Performance Analysis of Cellular Networks by simulating Location Aided Handover Algorithms

Antonis Markopoulos, Panagiotis Pissaris, Sofoklis Kyriazakos, Artemis Koutsorodi, Prof. E.D. Sykas

National Technical University of Athens,
Dept. of Electrical & Computer Engineering, Telecommunications Laboratory,
157 73 Athens, Greece
Tel: +30 107721512, email: antony@telecom.ntua.gr

Abstract: **Future-generation mobile communications will provide broadband multimedia services to users, anywhere, anytime. Network performance should be guaranteed to support these applications and services. To avoid serious network shortcomings such as call dropping and blocking in the existing cellular systems, "smart" handoff algorithms and their implementation should be considered especially when handoff is much more complicated in 3rd generation systems (UMTS). Both UMTS and those of the second generation (GSM) systems will require redefined handoff algorithms of active connections as the smooth mobility support and continuous connection are essential issues for obtaining high performance. In this paper we present a set of intelligent algorithms using the mobile terminal (MT) location information and area awareness to assist safe handoff decisions. The implemented algorithms are validated by means of cellular network simulators that clearly show the impact of these techniques to major system performance metrics.**

1. Introduction

The paper mainly focuses on the improvement of network performance when the user's position is taken into account. For that purpose two network simulators are developed, one for GSM and one for UMTS, both based partially on the same core. The simulators were used to evaluate the performance of existing handover algorithms and also to validate the simulator models [1]. Subsequently a large number of simulations were performed in order to evaluate the proposed Location Aided Handover (LAH) algorithms.

This paper is organized around 5 sections. Section 1 is the introduction. In the next section the LAH algorithms are presented. There are currently a lot of LAH algorithms under investigation, but in this paper we only present 3 of them that have already been validated. In section 3 we present the result of the simulations that show the network improvement. The results are rather optimistic since show increased network performance under normal and high traffic load situations. In addition we present how LAH could possible be integrated in a real networking environment. Finally in section 5 we sum up with the conclusions.

2. Location Aided Handover Algorithms

2.1. Introduction

Stability and optimization of network performance in wireless systems will be the bedrock for network and service providers to maintain a smooth operation and flourish revenue results. Such providers hold the opinion that "user satisfaction and experience" has become an essential prospective to retain subscribers and increase new customers. Inaccessibility of network, low call quality, coverage and interference issues, block and drop of calls lead customers easily to change loyalties in a competitive wireless market [1]. A critical mechanism affecting network performance for existing and next generation systems is the handoff procedure.

Handoff is the mechanism that transfers an ongoing call from one cell to another as a user moves through the coverage area of a cellular system. Each handoff requires network resources to reroute the call to the new base station. Minimizing the expected number of handoffs minimizes the switching load. Another concern is delay. If handoff does not occur quickly, the quality of service (QoS) may degenerate below an acceptable level. Minimizing delay also minimizes co-channel interference. It is also known that during the handoff procedure there is a brief service interruption. As the frequency of these interruptions increases the perceived QoS is reduced. Furthermore, the chances of dropping a call due to factors such as the availability of channels increase with the number of handoff attempts. Moreover, as the rate of handoff increases, handoff algorithms need to be enhanced so that the perceived QoS does not degenerate and the cost to the cellular infrastructure does not skyrocket. Handoff procedure and performance is expected to receive increased attention by researchers in the immediate future. Much effort will be expended to improve the existing handoff schemes to meet the new challenges.

Several approaches for handoff utilize the relative signal strength criterion, which induces a handoff to a base station whose signal strength is stronger than that of the current base station. This criterion may generate an unnecessary handoff when the current base is still strong enough. In this paper we present handoff algorithms aided by MT location and area information.

2.2. Ping-Pong Avoidance (PPA) Algorithm

One very undesirable effect that occurs relatively frequently is the so-called ping-pong handoff. This is a handoff that takes place when the MT being at the cells' border oscillates from the current cell to a neighboring cell and back. A ping-pong handoff depends on the power budget criterion.

