Department of Electronics and
Electrical Communications Engineering
Faculty of Engineering - Cairo University

Capacity Optimization for Cellular Networks (3G and 4G)

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Submitted by

Nourhan Mohamed Abdelmaksoud

Sara Ibrahim Mohamed

Zeinab Mohamed Shaaban

Under the supervision of

Academic Supervisor:
Prof. Mohamed Khairy

Technical Supervisor:
Eng. Hoda Hafez

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ABSTRACT

During the past few decades wireless technology has seen a tremendous growth. The recent introduction of high-end mobile devices has further increased subscribers' demand for high bandwidth. In cellular networks design, cell planning is the primary and most important phase before the deployment of the network's infrastructure. Cell planning aims to determine the best Base Stations (BS) placement in a given area, in order to meet traffic and coverage requirements, and to minimize overshooting that may affect user equipment. Overshooting consists in a signal from a given cell forming a discontinuous coverage area in another adjacent cell and as mobile end users continue to use network resources while moving from a cell boundary to other, traffic load within a cell does not remain constant Load balancing as a part of self-organized network solution, has become one of the most active and emerging fields of research in Cellular Network. It involves transfer of load from overloaded cells to the neighboring cells with free resources for more balanced load distribution in order to maintain appropriate end-user experience and network performance. In this project, our objective is to develop a method for the detection of the highly utilized, low quality and overshooted 4G & 3G cells using machine learning algorithms then we recommend solutions for each of these problems to increase capacity of 4G & 3G cellular networks.

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CHAPTER 1: INTRODUCTION

LTE stands for Long Term Evolution and it was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP). The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. Same time its network architecture has been designed with the goal to support packet-switched traffic with seamless mobility and great quality of service [1].

LTE is a packet switch IP technology based on OFDMA digital modulation scheme to supports channels bandwidth up to 20MHz and antenna techniques with Multiple-Input-Multiple-Output (MIMO), such that multiple data streams are delivered and received on a given frequency time by multiple antennas. Figure 4 shows an example of 4x2 MIMO where 4 antennas are transmitting, on network side, and 2 are receiving, on User Equipment (UE).

The 3rd Generation Partnership Project (3GPP) was formed in 1998 to foster deployment of 3G networks that descended from GSM. In order to be considered as 3G, a certain network needs to meet the different criteria set by technical standards when it comes to reliability and speed. 3G must also offer a peak data transfer of at least 200 Kb (Kilobits) per second. The first ever network that was considered 3G was actually introduced in the United States around the year 2003.

Mobile users and the resulting data usage are random, time varying, and often unbalanced, this make unequal load scenario for neighbor cells; consequently one cell may be overloaded while, other has much less users and its resources are not fully utilized; overloaded cell faces resource shortage, which affects access of new users and impacts the QoS of active users. Thus load imbalance seriously deteriorates the overall performance of the cellular network due to inefficient resource utilization [2].

Both 4G and 3G networks have their own advantages and disadvantages. In order to meet the high requirements of quality of service (QoS); the essential tasks identified by operators are coverage and cell planning. Generally, cell-planning process starts by determining the number and location of Base Stations (BS) as well as choosing judicious antenna parameters. Once set, the modification of those parameters may have negative impact on networks, such as the overlapping and overshooting phenomena. Overshooting consists in a signal from a given cell forming a discontinuous coverage area in another adjacent cell.

CHAPTER 2: BACKGROUND

2.1 LTE ARCHITECTURE

A standard LTE system architecture consists of an Evolved UMTS Terrestrial Radio Access Network, more commonly known as E-UTRAN, and the System Architecture Evolution, also known as SAE. SAE's main component is the Evolved Packet Core, also known as an EPC.

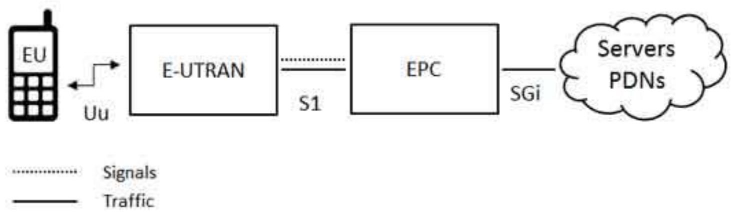


FIGURE 1: LTE SYSTEM ARCHITECTURE

The E-UTRAN is comprised of:

- User Equipment (UEs)
- evolved Node B base stations (eNodeBs)
- the Evolved Universal Terrestrial Radio Access (E-UTRA)

The EPC is comprised of:

- the Mobility Management Entity (MME)
- the Serving Gateway (SGW)
- the Packet Data Network Gateway (PGW)
- the Home Subscriber Server (HSS)
- the Access Network Discovery and Selection Function (ANDSF)
- the Evolved Packet Data Gateway (ePDG)

2.1.1 THE USER EQUIPMENT (UE)

The internal architecture of the user equipment for LTE is identical to the one used by UMTS and GSM which is actually a Mobile Equipment (ME). The mobile equipment comprised of the following important modules:

Mobile Termination (MT): This handles all the communication functions.

Terminal Equipment (TE): This terminates the data streams.

Universal Integrated Circuit Card (UICC): This is also known as the SIM card for LTE equipment. It runs an application known as the Universal Subscriber Identity Module (USIM).

2.1.2 THE E-UTRAN (THE ACCESS NETWORK)

The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved base stations, called eNodeB or eNB. Each eNB is a base station that controls the mobiles in one or more cells. The base station that is communicating with a mobile is known as its serving eNB.

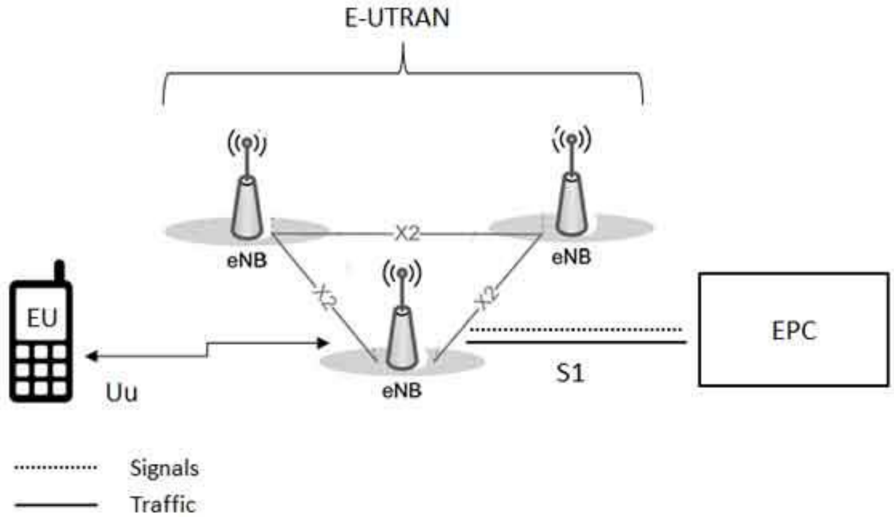


FIGURE 2: THE E-UTRAN

LTE Mobile communicates with just one base station and one cell at a time and there are following two main functions supported by eNB:

- The eNB sends and receives radio transmissions to all the mobiles using the analogue and digital signal processing functions of the LTE air interface.
- The eNB controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands.

Each eNB connects with the EPC by means of the S1 interface and it can also be connected to nearby base stations by the X2 interface, which is mainly used for signalling and packet forwarding during handover.

2.1.3 THE EVOLVED PACKET CORE (EPC) (THE CORE NETWORK)

The architecture of Evolved Packet Core (EPC) has been illustrated in Figure (3) below:

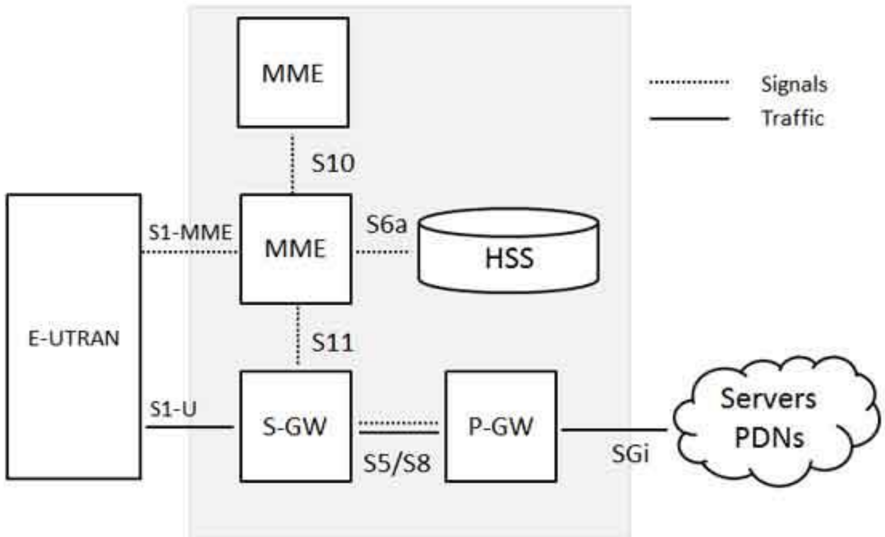


FIGURE 3: THE EVOLVED PACKET CORE

A brief description of each of the components shown in the above architecture is illustrated below:

- **The Home Subscriber Server (HSS)** component has been carried forward from UMTS and GSM and is a central database that contains information about all the network operator's subscribers.
- **The Packet Data Network (PDN) Gateway (P-GW)** communicates with the outside world ie. packet data networks PDN, using SGi interface. Each packet data network is identified by an access point name (APN). The PDN gateway has the same role as the GPRS support node (GGSN) and the serving GPRS support node (SGSN) with UMTS and GSM.
- **The serving gateway (S-GW)** acts as a router, and forwards data between the base station and the PDN gateway.
- **The mobility management entity (MME)** controls the high-level operation of the mobile by means of signalling messages and Home Subscriber Server (HSS).

2.2 LTE FREQUENCY BANDS, SPECTRUM & CHANNELS

There are many frequency bands allocated to accommodate available spectrum in different countries for LTE (FDD & TDD) which are numbered and have defined limits. Radio channel numbers are also allocated [3].

FDD LTE bands: FDD spectrum requires pair bands, one of the uplink and one for the downlink. It is also important that there is sufficient spacing between the top of the lower band and the bottom of the upper band to allow sufficient filtering. Also the uplink to downlink channel spacing must be sufficient to allow sufficient filtering to prevent the transmitted signal from entering he receiver and desensitizing it.

TDD LTE bands: TDD transmissions only require a single band and in this way paired spectrum is not needed.

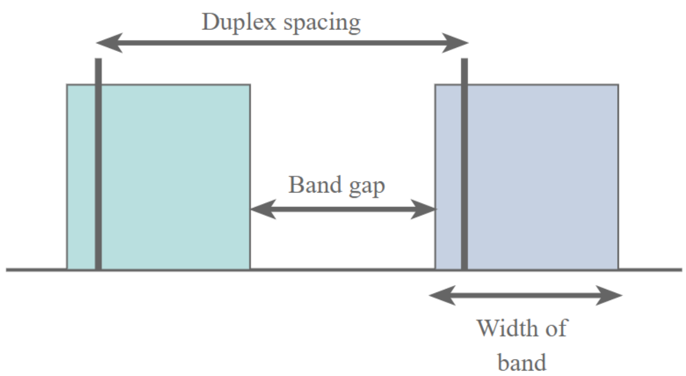


FIGURE 4: LTE FREQUENCY BAND DEFINITIONS

As shown in Figure (4), the FDD LTE frequency bands are paired to allow simultaneous transmission on two frequencies. The bands also have a sufficient separation to enable the transmitted signals not to unduly impair the receiver performance. If the signals are too close then the receiver may be "blocked" and the sensitivity impaired. The separation must be sufficient to enable the roll-off of the antenna filtering to give sufficient attenuation of the transmitted signal within the receive band [4]. Table (1) below from 3GPP TS 36.101 lists the LTE operating bands and frequencies.

TABLE 1: LTE OPERATING BANDS AND FREQUENCIES

Band number	Type	MHz	Band name	Uplink frequency	Downlink frequency
1	FDD	2100	IMT	1920 - 1980	
2	FDD	1900	PCS blocks A-F	1850 - 1910	1930 - 1990
3	FDD	1800	DCS	1710 - 1785	1805 -1880
4	FDD	1700	AWS blocks A-F (AWS-1)	1710 - 1755	2110 - 2155
5	FDD	850	CLR	824 - 849	869 - 894
7	FDD	2600	IMT-E	2500 - 2570	2620 - 2690
8	FDD	900	E-GSM	880 - 915	925 - 960
9	FDD	1800	Japan UMTS 1700 / Japan DCS	1749.9 - 1784.9	1844.9 - 1879.9
10	FDD	1700	Extended AWS blocks A-I	1710 - 1770	2110 - 2170
11	FDD	1500	Lower PDC	1427.9 - 1452.9	1475.9 - 1500.9
12	FDD	700	Lower SMH blocks A/B/C	698 - 716	728 - 746
13	FDD	700	Upper SMH block C	777 - 787	746 - 756
14	FDD	700	Upper SMH block D	788 - 798	758 - 768
17	FDD	700	Lower SMH blocks B/C	704 - 716	734 - 746
18	FDD	850	Japan lower 800	815 - 830	860 - 875

19	FDD	850	Japan upper 800	830 - 845	875 - 890
20	FDD	800	EU Digital Dividend	832 - 862	791 - 821
21	FDD	1500	Upper PDC	1447.9 - 1462.9	1495.5 - 1510.9
22	FDD	3500		3410 - 3500	3510 - 3600
23	FDD	2000	S-Band (AWS-4)	2000 - 2020	2180 - 2200
24	FDD	1600	L-Band (US)	1625.5 - 1660.5	1525 - 1559
25	FDD	1900	Extended PCS blocks A-G	1850 - 1915	1930 - 1995
26	FDD	850	Extended CLR	814 - 849	859 - 894
27	FDD	850	SMR	807 - 824	852 - 869
28	FDD	700	APT	703 - 748	758 - 803
29	FDD/CA	700	Lower SMH blocks D/E	N/A	717 – 728
30	FDD	2300	WCS blocks A/B	2305 - 2315	2350 - 2360
31	FDD	450		452.5 - 457.5	462.5 - 467.5
32	FDD/CA	500	L-Band (EU)	N/A	1452 – 1496
33	TDD	2100	IMT		1900 – 1920
34	TDD	2100	IMT		010 – 2025
35	TDD	1900	PCS (Uplink)		1850 – 1910
36	TDD	1900	PCS (Downlink)		930 – 1990
37	TDD	1900	PCS (Duplex spacing)		1910 – 1930
38	TDD	2600	IMT-E (Duplex Spacing)		2570 – 2620
39	TDD	1900	DCS-IMT gap		1880 – 1920
40	TDD	2300			2300 – 2400
41	TDD	2500	BRS / EBS		496 – 2690
42	TDD	3500			3400 – 3600
43	TDD	3700			3600 – 3800
44	TDD	700	APT		703 – 803
45	TDD	1500	L-Band (China)		1447 – 1467
46	TDD	5200	NII		5150 – 5925
65	FDD	2100	Extended IMT	1920 – 2010	2110 – 2200
66	FDD	1700	Extended AWS blocks A-J (AWS-1/AWS-3)	1710 – 1780	2110 – 2200
67	FDD / CA	700	EU 700	N/A	738 – 758

2.3 KEY TECHNIQUES FOR LTE

LTE has introduced a number of new technologies when compared to the previous cellular systems. They enable LTE to be able to operate more efficiently with respect to the use of spectrum, and also to provide the much higher data rates that are being required [5].

2.3.1 OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEX)

OFDM technology was used for the signal format for LTE because it enabled high data bandwidths to be transmitted efficiently while still providing a high degree of resilience to reflections and interference. As data was carried on a large number of carriers, if some were missing as a result of interference from reflections, etc, the system was still able to cope [6]. The access schemes differed between the uplink and downlink: OFDMA (Orthogonal Frequency Division Multiple Access was used in the downlink; while SC-FDMA(Single Carrier - Frequency Division Multiple Access) was used in the uplink. SC-FDMA was used in view of the fact that its peak to average power ratio is smaller than for OFDMA - the lower peak to average power ratio enabling better levels of final RF power amplifier to be achieved - this was and is an important factor for mobile handset battery life.

2.3.2 MIMO (MULTIPLE INPUT MULTIPLE OUTPUTS)

One of the main problems that previous telecommunications systems have encountered was that of multiple signals arising from the many reflections that are encountered. By using MIMO, these additional signal paths could be used to advantage and were able to be used to increase the throughput [7].

When using MIMO, it is necessary to use multiple antennas to enable the different paths to be distinguished. Accordingly schemes using 2 x 2, 4 x 2, or 4 x 4 antenna matrices could be used. While it is relatively easy to add further antennas to a base station, the same was not true of mobile handsets, where the dimensions of the user equipment limited the number of antennas which should be placed at least a half wavelength apart.

2.3.3 SAE (SYSTEM ARCHITECTURE EVOLUTION)

With the very high data rate and low latency requirements for 3G LTE, it was necessary to evolve the system architecture to enable the improved performance to be achieved. One change was that a number of the functions previously handled by the core network were transferred out to the periphery. Essentially this provided a much "flatter" form of network architecture. In this way latency times could be reduced and data routed more directly to its destination [8]. As part of the upgrade the Evolved Packet Core, EPC was developed to ensure that the packet data was routed as efficiently as possible.

2.3.4 IP DATA

4G LTE is an all IP data system. 3G UMTS had included circuit switched voice, but LTE had not provision for any circuit switched voice. Originally it had been anticipated that operators would supply the data capability and voice would be via OTT applications. As operators would lose out significant revenues as voice, at the time, constituted a major element of the revenue. To overcome this GSMA set the standard for voice connectivity as the Voice over LTE scheme, **VoLTE**.

VoLTE required the implementation of an IMS core and this slowed roll out of this capability in view of the expense. To help operators overcome this, a limited implementation of IMS was developed and this considerably reduced the capital expenditure required by operators.

2.4 OVERSHOOTING

The overshooting is the cell which transmitted radio frequency signal over propagates beyond the defined coverage range. The overshooting of the cell is occurred due to several reasons such as reflections from buildings, lakes or high terrain areas.

The overshooting cell:

- Provides a significantly lower SNR than the other cells in the wireless network
- Provides communication links with low quality.
- Suffers from call drops and bad quality of experience.

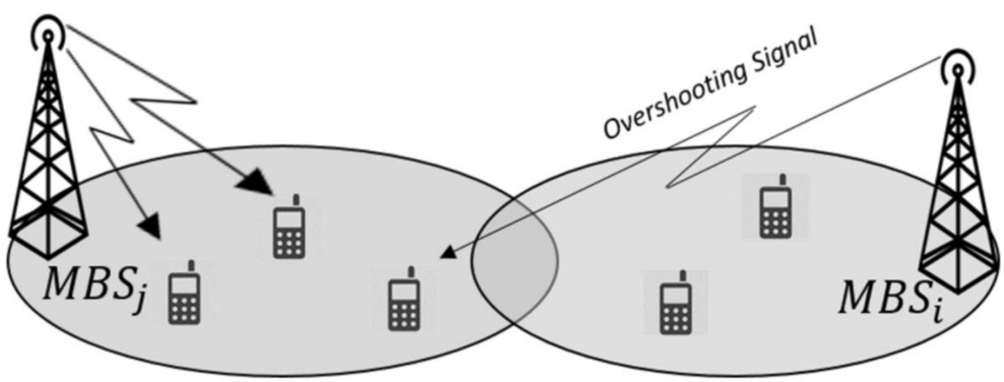


FIGURE 5: ILLUSTRATION OF OVERSHOOTING PHENOMENON

2.5 UTILIZATION OF CELL RESOURCE

Physical Resource Block (PRB)

Resource Block is the minimum unit for resource allocation used for the data transmission in physical layer; it consists of two dimensional domains:

- Frequency Domain: 12 Subcarriers.
- Time Domain: 1 Slot= 7 OFDM Symbol (normal CP).

Insufficiency

Growing traffic leads to a big increase in PRB usage. When the PRB usage approaches to 100%, user rates will decrease which leads to:

- New UEs may fail to be admitted.
- Admitted users experience is affected.

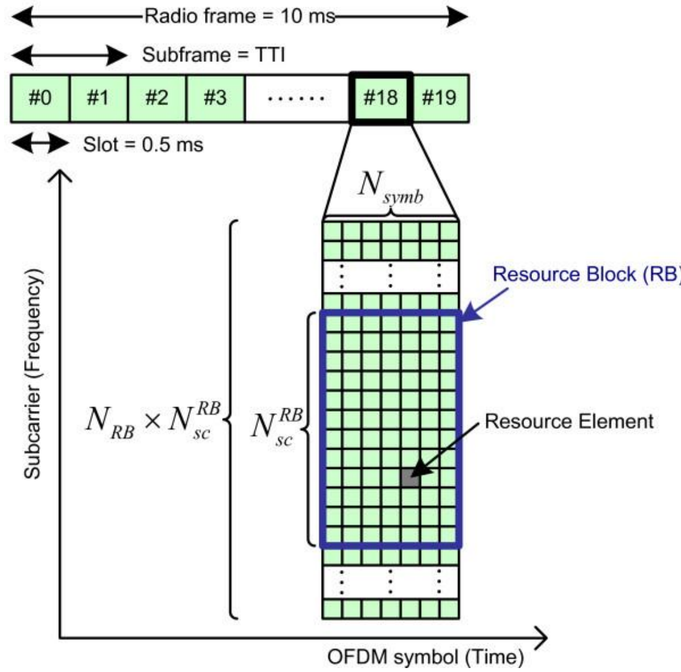


FIGURE 6: LTE PHYSICAL RESOURCE BLOCK

Control Channel Element (CCE)

The CCE is a group of resources which is used to send a PDCCH (Physical Downlink Control Channel).

Each CCE consists of 9 REGs (Resource Element Group).

In each radio frame CCEs is allocated to uplink and downlink UEs to be scheduled and common control signaling. PDCCH CCEs must be configured and allocated to reduce downlink control overheads and to ensure satisfactory user-plane throughput [9].

Insufficiency

When PDCCH symbols are insufficient, UEs may fail to be scheduled as CCEs miss to be allocated to UEs, This will cause a long service delay as well as unsatisfactory user experience.

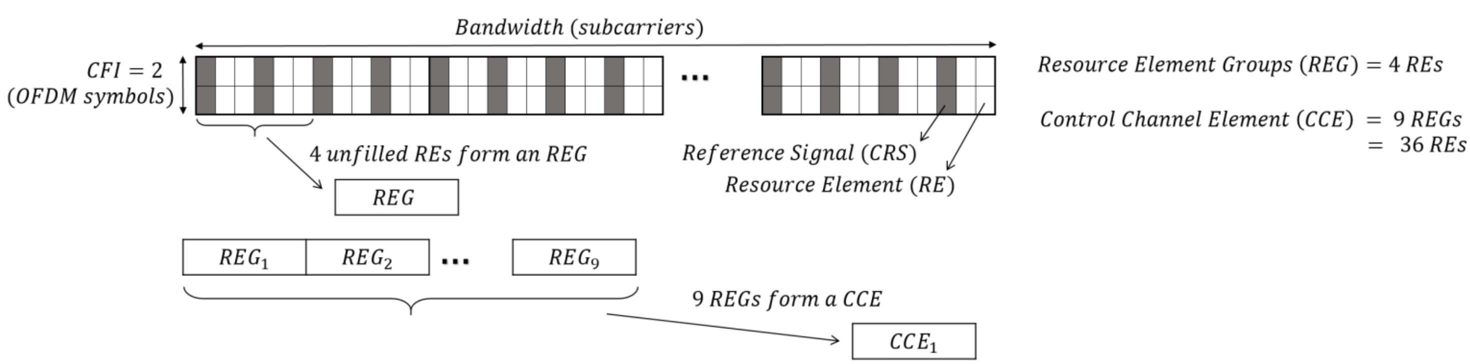


FIGURE 7: CCE FORMATION IN LTE PDCCH

2.6 3G UMTS ARCHITECTURE

The UMTS network architecture can be divided into three main elements:

- ***User Equipment (UE):*** The User Equipment or UE is the name given to what was previous termed the mobile, or cellphone. The new name was chosen because the considerably greater functionality that the UE could have. It could also be anything between a mobile phone used for talking to a data terminal attached to a computer with no voice capability.
- ***Radio Network Subsystem (RNS):*** The RNS also known as the UMTS Radio Access Network, UTRAN, is the equivalent of the previous Base Station Subsystem or BSS in GSM. It provides and manages the air interface for the overall network.
- ***Core Network:*** The core network provides all the central processing and management for the system. It is the equivalent of the GSM Network Switching Subsystem or NSS.

