Adaptive Design of Tracking Area List in LTE

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***Abstract*—In Long Term Evolution (LTE), service area is divided into tracking areas (TAs), which consist of a group of cells and do not overlap with each other, and a TA list (TAL) is assigned to a mobile station (MS). Thus, location of an MS is managed by a granularity of a TAL and an MS does not need to register its location when it moves within TAs of the assigned TAL. In this paper, it is assumed that each TA consists of only one cell and TAL is formed by a group of cells. As a preliminary work to the optimal design of TAL for an individual MS, we validate the usefulness of the proposition that a TA consists of only one cell and TAL can be adaptively designed for each MS, by assuming uniform mobility model of MSs to simplify the analysis. TAL for an MS is designed as rings of cells (TAs) from the last update cell (TA), as an example of optimal design of TAL, by applying the concept of movement-based location registration. An optimal movement threshold for the TAL is derived periodically, using measured traffic and mobility characteristics of an MS during the time interval between two consecutive session arrivals. Finally, a new TAL is adaptively designed for an MS, based on the newly derived optimal movement threshold.**

Keywords: location management, location update, paging, LTE, movement-based

I. Introduction

In cellular communication networks, location management consists of location registration and paging, and it is one of the most essential techniques to provide communication services to mobile stations (MSs). An MS registers its location area (LA), whenever it moves into a new LA, and paging requests are sent to all cells within the registered LA to deliver an incoming call to the called MS.

Since location registration and paging result in significant signaling loads, numerous works on reducing signaling load have been carried out [1], [2]. In conventional cellular communication systems, LA configuration is fixed and there is a tradeoff between location registration signaling load and paging signaling load based on the size of LA [1], [2]. The optimal size of LA depends on the call-to-mobility ratio (CMR) of MSs.

Since static LA-based location management scheme does not meet the diverse traffic and mobility characteristics of different MSs and high signaling loads are generated at the cells of LA boundary, dynamic location registration schemes, such as timer-based [3], distance-based [4], and movement-based [5], [6] schemes were proposed. In timer-based location management scheme, an MS updates its location whenever a predefined time is elapsed. In distance-based location management scheme, an MS updates its location whenever a predefined distance is traveled form the location where the last location update was performed. Finally, location update is performed whenever a predefined number of cells are crossed from the last updated cell in movement-based location management.

In Long Term Evolution (LTE), which is one of the most promising next generation cellular systems, the location of MSs is tracked by tracking area (TA), which is defined as a group of cells and it does not overlap with another TA. In LTE, the concept of TA list (TAL), which consists of a set of TAs, has been newly defined, and different TALs are assigned for different MSs. An MS does not need to register its location when it resides within TAs of the assigned TAL. Different mobility and traffic characteristics of MSs can be accommodated by appropriately assigning TAL. However, optimal design of TA and TAL is a very challenging task in LTE.

Recently, works on location management for LTE have been carried out actively [7] - [10]. In [7], the authors proposed two LTE architectures, i.e., distributed mobility management entities (MMEs) and centralized MME, and then, compared the signaling loads of the two proposed architectures. The authors also proposed a multicast paging procedures in order to reduce the MME signaling load and compared the performance of the proposed paging procedures with unicast paging procedures. In [8], the authors proposed a new scheme to minimize serving gateways (SGWs) and MMEs relocations in LTE, which occur due to fixed/hard service area boundaries. In the proposed scheme, every SGW configures flexible service area consisting of a set of TAs and the proposed scheme reduced the number of SGW relocations. In [9], the authors proposed an efficient location management scheme for LTE femtocells by considering overlay macro cells and applying two step paging for femto and macro cells. From the analysis results, the proposed scheme minimized paging overload in macro cells and optimized location management cost. In [10], the authors proposed a femtocell architecture for LTE and two handover procedures, where home eNodeB gateway acts as either a mobility anchor or relay. Then, it was shown that home eNodeB gateway as a mobility anchor reduces the signaling load.

