COMPENSATION OF OUTAGE IN A CELLULAR RADIO NETWORK USING CELL ZOOMING TECHNIQUE

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2017

Compensation of Outage in a Cellular Radio Network Using Cell Zooming Technique

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A thesis submitted in partial fulfillment for the degree of Master of Science in Telecommunication Engineering in the Jomo Kenyatta University of Agriculture and Technology

2017

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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This thesis has been submitted for examination with our approval as university supervisors

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DEDICATION

To my Mom and Dad

ACKNOWLEDGEMENTS

I wish to acknowledge the efforts of my supervisors in guiding and encouraging me through this research. I have to accept it was tough and without them I would have given up. Special mention goes to the staff of Safaricom Limited, who generously provided the desired information, without which this thesis would not have made much of a difference. My family has stood by me through thick and thin. Thank you all for your support.

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NOMENCLATURE

2G	Second Generation Mobile Network
3G	3rd Generation Cellular Network
3GPP	3rd Generation Partnership Project
AMR	Adaptive Multi-Rate
AMR-HR	Adaptive Multi-Rate Half Rate
BS	Base Station
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CSP	Communication Service Provider
COC	Cell Outage Compensation
COD	Cell Outage Detection
COST	European Cooperation in Science and Technology
COW	Cell On Wheels (Cell on Wings)
CSSR	Call Setup Success Rate
DL	Down Link
EIRP	Equivalent Isotropically Radiated Power
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FR	Full Rate
GSM	Global System for Mobile communication
HOSR	Handover Success rate

HR	Half Rate
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAPL	Maximum Allowable Path Loss
MS	Mobile Station
Multi-RAT	Multiple Radio Access Technology
NGMN	Next Generation Mobile Network
O&M	Operation and Maintenance
OPEX	Operation Expenditure
OSS	Operation and Maintenance Sub System
PA	Power Amplifier
PL	Path Loss
QoS	Quality of Service
RET	Remote Electrical Tilt
RF	Radio Frequency
RSSI	Receiver Signal Level Indicator
SDCCH	Standalone dedicated control Channel
SOCRATES	Self-Optimisation and self-ConfiguRATion in wireless networkS
SON	Self Organizing Networks
TCH	Traffic channel
TRX	Transceiver
UL	Uplink

UMTS	Universal Mobile Telecommunication Service

ABSTRACT

In the Third Generation Partnership Project (3GPP) long term evolution release 8, it was proposed to have networks that have intelligence to carry out most of the activities on their own. Among these activities include configuration, optimization and self-healing. These networks are called self-organizing networks (SON). This technology has so far been realized mainly in a laboratory situation or on a trial basis. The main reason for the slow development of the technology has been attributed to the complexity of the available algorithms that makes the implementation costly.

This research was to identify corrective measures that could be taken to adapt existing mobile network infrastructure so that it exhibits significant level of intelligence that would lower overall downtime in mobile network and thus reap the benefits of SON.

The scope of the study was limited to the mobile radio network and it simulated how radio units can be clustered together to share load incase a member of the cluster fails. To demonstrate this, a visual basic algorithm that solved for the compensation parameters was developed using Okumura-Hata propagation model. The Parameters from the algorithm were fed to a simulator (Atoll Planning Software) and the effect analyzed. The algorithm was validated by feeding it with the same parameters as had been used in a previous study and the output matched perfectly. The result of the study identified two region of compensation that can be categorized as densely populated and scarcely populated. The scarcely populated region can primarily rely on the use of cell zooming technique for outage compensation but the densely populated should consider other means as well. Most important, the study revealed that the Azimuth of the antenna should also be adjusted as part of cell zooming.

CHAPTER ONE

INTRODUCTION

1.1 Background

Cellular network hardware and software protection mechanisms have been implemented in the core network to ensure the system does not experience total outage during operation. Coverage area of one radio is much smaller and thus the stabilization of radio cells has not been a priority, making faults occurrence frequent in the radio network.

When these faults occur on radio network, the attendant may be required to travel physically to the site to attend to the faults. This is time consuming, costly and dangerous to the person on duty as this might involve travelling to a security compromised zone. At times, failed cell cannot be accessed for repair as it might be in a disaster situation. In such cases coverage compensation becomes critical as this would also help in rescue operations.

This research demonstrates a cellular system in which traffic from a failed cell can be redistributed automatically to its neighbouring cells as stop gap measure, at least until the fault is cleared at the appropriate time. The methods that have been used for the compensation have been limited to cell zooming by power adjustment and by height adjustment. This compensation is in line with the 3GPP proposal to design self-organizing networks (SON) to minimize human intervention in fault clearance (NEC corporation, 2009). Outage compensation falls in the category of self-healing.

During simulations a target cell is identified within a cluster. Configurations of its neighbours is learned so as to redistribute traffic during fault situation. Normal configuration is to resume when planning condition are reverted.

1.2 Problem Statement

Fault management and correction requires a lot of human interventions and should be automated as much as possible; hence identification and self-healing of the faults is a significant solution. Any loss of service within the base station will result in users experiencing complete service outage or significantly degraded service. This can result in loss of revenue for the operator and an increase in the level of subscribers moving to competitors' networks. (Nokia Siemens Networks, 2010), (Ericssons, 2012), (Feng & Seide, May 2008), (Ramiro & Hamied, 2011), (Pras, A., Schonwalder, J., Burgess, M., Festor, O., Perez, G. M., Stadler, R., & Stiller, B., 2007), (Marwangi, 2011)

These faults on the radio network are mostly random events and in most cases necessitate intervention on site. It involves traveling long distances sometimes at night and in insecurity prone areas. Even when a fault is anticipated, it may involve replacement of a module which again has to be delivered and changed. More so, some events may hinder effort to bring the site back into use. These include disasters and insecurities. Within this time, there will be a network outage that definitely leads to loss of revenue and a lot of inconvenience to users. Implementing a self optimizing network would place a stop gap measure to ensure uninterrupted coverage while at the same time allowing for time to clear the faults.

Sometimes it is not cell failure but some other events like political rallies, social gathering and graduations are known to suddenly increase the offered traffic which overwhelms a particular site. If this issue is not noted and addressed in time, degradation of service may extend to adjacent cells. However, it is possible that when one cell is overloaded, the neighbouring cells could be carrying way below average capacity and thus these neighbouring cells are candidates for compensating for the outage.

1.3 Justification

The benefits of employing cell zooming in outage compensation are the same as those that will be achieved by use of Self Organizing Networks (SON) in general and they include

- Saving in cost on overtime, hiring security escort, injuries from accidents caused by fatigue as a result of working odd and long hours
- Faster fault clearance
- Better customer experience as the customer experience minimum outage
- Better employee experience because they work within normal working hours and have reduced exposure to insecurity
- Employees can concentrate on better planning and schedule maintenance without ad hoc need to attend to faults and overloads
- In case of disasters like earthquake, floods, fire, lightning and insecurity, this may be the only way to be able to provide the much needed service
- Sometimes, a cell will be overloaded because of a temporary event and in such a case you want to address the problem with a temporary solution.

1.4 Objectives

1.4.1 Main Objective

To develop a simulation model of a self-healing cellular radio network to mitigate the effects of cell outages by introducing compensation through cell zooming

1.4.2 Specific objectives

- To develop a model of a healthy network with optimal parameter settings in a radio network cluster
- Develop a test algorithm to be used to provide parameters for self-healing
- To validate the developed algorithm against existing ones
- To simulate faults at different points in the system by altering the parameters and use the algorithm to generate optimal compensation parameters

1.4.3 Scope

This study is limited to only one cell failing within a cluster of cells. The failure of multiple cells may mean that the other says may not be able to compensate for the loss adequately. One cell with the immediate neighbors that have direct interaction with this cell forms a cluster. However, both theoretical and actual values have been considered.

The algorithm is limited to only providing the necessary parameters to be fed to the simulator.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Radio planning and maintenance becomes difficult and complex as data usage increases with growth. SON concept was introduced with various aims such as (Network E. U. T. R. A, 2010), (3GPP , 2009), (Network E. U. T. R. A., 2009);

- Reducing expenditure on design, planning, maintenance and optimization
- Reduce human errors
- Continuous, optimized and matched Uplink (UL) and Downlink (DL) coverage
- Optimized DL and UL capacity of the system
- Balanced tradeoff between coverage and capacity
- Interference reduction
- Controlled cell edge performance
- Minimized human intervention in network management and optimization tasks
- Energy savings

In order to achieve these objectives, 3GPP suggests an implementation of three key functions (Network E. U. T. R. A, 2010), (3GPP , 2009), (Network E. U. T. R. A., 2009) namely, detection of unintended holes in the coverage, perform coverage optimization, including DL/UL channel coverage and ability to balance the trade-off between coverage and capacity

The proposal provides for three classes of key functions as defined in the proposal and specification

2.1.1 Self-configuration

This is what is popularized as ‘plug and play’ or as guided installation in Microsoft. It comprises all tasks necessary to automate the deployment and commissioning of networks and the configuration of parameters. Network elements operate autonomously, running setup routines, authenticating and connecting to the Operation and maintenance Sub System (OSS), as well as linking up and swapping parameters with need-to-know neighbors.

2.1.2 Self-optimization

This serves to improve or recover network quality by tuning network parameters continuously. The system monitors the changes in the performance indicators and adjusts various parameters to give optimal performance. Key tasks involve brokering handovers and balancing loads among neighboring cells. SON offers advanced energy-saving features that contribute to a greener network environment.

2.1.3 Self-planning

This combines configuration and optimization capabilities to dynamically re-compute parts of the network, the aim being to improve parameters affecting service quality.

2.1.4 Self-healing

This encompasses a set of key functions designed to cope with major service outages, including detection, root cause analysis, and outage mitigation mechanisms. Auto-restart and other automatic alarm features afford the network operator even more quick-response options. The main aim of a self-healing network is to promptly reduce the impact of the failure as much as possible. These failures can be caused by a disruptive event such as power failure, equipment failure and a traffic surge.

2.2 Application of self-healing in radio network

Within the current understanding of cellular self-healing networks there are a number of main areas that are addressed:

- Self-recovery of software - the ability to return to a previous software version should issues arise. This is done by initiating a restart that rolls back to the previous version and should happen without human intervention.
- Self-healing of board faults - this often involves redundant circuits where a spare can be switched in. Processing is also done by multiple processor with just one generating output and when the primary one fails the standby will just forward the output without the need to reprocess
- Cell outage detection - it must be possible to remotely detect when there is an issue with a particular cell. When the mechanism for communicating information from a cell fails, detection of fault is not possible and the cell is referred to as dead cell. Such a cell may be working but its status will not be available immediately to the OSS.

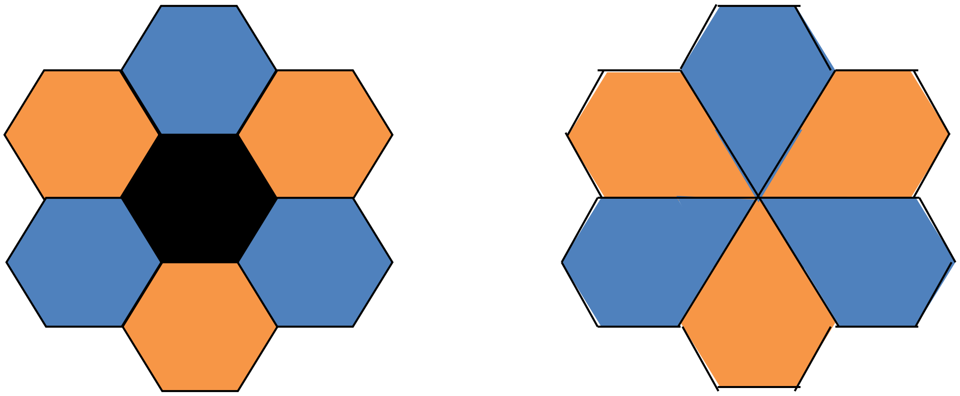
- Cell outage recovery - routines to assist with cell recovery, this may include detection and diagnosis and along with an automatic recovery solution, together with a report of the outcome of the action.
- Cell outage compensation - methods of maintaining the best service to users while repairs are effected.
- Return from cell outage compensation - A rushed return to original configuration may negate the gains made. Returning to the pre fault status must be well calculated to ensure the return is easily achieved without impacting on existing connections.

2.3 Cell outage compensation

An important element of the self-healing network is the compensation when a cell outage occurs. The network should be able to respond quickly when as fault is detected, quantify the impact quantified and immediately compensation is introduced. The speed at which this should be implemented means that the compensation cannot be done manually and hence the need for automation. The first step involves the effort to mitigate the problem by means within the radio equipment itself but when there is a complete cell outage, this is not possible and the compensation has to be done by the neighbouring cells

During compensation using neighbouring cells, a tradeoff between capacity and coverage is made in order to alleviate the impact as much as possible. Optimization must also be done in order to maintain the affected cells within the planning parameter range as much as possible. (Nokia Siemens Networks, 2010) (Litjens, 2012) (Nokia Siemens Networks, 2009)

The Figure 2.1 below gives a summary what happens in a cell compensation scenario. It consists of a 7 cell cluster which when the central cell goes out of coverage, the other cells extend to cover the area once covered by the cell that is in outage.



7 cells cluster with mid
cell as candidate

Cluster after
compensation

Figure 2.1: Cell Compensation Scenario

Several reasons may put a cell out of service by affecting the normal operation of the cell and thus create a denial of service to subscriber. The main aim of a self-healing network is to promptly reduce the impact of the failure as much as possible. However, this does not mean that the impact of a failure is completely eliminated (Litjens, 2012). In the study (Litjens, 2012) it was shown that a self-healing network will always have a better quality of service even during normal operations than normal cell operation. The result of the study is shown in Figure 2.2. The diagram shows that those networks with self-healing will remain better than those without because with the self healing mechanism the equipment will continuously correct itself internally thus maintaining high quality unlike the one without which will be degrading slowly. The curves in the diagram had the same quality initially but the network without healing has been weakening over time and thus the reason why these curves show a superior quality of service for self-healing network prior to failure.

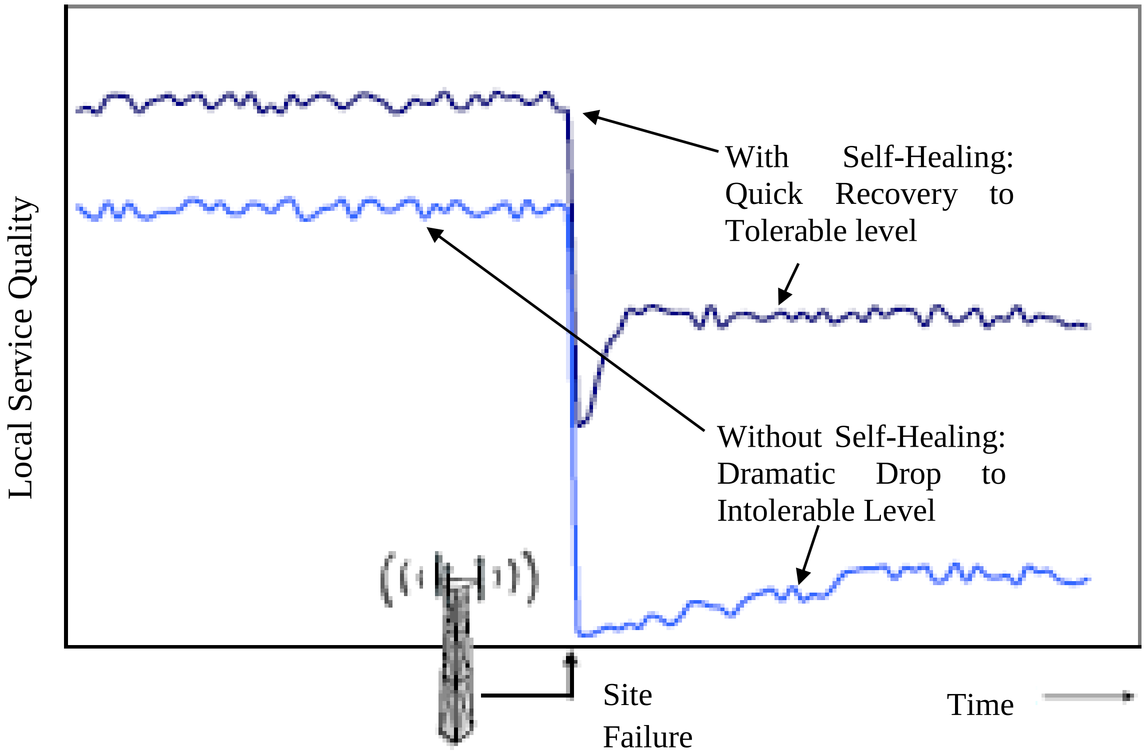


Figure 2.2: Impact of self-healing

The techniques used for cell zooming are discussed in details in the next section

Cellular self-healing network technology can be used to mitigate the effects of a complete cell outage or other failure. However, there is likely to be an impact on performance and therefore a fast response once the fault is diagnosed is required to ensure that the network can return to its pre-fault condition. Compensation should not result in completely abandoning the fault but repairs should be done at the earliest possible time and the original configuration reverted.

2.4 Link Budget, Path Loss and Propagation Models

Communication link depends on the quality of the transmit power, transmitting antenna gain, and receiving antenna gain. In between the transmitting and receiving antenna, the signal gets attenuated and this attenuation is the path loss. Thus Path Loss is the attenuation of the power density of an electromagnetic wave as it travels through space. Link budgeting is used to account for the all the losses and gains in the link to ensure that acceptable signal level is received for effective communication.

To determine path loss, transmitter output is first determined. Transmitter output is boosted by system Antenna gain and reduced by transmission line and connector losses.

Effective Isotropic Radiated Power (*EIRP*) is given by:

$$EIRP\ (\text{dBm}) = \text{Transmitter Output (dBm)} + \text{Antenna Gain (dBi)} - \text{Cable and Connector Losses (dB)} \tag{2.1}$$

The losses within the antenna systems are also taken into account. When the power transmitted by the antenna minus all the losses is greater than the minimum allowed signal level of the receiving antenna, then communication is possible between the two radios. However, it is prudent to add margin to the minimum allowed received levels for a more reliable link.

In order to determine the received signal, link budget calculations are done to determine the maximum allowable path loss (MAPL) in the system (SIEMENS AG, 2006).

$$\mathrm{MAPL} = \mathrm{MS}_{\mathrm{TX}_{\mathrm{pwr\_max}}} - \mathrm{BS}_{\mathrm{RX}_{\mathrm{sensitivity}}} - \mathrm{Loss} - \mathrm{Margins} + \mathrm{Gains} \tag{2.1}$$

where

- $\mathrm{MS}_{\mathrm{TX}_{\mathrm{pwr\_max}}}$ is peak RF power of the MS
- $\mathrm{BS}_{\mathrm{RX}_{\mathrm{sensitivity}}}$ is the BTS sensitivity
- Loss is the losses of the system
- Margins is the margins coming from the propagation phenomena
- Gains is the system gains

When we know the MAPL, then it is possible to estimate the power that must be fed into an antenna. This is because the minimum acceptable received levels are known and specified as In-car = -100dBm, Indoor = -95dBm and Outdoor = -105dBm for downlink and minimum power of -114dBm (SIEMENS AG, 2006). The end result of link budgeting is the maximum cell radius since the other parameters are considered be fixed from equation **Error! Reference source not found.**

$$EIRP = MAPL + RSSI + Margin \tag{2.2}$$

Where RSSI is the received signal level indicator and Margin is an allowance given to cater for interference.

