

**REAL TIME TRAFFIC BALANCING IN CELLULAR  
NETWORK BY MULTI-CRITERIA HANDOFF  
ALGORITHM USING FUZZY LOGIC**

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**Real Time Traffic Balancing in Cellular Network by Multi-Criteria  
Handoff Algorithm Using Fuzzy Logic**

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## **DECLARATION**

This thesis is my original work and has not been submitted to any other University for examination.

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## **DEDICATION**

I dedicate this thesis to my parents and my fiancée Nitsuh Haile whose love; understanding and sincere support gave me the inspiration to complete the work.

## **ACKNOWLEDGEMENTS**

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## LIST OF ACRONYMS

<b>ANFIS</b>	Adaptive- Network based Fuzzy Inference System
<b>BSC</b>	BTS Controller
<b>BTS</b>	Base Transceiver Station
<b>CBQ</b>	Cell bar Quality
<b>CDMA</b>	Code Division Multiple Access
<b>FDMA</b>	Frequency Division Multiple Access
<b>FIS</b>	Fuzzy Inference System
<b>FLC</b>	Fuzzy Logic Controller
<b>GSM</b>	Global System for Mobile Communications
<b>KPI</b>	Key Performance Indicators
<b>MF</b>	Membership function
<b>MODM</b>	Multiple Objective Decisions Making
<b>MS</b>	Mobile Station
<b>PBGT</b>	Power Budget
<b>POA</b>	Point of Attachment
<b>QoS</b>	Quality of service
<b>RF</b>	Radio Frequency
<b>RSS</b>	Received Signal strength
<b>SIR</b>	Signal to Interference Ratio
<b>SNR</b>	Signal to Noise Ratio
<b>TA</b>	Timing Advance
<b>TCH/H</b>	Half-rate
<b>TCH/F</b>	Full-rate
<b>TCH</b>	Traffic Channel

**TDMA**

Time Division Multiple Access

**VHO**

Vertical Handoff

## **ABSTRACT**

Cellular systems are extremely popular. These are the systems that ignited the wireless revolution. Cellular systems provide duplex voice and data communication with regional and national coverage. The basic premise behind cellular system design is frequency re-use pattern, which exploits the fact that signal power falls off with distance to re-use the same frequency spectrum at spatially separated locations.

Cellular systems' frequency band is a very limited resource, even after applying multiple access methods and aggressive frequency re-use, mobile service providers still face the challenge of over-congestion due to growing size and demand. The degree of Traffic Channel (TCH) congestion in the network results in large number of TCH blocking which greatly affects negatively the subscriber satisfaction and revenue of a mobile service provider. The available congestion relief methodologies such as cell splitting, microcells and expanding frequency bands depend on time and cost factors for implementation.

Network parameters are manually adjusted to obtain a high level of network performance. There are many parameters for solving uneven load distribution in the cluster. Some of them are transmitter power, Cell Bar Quality (CBQ), Half-Rate, RXLEV-ACCESS-MIN, Timing Advance (TA) and Handoff threshold and among others. All the above techniques of load balancing are not self-adaptive in the sense that every time congestion occurred in the network either of the above methods has to be manually applied.

In an effort to address the above challenges, this research presents a design and implementation of a fuzzy multi-criteria handoff algorithm based on signal strength, path-loss, traffic load of BTS and Signal to Noise Ratio (SNR). The algorithm balances traffic in all the neighboring BTSs at any time and enhances the performance of the cellular system by selecting the best network segment. This was achieved by multi-criteria handoff algorithm using fuzzy logic. The proposed algorithm has been tested using data from wireless propagation models based on straight line mobility between two BTSs in suburban area.

Simulation results show the MS in the region between 2000m to 7000m dynamically swing between BTS I and J depending the load on the BTSs. The coverage area of a BTS can dynamically be expand towards a nearby loaded cell or shrunk towards cell center for a loaded sector. Therefore, this mechanism activates a handoff procedure to shift some traffic of a loaded cell towards a lightly loaded cell thereby increase the resource utilization. In case of low load scenarios, the coverage area of a BTS is presumed to be virtually widened to cover up to the partial serving area of neighboring BTS. This helps a highly loaded neighboring BTS.



# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Cellular systems are extremely popular. These are the systems that ignited the wireless revolution [1]. Cellular systems provide duplex voice and data communication with regional and national coverage. The basic premise behind cellular system design is frequency re-use pattern, which exploits the fact that signal power falls off with distance to re-use the same frequency spectrum at spatially separated locations. The coverage area of a cellular system is divided into non-overlapping cells theoretically where a set of channels is assigned to each cell according to density of subscriber [1]. This same channel set is used in another cell some distance away, as shown in Figure 1.1.

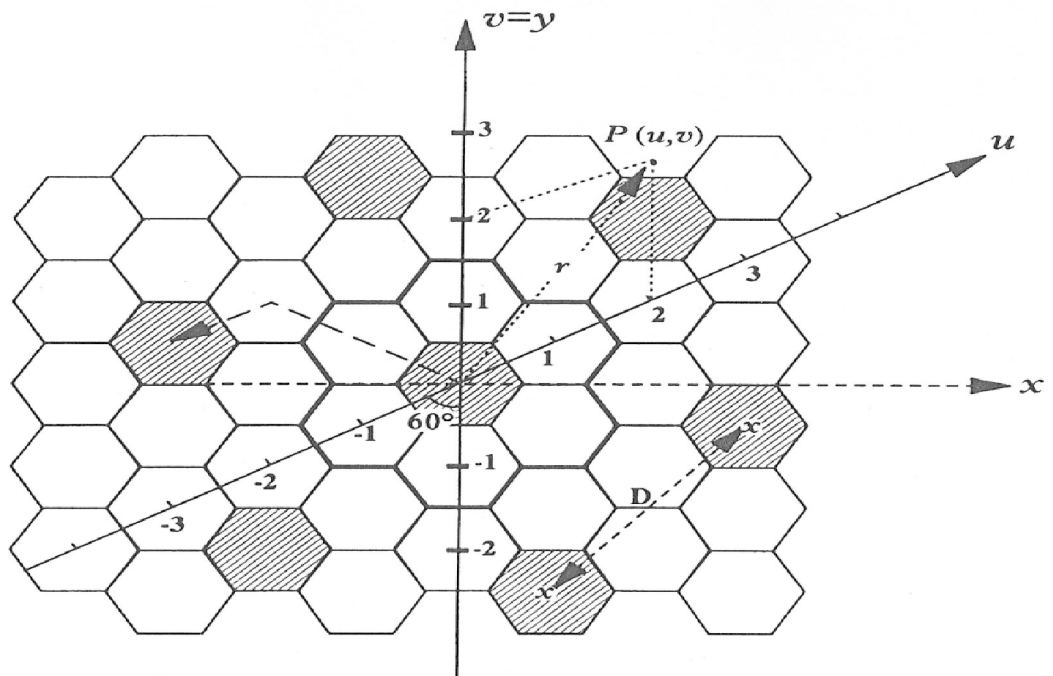


Figure 1.1 Cellular Clusteries

Operation within a single cell is controlled by a centralized Base Transceiver Station (BTS). The interference caused by mobile users in different cells operating on the same frequency set is called inter-cell interference. The re-use factor of cells that use the same channel set should be as small as possible so that frequencies are re-used as often as possible, thereby increasing spectral efficiency. However, as the re-use distance decreases, the inter-cell interference increases, because of the smaller propagation distance between those interfering cells. Since inter-cell interference must remain below a given margin for tolerable system performance, re-use distance cannot be reduced below some minimum threshold margin.

In practice it is difficult to determine this minimum value since both the transmitting and interfering signals experience arbitrary power variations due to the characteristics of wireless channel. So as to get the best re-use distance, an accurate characterization of signal propagation within the cells is needed [1]. The power transmitted by each BTS is controlled in such a way that the Mobile Stations (MSs) in the BTS are served while co-channel interference is kept to a minimum.

An added characteristic feature of cellular system is its ability to adjust to the increasing traffic demand through cell splitting [2]. By further dividing a single cell into smaller cells, a set of channel frequencies are re-used more often, leading to a higher spectral efficiency.

### **1.1.1 Measure of Spectral Efficiency in Cellular Network**

Since the radio frequency spectrum is a limited resource in nature, it should be utilized it very effectively [3]. Spectral efficiency in a cellular system is the way the system uses its total resource to offer a particular public service to its highest capacity. Some of spectral efficiency methods in cellular network are discussed as follows [4].

- i. Users/channel: In the measure of users/channel, the number of mobile unit per voice channel is used to indicate the spectral efficiency. A traffic channel in Global System for Mobile Communications (GSM ) can carry user speech or data that can be either be in full-rate (TCH/F-13kbits/s) or half-rate (TCH/H-5.6kbits/s) channel mode [4]. When TCH/H is in use, one time slot may be shared by two connections thus the efficiency of spectrum in TCH/H is as twice as THC/F. This is the simplest way of measuring the spectral efficiency of mobile radio system.
- ii. Users/cell: The measure of spectral efficiency as more mobile users in a BTS is introduced to account for cellular coverage. In a practical GSM network, the configurations of users /cell depend on the physical hardware of the BTS. Typical configurations in GSM 900MHz are S222, S444, S666 and S888. It means, for example S666, that there are 6 frequencies set in each sector of antenna. Each frequency can serve 8 users with Time Division Multiple Accesses (TDMA). From the above configuration S888 is as twice as efficient as S444 configuration. The limitation of users/cell is that it does not take into account a geographical area covered by a BTS.

- iii. Channels/MHz: Channel/MHz measures spectral efficiency as the number of traffic channels which a mobile radio system can provide per MHz. This spectral efficiency measure is suitable for point-to-point radio communication. It is not adequate for cellular mobile radio communication [2].
- iv. Erlang: The Erlang (E) is a dimensionless unit that is used in Tele-traffic as a measure of offered load or carried load on mobile service-provider. The Erlang (E) measures the quantity of traffic on a voice channel or group of channels per unit time and as ratio of time [2]. One Erlang of traffic would occupy one channel for 100% of the time and 0.5 Erlang would occupy it 50% of the time. Hence the number of Erlangs carried cannot exceed the number of channels. The better the value of Erlang on the system the better the spectrum usage.
- v. Carried Traffic: For carried traffic, the number of Erlangs represents the average number of concurrent calls carried by the circuits where that average is calculated over some reasonable period of time [5].
- vi. Offered Traffic: For offered traffic, the number of Erlangs represents the average number of concurrent calls that would have been carried if there were an unlimited TCH in the BTS (that is, if the call-attempts that were made when all circuits were in use had not been rejected) [5].

The difference between offered traffic and carried traffic are blocked calls or congested calls. They are rejected, and never come back. This is where the idea of this thesis came in. Why not use channels from a neighboring base station if they are underutilized? A simple borrowing scheme implies that if all TCH allocated to BTS have already been

used, then additional TCH can be borrowed from any BTS that has free unused TCH through handoff process [6].

In this thesis, TCH borrowing is done by handing off MS on the edge of over-loaded BTS to overlapping non-loaded BTS as long as the minimum thresholds for keeping calls are obtained. By doing so, the over-loaded BTS would have free TCH for new originating calls or new incoming calls due to handoff.

### **1.1.2 Total Available Resource in GSM System**

BTS has limited number of resources that can be allocated to users. Depending on the mobile technology considered, the resources differ. The 900MHz band is the most widely used band worldwide. It provides a benefit of increased coverage and subsequent reduction in network deployment compared to higher frequencies and it offers improved building penetration [5]. However, this band has a very limited resource compared to higher frequency band. GSM 900MHz uses 890 to 915MHz for uplink and 935 to 960 MHz for down link communication, the duplex separation between the uplink and downlink is 45MHz and channel band width is 200 kHz [5]. Therefore GSM 900MHz has only 25 MHz/200kHz which equals to 125 channels. The 125 channels have to be shared among different service providers in the country. Hence to maximize resource utilization, the service providers use aggressive frequency re-usage [1].

GSM 1800MHz uses 1710 to 1785MHz for uplink and 1805 to 1880MHz for down link communication, duplex separation is 95MHz between uplink and downlink communication and channel band width is 200 kHz [5]. Therefore the total available

channels in 1800MHz are 75MHz/200kHz equals to 375 channels. GSM 1800MHz provides a better resource compared to GSM 900MHz but it suffers from penetration loss and less coverage [5]. Ethio-Telecom uses dual-band to take capacity advantage of 1800MHz and improved coverage of 900MHz.

Due to the fact that the GSM frequency band is limited, the system needs to be able to carry out intelligent frequency band division [5 6]. The GSM system combines Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) for effective use of the frequency band [5, 6]. TDMA is a process of sharing a single frequency by dividing the channel into time slots that are shared between simultaneous users. TDMA divides each carrier frequency into equal 8 time slots. The length of one time slot is 0.577ms [5].

GSM frequency band is a very limited resource, even after applying multiple access methods and aggressive frequency re-use, mobile service providers still face the challenge of over-congestion due to growing size and demand. It is commonly accepted that the problem of network congestion control remains a critical issue and a high priority. This is where the need for an intelligent load sharing algorithm among all the neighboring BTS is apparent. An intelligent load balancing algorithm is important in serving more mobile stations in a given cluster.

## **1.2 Problem Statement**

The term load balancing can be used to describe any mechanism whereby highly loaded cells issue some of their traffic to less loaded neighbors in order to make the use of the

radio resource more efficient across the whole network. In Ethio telecom, generally there are two methods to balance load among BTS in the cluster. The first method is physical optimization. In this case antenna tilt or height of antenna is manually adjusted to vary the coverage area of the BTS to solve the issue of congestion accordingly. For example, when a BTS is over-congested, then down tilting antenna or reducing height of antenna will reduce coverage so that the MSs at the edge of the cell will be served by adjacent cell. The second method is network parameter optimization. In this case network parameters are manually adjusted to obtain a high level of network performance. There are many parameters for solving uneven load distribution in the cluster. Some of them are transmitter power, Cell Bar Quality (CBQ), Half-Rate, RXLEV-ACCESS-MIN, Timing Advance (TA) and Handoff threshold and among others.

The most effective parameter to balance uneven load distribution is transmitting power of BTS. Lower power effectively prohibits distant MS to access the cell, thereby decreasing the coverage area. However, automatic adjustment of cell coverage area runs the danger of creating coverage holes. The maximum power allows a distant mobile to access a BTS however; it may introduce interference to neighboring BTS. Another way to balance traffic load is to modify the handoff threshold manually between neighboring cells. Such an approach is referred to as mobility load balancing. The theory behind mobility load balancing is to adjust the handoff regions by biasing the handoff measurements, causing cell-edge users in loaded cells to migrate to less load neighbor cells, thereby improving the efficiency of resource utilization.

Both physical and network parameter optimization methods are not self adaptive in the sense that every time over-congestion occurs in the network either of the above methods have to be manually applied. Once congestion is relieved with any of the methods discussed above, those tuned parameters still take effect which in turn affect customer satisfaction.

Therefore, the problem of network congestion control remains a critical issue and a high priority, mainly given the growing size and demand. Network congestion is becoming a real threat to the growth of existing real-time networks (circuit switching). And therefore this is a problem that cannot be ignored.

### **1.3 Scope of the Research**

The scope of this research was limited to data from Ethio Telecom and Huawei. Data collected from these companies has been used to determine the universe of discourse and numbers of membership function of the inputs parameters. The research used fuzzy logic to resolve the issue of conflict between individual single-criteria. The proposed algorithm has been tested using data from two ray propagation model based on straight line mobility between two BTSs.



## **1.4 Objectives**

### **1.4.1 Main Objective**

To improve real time traffic balancing in a cellular network using a multi-criteria handoff algorithm

### **1.4.2 Specific Objectives**

- i. To design and analyze an intelligent system controller based on Fuzzy Logic for load balancing in cellular system.
- ii. To develop and simulate a multi criteria hand off algorithm with MATLAB
- iii. Evaluate and compare the performance of multi-criteria and single-criteria handoff system

## **1.5 Significance of the study**

Call blocking rate is one of the key performance indicators (KPI) which influence the network performance and customer satisfaction in cellular networks. The degree of TCH congestion in the network results in large number of TCH blocking which greatly affects negatively the subscriber satisfaction and revenue of a mobile service provider.

This thesis outlines the problem of uneven load distribution on the cellular system. In attempt to distribute the traffic load in the cluster a fuzzy logic is used to make the handoff decision.

## **1.6 Thesis Outline**

The thesis is organized in five chapters. Chapter one provides background of cellular system. How they operate and measure of spectral efficiency, problem statements,

objectives and significance of the study. Chapter two provides literature review, handoff process, manual load balancing methods and their short comings. Chapter three provides the methodology used; including the design of multi-criteria handoff algorithm. Chapter four discusses the results obtained from simulations. Conclusions and recommendations are given in chapter five.

## CHAPTER TWO: LITERATURE REVIEW

This chapter covers different aspects of handoff process, performance of handoff manual load balancing techniques and their limitations. Some related works with this thesis are also highlighted in detail. Based on the limitation of the manual load balancing method, a fuzzy logic multi-criteria handoff algorithm has been proposed in the chapter.

### 2.1 Handoff Process Background

Handoff is defined as the mechanism by which an ongoing call is transferred from one BTS to another [7]. The performance of the handoff mechanism is tremendously important in mobile cellular networks, in maintaining the preferred Quality of Service (QoS). In a cellular system, when a mobile user travels from one cell to another, the serving BTS changes according to the planning of the network. Repeated handoffs influence the QoS, increase the signaling overhead on the network, and reduce throughput in data communications. Thus, network operators should emphasize the optimization of handoff decisions.

Handoffs are extremely important in any cellular network because of the cellular architecture employed to maximize spectrum utilization. When a mobile terminal moves away from the BTS, the signal level degrades and there is a need to switch the communications to another BTS, that time there is a need for a handoff to be executed. Handoff is the process of shifting the channel (frequency, time slot, spreading code, etc) associated with the current connection while a call is in progress [8].

