Telecommunication Systems (2019) 72:1–10
https://doi.org/10.1007/s11235-018-00540-w

Traffic aware cell selection algorithm for Tetra Trunk based professional mobile radio

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Published online: 3 January 2019

Abstract
Load balancing and traffic management are the critical needs in cell selection decision for a better and seamless communication demands in professional mobile radios. For the cases where cell selection algorithms do not consider the traffic load, there may be call drops due to the congestion in networks or longer call setup times for the users. These undesired consequences can cause dramatic quality degradation especially for the emergency cases or public safety services. In this paper, we propose two algorithms for Tetra Trunk based professional mobile radios by considering both traffic load and received signal strength indication (RSSI) in order to reduce the significant delays while establishing transmissions. The proposed full set cell selection algorithm is prioritized to reduce the call setup time for the mobile users and the proposed reduced set cell selection algorithm is focused on minimizing the number of RSSI measurements which causes significant delay in practical professional mobile radio. We illustrate the performance results in terms of delay for Tetra Trunk based professional mobile radio.

Keywords Tetra Trunk · Professional mobile radio · Cell selection algorithm · Traffic aware

1 Introduction

Recently, the demand for Professional Mobile Radio (PMR) has been dramatically increased for public safety network in wireless communications. This causes the need for higher bandwidth efficient systems and traffic management. Terrestrial Trunked Radio (Tetra) is one of the promising solutions 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 (BSs) support antenna diversity techniques such as selection diversity, equal gain combining and maximal ratio combining. The studies have shown that [1] selection diversity improves the Bit Error Rate (BER) significantly for Tetra systems. Due to the limitations of available bands, efficient cell selection algorithms are required to guarantee the demands for PMR systems, as seamless connectivity and fast call setup time.

In the literature, there are several efficient cell selection algorithms for the cellular systems. In order to distribute the traffic load in mobile systems fairly, mobility load balancing has been presented in [2] to improve the efficiency of resource utilization. In [3], traffic load scheme has been examined while maximizing the throughput of traffic control. while assigning the users to the cell with minimum load to minimize the call blocking ratio. In [4], the congested network load has been transfered to less congested network by adapting transmitter power level of users and switching them between cell sites. In [5], a coalitional game has been formulated for joint cell selection and resource allocation problem. The cell selection algorithm in [6] has been balanced the load to offload the excess traffics based on n-dimensional Markov chain.

In [7], cell selection process has been applied with a competition based among group of users. Each user in groups selects the cell with the minimum required transmit power.

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The results of this approach gives better performance in terms of number of supportable users and transmit power levels for a target SINR value. In [8], a cell selection algorithm has been presented to improve the system energy efficiency of small cell networks by considering both user equipment and backhaul link data rate constraints. In [9], the cell selection algorithm has considered both load balancing and total energy consumption. The users are assigned to the femtocells considering the capacity improvement obtained per unit increase in transmit power. In [10], a cell selection problem has been formulated as hidden Markov model by creating a candidate set and targeting handover base station (BS) to observe and predict cell load information of BSs.

The cell selection algorithms for the cellular networks have not been applied directly to Tetra Trunk based PMR systems. In this paper, we propose two cell selection algorithms by taking into account both traffic load and received signal strength indication (RSSI) values. The goal of the proposed traffic aware full set cell selection algorithm is to reduce call setup while the objective of the proposed traffic aware reduced set cell selection algorithm is to minimize also the number of RSSI measurements. Compared to the our previous works in [11] in which the cell load has been calculated by using the number of connected users, in this work, we determine the traffic load based on the call duration in a realistic Tetra Trunk scenario including a cell re-selection procedure.

The rest of the paper is organized as follows. In Sect. 2, system model is given. In Sects. 3 and 4, the proposed traffic aware full set and reduced set cell selection algorithms are described in detail. Then, the performance evaluations are provided in Sect. 5 and the work is concluded in Sect. 6.