A number of propagation models have been proposed that help in predicting path loss and propagation pattern (Molisch, 2011) (Dalela, 2013) (Shabbir, Sadiq, Kashif, & Ullah, 2011). Three models used in this research follow:

2.4.1 Okumura-Hata Model

In this model, Path Loss is given by (Molisch, 2011) (Dalela, 2013) (Shabbir, Sadiq, Kashif, & Ullah, 2011),

$$PL = A + B\ log(d) + C \tag{2.3}$$

where A, B, and C are factors that depend on frequency and antenna height.

$$A = 69.55 + 26.16\ log(f_c) - 13.82\ log(h_b) - a(h_m) \tag{2.4}$$

$$B = 44.9 - 6.55\ log(h_b) \tag{2.5}$$

Where

f_c is frequency in MHz
d is distance in km

h_b is height of base station in meters

h_m is height of mobile station in meters

The function $a(\mathrm{h_m})$ and the factor C depend on the environment. This implies that the perceived height of a mobile phone is dependent on the environment one is in and thus the function $a(\mathrm{h_m})$:

- Small and medium-size cities:

  $$a(h_m) = (1.1\ log(f_c) - 0.7)h_m - (1.56\ log(f_c) - 0.8) \tag{2.6}$$

  C = 0

- Metropolitan areas

$$a(h_m) \ = \left\{\begin{matrix} 3.2(log(11.75h_m)^2 - 4.97 \ for \ f \ \geq \ 400 \ MHz \\ 8.29(log(1.54h_m))^2 - 1.1 \ \ for \ f \ \leq \ 200 \ MHz \end{matrix}\right\} \tag{2.7}$$

C = 0

- Suburban environments

$$C = -2 \ \left[log\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \tag{2.8}$$

- Rural area

$$C = -4.78 \ [log(f_c)]^2 + 18.33logf_c - 40.98 \tag{2.9}$$

The function $a(h_m)$ in suburban and rural areas is the same as for urban (small and medium-sized cities) areas

2.4.2 COST-Hata Model

The Cost-Hata (Pedersen, 1999)propagation model given as:

$$PL = \ 46.3 + 33.9 \log f - 13.82 \log h_b - R_a(h_m) + (44.9 - 6.55logh_b)logR_a + C \tag{2.10}$$

where

- PL is the maximum path loss in dB
- f is the frequency in Hz
- h_b is the base station height in meters
- R_a is the cell radius in km
- h_m is the mobile receiver height in meters
- C is 0dB for medium cities and sub-urban areas or 3dB for metropolitan cities

In a comparative study (Dalela, 2013) , COST-Hata propagation model was shown to be the most consistent model for urban areas.

2.4.3 The standard propagation model

This model is a model derived from the Hata formula and is most suitable for predication in the range of 150MHz~3500MHz for distances between 1km and 20km. This model may be used for any technology; it is based on equation (2.11) (Cichon & Kürner, 1999), (Rani, Behara, & K.Suresh, 2012): This model is very commonly used in Asset and Atoll planning tools.

$$PL_{SPM} = K_1 + K_2 \log(d) + K_3 \log(HT_{xeff}) + K_4\, DiffractionLoss + K_5 \log(d)\log(HT_{xeff}) + K_6 HR_{xeff} + K_{clutter}\, f(clutter) \tag{2.11}$$

Where:

- PL_{SPM} is path loss for Standard Propagation Model
- K_1 Constant offset (dB)
- K_2 Multiplying factor for log(d)
- d Distance between the receiver and the transmitter (m)
- K_3 Multiplying factor for log(HT_{xeff})
- HT_{xeff} Effective height of the transmitter antenna(m)
- K_4 Multiplying factor for diffraction calculation, K4 has to be a positive number
- K_5 Multiplying factor for log(d)log(HT_{xeff})

- K_6 Multiplying factor for HR_{xeff}
- HR_{xeff} Mobile antenna height (m)
- $K_{Clutter}$ Multiplying factor for f(clutter)
- *f(clutter)* Average of weighted losses due to clutter

In Asset and Atoll these values are set to default value but can be adjusted to tune the propagation model according to actual propagation conditions. Table 2.1 below shows a sample tuned values for and metropolitan town in India (Rani, Behara, & K.Suresh, 2012). These results are the only one of the kind that have been published.

Table 2.1: Example of tuned values for an Indian Metropolitan Region

K value	Dense Urban	Urban	Sub Urban	Rural	Highways
K_1	16.375	17.575	17.675	5.275	26.625
K_2	48	45.9	44.9	48	40.1
K_3	5.83	5.83	5.83	5.83	5.83
K_4	0.8	0.8	0.8	0.8	0.8
K_5	-6.55	-6.55	-6.55	-6.55	-6.55
K_6	0	0	0	0	0
Kclutter	1	1	1	1	1

2.5 Outage Compensation Using Cell Zooming

Cell zooming involves the adjustment of the cell size by varying electrical power dissipated by the antenna or by varying the tilt angle of the antenna either by mechanical or electrical means (Pedrini, 2008), (Meyer, 2010) or by varying the height of the antenna. Each of the approaches to cell zooming has its advantages and disadvantages but the best approach would involve an optimal combination of the three.

2.5.1 Electrical Zooming

For a specific region, path loss is dependent on frequency and distance. Thus at fixed frequency, path loss will be dependent only on distance. Consequently, increasing the radiated power means there is a net margin to allow for a longer distance. Similarly, reducing the power would lower the overall distance that the acceptable signal can cover. This is the electrical zooming. It is achieved by varying the power fed to the transmitting antenna to vary the coverage radius

2.5.2 Mechanical tilt

A mechanical tilt involves tilting the antenna usually through specific accessories on its bracket consequently altering the direction of propagation of the signal. This tilt can be done manually or electronically. A mechanical down tilt will tilt the front lobe downward but the back lobe will tilt upward. An illustration is given in Figure 2.3 (Pedrini, 2008)

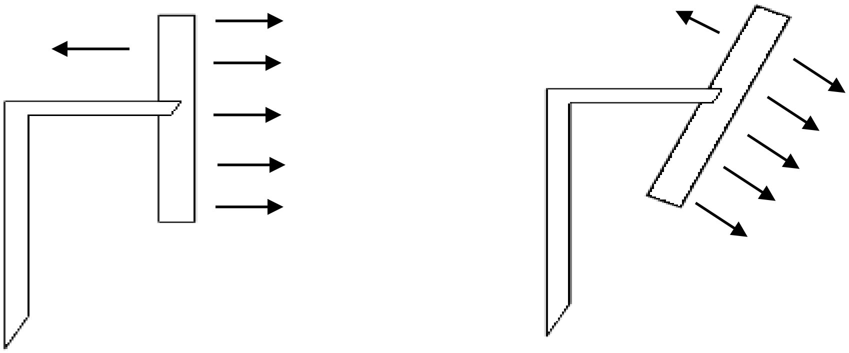
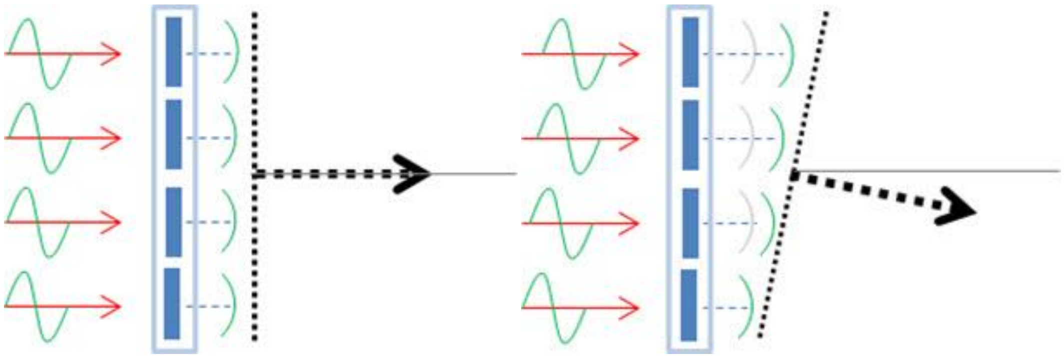


Figure 2.3: Illustration of Mechanical tilt

When using mechanical down tilt, one is exposed to unexpected and often undesirable pattern variances. This effect holds true beyond pattern blooming and can be seen in other horizontal pattern characteristics such as front-to-back ratio, beam squint, sector power ratio, and cross-polarization ratio (Meyer, 2010).

2.5.3 Electrical tilt

This is obtained by changing the characteristics of signal phases on each element of the antenna, as seen in Figure 2.4 (Pedrini, 2008). A BTS antenna is constructed using several antenna elements usually 2 to 8 and each element is fed with the same signal but at different phases in order to achieve the tilt. The electrical tilt may have a single fixed value or may be variable. If the variation is done electrically, this is referred to as Remote Electrical Tilt (RET). An electrical down tilt, tilts both the front and the back lobe downwards. Figure 2.4 below shows an illustration of 4 element antenna fed with signal at different phases in order to achieve the tilt.



Antenna without tilt

Antenna with electrical tilt

Figure 2.4: Illustration of Electrical Tilt

In addition to reducing horizontal pattern blooming, the increased beam forming capabilities of the electrically tilted antennas have yielded significant improvement in controlling other negative pattern characteristics. These include beam squint, front-to-back ratio and cross polarization ratio. It is noted that, antennas using only electrical tilt produce horizontal patterns that maximize sector coverage while minimizing potential interference, and that their patterns demonstrate a high degree of consistency regardless of the tilt angle (Meyer, 2010).

A comparison of the effect of electrical and mechanical tilt on the coverage is shown in Figure 2.5 (Pedrini, 2008)

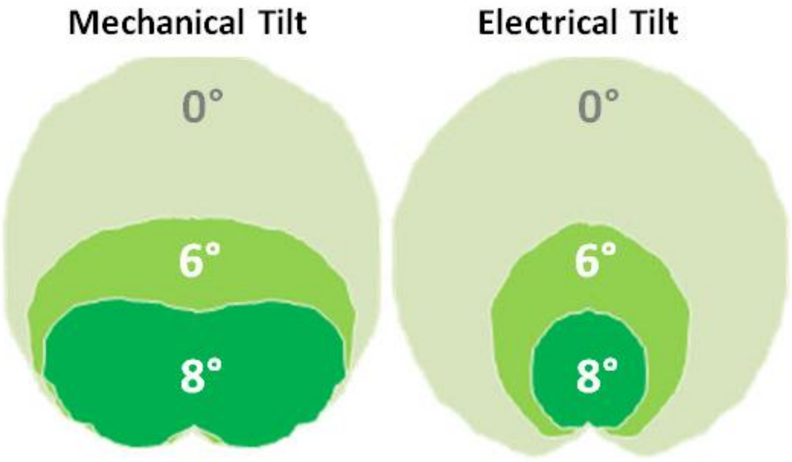


Figure 2.5: Radiation patterns of mechanical and electrical tilts

2.5.4 Height adjustment

As described above it is possible to achieve a cell zoom by adjusting the height of the antenna on the tower and by using Okumura-Hata model, it is possible to determine the correct height to achieve a particular cell size.

2.6 Factors affecting compensation using cell zooming

There are two main considerations that determine the requirement of a particular cell for adequate coverage.

- The minimum power required by the MS in order to sustain a communication between the radio and the MS and a minimum power of -114dBm is required to be received at the BTS antenna to sustain communication with a MS (SIEMENS AG, 2006). Equations (2.4) to (2.10) given previously are used to calculate the desired or the expected signal levels at various distances.
- The size of available resources for carrying traffic. Usually, the limiting capacity is that of traffic channels (TCH). The other channels on a radio hardly get congested except in a case of extreme traffic or as a result of equipment fault.

The goal of every cellular network planning team is to strike a balance between coverage and capacity. There are two aspects of coverage. One looks at the number of subscriber covered while the second is the geographical region. The end product is the volume of traffic generated in an area.

2.7 Methods of addressing capacity issue

As noted earlier, compensation cannot be achieved without enough capacity. This may aggravate the situation leading to serious congestion or complete outage. Compensation should thus not be a cause for further degradation of service. The following are some of the measures that address capacity issue in the event that the planned capacity gets overwhelmed.

- Multi Radio Access Technology (Multi-RAT):

This is where one site is served by multiple radios of different radio technologies. This is termed as a technology collocation (Network E. U. T. R. A, 2010) (3GPP , 2009).

- Adaptive Multi Rate-Half Rate (AMR-HR)

  A standard voice encoding is at 16Kbps at the radio level. Any encoding method reducing the bit-rate to 8kbps or less is the half rate. The AMR codec provides operators with a means to optimize the balance between voice quality and spectral efficiency by continuously selecting the optimal speech codec rate for the current radio and traffic conditions (DITECH NETWORKS, 2012).

- Dynamic channel allocation

  Some channels in a radio can be configured as dual channels (capable of both voice and data). Dynamic adjustment can be made either to increase the allocation for voice or data, depending on which traffic type is high or has higher priority (Zhang & Soong, 2004).

- COW (Cell on Wheel/Wings)

  This is a radio that is normally mounted on a movable container that is transported on road or by air to a location which has no coverage or has gone out of coverage to help offer services.

2.8 Indicators of cell failure

There are three sources that can provide information that would indicate a cell has failed. Two of them are measurements relating to the cell while the others come from the user equipment. The information from the user equipment may not be accessible to the network provider and therefore has little contribution to the assessment that may help identify a failed cell. The two sources relating to cell measurement are taken from the cell itself or from the operation and maintenance data.

All cells generate data of their performance. This data is summarized in form of statistics that is used to compare with defined standard termed quality of service while O&M continuously monitor the KPIs. Any deviation from the normal will indicate a cell failure. For example the following are indicators of potential cell outage

- Increased load in some cells
- High inter-cell interference
- Increased number of handover failures
- Sudden increase in radio link failures
- High number of dropped calls

If outage is not detected and compensated for in time, it may lead to degradation of services and in worst case it may lead to complete loss of service as a result of extreme number of retries.

2.9 Related studies

The studies in the area of self-healing have been carried out in two categories. The area with the most studies has been in the detection of cell outage commonly referred to as cell outage detection (COD). This is of course because detection precedes compensation. COD can be divided into stages (M. Amirijoo L. J., 2009), starting at the time of the instant of the failure and ends when it is corrected.

The main reason for the concern with COD has been due to presence of sleeping cells (M. Amirijoo L. J., 2009). These are cells that have lost communication to the OAM and therefore no statistics about their operation is available. Such cases happen when the OAM module in the cell required to sends alarms to the OAM center is the one that is faulty (Ciocarlie, Lindqvist, Novaczki, & Sanneck, 2013). In the absence of alarms, the operator may have the impression that the cell is healthy. Such detection requires the use of data coming from the neighbouring cells such as handover statistics (de-la-Bandera, Barco, Muñoz, & Serrano, 2015) from neighbouring cells for COD or by profiling normal operation of cells from their statistics (Zoha, Saeed, Imranz, Imrany, & Abu-Dayya, 2015) it is possible to detect and localize a fault.

The second type of study is on Cell Outage Compensation (COC) where the initial studies have analyzed the steps in compensation.

A number of organizations have engaged in research in the area: 3rd Generation Partnership Project (3GPP), Next Generation Mobile Networks (NGMN) and Self-Optimization and self-ConfiguRATion in wireless networkS (SOCRATES) project, have conduct both research and projects in the area. 3GPP gives a detailed description of self-healing (Network E. U. T. R. A, 2010) (3GPP , 2009) (Network E. U. T. R. A., 2009). NGMN research report gives analysis on control parameters used for effective compensation in case of cell outage (Li, Yu, Yin, & Meng, 2015) while SOCRATES project (Kürner, 2010) also describes the procedure, scenarios and framework of self-healing, and indicates that the coverage gap could be compensated by adjusting the parameters, such as transmit power and the antenna down tilt (Meyer, 2010) of the surrounding cells to achieve compensation (Li, Yu, Yin, & Meng, 2015) (Jie, Alsharoa, Kamal, & Alnuem, 2015) (Bramah, 2016). These proposals give instructions on how to carryout compensation but the specific mechanisms and algorithms are not provided.

Some specific compensation algorithms are put forward to achieve the compensation for the outage area by adjusting the pilot power, the uplink target received power and other parameters of surrounding cells (M. Amirijoo L. J., 2009) (M. Amirijoo L. J., 2011) (Wenjing Li, 2012) (Chernogorov, 2015) (Li F. Q., 2011). Initially a centralized compensation mechanism and a heuristic algorithm are proposed to adjust the power of neighbouring antennas (Wenjing Li, 2012). The same authors of (Wenjing Li, 2012) in a more recently (Li, Yu, Yin, & Meng, 2015) have suggested use of distributed mechanism in compensation.

Some studies have generated and tested an algorithm for COC.

Figure 2.6: Compensation of a Homogeneous Network 1

and Figure 2.7 shows the simulation results done in studies (Li, Yu, Yin, & Meng, 2015) and (Chernogorov, 2015) respectively. As seen, the simulations use a seven cells cluster to test the compensation with a significant improvement in signal level when the failed cell is compensated by zooming the neighbouring cells. However, the algorithm zooms all the sectors in the compensating cells which is an unnecessary waste of power.

