CELL SELECTION ALGORITHMS FOR TERRESTRIAL TRUNKED NARROW BAND RADIO SYSTEMS

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ABSTRACT

CELL SELECTION ALGORITHMS FOR TERRESTRIAL TRUNKED NARROW BAND RADIO SYSTEMS

Since the interest in mobile communication sector is increasing day by day, it makes traffic volume problem more important. There are different works focused on developing more secure and qualified service for professional users and companies. The Professional Mobile Radio (PMR) system, specially developed for professional users in the communication sector, can be offered to the service of professional users and companies with the desired specifications. With the Tetra system, which is one of the PMR systems, users can get more advanced technological services than the conventional PMR systems. Cell selection algorithms have a great importance for these systems which are needed for more reliable, private and seamless communication. In this thesis, we present two novel cell selection algorithms that can be applied to the Tetra based PMR systems. In these algorithms, both the received power of users and the fair distribution of the overall system are considered. Performance evaluation of algorithms with different traffic characteristics is considered in different environments.

ÖZET

KARASAL DAR BANTLI TELSİZ SİSTEMLER İÇİN HÜCRE SEÇİM ALGORİTMALARI

Mobil haberleşme sektörüne duyulan rağbetin her geçen gün artması trafik problemini her geçen gün daha önemli kılmaktadır. Profesyonel kullanıcılara verilecek hizmetin daha kaliteli ve daha güvenilir olması için farklı çalışmalar yapılmaktadır. Haberleşme sektöründe profesyonel kullanıcılar için özel olarak geliştirilen Profesyonel Mobil Radyo (PMR) sistemi, isteğe özel olarak istenilen özelliklerde kişilerin ve şirketlerin hizmetine sunulabilmektedir. PMR sistemlerinden biri olan Tetra sistemi ile kullanıcılar geleneksel PMR sistemlerine oranla daha teknolojik hizmet alabilmektedirler. Daha güvenilir, özel ve kesintisiz haberleşme için ihtiyaç duyulan bu sistemler için hücre seçim algoritmaların büyük önemi vardır. Bu tezde, Tetra sistemi için uygulanabilecek iki ayrı hücre seçim algoritması sunuyoruz. Bu algoritmalarda, kullanıcıların baz istasyonlarına bağlanırken sahip oldukları güç ve genel sistemdeki kullanıcıların dengeli dağıtılması hesaba katılmaktadır. Algoritmaların farklı ortamlarda farklı trafik özellikleriyle performans değerlendirmeleri sunulmaktadır.

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LIST OF ABBREVIATIONS

PMR .... Professional Mobile Radio
PAMR .... Public Access Mobile Radio
DMO .... Direct Mode Operation
ETSI .... European Telecommunications Standards Institute
TDMA .... Time Division Multiple Access
DQPSK .... Differential Quadrature Phase Shift Keying
RSSI .... Received Signal Strength Indicator
SINR .... Signal-to-Interference Noise Ratio
QoS .... Quality of Service
AS .... Admissibility Score
BS .... Base station
SNR .... Signal-to-Noise Ratio
BER .... Bit Error Rate
UCL .... Unmapped Cell Load
UTL .... Unmapped Traffic Load
MCL .... Mapped Cell Load
MTL .... Mapped Traffic Load
GPS .... Global Positioning System

CHAPTER 1

INTRODUCTION

Developing mobile communication sector borns new requirements every day. Professional companies need dedicated systems rather than public cellular systems which provides reliable voice and data communication. This is the main reason of Professional Mobile Radio (PMR) systems to come up. In PMR systems, users have their own dedicated channel to communicate and Terrestrial Trunked Radio (Tetra) is the digital PMR standard which satisfy the current needs.

Traffic issue is one of the big problems of the developing communication sector. One method to solve the traffic issue is the design the cell selection algorithm to provide a fairer distribution of users so that balances the traffic overall system. For better and seamless communication, traffic management and load balancing become critical factors for cell selection algorithms. Traffic congestions may cause the call setup times to be longer or cause drops in calls. Undesired consequent in these situations may cause disasters specifically for the emergency cases or public safety services.

In this thesis, two cell selection algorithms are proposed for Tetra based PMR systems. The proposed algorithms are designed to provide a fairer distribution of users among cells. The performances of algorithms are obtained in urban, rural and suburban areas.

This thesis consists of 5 chapters and its outline is given as follows:

- Chapter 2 gives background information about the PMR and Tetra system. Technical details of Tetra and brief information about cell selection algorithms are given.
- Chapter 3 proposes cell selection algorithms based on cell load system. Full set cell selection and reduced set cell selection algorithms are given. The proposed algorithms are designed to reduce the number of waiting users while satisfying the quality of service of users. The performances of proposed algorithms are obtained in the urban, rural and suburban environments with different traffic characteristics.

- Chapter 4 examines the performance of the proposed algorithms in traffic based system. Both the full set and reduced set algorithms are applied in traffic based system. The performances are obtained for traffic based system in the urban, rural and suburban environments.

- Chapter 5 concludes and summarizes the final remarks.

CHAPTER 2

BACKGROUND

In this chapter, Professional Mobile Radio (PMR) systems, brief information about Tetra system and its technical specifications will be explained. In addition to that, the reasons that lie behind the critical role of cell selections for digital PMR and Public Access Mobile Radio (PAMR) systems and the existing cell selection algorithms will be given.

2.1. Professional Mobile Radio (PMR)

Private Mobile Radio or Professional Mobile Radio was developed with demands of business and professional users who need reliable and dedicated communication. In order to address the PMR systems, dedicated licensed frequencies are allocated for avoiding interference with other radio frequencies. In a PMR network, a number of base stations are deployed to cover the area for organization users with mobile terminals. This system serves to closed user groups owned by the same organization.

Compared with cellular system, PMR systems have really short call setup time and provide possibilities for closed user, push-to-talk (PTT) and group calls. In the cases where there are not any base station (BS), mobile users are able to use Direct Mode Operation (DMO). In this operation mode, terminals can communicate with each other directly without needing a BS.

Different from traditional PMR systems, Public Access Mobile Radio (PAMR) is developed by offering public network access for other users. The essential necessities of PMR systems rise up out of particular sorts of professional usage which can be separated into various sectors. Important areas for PMR market can be seen in Table 2.1.

2.1.1. Features of PMR Systems

Some of the important features of PMR systems are:

- Coverage: PMR networks are deployed to provide coverage for all users so that the users are able to communicate whenever needed.

- Group Communications: For better operational communications, business users or organisations choose the group calls. For example, a security staff of an university can call for aid from a number of staffs in group just by one call.

- Reliability: PMR systems are often chosen as primary choice when safety critical communication is required. This is the reason of PMR being used by the fire departments, police and ambulance services as primary voice communication.

- Performance: Some organisations may have requirements to be able to start call as quick as possible without need for answering the call. Because of this, PMR systems are designed as to provide press to talk systems with a short call set-up time.

- Contention: PMR system can be designed according to demand of customers' service quality. While system can be designed as a small system in a way that users can be queued until resources are available, it can also be designed with a large capacity to ensure the communications completed without waiting even in busy traffic.

- Security: Professional users may need their conversations to be secured and remained private. PMR systems support different levels of security from basic voice scrambling up to complex encryption algorithms.

Table 2.1. Usage Areas of PMR by Applications

Commercial	**Public Safety**
Industry	Military and Defense
Transportation	Home Security
Mining	Emergency and Medical Services
Utility	Fire Department
Others (Entertainment, Construction, Manufacturing, Tourism)	Others (Public Places, Events)

2.2. Terrestrial Trunked Radio (Tetra)

Tetra is a technical platform providing integrated voice and data services and modern standard for PMR and PAMR systems. Tetra platform was published by European Telecommunications Standards Institute (ETSI) in 1995. Manufacturers and end users have played roles for deciding the necessaries and technical developments of Tetra standard. It is an open standard and some specifications are left open for manufacturers' design and it is allowed to be used different manufacturers' equipment on the same system. Today, many radio communication companies in worldwide support Tetra system.

Tetra standard brings dynamical assignment of channels to the individual users with trunked radio system, unlike earlier conventional analogue fixed-channel systems where users are allocated fixed radio channels. Tetra standard has rich features and is well supported so that makes it a vital option for safety communication. It is designed for emergency services, government agencies, mining, transportation, industrial and military services.

Supporting fast data and video communication as in mobile cellular communication and to be able to work with groups as in PMR systems give Tetra excellent feature. Today, Tetra becomes one of the most important radio standards for secure and reliable voice and data communication. Complete digital communication technology provides low noise voice quality.

2.3. Advantages of Tetra standard

There are main technologies used in Tetra standard provide many advantages that make Tetra ideal choice for many radio communications. These distinctive technologies are being digital system, trunking and Time Division Multiple Access (TDMA).

Almost every electronic corporation prefers digital technology instead of analog so Tetra standard also uses digital technology. The move towards digital PMR systems started decades ago and developments move rapidly to digital technologies. There are many advantages of digital technology such as RF coverage, voice quality, data transmission, security and cost.

Tetra mobile stations have the ability to communicate in both way, direct-mode operation or trunked-mode operation. For conventional radio systems, network has dedicated channels to specific users and groups as seen in Figure 2.1. Trunked radio systems apart from public mobile radio systems in terms of group and priority calls, end-to-end encryption and shorter call set-up time. Trunked systems are also used in switched telephone networks and have advantages over supportable number of users for same channel, which allocates available slots to users dynamically by the system as seen in Figure 2.2. Groups are able to use any available channel because they are not dedicated to use any predefined channel.

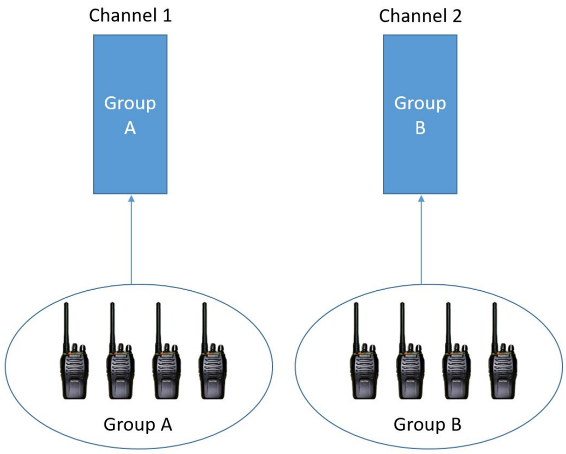

Figure 2.1. Channel allocation in conventional radio system

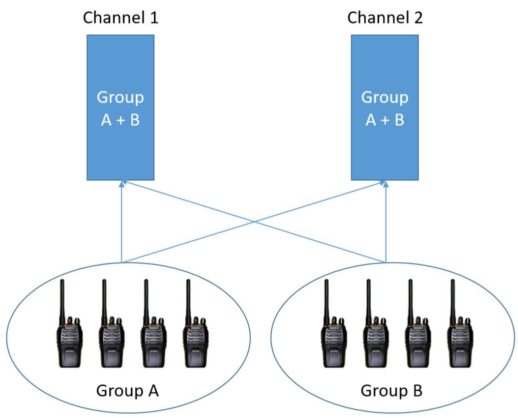

Figure 2.2. Channel allocation in trunked radio system

2.4. Tetra Technology

TDMA technique provides four user channels on one radio carrier and the channel spacing (Δf) between radio carriers is 25 kHz as shown in Figure 2.3. Modulation scheme used in Tetra standard is $\pi/4$ DQPSK (ETSI EN 100 392-2 V3.6.1, 2013).

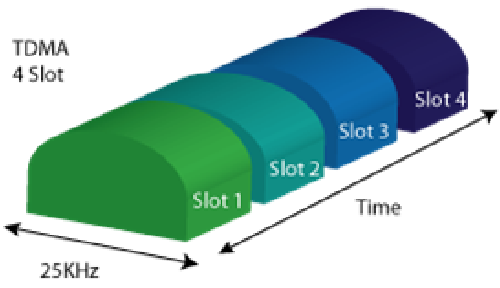

Figure 2.3. TDMA technique for Tetra

The $\pi/4$ DQPSK modulation is one of the most widely used modulation schemes for wireless applications (Chandra and Bose, 2008) and data is encoded in the change in the phase. One of the biggest advantages of this modulation scheme is that it can be differentially detected. The constellation diagram of this modulation scheme is shown in Figure 2.4.