In these works, however, it is generally assumed that a TA consists of multiple cells basically, and TAs are statically configured by network operators, not by MSs, considering characteristics of aggregate MSs, such as density, movement patterns, and call arrivals of MSs as well as geographic layout of road, building, river, etc. Although this kind of static TA design by network operators may be appropriate from the aspect of aggregate MSs, it is not optimal from the aspect of individual MSs, which have diverse mobility and traffic characteristics. Therefore, the area covered by all the cells within a TAL may not be optimal for all the MSs, since TAs themselves within a TAL may not be optimally designed for all the MSs. In this paper, instead, each TA consists of only one cell and thus, cell is considered as a basic unit of a TAL. By doing this, it is more likely that optimal TAL for an MS can be designed individually, by considering dynamic mobility and traffic characteristics of an MS, compared to the conventional scheme, where TA consists of multiple cells and it is a basic unit of TAL.

As a preliminary work to the optimal design of TAL for an individual MS considering characteristics of the MS as well as geographic layout of road, building, river, etc., the main objective of this paper is to validate the assumption that a TA consists of only one cell and TAL can be adaptively designed for each MS, by assuming uniform mobility model of MSs to simplify the analysis, since optimal design of TAL is a very complex task if we consider all the realistic characteristics. In this work, TAL for an MS is designed as rings of cells (TAs) from the last update cell (TA) as a preliminary work to the optimal design of TAL, by applying the concept of movement-based location registration [5]. Then, we show that optimal TAL for an MS in uniform mobility model of MSs can be obtained by deriving optimal movement threshold periodically using binary search algorithm, based on measured mobility and traffic characteristics of an MS during the time interval between two consecutive session arrivals.

The remainder of this paper is organized as follows: Section 2 analyze the performance of the TAL based on movement-based location registration, for varying the values of movement threshold. An adaptive design of TAL is proposed, based on binary search algorithm, in Section 3. Finally, Section 4 summarizes this work and presents further works.

II. Performance Analysis

A. Analytical Modeling

We assume that session arrival to an MS follows a Poisson distribution with λ_s and session duration of an MS follows an exponential distribution with λ_μ. For simplicity, a session arrival interval is assumed to be much larger than a session duration. Cell (TA) residence time of an MS is assumed to follow a general distribution with $f_m(t)$ and its Laplace Transform is denoted by $f_m^*(s)$ with mean value of $1/\lambda_m$. In LTE, an MS is in connected mode or idle mode depending on its traffic characteristics and it alternates with these modes [11]. In connected mode, an MS registers its location every cell change. In idle mode, an MS registers its location every TAL change. Thus, the number of cell crossings in connected mode and the number of TAL crossings in idle mode between two consecutive session arrivals should be derived to analyze the signaling load.

The probability that an MS moves across K cells (TAs) between two consecutive session arrivals, $\alpha(K)$, can be derived as follows, using the results in [12]:

$$\alpha(K)=\begin{cases} 1-\frac{1-f_m^*(\lambda_s)}{\theta_\alpha}, & K=0, \\ \frac{1}{\theta_\alpha}[1-f_m^*(\lambda_s)]^2[f_m^*(\lambda_s)]^{K-1}, & K>0. \end{cases} \quad (1)$$

where θ_α is the session to mobility ratio (SMR) of an MS and is defined by λ_s/λ_m. Using Eq. (1), we can also derive the probability that an MS moves across K cells (TAs) during a session duration, $\beta(K)$ similarly as follows:

$$\beta(K)=\begin{cases} 1-\frac{1-f_m^*(\lambda_\mu)}{\theta_\beta}, & K=0, \\ \frac{1}{\theta_\beta}[1-f_m^*(\lambda_\mu)]^2[f_m^*(\lambda_\mu)]^{K-1}, & K>0. \end{cases} \quad (2)$$

where θ_β is defined by λ_s/λ_μ.

Then, the location registration signaling cost in connected mode is derived as follows:

$$C_U^{connected} = U*\sum_{i=1}^{\infty} i\beta(i) = U\frac{1-f_m^*(\lambda_\mu)}{\theta_\beta}, \quad (3)$$

where U is the weight factor for location registration signaling load. The location registration signaling cost in idle mode is obtained as follows, using the results in [5]:

$$\begin{aligned} C_U^{idle} &= U * \sum_{i=1}^{\infty} i \sum_{j=id}^{(i+1)d-1} (\alpha(i) - \beta(i)) \\ &= U \frac{1 - f_m^*(\lambda_s)}{\theta_\alpha} \frac{f_m^*(\lambda_s)^{d-1}}{1 - f_m^*(\lambda_s)^d} \\ &- U \frac{1 - f_m^*(\lambda_\mu)}{\theta_\beta} \frac{f_m^*(\lambda_\mu)^{d-1}}{1 - f_m^*(\lambda_\mu)^d}. \end{aligned} \quad (4)$$

