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Location-Sensitive Radio Resource Management in Future Mobile Systems

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Abstract-- Mobile positioning is becoming of the most attractive features of the cellular systems in the near future. In addition to the general location-based services, assistance data can help to optimize the radio resource allocation and increase the intelligence of radio resource management in cellular systems. An essential component of radio resource management is handoff control. It seems that location assistance data can bring the most benefits when in association with handoff mechanism rather than with other components of radio resource management. In this paper we outline how location assistance data can be exploited to improve the performance of the radio resource management in terms of the signalling cost due to the switching and routing of the connections involved in the handoff process. A novel handoff approach, Location-Sensitive Handoff (L-SH) is presented. The performance of the L-SH is evaluated through the simulation results and the results are discussed.

Index Terms—Radio resource management, handoff control, mobile positioning, location assistance data, location-sensitive handoff.

1. Introduction

Handoff is one of the essential means to guarantee the user mobility in a mobile communications network, where the subscriber can move around. Maintaining the traffic connection with a moving subscriber is made possible with the help of the handoff function. The basic concept is that when the subscriber moves from the coverage area of one cell to another, a new connection with the target cell has to be set up and the connection with the old cell has to be released.

Depending on the diversity used in association with handoff mechanisms, they can be categorised as hard handoff, soft handoff, and softer handoff. During the handoff process, if the old connection is released before making new connection it called as a hard handoff. Unlike in hard handoff, if a new connection is established before the old connection is released then the handoff is called a soft handoff. The soft handoff is an essential feature of any Code Division Multiple Access (CDMA)-based mobile system in which the same portion of the radio bandwidth is shared simultaneously. The concept of soft handoff has thoroughly been discussed in [1-10]. During the soft handoff process, the existing radio link may be replaced (added new radio link and deleted the old one) within the different sectors of the same cell. It is also possible to add a new signal branch or delete the old branch, which does not meet the required signal quality. Soft-softer handoff, on the other hand, refers to the situation when both soft and softer handoffs occur simultaneously. All of these mechanisms are provided by the third-generation mobile system [11].

As an essential component of radio resource management, handoff entity is responsible for managing an ongoing call process even when a mobile station crosses the border from one cell into another. The handoff entity manages hard handoffs, soft, and softer handoffs. Because handoff decisions are based on radio network measurement down by the mobile station, a close cooperation is needed between handoff control and other entities of the radio access network.

So far, many handoff methods have been developed for mobile system application [12-22]. These approaches vary in the way they finalize the handoff decision-making. The conventional handoff execution criteria rely mainly on the signal quality, user mobility, traffic distribution, bandwidth, and so forth. Many of those have also been implemented in second generation mobile systems like Global System for Mobile communications (GSM). However, none of the conventional approaches utilise mobile location assistance data in association with handoff mechanism. A mobile location-based handoff approach has very recently been presented in [23]. It proposes a predictive channel reservation approach based on real-time position measurement and movement extrapolation. The underlying assumption of the scheme is that the position and orientation of the mobile can be estimated by the mobile itself, by the base station, or cooperatively by both mobile and base station. The measurements are used by the base station to predict the next cell for each mobile station. This approach, however, concentrates on predicting the required radio resource for handling the connections during the handoff procedures in target cells. Therefore, it does not address the switching and signalling aspects of the handoff when utilizing the location assistance data. Furthermore, it does not embrace the hierarchical structure of the radio network in connection with handoff mechanism. Yet, it does not cover the soft handoff mechanism, which is an inherent part of e.g. Wideband Code Division Multiple Access (WCDMA)-based third-generation radio network operation.

The proposed predictive channel reservation based on solely the location assistance data may be an efficient approach, as far as the Frequency Division Multiple Access or Time Division Multiple Access-based system is in question. In such systems a specific bandwidth portion channel is fixedly allocated to the mobile handset for a period of time, hence, the multi-user interference is not as critical as for CDMA-based systems with one shared frequency portion.

Due to the radio network environment and nature of radio communication the location information can not alone be reliable for the handoff application in an interference-limited system like Wideband CDMA.

In order to improve the above-mentioned drawback we propose an enhanced handoff method, that is, Location Sensitive Handoff (L-SH). The purpose of the proposed method is to help ensure that both the quality of the connection and caused interference are acceptable by utilizing a secondary signal threshold criterion in association with the location assistance data for handoff decision-making.

The rest of this paper is organized as follow. In Section 2, we present the proposed handoff approach, that is L-SH, by describing its main principles and basic algorithms for both soft and hard handoffs. We further give insight into the utilizing the location assistance data in association with the soft handoff range optimization. In Section 3, we present the simulation results and those results are also discussed. Finally, in Section 4 we conclude the paper.

