CELL SELECTION ALGORITHMS FOR CONVENTIONAL NARROW BAND WIRELESS SYSTEMS

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ABSTRACT

CELL SELECTION ALGORITHMS FOR CONVENTIONAL NARROW BAND WIRELESS SYSTEMS

Public safety organizations provide a stable and secure environment for the society. Wireless communication between public safety officers is very important to transmit voice or data during an emergency crisis. When the public communication networks can not provide service during crisis, disaster and high traffic cases, Professional Mobile Radio systems (PMR) such as conventional Association of Public Safety Communications Officials (APCO25) and trunked Digital Mobile Radio (DMR) systems are needed to improve the service quality and to provide uninterrupted service provided to the users. While providing continuous voice and data service, it is very important to efficiently select the base station to be served and to ensure that a mobile user can seamlessly attach from one base station to another base station while moving within a cell. In this sense, it is critical to determine the base station to be served by efficient cell selection algorithms. Cell selection is the process of deciding the base station which provides services to the users. Cell selection plays an important role in balancing the system load and thus overall system performance. By means of efficient cell selection algorithms, it is aimed to reduce the waiting time and to connect a base station as soon as possible while establishing reliable transmission link for PMR systems in emergencies.

In this thesis, the full set and the reduced set based cell selection algorithms are proposed by considering load based and traffic based cell selection algorithms. In load based cell selection algorithm, each user selects the base station according to the calculated utility value determined based on both received signal strength indicator (RSSI) value and cell load information. In addition, it is performed that each user selects the base station according to the calculated utility value determined based on both biased signal to interference plus noise ratio (SINR) value and cell load information. In traffic based cell selection algorithm, while calculating cell load information, traffic intensity is considered. The performances of the proposed algorithms are evaluated based on with various scenarios by taking into account different performance metrics for conventional APCO25 and trunked DMR systems.

ÖZET

KONVANSİYONEL DAR BANTLI TELSİZ SİSTEMLER İÇİN HÜCRE SEÇİM ALGORİTMALARI

Kamu güvenliği kuruluşları, toplum için istikrarlı ve güvenli bir ortam sağlar. Acil durum krizi sırasında, ses veya veri iletimi için kamu güvenlik görevlileri arasındaki iletişim çok önemlidir. Kriz, afet ve trafik yoğunluğunun yüksek olduğu durumlarda kamu iletişim ağlarının hizmet sunamadığı zaman, hizmet kalitesini arttırmak ve kullanıcılara kesintisiz hizmet sunabilmek için konvansiyonel Kamu Güvenliği İletişim Yetkilileri Birliği (APCO25) ve trunk Dijital Mobil Radyo (DMR) sistemleri gibi Profesyonel Mobil Radyo sistemlerine (PMR) ihtiyaç duyulmaktadır. Sürekli ses ve veri hizmeti sunarken, hizmet alınacak baz istasyonunun verimli bir şekilde seçilmesini ve hareketli kullanıcıların bir baz istasyonundan diğer bir baz istasyonuna sorunsuz geçmesini sağlamak çok önemlidir. Bu anlamda, hücre seçim algoritmaları ile kullanıcıların hangi baz istasyonundan hizmet alacağının belirlenmesi kritik önem taşır. Hücre seçimi, kullanıcılara hizmet sunan baz istasyonunu belirleme sürecidir. Hücre seçimi, sistem yükünün dengelenmesinde ve dolayısıyla genel sistem performansında önemli bir rol oynamaktadır. Etkin hücre seçim algoritmaları ile, acil durumlarda PMR sistem kullanıcısının hizmet alacağı baz istasyonuna olan bekleme süresini azaltmak ve o baz istasyonuna mümkün olan en kısa sürede bağlanmak amaçlanmaktadır.

Bu tez çalışmasında yük tabanlı ve trafik tabanlı hücre seçim algoritmaları göz önüne alınarak tam set ve indirgenmiş set tabanlı hücre seçim algoritmaları önerilmiştir. Yük tabanlı hücre seçim algoritmasında, her kullanıcı hem alınan sinyal gücü (RSSI) değerine hem de hücre yük bilgisine dayalı olarak hesaplanan faydalı değere göre baz istasyonunu seçer. Buna ek olarak, her kullanıcının hem yanlı sinyal gürültü karışım oranı (SINR) değerine hem de hücre yük bilgisine dayalı olarak hesaplanan faydalı değere göre baz istasyonunu seçtiği durum incelenmiştir. Trafik tabanlı hücre seçim algoritmasında, hücre yükü bilgisi hesaplanırken konuşma sürelerine bağlı trafik yoğunluğu hesaba katılır. Önerilen algoritmaların performansları, konvansiyonel APCO25 ve trunk DMR sistemleri için farklı performans metriklerini dikkate alarak çeşitli senaryolara dayalı olarak değerlendirilmiştir.

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M_u	Number of available channels
B	Available bandwidth per cell
Δf	Channel spacing
INT	Interference power
N	Noise power
h_b	BS Antenna Height
h_m	MS Antenna Height
N_0	Noise Spectral Density
$RSSI_{rec}$	Receiver Sensitivity
$RSSI_{th}$	threshold
U_{th}	Utility Threshold

LIST OF ABBREVIATIONS

APCO25	Association of Public Safety Communications Officials
BS	Base Station
BSs	Base Stations
CRE	Cell Range Expansion
C4FM	Continuous 4 level FM
DMR	Digital Mobile Radio
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
PMR	Professional/ Private Mobile Radio
PTT	Push To Talk
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SINR	Signal to Interference Plus Noise Ratio
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
TIA	Telecommunications Industry Association
UE	User

CHAPTER 1

INTRODUCTION

For public safety services, uninterrupted and fast communication are very significant. In general, the public cellular system (GSM) may not work in emergency cases due to the saturation of the available channels in the cells. This causes high traffic and making communication is impossible. A radio system should provide communication success even during overload situations. Users have to communicate and it is important to perform a very fast group call set-up in a short time in Professional Mobile Radio (PMR) systems. Therefore, PMR requires an affordable, flexible and highly reliable radio communications network. PMR is widely used in the business community to ensure communications except the public cellular or public switch telephone networks. A PMR network is operated on the basis of a closed user group and refers to wireless systems used for coordinating groups and providing rapid response.

There are different PMR technologies that are currently in use. Association of Public Safety Communications Officials (APCO25) and Digital Mobile Radio (DMR) are two of the mobile radio standards developed to meet the needs of traditional PMR organizations such as public safety, transportation, government and military.

Transmitted data or voices by PMR users are frequent and short-time. These data may also contain emergency messages, so it is very important to provide the uninterrupted and reliable communication. In order to provide these needs, users must get service from a base station in a short period of time. At this point, cell selection algorithms are used to decide the base station based on different criteria. Choosing base station for all users potentially improve the system performance.

Generally, cell selection algorithms are applied to heterogeneous networks to balance the load between macro and micro cells. These applied cell selection algorithms can not directly use for PMR systems due to their complexity. On the other hand, conventional cell selection algorithms do not consider the cell load. Therefore, we need an efficient cell selection algorithm for PMR systems by considering received signal, cell load of base stations and traffic density of base stations to balance the load among cells while reducing the waiting time of users to connect a cell.

In this thesis, the full set based and the reduced set based cell selection algorithms are proposed and performances are evaluated in load based cell selection and traffic based cell selection. Moreover, the performance of the load based biased full set cell selection algorithm is examined. We compare the performance results of the proposed cell selection methods to the other conventional cell selection criteria such as signal to interference plus noise ratio (SINR) and received signal strength indicator (RSSI) based cell selection algorithms.

The thesis is organized as the following:

- In Chapter 2, the main requirements of PMR systems are discussed. The technical characteristics of APCO25 and DMR systems are given. In addition, the cell selection process and the algorithms from the literature are discussed.
- Chapter 3 examines the load based cell selection algorithm for trunked DMR systems. Full set and reduced set based cell selection algorithms are proposed. In addition, the biased full set cell selection algorithm is performed. Then, the performance of proposed algorithms are compared with SINR based cell selection algorithm and RSSI based cell selection algorithm.
- Chapter 4 examines the traffic based cell selection algorithm for conventional APCO25 systems. The performance of proposed algorithms are compared with SINR based cell selection algorithm and RSSI based cell selection algorithm.
- The last chapter is entirely dedicated to the discussion and interpretation of the results.

CHAPTER 2

BACKGROUND

This chapter briefly describes the background of professional or private mobile radios (PMR). Two well known PMR systems which are Association of Public Safety Communications Officials (APCO25) and Digital Mobile Radio (DMR) are introduced and more detailed information about the these standards are given. Cell selection problem statement is examined. Cell selection algorithms in the literature are described.

2.1. Professional Mobile Radio

During natural disasters and emergencies, continuous voice and data services play a critical role for the communications of public safety networks. During a disaster such as earthquake or flooding, the main network structure can be affected since the stations are damaged. Moreover, even if the infrastructure is not damaged, major disasters are the most important factor to cause telecommunications dense. The public communication networks may fail because of physical damages and traffic overload. Since they should keep working in case of a natural disaster, their robustness and reliability are critical. They must work when the conventional networks are out of order. Therefore, the conventional public networks alone are not sufficient. For reliable, efficient and uninterrupted communication between wireless radio users, PMR systems are needed.

PMR networks provide radio services for closed user groups. PMR refers to a set of radio mobile network technologies for different emergency services like police forces, fire department, military forces, transportation (taxi, buses) and health emergency associations. Even in extreme situations, when other communications networks are out of order, they provide communications.

PMR systems are designed to maximize the efficiency of some important features such as group call, low bandwidth per call and instant communications as push to talk (Allen et al., 2000).

PMR is designed for short call set-up times compared with cellular systems. This short call set-up times provide a large number of users to be accommodated within a particular frequency allocation. PMR refers to the two-way radio communication system that allows users sharing the same range of frequency to communicate with the others. PMR systems can use dedicated radio frequencies licensed by the regulator which manages the radio spectrum for each country. In addition, unlike public cellular mobile systems, PMR systems are set up by a company or a group of users to provide mobile radio services for that group of users alone and typically consist of hand-held portable radios, vehicle radios, base stations (BSs), a network and repeaters.

2.2. PMR Service Requirements

Some important requirements of PMR system can be listed as (Dunlop et al., 2013):

- **Reliability**. Many PMR services are used in critical systems for security reasons. The advantage is that they are not dependent on cellular operators and they are in the position to ensure reliability.
- **Speech and data transmission capability**. Mobile data services are increasingly being used. As data services develop, several applications will also improve. Providing a flexible data service is very important.
- **Point-to-point, group calls and broadcast calls**. When PMR systems are used, a flexible group call structure is essential so that users can share information directly.
- **Fast call set-up**. PMR systems have a push to talk to active a call to the dispatcher or user group with the receiving terminal announcing the message without answering procedure. Calls consist of a few sentence and users expect to be connected to the called terminal without delay.
- **Good coverage**. PMR networks should be able to attend the communication under all circumstances. Particularly for emergency services, PMR networks should provide good coverage.

2.3. PMR Standards

Early PMR systems were analog. Considering the success of wireless communications systems, particularly public access cellular systems, it was realized that new types of PMR systems are needed. Since PMR systems provide the required services to more customers, the systems have to expand their capacity to satisfy these requirements. Some of reasons for the moving towards new digital PMR systems are to provide less costly ways to expand the system and to be capable of supporting many new services. The basic advantages of digital PMR systems over analogue systems are given as (Harte, 2000): A significant increase in system capacity, improved quality of service, economic advantages, added security, voice privacy and new services such as data messaging, video services and priority access.

There are several digital PMR system standards have been developed and adopted. The well known digital PMR systems are Terrestrial Trunked Radio System (TETRA), APCO25, DMR, Integrated Dispatch Radio System (IDRA), Digital Integrated Mobile Radio System (DIMRS), TETRAPOL and Enhanced Digital Access Communications System (EDACS).

In this thesis, we focus on APCO25 and DMR systems. These technologies ensure improved range, higher data rates, more efficient use of spectrum and improved battery. Both APCO25 Phase 1 and DMR are designed to operate in the narrowband region of the frequency spectrum for providing uninterrupted voice and data communications to users.

2.3.1. APCO25

In the literature, different names such as Project 25, P25, APCO, APCO Project 25 and APCO25 are used for the standards. APCO25 is an open standard initiated by the Association of Public Safety Communications Officials (APCO) and developed by the Telecommunications Industry Association (TIA) (Telecommunications Industry Association, 2012). APCO25 radio system is qualified to meet the communication needs in case of disaster and communication traffic that created by different wireless radio users at Public Safety and Emergency Support Organizations.

APCO25 has four main objectives (Guide, 2004):

- Ensuring competition in system life cycle procurements as a result of Open Systems Architecture,
- Allowing effective, efficient and reliable intra-agency and inter-agency communications,
- Providing enhanced functionality and capabilities by focusing on public safety needs,
- Improving radio spectrum efficiency.

There are two methods of organizing frequency/channel usage in a radio system: “Conventional” and “Trunked” radio systems. APCO25 is defined for these two different working modes as shown in Figure 2.1.

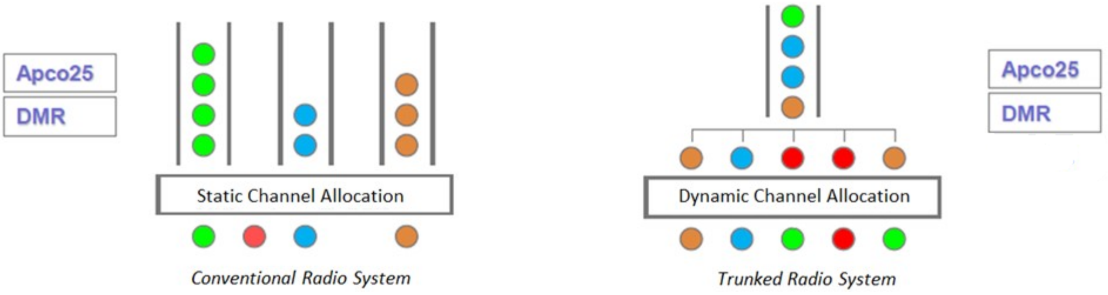

Figure 2.1. Conventional and Trunked Radio System
(Source: Malaysian Communications and Multimedia Commission (SKMM), 2009)

- Conventional mode provides a simple infrastructure (such as a repeater network) system that normally repeats radio calls from one frequency to another (Guide, 2004). Conventional radio systems have dedicated frequencies and channels assigned to individual user groups. When a user makes a call and selects a channel, other members of the group cannot use the channel until the end of call.
- In trunked mode, there is a controller inside the infrastructure that provides to manage call set up and channel assignment. Trunked systems are assigned a pool of channels to be used by multiple individuals. When a call is made by a user on a trunked system, an available channel is automatically selected by the system from the pool of channels, leaving the remaining channels available for others.

Although trunked systems are more complex and require more infrastructure than conventional systems, they allow channels to be shared among a large group of users, reduce congestion, increase capacity and interoperability. Thus, the more efficient use of communication channels is provided.

Table 2.1 clearly sets out the main functional differences between conventional and trunked systems (Public Safety Wireless Network, 1999).

Table 2.1. Conventional and Trunked Systems Comparison

Conventional System	**Trunked System**
Radio channels selected by the user	Radio channels automatically assigned to the user
Instantaneous channel access	Channel access time varies with technology and other factors
Control channel not needed	Control channel used
Suitable for smaller groups of users	Better for larger organizations
No switching needed	Core switching essential for operation

APCO25 consists of two phases: Phase 1 and Phase 2.