The conventional handoff decision compares the Received Signal Strength (RSS) from the serving BTS with that from one of the target BTSs, using a constant handoff margin. The choice of this margin is important to handoff performance. If the margin is small, numerous unwanted handoffs may be processed. Conversely, the QoS could be low and calls could be dropped if the margin is large. The sudden drop of signal strength associated with shadow fading cause a call to be repeatedly handed over back and forth between neighboring BTSs, in what is called the “ping-pong effect” [7].

### **2.1.1 Handoff Classification**

Handoffs can be classified in several ways as discussed below:

**Horizontal and Vertical Handoff:** Depending on the type of network technologies involved, handoff can be classified as either horizontal or vertical [9]. Traditional handoff, also called horizontal handoff occurs when the MS switches between different BTSs of the same access network. For example, this typically happens when the user moves between two geographically adjacent cells of a GSM cellular network. On the other hand, vertical handoff involves two different network-interfaces representing different wireless access networks or technologies [8, 9].

**Hard and Soft Handoff:** This classification of handoff depends upon the number of to which an MS is associated with at any given moment. Hard handoff, also called “break before make”, involves only one BTS at a time. For example, handoff process in GSM network is hard handoff [6]. The MS must break its connection from the current access network before it can connect to a new one. In a soft handoff, also called “make before

break”, an MS can communicate and connect with more than one access network during the handoff process [9]. Code Division Multiple Access (CDMA) is an example of soft handoff [6].

### **2.1.2 Desirable Features of Handoff**

Several wanted features of handoff algorithms have been mentioned in [9-11].

- a. Speed: Handoff should be fast to avoid service degradation and/or interruption at the MS. Mobility of an MS at a high speed requires the handoff to be done promptly.
- b. Reliability: Handoff should be reliable such that the MS will be able to maintain the required QoS after handoff.
- c. Successful: Free channels and resources must be available at the target access network in order to make the handoff successful.
- d. Number of Handoffs: The number of handoffs must be minimized. Excessive number of handoffs results in poor QoS and excessive processing overheads as well as power loss, which is a critical issue in MSs with limited battery power.
- e. Multiple-Criteria Handoffs: The target access network should be intelligently chosen based on multiple-criteria. Identification of a correct BTS prevents unnecessary and frequent handoffs.

### **2.1.3 Performance Evaluation of Handoff Algorithms**

The performance of different vertical handoff algorithms can be evaluated and compared by measuring the following metrics [9].

1. Handoff Delay: This metric represents the time elapsed between the handoff initiation and completion. The difficulty of the handoff algorithm has a direct effect on this metric; a simple algorithm results in a smaller value of this metric. The smallest possible value of handoff delay is preferred for real-time and delay-sensitive applications.
2. Number of Handoffs: unwanted handoffs must be reduced as they waste network resources and increase processing overheads on the system.
3. Number of Handoff Failures: A handoff failure occurs when the target network fails to assign resources for the MS that is handed over from neighboring network. This failure is also possible when a moving MS goes out of the serving area of the network before the completion of the handoff process. This metric leads the mobile users eventually to call drop.

## **2.2 Related Works**

Authors in [12] had proposed a multi-criteria vertical handoff decision algorithm which selects the best available network with optimized parameter value in heterogeneous wireless environment. The neural network and genetic algorithm tools have been used to optimize the multi-criteria vertical handoff decision metrics. Authors in [13] utilized fuzzy logic with Multiple Objective Decision Making (MODM) approach to select the best network segment. Research in [14] implemented handoff initiation scheme by combining multiple parameters of all available networks in a cost function. However, the selection of the target network was done using a Fuzzy Inference System (FIS) that only utilizes two input parameters such as velocity and available bandwidth. The lack of other

important parameters might not produce optimal results. Research paper in [15] used fuzzy logic with only QoS and RSS to estimate the necessity of handoff. The projected algorithm in [16] utilized fuzzy logic in dealing with incorrect traffic information, making load allocation decisions, and keeping overall system stability. In terms of control, they studied new approach that specifies how, when, and by which BTS the load balancing was implemented.

Authors in [17] proposed a module to estimate the necessity of vertical handoffs in a hybrid wireless environment. The studied scheme used fuzzy logic to determine if a Vertical Handoff (VHO) is required based on the measured values of the network parameters obtained from the serving Point of Attachment (PoA) and other available wireless networks. A VHO factor was calculated using multiple parameters, including predicted value of RSS, the degree of provided QoS, the speed of the MS including its moving direction (towards/away from the serving cell), and the distance between the MS and the serving PoA. To determine the need for handoff, this calculated VHO factor is then compared against a threshold value that was predetermined based on the type of the serving cell. Grey Prediction Theory (GPT) was utilized to predict the future values of RSS that can minimize the call dropping probability of the MS due to a sudden drop in RSS, which was common in lognormal fading heterogeneous wireless networks.

Authors in [18] presented a dynamic load balancing algorithm based on sojourn time for heterogeneous hierarchical wireless networks composed of macro-cell network and micro-cell network. The sojourn time was calculated by velocity, direction of motion and local position of MS. Research in [19] introduced the novel load balancing algorithm

using fuzzy logic in cloud computing, in which load balancing is a core and challenging issue in Cloud Computing. Authors in [20] proposed a fuzzy  $Q$ -Learning algorithm to find the optimal set of fuzzy rules in a fuzzy logic controller for traffic balancing in GSM Network. Researchers in [21, 22] used RSS, mobile location and velocity as metrics for making handoff decisions using fuzzy logic.

### **2.3 Conventional Blocking Relief Methodologies in Cellular System**

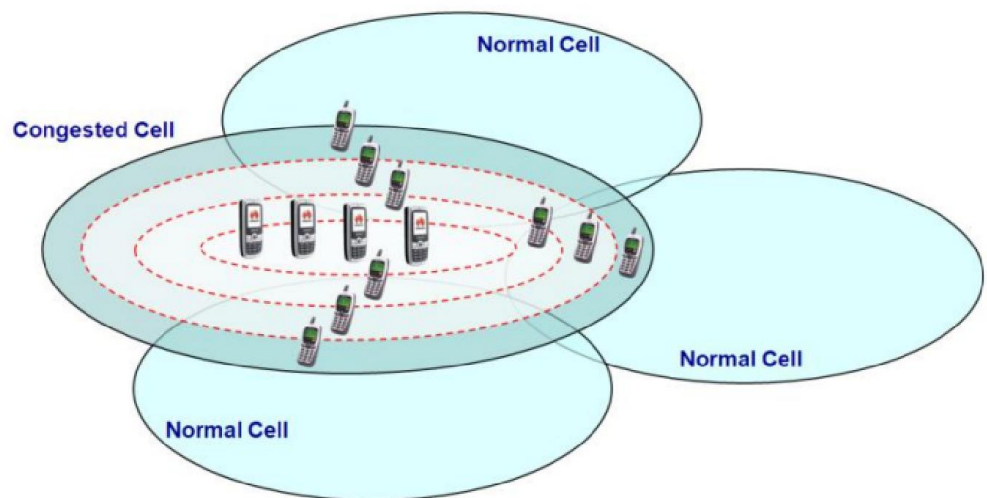
Call blocking rate is one of the key performance indicators (KPI) which influence the network performance and customer satisfaction in cellular networks. The degree of TCH congestion in the network results in large number of TCH blocking which greatly affects negatively the subscriber satisfaction and revenue of a mobile service provider [4]. The available congestion relief methodologies such as cell splitting, aggressive frequency re-use pattern, microcells and expanding frequency bands depend on time and cost factors for implementation [4]. The additional investment on capacity methods would be beneficial only if there is congestion on the whole network and proportional increase in traffic throughout the year. In the following section load balancing methodologies used in cellular networks are discussed, without additional investment on capacity, to relief the problem of blocking rate.

#### **2.3.1 Load Balancing in Cellular Network**

The basic premise behind load balancing is that the coverage area of serving and neighboring BTS partially overlaps [5]. However, the Mobile Station (MS) is always forced to stay on better serving BTS in terms of RSS and this in turn makes the resource



on partial overlapping areas to be wasted. So the main aim in this work was to use the available resource in neighboring uncongested BTS at that particular overlapping region with multi handoff criteria based on fuzzy. Figure 2.1 indicates the over-congestion on the middle cell while three neighboring BTS have less-load on their entire coverage area. Load of the BTS can be shared among the neighboring BTS by manual optimization methods. Manual load balancing methods have been discussed in the literature [1, 4, 5, 25, 26]. Some of them are antenna tilting, antenna height, transmitter power, half rate, timing advance and among other. Their shortcoming and strength will be discussed one by one in following section.



**Figure 2.1 Overlapping Neighbors in Cellular System**

## **1. Antenna Tilting**

Antenna tilt is defined as the angle between the main beam of antenna and the horizontal plane. It is measured in degrees and can have positive or negative values. The positive value is referred to as down-tilt and negative value means up-tilting. A tilt value of 0° shows that the direction of the main beam is parallel to the ground plane [26]. Antenna tilt can be achieved either mechanically or electrically [26]. The mechanical tilt is achieved by manually tilting an antenna for the required orientation [4]. Whereas, the electrical tilt is achieved by changing the characteristics of signal phases on each element of the array. The electrical down tilt provide a smooth reduction in the coverage when compared to mechanical down tilt [4].

With the down tilt, one directs an antenna radiation further down to the ground. The down tilt is advisable when one wishes to decrease interference and coverage in some specific areas each BTS to meet only its designated area [4]. When selecting an optimum tilt angle, the goal is to have as high signal strength as possible in the area where the BTS should be serving [26]. Beyond this serving area, the signal strength should be as low as possible. Therefore, down tilting effectively reduces the coverage area of the BTS and disallows distant MS to access the BTS. A too aggressive down tilting strategy however leads to an overall loss of coverage and creates coverage holes which eventually lead to call drop [26].

## **2. Antenna Height**

The antenna height is fundamental to BTS coverage area. If the antenna height is increased, path-loss will reduce. The relation between antenna height and coverage is stated on two-ray model, Hata, Okumura and COST 231 [1]. If antenna height is doubled, then the coverage will be increased by 6dB in two-ray model [1]. To share load on a congested cluster, either of the following method can be applied; (a) lowering an antenna height of over-congested BTS, or (b) raising the antenna height of under-congested neighboring BTSs. However, this method is at risk of creating coverage holes or interference in the whole cluster.

## **3. Transmitter Power**

The most efficient method of varying the coverage area of a BTS is to adjust the BTS's transmitter power. A minimal transmit power effectively disallows more distant mobiles to access the BTS, thereby decreasing the coverage area and prohibits distant MS to access the BTS [25]. Hence, reducing BTS coverage area runs at the danger of creating coverage holes. Having the coverage holes on the cellular system adversely affect the performance of cellular system leading to call drop. Conversely maximum transmitter power allows distant MS to access the BTS, at the cost of producing interference on those BTS using the same frequency [25].

## **4. Cell Bar Quality**

The parameter such Cell Bar Quality (CBQ) can be adjusted to control TCH congestion [4]. The CBQ is represented as a character, with a value of YES or NO. Default value is NO. If CBQ of a BTS is equal to NO, the BTS selection priority is normal. If CBQ is

equal to YES, the selection priority is low. By setting the value of CBQ as YES in over-loaded BTS and NO in under-loaded BTS, traffic loading is balanced in the wireless cluster.

#### **5. Rxlev\_Access\_Min**

It is a threshold that allows MS to select a BTS only if the receiving signal level of the BTS is greater than a certain specified value [4]. The Rxlev\_Access\_Min is a decimal number within the range of -47 to -110dBm [4]. Its default value should be close to the reception sensitivity of the MS (for example this parameter is -102dBm in Ethio Telecom for GSM 900MHz and -100dBm in GSM 1800MHz). The increase in Rxlev\_Access\_Min decreases its logical coverage area of BTS [4]. Even traffic balance in the network is achieved by adjusting the logical coverage area of BTS's, Rxlev\_Access\_Min cannot be set beyond a certain values else they will result in a blind area on the edge of BTS. The blind area in the network leads to frequent call drop and unsatisfactory customer experience.

#### **6. Half Rate**

The traffic channel in GSM can carry user speech or data can be either in full-rate (TCH/F-13kbps/s) or half-rate (TCH/H-5.6kbps/s) channel mode [4]. When TCH/H is in use, one time slot is shared by two connections thus doubling the overall capacity of the BTS. However the use of half-rate has associated degradation in speech quality and hence it is not recommended to solve the issue of congestion in mature mobile service providers.

## **7. Timing advance (TA)**

TA is a parameter used to indicate how far the MS is from the BTS. The actual measure is time-how much time it takes for the signal to travel the distance from the BTS to MS. The speed of the Radio Frequency (RF) is equal to speed of light, and in this way the distance can be calculated. The maximum radius of a normal GSM is 35km and this radius is divided into 64 (i.e. 0-63) equal TA steps [5]. Each step is therefore approximately 550m. For example, a TA value for a mobile that is 1500m from the BTS is 2. This parameter can be used to limit the maximum coverage, for example if TA value is set to 2, only MS within the region of 1500m can be served. Hence from the network side if lower TA is set for over-congested BTSs and higher TA for under-congested BTS, traffic load can be balanced in the cluster. By doing so, it is possible to share from over-congested BTS to under-congested BTS. However, if the load distribution changes (i.e. formerly under-congested BTS becomes over-congested and vice-verse), optimization Engineers have to reverse the TA accordingly to solve problem.

## **8. Handoff Process**

An MS, in the presence of overlapping cellular coverage, can connect to any BTS depending on the RSS value. MS in a wireless network switches its current Point of Attachment (PoA) to a new wireless network using a process called Handoff [19]. To have global connectivity, Handoffs are extremely crucial in cellular communication because of the cellular architecture employed to maximize spectrum utilization. When a mobile terminal moves away from a BTS, the signal level drops and there is a need to switch the communications channel to another base station. That time, there is a need for

a handoff to be executed. Handoff is the process of changing the communications channel associated with the current ongoing connection while a call is in progress [8].

Many metrics have been used to support handoff decisions, including RSS, Signal to Noise Ratio (SNR), path-loss, and distance between the MS and BTS, traffic load, mobile velocity and among others [5]. A single-criteria handoff decision compares one of the metric from the serving BTS with that from one of the neighboring BTSs, using a constant handoff threshold value [8]. The selection of a threshold is important to handoff performance. If the threshold is too small, the handoff process will be speeded up and therefore, many unnecessary handoffs may take place [8]. On the contrary, the QoS could be low and calls could be dropped if the threshold is too large [8]. It means a mobile station keep its current BTS even though the neighboring BTS is providing a better service. This leads to call drop prematurely. Hence by varying the constant threshold value, it is possible for optimization Engineers to force a mobile station from over-congested BTS to under-congested BTS by tuning the constant threshold accordingly.

The steps that are used to follow for balancing uneven load distribution in cluster using handoff process are as follows:

- i. Identify top over-congested BTS in the cluster.
- ii. Check the status of the neighbors' of over-congested BTS and identify only under-congested neighbors
- iii. Check the number of outgoing handoff from over-congested BTS to the neighboring under-congested BTSs.

- iv. Identify a higher type of handoff undertaking ( is it due to RSS, due to path-loss, due to interference, due to TA, due to mobility).
- v. Introduce handoff threshold for the type of handoff in step IV.

Therefore, by adjusting the handoff regions between neighboring BTS, It is possible to cause cell edge users in over-loaded BTS to migrate to less-loaded neighboring BTS. Such an approach is referred to as mobility load balancing, thereby increasing the efficiency of resource utilization [27].

### **2.3.2 Limitations of Manual Blocking Relief Methodologies**

All the above techniques of load balancing are not self adaptive in the sense that every time congestion occurred in the network either of the above methods has to be manually applied. Once congestion is relieved with any method discussed above, those parameters still take effect which in turn affect customer satisfaction. Therefore, the problem of network congestion control remains a critical issue and a high priority, mainly given the growing size and demand. Network congestion is becoming a real threat to the growth of existing real-time networks (circuit switching). It is a problem that cannot be ignored.

### **2.3.3 Proposed Solution**

In an effort to address the above challenges, this thesis presents a design and implementation of a fuzzy multi-criteria handoff algorithm based on signal strength, path-loss, traffic load of BTS and signal to noise ratio (SNR). The algorithm balances traffic in all the neighboring BTSs at any time and enhances the performance of the cellular system by selecting the best network segment. This can be achieved by using Fuzzy Logic.

A multi-criteria handoff algorithm can provide better performance than a single-criterion handoff algorithm due to the extra number of evaluation parameters and the greater potential for achieving the desired balance among different systems characteristics. This multi-criteria nature of the algorithm allows simultaneous consideration of several significant aspects of the handoff procedure in order to enhance the system performance [8].

#### **2.3.4 Justification of Using Fuzzy Logic in Handoff process**

A wireless environment is characterized by its dynamic nature, inherent uncertainty, and imprecise parameters and constraints. Network parameters like RSS, Path-loss SNR and traffic load of BTS are intrinsically imprecise, vague and uncertain [17]. Due to this Fuzziness, the accurate measurement of these network parameters in a wireless environment is a difficult task. Consequently a fuzzy logic method seems to produce better results when used for system design in such condition. Though Fuzzy Logic might be slower for handoff algorithms, classical crisp value based techniques can be used to lower handoff latency, these classical techniques cannot produce intelligent handoff decisions. Hence, a scheme incorporates fuzzy logic based techniques to select target BTS and handoff execution [17].

The fact that fuzzy logic can mimic human expert reasoning and that many of the terms used to describe a signal (weak, far, strong, congested) are fuzzy in nature, makes fuzzy logic a strong candidate for performing handoff decisions. Fuzzy logic can adapt easily to these decisions as it can overcome radio environment uncertainty, fluctuations, and can



deal with heterogeneous inter-system parameters (shadowing effect, traffic variations, etc.) [9].

All the previous references prove that Fuzzy Logic Controller (FLCs) can be successfully applied to automatic network parameter optimization. Its main advantage is a capability to convert human knowledge into a set of basic rules. When an FLC is designed, a set of 'IF-THEN' rules must be defined, which represent the mapping of the input to the output in linguistic terms [20]. Such rules might be extracted from operator experience.