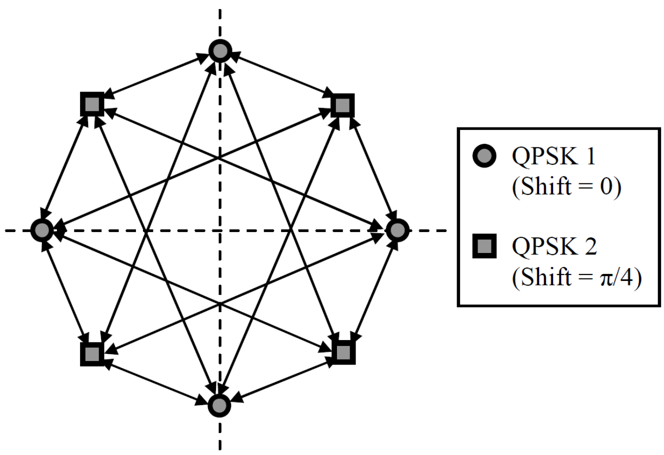

Figure 2.4. $\pi/4$ DQPSK Consellation Diagram
(Source: Chandra and Bose, 2008)

In Figure 2.4, there are two superpositions of QPSK signals with offset by $\pi/4$ relative to each other. Every symbol has 2 bits. In the consellation diagram, odd numbered symbol represents the modulation with 0 phase shifting, and even numbered symbols represent the $\pi/4$ phase shifting. So, there are eight possible phases that the modulated signal may have (Mark and Zhuang, 2005).

BER performance of the $\pi/4$ DQPSK modulation without diversity is shown in Figure 2.5. Voice users require 2.5% BER value which corresponds to 5 dB of E_b/N_0.

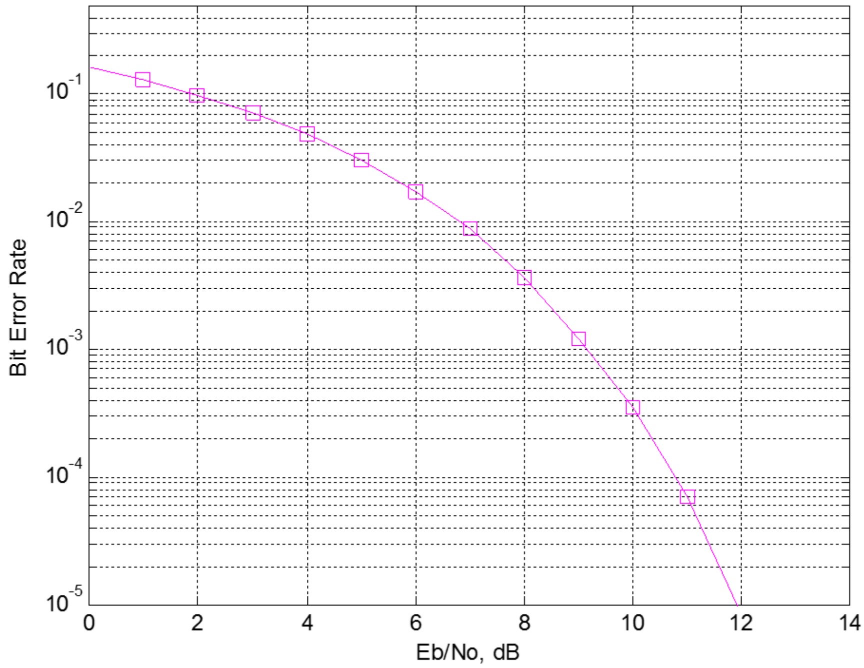

Figure 2.5. BER performance of $\pi/4$ DQPSK

Each BS *u* has a total number of time slots M_u that can be calculated as follows:

$$M_u = 4\frac{B}{\Delta f} \tag{2.1}$$

where *B* represents the bandwidth per cell. One of these time slots is used for control. Users can have more than one time slot for greater transmission capacity.

Tetra standard supports 3 different bit rates with $\pi/4$ DQPSK modulation with different number of occupied time slots for different codings:

- *n* x 7.2 kbit/s (unprotected, required BER = 2.5%)
- *n* x 4.8 kbit/s (slightly protected, required BER = 0.4%)
- *n* x 2.4 kbit/s (highly protected, required BER = 0.01%)

where n represents the number of time slots.

The indicated BERs are applied for the dynamic receiver sensitivity of Tetra in a specific environment. Bit rates of users depends on the number of time slots allocated to user. Bit rate can be up to 28.8kbps when all 4 time slots are occupied for the user.

Tetra standard has security mechanisms for reliability of transmission. Air interface is one of these security mechanism where users have individual communication key to negotiate BS and end-to-end encryption mechanism which encrypts the data between the control center and the BS.

For the areas without coverage or where the traffic of BSs are so high, there must be another communication option for emergency cases. In these cases, there is DMO, also known as walkie-talkie, enables a direct communication between mobile users without BSs. In DMO, only simplex communication is used in direct mode where users operate with the same frequency carrier.

2.4.1. Framing Structure

Allocation of resources is performed partitioning both in frequency and time. While frequency allocation is managed by channels divided into bands, resource allocation for time is partitioned by TDMA frames and time slots.

Duration of a time slot is 14.167 ms which corresponds to 255 symbols duration for phase modulations (ETSI EN 100 392-2 V3.6.1, 2013). Each symbol duration is 55.56 μs. A TDMA frame is divided into 4 time slots and each timeslot has duration of 56.67 ms. 18 frames compose a multiframe with duration of 1.02 s. Hyperframe level consists of 60 multiframes which corresponds to 61.2 s. Figure 2.6 represents the frame structure.

While measuring received signal strength for serving or adjacent cells, a number of measurement samples must be taken in order to measure the signal strength correctly.

2.4.2. Signal Strength Measurement

Serving Cell Measurement

For serving cell measurement, mobile user should take at least 5 measurement samples within 5 seconds to 60 seconds to get correct received signal strength information. Measurements should be in downlink physical channel which mobile user is attached to serving cell.

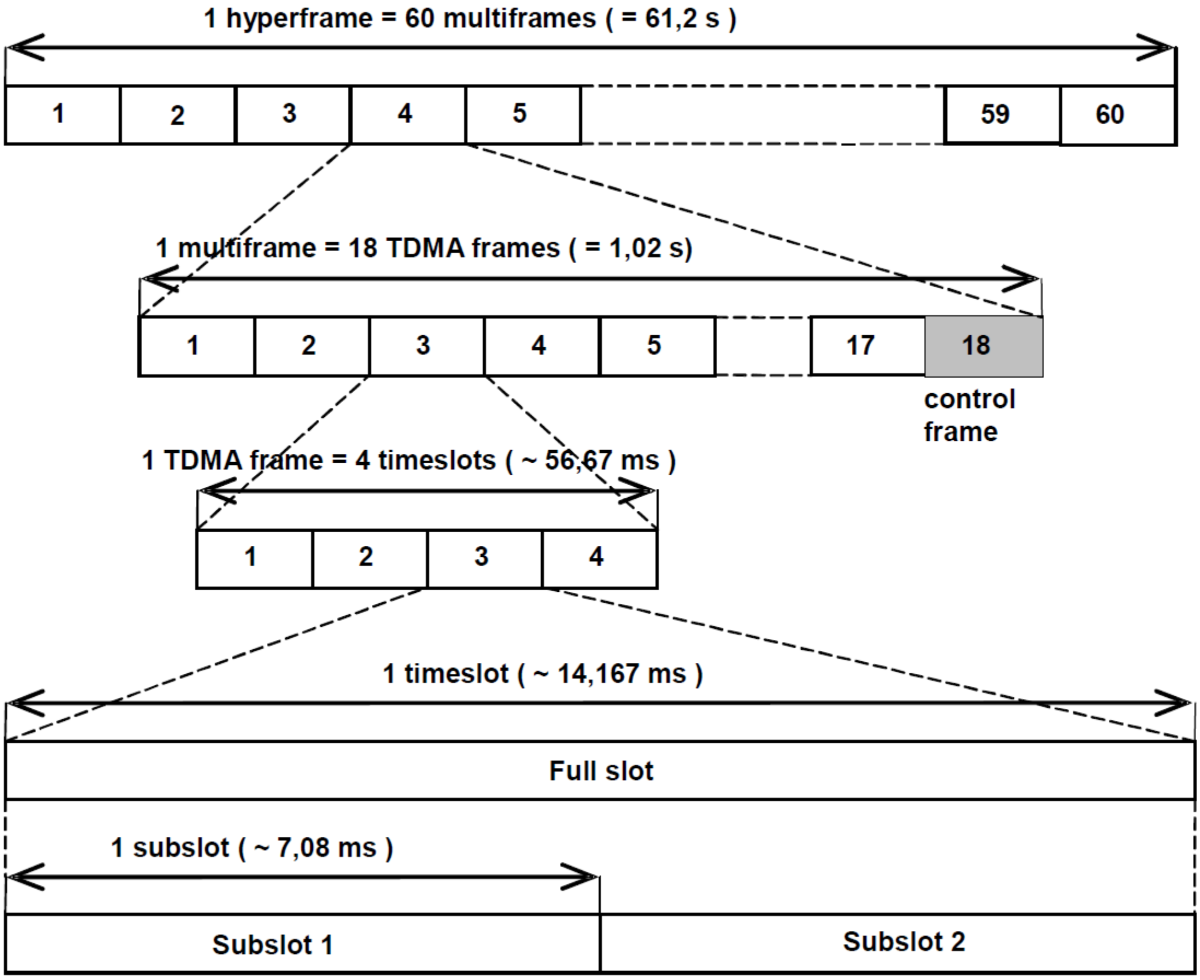

Figure 2.6. Tetra frame structure
(Source: ETSI EN 100 392-2 V3.6.1, 2013)

Monitoring Measurement

Mobile user may want to know the signal strength of carriers other than serving cell channel. This procedure is called monitoring which performed in mobile user side. This monitoring procedure can be used for neighbour cell monitoring where user measures the signal strength and calculates path loss parameter with the main carrier of the adjacent cell. During this monitoring procedure mobile user is not synchronized with the neighbour cell.

For monitoring measurement, mobile station should take the average of 5 measurement samples separated by at least 50 ms.

Scanning Measurement

Scanning is used when mobile user wants to know signal strength on the main carrier of adjacent cell and calculate the path loss parameter by synchronizing to cell and obtaining the broadcasted information. Mobile users can perform scanning with 3 different methods (ETSI EN 100 392-2 V3.6.1, 2013):

- Foreground scanning: User is in idle mode and scanning is the only activity.
- Background scanning: User is communicating and scanning is performed parallel with the communication.
- Interrupting scanning: Communication is being interrupted for a limited time and while user performs the scanning process.

During initial cell selection process, mobile user has no serving cell and initiates the foreground scanning where it is in idle mode. Mobile user scans all cells and obtain the information of received signal strength. Foreground scanning can also be used for the situations where user is attached a cell in idle mode. For some cell reselection types, user performs background scanning with neighbour cells and attach to the new cell.

For foreground scanning measurement, mobile users should take the average of at least 5 measurement samples spread over at least 300 ms.

2.4.3. Received Signal Strength Indicator

Each user *k* obtains instantaneous received signal strength value for BS *u* as follows:

$$RSSI_{u,k}(dB) = EIRP_u - PL_{u,k} - BuL - Sh_k - BL + G_r - CL_r - fading(dB) \quad (2.2)$$

where $PL_{u,k}$ is path loss between user *k* and BS *u*, BuL is building loss, Sh_k is log-normal shadowing, BL is body loss, G_r is receiver antenna gain, CL_r is receiver cable loss and *fading* is Rayleigh fading generated with Jakes' model. $EIRP_u$ is effective isotropic radiated power value for BS *u*:

$$EIRP_u(dB) = P_t + G_t - CL_t(dB) \quad (2.3)$$

where P_t is transmit power, G_t is transmitter antenna gain and CL_t is transmitter antenna cable loss.