- Phase 1 radio systems operate in analog, digital or mixed mode. Channel spacing is 12.5 kHz. Phase 1 radios use Continuous 4 level FM (C4FM) non-linear modulation for digital transmissions. The modulation sends 4800 symbols/sec with each symbol conveying 2 bits of information (TAIT Radio Communications, 2010). In the 4-level FSK modulation, each set of two bits is represented as a symbol with a fixed deviation from the transmit frequency (Ketterling, 2003). The four frequency deviations from the transmit frequency and the information bit values are given in Table 2.2.

Table 2.2. Dibit symbol mapping to 4FSK deviation

Information bits		Symbol	4FSK deviation
Bit 1	Bit 0		
0	1	+3	+1.8 kHz
0	0	+1	+0.6 kHz
1	0	-1	-0.6 kHz
1	1	-3	-1.8 kHz

- In Phase 2, digital information is transmitted over a 6.25 kHz channel using the CQPSK modulation format (Icom Governments and Systems, 2008).

E_b/N_0 is the measure of signal to noise ratio for a digital communication system. It is used for the measure of how strong the signal is. Figure 2.2 shows the theoretical BER versus E_b/N_0 for C4FM.

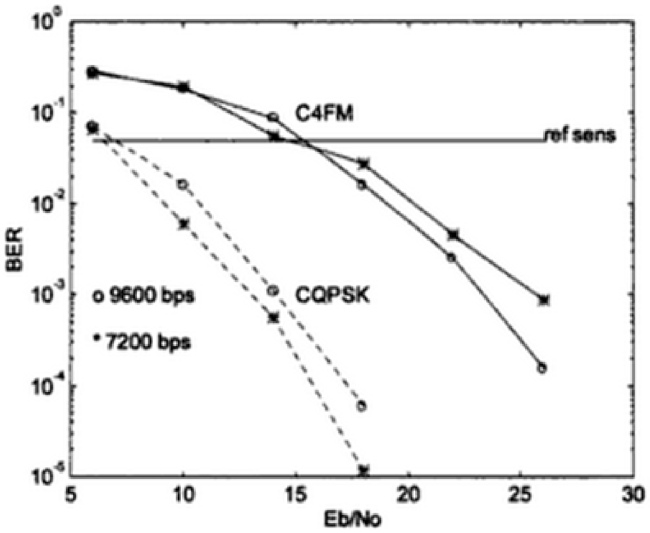

Figure 2.2. C4FM BER performance
(Source: Tranter, 2000)

Looking at the Figure 2.2, it is defined that for C4FM modulation with 9600 bps, a BER of 0.05 for voice users requires an E_b/N_0 of 5.4dB. BER of 0.01 for data users requires an E_b/N_0 of 20dB.

For this thesis, APCO25 Phase 1 is used and the operating mode of this radio system is defined in a conventional mode. Phase 1 uses Frequency Division Multiple Access (FDMA) technique that is a method of dividing the spectrum into frequency to provide a service to a user in a channel. On the other hand, Phase 2 uses Time Division Multiple Access (TDMA) technique that divides the spectrum by time divisions.

APCO25 offers high power operation allowing large geographic areas to be covered with fewer BSs than other technologies. This makes APCO25 technology an economical and efficient choice (TAIT Radio Communications, 2012). In addition, APCO25 maximizes spectrum efficiency by narrowing bandwidths compared with analog systems as shown Figure 2.3.

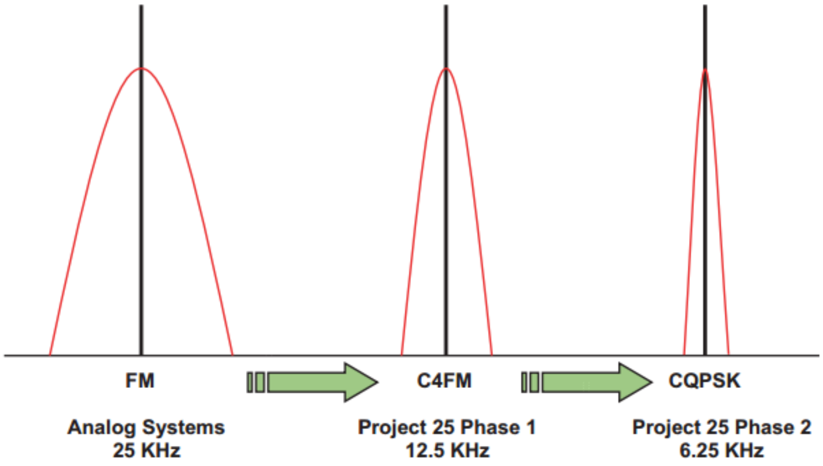

Figure 2.3. Spectrum Efficiency for APCO25
(Source: Guide, 2004)

Regarding the APCO25 voice frame structure, it can be mentioned that each voice frame is 88 bits in length that represents 20 ms of speech. The voice frames are protected with error correction codes which add 56 parity check bits resulting in an overall voice frame size of 144 bits. The voice frames are grouped into Logical Link Data Units (LDU1 and LDU2) including 9 voice frames each. Each Logical Link Data Unit is 180 ms in length and can be grouped into 360 ms superframes consecutively. LDU1 is the first half of a superframe. LDU1 is composed of the FS (48 bits), NID (64 bits), nine voice code words, numbered VC1 through VC9 (1296 bits), Link Control Word (240 bits) and Low Speed Data (32 bits). 24 status symbols are also interleaved throughout LDU1 yielding 1728 bits total. **In order to obtain accurate received signal measurements, the average of 9 frames with 20 ms is taken**.

APCO25 voice frame structure is given in Figure 2.4 that shows the voice message begins with a Header Data Unit and then continues with Logical Link Data Units. These Logical Link Data Units alternate up to the end of the voice message. Terminator Data Unit indicates the end of the message.

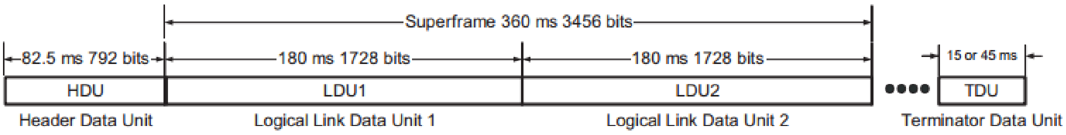

Figure 2.4. APCO25 Voice Message Frame Structure
(Source: Guide, 2004)

For APCO25 system, the number of available channels M_u belonging to u^{th} base station (BS) is determined as:

$$M_u = \frac{B_u}{\Delta f}, \tag{2.1}$$

where B_u is the available bandwidth for cell u and Δf is channel spacing. One of M_u channels is dedicated for control and all remaining channels are available for data communications (ETSI Technical Specification 102 361-1 V1.4.5, 2007).

2.3.2. Digital Mobile Radio

DMR is one of a digital radio standard for PMR developed by the European Telecommunications Standards Institute (ETSI) and published in 2006 (TAIT Radio Communications, 2010). DMR targets a digital radio specification for professional, commercial and private radio users.

DMR systems are divided into 3 Tiers: Tier I, Tier II and Tier III. Tier I and Tier II are conventional, whereas Tier III is trunked (Telecommunications Industry Association, 2012).

- Tier 1: It is license-free and allows transmit power output up to 500 mW in VHF and UHF frequency bands. Operation is peer-to-peer, so repeaters are not required.
- Tier II: Tier II is digital conventional and operates between 66 to 960 MHz frequency bands. This tier specifies two channel spacing at 12.5 kHz using TDMA for spectral efficiency and integrated IP services. It achieves 6.25 kHz channel equivalent with two TDMA timeslots on an existing 12.5 kHz narrow band FM channel.
- Tier III: For trunking systems operating between 66 to 960 MHz frequency bands.

In this thesis, we focus on DMR Tier III. Audio and data channels are managed with two TDMA timeslots where each timeslot acts as a separate communication path sharing the same radio 12.5 kHz channel width (ETSI Technical Specification 102 361-2 V2.2.1, 2013). TDMA system is illustrated in Figure 2.5.

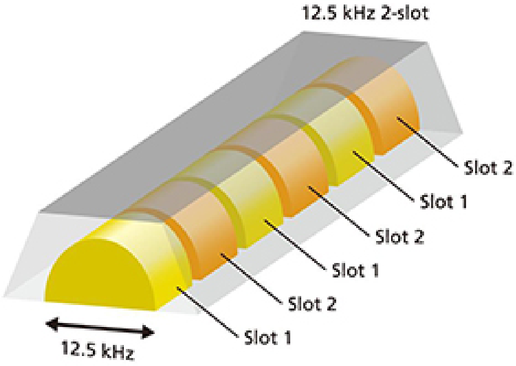

Figure 2.5. DMR TDMA System
(Source: Motorola, 2008)

Each TDMA frame is 60 ms length and is divided into two 30 ms timeslots. **In order to obtain accurate received signal measurements, the average of 4 frames with 60 ms is taken.** There is a 2.5 ms guard time around each timeslot, so 27.5 ms of data is transmitted in each TDMA channel. Each 27.5 ms frame transmits 132 symbols that corresponds to 264 bits. Figure 2.6 represents the DMR frame structure and the SYNC timeslots are designed for frame synchronization. The Common Announcement Channel (CACH) is used for channel management.

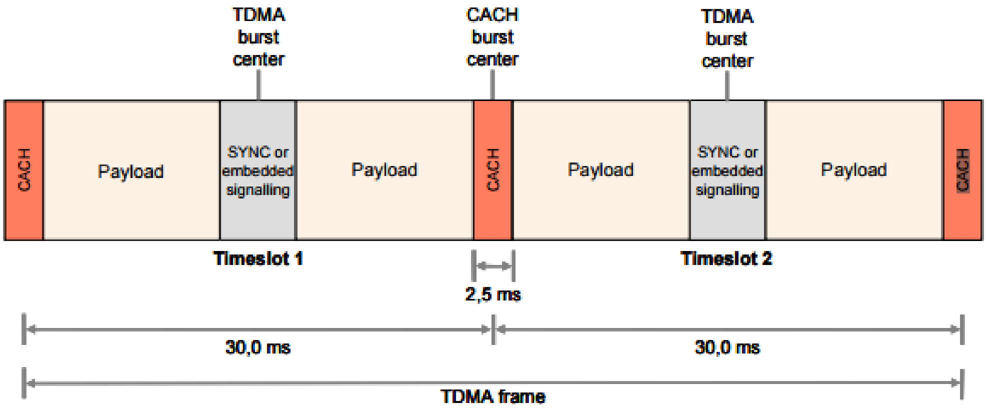

Figure 2.6. DMR BS Frame Structure
(Source: ETSI Technical Report 102 398 V1.3.1, 2013)

In DMR system, each slot can be separately allocated to two different users by a BS at the same time. A DMR system supports two simultaneous and independent calls over the 12.5 kHz narrow band channel, which an analog system uses the same entire channel to provide a single talk path. As a result, the channel capacity of the radio system is doubled enabling independent and private talk groups (Digital Mobile Radio Association, 2017).

The modulation is 4FSK which creates four possible symbols at a rate of 4800 symbols/s, corresponding to 9600 bps (ETSI Technical Specification 102 361-1 V2.2.1, 2013). Both the downlink (BS to terminal) and uplink (terminal to BS) use this modulation. In the 4-level FSK modulation, each set of two bits is represented as a symbol with a fixed deviation from the transmit frequency (DMR Association, 2012). The four frequency deviations from the transmit frequency and the information bit values are given in Table 2.3.

Table 2.3. Dibit symbol mapping to 4FSK deviation

Information bits		Symbol	4FSK deviation
Bit 1	Bit 0		
0	1	+3	+1.944 kHz
0	0	+1	+0.648 kHz
1	0	-1	-0.648 kHz
1	1	-3	-1.944 kHz

Each *u* BS has a number of available channels M_u that can be calculated as following:

$$M_u = 2\frac{B_u}{\Delta f}. \tag{2.2}$$

2.4. Cell Selection Algorithms

Cell selection is the process of deciding the BS which provides services to every user under certain criterion. In wireless communication systems, selection of the serving cell is crucial to enhance the quality of service given to the users. In terms of user, cell selection process must be uninterrupted and also this process must provide all users a certain quality and continuous service. It plays an important role in the balance of the traffic load in the system and consequently affects the overall system performance.

Cell selection has received enormous attention in recent years which uses different types of cell selection criteria. The some important parameters to be considered for the cell selection can be received power, distance, signal to noise ratio (SNR), signal to interference plus noise ratio (SINR), bit error rate (BER), traffic density, priority, quality of service or the various combinations of these parameters.

For the APCO25 and DMR systems, in terms of cell positions and frequency reuse an example of cell planning can be illustrated with 7 BSs in Figure 2.7. If any user is located in edge or in the overlapping area of cells, both cells can be candidates as a serving cell. Thus, cell selection process should be carefully performed to improve the performance of users. The same color represents the same frequency. It is assumed that the users are distributed randomly in the considered area. In terms of spectrum efficiency DMR is more efficient than APCO25 for the equal number of available channels as given Eq.(2.1) and Eq.(2.2).

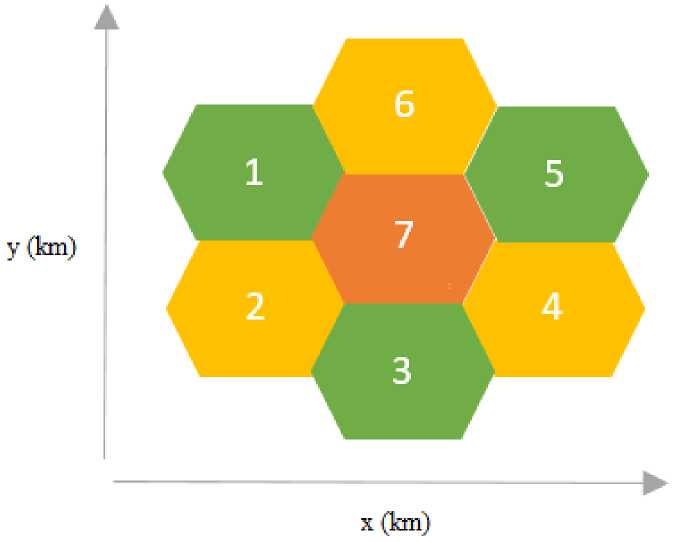

Figure 2.7. An example of cell planning for APCO25 and DMR systems

There are many studies in order to perform cell selection and user assignment for wireless networks.

2.4.1. RSSI Based Cell Selection Algorithm

The common cell selection is the one based on RSSI. In RSSI based cell selection, each k user measures the RSSI value for u^{th} BS in the system. Instantaneous RSSI calculation is given as following:

$$RSSI_{u,k} = EIRP_u - PL_{u,k} - BuL_k - Sh_k - BL_k + G_r - CL - Fading_{u,k} \quad (2.3)$$

with CL is receiver cable loss, G_r is receiver antenna gain, Sh_k is shadowing modeled by log normal distribution, $Fading_{u,k}$ is Rayleigh fading channel modeled with Jakes' model, BL_k is body loss, BuL_k is building loss when the user k is physically in the building, $PL_{u,k}$ is path loss between BS u and user k and $EIRP_u$ is the effective isotropic radiated power (EIRP) for BS u which is determined by,

$$EIRP_u = P_u^t + G_t \quad (2.4)$$

where P_u^t is transmit power for BS u and G_t is transmitter antenna gain.