Fuzzy logic reasoning scheme is applied for mapping of non-linear inputs data set to scalar output figure. When the problems are with doubt and ambiguity, then to anticipate the correct value among all uncertainties we select fuzzy logic reasoning for two intentions [29]: (a) To develop computational techniques that can carry out reasoning and problem solving tasks that require human intelligence and (b) To explore an efficient trade-off between precision and the cost in developing an approximate model of a complex system. Thus, fuzzy logic is used to choose the optimal serving base station amongst given neighboring base stations for handoff decision founded on the multiple parameters as crisp inputs and give the best possible answer to choose the best base station.

## **2.4 Summary of the Chapter**

This chapter covered different aspects of handoff process and manual load balancing techniques and their limitations. Based on these limitations of the manual load balancing

method, a fuzzy logic multi-criteria handoff algorithm has been proposed. Justification of using a fuzzy logic and proposed solution have been provided.

## **CHAPTER THREE: METHODOLOGY**

The first section of this chapter covers the design of single-criteria handoff algorithms based on the wireless propagation model. Data from these models are used for analysis of both single-criteria and multi-criteria handoff algorithm. The second section covers the design of multi-criteria handoff algorithm based on fuzzy logic. The third section then presents a system model of cellular system with mobility.

### **3.1 Design of Single-criteria Handoff Algorithm**

Propagation models have been developed to estimate the radio propagation as accurately as possible [5]. Models have been created for different environment to predict the path-loss between the transmitter and receiver. How much power needs to be transmitted using BTS to be able to receive the certain level from the MS? The complexity of the model affects the applicability as well as the accuracy. Some of well known models are Hata, Okumura-Hata, Walfish-Ikegami, Two-Ray Model, Okumurah and COST 231 [1].

The basic electromagnetic wave propagation mechanism is free space loss, reflection, diffraction and scattering. In this thesis we considered sub-urban environment where there is usually line of sight between transmitter and receiver, hence Two-ray Model fits our work better.

#### **3.1.1 Received Signal Strength (RSS)**

The two-ray model is used when a single ground reflection dominates the multipath effect. The received signal consists of two components: the line of sight component which is just the transmitted signal propagating through free space, and a reflected

component which is the transmitted signal reflected off the ground [1]. Equation 3.1 indicates that the received power falls off to inversely the fourth power of  $d$  and independent of wavelength.

$$P_r dBm = p_t dBm + 20 \log_{10}(h_t h_r) - 40 \log_{10} d + G_r + G_t - losses \quad (3.1)$$

Where  $P_r$  is the received power in dBm,  $p_t$  is transmitted power in dBm,  $G_r$  is receiver antenna gain in dB,  $G_t$  is transmitter antenna gain in dB,  $h_t$  is transmitter height in meter, and  $h_r$  is receive antenna height in meter and  $d$  is the distance between transmitter and receiver in meter.

In this algorithm, the RSSs of the different neighboring BTS are measured over time and the BTS with the strongest signal strength is selected to carry out a handoff if it satisfies the minimum threshold set by the network provider [28]. Additional handoff initiation strategies have been defined based on the comparison between the current RSS and that of the candidate RSS in neighboring BTS [28 29].

- i. Conventional RSS: handoff takes place if the neighboring BTS's RSS is higher than the current RSS ( $RSS_j > RSS_i$ ).
- ii. RSS plus hysteresis: handoff takes place if the neighboring BTS's RSS is higher than the current RSS with a pre-defined hysteresis margin  $H$ . ( $RSS_j > RSS_i + H$ ).

### 3.1.2 Path-Loss

Link budget is the calculation of all the gains and losses in a transmission system. It looks at the elements that will decide the signal strength incoming at the receiver. It is necessary to determine link budget in the whole design of radio communication system.

Link budget calculations are used for calculating the power levels wanted for cellular communications systems, and for obtaining the BTS coverage [31].

To determine a link budget equation, it is necessary to look into all the areas where gains and losses may take place between the transmitter and the receiver. The calculation of the basic link budget is as follow.

$$\textit{Received power} = \textit{Transmitted power} + \textit{gains} - \textit{losses} \quad (3.2)$$

In the basic calculation of link budget equation, it is assumed that the power spreads out equally in all directions from the transmit antenna source. This is good for theoretical calculations, But not for practical calculations [31].

$$P_r = P_t + G_t + G_r - LT - LFS - LFM - LR \quad (3.3)$$

Where:

$P_r$ = received power in dBm

$P_t$ = transmitter output power in dBm

$G_t$  = transmitter antenna gain in dB

$G_r$  = receiver antenna gain in dB

$LT$  = transmit feeder and associated losses (feeder, connectors, etc) in dB

$LFS$  = free space loss or path loss

$LFM$  = many-sided signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...)

$LR$  = receiver feeder losses (feeder, connectors, etc) in dB.

### 3.1.3 Signal to Noise Ratio (SNR)

In a cellular system, the basic idea is the re-use of frequency pattern; same frequency is assigned to different BTS. The frequency allocation is done in such a way that the probability of co-channels interference between BTS using the same frequency is less than a given value [6]. It is worth mentioning that in cellular system the co-channel interference is actually the limiting factor in their efficiency and performance and not the total in-band noise in the system. This is because the unwanted signal power is very much higher than the total in-band noise (thermal, man-made) power in the system; hence the noise can be ignored [2].

Mathematically:

$$\text{Signal to noise ratio, SNR} = \frac{RSS}{I+N_s} \quad (3.4)$$

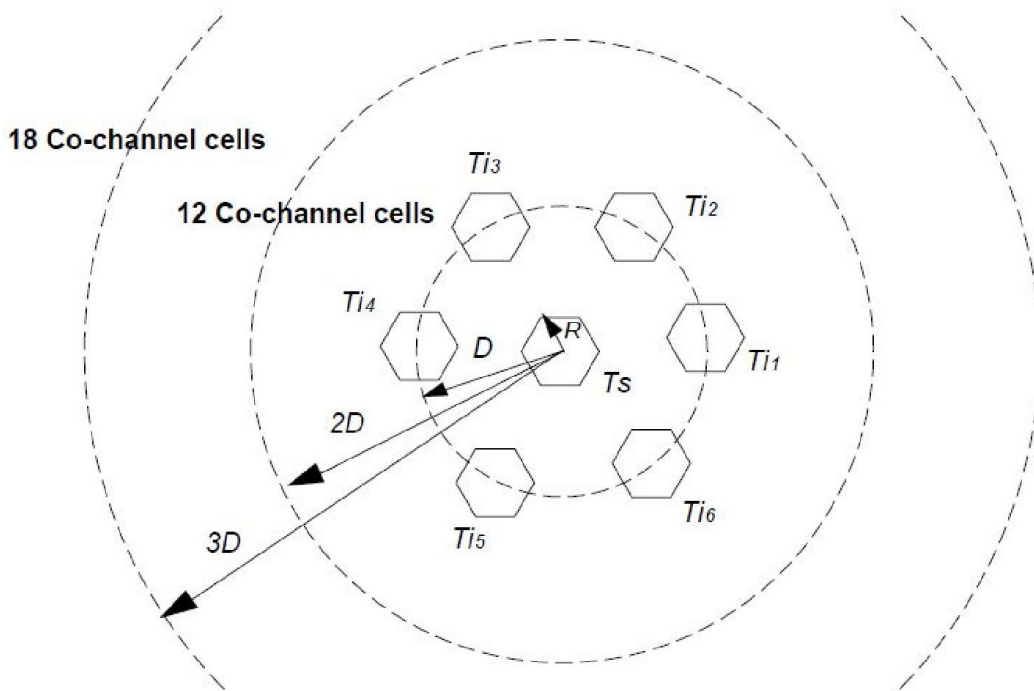
$$\text{Signal to interference ratio, } \frac{C}{I} = \frac{RSS}{I} \quad \text{for } I \gg N_s \quad (3.5)$$

Where RSS is the wanted signal power in dBm,  $I$  is the unwanted co-channel interfering signal power in dBm and  $N_s$  is the total in-band noise power in the system. The signal to interference ratio is a valuable measure of the performance of the modulation technique in the cellular system and it can indeed influence its spectral efficiency.

### 3.1.4 Geographical Model with Second Tier

This model is built depending on the relative geographical location of the serving and interfering BTS with respect to mobile station [2]. The model accounts for the signal path loss due to free space and propagation loss over the flat earth.

In fully hexagon-shaped cellular system, there are always  $6m$  co-channel cells in the  $m^{\text{th}}$  tier, regardless of the number of cell per cluster. It is assumed that all co-channels interfering BTS, up to the  $m^{\text{th}}$  tier considered are active as in a busy hour situation [2]. Mobile user in the center BTS can be interfered by six BTSs on the first tier, 12 BTSs on the second tier, and 18 BTSs on the third tier and so on as shown on Figure 3.1 [2].



**Figure 3. 1 Geographical Model for Several Tiers of Interfering BTS**

At the MS user, which is being served by BTS on the center of the cluster, the RSS is given by equation 3.6 [2].

$$RSS \propto \frac{1}{R^\alpha} \quad (3.6)$$

Where R is distance between a MS and BTS in meters and  $\alpha$  path-loss constant

The total interference from all the co-channel cells is given by equation 3.7 [2].

$$I \propto \left[ \frac{6}{D^\alpha} + \frac{12}{(2D)^\alpha} + \frac{18}{(3D)^\alpha} + \frac{24}{(4D)^\alpha} + \dots \right] \quad (3.7)$$

$$I \propto \left[ \frac{6x1}{D^\alpha} + \frac{6x2}{(2D)^\alpha} + \frac{6x3}{(3D)^\alpha} + \frac{6x4}{(4D)^\alpha} + \dots \right] \quad (3.8)$$

Where D is the frequency re-use distance in meter and  $\alpha = 4$

Hence:

$$I \propto \sum_{M=1}^T \frac{6m}{(mD)^\alpha} \quad (3.9)$$

Where T is the number of tier and  $\alpha$  path-loss constant

$$\frac{RSS}{I} = \left( \frac{D}{R} \right)^\alpha \frac{1}{6 \sum_{m=1}^T \frac{1}{m^{\alpha-1}}} \quad (3.10)$$

Where T is the number of tier and  $\alpha$  is path-loss constant

For second tier co –channel cell the equation 3.10 will reduce to in the following and the third and higher tier can be ignored because equation 3.11 is Taylor series.

$$SNR = \frac{RSS}{I} = \left( \frac{D}{R} \right)^4 \quad (3.11)$$

In dB the same equation will be reduced to:

$$SNR = \frac{RSS}{I} = 40 \log_{10}(D) - 40 \log_{10} R - 10 \log_{10} 6.75 \quad (3.12)$$

Where *the Re – use distance*(D) =  $\sqrt{21} * R$  for seven cluster cells [5].



### 3.1.5 Mathematical Justification of Geographical Model

The analytical results for propagation over a plane earth or two-ray models have been derived [1]. For the BTS and mobile station elevated heights  $h_t$  and  $h_r$  respectively above the ground level and separated a distance  $d$  apart, the received power  $P_r$  is given in terms of the transmitted power  $p_t$  as:

$$RSS = P_r = G_{ts}G_r \left[ \frac{h_{ts}h_r}{R^2} \right]^2 p_{t(s)} \quad (3.13)$$

$P_r$  is the desired signal power received at the MS from the serving BTS,  $p_{t(s)}$  is the transmitted power from the serving BTS,  $h_{ts}$  height of the serving BTS antenna in meter,  $h_r$  height of the mobile station antenna in meter,  $G_{ts}$  is the serving BTS antenna gain and  $G_r$  the mobile station antenna gain.  $R$  is the distance between the MS and BTS in meter

Similarly for the interfering signal power from the interfering BTS:

$$I \approx 6.75G_{ts}G_r \left[ \frac{h_{ti}h_r}{D^2} \right]^2 p_{t(i)} \quad (3.14)$$

$I$  is the unwanted signal power received at the mobile station from the interfering BTS,  $p_{t(i)}$  is the transmitted power from the interfering BTS,  $h_{ti}$  height of the interfering BTS antenna in meter,  $h_r$  height of the mobile station antenna in meter,  $G_{ts}$  is the interfering BTS antenna gain and  $G_r$  the mobile station antenna gain and  $D$  is the frequency re-use distance in meter.

Hence combining equations

$$\frac{RSS}{I} = SNR = \frac{G_{ts}G_r \left[ \frac{h_{ts}h_r}{R^2} \right]^2 p_{t(s)}}{6.75G_{ts}G_r \left[ \frac{h_{ti}h_r}{D^2} \right]^2 p_{t(i)}} \quad (3.15)$$

From equation (3.15), it can be shown that SNR can be maximized by maximizing  $G_{ts}$ ,  $h_{ts}$  and  $p_{ts}$ .

$$SNR = \frac{RSS}{I} = \frac{\left(\frac{D}{R}\right)^4}{6.75} \quad \text{same as 3.11}$$

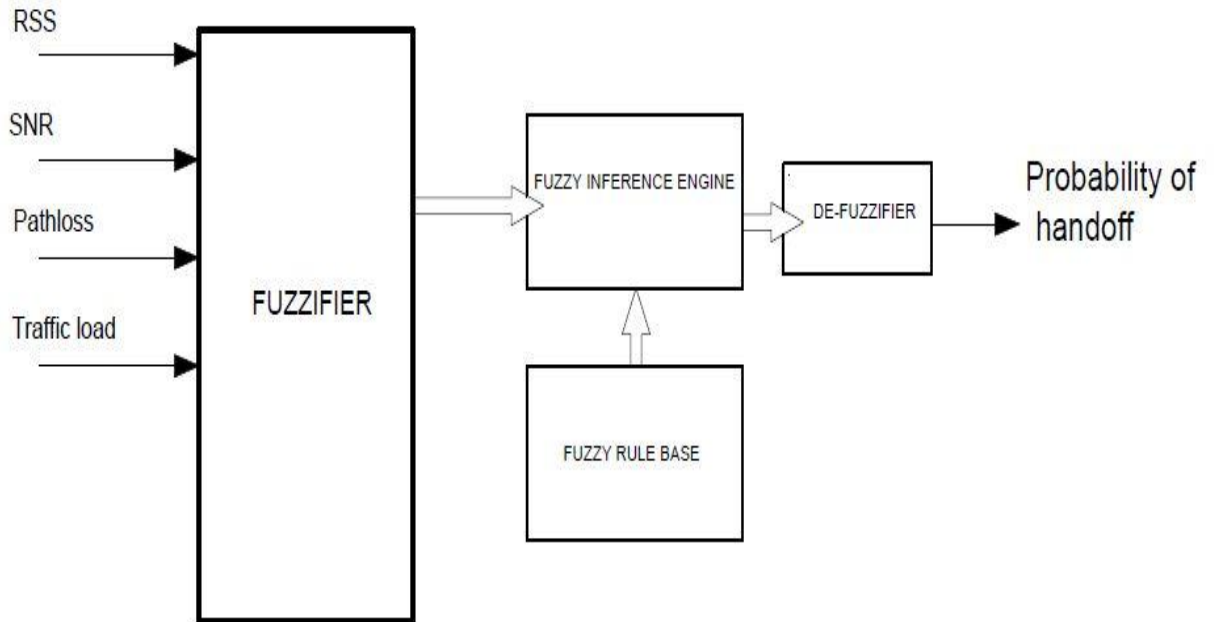
Which agree with equation 3.11 based on the assumption there is equal radiated power on the entire cellular system and the same system with in cellular system, nevertheless equation 3.11 remains valid for mixed cell size when

$$G_{ts} \neq G_{ti}, p_{t(s)} \neq p_{t(i)}, G_{ts} \neq G_{ti} \text{ and } h_{t(s)} \neq h_{t(i)}.$$

### 3.2 Design of multi-criteria Handoff Algorithm

The theory of fuzzy logic is based on the notion of relative graded membership, as inspired by the processes of human opinion and cognition [17]. Fuzzy logic can deal with information arising from computational perception and cognition that is imprecise, vague, uncertain, somewhat true, or without clear boundaries. Fuzzy logic allows inclusion of vague human assessments in computing problems. Also, it provides a successful means for conflict resolution of multiple criteria and better assessment of options. New computing methods based on fuzzy logic can be used in the development of intelligent systems for decision making for selecting the best network segment [17].

The four input parameters which have been considered are: RSS, Path-Loss, SNR and Traffic load of BTS. Figure 3.2 shows the general structure of the proposed algorithm with inputs, fuzzifier, fuzzy inference engine, fuzzy rule base and de-fuzzifier. The output of the fuzzy inference system is the handoff decision which is used later to decide if handoff is necessary or not.



**Figure 3. 2 Structure of the Proposed Algorithm**

The only output parameter of the FIS is handoff decision. In the proposed algorithm a range of RSS is taken to be -50dBm to -100dBm, the Path-loss varies from 50dB to 140dB, the SNR range from the lowest 0dB to highest 50dB. The BTS traffic load range from 0 to 100%.

### 3.2.1 Fuzzification

In the first step of the handoff process, the model would collect all the four parameters and feed into a fuzzifier. The fuzzifier transforms real-time measurements into fuzzy sets. To improve the reliability and robustness of the system, Gaussian membership functions (MFs) are used as an alternative to the traditional triangular MFs [32]. For instance, if RSS is considered in crisp set, it can only be weak or strong. RSS cannot be both at same

time. However, in a fuzzy set, the signal can be considered as weak and medium at same time with graded membership. The membership values are obtained by mapping the values obtained for the particular parameter into a membership.

