Dynamic Tracking Area List Configuration and Performance Evaluation in LTE

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***Abstract*—Reducing the signaling overhead for tracing user equipment (UE), while maintaining the improved performance over time despite the changes in UE location and mobility patterns, is a challenging issue in the area of mobility management. Flexibility and automatic reconfiguration are two significant features in Long Term Evolution (LTE) systems. The Tracking Area List (TAL) is a novel concept in LTE systems, which allows a more flexible configurations, expecting to reduce the overall signaling overhead. In this paper, we first present a "rule of thumb" method to allocate and assign TALs for a network. The easily applied approach does not require any data other than what is available for conventional TA design. Second we compare the performance of an optimum conventional TA design with the suggested TAL design for a large scale network in Lisbon, Portugal. A thorough computation is done to make a justified evaluation. We follow the comparison during specific time intervals for one complete day, and we illustrate the performance of reconfiguration for each approach. The results clearly demonstrate the ability of dynamic TAL in reducing the signaling overhead and maintaining a good performance due to reconfiguration compared to the conventional TA design.**

I. INTRODUCTION

Flexibility is one of the key features in introducing the Long Term Evolution (LTE) systems. One of the flexibilities in LTE can be found in the area of mobility management. The mobility management deals with tracing the users' equipment (UE). In LTE, while a UE is switched on, it always has an assigned IP address. To save battery and reduce signaling, two basic activity states are defined: active and idle states. While UE is exchanging data, it is in the "connected" or "active" state. If no data is transferred for some period of time, the network changes the connection to "idle" state. In idle state the UE has no connection to the radio network [1], [2].

While the UE is active, the Mobility Management Entity (MME) knows the serving base station of the UE, but when the UE is in idle state, the MME has more crude location information about the UE. Traditionally, the location is known per group of cells, denoted Location Area (LA) in GSM, Routing Area (RA) in GPRS and UMTS, and Tracking Area (TA) in LTE. In LTE, this concept has been evolved to also enable allocation of one or several TAs per UE - a Tracking Area List (TAL). Although there is a great amount of literature on different registration strategies [3], [11], [16], [19] and paging schemes [3], [11], [18] aiming to reduce the signaling overhead of location management, their implementation requires system modification and additional UE information, due to the selective update and paging. Thus the conventional TA concept remains widely used.

TAL is a feature introduced in 3GPP, Release 8. In this scheme, instead of assigning one TA to each UE (like the conventional LA, RA and TA concepts), one UE can have a list of TAs. The UE receives a TAL from a cell, and keeps the TAL, until it moves to a cell that is not included in its TAL. In the LTE standard, a cell is able to give different TALs to different UEs. The UE location is known in the MME to at least an accuracy of the TAL allocated to that UE. It has been already shown that TAL concept can first prevent the frequent registrations when a UE keeps hopping between two cells in different TAs (ping pong effect) and second it can solve the problem of high uplink traffic due to simultaneous registrations of a large number of UEs crossing a boundary (train scenario) [14], [15]. In this paper we are using almost the same system framework as it was used in [8] and [9], however the problem addressed in this paper is largely different from both of these papers. In [8], a re-optimization approach was suggested for reconfiguring the conventional TA configuration and in [9], we have illustrated the limitations of conventional TA concept with two examples and we suggested an algorithm to design TAL for a large scale network with the available data in hand. However the evaluation was static and made for one set of data.

As UE distribution and mobility patterns change over time, the optimized configuration of the initial planning phase may no longer perform well. Thus, both the conventional TA design and TAL must be revised over time. In conventional TA concept, reconfiguring TAs, such as moving a cell from one TA to another, typically requires temporarily tearing down the cell and therefore service interruption. This is a costly process from the operator standpoint and thus it is not often feasible to make small time interval reconfigurations (i.e. one hour or even one day).