The hysteresis margin and the duration of averaging window length are two parameters that could be used to prevent the MT from such a situation. Previous research studied the handoff process in terms of the level crossing process of the difference between the two base stations' received signals, where the MTs move on the straight line that connects them [2]. At first the level crossing process was assumed to be stationary; later work [3] included the nonstationary case. A simulation study [4] used to evaluate the trade-off between delay and number (and probability) of unnecessary handoffs. Basic simulation parameters were the hysteresis level and the averaging window length. A work that has focused on the shape of the averaging window and considered both rectangular windows and exponential windows with various weights concludes that long windows reduce the number of handoffs but increase the delay [4].

A conclusion from these simulation studies is that none of these parameters is appropriate in actual operation. A high hysteresis value would practically eliminate a power budget handoff. A change in the boundary area of two cells will also be delayed far beyond the boundary. A high averaging length makes the handoff process too sluggish and leads to a situation in which a really necessary handoff sometimes is not carried out in time and the connection is then broken off. This is the reason why ping-pong handoff cannot be avoided with the current handoff algorithms and the modified variants, even if the appropriate parameter adjustments are used.

Our PPA algorithm on the other hand aims to minimize such undesirable handoffs using MT location and taking advantage the area information and mobility model to predict the user's movement. The objective is to avoid continuous unnecessary handoffs between two neighboring cells. The basis of the algorithm is the movement prediction of each user, who appears to have such a behavior. The major steps are to define when the algorithm should be triggered and how it could be applied more efficiently. For that purpose some new parameters are attached to the MT. A timer (for each user) is used to keep the time period from the last successful handoff. If that timer has not exceeded a specific threshold, which is an input for the PPA algorithm, (e.g. 10secs) and the user is again requesting a handoff to his previously serving cell, the algorithm is triggered. Given the user location info, the algorithm predicts his future move. Before applying this algorithm there was a need to validate the accuracy of user's movement prediction. How much does it converge to the real movement? The knowledge of area (Grid of pixels classified into building or street – Movement is only allowed to streets) combined to the exact mobility model give us a very high prediction accuracy. In Figure 1 the predicted movement versus the real movement is shown.

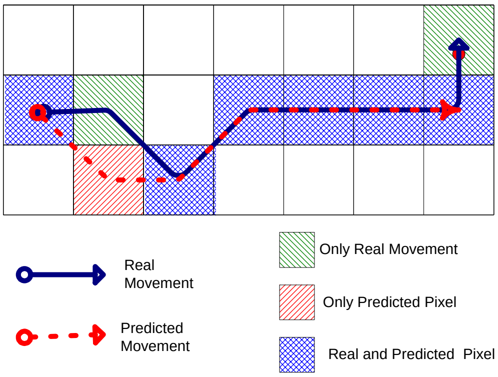


Figure 1: Comparison between real and predicted movement

As soon as the algorithm is triggered, the objective is to decide which cell appears to be the most appropriate for accommodating the MT, avoiding unnecessary repeated handoffs at the same time. In Figure 2 a ping-pong phenomenon is depicted. We assume that the predicted movement is the one shown in that figure.

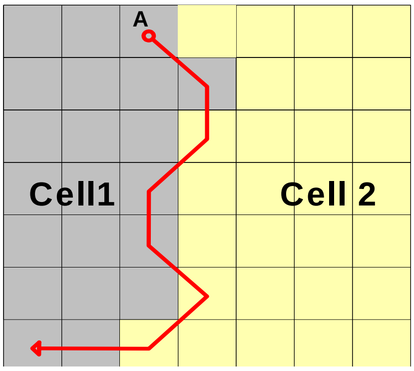


Figure 2: Cell prediction example

In a short time, several handoffs are requested. Suppose that the algorithm is triggered at position A. The dominant cell in the pixel where the algorithm is triggered is C_A. In the specific example, C_A=Cell 1. A new parameter S is then attached to MT. This parameter will assist the algorithm to attach the user to the most proper cell. Assume that P is the number of pixels that MT will go through during its complete route, p_i $\forall i \in P$ is the current pixel and $Rx(p_i)$ is the received field strength in p_i from the dominant cell $C_d(p_i)$ in p_i . S_i is initialized in the pixel where the algorithm is triggered and evolves during the movement as follows:

$$S_i = \begin{cases} S_{i-1} + Rx(p_i) & \text{, if } C_d(p_i) = C_A \\ S_{i-1} - Rx(p_i) & \text{, if } C_d(p_i) \neq C_A \end{cases} \quad \forall i \in P, \quad S_0 = 0$$