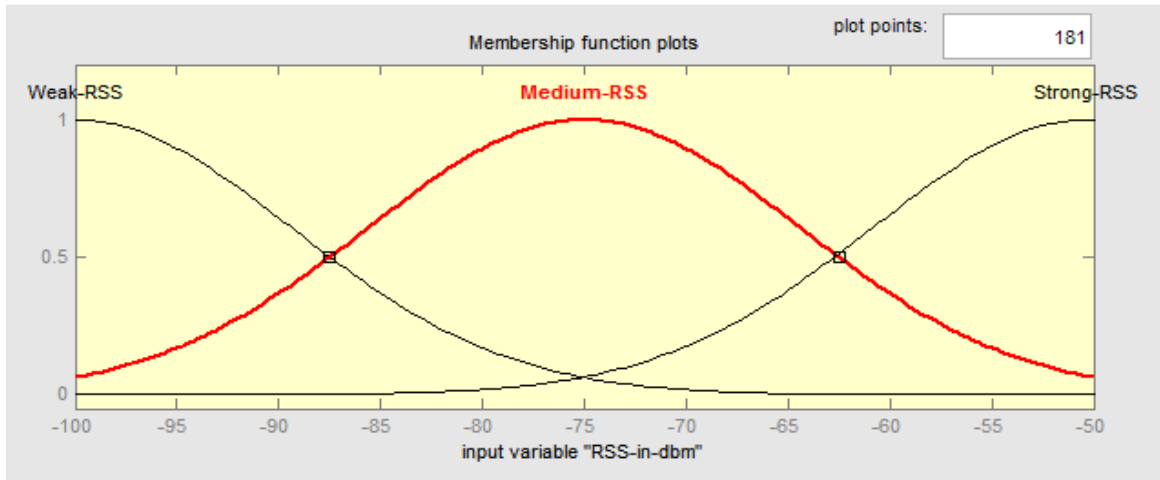
Membership of the inputs parameters are designed using data fetched from live network from Ethio Telecom. For example, as shown in Table 3.1, there are three color legends indicated. The strong RSS is labeled with green, the medium RSS is yellow and the weak RSS is on orange.

**Table 3. 1 Measurement from Live GSM Network**

Cell Name	BSIC	ARFCN	RxLev	C1	C2	C31	C32
VH_ZTE079E_DM0T01...	6-2	537	-63				
VH_ZTE079E_GM0T01...	5-3	36	-57				
VH_ZTEG093E_M0T34...	1-6	58	-67				
AA_ZTED092E_M0T34...	7-4	567	-75				
AA_ZTED093E_M0T34...	0-0	635	-77				
VH_ZTE079E_GM0T01...	5-0	64	-80				
	7-0	72	-84				
		687	-85				
		95	-85				
		598	-86				
		561	-87				
		653	-87				
VH_ZTE085E_GM0T01...	7-1	43	-88				
		52	-89				
		77	-90				
		608	-91				
		25	-91				
		606	-92				
		71	-92				
		85	-92				
		690	-93				
		8	-93				
	101	-94					
	626	-96					
	643	-100					
	553	-102					

### 3.2.1.1 Fuzzification of the Input Parameter RSS

The main objective of the proposed scheme is to maximize the end-user’s satisfaction in terms of the quality and continuity of the currently utilized service. RSS plays a very significant role in maintaining this objective.



**Figure 3.3 Membership Functions of RSS**

**Table 3.2 Description of Input Variable RSS**

Serial number	RSS description	Fuzzy Nomenclature	RSS range in dBm
1	Weak RSS	WRSS	[-100 -75]
2	Medium RSS	MRSS	[-100 -75 -50]
3	Strong RSS	SRSS	[-75 -50]

The fuzzy logic controller (FLC) in Figure 3.3 is designed to make sure that the MS performs handoff before RSS falls below the minimum network values required to sustain the quality of the currently utilized service.

The universe of discourse for RSS is between -50dBm to -100dBm, as summarized in Table 3.2 and Figure 3.3. There are mainly three colors indicated on the legend of Table 3.1. Therefore, three membership functions are used for RSS and same applied for the Path-loss, SNR and Traffic load.

Weak RSS is between -100dBm to -75dBm. So the MS in this region have higher probability of handoff because the RSS is started to deteriorate. This is to be determined by the rule base to be developed in following section.

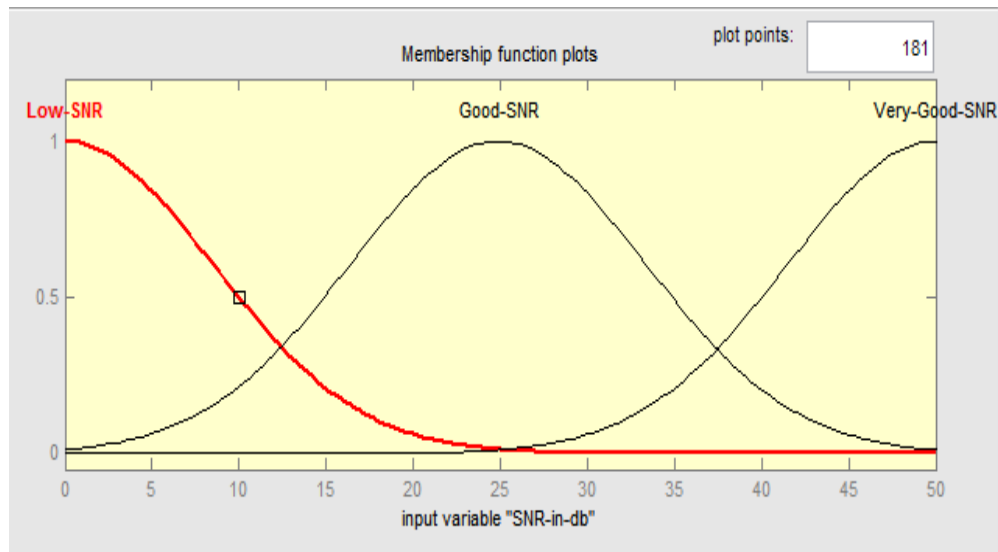
If this parameter falls below a threshold the overall quality of the current application session diminishes resulting in reduced end-user's satisfaction level and call drop eventually. Before call drop, the proposed algorithm must execute handoff even if the other parameter fulfills the required threshold for continuing calls. This threshold is -100dBm in GSM 900MHz in Ethio telecom.

### **3.2.1.2 Fuzzification of the Input Parameter SNR**

SNR is a measurement that describes how much noise is in the output of a device, in relation to the signal level [5]. In cellular network, to maximize efficiency of radio resource, frequencies are re-used at some distance away [1]. So every set of frequencies is interfered in some way from other BTS that use the same frequency. The question is, "How much is too much?" The answer is, "it's all relative". A small amount of interference may not be objectionable if the received RSS is very strong [1]. In many cases, the interference may not be audible at all. But if the signal level is very small, even a very low noise level can have an adverse effect [1]. To make the determination objectively, the relative strengths of the RSS and the interference level are needed to be looked at. To put it another way, it is a Signal-to-Noise Ratio (SNR).

SNR plays a very important role in achieving the end-user's satisfaction in terms of the quality and continuity of the currently utilized service. It is this parameter that usually

determines which service provider to choose among all. The better this parameter is kept, the more subscribers have been served. If SNR drops below the minimum threshold set by operator, then the overall value of the current call reduces resulting in degraded quality of service.



**Figure 3. 4 Membership Function of SNR**

**Table 3. 3 Description of Input Variable SNR**

Serial number	SNR description	Fuzzy Nomenclature	SNR in dB
1	Low SNR	LSNR	[0 25]
2	Good SNR	GSNR	[0 25 50]
3	Very Good SNR	VSNR	[25 50]

The universe of discourse for SNR is between 0dB to 50dB, as summarized in Table 3.3 and Figure 3.4. Low SNR is between 0dB to 25dB. An MS in low SNR region have high probability of handing off to the neighboring BTSs. This is to be determined by the rule

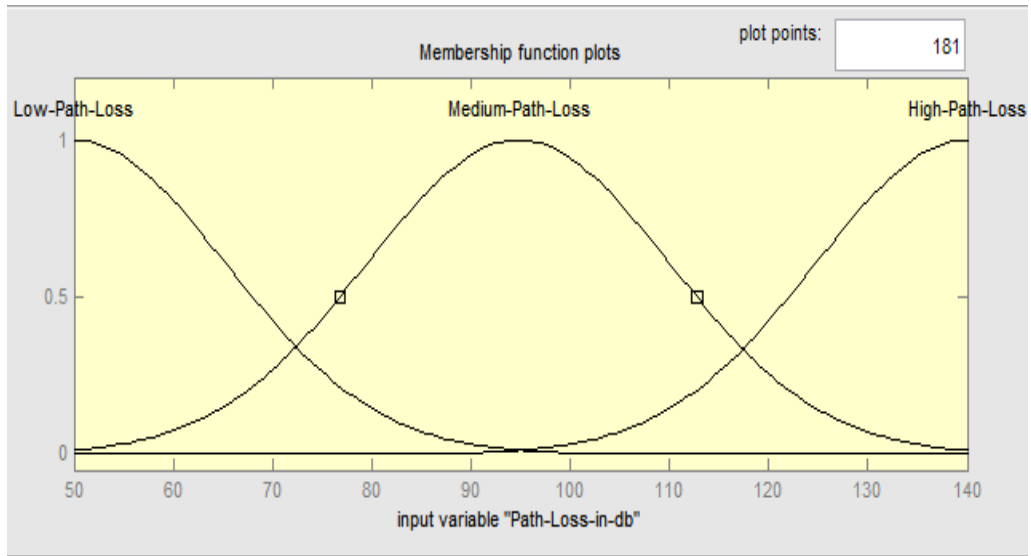
base. The FLC in Figure 3.4 is designed to make sure that the MS performs handoff before SNR falls below the minimum network values. In Ethio Telecom this value is 9dB.

### **3.2.1.3 Fuzzification of the Input Parameter Path-loss**

The aim of power budget calculation is to balance the uplink and down link. The received signal sensitivity may be different because the MS and the BTS have different radio frequency architecture. The power of BTS can be adjusted to balance the whole link. The power balance (uplink and down link) decide the cell range.

If the down link is greater than the uplink, it will result in range of BTS being greater than the range of MS, and coverage area is smaller in reality than the prediction. This condition is most frequent. If this parameter exceeds a certain threshold, the overall quality of the current application session reduces resulting and the call drops eventually. Therefore this parameter significantly affects the performance of the cellular system as radio propagation is strongly site specific and varies significantly depending on geography, frequency of operation and other dynamic factors.





**Figure 3. 5 Membership Function of Path-loss**

**Table 3. 4 Description of Input Variable Path-Loss**

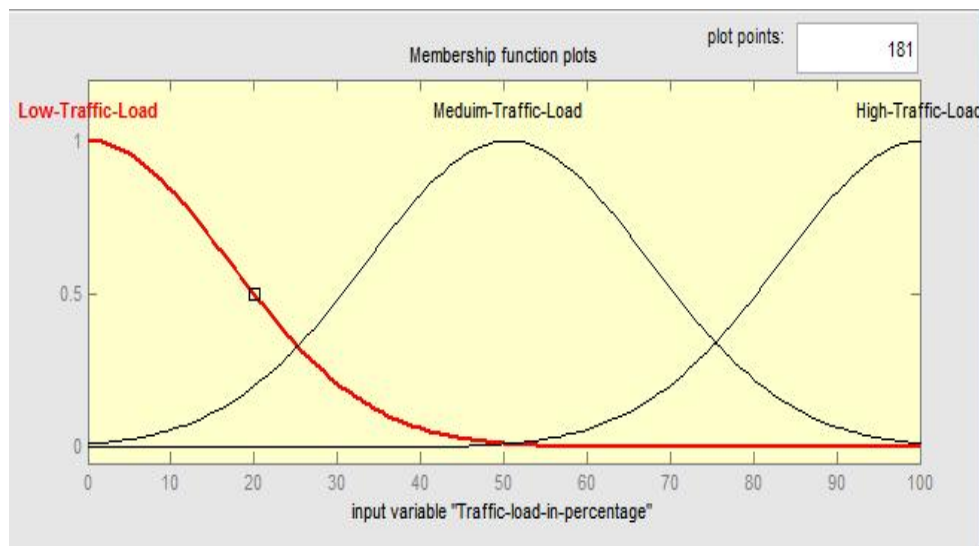
Serial number	Path-loss description	Fuzzy Nomenclature	Path-loss range
1	Low Path-loss	LPL	[50 95]
2	Medium Path-loss	MPL	[50 95 140]
3	High Path-loss	HPL	[95 140]

The universe of discourse for Path-loss is between 50dB to 140dB, as summarized in Table 3.4 and Figure 3.5. High Path-loss is between 95dB to 140dB. The FLC in Figure 3.5 is designed to make sure that the MS performs handoff before the Path-Loss factor exceeds a maximum network values required to sustain the quality of the currently utilized service. Path-loss higher than 120dB is considered as limiting factor to sustain a call in Ethio telecom.

### 3.2.1.4 Fuzzification of the Input Parameter Traffic Load

The main objective of the load balancing is to optimize network operation, increase network utilization usage as high as possible and improve network performance.

The universe of discourse for Traffic load is between 0 to 100% as shown in Figure 3.6 and Table 3.5. In Ethio Telecom, when 90% traffic load of a BTS has been used, a cell is considered as high load BTS. Load balancing helps to reduce cell traffic over-congestion, enhance the success rate of assignment, and balance the traffic load between cells. The FLC in Figure 3.6 is designed to make sure that the MS performs handoff before the serving BTS is fully congested to have some free channels for new coming calls.



**Figure 3. 6 Membership Function of Traffic Load**

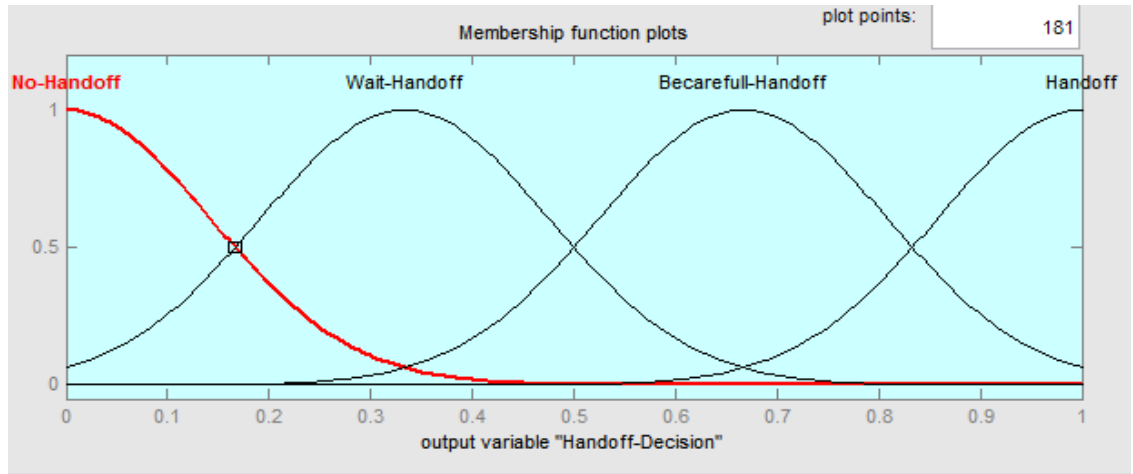
**Table 3. 5 Description of Input Variable Traffic Load**

Serial number	Traffic load description	Fuzzy Nomenclature	Traffic load in %
1	Low Traffic Load	LTL	[0 50]
2	Medium Traffic Load	MTL	[0 50 100]
3	High Traffic Load	HTL	[50 100]

This will help to accommodate a new call originating in the coverage area of the BTS or the new incoming call from the neighboring BTS. If the BTS doesn't have free channels at any time, then both incoming and originating call end up being blocked from accessing a network. So this FLC is designed in such a way that the BTS hands off some of ongoing calls. This allows the BTS to have free channels at any time unless the whole cluster is congested. If the whole cluster is over-congested, then obviously there is no way the traffic load can be shared. When the whole cluster is over-congested then the problem may only solved by expanding the network by adding hardware.

### **3.2.3.5 Fuzzification of the Output Handoff Decision**

The fuzzy set values for the output decision variable handoff decisions are No-handoff, Wait-Handoff, Be careful-Handoff and Handoff. The universe of discourse for the variable handoff decision is defined from zero to one. This value is important in comparing the rank of the BTSs



**Figure 3. 7 Handoff Decision Membership Function**

**Table 3. 6 Description of Input Variable Handoff Decision**

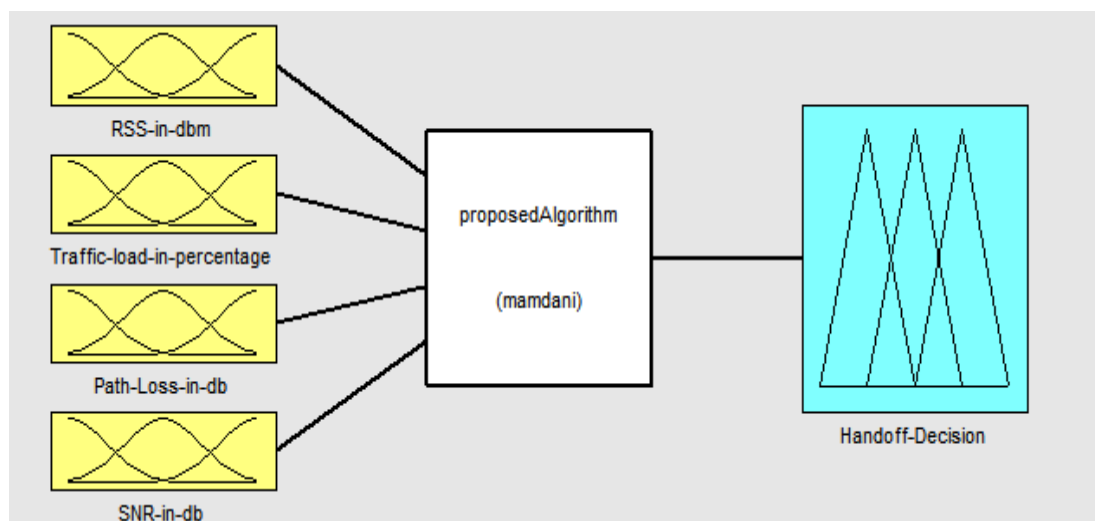
Serial number	Handoff decision description	Fuzzy Nomenclature	Handoff decision
1	No-Handoff	NHO	[0 0.4]
2	Wait-Handoff	WHO	[0 0.33 0.67]
3	Be careful-Handoff	BHO	[0.33 0.67 1]
4	Handoff	HO	[0.6 1]

### 3.2.2 Fuzzy Inference System

The second step of the handoff process involves feeding the fuzzy sets into an inference engine, where a set of fuzzy IF-THEN rules is applied to obtain fuzzy decision sets. There are 3\*3\*3\*3 "IF-THEN" rules in fuzzy inference system (FIS) to mapping the fuzzy inputs. Fuzzy rules can be defined as a set of possible scenarios which decides whether handoff is necessary or not. For simple understanding, we used the set [No-Handoff, Wait-Handoff, Be Careful-Handoff and Handoff] to represent the fuzzy set of

output handoff decision, the range of the decision matrix is from zero to one, where 0 is No-Handoff and 1 is exactly Handoff.

