COMMON PILOT CHANNEL POWER CONTROL FOR 3G CELLULAR NETWORKS TRAFFIC LOAD BALANCING BASED ON FUZZY LOGIC CONTROL

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DECLARATION

This Thesis is my original work, except where due acknowledgement is made in the text, and to the best of my knowledge has not been previously submitted to Pan African University or any other institution for the award of a degree.

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ABSTRACT

Mobile communication has increasingly become popular and in addition there has been an accelerated penetration of smart phones which has led to a significant increase in the use of mobile data services. Network congestion control remains important and of high priority, especially given the growing size, demand, and speed of cellular networks. One way of dealing with this problem has been automatic base transceiver station (BTS) optimization. Recent research in this area has come up with Capacity and Coverage Optimization techniques based on self-organizing networks (SON). However, control of the Common Pilot Power Channel (CPICH) power in order to increase the cell capacity still presents a major challenge. In this research the problem of traffic load balancing in third generation (3G) cellular networks was addressed using rule-based fuzzy logic to control the CPICH power and as a result optimize the cell capacity. The CPICH power is an essential parameter and is used by engineers to enhance network performance and coverage, and increase the network's capacity and coverage. One of the reasons for choosing fuzzy logic controllers is its logical resemblance to a human operator. It operates on the foundations of a knowledge base derived from an expert operator's knowledge. The autonomous operation will reduce the frequent attention and effort required by the radio optimization engineer to carry out traffic load balancing tasks which are currently done mostly manually.

In the study fuzzy logic was used in the detection of high load 3G cells that do not have enough cell resources available and could benefit from CPICH power adjustment as a radio optimization engineer would normally do manually. A fuzzy logic controller (FLC) was then designed with the downlink cell load, received total wideband power (RTWP) and the neighboring cells' load as the inputs. The output of the FLC was the CPICH power setting which determined whether to increase or decrease the coverage footprint of the cell hence influencing the cell downlink power utilization. The effect of varying the CPICH power on the downlink cell utilization based on fuzzy logic was investigated and the proposed FLC based cell capacity enhancement approach was evaluated through a comparison with a cell with constant proportion CPICH power. Simulation results showed that the fuzzy logic based CPICH power control achieved a significant improvement in the downlink cell utilization which in turn improved the cell performance.

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LIST OF ABBREVIATIONS AND ACRONYMS

3G	3rd Generation Cellular Network
3GPP	3rd Generation Partnership Project
AC	Admission Control
AMR	Adaptive Multi-Rate Wideband
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CCH	Common Channel
CN	Core Network
CPC	Continuous Packet Connectivity
CPICH	Common Pilot Power Channel
DL	Downlink
EAT	Electrical Antenna Tilt
EDGE	Enhanced Data Rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controller
GERAN	GSM EDGE Radio Access Network
GPRS	General Packet Radio Service
GSM	Global System For Mobile Communications
HO	Hand Over
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LTE	Long-Term Evolution
MAT	Mechanical Antenna Tilt
MF	Membership Functions
MGW	Media Gateway
MSC	Mobile Switching Center
MSS	MSC Server
OAM	Operation and Maintenance
QOS	Quality Of Service
RAN	Radio Access Network

RAB	Radio Access Bearer
RET	Remote Electrical Downtilt
RNC	Radio Network Controller
RoT	Rise over Thermal
RRC	Radio Resource Control
RRM	Radio Resource Management
RTWP	Received Total Wideband Power
SON	Self-Organizing Networks
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

CHAPTER 1 INTRODUCTION

1.1 Background

Mobile communication has increasingly become popular and in addition there has been an accelerated penetration of smart phones which has led to a significant increase in the use of mobile data services. Network congestion control remains important and of high priority, especially given the accelerated growth in size and demand of cellular networks [1]. Hence, the need for an intelligent multi criteria traffic load balancing algorithm becomes apparent. The Third Generation (3G) network wideband code division multiple access (WCDMA) system is a self-interfering system. As the network load increases, the interference rises thereby negatively impacting the quality of service and the coverage of cells. Therefore, the capacity, coverage, and quality of service of the WCDMA system are mutually dependent [2]. In other words, when one of these factors undergoes a change, the other factors are affected. The operator can trade quality against coverage, capacity against quality, but the amount of resources does not change, but is only redistributed. For example, to extend the coverage of a cell, it is required to either offer less capacity or decrease the quality requirements, or both. Conversely in order to increase the capacity, it is necessary to shrink the coverage or decrease the quality requirements, or both.

Capacity Planning is essential in WCDMA radio access networks (RAN) so as to evaluate the optimal site configuration in terms of pilot and common control channel powers, throughput, and the soft handover parameter [3][4]. The objective for capacity optimization is to support the subscriber traffic with sufficiently low blocking probability and delay. The capacity of a cell affects the coverage of the cell. The cell coverage area changes as the number of users varies. To keep the quality of services in suitable levels, admission control, packet scheduling, and handover mechanisms are used [2]. The importance of capacity increases when the network expands and the amount of traffic grows. Each cell should be loaded relatively equally and in a way that there is room for future growth. Automated optimization algorithms are required to perform the radio network optimization process quickly and efficiently, with minimal cost, time and effort contribution [2].

In radio access networks (RAN) using WCDMA, the CPICH is used by the user equipment for channel quality estimation, cell selection, and handover. The CPICH signal strength determines the coverage area of the cell, affects the cell capacity, and in addition the quality of service, and is therefore a crucial parameter in radio network planning and optimization. The CPICH pilot power allows for control of the strength of the CPICH signal such that the more the power set for the pilot signals, the larger coverage that is obtained. The optimal setting of CPICH power requires overcoming several challenges such as the coverage-capacity-quality tradeoff, ensuring adequate handover performance, controlling the amount of interference in the network and balancing the load among neighbor cells [1] [2].

A conventional strategy is to uniformly assign a constant proportion, typically 10-15%, of the total cell power to CPICH [5]. Although convenient, this strategy may be inefficient in traffic varying cells. It has been shown in previous research that adopting non-uniform CPICH and optimizing its power setting can save CPICH power and balance cell load [6, 7]. Whereas power saving on CPICH may not be a crucial aspect to the power-controlled voice traffic, it is of great significance to data traffic. Moreover, reducing the CPICH power enables additional power saving on some of the other common control channels, of which the power is typically set in proportion to that of CPICH.

Several studies exist focusing on the optimization of the CPICH power of the 3G cells which influences the network capacity [5, 6, 7]. While these studies provided a good foundation for this research, they focused on exploring various mathematical approaches with no practical end to end completeness. In this thesis, an approach based on fuzzy logic for CPICH power optimization for downlink cell utilization is used because of its logical resemblance to a human operator. It operates on the foundations of a knowledge base derived from an expert operator’s knowledge. Fuzzy logic was used to control the CPICH power by controlling the coverage of the network cell which influences the downlink cell utilization.

1.2 Problem Statement

The cell capacity requires frequent attention by the radio optimization engineer due to the constantly shifting traffic patterns as subscribers are added to the network. Specific considerations for capacity optimization include difference in the capacity requirements between peak and off-peak hours of the day. Therefore this requires more frequent changes in the network several times a day to address moving patterns and varying user concentrations, and are quite complex as they require learning and pattern recognition algorithms. To deal with the complexity and expense of manually optimizing network coverage and capacity, particularly as network operations and performance management for data networks such as 3G get cumbersome, fuzzy logic is a good candidate for automated processing.

1.3 Justification of the Study

Network congestion control remains important and of high priority, especially given the accelerated growth in size and demand of cellular networks. In this study the problem of traffic load balancing in 3G cellular networks is addressed using Rule-Based Fuzzy Logic to control the CPICH power and as a result optimize the cell capacity. Fuzzy Logic Control would be the best technique to implement the automation of the radio traffic load balancing through CPICH power changes because of its logical resemblance to a human operator. The system will operate on the foundations of a knowledge base derived from an expert operator’s knowledge. The autonomous operation will reduce the frequent attention and effort required by the radio optimization engineer to carry out traffic load balancing tasks which are currently done mostly manually.

1.4 Objectives

1.4.1 Main Objective

The main objective of this research was to develop a fuzzy logic based cell traffic load balancing algorithm for a 3G cellular network.

1.4.2 Specific Objectives

1) To develop a fuzzy logic based CPICH power control algorithm for 3G cellular network traffic load balancing
2) To investigate the effect of varying the CPICH power on the downlink cell utilization using the developed fuzzy logic controller
3) To evaluate the performance of the developed CPICH power optimization and control system against a constant proportion CPICH power cell based on downlink cell utilization load

1.5 Outline of the Thesis

This thesis contains five chapters. The first chapter provides an introduction to the research by highlighting the existing problem and the objective of the research work. Chapter 2 is a literature review on the various methods employed in the 3G cellular networks traffic load balancing and application of fuzzy logic in cellular networks. This chapter also outlines the architecture and the function of the various nodes in a 3G cellular network. Chapter 3 outlines the design procedure for the fuzzy logic based CPICH power optimization approach, its simulation and implementation. The simulated results and their discussion are presented in Chapter 4. Chapter 5 gives the thesis conclusions and recommendations, as well as the suggestions for future work.

1.6 Note on Publication

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CHAPTER 2 LITERATURE REVIEW

Cellular networks have experienced a rapid growth in size and complexity over the last years. This has contributed to increase in strong research activity in the field of self-organizing networks (SONs) [8], [9]. A major issue tackled by SONs is the irregular and frequently changing distribution of cellular subscribers both in time and area. In order to cope with such a trend in a cost-effective manner, operators of mature networks, such as GSM EDGE radio access network (GERAN) [10], use traffic management techniques instead of adding new resources while new technologies such as LTE use parameter tuning which is done automatically based on periodical measurements [11].

For 3G technologies on the other hand using the universal terrestrial radio access network (UTRAN), the issue of congestion is tackled using physical or soft parameter optimization. As existing network technologies continue to evolve, more and more tunable parameters and various customizations are being introduced [12]. This has resulted in a rise in complexity that is making traditional manual optimization challenging. On the other hand, even though current 3GPP Self-Organizing Networks (SON) focus is on Long Term Evolution (LTE) and beyond, legacy networks such as 3G are adopting different SON based solutions to address the above mentioned challenges in other radio access network (RAN) types [13,14].

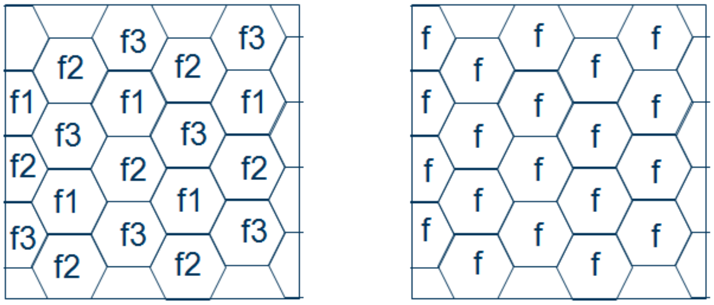
2.1 Radio Access Network Traffic Load Balancing

In an operational cellular network, coverage and capacity is affected by a number of factors; environmental factors such as the topography and the climate variations affect the wireless signal propagation, whereas, mobile users' behavior and movements influence the service demand distribution of the network. As network operators have no control over these issues, so, it is extremely challenging for them to maintain the coverage and capacity targets. Therefore, great efforts are spent on network planning and optimization in order to make sure that the required network resources are available in the targeted areas of network operation.

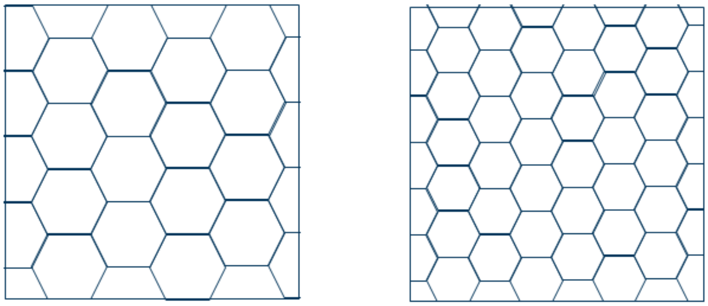
There exist numerous configurable base station parameters that the network operator can modify to influence the coverage and capacity for example antenna settings such as azimuth, height and tilt, CPICH power and handover parameters. These parameters also have a strong influence on the interference in the system and therefore on the amount of served mobile terminals. The deciding factors in the selection of parameters for optimizing the coverage and capacity optimization are; the effectiveness of that parameter to overcome the problem, the ease with which it can be modified especially in an automatic manner and how quickly it can be modified [12].

2.1.1 Frequency Spectrum and Frequency Reuse

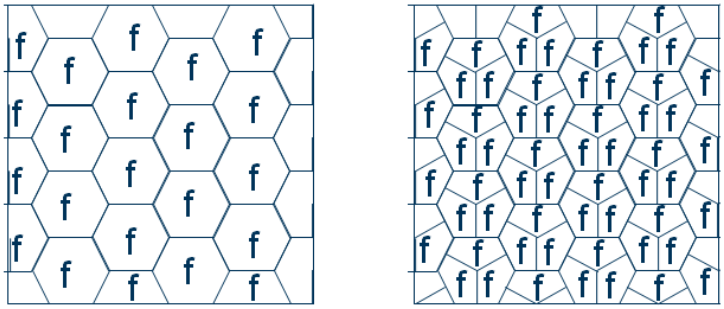
The available frequency spectrum is a crucial factor in determining the capacity of a 3G cellular system. To reduce the co-channel interference, second generation cellular networks like GSM (Global System for Mobile Communications) split the available frequency spectrum among the cells to have distinct frequencies in the adjacent cells. This allows the possibility of dynamic spectrum allocation to the cells to match the traffic dynamics. However, 3G cellular networks are frequency re-use 1 systems, meaning they use the complete available spectrum in each cell, to increase the spectrum utilization [15]. Therefore in these networks, dynamic capacity enhancement in a cell by spectrum allocation is not a feasible solution.



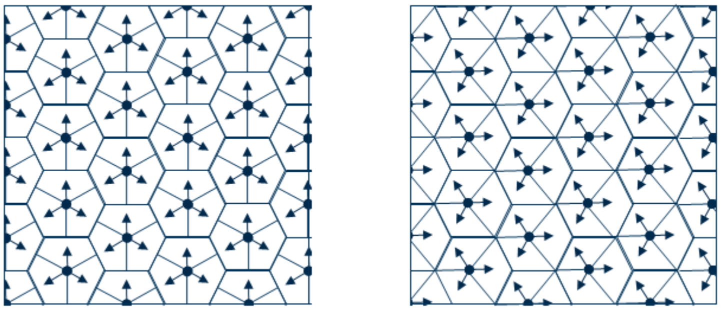
f = f1+f2+f3: larger spectrum per cell means more radio resources per cell



Higher BS density means larger number of radio Resources per unit area



Sectorization also increases the available radio resources per unit area



Azimuth setting helps to avoid radiation in the direction of adjacent neighbor

Figure 2-1: Parameters for capacity and coverage optimization

2.1.2 Base Station Density

The densification of base transceiver station (BTS), such that the interference remains under a certain limit can provide significant gains in network coverage and capacity. However, BTSs cannot be deployed at arbitrary places. Due to legal obligations and cost, they can only be deployed at some carefully selected places. Moreover, financial and timing constrains also make this option feasible only to cater for the long term coverage and capacity upgrades.

2.1.3 Sectorization

The BTS coverage can be divided into multiple sectors using directional antennas [15]. Unlike Omni-directional antennas, directional antennas radiate the transmitted signals in a particular direction and therefore can increase the capacity of the network by reducing the interference in other directions. In traditional networks the number of sectors each BTS has, is decided at the planning phase. As it requires site visit and hardware upgrades to change the sectorization configuration, it can only be done over large periods of time.

2.1.4 Antenna Azimuth

Antenna azimuth is defined as the angle of main beam of a directional antenna with respect to the North Pole in the horizontal direction. It can be used to steer the antenna radiation pattern and to reduce the interference to the adjacent cells. If the adjacent antennas point towards each other they produce more interference compared to if they are directed away from each other as also shown in Figure 2-2. The value of azimuth is normally influenced by the relative positions of the adjacent BS and the targeted coverage areas. Therefore, the possibility of dynamic capacity enhancements by antenna azimuth adaptation are limited [16].