The details of RSSI based cell selection algorithm for DMR can be described (Yılmaz et al., 2016). There are two kinds of users: Active and inactive users. The active users are attached to a BS and communicate whereas the inactive users are only attached but do not communicate. The flowchart of the RSSI cell selection algorithm for trunked APCO25 and trunked DMR systems is illustrated in Figure 2.8. The flowchart can be followed from the numbers respectively. In the first part, each k user is set to the f_u frequency of the first cell contained in the channel. Based on the measured RSSI values, each user selects the BS which has the maximum RSSI value, as long as passes the threshold value ($RSSI_{th}$) and provides the necessary conditions, user connects to that BS:

$$u^{'} = \underset{1 \leq u \leq U}{\arg\max} \ \overline{RSSI}_{u,k}, \quad \forall k \quad (2.5)$$

where $\overline{RSSI}_{u,k}$ is the average RSSI value that calculated by considering frame structure of APCO25 and DMR systems as explained before.

These necessary conditions are:

- That BS does not have fallback. **Fallback condition** occurs when disconnection between BSs and infrastructure.
- That BS must have enough capacity in terms of cell load. Cell load of any BS shows its own traffic. In order to have enough capacity of u^{th} BS in terms of cell load, the following condition must be satisfied:

$$M_u - (F_u + D_k) \geq 0 \tag{2.6}$$

where F_u shows the total required channel slot of users at u^{th} BS and D_k indicates the required channel slot of *k* user. The required channel slot can be alternated in terms of voice or data user. It is supposed that the required channel slot is 1 for voice user, whereas for data user it is 2. The number of available channels of any *u* BS can be changed according to APCO25 or DMR systems.

As long as threshold value or necessary conditions are not provided, RSSI value of another BS in f_u frequency is controlled to exceed a certain threshold value and have enough capacity. If these conditions can not provided, user is set to other frequency and measures RSSI value of BSs. In the second part of the flowchart, if any BS in the system for all frequencies does not provide these conditions, active user is connect to having highest RSSI value higher than receiver sensitivity in case of enough capacity. Otherwise, in the third part, user waits to connect to the BS which with the highest RSSI value.

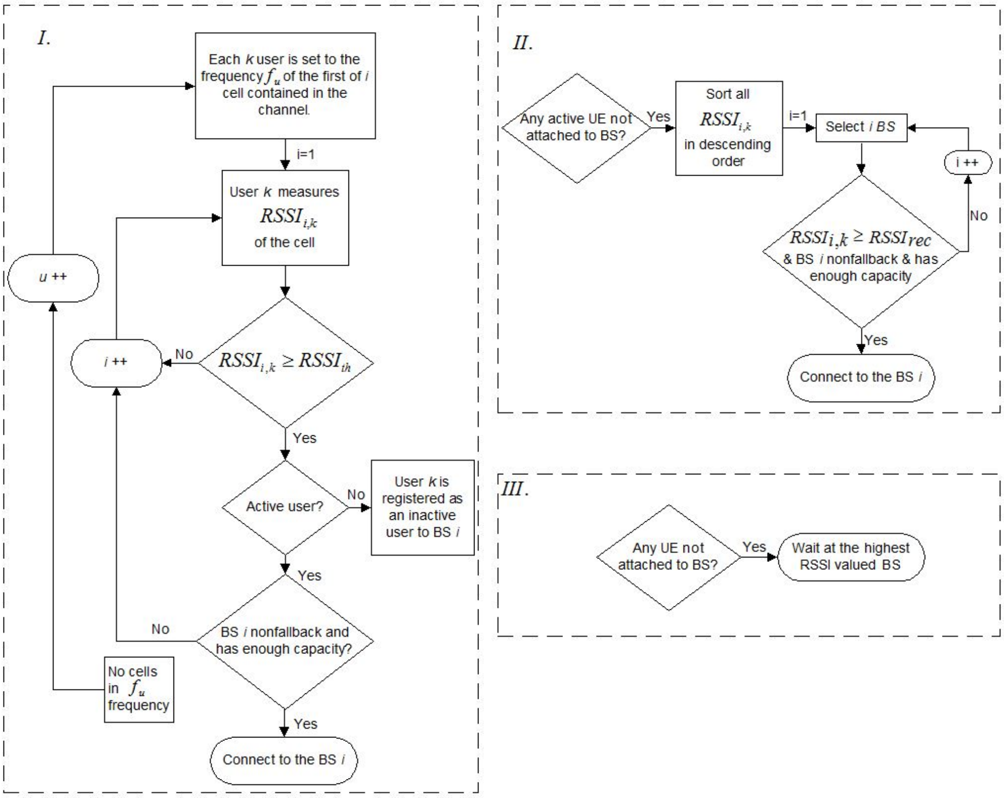

Figure 2.8. Flowchart of RSSI Cell Selection Algorithm for Trunked APCO25 and Trunked DMR

2.4.2. SINR Based Cell Selection Algorithm

Besides RSSI based cell selection, it is possible to apply SINR based cell selection. Each user selects the BS which has the maximum average SINR value:

$$u^{''} = \underset{1 \leq u \leq U}{\arg\max} \ \overline{SINR}_{u,k} \quad \forall k \tag{2.7}$$

where

$$\overline{SINR}_{u,k} = \frac{P_{u,k}}{INT_{u,k} + N} \tag{2.8}$$

where $P_{u,k}$ is the received power for user k from BS u and is calculated as in Eq.(2.3), $INT_{u,k}$ is the interference power caused by the other cells having the same frequency and N is the noise power. Interference power can be determined by assuming that the cell planning is known at each user.

2.4.3. Transport Prioritized Cell Selection

In the transport prioritized cell selection algorithm (Olmos et al., 2013), the serving BS is selected from a set of candidate BSs, denoted by CS_k for each user *k*. CS_k consists of all the BSs having a difference in path loss with respect to the best serving cell (BS with lowest propagation loss) of k^{th} user which is not higher than a certain path loss margin (PLM) in dB:

$$CS_k = \left\{ BS_u : BS_u \in Cs, 10\log_{10}\left(\frac{PL_{u,k}}{\min PL_{u,k}}\right) \leq PLM, \forall k \right\} \tag{2.9}$$

where Cs denotes a set of candidate cells. For all BSs in the candidate sets, the available capacity is calculated. The required data rate of each user is chosen according to its QoS value. These QoS values represent voice and different data rate demands. If an user attaches to a BS, data rate of user is subtracted from total capacity of that BS and the available capacity reduces.

If at least one of the capacities of BSs is equal or below the defined threshold and the maximum capacity of the BSs is higher than the data rate of user, then user *k* is attached to the first BS in its candidate BSs list. The threshold is chosen according to traffic consideration. When threshold is selected 0, it means the system does not consider the number of attached user to BSs and the system attaches the user to the first cell in user's candidate cell. Whereas threshold is selected different from 0, then system will take into consider capacity of cells while attaching users and it results in balancing the distribution of attached users.

2.4.4. Rule Based Cell Selection Algorithm

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

For the first rule, user *k* selects the serving BS with the highest SINR among the set of candidate cells that have enough capacity and guarantees smaller than determined threshold to serve the user with its QoS. For the second rule, each user calculates the Admissibility Score AS_u, for all its candidate cells as following:

$$AS_u = \log_2(1 + \overline{SINR_k})\delta^{\frac{AC_u}{M_u}} \tag{2.10}$$

where δ is the intensity factor and should be chosen carefully so that the function does not grow very rapidly, at least for values less than 5 and AC_u stands for available capacity at the u^{th} cell as described in Eq.(2.11):

$$AC_u = M_u - F_u. \tag{2.11}$$

Then, user selects 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.

2.4.5. Other Cell Selection Algorithms

Apart from the cell selection algorithms described above, various algorithms have been developed on cell selection in the literature and some of them are mentioned.

In (AboulHassan et al., 2014), a cell selection algorithm has been performed by utilizing Proportional Fair scheduling algorithm to assist the new user by selecting the best serving cell and achieving maximum user's achievable data rate.

In (Wang et al., 2011), in order to achieve proportional fairness for all UEs in BS, cell selection problem has been arranged into a network-wide utility maximization problem.

Considering conventional cell selection algorithm that UE is assigned to the BS with maximum received power causes unequal cell association in HetNets because of large difference in transmission power between macro cells and micro cells. As a solution to this problem, (Chinipardaz et al., 2014) describes the importance of considering both load balancing and interference management in cell selection process to achieve the throughput gain of multi tiering. Load balancing is achieved by transferring users' traffic from macro cells to micro cells. In two cell selection algorithms which uses in LTE system maximize the network throughput: In Reference Signal Received Power (RSRP) based cell selection algorithm, the BS with maximum received power of reference signal is selected. In Reference Signal Received Quality (RSRQ) based algorithm that a BS is selected which maximize the RSRQ metric that is RSRP divided by aggregate received power.

In cell range expansion (CRE) approach in (Jo et al., 2012), the received power is biased by multiplying the received power by a bias value. Then, the BS with maximum biased power is selected for connection. Since the smaller tier has greater bias value, this approach transfers the users toward lightly loaded BSs. However, bias values optimization is needed for achieving the desired system utility.

In path loss based cell selection, UE selects the cell with the minimum path loss.

(Balachandran et al., 2011) states two downlink cell selection techniques to provide the desired throughput gains for end users. In the first method, a serving cell is selected based on maximizing received signal strength with bias. Other method mentions that a serving cell is selected based on maximizing the product of SINR and bias. However, bias values optimization is hard.

(Chou et al., 2015) indicates an alternative solution for cell range expansion method to balance the cell load between macro and micro cells in HetNets. This solution is that a constant range expansion bias (REB) is added to the RSRP of small cells to allow users connecting to a nearby small cell instead of a distant macro cell. Although CRE helps to offload the congested macro cells onto small cells, biased association have a negative effect on the average user rate since some users are associated with the BS not offering the strongest signal strength. They states dynamically balancing the cell load according to the current network conditions, a load-based cell association scheme which adjusts the REB according to the macro cell load. In order to adjust this bias, the load of BS and overloading factor parameters must be considered. However, the selection of these parameters to apply a dynamic REB for load balancing is hard.

In (Kuboniwa et al., 2015), the efficient network selection scheme has been performed by using the positioning information and the map information. The purpose is that the enhancement of system performance by considering the traffic load. By using load information, user selects a network based on the expected throughput and their location. This algorithm provides users to select the network where they can communicate with higher throughput. By using the map information, users can select the cell which has a better channel quality without cell discovery. Consequently, users can avoid the congested network and select a cell which has a low traffic demand.

Generally, listed cell selection algorithms are applied for heterogeneous networks to balance the load between macro and micro cells. However, in this thesis we consider the public mobile networks, a type of single tier network. These techniques can not be directly applied for PMR systems due to their complexity and high overhead.

CHAPTER 3

LOAD BASED CELL SELECTION ALGORITHM

For APCO25 and DMR systems, all the mentioned cell selection algorithms and conventional cell selection schemes such as RSRP, CRE and path loss based strategies ignore the cell load. RSSI based cell selection algorithm is commonly used for APCO25 and DMR systems because of its simplicity. However, these cell selection algorithms do not take into account the cell load while assigning users to the BSs. When the cell load is not balanced in these systems, the users have to wait in the queue since the number of available channels is limited in PMR systems.

In order to cope with these problems, two cell selection algorithms are proposed that enable user to select best serving cell whereas several factors are put into consideration other than highest SNR or RSSI (Yılmaz S et al., 2017a). These proposed cell selection algorithms consider both cell load and RSSI values. The basic idea of this load based algorithm is to balance the number of users among the cells and reducing the number of waiting users to attach any cells.

3.1. Load Based Full Set Cell Selection Algorithm

The main aim of this algorithm is that users select the BS having the best utility value which takes into account both RSSI and cell load information. As a result, the waiting time to establish a connection is reduced while satisfying the BER requirements for reliable transmission. The flowchart of the full set cell selection algorithm is given Figure 3.1 and can be followed from the numbers respectively. In the first part of the flowchart:

- Each user measures the received power of all BSs in the system.
- User k is constructed a $\mathbb{P}_k$ set that the received signal strength of BS u should exceed a given predefined receiver sensitivity threshold, denoted by $RSSI_{rec}$:

$$\mathbb{P}_k = \left\{ \overline{RSSI}_{u,k} \geq RSSI_{rec}; u \in 1, 2, ..., U \right\}. \tag{3.1}$$

- Then, each user calculates an utility value considering the BS in the $\mathbb{P}_k$ set.

For user k, the utility value is obtained by taking into account both RSSI value and cell load parameter.

$$U_{u,k} = wf(\overline{RSSI}_{u,k}) + (1-w)g(UCL_u), \forall u \in \mathbb{P}_k \tag{3.2}$$

where w is the weight parameter between RSSI and cell load, the function $f(.)$ represents the transformation of RSSI values to the normalized RSSI values and the function $g(.)$ transforms the unmapped cell load (UCL) to the mapped one according to the predefined Table 3.7. It is also possible to use SINR value instead of RSSI value in Eq.(3.2) and the detailed algorithm is described in Section 3.1.1 (Yılmaz S et al., 2016).

The UCL_u is calculated by BS as following:

$$UCL_u = (1-c)\frac{A_u}{M_u} + c\frac{I_u}{K_u} \tag{3.3}$$

where A_u and I_u are respectively the number of active and inactive users attaching to u^{th} BS. c represents the importance of contribution of inactive users while determining the cell load. M_u and K_u represent the maximum possible number of active and inactive users in the cell respectively. M_u is defined in Eq.(2.1) and K_u is calculated by,

$$K_u = N_u - M_u \tag{3.4}$$

where N_u is determined by Z/U, Z is the total number of users and U is the total number of BSs in the system, so Z/U gives the total number of users per cell.

- Calculated utility values are sorted in descending order.
- For each user k, based on the utility value belonging to each BS, the BS which has the maximum utility value is selected as the target cell by,

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

- Inactive user registers to the highest utility valued BS. If user is active user, it is checked whether the BS has enough capacity.

In the second part of the flowchart, if active users can not connect to any BS because of limited number of channels, they become a waiting user at the BS which with the highest RSSI value.

In order to calculate the utility value at the user side for each BS, the UCL_u value is critical importance. All related information including the number of active and inactive users, the total number of channels, the total number of BSs to obtain UCL_u is available at BS u. Then, each BS calculates UCL_u, transforms it by using function $g(.)$ according to given Table 3.7. Finally, each BS broadcasts the corresponding index belonging its mapped value to all users at every predefined time slots.

