Mobility-Aware TAC Configuration in LTE-Based Mobile Communication Systems

Hyung-Woo Kang and Seok-Joo Koh

Abstract In LTE-based mobile communication systems, a Tracking Area Code (TAC) defines a group of cells for a paging area. In mobile networks, the paging performance is a critical factor to be considered, since it may give large impacts on paging response time as well as paging traffic load in the mobile system. This paper proposes a mobility-aware TAC configuration scheme to increase the paging success rate in mobile communication systems. We first construct an optimization model for TAC configuration by considering the mobility (handover) patterns of mobile users as well as the TAC size and the capacity of paging traffic. Then, we propose the tow algorithms for TAC configuration to maximize the paging success rate, while some constraints are satisfied. From the performance analysis with real traffic data of SK Telecom in Korea, we can see that the proposed TAC configuration provides larger paging success rates than the existing TAC configuration.

Keywords Mobile communication · Paging · Tracking area code · Optimization · Algorithms

1 Introduction

With the advent of smart phones, mobile communication system has been rapidly evolved to the Long Term Evolution (LTE) technology [1, 2]. In the design of the LTE-based mobile system, the paging performance is one of the important factors to be considered. The paging operation is initiated to locate a mobile user in the network, when a call request to the user arrives. In the LTE-based mobile systems, a paging area is defined by a Tracking Area Code (TAC) [3, 4].

H.-W. Kang · S.-J. Koh (✉)
School of Computer Science and Engineering, Kyungpook National University,
Daegu, Korea
e-mail: sjkoh@knu.ac.kr

H.-W. Kang
e-mail: hwkang0621@gmail.com

In this paper, we address the TAC configuration for paging optimization. In the existing TAC configuration, a network operator arbitrarily constructs a TAC with a group of cells, in which only the geographical topology information of cells is considered. However, this scheme tends to incur low paging success rate, which induces large paging response time and large paging traffic loads.

In this paper, we propose a new mobility-aware TAC configuration scheme for paging optimization. The proposed scheme is based on a mathematical optimization model for TAC configuration, in which we consider the mobility (handover) patterns of mobile users as well as the TAC size and the capacity of paging traffic. Then, we propose the two algorithms for TAC configuration to maximize the paging success rate, while some constraints are satisfied.

This paper is organized as follows. In Sect. 2, we discuss the TAC optimization and the paging operations. In Sect. 3, we describe an optimization model for TAC configuration and propose the TAC configuration algorithms. Section 4 analyzes the paging performance of the existing and proposed schemes in term of the paging success rate, with the real traffic data of SK Telecom. Finally, Sect. 5 concludes this paper.

2 TAC Configuration and Paging Operations

Usually, when a mobile user is connected to a cell in network attachment phase, the user is assigned to the TAC in which the cell is contained. Given a TAC configuration, when a paging is required for a mobile user, the paging process is performed as follows.

If the user was registered with a TAC, then a gaging signal will be broadcast to all of the cells contained in the TAC. This is called the *first* paging. If the first paging request fails (i.e., no response to the paging request from the user), then the *second* paging is performed. In the second paging, the paging request will be broadcast to all of TACs in the area, in which a large amount of paging messages are generated in the network and the paging response time will also get larger. Therefore, it is very important to optimize the TAC configuration so as to maximize the paging success rate for the first paging.

However, at present, most of the mobile operators configure TACs in an arbitrary way. In this TAC configuration, only the geographical location information of cells in the network is considered, and a network manager manually configures a group of cells as a TAC. That is, the mobility or handover pattern was not considered in the TAC configuration. So, if the user has already moved to another cell during a dormant mode, the actual TAC of the user may be changed and thus it is likely that the first paging process fails.

In this paper, we propose a new TAC configuration scheme for paging optimization. The proposed scheme is designed by considering the mobility (handover) patterns of mobile users as well as the TAC size and the capacity of paging traffic.

3   Proposed TAC Configuration Scheme

3.1   Optimization Model for TAC Configuration

We first construct a mathematical optimization model for TAC configuration. Given a network area with many cells, the goal is to find an optimal TAC configuration (mapping from a group of cells to a TAC) by considering the paging traffic and the user mobility between cells. The paging success rate (PSR) will be used as an objective function of the optimization model. The PSR represents the success probability for the first paging.

To derive the optimization model of TAC configuration, we define the following variables and parameters:

- h_{ij}: handover ratio that a user moves from cell i to cell j, where $\Sigma_{j \in N}\ h_{ij} = 1$;
- λ_i: average paging traffic load for cell *i*, which is calculated as the number of LTE connections established in the cell;
- d_{ij}: geographical distance between cell *i* and *j*;
- N: a group of total cells in the area, with the size of *n*;
- M: a group of TACs in the area, with the size of *m*;
- S_{TAC}: the maximally allowable number of cells for a TAC;
- C_{TAC}: the maximum paging traffic load allowable for a TAC;
- D_{TAC}: the maximally allowable distance between two cells contained in a TAC; and
- x_{ik}: a decision variable, $x_{ik} = 1$ if cell *i* is assigned to TAC *k*, $x_{ik} = 0$ otherwise.