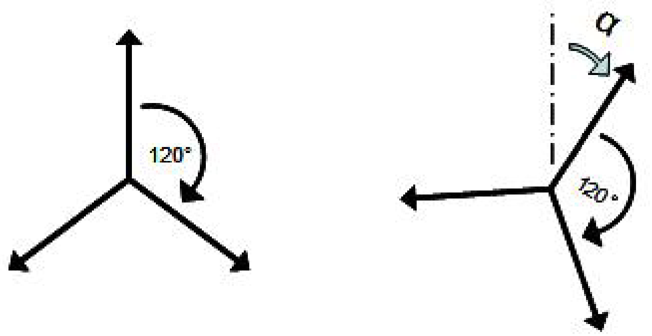


Figure 2-2: Adjustment of base station azimuth

2.1.5 Antenna Height

Antenna height of the BSs also influences the received signal strengths in its coverage area. The higher the antenna height is, further the radio signals can propagate and therefore the larger is the coverage area. However, its value is fixed at the planning phase and it is extremely difficult to modify it dynamically.

2.1.6 Antenna Tilt

Antenna tilt is defined as the elevation angle of the main lobe of the antenna radiation pattern relative to the horizontal plane. If the main lobe moves towards the earth it is known as downtilt and if it moves away it is known as uptilt. Higher antenna downtilts move the main lobe closer to the BTS and vice versa. Therefore, the antenna tilt value has a strong influence on the effective coverage area of the cell as shown in Figure 2-3. The antenna tilt is measured in degrees and can have positive and negative values. Positive values mean that the beam is directed downwards, i.e. downtilting while negative values mean that the beam is directed upwards, i.e. uptilting as shown in figure 2-4. Moreover, with relatively close direction of the main lobe to the BS the received signal strengths in own cell improves and the interference to neighboring cells reduces [17]. This improves the signal to interference plus noise (SINR) ratio for the mobile terminals and the network capacity increases. Therefore, antenna tilt can be used to alter both coverage and capacity of the network at the same time [18, 19].

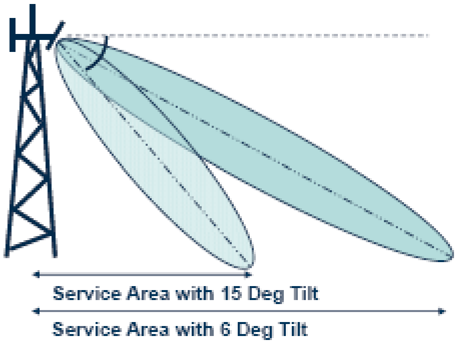


Figure 2-3: Antenna Tilt Optimization

Primarily antenna tilt can be modified either mechanically or electrically. Mechanical Antenna Tilt (MAT) involves, physically changing the BTS antenna so that the main lobe is directed towards the ground. The antenna radiation pattern mostly remains unchanged only a notch develops at the end of main lobe [20]. This reduces the interference in the main lobe direction. However, the effective tilt experienced by the side lobes varies and the rear lobe in fact experiences an uptilt. Adaptation of MAT also requires a site visit, which makes it an expensive and time-consuming task.

Figure 2-4: Illustration of uptilting and downtilting

Electrical Antenna Tilt (EAT) involves, adjusting the relative excitation current phases of antenna elements of an antenna array in such a way that the radiation pattern can be tilted uniformly in all horizontal directions [20]. Antenna tilts can also be modified without a site visit with the help of the remote electrical tilt (RET). It can adjust the antenna tilt remotely e.g. from network management centers. Hence, it can save the cost and time required for antenna tilt optimization.

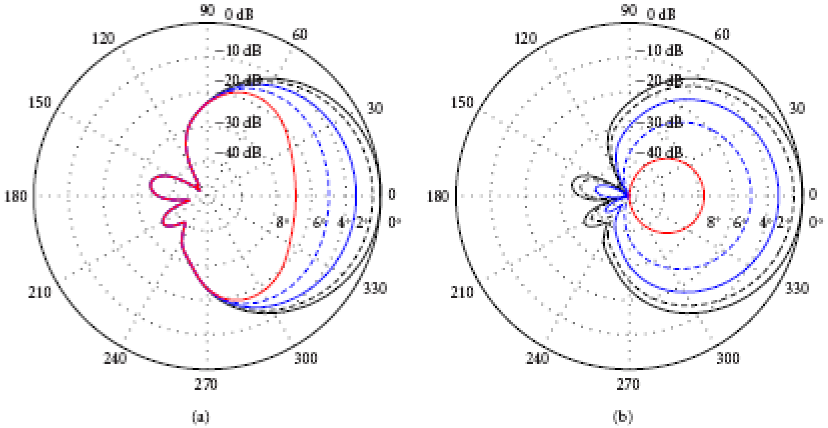


Figure 2-5: Radiation patterns for (a) Mechanical Tilt Vs. (b) Electrical Tilt

2.1.7 CPICH Power

The CPICH pilot power determines the cell coverage area and the number of user equipment (UEs) connected to the cell. For example, the authors of [5] and [21] show that the 3G cellular network performance can be improved by proper adjustments of the pilot power. Increasing or decreasing the pilot power makes the cell larger or smaller. Thus, the adjusting of CPICH pilot power can be done to balance the cell load among neighboring cells, which facilitates the traffic load balancing. Load balancing using the CPICH power must be carefully done so as not to make the pilot power too weak because if pilot power is too weak for the UE receiver to decode the signal then call setup will not be possible. How low the received power can be, depends on the

UE receiver electronics and the level is thus specific to the UE. The specifications of the Third Generation Partnership Project (3GPP) require that the UE receiver must be able to decode the pilot from a signal with Ec/Io of -20dB [22]. Therefore the CPICH pilot power control is a compromise between the load balance and the coverage balance.

2.1.8 Handover for Load Balancing

In a cellular network, load balancing can also be performed by shifting traffic between neighboring cells. Handover (HO) is the process of transferring a call which is in progress from one channel to another. A basic handover process is illustrated in Figure 2-6. It consists of three main phases: measurement phase, decision phase and execution phase. By adjusting HO parameters settings, the size of a cell can be modified to send users from the current cell to neighboring cells [25,26]. Thus, the coverage area of the cell with high congestion can be reduced and that of neighboring cells take up traffic from the congested cell edge and as a result of a more even traffic distribution, the call blocking probability in the congested cell decreases [27]. Several studies in handover for load balancing have been done. In [28], a real time traffic balancing in cellular network by multi-criteria handoff algorithm using fuzzy logic for GERAN is presented. An algorithm to decide the balancing of the load between LTE, UMTS and GSM is presented in [29]. The load balancing and handover optimization functions may be used to improve the network performance and a conflict may arise when both functions attempt to adjust the same parameters at the same time. In [30] coordination algorithm of both functions is proposed with and aim to avoid the situation in which a parameter is simultaneously increased by both functions, achieving extreme values that may negatively affect network performance.

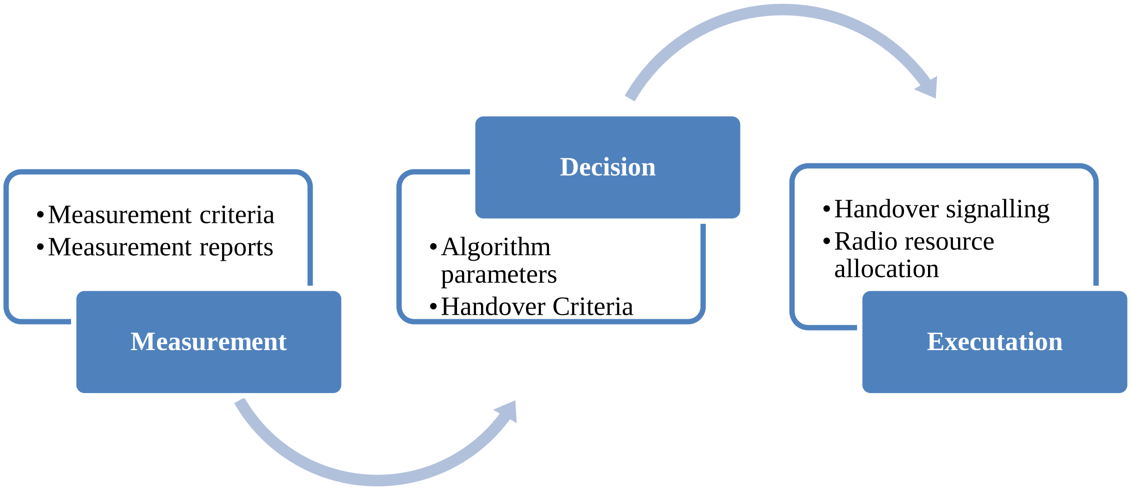


Figure 2-6: The basic handover process

2.2 UMTS Third Generation (3G) Network Architecture

A UMTS 3G network consists of three interfacing domains; Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE), Figure 2-7 [2]. The main function of the Core Network is to provide switching, routing and transit for user traffic and it also contains the databases and network management functions. The UTRAN provides the air interface access method for User Equipment [1] [2].

2.2.1 Node-B

The Node-B is the name given to the 3G Base Stations and it is the logical node responsible for radio transmission/reception in one or more cells to/from UE. The main function of a Node-B is to establish the physical implementation of Uu interface and Iub interface. The Uu interface means that Node B implements WCDMA physical channels and converts the information coming from transport channels to the physical channels under guidance of RNC. For the Iub interface, Node B works through the inverse functionality. The Node B contains only physical channels' resources whereas transport channels are completely managed by RNC. Other functions of the Node-B include spreading, scrambling, modulation, channel coding, power control, interleaving, synchronization and measurement reporting [31].

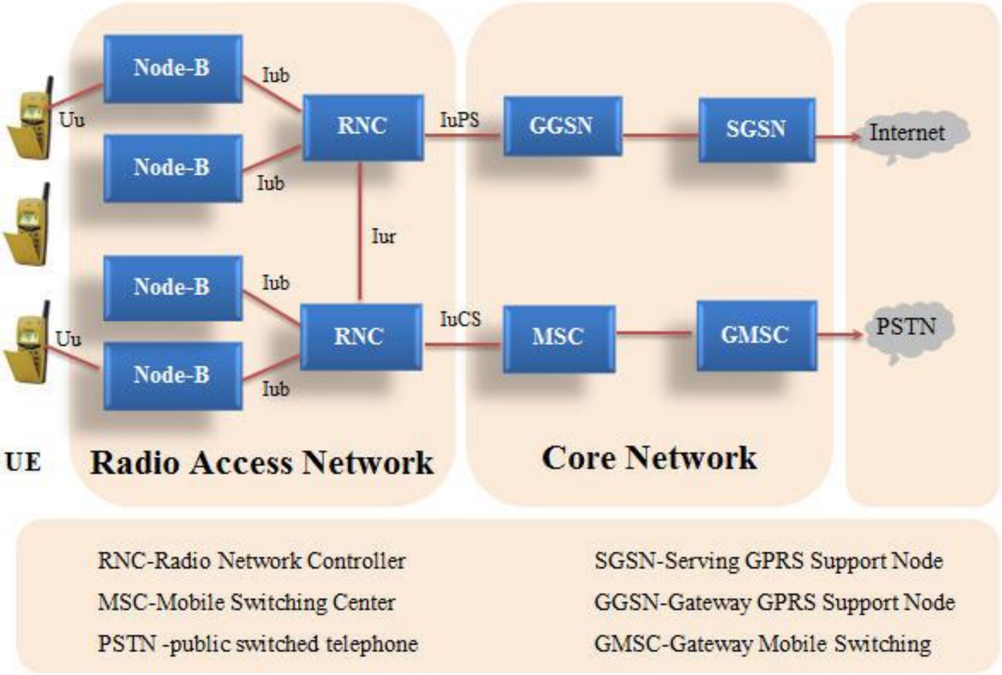


Figure 2-7: 3G Network Architecture

2.2.2 Radio Network Controller (RNC)

The RNC is the central unit in 3G RAN. It is a governing element in the UMTS radio access network (UTRAN) and is used for controlling the Node-Bs that are connected to it [31]. It is also responsible for controlling the use of all 3G radio resources by performing Radio Resource Management (RRM) procedures [32,33]. It also plays an important role in configuration management because the radio related parameters for the whole RNS are stored in RNC. For performance management, the RNC updates performance counters, which are later used to calculate the key performance indicators (KPIs) for RAN. RNC is also responsible for fault management by keeping track of the alarms in any Node B controlled by that particular RNC. Its functions can be summarized as below;

- Radio Resource Management
- Management of System information
- Alarms Management
- Iub and Iu interfaces Interworking
- Operation and Maintenance (OAM)
- Performance Measurement and management

RNC serves as the intermediate node which connects Core Network (CN) to RAN. It is possible that the transport technologies in RAN and Core are different (e.g., One side is using ATM and the other side IP). In that case, RNC performs the protocol conversion required for interworking [33].

2.3 Radio Resource Management Algorithms

The task of radio resource management is to optimize the use of the available physical and logical resources in order to provide as much capacity as possible to the users [33]. This is achieved through the combined effort of a number of closely connected radio resource management algorithms. The RNC is responsible for storing the radio parameters for the whole radio network subsystem. It also stores the cell specific uplink load target and downlink load target. For example, if the target downlink (DL) load is 80% and the current load is 75%, radio resource management (RRM) can easily decide about the next strategy. Therefore, the parameters stored in RNC’s database are important input for RRM functionality [34]. The Load areas (Figure 2-10) can be summarized as follows;

The ***planned area*** is the area of safe operation where the cell load is under manageable limits and neither coverage nor the quality of active connections gets affected. The threshold which defines the upper limit of planned area is decided in co-ordination with radio network planning strategy. In this area, admission control is advised to allow all radio access bearer (RABs) and packet scheduler is advised to schedule higher bit rates.

The ***marginal area*** is the safe window between ‘planned’ and ‘overload’ areas. In this situation, the new real-time voice calls are generally rejected. Ongoing packet sessions continue but their bit rates are neither throttled nor increased. The threshold which defines the upper limit of marginal area is decided by the engineer and defined relative to the threshold for the planned area, for example, 2 dB above the threshold for planned area.

The ***overload area*** is the area where the cell load is beyond the controllable limits. This can affect the coverage and quality of the cell-edge users. Generally, in this state, the admission control stops allowing more voice real time RABs in the cell while the packet scheduler tries to reduce the load by scheduling lower bit rates.

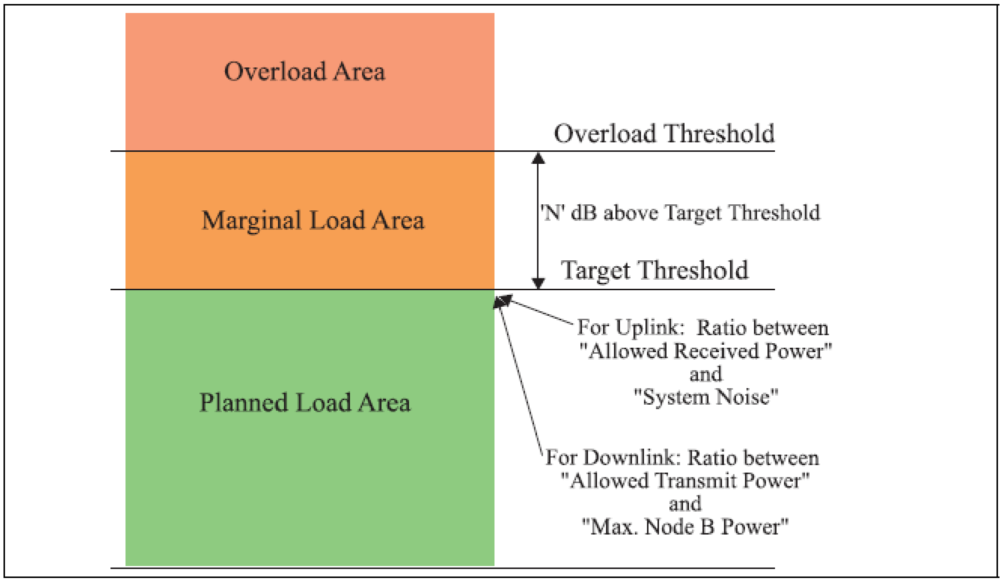


Figure 2-8: Load Regions used in Radio Resource Management

Resource Management algorithms can be divided into cell-based and connection-based algorithms on the basis of their different purposes. However, this distinction should not be taken to suggest that there is a clear-cut division between the radio resource algorithms. It has to be stressed that the radio resource algorithms are closely interdependent, and therefore are best considered as a functional whole [35].

2.4 Introduction to Fuzzy Logic

Fuzzy Logic is a form of Artificial Intelligence invented by Lofti Zadeh, a professor at the University of California, Berkley, who developed fuzzy set theory in 1965 [36]. The basic idea behind fuzzy logic is that of a linguistic variable, which is a variable whose values are words and sentences rather than numbers (such as warm, hot and cold). Fuzzy logic uses fuzzy sets which are sets without crisp and clearly defined boundaries in which membership is a matter of degree. Fuzzy set theory provides a mathematical approach for carrying out approximate reasoning processes when available information is uncertain, incomplete, imprecise, or vague [37].