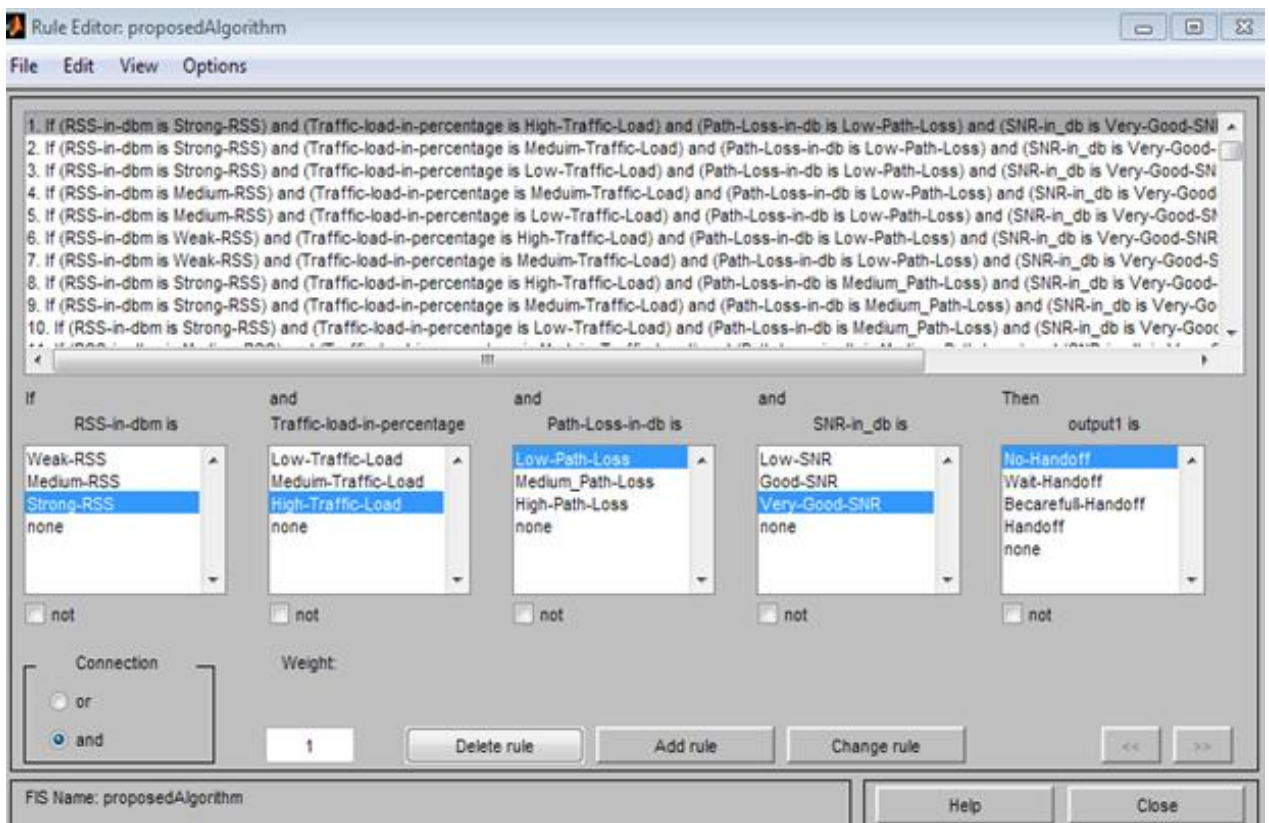
Figure in 3.8 indicates the four inputs to FIS. The output of FIS is a decision if handoff process is to execute or not. The decision to execute handoff process depends on the preset threshold value (i.e. the threshold handoff execution has to meet) or the rank of the neighboring BTS (i.e. the rank of neighboring BTS has to be better).



**Figure 3. 8 Input and Output Representation**

A fuzzy knowledge base can represent a complex system not as a set of complex, nonlinear differential equation but as simple as set of input-output rule [33]. Designing the rule base is an important step of development of a fuzzy knowledge- based system [33]. Inference can be made by matching data with individual rules and then combining these individual rule-based inferences [33].

The antecedent part of a rule corresponds to input of the fuzzy decision-making system. Several input variables may be connected by AND connectives [33]. Different rule in the rule base will involve different fuzzy states of the antecedent variable. The consequent part of a rule gives action.



**Figure 3.9 IF- Then Rules**

For example as shown on Figure 3.9: IF RSS in dBm is Strong RSS and Traffic Load in percentage is High traffic Load and Path-loss in dB is low-Path-loss and SNR in dB is Very Good SNR then the output is No Handoff.

### **3.2.3 Defuzzification**

Finally, 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 is chosen to defuzzify for changing the fuzzy value into the crisp set [29, 33]. The centroid method uses the entire membership function of a control inference [33]. Thus, the defuzzifier value depends on both size and shape of the membership function. As a result it is a more complete representation. Due to an inherent averaging over the support set, the control action is diluted and less sensitive to small variation [33]. Accordingly, the centroid method represents a very robust procedure, which generates less oscillatory process response [33].

### **3.3 Network Model**

Omni-directional GSM cellular network is considered. Each cell is served by central BTS and has 100 TCHs. Mobile users inside the coverage area of a BTS are assumed to be normally distributed. BTSs are connected to a single BTS Controller (BSC) where the proposed algorithm is to be located. An MS measures RSS, Path-loss and SNR from a current serving BTS and all the neighboring BTS. This measurement report is done by mobile station every 480ms and report to BTS through common control channel [5].

In this thesis, a suburban area environment was considered. In instances of low load scenarios, a coverage area of a cell sector is assumed to be virtually extendable to cover up to a partial serving area of a nearby BTS when the BTS has low or medium load. This helps a nearby highly loaded BTS.

### 3.3.1 Multi-Criteria Handoff Algorithm

Fuzzy logic reasoning scheme is applied for mapping of non-linear data set to scalar output figure. When the problems are in doubt and ambiguous, then to anticipate the correct value among all uncertainties fuzzy logic is selected to develop computational techniques that can carry out reasoning and problem solving tasks that requires human intelligence [29]. Thus, fuzzy logic is used to choose the optimal serving BTS amongst given neighboring BTSs for handoff decision founded on the multiple parameters.

RSS, Path-Loss and SNR are users' mobility related parameters; they are fetched from the propagation model in section 3.1. Meanwhile traffic load on the BTS is network-related parameter. It can be obtained in the counter of BSC [5]. The four parameters are fed into proposed algorithm.

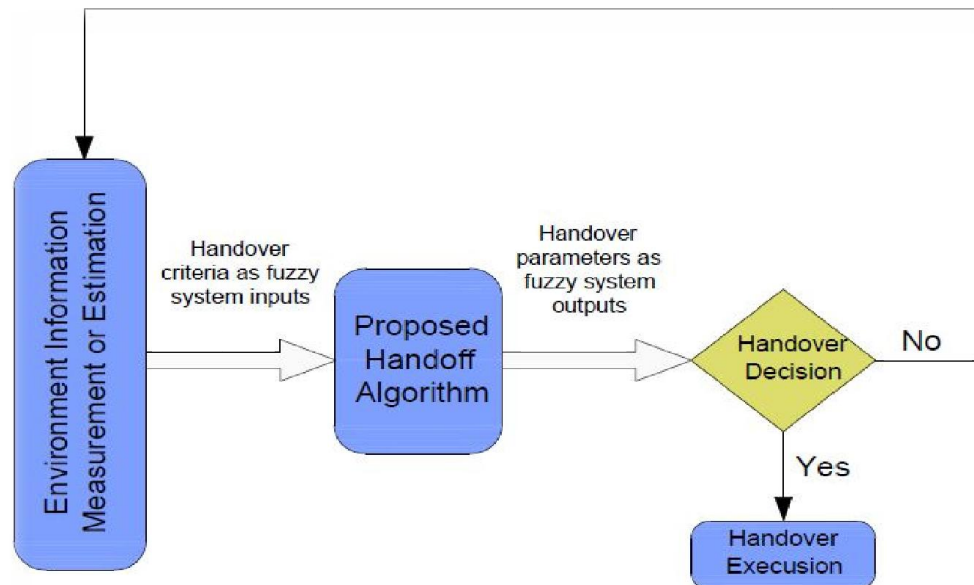


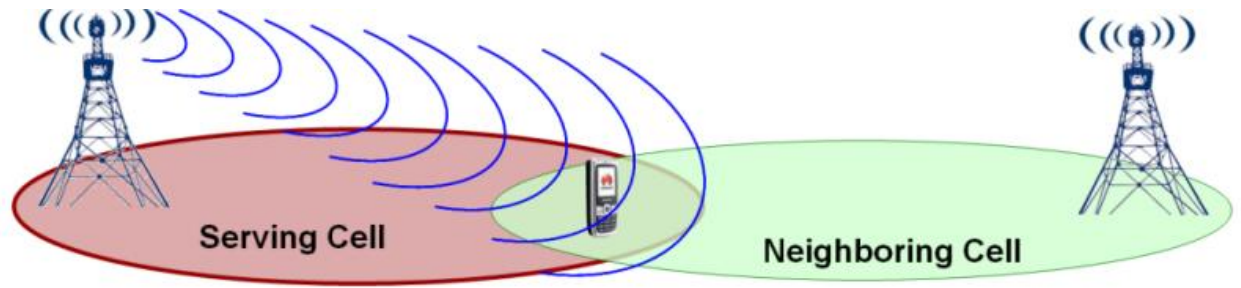
Figure 3. 10 General Structure of the Proposed Multi-Criteria Handoff Algorithm



The output of the FIS is between 0 and 1, where 0 is no handoff and 1 is exactly handoff. Ideally when the output of FIS is near 0, it means a MS is served on a better BTS so there will no necessity for handoff. On contrary, when the output of FIS is near 1, the mobile station is being served on deteriorated parameters and hence it requires being handoff to a better BTS.

### **3.3.2. Environment Information Measurement from Propagation Model**

Figure 3.11 shows an MS is moving from one BTS (named BTS I) to another BTS (named BTS j). Under normal condition (when traffic is equally distributed) BTS I serves the first 5000m and BTS j serves the second 5000m. Assumption we made here was traffic distribution in each cell sector is uniform, but network traffic distribution is non-uniform in the cluster. Mobility of MS user is random. It can be in any direction. For simplicity in this simulation, a mobility to be only in positive X direction (from BTS I to BTS J) was considered. For our analysis a MS moves in a straight line between both BTSs.



**Figure 3. 11 Two Neighboring BTS.**

During a measurement report (i.e. every 480ms) a mobile station measures the RSS, SNR and Path loss from both serving and neighboring BTS [5]. The traffic load of each BTS is registered in the counter of the BSC [5]. In our simulation the values of RSS, SNR and path loss are fetched from the wireless propagation model. This data along with traffic load of the BTS are fed into the proposed algorithm.

### **3.4 Summary of the Chapter**

This chapter contained the description of different propagation models which are used to analyze both single-criteria and multi-criteria handoff algorithms, Fuzzification of the inputs and output parameters, universe of discourse of the inputs and the output, the inference system and Defuzzification, design of the multi-criteria handoff algorithm and a network model used to simulate a proposed algorithm.

## **CHAPTER FOUR: RESULTS AND DISCUSSION**

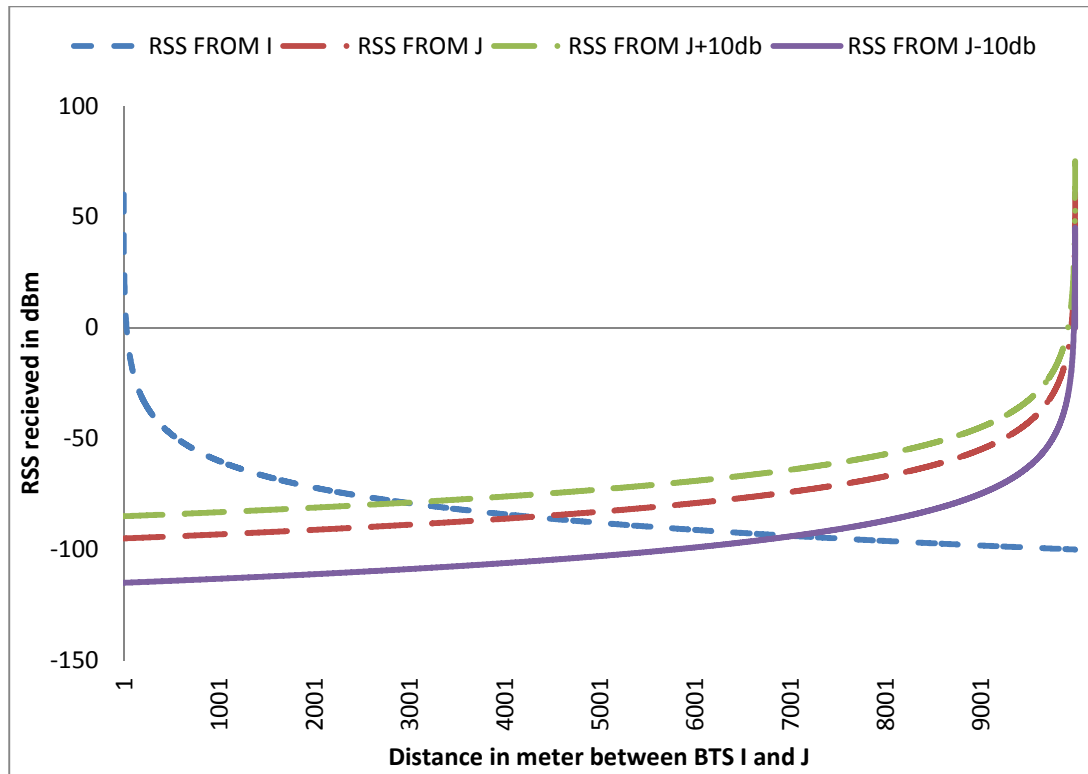
### **4.1 Result of Single –Criteria Handoff Algorithm**

In this section all single-criteria handoff algorithms are discussed with respect to how to achieve load balancing in the cluster. Similar horizontal mobility plane has been used throughout the discussion. Mainly a distance at which handoff takes place between the neighboring BTS has been used to as how load balancing is achieved.

#### **4.1.1 RSS Based Handoff Algorithm**

Figure 4.1 shows the RSS from two neighboring BTS. Figure 4.1 also shows an MS moving from BTS I to BTS J. The RSS of BTS I decrease as MS moves away from the BTS and from BTS j increases as it approaches. With conventional algorithm, looking at the variation of RSS from either BTS, 4500m is optimum area where handoff can take place.

However, as shown in Figure 4.1, the conventional algorithm with hysteresis allows a MS to make handoff decision only if the RSS received from the neighboring BTS is sufficiently stronger than the current one by the specified hysteresis margin, provided a certain minimum signal level is assured.



**Figure 4. 1 RSS from Base Station I and J in dBm**

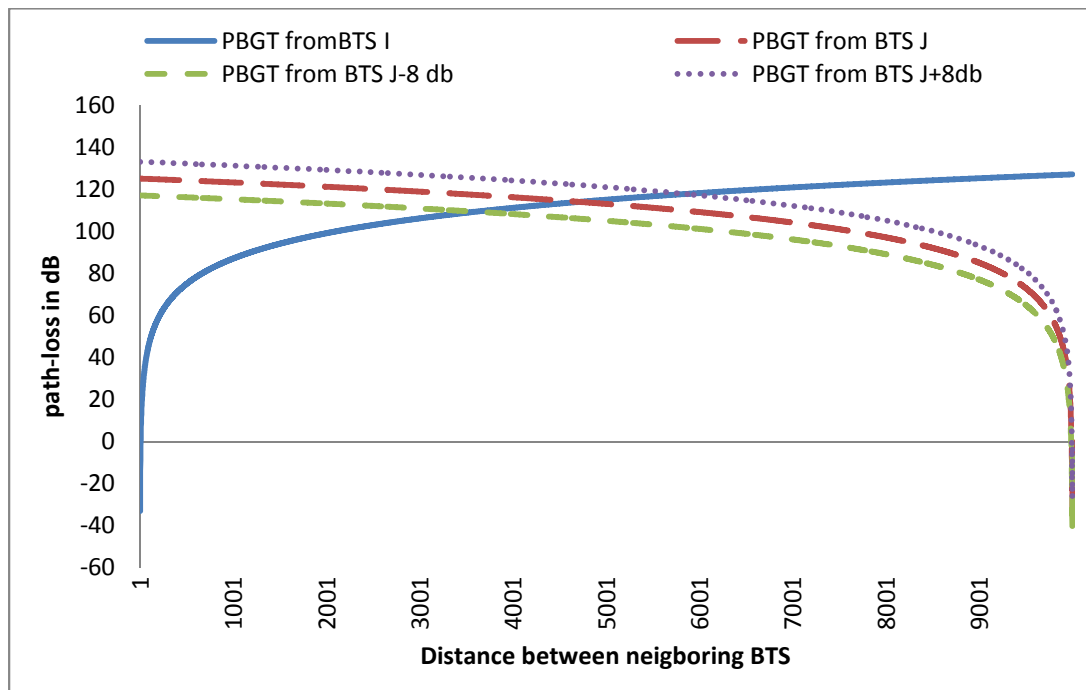
Load balancing can be achieved with RSS based handoff algorithm by handing-off cell edge users in over- loaded cells to migrate to under-loaded neighboring BTS. But this type of load balancing is manual. Optimization engineers have to tune the hysteresis to achieve load balance in the cluster.