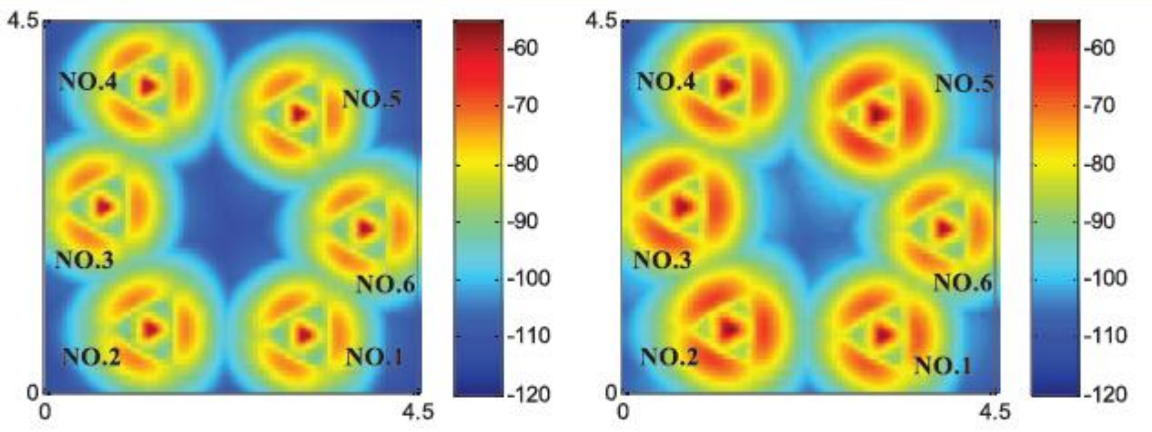


Figure 2.6: Compensation of a Homogeneous Network 1

In Figure 2.6, the cluster is made up of seven cells. The diagram to the left shows the network wuth the seventh cell failed while the one to the right shows the cluster after the compensation has been applied by zooming the six neighbouring cells. There is an indication of improvement in the signal level as the colour changes from dark to light blue as a result of compensation

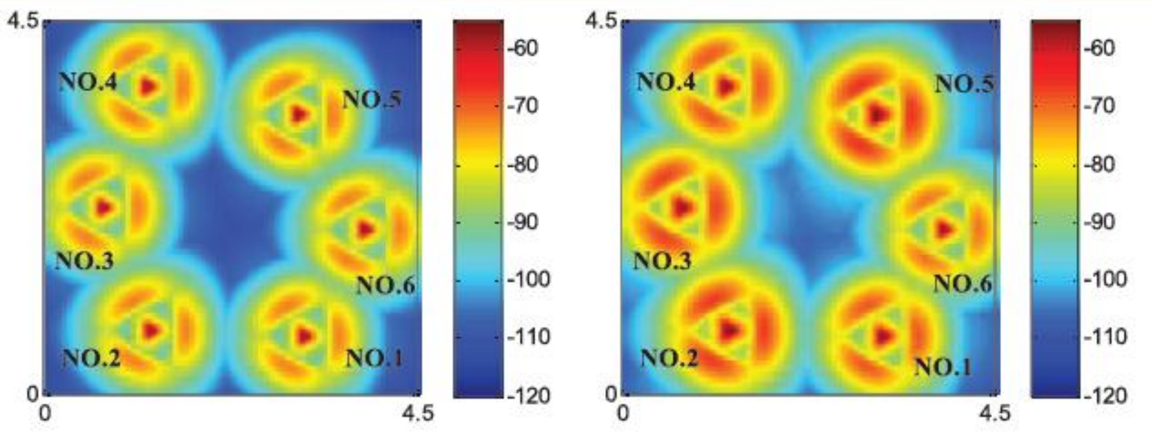


Figure 2.6: Compensation of a Homogeneous Network 1

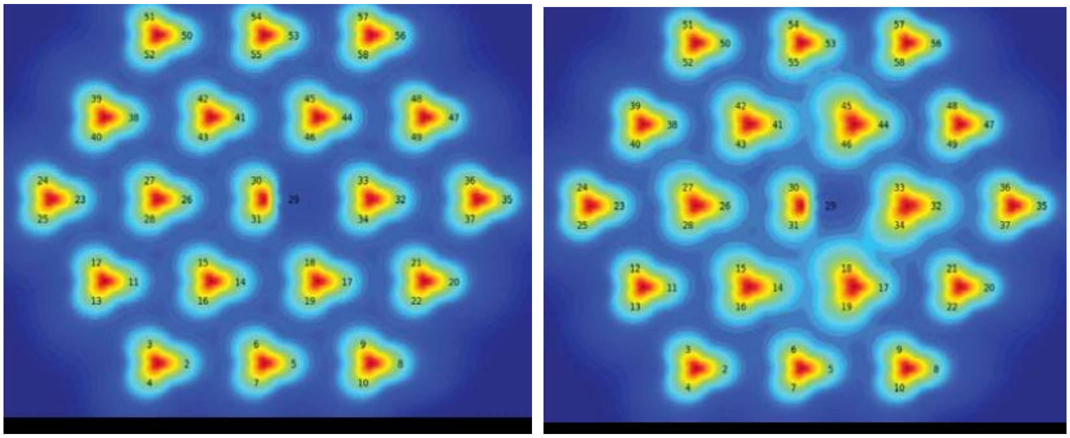


Figure 2.7: Compensation of a Homogeneous Network 2

Figure 2.7 shows 20 cells with the inner 7 cells making a cluster. The central cell has sectors 29, 30 and 31 but sector 29 has failed. The normal signal levels are indicated on the left diagram. In the diagram on the right (Figure 2.7), compensation for the failed sector has been done by zooming all the cells surrounding the cell with the failed sector

2.10 Gap in the existing studies

The main weaknesses of these studies are

- The zooming is done in all the neighbouring cells and sectors. This is not optimal as some of the sectors pointing in the opposite direction to the failed cell do not contribute to improvement of the coverage. This leads wasted energy
- These studies do not test the functionality of the algorithm using actual data and thus they do not stand the test of time.

This research intended to improve on the flows of these studies by showing that compensation can be implemented by zooming only three sectors out of the eighteen thus contributing to saving in power. This study has also been carried out using theoretical and actual data to improve on the weaknesses of the previous studies.

CHAPTER THREE

METHODOLOGY

3.1 Development of the algorithm

The key requirement for this algorithm was to solve the Okumura-Hata path loss equations on section 2.4.1. This helped solve for the maximum allowable path loss and hence the coverage distance. For the compensation, the algorithm needed to provide either the new *EIRP* requirement or the new BS height.

Thus, a modular approach was adopted and the flow chart in **Error! Reference source ot found.** summarizes how the algorithm works

3.1.1 Solving for coverage distance

Equation (2.4) is used to calculate the maximum allowable distance as follows

$$\mathrm{d} = \mathrm{antilog}\ \frac{\mathrm{PL} - \ \mathrm{A} - \mathrm{C}}{\mathrm{B}} \tag{3.1}$$

The value obtained from equation (3.1) was used to calculate the coverage radius for specific path loss. The expanded version after substituting the values of *A* (from equation (2.5)), *B* (from equation (2.6)) and *C* (=0) as given in section 2.4.1 gives the value of *d* as equal to:-

$$d = antilog(\frac{PL - 69.55\ +\ (26.16\ *\ Log(f\_c)\,)\ -\ (13.82\ *\ Log(h_b) - a(h_m))}{44.9 - 6.55\log(h_b)}) \tag{3.2}$$

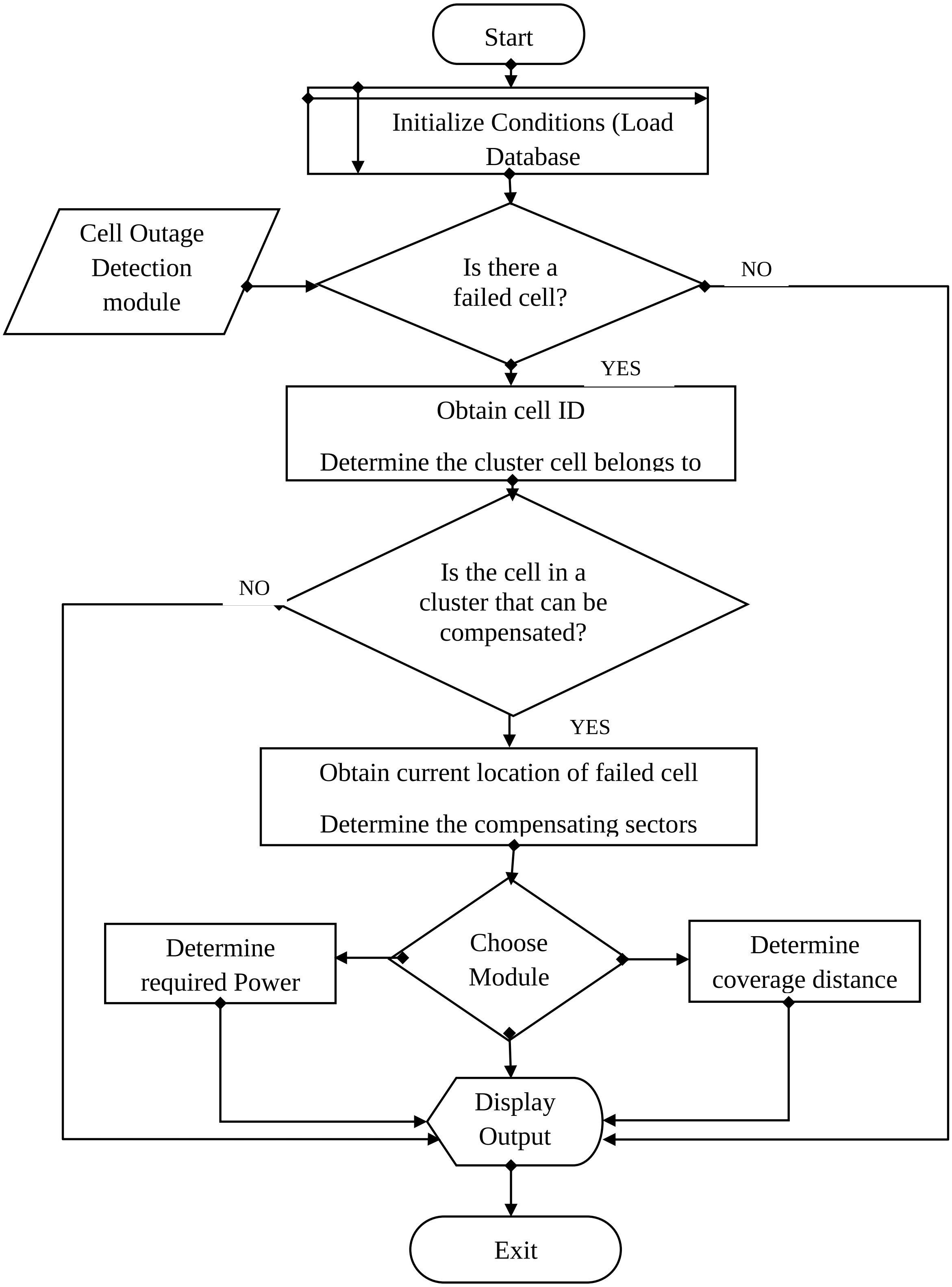


Figure 3.1: Algorithms Flow Chart

3.1.2 Solving for BS height and transmitter power

By use of equation (2.4) the height of the base station can be estimated as shown on equation (3.3). The values

$$(h_b) = \text{antilog}\left(\frac{69.55 + 26.16\log(f_c) - a(h_m) + 44.9\log(d) - PL}{(13.82 + 6.55\log(d))}\right) \tag{3.3}$$

Therefore, for known values of Maximum Allowable Path Loss and coverage distance, the height of the base station was evaluated using this formula.

Using equation (2.2) target RSSI is set for a specific distance. MAPL can be calculated as already shown.

3.1.3 Testing the algorithm

To verify the consistency of the algorithm the following graphs were generated and compared to others that have been done in other research

- Relationship Between Height of Transmitter and Path Loss
- Relationship between required *EIRP* and required BS height for varying coverage distance

The test run done on the algorithm was set to MS height of 7.5m and a frequency of 2GHz. The algorithm was set to generate plots of path loss for transmitter height of 10, 20, 40 and 100 meters for a coverage distance of up to 2km.

3.2 Simulation

Four simulations were considered for this research and parameters used assumed a small city region. Hence the algorithm and the simulator were tuned to specifications of the small city conditions using Okumura-Hata propagation model. The algorithm provided the required adjustment values that were fed on the simulator to view the simulation.

3.2.1 Homogeneous single sector, 7 cells cluster network

A homogeneous network is a network which all parameters are uniform. A homogenous network is more of a theoretical network that assumes a cluster which has even distribution of cells in the cluster, all antennas are at the same height, the traffic is evenly distributed, the cells are of equal capacity and the terrain is ideal.

Two types of homogenous networks were considered: 3 sector cell and 1 sector cell. For each of the networks the following process was carried out and the results recorded in the result chapter.

Table 3.1: Simulation parameters

PARAMETER	**VALUE**
Target RSSI	-90dBm
EIRP	60dBm
MAPL	150dBm
Mobile station antenna height (h_b)	1.8m
Base station height (h_m)	35m
Frequency (f_{MHz})	900
Propagation Model	Okumura-Hata (Medium & small city)

With these settings, the algorithm gave a separation distance of 5.3km which for simulation purposes was approximated to 5km.

By use of iterative means the value of 1.8m the mobile station height was found to give the best fit

- **Step 1:** A healthy condition of the network was simulated using the parameters on Table 3.1 and recorded
- **Step 2:** A target cell was switched off to simulate fault in the model
- **Step 3:** This fault was assumed to trigger the compensation process which obtain the status of the healthy cells to determine the amount of compensation each cell can contribute to the failed cell.
- **Step 4:** Cell compensation was done by adjusting the power level or the height of the neighbouring cells as per the calculated weights
- **Step 5:** The effect of the compensation on the radio coverage was recorded.
- **Step 6:** The fault cell was ‘repaired’ and a reversal to normal condition is gradually implemented to prevent interruption of service or ‘shocking’ the repaired cell. This is an assumption in consideration of what should be done in a live environment

3.2.2 Homogeneous 3 sectored, 7 cells cluster system

Compensation of a 3 sectored cell is a bit different from that of an omnidirectional antenna because of the signal distribution in such an antenna. While the pattern of an omnidirectional antenna is circular, that of 3 sectored cells is best represented using an equilateral triangle.

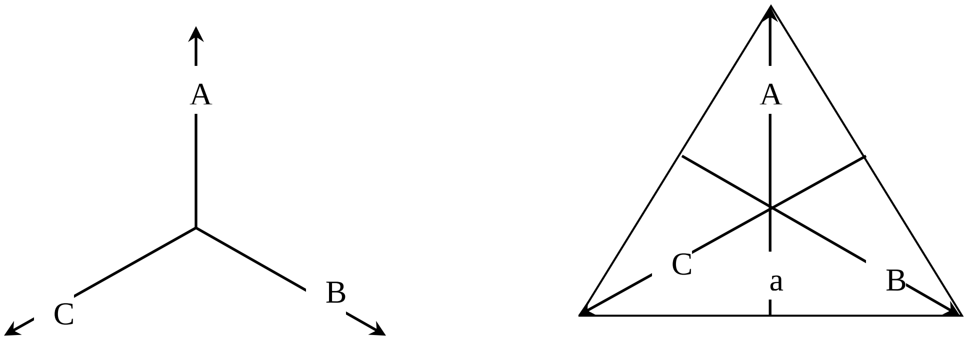


Figure 3.2: Representation of a 3 sector signal

Referring to Figure 3.2, it can be shown mathematically that the ratio A: a is 2:1. Thus during compensation, only a half extra distance is to be compensated for. In this case compensation was achieved by multiplying the distance of the healthy cell by 1.5 to get the compensation distance. Thereafter, steps 1 to 6 in page 31 above were followed in the simulations

3.2.3 Non-homogeneous network

This network was set up such that the cells are evenly distributed in an ideal environment but the antenna height and power were not equal. However, calculations were done to ensure a healthy network conditions is achieved. A healthy condition in this case meant all the antennas are able to cover the same distance which required balancing between power and antenna height in relation to path loss. Therefore, despite the varying height and power, each antenna was set to be able to have a coverage distance of 5km. Nevertheless, cells A, E and F as appearing in Table 4.9 are not affected during compensation and thus their parameters were left as default. Results of the compensation for a three sectored cell cluster are shown in Results of the compensation for a three sectored cell cluster are shown in Figure 4.11 and Figure 4.12

Table 4.8 has ideal settings that were calculated and used to simulate a healthy network. Steps 2 to 6 were then followed for the other simulations. The distance was changed from 5 to 7.5 km during compensation. This adjustment was made to specific sectors of the candidate cells.

3.2.4 Simulation using actual network data

Data for cells around Juja town were provided by Safaricom. The information included all required parameters and is annexed as APPENDIX 6 and APPENDIX 7. This information was used for simulations by following steps 2 to 6 above and recording the results.

3.3 Traffic Trends Analysis

To show the environment under which compensation can be applied, the following analyses were carried out.

- The busy hour call attempts plot for sites around JKUAT from 1st October 2013 to January 11th 2014 in APPENDIX 3: Busy Hour Traffic Data was provided but only the truncated version of up to November 28th 2013 was considered because the data includes traffic for 29th November when there was graduation and the traffic was way beyond capacity and it is seen even the Cell On Wheel (COW) that was introduced did little to contain the extra load. The other traffic which is a little out of pattern is that from 20th December and January 4th when the university was closed and therefore a significant source of traffic was not present.

- One Week Hourly Traffic trend was plotted using the data on APPENDIX 4
- Busy Day Hourly Traffic trend was obtained by plotting the data on APPENDIX 5

CHAPTER FOUR

SIMULATION RESULTS ANALYSIS AND DISCUSSION

4.1 Algorithm test

From link budget calculation equation (2.2) the values of *RSSI* was set -105dBm and margin of 10dBm was allowed for good call quality. This gave

$$MAPL = EIRP + 95dBm \tag{4.1}$$

Two approaches were considered for solving equation (4.1). One is by fixing the *EIRP* to 60dBm and calculating the cell radius for the two frequencies bands of 900 and 1800 MHz and the second one was by fixing the radius and then calculating the *EIRP*.

From equation (4.1) and setting the *EIRP* to 60dBm

MAPL = 60dBm +95dBm =155dBm=*PL*

To solve for *PL* the parameters on Table 4.1 were considered as well application of equation (2.3)

Table 4.1: Table of Path Loss Parameter Values

PARAMETER	**VALUE**
Target Received Signal Levels	-105dBm
Loss margin	10dBm
Antenna Gain	17dBi
Cable losses	10dBm
Mobile station antenna height (h_m)	1.5m
Base station height (h_b)	35m
Frequency (f_{MHz})	900/1800

Values of C were calculated and recorded on Table 4.2 below using equations on sections 2.4.1

Table 4.2: Calculated values of C for different environments

AREA	**C calculation formula**	C for 900MHz	C for 1800MHz
Open/Rural	$-4.78\,[log(f_c)]^2 + 18.33log(f_c) - 40.98$	-28.55	-31.96
Suburban	$-2\left[log\left(\frac{f_c}{28}\right)\right]^2 - 5.4$	-9.94	-11.94
Small city Large city	0	0	0

Values of $a(h_m)$ were calculated using section 2.4.1 and recorded in Table 4.3 below

Table 4.3: Values of $a(h_m)$

AREA	$\mathbf{a(h_m)}$	$\mathbf{a(h_m}$ **)for 900 MHz**	$\mathbf{a(h_m)}$ **for 1800 MHz**
Large city	$3.2(\log(11.75h_m))^2 - 4.97$	$-9.19*10^{-4}$	$-9.19*10^{-4}$
Rural Suburban Small city Medium city	$(1.1Log10(f_{MHz}) - 0.7)h_m$ $- (1.56Log10(f_{MHz}) - 0.8)$	$15.88*10^{-3}$	$4.297*10^{-2}$

Using equation (2.4) and the values in Table 4.3, the values of A were tabulated in

Table 4.4 below

Table 4.4: Calculated values of A

AREA	900MHz	1800MHz
Large city Metropolitan	125.4949	133.3698
Rural Suburban Small city Medium city	125.4781	133.3259

The value of B was calculated for an antenna height of 35m using equation (2.5)

B= 34.7894

Equation (3.2) was used to evaluate the values of d (coverage radius) for various environments and recorded on Table 4.5 and Table 4.6. *EIRP* of 60dBm was assumed and this gave PL of 155dBm

Table 4.5: Radius of cell for GSM900 in different environment

Area	**A**	**C**	**B**	**PL**	**(PL-A-C)/B**	**d (km) for 900MHz**
Open/Rural	125.478	-28.546	34.789	155	1.669137726	46.68
Suburban	125.478	-9.9426	34.789	155	1.134382887	13.63
Small city	125.478	0	34.789	155	0.848588938	7.05
Large city/ Metropolitan	125.495	0	34.789	155	0.848106032	7.04

Table 4.6: Radius of cell for GSM1800 in different environment

Area	**A**	**C**	**B**	**PL**	**(PL-A-C)/B**	**d (km) for 1800MHz**
Open/Rural	133.326	-31.96	34.789	155	1.541697088	34
Suburban	133.326	-11.94	34.789	155	0.966227831	9.25
Small city	133.326	0	34.789	155	0.623015896	4.19
Large city/ Metropolitan	133.37	0	34.789	155	0.621754003	4.18

These calculations were used to tune the algorithm to provide the correct figures

Figure 4.1 was the resultant plot generated by the algorithm for path loss against distance for various BS heights. This plot compared perfectly with Figure 4.2 from a study (Ephan & Gabriel) done on Kathrein antenna.