2.4.1 Fuzzification

Fuzzification is the process of transforming crisp numerical values into fuzzy linguistic values through the use of membership functions (MF) [38]. In other words, determining how much each discrete input value belongs to each input fuzzy set using the corresponding membership function. A MF is used to quantify a linguistic variable, in that, it takes a crisp numerical value and returns the degree to which that numerical value belongs to the fuzzy set the MF represents [39]. The degree of membership determined by any MF is always in the range [0, 1]. For example, a value will have a membership degree of 0 if it is completely outside a fuzzy set, and 1 if it is wholly within the fuzzy set, or any value in between. Since most variables in a fuzzy system have several MFs attached to them, fuzzification will result in the translation of a single crisp numerical value into multiple degrees of membership [40]. The steps in the fuzzification process are:

- Definition of a universe of discourse,
- Identification and definition of the linguistic variables,
- Definition of the membership functions for each linguistic variables bounded by the universe of discourse,
- Representation of the membership functions graphically by choosing suitable membership functions

The membership functions can take different shapes such as triangular, trapezoidal, piecewise linear, Gaussian, or singleton depending on the notion the set is intended to describe and on the particular application involved. The chosen shape of the membership function should be representative of the respective variable and also dependent on the computing resources available [41]. Figure 2-9 below shows the different types of membership functions;

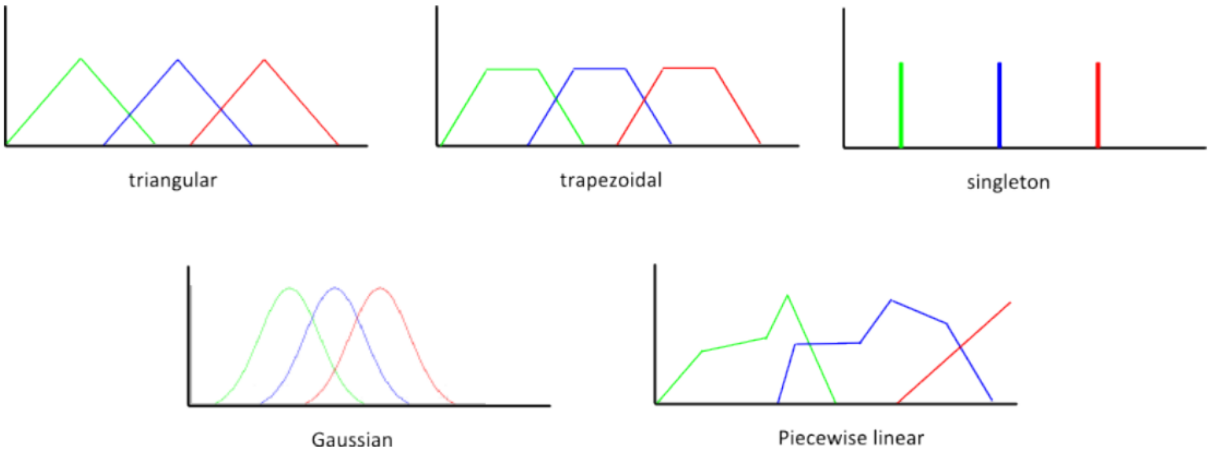


Figure 2-9: Different Types of Membership Functions

2.4.2 Fuzzy Rule Base

The fuzzy rule base is simply a database of the desired control rules for the system. It is the equivalent of a controller in a conventional control system, and is constructed to control the output variable [38, 39]. It consists of a number of linguistic If-Then rules comprising an antecedent or condition which is the If part and a consequent or conclusion which is the Then part. These rules resemble the Human thought process and the computer uses the linguistic variables, derived after fuzzification for execution of the rules [42]. They are very simple to understand and write, which makes the fuzzy logic controller programming very simple [43]. The actual calculation of the consequent using the conditions calculated from the fuzzified inputs is reserved for the inference engine. The fuzzy rules maybe in the following form:

- IF <condition1 AND/OR condition2> THEN <consequence>

2.4.3 Fuzzy Inference Engine

The inference engine is the reasoning mechanism, which controls rule matching, coordinates and organizes the sequence of steps used in solving a particular problem, and resolves any conflicts [39]. It is the heart of the fuzzy logic controller and acts as the bridge between the fuzzification input stage and defuzzification output stage of the controller, translating the designer's desired control rules from a linguistic representation to a numeric computation. The inference engine can be divided into three elements: aggregation, composition, and accumulation [41].

The first step of the inference process is known as "aggregation." During fuzzification, each condition in the antecedent is mapped to a degree of membership in the corresponding input fuzzy set. In the aggregation process these conditions are aggregated according to the logical statement connecting them, such as AND/OR. The result of an AND operation is often defined as either the minimum (min) of the two fuzzy values compared, or the product (prod) of the two values. While, an OR operation is often defined as either the maximum (max) of the two fuzzy values compared, or the probabilistic sum (sum). The probabilistic sum is defined as the sum of the two values compared, minus their product. A rule is active or is said to be 'fired' if it has a nonzero value. The degree to which a rule activates depends on the degree to which the facts and antecedents match and the method of fuzzy inference used.

"Composition" or "implication" is the second step in the inference process in which the consequent part of each rule is made using the premises calculated in the aggregation step. The product of the composition step is not a single output value for each rule in the rule base, but rather one modified output controlled by the premise calculated in the aggregation step fuzzy set for each rule known as "implied" fuzzy sets. There are two fundamental methods of creating the fuzzy sets that are the result of composition similar to the function described in the AND operation ie; minimum and product. The minimum operation truncates the output fuzzy set based on the value of the premise while the product operation scales the output fuzzy set based on the premise.

The third and last step of the inference process is the "accumulation," or "results aggregation." In this step the output of the composition process i.e. the implied fuzzy sets are combined into an accumulated fuzzy set, which is the input to the defuzzification process. The sets are combined by calculating the union of the implied membership functions.

Types of fuzzy inference systems are explained below:

i) Mamdani type fuzzy inference

The Mamdani method (also known as MAX-MIN algorithm) operates on each rule (min fashion) and combining all the rules (max fashion) [37]. In addition the in Mamdani rules the antecedents and the consequent parts of the rule are expressed using linguistic labels. It gives an output that is a fuzzy set e.g.

If A is x_1 and B is x_2 then C is x_3 where x_1, x_2, x_3 are Fuzzy sets as shown in Figure 2-9 below;

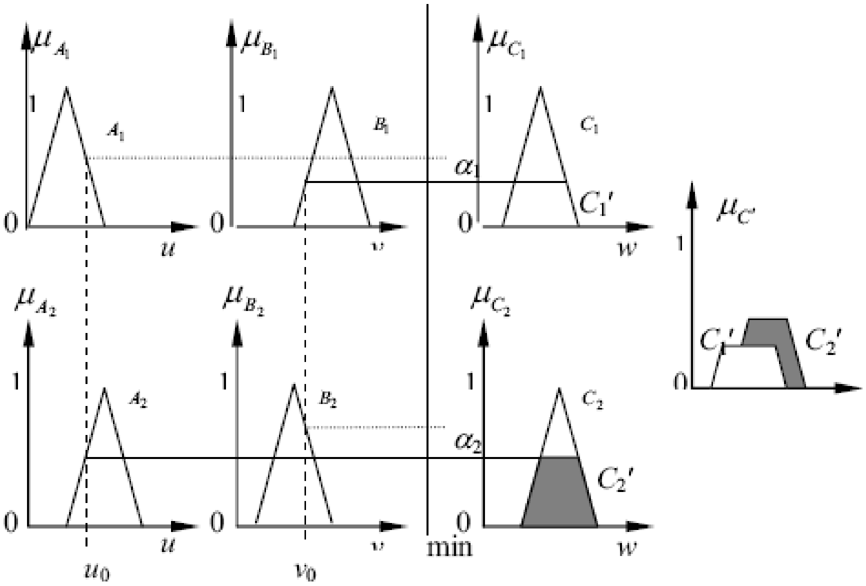


Figure 2-10: Graphical representation of Mamdani method with singleton input

ii) Takagi-SugenoModel

The Takagi-Sugeno fuzzy model uses crisp functions as the consequences of the rule. In the Sugeno rules the consequent part is expressed as an analytical expression or equation [37]. It gives an output that is either constant or a linear (weighted) mathematical expression e.g.

If A is x_1 and B is x_2 then $C = \mathrm{a}x_1 + \mathrm{b}x_2 + c$ where a, b and c are constants as shown in Figure 2-10.

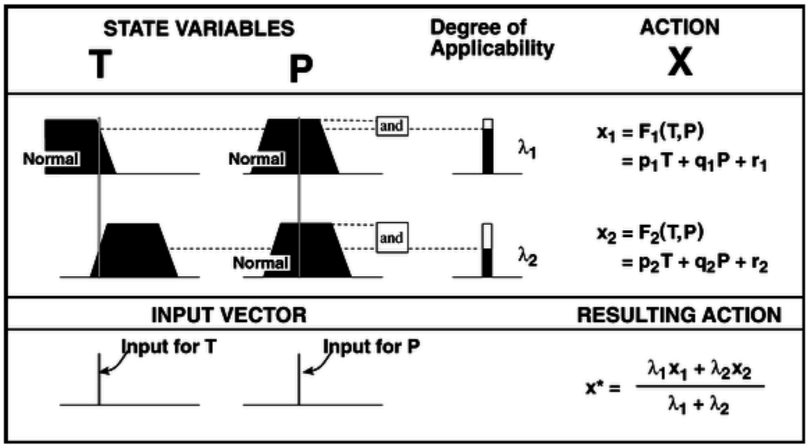


Figure 2-11: A two input, two rule Sugeno FIS

2.4.4 Deffuzification

The system to be controlled using a fuzzy logic controller requires a crisp or discrete output, rather than a fuzzy membership function such as is produced by the inference engine [39]. Defuzzification is the process of converting the fuzzy output set which is a result of the inference process into a discrete value. There are many different methods of defuzzification with varying levels of complexity including the Center of Gravity (CoG) method, the Mean of Maxima (MoM) method and the Threshold methods [39, 40].

i) Centroid method

Suppose that the membership function of a control inference is$\mu_B(z)$, and its support set (the "crisp" set for which the membership grade is greater than zero) is given by: $S = \{c|\mu_B(z) > 0\}$ Then, the centroid method of defuzzification is expressed as

$$z^* = \frac{\int \mu_B\,(z).zdz}{\int \mu_B\,(z)dz} \qquad (2-1)$$

where z is the defuzzified control action, which is given by the centroid (or center of gravity) of the membership function of control inference. The discrete case is given by:

$$fr_c = \frac{\sum_{i=1}^{s} area_i m_i}{\sum_{i=1}^{s} area_i} \qquad (2-2)$$

ii) Mean of maxima method

In the mean of maxima method, if the membership function of the control inference is unimodal (i.e., it has just one peak point), the control value at the peak membership grade is chosen as the defuzzified control action. Specifically,

$\hat{c} = c_{max}$ such that $\mu_c\ (c_{max}) = max_{c\epsilon S}\mu_c\ (c)$

The result for the discrete case follows from this relation. If the control membership function is multi-modal (i.e., has more than one peak), the mean (average) of the control values at these peak points, weighted by the corresponding membership grades, is used as the defuzzified value. Hence, if we have

c_i such that $\mu_c\ (c_i)\Delta = max_{c\epsilon S}\mu_c\ (c), \qquad i = 1, 2, 3, \dots, p$

Then $\hat{c} = \frac{\sum_{i=1}^{p} \mu_i c_i}{\sum_{i=1}^{p} \mu_i} \qquad (2-3)$

Here, p is the total number of modes (peaks) in the control inference membership function.

iii) Threshold methods

When the threshold method is used it is desirable to leave out the boundaries of the control inference membership function such that only the main core of the control inference is used.

Specifically, we select:

$S_\alpha = \{c|\mu_c(c) \geq \alpha\}$ in which α is the threshold value

2.5 Related Work

Due to its significant impact on 3G cellular networks, CPICH power control has been the subject of various studies. Siomona et al [6,7] consider the problem of minimizing the total amount of pilot power subject to a coverage constraint. They studied the problem of minimizing the CPICH pilot power of 3G networks subject to service coverage and smooth handover. The conclusion on ensuring smooth handover in addition to full coverage results in a moderate increase in pilot power formed a basis of our research where the CPICH power coverage impact is widened to perform traffic balancing based on fuzzy logic.

Muhammad *et al* [23] present a framework for a self-optimizing RAN, which adapts Antenna Tilt and Pilot Power according to the current load in the system. The framework uses distributed optimization and network performance-based optimization triggers. Additionally, they introduce the concept of Coupling Matrix, to avoid the traditional global network optimization.

Gerdenitsch *et al* [24] developed an optimization algorithm for finding the best settings of the antenna tilt and common pilot channel power of the base stations. This algorithm is a parametric method, based on a set of rules. Both studies [23] and [24] proposed the use of the antenna tilts together with the CPICH power which requires the installation of RETs, this would bring a cost implication which most operators may not be willing to invest in. Furthermore the physical antenna tilt optimization caused longer optimization cycles due to manual electrical and mechanical tilting of antennas, the automatic control of the CPICH power only would offer fast feedback cycles of traffic balancing.

In [5], Mfula *et al* presented a self-optimization based algorithm for tuning the CPICH pilot power which when running automatically, the algorithm could be used to autonomously control the pilot power and load balance traffic in the network and when scheduled or triggered manually, the algorithm could also be used to optimize the network capacity in clusters expecting a surge in during a certain time for example at a stadium during a match. The research did not factor the interference of the cell during traffic balancing which is a major quality component of a 3G cell. This was factored in this research resulting to an even more robust traffic balancing system.

Chen *et al* [4] present and demonstrate mathematical modeling and optimization algorithm for enhancing HSDPA performance by automatically linking Common Pilot Channel (CPICH) power to HSDPA transmit power. Their approach uses non-uniformly allocated CPICH power and focuses on HSDPA performance with the side constraint of R99 soft handover. Solving the mathematical model gives the optimal CPICH allocation for small networks. While this study provided a good foundation for this research, the authors focused on the various mathematical approaches with no practical end to end completeness and they did not address challenges with efficiency and automating operations in their solutions.

2.6 Literature Review Summary

Previous research studies have used varied approaches to optimizing the 3G cellular networks cell capacity. These can be grouped into the physical and soft parameter approaches where the physical approach targets antenna height, azimuth and tilt changes while the soft parameter approach targets handover and CPICH power changes. While these studies provided a good foundation for this research, they focused on exploring various mathematical approaches with no practical end to end completeness. In addition though a rule-based parametric algorithm for CPICH power and antenna tilt optimization in 3G cellular networks which is close to the fuzzy logic approach used in this research has been presented, the algorithm in this research entirely focuses on CPICH power optimization because, based on the practical field experience, usually not all base stations in the network have antennas which support remote electrical tilt (RET). Furthermore, unlike physical antenna tilt optimization, which may offer longer optimization cycles due to manual electrical and mechanical tilting of antennas, automatic control of the CPICH power offers fast feedback cycles of optimization which the proposed solution is built to specifically support. Therefore, the current work seeks to develop a practical CPICH power control system that would balance the traffic load of a cell in a 3G cellular network.

CHAPTER 3 METHODOLOGY

A fuzzy logic controller was designed and simulated in MATLAB. The fuzzy logic controller (FLC) was involved in the detection of high load 3G cells that do not have enough cell resources available and could benefit from CPICH power adjustment as a radio optimization engineer would normally do manually. The FLC was designed with 3 inputs which are the Downlink cell load, Received Total Wideband Power (RTWP) which is the Interference in the cell and the neighboring cells' load. The output of the FLC was the CPICH power setting which would determine whether to increase or decrease the coverage footprint of the cell hence influencing the cell downlink power utilization.