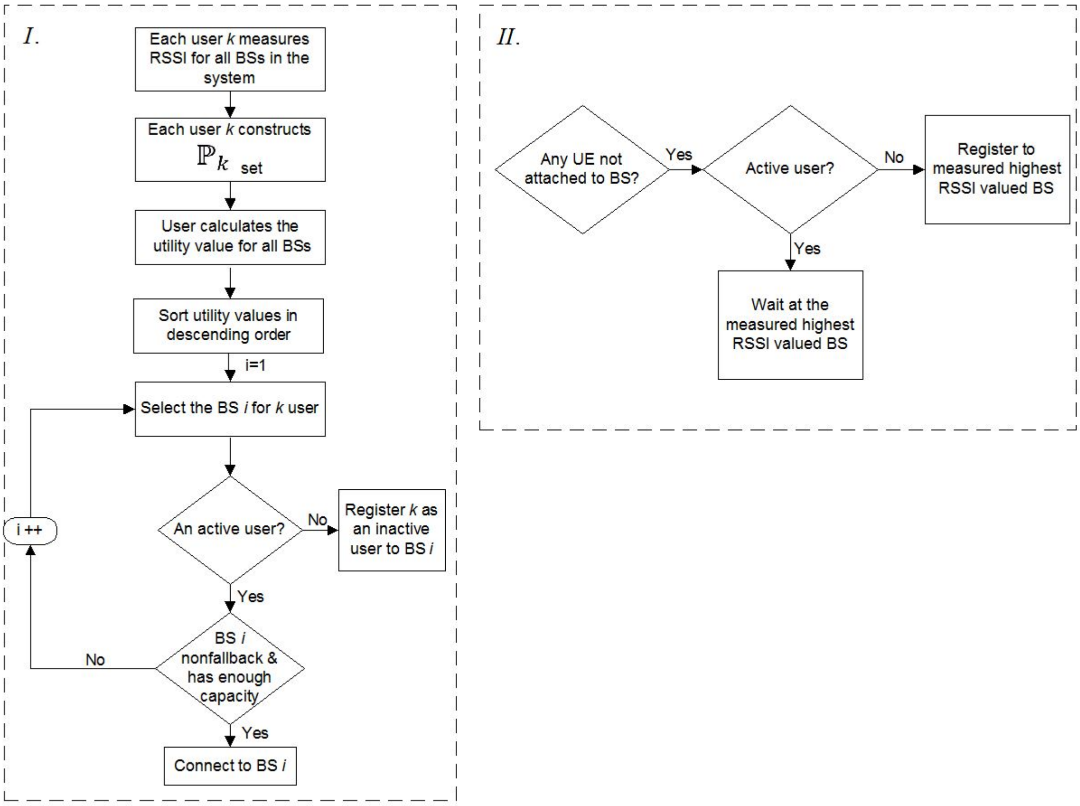

Figure 3.1. Flowchart of Load Based Full Set Cell Selection Algorithm

3.1.1. Load Based Biased Full Set Cell Selection Algorithm

In the biased full set cell selection algorithm, the same algorithm is performed with the load based full set cell selection algorithm in Section 3.1. The only difference from the full set cell selection algorithm, each user selects the BS according to the proposed utility value determined based on both cell load and biased SINR value.

For user k, the utility value is obtained by taking into account both SINR value and cell load parameter as follows:

$$U_{u,k} = b\ s(\overline{SINR}_{u,k} + Q_u) + (1-b)\ g(UCL_u), \forall u \in \mathbb{P}_k. \tag{3.6}$$

where b is the weight parameter between SINR and cell load, Q_u is the given bias value for BS u, the function $s(.)$ represents the transformation of SINR values to the normalized SINR values according to the predefined table.

3.2. Load Based Reduced Set Cell Selection Algorithm

The main target of reduced set cell selection algorithm is that users select the BS passing the defined utility threshold value which takes into account both RSSI and cell load information. By constructing an efficient set of BSs, its aim is to measure RSSI value of BSs in least number. The other important point related to reduced set cell selection algorithm is that utility value is not calculated for all BSs in the system. For the reduced set cell selection algorithm, the waiting time to establish a connection is reduced. The reduced set cell selection algorithm flowchart is given Figure 3.2. The flow diagram can be followed from the numbers respectively. In the first part of the flowchart:

1. Neighbor Cell Set

    - With the aid of GPS system, neighbor cell set is obtained in terms of distances. User tries to attach to the closest neighbor cell. The number of neighbor cells can be changed according to system plan.

2. Utility Value Calculation

    - User calculates the utility value of closest neighbor cell until utility value threshold (U_{th}) is satisfied.

      Utility value is calculated by taking into account RSSI values and cell load parameters:

      $$U_{u,k} = wh(\overline{RSSI}_{u,k}) + (1-w)g(UCL_u) \tag{3.7}$$

      where the function $h(.)$ represents the transformation of RSSI values to the normalized RSSI values for reduced set based cell selection algorithm.

3. Connecting to BSs

    - Active user k is connected to BS when measured utility value for the BS is higher than U_{th} and RSSI of that BS is higher than $RSSI_{rec}$ in case of enough capacity for BS.

- Inactive user k is registered to BS when measured utility value for the BS is higher than U_{th} and RSSI of that BS is higher than receiver sensitivity.

In the second part of the flowchart, when active user does not connect to any neighbor BSs due to capacity or any threshold problems, user tries to connect to the BS with a measured utility value less than U_{th} provided that RSSI of the BS higher than $RSSI_{rec}$ and has enough capacity. For inactive users, in case there are not any cells satisfying utility threshold value and receiver sensitivity in the neighbor set, user registers to BS which with calculated highest utility value.

In the third part, if the active user still can not connect to any BS, another option is trying non-neighbor cells. The same conditions as described previously are applied.

In the fourth part, when the active user that can not connect to any BS in the above cases, they become a waiting user at BS which with calculated highest utility value.

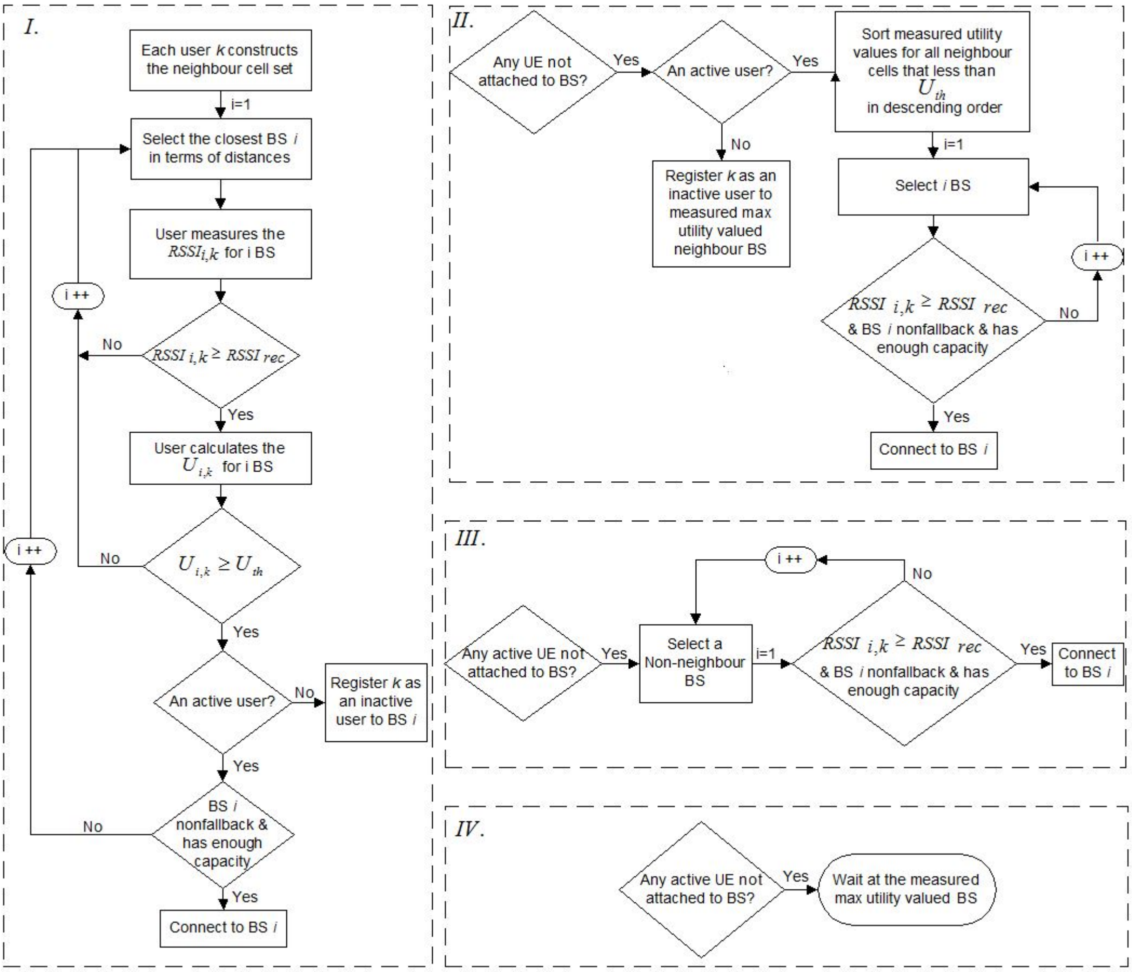

Figure 3.2. Flowchart of Load Based Reduced Set Cell Selection Algorithm

3.3. Simulation Parameters

In order to perform the cell selection algorithms, various scenarios are examined by designing different system models for 3 different environments as **urban, suburban and rural**. The number of BSs, users and available channels are defined according to each environment.

The users are uniformly distributed and different number of users are assigned to be indoor users. There are only voice users which are required to allocate only one physical channel.

The percentage of active users determines the traffic load in the cell. In this thesis, we consider medium and high traffic load cases. It is known that high traffic is more critical case in terms of cell load. If one of the available channels is assumed to be a control channel, the high traffic load case system will be examined when considering the percentage of active users, the number of BSs and the number of available channels for all environments individually.

For all the environments, the frequency reuse factor is taken as $1/3$. In addition, the overlapping ratio between cells is taken as 40%. It is assumed that BSs do not have fallback.

Simulation results are performed by considering $U = 7$ BSs and the total number of $Z = 700$ users in urban area. The illustration of the distribution of users in urban area is given in Figure 3.3. Total area, the number of available channels per cell, percentage of active users, available bandwidth per cell and cell radius are given in Table 3.1.

Table 3.1. Load Based Urban Area Simulation Parameters

Environment	**Parameter**	**Setting**
Urban	Area	16.4 km x 21.2 km
	Available Channels per Cell u (M_u)	32
	Percentage of Active Users	31$\%$
	Available Bandwidth per Cell u (B_u)	200 kHz
	Cell Radius	6 km

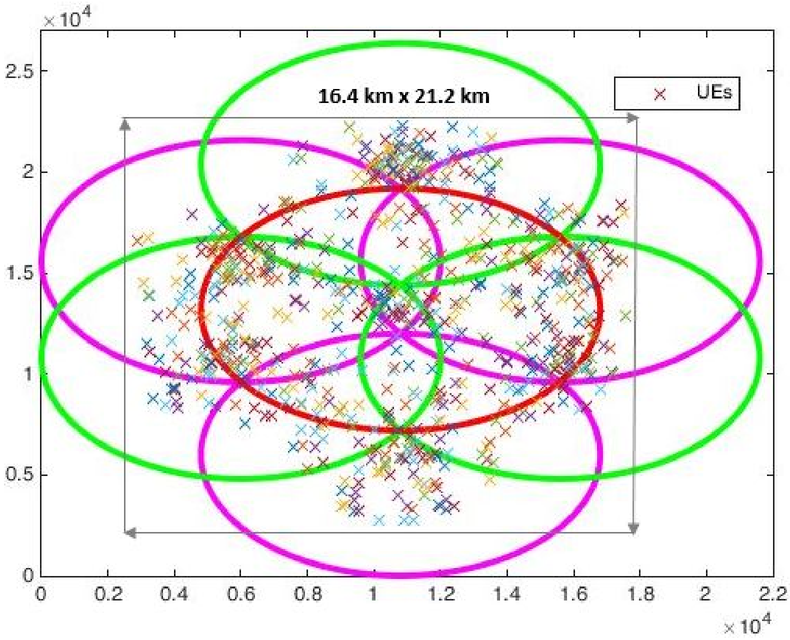

Figure 3.3. Cell planning for trunked DMR system in urban area

For suburban area, a system model is designed with $U = 6$ BSs and the total number of $Z = 600$ users. The illustration of the distribution of users in suburban area as shown in Figure 3.4. Total area, the number of available channels per cell, percentage of active users, available bandwidth per cell and cell radius are given in Table 3.2.

Table 3.2. Load Based Suburban Area Simulation Parameters

Environment	**Parameter**	**Setting**
Suburban	Area	24 km x 37.5 km
	Available Channels per Cell u (M_u)	24
	Percentage of Active Users	23%
	Available Bandwidth per Cell u (B_u)	150 kHz
	Cell Radius	10.5 km

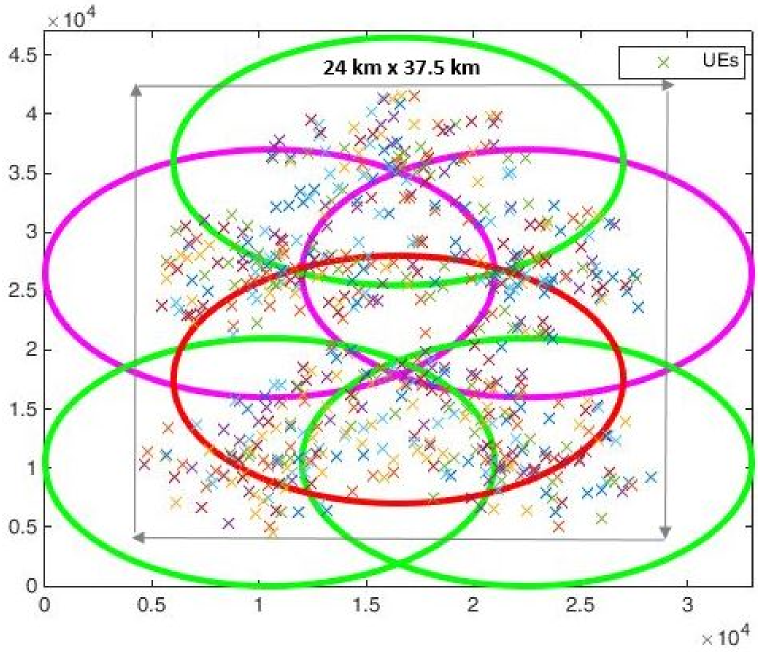

Figure 3.4. Cell planning for trunked DMR system in suburban area

To perform the cell selection algorithms in rural area, a system model is designed by considering $U = 5$ BSs and the total number of $Z = 500$ users. The example distribution of users in rural area as shown in Figure 3.5. Total area, the number of available channels per cell, percentage of active users, available bandwidth per cell and cell radius are given in Table 3.3.

Table 3.3. Load Based Rural Area Simulation Parameters

Environment	**Parameter**	**Setting**
Rural	Area	76 km x 76 km
	Available Channels per Cell u (M_u)	18
	Percentage of Active Users	17%
	Available Bandwidth per Cell u (B_u)	115.2 kHz
	Cell Radius	30 km

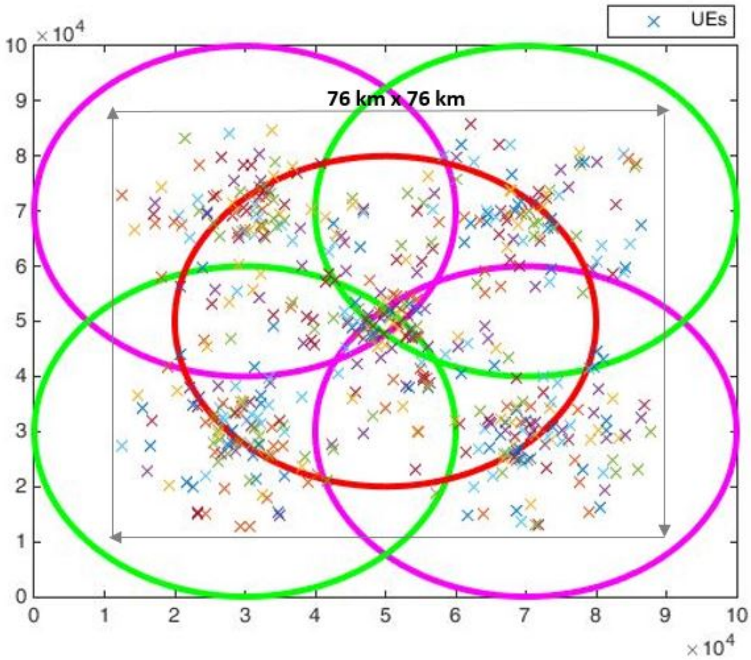

Figure 3.5. Cell planning for trunked DMR system in rural area

Hata path loss model (ETSI Technical Report 143 030 V9.0.0, 2010) is used and indoor users experience extra building loss.