Based on these variables and parameters, we can make an optimization model for TAC optimization, as shown in Fig. 1.

In the model, the objective function represents the PSR that is defined as the ratio of $\lambda_i \times h_{ij}$ in which a user moves cell *i* to cell *j*, and both *i* and *j* are assigned to the same TAC *k* (i.e., $x_{ik} = 1$ and $x_{jk} = 1$).

In addition, we consider the following four constraints:

1. TAC *assignment*: each cell should be assigned to one TAC;
2. TAC *size*: the number of cells assigned to a TAC cannot exceed S_{TAC};

$$
\begin{aligned}
&\text{Maximize} \qquad \Sigma_{k \in M}\, \Sigma_{i \in N}\, \Sigma_{j \in N}\ \lambda_i \times h_{ij} \times x_{ik} \times x_{jk}\\
&\text{Subject to (constraint conditions)}\\
&\qquad \Sigma_{k \in M}\ x_{ik} = 1,\ \text{for all } i \in N \qquad\qquad\quad (1)\\
&\qquad \Sigma_{i \in N}\ x_{ik}\ \le S_{TAC},\ \text{for all } k \in M \qquad\quad (2)\\
&\qquad \Sigma_{i \in N}\ \lambda_i \times x_{ik} \le C_{TAC},\ \text{for all } k \in M \qquad (3)\\
&\qquad d_{ij} \times x_{ik} \times x_{jk} \le D_{TAC}\ \text{for all } i, j \in N,\ k \in M \quad (4)\\
&\qquad x_{ik} = 1 \text{ or } 0,\ \text{for all } i \in N,\ k \in M \qquad\quad (5)
\end{aligned}
$$

Fig. 1 TAC Optimization Model

3. *Paging traffic capacity*: the paging traffic load for a TAC cannot exceed C_{TAC}; and

4. *Distance*: the distance between any pair of two cells within a TAC cannot exceed D_{TAC}.

It is noted that this optimization problem is similar to the knapsack problem [5], which is known as an NP-complete problem. The TAC optimization problem can be reduced to the knapsack problem by considering only a single TAC (i.e., m = 1) and by taking only the constraints (3) and (5). Accordingly, we need to design some heuristic algorithms to solve the TAC optimization problem.

3.2 Optimization Model for TAC Configuration

To solve the TAC optimization problem, we propose the two algorithms: *TAC reconfiguration* and *local improvement*. We apply these two algorithms sequentially and iteratively, until no further improvement of the PSR objective function is made.

3.2.1 TAC Reconfiguration with a Center Cell

Given a TAC configuration, we first find a *center* cell for each TAC. Such a center cell will be determined by calculating the distances from a candidate center cell to the other cells within the TAC. Then, we define a center cell as the cell with the minimum distance to the other cells.

In the next step, a feasible TAC will be gradually configured, starting from the initial center cell. for each TAC k, let $S(k)$ be the set of cells contained in TAC k. We also define S* as the set of the remaining cells that have not been assigned to any TAC. Initially, $S(k)$ contains only the center cell of TAC k. Then, we select a cell $j \in$ S* that gives the largest mobility rate from the cells in $S(k)$, $\Sigma_{i \in S(k)} \lambda_i \times h_{ij}$. Now, the selected cell j will be assigned to TAC k (i.e., $S(k) = S(k) + \{j\}$), if the inclusion of cell j satisfies the constraints (2), (3), and (4) of Fig. 1. These operations will be repeated until all cells are assigned to one of the TACs in the area.

3.2.2 Local Improvement by TAC Change

The local improvement algorithm is used to find a more optimal solution, based on the TAC configuration obtained in Sect. 3.2.1. For the given TAC configuration, we try to change the TAC of a cell into another TAC. A trial of TAC change will be accepted, only if the PSR value is improved and the resulting TAC configuration satisfies the constraints (2), (3), and (4) of Fig. 1. Otherwise, we do not change the TAC of the cell. These procedures are performed until no improvement of PSR is made for all cells.

4 Experimental Results

4.1 Test Networks

In experiments for performance analysis, we use the real-world data of network topology, user paging traffic, and mobility rates, which are given by *SK Telecom* in Korea. The proposed TAC configuration scheme was applied to a total of 20 target areas, and we calculate the PSR values.

For experiments, the default parameter values are set as follows: $S_{TAC} = 150$, $C_{TAC} = 2100$, $D_{TAC} = 1/2 *$ the maximum distance between cells in target area.