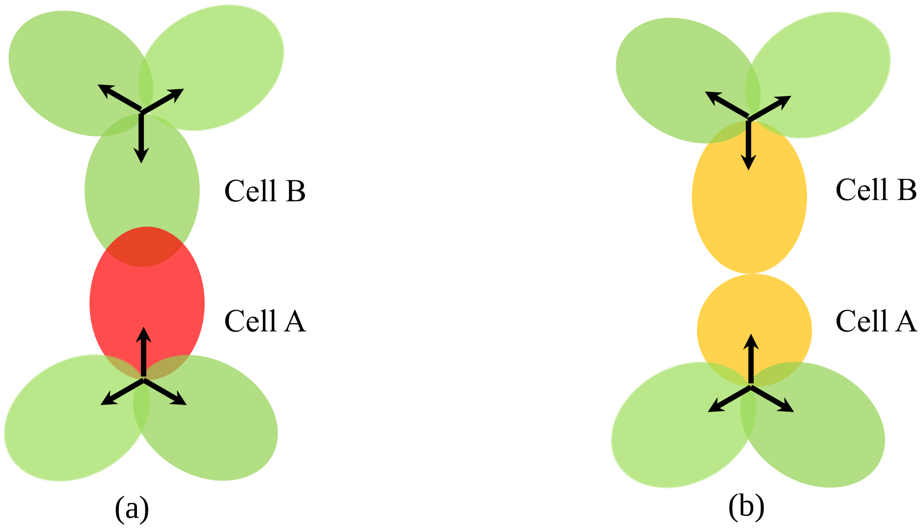


Figure 3-1: Network cells with different cell loading

Increasing the CPICH pilot power makes the cell coverage size bigger while reducing pilot power makes the cell coverage size smaller. Therefore, pilot power can be used as a tool for traffic load balancing among cells. For this study we shall consider a network of two cells as in Figure 3-1. Cells before pilot power adjustment are as shown in Figure 3-1(a). The cell with a high downlink cell load is represented in red color while green cells represent cells with normal load. The intersection between the red and green cells in Figure 3-1(a) represents a coverage area which is receiving a radio signal which is greater than a given threshold from more than one cell. Figure 3-1(b) shows the cells after pilot power adjustment. The yellow cells represent the load after redistribution.

3.1 CPICH Power Fuzzy Logic Controller parameters

There are three input parameters considered in this study; Downlink cell load, RTWP (Interference in the cell) and the neighboring cells' load. The only output parameter of the fuzzy inference system is the CPICH power adjustment.

3.1.1 Downlink Cell Load

The downlink cell capacity is limited by its total available transmit cell power, which is determined by the NodeB RF module capability and the maximum output power configured for the cell. The proportion between Voice and Data traffic varies all the time. The capacity left over from Voice traffic is reserved for best effort Data traffic. The overall goal is to provide as much radio resources as possible to the users [31].

The downlink transmit power consists of the following, as shown in Figure 3-2:

a. Common channel (CCH) power

b. Non-HSPA power without CCH

c. HSPA power

d. Power margin

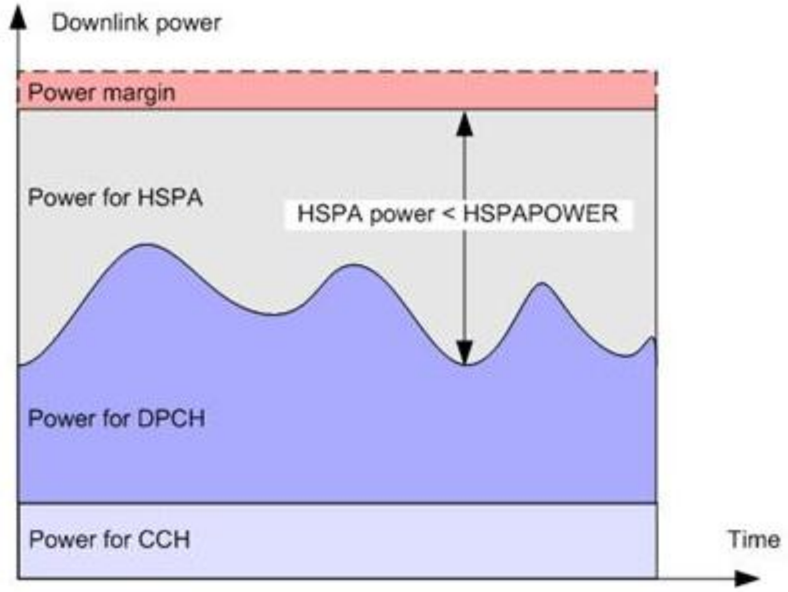


Figure 3-2: Dynamic power resource allocation [32]

The downlink cell power resources are allocated as follows:

1. Downlink power resources are first reserved for Common Control physical channels and allocated to the Dedicated Physical Channel. The remaining power resources are available for Data traffic.
2. The Data power resources are first allocated to the high speed uplink packet access (HSUPA) downlink control channels while the remaining downlink cell power resources are allocated for high speed downlink packet access (HSDPA).
3. The HSDPA power resources are allocated first to the downlink control channel high-speed shared control channel (HS-SCCH) while the remaining power resources are allocated for the traffic channel high-speed physical downlink shared channel (HS-PDSCH) [33].

The downlink cell power consumption is affected by the cell coverage area, user equipment (UE) locations, and the traffic load in the cell. A large cell coverage area, UEs being far away from the base station, and high traffic load contribute to a high downlink cell power consumption. Therefore, downlink power congestion is more likely to occur in hotspots or in cells with large coverage. When the downlink cell power consumption is insufficient, the following occurs:

1. The data throughput decreases.
2. The service quality degrades.
3. New subscriber service requests are likely to be rejected.

3.1.2 Uplink Interference

The WCDMA system is limited by interference (the less interference there is, the more capacity the system can offer to the users). Every user equipment (UE) accessing the network generates a signal which, from the point of view of the base transceiver station (BTS), increases interference in the system. At the same time, the capacity of a WCDMA system is proportional to the level of interference in the system. The less interference there is, the more capacity the system can offer [31]. The RTWP range is from -110 dBm to -70 dBm where the normal, acceptable RTWP average value is generally below -104.5. Values around -95 dBm indicate that the cell has some uplink interferers and if the value is above -85 dBm the cell has strong uplink interferers. The relationship between the rise over thermal (RoT) and the uplink load factor is as indicated in Figure 3-3 below:

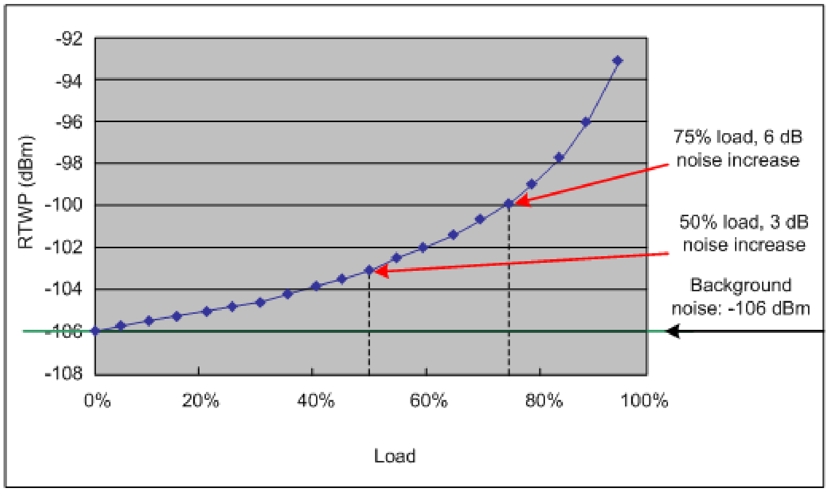


Figure 3-3: Relationship between RTWP, noise increase, and uplink load [32]

RTWP measures the uplink cell capability on WCDMA networks. RTWP includes the following:

1. Background noise
2. Intra-system interference, including uplink signals sent by the UEs in the serving and neighboring cells or faulty equipment
3. External interference [33]

3.1.3 Neighbor Cells' Load

The Neighbor cells' load as shown in figure 3-4 below; is factored so as to prevent traffic steering to high loaded cells, *pilot* power adjustment is not done when the neighbor cell is already overloaded. As Figure 3-4 illustrates below the serving cell is highly loaded same applies to the neighboring cells. Therefore in this case it wouldn't be advisable to ramp down the CPICH power of the current serving cell as the traffic would be off-loaded to an already overloaded cell therefore negatively impacting further on the cell quality.

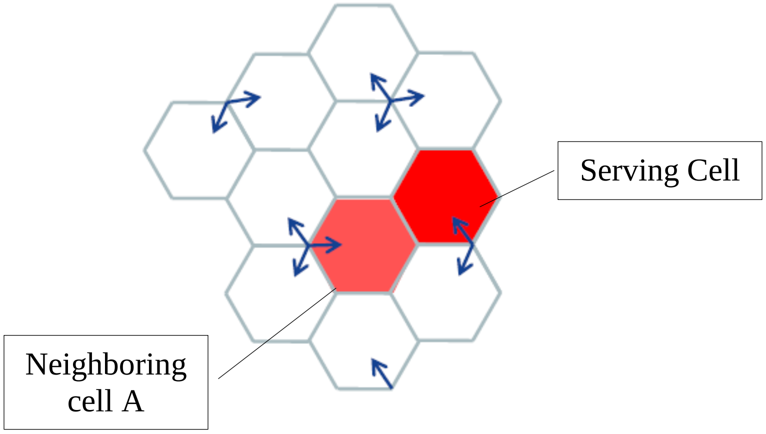


Figure 3-4: Neighbor cells' load [33]

3.1.4 CPICH Power

The CPICH power allocation greatly influences the cell coverage area and pattern. A conventional strategy is to uniformly allocate a constant proportion of the total Downlink cell power to CPICH which may not always be practical due to the changing traffic levels. In mobile networks using WCDMA, the CPICH signals are used by mobile terminals for cell selection, handover and channel quality estimation. The strength of the CPICH signal largely impacts the coverage area of the cell, affecting the network capacity, and thereby the QOS, and is therefore a crucial parameter in Radio network planning and optimization. Pilot power is an important parameter that allows us to control the strength of the CPICH signal. The more power spent for CPICH, the better coverage is obtained. On the other hand, a higher value of the CPICH power level in a cell may bring pilot pollution in the network and less power available to serve user traffic in the cell.

While setting the CPICH power level the first challenge we meet is a coverage-capacity tradeoff; this tradeoff rises such that the higher the CPICH power the bigger the coverage, while the lower the CPICH power allows more power to be used by traffic channels. For this study the CPICH power is optimized in such a way that the Cell coverage is reduced when a high cell load is detected by reducing the CPICH power. When a low load cell is detected the CPICH power is increased causing an increase in the Cell coverage hence ensuring the cell is well utilized. The CPICH power is usually between 30dBm (5%) and 36dBm (20%) of the total cell transmit power. Commonly, the CPICH power is 10% of the typical total transmit power of 43 dBm.

3.2 Development of Fuzzy Logic Controller for CPICH Power Optimization

A functional block diagram representation of the fuzzy controller is shown in Figure 3-8. The inputs to the controller are the Downlink cell load, RTWP and the neighboring cells' load. The output of the fuzzy controller is the CPICH power setting.

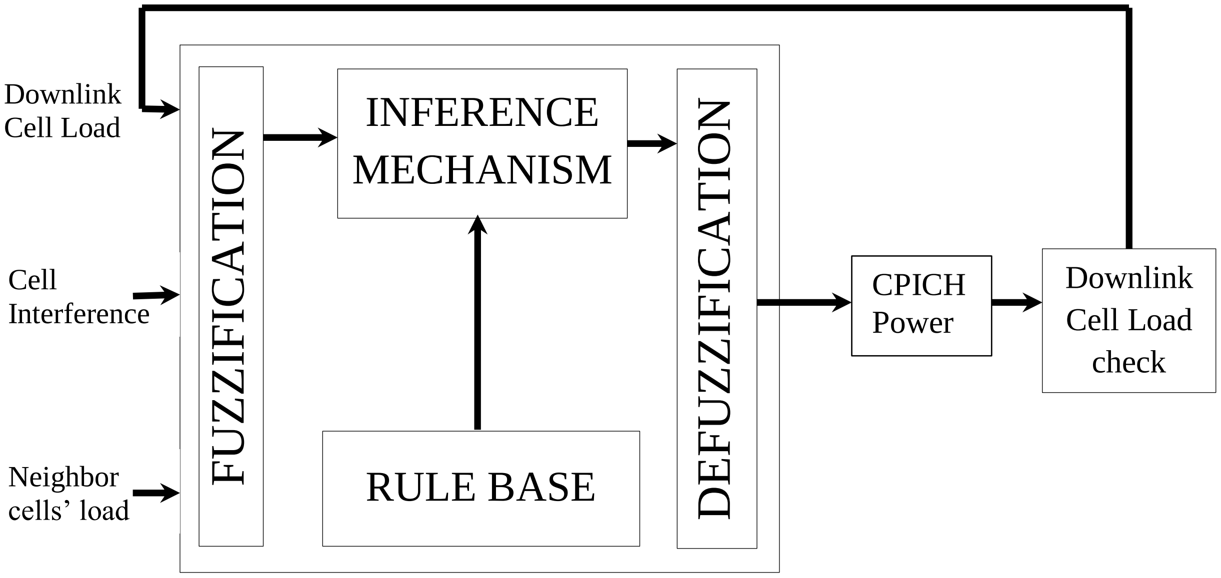


Figure 3-5: The CPICH Power Fuzzy Logic Controller

3.2.1 Fuzzification

Fuzzy sets for each input and output variable were defined and the number of fuzzy partitions determined for the input and output linguistic variables. The range of the Downlink cell load was taken to be 0% to 100%, the RTWP varied from -110 dBm to -70 dBm and the neighboring cells' load ranged from 0% to 100%. The CPICH power setting was from 30dBm to 36dBm.

The input linguistic variables were chosen as in Table 3-1 to Table 3-3:

Table 3-1: Downlink Cell Load fuzzy set

Fuzzy set or label	Set Description
VLL: Very Low Load	The load is very low as compared to the desired value
MLL: Medium Low Load	The load is low but close to the desired value
NL: Normal Load	The load is in the normal range
MHL: Medium High Load	The load is high but close to the desired value
VHL: Very High Load	The load is very high as compared to the desired value

Table 3-2: Uplink Interference fuzzy set

Fuzzy set or label	Set Description
VWI: Very Weak Interference	The cell has very weak interference
MWI: Medium Weak Interference	The cell has medium weak interference
ZI: Zero Interference	The cell interference is within the acceptable levels
MSI: Medium Strong Interference	The cell has medium strong interference
VSI: Very Strong Interference	The cell has very strong interference (very poor quality)

Table 3-3: Neighbor cells' load fuzzy set

Fuzzy set or label	Set Description
NLL: Neighbour Low Load	The Neighbor cells' load is very low as compared to the desired value
NNL: Neighbour Normal Load	The Neighbor cells' load is in the normal range
NHL: Neighbour High Load	The Neighbor cells' load is very high as compared to the desired value

The output linguistic variables are given Table 3-4 below:

Table 3-4: CPICH Power fuzzy set

Fuzzy set or label	Set Description
NLC: Negative Large CPICH Power	CPICH power to be large in the negative direction
NSC: Negative Small CPICH Power	CPICH power to be small in the negative direction
ZC: Zero CPICH Power	CPICH power to be around the normal value
PSC: Positive Small CPICH Power	CPICH power to be small in the positive direction
PLC: Positive Large CPICH Power	CPICH power to be large in the positive direction

The design of a Fuzzy Logic Controller required the choice of membership functions covering the entire universe of discourse and overlapping each other in order to avoid any kind of discontinuity with respect to the minor changes in the inputs. Figures-3-9 to 3-12 show the fuzzy input variable for Downlink Cell Load, RTWP (Interference in the cell) the neighboring cells' load and CPICH power setting respectively. The membership functions define how each point in the input space is mapped to a membership value between 0 and 1. The Gaussian type membership function was chosen for the inputs and outputs because it represents the nonlinear nature of the problem in a better way than triangular or trapezoidal membership functions. Furthermore, the triangular and trapezoidal membership functions contain discontinuities in their derivatives, which can result in abrupt changes in the output of the controller. The membership functions for the downlink cell load and uplink interference were made denser at the center in order to provide more sensitivity.