2.5. Cell Selection Algorithms

Cell selection is the process of deciding the cell to provide services to every mobile station. There are different techniques and choices to be taken into account while selecting the cell to be attached. In order to establish seamless connection or make a quick call, cell selections becomes critical decision. Making an urgent call plays vital role for emergency and security services.

In this section, some of the cell selection algorithms will be explained. These are Tetra based cell selection, Signal-to-Interference Noise Ratio (SINR) based cell selection and rule based selection algorithms.

2.5.1. Tetra Based Cell Selection

In Tetra Based cell selection algorithm, users first calculate C1 path loss parameters belonging to each BS (ETSI EN 100 392-2 V3.6.1, 2013):

$$C1_{u,k} = Pr_{u,k} - Rec\_Sens - Max(0, Ms\_TxPwr\_Max\_Cell - P_{MSMAX}) \quad (2.4)$$

where $Pr_{u,k}$ is the received power of user *k* from BS *u* obtained by averaging the of 5 RSSI values as described in Section 2.4.2, *Rec_Sens* denotes minimum acceptable received power at the mobile user, *Ms_TxPwr_Max_Cell* stands for the maximum allowable transmit power at that channel and P_{MSMAX} is the maximum transmit power for π/4 DQPSK modulation.

After C1 path loss calculation, each user adds the BS that has C1 higher than 0 to their candidate sets. These cells are sorted in descending order and users attempt to attach the first BS with available capacity. The BS is called available if it has enough time slots for the user to be attached.

Flowchart of the cell selection algorithm for Tetra system is shown in Figure 2.7 (Karataş et al., 2016).

2.5.2. SINR Based Cell Selection

In the signal-to-noise-ratio based cell selection algorithm, each user selects the BS with the strongest SINR value (Sangiamwong et al., 2011).

$$u_k^* = \underset{1 \le u \le U}{\arg\max}\ SINR_{u,k} \quad \forall k. \quad (2.5)$$

SINR value belonging to BS *u* for user *k* is determined by,

$$SINR_{u,k} = \frac{Pr_{u,k}}{I_k + N_0 B_t} \quad (2.6)$$

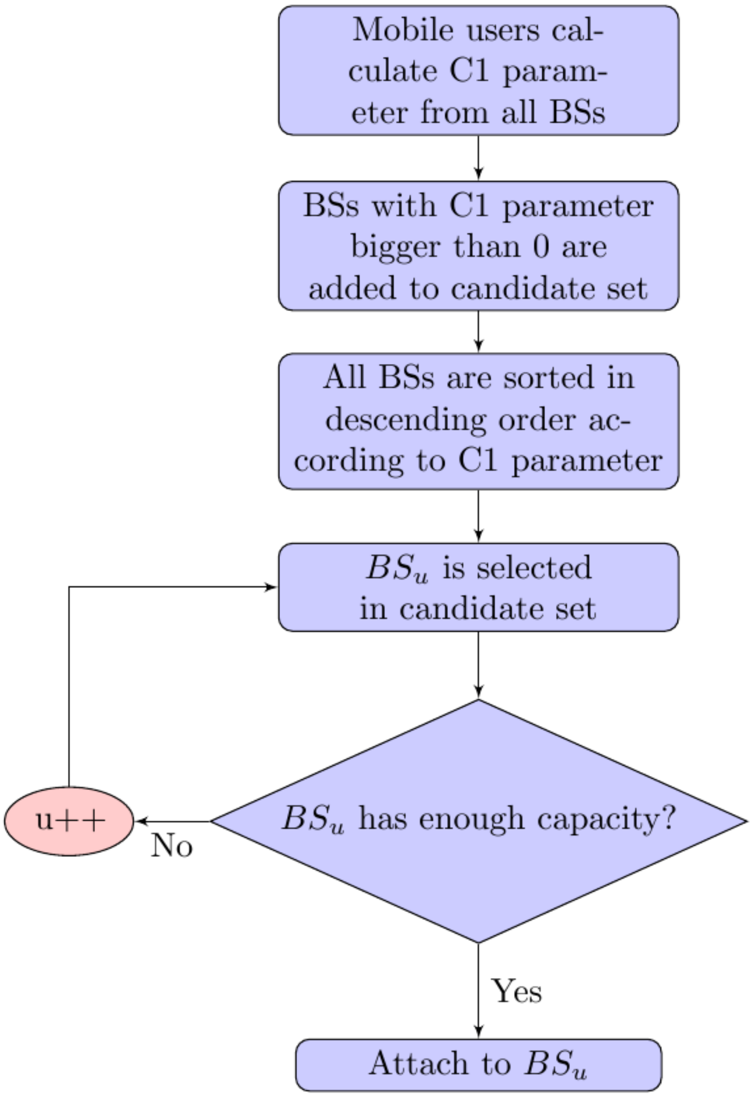

Figure 2.7. Flowchart of TETRA Based Cell Selection

where N_0 is the noise spectral density of the Additive White Gaussian Noise (AWGN) and B_t is the available transmission bandwidth. I_k is the total interference power of user *k* caused by the other cells having the same frequency,

$$I_k = \sum_{j=1, j \neq u}^{u'} Pr_{j,k} \tag{2.7}$$

where *u'* is the number of BSs having the same frequencies.

2.5.3. Rule Based Cell Selection

In the rule based cell selection algorithm (Gomes, 2009), the serving BS for each user is selected from within a set of candidate BSs, denoted by CS_k, for each user *k*. These candidate cells are formed according to highest SINR values.

For the first rule, user k selects the serving cell with the highest SINR among the set of candidate cells that has enough capacity and guarantees to serve the user with its quality of service (QoS).

The total supported capacity of BS *u*, C_u, is calculated as:

$$C_u = M_u D \tag{2.8}$$

where D is the data rate for one of time slot.

For the second rule, each user calculates the Admissibility Score, AS_u, for all its candidate cells as following:

$$AS_u = log_2(1 + SINR_{u,k})\delta^{\frac{AC_u}{C_u}} \tag{2.9}$$

where AC_u stands for available capacity at the BS *u* and δ is the intensity factor.

Then, user select the serving BS according to highest admissibility score AS_u among the set of candidate cells that have enough capacity to serve the user with its QoS. If none of these rules are triggered, then user becomes unregistered.

2.6. Antenna Diversity

One of the technique for reducing co-channel interference and fast fading effects is the antenna diversity where receiver antenna obtains uncorrelated samples of the same signal. Combining these uncorrelated signals gives better signal quality so that it will improve the performance of the overall system in an area where there is no line of sight between transmitter and receiver antennas.

Tetra standard has many advantages over reliability of the link. This can be enhanced by antenna diversity by using multiple antennas at BS side. BS selects the signal which has the greatest Signal-to-Noise Ratio (SNR) from incoming signals to antennas with different channels. This antenna diversity at BS side, which is also called as selection combining diversity, will improve reliability for uplink direction in a manner of BER and coverage area. Selection combining diversity scheme is illustrated in Figure 2.8.

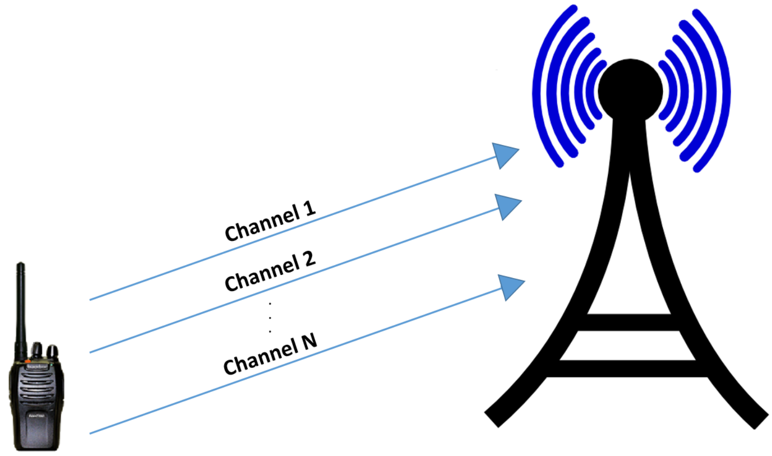

Figure 2.8. Antenna diversity in uplink direction

Instantaneous SNR in *i* branch is given as (Jakes, 1974) :

$$\gamma_i = \frac{Pr_i}{N_0 B_t}, i = 1, ..., N \tag{2.10}$$

where Pr_i represents the received power at antenna i and N is the number of antennas at the BS. The output SNR of the selection diversity scheme is:

$$i^* = \arg\max_{\forall i}{}_i \ \gamma_i \tag{2.11}$$

CHAPTER 3

LOAD BASED CELL SELECTION ALGORITHMS

In this chapter, two different cell selection algorithms are proposed for Tetra systems considering both the cell load and RSSI value (Karataş et al., 2016)(Karataş et al., 2017a).

Performance evaluations of these two algorithms are obtained in urban, suburban and rural area with different traffics and compared with SINR and Tetra based cell selection algorithms. To analyze effect of diversity in Tetra system for uplink direction, BER performance results for the system with and without antenna diversity are obtained.

System models of urban, rural and suburban areas are given in Figure 3.1, Figure 3.2 and Figure 3.3. In urban environment, there are 14 BSs with a frequency reuse factor as 1 to 7. For the rural environment, 7 BSs with 1 to 3 frequency reuse factor are deployed the area. For the last environment, 10 BSs are deployed for suburban area with a frequency reuse factor as 1 to 3. Overlapping ratio among cells is taken as 40% for all environments. The same color represents the same frequency.

Figure 3.1. Urban Environment

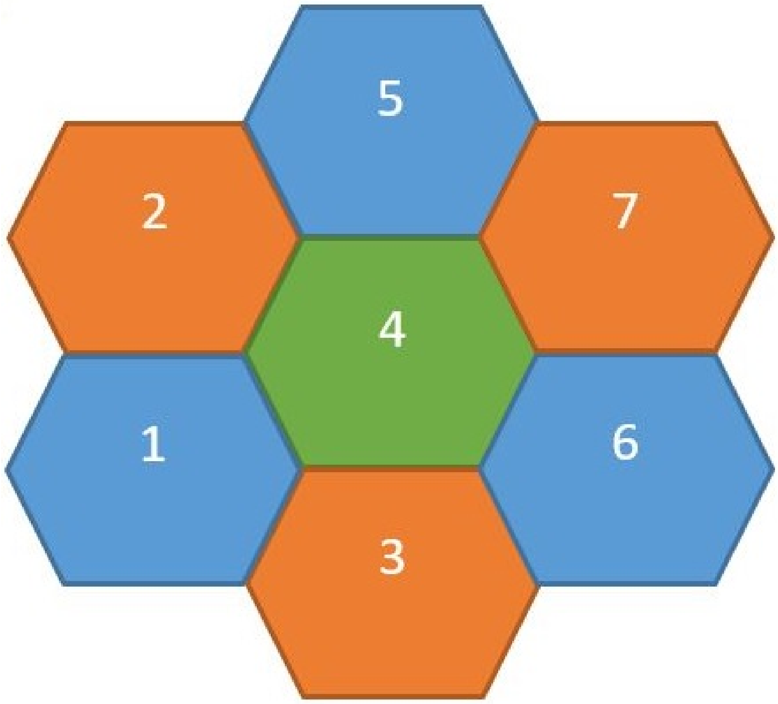

Figure 3.2. Rural Environment

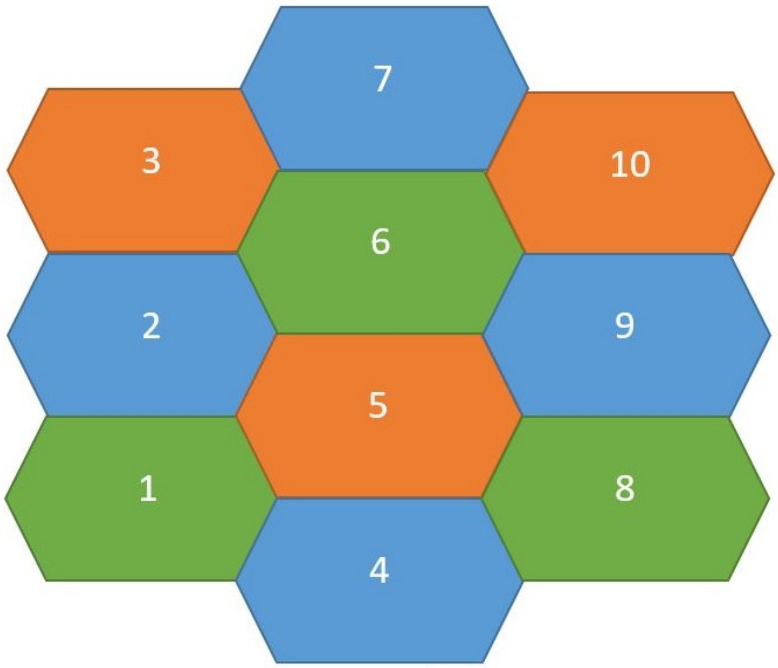

Figure 3.3. Suburban Environment

3.1. Load Based Full Set Cell Selection Algorithm

The proposed load based full set cell selection algorithm is described in the following:

