Cell Load Based User Association For Tetra Trunk Systems

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Abstract

Increasing traffic in communication systems need efficient new cell selection algorithms to control the distribution of users. For better and seamless transmission, load balancing become critical factors for cell selection algorithms. Undesired consequents in these situations may cause disasters specifically for the emergency cases in public safety services. In this paper, a cell selection algorithm is proposed for Terrestrial Trunked Radio (TETRA) based Professional Mobile Radio (PMR) systems. The proposed algorithm is designed to provide a fairer distribution of users among cells while keeping the number of received power measurement less. The performances of the proposed algorithm are obtained in urban and rural environment.

1. Introduction

Developing mobile communication sector borns new requirements every day. Professional applications need dedicated systems rather than public cellular systems which provides reliable voice and data communication. This is the main reason of PMR systems to come up. In PMR systems, users have their own dedicated channel to communicate and TETRA is the digital PMR standard which satisfies the current needs.

Recently, the demand of PMR has been dramatically increased for public safety network in wireless communications. This causes the need for higher bandwidth efficient systems and traffic management. TETRA is one of the promising solution and bandwidth efficient standard published by European Telecommunication Standards Institute (ETSI) in 1995. TETRA is a technical platform with data and voice services and targeted for the needs of emergency services, government agencies, military and transport services. TETRA base stations supports antenna diversity techniques such as selection diversity, equal gain combining and maximal ratio combining which improve the Bit Error Rate (BER) of users.

There are different techniques and choices to be taken into account. In order to establish seamless connection or make a quick call, a cell selection becomes critical decision. Making an urgent call plays vital role for emergency and security services.

While in distance based cell selection algorithm [1], which is one of the conventional methods, users are assigned to the closest BS, in the received signal strength indicator (RSSI) based cell selection method [2], users attach to the BS with the maximum RSSI value. In these cell selection algorithms without cell load consideration may cause undesired consequents due to the limited number of available channels in the system.

To satisfy the requirements of PMR systems such as fast call setup time and seamless connectivity, the cell selection processes must include the effect of cell loads. In the earlier work of [3], the cell selection algorithm attached the users to minimum loaded cells and minimizes the call blocking ratio while maximizing the throughput of traffic control. For mobile systems, an algorithm called Mobility Load Balancing (MLB) was examined in [4] for more efficient resource utilization. Another cell selection algorithm [5] was given by formulating the utility maximization problem in order to achieve proportional fairness for all users. Another work in [6], transmitter power levels of users were adapted to transfer the high network loads to less loaded cells. This load balancing procedure results in relieve for local networks. In [7], an n-dimensional Markov chain based load balanced method was examined to offload the excess traffic. All these works point to the importance of balanced distribution of users as a cell selection parameter.

In this paper, we proposed a cell selection algorithm considering both cell loads of the system and received power values of users. The proposed reduced set cell selection algorithm minimizes the waiting time for users which corresponds to call setup time. In the proposed algorithm, the assignment of users is determined by the calculated utility values in the constructed set. Different from [8], construction of the sets targets the less number of RSSI measurement.

The rest of the paper is organized as follows. In Section II, Tetra based PMR systems and SINR based cell selection algorithms are explained. In Section III, the proposed reduced set cell selection algorithm is described in detail. Then, performance evaluations are discussed in Section IV and the paper is concluded in Section V.

2. System Model

TDMA technique provides four user channels on one radio carrier and the channel spacing (Δf) between radio carriers is 25 kHz as shown in Figure 1. Modulation scheme used in Tetra standard is π/4 DQPSK [9]. The π/4 DQPSK modulation is one of the most widely used modulation schemes for wireless applications and data is encoded in the change in the phase. One of the biggest advantages of this modulation scheme is that it can be differentially detected.

