Efficient Location-Based Hard Handoff Algorithms for Cellular Systems

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Abstract. Mobile world's rapid growth has spurred development of new protocols and new algorithms to meet changing operation requirements- such as mobile networking, and quality-of-service support. Handoff is one of the most critical procedures in cellular systems. Network operators give emphasis to optimize handover, since it is strongly related to dropped calls, network overload and subsequently users' criticism. Handoff can be seen as a blind procedure, if it is only based on the comparison of measurements, without the information of location. Since signal propagation and pathloss are complex in nature, we can expect unnecessary and wrong handoff executions. 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 and increasing user satisfaction. 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 MT position is taken into account. For that purpose, we defined and implemented new innovative handoff algorithms. We have also developed two network simulators, one for GSM and one for UMTS, to validate those algorithms. The simulators were developed from scratch and are used to evaluate the performance of existing handoff algorithms as well as to validate the simulator models of our new algorithms. To produce safe results a large number of simulations were performed.

The paper is organized around 5 sections. Section 1 is the introduction. Section 2 introduces innovative handoff algorithms based on MT location and area information. In section 3 we present the basic simulators layout and results of numerous simulations that show the network performance behavior for both systems. The results are very optimistic since increased network performance under normal and high traffic load situations is clearly shown. Finally in section 4 we sum up with the conclusions.

2 Location Aided Handover Algorithms

Stability and optimization of network performance in wireless 2G-3G 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 hand-off 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 handover requires network resources to reroute the call to the new base station. Cellular networks recommendations do not specify an algorithm for the handover decision or target cell selection. Usually the vendor defines the handover algorithm. Network operators and manufacturers have hence the possibility of defining and using a handover algorithm based on the various parameters. The signal level of the mobile stations, which can be used to estimate the path loss of a radio signal, is one of the criteria for the handover initiation. Besides the signal strength, the measured bit-error ratio is also a very important indication of the signal quality of the uplink and downlink.

Some complementally intelligent software technologies, i.e. fuzzy logic [2], neural networks and pattern recognition techniques [3]-[5] were proposed to optimize the handover process. Moreover, hardware solutions such as adaptive antennas were introduced to make the handovers “smart”. However, it is worthwhile observing that intelligent handover based on mobile location information and cell RF propagation statistic could decrease the occurrence of unnecessary handovers and so the signaling for handover procedure can be reduced [6]. Triggered by that, we introduce a set of new intelligent handover algorithm (Location-Aided Handover, LAH) based on mobile phone location capability and area information.

LAH is a set of algorithms uses the information of instantaneous mobile location, data from the Mobile Network Geographic Information System (MGIS) [7] and area characteristics to make the decision of the most appropriate target base station for handover. MGIS database consists of all these essential performance metrics (see Section 2) per cell. MGIS is specified in [7]. The major benefits from the above described use of the MGIS data for efficient handover procedures are the decreasing of signaling traffic, avoidance of drop calls, increased speech quality, solution of several planning shortcomings and enabling seamless handovers for high data-rate users in UMTS by providing a mechanism for resource allocation in the target cell.

In the following sections follow a detailed description of Location Aided Handover algorithms for GSM and UMTS networks. These algorithms are:

- Ping-Pong avoidance (PPA)
- Towards the border (TTB)
- MGIS Data Resolution (MDR)
- Transmission Power and Interference Optimization (TPIO) for UMTS

2.1 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 [9]. At first the level crossing process was assumed to be stationary; later work [10] included the nonstationary case. A simulation study [11] 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 [11].

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 (see Section 4.1 - Mobility model) give us a very high prediction accuracy. In Figure 1 the predicted movement versus the real movement is shown.

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, $C_A = \text{Cell 1}$. 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, $p_i \quad \forall i \in P$ 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:

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 cannot request another handoff.

2.2 “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 behavior (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 [12].

For example, assume that a user is inside Cell 1 and moves toward Cell 2 (Figure 3). The algorithm predicts that within a specified time period this user will reach the boundary.

Fig. 3. Prediction of movement towards the border

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. Taking into account the prediction time, user speed, angle 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, with speed and possible angle the user will end up in any of six different destination pixels (1 to 6 in Figure 3). Cell 2 and only one by Cell 1 dominate five of these pixels. There is a high probability therefore for Cell 2 to cover this user after time. 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 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 4.1- Mobility Model). What happens when the movement prediction fails? In this case the network releases the reserved resources after the timeout period.