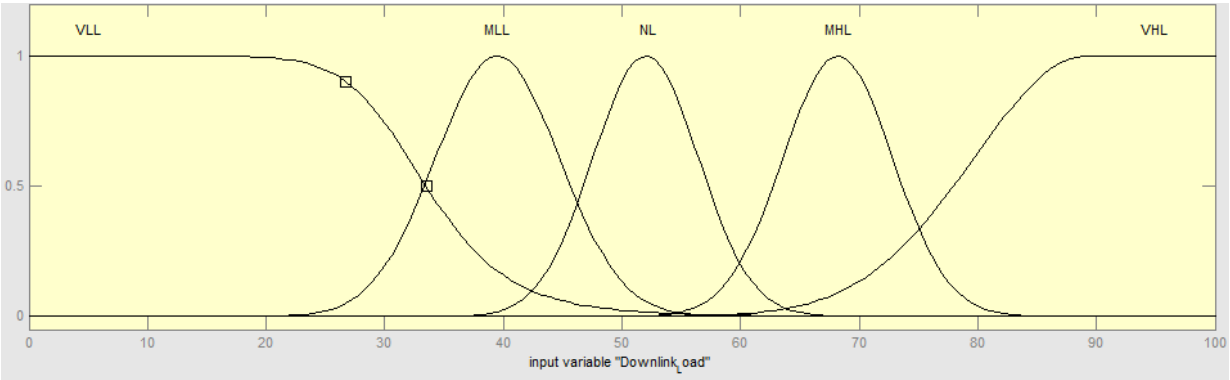


Figure 3-6: Membership function for Downlink cell load

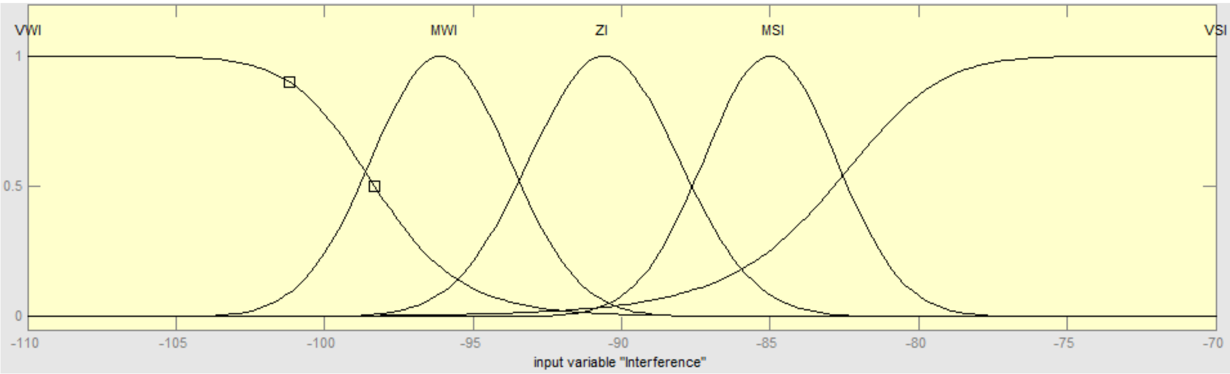


Figure 3-7: Membership function for RTWP (Interference in the cell)

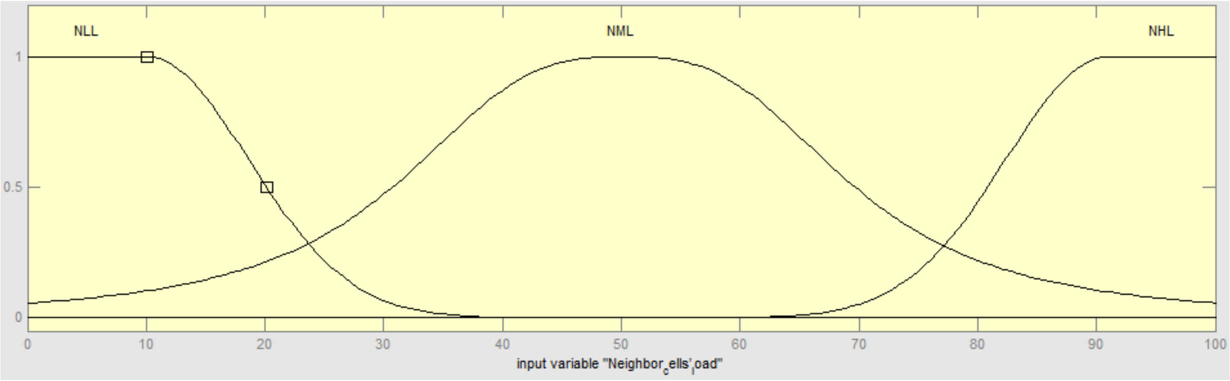


Figure 3-8: Membership function for neighboring cells' load

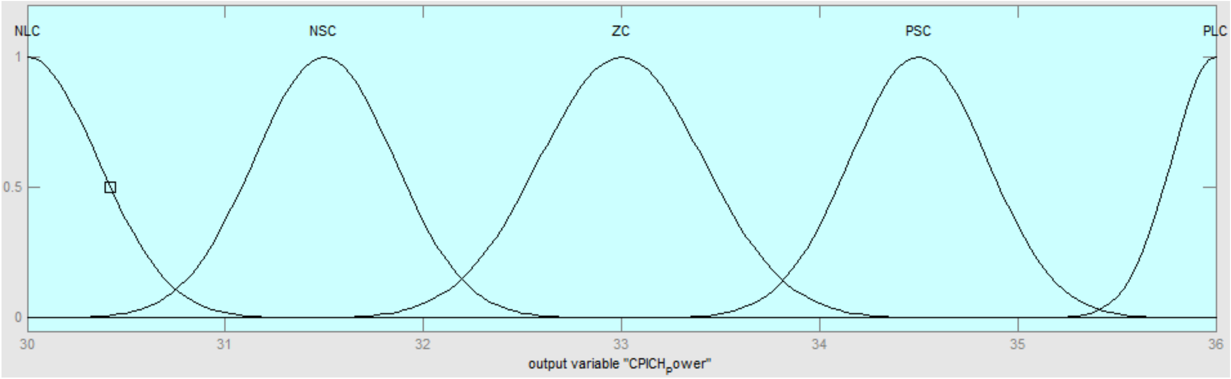


Figure 3-9: Membership function for CPICH power setting

3.2.2 Fuzzy Inference

After choosing the appropriate membership functions, a rule base was created. It consisted of a number of Fuzzy If-Then rules that completely define the behavior of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system. The rules were fine-tuned by simulations by adjusting the choice of the number of rules, setting membership function boundaries, and adjusting the number of fuzzy partitions. The developed rule base consisted of the following 75 If-Then rules:

If Downlink Load is VLL and interference is VWI and Neighbor cells' load is NLL then CPICH power is PLC
If Downlink Load is VLL and interference is MWI and Neighbor cells' load is NLL then CPICH power is PLC
If Downlink Load is VLL and interference is ZI and Neighbor cells' load is NLL then CPICH power is PLC

If Downlink Load is VLL and interference is MSI and Neighbor cells' load is NLL then CPICH power is PLC

If Downlink Load is VLL and interference is VSI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is MLL and interference is VWI and Neighbor cells' load is NLL then CPICH power is PSC

If Downlink Load is MLL and interference is MWI and Neighbor cells' load is NLL then CPICH power is PSC

If Downlink Load is MLL and interference is ZI and Neighbor cells' load is NLL then CPICH power is PSC

If Downlink Load is MLL and interference is MSI and Neighbor cells' load is NLL then CPICH power is PSC

If Downlink Load is MLL and interference is VSI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is NL and interference is VWI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is NL and interference is MWI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is NL and interference is ZI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is NL and interference is MSI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is NL and interference is VSI and Neighbor cells' load is NLL then CPICH power is ZC

If Downlink Load is MHL and interference is VWI and Neighbor cells' load is NLL then CPICH power is NSC

If Downlink Load is MHL and interference is MWI and Neighbor cells' load is NLL then CPICH power is NSC

If Downlink Load is MHL and interference is ZI and Neighbor cells' load is NLL then CPICH power is NSC

If Downlink Load is MHL and interference is MSI and Neighbor cells' load is NLL then CPICH power is NSC

If Downlink Load is MHL and interference is VSI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VHL and interference is VWI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VHL and interference is MWI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VHL and interference is ZI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VHL and interference is MSI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VHL and interference is VSI and Neighbor cells' load is NLL then CPICH power is NLC

If Downlink Load is VLL and interference is VWI and Neighbor cells' load is NNL then CPICH power is PLC

If Downlink Load is VLL and interference is MWI and Neighbor cells' load is NNL then CPICH power is PLC

If Downlink Load is VLL and interference is ZI and Neighbor cells' load is NNL then CPICH power is PLC

If Downlink Load is VLL and interference is MSI and Neighbor cells' load is NNL then CPICH power is PLC

If Downlink Load is VLL and interference is VSI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is MLL and interference is VWI and Neighbor cells' load is NNL then CPICH power is PSC

If Downlink Load is MLL and interference is MWI and Neighbor cells' load is NNL then CPICH power is PSC

If Downlink Load is MLL and interference is ZI and Neighbor cells' load is NNL then CPICH power is PSC

If Downlink Load is MLL and interference is MSI and Neighbor cells' load is NNL then CPICH power is PSC

If Downlink Load is MLL and interference is VSI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is NL and interference is VWI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is NL and interference is MWI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is NL and interference is ZI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is NL and interference is MSI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is NL and interference is VSI and Neighbor cells' load is NNL then CPICH power is ZC

If Downlink Load is MHL and interference is VWI and Neighbor cells' load is NNL then CPICH power is NSC

If Downlink Load is MHL and interference is MWI and Neighbor cells' load is NNL then CPICH power is NSC

If Downlink Load is MHL and interference is ZI and Neighbor cells' load is NNL then CPICH power is NSC

If Downlink Load is MHL and interference is MSI and Neighbor cells' load is NNL then CPICH power is NSC

If Downlink Load is MHL and interference is VSI and Neighbor cells' load is NNL then CPICH power is NSC

If Downlink Load is VHL and interference is VWI and Neighbor cells’ load is NNL then CPICH power is NSC
If Downlink Load is VHL and interference is MWI and Neighbor cells’ load is NNL then CPICH power is NSC
If Downlink Load is VHL and interference is ZI and Neighbor cells’ load is NNL then CPICH power is NSC
If Downlink Load is VHL and interference is MSI and Neighbor cells’ load is NNL then CPICH power is NSC
If Downlink Load is VHL and interference is VSI and Neighbor cells’ load is NNL then CPICH power is NSC
If Downlink Load is VLL and interference is VWI and Neighbor cells’ load is NHL then CPICH power is PLC
If Downlink Load is VLL and interference is MWI and Neighbor cells’ load is NHL then CPICH power is PLC
If Downlink Load is VLL and interference is ZI and Neighbor cells’ load is NHL then CPICH power is PLC
If Downlink Load is VLL and interference is MSI and Neighbor cells’ load is NHL then CPICH power is PLC
If Downlink Load is VLL and interference is VSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is MLL and interference is VWI and Neighbor cells’ load is NHL then CPICH power is PSC
If Downlink Load is MLL and interference is MWI and Neighbor cells’ load is NHL then CPICH power is PSC
If Downlink Load is MLL and interference is ZI and Neighbor cells’ load is NHL then CPICH power is PSC
If Downlink Load is MLL and interference is MSI and Neighbor cells’ load is NHL then CPICH power is PSC
If Downlink Load is MLL and interference is VSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is NL and interference is VWI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is NL and interference is MWI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is NL and interference is ZI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is NL and interference is MSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is NL and interference is VSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is MHL and interference is VWI and Neighbor cells’ load is NHL then CPICH power is NSC
If Downlink Load is MHL and interference is MWI and Neighbor cells’ load is NHL then CPICH power is NSC
If Downlink Load is MHL and interference is ZI and Neighbor cells’ load is NHL then CPICH power is NSC
If Downlink Load is MHL and interference is MSI and Neighbor cells’ load is NHL then CPICH power is NSC
If Downlink Load is MHL and interference is VSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is VHL and interference is VWI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is VHL and interference is MWI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is VHL and interference is ZI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is VHL and interference is MSI and Neighbor cells’ load is NHL then CPICH power is ZC
If Downlink Load is VHL and interference is VSI and Neighbor cells’ load is NHL then CPICH power is ZC

The program below was implemented in designing the Fuzzy Logic Controller using the FIS editor in MATLAB/SIMULINK®:

```
[System]
Name='Final Project_Jane 2nd Iteration'
Type='mamdani'
Version=2.0
NumInputs=3
NumOutputs=1
NumRules=75
AndMethod='min'
OrMethod='max'
```

```
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Downlink_Load'
Range=[0 100]
NumMFs=5
MF1='VLL':'gbellmf',[28.4 4.05 5.09]
MF2='MLL':'gaussmf',[5.24 39.5]
MF3='NL':'gaussmf',[4.46 52]
MF4='MHL':'gaussmf',[4.64 68.2]
MF5='VHL':'gauss2mf',[9.62 89.2455026455027 9.52 110.645502645503]

[Input2]
Name='Interference'
Range=[-110 -70]
NumMFs=5
MF1='VWI':'gbellmf',[16.6931216931217 5.83 -115]
MF2='MWI':'gaussmf',[2.32372647052347 -96.1]
MF3='ZI':'gaussmf',[2.51 -90.5846560846561]
MF4='MSI':'gaussmf',[2.22441423884957 -85]
MF5='VSI':'gbellmf',[12.8571428571429 3.46 -70]

[Input3]
Name='Neighbor_cells’_load'
Range=[0 100]
NumMFs=3
MF1='NLL':'gauss2mf',[10.4 -7.8 8.554 10.08]
MF2='NML':'gbellmf',[19.5 1.49 50.2]
MF3='NHL':'gauss2mf',[8.61305506238305 90.956340956341 4.07 110]

[Output1]
Name='CPICH_Power'
Range=[30 36]
NumMFs=5
MF1='NLC':'gaussmf',[0.3573 30]
MF2='NSC':'gaussmf',[0.355 31.5]
MF3='ZC':'gaussmf',[0.414 33]
MF4='PSC':'gaussmf',[0.347 34.5]
MF5='PLC':'gaussmf',[0.2227 36]

[Rules]
1 1 1, 5 (1) : 1
1 2 1, 5 (1) : 1
1 3 1, 5 (1) : 1
1 4 1, 5 (1) : 1
1 5 1, 3 (1) : 1
2 1 1, 4 (1) : 1
2 2 1, 4 (1) : 1
2 3 1, 4 (1) : 1
2 4 1, 4 (1) : 1
2 5 1, 3 (1) : 1
3 1 1, 3 (1) : 1
3 2 1, 3 (1) : 1
3 3 2, 3 (1) : 1
```

```
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3 5 1, 3 (1) : 1
4 1 1, 2 (1) : 1
4 2 1, 2 (1) : 1
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4 1 3, 2 (1) : 1
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4 3 3, 2 (1) : 1
4 4 3, 2 (1) : 1
4 5 3, 3 (1) : 1
```

```
5 1 3, 3 (1) : 1
5 2 3, 3 (1) : 1
5 3 3, 3 (1) : 1
5 4 3, 3 (1) : 1
5 5 3, 3 (1) : 1
```

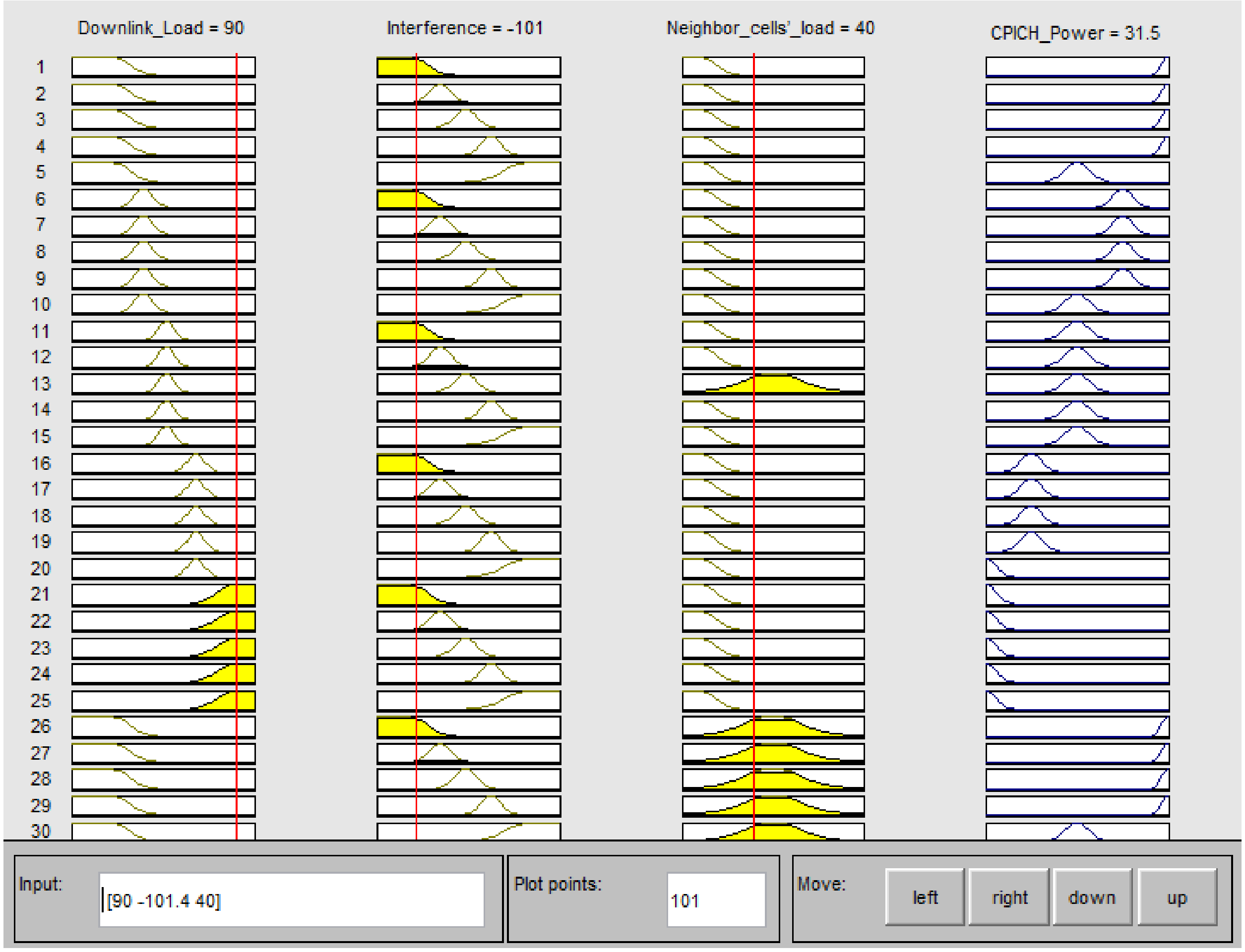
3.2.3 De-fuzzification

The output of the inference process is a fuzzy set specifying a distribution space of fuzzy control actions defined over an output universe of discourse. The output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity during the last stage of the handoff decision. The centroid of area method was elected to defuzzify for changing the fuzzy value into the crisp set.