1. Constructing RSSI Threshold Set:

   The received signal strength of BS *u* at the user should exceed a predefined signal strength threshold which is receiver sensitivity,

$$\mathbb{P}_k = \{u \ni Pr_{u,k} \geq Rec\_Sens, \forall u\}, \forall k \tag{3.1}$$

2. Calculation of Utility Values:

   For user *k*, utility value is determined by each BS by considering RSSI values and corresponding index value is broadcasted from BSs according to calculated unmapped cell loading (UCL) information. UCL value of a BS *u* is calculated as:

$$UCL_u = (1-c)\frac{A_u}{M_u} + c\frac{I_u}{K_u} \tag{3.2}$$

   where A_u and I_u are the number of active and inactive users attaching to BS *u*, respectively. Active users are attached to a cell while communicating whereas inactive users are only attached but not communicating. Active users are accepted as communicating during all simulation time and inactive users are not communicating. c represents the importance of contribution between active and inactive users while calculating cell load.

   M_u and K_u are defined as the maximum number of active and inactive users per BS in all system, respectively. M_u is defined in Eq. (2.1) and K_u can be calculated as:

$$K_u = \frac{N_u - X_u}{N_b} \tag{3.3}$$

   where N_u is the number of users, N_b is the number of BSs and $X_u = N_b M_u$ gives the total number of time slots in the Tetra system in the considered area.

   The utility value of BS *u* in $\mathbb{P}_k$, calculated by user *k*, denoted by $U_{u,k}$, is defined as

$$U_{u,k} = wf(Pr_{u,k}) + (1-w)h(UCL_u), \forall u \in \mathbb{P}_k \tag{3.4}$$

   where w is the weight of RSSI and $(1-w)$ is the weight of mapped cell loading (MCL). The function *f* represents the normalization of RSSI values by sorting the RSSI values and function *h* transforms the UCL to MCL.

3. Attaching to a BS:

   After calculating utility values of all BSs for $\mathbb{P}_k$ set, the BS with the maximum utility value is selected as the target cell for call request. The target cell for call request can then be obtained by

$$u^* = \underset{u \in \mathbb{P}_k}{\arg\max}\ U_{u,k} \tag{3.5}$$

The flowchart of proposed load based full set cell selection algorithm is given Figure 3.4.

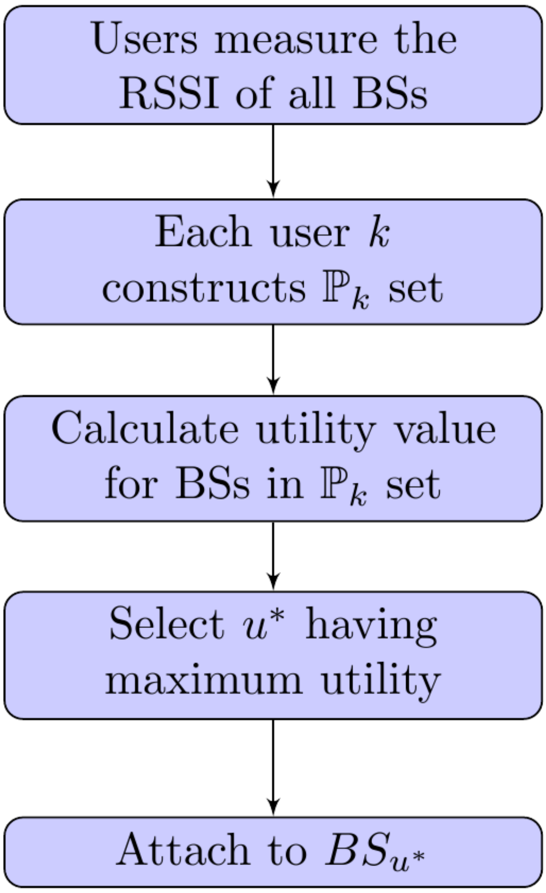

Figure 3.4. Flowchart of Proposed Load Based Full Set Cell Selection Algorithm

3.2. Load Based Reduced Set Cell Selection Algorithm

The proposed load based reduced set cell selection algorithm focuses on to minimize the number of RSSI measurements while considering balanced distribution of users among all BSs. The proposed algorithm works as follows:

1. Constructing neighbor cells set

   From the broadcasted network informations, neighbor cells set, $\mathbb{Z}_k$, is created with the aid of Global Positioning System (GPS) system and these cells are sorted by user in ascending order.

2. Calculation of utility value

   After deciding the neighbor cells, user starts to calculate utility value for the first BS, which is the closest. Utility value is calculated by taking into account measured received power value and broadcasted cell load parameter from BS *u*:

   $$U_{u,k} = wg(Pr_{u,k}) + (1-w)h(UCL_u), \forall u \in \mathbb{Z}_k \tag{3.6}$$

   where the function *g* gives the normalization value of measured RSSI.

3. Attaching to a BS

   - If the calculated utility value of the cell is higher than defined utility threshold value, U_{th}, user attaches to this BS. If this utility threshold value is not satisfied, user connects the next cell in the neighbor set one by one. In case, there are no cells that satisfies this utility threshold value, then user tries to attach to BS with the maximum calculated utility value.
   - When there are no cells satisfying this threshold in neighbor set, user calculates received powers of all remaining BSs and attaches to available one.

The proposed load based reduced set cell selection algorithm flowchart is given Figure 3.5.

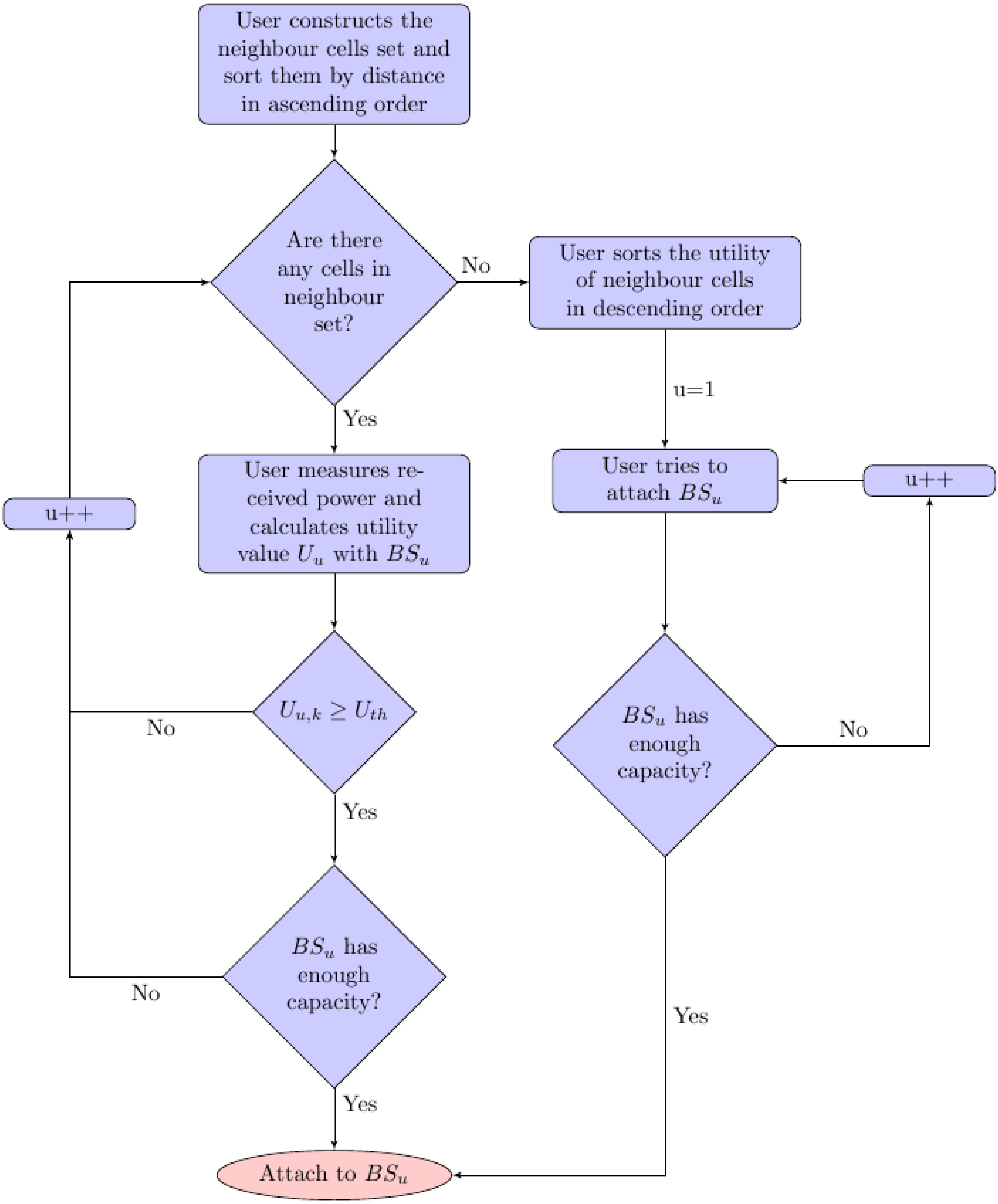

Figure 3.5. Flowchart of the Proposed Load Based Reduced Set cell selection algorithm

3.3. Performance Evaluations

While obtaining performance results, there are only fixed voice users which use one physical channel to communicate. Indoor users have extra building loss and simulations performed with different percentages of indoor users. Traffic load of the system depends on the percentage of active users. Simulation results are obtained in urban, rural and suburban areas. The percentages of active users are different in every environment. Simulation parameters are listed in Table 3.1.

Table 3.1. Simulation parameters

PARAMETERS	**TETRA**
Transmit Power	44 dBm (25 W)
Modulation Bandwidth	20 kHz
Channel Spacing	25 kHz
Noise Spectral Density	-174 dBm/Hz
Shadowing	6 dB
Receiver Sensitivity	-115 dBm
TX Antenna Gain	8 dB
TX Cable Loss	6 dB
RX Antenna Gain	-2 dB
RX Cable Loss	0 dB
BS Antenna Height	30 m
MS Antenna Height	1.5 m
Building Loss	16.5 dB
Weight of RSSI (w)	0.2, 0.5, 0.8
Percentage of Indoor Users	20%, 30%
c	0.1
U_{th}	0.5

Hata path loss model is used for urban area (ETSI Technical Report143 030 V9.0.0, 2010) as following:

$$PL_{u,k}(dB) = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b - (3.2(\log_{10}(11.75h_m))^2 - 4.97) + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} \quad (3.7)$$

where f_u is the frequency of BS u, h_b represents BS antenna height, h_m is mobile station antenna height and $R_{u,k}$ is the distance between BS *u* and user *k*.