Each BS u has a total number of time slots M_u that can be

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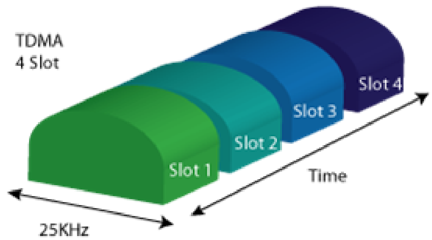

Figure 1. TDMA technique for TETRA

calculated as follows:

$$M_u = 4\frac{B}{\Delta f} \tag{1}$$

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

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

$$\begin{aligned} RSSI_{u,k} = EIRP_u - PL_{u,k} - BuL - Sh_k - BL \\ + G_r - CL_r - fading \end{aligned} \tag{2}$$

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

$$EIRP_u = P_t + G_t - CL_t \tag{3}$$

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

In Tetra Based cell selection algorithm, the users first calculate C1 path loss parameters belonging to each BS [9]:

$$\begin{aligned} C1_{u,k} = Pr_{u,k} - Rec\_Sens \\ - Max(0, Ms\_TxPwr\_Max\_Cell - P_{MSMAX}) \end{aligned} \tag{4}$$

where $Pr_{u,k}$ is the received power of user *k* from BS *u*, *Rec_Sens* denotes minimum acceptable received power at the mobile user, *Ms_TxPwr_Max_Cell* stands for the maximum allowable transmit power at that channel and P_{MSMAX} is the maximum transmit power for π/4 DQPSK modulation.

After C1 path loss calculation, each user adds the BS that has C1 higher than 0 to their candidate sets. These cells are sorted in descending order and users attempt to attach the first BS with available capacity. The BS is called available if it has enough time slots for the user to be attached [10].

In the other conventional cell selection algorithm, which is the signal to interference and noise ratio (SINR) based cell selection algorithm, each user selects the BS with the strongest SINR value [11].

$$u_k^* = \arg\max_{1 \le u \le U} \ SINR_{u,k} \quad \forall k. \tag{5}$$

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

$$SINR_{u,k} = \frac{Pr_{u,k}}{I_k + N_0 B_t} \tag{6}$$

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

$$I_k = \sum_{j=1, j \neq u}^{u'} Pr_{j,k} \tag{7}$$

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

3. Proposed Algorithm

The proposed load based reduced set cell selection algorithm focuses on to minimize the number of RSSI measurements while considering balanced distribution of users among all BSs. The proposed reduced set algorithm focuses on to minimize the number of RSSI measurement instead of measuring RSSI values of all BSs in the system as in our previous work [8]. This approach make reduced set algorithm more suitable for practical systems. The proposed algorithm works as follows:

3.1. Neighbor Cells Set Construction

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

3.2. Utility Value Calculation

For user *k*, the utility value is determined by each user by considering RSSI value and corresponding index broadcasted from BSs according to calculated unmapped cell loading (UCL) information. UCL value of a BS *u* is calculated as [8]:

$$UCL_u = c\frac{A_u}{M_u} + (1-c)\frac{I_u}{K_u} \tag{8}$$

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

M_u and K_u are defined as the maximum number of active and inactive users per BS in all system, respectively. M_u is defined in Eq. (1) and K_u can be calculated as:

$$K_u = \frac{N_u - X_u}{N_b} \tag{9}$$

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

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

$$U_{u,k} = wf(Pr_{u,k}) + (1-w)g(UCL_u), \forall u \in \mathbb{Z}_k \tag{10}$$

where the $Pr_{u,k}$ is the averaged received power of user *k* from BS *u* and UCL_u stands for the unmapped cell load value of the BS *u*. Here w is the weight of RSSI and $(1-w)$ is the weight of mapped cell loading (MCL). The function *f(.)* gives the normalization value of measured RSSI and *g(.)* function normalizes the unmapped cell load value to mapped cell load value.