#### **4.1.2 Power Budget Based Handoff Algorithm**

Figure 4.2 shows path-loss from two neighboring BTS. In cellular networks, the handoff process takes on the responsibility of ensuring that any MS is always connected to the most suitable BTS.

Power budget (PBGT) handoff assures that, under normal conditions, any MS is served by BTS that provides minimum path-loss and hence handoff due to power budget takes place at about 4700m.

However, the conventional algorithm with hysteresis allows an MS to make handoff decision only if the path-loss received from the neighboring BTS is better than the current one by the specified hysteresis margin, provided a certain threshold path-loss is assured.



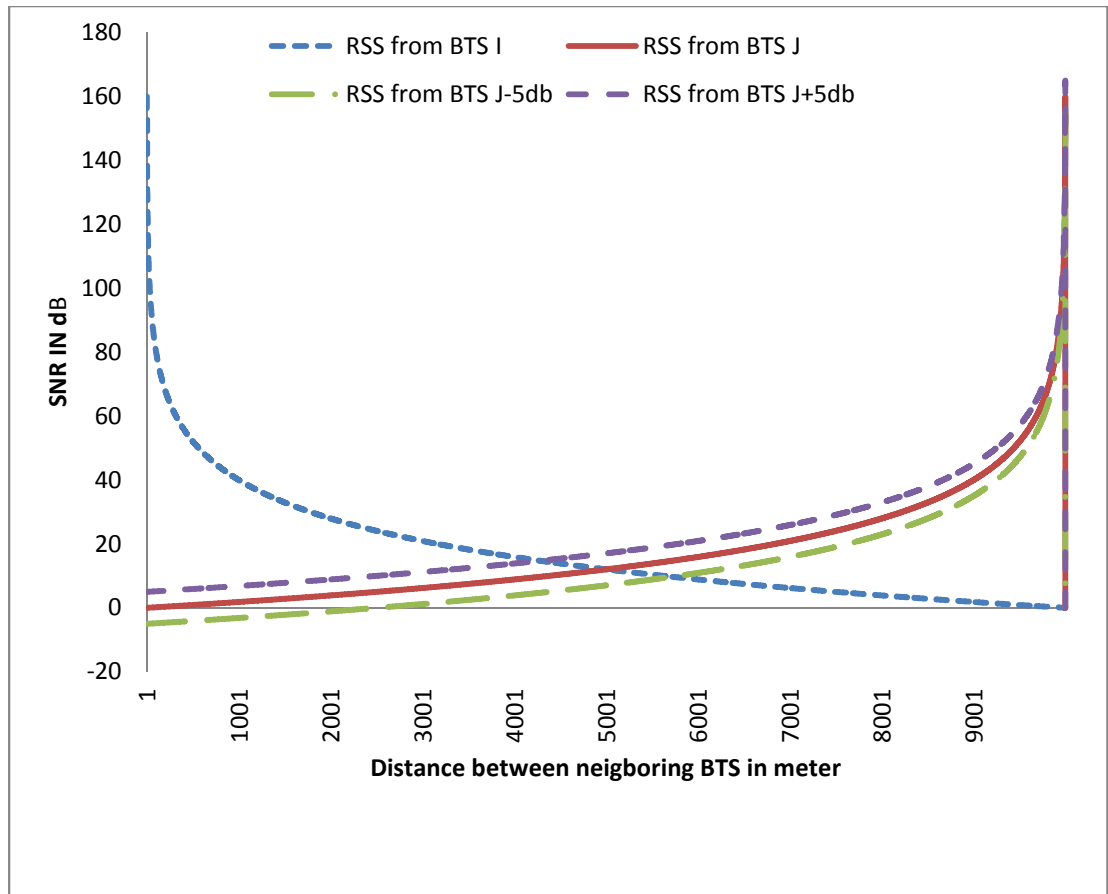
**Figure 4. 2 Path- Loss from Base Station I and J in dB**

Same as in RSS based handoff algorithm, load balancing can be achieved manually by handing-off cell edge users in over-loaded cells to migrate to under-loaded neighboring BTS.

### **4.1.3 Interference Based Handoff Algorithm**

Figure 4.3 shows the RSS/I from two neighboring BTS. In cellular networks; the handoff due to Interference takes on the responsibility of ensuring that any MS is always connected to BTS having a better RSS/I. Therefore, conventional handoff algorithm takes place at about 5000m (the radius of the cells) to ensure better SNR.

Constant hysteresis can also be introduced in interference based handoff algorithm, for quick handoff process when BTS I is congested. This time MS on the edge of BTS I can migrate to BTS J and the load on BTS I can be decongested. If BTS J is congested next time, the optimization engineers have to tune hysteresis to decongest BTS J. This task is how load is manually shared between neighboring BTS and it cannot be effective.



**Figure 4. 3 SNR from Base Station I and J in dB**

#### 4.2 Multi criteria Handoff Algorithm

In this section detail analysis of multi-criteria handoff is discussed with respect to how to achieve the load balancing with numerical example. The neighboring BTSs are ranked using the proposed algorithm. Handoff necessity and estimation are discussed and threshold of 0.55 is introduced to reduce unnecessary handoff. In this section, it was showed that it is possible to balance load of cellular network by handing off some ongoing calls on the cells edge in over-loaded BTS. Single –criteria has been used as a reference to evaluate the performance of a proposed algorithm.

#### **4.2.1 Rule Base Evaluation for FIS**

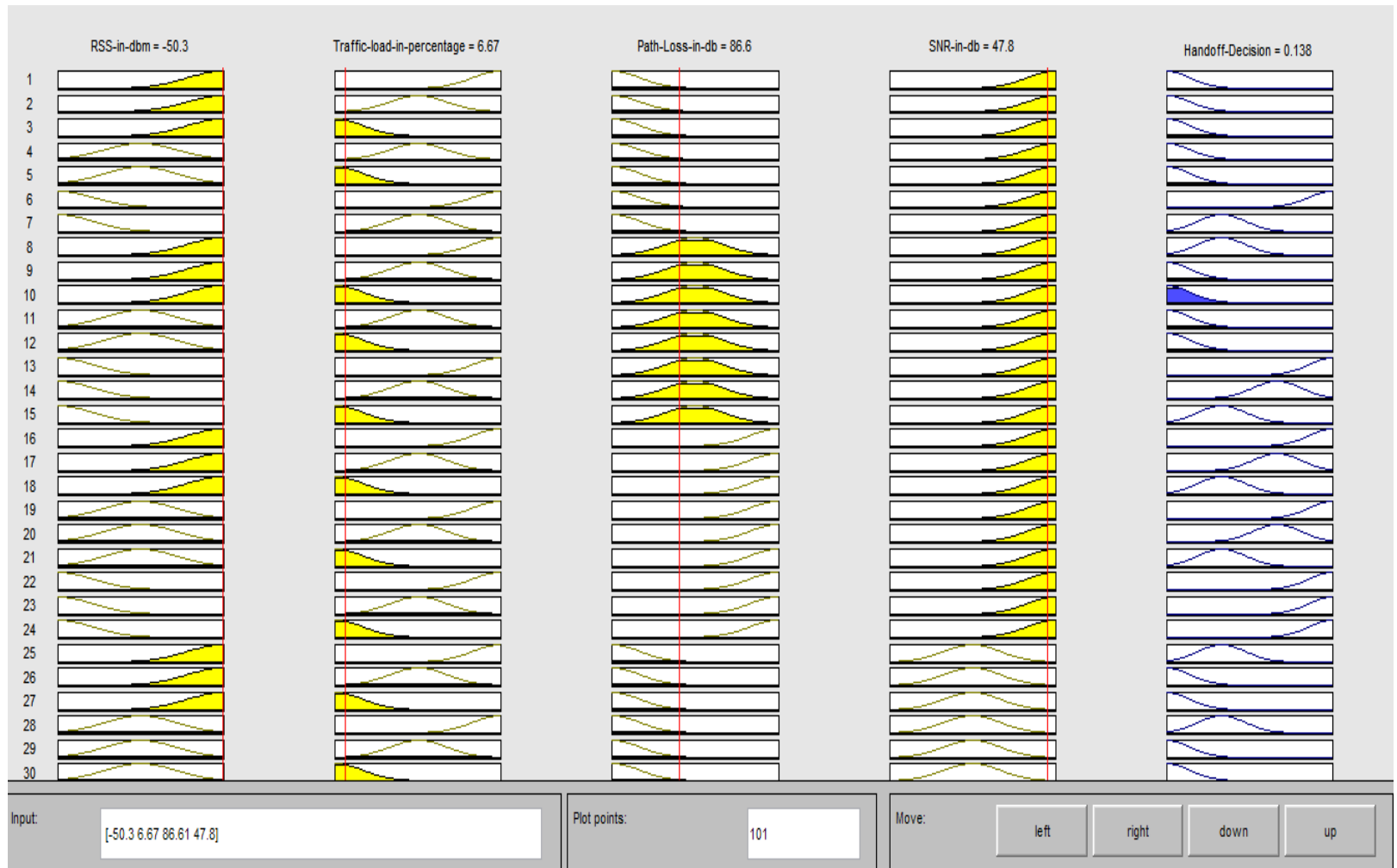
A handoff initiation technique in the proposed algorithm utilizes fuzzy logic with Multiple Objective Decision Making (MODM) approach to select the best network segment. All the available BTSs including the current serving BTS are then ranked. The selection of the target network is done using four fuzzy inputs that utilizes the RSS, Path-loss, Interference and traffic load of the serving and the neighboring BTS.

Based on those parameters, the fuzzy logic will rank both the serving and the neighboring BTSs. If a better neighbor BTS is found, a handoff is requested. BTS ranking is performed every time a MS reports measurement on regular basis. In a cellular system a measurement report is done in every 480ms [5].

Figure 4.4- 4.6 illustrate three examples of the rank of BTS for three different cases. Case one when all the four parameters are excellent, Case two when all parameter are average and case three when all the four parameters are worst:

As expected when all the parameters are excellent then the probability to requisite handoff is minimal. On contrary, when all the parameters are worst, the probability to handoff is maxima.



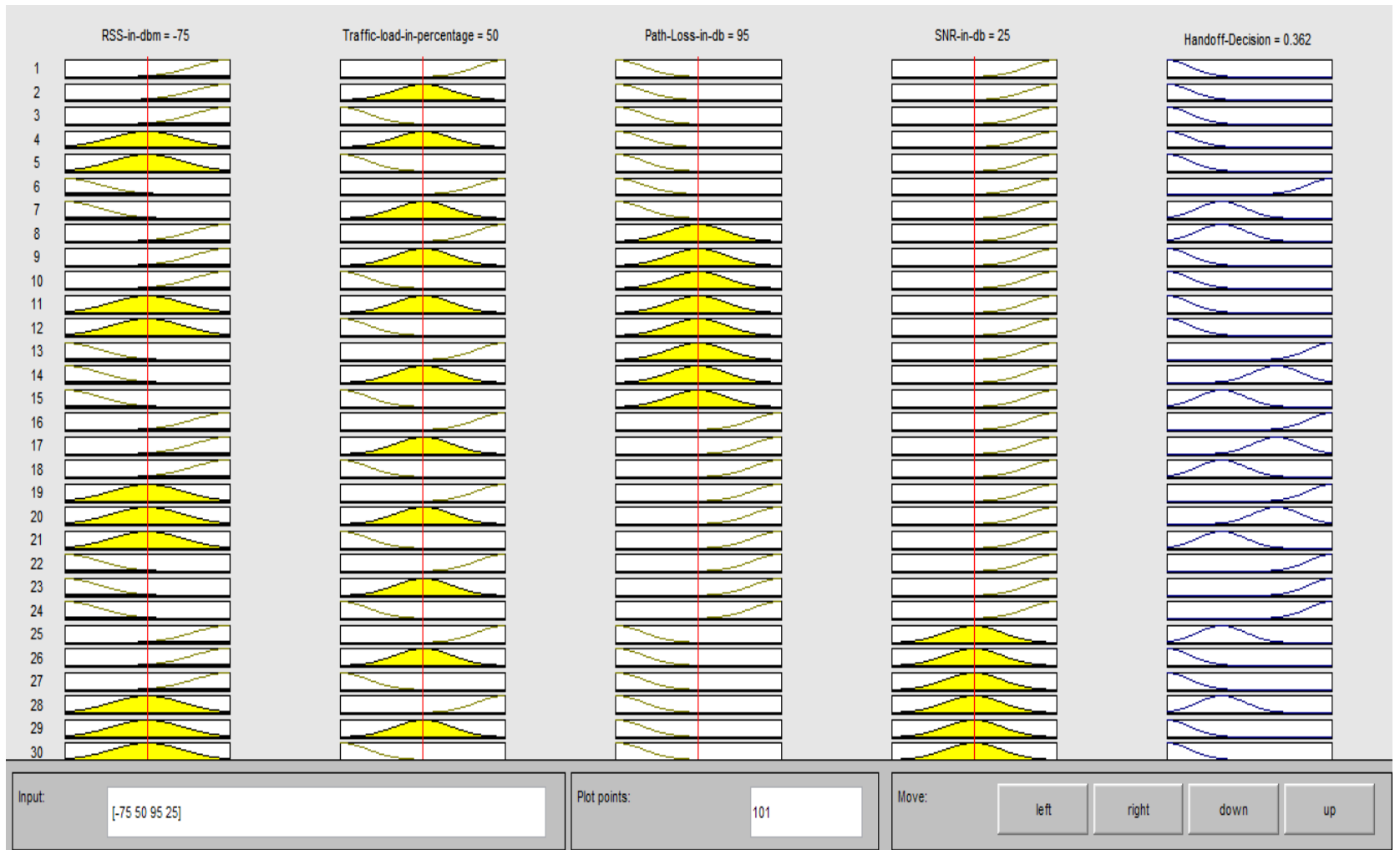


**Figure 4. 4 Rule Base Evaluations When All the Four Parameters Are Excellent**

From this, it is evident that MS on worst BTS should handoff to BTS providing better rank to sustain a call. Thus, ranking all the neighboring BTS including a serving BTS is important step in the handoff process.

Case one, as shown on Figure 4.4, when a mobile station is receiving  $RSS = -50.3\text{dBm}$ , 6.87% of all the available TCH are occupied, path-loss = 58.3dB,  $SNR = 47.8\text{dB}$ , the rank of this BTS is found to be 0.138. This value indicates the MS doesn't need to handoff because the current BTS is providing a maximum service.

Case two, as shown on Figure 4.5, when a mobile station is receiving  $RSS = -75\text{dBm}$ , 50% of all the available TCH are busy, a path-loss = 95dBm and  $SNR = 25\text{dBm}$ . The rank of the BTS is calculated by the proposed algorithm to be 0.362. Again the decision made by our FIS is not to perform handoff from this BTS as the current BTS still provide a good service. Even though BTS in case one provides a better service compared to Case two, the FIS decide not to handoff as this leads to unnecessary handoff. This unnecessary handoff is protected by introducing a minimum threshold for a MS to handoff. For this work the minimum threshold is found to be 0.55. The rank of the BTS has to be higher than this value for a MS to requisite a handoff process. But even if this threshold is met and a mobile station cannot get a better ranked BTS, then the MS will be forced to stay on serving BTS.



**Figure 4. 5 Rule Base Evaluations when all the Four Parameters are good**

Case three, as shown in Figure 4.6, when a mobile station is receiving  $RSS=-95.6\text{dBm}$ , 94.9% of all the available TCH is busy (only 5% TCH is free), path-loss =132dB and  $SNR=6.94\text{dB}$ , the rank of this BTS is 0.807 which is much higher than a pre-set value for handoff to take place. This value shows a BTS is not suitable to keep the connection due the fact that the RSS has begun deteriorating, BTS has only 5% of its free channel which is alarming for the incoming calls to be blocked and the MS is also interfered. Hence a mobile station requires to handoff to neighborhood that provide a better service. This is a method by which call drop is tackled.

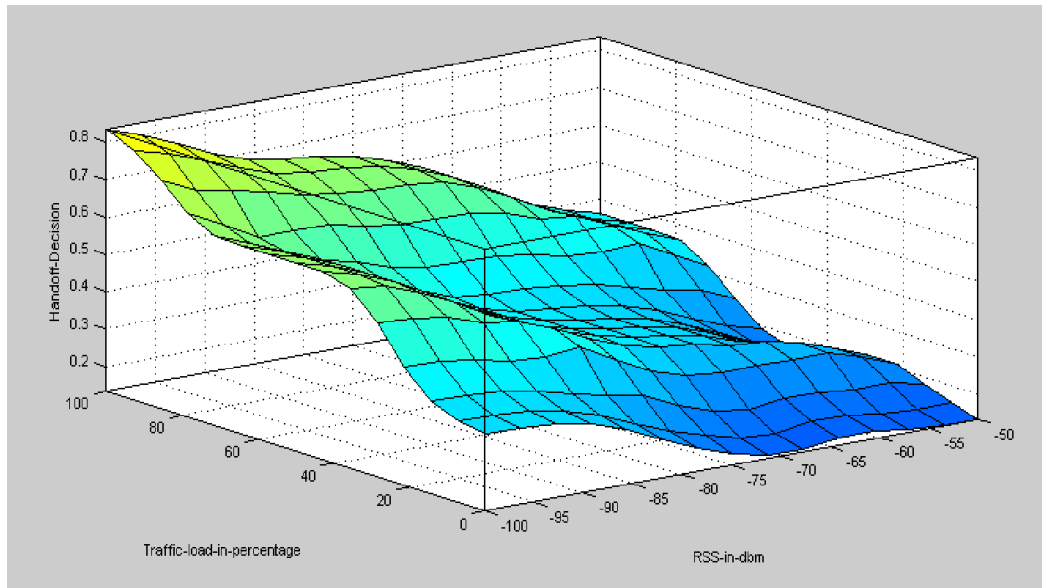
When the RSS has deteriorated, RF is interfered with, the path loss is maxima, and the BTS is over-congested, then rank of a BTS becomes the worst of all. This time a MS must handoff otherwise KPI will be affected. To facilitate this process, the algorithm gives higher probability of handoff (i.e. 0.805).