For rural area, Hata path loss model (ETSI Technical Report143 030 V9.0.0, 2010) is used and given as following:

$$PL_{u,k}(dB) = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b - (1.1 * \log_{10}(f_u) - 0.7) * hm + (1.56 * \log_{10}(f_u) - 0.8) + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} - 4.78 * (\log_{10}(f_u))^2 + 18.33 * \log_{10}(f_u) - 40.94 \quad (3.8)$$

For suburban area, Hata path loss model (ETSI Technical Report143 030 V9.0.0, 2010) is used and given as following:

$$PL_{u,k(dB)} = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} - 2 * (\log_{10}(f_u/28))^2 - 5.4 \quad (3.9)$$

While calculating utility value, normalization of RSSI value is performed by using f function, comparison of RSSI value within fixed values is done in g function and mapping of cell load is calculated in h function. In f function, RSSI values of cells is simply sorted and assigned to a normalized value according to Table 3.2. In g function, corresponding mapped value of calculated RSSI value of cell is assigned according to Table 3.3. Since RSSI values are more intense in certain intervals, nonlinear sorting is applied to RSSI values. In h function, an index value is broadcasted by BS according to calculated UCL value performed by BS. BSs have 2 bits for cell load broadcasting and if none of the channel is available, BS broadcast a value to inform the users. During utility value calculation, these index values are then transformed to a mapped value as shown in Table 3.4.

Table 3.2. Normalization of RSSI Values in f function for Proposed Full Set Algorithm

Sorted RSSI Indices	f (.)	**Sorted RSSI Indices**	f (.)
1	1	8	0.5
2	0.928	9	0.429
3	0.857	10	0.357
4	0.786	11	0.286
5	0.714	12	0.214
6	0.643	13	0.143
7	0.571	14	0.071

Table 3.3. Mapping of RSSI Values in g function for Proposed Reduced Set Algorithm

RSSI Value (dBm)	g (.)	**RSSI Value (dBm)**	g (.)
$RSSI \leq -100$	0.125	$-75 > RSSI \geq -80$	0.625
$-90 > RSSI \geq -100$	0.25	$-70 > RSSI \geq -75$	0.75
$-85 > RSSI \geq -90$	0.375	$-65 > RSSI \geq -70$	0.875
$-80 > RSSI \geq -85$	0.5	$RSSI \geq -65$	1

Table 3.4. Mapping of Cell Load Values in h Function

Calculated UCL Interval	**Index** $h(.)$	**MCL**
0-0.5	1	1
0.5-0.8	2	0.66
0.8-1	3	0.33
No channel	4	0

In order to examine the performance of proposed full set and reduced set cell selection algorithms, we obtain the performance of algorithms with 3 different weight of RSSI values (w) compared with SINR and Tetra based algorithms.

The metrics that are considered to compare performance results are the number of RSSI measurement, the number of request and the number of waiting users. The number of RSSI measurement performance metric is the average number of RSSI measurement of a user to attach a cell. The number of request is the average number of requests of a user to be attached to BS and number of waiting users gives the number of unattached active users who can not establish the call. BER performance of active users are also provided.

The performance evaluations are obtained with different percentage of indoor and active users with different locations of users with 300 Monte Carlo iterations.

3.3.1. Urban Environment

Urban area cell model is shown in Figure 3.6. In this area, there are uniformly distributed 600 users and 14 BSs. Each BS has 24 channels (one for control) which corresponds to 6 physical carrier and 150kHz. Frequency reuse factor is used as 1 to 7. Medium and high traffic situations are given in Table 3.5. High traffic percentage is chosen as to make all channels of BSs full.

Table 3.5. Percentage of active users in urban area

Percentage of Active Users	**Traffic load**
45 %	Medium
50 %	High

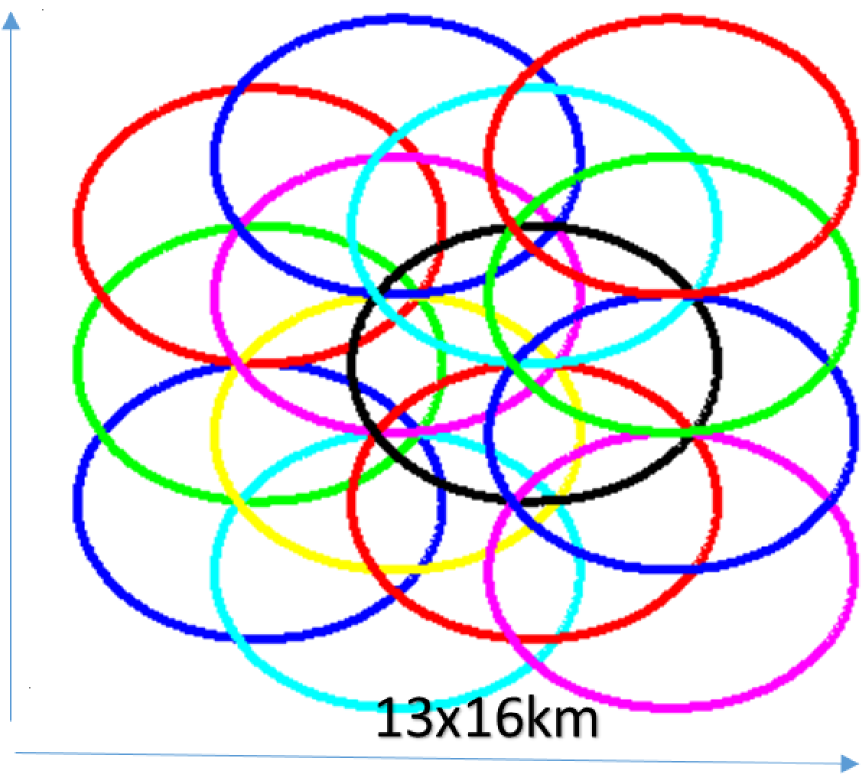

Figure 3.6. Urban Area for Load Based System

3.3.1.1. High Traffic Results

The performance results of the cell selection algorithms with 20% of users are indoor and for 50% active users are shown in Table 3.6 and Table 3.7.

Table 3.6. High traffic with 20% indoor users for urban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	14	1.4169	6.9495
TETRA Based	14	1.1391	4.7677
Proposed Full Set with *w*=0.2	14	1	**3.2525**
Proposed Full Set with *w*=0.5	14	1	3.596
Proposed Full Set with *w*=0.8	14	1	4.4646
Proposed Reduced Set with *w*=0.2	**3.3527**	1	**3.5253**
Proposed Reduced Set with *w*=0.5	4.9973	1	3.697
Proposed Reduced Set with *w*=0.8	5.1683	1	4.2121

Table 3.7. Outage probabilities of high traffic with 20% indoor users for urban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.06595	0.04312
TETRA Based	0.02575	0.01388
Proposed Full Set with *w*=0.2	0.04360	0.02700
Proposed Full Set with *w*=0.5	0.03331	0.01868
Proposed Full Set with *w*=0.8	0.02589	0.01412
Proposed Reduced Set with *w*=0.2	0.04300	0.02543
Proposed Reduced Set with *w*=0.5	0.04049	0.02543
Proposed Reduced Set with *w*=0.8	0.03181	0.01780

Performance results of cell selection algorithms with 30% of users are indoor and for 50% active users are shown in Table 3.8 and Table 3.9.

Table 3.8. High traffic with 30% indoor users for urban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	14	1.4169	8.33
TETRA Based	14	1.1391	6.44
Proposed Full Set with *w*=0.2	14	1	**4.1567**
Proposed Full Set with *w*=0.5	14	1	4.55
Proposed Full Set with *w*=0.8	14	1	6.1633
Proposed Reduced Set with *w*=0.2	**3.3564**	1	**4.59**
Proposed Reduced Set with *w*=0.5	4.9842	1	4.8833
Proposed Reduced Set with *w*=0.8	5.1558	1	5.85

Table 3.9. Outage probabilities of high traffic with 30% indoor users for urban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.054945	0.034719
TETRA Based	0.020773	0.010435
Proposed Full Set with *w*=0.2	0.035141	0.021402
Proposed Full Set with *w*=0.5	0.026369	0.014282
Proposed Full Set with *w*=0.8	0.020729	0.010333
Proposed Reduced Set with *w*=0.2	0.034054	0.018777
Proposed Reduced Set with *w*=0.5	0.031458	0.018777
Proposed Reduced Set with *w*=0.8	0.026049	0.013967

While examining the high traffic results in Table 3.6 and Table 3.8, most salient point is the increment in number of waiting users due to increasing number of calls. Proposed algorithms reduce the number of waiting users about %35 according to Tetra based and %50 according to SINR based algorithm. The proposed full set with *w*=0.2 algorithm gives the best result due to higher importance of cell load value. The effect in cell load parameter in utility calculation process can be observed based on the results of number of waiting users of proposed algorithms with ascending w orders. The higher we choose w weight value, also means the higher importance we give to RSSI value, we get lower performance on number of waiting users.

In high traffic system, the number of RSSI measurements is lowest in proposed reduced set with w=0.2 cell selection algorithm and average number of requests are 1 for the proposed algorithms which means users attach the BS at their first attempt. Again, from Table 3.7 and Table 3.9, outage probabilities of all algorithms are below 5%.

Drastic results of the proposed reduced set cell selection algorithm can be observed in terms of the number of RSSI measurement. While users in all algorithms except reduced set algorithms attach any BS with 14 RSSI measurements, in reduced set algorithms, the number of RSSI measurements are much less than other algorithms. We can observe the best result in the proposed reduced set algorithm with 0.2 RSSI weight for cases with 20% and 30% percentages indoor users in Table 3.6 and Table 3.8. The reason that the reduced full set with w=0.2 algorithm giving best result is that the proposed algorithm gives more importance to cell load value rather than RSSI values in utility calculation giving in Eq. (3.6).

Apart from SINR and Tetra based algorithms, the average number of requests are 1 for all proposed algorithms. It's because the proposed algorithms consider the cell load of BSs while trying to attach the users, while SINR and Tetra based algorithms do not consider the cell loads.

In Table 3.7 and Table 3.9, outage probabilities of users are given with the 5% BER target. Furthermore, the effect of diversity in uplink reduces the BER and outage values.

3.3.1.2. Medium Traffic Results

Performance results of cell selection algorithms with 20% of users are indoor and for 45% active users are shown in Table 3.10 and Table 3.11.

Table 3.10. Medium traffic with 20% indoor users for urban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	14	1.1706	1.3838
TETRA Based	14	1.0138	0.51515
Proposed Full Set with *w*=0.2	14	1	**0.05050**
Proposed Full Set with *w*=0.5	14	1	0.08080
Proposed Full Set with *w*=0.8	14	1	0.43434
Proposed Reduced Set with *w*=0.2	**3.2148**	1	**0.10100**
Proposed Reduced Set with *w*=0.5	4.9372	1	0.13500
Proposed Reduced Set with *w*=0.8	5.1309	1	0.17100

Table 3.11. Outage probabilities of medium traffic with 20% indoor users for urban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04881	0.02707
TETRA Based	0.01994	0.00351
Proposed Full Set with *w*=0.2	0.03378	0.01975
Proposed Full Set with *w*=0.5	0.02237	0.00946
Proposed Full Set with *w*=0.8	0.01262	0.00348
Proposed Reduced Set with *w*=0.2	0.03001	0.01538
Proposed Reduced Set with *w*=0.5	0.02724	0.01531
Proposed Reduced Set with *w*=0.8	0.01689	0.00648

Performance results of cell selection algorithms with 30% of users are indoor and for 45% active users are shown in Table 3.12 and Table 3.13.

Table 3.12. Medium traffic with 30% indoor users for urban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	14	1.1525	2.1767
TETRA Based	14	1.0121	0.85333
Proposed Full Set with *w*=0.2	14	1	**0.19667**
Proposed Full Set with *w*=0.5	14	1	0.24667
Proposed Full Set with *w*=0.8	14	1	0.73333
Proposed Reduced Set with *w*=0.2	**3.2380**	1	**0.22**
Proposed Reduced Set with *w*=0.5	4.9697	1	0.3
Proposed Reduced Set with *w*=0.8	5.1445	1	0.59667

Table 3.13. Outage probabilities of medium traffic with 30% indoor users for urban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04531	0.02597
TETRA Based	0.00956	0.00292
Proposed Full Set with *w*=0.2	0.02983	0.01811
Proposed Full Set with *w*=0.5	0.01898	0.00835
Proposed Full Set with *w*=0.8	0.00986	0.00285
Proposed Reduced Set with *w*=0.2	0.02826	0.01523
Proposed Reduced Set with *w*=0.5	0.02475	0.01523
Proposed Reduced Set with *w*=0.8	0.01301	0.00461

In order to examine the performance results of medium traffic system in urban area, as seen from Table 3.10 and Table 3.12, SINR and Tetra based algorithms give poor performance compared with the proposed algorithms. This result is another consequence of choosing RSSI weight parameter small while calculating utility in Eq. (4.2). In terms of the number of waiting users, proposed algorithms have less waiting users than SINR based algorithm approximately 90% and 60% less than Tetra based algorithm. The proposed full set algorithms are slightly better than the proposed reduced set algorithms since full set calculates utility value of all BSs in environment and chooses the best BS with greatest utility value. However, the drawback of this algorithm is the number of RSSI measurement which also causes delay for attaching a BS.