All the subsequent results from this algorithm were thus considered authentic.

Figure 4.3 below shows the relationship between *EIRP* and BS height for different coverage distance. For the same distance of coverage, increasing the BS height would mean lowering the *EIRP* and vice versa. For example, to cover 1km radius with RSSI of -90dBm the network can be set to *EIRP* of 30dBm and 80m high antenna or *EIRP* of 35dBm and 30m antenna. To double this coverage distance to 2km would mean adjusting the power or the height to values that are on 2km plot.

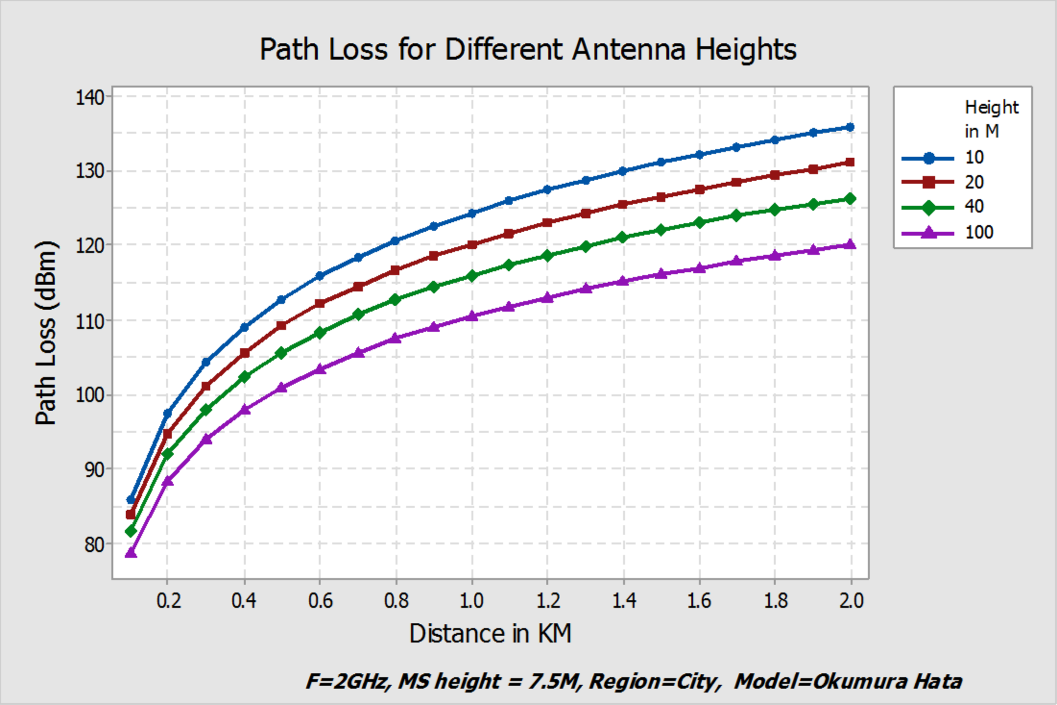


Figure 4.1: Relationship between path loss and Height of Transmitter as generated by the algorithm

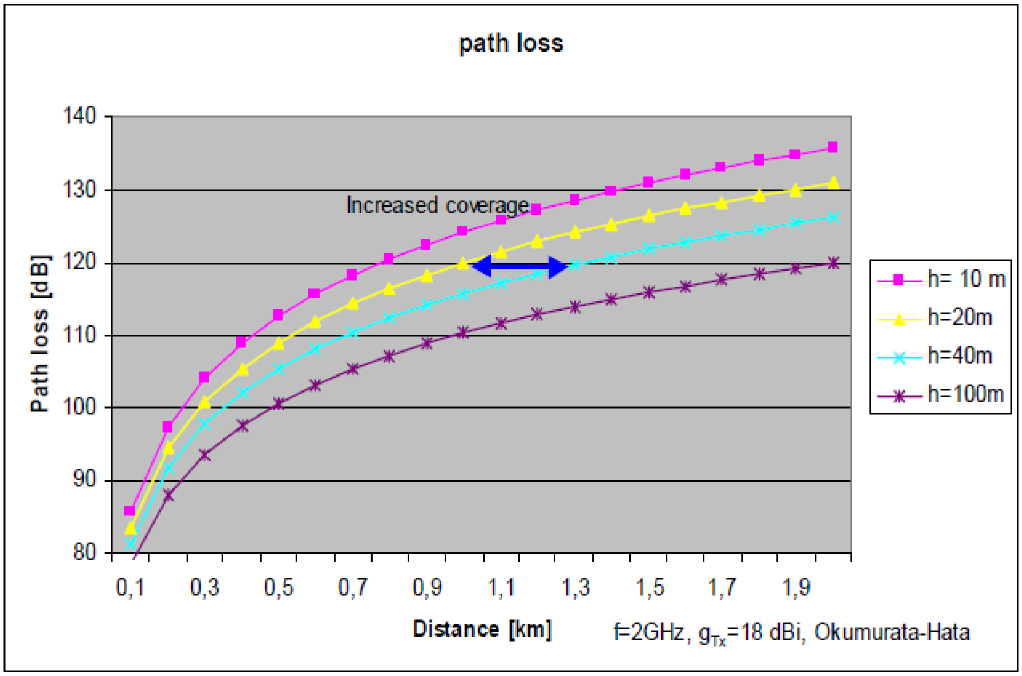


Figure 4.2: Relationship between path loss and Height of Transmitter as generated in a different study

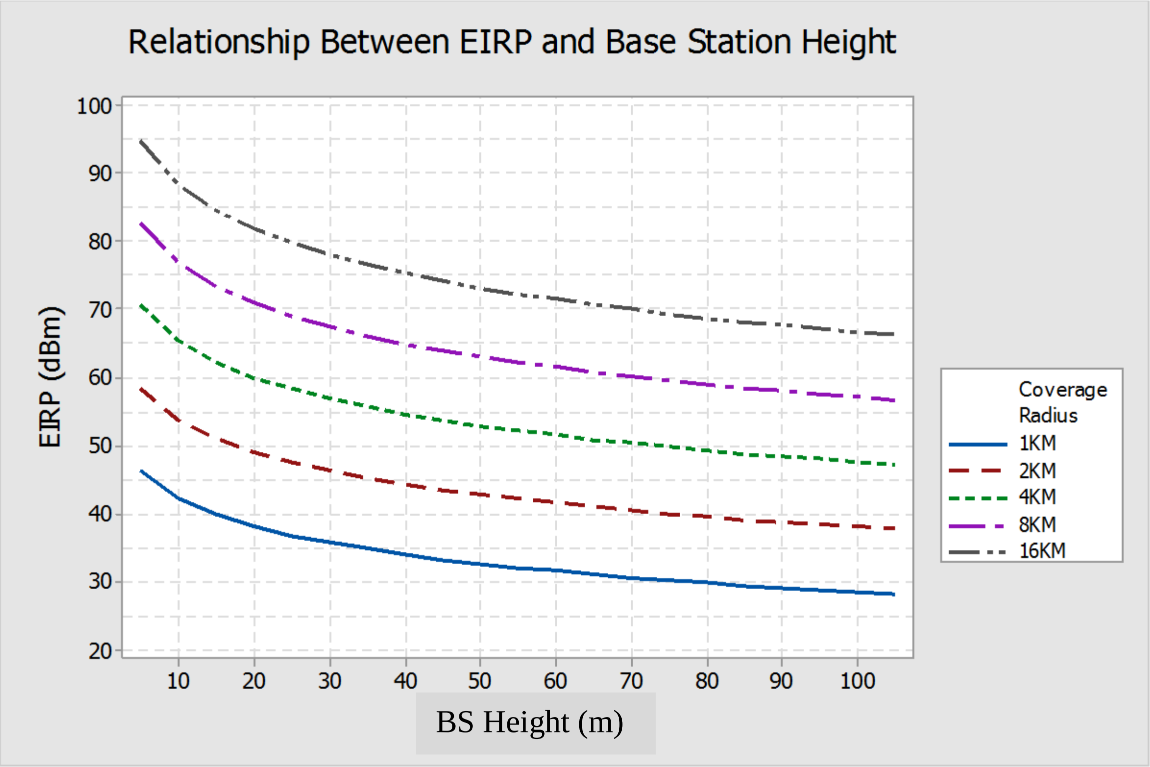


Figure 4.3: Required *EIRP* and BS height for various coverage distances

4.2 Simulations

This section contains the results of the simulations. The specific data used is provided or referred to in section 3.2. The simulations for the compensation using either BS height adjustment or *EIRP* adjustment gave the same output and therefore only one simulation representation was captured for both compensation cases.

4.2.1 Homogeneous single sectored 7 cells cluster

Table 4.7: Compensation values for single sectored configuration

	Before compensation	Compensation by height	Compensation by *EIRP*
Antenna height	35m	102m	35m
EIRP	60dBm	60 dBm	69.4dBm
Distance	5km	10km	10km

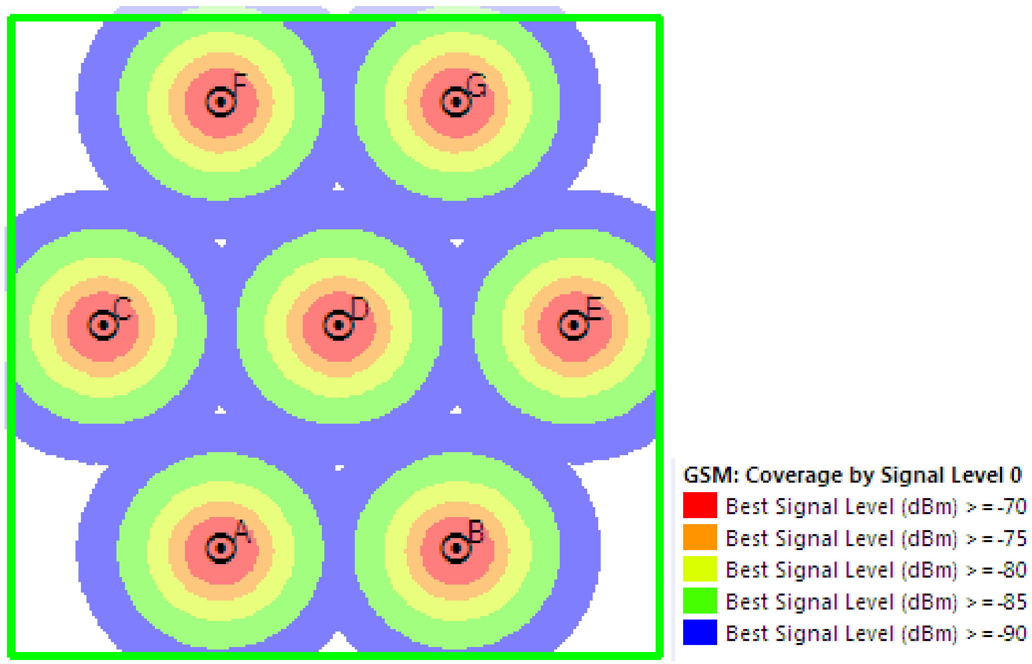
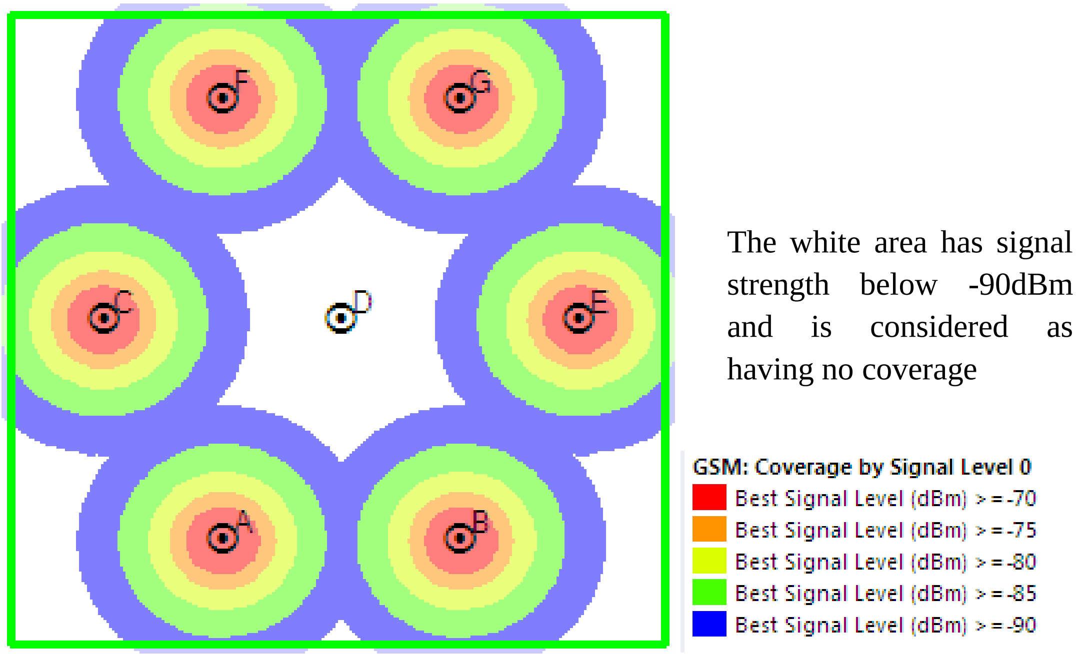


Figure 4.4: Coverage by Signal Level in Healthy Conditions for a homogenous single sectored cluster



The white area has signal strength below -90dBm and is considered as having no coverage

Figure 4.5: Coverage by Signal Level for a homogenous single sectored cluster after Cell D is switched off

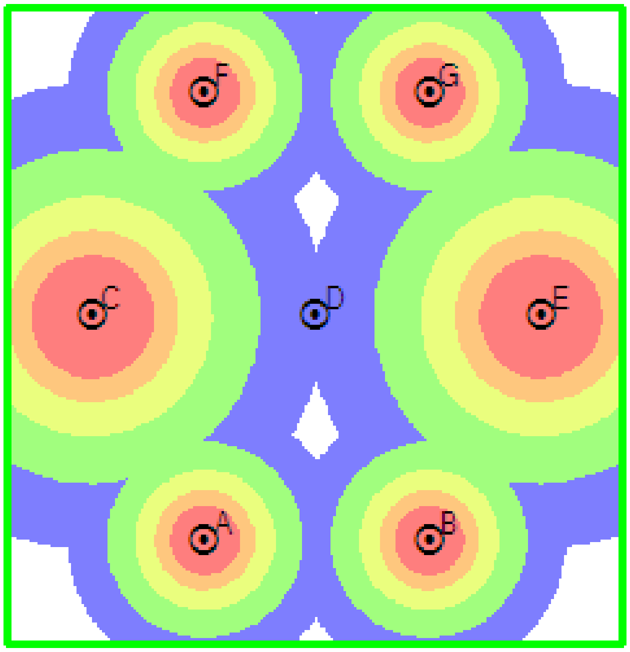


Figure 4.6: Coverage by Signal Level for a homogenous single sectored cluster after Cell D is switched off but with compensation using cell C and E

Note that irrespective of whether the adjustment is made by varying the power or the height as provided in Table 4.7, the output pattern is the same and therefore only one diagram was used to represent either. When the signal from the opposite sides of site D meets at the center of site D, some small region is left without coverage. This may be acceptable trade off depending on the acceptable threshold.

For the subsequent compensation using 3 and 6 cells, the area was fully covered. Therefore, a homogenous network needs at least 3 cells to adequately cover the area without overlapping the signal from the compensation cells. The more the cells the better because of traffic sharing, though it is possible to negate the benefit especially if the compensation is done by power adjustment as it has an operational cost tied to it.

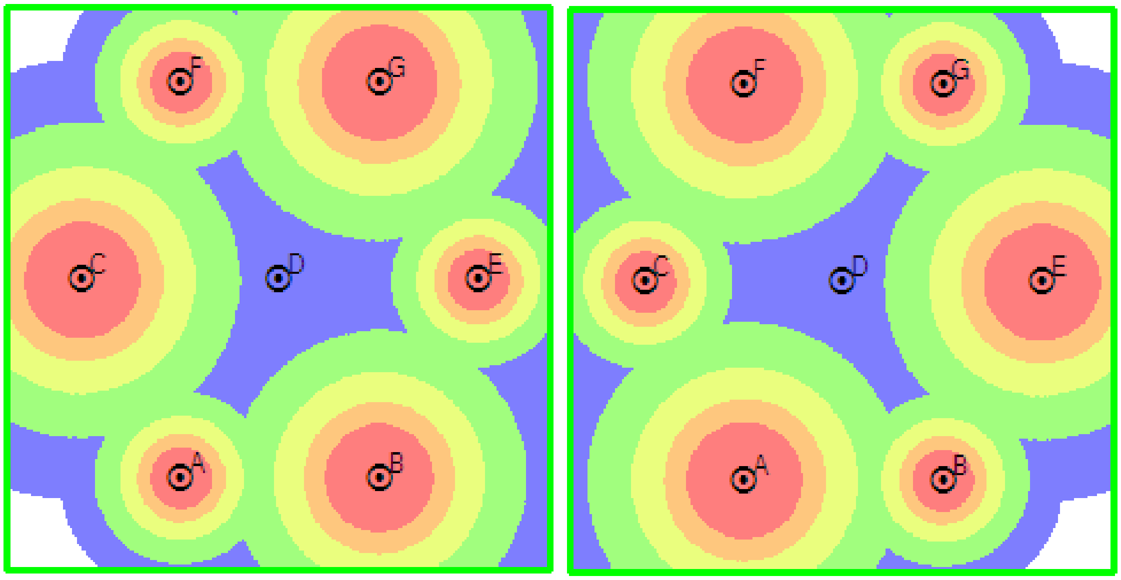


Figure 4.7: Compensation using 3 cells (B,C, G & A, E, F)

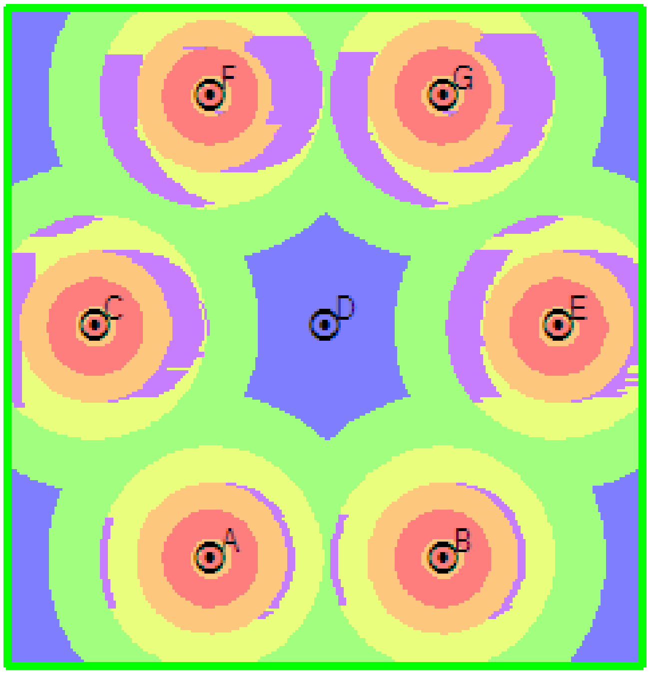


Figure 4.8: Compensation using all cells

Figure 4.7 and Figure 4.8 shows shat compensation by any 2 cells that are directly opposite each other adequately covers the area.