4.2 Results and Discussion

In experiments, the distance between two cells is calculated by using the Euclidean distance. As a performance metric, we calculate the *paging success probability (PSP)* = $PSR/\Sigma_{i \in N} \lambda_i$, which represents the ratio of successfully paged traffics over total paging traffics in the network. Table 1 shows the results of the existing and proposed TAC configuration schemes for the target area 27, which has n (total number of cells) = 1498 and m (the number of TACs) = 15.

Table 1 TAC configurations for target area 27

| TAC Index	Existing configuration			Proposed configuration		
	# of cells	Maximum distance	PTL	# of cells	Maximum distance	PTL
2700	146	13040	1151	97	17750	677
2701	145	9378	838	100	17020	662
2702	142	17778	1126	100	32191	913
2703	138	10249	1184	100	8938	652
2704	125	4139894	1090	100	11799	635
2705	145	8811	926	100	13202	1229
2706	171	35699	941	99	99153	336
2707	135	90849	821	100	18925	307
2708	141	4989	1074	100	4501	782
2709	152	4144829	429	100	12687	580
270A	2	0	0	100	11385	535
270B	54	95494	48	99	19922	390
270C	1	0	34	100	18619	850
270D	2	1121	0	99	17411	524
270E	5	3837	0	104	90164	589
PSP	72.66 %			87.30 %		
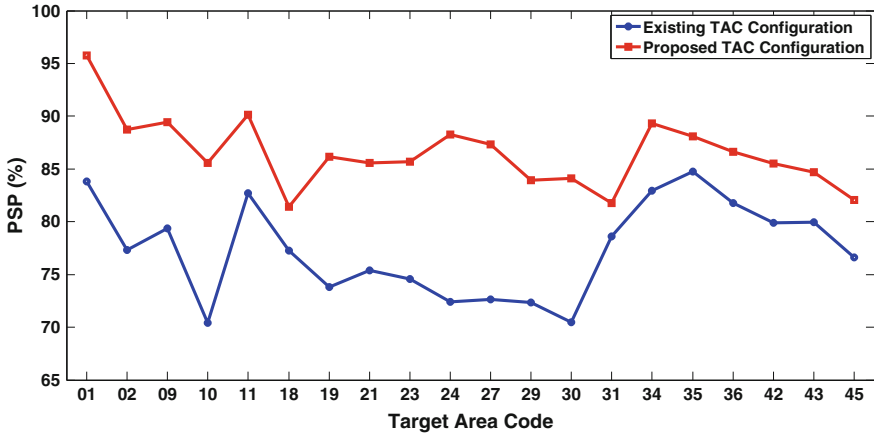
Fig. 2 Paging success probability for 20 target areas (color figure online)

For the existing TAC configuration in the table, we can see that TAC 2706 contains 171 cells, whereas TAC 270A, 270C, 270D, 270E have smaller than 10 cells. This implies that the existing TAC configuration is severely unbalanced in terms of the TAC size. We can also see such unbalanced configuration in the viewpoint of the maximum distance between cells in TAC and the paging traffic load (PTL) per TAC. Overall, this result gives the PSP of 72.66 %.

In the table, on the other hand, we can see that the proposed scheme leads to a balanced TAC configuration. Most of the TACs have the TAC size of a minimum 97 cells and up to 104 cells. In the proposed scheme, the maximum distance between cells and PTL in TAC are also equally distributed for all TACs. Finally, the proposed TAC configuration provides the PSP of 87.30 %, which is higher than the existing scheme by 14.64 %.

Finally, Fig. 2 compares the PSP values of the 20 target areas for the existing and proposed TAC configuration schemes. From the figure, we can see that the proposed scheme provides greater PSPs than the existing scheme. Overall, it seems that the proposed TAC configuration scheme can improve the PSPs of the existing scheme by 10.16 % on the average and 15.16 % in the maximum.

5   Conclusions

In this paper, we presented a new TAC configuration scheme to maximize the paging success rates in LTE-based mobile communication networks, with a mathematical optimization model. The proposed scheme consists of the two algorithms: TAC reconfiguration with a center cell and local improvement by TAC change.

By experimentations with real-world data of SK Telecom in Korea, the proposed scheme is compared with the existing scheme in terms of the paging success rate.

From the results, we can see that the proposed scheme provides more optimized TAC configurations than the existing scheme by maximizing the paging success rate. It is also noted that the proposed scheme can give much more balanced TAC configurations, compared to the existing scheme.

References

1. David Astély et al (2009) LTE: the evolution of mobile broadband. IEEE Commun Mag 47 (4):44–51
2. 3GPP TS 36.300 (2008) Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN). Overall Description Stage 2
3. Lyberopoulos GL et al (1995) Intelligent paging strategies for third generation mobile telecommunication systems. IEEE Trans Veh Technol 44(3):543–554
4. Amotz Bar-Noy et al (2013) Paging mobile users in cellular networks: optimality versus complexity and simplicity. Theoret Comput Sci 470:23–35
5. Johnsonbaugh R, Marcus Schaefer M (2004) Algorithms. Prentice Hall