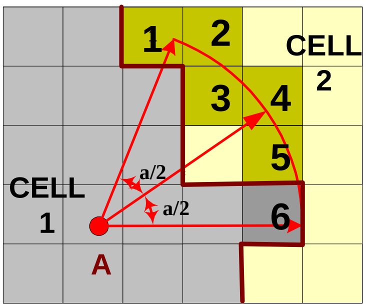
If the final value $S_P \geq 0$, the most appropriate cell to cover MT is the C_A (Cell 1), otherwise if $S_P < 0$ Cell 2 should cover it. In that case a handoff will take place. Then, the MT is locked to the estimated most proper cell for a fixed time period. During this period, MT can not request another handoff.

2.3. "Towards The Border" (TTB) algorithm

PPA algorithm tries to avoid continuous handoffs between two cells whenever users move almost parallel to cell borders. What happens when a user moves almost vertically towards a border? In this case it is almost certain to expect a handoff from one cell to another. According to the mobility model, the direction of a user can change in every step. Despite the fact that the user might change direction of 360° or even 180°, the probability of this to happen is extremely low due to the fact that the mean of the normal distribution, that we choose to model the user's probability of changing direction, is small (10° to 20°). Practically, it is not common to dramatically change your direction within a few seconds when you are moving on a straight highway.

This additional information gives us a significant advantage. A user moving towards a different cell is almost certain that is going to request for a handoff within a small period of time. The idea is that whenever such behaviour (i.e. vertical movement towards the border) is detected, the target cell needs to bind sources for a dynamically configured period of time. The most popular non-predictive channel reservation approach for handoff prioritization in cellular systems is the guard channel (GC) protocol. The logical channels that are set aside are often called guard channels. Initially, the guard channel scheme improves the handoff success rate; on the other hand it might increase the blocking probability, since it reserves channels for the handoff procedure. Predictive channel reservation scheme considers the probabilistic user's movement and can result in a higher network performance. The predictive channel reservation scheme (PCR) is based on the MT position, which can be either the result of an accurate location server, or prediction of the location. According to PCR, if the MT is moving towards a new cell, it transmits a channel reservation request to the new cell. At this time a counter is set in order to cancel the reservation in case the MT direction changes dramatically [5][6][7].

For example, assume that a user is inside Cell 1 and moves toward Cell 2 (Figure 3).



CELL 2 - Target Cell

Figure 3: Prediction of movement towards the border

The algorithm predicts that within a specified time period this user will reach the boundary. In such a case, Cell 2 binds resources for this user before his actual handoff request. When this request takes place the user utilizes the already bound resource to the effect that the call will not be blocked. This algorithm uses the position and velocity of each user in order to predict the new cell which we call "Target Cell". The direction of the user can be extracted by two sequential positions. We extend this direction by a selected angle $\hat{a}$. Taking into account the *prediction time* t, *user speed* $\overline{U}$, *angle* $\hat{a}$ and the area characteristics we have an estimate whether the user is moving towards another cell.

In the example of Figure 3 cell number 2 is the "Target Cell". The question that arises is how the network would know whether the user approaches or actually enters another cell in order to trigger the execution of handoff. The user starts from position **A,** and after a predicted *time* t, with *speed* $\overline{U}$ and possible *angle* $\hat{a}$ *the user* will end up in any of six different destination pixels (1 to 6 in Figure 3)**.** Five of these pixels are dominated by Cell 2 and only one by Cell 1. There is a high probability therefore for Cell 2 to cover this user after *time* t. Taking that as a fact, the network will be able to make the handoff in a more efficient way by reserving appropriate resources to the "Target Cell" thus avoiding undesirable events such as drop and block call. To improve the prediction , *angle* $\hat{a}$ is initially selected to have the same value as the mean value of the normal distribution used by the mobility model for the user direction changes (see Section IV.I-Mobility Model). What happens when the movement prediction fails? In this case the network releases the reserved resources after the timeout period.