Automatic reconfiguration is another important feature in LTE. The network continuously collects UE statistics and monitors performance indicators and the management system can adapt network configuration to changes and trends in UE distribution and demand. Therefore in LTE, there is a

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possibility to change the TAL assigned to each cell in short time intervals *without any cost of service interruption*. If we divide time into equal time intervals, the challenge is that the collected data belongs to the previous time intervals, and even the optimum TAL designed from the history of UE movements, might not perform well for the next time interval.

We propose an intuitive "rule of thumb" method to assign a proper TAL to each cell. Although the approach might not result to an optimum TAL configuration, the extreme simplicity and speed of the algorithm is an advantage especially for the dynamic automatic reconfiguration procedure. We compare our proposed dynamic TAL design with both the conventional TA and static configurations by applying them to the large scale network of Lisbon. The evaluation is done in a *dynamic time frame*. We present computational experiments to analyze the signaling overhead of each approach and make a comprehensive study to justify our evaluation method. The experiments illustrates both the potential of TAL and the advantage of reconfiguration for small time intervals in reducing the signaling overhead of a large scale network.

II. Preliminaries

LTE gives the cell a possibility to assign UEs different TALs. If the information of each individual UE's movement and calls were available for the network, then designing an optimum TAL would become trivial and could essentially result to elimination of signaling overhead. In this situation the cell could give a specific tailored TAL to each UE including all the cells the UE is intended to pass before it will be paged. This information, if at all available, is costly to obtain. Here, we are not considering this feature. We assume that a cell will give only one specific TAL to all UEs getting registered in that cell. ~~All the signaling overhead analysis is done under this restriction.~~

We can without loss of generality assume that each cell is a TA and consider TALs. It is the same as assuming that the TAs are predefined, and that we consider data per TA and between TAs while designing the TALs.

The total update and paging signaling overhead of a network is calculated by equation (1):

$$c(\mathbf{t}) = \sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{N}: j \neq i} (h_{ij} c^u (1 - \mathbf{S}_{ij}(\mathbf{t})) + \alpha u_i c^p \mathbf{S}_{ij}(\mathbf{t})). \quad (1)$$

u_i which is representing the load of cell i is the total number of UEs in cell i scaled by time proportion each UE spent in cell i. This is obtained by collecting UE statistics over a given time. For the same time period, h_{ij} is the number of UEs moving from cell i to cell j. The value of h_{ij} can be assessed by handover statistics. Handover statistics can be a good estimation of UE′s movement, assuming that idle UEs are having the same mobility behavior as the active UEs. Analogously, we consider a case when TA definitions are predetermined, and the statistics is gathered per TA, not per cell. The amount of overhead of one paging and one update are denoted by c^p and c^u, respectively. Parameter α is the call intensity factor (i.e., probability that a UE has to be paged). $\mathbf{S}(\mathbf{t})$ is an $N \times N$ matrix representing the TA design $\mathbf{t}$. Within the outer parenthesis of (1), the first term is the update overhead for UEs moving from i to j, and the second term is the paging cost of cell j, while paging UEs in i.

In the conventional TA concept, if we consider t_i as the TA of cell i and t_j as the TA of cell j, then:

$$s_{ij}(\mathbf{t}) = \begin{cases} 1 & \text{if } t_i = t_j, \\ 0 & \text{otherwise.} \end{cases}$$

$\mathbf{S}(\mathbf{t})$ in conventional TA concept has two features:

- $\mathbf{S}(\mathbf{t})$ is a binary matrix, which $s_{ij}(\mathbf{t})$ represents whether or not two cells are in the same TA.
- $\mathbf{S}(\mathbf{t})$ is a symmetric matrix, representing an obvious fact that if cell i and j are in a same TA, then cell j and i are also in the same TA!