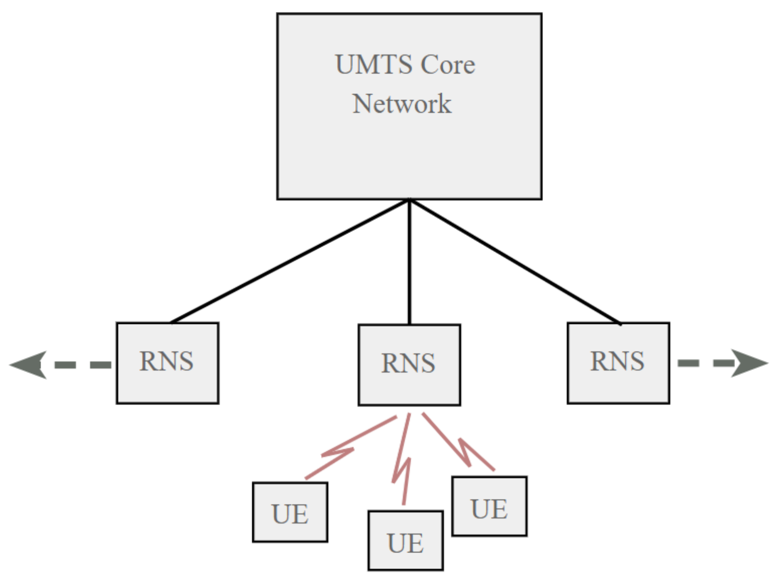


FIGURE 8: THE MAIN UMTS NETWORK BLOCKS

The core network is then the overall entity that interfaces to external networks including the public phone network and other cellular telecommunications networks. In view of the different ways in which data may be carried, the UMTS core network may be split into two different areas:

- ***Circuit switched elements:*** These elements are primarily based on the GSM network entities and carry data in a circuit switched manner, i.e. a permanent channel for the duration of the call.
- ***Packet switched elements:*** These network entities are designed to carry packet data. This enables much higher network usage as the capacity can be shared and data is carried as packets which are routed according to their destination.

2.7 KPIS FOR 4G NETWORK

The purpose is to check the performance 4G of Network. We have categories of KPI and numbers of KPI of each category. In the Optimization process we have to check the KPI value to monitor and optimize the radio network performance in order to provide better subscriber quality or to achieve better use of installed network resources.

LTE KPIs can be classified into:

- **Radio Network KPIs** which focus in radio network performance.
- **Service KPIs** which focus on the user experience.

Typically **Radio Network KPIs** can be categorized into following subcategories:

1. Accessibility KPI

It is used to measure properly of whether services requested by users can be accessed in given condition, also refers to the quality of being available when users needed, such as user request to access the network, access the voice call, data call.

2. Retainability KPI

It is used to measure how the network keep user's possession or able to hold and provide the services for the users.

3. Mobility KPI

It is used to measure the performance of network which can handle the movement of users and still retain the service for the user, such as handover.

4. Integrity KPI

It is used to measure the character or honesty of network to its user, such as what is the throughput, latency which users were served.

5. Availability KPI

It is used to measure the availability of network, suitable or ready for users to use services.

6. Utilization KPI

It is used to measure the utilization of network, whether the network capacity is reached its resource.

LTE-KPIs	INDICATORS
Accessibility KPI	- RRC Setup Success Rate. - ERAB Setup Success Rate. - Call Setup Success Rate.
Retainability KPI	- Service Call Drop Rate. - Call Drop Rate.
Mobility KPI	- Intra-Frequency HO. - Inter-Frequency HO. - Inter-RAT HO.
Integrity KPI	- E-UTRAN IP Throughput. - IP Throughput in DL. - E-UTRAN IP Latency.
Availability KPI	- E-UTRAN Cell Availability. - Partial cell availability.
Utilization KPI	- Mean Active Dedicated EPS Bearer Utilization.

Typically **Service KPIs** can be categorized into following subcategories:

1. **Latency KPI**
2. **Integrity KPI**

LTE-KPIs	INDICATORS
Latency KPI	- Access latency. - Service latency. - Interrupt latency.
Integrity KPI	- Service UL / DL throughput.

2.8 KEY TECHNIQUES FOR 3G UMTS

UMTS uses **Code Division Multiple Access (CDMA)** on the air interface which is an access procedure that enables multiple users to telephone simultaneously via a single base station, while their conversations are kept separate as the Individual conversations are encoded with a pseudo-random digital sequence. UMTS utilizes CDMA as it is far better suited for fast data stream transfer [10]. CDMA was introduced by the Telecommunications Industry Association (TIA) in 1993. CDMA is characterized by high capacity and small cell radius, employing spread spectrum technology and a special coding scheme.

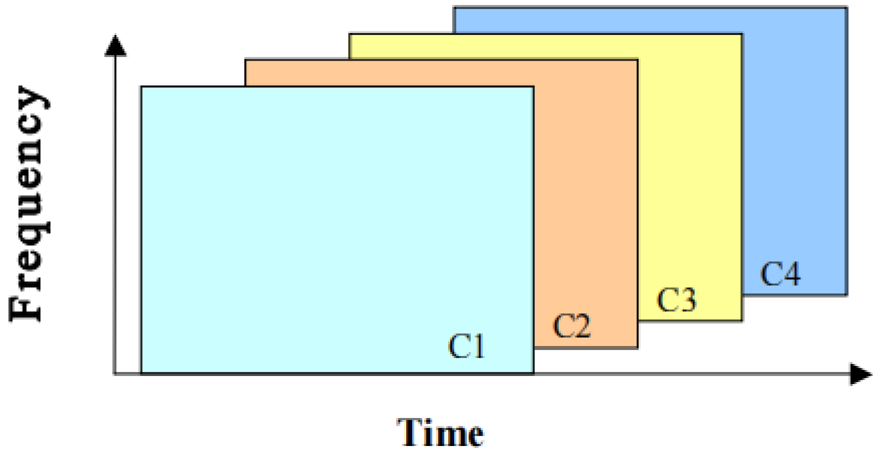


FIGURE 9: CODE DIVISION MULTIPLE ACCESS

The basic DS-CDMA transmission and reception is illustrated in Figure below:

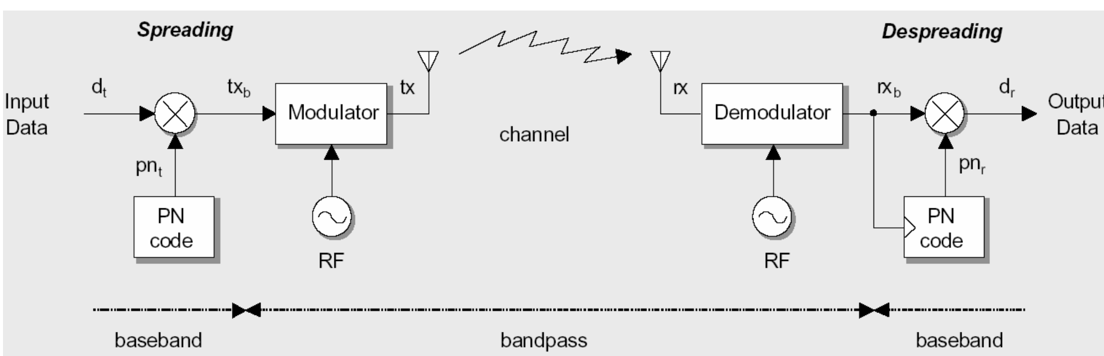


FIGURE 10: DS-CDMA TRANSMISSION AND RECEPTION

Signal transmission consists of the following steps:

1. A pseudo-random code is generated
2. The data is spread by pseudo random code
3. The resulting signal modulates a carrier
4. The modulated carrier is broadcast

Signal reception consists of the following steps:

1. The carrier is received and amplified
2. The received signal demodulates
3. A pseudo- random code is generated
4. The received signal is correlated with the generated code, extracting the information data

2.9 RADIO RESOURCES CONTROL (RRC)

The RRC protocol is the main control protocol for the Access Stratum (AS) and is responsible for the control and configuration of the underlying protocols that establish the radio connection between the user equipment and the network.

Services provided by the RRC can be arranged into three groups:

- **General control,** which provides information broadcasting services to all the UEs located in a specific geographical area.
- **The notification,** which provides services for paging and information broadcasting to specific UEs
- **The dedicated control,** which provides services for connection establishment and release as well as messages transfer through that connection.

RRC messages transferred between the UE and the UTRAN/RNC configure and control the RRC connection, and can be divided into four categories:

- **RRC connection management.**
- **RRC connection mobility.**
- **RRC measurements.**
- **Radio Bearers control.**

UE needs resources from UTRAN network when it wants to establish either CS call or PS call. In order to do this following three steps are performed:

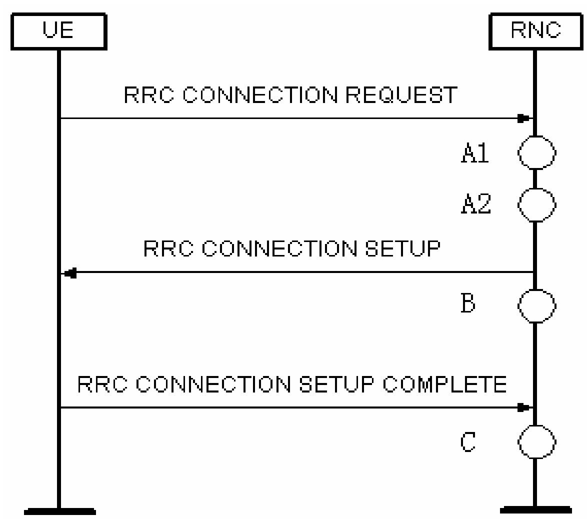


FIGURE 11: RRC CONNECTION ESTABLISHMENT PROCEDURE

A. RRC Connection Request: From UE to RNC
B. RRC Connection Setup: RNC assigns traffic channel (i.e. transport channel) and creates SRB(Signaling Radio Bearer).
C. RRC Connection Complete.

RRC Establishment Counters we used in our work:

- **RRC connection request:**

  VS.RRC.AttConnEstab.Cell: Number of RRC connection requests

- **RRC connection setup:**

  VS.RRC.SetupConnEstab.Cell: Number of successful RRC connection setup

- **RRC connection Failure:**

  VS.RRC.Rej.UL.CE.Cong: Cell UL CE resource request failure

  VS.RRC.Rej.DL.CE.Cong: Cell DL CE resource request failure

2.10 THE RADIO ACCESS BEARER (RAB)

The Radio Access Bearer (RAB) is the entity responsible for transferring radio frames of an application over the network in UMTS. The parameters of a RAB, the maximum bandwidth and the allowed frame sizes, can be configured according to the requirements of the application. The RAB bandwidth determines the QoS received by the application. Given an application, it is so important to define its RAB well adapted to its requirements; too large bandwidth or improper frame sizes will result in a waste of resources while too small bandwidth will result in a bad quality [11].

The following properties are specified for a RAB:

- service class (conversational, streaming)
- maximum speed
- guaranteed speed
- delay
- error probability

The transmission of data within a RAB in UMTS works as follows. Data of an application at the UE is stored in a buffer. This internal buffer is emptied periodically, then a radio frame is created, once the frame has been created, it is transported through the air interface to the Node -B, where an IP packet containing the frame is created. The data is then transferred through the Radio Access Network (RAN) to the RNC. The RABs with the highest priority will be allocated first and the RABs with the lower priority may be placed in a queue.

RAB Establishment Counters we used in our work:

- **VS.RAB.AttEstabCS.Conv** & **VS.RAB.AttEstabCS.Str** : CS RAB setup request based on QoS
- **RAB.AttEstabPS.Conv** & **VS.RAB.AttEstabPS.Str** :PS RAB setup request for different QoS

2.11 KPIS FOR 3G NETWORK

3G KPIs are parameters that measure 3G network performance and are to be observed when the network monitoring is going on.

As discussed previously in section 2.7, in 3G Optimization process it is necessary to check the KPI value to monitor and optimize the radio network performance in order to obtain better quality or to achieve better use of network resources.

The main KPIs are monitored for UMTS:

3G-KPIs	INDICATORS
Accessibility KPI	**- RRC Setup & Access Rate. - RAB Setup & Access Rate. - Call Setup Success Rate.**
Retainability KPI	**- RRC Drop Rate. - RAB Drop Rate.**
Mobility KPI	**- SHO/ISHO Success Rate. - SHO Overhead.**
Usage KPI	**- Cell Availability. - Cell Throughput.**

Clustering is the classification of objects into different groups, or more precisely, the partitioning of a data set into subsets (clusters), so that the data in each subset (ideally) share some common trait - often according to some defined distance measure.

3.1 K-MEANS CLUSTERING

K-means clustering is the most popular form of an unsupervised learning algorithm which is an algorithm for partitioning (or clustering) N data points into K disjoint subsets S_i containing data points so as to minimize (WCSS) Within Cluster Sum of Squares which defines the total variations within a cluster [12].

$$\boldsymbol{WCSS} = \sum_{j=1}^{k} \sum_{i:S_i=j} |\boldsymbol{x_i} - \boldsymbol{\mu_j}|^2$$

Where $\boldsymbol{x_i}$ is a vector representing the $\boldsymbol{i^{th}}$ data point and $\boldsymbol{\mu_j}$ is the geometric centroid of the data points in S_j.

It divides the data into clusters by satisfying these two requirements:

- Each group should consist of at least one point.
- Each point must belong to exactly one group.

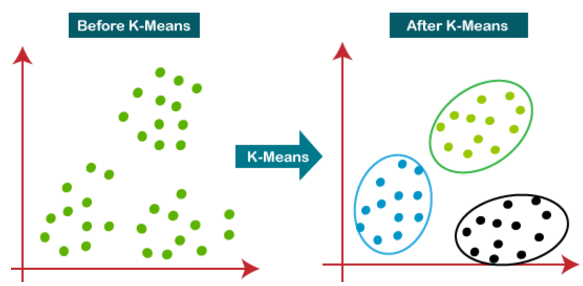


FIGURE 12: K-MEANS CLUSTERING

K-MEANS Algorithm steps:

1. Initialize cluster centers.
2. Assign observations to closest cluster center.

$$S_i \leftarrow \boldsymbol{argmin_j}||\boldsymbol{\mu_j} - \boldsymbol{x_i}||^2$$

3. Revise cluster centers as mean of assigned observations.

$$\boldsymbol{\mu_j} \leftarrow \boldsymbol{argmin_\mu} \sum_{i:S_i=j} ||\boldsymbol{\mu} - \boldsymbol{x_i}||^2$$

4. Repeat (1) and (2).until convergence to Local optimum.

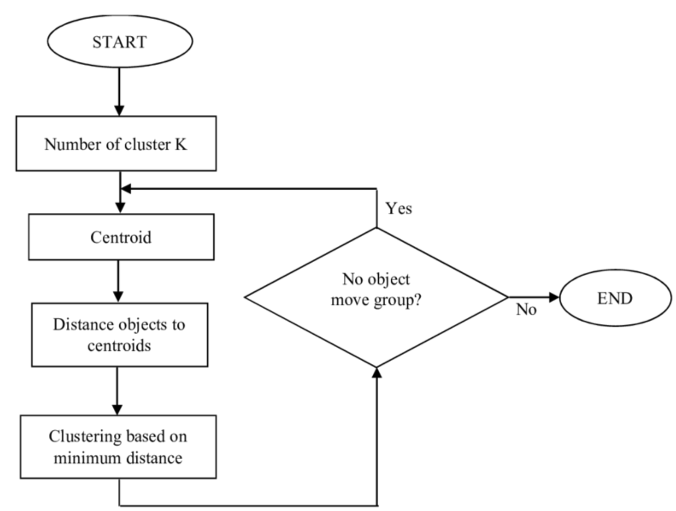


FIGURE 13: K-MEANS ALGORITHM STEPS

3.2 ELBOW METHOD

The Elbow method is one of the most popular ways to find the optimal number of clusters. This method uses the concept of WCSS value [13].

The elbow method steps:

1. It executes the K-means clustering on a given dataset for different K values (ranges from 1-10).
2. For each value of K, calculates the WCSS value.
3. Plots a curve between calculated WCSS values and the number of clusters K.
4. The sharp point of bend or a point of the plot looks like an arm, then that point is considered as the best value of K.

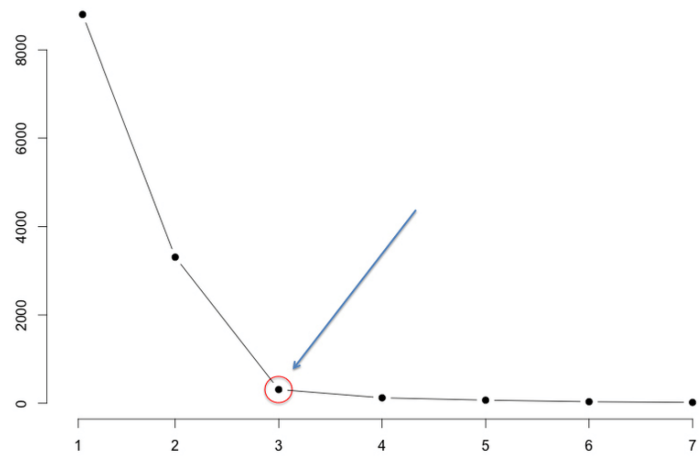


FIGURE 14: THE ELBOW METHOD

3.3 DETECTION TECHNIQUES

3.3.1 DETECTION OF OVERSHOOTING

We use **Huawei 4G TA Counters** to get footprint of each cell, the algorithm takes the summation of the counter steps till reach to 80% from the total counts and by that we succeeded in calculating the footprint range in meters. Once we calculate the footprint, we will use two techniques to detect overshooting.

TABLE 2: HUAWEI 4G TA COUNTERS

Counter name	Distance(m)
L.RA.TA.UE.Index0	**0_156**
L.RA.TA.UE.Index1	**156_312**
L.RA.TA.UE.Index2	**312_624**
L.RA.TA.UE.Index3	**624_1092**
L.RA.TA.UE.Index4	**1092_2028**
L.RA.TA.UE.Index5	**2028_3588**
L.RA.TA.UE.Index6	**3588_6630**
L.RA.TA.UE.Index7	**6708_14508**
L.RA.TA.UE.Index8	**14508_30108**
L.RA.TA.UE.Index9	**30108_53508**
L.RA.TA.UE.Index10	**53508_76908**
L.RA.TA.UE.Index11	**≥76908**

THE FIRST TECHNIQUE

This technique is depending on comparing the cell's footprint with threshold which depending on type of cell (Rural or Dense), the Rural cell's footprint is compared with 5Km and the dense cell's footprint is compared with 1Km.

THE SECOND TECHNIQUE

This technique is depending on calculating the overshooting indicator which consists of two parameters and compare it with threshold equal two.

The first parameter in this technique is the footprint of specific cell.

The second parameter is the average site to site distance that calculated from neighbor list by calculating the distance between the site and each neighbor and then average the calculated values.

After that we calculate the Overshooting Indicator by getting the ratio between the cell footprint and the average site to site distance as per equation (1) below. We can take decision of overshooting on cells which have indicator larger than or equal two. We will depend on this technique in our results.

$$\boldsymbol{Overshooting\ Indicator} = \frac{\boldsymbol{Footprint\ of\ cell}}{\boldsymbol{Average\ Site\ to\ Site\ distance}} \quad (\mathbf{1})$$

3.3.2 DETECTION OF UNBALANCED CELLS

The unbalancing problem mainly appears if there is a difference between the utilization on specific sector's bands (2100, 1800, 900, 2600); to detect the unbalanced sectors in specific Enode-B.

The Algorithm considers the 1^{st} band (2100) as a reference and then gets the difference between the (1^{st} and 2^{nd}) bands, the ($1^{st}$and 3^{rd}) and the (1^{st} and 4^{th}) bands.

The K-means algorithm is used to detect the unbalanced sectors by clustering deltas between bands to get the unbalanced cells relative to the network status and not by fixing a certain threshold.

3.3.3 DETECTION OF HIGH UTILIZED CELLS

3.3.1 Monitoring Physical Resource Block

Monitoring Principle	Measurement	Formula	Monitoring Threshold	Impact	Proposed solution
Resource block utilization	DL RB Utilization	$\frac{L.ChMeas.PRB.DL.UsedAvg}{L.ChMeas.PRB.DL.Avail} * 100\ \%$	DL RB Utilization>70%	User may failed in admission or poor user experience	1. Add eNodeB 2. Bandwidth expansion
	DL User throughput	$\frac{L.Thrp.bits.DL}{L.Thrp.Time.DL}/1000$	DL User Throughput < 2Mbps		
	UL RB Utilization	$\frac{L.ChMeas.PRB.UL.Used.Avg}{L.ChMeas.PRB.UL.Avail} * 100\ \%$	UL RB Utilization>70%	User may failed in admission or poor user experience	1. Add eNodeB 2. Bandwidth expansion
	UL User throughput	$\frac{L.Thrp.bits.UL}{L.Thrp.Time.UL}/1000$	UL User Throughput < 512Kbps		

3.3.2 Monitoring Control Channel Element

Monitoring Principle	Measurement	Monitoring Threshold	Impact	Proposed solution
Control channel element for PDCCH	CCE Utilization	CCE Utilization >70%	Scheduling delayed or poor user experience	Add cell

Formula:

$$\frac{L.ChMeas.CCE.CommUsed + L.ChMeas.CCE.ULUsed\ + L.ChMeas.CCE.DLUsed}{L.ChMeas.CCE.Avail} * 100\ \%$$

3.3.4 DETECTION OF LOW QUALITY-CELLS

E-UTRAN Average CQI:

In the LTE system, Channel Quality Indicator is used by the UE to indicate the channel quality to the eNB and then indicate the level of modulation and coding the UE could operate.

In LTE, there are 15 different CQI values randing from 1 to 15 and mapping between CQI and modulation scheme, transport block size is defined as follows:

In our work, we calculated E-UTRAN Average-CQI to classify the cells according to the quality of each of them as per the following illustration:

Formula used to calculate E-UTRAN Avg CQI:

$$\textbf{E-UTRAN Average CQI} = \frac{A}{B}$$

Where:

$$A = [L.ChMeas.CQI.DL.0]*0 + [L.ChMeas.CQI.DL.1]*1 + [L.ChMeas.CQI.DL.2]*2 + [L.ChMeas.CQI.DL.3]*3 + [L.ChMeas.CQI.DL.4]*4 + [L.ChMeas.CQI.DL.5]*5 + [L.ChMeas.CQI.DL.6]*6 + [L.ChMeas.CQI.DL.7]*7 + [L.ChMeas.CQI.DL.8]*8 + [L.ChMeas.CQI.DL.9]*9 + [L.ChMeas.CQI.DL.10]*10 + [L.ChMeas.CQI.DL.11]*11 + [L.ChMeas.CQI.DL.12]*12 + [L.ChMeas.CQI.DL.13]*13 + [L.ChMeas.CQI.DL.14]*14 + [L.ChMeas.CQI.DL.15]*15)$$

$$B = ([L.ChMeas.CQI.DL.0] + [L.ChMeas.CQI.DL.1] + [L.ChMeas.CQI.DL.2] + [L.ChMeas.CQI.DL.3] + [L.ChMeas.CQI.DL.4] + [L.ChMeas.CQI.DL.5] + [L.ChMeas.CQI.DL.6] + [L.ChMeas.CQI.DL.7] + [L.ChMeas.CQI.DL.8] + [L.ChMeas.CQI.DL.9] + [L.ChMeas.CQI.DL.10] + [L.ChMeas.CQI.DL.11] + [L.ChMeas.CQI.DL.12] + [L.ChMeas.CQI.DL.13] + [L.ChMeas.CQI.DL.14] + [L.ChMeas.CQI.DL.15])$$

TABLE 3: CLASSIFICATION OF CELLS ACCORDING TO AVG-CQI VALUE

E-UTRAN Avg-CQI value	From 0 to 1	From 1 to 7	Greater than 7
indication	Poorest Channel Quality	Poor Channel Quality	Acceptable Quality

3.3.5 DETECTION OF HIGH SERVICE DROP RATE-CELLS

In our work we used Service Drop Rate KPI can be used to evaluate the call drop rate of all services, including VoIP service as the following illustration:

Formula used to calculate Service Drop Rate KPI:

$$Service\ Drop\ Rate = \frac{[L.E-RAB.AbnormRel]}{[L.E-RAB.AbnormRel] + [L.E-RAB.NormRel]} * 100$$

TABLE 4: CLASSIFICATION OF CELLS ACCORDING TO SERVICE DROP RATE VALUE

Service Drop Rate value	Less than 2 %	Greater than 2 %
indication	Acceptable Service Drop Rate Cells	High Service Drop Rate Cells

3.3.6 DETECTION OF RRC CONGESTION & BLOCKING

RRC Setup Failure Due To congestion one of the most common RRC failure which is present in every network To detect the congestion of RRC Attempt in a cell we calculate an important KPI called **RRC Attempt Congestion Ratio** using the following formula:

RRC Attempt Congestion Ratio (Cell) = (RRC.FailConnEstab.Cong/VS.RRC.AttConnEstab.Cell)*100%.

Where:

- **RRC.FailConnEstab.Cong: Number of RRC Connection Reject due to network congestion.**
- **VS.RRC.AttConnEstab.Cell: Number of RRC Connection Attempts.**

The next step is to monitor the **RRC Blocking (UL&DL)** counters: **VS.RRC.Rej.UL.CE.Cong** & **VS.RRC.Rej.DL.CE.Cong** in each cells and correlate them to RRC congestion ratio in this cell

3.3.7 DETECTION OF DCCC FAILURES

DCCC: **D**ynamic **C**hannel **C**onfiguration **C**ontrol.

DCCC is one of the most important RAN features that allocate dynamic resource according to the service request and it increase the radio resource utilization efficiency.

DCCC feature in Huawei 3G is mainly used to control the rate of best effort services on the DCH and E-DCH. We used the following counters to detect the DCCC Failures in UL & DL:

- **VS.RAC.DCCC.Fail.ULCE.Cong: Number of UL Failures in the DCCC procedure.**
- **VS.RAC.DCCC.Fail.DLCE.Cong: Number of DL Failures in the DCCC procedure.**

3.3.8 DETECTION OF RAB FAILURE

CS RAB Failure: The sum of all unsuccessful CS RAB establishments in the network due to insufficient resources, divided by sum of all such CS RAB establishment attempts, expressed as a percentage.