From Table 3.11 and Table 3.13, outage probabilities of all algorithms are below the 5% and effect of diversity can also be seen.

3.3.2. Rural Environment

Rural area cell model is shown in Figure 3.7. In this area, there are uniformly distributed 200 users and 7 BSs. Each BS has 8 channels (and one channel for control usage) which corresponds to 2 physical carriers and 50kHz. Frequency reuse factor is used as 1:3. Due to low number of users in area and high coverage of BSs, only high traffic situation is concerned. For the high traffic load, 25% of users are chosen as active user.

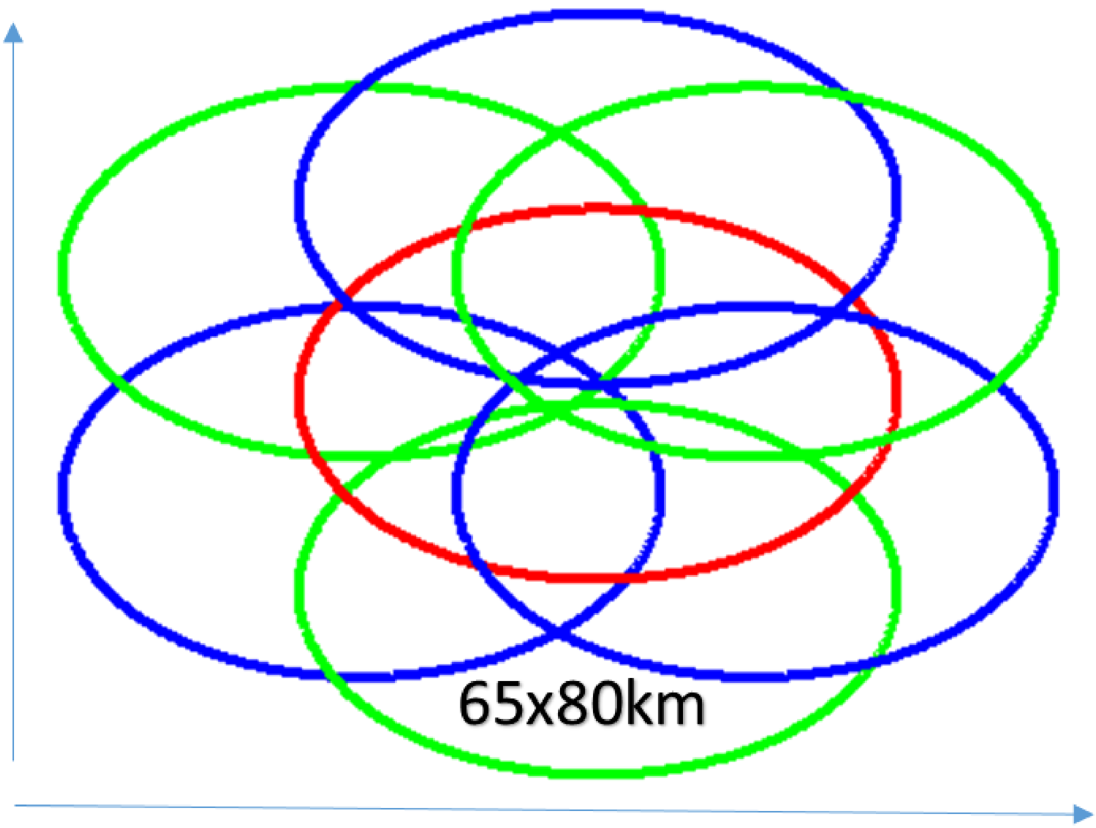

Figure 3.7. Rural Area for Load Based System

3.3.2.1. High Traffic Results

Performance results of cell selection algorithms with 20% of users are indoor and for %50 active users are shown in Table 3.14 and Table 3.15.

Table 3.14. High traffic with 20% indoor users for rural area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	7	1.208	1.4667
TETRA Based	7	1.0796	1.3
Proposed Full Set with *w*=0.2	7	1	**0.63333**
Proposed Full Set with *w*=0.5	7	1	0.8
Proposed Full Set with *w*=0.8	7	1	1.3
Proposed Reduced Set with *w*=0.2	**2.6867**	1	**0.7**
Proposed Reduced Set with *w*=0.5	3.9892	1	0.8
Proposed Reduced Set with *w*=0.8	4.1033	1	1.0333

Table 3.15. Outage probabilities of high traffic with 20% indoor users for rural area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04595	0.03312
TETRA Based	0.02575	0.01588
Proposed Full Set with *w*=0.2	0.04360	0.02700
Proposed Full Set with *w*=0.5	0.03331	0.01868
Proposed Full Set with *w*=0.8	0.02529	0.01412
Proposed Reduced Set with *w*=0.2	0.04300	0.02543
Proposed Reduced Set with *w*=0.5	0.04049	0.02543
Proposed Reduced Set with *w*=0.8	0.03181	0.01780

Performance results of cell selection algorithms with 30% of users are indoor and for %50 active users are shown in Table 3.16 and Table 3.17.

Table 3.16. High traffic with 30% indoor users for rural area

Algorithms / Results	Number of RSSI Measurement	Number of Request	Number of Waiting Users
SINR Based	7	1.183	1.2667
TETRA Based	7	1.0887	1.28
Proposed Full Set with w=0.2	7	1	**0.77**
Proposed Full Set with w=0.5	7	1	0.91
Proposed Full Set with w=0.8	7	1	1.28
Proposed Reduced Set with w=0.2	**2.7393**	1	**0.83**
Proposed Reduced Set with w=0.5	4.05	1	0.86
Proposed Reduced Set with w=0.8	4.1425	1	1.0933

Table 3.17. Outage probabilities of high traffic with 30% indoor users for rural area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.050531	0.023436
TETRA Based	0.031201	0.011783
Proposed Full Set with w=0.2	0.054159	0.030798
Proposed Full Set with w=0.5	0.036907	0.015974
Proposed Full Set with w=0.8	0.031062	0.011643
Proposed Reduced Set with w=0.2	0.057572	0.032176
Proposed Reduced Set with w=0.5	0.052151	0.032242
Proposed Reduced Set with w=0.8	0.038934	0.017643

While examining the high traffic results in Table 3.14 and Table 3.16, different behavior is observed than urban area. In rural areas, low traffic is expected due to less number of users. Even both 20% and 30% indoor users, again the proposed algorithms have better performances than SINR and Tetra based algorithms. The proposed full set algorithm with w=0.2 reduces the number of waiting users about 50% according to both SINR and Tetra based algorithms in 20% indoor user and reduces about 30% in system with 30% indoor user.

Again, from Table 3.15 and Table 3.17, outage probabilities of all algorithms are below the 5%.

3.3.3. Suburban Environment

Suburban area cell model is shown in Figure 3.8. In this area, there are uniformly distributed 400 users and 10 BSs. Each BS has 12 channels (one for control) which corresponds to 3 physical carrier and 75kHz bandwidth per cell. Frequency reuse factor is used as 1:3. Only high traffic load situation is considered and 38% of users are chosen as active user.

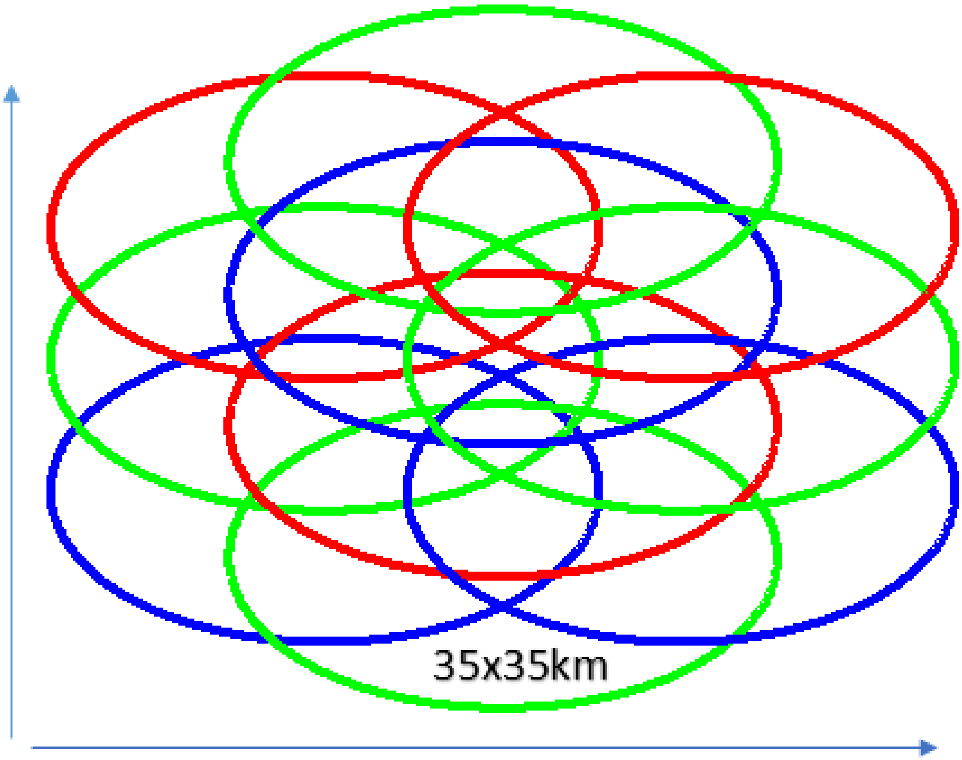

Figure 3.8. Suburban Area for Load Based System

3.3.3.1. High Traffic Results

Performance results of cell selection algorithms with 20% of users are indoor and for %50 active users are shown in Table 3.18 and Table 3.19.

Table 3.18. High traffic with 20% indoor users for suburban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	10	1.5203	1.1633
TETRA Based	10	1.1351	1.29
Proposed Full Set with w=0.2	10	1	**0.73667**
Proposed Full Set with w=0.5	10	1	0.78667
Proposed Full Set with w=0.8	10	1	1.2333
Proposed Reduced Set with w=0.2	**2.9504**	1	**0.75333**
Proposed Reduced Set with w=0.5	4.1018	1	0.78333
Proposed Reduced Set with w=0.8	4.2878	1	1.01

Table 3.19. Outage probabilities of high traffic with 20% indoor users for suburban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04595	0.03312
TETRA Based	0.02575	0.01588
Proposed Full Set with w=0.2	0.04360	0.02700
Proposed Full Set with w=0.5	0.03331	0.01868
Proposed Full Set with w=0.8	0.02529	0.01412
Proposed Reduced Set with w=0.2	0.04300	0.02543
Proposed Reduced Set with w=0.5	0.04049	0.02543
Proposed Reduced Set with w=0.8	0.03181	0.01780

Performance results of cell selection algorithms with 30% of users are indoor and for %50 active users are shown in Table 3.20 and Table 3.21.