2.3 MGIS Data Resolution (MDR)

Next algorithm uses the stored data collected by the Mobile Network Geographic Information System server (MGIS server)[7]. The Set of cells is C and pixels is P . We assume that every selected 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 of them come from the constantly and remotely collected MGIS data. The above features are attached to the cells as a total attribute. We have to map these to each pixel $p_{i,j} \quad \{\forall(i,j) \in (C \times P)\}$. A formula is used for this purpose (Equation 2) based on these attributes and the signal strength $Rx(p_{i,j}) \quad \{\forall(i,j) \in (C \times U)\}$. Each of the components participates with a selected weight in the proposed cost function. Thus:

$$C_{i,j} = w_1 \cdot (1 - Rx_{IND}) + w_2 \cdot DCR_{IND} + w_3 \cdot BR_{IND} \quad 0 \leq C_{i,j} \leq 1 \quad \forall j \in C \quad (2),$$

$$Rx_{IND} = \frac{Rx(p_{i,j})}{Rx_{MAX}} \quad (3),$$

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

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

Where $w_1 + w_2 + w_3 = 1$.

This formula (Equation 2) calculates a cost $C_{i,j}$ at a specific pixel i for each cell j . This pixel is the reply of the Location Server (LS), which is used (as in previous algorithm) to estimate the real user position (location error).

The core of the algorithm is the calculation of the cost $C_{i,j}, \forall j \in C$ at a specific pixel p_i . If a user, while he is moving, comes to a pixel p_i where the cost of his serving $Cell_j, j \in C$ is above a selected threshold, we consider that the coverage area of $Cell_j$ is a malicious one. Before a handover execution, MDR algorithm makes the calculation $\forall j \in C$ and provides the system with an extra check. The cell of the best cost should not be the same with serving cell ($Cell_j$). Only if there is another cell with a better cost, a handover should take place. Therefore the basic criterion of executing the handover procedure based on MDR algorithm is that a user gets inside a “critical/problematic area/hot spot” and prevision for a better cell coverage. However, if PPA algorithm is active and a user is “locked”, as explained in previous section, a handover (even a “MGIS handover”) is not permitted and user still remains locked.

As in PPA algorithm, there are also some critical parameters that need to be initiated and fine tuned through a large number of simulations. First and most important is the selection of the cost threshold that indicates whether a user is inside a “critical area” or not. Last but not least, the three weights used in cost calculation formula are needed to be fixed depending on which metric is more essential for the provider policy. Depending on what the provider consider more critical in defining cell cost (i.e. Rx Level, DCR or BR), we need to choose the right weights for the cost function.

2.4 Transmission Power and Interference Optimization (TPIO)

Handover is a critical feature in cellular systems and therefore handover algorithms are under extensive research. Problems in handover algorithm or its parameters may lead into call drops with a direct effect on user satisfaction. This is particularly critical for 3G systems, where high data rate users will be prime candidates for being dropped. Unnecessary handovers may lead to degraded call quality and waist of capacity in signaling. Since the cell-size is constantly decreasing, it is important for the handover algorithm to identify users with different mobility and data rate characteristics. The user position can affect in different ways the interference that is caused to serving and neighboring base stations (intracell and intercell interference). Moreover since in a multimedia system, there are different kinds of services (see Table 1), the users have different requirements in terms of bandwidth, maximum bit rate, bit rate availability, BER, delay tolerance, grade of service and so on [16]. For example, these users that demand high throughput (e.g. video conference) it would be more efficient to be close to a cell center. If they are quite far from the center, position near the cell boundary, it is possible to transmit with high power (due to power control by the base station), so that they will cause interference and probably be dropped. This algorithm copes with a problem, called Transmission Power and Interference Optimization

(TPIO). The core concept of the algorithm is based on the following: “Given the service area layout, mobile position, the services and their requirements, aim at optimizing the transmitted powers and therefore the interference levels in both uplink and downlink” [14].

The service area is split into a set of pixels, P . Each pixel $p \in P$ corresponds to a small part ($10 \times 10m$) of the area. The set of services is S . The QoS requirements of $s \in S$ are expressed through the minimum signal-to-interference ratio, SIR_s . It takes into account the bit-rate, service activity factor (SAF) and the minimum required E_b/I_0 . The set of cells is C and the set of active users U . UTPIO algorithm uses a cost function applied not only for each new connection but also performed for each active user in every step since UMTS simulator investigates also mobility issues.

$$Q_i = w_1 \cdot [1 - fs(p_i)] + w_2 \cdot s_i + w_3 \cdot d_{i,j} \quad (6)$$

Equation 6 denotes the cost function $Q_i \forall i \in U$, given field strength $fs(p_i)$ in specific pixel $p \in P$, requested service $s_i \in S$ and in distance $d_{i,j}$ from cell $j \in C$.

This algorithm should aim to define the following thresholds/targets according to the location (pixel) and service distribution of the offered load.