Hata path loss model for ***urban environment*** is given as following:

$$PL_{u,k} = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b - (3.2(\log_{10}(11.75h_m))^2 - 4.97) \\ +(44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} \quad [dB] \tag{3.8}$$

Hata path loss model for ***suburban environment*** is given as following:

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

Hata path loss model for ***rural environment*** is given as following:

$$PL_{u,k} = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b - (1.1\log_{10} f_u - 0.7)h_m + (1.56\log_{10} f_u \\ -0.8) + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} - 4.78(\log_{10}(f_u))^2 + 18.33\log_{10} f_u - 40.94 \quad [dB] \tag{3.10}$$

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

The simulation parameters for trunked DMR system are given in Table 3.4.

Table 3.4. Simulation Parameters for Load Based Cell Selection Algorithm

PARAMETERS	**SYSTEM**
	Trunked DMR
Transmit Power	50 dBm (100 W)
Channel Spacing (Δf)	12.5 kHz
Modulation Bandwidth	10 kHz
Carrier Frequency	415 MHz
TX Antenna Gain	8 dB
TX Cable Loss	2 dB
RX Antenna Gain	-2 dBi
BS Antenna Height (h_b)	30 m
MS Antenna Height (h_m)	1.5 m
Building Loss	16.5 dB
Body Loss	10 dB
Coefficient (c)	0.3
Weight (w)	0.1, 0.5 and 0.7
Utility Threshold (U_{th})	0.8
Receiver Sensitivity ($RSSI_{rec}$)	-110 dBm
Noise Spectral Density (N_0)	-174 dBm/Hz
threshold ($RSSI_{th}$)	-80 dBm
Shadowing Standard Deviation	6 dB
Percentage of Indoor Users	20%-40%

While calculating the utility value, the mapping is applied based on the $f(.)$, $h(.)$ and $g(.)$ functions.

Firstly, RSSI values belonging to all BSs in $\mathbb{P}_k$ set given by Eq.(3.1) are sorted in descending order. Then, all RSSI values are assigned to the normalized values proportionally to their sorted RSSI indexes given in Table 3.5. This table is given for an example that there are 7 BSs in the $\mathbb{P}_k$ set. Normalization of RSSI values is applied linearly according to the changing number of BSs in $\mathbb{P}_k$ set. Since one of the aim is that user connects the BS having the highest RSSI value, the maximum RSSI represents with the highest normalized value.

Table 3.5. Normalization of RSSI values with $f(.)$ function

Index for ranked RSSI	**f(RSSI)**
1	1
2	0.8571
3	0.7143
4	0.5714
5	0.4286
6	0.2857
7	0.1429

$h(.)$ function is used to map RSSI values of BSs in the reduced set based cell selection to calculate utility value of BSs. According to nonlinear mapping, RSSI values of BSs can be divided into some intervals. This mapping is done so that high RSSI values can take high normalized values. While calculating utility values of BSs as in Eq.(3.7), the aim is that user connects the BS having the highest RSSI value, the maximum RSSI represents with the highest normalized value. Mapping of RSSI values with $h(.)$ function is given in Table 3.6.

Table 3.6. Mapping of RSSI values with $h(.)$ function

RSSI values [dBm]	h$(.)$	**Index**
$RSSI \geqslant -65$	1	1
$-65 > RSSI \geqslant -70$	0.88	2
$-70 > RSSI \geqslant -75$	0.75	3
$-75 > RSSI \geqslant -80$	0.63	4
$-80 > RSSI \geqslant -85$	0.50	5
$-85 > RSSI \geqslant -90$	0.38	6
$-90 > RSSI \geqslant -100$	0.25	7
$RSSI < -100$	0.13	8

The function $g(.)$ calculates the cell load parameter that is modeled non-linearly to remark the high traffic behavior properly as given in Table 3.7. Since our aim is to connect user to BS with low cell load, BS with highest UCL value which corresponds to the highest number of attached users is mapped to the lowest value. Based on the calculated UCL values in Eq.(3.3), the corresponding cell load indexes are assigned and then, each BS broadcasts its cell load at every predefined time slots by using 3 bits. When there is not any available channel, BS broadcasts a value so that the user does not try to connect to that BS.

Table 3.7. Mapping of cell load values with $g(.)$ function

Interval for UCL values	**g(UCL)**	**Index**
0 - 0.6	1	1
0.6 - 0.7	0.86	2
0.7 - 0.8	0.71	3
0.8 - 0.85	0.57	4
0.85 - 0.9	0.43	5
0.9 - 0.95	0.29	6
0.95 - 1	0.14	7
No Channel	0	8

Different performance metrics are used such as average delay counter, average RSSI measurement counter, load fairness index and the number of waiting active users:

- **The average delay counter** is increased at each times when the user tries to connect any BS.
- **The average RSSI measurement counter** is increased at each times when the user tries to calculate received power value for each BS.
- **Load fairness index** is calculated to evaluate the fairness of the users' association among BSs by

  $$JI = \frac{Z^2}{U \sum_{j=1}^{U} (A_u^2 + I_u^2)}. \tag{3.11}$$

  The higher load fairness index represents a higher balanced among BSs.
- **The number of waiting active user** is increased when an active user can not connect to any BS.
- In addition, **BER performances** of the cell selection algorithms under Rayleigh fading channels for different traffic cases are examined. In order to guarantee service quality, BER must be under 0.05 for voice users.

3.3.1. Load Based Biased Full Set Cell Selection Algorithm Simulation Parameters

For the biased full set cell selection algorithm, urban environment performance results are obtained in high traffic. The considered cell planning is given in Figure 3.3. The users are uniformly distributed and 30% of users are assumed to be indoor users. The percentage of active users is taken 31%. The BS labeled as 7 in red color has not receive any interference and its SINR is relatively high compared to other BSs. Therefore, $Q_7 = -15$dB bias is applied to BS labeled as 7 and 0dB bias for the other BSs.

While calculating the utility value, the mapping is applied based on the predefined $s(.)$ function. Firstly, SINR values belonging to all BSs are sorted in descending order. Then, all SINR values including bias are assigned to the normalized values proportionally to their sorted SINR indexes given in Table 3.8. Since one of the purpose is that user connects the BS having the highest SINR value, the maximum SINR represents with the highest normalized value.

Table 3.8. Normalization of SINR values with $s(.)$ function

Index for ranked SINR	$\mathbf{f(\bar{SINR} + Q_u)}$
1	1
2	0.8571
3	0.7143
4	0.5714
5	0.4286
6	0.2857
7	0.1429

The simulation results are compared for the biased full set cell selection algorithm as unbiased and biased by considering different weights (b) at the high traffic.

3.3.2. Simulation Results

In this section, the performance results of the full set and the reduced set based cell selection algorithms with various weights and various percentage of indoor users are compared with RSSI and SINR based cell selection algorithms in high traffic load for urban, suburban and rural environments, respectively.

3.3.2.1. Urban Area Results in High Traffic Load

- **Urban Area with 20% Indoor Users in High Traffic**

Table 3.9 shows the simulation results in high traffic for the urban area. There are 20% indoor users in the system. Figure 3.6 gives the distribution of users.

Table 3.9. 20% Indoor Users in Urban Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.50787	7	1.1745	7.2333
RSSI BASED	0.9888	6.3702	1.0496	4.8667
FULL SET, *w=0.1*	0.98896	**7**	**1**	**2.1**
FULL SET, *w=0.5*	0.99034	7	1	3.3
FULL SET, *w=0.7*	0.99082	7	1	4.5333
REDUCED SET, *w=0.1*	0.98029	**2.1663**	**1**	**2.3**
REDUCED SET, *w=0.5*	0.98487	3.9213	1	2.7333
REDUCED SET, *w=0.7*	0.99193	4.13	1	3.4333

Algorithms	**Outage Probability**
SINR BASED	0.021
RSSI BASED	0.017
FULL SET, *w=0.1*	0.041
FULL SET, *w=0.5*	0.016
FULL SET, *w=0.7*	0.015
REDUCED SET, *w=0.1*	0.042
REDUCED SET, *w=0.5*	0.024
REDUCED SET, *w=0.7*	0.018

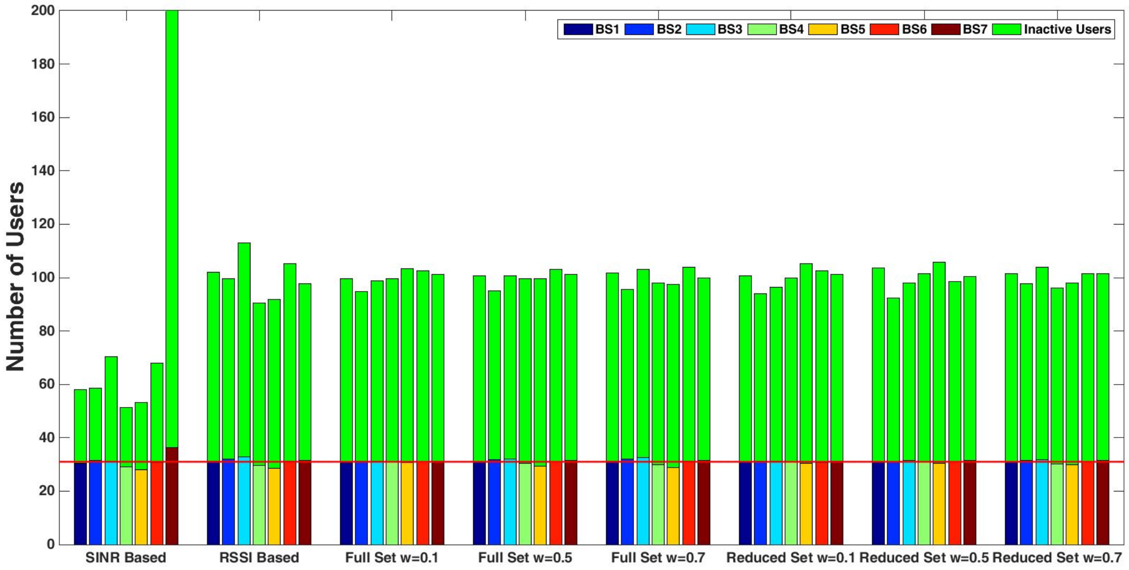

Figure 3.6. Distribution of Users to Cells in High Traffic with 20% Indoor Users in Urban Area

The numerical results in Table 3.9 show the full set and the reduced set cell selection algorithm with weight $w = 0.1$ give the best performance in terms of the number of waiting active users while balancing the active and inactive users among the BSs to reduce the transmission delay.

When we compare the different weighted results of the full set and the reduced set algorithms within itself in terms of the number of waiting active user, weight with $w = 0.1$ has the lowest number of waiting active user since cell load is more important in the utility calculation. Thus, users are distributed to BSs in balance manner as shown in Figure 3.6 and the number of waiting user decreases. The number of waiting active user is reduced by 56.8% with the full set $w = 0.1$ and 52.7% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm.

The reduced set cell selection algorithm achieves less RSSI measurement counter. RSSI measurement counter is reduced by 69.1% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

- **Urban Area with 40% Indoor Users in High Traffic**

Table 3.10 shows the simulation results in high traffic with 40% indoor users for the urban area. Figure 3.7 gives the distribution of users in high traffic.

Table 3.10. 40% Indoor Users in Urban Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.63284	7	1.1302	12.7333
RSSI BASED	0.98923	6.3719	1.0414	9.0333
FULL SET, *w=0.1*	0.98943	**7**	**1**	**3.6333**
FULL SET, *w=0.5*	0.99098	7	1	6.2
FULL SET, *w=0.7*	0.99154	7	1	8.6333
REDUCED SET, *w=0.1*	0.97693	**2.1865**	**1**	**4.0333**
REDUCED SET, *w=0.5*	0.98447	3.9464	1	5.0667
REDUCED SET, *w=0.7*	0.99184	4.1512	1	6.9667

Algorithms	**Outage Probability**
SINR BASED	0.013
RSSI BASED	0.012
FULL SET, *w=0.1*	0.028
FULL SET, *w=0.5*	0.015
FULL SET, *w=0.7*	0.013
REDUCED SET, *w=0.1*	0.031
REDUCED SET, *w=0.5*	0.020
REDUCED SET, *w=0.7*	0.014

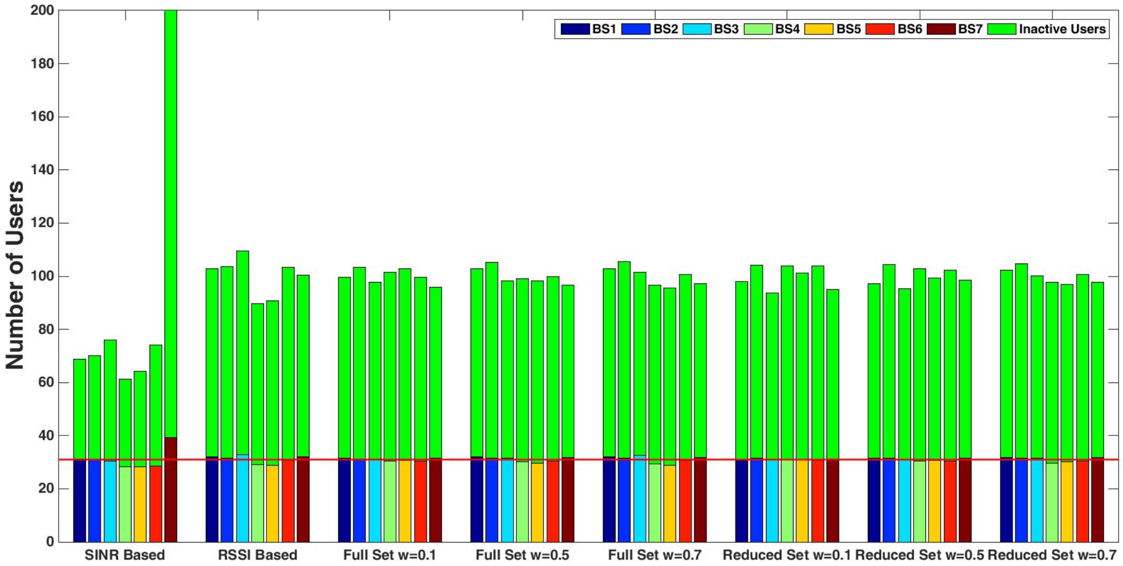

Figure 3.7. Distribution of Users to Cells in High Traffic with 40% Indoor Users in Urban Area

When the percentage of indoor users is increased to 40% , it is observed that the number of waiting active users increases in number. The reason for this increment is the decrease in received power due to the fact that indoor users have extra building loss.