Finally, the total location registration signaling cost, C_U, is obtained as follows:

$$\begin{aligned} C_U &= C_U^{connected} + C_U^{idle} \\ &= U \frac{1 - f_m^*(\lambda_\mu)}{\theta_\beta} + U \frac{1 - f_m^*(\lambda_s)}{\theta_\alpha} \frac{f_m^*(\lambda_s)^{d-1}}{1 - f_m^*(\lambda_s)^d} \\ &- U \frac{1 - f_m^*(\lambda_\mu)}{\theta_\beta} \frac{f_m^*(\lambda_\mu)^{d-1}}{1 - f_m^*(\lambda_\mu)^d}. \end{aligned} \quad (5)$$

In this paper, we adopt blanket paging scheme, where all the cells of a TAL are paged at the same time, and the paging signaling cost, C_P, is obtained as follows, as in [5]:

$$C_P = P * [1 + 3d(d-1)], \quad (6)$$

where P is the weight factor for paging signaling load and d is a movement threshold. Now, the total cost is obtained by:

$$\begin{aligned} TC &= C_U + C_P \\ &= U \frac{1 - f_m^*(\lambda_\mu)}{\theta_\beta} + U \frac{1 - f_m^*(\lambda_s)}{\theta_\alpha} \frac{f_m^*(\lambda_s)^{d-1}}{1 - f_m^*(\lambda_s)^d} \\ &- U \frac{1 - f_m^*(\lambda_\mu)}{\theta_\beta} \frac{f_m^*(\lambda_\mu)^{d-1}}{1 - f_m^*(\lambda_\mu)^d} \\ &+ P * [1 + 3d(d-1)]. \end{aligned} \quad (7)$$

B. Numerical Examples

For numerical examples, we assume an exponential distribution as a cell residence time, where the Laplace Transform of an exponential distribution with mean $1/\lambda_m$ and variance V is expressed as $f_m^*(s) = \frac{\lambda_m}{s+\lambda_m}$.

Figure 1 shows the effect of U on the total cost with $P = 1$, $\lambda_c = 1(/hour)$, $\lambda_m = 10(/hour)$, and $\lambda_\mu = 10(/hour)$. Depending on the values of U, the shape of the total cost is different and optimal movement threshold values are different. For example, if $U = 1$, the total cost is an increasing function and the optimal movement threshold value is 1. Otherwise, the total cost is a convex function and the optimal movement threshold value is found, which is larger than 1.

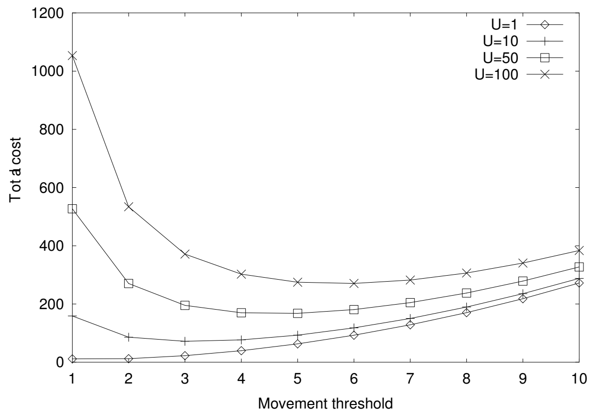

Figure 1. The effect of U on total cost.

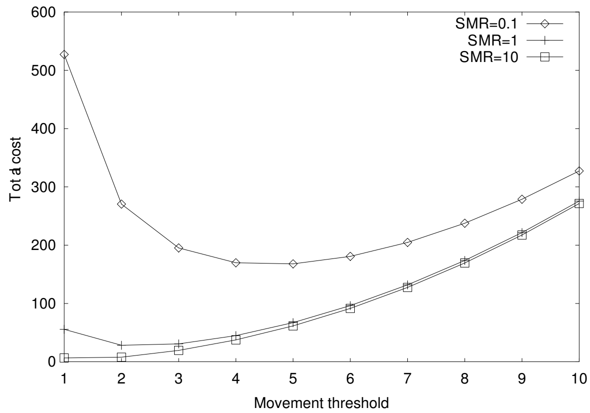

Figure 2. The effect of SMR on total cost.