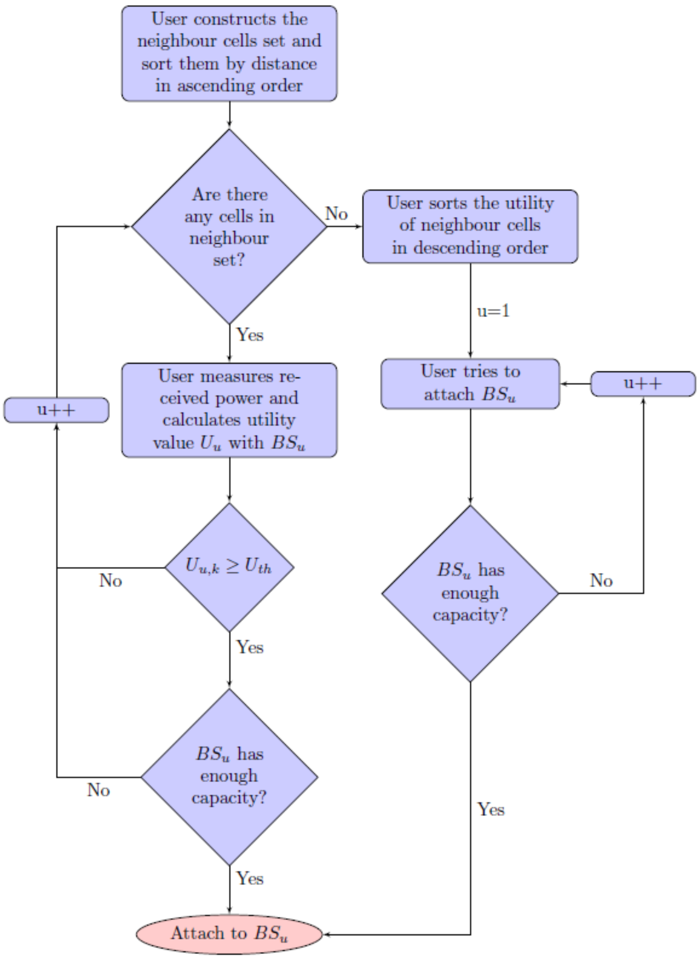

Figure 2. Flowchart of the proposed algorithm

3.3. Assignment of Users

If the calculated utility value of the cell is higher than defined utility threshold value, U_{th}, user attaches to this BS. If this utility threshold value is not satisfied, user connects the next cell in the neighbor set, $\mathbb{Z}_k$, one by one. In case, there are no cells that satisfies this utility threshold value, then user tries to attach to BS with the maximum calculated utility value.

When there are no cells satisfying this threshold in neighbor cells set, user calculates received powers of all remaining BSs and attaches to available one. The flowchart of proposed algorithm is in Figure 2.

4. Performance Evaluations

We provide performance results considering urban and rural environments. There are only voice users which needs to allocate only one physical channel. Hata path loss model [12] is used for the urban and rural environments and indoor users experience extra building loss. The percentages of active users determines the traffic load in the system. The simulation parameters are given in Table I.

While calculating utility value, the mapping functions are applied based on pre-defined f(.) and g(.) functions. The RSSI value of BS is measured and then the corresponding RSSI value

Table 1. Simulation parameters

PARAMETERS	TETRA
Transmit Power	44 dBm (25 W)
Modulation Bandwidth	20 kHz
Channel Spacing	25 kHz
Noise Spectral Density	-174 dBm/Hz
Shadowing	6 dB
Receiver Sensitivity	-115 dBm
TX Antenna Gain	8 dB
TX Cable Loss	6 dB
RX Antenna Gain	-2 dB
RX Cable Loss	0 dB
BS Antenna Height	30 m
MS Antenna Height	1.5 m
Building Loss	16.5 dB
Weight of RSSI (w)	0.2, 0.5, 0.8
c	0.9
U_{th}	0.5

is assigned according to Table 2. For the cell load, the mapped values are assigned based on Table 3 according to broadcasted unmapped cell load value. In the Tetra system, BSs broadcast their cell loads by using 2 bits.

Table 2. Normalization Values of Measured RSSI Values in f function

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

Table 3. Mapping of Unmapped Cell Load Values in g Function

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

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

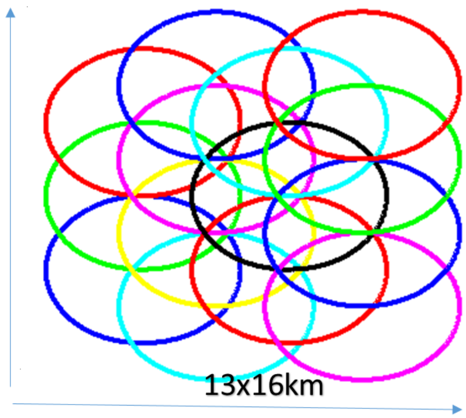

Figure 3. Urban Area

4.1. Urban Environment

Urban area cell model is shown in Figure 3. In this area, there are uniformly distributed 600 users and 14 BSs. Each BS has 24 channels (one for control) which corresponds to 6 physical carrier and 150kHz. Frequency reuse factor is used as $1/7$. Only high traffic situations are considered and 50% of users are active. High traffic percentage is chosen as to make all channels of BSs full.