2 System model

Time Division Multiple Access technique in Tetra Trunk standard provides four user channels on one radio carrier and 25 kHz spacing between carriers by using $\pi/4$ DQPSK modulation scheme [12]. Each BS u has a total number of timeslots M_u:

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

where B represents the bandwidth and Δf is the channel spacing. One of these time-slots is used for control and the users can have several time slots to obtain higher transmission capacity.

Each user k measures instantaneous RSSI value for the BS u as follows:

$$RSSI_{u,k}(dB) = EIRP_u - PL_{u,k} - BuL - Sh_{u,k} - BL + G_r - CL_r - F_{u,k} \tag{2}$$

where $PL_{u,k}$ is path loss between user k and the BS u, BuL is building loss, $Sh_{u,k}$ is log-normal shadowing, BL is body loss, G_r is receiver antenna gain, CL_r is receiver cable loss and $F_{u,k}$ is fading coefficient. $EIRP_u$ is effective isotropic radiated power value for the BS u:

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

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

In C1 based cell selection algorithm [13], all users firstly calculate the loss parameter for the BS u [12]:

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

where $Pr_{u,k}$ is the received power of user k from the BS u obtained by averaging N_s consecutive RSSI values, *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 $\pi/4$ 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 to the first BS with available capacity. The BS is called available if it has enough time slots for the user to be attached.

3 Proposed traffic aware full set cell selection

In the proposed traffic aware full set cell selection algorithm, the system focuses on the distribution of users over the BSs which affects directly the system performance in terms of delay. Therefore, the proposed full set algorithm is not take into account the total number of RSSI measurements while establishing transmission link. The procedure of the proposed full set algorithm is given in the following:

1. Constructing the set based on receiver sensitivity:
   Each user k measures the RSSI values from all BSs and then add the index of BS into set $\mathbb{P}_k$ satisfying the criterion given below.

$$\mathbb{P}_k = \left\{u \in N_b : RSSI_{u,k} \geq RSSI_{th}\right\}. \tag{5}$$

where N_b is the total number of BSs in the considered system and $RSSI_{th}$ is the receiver sensitivity.

2. Calculating the utility value:
   For user k, utility value is calculated by considering the RSSI values and traffic load information.
   At each BS, the unmapped traffic load (UTL) information is determined by,

$$UTL_u = (1-c)\frac{I_u}{N_u/N_b} + c\frac{1}{M_u}\frac{H}{D} \quad (6)$$

   where I_u is the number of inactive users which can not establish a call yet, N_u is the total number of users H represents the duration of talks of active users in seconds, D stands for the defined time interval and c is the weight for the active users. BSs include the total traffic volume of defined time interval in their cell broadcast information. Each BS broadcasts the index of UTL_u obtained from the predefined table given in the next sections.
   In Tetra Trunk systems, all users measures RSSI values and obtain the UTL information from all BSs in a given time interval. Then, the user k calculates the utility values for all BSs:

$$U_{u,k} = wf(RSSI_{u,k}) + (1-w)h(UTL_u), \quad \forall u \in \mathbb{P}_k \quad (7)$$

   where w is the weight of either RSSI or UTL value, the function $f(.)$ is mapped the measured RSSI to the sorted RSSI, the function $h(.)$ transforms the UTL value to the mapped traffic load value. These mapping functions will be given in the next sections.
   For initial cell selection, BSs broadcast a traffic load information by considering only the number of inactive users attached to the BSs. Therefore, for the initial UTL calculation, c parameter is set to 0 since there will be no active users and no calls occurred.
   For cell re-selections, in addition to the inactive users term, UTL value includes a term keeping history of talking time duration of active users for the last defined traffic duration.
3. Attaching to the BS:
   In order to reduce the delay, the user k sends a request for attaching to the BS with the highest utility function as:

$$u_k^* = \underset{\forall u \in \mathbb{P}_k}{\text{argmax}} \; U_{u,k} \quad (8)$$

The flowchart of the traffic aware full set cell selection algorithm for each user k is given in Fig. 1.