III. An intuitive *Rule of Thumb* for TAL configuration

The flexibility of TAL comparing to the conventional TA concept is that $S(t)$ is not binary nor symmetric. Let's consider a network with only two cells (i.e., cells i and j in Figure 1 and ignoring the rest of the cells). There are two situations for designing TAL of cell i:

1) $TAL(i) = \{i\}$ In this case, the signaling overhead resulted from cell i is $c^u h_{ij}$. This means that all the flow moving from i to j should have an update, as cell i doesn't have j in its TAL.
2) $TAL(i) = \{i, j\}$ Here, the signaling overhead resulted from cell i is $\alpha c^p u_i$. Which means that if a UE is paged in i, there will be paging in cell j, but no update for the UEs moving from i to j.

Thus for minimizing the signaling overhead resulted from cell i, the following decision should be made:

$$l_{ij} = \begin{cases} 1 & \text{if } \alpha c^p u_i < c^u h_{ij}, \\ 0 & \text{otherwise.} \end{cases}$$

If h_{ij} is larger than $\alpha c^p / c^u$ times of u_i, then we consider j in the TAL of cell i. The same logic can be applied for designing TAL of cell j, which results to minimum signaling overhead from cell j. Equation (2) allows us to calculate the signaling overhead for the designed TAL. If the network only consisted of two cells, the following rule of thumb in designing TAL, would give us an optimum signaling overhead. While generalizing the approach to a large scale network, then we don't have the exact number of UEs holding each TAL (the UE traces are not available) and therefore the calculation is not strictly accurate.

The method is simple and easily applied procedure, which usually gives a good local minimum. That is why we call it a *rule of thumb* in designing TAL. We can not guarantee to reach the global optimum, simply because in this approach, each cell is "selfishly" optimizing the signaling overhead according to their own data and does not consider the impact of other cells on their modified TAL.

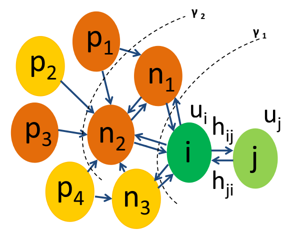

Fig. 1. Part of a network involved in s_{ij} definition. Assume: $l_{n_1 i} = l_{i n_1} = l_{n_2 i} = l_{p_1 n_1} = l_{p_1 i} = l_{p_1 n_2} = l_{p_3 n_2} = l_{p_3 i} = l_{n_1 n_2} = 1$

IV. Signaling Overhead Calculation in TAL

In the TAL concept, the UEs in one cell might have different TALs depending on the original cell they have been registered. This perspective difference of each UE, makes the signaling overhead calculation complicated. In this paper, we define $s_{ij}(\mathbf{t})$ as the number of UEs in cell i, who have j in their TAL divided by the whole number of UEs in cell i. Thus $\mathbf{S}(\mathbf{t})$ matrix would contain fractional values which are all between 0 and 1. Although the matrix is not binary any more, equation (1) remains valid.

In equation (2), the denominator is showing an estimation of the overall number of UEs in i. The whole number of UEs in cell i is estimated by the sum of cell load of i and the UEs entering i with i in their TAL. The numerator of (2) is giving the number of UEs in i which is estimated to hold j in their TAL.

$$s_{ij}(\mathbf{t}) = \frac{u_i l_{ij} + \gamma_1 \sum_{n \in Q_i} h_{ni} l_{nj} + \gamma_2 \sum_{n \in Q_i} \sum_{p \in Q_{ni}} min(h_{pn}, h_{ni}) l_{pj}}{u_i + \gamma_1 \sum_{n \in Q_i} h_{ni} + \gamma_2 \sum_{n \in Q_i} \sum_{p \in Q_{ni}} min(h_{pn}, h_{ni})} \quad (2)$$

Parameter l_{ij} is 1 if j is in the TAL of i and 0 otherwise. Q_i are the neighbors of i which have i in their TAL. Q_{ni} $(n \in Q_i)$ are the neighbors of neighbors of i (possibly i itself), which have both n and i in their TALs, and therefore while UEs move from these cells to n and thereafter to i, there will be no update (i.e. in Fig. 1, $Q_i = \{n_1, n_2\}$, $Q_{n_1 i} = \{i, p_1\}$, $Q_{n_2 i} = \{n_1, p_1, p_3\}$). Factor γ_1 represents the probability of UEs entering cell i which have been registered in Q_i and not from a further cell away. Consequently, γ_2 is the probability of UEs entering cell i which have been registered in $Q_{n_k i}$ and not a further cell away. The reason for picking the minimum value between h_{pn} and h_{ni} in the last term, is simply because we don't want to overestimate the number of UEs in i.