The Crisp value is given by:

$$z^* = \frac{\int \mu_B\,(z).zdz}{\int \mu_B\,(z)dz} \qquad (3-1)$$

Example



Input: [90 -101.4 40]

Plot points: 101

Inputs:

Downlink Load: 90% **Interference:** -101dBm **Neighbor cells' load:** 40%

Output:

CPICH Power: 31.5dBm

3.3 CPICH Power and Downlink Cell Utilization

In the network scenario, we considered 2 base stations with 3-sector antennas each thus comprising 6 cells. In order to investigate the performance and accuracy of the proposed fuzzy logic controller, data was collected on a whole day every 30 minutes. The FLC was then applied to the identified cell for a whole day and the CPICH power of the cell modified based on the output of the fuzzy system.

The total available cell power $P_{TOT}(dBm)$ for the cell is 43dBm. The power conversion of dBm to watts is given by the formula:

$$P_{TOT}(W) = 1W.10^{(P_{TOT}(dBm)/10)}/1000 \qquad (3-2)$$

$$P_{TOT}(W) = 1W.10^{(43)/10)}/1000 \qquad (3-3)$$

$$P_{TOT}(W) = 19.95W \qquad (3-4)$$

The calculation for the Downlink cell load without the FLC at any time i in percentage ($D_{Util}^{i}(\%)$) will be given by the equation below;

$$D_{Util}^{i}(\%) = \frac{10^{(P_{Util}^{i}(dBm)/10)}}{10^{(43)/10)}} \times 100 \qquad (3-5)$$

Where $P_{Util}^{i}(dBm)$ is the Cell Utilization in dBm.

The constant CPICH power $P_{CPICH}(dBm)$ for the cell is 33dBm. The power conversion of dBm to watts is given by the formula:

$$P_{CPICH}(W) = 1W.10^{(P_{CPICH}(dBm)/10)}/1000 \qquad (3-6)$$

The constant CPICH power as a percentage of the Downlink cell load is given by equation 3-7

$$P_{CPICH}(\%) = \frac{10^{(33)/10)}}{10^{(43)/10)}} \times 100 = 10\% \qquad (3-7)$$

The calculation for the Downlink cell load with the FLC at any time i in percentage ($D^{i}_{Fuzzy\ Util}(\%)$) will be given by the equation 3-8;

$$\begin{aligned} D^{i}_{Fuzzy\ Util}(\%) \\ &= \left\{ \left(D^{i}_{Util}(\%) - P_{CPICH}(\%) \right) \times \frac{10^{(\text{Fuzzy CPICH}(dBm)/10)}}{10^{(33)/10)}} \right\} \\ &+ \left\{ \frac{10^{(\text{Fuzzy CPICH}(dBm)/10)}}{10^{(43)/10)}} \times 100 \right\} \qquad (3-8) \end{aligned}$$

Where $D^{i}_{Util}(\%)$ is the Downlink cell load

And Fuzzy $\text{CPICH}(dBm)$ is the output of the Fuzzy logic controller

In wireless communications, while the transmit power is under the control of the transmitter, the received power is affected by a number of environmental factors and device characteristics. For the accuracy of the simulation studies, it is vital to have accurate propagation models for the calculation of received power as all other metrics of system performance such as capacity, coverage, etc. are calculated from it. The COST231 Extension to Hata Model was used in this study to analyze the coverage prediction of the UMTS cell on the Atoll Simulation tool. The standard formula for median path loss in urban areas under the model is:

$$\begin{aligned} P_{L,Urban}(dB) = {} & 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) \\ & + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d) + C_M \qquad (3-9) \end{aligned}$$

where $a\ (hr)$ is a correction factor for the mobile antenna height based on the size of the coverage area and CM is 0 dB for medium sized cities and suburbs, and 3 dB for metropolitan areas. This model is restricted to the following range of parameters:

$$1.5GHz < f_c < 2\ GHz$$

$$30m < h_t < 200\ m$$

$$1m < h_r < 10\ m,$$

$$1Km < d < 20\ Km$$

The Inputs for the Atoll Simulation tool were as in Table 3-5 below;

Table 3-5: Atoll Cell Simulation Parameters

Parameter	Value
Antenna Electrical tilt	5deg
Antenna Gain	17.92dBi
Antenna Half-Power Beam width	65deg
Antenna Height	30m
Antenna Mechanical tilt	2deg
Antenna Type	K742215_2100
Frequency	2100Mhz
Initial CPICH power	33dBm
Max. Cell Power	43dBm
Max. CPICH Power	36dBm
Min CPICH Power	30dBm

3.4 Evaluation of the CPICH Power Optimization Based on Fuzzy Logic Controller

The performance of the CPICH power control system based on fuzzy logic control was evaluated through cell key performance indicator (KPI) analysis. The main KPIs to be considered are the Call setup success rate (CSSR) and the downlink cell utilization. The KPIs were monitored from the Huawei monitoring tool U2000.

3.4.1 Call Setup Success Rate (CSSR)

The Call setup success rate refers to the percentage of all the call attempts made that were successful and is an important KPI in the evaluation of the performance of a 3G cellular network. The CSSR of is made up of two components; radio access bearer (RAB) and radio resource control (RRC) with the formula given by equation 3-10:

$$\mathrm{CSSR}(\%) = RRC\ Setup\ Success\ Ratio \times RAB\ Setup\ Success\ Ratio \times 100 \qquad (3-10)$$

$$\mathrm{CSSR}(\%) = \frac{\text{Number of } RRC\ Setup\ Success}{Number\ RRC\ connection\ attempts} \times \frac{\text{Number of } RAB\ Setup\ Success}{Number\ RAB\ connection\ attempts} \times 100 \qquad (3-11)$$

The RRC setup procedure is the process that establishes the layer-3 connection between UE and RNC that is used for signaling traffic only. After RNC receives the RRC connection request, processes it and allocates relevant resources on layer-1, layer-2 and layer-3 of the air interface for this signaling connection, it notifies the UE for the prepared configuration with the RRC connection setup message after which the UE reports its capabilities to the RNC with the RRC connection setup complete [35]. Figure 3-13 below shows the procedure for successful RRC connection setup;

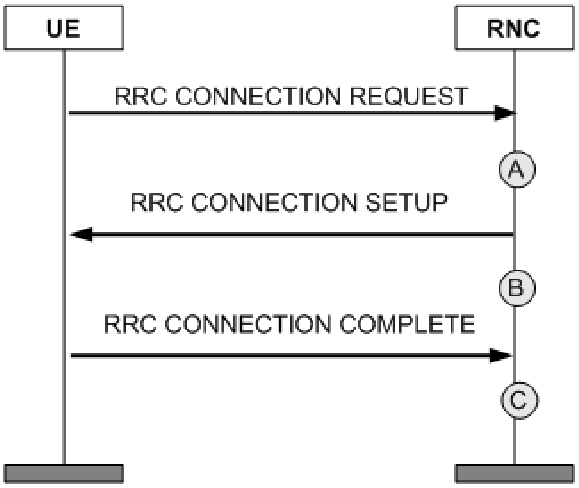


Figure 3-10: Procedure for successful RRC connection setup [35]

RAB setup procedure is the process that establishes the higher-layer connection between UE and the core network (CN) that is used to transfer the user data traffic only. When the RNC receives the RAB assignment request it allocates the necessary resources for the requested service, after successful call admission. The 3G radio resources include channelization, codes, channel elements, downlink power and IUB bandwidth. Then the radio bearer (RB) is setup which is the UTRAN part of the RAB. Upon successful completion of the RB setup, the RNC responds to the CN with the RAB assignment respond message [35].

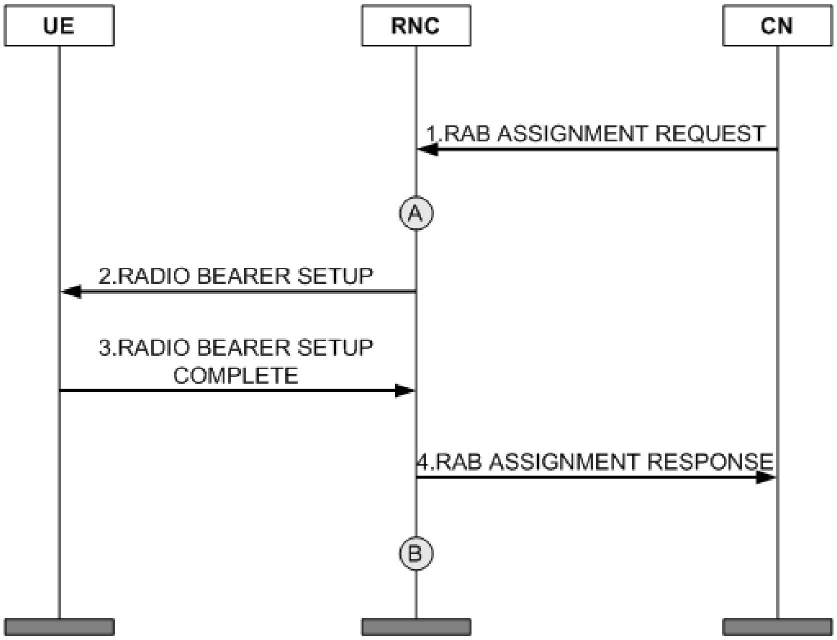


Figure 3-11: RAB setup procedure [35]

3.4.2 Downlink Cell Power Utilization

Base stations for mobile communications have a limited number of resources that can be allocated to users. The main downlink resources for a WCDMA cell are transmit power is shared between common channels and traffic channels. The common channels are transmitted at fixed power, and thus their contribution to the downlink load is constant. However, the power required to support traffic channels will be dependent on the user location and supported service. The downlink power load can be defined as:

$$D_L = \frac{P_{used}}{P_{total}} \qquad (3-12)$$

where P_{used} represents the amount of utilized power and P_{total} represents the total available power at the cell.

CHAPTER 4   RESULTS AND DISCUSSION

This chapter presents simulation and experimental results of the fuzzy CPICH power controller for 3G cellular networks cell traffic load balancing. The fuzzy logic control algorithm developed in Chapter 3 is used to set the optimal CPICH power setting depending on the downlink cell utilization. A 3G network cell was identified (Cell A) whose Downlink Cell Load and Call Setup Success Rate are as shown in Figure 4-1. As the cell load increases, the quality of the cell degrades and it has poor call set up success rate.

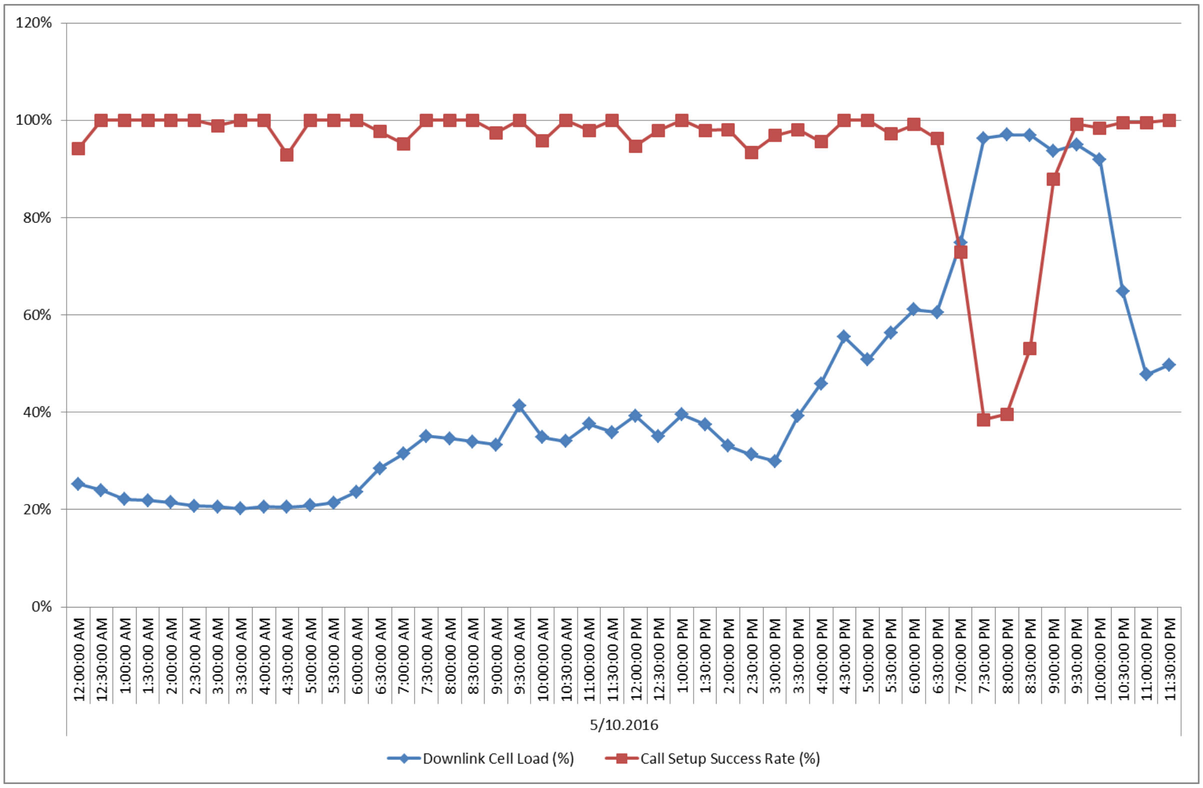


Figure 4-1: Hourly Downlink Cell Load and Call Setup Success Rate for Cell A

The Overall goal was to balance the load between neighboring cells therefore improving the performance of the cell with congestion issues. Figure 4-2 shows the Hourly Downlink Cell load for two neighboring cells A and B. It can be seen that Cell A has a high load especially in the busy hour as compared to cell B. Therefore, Cell A load can be relieved by handing over some of its traffic to Cell B.