The performance results of the cell selection algorithms with 20% of users are indoor shown in Table 4 and Table 5.

Table 4. Urban area results for cell load based system

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

While examining the high traffic results for urban environment in Table 4, the most obvious point is the increment in the number of waiting users due to increasing number of calls. The proposed algorithms reduce the number of waiting users about 35% according to Tetra based and 50% according to SINR based algorithm. The proposed reduced set with w=0.2 algorithm gives the best result due to higher importance of cell load value. The higher w value, means the higher importance on RSSI value, gets lower performance on number of waiting users.

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

The drastic results of the proposed reduced set cell selection algorithm can be observed in terms of the number of RSSI measurement. While the users in SINR and Tetra based algorithms attach any BS with 14 RSSI measurements, in the reduced set algorithms, the number of RSSI measurements are much less than other algorithms. We can observe the best result in the proposed reduced set algorithm with RSSI weight 0.2.

Table 5. Outage probabilities of urban area

Algorithms Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.05494	0.03471
TETRA Based	0.02077	0.01043
Reduced Set with w=0.2	0.03405	0.01877
Reduced Set with w=0.5	0.03145	0.01877
Reduced Set with w=0.8	0.02604	0.01396

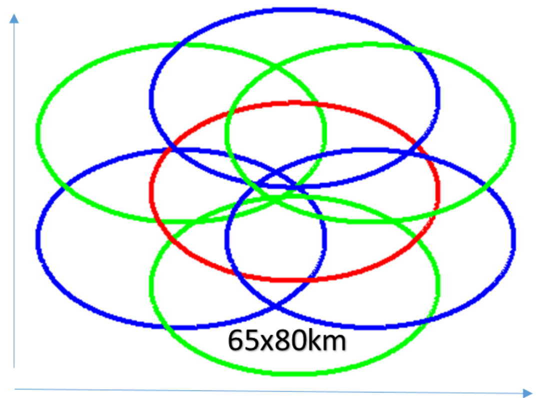

Figure 4. Rural Area for Load Based System

In Table 5, outage probabilities are given with the 5% BER target. Furthermore, it is observed that the diversity in uplink reduces the BER.

4.2. Rural Environment

Rural area cell model is shown in Figure 4. In this area, there are uniformly distributed 200 users and 7 BSs. Each BS has 8 channels (and one channel for control usage) which corresponds to 2 physical carriers and 50kHz. Frequency reuse factor is used as $1/3$.

Performance results of cell selection algorithms with 20% of users are indoor and for %50 active users are shown in Table 6 and Table 7, respectively.

While examining the high traffic results for rural environment in Table 6, similar behavior is observed as urban area. The proposed reduced set algorithm with w=0.2 reduces the number of waiting users about 50% according to both SINR and Tetra based algorithms. Again, from Table 7, outage probabilities of all algorithms are below 5%.

Table 6. Rural area results for cell load based system

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

Table 7. Outage probabilities of rural area

Algorithms Results	Outage Probability without Diversity	Outage Probability with Diversity
SINR Based	0.04595	0.03312
TETRA Based	0.02575	0.01588
Reduced Set with w=0.2	0.04300	0.02543
Reduced Set with w=0.5	0.04049	0.02543
Reduced Set with w=0.8	0.03181	0.01780

5. Conclusion

Cell selection algorithms have key role for traffic management. Therefore, a cell selection algorithm considering fair distribution of users can overcome this issue. In this paper, a cell selection algorithm for Tetra system has been proposed. In the proposed algorithm, both received power of users and cell load of BSs have a weight in utility function which decides the serving BS. Since the minimum number of RSSI measurement is targeted in the proposed algorithm, users attach the BS after calculating utility value. The performance results for different weight values for urban and rural scenarios have been obtained. Performance evaluations show that the fairly balancing of users reduces the number of waiting users in cell load based system. All these improvements in results occurred while satisfying the BER demands of users.

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