From the equation we can easily see that the same as conventional TA concept, the TAL of each cell consists that cell and the values on the diagonal of $\mathbf{S}(\mathbf{t})$ is always equal to 1. Here in equation (2), two hops are considered, which means that the impact of neighbors of neighbors is also included in the calculation and this increases the accuracy of $\mathbf{S}(\mathbf{t})$.

V. Performance Evaluation

Cell load and handover are the only data required for designing both the optimum conventional TA design and the TAL rule of thumb. (Note: Although the technical terms cell load and handover are generally representing the active UEs, in this study we consider them as both active and idle UEs.)

In order to analyze the behavior of each approach over time, the data should be given for each time interval during the evaluation time frame. Here, the time frame is the 24 hours of one day and the time intervals are for each 15 min. The only argument, which we have to recall is that while we calculate the signaling overhead over time, the designed configuration is based on the data collected from the current data set, and in practice it should be applied to the data set of the next time interval.

In this part, we introduce some signaling overhead parameters, which has been used for the evaluation of our numerical results. For simplicity $[t]$ defines the current time interval and $[t+1]$ gives the next time interval.

- *Ideal Overhead*: It represents the signaling overhead of applying design $[t]$ to the data $[t]$. This is not possible as we can't get back in time and apply the optimum design to the same data. If we could, the resulted overhead would have be the ideal value one could achieve by conventional TA concept.
- *Potential Overhead*: The same definition as ideal overhead, but this one would be used for TAL, just because we can not claim that for TAL we are calculating the ideal overhead.
- *Actual Overhead*: It represents the signaling overhead of applying design $[t]$ to the data $[t+1]$. This is a practical overhead due to reconfiguration for both conventional TA concept and TAL.
- *Average Overhead*: It represents the signaling overhead of the configuration designed for the average data of the whole T period, applying to the data $[t]$. This can be interpreted as a static configuration which is applied to the whole time frame.

VI. Numerical Results

The cellular network of Lisbon down-town area provided by the EU MOMENTUM project [10], used in this study consists of 60 sites and 164 cells. From the network standpoint defining two cells of one site in different TA is not desirable, therefore although all the theoretical structure in this paper is based on cell level, the evaluation performance of Lisbon network has been done based on sites. Traffic is assumed to vary over the day, and we have utilized a predefined traffic density variation where traffic is very low during the night, and higher during the day with two peaks at the beginning and the end of the office hours. This gives varying simulated traffic over 96 -15 minute- periods of a day.

For each set of data, the optimum conventional TA configuration is computed by CPLEX [6] using model [17]. The exact relationship between the overhead of a single update c^u with the overhead of a single paging c^p depends on the ratio resources consumption. Here we assume c^u/c^p is 10, a value common in the literature [4], [5], [7]. The call intensity factor is assumed to be $\alpha = 0.05$, meaning that 5% of UEs are paged

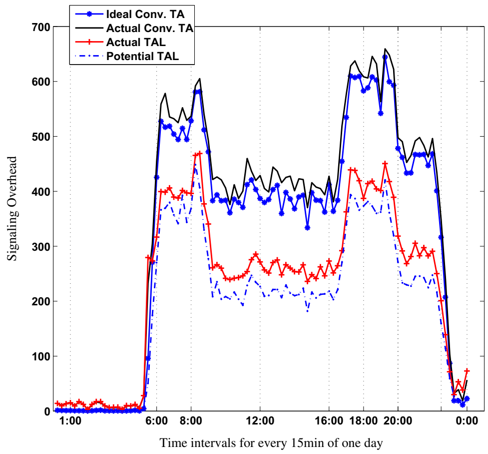

Fig. 2. Actual signaling overhead comparison of conventional TA vs. TAL designs for each time intervals ($\gamma_1 = 0.75$, $\gamma_2 = 0.15$).