4.2.2 Homogeneous 3 sectored 7 cells cluster

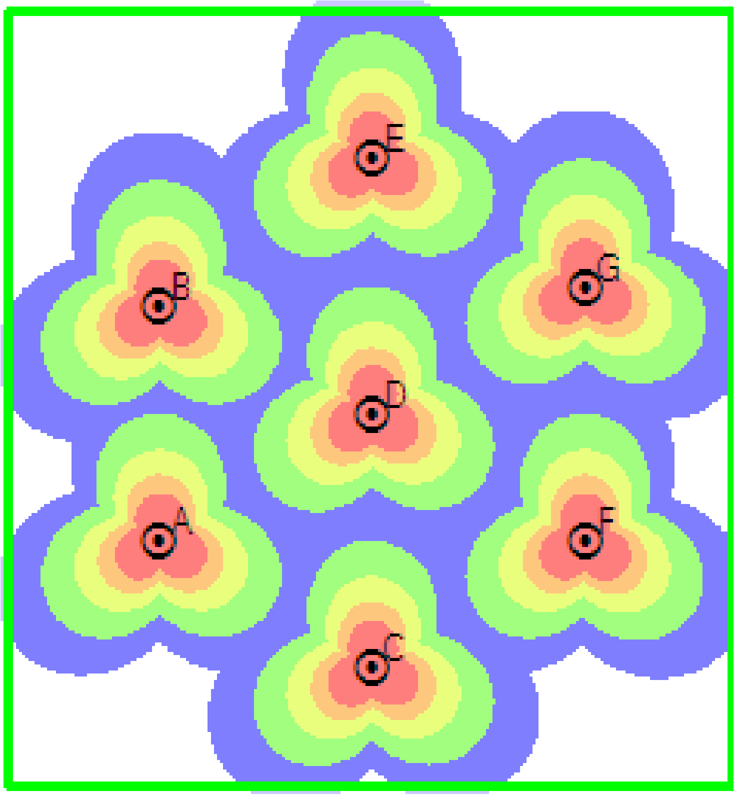


Figure 4.9: Coverage by Signal Level for a homogenous 3 sectored cluster

Results of the compensation for a three sectored cell cluster are shown in Figure 4.11 and Figure 4.12

Table 4.8: Compensation values for 3 sectored Configuration

	Before compensation	Compensation by height	Compensation by *EIRP*
Antenna height	35m	63.9m	35m
EIRP	60dBm	60dBm	65.1dBm
Distance	5km	7.5km	7.5km

From table Table 4.7 and Table 4.8 it is apparent that compensation by height adjustment is not practical. Building a mast to the height of 100 meters is extremely expensive compared to increasing power by 10dbm

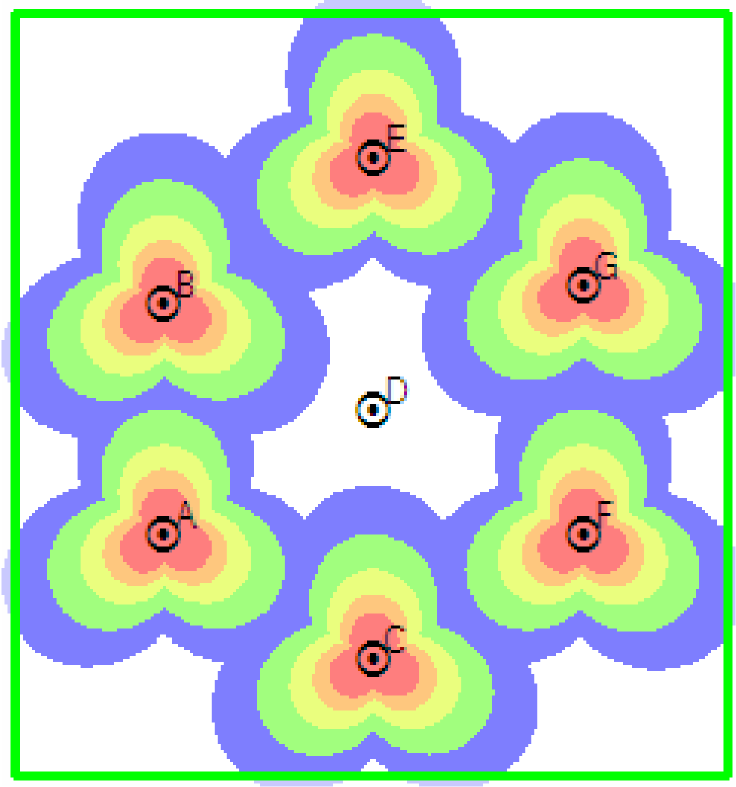


Figure 4.10: Coverage by Signal Level for a homogenous single sectored cluster after

Cell D is switched off

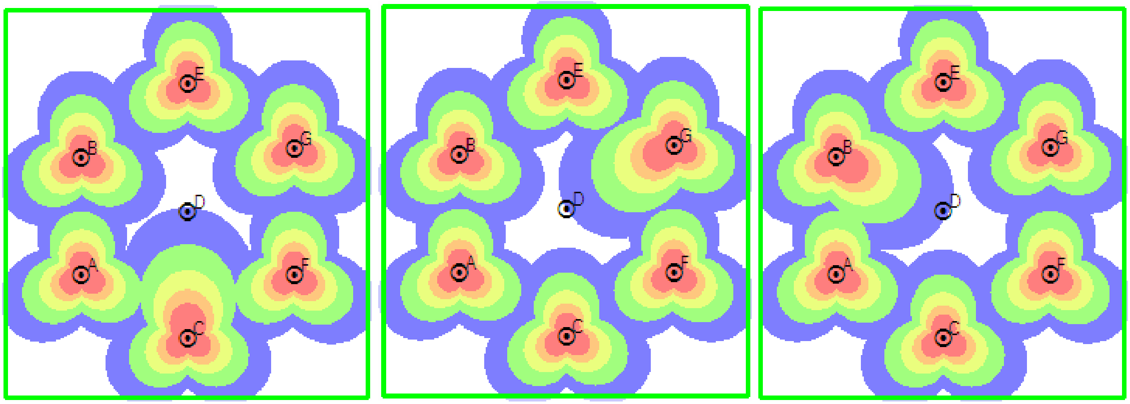


Figure 4.11: Compensation using cell C sector 0, cell G sector 240 & B sector 120

Figure 4.11 shows compensation effect of using each cell individually and that of the combine effect are shown in Figure 4.12. If the power or height is adjusted such that the target RSSI is at the center of cell D, then small pockets of lower RSSI are experienced as white spots within the coverage area

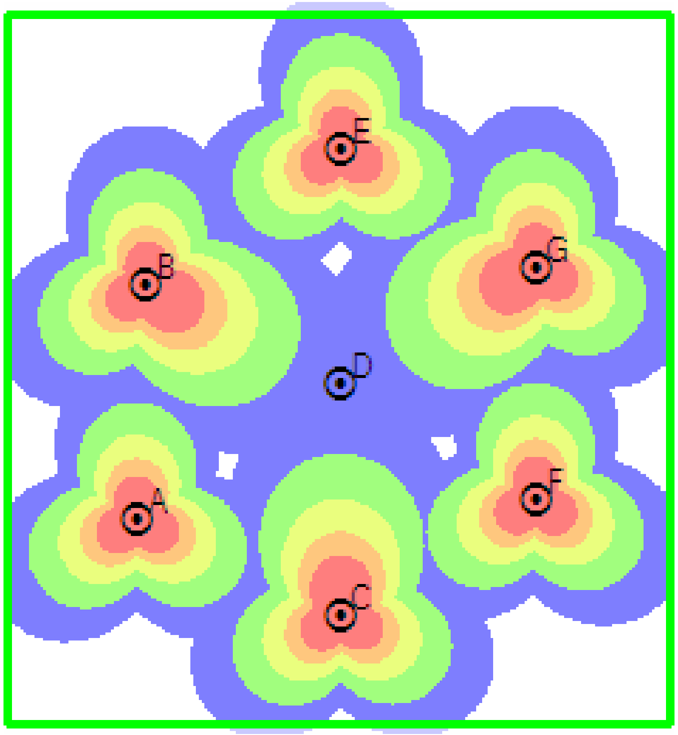


Figure 4.12: Coverage by Signal Level for a homogenous 3 sectored cluster after Cell D is switched off but with compensation using cells B, C & G

4.2.3 Non homogeneous equally spaced 3 sectored 7 cells cluster

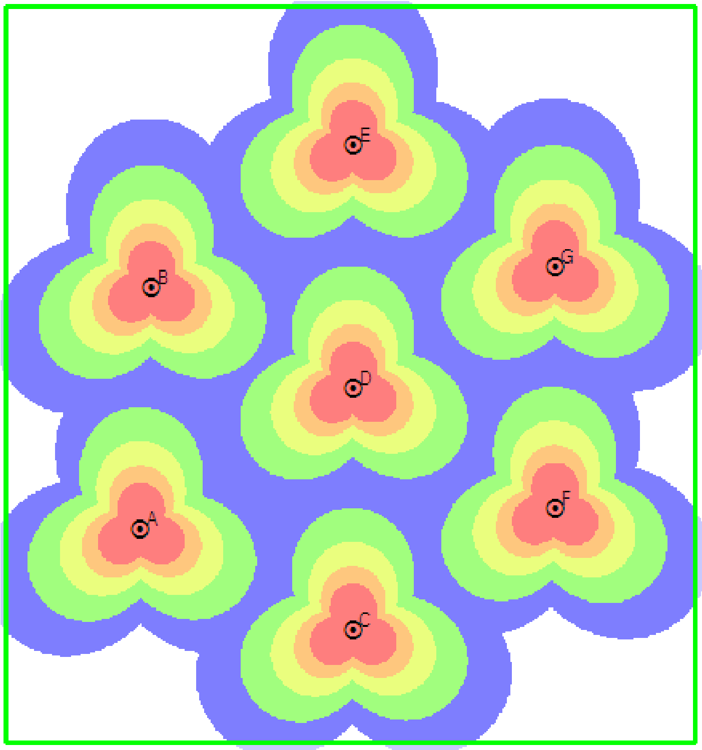


Figure 4.13: Non homogeneous 3 sectored 7 cells cluster healthy conditions

Table 4.9: Compensation values used for non-homogeneous network

	Before compensation		Compensation by height		Compensation by *EIRP*	
	EIRP	h_b	*EIRP*	h_b	*EIRP*	h_b
A	60	35	60	35	60	35
B	61.7	25	61.7	52.3	68	25
C	57.9	40	57.9	81.8	64	40
D	60	35	60	35	60	35
E	60	35	60	35	60	35
F	60	35	60	35	60	35
G	55.4	55	55.4	109.8	61.3	55

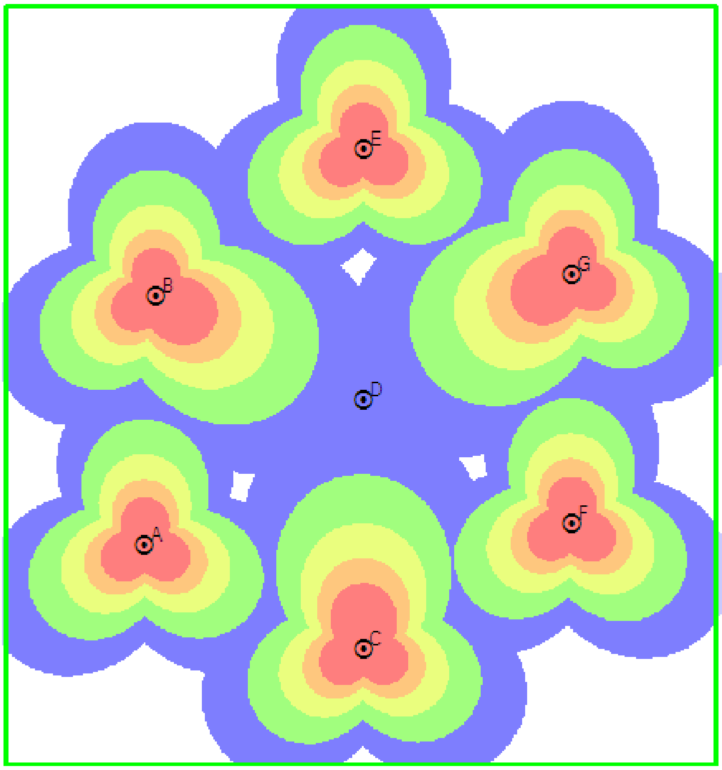


Figure 4.14: Non homogeneous 3 sectored 7 cells cluster after compensation using cells B, C & G

When the values on Table 4.9 were used the above compensation diagram was achieved. It is exactly as in Figure 4.12 because the antennas have been designed to cover the same area. The same case applies to the signal level distribution pattern after D has been switched off which duplicates that of Figure 4.10 above

These results compares well with Figure 4.15 (Chernogorov, 2015) and Figure 4.16 (Li, Yu, Yin, & Meng, 2015) show below. However, these algorithms increased power in all the sectors of the compensating cells as opposed to just 3 sectors of all the six healthy member of the cluster only. The simulation results given in Figure 4.7 and Figure 4.8 concluded that three cells can adequately compensate for a failed cell in the cluster. This is further supported by the results on Figure 4.12. It is thus a weakness in these studies to suggest increasing power in 18 sectors of the cluster for COC yet 3 cells can adequately cover the failed cell. In theory, the proposal in this report would reduce the extra power required by 6 time that suggested by other studies (Li, Yu, Yin, & Meng, 2015) , (Chernogorov, 2015).