2.4. MGIS Data Resolution (MDR) Algorithm

Next algorithm uses the stored data collected by the Mobile Network Geographic Information System server (MGIS server) [8]. The Set of cells is C, the set of pixels is P. We assume that each cell $j \in C$ has two extra features: a) mean value of Drop Call Rate ($DCR_j \quad \forall j \in C$) and b) mean value of Block Rate

($BR_j \quad \forall j \in C$). Both are remotely collected and constantly available through the MGIS data.

The above features are attached to the whole cell. We have to assign these features to each pixel within each cell $p_{i,j} \quad \{\forall (i,j) \in (C \times P)\}$. We propose a cost function for this purpose (Equation 2) based on the above attributes and the signal strength at the given pixel $Rx(p_{i,j}) \quad \{\forall (i,j) \in (C \times U)\}$ given by Rx level and not dimensioned in any metric (dBw, dBm). Each pixel participates with a selected weight in the proposed cost function. Thus:

$$C_{i,j} = (1 - Rx_{ij})(w_1 \cdot DCR_{ij} + w_2 \cdot BR_{ij}) \ \mathbf{(2)}, \ 0 \le C_{i,j} \le 1, \ \forall j \in C$$

$$Rx_{ij} = \frac{Rx(p_{i,j})}{Rx_{MAX}} \qquad \mathbf{(3)},$$

$$DCR_{ij} = DCR_j \cdot \frac{\sum_{\forall i \in j} Rx(p_{i,j})}{\sum_{\forall i \in j} p_{(i,j)}} \cdot \frac{1}{Rx(p_{i,j})} \ \mathbf{(4)},$$

$$BR_{ij} = BR_j \cdot \frac{\sum_{\forall i \in j} Rx(p_{i,j})}{\sum_{\forall i \in j} p_{(i,j)}} \cdot \frac{1}{Rx(p_{i,j})} \ \mathbf{(5)},$$

Where $w_1 + w_2 = 1$ and $Rx_{ij}, DCR_{ij}, BR_{ij}$ are normalized parameters given by (3),(4),(5). The following fraction (6) of sums gives the average Rx value in a specific cell.

$$\frac{\sum_{\forall i \in j} Rx(p_{i,j})}{\sum_{\forall i \in j} p_{(i,j)}} (6)$$

This formula (Equation 2) calculates a cost $C_{i,j}$ at pixel i of cell j. The current pixel is known by means of the Location Server (LS), used (as in the previous algorithm) to estimate the user position.

The calculation of the cost $C_{i,j}$, for each pixel p_i in every cell C_j is the core of the algorithm. If the user's current pixel p_i produces a cost above the selected threshold a handoff is needed for this user. Before the handoff initiation, the MDR algorithm calculates the cost for the current pixel in each cell. The cell having the lowest cost should not be the current cell, this provides the system with an extra check. Only in the case where some other than the current cell appears with a lower cost in the current pixel, a handoff is actually initiated to this better cell. The concept therefore behind this algorithm is executing the handoff procedure to the best cell whenever the MT gets inside a "critical area".

However, if the PPA algorithm is also active and a user is "locked", as explained in the previous section, a handoff (even a MDR triggered handoff) is not permitted and the user remains locked.

As in the PPA also in the MDR algorithm, there are also some critical parameters that need to be initiated and fine tuned through a large number of simulations. Most important of these parameters is the selection of the cost threshold that indicates whether a user is inside a "critical area" or not, as well as the weights used in the cost function that need to be tuned according to the most appropriate metric for the operator's policy.

3. Simulations Models and Results

While measurement and experimentation provide a means for exploring the "real world", simulation is restricted to exploring a constructed, abstracted model of the world. Measurements are needed for a crucial "reality check". Experiments are frequently vital for understudying the behavior of otherwise intractable systems. However, measurements and experiments have limitations in that can only be used to explore the existing handover procedures. They cannot be used to explore different possible new handover procedures [9].

