Cell Load Based User Association for Professional Mobile Radio Systems

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Abstract

When the public communication networks can not provide service during disaster and high traffic cases, Professional Mobile Radio systems (PMR) such as trunked Digital Mobile Radio (DMR) systems are needed to improve the service quality and to provide uninterrupted service to the public safety officers. While providing continuous voice and data service, it is very important to select the base station (BS) to be served by efficient cell selection algorithms. The aim of the user association algorithms is to reduce the waiting time while establishing reliable transmission link for PMR systems in emergencies. In this sense, we propose the full set user association algorithm that each user selects the BS according to the calculated utility value determined based on both received signal strength indicator (RSSI) value and cell load information. The performance of the proposed algorithm is evaluated by considering different performance metrics for trunked DMR systems in urban area.

1. Introduction

PMR systems are designed for communication between public safety users and for voice and data transmission in emergency situations. DMR is one of a digital radio standard for PMR developed by the European Telecommunications Standards Institute (ETSI) and published in 2006. DMR targets a digital radio specification for professional, commercial and private radio users. DMR group users need to communicate with each other or other groups of users without waiting to attach a BS while establishing reliable transmission link. While providing these needs, the distribution of users among cells must be balanced so that overall system performance can be improved. In order to achieve these demands, cell selection process has critical importance. Cell selection must be uninterrupted in terms of users and also this process must provide all users a certain quality and continuous service. Cell selection uses different types of cell selection criteria such as 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.

In literature, several user association schemes have been given for HetNets. Considering conventional cell selection algorithm that user is assigned to the BS with maximum received power causes unequal cell association in HetNets. As a solution to this problem, [1] described the importance of considering both load balancing and interference management in cell selection process to achieve the throughput gain of multi tiering. 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. Cell range expansion (CRE) approach is applied in [2], [3]. In [2], the received power is biased by multiplying the received power by a value. Then, the BS with maximum biased power is selected for connection. However, bias values optimization is needed for achieving the desired system utility. [3] stated 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. In [4], the transmission power control (TPC) method was investigated in the heterogeneous networks that employs cell range expansion (CRE) and evaluates the cell-edge user throughput performance. In [5], a load balancing scheme for femtocell networks was presented to allocate femtocell user equipments to femtocell access points optimally in terms of fairness of per user capacity. The evolutionary game model was given to describe the dynamics of the cell selection process [6].

For DMR systems, conventional user association schemes ignore the cell load. When the cell load is not balanced in these systems, users have to wait in the queue since the number of available channels is limited. In order to cope with these problems, we propose a user association algorithm for DMR system. The main aim of the proposed 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 number of users is reduced while satisfying the BER requirements for reliable transmission. In [7], we considered biased SINR values instead of RSSI information for utility calculation. Besides, in [8], the proposed cell selection algorithm has been applied for TETRA based PMR systems instead of DMR. In TETRA systems, the coverage area of each BSs is less than DMR systems. Therefore, more BSs are needed for the same area in TETRA systems than DMR system.

This work has been supported by Republic of Turkey Ministry of Science, Industry and Technology under SAN-TEZ 0686.STZ.2014 Programme.

The paper is organized as follows; in Section II describes the system model. Section III introduces the proposed user association algorithm. Section IV is dedicated to the simulation parameters and the performance results. Finally, Section V yields concluding remarks.

2. System Model

In this paper, trunked DMR system is performed consisting U BSs and the total number of Z users in the whole area. DMR systems are divided into 3 Tiers. Tier I and Tier II are conventional, whereas we focus on Tier III that is trunked [9]. In trunked mode, there is a controller inside the infrastructure that provides to manage call set up and channel assignment. 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. Audio and data channels are managed with two TDMA time slots where each time slot acts as a separate communication path sharing the same radio 12.5 kHz channel width [10]. The modulation is 4FSK which creates four possible symbols at a rate of 4800 symbols/s, corresponding to 9600 bps [11]. Each u BS has a number of available channels M_u that can be calculated as following:

$$M_u = 2\frac{B_u}{\Delta f} \tag{1}$$

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.

There are two most widely used cell selection algorithms. The most 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 in dB scale is given as following:

$$\begin{aligned} RSSI_{u,k} = EIRP_u - PL_{u,k} - BuL_k - Sh_k - BL_k \\ +G_r - CL - Fading_{u,k} \end{aligned} \tag{2}$$

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 modeled by Rayleigh distribution, 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,

$$EIRP_u = P_u^t + G_t \tag{3}$$

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

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. Firstly, 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 it passes the threshold value ($RSSI_{th}$) and has enough capacity in terms of cell load, user connects to that BS:

$$u^{'} = \underset{1\leq u\leq U}{\arg\max}\ \overline{RSSI}_{u,k}, \quad \forall k \tag{4}$$

where $\overline{RSSI}_{u,k}$ is the average RSSI value. In order to obtain accurate received signal measurements, the average of 4 RSSI values of 60 ms is taken.