- Uplink interference threshold, $I_{up}^{thres}(c) \forall c \in C$.
- Total downlink transmitted power threshold, $P_{down}^{thres}(c) \forall c \in C$.
- Uplink power target level per pixel and service, $p_{up}^{thres}(p, s) \forall p \in P, s \in S$.
- Downlink power target level per pixel and service, $p_{down}^{thres}(p, s)$

The above parameters are used for a) the admission control mechanism, [15]-[19], and b) the power control mechanism, [20][21]. In the first case, the admission of a new call or a handover depends on the interference it would have caused if accepted. If there is a feasible power level that can be assigned to the new connection so as to alleviate with the new interference conditions, in both uplink and downlink, the MT is admitted otherwise the call is blocked. In the second case, during the system operation, the TPIO algorithm assigns the optimum power levels for the MT/Node-B and the respective Node-B/MT gives the appropriate power commands in order to reach these levels. In any case, the algorithm should maintain the QoS levels required by the transmissions, namely bit rate and SIR levels, ensuring the compatibility of the assigned powers to the terminal capabilities.

3 The Simulation 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 [22].

Simulations 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 [22]. To simulate each one of the previously mentioned algorithms, two cellular system simulators were developed (GSM & UMTS) [23]. The objectives of those simulators were to investigate network performance metrics (mean blocking and dropping call rates, handover failure rate, and power allocation in UMTS, interference issues and QoS provisioning), existing handover procedures and simulating and validating the proposed above innovative algorithms. LAH simulators consist of several software modules. Each module is responsible for a set of tasks and communicates with other modules [23].

Each simulator characterized by:

1. For GSM Simulator

- Area definition: An urban geometry (Downtown, Athens, Greece) given area's low left point coordinates (WGS 84, UTM Zone 32, Southern Hemisphere), the dimensions of the area (given in pixels of 10X 10m and 3,2 Km X 3,2 Km totally) grid having 14 cells.
- Cell radius: 200 m to 2 Km
- Environment of application: outdoor (typically urban areas)
- Main propagation mechanisms: forward and backward diffraction over rooftops
- Location Accuracy - GPS solutions are assumed
- Traffic model: Defines traffic model parameters (Erlangs per user, Mean call duration, Number of SDCCHs, Number of TCHs per cell, etc).
- 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.

2. For UMTS Simulator

- Generic Principles of CDMA systems [24]
- Area definition, Mobility model, Location Servers: The same as in GSM
- Cell radius: 200m to 2 Km.
- Traffic model: Defines traffic model parameters (Circuit and Packet Switched services, Erlangs per user, Mean call/session duration, Average number of users per service and cell).

- Services: The traffic model with the assumed service characteristics is summarized in Table 1
- Admission and Power Control: In conjugation with the thresholds defined by the TPIO algorithm

Table 1. Assumed UMTS service characteristics

	Voice Call		Videoconference		Interactive Data		Streaming Video	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Bit Rate (kbps)	12.2	12.2	64	64	144	144	-	384
Eb/Io requirement (dB)	4	6.5	2	5	1.5	4	-	3
Service Activity Factor	0.67	0.58	1.0	1.0	1.0	1.0	-	1.0
Orthogonality factor	-	0.5	-	0.5	-	0.5	-	0.5

Several simulations lead us to the following results described in the next section. Results are categorized for GSM in the investigation of performance metrics such as Drop Call, Handover and Handover Failure Rates and for UMTS analyzing uplink power transmission and interference behavior depending on mobile distance from the cell and the type of service being requested.

3.1 Simulation Results

Figure 4 (left side) 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.

Fig. 4. Handover Failure and HO Statistics

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. Figure 4 (right side) 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 (Inc-incoming, out-outgoing, intra-intra handover).

The total number of around 150 million handoffs per week and the average handoff failure (around 10%) shows the need for handoff procedure enhancement. 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 5 depicts. The right side of this figure 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.

Fig. 5. HOR progress and improvement and No Of Ping-Pong HO

Figure 6 (left side) 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. A similar behavior can be observed in the same figure (right side) 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.

Fig. 6. DCR progress and improvement and HO progress and improvement

From Figure 7 (left side) 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 7 (right side) when the TTB algorithm is applied.

Fig. 7. DCR and HOBR improvement due to MDR and TTB respectively

In the case of the UMTS simulations each of the 10 cells is split into 4 zones around the respective NodeB. A zone consists of several pixels according to the distance from their controlling NodeB. Mobile terminals can transmit at maximum 300mW(25dBm) for all the provided services, while base stations can transmit at maximum 20W(43dBm). Chip rate is set to 3,84Mcps. The thermal noise density is -174dBm/Hz corresponding to a noise power of -108,1dBm. Figure 8 depicts the number of active downlink connections per service (columns) and the total power that should be transmitted by each NodeB in the forward link (row) with and without TPIO algorithm respectively.

Fig. 8. Downlink load – Transmitted power per NodeB

The uplink/downlink power control mechanisms should drive the mobile/NodeBs, respectively, to transmit at these power levels in order to cope with the offered load and satisfy the QoS requirements of the requested services. The algorithm is capable of handling with different load situations and traffic variations and should be run at any time that re-engineering process is needed.

4 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. Moreover, the TPIO algorithm addresses a hot issue for 3rd generation systems, which is the optimal transmission power allocation and interference optimization, aided by MT location and variant service characteristics.

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