**Figure 4. 6 Rule Base Evaluations when all the Four Parameters are worst**

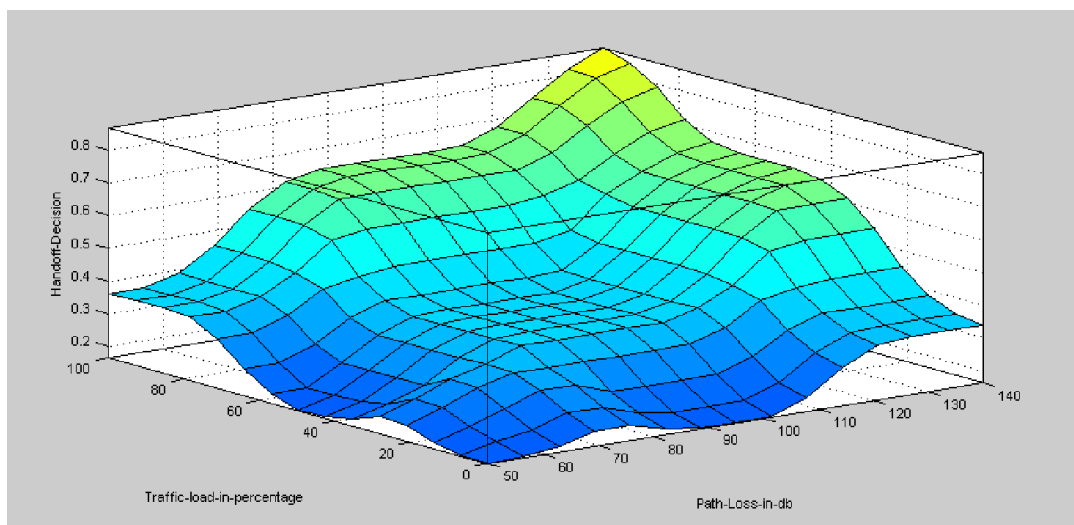
A fuzzy decision surface viewer is used to analyze a decision of handoff in 3D. In our algorithm we do have four inputs and one output. The surface viewer can generate a three-dimensional output surface where any two of the inputs vary, but two of the inputs must be held constant because computer monitors cannot display a five-dimensional shape. For example when we wanted to see the effect of RSS and traffic load on the decision making process, we set SNR and path-loss a constant value (average value).

As shown on Figure 4.7, the handoff decision viewer increases as one moves from the very strong RSS to weak RSS for the low load on the BTS. For medium load on the BTS, the handoff decision viewer increases from strong received signal to weak signal. For high load on the BTS, the handoff decision viewer increase from the strong RSS toward the weak RSS. The handoff decision viewer can be seen higher for high load percentage and weak RSS and it is lower for strong RSS and low load on the BTS. Hence when BTS is congested, it will start sharing load from the edge of the coverage area.



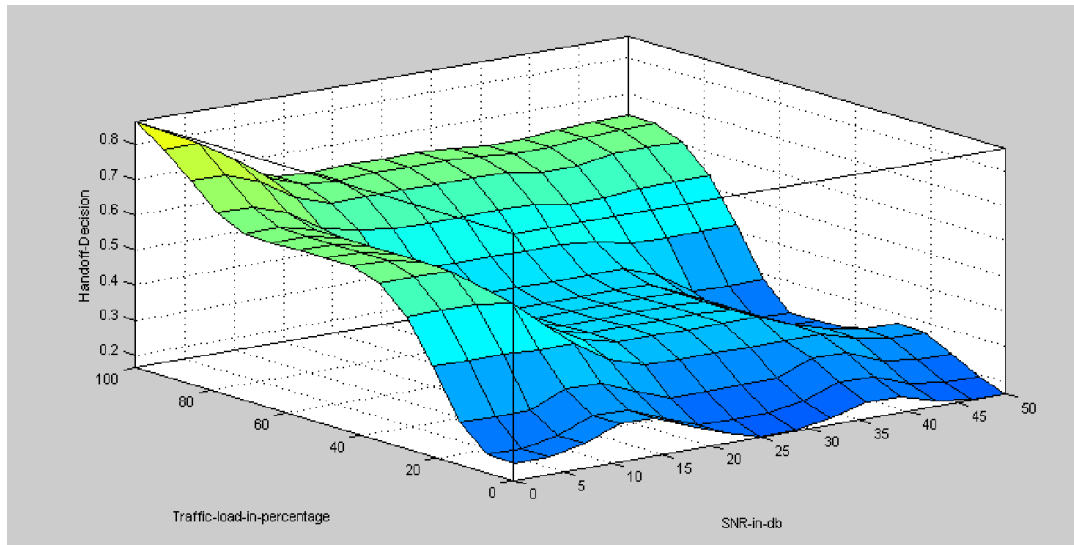
**Figure 4. 7 Surface Viewers between RSS and Traffic Load for Constant SNR and Path-Loss**

Figure 4.8 shows the increase in the surface viewer from low path-loss toward high path-loss for each category of load (low load, medium load and high load).



**Figure 4. 8 Surface Viewers between Path-Loss and Traffic Load for Constant SNR and RSS**

The surface hits a high value for high load on the BTS and high path-loss. It means load sharing would start from the MS on high path-loss. MS on a better BTS keeps the connection on the current BTS though the BTS is over-congested.



**Figure 4. 9 Surface Viewers between SNR and Traffic Load for Constant Path-Loss and RSS**

Figure 4.9 shows the surface viewer for BTS load and SNR. The probability of handoff increases with decrease in the SNR and increase in the load of the BTS. The maximum value is obtained when the load of BTS is very high and SNR is minimal. As in the preceding surface viewer the load sharing begin from those MS on having minimal SNR.

Figures 4.7- 4.9 conclude that when the base station is over-congested load balancing start either from the MS on low RSS, high path-loss , minimal SNR or combination of all these. MS on strong RSS, low path-loss and very high SNR keeps the connection on current even though BTS is over congested.



#### **4.2.2 BTS ranking using proposed algorithm**

Ranking the neighboring BTS based only on single-criteria is not effective in the sense that the best ranked BTS in terms of RSS may have interference or may have been congested. Due to this fact, it is not recommended to handoff the MS to congested BTS as this lead to call drop because BTS cannot provide a free TCH if all are busy.

Table 4.1 shows how neighboring BTSs are ranked based on the RSS from live GSM network in Ethio Telecom using TEMS Investigation 8.2.2 data collection. BTS with Absolute Radio Frequency Channel number (ARFCN) 537 is serving a current connection and ARFCN 36 is the highest ranked BTS among all the neighboring BTS. ARFCN 36 is a potential candidate for handoff but this BTS might be overloaded. If this BTS is over-congested then the outgoing handoff will be unsuccessful which lead to call drop prematurely. Hence, it is not recommended to rank the candidate BTS based on a single parameter.

**Table 4. 1 GSM Serving and Neighbors Based on RSS**

Cell Name	BSIC	ARFCN	RxLev	C1	C2	C31	C32
VH_ZTE079E_DM0T01...	6-2	537	-63				
VH_ZTE079E_GM0T01...	5-3	36	-57				
VH_ZTEG093E_M0T34...	1-6	58	-67				
AA_ZTED092E_M0T34...	7-4	567	-75				
AA_ZTED093E_M0T34...	0-0	635	-77				
VH_ZTE079E_GM0T01...	5-0	64	-80				
VH_ZTE079E_GM0T01...	7-0	72	-84				
		687	-85				
		95	-85				
		598	-86				
		561	-87				
		653	-87				
VH_ZTE085E_GM0T01...	7-1	43	-88				
		52	-89				
		77	-90				
		608	-91				
		25	-91				
		606	-92				
		71	-92				
		85	-92				
		690	-93				
		8	-93				
		101	-94				
		626	-96				
		643	-100				
		553	-102				

Therefore it is important to rank the neighboring BTS based on multi-criteria. A multi-criteria ranking can provide better performance than a single-criterion ranking due to the extra number of evaluation parameters and the greater potential for achieving the desired balance among different systems characteristics. This multi-criteria ranking allows simultaneous consideration of several significant aspects of the handoff procedure in order to enhance the system performance.

Important parameters like RSS, Path-loss, signal to interference ratio and traffic load of the BTS were combined together to rank all the neighboring BTS including a serving BTS. The rank of the BTS is compared against a threshold value and a better ranked BTS has to be found to determine if a handoff from the serving BTS is required.

Table 4.2 shows the ranking of seven neighboring BTS with different scenarios. For example a mobile being served on BTS 5 needs handoff because the threshold for handoff is met (threshold value is 0.55). Since all the neighboring BTSs are found to be better than BTS 5, then the handoff takes place to BTS 1 because BTS 1 is best ranked BTS based on multi-criteria. MS on BTS 1- 4, 6 and 7 have not yet met the threshold so there will not be handoff request. Therefore the introduced threshold value reduces unnecessary handoff.

**Table 4. 2 The Rank of the BTS Based on RSS, Path-loss, SNR and Traffic Load of BTS**

NO.BTS	RSS in indBm	Path-Loss in dB	SNR in dB	Percentage of Load BTS	Handoff in index	Rank of BTS based on multiple criteria
1	-54(1)	68(1)	41(1)	29(1)	0.246	1
2	-68(4)	82(3)	30(3)	47(2)	0.329	2
3	-64(2)	86(4)	34(2)	81(6)	0.510	6
4	-84(6)	100(6)	27(4)	70(4)	0.480	5
5	-84(6)	100(6)	27(4)	98(7)	0.675	7
6	-67(3)	70(2)	15(7)	72(5)	0.435	4
7	-75(5)	98(5)	25(6)	50(3)	0.364	3

*Bracket in the table 4.2 show the rank of the BTS on single-criteria*

In order to select the best neighboring BTS, which maximizes the end-user satisfaction in terms of service continuity and QOS, the four parameters are fed into the proposed

algorithm every 480ms. The algorithm at any time produces the rank of all the neighboring BTS and MS choose to connect to the best among all with handoff process if the pre-set threshold value is met. The table 4.2 shows the rank and the corresponding values of individual parameters. If single-criteria had been used to choose the best segment of the network, there would have been a conflict in resolving. The best network in terms of RSS doesn't necessary means that it is the best in terms of SNR or Path-Loss. Therefore this is a magnificent justification as to why we chose fuzzy logic to the solve conflict. Hence a mobile station, at any particular time, connects to a better ranked BTS based on multi-criteria if the threshold is met. When RSS is deteriorating or the BTS is over-congested, then rank of the BTS will be reduced. Then a MS will not keep connecting to over-congested BTS and deteriorating RSS. Through handoff process, a MS switches the current point of attachment to a BTS providing a better rank. This is how the algorithm makes sure that a BTS will not remain over-congested.

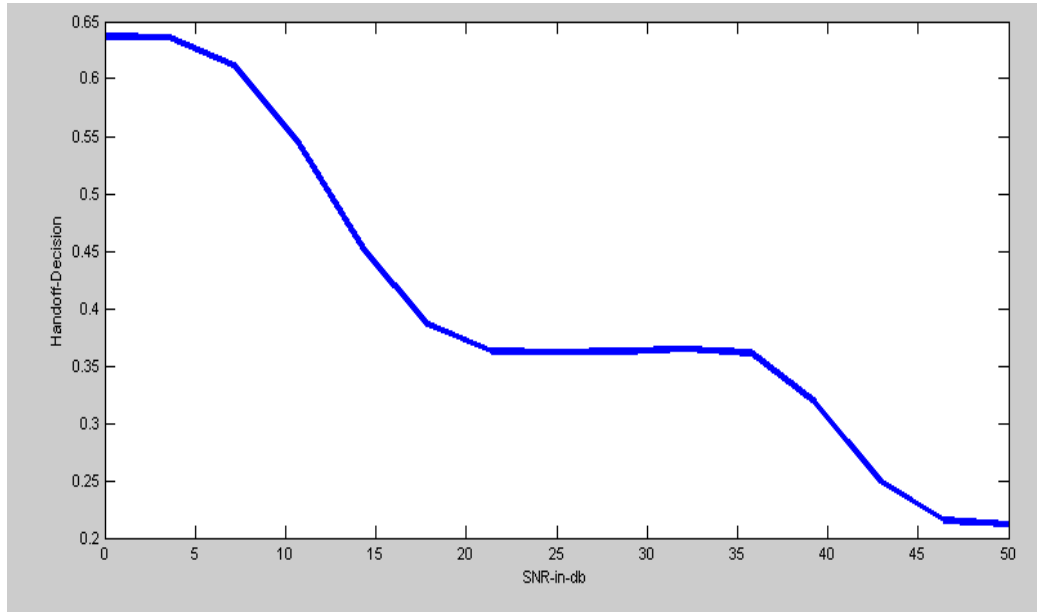
### **4.2.3 Handoff Necessity and Estimation**

The final weight handoff is obtained as output from a Fuzzy inference system (FIS). The output of FIS is compared against a threshold value to determine if a handoff from the serving BTS is required. This threshold value can be adjusted according to the need of the service provider. If the margin is too small, numerous unwanted handoffs may take place. In contrast, if the margin is too large, this may result in high call drops. In both cases overall system performance would be affected. Thus, a balanced value for this threshold is required and need to be found from the simulation. Performing simulation and

observing the need for handoffs based on the coverage threshold of rural ( $>-95\text{dBm}$ ) and in-car ( $>-90\text{dBm}$ ) [5], we proposed 0.55 to be an optimum value for the threshold value.

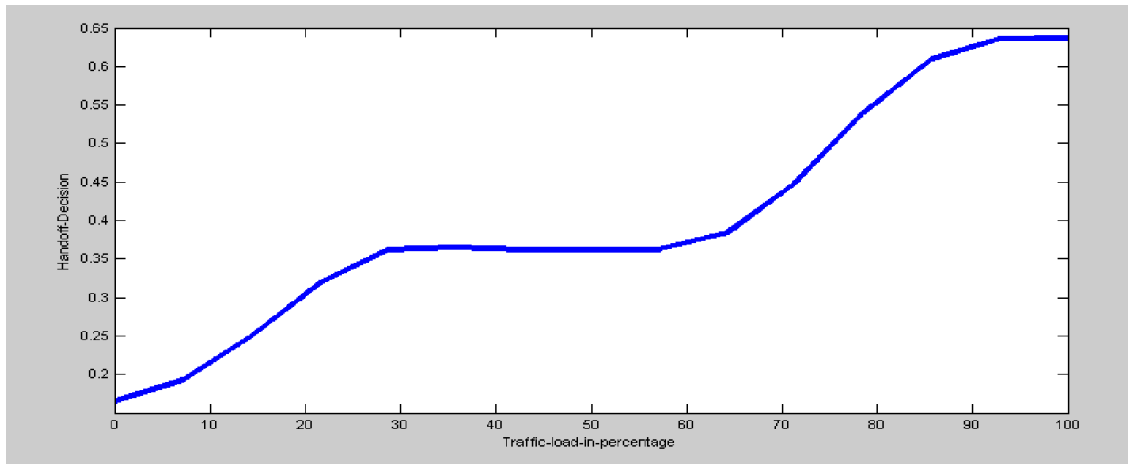
Figure 4.10 – 4.13 show variation of handoff index for RSS, Path-loss, SNR and traffic load. Our assumption in this analysis is that the other three parameters remain constant. When each parameter is getting worse, the proposed algorithm gives a higher value of handoff index. Then eventually, handoff would take place when the pre-set threshold values meet and better adjacent BTS is found.

For example, Figure 4.10 shows the variation of the handoff index with SNR for constant values of BTS traffic load=50%, path-loss=100 dB and RSS=-75dBm. The graph decreases in non-linear way with increase in SNR. When the MS is interfered from the neighboring BTS even though the remaining parameters are quite good enough to keep the connection, the developed algorithm reacts by increasing the handoff index and therefore the MS would be handed off to the better BTS (in terms of multi criteria) once the pre-set threshold is met and a better BTS is found from the neighboring cluster.



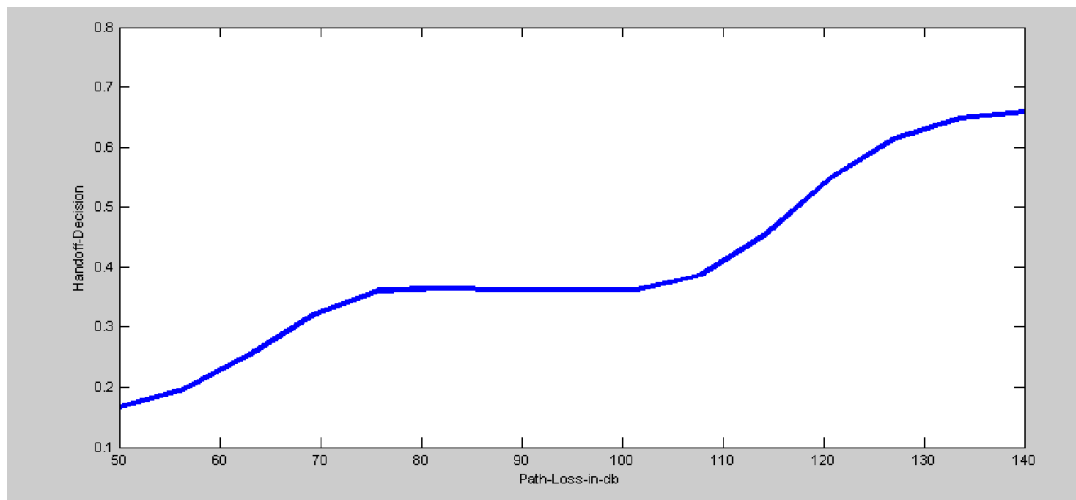
**Figure 4. 10 Variation of Handoff Index with SNR (dB) Values of Load of BTS=50%, Path- Loss=100 dB and RSS=-75dBm**

Figure 4.11 shows how the handoff index is varying with load, the increase in load would increase handoff index for constant values of other parameters. Unlike the conventional algorithm, the proposed algorithm is real-time, the handoff index increase with load increase and vice-verse.