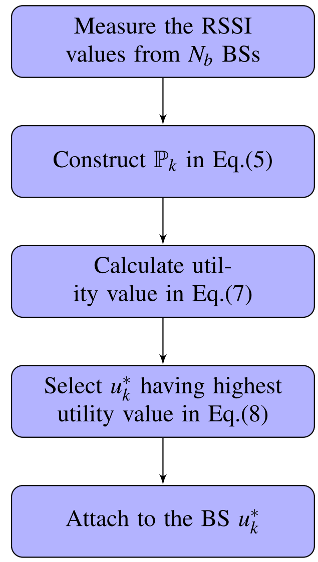

Fig. 1 Flowchart of the proposed traffic aware full set cell selection algorithm

4 Proposed traffic aware reduced set cell selection

The proposed traffic aware reduced set cell selection algorithm considers both the traffic load in the cells while shortening the elapsed time to attach to a BS. One of the main causes of this delay is to obtain RSSI measurements from all BSs. Since the proposed reduced set algorithm intends to decrease the elapsed time by reducing the RSSI measurements unlike the proposed full set algorithm. While reducing the connection time, the proposed reduced set algorithm also takes into account the traffic load by assigning the users to the BSs fairly. The unbalanced distribution of users among cells may cause higher waiting time to communicate because of the limited number of available channels in Tetra Trunk. The proposed traffic aware reduced set cell selection is described as follows:

1. Constructing the neighbour cells set:
   With the aid of global positioning system (GPS), the users create their set of neighbour cells, $\mathbb{Z}_k$ and sort them in ascending order. Then, all users measure the RSSI values of the BSs starting from the nearest one.
2. Calculating the utility value:
   All users calculate their utility values starting from the first BS in the set $\mathbb{Z}_k$ as:

$$U'_{r,k} = wg(RSSI_{r,k}) + (1-w)h(UTL_r) \quad \forall r \in \mathbb{Z}_k \quad (9)$$

   where the function $g(.)$ is mapped the measured RSSI value to the normalized RSSI. This mapping function will be described in the next sections.