2. LOCATION SENSITIVE HANDOFF

The availability of the mobile location information either at the network side (in network-based and the mobile-assisted positioning) or at the mobile side (in mobile-based and network-assisted positioning) will bring considerable opportunity to improve the performance of the handoff mechanism in the future cellular systems.

On the other hand, the number of mobile users is increasing rapidly especially in highly populated regions. In order to meet the required capacity hierarchical cellular layout comprised of macro-cell, micro-cell, and pico-cells has been developed. Micro-cells and pico-cells structures alleviate the capacity restriction in terms of bandwidth considerably, but at the same time they increase the number of handoffs, leading to more signalling load and ongoing call termination probability. From the Quality of Service standpoint, the ongoing call termination is trickier than the probability of call rejection.

The proposed handoff approach in this paper, L-SH, facilitates the previously mentioned shortage remarkably by utilizing both the mobile location information and signal strength jointly for handoff decision-making, providing more intelligent handoff mechanism for cellular applications. Moreover, we also extend this approach for soft handoff range optimization during soft handoff in a system like WCDMA, which supports the diversity feature.

Unlike conventional handoff methods, in the L-SH method the handoff decision is made both based on mobile location information and signal strength. In second-, and third-generation systems, location assistance data will be soon available at the Base Station Controller (BSC) and the Radio Network Controller (RNC), respectively. These network elements have a central rule in association with handoff decision-making. Therefore, it would be efficient and practically feasible to utilise this valuable data for handoff decision-making and optimizing the cost of switching and signalling caused by the handoff process when steering the ongoing call to the suitable target cells or traffic areas.

2.1 Main Principles

Assume that the mobile is accommodated in a micro-cell where there is also a macro-cell overlaying the micro-cell cluster as illustrated in *Figure 1*.

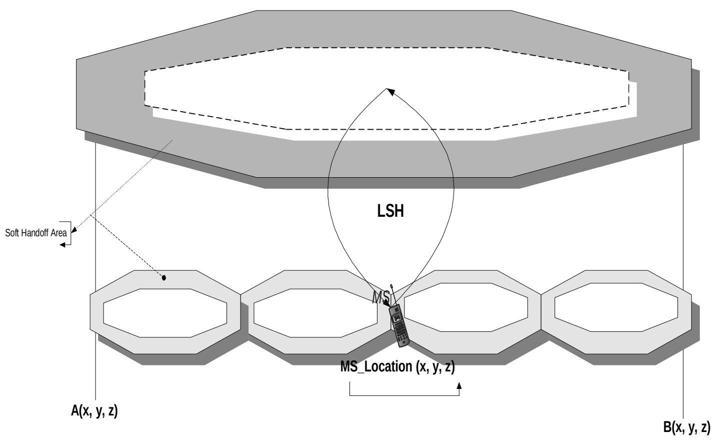

Figure 1. An example of the L-SH application

Suppose that the mobile user is moving from location (A) towards location (B) in the micro-cell level. The location information can be extracted either by the mobile, having positioning capability or by radio network. In the third-generation system, for instance, in any cases, excluding standalone Global Positioning System (GPS) this information is available at the RNC or Serving Mobile Location Center (SMLC). The location information may be extracted either periodically or it can be gathered on demand. The location assistance data may also be transferred in association with handoff measurements fulfilled by the mobile. Then, the reported measurements are analyzed and compared with the handoff criteria set by the handoff algorithm. A heuristic location margin may be applied to avoid undesirable handoff events. In our approach, the handoff threshold is defined based on the distance between the mobile and the home cell boundary. It is assumed that the micro-cell is completely overlaid by the macro-cell, to which the mobile is intended to be handed overed. When the mobile is bordering within the handoff area in a micro-cell then its signal strength is compared with a predefined handoff threshold set by handoff control, providing the required parameters for the handoff decision-making. This is different from the conventional signal strength-based handoff approaches, in which the signal strength of the target cell is compared with the present cell and if the former is superior to the latter then a handoff event is triggered. The predefined threshold is based on minimum signal level which is needed to reach the minimum QoS attribute of the on going connection. This also includes a handoff margin to avoid the "*ping pong*" effect, which is a common problem especially with hard handoff mechanisms. If the secondary criteria are also met and if there is resource available the handoff is executed.

If both primary and secondary criteria are not met the handoff request is rejected. If these criteria are met but there is no resource available at the time of handoff, the handoff request is put into a queue within a predefined time span. If the time is expired then the handoff request is rejected otherwise it is executed. The general algorithm of L-SH is depicted in *Figure 2*.