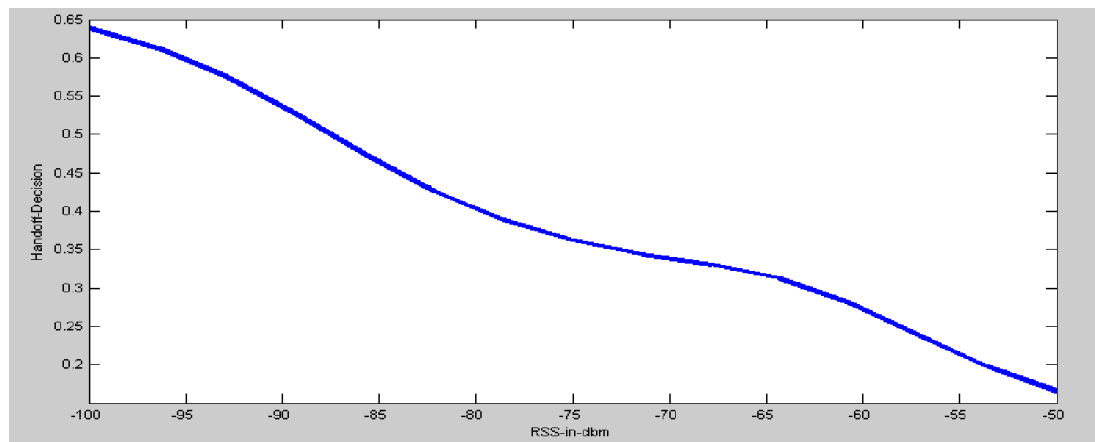
**Figure 4. 11 Variation of Handoff Index with Load (%) Values of SNR=25dB, Path-Loss=100dB and RSS=-75dBm**

This makes sure that at any time BTS is over-congested, the probability to handoff increase with load. But this value differs to those MS on strong RSS and weak RSS, or those on excellent SNR and interfered frequency. Obviously those MS on weak RSS or interfered frequency becomes even higher in probability of handoff



**Figure 4. 12 Variation of Handoff Index with Path-Loss (dB) For SNR=25dB, Load of BTS=50% and RSS=-75dBm**

Figure 4.12 shows, the handoff index gradually increases with increase the path-loss, MS on higher path-loss has higher probability to be handoff than a MS on lower path-loss. When a pre-set threshold value is met or better neighboring BTS is found, the algorithm would requisite handoff to be executed. At any particular time if the path-loss is deteriorating the handoff has to take place even though the remaining parameters are good enough to sustain a call. This will ensure that there would not be call drop due to this deterioration of RSS. It means a mobile station would handoff to the target BTS when the current serving BTS is deteriorating.



**Figure 4. 13 Variation of Handoff Index with RSS dBm For SNR=25dB, Path-Loss=100dB and Load of BTS=50%**

The main objective of the proposed scheme is to maximize the end-user's satisfaction in terms of the quality and continuity of the currently utilized service. RSS plays a very significant role in maintaining this objective. Hence to keep this objective, Handoff index gradually decreases with RSS increases. When a pre-set threshold value is met and better neighboring BTS is found, the algorithm would requisite handoff to be executed. It is



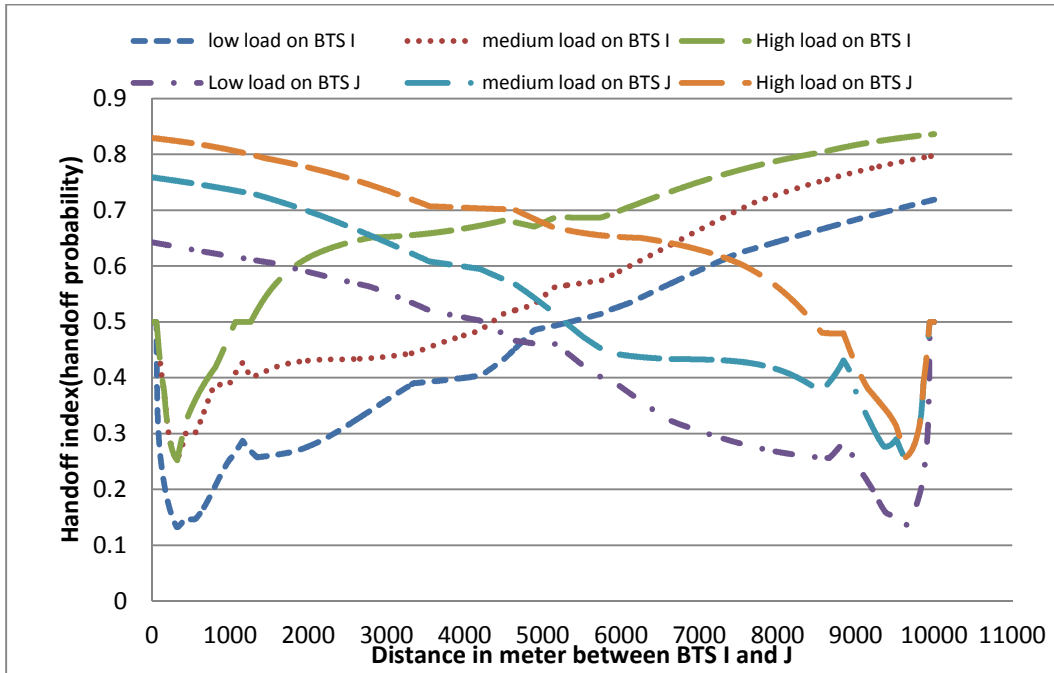
very important for any service provider to always have the MS connected to BTS providing higher RSS to avoid call drop.

If the base station is over- congested, handoff process first start from the edge of cell. For example from Figure 4.13, an MS on -95dBm has high handoff index compared to a mobile station on -70dBm or -60dBm. In any case, if this BTS needs to relief over-congestion through handoff process, it is imminent that a mobile station receiving RSS values of -90dBm starts to be handoff. Again if the BTS within the coverage of more than -90dBm, then it will be a MS in the range of -85dBm to -90dBm to be handoff to relief congestion and so on

#### **4.3 Load Balancing with Multi-criteria Handoff Algorithm**

The quickest handoff takes place at about 2000m when BTS *I* has high load and BTS *J* has low load. Therefore the coverage area of a BTS *I* virtually shrink inwards and MSs on that region to be served by the neighboring BTS *J*. This technique is called dynamic mobility load balancing. The logic behind this method is to adjust the handoff regions depending on the load of the BTSs, causing cell-edge users in loaded cells to migrate to less loaded overlapping cells, thereby releasing some traffic channel being occupied by edge user so that the call can proceed. However, If the neighboring BTS has High load then the handoff takes place on the ideal boundary of the BTS as the conventional handoff as shown in Figure 4.14. This process allows under-congestive BTS to take some of traffic from over-congested BTS thereby distributing traffic among all the neighboring BTS dynamically. Balanced traffic in the cluster maximizes resource utilization and

revenue for mobile service provider. Unlike the conventional algorithm, when the congestion problem is relieved, BTS starts to serve their designed area.



**Figure 4. 14 Movement of the Mobile Station between Two Adjacent BTS I and J**

From a MS user’s point view, dropping call is equally annoying as blocking a new call, so the proposed algorithm accelerates the handoff process toward the under-congested BTS and reserve a resource for both originating calls and incoming call from the neighboring BTS.

If the BTS is over-congested, this affects two key performance indicators (KPI). The first KPI to be negatively affected is the congestion rate, for the obvious reason if there is no free TCH available, the new calls will be blocked. The second KPI is call drop due to handover. In the GSM network the type of handoff is hard handoff [9]. The MS must

break its connection from the current access network before it can connect to a new one [9]. Now if the GSM mobile user attempts to handoff toward an over-congested BTS. Since there is no free TCH on new BTS and the old connection has already broken the connection ended up being dropped.

Therefore, at any time, over-congested BTS has to handoff those mobile users on the edge of cell toward under-congested BTS as to have a free TCH for either incoming handoff or a new originating call. This makes a resources utilized in a better way compared to the conventional way of handing off a mobile station from serving to neighboring BTS since only RSS of the neighboring BTS is found to better than serving BTS without looking important parameter like the congestion on the neighboring BTS.

When the RSS of the neighboring BTS is higher than the current serving BTS, it does not necessarily mean that the calls cannot continue on the current BTS. This is the main drawbacks of the conventional type handoff algorithm. For example, if the current calls on RSS values of -85dBm and the immediate neighbor is having the RSS values of -70dBm. It is not logical at all to handoff from -85dBm to -70dBm, even though the latter is 15dB better. Because RSS= -85dBm is quite enough to sustain the call. This logic is valid in sense that if the BTS having RSS values of -70dBm is over-congested, and when MS tries to handoff from -85dBm to -70dBm, it may end up being dropped. Therefore, the decision to choose the best target in terms of multi-criteria is important.

The most delayed handoff takes place at about 7000m when the BTS I has low load and BTS J has high load. In this case BTS I coverage area can virtually be expand towards loaded BTS J. This is due to fact that if no TCH is available in BTS J, the handoff call will be

blocked which leads a call to terminate prematurely due to dropout .The MS keeps on BTS I as long as RSS, path-loss and SNR of BTS I are fulfilling the recommended threshold . This is a method by which handoff blocking is reduced and avoid call drop due to handover failure as there is no TCH available in BTS J. If the neighboring BTS has also low load, then there is no need to delay handoff process. Handoff will takes place on the ideal boundary between the base stations.

For the worst case scenario, when BTS I is fully over-congested and BTS J is under-congestion on the entire coverage area. Handoff takes place at about 2000m from BTS I, in this case up to 60% coverage area of BTS I to be served by BTS j. In contrary when BTS I is under-congested and BTS J is over-congested, keeping the same mobility plane, handoff takes place at 7000m from BTS I. Since BTS J is fully over-congested, cannot provide a free TCH for incoming handoff from BTS I, the algorithm forces a MS to be served by BTS I if BTS I is fulfilling the minimum threshold to keep call. This method helps to reduce call drop due to handoff process

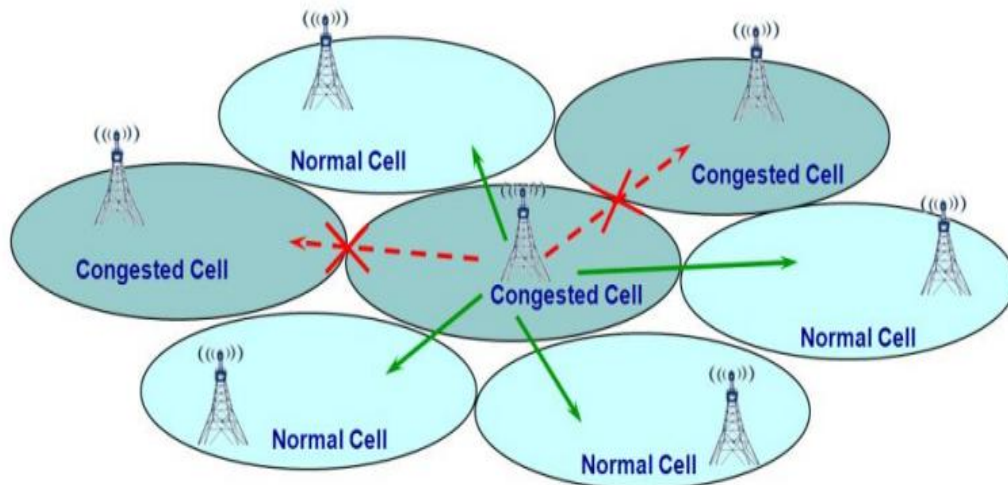
Figure 4.14 also shows how the MS in the region between 2000m to 7000m dynamically swing between BTS I and J depending the load on the BTSs. Such that the coverage area of a BTS can dynamically be expand towards a nearby loaded cell or shrunk towards cell center for a loaded sector. Therefore, this mechanism activates a handoff procedure to shift some traffic of a loaded cell towards a lightly loaded cell thereby increase the resource utilization.

For the same load on either BTS, proposed handoff algorithm has the same performance as single-criteria handoff algorithm as depicted on figure 4.1, 4.2 and 4.3 where, the hand

off process takes place at an ideal boundary between the BTSs. When the load of the BTS is same on both neighboring and serving base station, the effect of the load on multi-criteria is same; hence there is no difference with single-criteria handoff algorithm.

#### **4.4 How call drop will reduce with proposed algorithm**

When a new call is attempted in a cell, one of the free TCH is used for communication between a mobile user and a BTS if any channel is available for the call. In the case that all the TCH are busy, the new call is blocked. This kind of blocking is called new call blocking and it refers to blocking of new calls [23]. The user releases the TCH under either of the following scenarios [23] (i) the user complete the call; (ii) the user moves to another cell before the call is completed. The process of moving from one cell to another, while a call is ongoing, is called handoff. During this handoff process, an MS requires that the BTS in the new will assign to it a TCH. If no TCH is available in the new BTS, the handoff call is blocked. This kind of blocking is called handoff blocking and it refers to blocking of ongoing calls due to the mobility of the users, which leads a call to terminate prematurely due to dropout [23]. When an active user moves out of a cell, the call has to be continued by the new cell that it enters [34]. If all available servers of the new cell are busy, and then the call will be dropped [34]. Figure 4.15 shows how call is dropped due to mobility toward over-congested BTS [34]. Had a traffic being shared equally among all the BTS in the cluster in the first place, this type of call drop could not have happened.



**Figure 4. 15 Calls Drop with Congestion**

Call drop rate in wireless networks refers to the ratio of call drop to successful seizures after the BSC successfully assigns traffic channel to mobile station. There are many reason for call drop some of them include handover, interference, path imbalance, transmission failure and wrong parameter settings [35]. Generally call drop can be classified as:

Call drop rate including handoff

Call drop rate excluding handoff

The call drop rate is one of the most significant key parameter indicators for mobile operators. It indicates the probability of call drops after mobile user access traffic channels. Too high call drop rate greatly affects negatively the subscriber satisfaction and revenue of a mobile service provider. Such a scenario is unacceptable.

Call drop including handoff can be solved if traffic load is equally distributed among all the BTS in the cluster. The proposed algorithm delays the process of handoff if the immediate neighbor has been over-congested. Hence, it forces the ongoing calls to continue on the serving BTS even though the

targets BTS provide a better RSS. During this delay time, some of MS may release channels so that once free TCH is available the delayed handoff will take place.

#### **4.5 Summary of the Chapter**

This chapter provided all the results of single-criteria handoff, rule base evaluation, how the BTSs are ranked with proposed algorithm, handoff necessity and estimation, in this chapter it was showed that it is possible to balance load of cellular system by handing off some ongoing calls on cell edge in the over-loaded BTS, how call drop was reduced with the proposed algorithm.

## **CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Conclusion**

In a cellular environment, the selection of a BTS that can fulfill end-user satisfaction while keeping ongoing call is very important task, a wrong selection of BTS may lead to call drop, network over-congestion and wastage of scarce resource. Usually a selection of a network segment is done through handoff process. Traditional network selection was done by single-criteria like RSS, Power Budget, interference, distance and among others. A single-criterion is not an intelligent enough as it does not take into account other important parameters like level of congestion on the BTS.

This thesis was on the design and analysis of an intelligent multi-criteria handoff algorithm that enabled the selection of the best network segment based on multiple parameters. The main objective of this work was to improve real time traffic balancing in a cellular network using a multi-criteria handoff algorithm

The results from this thesis showed that it is possible to balance traffic load of cellular network by handing off some ongoing calls on cell edge in over-loaded BTS to migrate to overlapping under-loaded BTS, such that the coverage area of loaded BTS virtually shrink towards BTS center of a loaded sector. In case of low load scenarios, the coverage area of a BTS is presumed to be virtually widened to cover up to the partial serving area of neighboring BTS. This was achieved using fuzzy logic.

Simulation using MATLAB and numerical examples were done comparing the performance of the proposed multi-criteria and single-criteria handoff algorithms.



Simulation results showed the load was shared in cluster using the proposed algorithm and further efficiently utilized the scarce available resource. The MS in the region between 2000m to 7000m dynamically swing between BTS I and J depending on the load on the BTSs. Such that the coverage area of a BTS can dynamically be expanded towards a nearby loaded cell or shrunk towards cell center for a loaded sector. In case of low load scenarios, the coverage area of a BTS is presumed to be virtually widened to cover up to the partial serving area of neighboring BTS.

Unlike single-criteria handoff algorithm, with the proposed algorithm the handoff region is dynamically changed with load of the BTS.

For the same load on either BTS, the proposed handoff algorithm has the same performance as single-criteria handoff algorithm, where the hand off process takes place at an ideal boundary between the BTSs.

The proposed algorithm has also been tested using data from wireless propagation models based on straight line mobility between two BTSs in suburban area.

## **5.2 Recommendations for future works**

The research work was based on membership function that is subjective in nature. Therefore, a research needs to be done in finding out the different types of membership functions that can result in optimal handoff performance. One alternative is to utilize an Adaptive-network based Fuzzy Inference System (ANFIS) where the system can build an input-output relation based on human knowledge. A second alternative is to include suitable learning such as neural network.

The proposed algorithm can further be improved by using real data from live cellular network.

An algorithm that combines fuzzy logic technique and crisp technique be developed that improves the speed of processing and at the same time ensures real time intelligence.

In a future study, distance between the MS and BTS, mobile velocity and direction can be included in multi- criteria handoff design.

## **PUBLICATION FROM THIS WORK**

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