Table 3.20. High traffic with 30% indoor users for suburban area

Algorithms / Results	Number of RSSI Measurement	Number of Requests	Number of Waiting Users
SINR Based	10	1.4886	1.6467
TETRA Based	10	1.1251	1.7567
Proposed Full Set with *w*=0.2	10	1	**1.0667**
Proposed Full Set with *w*=0.5	10	1	1.1267
Proposed Full Set with *w*=0.8	10	1	1.6633
Proposed Reduced Set with *w*=0.2	**2.9965**	1	**1.1733**
Proposed Reduced Set with *w*=0.5	4.2134	1	1.2367
Proposed Reduced Set with *w*=0.8	4.3498	1	1.45

Table 3.21. Outage probabilities of high traffic with 30% indoor users for suburban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.054945	0.034719
TETRA Based	0.020773	0.010435
Proposed Full Set with *w*=0.2	0.035141	0.021402
Proposed Full Set with *w*=0.5	0.026369	0.014282
Proposed Full Set with *w*=0.8	0.020729	0.01033
Proposed Reduced Set with *w*=0.2	0.034054	0.018777
Proposed Reduced Set with *w*=0.5	0.031458	0.018777
Proposed Reduced Set with *w*=0.8	0.026049	0.013967

While examining the high traffic results for suburban area in Table 3.18 and Table 3.20, the results show that there is a decrease in number of waiting users for the proposed algorithms. Both in the proposed full set and the proposed reduced set algorithms with *w*=0.2, about 35% decrease can be observed than SINR and Tetra based algorithms for 20% and 30% indoor systems. Cell selection algorithms except the proposed reduced set cell selection algorithms give number of RSSI measurement metric as 10. Again with the increasing RSSI weight value, increment in number of RSSI measurement is observed.

Again, from Table 3.19 and Table 3.21, outage probabilities of all algorithms are below the 5%.

CHAPTER 4

TRAFFIC BASED CELL SELECTION ALGORITHMS

In this chapter, the cell selection algorithms proposed for cell load systems are developed by considering the mobility and group talks (Karataş et al., 2017b). The proposed algorithms consider both the RSSI values of BSs and traffic density of active and inactive users. Traffic loads of BSs are calculated for initial cell selection and cell reselection cases differently.

Performance evaluations of proposed algorithms are obtained in urban, rural and suburban environments with different number of BSs, users and groups. In these environments, users have different Push-to-Talk (PTT) probabilities so that systems have varying traffic loads. With the beginning of simulation, users do initial cell selection and can do cell reselection.

In urban environment, there are 10 BSs with 1 to 3 frequency reuse factor as shown in Figure 4.1. For the rural area, 5 BSs are deployed with 1 to 3 frequency reuse factor as shown in Figure 4.2. In suburban environment, there are 7 BSs with frequency reuse factor as 1 to 3 given in Figure 4.3. The same color represents the same frequency.

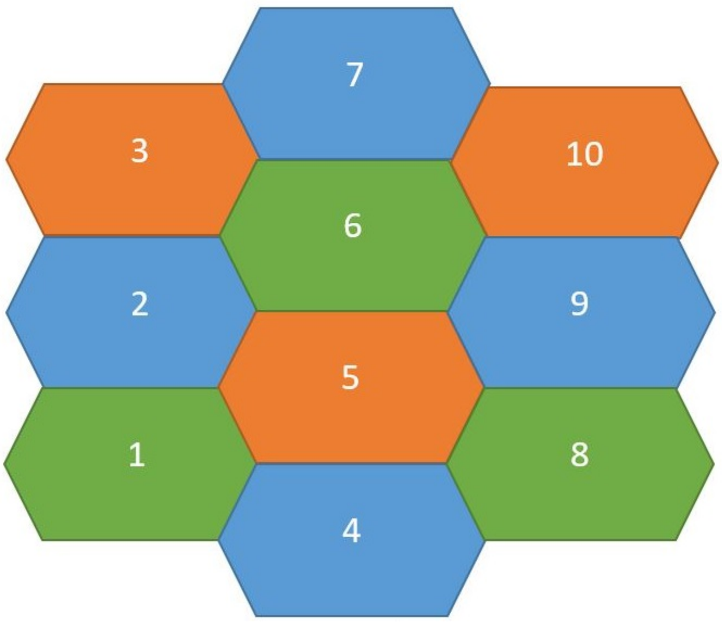

Figure 4.1. Urban Environment

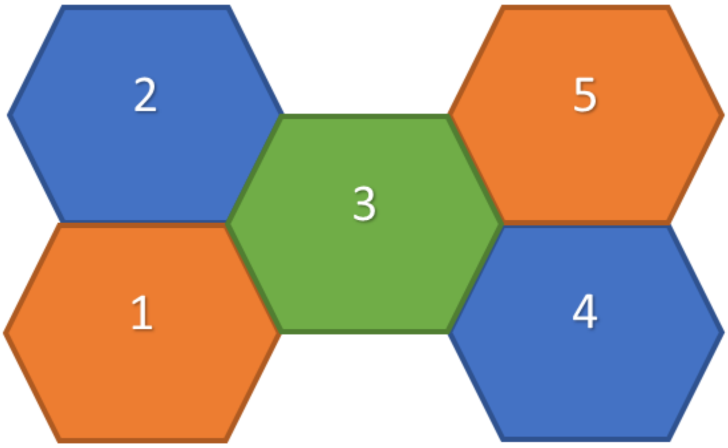

Figure 4.2. Rural Environment

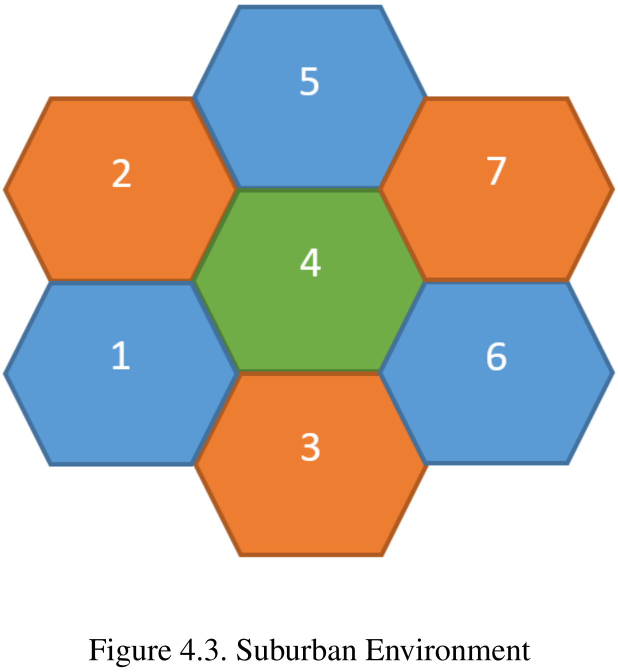

Figure 4.3. Suburban Environment

4.1. Traffic Based Full Set Cell Selection Algorithm

The full set cell selection algorithm for traffic based system works as follows:

1. Constructing RSSI Threshold Set:

   Users create RSSI threshold set, denoted by $\mathbb{P}_k$, as in load based full set cell selection algorithm given in Eq. (3.1).

2. Calculation of Utility Values:

   For user *k*, utility value is calculated by considering all RSSI values and unmapped traffic loading (UTL) information broadcasted from BSs. For initial cell selection, BSs broadcast a traffic load information by considering only the number of inactive users. For cell reselections, in addition to the inactive users term, UTL value includes a term keeping history of talking time duration of active users for the last defined traffic duration. For general representation, BSs broadcast UTL value as:

   $$UTL_u = (1-c)\frac{I_u}{N_u/N_b} + c\frac{H}{DM_u} \tag{4.1}$$

   where *H* represents the duration of talks of active users in seconds and *D* stands for the defined time interval. BSs include the total traffic volume of defined time interval in their cell broadcast informations. For initial UTL calculation, since there will be no active users and no calls occurred, c parameter is set to 0.

   The utility value of cell *u* in the RSSI threshold set is calculated as follows:

   $$U_{u,k} = wf(Pr_{u,k}) + (1-w)h(UTL_u), \forall u \in \mathbb{P}_k \tag{4.2}$$

   The f function, which normalize the RSSI values and the h function, which transforms the UTL to Mapped Traffic Load (MTL) are different in traffic based algorithms.

3. Attaching to a BS:

   Target cell selection process after calculating utility values of all BSs for $\mathbb{P}_k$ set, is the same the load based cell selection algorithm as Eq. (3.5). The same flowchart of the proposed traffic based cell selection algorithm in Figure 3.4 is used except the UTL calculation.

4.2. Traffic Based Reduced Set Cell Selection Algorithm

The reduced set cell selection algorithm for traffic based system works as follows:

1. Constructing neighbor cells set

   With the aid of GPS system, users create neighbor cells set, $\mathbb{Z}_k$, and sorts in ascending order as in the load based reduced set cell selection algorithm.

2. Calculation of utility value

   Utility value is calculated as the following:

$$U_{u,k} = wg(Pr_{u,k}) + (1-w)h(UTL_u), \forall u \in \mathbb{Z}_k \tag{4.3}$$

   While the $g(.)$ function, which normalize the RSSI values, remains the same as in the load based system, the $h(.)$ function is different in traffic based system.

3. Attaching to a BS

   Process of BS selection of users works the same in load based system described in Section 3.2. The proposed traffic based reduced set cell selection algorithm flowchart works the same in Figure 3.5 except the UTL calculation.

4.3. Performance Evaluations

While performing simulations, users are divided into groups. Group calls can only occur between the same group users where users can be both inactive and active. All talks in group conversations are arranged by considering short PTT talk durations of all users. The number of talking users in the groups is determined with the probability of PTT and varies with environment.

These group talks are broadcasted by BSs to all users in the group so that each listener user does not need for an assigned channel. Channels are occupied by active users who needs to talk. If the serving cell has no available channel for the active user, then user is queued by BS. This user must wait until there is available channel in the serving cell.

The percentage of mobile users with vehicle or pedestrian velocities are considered the same for all environments. Table 4.1 categorizes the users with mobility. All outdoor users are accepted as mobile and velocities up to the values given in Table 4.1 are randomly generated. These mobile users can do cell reselection depending on the reselection criteria. If the defined number of RSSI values, also called reselection counter limit, are less then defined RSSI reselection value during last 10 measurements of RSSI, then users deattach the serving cell and search a new cell with reselection algorithm.

Table 4.1. Users with mobility informations

User Type	**Velocity**
Immobile	0 km/h
Pedestrian	up to 3km/h
Vehicle	up to 80 km/h

In simulations, BSs broadcast their traffic load values considering the UTL values calculated within the last minute. Since BSs calculate UTL value every second, BSs average the last 60 UTL values and broadcast an index value according to Table 4.2.

In utility calculation, normalization process of RSSI values in the *f* and *g* functions are the same in Table 3.2 and Table 3.3. Transformation of UTL values in utility calculation in *h* function is different and listed in Table 4.2. Since UTL values of BSs are calculated differently for initial and cell reselection cases, table is divided into two parts.

Table 4.2. Mapping of Traffic Load Values in h Function

Calculated UTL Interval For Initial Selection	**Averaged UTL Interval For Cell Reselection**	**Index** $h(.)$	**MTL**
0 - 0.7	0 - 0.6	1	1
0.7 - 1.2	0.6 - 1	2	0.66
1.2 - more	1 - more	3	0.33
None	No available channel	4	0

Simulation parameters for traffic based system is listed in Table 4.3.

Table 4.3. Simulation parameters

PARAMETERS	TETRA
Defined Time Interval (D)	1 min
Total Simulation Time	30 min
Reselection Criteria	-100 dBm
Reselection Counter Limit	7
Weight of RSSI (w)	0.2, 0.5, 0.8
Percentage of Indoor Users	20%
Percentage of Pedestrian Users	50%
Percentage of Vehicle Users	30%
U threshold	0.5
c (Initial Cell Selection)	0
c (Cell Reselection)	0.2

The critical performance metric of the traffic based system is the average waiting time for user to establish a call. Another metric is the number of reselection, which gives the average number of reselections of a user during all simulation time. The other metrics are the same in the load based system.

4.3.1. Urban Environment

Urban environment cell model is given in Figure 4.4. In this environment, there are 500 users and 10 BSs. Users are divided into 10 groups and the probability of PTT is 0.6. This results in 300 talking users. BSs have 8 time slots (one for control purposes) which corresponds to 2 physical channels with 50 kHz.