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. However, 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 ($RSSI_{rec}$) in case of enough capacity. Otherwise, user waits to connect to the BS which with the highest RSSI value. The performance results of RSSI based cell selection algorithm for DMR was given in [12].

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:

$$u^{''} = \underset{1\leq u\leq U}{\arg\max}\ \overline{SINR}_{u,k} \quad \forall k \tag{5}$$

where

$$\overline{SINR}_{u,k} = \frac{P_{u,k}}{INT_{u,k} + N} \tag{6}$$

where $P_{u,k}$ is the received power for user k from BS u and is calculated as in (2), $INT_{u,k}$ 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.

RSSI based cell selection algorithm is commonly used for DMR systems because of its simplicity. However, RSSI based cell selection algorithm does not consider the cell load while assigning users to the BSs and users have to wait to attach any BS. In order to cope with these problems, a load based full set user association algorithm is proposed that enables user to select best serving cell and additional factors are put into consideration other than highest SNR or RSSI. The proposed user association algorithm considers both cell load and RSSI values. The basic idea is to balance the number of users among the cells and reducing the number of waiting users to attach any cells.

3. Load Based Full Set Cell Selection Algorithm

The flowchart of the full set cell selection algorithm is given in Fig. 1. The proposed algorithm can be explained in the following:

- 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 $RSSI_{rec}$:

$$\mathbb{P}_k = \left\{\overline{RSSI}_{u,k} \geq RSSI_{rec}; u \in 1, 2, ..., U\right\}. \tag{7}$$

- 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 considering both RSSI value and cell load parameter.

$$U_{u,k} = wf(\overline{RSSI}_{u,k}) + (1-w)g(UCL_u), \forall u \in \mathbb{P}_k \tag{8}$$

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 values.

The UCL_u is calculated and broadcasted by BS as following [7]:

$$UCL_u = (1-c)\frac{A_u}{M_u} + c\frac{I_u}{K_u} \quad (9)$$

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 (1) and K_u is calculated by,

$$K_u = N_u - M_u \quad (10)$$

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,

$$k_{u^*} = \arg\max_{u \in \mathbb{P}_k} \; U_{u,k}. \quad (11)$$

- Inactive user registers to the highest utility valued BS. If user is active user, it is checked whether the BS has enough capacity. However, 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 mapping table. Finally, each BS broadcasts the corresponding index belonging its mapped value to all users at every predefined time slots.

4. Simulation Parameters

In order to perform the user association algorithms, **urban** environment is used. The frequency reuse factor is taken as $1/3$.

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. Hata path loss model is used and indoor users experience extra building loss. The percentage of active users determines the traffic load in the cell. High traffic load cases results are given since high traffic is more critical case in terms of cell load.

The simulation parameters for trunked DMR system are given in Table 1.

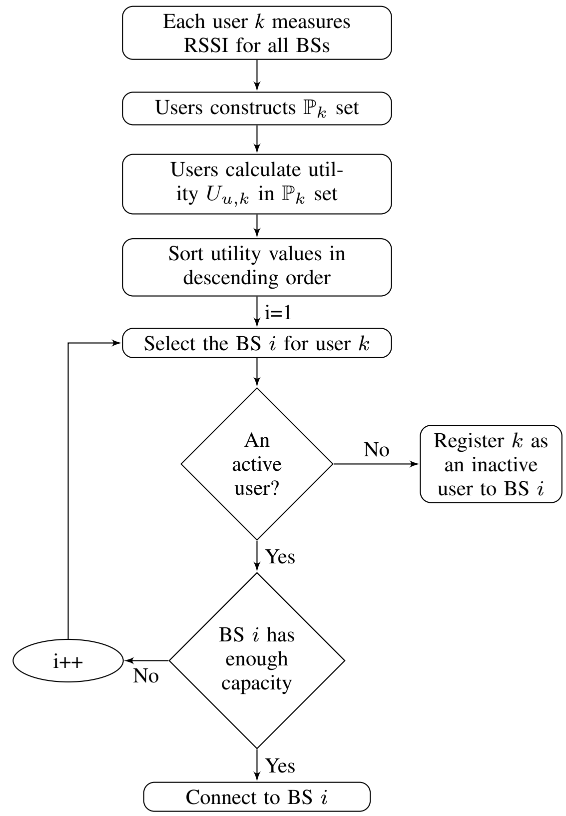

Fig. 1. Flowchart of load based full set cell selection algorithm

Table 1. Simulation parameters

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
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	40%

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

Fig. 2. Same colors show the same frequency.