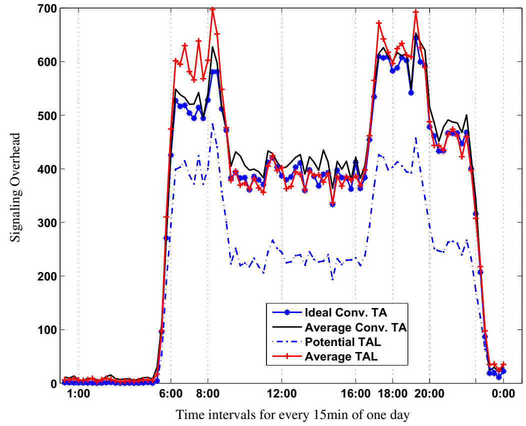

Fig. 3. Average signaling overhead comparison of conventional TA vs. TAL designs for each time intervals ($\gamma_1 = 0.75$, $\gamma_2 = 0.15$).

in every site. The optimum design for time interval $[t]$ was once applied to the data set $[t]$ to get the ideal conventional TA overhead, and another time to data set $[t+1]$ to obtain the actual conventional TA overhead.

The proposed rule of thumb method was used to design the TAL for each set of data. The same as conventional TA design, we apply the TAL design of time interval $[t]$ to the data set $[t]$ to obtain the potential TAL overhead, and to the data set $[t+1]$ to get the actual TAL overhead.

Figure 2 is showing all four different signaling overhead calculations for each data set of the network. All four graphs in this figure are presenting the overhead of the network in different times of one complete day according to our traffic simulation. The graphs show that the actual overhead curves are very close to the ideal/potential overheads for conventional TA/TAL. This shows that the data has a correlation between the adjacent time intervals. For small time intervals such as 15 min, the design for current data for most period of time is close to optimum for the next time interval. Another obvious observation from the graph is the large gap between the conventional TA overheads and TAL overheads. Aside from the time duration between (midnight - 6am), which the network load is very low and TAL is not performing as good as conventional TA, for the rest of the day, TAL is significantly better than conventional TA design.

As it was mentioned in the introduction, under the conventional TA concept, reconfiguration is costly and it is not a feasible option to reconfigure the optimum design every 15 min. In contrast, this reconfiguration is considered to be cost free in TAL. Therefore dynamic configuration is highly feasible. To compare the dynamic framework with the static one, another evaluation is to take an average of cell load and handover of all data sets of the whole day and make an optimum conventional TA and a TAL design based on the average data. This average design is considered as a static approach. Figure 3 shows the average design for each approach, applied to each time interval data. For simplifying the evaluation, the ideal/potential overheads are again illustrated in this graph.

TABLE I
SIGNALING OVERHEAD COMPARISON OF CONVENTIONAL TA AND TAL($\gamma_1 = 0.75$, $\gamma_2 = 0.15$).

Total Overhead	Conventional TA	TAL	Improvement
Ideal/Potential	$3.1387 * 10^4$	$2.0362 * 10^4$	35.1%
Actual	$3.3832 * 10^4$	$2.3805 * 10^4$	29.6%
Average	$3.3045 * 10^4$	$3.2796 * 10^4$	0.8%

Figure 3 illustrates the fact that the overhead of the optimum design based on average data is close to ideal conventional TA overhead in all time intervals, but in TAL the gap between the average overhead and the potential TAL overhead is very high. In some time intervals the TAL average overhead is even higher than the conventional TA overheads. This shows the fact that a static configuration works close to optimum for the conventional TA design. On the other hand, if one wants to use a TAL design, it is recommended to follow a dynamic configuration. Table I presents the total overheads in different calculations of two approaches of Figures 2 and 3. The numerical results show that TAL has a significant improvement in comparison to conventional TA concept.

