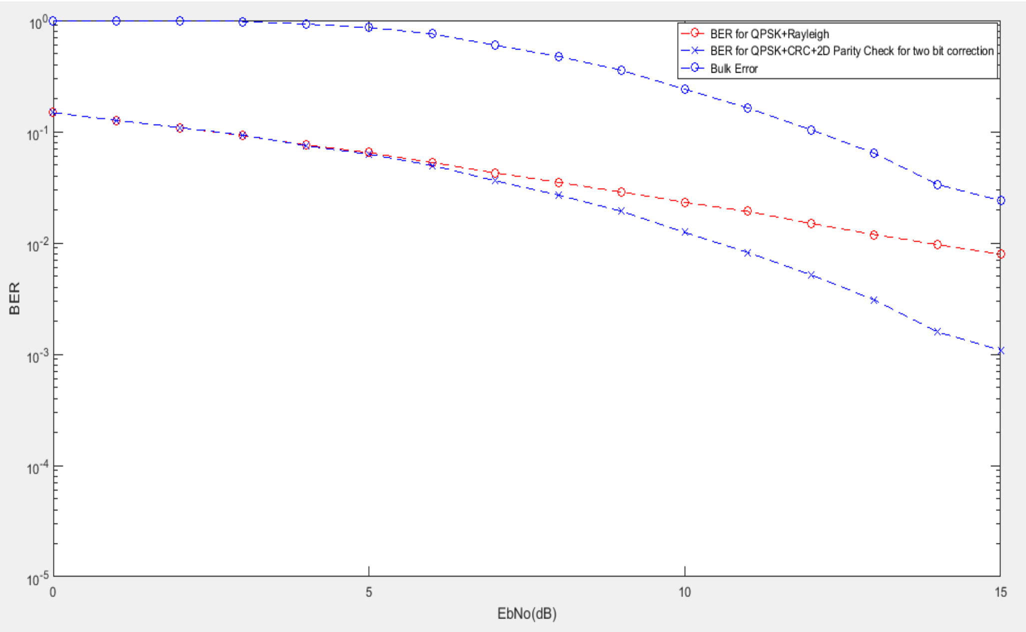


**Fig 5.4: BER Performance of CRC+2D Parity Check Code**

## 5.4 Conclusions

Performance of CRC+2D parity check code is analysed. It is concluded that 1 bit error and 2 bit errors of the received data block can be corrected by properly examining parity check results and CRC syndrome matching. The efforts are making to correct 3 bit errors also.

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