CS RAB Congestion Ratio= [(VS.RAB.FailEstabCS.DLIUBBand.Cong + VS.RAB.FailEstabCS.ULIUBBand.Cong +VS.RAB.FailEstabCS.DLCE.Cong + VS.RAB.FailEstabCS.DLCE.Cong +VS.RAB.FailEstabCS.Code.Cong + VS.RAB.FailEstabCS.ULPower.Cong+ VS.RAB.FailEstabCS.DLPower.Cong) / (VS.RAB.AttEstabCS.Conv+ VS.RAB.AttEstabCS.Str)] x100%

PS RAB Failure: The sum of all unsuccessful PS RAB establishments due to insufficient resources, divided by sum of all such PS RAB establishment attempts, expressed as a percentage.

PS RAB Congestion Ratio= [(VS.RAB.FailEstabPS.DLIUBBand.Cong +VS.RAB.FailEstabPS.ULIUBBand.Cong+VS.RAB.FailEstabPS.ULCE.Cong+VS.RAB.FailEstabPS.DLCE.Cong +VS.RAB.FailEstabPS.Code.Cong+VS.RAB.FailEstabPS.ULPower.Cong+VS.RAB.FailEstabPS.DLPower.Cong +VS.RAB.FailEstabPS.HSDPAUser.Cong+ VS.RAB.FailEstabPS.HSUPAUser.Cong) / VS.RAB.AttEstabPS.Str + VS.RAB.AttEstabPS.Int +VS.RAB.AttEstabPS.Bkg] x 100%

We then apply a threshold for SC & PS RAB failure <u>greater than or equal 1% to be accepted</u>; otherwise the cell is considered congested [14]

3.3.9 DETECTION OF OVERLOAD CONGESTION

To detect the overloaded RNC we calculate the following KPI:

$$\textbf{Congested Cell Ratio} = \frac{\textit{Number of cells where } \mathrm{VS.LCC.OverCongNumUL}>0 \text{ or } \textit{Number of cells where } \mathrm{VS.LCC.OverCongNumDL}>0}{\textit{Total Number of Cells in RNC}} * \mathbf{100}$$

Where:

VS.LCC.OverCongNumUL, VS.LCC.OverCongNumDL: Number of UL/DL Overload Congestions.

4G Results

4.1 Overshooting

The figure below illustrates **the overshooting cells** depending on the second technique.

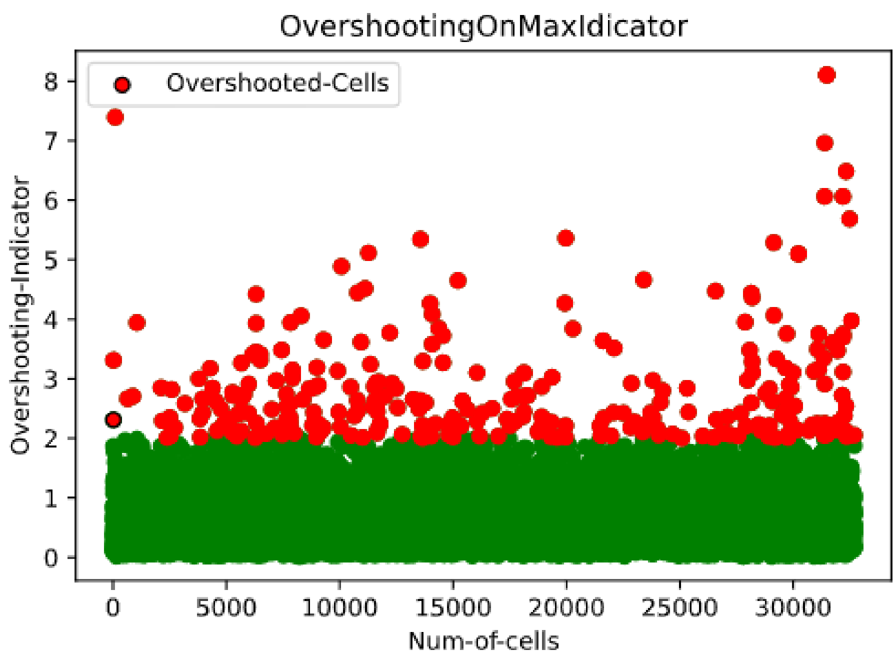


FIGURE 15: OVERSHOOTED CELLS CLUSTERS

The figures below illustrate **the overshooting cells** depending on the second technique which have high Service drop rate **(drop rate >=2%).**

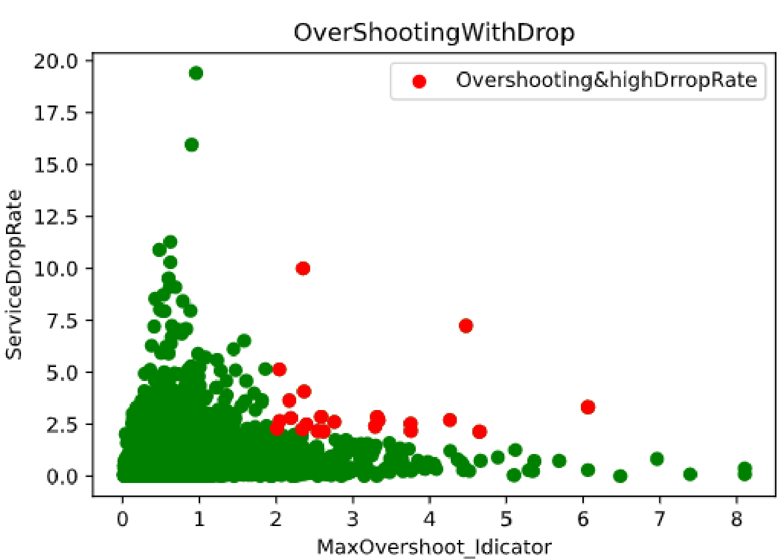


FIGURE 16: OVERSHOOTED AND HIGH DROP RATE CELLS CLUSTERS

NameOfCell	MaxOvershoot_Idic	ServiceDropRate
[illegible]	2.011651192	2.2938
[illegible]	2.044592469	2.6593
[illegible]	2.19325813	2.8028
[illegible]	2.58599254	2.8614
[illegible]	3.315962699	2.856
[illegible]	2.35056371	10
[illegible]	4.265302522	2.6999
[illegible]	4.650021041	2.1432
[illegible]	2.364142062	4.0805
[illegible]	2.173058014	3.6472
[illegible]	2.342921761	2.2652
[illegible]	4.471980766	7.2441
[illegible]	2.041768622	5.1397
[illegible]	3.290168953	2.3967
[illegible]	2.758699373	2.6108
[illegible]	2.617260788	2.1585
[illegible]	3.333946135	2.6898
[illegible]	2.394098913	2.4935
[illegible]	2.543121582	2.1733
[illegible]	3.755435908	2.1884
[illegible]	6.061922868	3.3278
[illegible]	3.752759382	2.5316

FIGURE 17: OVERSHOOTED AND HIGH DROP RATE CELLS

The figures below illustrate **the overshooting cells** depending on the second technique which have low average CQI (**Avg-CQI**<7).

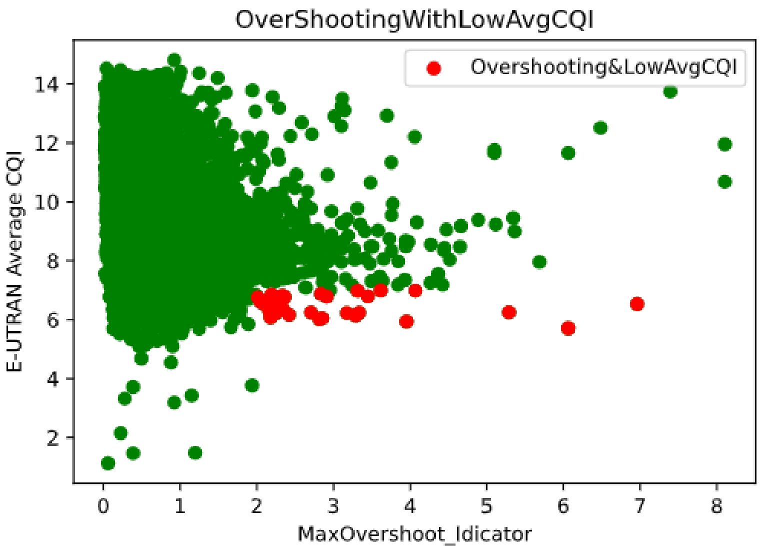


FIGURE 18: OVERSHOOTED AND LOW CQI CELLS CLUSTERS

Cell Name	MaxOvershoot_Idicator	Avg_CQI
[illegible]	2.705901559	6.247787452
[illegible]	2.850910806	6.048472776
[illegible]	2.348789017	6.337757404
[illegible]	2.044592469	6.624839371
[illegible]	2.817853397	6.010873999
[illegible]	2.19325813	6.57531195
[illegible]	2.179360072	6.07586273
[illegible]	3.176208708	6.229201858
[illegible]	2.32843998	6.811881282
[illegible]	2.423371808	6.164957339
[illegible]	3.449725353	6.78777434
[illegible]	3.315962699	6.981126869
[illegible]	2.193403249	6.850066413
[illegible]	3.616061414	6.991629333
[illegible]	2.836606341	6.874997093
[illegible]	2.278624156	6.588383046
[illegible]	2.361059124	6.747007118
[illegible]	2.181719751	6.194794018
[illegible]	2.160922279	6.32785462
[illegible]	2.013606269	6.755457691
[illegible]	2.078500219	6.559311076
[illegible]	2.356304104	6.790350783
[illegible]	3.952487332	5.936296484
[illegible]	3.290168953	6.139977372
[illegible]	2.2365419	6.766244216
[illegible]	2.200683772	6.41290857
[illegible]	5.288906711	6.252970249
[illegible]	4.066713385	6.986447583
[illegible]	3.333946135	6.239125178
[illegible]	2.248918789	6.223927579
[illegible]	6.061922868	5.70985116
[illegible]	2.911323822	6.781534719
[illegible]	6.96127825	6.531593169

FIGURE 19: OVERSHOOTED AND LOW CQI CELLS

The figures below illustrate **the overshooting cells** depending on the second technique which have **Low Average CQI** (**Avg-CQI<7**) and **High Service Drop Rate (drop rate >=2%).**

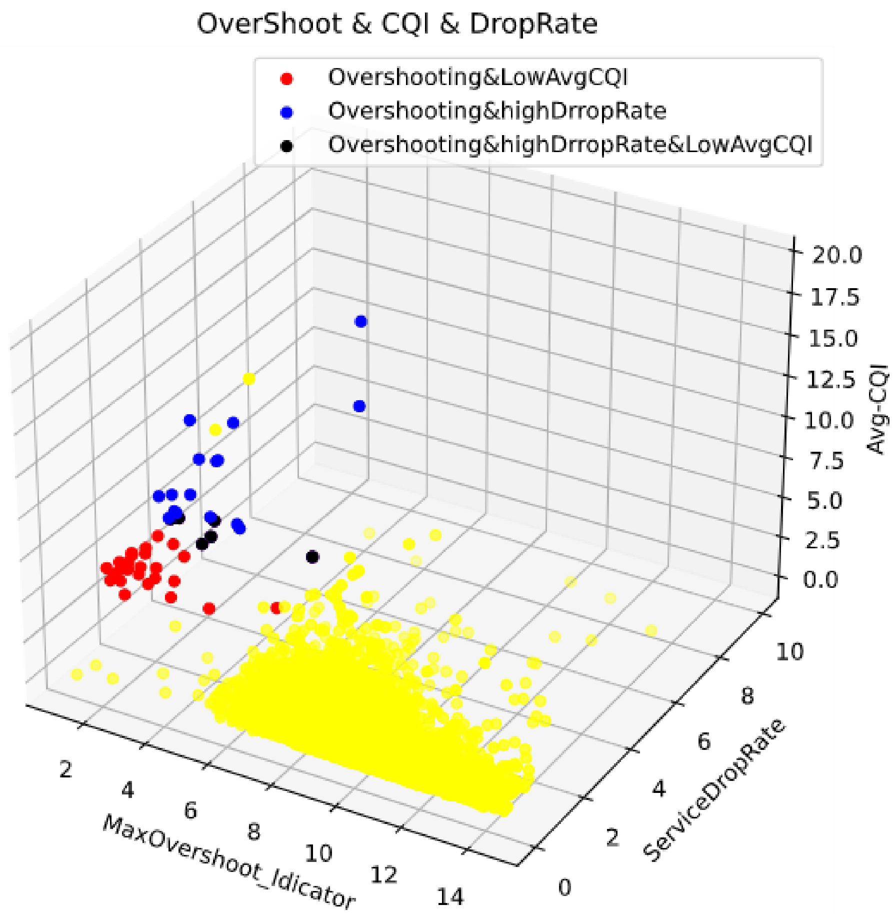


FIGURE 20: OVERSHOOTED, LOW CQI AND HIGH DROP RATE CELLS 3D CLUSTERS

Cell Name	MaxOvershoot_Idicator	ServiceDropRate	E-UTRAN Average CQI
[illegible]	2.044592469	2.6593	6.624839371
[illegible]	2.19325813	2.8028	6.57531195
[illegible]	3.315962699	2.856	6.981126869
[illegible]	3.290168953	2.3967	6.139977372
[illegible]	3.333946135	2.6898	6.239125178
[illegible]	6.061922868	3.3278	5.70985116

FIGURE 21: OVERSHOOTED, LOW CQI AND HIGH DROP RATE CELLS

4.2 Unbalanced Cells

4.2.1 CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 18

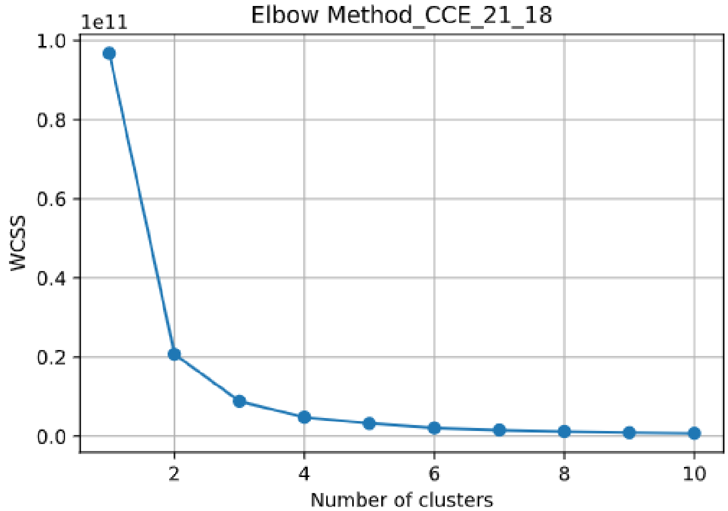


FIGURE 22: ELBOW METHOD FOR CLUSTERING CCE UTLIZATION DELTAS BET BANDS 21 & 18

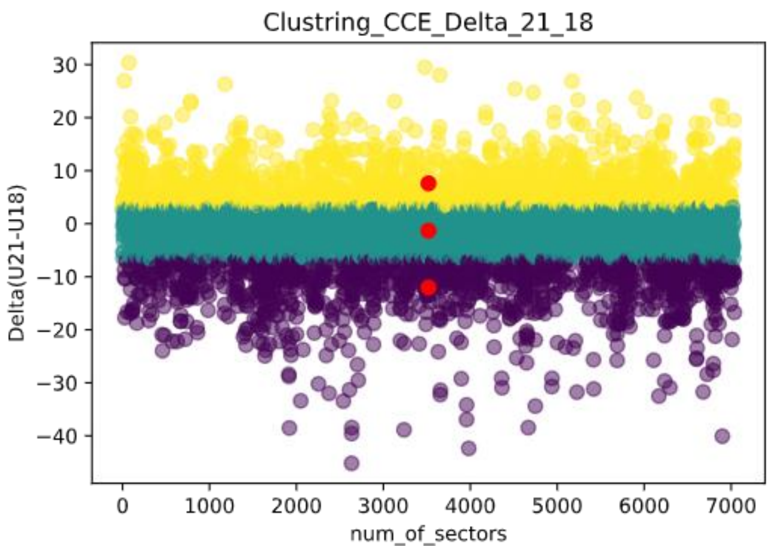


FIGURE 23: CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 18

TABLE 5: CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 18

Cluster No.	1	2	3
Center	**-12.03145241**	**-1.31449748**	**7.6035536**
Number of sectors	**1258**	**4116**	**1664**

From the results above; Clusters 1 & 3 Contains Unbalanced sectors as follows:

Cluster 1 contains 1258 unbalanced sectors as Band 18 is highly utilized

Cluster 3 contains 1664 unbalanced sectors as Band 21 is highly utilized

4.2.2 CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 09

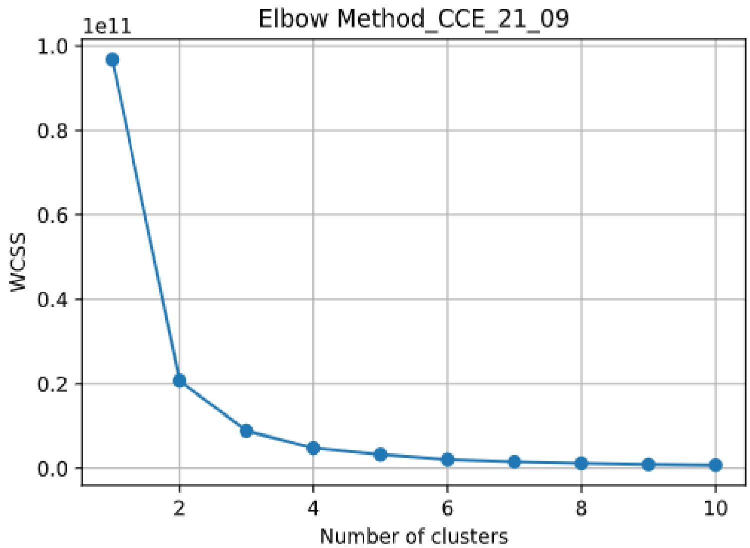


FIGURE 24: ELBOW METHOD FOR CLUSTERING CCE UTLIZATION DELTAS BET BANDS 21 & 09

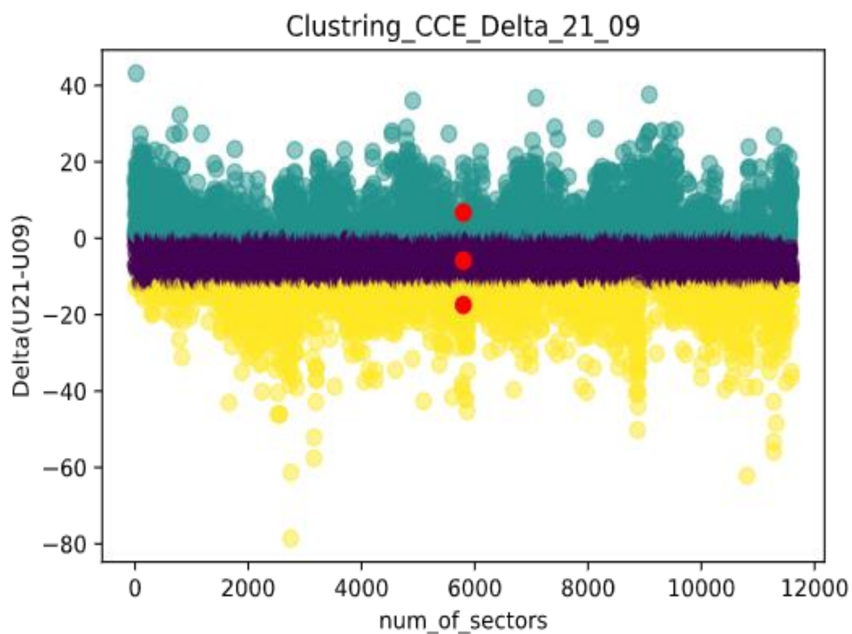


FIGURE 25: CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 09

TABLE 6: CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 09

Cluster No.	1	2	3
Center	**-5.81655909**	**6.72723689**	**-17.45245953**
Number of sectors	**6238**	**2985**	**2372**

From the results above; **Cluster 3 contains 2372 unbalanced sectors as Band 18 is highly utilized**

4.2.3 CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 26

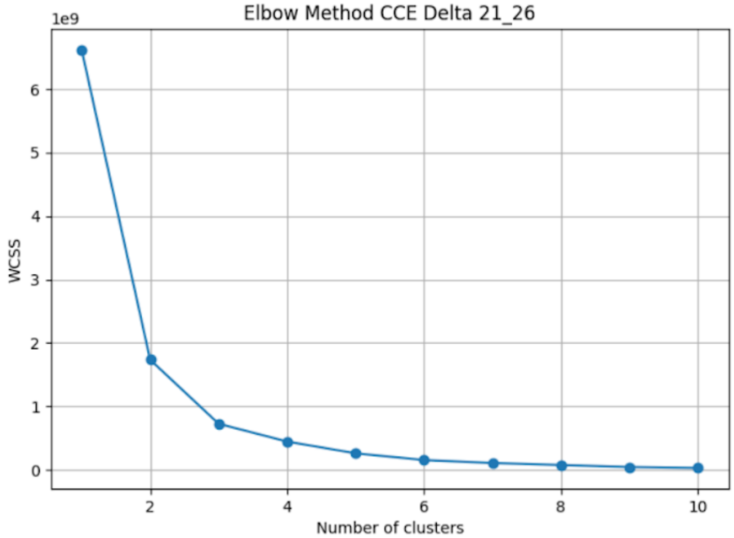


FIGURE 26: ELBOW METHOD FOR CLUSTERING CCE UTLIZATION DELTAS BET BANDS 21 & 26

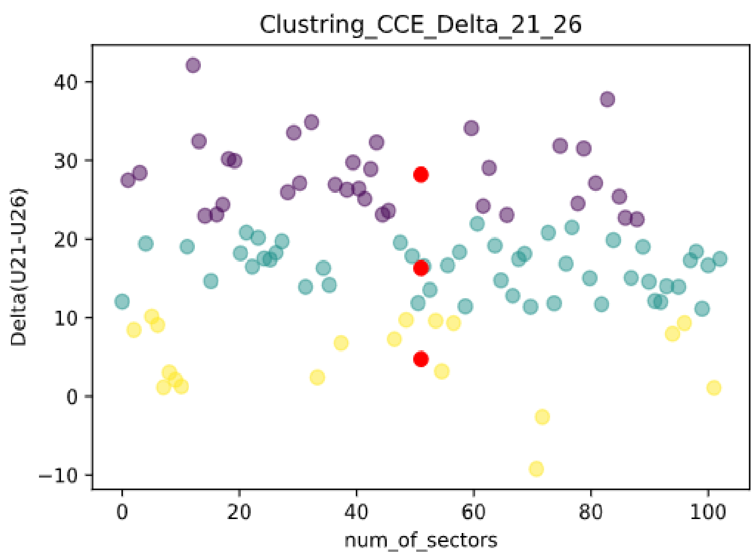


FIGURE 27: CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 26

TABLE 7: : CLUSTERING CCE UTILIZATION DELTAS BETWEEN BANDS 21 & 26

Cluster No.	1	2	3
Center	**28.19030294**	**16.29731429**	**4.73390526**
Number of sectors	**34**	**49**	**19**

From the results above; Clusters 1 & 2 Contains Unbalanced sectors as follows:

Cluster 1 contains 34 unbalanced sectors as Band 21 is highly utilized

Cluster 2 contains 49 unbalanced sectors as Band 21 is highly utilized

4.2.4 CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

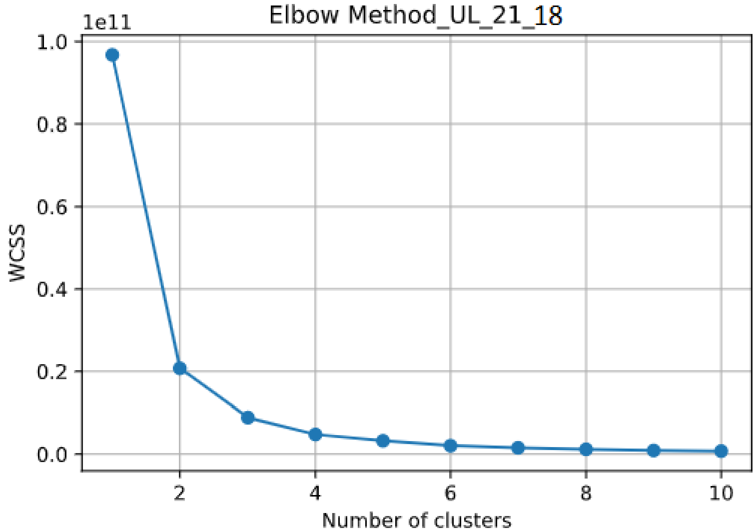


FIGURE 28: ELBOW METHOD FOR CLUSTERING UL UTLIZATION DELTAS BET BANDS 21 & 18

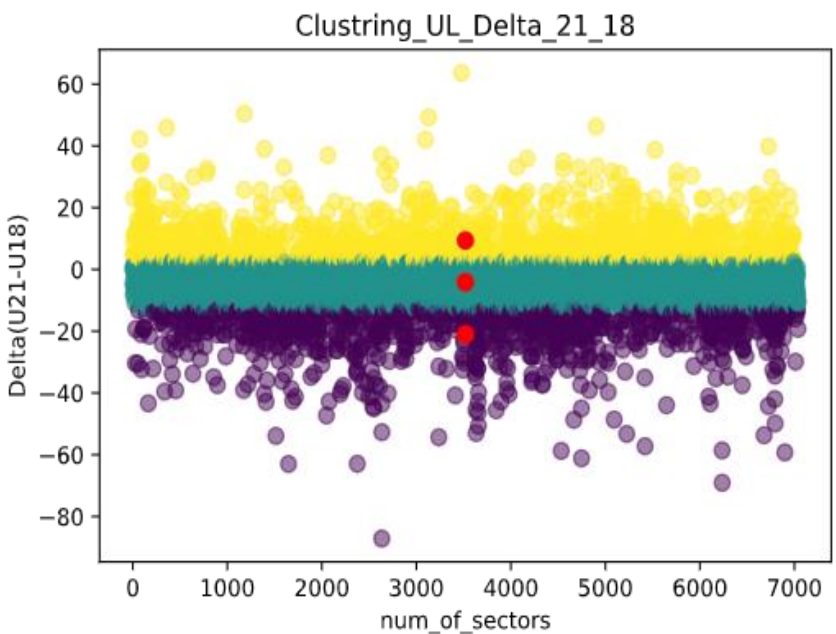


FIGURE 29: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

TABLE 8: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

Cluster No.	1	2	3
Center	-20.98655046	-4.14996497	9.36870174
Number of sectors	987	4540	1511