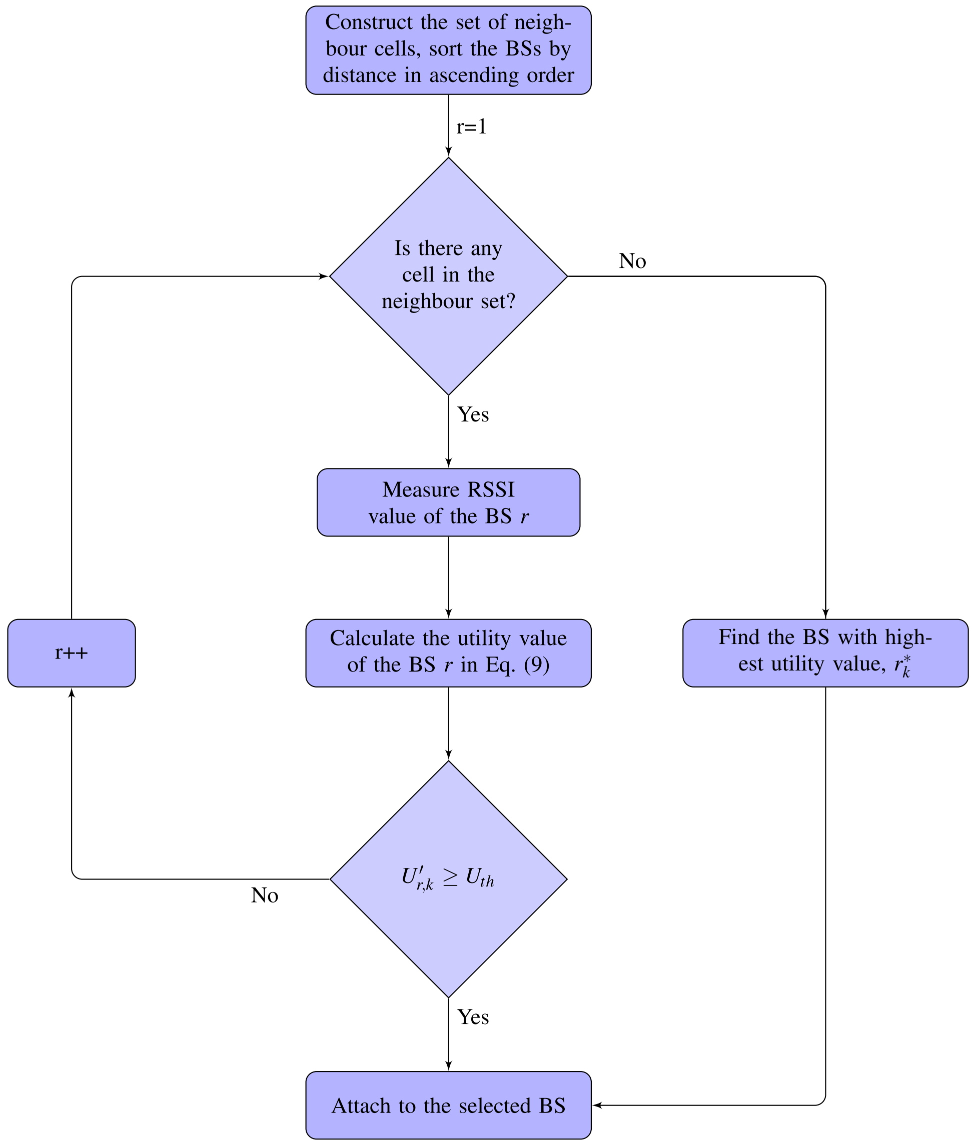

Fig. 2 Flowchart of the proposed reduced set cell selection algorithm

3. Attaching to the BS:
   If the corresponding utility value is higher than a defined utility threshold value, U_{th}, the user attaches to this BS. If this condition is not satisfied by this BS, the user connects the next cell in its neighbor set one by one. If there are no cells that satisfies this utility threshold value, then user attaches to the BS having the highest utility value.
   The flowchart of the proposed traffic aware reduced set cell selection algorithm is given for each user k in Fig. 2.

5 Performance evaluations

In order to implement the practical Tetra Trunk PMR scenario, the users are divided into a number of groups. The group calls can only occur between the same group in which the users can be both inactive and active during simulation time. All talks in group conversations are arranged by considering short talk duration within 5 and 15 s. The number of active users in the groups is determined with the probability of push-to-talk (PTT). These group talks are broadcasted by BSs to all users in the group so that each listener user does not need for an assigned channel. Channels are occupied by active users who establish a talk. If the serving cell has no available channel for the active user, then the user is queued by this BS. Therefore, this user must wait until there

Table 1 Users with mobility information

User type	Velocity
Immobile	0 km/h
Pedestrian	Up to 3 km/h
Vehicle	Up to 80 km/h

Table 2 Sorted RSSI values in f function for the full set

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

Table 3 Normalized RSSI values in g function for the reduced set

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

is an available channel in the serving cell. While obtaining the RSSI value for the cell selection, the average of $N_s = 5$ samples spread over at least 300 ms is taken in [15]. The flat fading channel is generated by Rayleigh distribution and the mobility is modelled by using Jakes' method. All users are randomly located in the cells.

The users are characterized with velocities up to the values given in Table 1. The mobile users can perform the cell re-selection depending on their mobility and location in the cell. If their RSSI values are less than the given RSSI re-selection threshold during the last 10 measurements, the users detach from the serving cell and attach to the new one.

The sorted of RSSI values are obtained by using f function in which measured RSSI values from all BSs are simply sorted and assigned to a normalized value according to Table 2. The normalized RSSI values are mapped using fixed intervals in g function according to Table 3. Since the RSSI values are more intense in certain intervals, nonlinear mapping is applied to them.