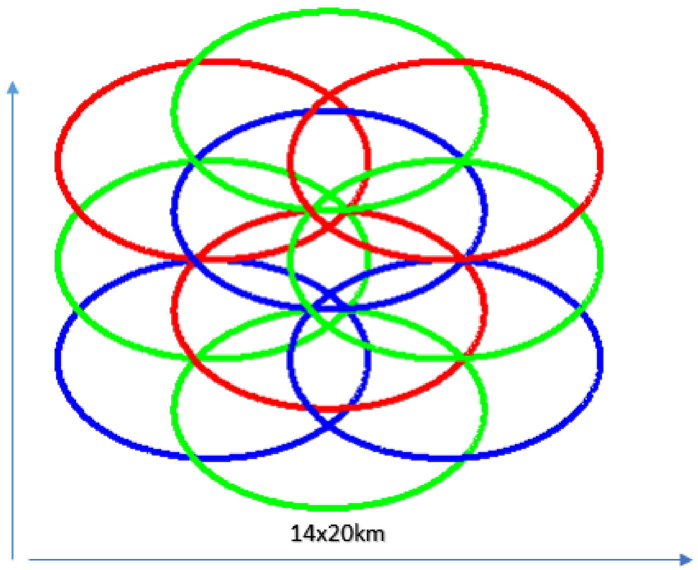

Figure 4.4. Urban Area for Traffic Based System

Performance results are shown in Table 4.4 and Table 4.5.

Table 4.4. Urban area results for traffic based system

Algorithms / Results	Number of RSSI Measurement	Number of Request	Number of Reselection	Waiting Time of Users (s)
SINR Based	10	1.4409	42.1027	2.9726
TETRA Based	10	1.4129	41.8979	2.8568
Proposed Full Set with w=0.2	10	1	44.152	**2.3435**
Proposed Full Set with w=0.5	10	1	44.0982	2.4144
Proposed Full Set with w=0.8	10	1	44.0972	2.4779
Proposed Reduced Set with w=0.2	**4.1004**	1	47.0269	2.5078
Proposed Reduced Set with w=0.5	4.2878	1	46.409	**2.4315**
Proposed Reduced Set with w=0.8	4.3831	1	44.6213	2.4815

Table 4.5. Outage probabilities of urban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.03313	0.01406
TETRA Based	0.03506	0.01574
Proposed Full Set with w=0.2	0.03582	0.01535
Proposed Full Set with w=0.5	0.03666	0.01563
Proposed Full Set with w=0.8	0.03583	0.01541
Proposed Reduced Set with w=0.2	0.03808	0.01977
Proposed Reduced Set with w=0.5	0.03917	0.01967
Proposed Reduced Set with w=0.8	0.03890	0.01892

Urban environment results show us that the proposed algorithms give better result than SINR and Tetra based algorithms in a manner of waiting time of user as seen from Table 4.4. While proposed full set algorithm with w=0.2 reduces the waiting time of a user about 18% than Tetra based algorithm, the proposed reduced set algorithm with w=0.2 reduces 15%. Again similar as the load based systems, number of RSSI measurement is far better for the proposed reduced set algorithms. In the proposed reduced set algorithms, the number of measurement is decreased around 57%. With the increasing value in w in the reduced set algorithms, increment in number of RSSI measurement can be observed. Average number of request is decreased about 30% for the proposed algorithms. The number of reselection shows that the users do cell reselection about 45 times during all simulation time.

From Table 4.5, it is seen that the diversity has important effect on BER values and outage probabilities are below than 5%.

4.3.2. Rural Environment

Rural environment cell model is given in Figure 4.5. In this environment, there are 5 BSs and 100 users with 3 groups. Only the BS at the center of the area has a different frequency. The probability of PTT is 0.35 which results in 35 talking users in every minute. Since traffic volume is less in rural environments, 4 time slots (one channel for control channel) are assigned to each BS. This requires 25 kHz bandwidth with 1 physical channel.

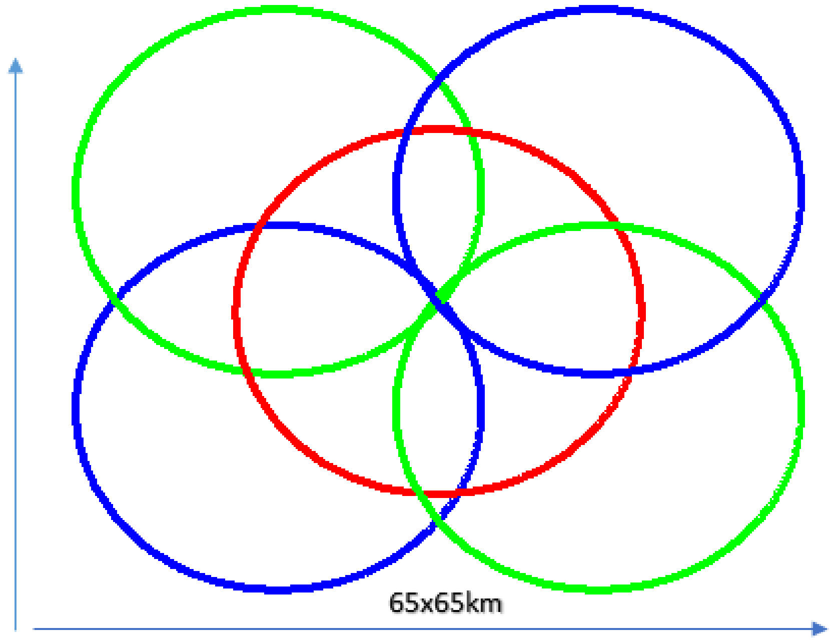

Figure 4.5. Rural Area for Traffic Based System

Performance results for rural environment are shown in Table 4.6 and Table 4.7.

Table 4.6. Rural area results for traffic based system

Algorithms / Results	Number of RSSI Measurement	Number of Request	Number of Reselection	Waiting Time of Users (s)
SINR Based	5	1.4034	10.223	0.83669
TETRA Based	5	1.2923	9.1583	0.7572
Proposed Full Set with w=0.2	5	1	8.22	**0.46789**
Proposed Full Set with w=0.5	5	1	7.81	0.50383
Proposed Full Set with w=0.8	5	1	6.55	0.54566
Proposed Reduced Set with w=0.2	**2.111**	1	12.48	**0.47737**
Proposed Reduced Set with w=0.5	2.2437	1	12.04	0.48406
Proposed Reduced Set with w=0.8	2.8168	1	7.14	0.49571

Table 4.7. Outage probabilities of rural area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04926	0.01419
TETRA Based	0.05688	0.01681
Proposed Full Set with w=0.2	0.06716	0.02345
Proposed Full Set with w=0.5	0.06132	0.01864
Proposed Full Set with w=0.8	0.05665	0.01704
Proposed Reduced Set with w=0.2	0.05285	0.01669
Proposed Reduced Set with w=0.5	0.05824	0.02230
Proposed Reduced Set with w=0.8	0.05801	0.02001

From the rural environment results, due to the low traffic volume and low number of users, a significant reduction in the waiting time of users is observed than the urban environment result. Proposed algorithms with w=0.2 give the best result in the waiting time of users metric, and reduces about 40% than the Tetra based and 45% than SINR based. The number of RSSI measurement is decreased about 70% in the reduced set algorithms. And there can be observed a 25% reduce in number of request.

From Table 4.7, outage probabilities of all algorithms are below the 5%.

4.3.3. Suburban Environment

Suburban environment cell model is given in Figure 4.6. In this environment, performance results are obtained with 300 users and 7 BSs. Users are divided into 3 groups and the probability of PTT is 0.20. This results in 60 talking users and each BS has 4 time slots (one for control channel) which corresponds to 25kHz per BS.

Performance results are shown in Table 4.8 and Table 4.9.

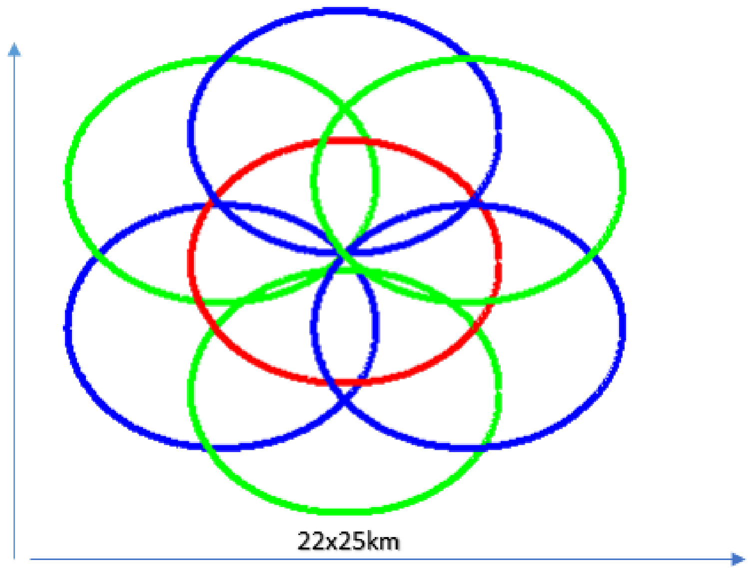

Figure 4.6. Suburban Area for Traffic Based System

Table 4.8. Suburban area results for traffic based system

Algorithms / Results	Number of RSSI Measurement	Number of Request	Number of Reselection	Waiting Time of Users (s)
SINR Based	7	1.437	25.3449	3.4831
TETRA Based	7	1.2946	22.4584	2.9676
Proposed Full Set with w=0.2	7	1	24.672	**2.5792**
Proposed Full Set with w=0.5	7	1	24.5824	2.5862
Proposed Full Set with w=0.8	7	1	24.5341	2.6246
Proposed Reduced Set with w=0.2	**3.7979**	1	24.7321	2.6586
Proposed Reduced Set with w=0.5	3.8687	1	24.2899	**2.6167**
Proposed Reduced Set with w=0.8	3.8419	1	22.8716	2.6655

Table 4.9. Outage probabilities of suburban area

Algorithms / Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04156	0.02596
TETRA Based	0.05024	0.03798
Proposed Full Set with w=0.2	0.05020	0.04230
Proposed Full Set with w=0.5	0.05072	0.03895
Proposed Full Set with w=0.8	0.05054	0.03997
Proposed Reduced Set with w=0.2	0.05743	0.04231
Proposed Reduced Set with w=0.5	0.05139	0.03848
Proposed Reduced Set with w=0.8	0.04839	0.03148

While examining suburban environment result from Table 4.8, we can observe around 45% reduction in the number of RSSI measurement for the proposed reduced set algorithms. Since users take into account the broadcasted traffic load values in our proposed algorithms, users attach to BSs at their first attempt and number of request is decreased about 25% than SINR and Tetra based algorithms. The number of reselection is about 24 for all algorithms. In this environment, for proposed full set algorithm with w=0.2, we observed 13% decrease in waiting time of users than Tetra based and 25% decrease than SINR based algorithms.

Again, from Table 4.9, outage probabilities of all algorithms are below the 5%.

CHAPTER 5

CONCLUSION

Since the interest in mobile communication is increasing day by day, traffic density becomes critical problem for customers. This situation causes customers and professional users request to have their dedicated communication system. In accordance with the request, PMR system was developed for reliable and dedicated communication. Tetra is one of the technical platform and modern standard of PMR system.

Cell selection algorithms have key role for traffic problem solution. Therefore, a cell selection algorithm considering fair distribution of users can overcome this problem. In this thesis, two cell selection algorithms for Tetra system have been proposed and the performance of these algorithms have been obtained for the load based and traffic based systems. In the load based system, users are assumed to be immobile and active for all simulation time. In traffic based system, users are mobile and group talks of users are considered where users have different duration of calls in all simulation time. In these proposed algorithms, both received power of users and cell or traffic load of BSs have a weight in utility function which decides the serving BS. While the RSSI of all BSs in the environment is measured in the proposed full set algorithm, the minimum number of RSSI measurement is targeted in proposed reduced set algorithm.

The performance results for different weight values for different scenarios and environments have been obtained. Performance evaluations show that the fairly balancing of users reduces the number of waiting users in load based system and waiting time of users in traffic based systems. While the proposed full set algorithm measures RSSI of all base stations, reduced set algorithm measures RSSI much less. Also decreasing RSSI weight has positive effect in balancing of users which reduces the number of RSSI measurement. All these improvements in results occurred while satisfying the BER demands of users.

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