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On dynamic signaling congestion mitigation by overlapping tracking area lists

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ABSTRACT

Mitigating signaling congestion of tracing user equipments (UEs), adaptively to the changes in UE location and mobility patterns is a challenging issue in mobility management of Long Term Evolution (LTE) networks. Signaling congestion usually occurs due to many UEs behaving in a similar manner, e.g., massive and simultaneous UE mobility in a train movement scenario. LTE networks allow the use of tracking area lists (TALs), each being a list containing multiple tracking areas (TAs). The overlapping TAL scheme has been previously used for signaling congestion mitigation for snapshot scenarios. For maintaining the improved performance over non-list-oriented TA configuration over time, an automatic dynamic configuration framework, which is a key aspect in Self-Organizing Network (SON), has been applied in this paper. We develop a linear programming model for optimal TAL configuration. Repetitively solving the model for different time intervals gives an evaluation framework on the performance of SON location management. Comprehensive numerical results are presented in this study using a large-scale realistic network scenario. The experiments demonstrate the effectiveness of the SON dynamic framework in reducing the total signaling overhead of the network compared to the static TA. Moreover, the overlapping TAL scheme significantly improves the performance of the network in the tracking area update congested scenarios over the conventional TA configuration.

1. Introduction

Location management, which is sometimes called reachability, aims to track and page user equipments (UEs) in cellular network. Tracking Area (TA) in Long Term Evolution (LTE) is a logical area-partition of the network, that each partition is a subset of cells 3GPP TS 23.002 (2009). In the idle state, a UE is in power-conservation mode and does not inform the network of each cell change. Hence, the location of idle UEs is known to the network to the granularity of TA. In the conventional TA scheme, when a UE passes a TA boundary, it sends an uplink signaling message to the Mobility Management Entity (MME). This procedure is called tracking area update (TAU). On the other hand, for placing a call to a UE, the MME sends downlink paging signaling messages to the cells inside the UE's current TA, in order to find the cell from which the UE can receive the call. UEs in active mode also perform TAUs as part of the handover (HO) procedure. However, while UEs are in active mode the corresponding signaling due to TAU is a small portion compared to the whole signaling including HO procedure. Therefore, the topic of this research becomes interesting while focusing on idle UEs, due to the fact that the number of idle UEs is significantly more than the active ones.

In designing the TA layouts of a network, the overheads resulted from TAU and paging signaling messages are the key parameters to be taken into account. Planning and optimization of TAs (or Location Areas (LAs) and Routing Areas (RA) for the previous generations of cellular networks) by considering signaling overhead have been dealt with in a large amount of literature (Bejerano et al., 2006; Cayirci and Akyildiz, 2003; Demirkol et al., 2004; Modarres Razavi et al., 2012; Tcha et al., 1997; Winter, 2004). There are two new concepts in LTE networks that need to be more explored and investigated with the objective of improving the network performance: one is the concept of self-organizing networks (SON) (3GPP TS 32.500, 2008; 3GPP TS 36.902, 2008), and two is the concept of TA list (TAL) (3GPP TS 23.401, 2009). Both of these concepts are standardized by 3rd Generation Partnership Project (3GPP), Release 8, for LTE. In this paper, we aim to reduce the operating expenditure (OPEX) cost and improve the overall performance of LTE's location management by deploying these two concepts in the network.

Conventionally, TAs are manually configured and the configuration is static. As UE distribution and mobility patterns change over time, the TA configuration of the network does not perform optimally for

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all time intervals. In the conventional TA scheme, reconfiguring TAs, such as moving a cell from one TA to another, requires temporarily tearing down the cell causing service interruption (Modarres Razavi and Yuan, 2008). Due to the excessive cost caused for the operator, it is not feasible to make small time interval reconfigurations in the conventional TA scheme. However in SON, an automated and efficient deployment of updated configurations is possible. For a stable optimization, a global view of the UEs' movements and call arrival rate statistics is a requirement. In a static TA, the average of this statistic is used for the TA design. However, in a dynamic framework, we incorporate time of day and day of week data patterns into our design, which can further strengthen the performance of the network over the static TA.

During signaling congestion, there is resource exhaustion for tracking UEs. Therefore, mitigating signaling congestion is to ensure no significant degradation in the quality of service (QoS) of a network. Normally, the TAU congestion occur in densely populated cities, where there is a huge number of UEs moving concurrently during specific times of day and night (rush-hours) (3GPP TR 23.880, 2007). Paging signaling congestion may also occur in scenarios where close-to-static UEs are simultaneously gathered at some hotspots. The focus in this paper is only on TAU congestion mitigation, with the assumption that it is a more critical issue in real-life deployments. The optimization framework used in this paper for mitigating TAU signaling congestion has been introduced in Modarres Razavi and Yuan (2012) and is based on the use of TA lists (TALs), which may contain overlapping TAs. Instead of updating the UE with one TA, the UE can be assigned a list of TAs, referred as a TAL. The UE performs a TAU, when it moves to a TA not being in its TAL. Hence, the location of a UE is known in the MME to the granularity of its allocated TAL. In the overlapping TAL scheme used in this paper, all cells in one TA use the same collection of TALs, and they update their UEs with the same proportional use of each TAL. The standard TA design is considered as the underlying structure. The optimal proportional use of the TALs for congestion mitigation is obtained via a linear program (LP).