The number of waiting active user is high for SINR and RSSI based cell selection algorithms since these algorithms do not consider cell load. As provided in Table 3.10, the number of waiting active user is reduced by 59.8% with the full set $w = 0.1$ and 55.4% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm.

Moreover, RSSI measurement counter is reduced by 68.8% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

Considering the cell load performance and the distribution of users to cell as given in Figure 3.7, the full set and the reduced set algorithms with the *w=0.1* provide balanced distribution than the algorithms with the *w=0.5* and the *w=0.7*. The reason is that when the *w* is 0.1, cell load becomes more important than RSSI as given in the Eq.(3.2). The numerical results given in tables show that as the weight value increases in the full set and the reduced set algorithms, the number of waiting active users results are close to the RSSI algorithm. The reason is that when the weight value is increased, the importance given to the RSSI value increases.

- **Load Based Biased Full Set Cell Selection Algorithm**

Table 3.11 and Table 3.12 shows the simulation results as unbiased and biased in high traffic, respectively.

Table 3.11. Performance results without bias for high traffic case

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active Users**	**Outage Probability with Bias**
SINR BASED	0.809	7	1.5362	41.7	0.018
RSSI BASED	0.988	6.3714	2.2475	39.3	0.010
FULL SET, *b=0.1*	0.997	7	1	38.6	0.021
FULL SET, *b=0.5*	0.996	7	1	38.6	0.014
FULL SET, *b=0.7*	0.986	7	1	39.1	0.012

Table 3.12. Performance results with bias for high traffic case

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active Users**	**Outage Probability with Bias**
SINR BASED	0.809	7	1.5362	41.7	0.018
RSSI BASED	0.988	6.3714	2.2475	39.3	0.010
FULL SET, *b=0.1*	0.994	7	1	35.4	0.039
FULL SET, *b=0.5*	0.993	7	1	35.7	0.029
FULL SET, *b=0.7*	0.980	7	1	36.2	0.028

It is clear that full set based cell selection algorithm with bias reduces the number of waiting active users compared to unbiased one. As provided in Table 3.11 and Table 3.12, the number of waiting active user is reduced by 8.29% with the biased full set $b = 0.1$, 7.51% with the biased full set $b = 0.5$ and 7.42% with the biased full set $b = 0.7$ algorithms compared with the unbiased full set based algorithms, respectively.

3.3.2.2. Suburban Area Results in High Traffic Load

- **Suburban Area with 20% Indoor Users in High Traffic**

Table 3.13 shows the simulation results in high traffic for suburban area. There are 20% indoor users in the system. Figure 3.8 gives the distribution of users in high traffic.

Table 3.13. 20% Indoor Users in Suburban Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.55712	6	1.1182	5.0333
RSSI BASED	0.99328	5.5525	1.0395	3.5333
FULL SET, *w=0.1*	0.97684	**6**	**1**	**1.9**
FULL SET, *w=0.5*	0.98254	6	1	2.9667
FULL SET, *w=0.7*	0.98543	6	1	3.5333
REDUCED SET, *w=0.1*	0.96408	**2.1576**	**1**	**2.2333**
REDUCED SET, *w=0.5*	0.97445	3.9192	1	2.6333
REDUCED SET, *w=0.7*	0.9881	4.0957	1	3.0333

Algorithms	**Outage Probability**
SINR BASED	0.016
RSSI BASED	0.019
FULL SET, *w=0.1*	0.038
FULL SET, *w=0.5*	0.020
FULL SET, *w=0.7*	0.018
REDUCED SET, *w=0.1*	0.044
REDUCED SET, *w=0.5*	0.029
REDUCED SET, *w=0.7*	0.023

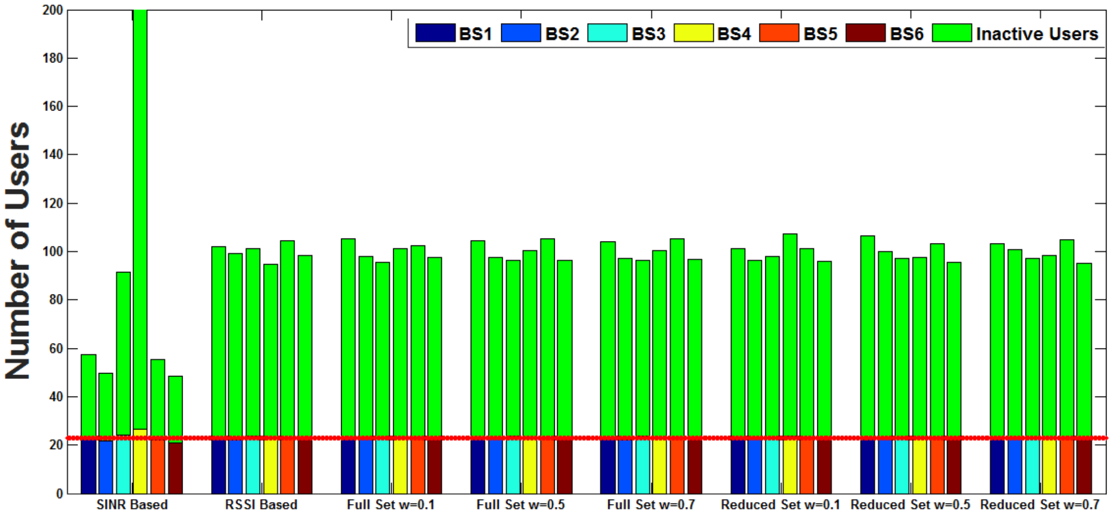

Figure 3.8. Distribution of Users to Cells in High Traffic with 20% Indoor Users in Suburban Area

The simulation results demonstrate that the proposed algorithms have performance improvement in terms of the number of waiting active user and average delay counter compared with the conventional algorithms, in which a user is assigned to a cell that considers cell load and RSSI by achieving the target BER performance.

Numerically, the number of waiting active user is decreased by 46.2% with the full set $w = 0.1$ and 36.8% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm. In addition, Table 3.13 indicates that RSSI measurement counter is reduced by 64% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

- **Suburban Area with 40% Indoor Users in High Traffic**

Table 3.14 shows the simulation results in high traffic with 40% indoor users in suburban area. Figure3.9 gives the distribution of users in high traffic.

Table 3.14. 40% Indoor Users in Suburban Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.66817	6	1.0837	8
RSSI BASED	0.9955	5.571	1.0335	5.5333
FULL SET, *w=0.1*	0.98496	**6**	**1**	**2.1333**
FULL SET, *w=0.5*	0.98934	6	1	4.1667
FULL SET, *w=0.7*	0.99169	6	1	5.4667
REDUCED SET, *w=0.1*	0.9617	**2.1656**	**1**	**3.2333**
REDUCED SET, *w=0.5*	0.976	3.9244	1	3.4
REDUCED SET, *w=0.7*	0.99096	4.0876	1	4.2333

Algorithms	**Outage Probability**
SINR BASED	0.017
RSSI BASED	0.018
FULL SET, *w=0.1*	0.035
FULL SET, *w=0.5*	0.019
FULL SET, *w=0.7*	0.018
REDUCED SET, *w=0.1*	0.033
REDUCED SET, *w=0.5*	0.026
REDUCED SET, *w=0.7*	0.021

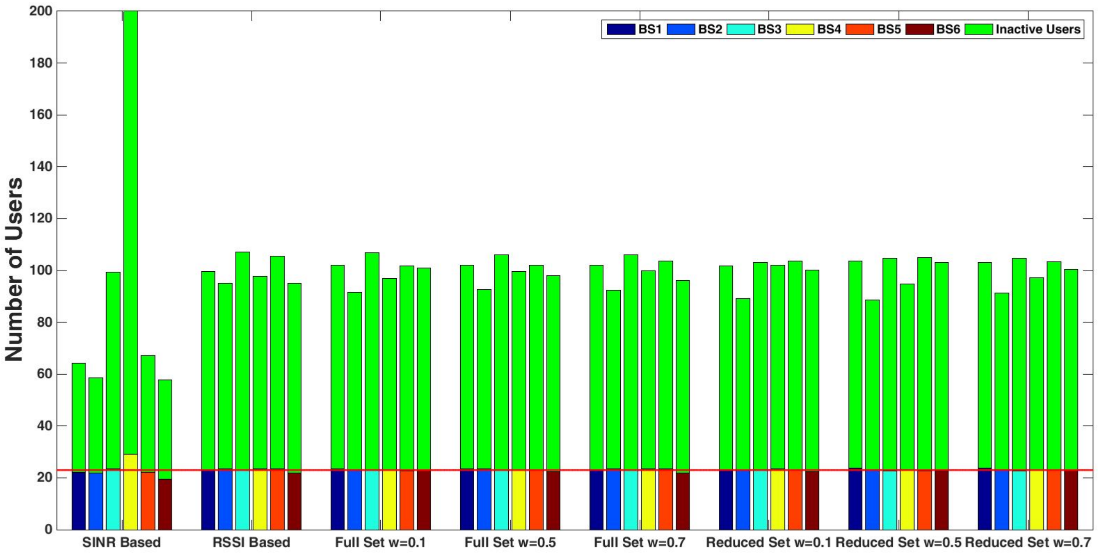

Figure 3.9. Distribution of Users to Cells in High Traffic with 40% Indoor Users in Suburban Area

The reduced set based cell selection algorithm achieves less RSSI measurement counter. In particular, reduced set based cell selection algorithm with $w = 0.1$ gives the lowest RSSI measurement counter and is reduced by 63.9% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

All cell selection algorithms provide the desired BER performance. From the values in Table 3.14, the number of waiting active user is decreased by 61.4% with the full set $w = 0.1$ and 41.6% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm.

3.3.2.3. Rural Area Results in High Traffic Load

- **Rural Area with 20% Indoor Users in High Traffic**

Table 3.15 shows the simulation results for rural area in high traffic. There are 20% indoor users in the system. Figure 3.10 gives the distribution of users in high traffic.

Table 3.15. 20% Indoor Users in Rural Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.55599	5	1.0885	3.8333
RSSI BASED	0.99133	4.6121	1.0275	2.5667
FULL SET, *w=0.1*	0.97195	**5**	**1**	**1**
FULL SET, *w=0.5*	0.97607	5	1	1.9333
FULL SET, *w=0.7*	0.97825	5	1	2.5333
REDUCED SET, *w=0.1*	0.94946	**2.1177**	**1**	**1.3**
REDUCED SET, *w=0.5*	0.96939	3.7423	1	1.7
REDUCED SET, *w=0.7*	0.98395	3.9326	1	2

Algorithms	**Outage Probability**
SINR BASED	0.011
RSSI BASED	0.008
FULL SET, *w=0.1*	0.023
FULL SET, *w=0.5*	0.009
FULL SET, *w=0.7*	0.007
REDUCED SET, *w=0.1*	0.021
REDUCED SET, *w=0.5*	0.015
REDUCED SET, *w=0.7*	0.006

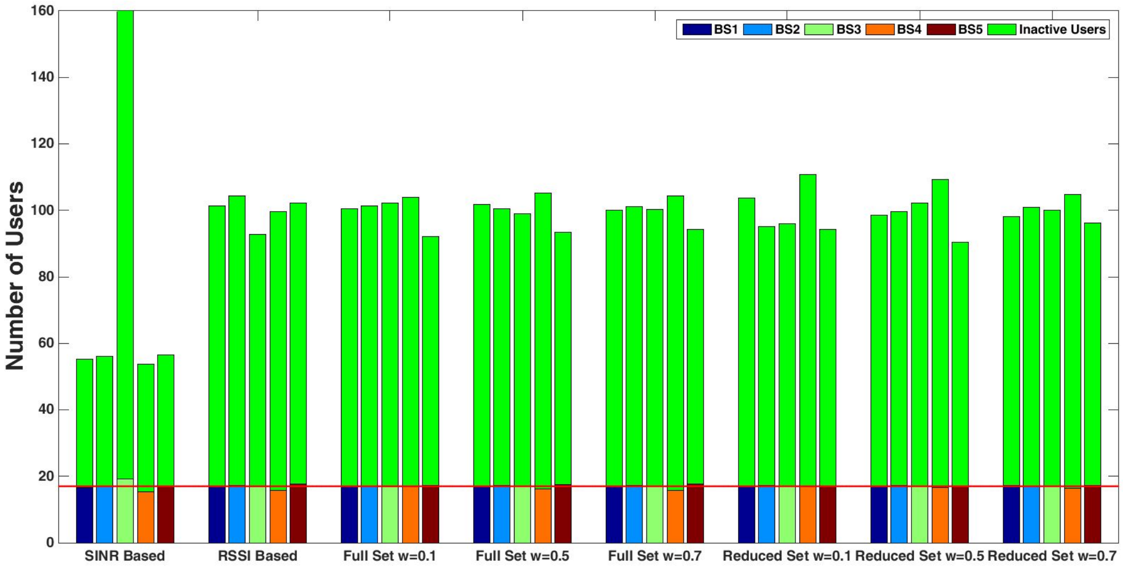

Figure 3.10. Distribution of Users to Cells in High Traffic with 20% Indoor Users in Rural Area

According to the Table 3.15, the number of waiting active user is reduced by 61% with the full set $w = 0.1$ and 49.4% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm. In addition, RSSI measurement counter is reduced by 57.6% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

Since the BS labeled as 7 has received no interference from other BSs, most of the users are intended to connect it when SINR algorithm is employed that is the reason load fairness index is lowest for SINR algorithm.

- **Rural Area with 40% Indoor Users in High Traffic**

Table 3.16 shows the simulation results in high traffic with 40% indoor users in the rural area. Figure 3.11 gives the distribution of users in high traffic.

Table 3.16. 40% Indoor Users in Rural Area with High Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.67908	5	1.0573	5.5333
RSSI BASED	0.99238	4.5764	1.025	4
FULL SET, *w=0.1*	0.98257	**5**	**1**	**1.5**
FULL SET, *w=0.5*	0.98669	5	1	3.0333
FULL SET, *w=0.7*	0.98851	5	1	3.9333
REDUCED SET, *w=0.1*	0.94856	**2.1368**	**1**	**1.9**
REDUCED SET, *w=0.5*	0.96148	3.7508	1	2.4667
REDUCED SET, *w=0.7*	0.98464	3.9357	1	3.2667

Algorithms	**Outage Probability**
SINR BASED	0.009
RSSI BASED	0.007
FULL SET, *w=0.1*	0.022
FULL SET, *w=0.5*	0.012
FULL SET, *w=0.7*	0.009
REDUCED SET, *w=0.1*	0.017
REDUCED SET, *w=0.5*	0.014
REDUCED SET, *w=0.7*	0.009

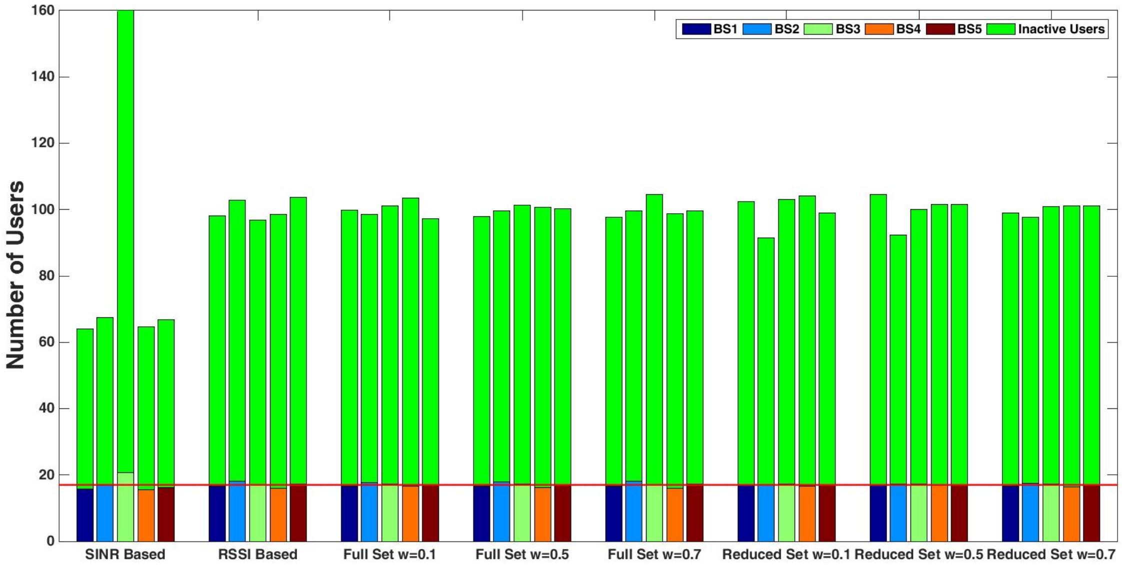

Figure 3.11. Distribution of Users to Cells in High Traffic with 40% Indoor Users in Rural Area

Among the different weights of the full set and the reduced set cell selection algorithms, the weight with $w = 0.1$ gives the best performance in terms of the number of waiting active users.