From the results above; **Cluster 1 contains 987 unbalanced sectors as Band 18 is highly utilized**

4.2.5 CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

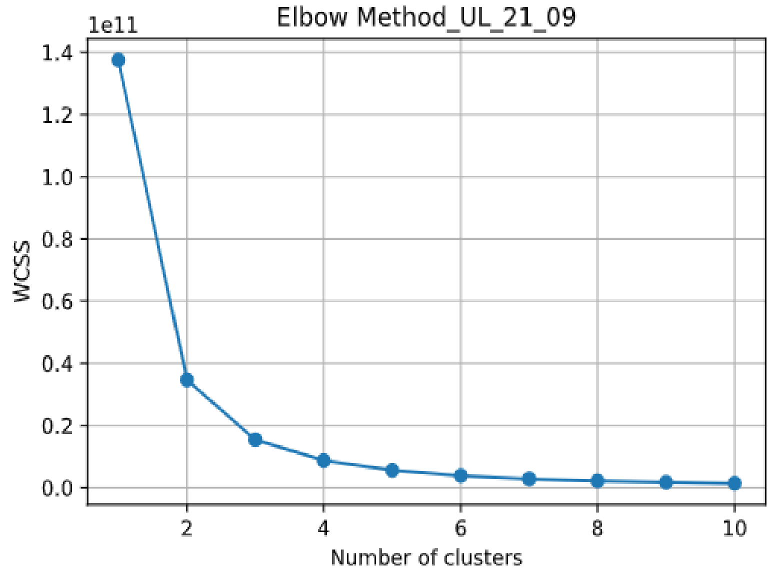


FIGURE 30: ELBOW METHOD FOR CLUSTERING UL UTLIZATION DELTAS BET BANDS 21 & 09

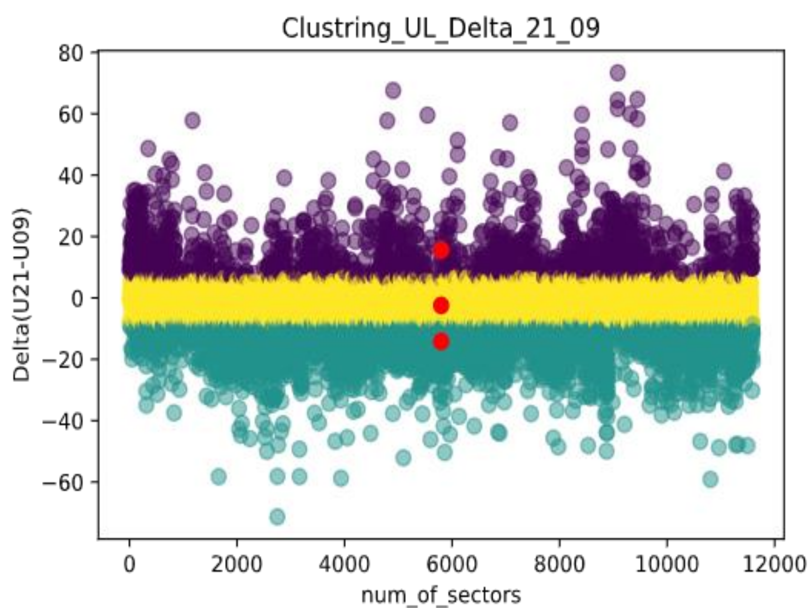


FIGURE 31: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

TABLE 9: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

Cluster No.	1	2	3
Center	15.61543469	-14.1770374	-2.43918983
Number of sectors	1417	5402	4776

From the results above; Clusters 1 & 2 Contains Unbalanced sectors as follows:

Cluster 1 contains 1417 unbalanced sectors as Band 21 is highly utilized

Cluster 2 contains 5402 unbalanced sectors as Band 09 is highly utilized

4.2.6 CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

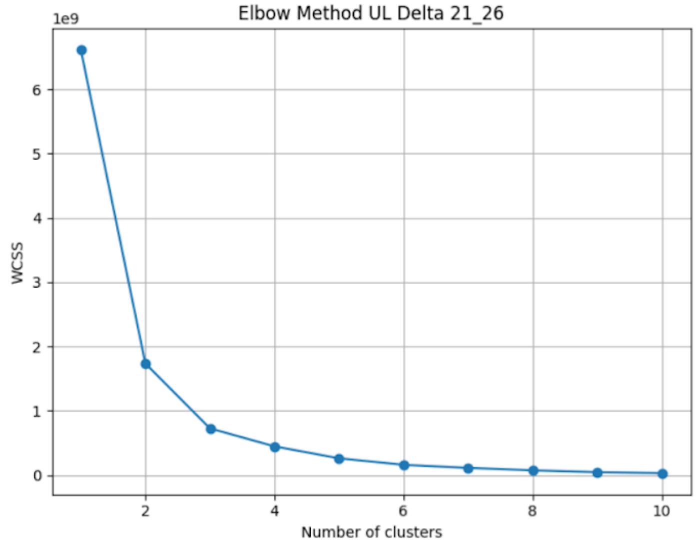


FIGURE 32: ELBOW METHOD FOR CLUSTERING UL UTLIZATION DELTAS BET BANDS 21 & 26

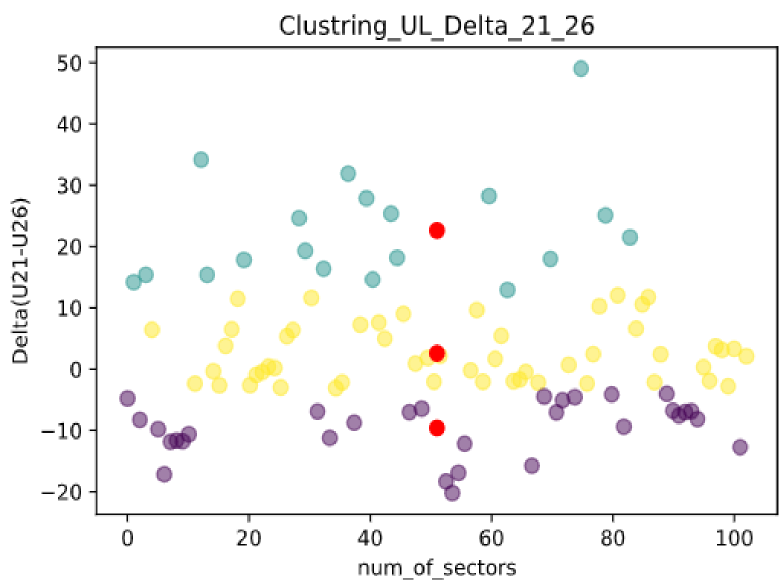


FIGURE 33: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

TABLE 10: CLUSTERING UL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

Cluster No.	1	2	3
Center	**2.58128846**	**22.62225789**	**-9.60147097**
Number of sectors	**52**	**19**	**31**

From the results above; **Cluster 2 contains 19 unbalanced sectors as Band 21 is highly utilized**

4.2.7 CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

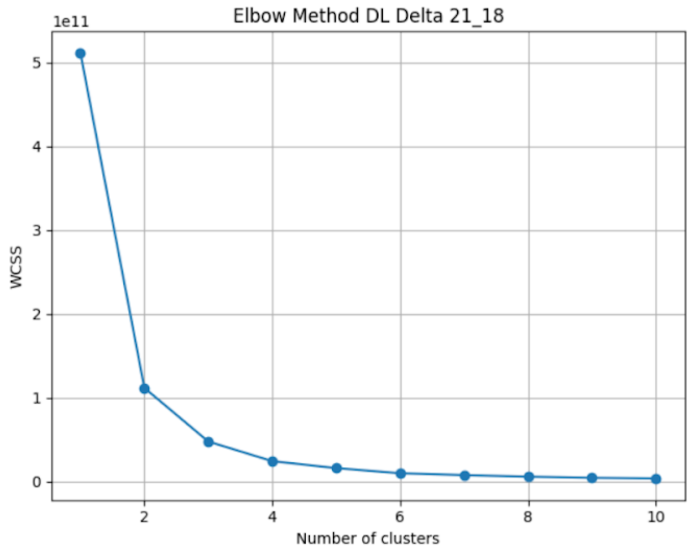


FIGURE 34: ELBOW METHOD FOR CLUSTERING DL UTLIZATION DELTAS BET BANDS 21 & 18

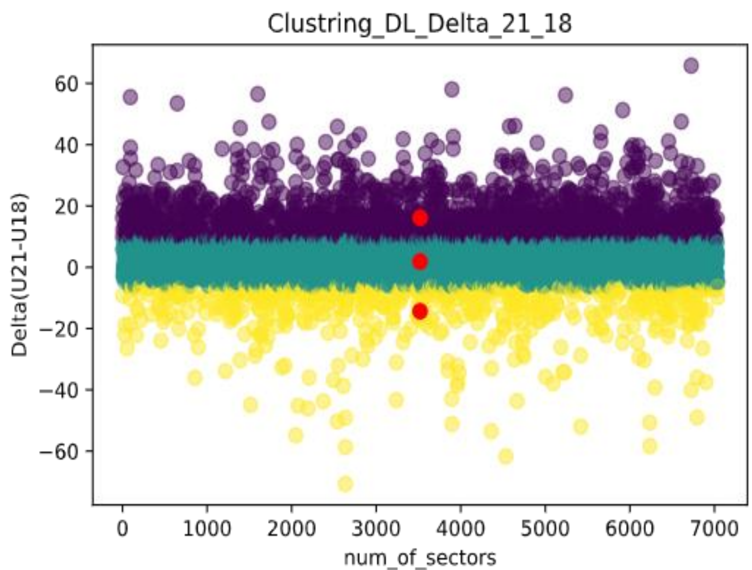


FIGURE 35: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

TABLE 11: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 18

Cluster No.	**1**	**2**	3
Center	**16.13991177**	**1.85978152**	-14.37462542
Number of sectors	**1992**	**4450**	596

From the results above; <u>Clusters 1 & 3 Contains Unbalanced sectors </u>as follows:

Cluster 1 contains 1992 unbalanced sectors as Band 21 is highly utilized

Cluster 3 contains 596 unbalanced sectors as Band 18 is highly utilized

4.2.8 CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

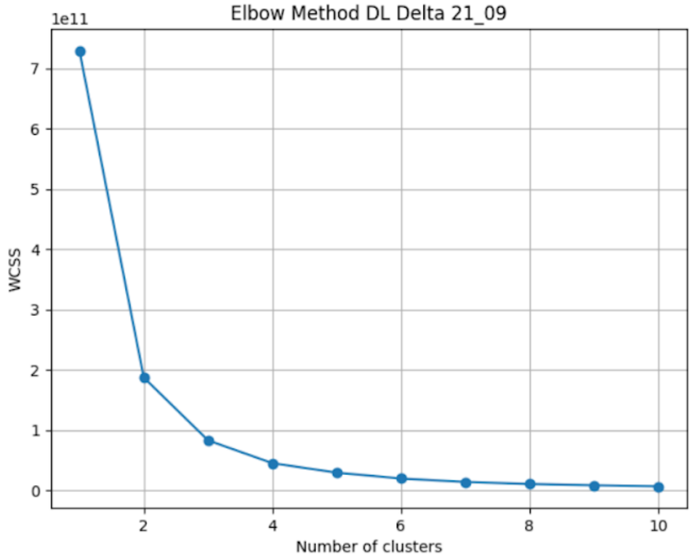


FIGURE 36: ELBOW METHOD FOR CLUSTERING DL UTLIZATION DELTAS BET BANDS 21 & 09

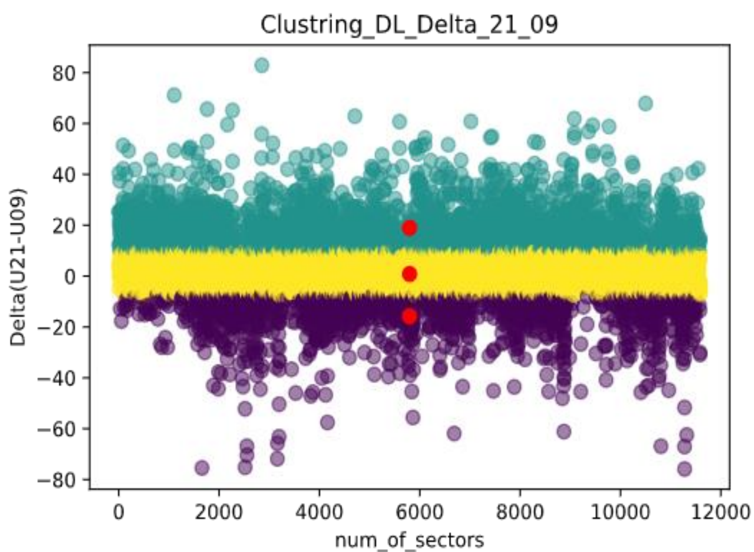


FIGURE 37: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

TABLE 12: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 09

Cluster No.	1	2	3
Center	-15.73935892	18.94394137	0.81066827
Number of sectors	1563	3011	7021

From the results above; Clusters 1 & 2 Contains Unbalanced sectors as follows:

Cluster 1 contains 1563 unbalanced sectors as Band 21 is highly utilized

Cluster 2 contains 3011 unbalanced sectors as Band 09 is highly utilized

4.2.9 CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

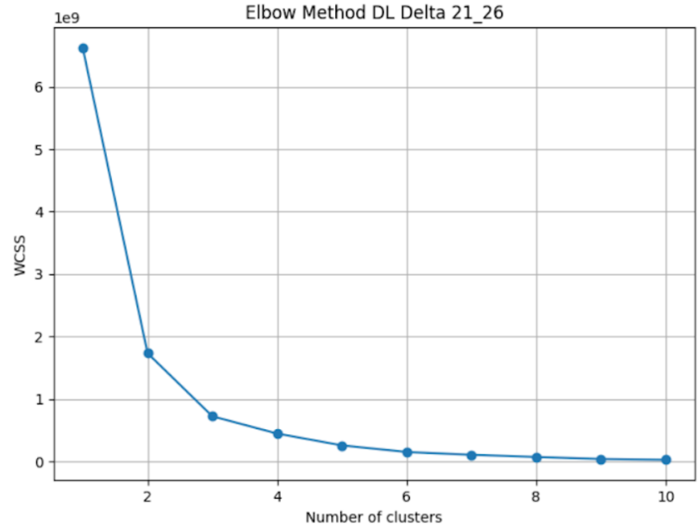


FIGURE 38: ELBOW METHOD FOR CLUSTERING DL UTLIZATION DELTAS BET BANDS 21 & 26

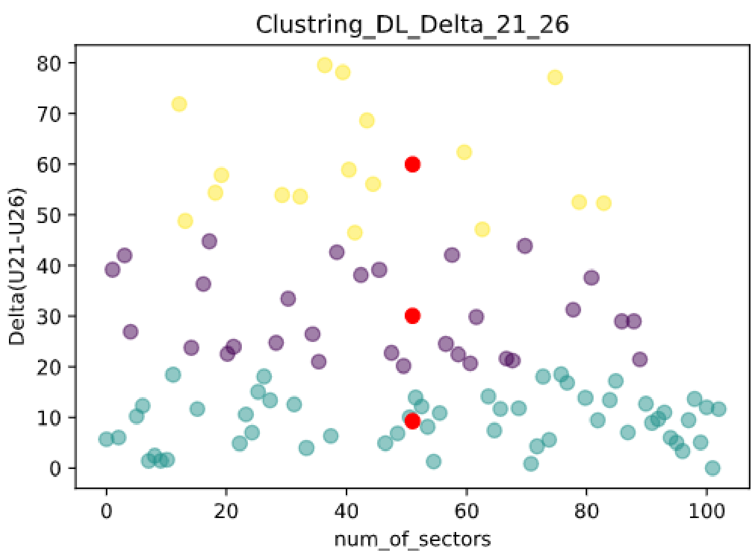


FIGURE 39: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

TABLE 13: CLUSTERING DL UTILIZATION DELTAS BETWEEN BANDS 21 & 26

Cluster No.	**1**	**2**	3
Center	**30.10436667**	**9.29752909**	60.00195882
Number of sectors	**30**	**55**	17

From the results above; Clusters 1 & 3 Contains Unbalanced sectors as follows:

Cluster 1 contains 30 unbalanced sectors as Band 21 is highly utilized

Cluster 3 contains 17 unbalanced sectors as Band 26 is highly utilized

4.2.10 HIGH UTILIZATION IN BAND 18

- From table 5 (CCE21_18), we found that cluster1 is highly utilized in Band18.
- From table 11 (DL21_18), we found that cluster3 is highly utilized in Band18.
- From table 8 (UL21_18), we found that cluster1 is highly utilized in Band18.

By intersecting the 3 clusters above, we will get the common cells which have a high utilization in the three parameters (CCE, DL, UL), which their count is 443 cells. After that we will cluster them again to get the most unbalanced cluster in band18.

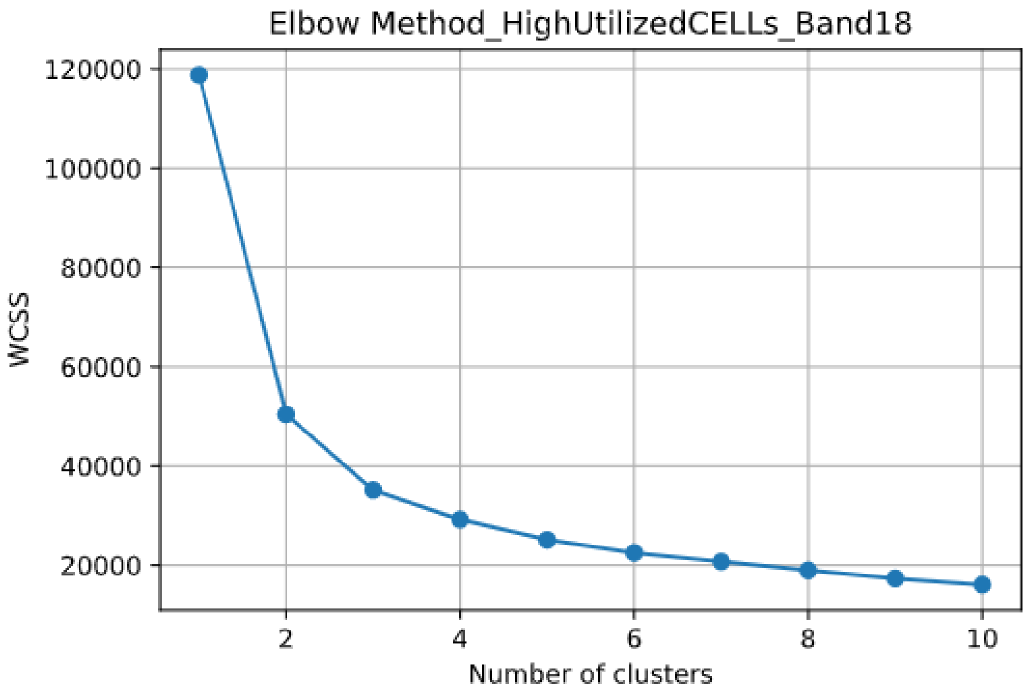


FIGURE 40: ELBOW METHOD FOR HIGH UTILIZAION IN BAND 18

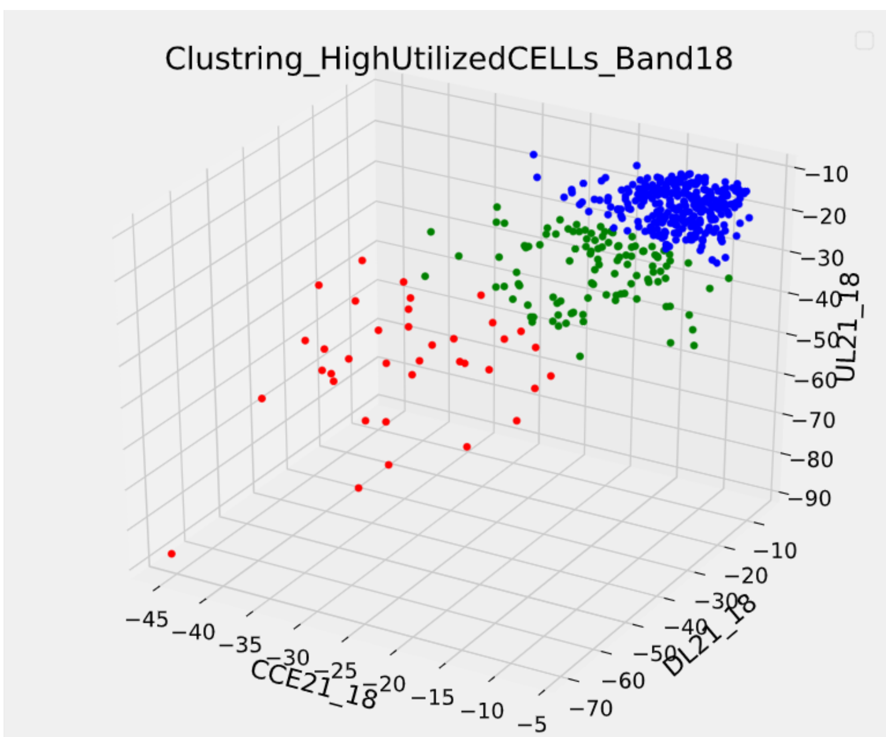


FIGURE 41: CLUSTERING HIGH UTILIZAION IN BAND 18

TABLE 14: CLUSTERING HIGH UTILIZATION IN BAND 18

Num of cluster	1	2	3
Center x y z	 -30.12 -42.7 -48.2	 -12.881 -10.78 -18.62	 -18.24 -20.38 -31.48
Num of sectors	37	296	110

From The table above, cluster 1 is the most unbalanced cluster in band18 and next is cluster 3

cell_Name	CCE21_18	DL21_18	UL21_18	cluster_num
[illegible]	-25.7496	-29.4257	-43.3641	1
[illegible]	-27.6702	-49.0142	-34.3829	1
[illegible]	-40.0801	-37.4769	-59.2395	1
[illegible]	-21.1118	-50.696	-58.5974	1
[illegible]	-31.3284	-38.6663	-37.951	1
[illegible]	-31.1645	-52.0343	-57.2477	1
[illegible]	-29.1518	-53.5377	-33.4707	1
[illegible]	-38.4496	-49.123	-43.5145	1
[illegible]	-20.6049	-35.9976	-38.9548	1
[illegible]	-14.2069	-46.0807	-40.3242	1
[illegible]	-20.3811	-32.1136	-44.9277	1
[illegible]	-34.3836	-29.1182	-61.1601	1
[illegible]	-17.9934	-44.9134	-53.9079	1
[illegible]	-23.7609	-45.1436	-42.761	1
[illegible]	-29.2291	-51.1682	-42.7339	1
[illegible]	-22.3728	-42.9167	-27.4552	1
[illegible]	-45.1863	-70.7418	-87.1517	1
[illegible]	-29.6899	-58.3541	-69.0813	1
[illegible]	-38.8731	-43.3609	-54.3258	1
[illegible]	-25.3108	-61.7081	-58.7538	1
[illegible]	-39.5807	-58.6887	-52.7007	1
[illegible]	-23.2385	-37.8594	-48.6193	1
[illegible]	-23.8673	-21.6707	-63.0026	1
[illegible]	-33.4552	-50.2985	-44.5173	1
[illegible]	-26.3982	-36.0158	-49.8933	1
[illegible]	-33.4055	-54.8517	-47.2808	1
[illegible]	-32	-43.7522	-62.9314	1
[illegible]	-34.1684	-32.0742	-36.5128	1
[illegible]	-30.9003	-39.2721	-34.6828	1
[illegible]	-28.3895	-40.0702	-44.2298	1
[illegible]	-36.9365	-38.6148	-38.994	1
[illegible]	-31.7229	-23.933	-53.6881	1
[illegible]	-38.4563	-43.7058	-48.6894	1
[illegible]	-22.0454	-36.7953	-41.1572	1
[illegible]	-42.3675	-34.4114	-40.3612	1
[illegible]	-31.7659	-34.2685	-53.2703	1
[illegible]	-38.5324	-32.0749	-33.6082	1

4.2.11 HIGH UTILIZATION IN BAND 09

- From table 6 (CCE21_09), we found that cluster3 is highly utilized in Band09.
- From table 12 (DL21_09), we found that cluster1 is highly utilized in Band09.
- From table 9 (UL21_09), we found that cluster2 is highly utilized in Band09.