Simulations on the other hand are not only complementary to analysis, but allow exploration of complicated scenarios that would be either difficult or impossible to analyze. Simulations can also play a vital role in helping researchers to develop intuition about the behavior of new handover procedures [9]. To simulate each one of the previously mentioned algorithms, a cellular system simulator was developed [10]. The purpose of such a simulator was to evaluate the network performance metrics (blocking and dropping call rates, handover failure rate), evaluate the existing handover procedures and at the same time simulate and validate the innovative algorithms proposed herein. A simulator for studying new algorithms should be extendable with new functionality as well as configurable for exploring a range of different scenarios. LAH simulators consist of several software modules. Each module is responsible for a set of tasks and capable to communicate with other modules [10]. A major objective of the LAH simulator is the construction of a scalable system where parameters, input data, models, algorithms, techniques and procedures can be easily integrated in the system. The simulator is characterized mainly by:

- *Area definition*: An urban geometry (Downtown, Athens, Greece) given the area's low left point coordinates (WGS 84, UTM Zone 32, Southern Hemisphere), the dimensions of the area grid (given in pixels $10 \times 10m$ - $3{,}2 \times 3{,}2Km$ totally) and covered by 16 cells. Each pixel corresponds to a building or street. All these information are available by a network operator planning tool.
- *Cell radius*: 200 m to 3 Km
- *Application environment*: Outdoor (typically urban areas)
- *Main propagation mechanisms*: Forward and backward diffraction over roof tops

- *Traffic model:* Defines traffic model parameters (Erlangs per user, Mean call duration, Number of SDCCHs, Number of TCHs per cell, Average number of users per cell).
- *Mobility model:* Medium and higher mobility. This model is used to move each user inside the selected area. Each user position corresponds to an exact pixel. Mobility is allowed only to pixel that corresponds to the Street class. When a user is generated, three mobility attributes are attached to her:
    - **A pair of two coordinates** (x,y) is initialized randomly defining the user's initial position.
    - **A speed value** is attached using an approximation to the normal distribution (average speed and distribution's standard deviation are given as inputs).
    - **A value for the direction** (given in degrees) is attached using an approximation to the normal distribution (Average direction and distribution's standard deviation are given as inputs). At each simulation time step the direction changes according to the above parameters.
- *Location servers* with an exponential location error with mean around 20m (GPS accuracy scenario).

3.1. Simulation Results

Figure 4 shows the handoff failure rate in cell level. The data were drawn from a real network and is a result of averaged measurements for a time period of two weeks.

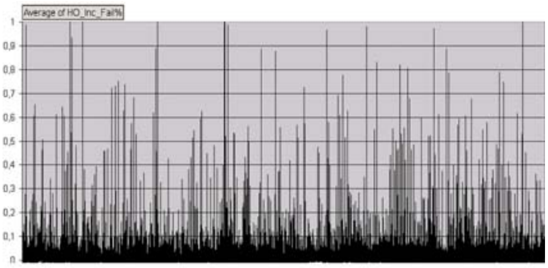


Figure 4: Handoff Failure

The first observation is that the average handoff failure is around 10%, which is quite high. Considering that users making calls while moving may require several handoffs during a call, the call-drop probability increases. According to the network system the main reasons for handoff failure are low field strength, quality or power budget.

Figure 5 shows the number of handoff attempts in a period of one week in the complete coverage of a GSM operator. The failure rate is shown according to the type of the handoff procedure. The total number of around 150 million handoffs per week and the average handoff failure (around 10%) shows the need for handoff procedure enhancement.

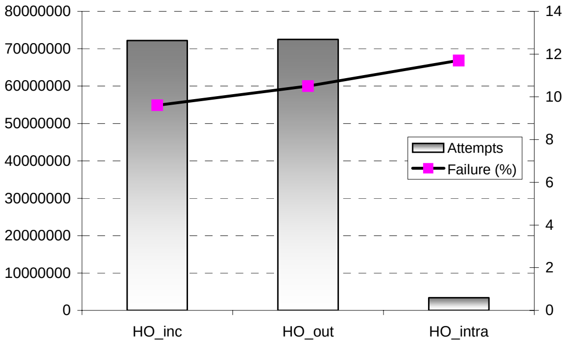


Figure 5: HO statistics

Another important issue is the extreme signaling overhead due to the increased number of handoff attempts and its influence to the system's performance. For the above reasons the reduction of the total number of handoffs in the whole system is of a high priority in all vendor's policies for network optimization. PPA algorithm leads the system to a 5% fewer total handoffs (HoRate) as Figure 6 depicts.