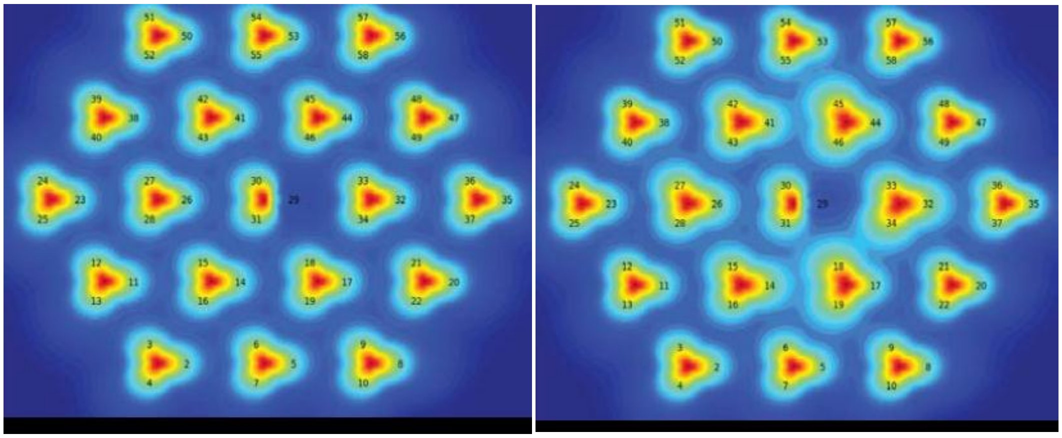


Figure 4.15: COC 1

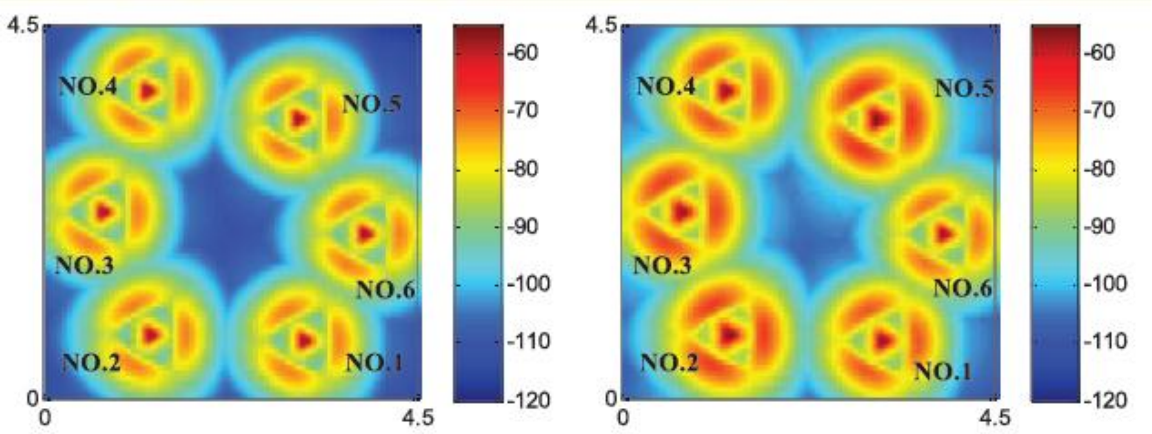


Figure 4.16: COC 2

4.2.4 Simulation using actual network data

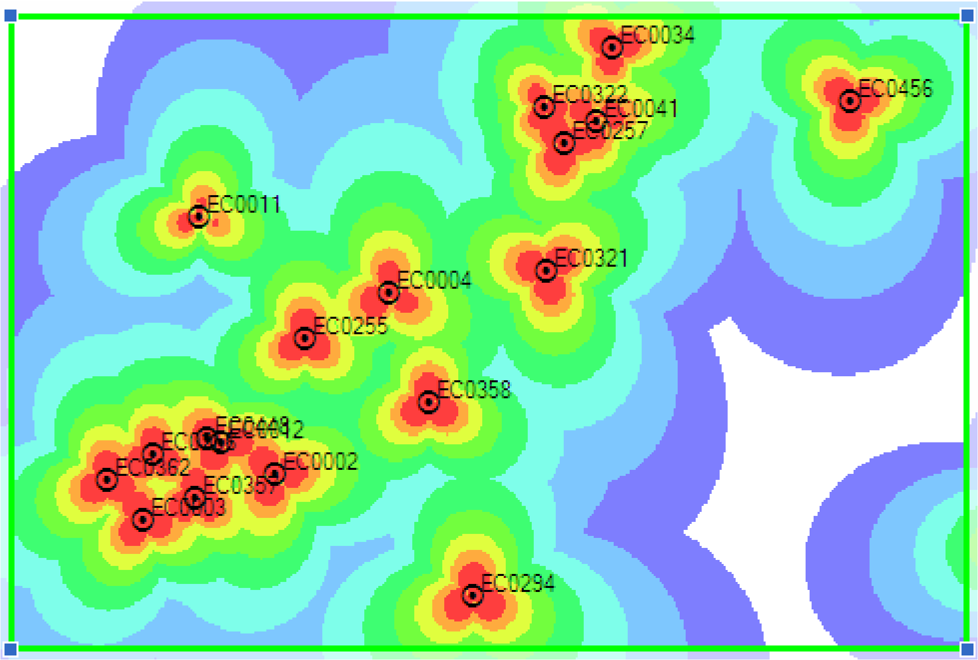


Figure 4.17: Signal Levels of Cells around Juja upto -105dBm RSSI

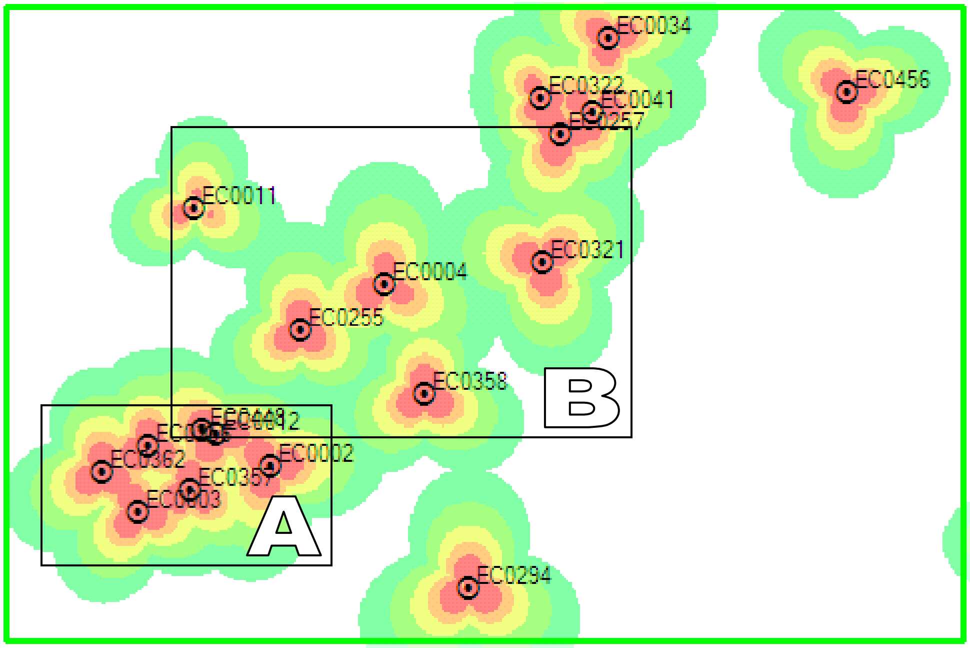


Figure 4.18: Signal Level of Cells around Juja upto -90dBm RSSI

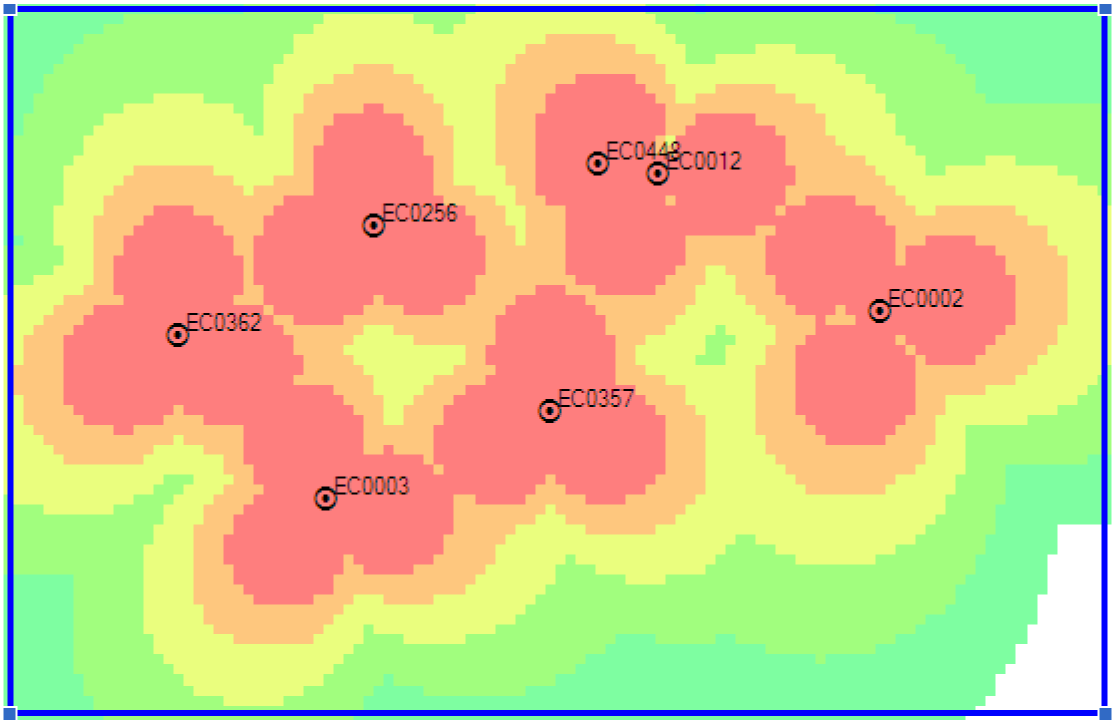


Figure 4.19: Close up for region A when healthy

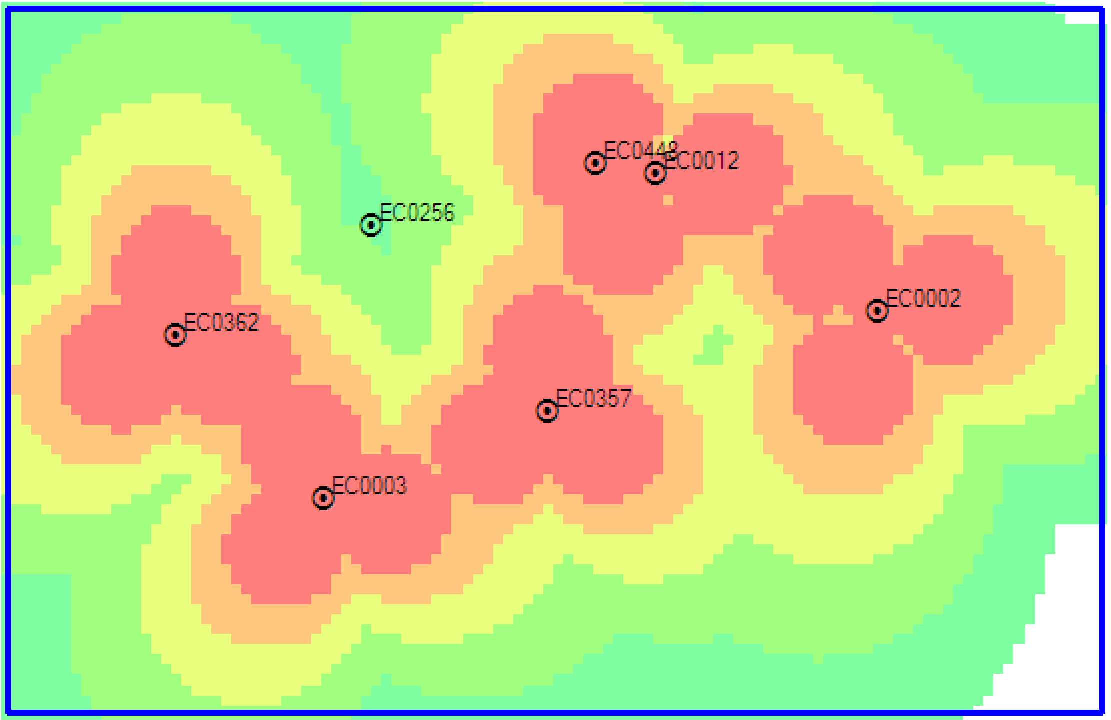


Figure 4.20: Region A with Cell EC0256 failed

Region A is a densely populated area with closely spaced radios which even with the failure of one cell, the received signal level is still high. Compensation for such a region is achievable only by ensuring that the trunk capacity for the neighbouring cells is enough to cover for the extra load.

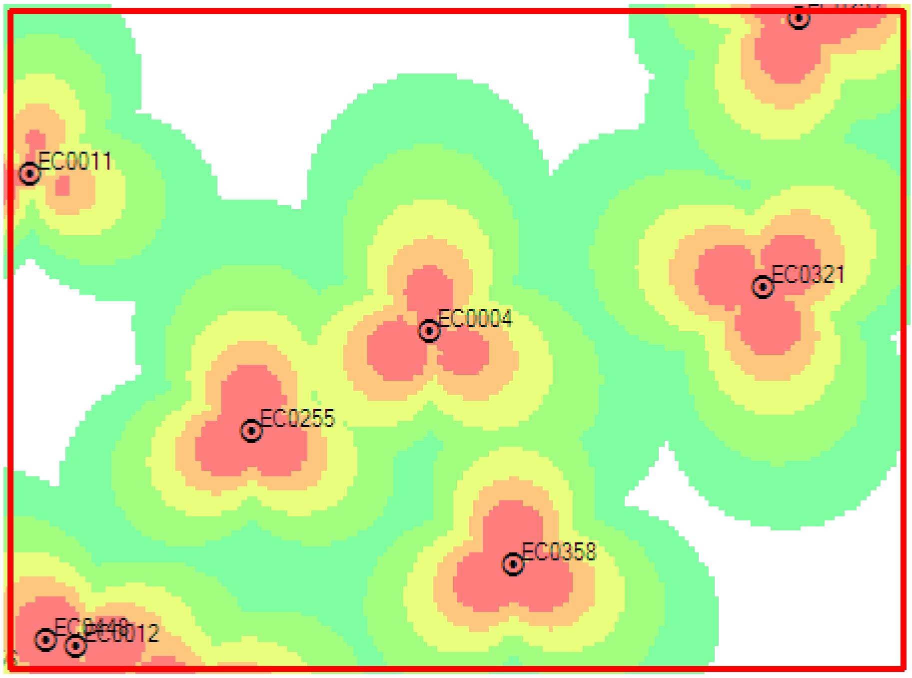


Figure 4.21: close-up for healthy region B

This is an example of an area with a relatively low density of radios. When cell EC0004 fails as shown in Figure 4.22 a significant area which was under the cell coverage is left with signal below the target RSSI necessitating compensation. Two cells were selected for compensation. Cell EC0321 sector 3, which is at an azimuth of 290° and cell EC0255 sector 1 at 0 azimuths. The power was increased for the two sectors from 57.3dBm to 62dBm *EIRP* and the azimuths changed from 290° to 270° and 0° to 30° respectively. This gave an acceptable compensation for the received signal level. However, use of only two sectors to compensate gives a huge load to the compensating cells. A huge reserve capacity will be required in the compensating cells in order to accommodate for the load. Nevertheless, it is not uncommon to have some cells that are of small capacity and their compensation can be adequately taken over by just one big cell. Figure 4.22 to Figure 4.25 demonstrate this compensation

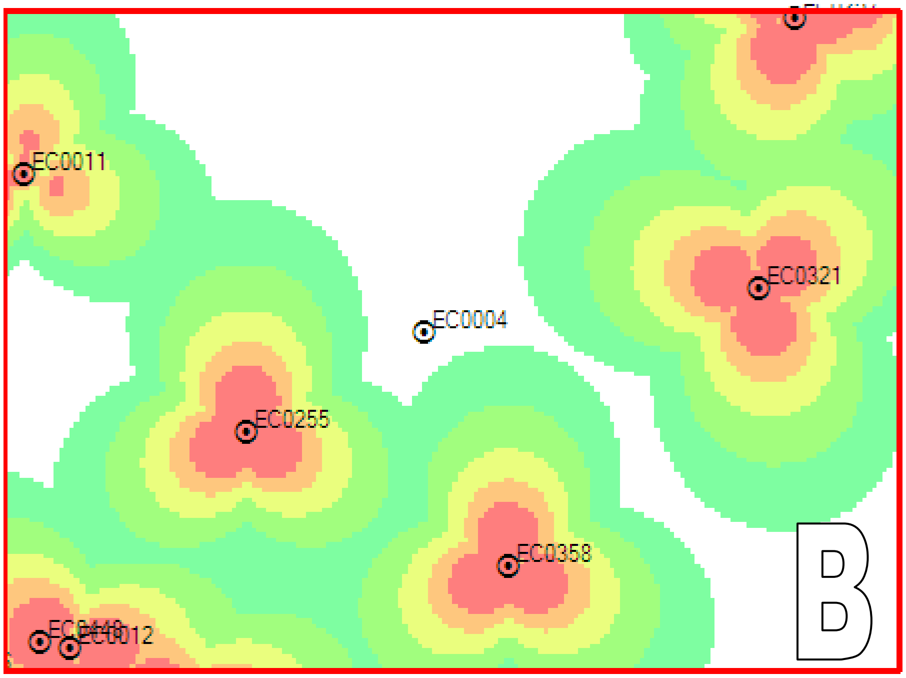


Figure 4.22: Close-up for region B with cell EC0004 Failed

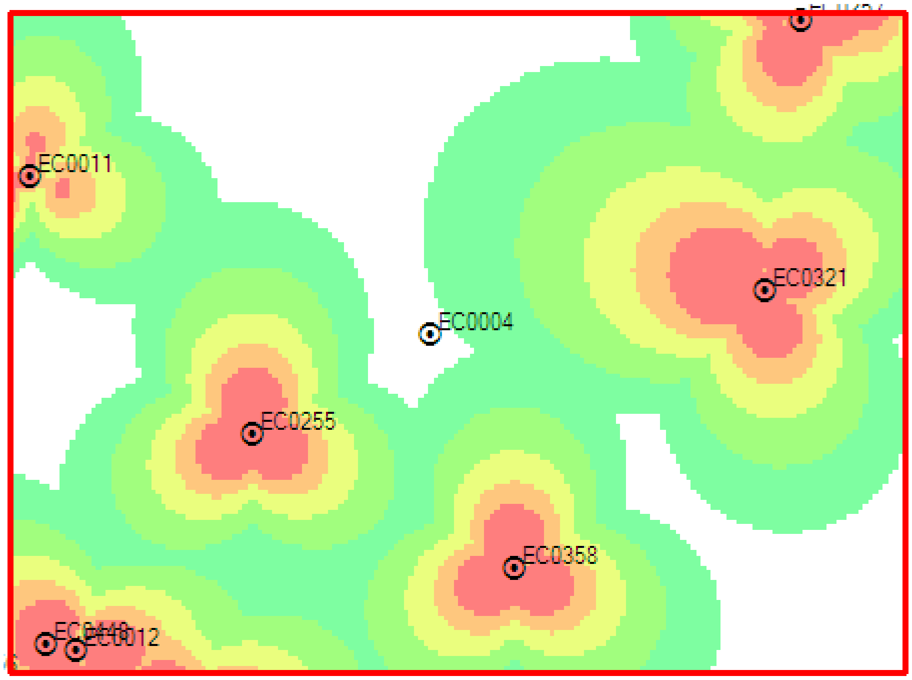


Figure 4.23: Compensation Using Cell EC0321 power adjustment

The *EIRP* Power on EC0321 changed from 57.3 to 62

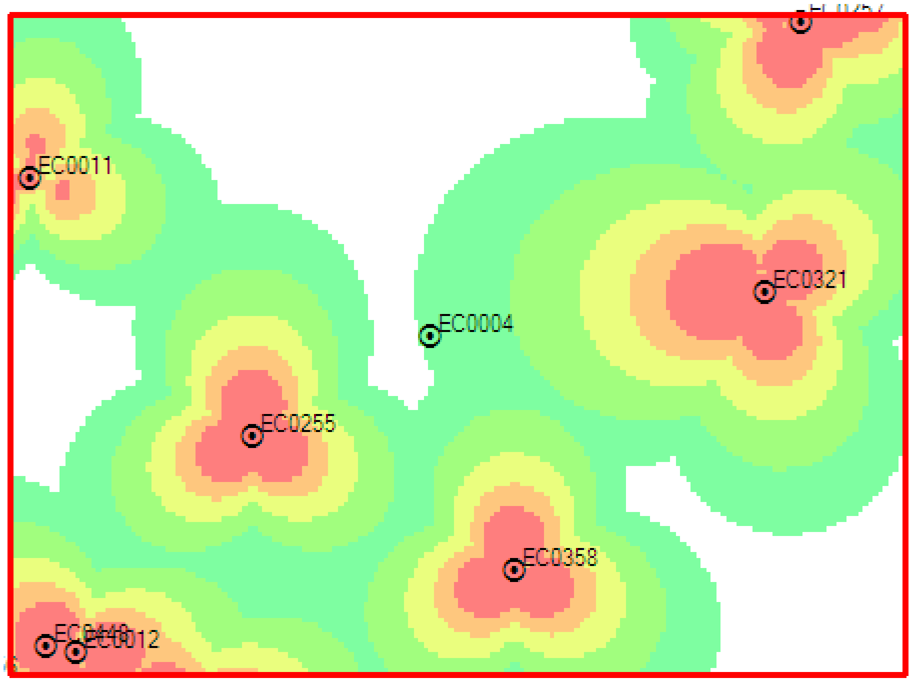


Figure 4.24: Additional compensation using azimuth

Azimuth of cell EC0321 changed from 290° to 270°

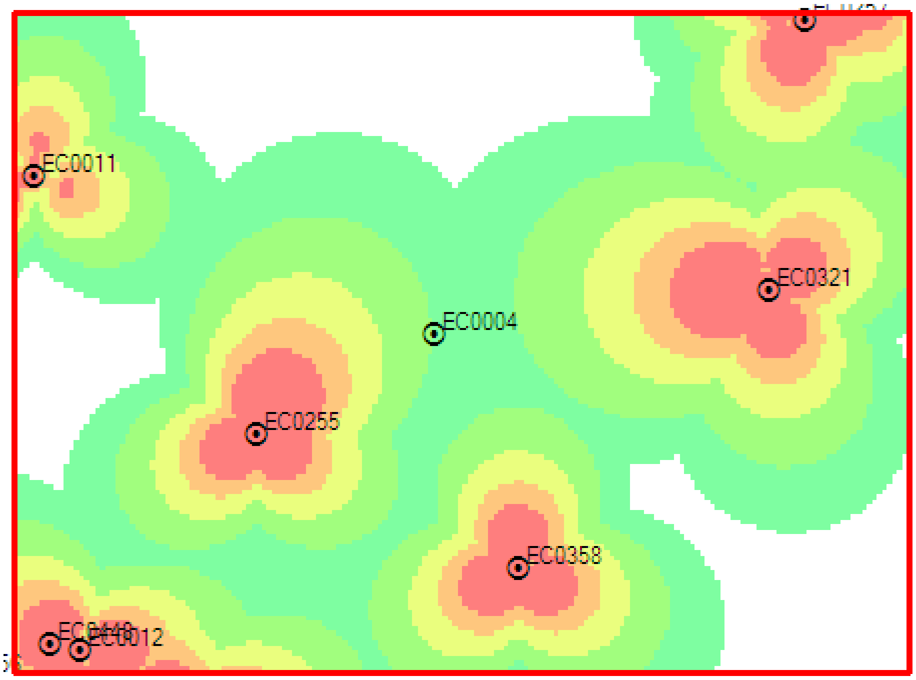


Figure 4.25: Additional compensation using cell EC0255

For cell EC0225 the power is changed from 57.3 to 62 and the azimuth from 0° to 30°

4.3 Traffic Trend

4.3.1 Busy hour trend

From below graphs, Figure 4.26 and Figure 4.27, these observations can be made:

- The traffic around Juja is predictable and uniform. A horizontal line can be drawn to represent the traffic for each site and the total traffic volume. The traffic is seen to begin at its lowest on weekends and gradually grows to a peaks on Fridays and then drops to its lowest again on weekends.
- Another good observation is that the peaks and troughs for the different sites seem to track each other. They follow the same pattern. When one goes high, the rest follow and vice versa. Thus, knowing the traffic trend for one site can give a representation of what is expected in other sites in the region