As given in the Table 3.16, the number of waiting active user is reduced by 62.5% with the full set $w = 0.1$ and 52.5% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm. In addition, RSSI measurement counter is reduced by 57.3% with reduced set $w = 0.1$ compared with full set and SINR based algorithms.

The full set and the reduced set based algorithms with different weights have the lowest average delay counter. This means that user is registered to the BS at the first trial on the average.

3.3.2.4. Urban Area Results in Medium Traffic Load

- **Urban Area with 20% Indoor Users in Medium Traffic**

Because there are enough cell capacities, there is no problem with low load and medium load traffics in terms of the number of waiting active users. Although the results in high traffic load are more critical, medium traffic load results are evaluated for the urban area.

Table 3.17 shows the simulation results in medium traffic. There are 20% indoor users in the system. Figure 3.12 gives the distribution of users in medium traffic.

Table 3.17. 20% Indoor Users in Urban Area with Medium Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.46221	7	1.1073	2.7
RSSI BASED	0.98496	6.3181	1.0025	0.46667
FULL SET, *w=0.1*	0.99419	**7**	**1**	**0.033333**
FULL SET, *w=0.5*	0.99465	**7**	**1**	**0.033333**
FULL SET, *w=0.7*	0.98936	7	1	0.16667
REDUCED SET, *w=0.1*	0.99306	**1.8389**	**1**	**0.033333**
REDUCED SET, *w=0.5*	0.99455	3.8347	1	0.033333
REDUCED SET, *w=0.7*	0.99457	4.0741	1	0.16667

Algorithms	**Outage Probability**
SINR BASED	0.010
RSSI BASED	0.011
FULL SET, *w=0.1*	0.027
FULL SET, *w=0.5*	0.012
FULL SET, *w=0.7*	0.009
REDUCED SET, *w=0.1*	0.031
REDUCED SET, *w=0.5*	0.022
REDUCED SET, *w=0.7*	0.013

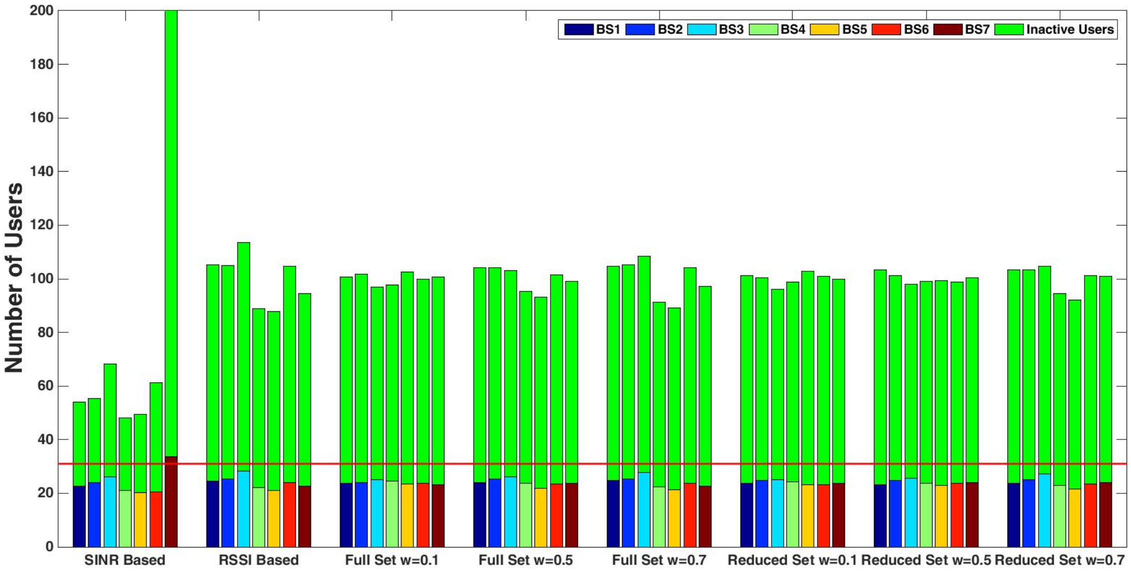

Figure 3.12. Distribution of Users to Cells in Urban Medium Traffic with 20% Indoor Users

The numerical results show that the full set based and the reduced set based cell selection algorithms achieve lower number of waiting active user and lower average delay counter than conventional cell selection methods.

Due to the traffic and there are enough cell capacities to attach users, particularly for the full set and the reduced set based algorithms with different weights, there are almost no any waiting active users. The number of waiting active user is reduced by 92.9% with full set and the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm.

The RSSI measurement counter is reduced by 73.7% with the reduced set $w = 0.1$ when compared to the performance of the full set and SINR algorithms.

- **Urban Area with 40% Indoor Users in Medium Traffic**

Table 3.18 shows the simulation results in medium traffic. There are 40% indoor users in the system. Figure 3.13 gives the distribution of users in medium traffic.

Table 3.18. 40% Indoor Users in Urban Area with Medium Traffic

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Number of Waiting Active User**
SINR BASED	0.58255	7	1.0783	5.7667
RSSI BASED	0.98719	6.3663	1.0004	0.4
FULL SET, *w=0.1*	0.99439	**7**	**1**	**0.13333**
FULL SET, *w=0.5*	0.99481	**7**	**1**	**0.13333**
FULL SET, *w=0.7*	0.98982	7	1	0.3
REDUCED SET, *w=0.1*	0.99127	**1.8802**	**1**	**0.13333**
REDUCED SET, *w=0.5*	0.99324	3.8661	1	0.2
REDUCED SET, *w=0.7*	0.99413	4.0899	1	0.3

Algorithms	**Outage Probability**
SINR BASED	0.008
RSSI BASED	0.006
FULL SET, *w=0.1*	0.022
FULL SET, *w=0.5*	0.011
FULL SET, *w=0.7*	0.009
REDUCED SET, *w=0.1*	0.025
REDUCED SET, *w=0.5*	0.021
REDUCED SET, *w=0.7*	0.013

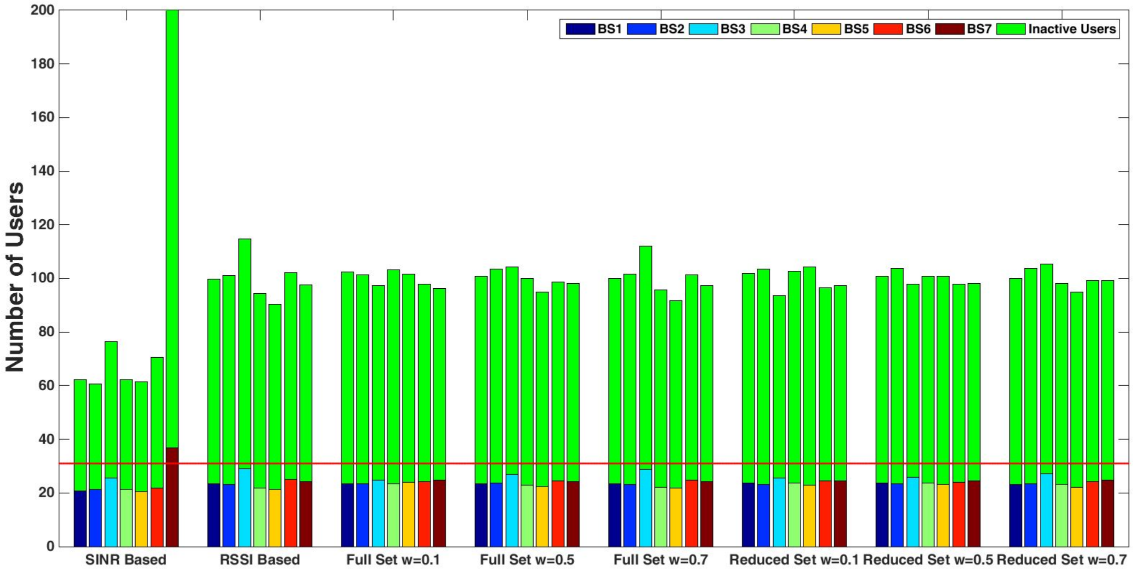

Figure 3.13. Distribution of Users to Cells in Medium Traffic with 40% Indoor Users in Urban Area

The number of waiting active user is reduced by 66.7% with the full set and the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm. In addition, compared to the SINR and the full set algorithms, RSSI measurement counter is decreased by 73.1% with the reduced set $w = 0.1$ algorithm.

Due to the medium traffic load, BSs have enough capacity as shown in the distribution of users to cells in Figure 3.12 and in Figure 3.13. The unbalanced distribution of users among cells leads to higher waiting time to communicate because of the limited number of available channels.

CHAPTER 4

TRAFFIC BASED CELL SELECTION ALGORITHM

In this chapter, it is investigated that users are making a call for a certain period while the user is moving from one cell to another. Some users are either vehicle or pedestrian users and cell reselection is taken into account for these users. The number of average waiting time and the number of reselections are obtained for a certain period of time.

4.1. Traffic Based Cell Selection Algorithms

Traffic based cell selection algorithm is applied to previously mentioned the full set and the reduced set based cell selection algorithms in Section 3.1 and Section 3.2, respectively (Yılmaz S et al., 2017b). The difference from the load based cell selection algorithms is that the traffic intensity is taken into account when calculating the cell load value of BSs to obtain utility value as in Eq.(3.2) and in Eq.(3.7).

- Since there is no call request at the first second ($t = 1$), all users are inactive users and the traffic load of BSs for the initial cell selection is calculated as:

$$UTL_{u,t} = \frac{I_{u,g}}{N_g} \tag{4.1}$$

where $I_{u,g}$ refers to the number of inactive users in u^{th} BS belong to g^{th} group. N_g is the number of users per group for each *u* BS.

- When active users request a call for a certain period of time, the traffic and call durations are taken into consideration and the traffic load of BSs is calculated as follows:

$$UTL_{u,t} = \frac{T_d}{T_f \times M_g} \tag{4.2}$$

where T_d is the total duration of calls in the defined time interval, T_f shows the defined fixed time interval and M_g is the number of channels per group in the cell.

4.2. Simulation Parameters

Three different scenarios are planned including different the number of group, total number of users, total number of cells and push to talk (PTT) of user. System models are planned by regarding urban, suburban and rural environments.

For all scenarios, there are only voice users that are required to allocate only one physical channel. The users are divided into specific groups according to the number of groups in each environment and the calls are done on the basis of the group. Users belong to one group. Group calls happen only in the same group users. PTT decides the number of communicating users in the groups.

Users can be both active and inactive throughout the simulation period. The user who calls in a group is assigned a call duration of 5-15 seconds at random within 1 minute.

Only active users occupy the channels for the call duration. If active user can not communicate for its call duration due to available capacity, user is added queue of serving cell. If active user is still at the same BS, user waits until there is available capacity in that BS. The total simulation time is taken as 30 minutes.

It is assumed that 30% of the users in the system are indoor users. The effect of extra building loss of indoor users is taken into account. Some of users are mobile, 40% of the users are vehicle users and 30% of the users are pedestrian users.

Reselection criteria of user is evaluated only according to instantly measured RSSI values. As a result of the measurement of 6 measurements from the last 10 RSSI values that below the reselection threshold value, the users make cell selection process one by one. The threshold value for reselection is -100 dBm.

$UTL_{u,t}$ shows the traffic intensity. BS calculates the $UTL_{u,t}$ value at every second, takes the average of the last given fixed time interval $UTL_{u,t}$ values and broadcasts its traffic load value at every given fixed time interval by using 3 bits. Based on the calculated $UTL_{u,t}$ values in Eq.(4.1) and in Eq.(4.2), mapping is done by g function and the corresponding traffic load indexes are assigned in Table 4.1 and in Table 4.2, respectively.

Table 4.1. Mapping of traffic load $UTL_{u,t}$ values for initial cell selection with $g(.)$ function

Interval for $\mathbf{UTL_{u,t}}$ values	**g(UTL)**	**Index**
0 - 0.3	1	1
0.3 - 0.5	0.86	2
0.5 - 1	0.71	3
1 - 1.06	0.57	4
1.06 - 1.10	0.43	5
1.10 - 1.20	0.29	6
1.20 - upper	0.14	7

Table 4.2. Mapping of traffic load $UTL_{u,t}$ values with $g(.)$ function

Interval for $\mathbf{UTL_{u,t}}$ values	**g(UTL)**	**Index**
0 - 0.2	1	1
0.2 - 0.3	0.86	2
0.3 - 0.4	0.71	3
0.4 - 0.5	0.57	4
0.5 - 0.6	0.43	5
0.6 - 0.8	0.29	6
0.8 - 1	0.14	7
No Channel	0	8

Simulation parameters for urban area are given in Table 4.3. The system model of urban area is indicated in Figure 4.1 and frequency reuse factor is taken as 3.

Table 4.3. Traffic Based Urban Area Simulation Parameters

Environment	**Parameter**	**Setting**
Urban	Area	15 km x 20 km
	Total Number of Groups	5
	Total Number of Users	400
	Total Number of Cells	7
	PTT	0.25
	Cell Radius	6 km

In the urban environment, there are 5 different user groups and the PTT of users is 0.25. The number of available channels per cell is determined as 6 and one of these channels is used as a control channel. Since the system is conventional, channels are allocated to a specific group of users in the cell.