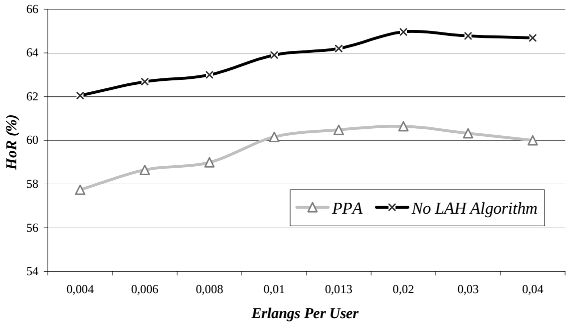


Figure 6: HOR progress and improvement

Figure 7 depicts that the PPA algorithm achieves a significant reduction in the number of ping-pong handoffs. An estimated 40% reduction is achieved in all traffic load scenarios.

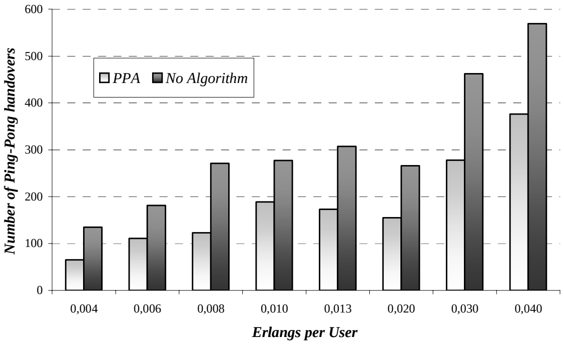


Figure 7: No Of Ping-Pong HO

Figure 8 presents the Drop Call Rate progress when no algorithm is applied compared to the case when PPA, MDR and TTB algorithms are triggered. The improvement to the drop call rate clearly increases with the traffic load.

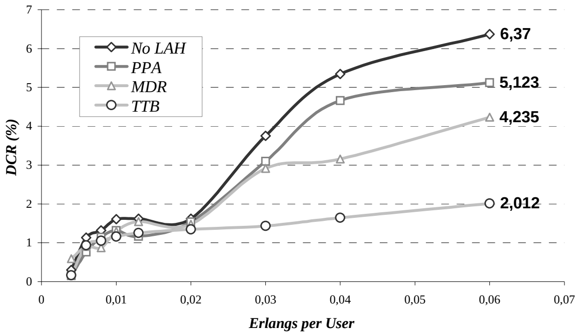


Figure 8: DCR progress and improvement

A similar behavior can be observed in Figure 9 where the Handoff Block Rate is plotted. Here, the improvement of the HOBR is even better than the DCR in the previous figure. When traffic load reaches 0,06 Erlangs per user, more than a 50% reduction in blocked handoffs is achieved. When the "towards the border" algorithm is applied an improvement of 80% is observed in such traffic load scenarios.

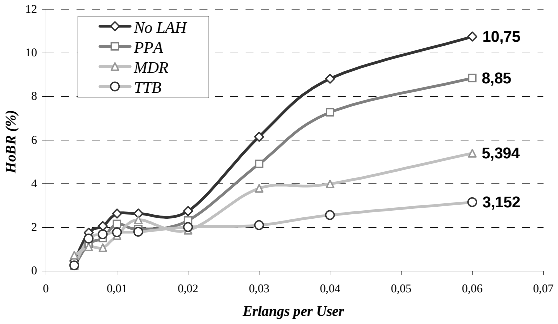


Figure 9: HOBR progress and improvement

From Figure 10 we can conclude that the MDR algorithm can optimize the network performance since two major performance metrics namely the Handoff Block Rate and the Drop Call Rate are drastically reduced. The mean decline is about 40% for the HOBR and 30% for the DCR.

Similarly a major reduce of around 60% in Handoff Block Rate and 40% in Drop Call Rate can be observed in Figure 11 when the TTB algorithm is applied.