By intersecting the 3 clusters above, we will get the common cells which have a high utilization in the three parameters (CCE, DL, UL), which their count is 1387 cells. After that we will cluster them again to get the most unbalanced cluster in band09.

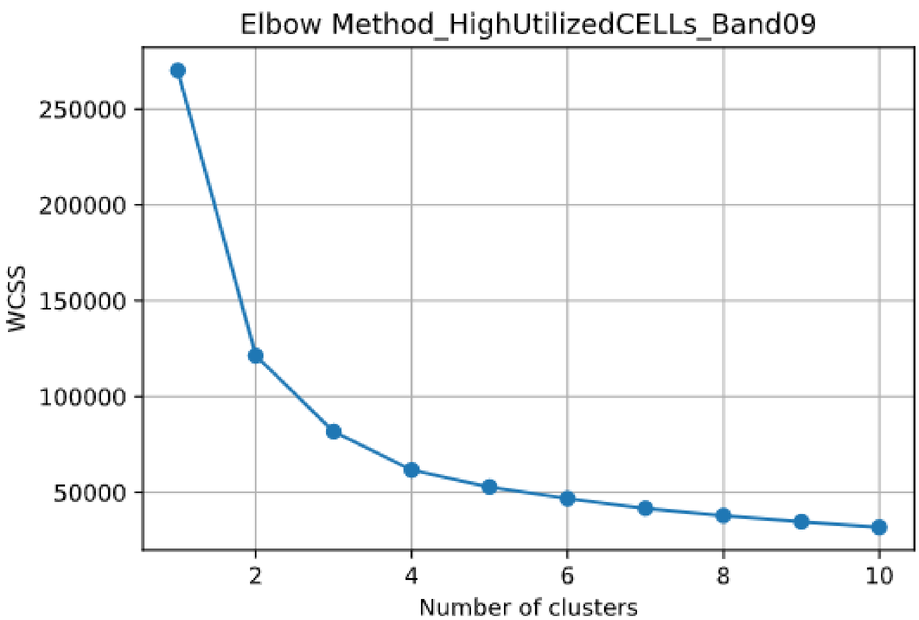


FIGURE 43: ELBOW METHOD FOR HIGH UTILIZAION IN BAND 09

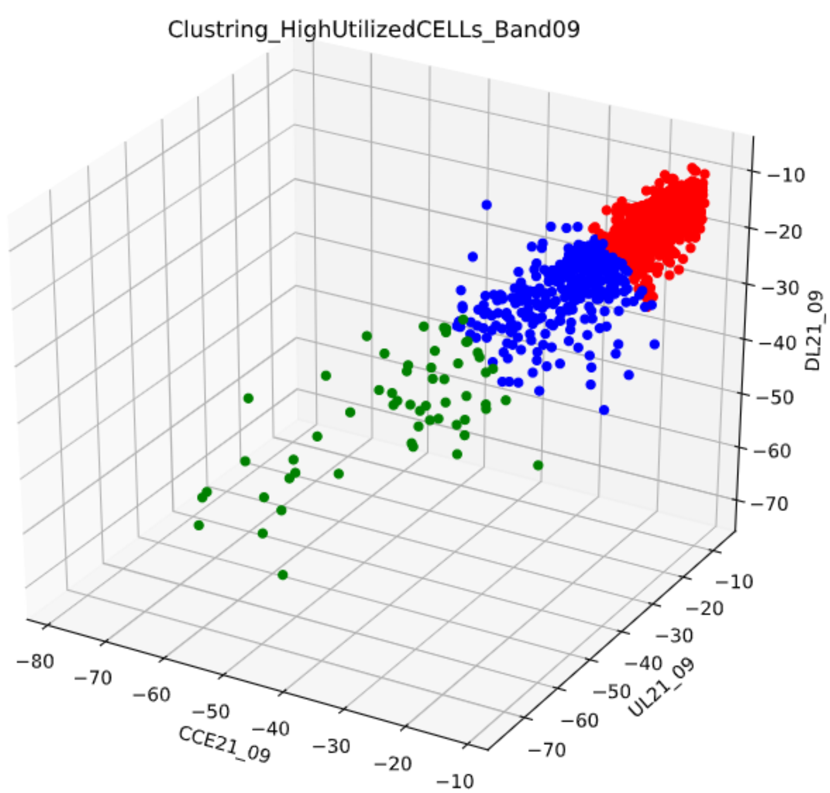


FIGURE 42: CLUSTERING HIGH UTILIZAION IN BAND 09

TABLE 15: CLUSTERING HIGH UTILIZAION IN BAND 09

Num of cluster	**1**	**2**	**3**
Center			
x	**-16.5**	**-25.25**	**-40.175**
y	**-17.225**	**-26.373**	**-41.25**
z	**-12.035**	**-24.19**	**-47.78**
Num of sectors	**992**	**337**	**58**

From table above, cluster 3 is the most unbalanced cluster in band09 and next is cluster 2

cell_Name	CCE21_09	DL21_09	UL21_09	cluster_num
[illegible]	-36.7336	-36.7349	-43.1434	3
[illegible]	-29.3123	-34.6666	-40.8337	3
[illegible]	-25.6044	-30.8248	-45.6528	3
[illegible]	-62.2072	-59.133	-66.8846	3
[illegible]	-78.6454	-71.3476	-26.6174	3
[illegible]	-39.6004	-35.0086	-45.6687	3
[illegible]	-46.1011	-45.361	-75.1568	3
[illegible]	-33.0441	-30.7359	-39.5227	3
[illegible]	-43.0351	-58.2539	-75.4251	3
[illegible]	-39.1454	-41.0614	-35.3019	3
[illegible]	-52.103	-58.2272	-65.7504	3
[illegible]	-28.7659	-58.7781	-25.1205	3
[illegible]	-31.3643	-31.5258	-45.4205	3
[illegible]	-29.5931	-30.2974	-42.8708	3
[illegible]	-42.673	-52.1218	-38.696	3
[illegible]	-38.8263	-31.8559	-35.3916	3
[illegible]	-35.0331	-27.2717	-43.0148	3
[illegible]	-39.6815	-43.9421	-39.8181	3
[illegible]	-42.838	-28.6652	-63.1712	3
[illegible]	-39.0372	-32.6928	-35.0999	3
[illegible]	-36.5506	-25.6687	-57.5553	3
[illegible]	-38.9528	-48.7949	-44.8872	3
[illegible]	-48.4628	-47.7799	-62.4626	3
[illegible]	-28.6661	-41.7721	-35.842	3
[illegible]	-26.9541	-37.7331	-45.133	3
[illegible]	-38.8289	-40.6486	-45.9777	3
[illegible]	-42.7809	-26.9291	-51.6573	3
[illegible]	-45.2705	-50.3714	-55.5901	3
[illegible]	-46.1111	-42.6574	-66.8793	3
[illegible]	-53.3168	-33.694	-67.0444	3
[illegible]	-44.0859	-43.9295	-40.4648	3
[illegible]	-50.2348	-49.9196	-61.1404	3
[illegible]	-38.8109	-45.6865	-43.5652	3
[illegible]	-38.0145	-27.594	-43.5718	3
[illegible]	-46.0904	-49.9877	-70.4423	3
[illegible]	-34.4334	-40.2073	-43.4484	3
[illegible]	-61.3102	-58.1622	-34.2423	3
[illegible]	-30.5892	-42.7426	-38.2541	3
[illegible]	-55.9057	-47.869	-75.8583	3
[illegible]	-34.4658	-29.5603	-46.6911	3
[illegible]	-41.9613	-41.8417	-45.3824	3
[illegible]	-40.4837	-35.6105	-52.1834	3
[illegible]	-33.7795	-48.1333	-38.8051	3

4.2.12 HIGH UTILIZATION IN BAND 09

- → From table 5 **(CCE21_18)**, we found that **cluster3** is highly utilized in **Band21**.
- → From table 6 **(CCE21_09)**, we found that **cluster2** is highly utilized in **Band21**.
- → From table 7 **(CCE21_26)**, we found that **cluster1** is highly utilized in **Band21**.
- → From table 8 **(UL21_18)**, we found that **cluster3** is highly utilized in **Band21**.
- → From table 9 **(UL21_09)**, we found that **cluster1** is highly utilized in **Band21**.
- → From table 10 **(UL21_26)**, we found that **cluster2** is highly utilized in **Band21**.
- → From table 11 **(DL21_18)**, we found that **cluster1** is highly utilized in **Band21**.
- → From table 12 **(DL21_09)**, we found that **cluster2** is highly utilized in **Band21**.
- → From table 13 **(DL21_26)**, we found that **cluster3** is highly utilized in **Band21**.

By intersecting the 9 clusters above, we will get the common cells which have a high utilization in Band21, caused by the unbalancing between bands which band18, band09 and band26 caused it, which are 2cells.

cell_Name	CCE21_18	DL21_18	UL21_18	CCE21_09	DL21_09	UL21_09	CCE21_26	DL21_26	UL21_26
[illegible]	12.9629	20.2676	18.0664	11.2827	24.0764	33.7961	32.2914	25.3585	68.6482
[illegible]	3.4823	10.8546	13.0728	9.0581	22.1922	14.3735	31.5035	25.0991	52.5425

By intersecting the first 6 clusters above, we will get the common cells which have a high utilization in Band21, caused by the unbalancing between bands which band18 and band09 caused only, which their count is 400 cells. After that we will cluster them again to get the most unbalanced cluster in band21.

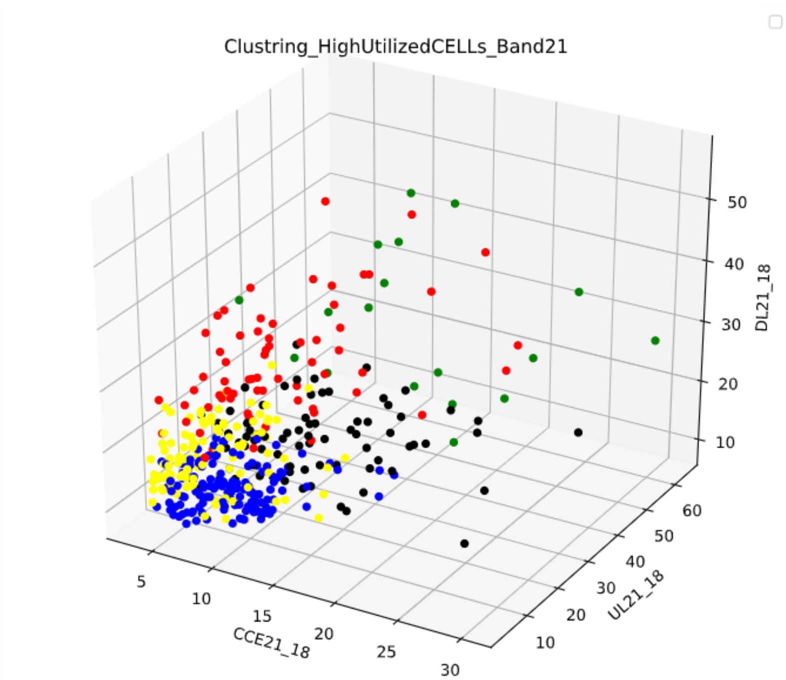


FIGURE 44: CLUSTERING HIGH UTILIZATION BETWEEN BANDS 21 & 18

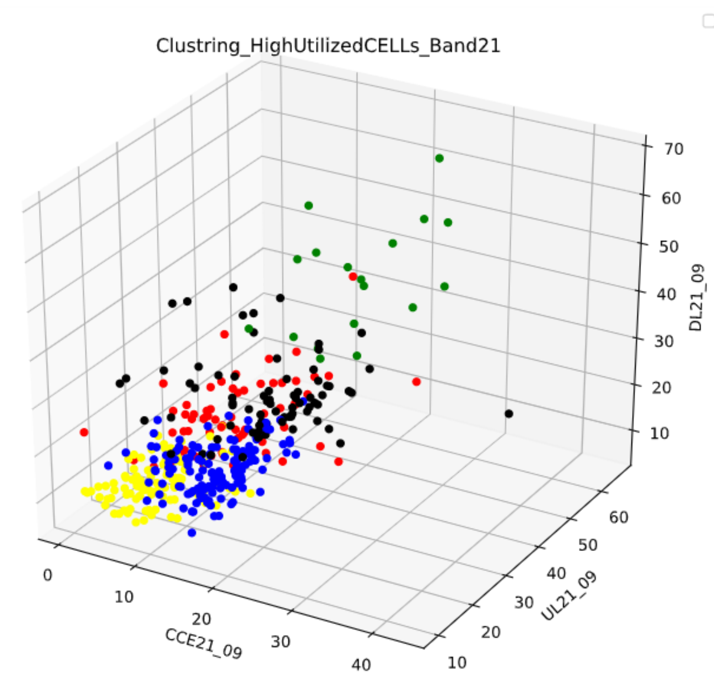


FIGURE 45: CLUSTERING HIGH UTILIZATION BETWEEN BANDS 21 & 09

TABLE 16: CLUSTERING HIGH UTILIZATION IN BAND 21

Cluster number	Centers						Number of cells
	FIGURE(44)			FIGURE (45)			
	X	Z	Y	X	Z	Y	
	[CCE21_18	DL21_18	UL21_18	CCE21_09	DL21_09	UL21_09]	
1	10.65	31.86	17.74	10.078	18.023	34.048	63
2	8.48	13.32	10.16	15.5	19.6	16.23	77
3	**16.89**	**33.588**	**38.011**	**23.83**	**49.754**	**38.61**	**20**
4	6.98	17.86	9.75	6.9	10.78	19.35	106
5	12.75	19.14	21.3	19.26	32.44	23.177	134

From the table above, we note that cluster 3 contains the most unbalanced cell in band21, which band18 and band09 are caused it only.

cell_Name	CCE21_18	DL21_18	UL21_18	CCE21_09	DL21_09	UL21_09	cluster_num
[illegible]	23.0499	26.568	49.2693	35.9946	67.5893	35.7439	3
[illegible]	7.7091	41.125	16.4955	25.0505	64.7095	59.2954	3
[illegible]	8.7431	20.9597	38.7013	22.8211	59.9377	29.0416	3
[illegible]	11.0449	40.589	46.2323	15.7528	59.78	42.7084	3
[illegible]	29.5069	27.0923	63.6545	27.3746	59.562	27.5546	3
[illegible]	17.5758	44.0033	18.577	27.5705	58.3693	48.9489	3
[illegible]	26.3082	38.6364	50.4219	27.3862	57.8025	40.252	3
[illegible]	15.1285	20.658	42.0309	29.0066	57.7371	27.5708	3
[illegible]	19.9589	16.2666	35.9317	36.7631	57.0739	24.1324	3
[illegible]	7.4563	24.9836	33.3234	17.3672	52.8972	35.8967	3
[illegible]	17.3085	17.1784	45.9151	19.1746	48.6892	18.5206	3
[illegible]	24.7332	27.2934	32.9813	28.7099	42.3945	27.1233	3
[illegible]	14.6413	45.3968	38.9893	19.5158	40.7646	50.1112	3
[illegible]	19.7015	29.4559	31.7587	23.1278	38.2216	29.3973	3
[illegible]	17.189	56.5132	32.9786	23.331	33.9611	65.6378	3
[illegible]	13.9804	39.1566	37.0177	18.145	32.4824	39.871	3
[illegible]	9.9065	33.1826	34.9666	14.1392	32.269	41.7796	3
[illegible]	20.1559	55.5221	34.97	17.7134	31.3371	51.3775	3

4.3 High Utilized Cells

4.3.1 UL AND DL PRB UTILIZATION

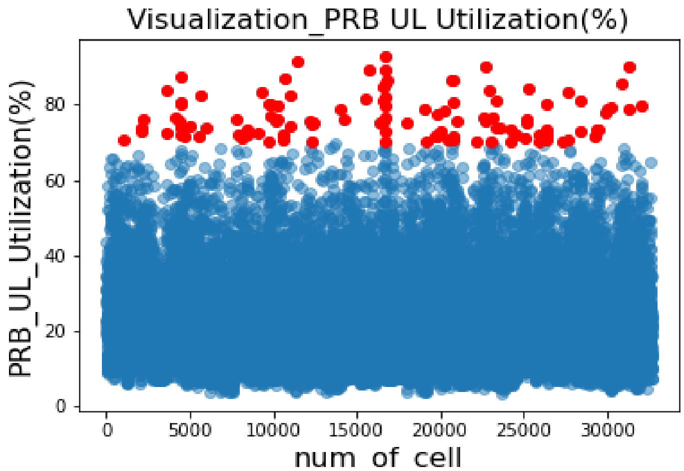


FIGURE 46: UPLINK PRB UTILIZATION

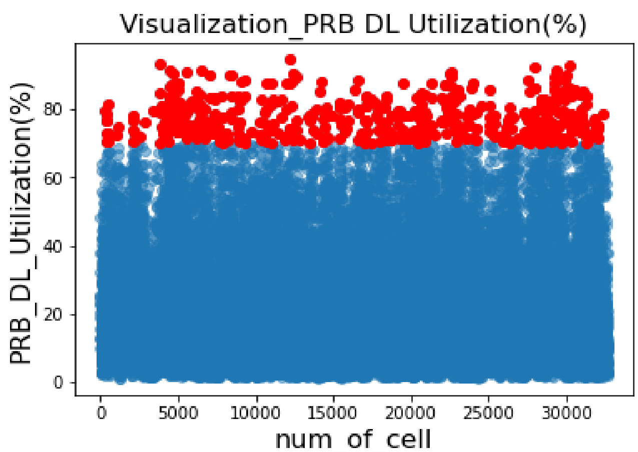


FIGURE 47: DOWNLINK PRB UTILIZATION

TABLE 17: UPLINK AND DOWNLINK PRB UTILIZATION

Resource block utilization	Number of Highly Utilized cells	Number of Normally Utilized cells
PRB UL Utilization	**113**	**32560**
PRB DL Utilization	**527**	**32146**

From the results above; there are 527 cells highly utilized in DL PRB and 113 cells highly utilized in UL PRB

Its proposed solutions:

- Adding eNodeB

4.3.2 CCE UTILIZATION

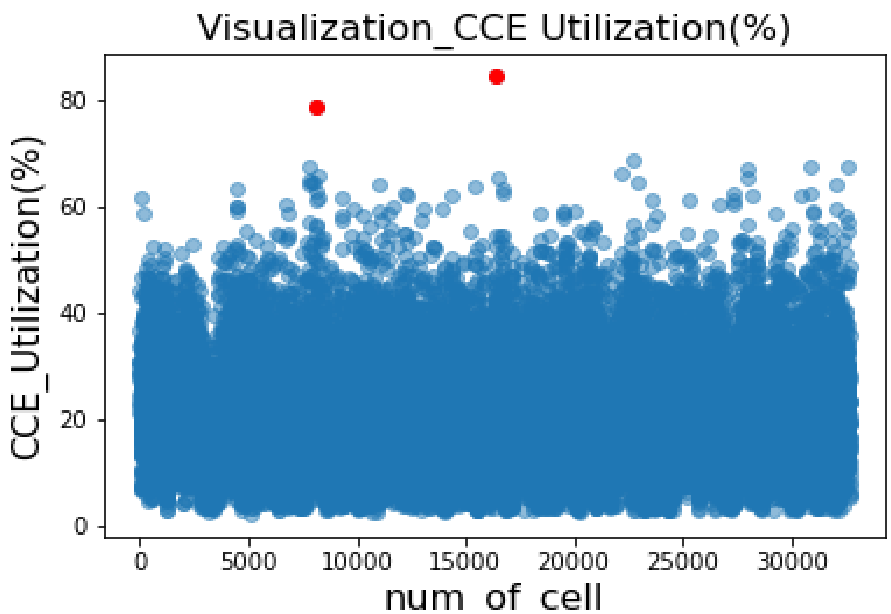


FIGURE 48: CCE UTILIZATION

TABLE 18: CCE UTILIZATION

Control channel element for PDCCH	Number of Highly Utilized cells	Number of Normally Utilized cells
CCE Utilization	**2**	**32671**

From the results above; there are 2 cells highly utilized in CCE

Its proposed solutions:

- Adding Cell

4.4 E-UTRAN AVERAGE CQI

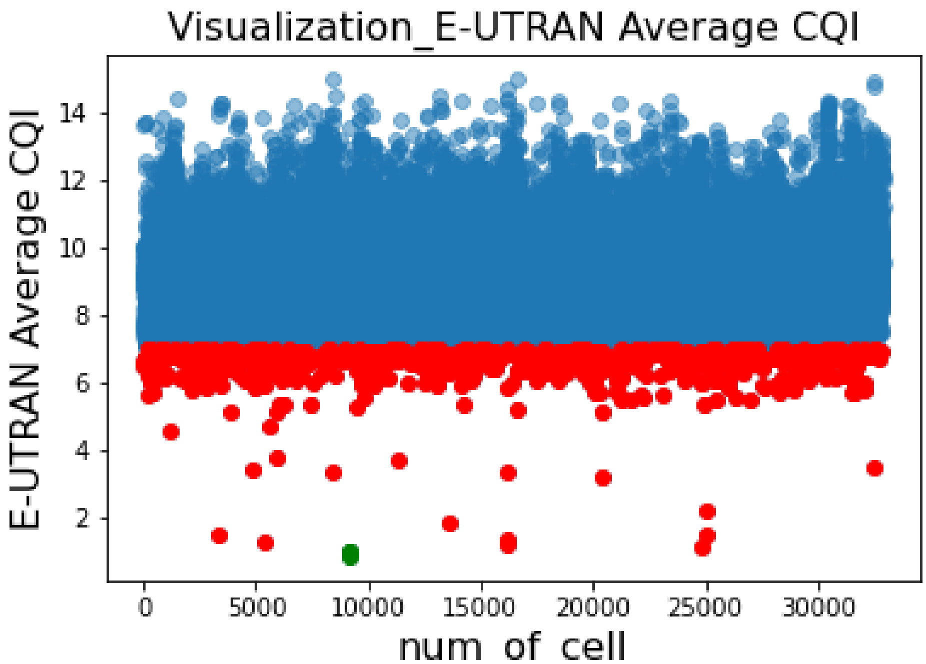


FIGURE 49: E-UTRAN AVG-CQI

TABLE 19: E-UTRAN AVG-CQI

E-UTRAN Avg-CQI value	From 0 to 1	From 1 to 7	Greater than 7
Number of Cells	**3**	**793**	**32080**

From the results above we found:

3 cells in the poorest channel quality case as their E-UTRAN Average CQI value is between 0 & 1

7793 cells in a poor channel quality case as their E-UTRAN Average CQI value is less than 7

32080 cells in an acceptable channel quality case as their E-UTRAN Average CQI value is greater than 7

4.5 SERVICE DROP RATE

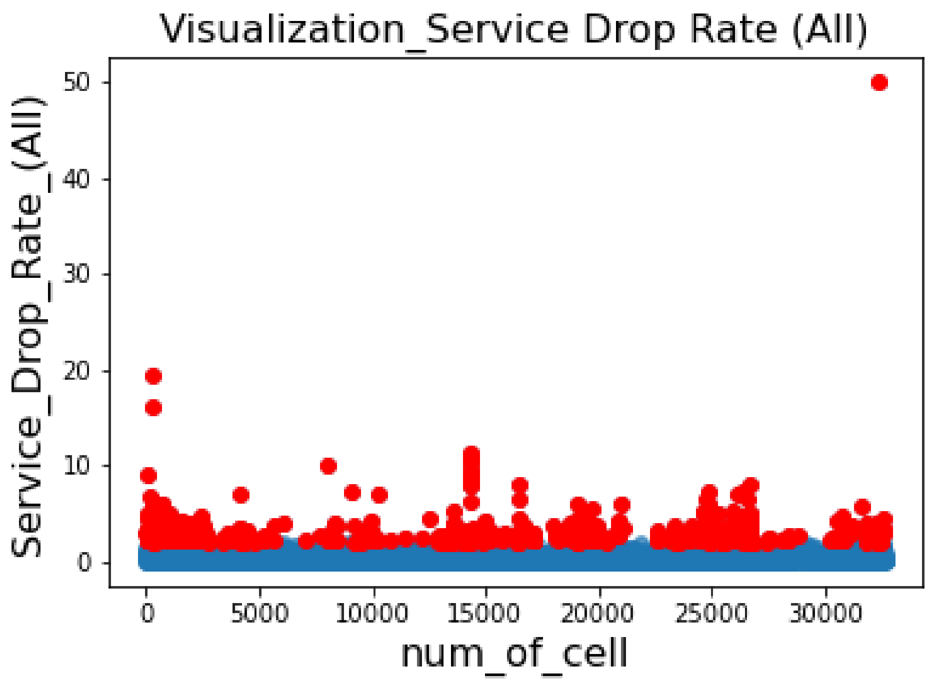


FIGURE 50: SERVICE DROP RATE

TABLE 20: SERVICE DROP RATE

Service Drop Rate value	Less than 2 %	Greater than 2 %
Number of Cells	**32112**	**561**

From the results above; there are 561 suffers from high Service Drop Rate

4.6 HIGH PRB UTILIZATION, LOW AVG CQI & HIGH DROP RATE CELLS

4.6.1 HIGH DL PRB UTILIZATION

The figures below illustrate the **high utilized DL PRB cells** which have **low average CQI (Avg-CQI < 7)** and **High Service Drop Rate (drop rate >=2%).**

Cell_Name	(Voda)_PRB_DL_Utilization(%)	Service_Drop_Rate_(All)	E-UTRAN Average CQI
[illegible]	71.801	2.1891	6.695075