All BSs calculate their UTL values at 1 second and then calculate the averaged value over the last 60 ones. Then, all BSs broadcast the corresponding index value at every second by using 2 bits as given in Table 4. Since the calculation of

Table 5 Simulation parameters

Parameters	Tetra Trunk
Defined time interval (D)	1 min
Total simulation time	30 min
Re-selection threshold	−100 dBm
Weight of RSSI (w)	0.2, 0.5, 0.8
Percentage of indoor users	20%
Percentage of pedestrian users	50%
Percentage of vehicle users	30%
U threshold	0.5
c (initial cell selection)	0
c (cell re-selection)	0.2

UTL values is different for initial and cell re-selection cases, the mapping values are given for these two cases separately.

The performance metrics are the number of RSSI measurements and the number of requests while attaching to a BS, and the average waiting time to establish communications. In addition to that, the outage probabilities in which the mobile user is not able to acquire the required BER in whole transmission time ($P_{out} = Pr(BER_{u,k} < BER_{th})$ where $BER_{th} = 0.025$), are provided for all cell selection algorithms.

The simulation parameters for the proposed traffic aware system are listed in Table 5. The performance results are provided for urban, rural and suburban environments by choosing the frequency reuse factor is 3. Then, the three frequencies which are 415 MHz, 415.2 MHz and 415.4 MHz are assigned to the BSs.

For urban area, Hata path loss model [15]:

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

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

Table 4 Mapping traffic load values in h function

Calculated UTL for initial selection	Averaged UTL for cell re-selection	Index	$h(.)$
0 - 0.7	0 - 0.6	1	1
0.7 - 1.2	0.6 - 1	2	0.66
1.2 - more	1 - more	3	0.33
None	No available channel	4	0

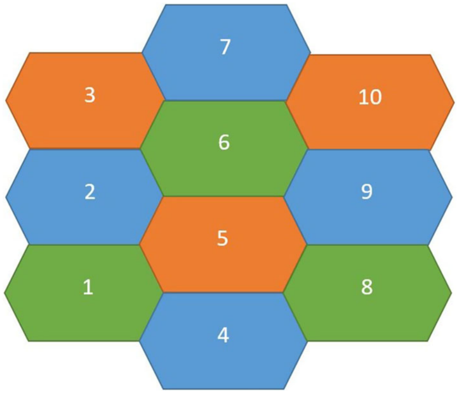

Fig. 3 Urban cell planning

For rural area, Hata path loss model [15]:

$$\begin{aligned}\mathrm{PL_{u,k}}(\mathrm{dB}) = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b \\ - (1.1\log_{10}(f_u) - 0.7)h_m \\ + (1.56\log_{10}(f_u) - 0.8) \\ + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} \\ - 4.78 * (\log_{10}(f_u))^2 \\ + 18.33 * \log_{10}(f_u) - 40.94 \qquad (11)\end{aligned}$$

For suburban area, Hata path loss model [15]:

$$\begin{aligned}PL_{u,k}(dB) = 69.55 + 26.16\log_{10} f_u - 13.82\log_{10} h_b \\ + (44.9 - 6.55\log_{10} h_b)\log_{10} R_{u,k} \\ - 2(\log_{10}(f_u/28))^2 - 5.4 \qquad (12)\end{aligned}$$

The antenna height of BS and the mobile device are 30m and 1.5m, respectively.

As shown in Fig. 3, in the urban environment, there are 10 BSs and 500 users which are divided into 10 groups and PTT is chosen as 0.6. Therefore, there are 300 talking users in every minute. All BSs have 8 time slots (one for control purposes) which corresponds to 2 physical channels with 50 kHz. Inter-site distances are chosen as 6.5km for urban, 9km for suburban and 28.5km for rural environment.

The performance results for the urban environment are shown in Table 6. The proposed traffic aware algorithms give better performance than C1 algorithm in a manner of the average waiting time. While the proposed full set algorithm with $w = 0.2$ reduces the waiting time about 20% than C1 algorithm, the proposed reduced set algorithm with $w = 0.2$ reduces it about 15%. The number of RSSI measurements is decreased around 55% for the proposed traffic aware reduced set algorithm. With the increasing weight value in the proposed traffic reduced set algorithm, it is observed that the number of RSSI measurements is increased. The average number of requests is decreased about 30% for the proposed traffic aware algorithms. As given in Table 7, it is seen that the diversity has important effect on BER performances and the outage probabilities are below 0.05, which is the required quality of service for Tetra Trunk PMR systems.