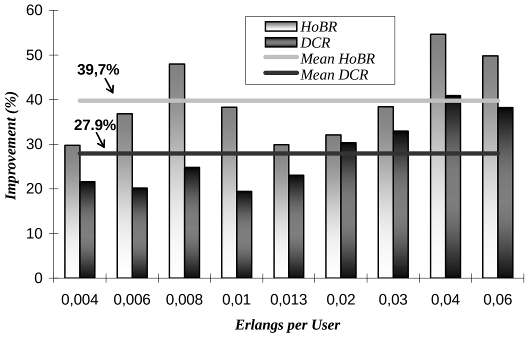


Figure 10: DCR and HOBR improvement due to MDR

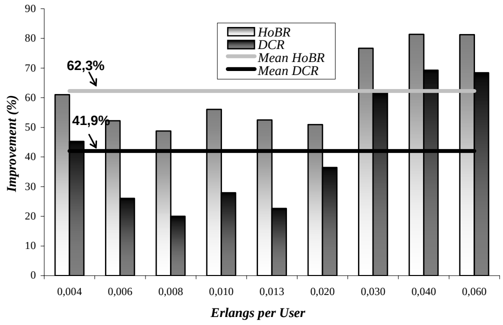


Figure 11: DCR and HOBR improvement due to TTB

4. Adjust LAH in real network

One of the major goals of the LAH activity under the framework of IST CELLO was the investigation how could this be integrated in a real networking environment. For the purposes of simplicity we introduce the LAH algorithm as an additional component to the system, while this can be integrated as software patch to the BSC (RNC) software. In the case of GSM, following figure depicts the logical architecture of a network that supports both position location and LAH. The figure is based on the proposal of ETSI TS 101723.

The LAH component, as part of the BSS interfaces with 2 components, namely the BSC and the LS. Since a LS architecture can be represented as LMUs (Location Measurement Units) and SMLC/GMLC Serving/Gateway Mobile Location Centers, LAH should communicate with the SMLC to retrieve the user's location. For that reason it should be investigated the possibility to communicate and interact with these elements.

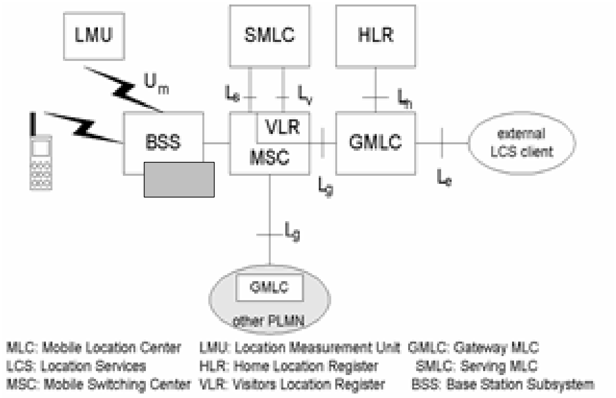


Figure 10: LAH supporting architecture

The requirements for the LAH-BSC communication can be summarized in:(i) LAH decisions should be executable from BSCs; (ii) LAH component should be connected to a BSC and (iii) these should be performed at a real-time basis. Concerning the first one, each manufacture provides a list of MMLs (Man Machine Language) commands that can be executed from a BSC. The LAH algorithms can all be translated into MMLs that can be executed in order to control the handover as described in the previous sections. The MML commands add practically no delay to the system since they are immediately executed. The communication can be realized over telnet, RS-232 and also over the OMC, if centralized LAH is required. The requirements for the LAH-LS communication can be summarized in: (i) LS requests should be forwarded to the SMLC for processing and the response should be performed immediately, (ii) SMLC should be able to handle a large number of requests, (iii) the accuracy should be as high as possible. Concerning the requests to SMLC and the responses, this depends on the LS, since there are many LS implementations. A general architecture, as the one shown in the figure above, supports communication of the LS components with the BSC, therefore, this is feasible. The main limitation is the number of location requests that an SMLC can simultaneously handle. The accuracy is also an important parameter, but this is proven to be a parameter for the LAH performance as described in the previous sections.

5. Conclusions

We have presented an investigation in the area of handoff optimization, aided by MT location and area information, which is an outcome of extensive simulative studies, performed both for GSM and UMTS systems. Intelligent handoff algorithms exploit MT location and area knowledge to increase the performance of several network metrics. PPA, TTB and MDR algorithms are implemented for GSM systems. Nevertheless the concept could be extended to UMTS with proper modifications as well. The objective is to eliminate all the existing problems in the handoff procedure, improve vital network performance metrics, and help systems to adapt to unforeseen situations such as critical areas and hot spots.

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