One difficulty in evaluating the performance of TAL is the existence of UEs in a same location with different TALs, and thus calculating the total number of TAUs depends on the specific mobility pattern of each individual UE. This information is not available, and therefore the performance of TAL configuration rely heavily on the validity of the assumptions made in the models (Chung, 2011; Modarres Razavi et al., 2010a,b). The main advantage of applying overlapping TAL is that no mobility information is required for the calculation of the signaling overhead. Moreover, as all cells in the same area will assign TAL consistently based on their proportional usage, the performance evaluation can be effectively assessed.

The creation and reconfiguration of TALs are supported in SON architecture, therefore our dynamic optimization framework is cost efficient in implementation. One main advantage of using overlapping TAL scheme for SON is the possibility of entering the TAs with high number of TAUs at their boundaries and their neighboring TAs to the optimization formulation and hence applying it only to the congested area and not to the whole network. This will significantly reduce the problem size, which makes it practically useful to implement. However, we should consider that as TAs are geographically connected to each other, solving the congestion problems for subsets of TAs may omit the optimum solutions of TAL proportions for the overall network. Hence in this paper, we apply the model to the whole network and solve the problem of exponentially higher size. Numerical evaluations for mitigating massive number of TAUs demonstrate the effectiveness of applying overlapping TAL on a dynamic framework compatible to SON.

The remainder of the paper is constructed as follows. In Section 2, we review some works which are relevant to our study. Section 3 is devoted to description of the dynamic framework, basic notation and an illustrative example of the overlapping TAL scheme. The optimization formulation for using the overlapping TAL scheme for congestion avoidance of TAU is given in Section 4. In Section 5, we explain a mechanism to apply the proposed overlapping TAL scheme on a SON dynamic framework. In Section 6, we present results of performance evaluation of the proposed approach and compare the static TA with the SON framework. Conclusions are provided in Section 7.

2. Related works

As mentioned in Section 1, there is an impressive number of surveys on optimization models and algorithms of conventional TA configuration (Bejerano et al., 2006; Cayirci and Akyildiz, 2003; Demirkol et al., 2004; Modarres Razavi et al., 2012; Tcha et al., 1997; Winter, 2004). On the design of unconventional location update and paging schemes, which form another line of research, see for example Akyildiz et al. (1996), Pollini and Chih-Lin (1997), and Wang et al. (2001). For thorough surveys on location management, we refer to Akyildiz et al. (1999) and Wong and Leung (2000).

Recently, the concept of TAL in LTE has received a great attention due to its flexibility over the conventional TA concept (Mitsubishi Electric, 2007; Motorola, 2007; NEC, 2007; QUALCOMM Europe and T-Mobile, 2007; ZTE, 2007). Previous studies of using TAL for minimizing the total signaling overhead, with the assumption that a cell updates one common TAL to all UEs getting registered in that cell, have been previously presented in Chung (2011) and Modarres Razavi et al. (2010a,b). TALs, in forms of rings of cells, are used in Chung (2011). In Modarres Razavi et al. (2010a,b), each cell belongs to a specific TAL. Any UE getting registered in the cell is updated by that specific TAL. In Modarres Razavi and Yuan (2014), the authors prove that the optimum TAL configuration solution for minimizing the sum of TAU and paging signaling overhead is to assign only one TAL to each cell.

In general, to optimize the configuration of TALs, a major challenge is to estimate the signaling overhead. UEs in the same location may be registered to different TALs, thus the resulting overhead, in contrast to the conventional TA case, heavily depends on the forthcoming UE behaviors. Hence, assumptions on UE behavior, ranging from simple rule of thumb to statistical mobility models, are required. Nevertheless, previous works, in particular Modarres Razavi et al. (2010a,b), show that TAL is promising in extending the capability of the conventional TA scheme.

TAL is promising for solving a couple of issues imposed by the conventional TA scheme. For example, TAL can be used to prevent the ping-pong effect, which is the frequent updates when a UE keeps hopping between two or more adjacent cells (Motorola, 2007). Another example is the train scenario associated with high uplink signaling traffic due to simultaneous updates of massive UEs crossing a boundary along a path (Mitsubishi Electric, 2007; Modarres Razavi and Yuan, 2011). In Modarres Razavi and Yuan (2012), the authors generalize the TAL optimization formulation of a line-form train scenario in Modarres Razavi and Yuan (2011) to an arbitrary network topology. In the current paper, we use the TAL optimization model for congestion mitigation of TAU given in Modarres Razavi and Yuan (2012). Hence, the following study is an extension to Modarres Razavi and Yuan (2012) by introducing a dynamic framework to the model and adapting the TAL optimization formulation to SON. Moreover, the large-scale realistic dynamic scenario used in performance evaluation of this paper not only presents the potential of overlapping TAL on a SON paradigm, but also presents a close-to-reality overview of mobility