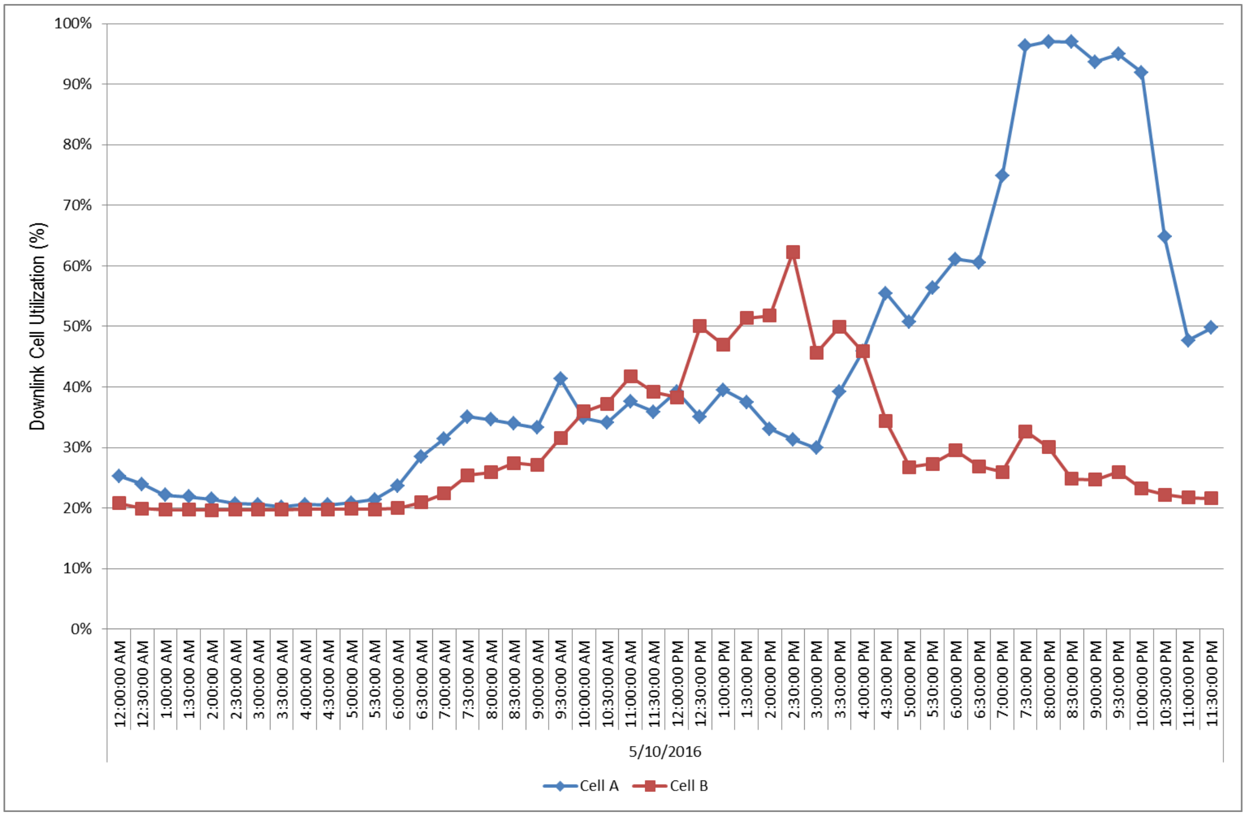


Figure 4-2: Hourly Downlink Cell Utilization for Cell A and Cell B

Figure 4-3 shows the Coverage Prediction plot based on the Hata Model of several cells in a cluster with the indicated signal levels while Figure 4-4 shows that the overlapping zones of several cells in a cluster. The overlap between the serving cells indicates that traffic can be balanced between two neighboring cells.

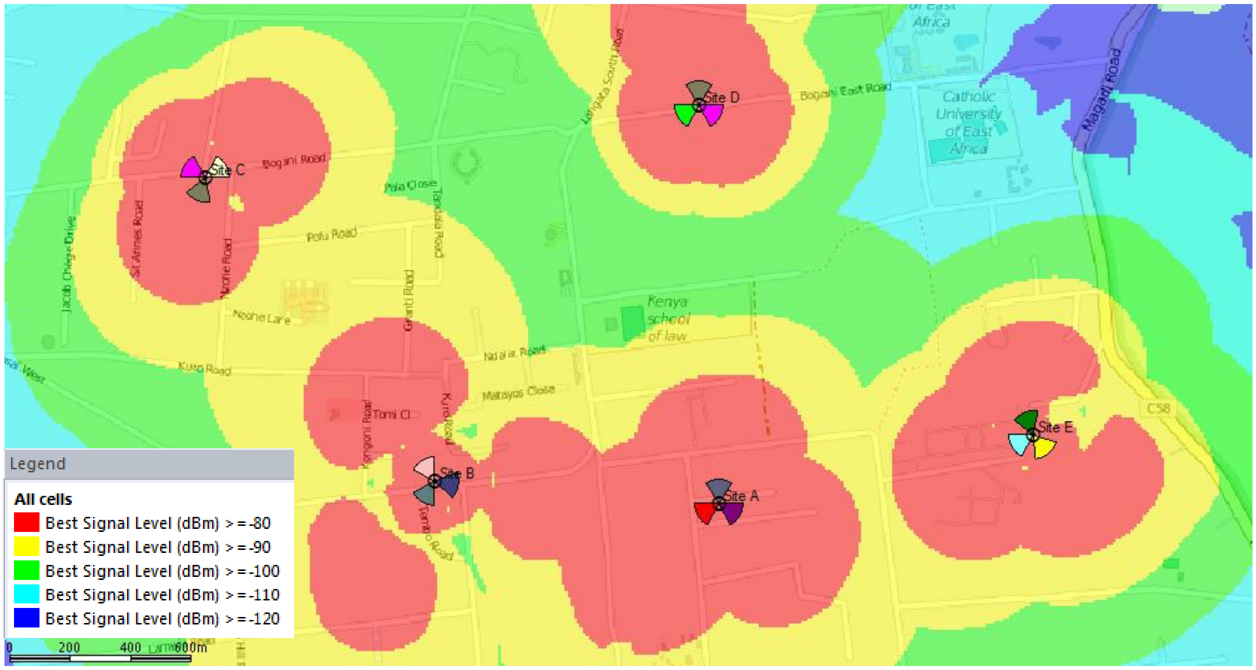


Figure 4-3: Coverage Prediction plot for the cells

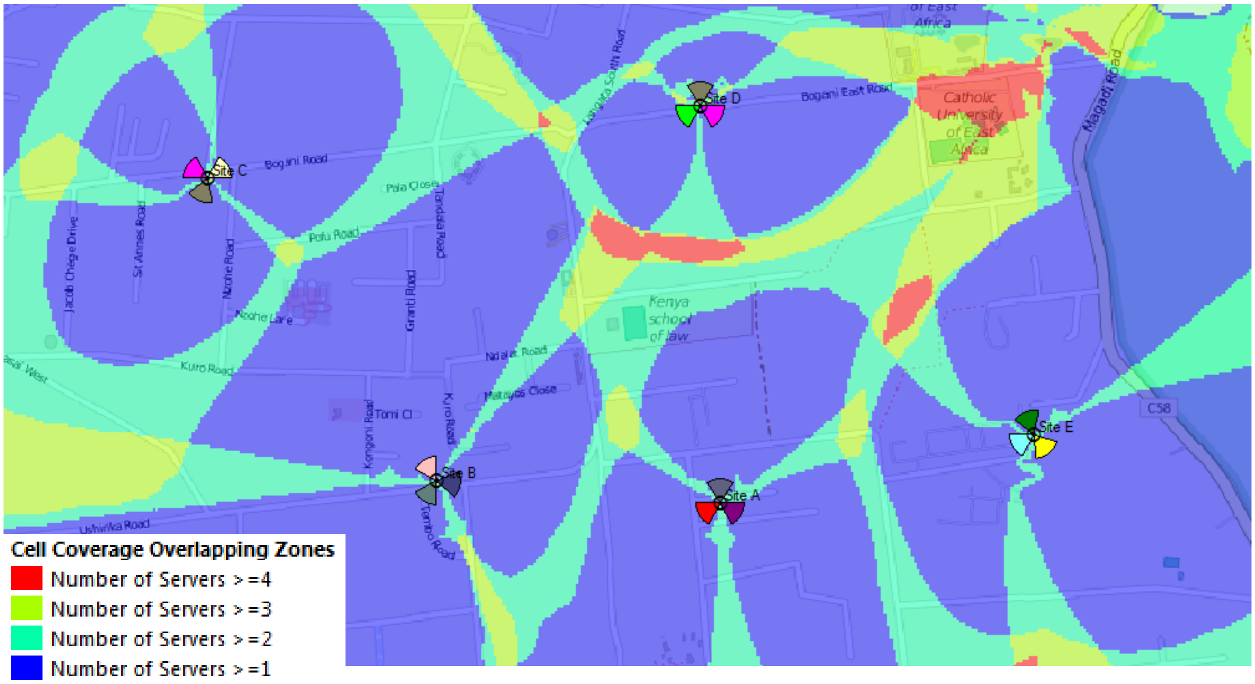


Figure 4-4: Overlapping zones for the cells

4.1 Effect of Varying the CPICH Power on the Downlink Cell Utilization

The developed fuzzy CPICH power controller was applied on Cell A in the network so as to observe the effect of varying the effect of varying the CPICH power on the downlink cell utilization as compared to the conventional method of keeping the CPICH power constant. The downlink cell utilization was monitored on the Huawei U2000 monitoring tool in 30 minutes intervals throughout the day so as to capture the peak and off-peak hours.

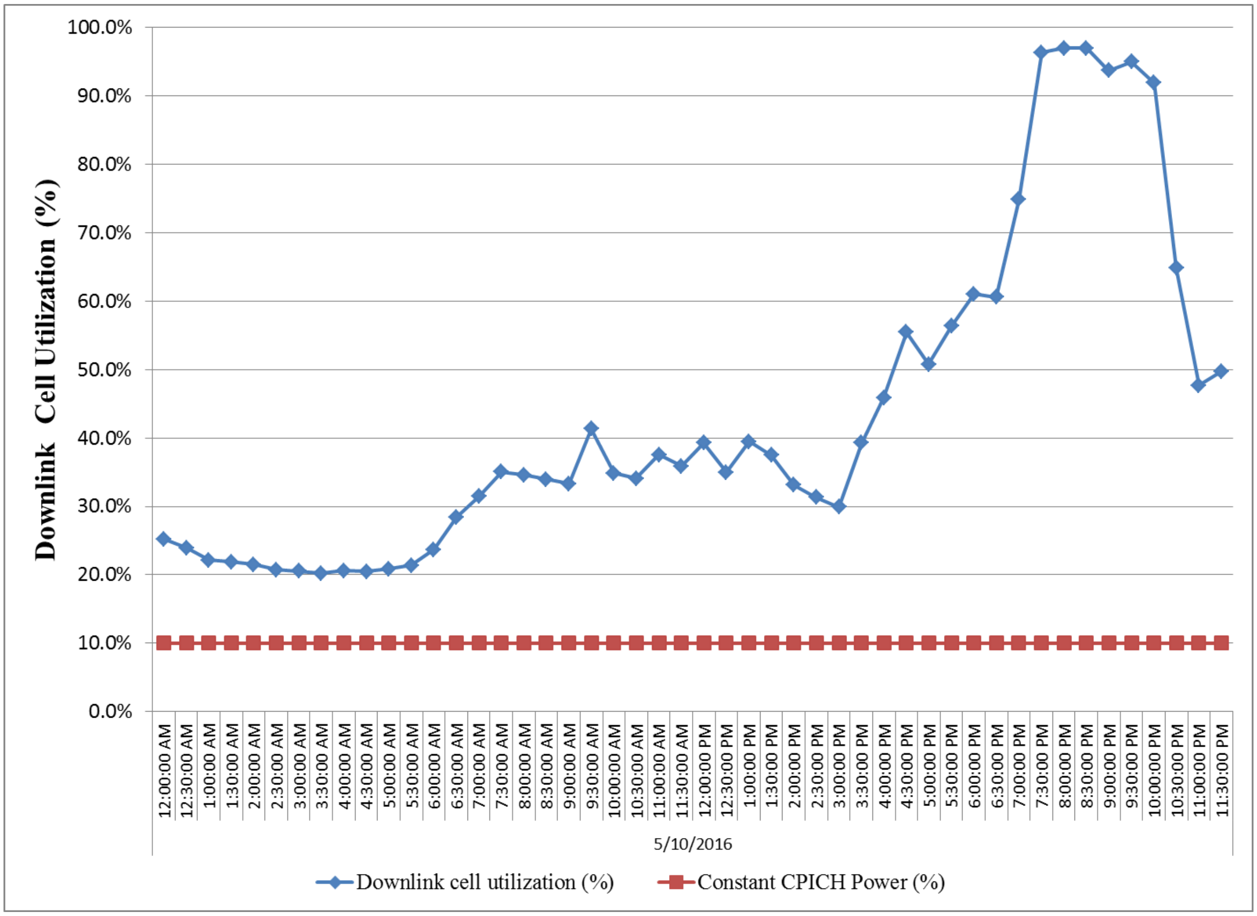


Figure 4-5: Normal Downlink Cell Utilization and CPICH power

Figure 4-5 shows the normal utilization trend of a cell with a constant CPICH power assigned. It can be seen that the CPICH power is constant at 33dBm, that is, 10% of the total downlink cell power as shown by equation 3-7. The downlink cell utilization varies throughout the day depending on the traffic. As seen from the figure in the early hours of the night i.e. 12 midnight to 6am the cell utilization is very low at about 20%. As the day progresses, the downlink cell utilization increases and at 8pm the cell utilization is at the highest at 96%. As stated before this will have an impact on the data throughput as the data only utilizes the remaining power on sharing mode among all the users. It therefore shows that there is a need for better utilization of the cell.

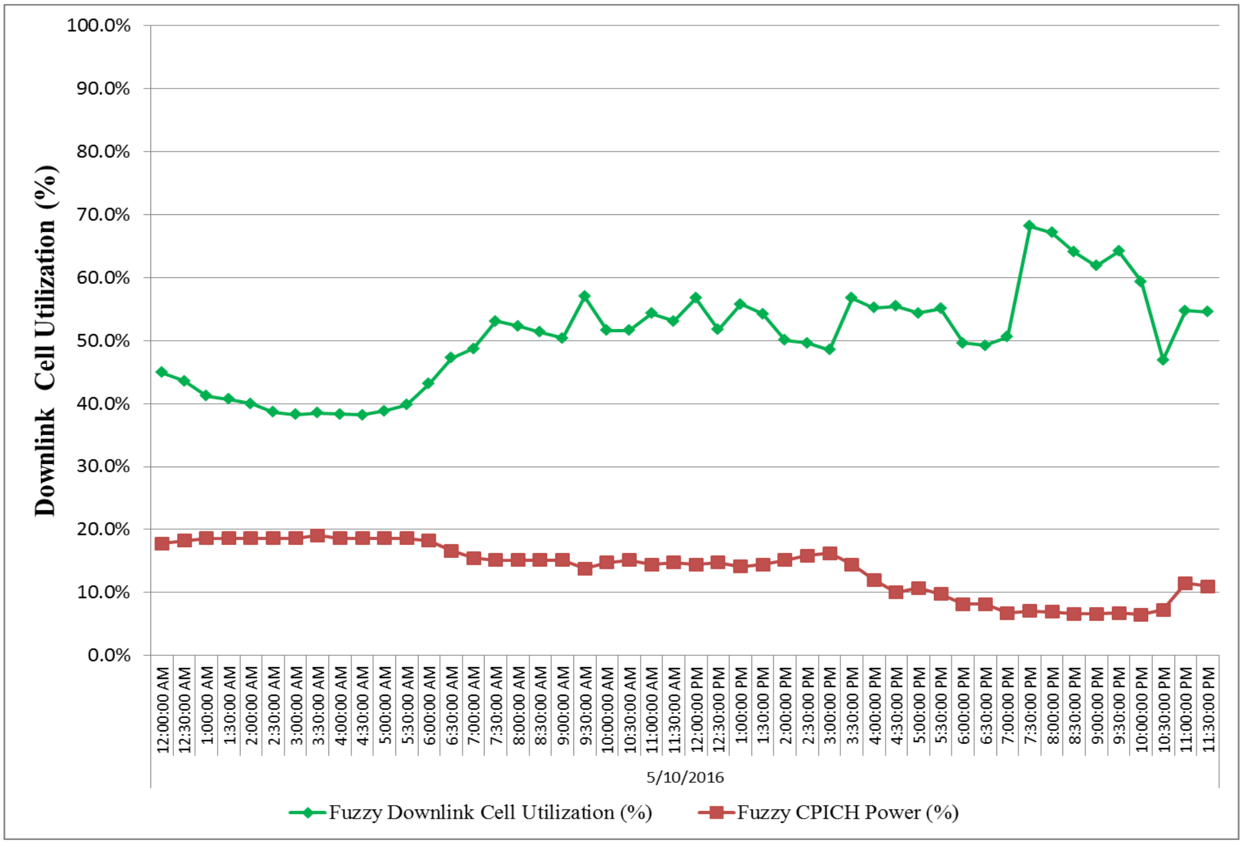


Figure 4-6: Fuzzy logic optimized Downlink cell utilization and CPICH power

Figure 4-6 shows the Downlink cell utilization trend of a cell after fuzzy logic has been applied to vary the CPICH power. In this case the CPICH power is no longer constant at 33dBm but varied from a high of 36dBm, that is, 20% of the total cell power to a low of 30dBm, that is, 5% of the cell power. Also the cell load utilization is seen to be better as the early hours of the night carrying more traffic than before as the CPICH power was increased, hence increasing the cell coverage footprint and the cell traffic. A comparison between the coverage foot print for a normal 3G cell with the CPICH power at 33dBm and with the CPICH power at 36dBm and 30dBm is shown in Figure 4-7. It can be seen that the CPICH at 36dBm has a larger coverage footprint as compared to 33dBm, while the CPICH at 30dBm has a smaller coverage footprint as compared to 33dBm.