Figure 2 shows the effect of SMR on the total cost with $U = 50$, $P = 1$, $\lambda_c = 1(/hour)$, and $\lambda_\mu = 10(/hour)$. Similar to Fig. 1, optimal movement threshold values are different, depending on the values of SMR. Based on the results, it is concluded that we can obtain the optimal movement threshold value and the optimal TAL, from the aspect of total cost, if mobility and traffic characteristics are given.

III. Adaptive Design of TAL

In the proposed scheme for adaptive design of TAL, the number of cell (TA) crossings and TAL crossings by an MS and average session durations are measured during the time interval between two consecutive session arrivals. Then, total cost is calculated based on measured mobility and traffic characteristics of the MS using Eq. (7). Finally, the optimal movement threshold d_{opt} for an MS, which minimizes the total cost, is derived, based on binary search algorithm [13] as follows:

- Step 1: $L = 1$ and $R = d_{max}$, where L and R are the smallest and the largest possible movement thresholds. If $\frac{\partial TC}{\partial d}|_{d=L} \times \frac{\partial TC}{\partial d}|_{d=R} > 0$, then $d_{opt} = L$ if $TC|_{d=L} < TC|_{d=R}$, and vice versa. Otherwise, $M = \frac{L+R}{2}$ and go to Step 2.
- Step 2: If $\frac{\partial TC}{\partial d}|_{d=M} < \delta$, where $\delta \ll 0$, $d_{opt} = M$, and go to Step 4. Otherwise, go to Step 3.
- Step 3: $M = \frac{L+R}{2}$. If $\frac{\partial TC}{\partial d}|_{d=M} = 0$, $d_{opt} = M$. Otherwise, if $\frac{\partial TC}{\partial d}|_{d=M} \times \frac{\partial TC}{\partial d}|_{d=R} > 0$, $R = M$ and go to Step 2. Otherwise, $L = M$ and go to Step 2.
- Step 4: $L = \lfloor d_{opt} \rfloor$ and $R = \lceil d_{opt} \rceil$. If $TC|_{d=L} < TC|_{d=R}$, $d_{opt} = L$. Otherwise, $d_{opt} = R$

Using the above algorithm, optimal movement threshold is derived and a new TAL is designed for an MS for the following time interval between two consecutive session arrivals, and this information is updated at MME in LTE. By doing this, the optimal TAL of an MS can be adaptively updated every time interval between two consecutive session arrivals, based on the measured mobility and traffic characteristics of MSs. In the proposed scheme, flexible TAL can be designed for each MS and location registration and paging signaling loads can be efficiently distributed, without concentrating at specific cells. Figure 3 shows the summary of the proposed adaptive TAL design scheme.

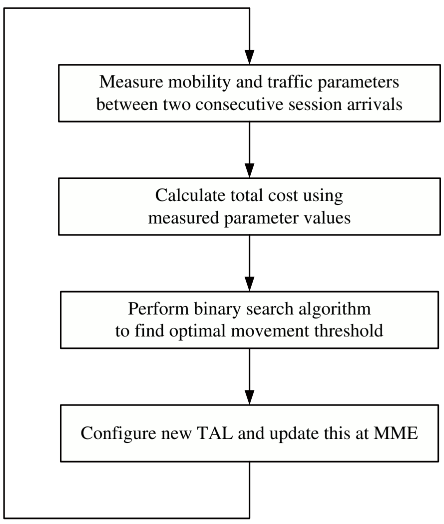

Figure 3. Proposed adaptive TAL design scheme.

IV. Conclusions and Further Works

In this paper, TAL is designed as a rings of cells (TAs), based on movement-based location registration, and adaptive design of TAL is proposed using measured mobility and traffic characteristics of an MS. Total signaling cost is obtained as the sum of location registration and paging signaling costs. Using the total cost, the optimal movement threshold for an MS is obtained, based on binary search algorithm, and a new TAL is designed for an MS for the following time interval between two consecutive session arrivals.

As further works, detailed algorithms and procedures to implement the proposed adaptive design algorithm will be elaborated more. An algorithm of deriving optimal TALs in an environment, where the assumption of movement-based location registration is relaxed, will be investigated, too. Finally, the analysis framework in this paper is extended by considering periodic TA update which is standardized in LTE specification.

Acknowledgments

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