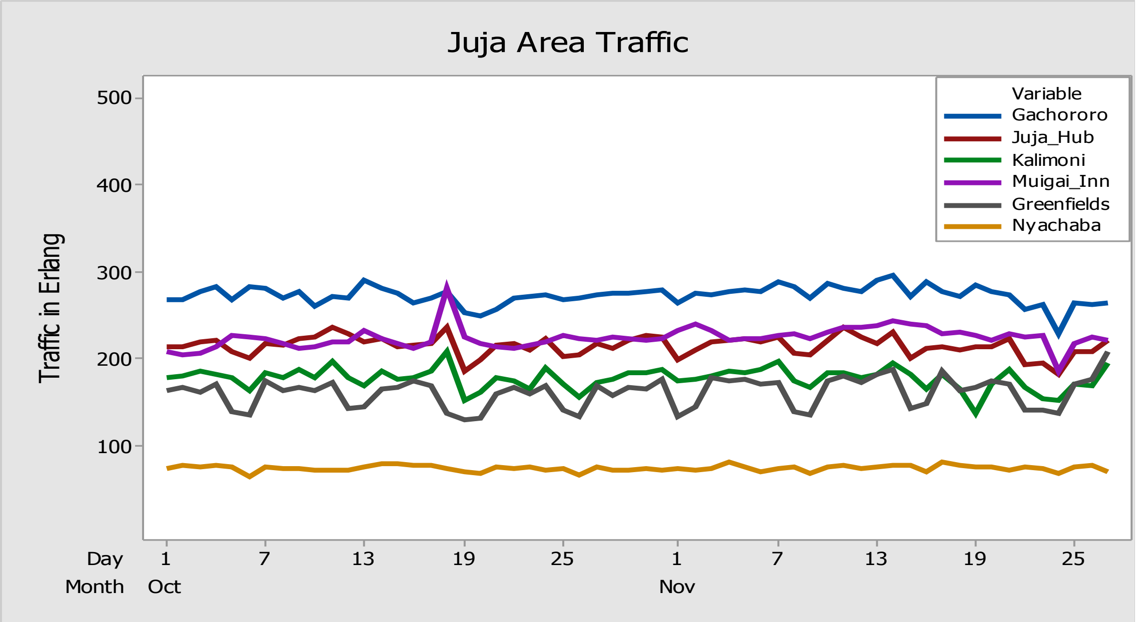


Figure 4.26: Graph of Busy Hour Traffic for Sites around JKUAT

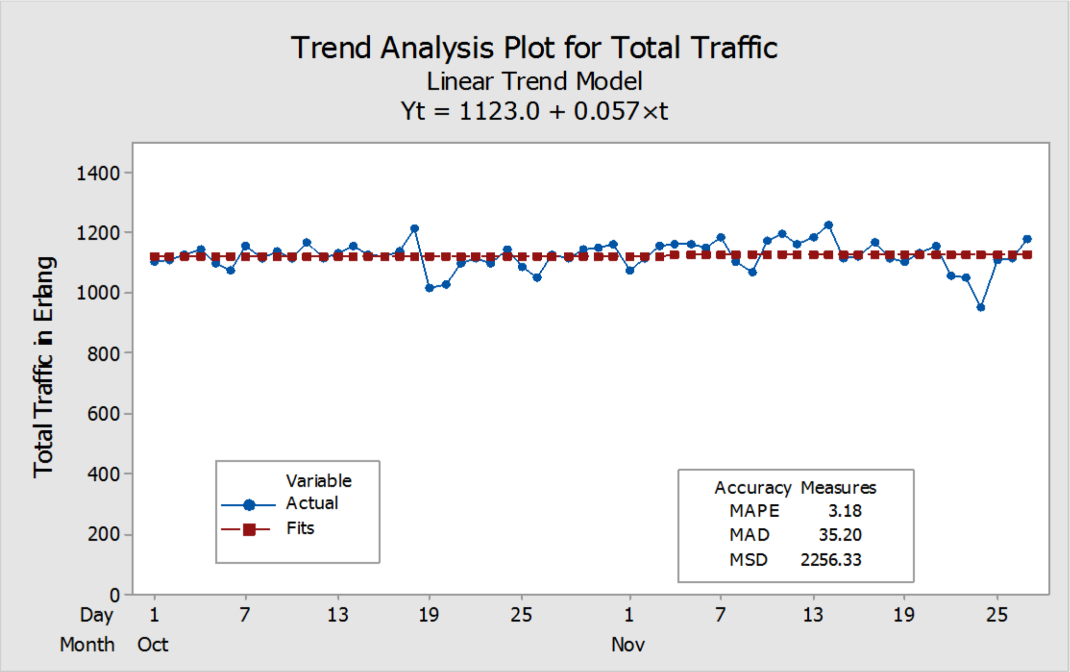


Figure 4.27: Trend for sum of busy hour traffic

4.3.2 Hourly traffic trend

The following analysis used hourly traffic data to generate the graphs.

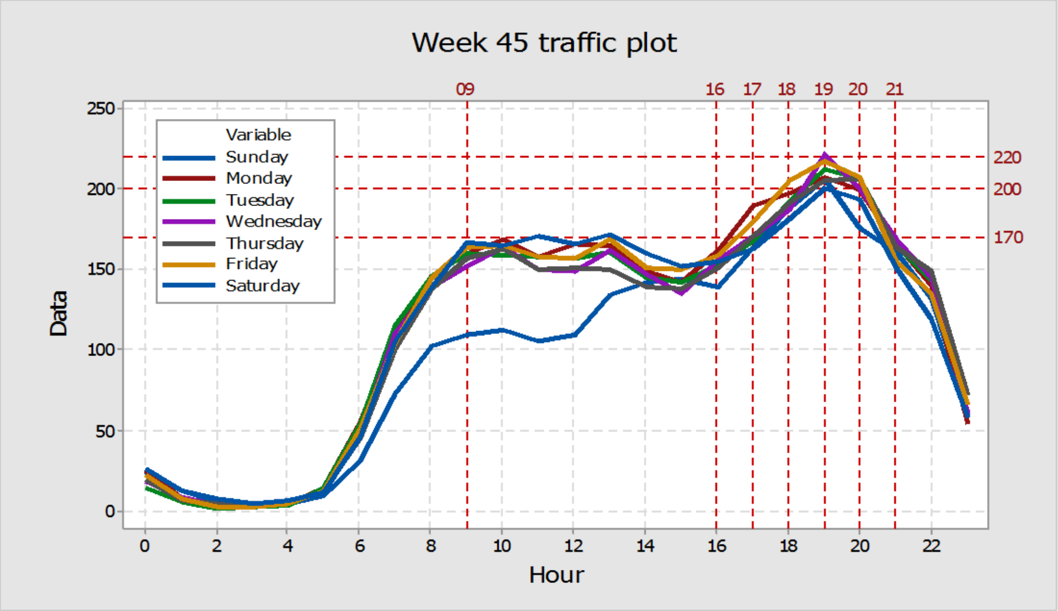


Figure 4.28: One week traffic plot

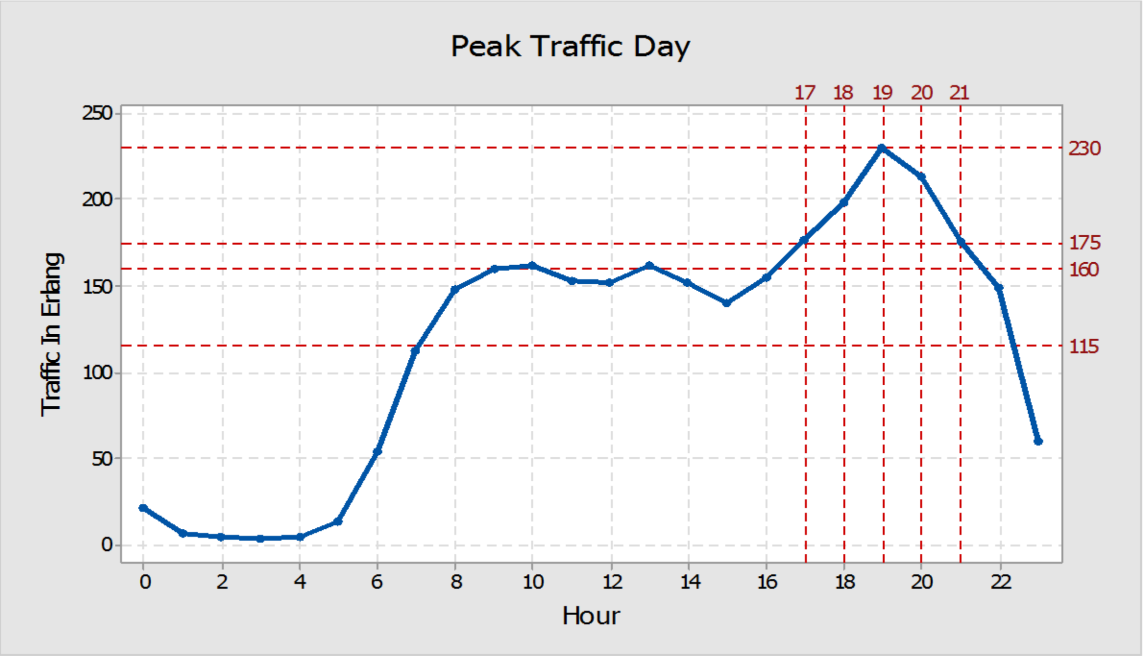


Figure 4.29: Busy day traffic plot

Figure 4.28 shows the traffic trend for different days in a week. Same trend was observed for other weeks. The traffic is below 25% from midnight to 5am where it grows to its first peak at 9 am. The next time traffic grows beyond the first peak is at 5 pm, reaches to peak at 7 pm and deeps to below 25% at midnight

Figure 4.29 gives a clearer plot as it represents just one day traffic. This was picked as the day with the highest traffic within the period of study. The graph shows that only 4 hours in a day have traffic above 170Erl which represents about 74% of peak traffic. Another observation is that only 2 hours have traffic above 200Erl. With the peak at 230Erl, this represents about 87% of peak traffic.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this work a self-healing radio network model has been developed and simulated. The simulation at different complexities shows that it is possible to implement this kind of network in practice. An actual network simulation was included by using actual data and this also agreed with theory. Though the study has concentrated on Okumura-Hata Propagation Model, it is worth noting that this model is one of the most complex in terms of the number of parameters to be solved. Hence, having found solutions for this study using Okumura-Hata model makes it easier for duplication of the study with other models.

The study shows how self-healing can be implemented by introducing compensation through cell zooming. Two methods of self-healing including height adjustment and power adjustment were considered and these gave good results. The results for the homogeneous networks tallied well with other studies in papers (Li, Yu, Yin, & Meng, 2015), (Chernogorov, 2015), (Ephan & Gabriel) .

The study included compensation scenarios for single sectored cell and a 3 sectored cell. It proved easier to compensate for 3 sectored scenario than a single sector since a single sectored cell required one and half as much power to compensate as compared to three sectored cell.

Unlike (Li, Yu, Yin, & Meng, 2015) and (Chernogorov, 2015) this study has also been carried out using data from an actual network and thus it’s a true heterogeneous network study. The study revealed that an actual network can be categorized into two regions according to the density of antennas. The much cluttered regions have high received signal levels and compensation should focus on additional capacity on the trunks. In a scattered area, the compensation can be achieved through neighbouring cells adjustment. However, consideration of power and height adjustment alone did not provide an optimal relief. Azimuth of the antenna proved to be a major player both to the success of the compensation as well as for maintaining the health of the unaffected cells.

The study also analyses traffic data which has demonstrated that there is actually no need to attend to fault in the middle of the night when utilization of capacity is below 25%. With at least 25% reserve capacity available in the network for 20 hours a day, it is possible to implement cell zooming without needing additional capacity during this period. However, during the 4 hours of high traffic, it can be proposed to use AMR-HR scheme to improve the capacity. In areas with good RF, AMR-HR has been found to double the radio capacity with a single TRX carrying upto 20Erl

Therefore, a compensation measure would adequately provide for capacity in any region without requiring the compensating cells to have reserve capacity.

However, in order to handle the extra traffic that results from the failed cells during the busy period, the study suggests provide some extra (reserve) capacity that should be calculated on an individual cell basis proportional to the traffic in the cluster.

The study objectives were thus met since a self-healing radio network model was developed and simulated. The algorithm developed also produced results that matched with those of international studies.

It’s worth noting that for cell zooming compensation method to maintain optimal characteristics, its various factors in Heighto.us Elecricfa aM eachaati aPt

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APPENDICES

APPENDIX 1: Algorithm

```
Private Sub CommandButton1_Click()

'Draw graph for testing accuracy of software

h_m = 7.5

f_c = 2000

E = (1.1 * Log(f_c) / 2.303 - 0.7) * h_m - (1.56 * Log(f_c) / 2.303 - 0.8)

C = 0

'C = (-4.78 * ((Log(f_c) / 2.303)) ^ 2) + (18.33 * (Log(f_c) / 2.303)) - 40.98

'C = -2 * (Log(f_c / 28) / 2.303) ^ 2 - 5.4


Dim j As Integer

For j = 1 To 4

Select Case j

Case 1

h_b = 10

Case 2

h_b = 20

Case 3

h_b = 40

Case 4

h_b = 100

End Select
```

```
d = 0.1

B = 44.9 - (6.55 * Log(h_b) / 2.303)

A= 69.55 + (26.16 * Log(f_c) / 2.303) - (13.82 * Log(h_b) / 2.303) - E


  Dim Counter As Integer

  For Counter = 2 To 22

    PL = a + B * Log(d) / 2.303 + C

    Worksheets("Test2").Cells(1, j + 1).Value = h_b

    Worksheets("Test2").Cells(Counter, 1).Value = d

    Worksheets("Test2").Cells(Counter, j + 1).Value = PL

    If j = 1 Then

    Worksheets("Test2").Cells(1, 1).Value = "Distance"

    Else

    End If

    d = d + 0.1

  Next Counter

Next j


End Sub

Private Sub CommandButton4_Click()

'Calculate coverage distance

f_c = 900

Dim PL As Double

Dim h_b As Double

PL = 150
```

```
h_m = 1.8

h_b = 35

E = (1.1 * Log(f_c) / 2.303 - 0.7) * h_m - (1.56 * Log(f_c) / 2.303 - 0.8)

C = 0

A = 69.55 + (26.16 * Log(f_c) / 2.303) - (13.82 * Log(h_b) / 2.303) - e

B = 44.9 - (6.55 * Log(h_b) / 2.303)


d = 10 ^ ((PL - A - C) / B)


MsgBox d


End Sub


Private Sub CommandButton2_Click()

'Calculate height of transmitter

PL = 150

d = 9

f_c = 900

h_m = 1.8


E = (1.1 * Log(f_c) / 2.303 - 0.7) * h_m - (1.56 * Log(f_c) / 2.303 - 0.8)

Top = (69.55 + 26.16 * Log(f_c) / 2.303 - e + 44.9 * Log(d) / 2.303 - PL)

bottom = (13.82 + 6.55 * Log(d) / 2.303)

h_b = 10 ^ (Top / bottom)
```

```
MsgBox h_b
End Sub

Private Sub CommandButton5_Click()

h_m = 1.8
f_c = 900
e = (1.1 * Log(f_c) / 2.303 - 0.7) * h_m - (1.56 * Log(f_c) / 2.303 - 0.8)
C = 0
d = 9
h_b = 35
B = 44.9 - (6.55 * Log(h_b) / 2.303)
a = 69.55 + (26.16 * Log(f_c) / 2.303) - (13.82 * Log(h_b) / 2.303) - e
PL = A+ B * Log(d) / 2.303 + C
RSSI = -90
EIRP = PL + RSSI
MsgBox EIRP
End Sub

Private Sub CommandButton5_Click()
h_m = 1.8
f_c = 900
e = (1.1 * Log(f_c) / 2.303 - 0.7) * h_m - (1.56 * Log(f_c) / 2.303 - 0.8)
C = 0
```

```
Dim j As Integer
For j = 1 To 5
Select Case j
Case 1
d = 1
Case 2
d = 2
Case 3
d = 4
Case 4
d = 8
Case 5
d = 16
End Select
h_b = 5

RSSI = -105

    Dim Counter As Integer
    For Counter = 2 To 22
        B = 44.9 - (6.55 * Log(h_b) / 2.303)
        a = 69.55 + (26.16 * Log(f_c) / 2.303) - (13.82 * Log(h_b) / 2.303) - e
        PL = a + B * Log(d) / 2.303 + C
        EIRP = PL + RSSI
        Worksheets("Test5").Cells(1, j + 1).Value = d
```

```
        Worksheets("Test5").Cells(Counter, 1).Value = h_b
        Worksheets("Test5").Cells(Counter, j + 1).Value = EIRP
        If j = 1 Then
        Worksheets("Test5").Cells(1, 1).Value = "BS Height"
        Else
        End If
        h_b = h_b + 5

    Next Counter
Next j
End Sub
```

APPENDIX 2: Effect of Height of Transmitter on Path Loss

Distance	10M	20M	40M	100M
0.10	86.10	83.91	81.72	78.83
0.20	97.64	94.86	92.08	88.40
0.30	104.39	101.26	98.13	94.00
0.40	109.18	105.81	102.43	97.97
0.50	112.90	109.33	105.77	101.05
0.60	115.94	112.21	108.49	103.57
0.70	118.50	114.65	110.79	105.70
0.80	120.73	116.76	112.79	107.54
0.90	122.69	118.62	114.55	109.17
1.00	124.44	120.28	116.12	110.62
1.10	126.03	121.79	117.55	111.94
1.20	127.48	123.16	118.85	113.14
1.30	128.81	124.43	120.04	114.25
1.40	130.05	125.60	121.15	115.27
1.50	131.19	126.69	122.18	116.22
1.60	132.27	127.71	123.15	117.11
1.70	133.28	128.66	124.05	117.95
1.80	134.23	129.57	124.90	118.74
1.90	135.13	130.42	125.71	119.49
2.00	135.98	131.23	126.48	120.20
2.10	136.80	132.00	127.21	120.87

APPENDIX 3: Busy Hour Traffic Data

Date	EC0034	EC0041	EC0257	EC0321	EC0322	EC0456	Total
2013-10-01	268.2	213.2	178.6	208.5	164.1	74.4	1107.0
2013-10-02	268.4	213.6	180.1	203.6	166.9	78.2	1110.8
2013-10-03	277.2	219.9	186.2	206.4	162.0	76.2	1127.8
2013-10-04	282.7	221.4	181.7	213.1	171.0	77.4	1147.3
2013-10-05	267.7	208.7	178.1	226.6	139.4	76.2	1096.7
2013-10-06	283.6	200.8	163.7	224.2	136.0	65.2	1073.5
2013-10-07	281.1	217.6	183.9	222.6	174.4	75.9	1155.6
2013-10-08	270.7	216.0	177.5	216.6	163.9	74.4	1119.1
2013-10-09	278.1	223.4	187.3	212.4	166.5	73.0	1140.7
2013-10-10	261.1	225.9	178.8	213.9	164.1	72.0	1115.8
2013-10-11	271.5	235.8	196.5	218.7	171.8	72.1	1166.3
2013-10-12	270.7	229.6	179.2	219.3	143.0	72.5	1114.3
2013-10-13	291.3	220.4	169.7	231.9	145.0	75.0	1133.2
2013-10-15	281.7	222.2	185.1	222.5	165.8	79.1	1156.6
2013-10-16	276.1	213.9	176.8	217.2	167.1	79.3	1130.5
2013-10-17	263.5	216.5	178.4	211.3	174.6	78.0	1122.3
2013-10-18	270.7	218.0	185.4	218.8	168.6	77.0	1138.5
2013-10-19	276.6	236.6	209.0	281.0	137.8	73.5	1214.4
2013-10-20	252.4	185.5	151.5	225.7	129.6	69.9	1014.6
2013-10-21	250.2	198.4	162.3	216.7	131.4	68.6	1027.6
2013-10-22	257.3	216.1	178.0	214.1	159.4	76.0	1101.0
2013-10-23	269.1	217.5	174.9	212.8	166.2	73.5	1114.0
2013-10-24	272.7	210.0	166.1	215.1	158.9	75.0	1097.8
2013-10-25	274.0	222.4	188.6	219.4	169.2	71.4	1144.9
2013-10-26	268.7	202.7	170.0	227.8	141.0	74.5	1084.7
2013-10-27	269.6	205.3	155.9	222.5	134.1	65.3	1052.7
2013-10-28	273.5	217.1	173.4	221.0	169.5	74.6	1129.1
2013-10-29	275.7	212.3	175.6	224.6	157.2	72.5	1117.8