In the rural environment, the cell model is given in Fig. 4 including 5 BSs and 100 users with 3 groups. Only the BS at

Table 6 Performance results for the urban area

Algorithms results	Numberof RSSI measurements	Numberof requests	Average waiting time (s)
C1	10	1.2115	2.5994
Cell load in [11]	10	1	2.3251
Full set traffic w = 0.2	10	1	2.1247
Full set traffic w = 0.5	10	1	2.1656
Full set traffic w = 0.8	10	1	2.3148
Reduced set traffic w = 0.2	3.049	1	2.3454
Reduced set traffic w = 0.5	3.1811	1	2.2552
Reduced set traffic w = 0.8	3.4713	1	2.3451

Table 7 Outage probabilities for the urban area

Algorithms results	Outage probability without diversity	Outage probability with diversity
C1	0.071454	0.027415
Cell load in [11]	0.0719	0.0295
Full set traffic w = 0.2	0.0742	0.030763
Full set traffic w = 0.5	0.0761	0.032031
Full set traffic w = 0.8	0.07079	0.02884
Reduced set traffic w = 0.2	0.0797	0.037013
Reduced set traffic w = 0.5	0.08533	0.041533
Reduced set traffic w = 0.8	0.08821	0.042558

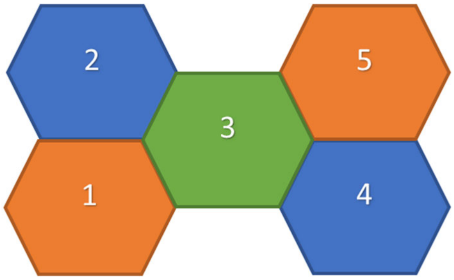

Fig. 4 Rural environment cell planning

the center of the area has a different frequency. The probability of PTT is 0.35 which results in 35 talking users in every minute. Since traffic volume is less in rural environments, 4 time slots (one channel for control channel) are assigned to each BS. This requires 25 kHz bandwidth with 1 physical channel.

The performance results in the rural environment is given in Table 8. Due to the low traffic volume and low number of users, a significant reduction in the waiting time is observed compared to the urban environment. The proposed traffic aware algorithms with w=0.2 give the best result in terms of the waiting time and reduces it about 40% than the C1 cell selection. The number of RSSI measurements is decreased about 70% and the number of requests is reduced about 25% in the proposed traffic aware reduced set algorithm. As shown in Table 9, the outage probabilities of all algorithms are below 0.05.

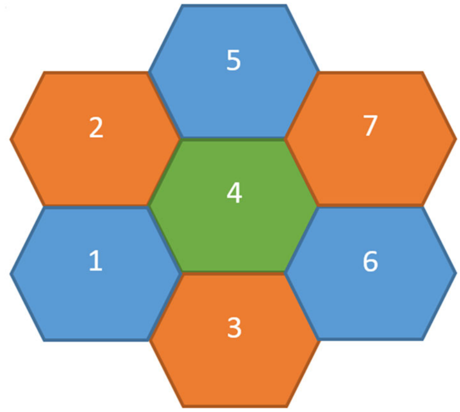

Fig. 5 Suburban environment cell planning

The cell modeling in suburban environment is given in Fig. 5. In this environment, the performance results are obtained with 300 users and 7 BSs. The users are divided into 3 groups and the probability of PTT is 0.20. This results in 60 talking users in each minute and each BS has 4 time slots (one for control channel) which corresponds to 25kHz per BS.