FIGURE 51: HIGH DL UTILIZATION, HIGH SERVICE DROP RATE & LOW AVG CQI

4.6.2 HIGH UL PRB UTILIZATION

The figure below illustrate the **High utilized UL PRB cells** which have **Low average CQI (Avg-CQI < 7)** and **High Service Drop Rate (drop rate >=2%).**

Cell_Name	PRB_UL_Utilization(%)	Service_Drop_Rate_(All)	E-UTRAN Average CQI
[illegible]	87.346	3.1156	6.493247
[illegible]	79.5223	2.1891	6.695075

FIGURE 52: HIGH UL UTILIZATION, HIGH SERVICE DROP RATE & LOW AVG CQI

4.7 RESOURCE BLOCK UTILIZATION

4.7.1 DL RB UTILIZATION & DL USER THROUGHPUT

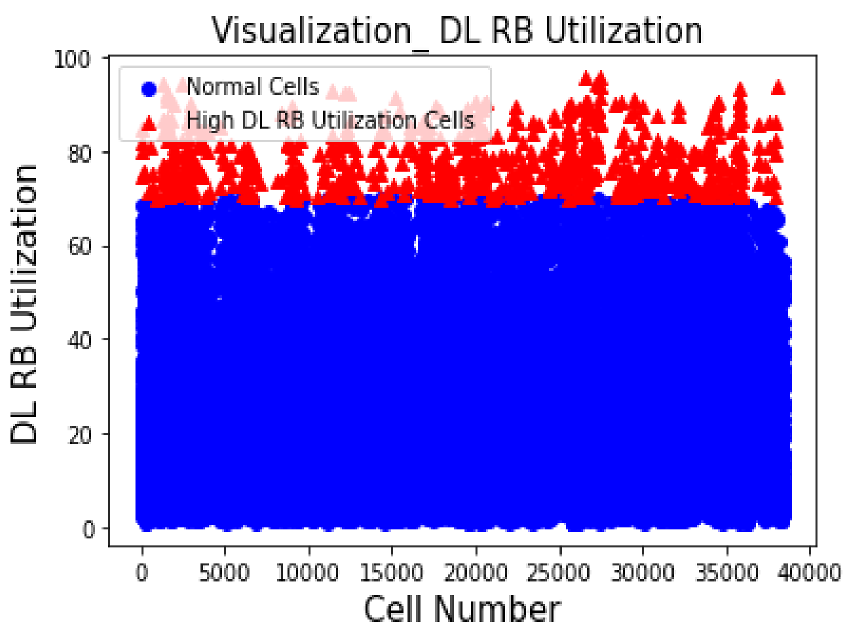


FIGURE 53: DL RB UTILIZATIOON

TABLE 21: DL RB UTILIZATION

Number of Normal Cells	Number of High DL RB Utilization Cells
37721	696

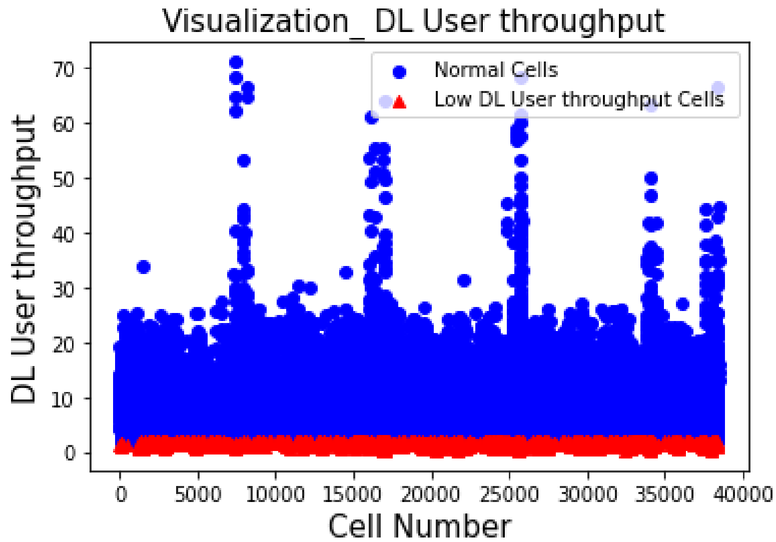


FIGURE 54: DL USER THROUGHPUT

TABLE 22: DL USER THROUGHPUT

Number of Normal Cells	Number of Low DL User throughput Cells
37160	1257

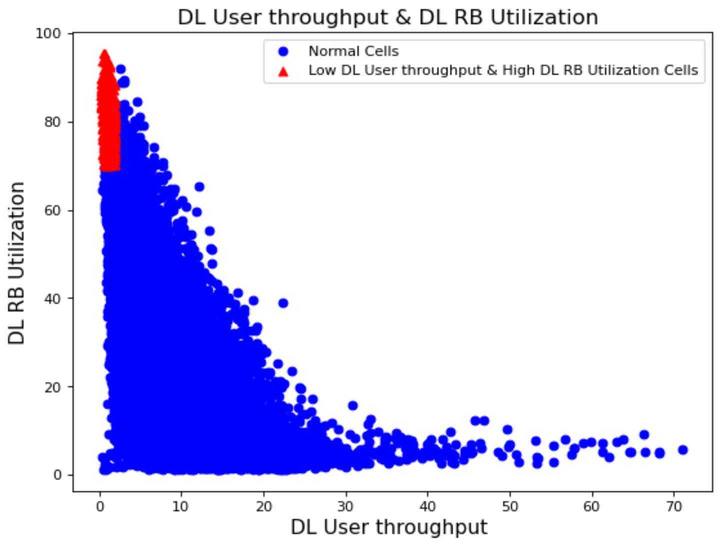


FIGURE 55: DL RB UTILIZATION & DL USER THROUGHPUT

TABLE 23: DOWNLINK RB UTILIZATION & DOWNLINK USER THROUGHPUT

Number of Normal Cells	Number of Low DL User throughput & High DL RB Utilization Cells
38020	397

- **Impact of Low DL User throughput & High UL RB Utilization**

User may failed in admission or poor user experience

- **Proposed solution**

1. Add eNodeB

2. Bandwidth expansion

4.7.2 UL RB UTILIZATION & UL USER THROUGHPUT

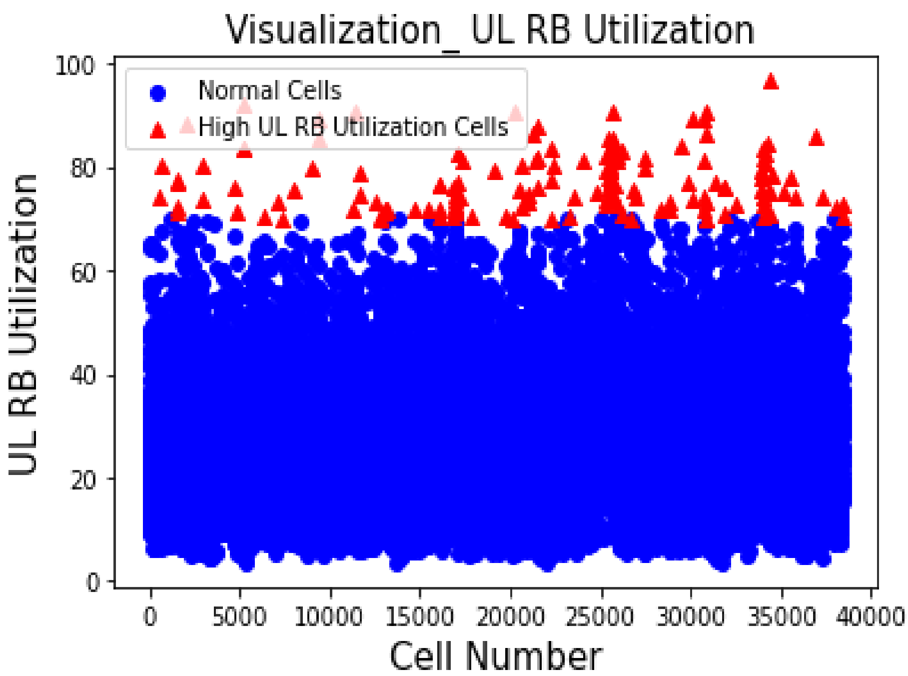


FIGURE 56: UL RB UTILIZATION

TABLE 24: UPLINK RB UTILIZATION

Number of Normal Cells	Number of High UL RB Utilization Cells
38260	**157**

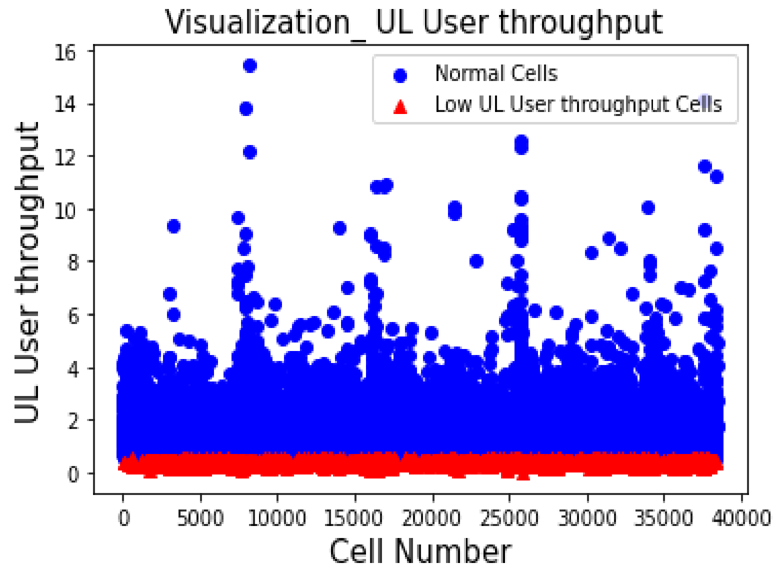


FIGURE 57: UL USER THROUGHPUT

TABLE 25: UL USER THROUGHPUT

Number of Normal Cells	Number of Low UL User throughput Cells
36262	2155

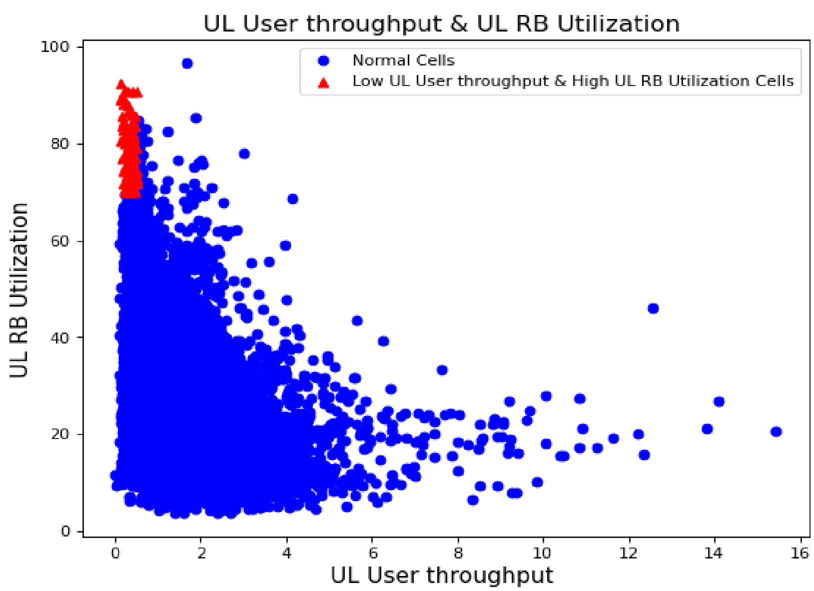


FIGURE 58: UL RB UTILIZATION & UL USER THROUGHPUT

TABLE 26: UPLINK PRB UTILIZATION & UPLINK USER THROUGHPUT

Number of Normal Cells	Number of Low UL User throughput & High UL RB Utilization Cells
38314	103

- **Impact of Low UL User throughput & High UL RB Utilization**

  User may failed in admission or poor user experience

- **Proposed solution**

  1. Add eNodeB
  2. Bandwidth expansion

4.4.3 DL/UL RB UTILIZATION & DL/UL USER THROUGHPUT

TABLE 27: DL/UL RB UTILIZATION & DL/UL USER THROUGHPUT

Number of Normal Cells	Number of Low DL/UL User throughput & High DL/UL RB Utilization Cells
38379	38

From the result there are 38 cells suffer from **Low throughput & High RB Utilization in both Uplink and Downlink**

4.8 PDCCH RESOURCE USAGE

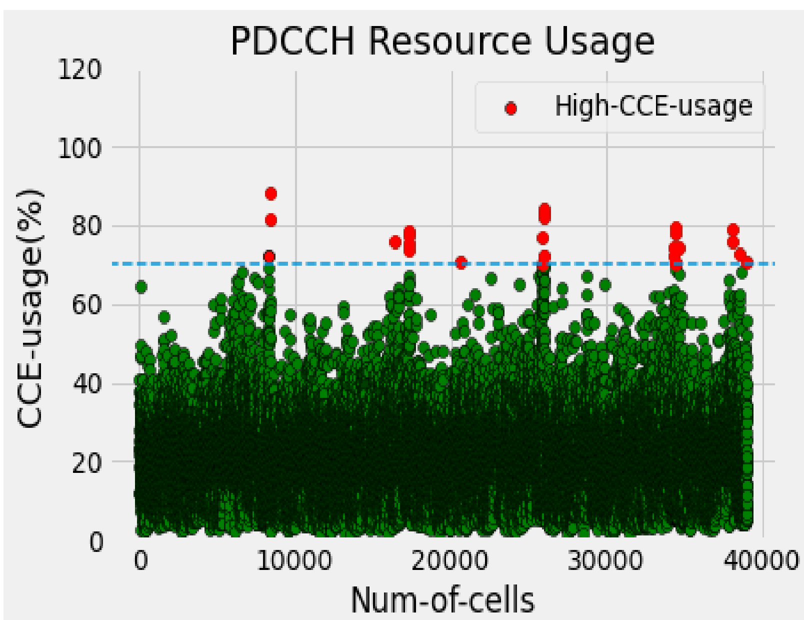


FIGURE 59: CELLS WITH HIGH CCE USAGE

We found that **27 cells** have high **CCE-Usage** whose value lies above the threshold 70%

4.9 CELL TRAFFIC VOLUME

We clustered the cell traffic volume to differentiate the traffic volume values between cells to know which has the highest traffic.

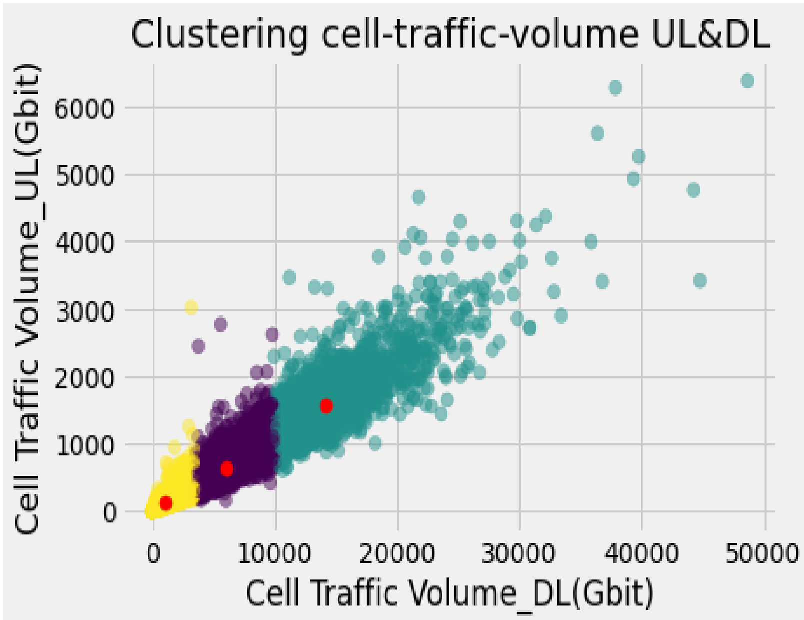


FIGURE 60: CLUSTERING CELL TRAFFIC VOLUME

TABLE 28: CLUSTERING CELL TRAFFIC VOLUME

Cluster number	1	2	3
Center x Center y	1140.3 124.4	14126.5 1591.8	5994.7 653.7
Num of cells	25195	2135	7276

From the table above, **Cluster 2** contains the cells which have the highest traffic.

4.10 CELL TRAFFIC VOLUME WITH CCE-USAGE

By correlating figure CCE-Usage and Cell Traffic Volume in sections 4.7 & 4.8 above, we will get value of traffic volume which its cells have high CCE-Usage.

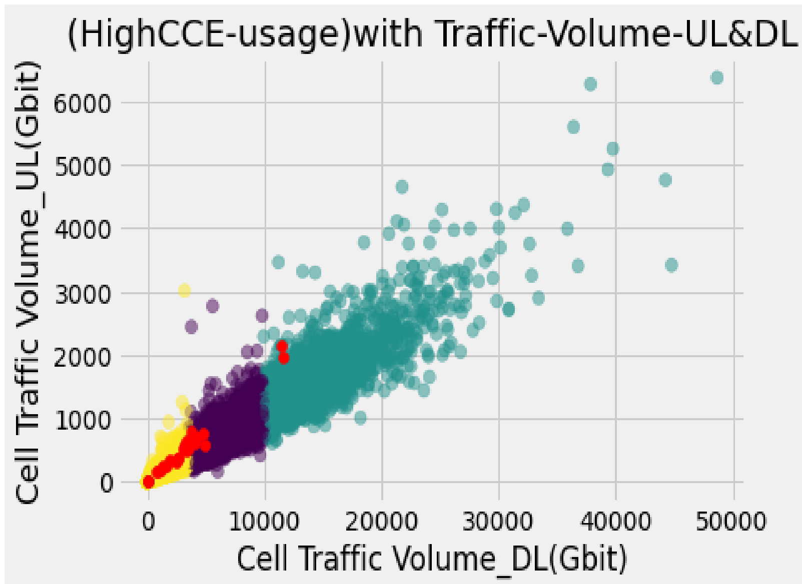


FIGURE 61: CORRELATION TRAFFIC VOLUME & CCE USAGE

Cell Name	Cell Traffic Volume_DL(Gbit)	Cell Traffic Volume_UL(Gbit)	CCE_usage	num_cluste
[illegible]	3715.0593	701.7996	77.893977	1
[illegible]	4909.9746	572.2965	75.575528	1
[illegible]	4697.7862	764.2355	75.214061	1
[illegible]	4020.2267	622.756	72.303998	1
[illegible]	4193.3803	706.5103	72.069099	1
[illegible]	3778.3367	798.9726	70.6448	1
[illegible]	3545.0375	603.7678	70.086068	1
[illegible]	11417.8284	2149.4622	73.995669	2
[illegible]	11570.6242	1958.9015	72.611796	2
[illegible]	0.1859	0.027	88.308726	3
[illegible]	723.9799	167.4888	84.196054	3
[illegible]	1906.1219	336.7136	82.901842	3
[illegible]	3086.6437	536.6968	81.900501	3
[illegible]	0.203	0.0421	81.252677	3
[illegible]	2598.1296	385.9903	79.174584	3
[illegible]	3366.4299	644.584	78.746181	3
[illegible]	2416.5659	355.9684	78.341755	3
[illegible]	2572.1699	371.0545	77.062952	3
[illegible]	3465.0324	538.2925	76.684642	3
[illegible]	3191.3212	596.3068	75.979964	3
[illegible]	982.6474	166.66	74.28088	3
[illegible]	1609.9339	240.1245	73.534826	3
[illegible]	3305.3574	482.6818	72.135466	3
[illegible]	1.2168	0.205	72.021849	3
[illegible]	1223.1232	191.4081	70.852747	3
[illegible]	1316.986	245.3478	70.499183	3
[illegible]	2499.0579	317.8932	70.202774	3

We found that only **2 cells** from **27 cells** which suffer from high **CCE-Usage** lie in **cluster 2** which has the highest **traffic volume**.

4.11 UL & DL PRB UTILIZATION

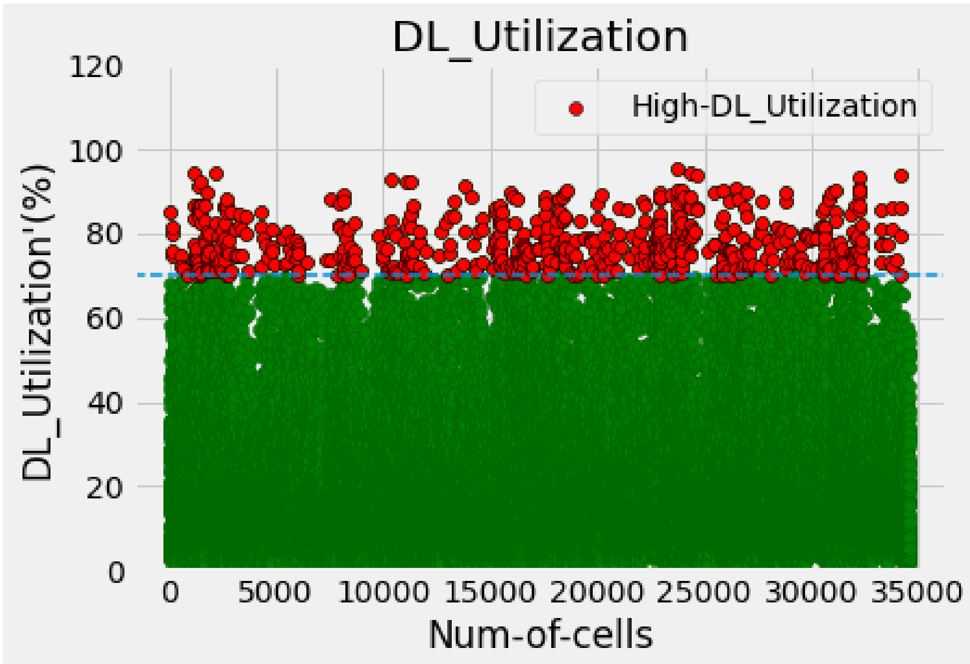


FIGURE 62: CELLS WITH HIGH DL PRB UTILIZATION

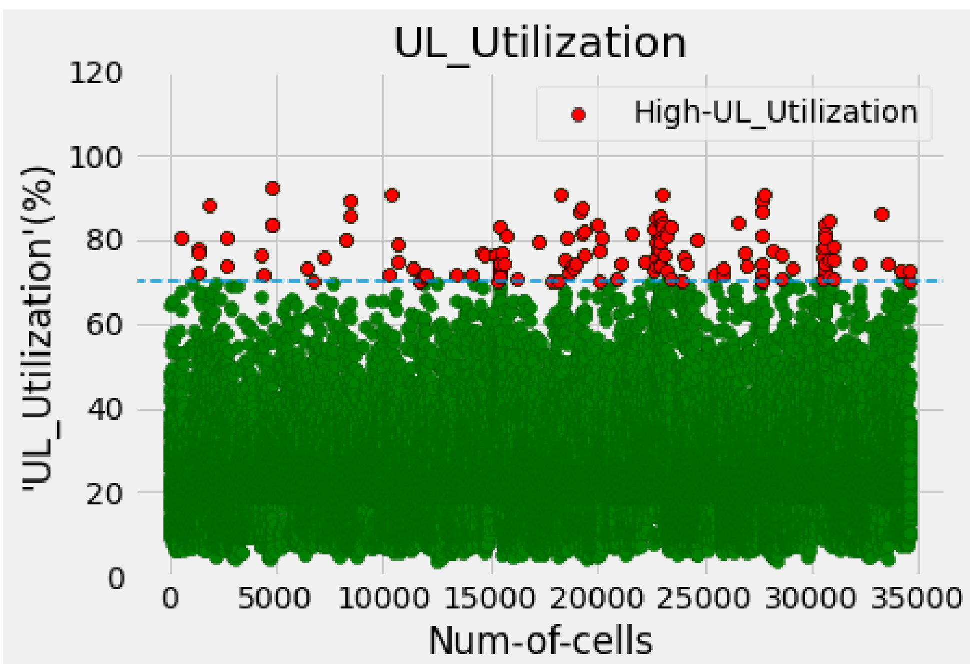


FIGURE 63: CELLS WITH HIGH UL PRB UTILIZATION

We found **803 cells** which have **(High-DL-Utilization)** as illustrated in **figure (62)** and **318 cells** which have **(High-UL-Utilization)** as illustrated in **figure (63).**

3G Results

4.12 RRC ATTEMPT CONGESTION RATIO

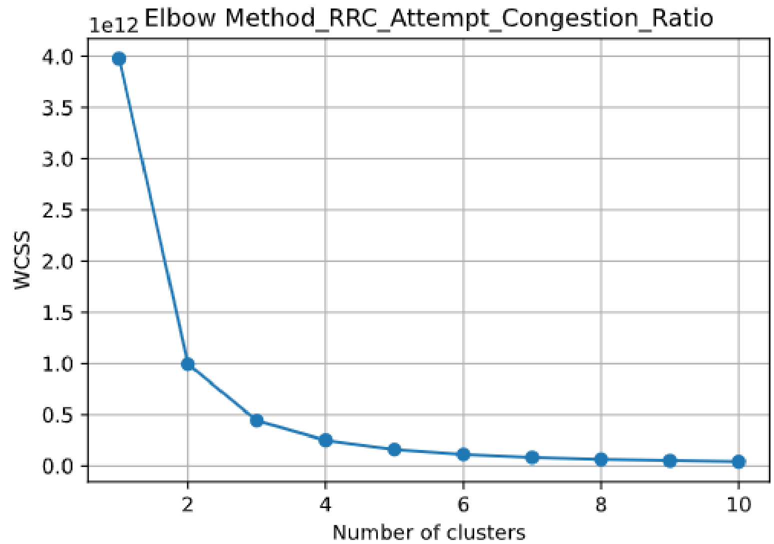


FIGURE 64: ELBOW METHOD FOR CLUSTERING RRC ATTEMPT CONGESTION RATIO

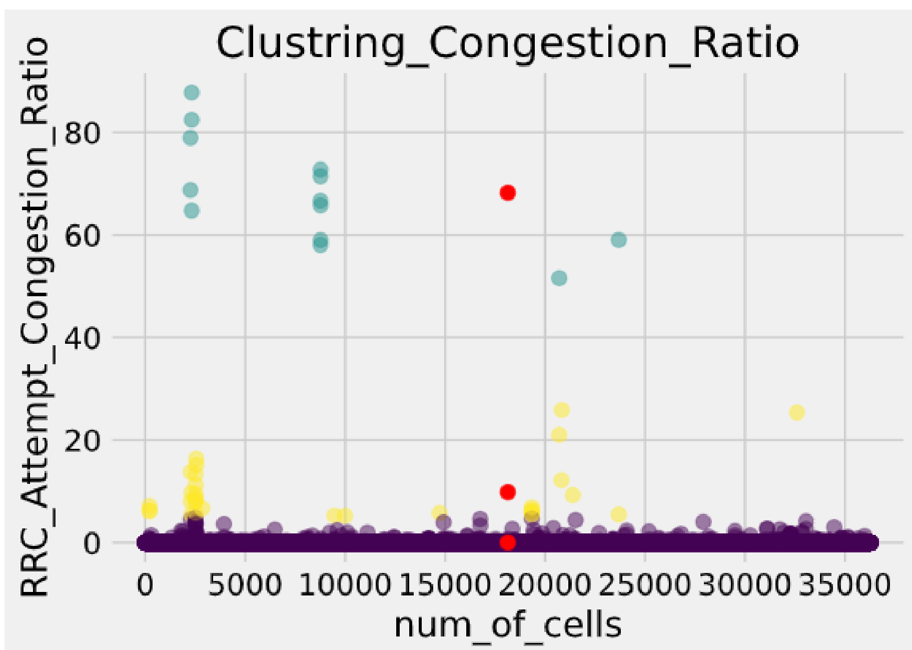


FIGURE 65: CLUSTERING RRC ATTEMPT CONGESTION RATIO

TABLE 29: CLUSTERING RRC ATTEMPT CONGESTION RATIO

Cluster Num	1	2	3
center	1.91640097	70.9568732	9.84189212
Num of cells	36229	13	31

4.13 RRC BLOCKING DUE TO CONGESTION

4.13.1 UL RRC BLOCKING

Monitoring **RRC blocking in UL** due to the congestion in **cluster 2 and 3** which are calculated from **(RRC Attempt Congestion Raito)** in section 4.12.