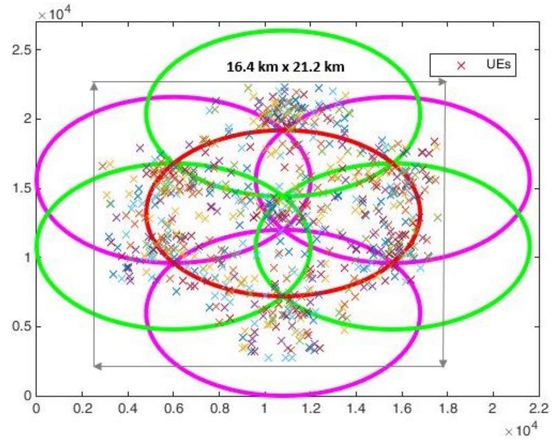

Fig. 2. Cell planning for trunked DMR system in urban area

Table 2 shows the total area, the number of available channels per cell, cell radius and the percentage of active users for urban environment.

Table 2. Urban area simulation parameters

Parameter	Setting
Area	16.4 km x 21.2 km
Available Channels per Cell u (M_u)	32
Percentage of Active Users	31%
Cell Radius	6 km

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

Firstly, RSSI values belonging to all BSs in $\mathbb{P}_k$ set given by (7) 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. This table is given for 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. 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

The function $g(.)$ calculates the cell load parameter that is modeled non-linearly to remark the high traffic behavior properly as given in Table 4. 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 (9), 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 no available channel, BS broadcasts a value so that the user does not try to connect to that BS.

Table 4. 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

The performance results of the full set based cell selection algorithm with various weights are compared with RSSI and SINR based cell selection algorithms. Different performance metrics are used such as average delay 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 number of waiting active user** is increased when an active user can not connect to any BS. **Load fairness index** is calculated to evaluate the fairness of the users' association among BSs by

$$JI = \frac{Z^2}{U \sum_{j=1}^{U} (A_u^2 + I_u^2)}. \tag{12}$$

The higher load fairness index represents a higher balanced among BSs. 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.

4.1. Simulation Results

Table 5 shows the simulation results in high traffic with 40% indoor users for the urban area. The numerical results show the full set algorithm with weight $w = 0.1$ give the best performance in terms of the number of waiting active users and average delay counter. As provided in Table 5, the number of waiting active user is reduced by 59.8% with the full set $w = 0.1$ algorithm compared with the RSSI based algorithm. The reason is that when the w is set to 0.1, cell load becomes more important than RSSI as given in the (8). The number of waiting active user is high for SINR and RSSI based cell selection algorithms since these algorithms do not consider cell load. The full set algorithm with different weights have the lowest average delay counter. This means that user is registered to the BS at the first trial on the averagely. Since the BS in the middle 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. All cell selection algorithms provide the desired BER performance.

Table 5. Urban area results with high traffic

Algorithms	Load Fairness Index	RSSI Measurement Counter	Average Delay Counter	Number of Waiting Active User	Outage Probability
SINR BASED	0.63284	7	1.1302	12.7333	0.013
RSSI BASED	0.98923	6.3719	1.0414	9.0333	0.012
FULL SET, *w=0.1*	0.98943	**7**	**1**	**3.6333**	0.028
FULL SET, *w=0.5*	0.99098	7	1	6.2	0.015
FULL SET, *w=0.7*	0.99154	7	1	8.6333	0.013

5. Conclusion

For public safety services, uninterrupted and fast communication are very crucial. DMR is one of PMR standard to meet the needs of traditional PMR organizations such as public safety, transportation, government and military. PMR users must get service from a BS in a short period of time. Thus, cell selection algorithms are used to decide the BS based on different criteria. The load based full set cell selection algorithm has been proposed by calculating a utility value including RSSI and cell load information. The proposed full set algorithm gives better performance compared to SINR and RSSI based cell selection algorithms in terms of the average delay counter and the number of waiting users. The numerical results have showed that as the weight value increases in the full set algorithm, 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. As a result of the proposed, users are distributed to BSs in balance manner and the number of waiting user decreases. All cell selection algorithms provide required BER performance.

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