As given in Table 10, in the suburban environemnt, it is observed around 45% reduction in the number of RSSI measurements for the proposed traffic aware reduced set algorithm. Since the users take into account the broadcasted traffic load values in the proposed algorithms, they can attach

Table 8 Performance results for the rural area

Algorithms results	Number of RSSI measurements	Number of requests	Average waiting time (s)
C1	5	1.2493	0.53981
Cell load in [11]	5	1	0.48029
Full set traffic w=0.2	5	1	0.46629
Full set traffic w=0.5	5	1	0.46867
Full set traffic w=0.8	5	1	0.48029
Reduced set traffic w=0.2	4.4757	1	0.49067
Reduced set traffic with w=0.5	4.5577	1	0.49533
Reduced set traffic w=0.8	4.5838	1	0.49371

Table 9 Outage probabilities for the rural area

Algorithms results	Outage probability without diversity	Outage probability with diversity
C1	0.071	0.035
Cell load in [11]	0.062	0.027
Full set traffic w = 0.2	0.067	0.035
Full set traffic w = 0.5	0.064	0.029
Full set traffic w = 0.8	0.064	0.027
Reduced set traffic w = 0.2	0.059	0.026
Reduced set traffic w = 0.5	0.061	0.027
Reduced set traffic w = 0.8	0.064	0.0275

Table 10 Performance results for the suburban area

Algorithms Results	Number of RSSI measurements	Number of requests	Average waiting time (s)
C1	7	1.3013	2.7979
Cell load in [11]	7	1	2.5745
Full set traffic w = 0.2	7	1	2.5173
Full set traffic w = 0.5	7	1	2.5366
Full set traffic w = 0.8	7	1	2.5772
Reduced set traffic w = 0.2	4.1004	1	2.7034
Reduced set traffic w = 0.5	4.2878	1	2.6743
Reduced set traffic w = 0.8	4.3831	1	2.667

Table 11 Outage probabilities for the suburban area

Algorithms results	Outage probability without diversity	Outage probability with diversity
C1	0.08112	0.010985
Cell load in [11]	0.0844	0.019332
Full set traffic w = 0.2	0.0836	0.02768
Full set traffic w = 0.5	0.0861	0.02351
Full set traffic w = 0.8	0.0836	0.02017
Reduced set traffic w = 0.2	0.0886	0.03018
Reduced set traffic w = 0.5	0.0911	0.0402
Reduced set traffic w = 0.8	0.0969	0.0377

to the BS at their first attempt and the number of requests is decreased about 25% compared to C1 based cell selection algorithm. For the proposed traffic aware full set algorithm with w=0.2, we provide about 15% decrease in the average waiting time than C1 algorithm. Again, from Table 11, outage probabilities of all algorithms are below 0.05.

Besides, we compare the proposed traffic aware algorithm with the cell load based algorithm in [11] in which the utility function is determined based on the number of active users in the BSs and the RSSI values. Based on the performance results, the proposed traffic aware full set algorithm reduces the average waiting time about 10% further in all environments.

6 Conclusion

The cell selection plays a very critical role in Tetra Trunk based PMR systems. In this paper, we have proposed two cell selection algorithms and the performance of these algorithms have been provided by considering practical scenarios. The users can be mobile and the group talks are considered where the users have different duration of calls during the simulation time. In these proposed algorithms, the received power and traffic load of BSs have a weight in the utility function which decides the serving BS. While the RSSI values of all BSs is measured in the proposed traffic aware full set algorithm, the minimum number of RSSI measurements is targeted in the proposed traffic aware reduced set algorithm.

The performance results in different environments have been obtained. It has been shown that the fairly balancing of users among BSs reduces the average waiting time in the traffic aware cell selection algorithms. While the proposed traffic aware full set algorithm measures RSSI from all BSs, the proposed traffic aware reduced set algorithm measures much less RSSI values. Also decreasing RSSI weight has positive effect in balancing of the users and it also reduces the number of RSSI measurements. All these improvements in results have been occurred while satisfying the BER requirements of the users.

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

Compliance with ethical standards

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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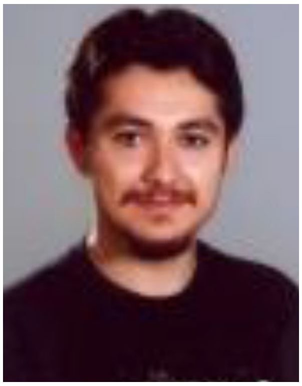

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