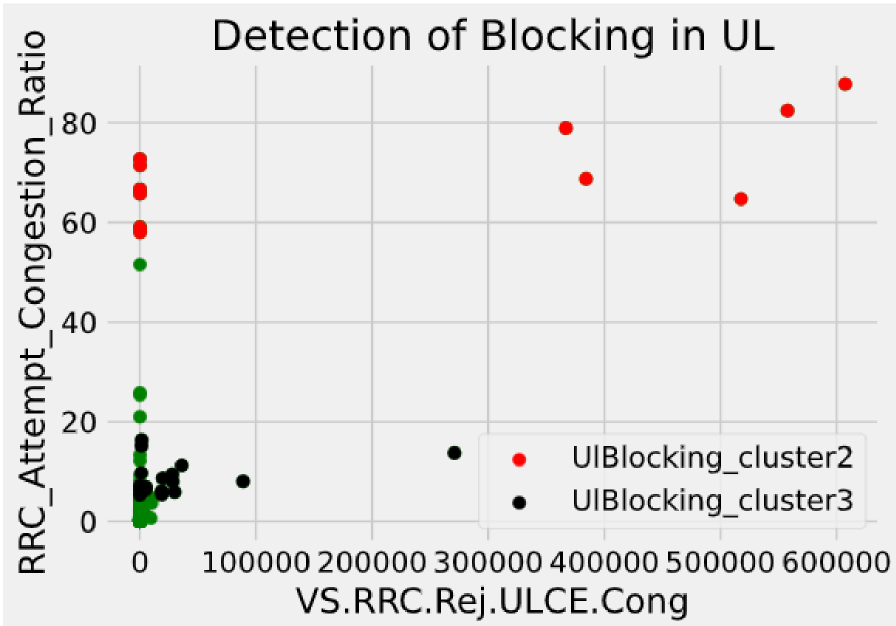


FIGURE 66: UL RRC BLOCKING DUE TO CONGESTION

ENodeB	Cell Name	RRC_Attempt_Congestion_Ra	VS.RRC.Rej.ULCE.Cong	num_cluster
[illegible]	[illegible]	87.76399106	607451	2
[illegible]	[illegible]	82.44618441	557911	2
[illegible]	[illegible]	78.92917002	366913	2
[illegible]	[illegible]	72.72727273	8	2
[illegible]	[illegible]	71.42857143	90	2
[illegible]	[illegible]	68.75543346	384314	2
[illegible]	[illegible]	66.66666667	4	2
[illegible]	[illegible]	65.75342466	48	2
[illegible]	[illegible]	64.73349016	517779	2
[illegible]	[illegible]	59.01639344	36	2
[illegible]	[illegible]	58.03571429	130	2
[illegible]	[illegible]	16.33902397	1501	3
[illegible]	[illegible]	15.14900233	1294	3
[illegible]	[illegible]	13.73230636	270955	3
[illegible]	[illegible]	11.2260707	36098	3
[illegible]	[illegible]	9.694251936	1188	3
[illegible]	[illegible]	9.455092952	27910	3
[illegible]	[illegible]	8.663464146	19719	3
[illegible]	[illegible]	8.027699301	88898	3
[illegible]	[illegible]	8.006311835	28171	3
[illegible]	[illegible]	7.195308315	1	3
[illegible]	[illegible]	6.899713319	5338	3
[illegible]	[illegible]	6.303327951	1	3
[illegible]	[illegible]	6.298216456	5075	3
[illegible]	[illegible]	6.072717646	18799	3
[illegible]	[illegible]	5.874101084	29916	3
[illegible]	[illegible]	5.814333155	19183	3
[illegible]	[illegible]	5.402911363	18956	3
[illegible]	[illegible]	5.269768458	1	3

4.13.2 DL RRC BLOCKING

Monitoring **RRC blocking in DL** due to the congestion in **cluster 2 and 3** which are calculated from **(RRC Attempt Congestion Raito)** in section 4.12.

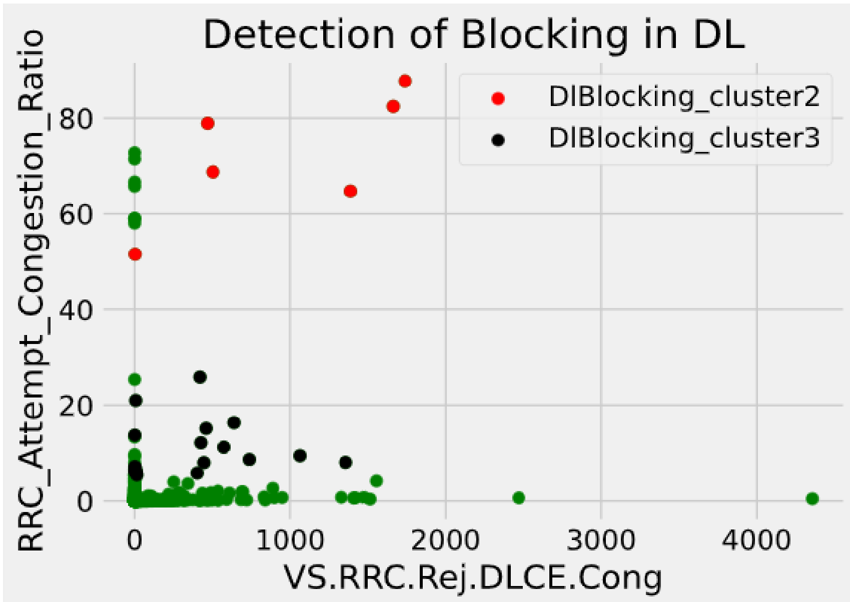


FIGURE 67: DL RRC BLOCKING DUE TO CONGESTION

ENodeB	Cell Name	RRC_Attempt_Congestion_Ratio	VS.RRC.Rej.DLCE.Cong	num_cluster
[illegible]	[illegible]	87.76399106	1739	2
[illegible]	[illegible]	82.44618441	1662	2
[illegible]	[illegible]	78.92917002	469	2
[illegible]	[illegible]	68.75543346	504	2
[illegible]	[illegible]	64.73349016	1389	2
[illegible]	[illegible]	51.55631509	3	2
[illegible]	[illegible]	25.85079451	420	3
[illegible]	[illegible]	20.99417417	7	3
[illegible]	[illegible]	16.33902397	640	3
[illegible]	[illegible]	15.14900233	459	3
[illegible]	[illegible]	13.73230636	1	3
[illegible]	[illegible]	12.14943527	426	3
[illegible]	[illegible]	11.2260707	575	3
[illegible]	[illegible]	9.455092952	1064	3
[illegible]	[illegible]	8.663464146	738	3
[illegible]	[illegible]	8.05732923	1357	3
[illegible]	[illegible]	8.006311835	445	3
[illegible]	[illegible]	7.195308315	1	3
[illegible]	[illegible]	6.899713319	5	3
[illegible]	[illegible]	6.298216456	3	3
[illegible]	[illegible]	6.082193816	1	3
[illegible]	[illegible]	6.072717646	10	3
[illegible]	[illegible]	5.874101084	11	3
[illegible]	[illegible]	5.814333155	402	3
[illegible]	[illegible]	5.402911363	14	3

4.13.3 CLUSTRING UL & DL RRC BLOCKING

Clustering **(UL_DL_RRC_REJ)** which has **high congestion (in cluster2 & cluster3)** above to get which has the **highest RRC blocking in (DL & UL).**

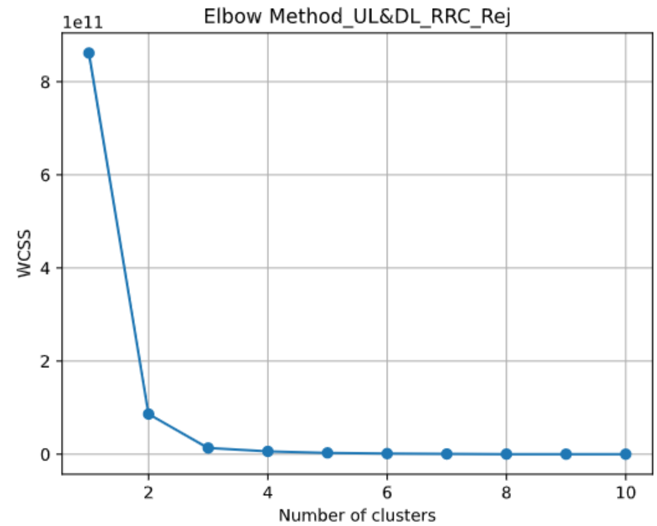


FIGURE 68: ELBOW METHOD FOR CLUSTERING UL & DL RRC BLOCKING

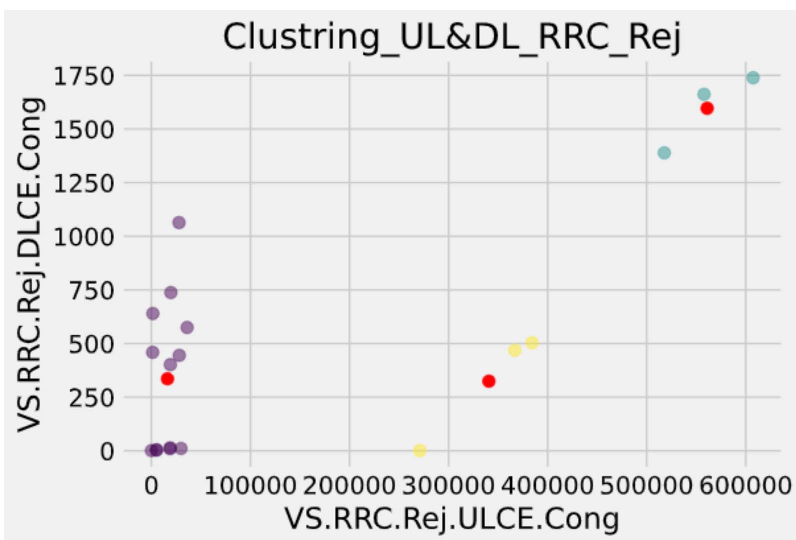


FIGURE 69: CLUSTERING UL & DL RRC BLOCKING

TABLE 30: CLUSTERING UL & DL RRC BLOCKING

Cluster Num	1	2	3
Centers (x,y)	**(16304.69,335.92)**	**(561047,1596.67)**	**(340727.3, 324.67)**
Number of cells	**13**	**3**	**3**

From the results above we notice the following:

Cluster 1 has high RRC Rejection in UL compared to rejection in DL.

Cluster 2 has the highest blocking in UL and DL due to congestion.

4.14 DCCC FAILURES

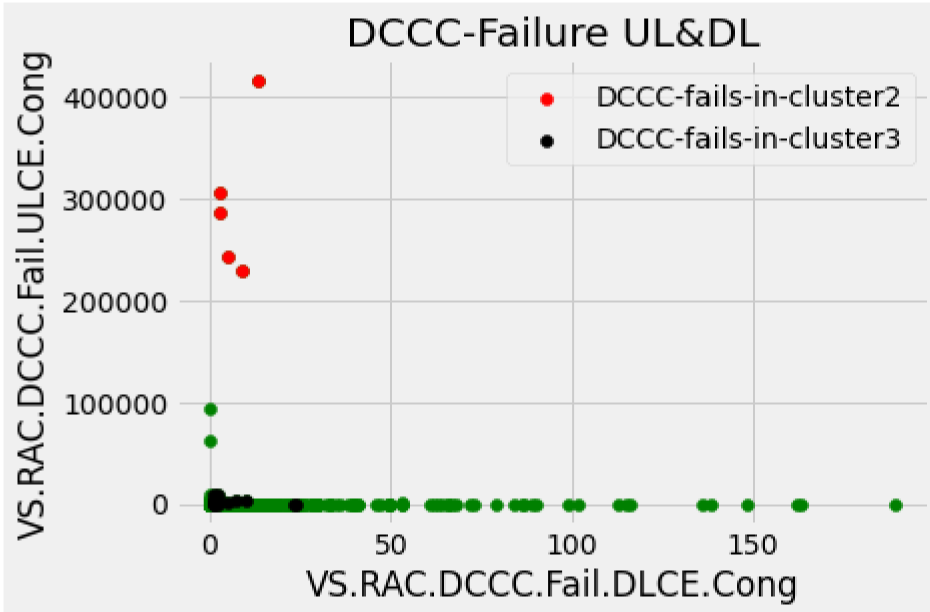


FIGURE 70: UL & DL DCCC FAILURES

Monitoring the DCCC failures in UL & DL in the cells and correlate them with high RRC congestion ratio which is in cluster 2 and cluster 3 which calculated pervious.

Cluster 2 contains 5 cells which has very high congestion in RRC congestion ratio.

Cluster 3 contains 13 cells which has medium congestion in RRC congestion ratio.

We found that there are **18 cells** which having both DCCC Failure in UL & DL.

Cluster 2 contains **5 cells** which has **very high congestion in RRC congestion ratio.**

Cluster 3 contains **13 cells** which has **medium congestion in RRC congestion ratio.**

ENodeB	Cell Name	VS.RAC.DCCC.Fail.DLCE.Cong	VS.RAC.DCCC.Fail.ULCE.Cong	num_cluster
[illegible]	[illegible]	3	286319	2
[illegible]	[illegible]	13	417281	2
[illegible]	[illegible]	9	228924	2
[illegible]	[illegible]	3	306820	2
[illegible]	[illegible]	5	244216	2
[illegible]	[illegible]	1	1	3
[illegible]	[illegible]	2	1	3
[illegible]	[illegible]	1	26	3
[illegible]	[illegible]	1	8824	3
[illegible]	[illegible]	2	4867	3
[illegible]	[illegible]	2	9230	3
[illegible]	[illegible]	24	235	3
[illegible]	[illegible]	23	255	3
[illegible]	[illegible]	5	1808	3
[illegible]	[illegible]	1	3081	3
[illegible]	[illegible]	7	4302	3
[illegible]	[illegible]	10	2823	3
[illegible]	[illegible]	1	4138	3

4.15 RAB BLOCKING DUE TO CONGESTION

4.15.1 RAB CS BLOCKING

Detection RAB blocking in UL & DL due to congestion which is in cluster 2 and 3 which calculated from (RRC_Attempt_congestion ratio)

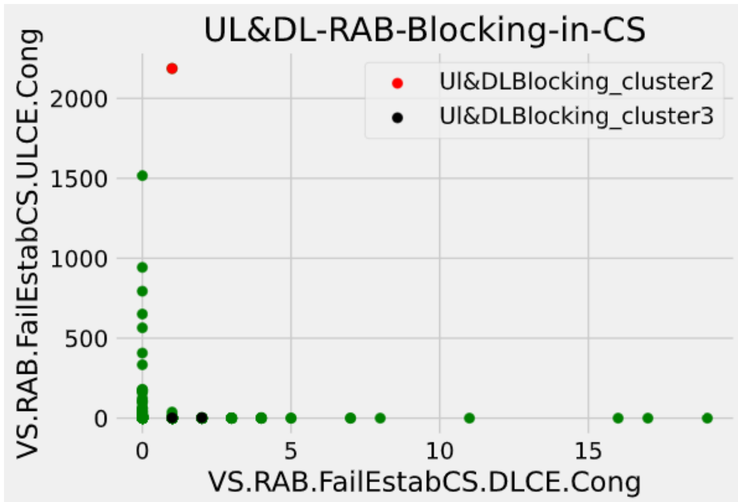


FIGURE 71: CS RAB BLOCKING (UL & DL)

ENodeB	Cell Name	VS.RAB.FailEstabCS.DLCE.Cong	VS.RAB.FailEstabCS.ULCE.Cong	num_cluster
[illegible]	**Cell "X"**	1	2187	2
[illegible]	[illegible]	2	3	3
[illegible]	[illegible]	1	2	3

We note that **Cell "X"** has the highest UL CS RAB Blocking due to the high congestion on this cell

4.15.2 RAB PS BLOCKING

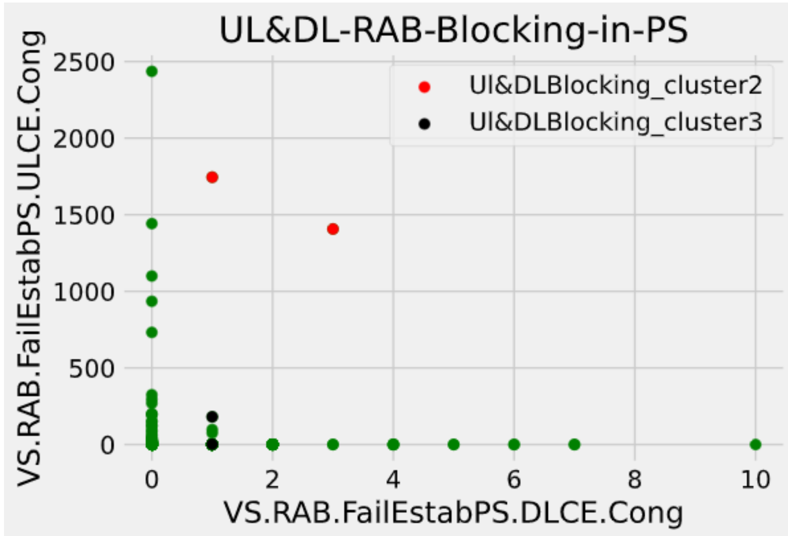


FIGURE 72: PS RAB BLOCKING (UL & DL)

ENodeB	Cell Name	VS.RAB.FailEstabPS.DLCE.Cong	VS.RAB.FailEstabPS.ULCE.Cong	num_cluster
[illegible]	**Cell "Z"**	3	1407	2
[illegible]	**Cell "Y"**	1	1745	2
[illegible]	[illegible]	1	181	3
[illegible]	[illegible]	1	2	3

From the results we note that:

Cell "Y" has the highest PS RAB Blocking due to the high congestion on this cell

Cell "Z" also has a high PS RAB Blocking due to congestion on cell

4.15.3 CLUSTERING CS & PS RAB BLOCKING

RAB Blocking due to the congestion in clusters 2 and 3 which is calculated from (RRC Attempt Congestion Raito)

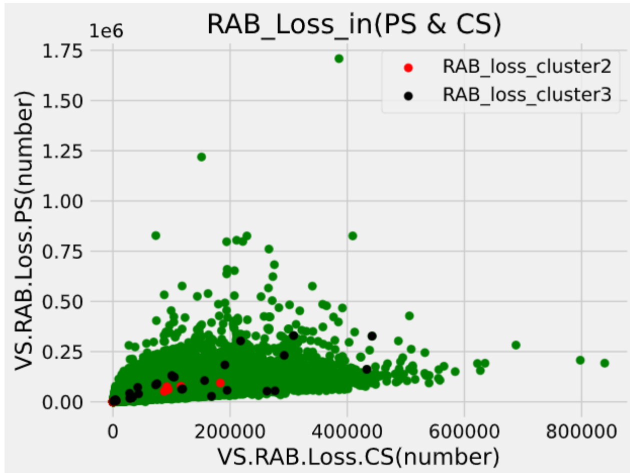


FIGURE 73: RAB LOSS (PS & CS)

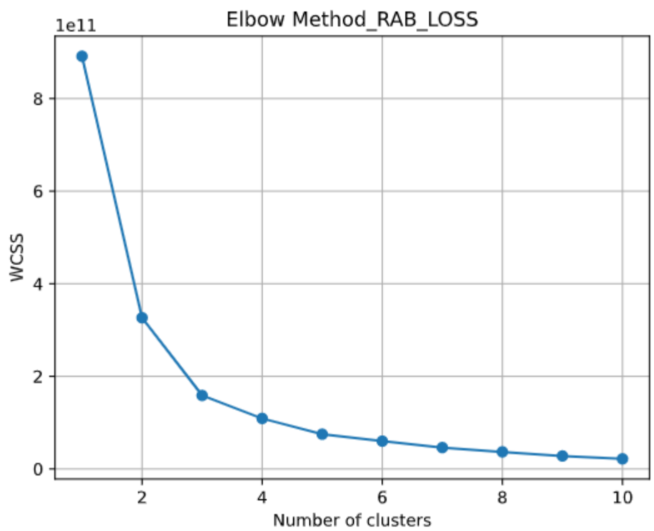


FIGURE 74: ELBOW METHOD FOR CLUSTERING CS & PS RAB LOSS

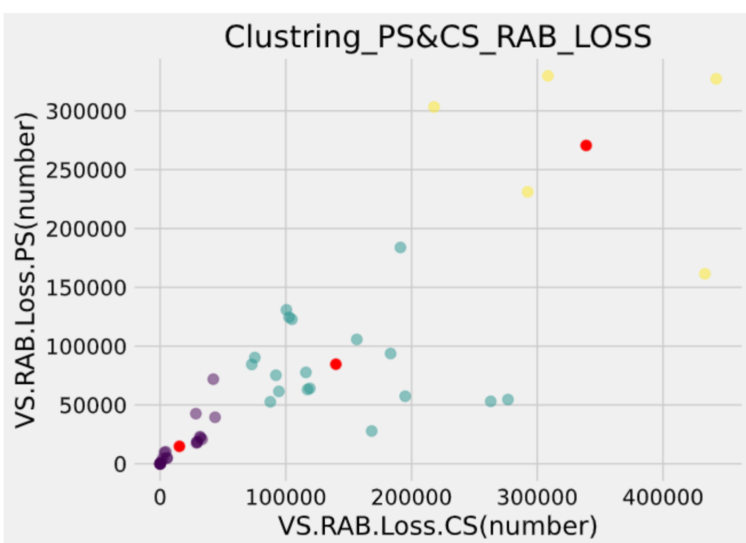


FIGURE 75: CLUSTERING CS & PS RAB LOSS

TABLE 31: CLUSTERING CS & PS RAB LOSS

Cluster Num	1	2	3
centers(x,y)	(15332.48 , 14814.43)	(139815.556 , 84623.778)	(338900.8 , 270573.8)
Num of cells	21	18	5

From the results above we note the following:

Cluster 1 has the **least RAB losses** in PS and CS, which lies in cluster 3 in FIGURE 42 which has a medium congestion in the RRC Congestion Ratio clustering.

Cluster 2 has **medium RAB losses** in PS and CS, which 8 cells lie in cluster 2 (the blue cluster in FIGURE 42 which has the highest congestion in the RRC Congestion Ratio clustering) and 10 cells lie in cluster 3 (the yellow cluster in FIGURE 42 which has a medium congestion in the RRC Congestion Ratio clustering).

Cluster 3 has the **highest RAB losses** in PS and CS, which lies in cluster 2 (the blue cluster in FIGURE 42 which has the highest congestion in the RRC Congestion Ratio clustering).