Date	EC0034	EC0041	EC0257	EC0321	EC0322	EC0456	Total
2013-10-30	275.7	221.2	184.3	223.5	167.6	72.6	1144.9
2013-10-31	277.0	227.7	183.0	222.0	165.9	73.0	1148.6
2013-11-01	279.9	225.7	187.7	224.0	176.6	71.8	1165.7
2013-11-02	264.3	199.7	174.5	232.3	132.7	74.5	1077.9
2013-11-03	275.9	210.1	176.0	239.2	145.1	71.1	1117.4
2013-11-04	273.1	219.6	180.4	232.4	178.2	73.0	1156.8
2013-11-05	277.6	221.1	184.9	220.9	174.0	81.8	1160.3
2013-11-06	278.5	223.9	183.9	223.7	175.8	74.7	1160.5
2013-11-07	277.2	220.2	188.1	222.6	170.8	69.7	1148.7
2013-11-08	288.8	224.4	197.7	226.4	172.8	74.2	1184.4
2013-11-09	283.5	206.6	175.4	228.5	138.2	75.0	1107.1
2013-11-10	270.7	205.3	167.7	222.2	135.8	68.0	1069.8
2013-11-11	286.6	221.3	183.7	230.2	174.5	76.3	1172.6
2013-11-12	281.4	235.9	184.8	235.4	180.8	77.9	1196.3
2013-11-13	278.2	225.2	178.1	236.6	173.5	73.7	1165.3
2013-11-14	289.6	216.9	182.6	238.4	181.5	74.5	1183.6
2013-11-15	295.8	229.9	194.3	243.1	187.0	76.5	1226.5
2013-11-16	271.6	201.0	182.2	240.3	143.3	77.3	1115.8
2013-11-17	288.1	212.3	164.5	238.0	149.0	69.3	1121.2
2013-11-18	277.6	213.6	182.3	229.1	185.4	81.4	1169.4
2013-11-19	271.1	210.4	165.2	231.5	163.4	77.1	1118.7
2013-11-20	284.4	213.6	136.3	227.0	166.4	75.9	1103.6
2013-11-21	278.2	214.0	171.5	220.9	174.1	74.9	1133.7
2013-11-22	273.2	223.0	188.0	229.6	171.0	72.3	1157.2
2013-11-23	256.8	194.1	167.4	225.0	141.0	75.8	1060.1
2013-11-24	263.0	195.1	154.1	226.2	140.9	74.4	1053.6
2013-11-25	229.0	182.7	151.6	186.1	137.0	68.6	955.1
2013-11-26	264.3	208.4	170.8	218.4	170.8	75.2	1107.8
2013-11-27	261.5	207.9	169.6	224.1	177.1	78.0	1118.3

2013-11-28	263.7	221.4	195.0	220.6	208.2	69.2	1178.2
Date	EC0034	EC0041	EC0257	EC0321	EC0322	EC0456	Total
2013-11-29	347.7	500.2	346.8	236.0	255.4	72.8	1758.9
2013-11-30	264.0	198.5	180.4	245.9	142.1	74.9	1105.7
2013-12-01	278.4	205.4	160.9	240.3	147.8	69.7	1102.5
2013-12-02	276.2	211.3	182.9	236.2	177.1	74.1	1157.7
2013-12-03	272.2	216.8	185.0	234.2	181.2	73.4	1162.9
2013-12-04	278.7	213.1	178.4	238.6	176.5	76.2	1161.5
2013-12-05	267.8	221.9	183.8	231.0	173.4	71.8	1149.6
2013-12-06	272.9	229.5	198.5	242.9	177.7	74.8	1196.1
2013-12-07	280.5	201.7	177.7	228.5	145.9	76.5	1110.7
2013-12-08	268.9	204.5	161.1	236.0	149.8	71.0	1091.2
2013-12-09	278.5	215.7	175.5	235.1	170.0	73.8	1148.7
2013-12-10	261.2	206.6	172.8	225.6	158.2	66.1	1090.6
2013-12-11	290.9	227.7	204.1	237.3	163.7	68.8	1192.4
2013-12-12	250.5	193.8	161.2	231.1	139.0	66.6	1042.3
2013-12-13	245.3	196.0	164.8	218.7	138.2	69.5	1032.4
2013-12-14	259.4	198.5	159.5	234.4	133.5	72.0	1057.4
2013-12-15	259.4	199.8	149.6	231.3	139.9	69.2	1049.3
2013-12-16	260.1	205.6	175.9	221.7	168.5	69.4	1101.3
2013-12-17	253.1	210.7	172.1	243.9	159.7	70.6	1110.1
2013-12-18	264.7	212.3	175.0	226.1	164.4	77.3	1119.8
2013-12-19	257.5	210.6	175.2	224.9	170.1	76.1	1114.6
2013-12-20	249.2	189.2	161.1	223.7	157.1	70.7	1051.0
2013-12-21	235.4	167.9	149.4	226.5	127.8	72.2	979.2
2013-12-22	236.8	150.1	125.1	229.3	119.0	71.4	931.7
2013-12-23	250.4	167.0	137.3	252.0	126.8	79.3	1012.8
2013-12-24	237.9	156.5	143.6	234.3	118.4	76.8	967.6
2013-12-25	213.3	144.0	102.8	202.7	102.5	68.9	834.1
2013-12-26	186.8	111.3	83.5	184.0	93.6	59.1	718.3
2013-12-27	183.3	125.8	101.7	191.9	95.9	64.9	763.4

2013-12-28	180.6	124.1	108.8	218.2	96.7	60.2	788.5
Date	EC0034	EC0041	EC0257	EC0321	EC0322	EC0456	Total
2013-12-29	197.2	126.0	101.7	196.0	102.2	60.6	783.6
2013-12-30	204.0	140.6	117.8	223.5	105.1	70.4	861.4
2013-12-31	243.8	164.4	138.8	247.0	123.4	80.1	997.5
2014-01-01	205.7	133.3	101.9	221.1	106.8	72.3	841.1
2014-01-02	202.4	145.2	119.8	214.3	107.5	73.4	862.5
2014-01-03	216.1	149.5	125.5	223.2	112.4	73.5	900.3
2014-01-04	222.1	149.0	131.3	211.6	113.0	70.6	897.7
2014-01-05	232.0	158.2	128.3	236.4	121.4	67.4	943.7
2014-01-06	236.3	167.5	144.9	230.6	133.3	73.6	986.3
2014-01-07	225.4	163.5	141.1	229.1	131.7	75.3	966.0
2014-01-08	225.5	161.5	137.3	230.8	137.7	73.5	966.2
2014-01-09	297.7	157.0	137.6	219.6	131.6	74.6	1018.1
2014-01-10	227.9	160.8	139.3	224.1	134.0	76.2	962.3
2014-01-11	236.1	155.5	136.0	216.4	119.4	74.1	937.5
2014-01-12	232.7	152.6	132.1	224.3	122.5	65.0	929.2
2014-01-13	244.5	183.2	154.5	226.6	150.5	75.2	1034.4

APPENDIX 4: Hourly Traffic Data

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
0	24.2	25.7	15.2	18.7	20.1	22.3	27.0	153.2
1	12.6	7.9	5.8	8.5	6.8	7.8	13.2	62.7
2	5.6	3.3	2.1	4.2	5.3	3.2	8.2	31.9
3	5.2	3.3	2.5	3.3	3.3	3.0	5.0	25.6
4	4.9	5.1	3.9	4.4	5.8	4.5	7.3	35.7
5	9.5	14.6	15.0	12.7	13.2	12.6	12.0	89.6
6	31.5	55.2	54.3	48.6	45.2	51.8	46.5	333.1
7	73.5	111.0	115.8	110.5	101.2	104.8	105.4	722.1
8	103.3	146.2	146.5	139.6	138.5	145.4	139.5	959.1
9	109.7	160.7	160.7	152.9	156.9	164.6	167.1	1072.6
10	112.7	169.1	159.6	164.2	163.1	164.9	165.1	1098.7
11	105.8	158.4	158.7	149.9	150.3	157.9	171.1	1052.2
12	109.6	165.8	157.8	149.6	151.1	157.3	166.2	1057.4
13	134.9	165.4	161.2	162.3	150.2	168.9	172.3	1115.2
14	142.4	149.4	145.8	147.2	140.0	151.1	160.1	1035.9
15	144.5	142.8	142.4	135.5	138.1	150.2	152.4	1005.7
16	140.0	162.5	153.6	156.0	151.3	158.9	155.2	1077.4
17	164.1	189.8	168.6	171.6	171.5	180.4	162.9	1208.8
18	189.5	197.7	192.7	187.6	191.6	206.0	181.7	1346.8
19	207.2	207.4	212.6	221.3	205.7	217.8	200.7	1472.7
20	176.4	200.2	207.2	201.0	207.1	208.0	194.1	1394.0
21	161.4	166.4	165.6	169.1	164.0	155.0	151.2	1132.7
22	132.5	140.5	144.0	145.5	149.9	135.1	119.3	966.8
23	60.9	53.9		59.9	71.9	66.0	58.3	370.9

APPENDIX 5: Busy Day Traffic Data

Hour	**Sum of Dual_Rate_Traffic**
0	22.329
1	7.92
2	4.967
3	2.737
4	5.468
5	12.279
6	49.86
7	107.319
8	142.662
9	164.177
10	164.564
11	157.096
12	163.763
13	166.833
14	152.518
15	149.754
16	164.829
17	179.842
18	193.503
19	212.951
20	202.316
21	170.62
22	139.431
23	67.731

APPENDIX 6: Radio Planning Data 1

Name	BTSName	Longitude	Latitude	Altitude(m)
EC0002	Njira – Igiri	36°58'7.96"E	1°9'10.46"S	1512
EC0003	Ruiru Fort Jesus	36°56'56.96"E	1°9'33.46"S	1534
EC0004	Murera Farm	36°59'10.96"E	1°7'33.47"S	1519
EC0009	Juja Farm	37°4'53.97"E	1°9'52.46"S	1472
EC0011	Mugutha	36°57'29.96"E	1°6'51.47"S	1540
EC0012	Ruiru Plaza	36°57'39.96"E	1°8'52.46"S	1519
EC0034	Gachororo	37°1'12.96"E	1°5'24.48"S	1519
EC0041	Juja	37°1'2.96"E	1°6'3.48"S	1519
EC0255	Murera Estate	36°58'25.4"E	1°7'58.3"S	1519
EC0256	Ruiru PCEA	36°57'3.6"E	1°8'58.4"S	1535
EC0257	Kalimoni	37°0'46.3"E	1°6'14.9"S	1519
EC0294	Gatongora	36°59'53.7"E	1°10'17"S	1500
EC0321	Muigai Inn	37°0'35.96"E	1°7'23.47"S	1507
EC0322	Greenfields	37°0'35.4"E	1°5'55.3"S	1519
EC0357	Ruiru Kihunguro	36°57'25.8"E	1°9'22.5"S	1525
EC0358	Murera	36°59'31.5"E	1°8'33.2"S	1509
EC0362	Ruiru Gitambaa	36°56'38.5"E	1°9'12"S	1539
EC0448	Ruiru Wakulima House	36°57'32.5"E	1°8'51"S	[1530]
EC0456	Nyachaba	37°3'19.3"E	1°5'55.2"S	[1483]

APPENDIX 7: Radio Planning Data 2

Site	Transmitter	Antenna	Height (m)	Azimuth (°)	Mechanical Downtilt (°)	*EIRP* (dBm)
EC0002	EC00020	900MHz 65deg 17dBi 4Tilt	45	80	0	55.2
EC0002	EC00021	900MHz 65deg 17dBi 4Tilt	45	200	0	55.2
EC0002	EC00022	900MHz 65deg 17dBi 4Tilt	45	320	0	55.2
EC0003	EC00030	900MHz 65deg 17dBi 4Tilt	40	100	0	55.41
EC0003	EC00031	900MHz 65deg 17dBi 4Tilt	35	220	0	55.41
EC0003	EC00032	900MHz 65deg 17dBi 4Tilt	35	340	0	55.41
EC0004	EC00040	900MHz 65deg 17dBi 2Tilt	44	0	0	55.41
EC0004	EC00041	900MHz 65deg 17dBi 2Tilt	44	120	0	55.41
EC0004	EC00042	900MHz 65deg 17dBi 4Tilt	44	240	0	55.41
EC0009	EC00090	900MHz 65deg 17dBi 2Tilt	44	30	2	50.98
EC0009	EC00091	900MHz 65deg 17dBi 2Tilt	44	130	0	50.98
EC0009	EC00092	900MHz 65deg 17dBi 4Tilt	44	260	0	50.98
EC0011	EC00111	900MHz 65deg 17dBi 2Tilt	43.7	110	0	50.9
EC0011	EC00112	900MHz 65deg 17dBi 2Tilt	43.7	250	2	50.9
EC0011	EC00110	900MHz 65deg 17dBi 2Tilt	43.7	10	0	50.9
EC0012	EC00120	900MHz 65deg 17dBi 4Tilt	40	90	0	54.99
EC0012	EC00121	900MHz 65deg 17dBi 4Tilt	40	210	0	54.99
EC0012	EC00122	900MHz 65deg 17dBi 4Tilt	40	305	0	54.99
EC0034	EC00340	900MHz 65deg 17dBi 0Tilt	44	70	3	54.41
EC0034	EC00341	900MHz 65deg 17dBi 4Tilt	35	195	0	54.91

Site	Transmitter	Antenna	Height (m)	Azimuth (°)	Mechanical Downtilt (°)	*EIRP* (dBm)
EC0034	EC00342	900MHz 65deg 17dBi 0Tilt	44	310	3	54.41
EC0041	EC00410	900MHz 65deg 17dBi 0Tilt	59	70	4	47.3
EC0041	EC00411	900MHz 65deg 17dBi 4Tilt	38.5	185	0	47.3
EC0041	EC00412	900MHz 65deg 17dBi 0Tilt	59	310	3	47.3
EC0255	EC02551	900MHz 65deg 17dBi 4Tilt	30	120	0	54.78
EC0255	EC02552	900MHz 65deg 17dBi 4Tilt	30	240	0	54.78
EC0255	EC02550	900MHz 65deg 17dBi 4Tilt	38	0	0	54.78
EC0256	EC02560	900MHz 65deg 17dBi 4Tilt	30	0	0	55.28
EC0256	EC02561	900MHz 65deg 17dBi 4Tilt	30	120	0	55.28
EC0256	EC02562	900MHz 65deg 17dBi 4Tilt	30	240	0	53.6
EC0257	EC02570	900MHz 65deg 17dBi 4Tilt	33.1	80	0	55.07
EC0257	EC02571	900MHz 65deg 17dBi 4Tilt	40	200	0	55.07
EC0257	EC02572	900MHz 65deg 17dBi 4Tilt	40	320	0	55.07
EC0294	EC02942	900MHz 65deg 17dBi 4Tilt	44	240	0	54.78
EC0294	EC02940	900MHz 65deg 17dBi 4Tilt	44	0	0	54.78
EC0294	EC02941	900MHz 65deg 17dBi 4Tilt	44	120	0	54.78
EC0321	EC03210	900MHz 65deg 17dBi 4Tilt	44	50	0	55.37
EC0321	EC03211	900MHz 65deg 17dBi 4Tilt	44	170	0	55.2
EC0321	EC03212	900MHz 65deg 17dBi 4Tilt	44	290	0	55.2
EC0322	EC03220	900MHz 65deg 17dBi 4Tilt	35	90	0	50.48
EC0322	EC03221	900MHz 65deg 17dBi 4Tilt	35	210	0	50.48

EC0322	EC03222	900MHz 65deg 17dBi 4Tilt	43.7	330	0	50.48
EC0357	EC03570	900MHz 65deg 17dBi 4Tilt	32	0	0	54.78
EC0357	EC03571	900MHz 65deg 17dBi 4Tilt	32	120	0	54.78
EC0357	EC03572	900MHz 65deg 17dBi 4Tilt	32	240	0	54.78
EC0358	EC03580	900MHz 65deg 17dBi 4Tilt	34	0	0	54.78
EC0358	EC03581	900MHz 65deg 17dBi 4Tilt	34	120	0	54.78
EC0358	EC03582	900MHz 65deg 17dBi 4Tilt	34	240	0	54.78
EC0362	EC03620	900MHz 65deg 17dBi 4Tilt	35	0	0	54.78
EC0362	EC03621	900MHz 65deg 17dBi 4Tilt	35	120	0	54.78
EC0362	EC03622	900MHz 65deg 17dBi 4Tilt	35	240	0	54.78
EC0448	EC04480	900MHz 65deg 17dBi 4Tilt	13	30	0	50.27
EC0448	EC04481	900MHz 65deg 17dBi 4Tilt	13	140	0	50.27
EC0448	EC04482	900MHz 65deg 17dBi 4Tilt	13	260	0	50.27
EC0456	EC04560	900MHz 65deg 17dBi 4Tilt	36	75	0	55.28
EC0456	EC04561	900MHz 65deg 17dBi 4Tilt	36	185	0	55.28
EC0456	EC04562	900MHz 65deg 17dBi 4Tilt	36	315	0	55.28

APPENDIX 8: List of Publication & Conferences

1. S. N. Manegene, S. Musyoki and P. L. Kibet: **Application of Cell Zooming in Outage Compensation,** IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 10, Issue 4, Ver. III (Jul - Aug .2015), PP 60-69 www.iosrjournals.org
2. S. N. Manegene, S. Musyoki and P. L. Kibet: **The Use of Cell Zooming for Outage Compensation in Cellular Radio Networks**, International Conference on Sustainable Research and Innovation, Volume 5, 7th-9th May 2014
3. S. N. Manegene, S. Musyoki and P. L. Kibet: **Traffic Analysis in The Use of Cell Zooming for Outage Compensation**, Kabarak University 4th Annual International Conference, Themed "Addressing The Challenges Facing Humanity Through Research And Innovation", 15th to 18th July 2014.
4. S. N. Manegene, S. Musyoki and P. L. Kibet: **Analysis of Received Signal Levels in The Use of Cell Zooming for Outage Compensation**, Kabarak University 4th Annual International Conference, Themed "Addressing The Challenges Facing Humanity Through Research And Innovation", 15th to 18th July 2014.