A. *Justification of the Performed Evaluation*

Until now all results and figures are obtained by the assumption of $\gamma_1 = 0.75$ and $\gamma_2 = 0.15$. To have a wider perspective towards the performance of TAL, we calculate the $\mathbf{S}(\mathbf{t})$ matrix for all combinations of $\gamma_1 = [0, 1]$ and $\gamma_2 = [0, 1]$ by steps of 0.1. It can be easily observed that from definition (2), we have:

1) $\gamma_1 + \gamma_2 \leq 1$
2) $\gamma_2 \leq \gamma_1$

Considering these two constraints, we will easily get to the conclusion that $\gamma_2 \leq 0.5$. Although we should still consider that not all combinations would be practically feasible. As an example $\gamma_1 = \gamma_2 = 0.5$ represents that the impact of second hop cells are as much as the first hop cells, which is very rare to happen!

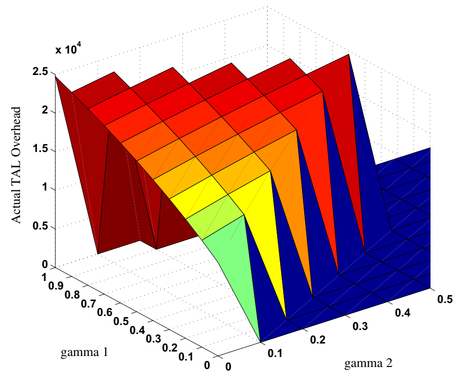

Fig. 4. The distribution of total actual overhead of TAL considering different combinations of γ_1 and γ_2.

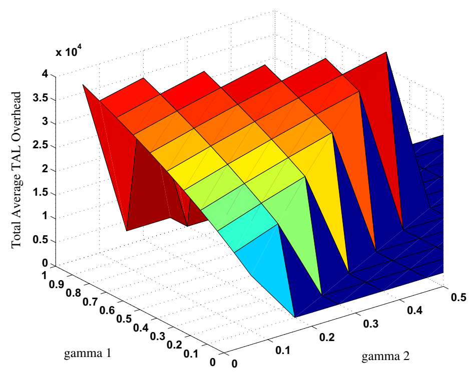

Fig. 5. The distribution of total average overhead of TAL considering different combinations of γ_1 and γ_2.

Figure 4 shows the distribution of total actual TAL overhead for different combinations of γ_1 and γ_2. It can be seen that the maximum total actual overhead of TAL would be $2.4778 * 10^4$, which is still 26.8% better than the same overhead in conventional TA concept.

Figure 5 is the same type of graph, but now for the total average overhead of TAL. The maximum overhead in this figure is at point $\gamma_1 = \gamma_2 = 0.5$ and it is equal to $3.5757 * 10^4$, which is 8.2% higher than the conventional TA overhead. This figure shows that the average (static) design for TAL in some situations would not be as efficient as the conventional TA concept. The minimum overhead in both figures are obtained at $\gamma_1 = \gamma_2 = 0$, which belongs to the time when the hop impacts in the calculation of $\mathbf{S(t)}$ matrix is ignored, and the result is the optimum value from the rule of thumb procedure.

VII. Conclusion

In this paper, we have examined the potential and reconfiguration performance of TAL in comparison to the conventional TA concept over time. A simple rule of thumb approach has been suggested for TAL configuration in LTE. A comprehensive study was done to first implement a reasonable calculation of signaling overhead for TAL and second to justify the accuracy of the approach. All computational efforts have been applied to the large scale network of Lisbon and the results illustrates that with even a simple approach in designing TAL, the reconfiguration performance of the network is being improved. ~~Another conclusion resulted from the study of average overhead is that unlike the conventional TA design which is a static configuration applied to long period of times without any reconfiguration, TAL works best if a dynamic frequent reconfiguration is applied for different time intervals. Fortunately, this is possible due to the automatic reconfiguration feature in LTE.~~

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