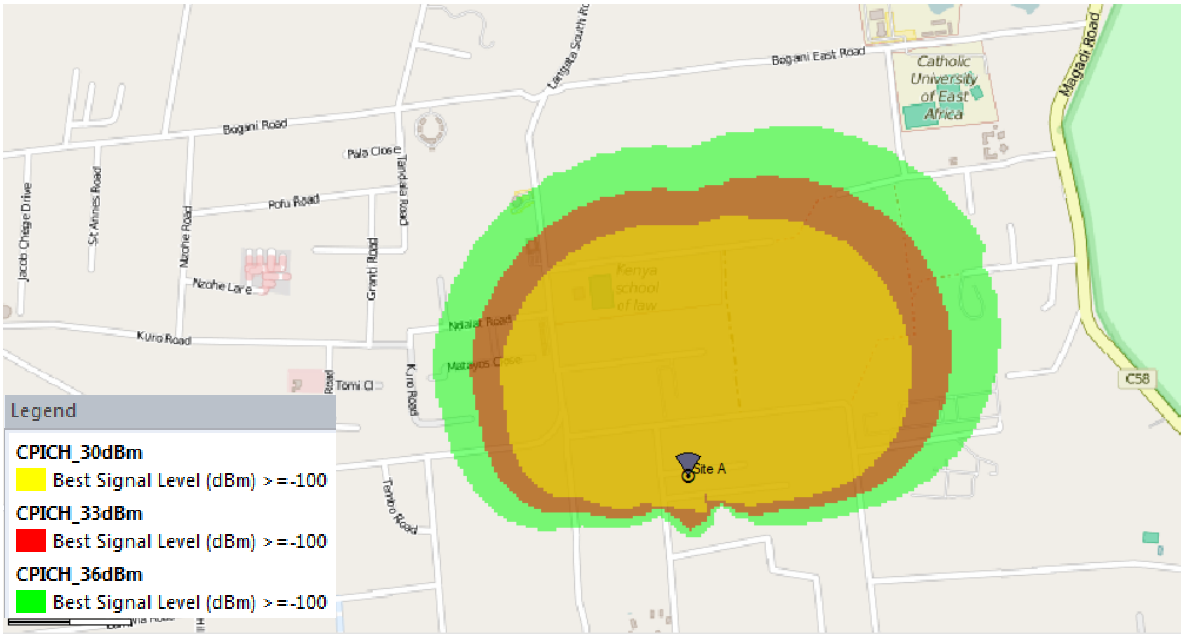


Figure 4-7: CPICH Power Coverage plot comparison for CPICH Power 33dBm, 30dBm and 36dBm

Figure 4-8 shows the hourly downlink cell utilization for cell A and cell B after the CPICH pilot power adjustment of cell A was done using fuzzy logic. The adjustment of the CPICH pilot power in cell A especially in the busy hours (7pm to 10pm) when the cell has excessive load resulted in the excessive traffic being steered to cell B which has less traffic during that time.

Therefore it can be concluded that the tuning of the CPICH power has a great impact on the downlink cell utilization largely due to the impact the tuning of the CPICH power has on the cell coverage area. Fuzzy logic control was successfully used to automatically control the CPICH power and improved the downlink cell load. In addition it was found that the CPICH power tuning has a large impact on the downlink cell utilization and it can be used to mitigate the load imbalance between neighboring cells by changing the coverage area of the cells.

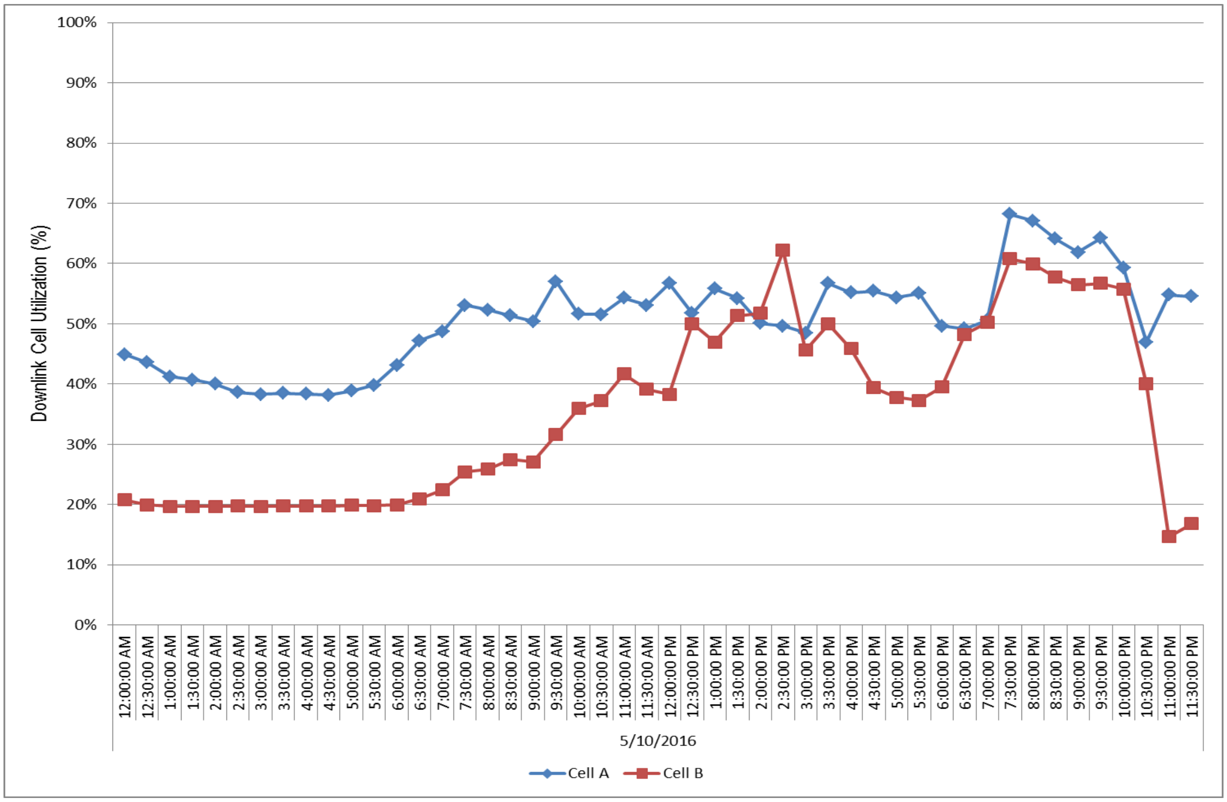


Figure 4-8: Hourly Downlink Cell Utilization for Cell A and Cell B after CPICH power control using fuzzy logic

4.2 Evaluation of the CPICH Power Control Based on Fuzzy Logic Controller

The evaluation of the performance of the CPICH power control system based on fuzzy logic was done through 2 metrics. These were the cell's call setup success rate (CSSR) and finally a comparison of the downlink cell utilization with and without fuzzy control was done.

Figure 4-9 shows the call setup success rate (CSSR) trend before and after the CPICH pilot power control using fuzzy logic. There was a great improvement especially in the peak hours when there was a dip as low as 38.5% previously improving to 88.5%. This indicates over 100% improvement in this KPI during the peak hour.

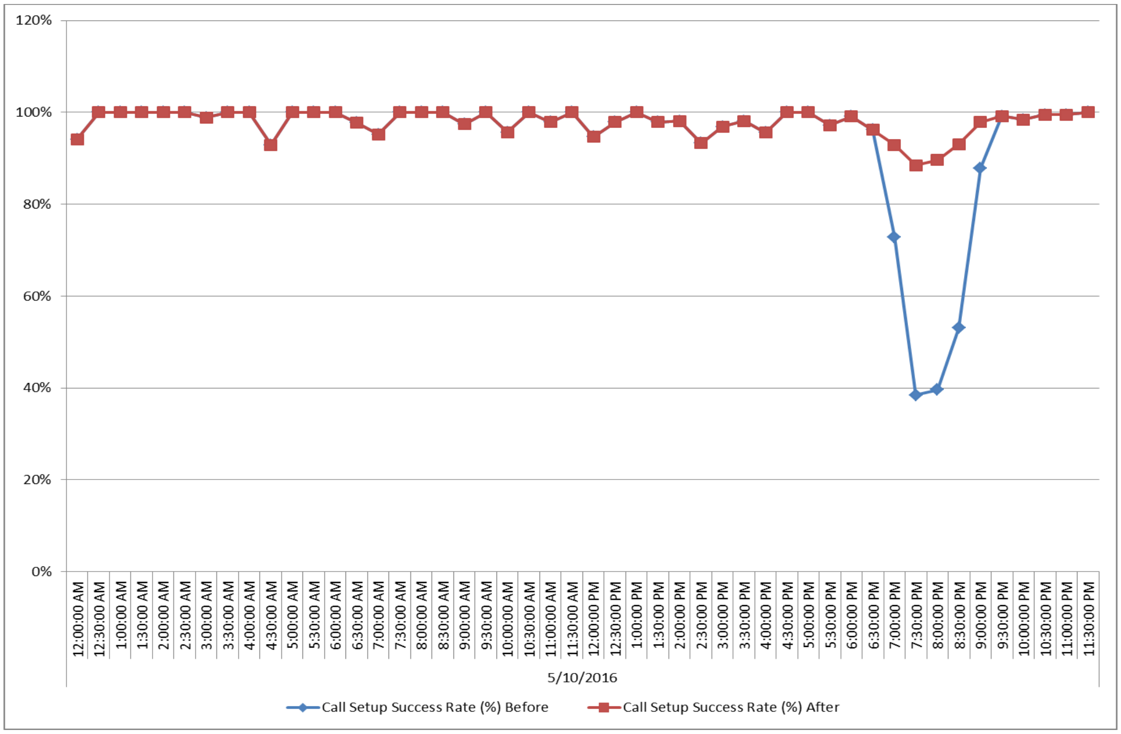


Figure 4-9: Comparison of the Downlink CSSR with and without fuzzy logic control

Figure 4-10 shows the comparison of the Downlink cell utilization trend of a cell with and without fuzzy logic control being applied to vary the CPICH power. It can be seen that the Downlink cell utilization with the FLC is better than without fuzzy. In the off peak hours of the day, that is, from midnight to mid-day the cell without fuzzy was very low utilized but after the application of fuzzy logic control the traffic increased and the cell is more efficiently utilized. In the peak hours of the day, that if, between 7pm and 10pm the cell was over utilized resulting to poor experience but after fuzzy logic is applied the cell has better utilization after the decrease in the CPICH power resulting to a lower congestion.

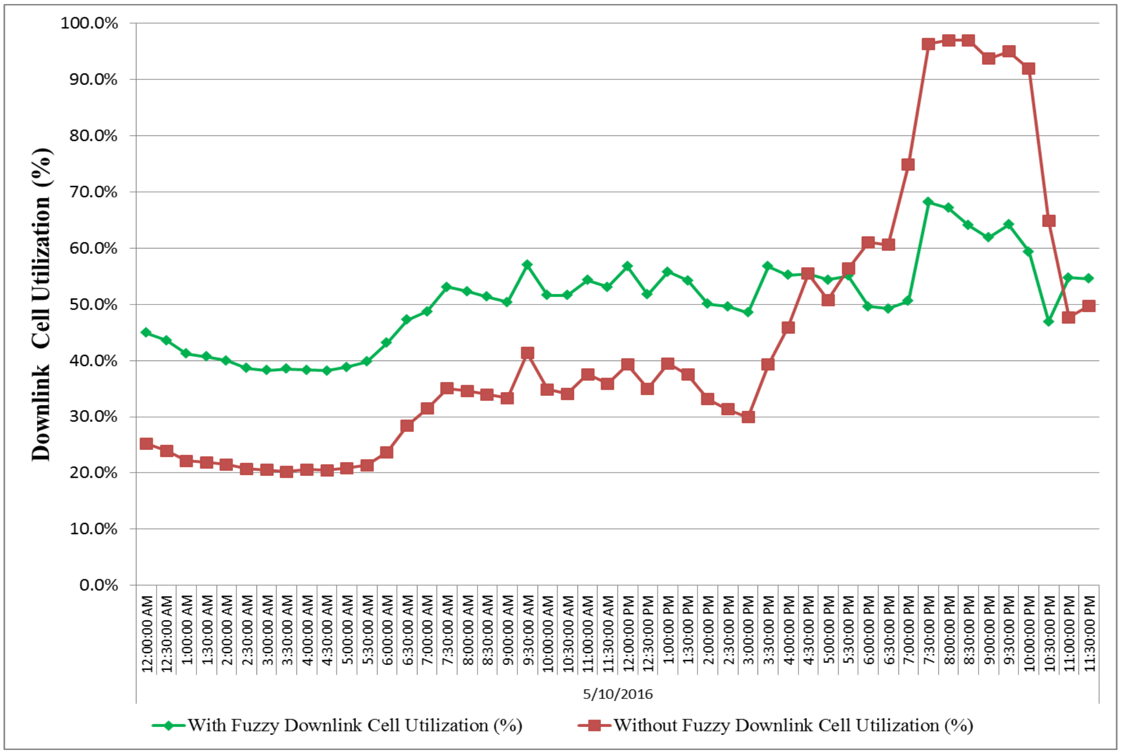


Figure 4-10: Comparison of the Downlink Cell load with and without fuzzy logic control

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this study a fuzzy logic based CPICH pilot power controller for 3G cellular networks cell traffic load balancing was developed. The concept of 3G cellular network traffic load balancing and various methods of addressing existing challenges were explored. A fuzzy logic based algorithm for CPICH power control for 3G cellular networks for cell traffic load balancing was used in this work. The developed algorithm addresses the challenge of increasing complexity of manually optimizing the ever growing and dynamically changing traffic patterns of a 3G network as it be used to autonomously optimize CPICH power and balance traffic load in the network, for example in the case of a traffic surge due to an accident or an event happening at a location.

First a CPICH pilot power controller for a 3G cellular network cell traffic load balancing system based fuzzy logic controller (FLC) was designed with the downlink cell load, received total wideband power (RTWP) and the neighboring cells' load as the inputs. The output of the FLC was the CPICH power setting which determined whether to increase or decrease the coverage footprint of the cell hence influencing the cell downlink power utilization. Fuzzy logic was successfully used to automatically control and tune the CPICH power just as a radio optimization engineer would do and it can be concluded that fuzzy logic was a good approach for this study.

Next the effect of varying the CPICH pilot power was investigated. Simulation from the Atoll coverage prediction tool showed that varying CPICH power affected the coverage area of a cell. From the data collected from the monitoring tool traffic patterns were identified, where KPI degradation due to the cell resource congestion predominantly occurred during the peak hours.

During these hours the CPICH pilot power control could be employed to improve the quality of service, without adding extra capacity to the base stations. It was observed that the CPICH power tuning had a large impact on the downlink cell utilization and by varying the CPICH pilot power a whole day, the downlink cell utilization was improved from a 98% peak to 68% in the busiest hours of the day when the load is excess and the cell is congested. It was concluded that CPICH power tuning can be done automatically based on fuzzy logic to mitigate cell congestion and load imbalance between neighboring cells by changing the coverage area of the cells.

Finally the performance of the CPICH Power optimization based on Fuzzy Logic Controller was evaluated. This was done by a monitoring 2 metrics which are the CSSR and the downlink cell utilization. A comparison was done for before and after the tuning of the CPICH pilot power for a day and all showed a great improvement. The CSSR degradation dip during the peak hours improved by 100% indicating a major improvement in the network quality from a user perspective. From a network perspective the load was reduced in the congested cell and offloaded to a neighboring cell thus achieving a more efficient resource utilization. The resource utilization becomes more efficient because the traffic load will be shared between multiple base stations in a cluster. In this way it is possible to take advantage of resources from base stations which have low traffic and increase the performance in a cluster.

On the whole, it is concluded that the overall objective to develop a fuzzy logic based cell traffic load balancing algorithm for CPICH Power control in a 3G cellular network has been met. Simulation results show that the CPICH power control based on fuzzy logic achieved a significant improvement in the downlink cell utilization compared to a constant CPICH power system which in turn indicates an improved the cell performance.

5.2 Recommendations

It was demonstrated that, the developed fuzzy logic controller can effectively be used to optimize a 3G cellular network cell capacity by controlling the CPICH pilot power resulting to load balancing between two neighboring base stations. The pilot power control should be extended to a network cluster with many cells for even more effective cell resource utilization. Due to time limitation only one neighbor to the subject cell was considered, it is recommended that for future work all the cell’s defined neighbors are considered so as to ensure a better load balancing in the network. Another area of interest is to look into applying fuzzy logic in other cellular networks such as the fourth generation and fifth generation cellular networks.

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