The 21 Cells of Cluster 1 are shown below:

ENodeB	Cell Name	VS.RAB.Loss.CS(number)	VS.RAB.Loss.PS(number)	cluster_num	Congestion Cluster
[illegible]	[illegible]	42300	71902	1	3
[illegible]	[illegible]	28471	42596	1	3
[illegible]	[illegible]	43725	39503	1	3
[illegible]	[illegible]	31701	23052	1	3
[illegible]	[illegible]	32116	22303	1	3
[illegible]	[illegible]	33425	20819	1	3
[illegible]	[illegible]	29392	18845	1	3
[illegible]	[illegible]	29458	18200	1	3
[illegible]	[illegible]	28996	17697	1	3
[illegible]	[illegible]	4575	10198	1	3
[illegible]	[illegible]	3418	9608	1	3
[illegible]	[illegible]	5649	4973	1	3
[illegible]	[illegible]	5500	4779	1	3
[illegible]	[illegible]	2249	4711	1	3
[illegible]	[illegible]	973	1885	1	3
[illegible]	[illegible]	4	10	1	3
[illegible]	[illegible]	18	9	1	3
[illegible]	[illegible]	2	7	1	3
[illegible]	[illegible]	7	4	1	3
[illegible]	[illegible]	2	1	1	3
[illegible]	[illegible]	1	1	1	3

The 18 Cells of Cluster 2 are shown below:

ENodeB	Cell Name	VS.RAB.Loss.CS(number)	VS.RAB.Loss.PS(number)	cluster_num	Congestion Cluster
[illegible]	[illegible]	191163	183846	2	2
[illegible]	[illegible]	100479	130832	2	2
[illegible]	[illegible]	102626	124556	2	2
[illegible]	[illegible]	104820	122786	2	2
[illegible]	[illegible]	156461	105665	2	2
[illegible]	[illegible]	183342	93680	2	2
[illegible]	[illegible]	75329	90264	2	2
[illegible]	[illegible]	72892	84413	2	2
[illegible]	[illegible]	116005	77694	2	3
[illegible]	[illegible]	92122	75273	2	3
[illegible]	[illegible]	119065	64083	2	3
[illegible]	[illegible]	117233	63120	2	3
[illegible]	[illegible]	94482	61515	2	3
[illegible]	[illegible]	194970	57393	2	3
[illegible]	[illegible]	276694	54571	2	3
[illegible]	[illegible]	262997	53056	2	3
[illegible]	[illegible]	87693	52630	2	3
[illegible]	[illegible]	168307	27851	2	3

The 5 Cells of Cluster 3 are shown below:

ENodeB	Cell Name	VS.RAB.Loss.CS(number)	VS.RAB.Loss.PS(number)	cluster_num	Congestion Cluster
[illegible]	**Cell “N”**	308483	329731	3	2
[illegible]	**Cell “M”**	442331	327206	3	2
[illegible]	[illegible]	217928	303300	3	2
[illegible]	[illegible]	292387	231189	3	2
[illegible]	[illegible]	433375	161443	3	2

The cell “N” has the highest loss (Block) in RAB PS.

The cell “M” has the highest loss in (Block) in RAB CS.

4.16 OVERLOAD CONGESTION

In some cases, we find many cells in the same RNC suffer from the problems discussed before, so we check on the congestion of RNC to solve the main cause of these problems.

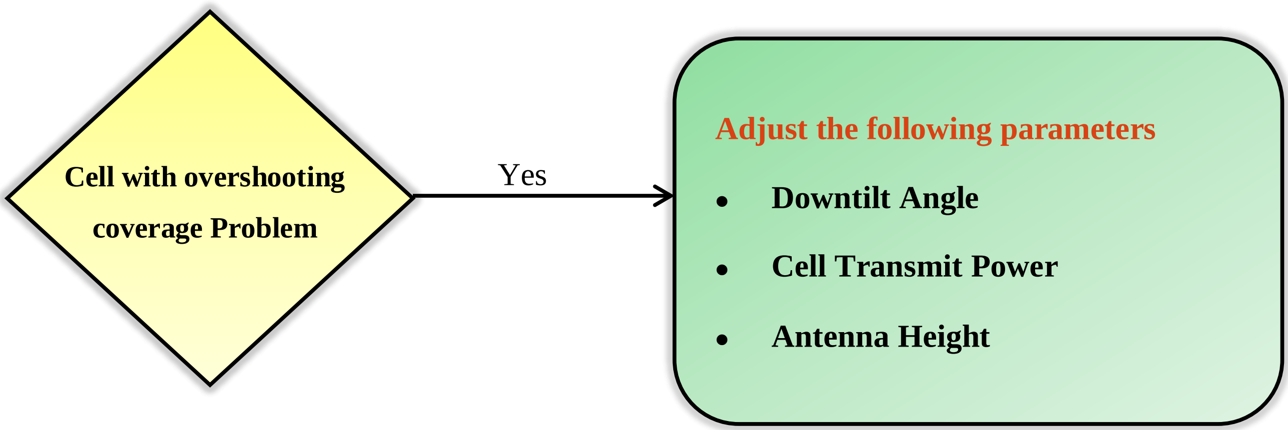
RNC	OLC
[illegible]	77.45750185
[illegible]	52.47148289
[illegible]	85.84070796
[illegible]	72.92035398
[illegible]	57.04898447
[illegible]	59.5599393
[illegible]	92.51336898
[illegible]	81.39097744
[illegible]	95.76427256
[illegible]	96.65379665
[illegible]	91.53031761
[illegible]	96.53558052
[illegible]	91.61290323
[illegible]	85.57692308
[illegible]	68
[illegible]	91.96832579
[illegible]	93.53301566
[illegible]	89.91121872
[illegible]	62.69883351
[illegible]	92.80022766
[illegible]	89.46808511
[illegible]	90.86563994
[illegible]	89.29049531
[illegible]	67.68589298
[illegible]	58.51364064
[illegible]	57.47863248

Overloaded RNC faces resource shortage for all the cells in this RNC, which affects access of new users and impacts the QoS of active users. Thus load imbalance seriously deteriorates the overall performance of the cellular network due to inefficient resource utilization.

CHAPTER 5: RECOMMENDATIONS

5.1 OVERSHOOTING SOLUTION ALGORITHM

Overshooting Solution



Downtilt Angle

If the downtilt angle is reduced too much, overshoot coverage can be easily caused. If downtilt angle is increased too much, coverage holes can be easily caused. Therefore, the downtilt angle must be adjusted properly to ensure network performance.

Cell Transmit Power

Cell Transmit Power indicates the maximum transmission power of the cell. This parameter ensures valid coverage and avoids overshoot coverage.

Antenna Height

If an eNodeB is in a too high or low place, serious overshoot coverage or insufficient coverage is caused.

5.2 OVERLOADED CELLS SOLUTIONS

CELL SPLITTING (BEAMFORMING)

Cell splitting using Beamforming is a technique of improving channel capacity which directly reduces call blocking probability and call delay probability

Beamforming techniques allow directing the signal toward the useful users while decreasing at the same time the interference toward and from the users of the neighboring cells.

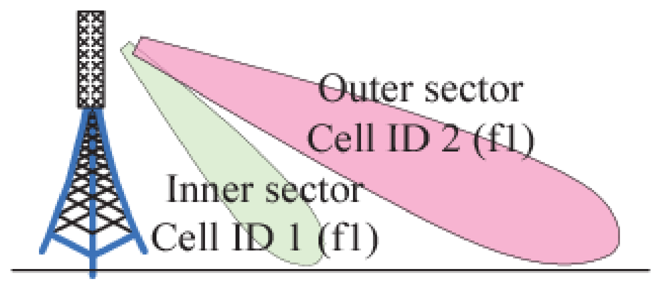
There are two types of Beamforming:

- **Vertical Beamforming**
- **Horizontal Beamforming**

Our proposed solution is vertical beamforming

Vertical Sectorization with Same Carrier Frequency:

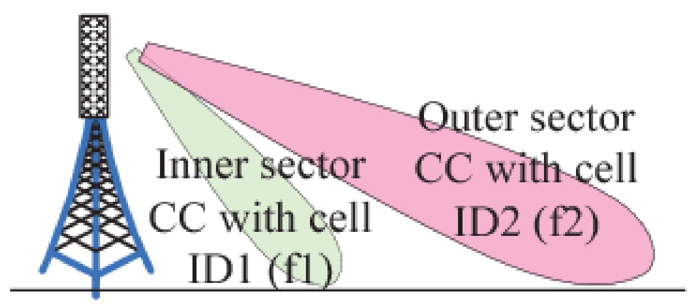
A cell is sectorized into inner sector and outer sector. Same carrier frequencies are used by all sectors in the system. The transmitting power for each vertical sector is halved to maintain the total transmitting power. Each user is associated to the sector with maximal received power.



Co-channel interference among the vertical sectors is unavoidable.

Vertical Sectorization with Different Carrier Frequency:

Different carrier frequency bands are assigned to the pair of sectors resulting in **zero co-channel interference** between the inner sector and the outer sector. In this scenario we may use the benefits of the carrier aggregation (CA) framework specified in current LTE systems, by configuring each vertical sector with one carrier component (CC).



5.3 DIFFERENT-PRIORITY INTER FREQUENCY

Cell reselection:

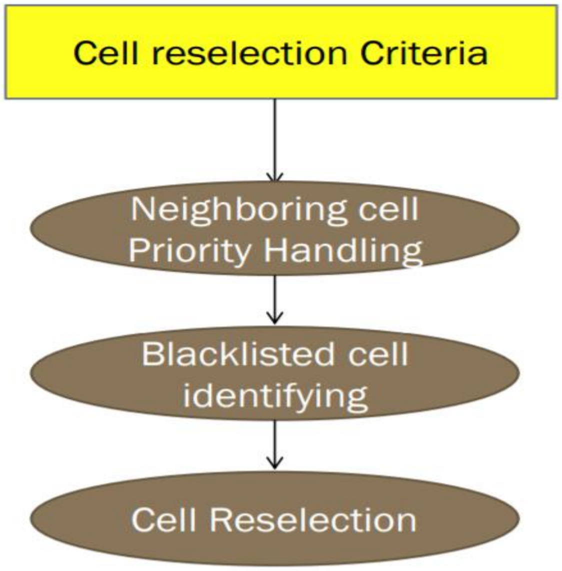


FIGURE 76: CELL RESELECTION CRITERIA

Classification:

Reselection to a different-priority inter-frequency cell can be classified into:

1. Reselection to a higher-priority cell.
2. Reselection to a lower-priority cell.

1. Reselection to a lower-priority cell:

UE reselects to a **lower-priority inter-frequency** neighboring cell when all the following conditions are met:

For EUTRAN neighbors:

1. No **higher-priority inter-frequency** neighboring cell meets the cell reselection criteria.
2. The neighboring cell has one of the following measurement results:
   - The **Squal** value of the serving cell is always **less than** the value of **threshServingLowQ** broadcast in the SIB3.
   - The **Squal** value of the evaluated neighboring E-UTRAN cell is always **greater than** the value of **EUTRANINTERNFREQ.threshXLowQ** broadcast in the SIB5.
   - Above Conditions should be achieved to specific time which is introduced by **EUTRANINTERNFREQ.EutranReselTime**.

<u>For UTRAN neighbors:</u>

1. No higher-priority inter-frequency neighboring cell meets the cell reselection criteria.
2. The neighboring cell has one of the following measurement results:
   - The **Squal** value of the serving cell is always **less than** the value of **threshServingLowQ** broadcast in the SIB3.
   - The **Squal** value of the evaluated neighboring E-UTRAN cell is always **greater than** the value of **UTRANINTERNFREQ.threshXLowQ** broadcast in the SIB5.
   - Above Conditions should be achieved to specific time which is introduced by **CELLRESELUTRAN.TreselUtran**.

2. Reselection to a higher-priority cell:

UE reselects to a **higher-priority inter-frequency** neighboring cell when all the following conditions are met:

<u>For EUTRAN neighbors:</u>

1. The neighboring cell has one of the following measurement results:

- The **Squal** value of the evaluated neighboring **E-UTRAN** cell is always **greater than** the value of **EUTRANINTERNFREQ.threshXHighQ** broadcast in the SIB5.
- Above Conditions should be achieved to specific time which is introduced by **EUTRANINTERNFREQ.EutranReselTime**.

<u>For UTRAN neighbors:</u>

1. The neighboring cell has one of the following measurement results:
   - The **Squal** value of the evaluated neighboring UTRAN cell is always **greater than** the value of **UTRANNFREQ.threshX-HighQ** broadcast in the SIB5.
   - Above Conditions should be achieved to specific time which is introduced by **CELLRESELUTRAN.TreselUtran**.

<table>
<tr><th>To a lower-priority cell</th><th>To a higher-priority cell</th></tr>
<tr><td>It will <u>start measurement</u> If

Srxlev< SnonintraSearchP

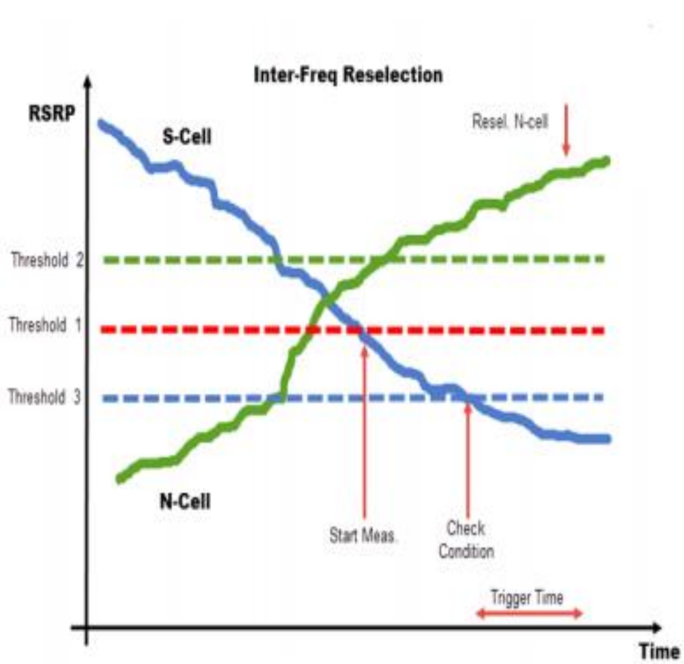
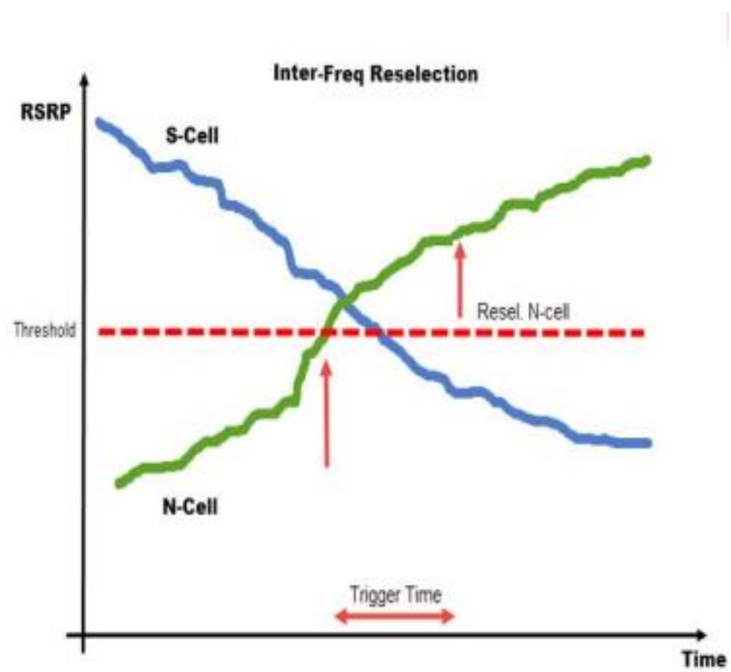
or

Squal< SnonintraSearchq

When can we do reselection?!!

1. Srxlev(S) < ThrshServLowlev.
2. Srxlev (N) > ThreshXLowlev.
3. Above two conditions achieved for EutranResetTime.</td><td>It <u>measure all time</u>.

When can we do reselection?!!

1. Srxlev (N) >ThreshXhighlev.
2. Above condition achieved for EutranResetTime</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Threshold 1= QRXLevMin- SNonIntraSearch

Threshold 2= QRXLevMin- ThreshXLowlev

Threshold 3= QRXLevMin- ThrshServLowlev</td><td>Threshold = QRXLevMin- ThreshXHigh</td></tr>
</table>

SnonIntraSearchP: The threshold of current cell **Srxlev** to perform inter-frequency.

SnonIntraSearchq: The threshold of current cell **Squal** to perform inter-frequency.

Srxlev = Qrxlevmeas - (Qrxlevmin + Qrxlevminoffset) – Pcompensation

Squal = Qqualmeas - (QQualMin + QQualMinOffset)

Where:

parameter	Description
Qrxlevmeas	Measured RSRP value.
Qrxlevmin	Minimal required Rx level (dBm) in SIB1.
Qrxlevminoffset	The offset to Qrxlevmin. It is broadcast in the SIB1.
Pcompensation	The result of the function: max ($P_{\text{Max-allowed-power}}$ - $P_{\text{UE-Maximum-Output Power}}$, 0), $P_{\text{Max-allowed-power}}$ is sent in SIB1.
Qqualmeas	The measured RX signal quality (RSRQ value) of the cell.
QQualMin	Minimal required signal Quality.
QQualMinOffset	The offset to QqualMin. It is broadcast in the SIB1.

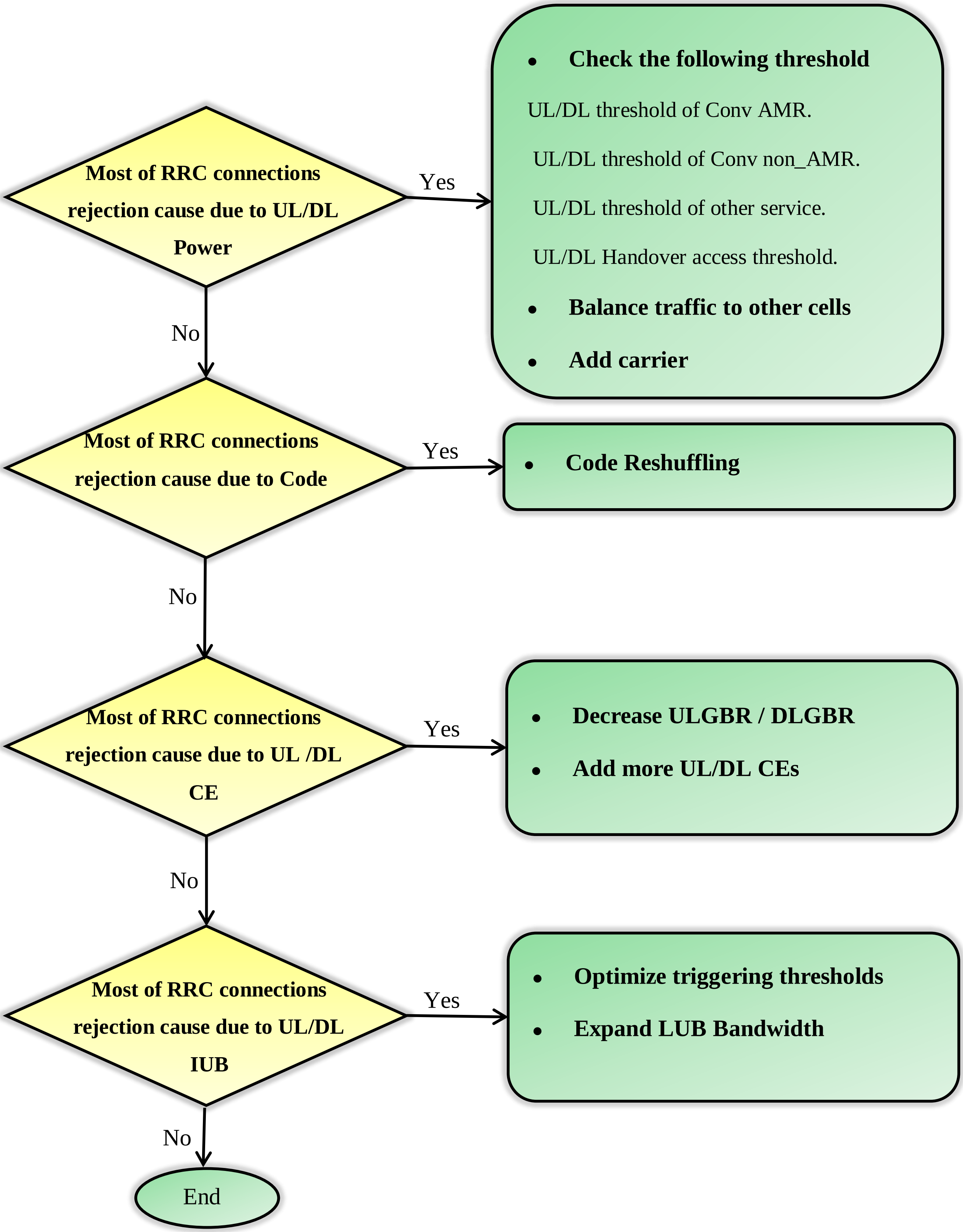
5.4 HIGH RRC Attempt Congestion Ratio

5.4.1 HIGH RRC ATTEMPT CONGESTION RATIO CAUSES

In order to reduce RRC Attempt Congestion Ratio we should **detect the reasons of increasing VS.RRC.FailConnEstab.Cong**, so we study the value of the counters listed below to check what types of resources are congested:

- **UL Power** → **VS.RRC.Rej.ULPower.Cong**
- **DL Power** → **VS.RRC.Rej.DLPower.Cong**
- **Code** → **VS.RRC.Rej.Code.Cong**
- **UL CE** → **VS.RRC.Rej.ULCE.Cong**
- **DL CE** → **VS.RRC.Rej.DLCE.Cong**
- **UL IUB Bandwidth** → **VS.RRC.Rej.ULIUBBand.Cong**
- **DL IUB Bandwidth** → **VS.RRC.Rej.DLIUBBand.Cong**

5.4.2 RRC CONGESTION SOLUTION ALGORITHM:



5.5 ADJUST PARAMETERS TO SOLVE 3G CAPACITY PROBLEM

To **Solve Capacity Problem** in **3G CDMA network**, we recommend **checking on specific parameters** that may influence the capacity of the network and try to adjust their values to their **default values**.

Check Admission Control Parameters

Parameter Meaning	Parameter ID	Physical Value Range	Impact on the cell capacity Performance
AMR Voice Uplink Threshold for Conversation Service	**UlConvAMRThd**	0 to 100% step is 1% The default value is 75%.	If the value is too low, the users are more likely to be rejected, and some resources are wasted. So the target capacity cannot be satisfied
Non AMR Voice Uplink Threshold of Conversation Service	**UlConvNonAMRThd**		
AMR Voice Downlink Threshold for Conversation Service	**DlConvAMRThd**	0 to 100% step is 1% The default value is 80%.	
Non AMR Voice Downlink Threshold of Conversation Service	**DlConvNonAMRThd**		
Uplink Threshold for Other Services	**UlOtherThd**	0 to 100% step is 1% The default value is 60%	
Downlink Threshold for Other Services	**DlOtherThd**	0 to 100% step is 1% The default value is 75%	
Resources Reserved for Common Channel Load	**ULCCHLOADFACTOR** **DLCCHLOADRSRVCOEFF**	0 to 100% step is 1% The default value for each parameter is 0	The higher value is set to the parameter, the more power resources are consumed, which may decrease the system capacity.

Check Cell Channel Power Distribution Parameters

Parameter Meaning	Parameter ID	Physical Value Range	Impact on the cell capacity Performance
Maximum Cell Transmit Power	**MaxTxPower**	0 to 50 dBm step 0.1 dBm The default value is 43 dBm	If its value is too low, the downlink capacity is limited.
Cell PCPICH Transmit Power	**PCPICHPower**	-10 dBm to 50 dBm step 0.1 dBm The default setting is 33 dBm.	If its value is too high, the downlink interference increases, and the cell capacity is decreased.
PSCH and SSCH Transmit Power	**PSCHPower** **SSCHPower**	-35 dB to 15 dB step 0.1 dB The default values are both -5 dB	If the value is too high, other channels are interfered, the power resources are occupied, and consequently the cell capacity is influenced.
BCH Transmit Power	**BCHPower**	-35 dB to 15 dB step 0.1 dB The default value is -2 dB.	
Maximum FACH Transmit Power	**MaxFachPower**	-35 dB to 15 dB step 0.1 dB The default value is 1 dB.	
PCH Transmit Power	**PCHPower**	-35 dB to 15 dB step 0.1 dB The default value of is –2 dB.	
PICH Transmit Power	**PICHPowerOffset**	-10 dB to 5 dB step 1 dB The default value is -7 dB	
AICH Transmit Power	**AICHPowerOffset**	-22 dB to 5 dB step 1 dB The default value is -6 dB	

CHAPTER 6: CONCLUSION AND FUTURE WORK

Satisfying the demand in a timely fashion is a critical task in any company. In a service sector like telecommunications where sold information transmission units cannot be stored in inventory or cannot be backordered, having appropriate capacity to fulfill all demand becomes crucial. In order to achieve this goal, not only a well-designed planning system but a good capacity expansion strategy is necessary. In our project, we made algorithms using machine learning to examine the QoS of 3G and 4G networks and investigate whether the examined cells need capacity expansion to have a proper QoS then we recommended solution for each of the resulted problems to increase capacity of the cellular network.

For future work, we recommend implementing an over-shooting algorithm using the available counters to adjust the tilting of the antenna and overcome the overshooting problem and working on increasing the accuracy of the used prediction and forecasting big data models. We also recommend executing our algorithms on 3G counters to detect high utilizations and unbalancing in 3G cellular network.

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