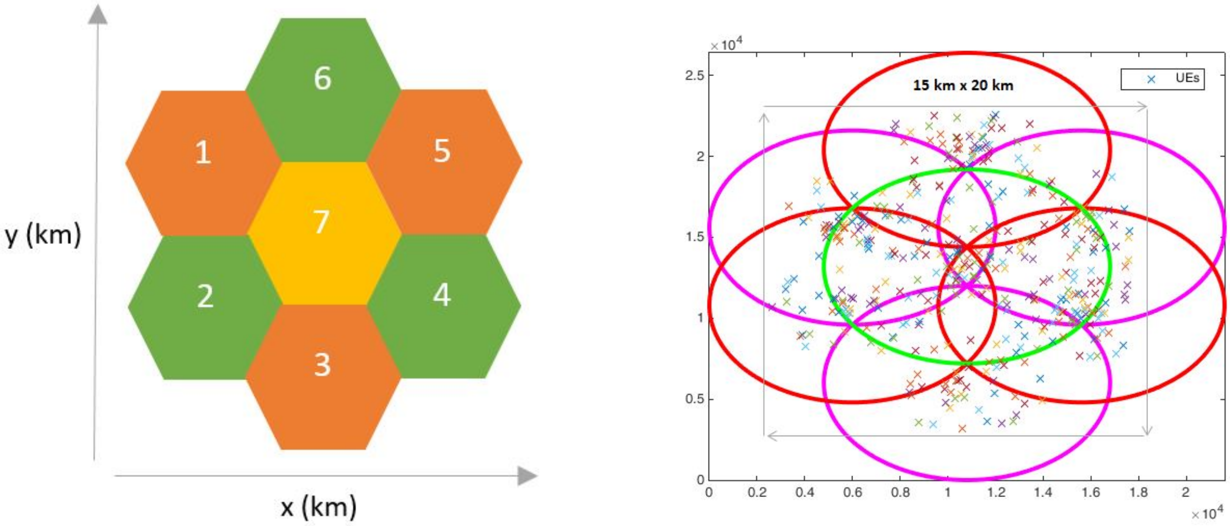

Figure 4.1. Cell planning for conventional APCO25 system in urban area

Simulation parameters for suburban area are given in Table 4.4. Suburban environment system model is given in Figure 4.2. Frequency reuse factor is taken as 3.

Table 4.4. Traffic Based Suburban Area Simulation Parameters

Environment	**Parameter**	**Setting**
Suburban	Area	24 km x 27 km
	Total Number of Groups	3
	Total Number of Users	200
	Total Number of Cells	5
	PTT	0.21
	Cell Radius	10.5 km

In the suburban environment, there are 3 different user groups and the PTT of users is 0.21. The number of available channels per cell is determined as 4 and one of these channels is used as a control channel. Since the system is conventional, channels are allocated to a specific group of users. There are 3 channels in each BS and it can be considered that channel one might be in one group, channel two and three might be in other groups.

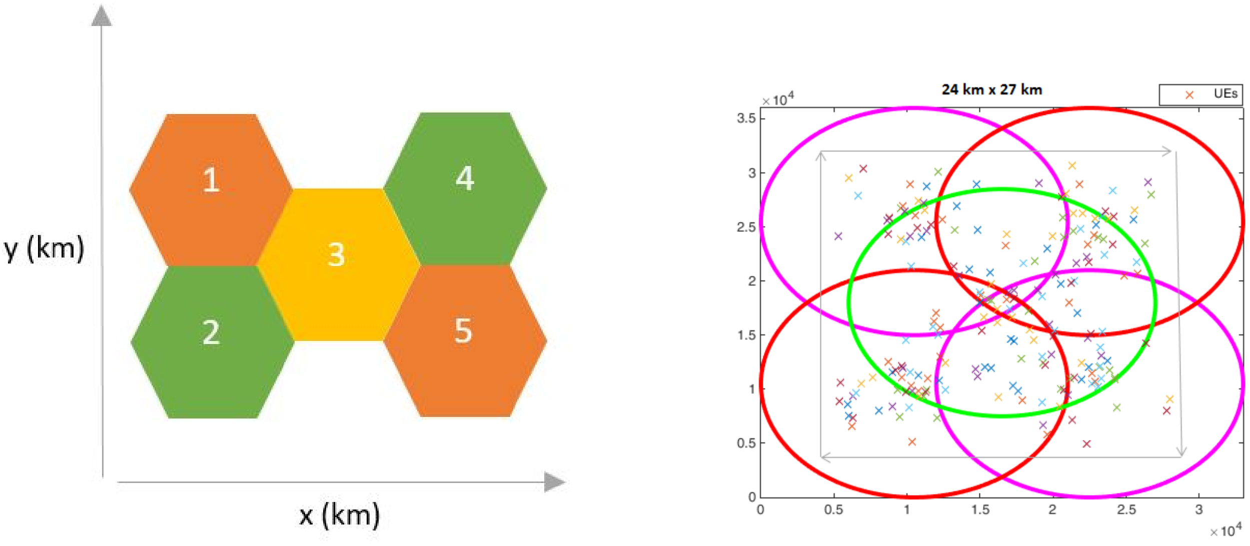

Figure 4.2. Cell planning for conventional APCO25 system in suburban area

Simulation parameters for rural area are given in Table 4.5. The system model of the rural environment is indicated in Figure 4.2. Frequency reuse factor is taken as 3.

Table 4.5. Traffic Based Rural Area Simulation Parameters

Environment	Parameter	Setting
Rural	Area	66 km x 66 km
	Total Number of Groups	4
	Total Number of Users	100
	Total Number of Cells	3
	PTT	0.32
	Cell Radius	30 km

In the rural environment, there are 4 different user groups and the PTT of users is 0.32. The number of available channels per cell is determined as 5 and one of these channels is used as a control channel. Channels are allocated to a specific group of users in the cell.

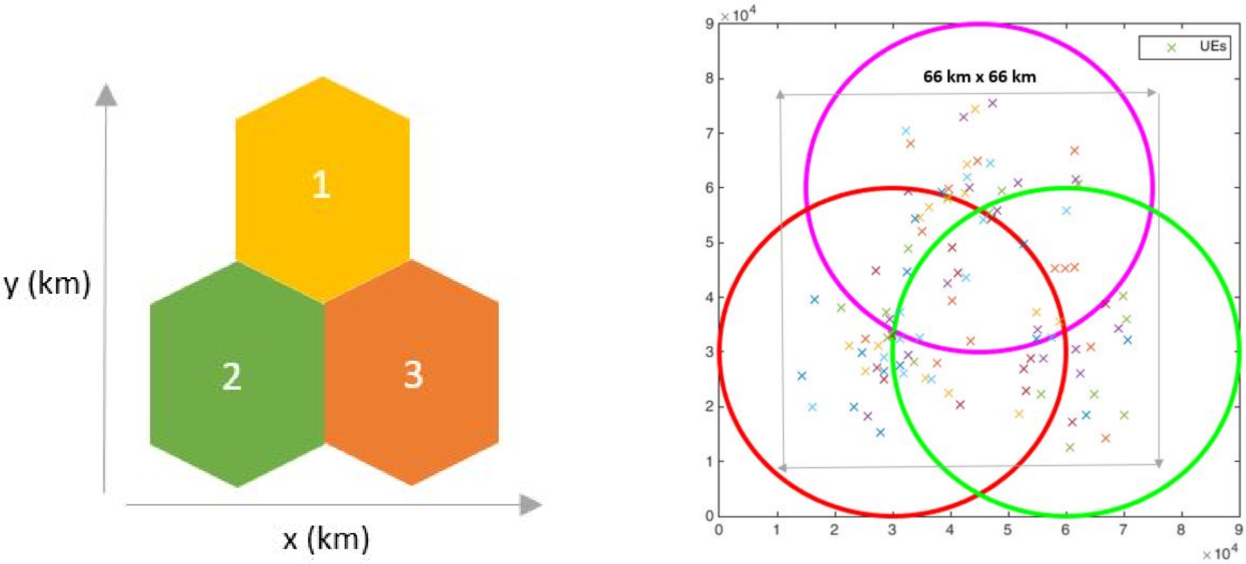

Figure 4.3. Cell planning for conventional APCO25 system in rural area

All simulations for conventional APCO25 system are obtained by using the parameters given in Table 4.6.

Table 4.6. Simulation Parameters for Traffic Based Cell Selection Algorithm

PARAMETERS	**SYSTEM**
	Conventional APCO25
Transmit Power	50 dBm (100 W)
Channel Spacing (Δf)	12.5 kHz
Modulation Bandwidth	10 kHz
Carrier Frequency	415 MHz
TX Antenna Gain	8 dB
TX Cable Loss	2 dB
RX Antenna Gain	-2 dBi
BS Antenna Height (h_b)	30 m
MS Antenna Height (h_m)	1.5 m
Building Loss	16.5 dB
Body Loss	10 dB
Receiver Sensitivity ($RSSI_{rec}$)	-116 dBm
Noise Spectral Density (N_0)	-174 dBm/Hz
Weight (w)	0.1, 0.5 and 0.7
Utility Threshold (U_{th})	0.5
Defined fixed time interval (T_f)	1 min
Shadowing Standard Deviation	6 dB

Simulation results are compared on the basis of some different performance metrics such as the number of average waiting time, the number of reselection, load fairness index, average RSSI measurement counter and average delay counter. The number of average waiting time represents the average waiting time of active users that want to make a call but can not attach to a BS due to traffic. The number of reselection refers to the average number of changing BSs for pedestrian and vehicle users due to the cell reselection process.

4.2.1. Simulation Results

4.2.1.1. Urban Area Results

Table 4.7 shows the simulation results for urban environment. The reduced set based cell selection algorithm achieves less RSSI measurement counter. In particular, the reduced set based with $w = 0.1$ gives the lowest RSSI measurement counter and is reduced by 85% compared with the full set and SINR based algorithms. The reduced set based with $w = 0.1$ has the lowest average number of reselections. All the cell selection algorithms provide the desired BER performance. From the values in Table 4.7, the number of average waiting time is decreased by 12.97% with the full set $w = 0.1$ and 15.28% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm.

Table 4.7. Traffic Based Simulation Results for Urban Area

Algorithms	Load Fairness Index	RSSI Measurement Counter	Average Delay Counter	Average Waiting Time (sec)	Number of Reselections
SINR BASED	0.51923	7	1.0324	5.8975	38.3
RSSI BASED	0.95592	6.8962	1.0252	4.6382	18.2825
FULL SET, w=0.1	0.9819	**7**	**1**	**4.0368**	**24.09**
FULL SET, w=0.5	0.96871	7	1	4.3232	18.99
FULL SET, w=0.7	0.95783	7	1	4.4133	18.3487
REDUCED SET, w=0.1	0.95422	**1.0507**	**1**	**3.9295**	**14.73**
REDUCED SET, w=0.5	0.97356	1.6912	1	4.1378	18.5613
REDUCED SET, w=0.7	0.97806	3.6254	1	4.328	20.7062

Algorithms	Outage Probability
SINR BASED	0.03125
RSSI BASED	0.04
FULL SET, w=0.1	0.04625
FULL SET, w=0.5	0.03875
FULL SET, w=0.7	0.035
REDUCED SET, w=0.1	0.02375
REDUCED SET, w=0.5	0.03625
REDUCED SET, w=0.7	0.04375

4.2.1.2. Suburban Area Results

Table 4.8 shows the simulation results for suburban environment. As given in the Table 4.8, the number of average waiting time is reduced by 13.24% with the full set $w = 0.1$ and 11.54% with the reduced set $w = 0.1$ algorithms compared with the RSSI based algorithm. In addition, RSSI measurement counter is reduced by 78.5% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms.

The full set and the reduced set based algorithms with different weights have the lowest average delay counter. This means that user is registered to the BS at the first trial on the average.

Table 4.8. Traffic Based Simulation Results for Suburban Area

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Average Waiting Time (sec)**	**Number of Reselections**
SINR BASED	0.72839	5	1.0166	4.0917	21.8975
RSSI BASED	0.96785	4.9588	1.018	3.8734	11.505
FULL SET, w=0.1	**0.98127**	**5**	**1**	**3.3607**	**16.59**
FULL SET, w=0.5	0.97275	5	1	3.531	12.505
FULL SET, w=0.7	0.96851	5	1	3.6591	11.525
REDUCED SET, w=0.1	0.97385	**1.075**	**1**	**3.4266**	**9.5175**
REDUCED SET, w=0.5	0.98024	1.8584	1	3.5179	12.4925
REDUCED SET, w=0.7	0.96812	3.6359	1	3.5635	12.4375

Algorithms	**Outage Probability**
SINR BASED	0.005
RSSI BASED	0.0225
FULL SET, w=0.1	0.045
FULL SET, w=0.5	0.0275
FULL SET, w=0.7	0.0225
REDUCED SET, w=0.1	0.02
REDUCED SET, w=0.5	0.0275
REDUCED SET, w=0.7	0.0325

4.2.1.3. Rural Area Results

Table 4.9 shows the simulation results for rural environment. According to the Table 4.9, the number of average waiting time is reduced by 18.71% with the full set $w = 0.1$ and 15.46% with the reduced set $w = 0.1$ algorithms compared with the RSSI and SINR based algorithms. In addition, RSSI measurement counter is reduced by 54.7% with the reduced set $w = 0.1$ compared with the full set and SINR based algorithms. The reduced set with $w = 0.1$ gives the lowest average number of reselections. Thus, base stations do not use extra effort for cell reselection process.

Since there is no interference in the rural system, SINR based algorithm shows the same performance as RSSI based algorithm just regarding RSSI value of BSs. Zero outage probability is provided by all cell selection algorithms.

Table 4.9. Traffic Based Simulation Results for Rural Area

Algorithms	**Load Fairness Index**	**RSSI Measurement Counter**	**Average Delay Counter**	**Average Waiting Time (sec)**	**Number of Reselections**
SINR BASED	0.99072	3	1.0184	3.3599	1.615
RSSI BASED	0.99072	2.8968	1.0184	3.3599	1.615
FULL SET, w=0.1	0.98883	**3**	**1**	**2.7313**	**4.875**
FULL SET, w=0.5	0.99362	3	1	3.1214	1.96
FULL SET, w=0.7	0.99143	3	1	3.1599	1.62
REDUCED SET, w=0.1	0.99093	**1.3603**	**1**	**2.8406**	**1.575**
REDUCED SET, w=0.5	0.9923	1.9369	1	2.8953	2.485
REDUCED SET, w=0.7	0.99278	2.3175	1	3.0281	2.005

CHAPTER 5

CONCLUSION

PMR systems are designed for communication between public safety users and for voice and data transmission in emergency situations. Both of APCO25 and DMR are two digital radio standards for PMR users. APCO25 and DMR group users need to communicate with each other or other groups of users as soon as possible and without waiting to attach a base station while establishing reliable transmission link. While providing these needs, the distribution of users to cells must be balanced so that overall system performance can be improved. In order to realize these demands, cell selection process has critical importance.

The proposed full set based and the reduced set based cell selection algorithms are aimed to balance the distribution of users to cells, reduce the waiting time and number of waiting users to attach any cell. In the proposed algorithms, a utility value is calculated based on RSSI value and the cell or traffic load of the BS. The significant difference between proposed algorithms is that in the reduced set based cell selection algorithm, the RSSI value of all BSs is not required to measure. In the load based cell selection algorithm, users are active for all simulation time. In the traffic based cell selection algorithm it is performed that user establishes a call with different duration at different time and cell reselection is considered for mobile users. In the load based cell selection algorithm, trunked DMR system is used, whereas conventional APCO25 system is implemented in the traffic based cell selection algorithm to obtain the simulation results. Trunked systems support more users than conventional systems and share channel capacity among many users. For small agencies, a conventional system is exactly ideal. However, when the number of groups or the number of users working on a system increases, trunking may be a better choice. Moreover, in terms of spectrum efficiency DMR is more efficient than APCO25 for the equal number of available channels.

The performance of cell selection algorithms have been obtained in urban, suburban and rural environments for different parameters including traffic load, weights and the number of indoor users. The proposed algorithms give better results compared to SINR and RSSI based cell selection algorithms in terms of the average delay counter, the number of waiting users and the waiting time. The RSSI measurement counter is decreased with the reduced set based cell selection algorithm.

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