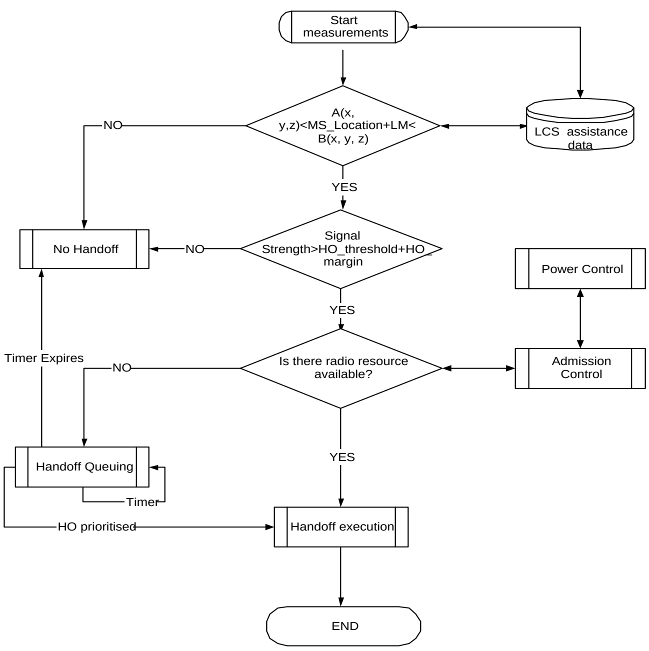

Figure 2. General algorithm for the L-SH, hard handoff

By comparing the location of a mobile located in a home cell sequentially or following the handoff frequency, the radio access controller can steer the mobile to the overlaying macro-cell, or underlying micro-cell, respectively.

For instance, when a mobile is located within an area where, according to the mobile's location information, an inter-frequency (inter-system, inter-layer) handoff is possible/needed then the radio access controller commands the mobile to start measuring the inter-frequency handoff measurement. The handoff decision may be made based on the measurement results and the additional mobile positioning parameters, which can be alternatively embedded on the handoff parameters.

Additionally, according to the latest changes of the mobile position it can be figured out whether it moves fast or slowly. By using the mobile's two most recent location (coordinates) based on the positioning information, its traveled distance and speed can be calculated. Thus, taking into account the basic definition of the velocity we have:

$$V_m = \frac{\sqrt{\left(x_{m2}-x_{m1}\right)^2+\left(y_{m2}-y_{m1}\right)^2+\left(z_{m2}-z_{m1}\right)^2}}{\Delta T} \quad (1)$$

Where V_m is the velocity of the mobile, T is the time between two consecutive mobile's location coordinates. (x_{mi}, y_{mi}, z_{mi}) are the mobile's coordinates, which can be figured out, for instance, using the equation defined in [24]. For instance, in case of Time Of Arrival (TOA) positioning method, the mobile coordinates can be defined based on:

$$D_i = \sqrt{\left(X_i-x_m\right)^2+\left(Y_i-y_m\right)^2+\left(Z_i-z_m\right)^2} \quad (2)$$

where (X_i, Y_i, Z_i) are the coordinates of the neighbouring base stations and D_i is the distance between the handset and the Time of Arrival circle.

By applying this basic calculation mobiles can be categorized based upon their velocity. Furthermore it is also possible to obtain information about their directions.

Based on the information about a mobile's velocity and in order to avoid undesired handoff triggering, the mobile can be directed from micro-cell to the macro-cell, and vice versa. The location information provides a useful basis in terms of mobile handset coordinates, speed, and direction of motion – when utilizing the Angle of Arrival (AOA) positioning method - in order to reserve radio resource in the target cell proactively.

Additionally, L-SH facilitates the *corner-effect*, which is a severe problem in an urban environment. The mobile location coordinates, velocity, and direction provided by either the mobile itself or the cellular network, which supports Location Services (LCS) are valuable information for the L-SH approach in association with corner-effect reason handoff. By utilizing L-SH approach a mobile can be connected to the neighbouring cell, towards which it is moving or to the macro-cell overlaying the serving cell, hence, avoiding missing the Line Of Sight (LOS) and sudden signal deterioration.

In general, in the L-SH mechanism, a target cell can be a macro-cell, micro-cell, pica-cell, a low-traffic cell, a cell within a private coverage with reduced terrific, an indoor/outdoor cell within other networks, and so forth.

2.2 Soft Handoff Range Optimization Based on Mobile Positioning

Soft handoff is an inherent feature of the CDMA-based cellular systems like third-generation system. It helps improve the system capacity by tackling the near-far effect and the overall interference. However, the drawback of soft handoff is that it causes more signalling and processing load to the system due to the fact that during soft handoff state the same data is transferred via many radio links between the mobile and the network. Therefore, soft handoff may cause lower truncking efficiency due to the multiple-channel assignment to the mobile [8]. As a result, fine-tuning of the soft handoff range or *cell-breathing* effect is essential in order to achieve the soft capacity advantages of the soft handoff. The number of mobiles having more than one-signal connections to the base stations, that is, living in the soft handoff state varies depending on the network structure. In general, it can be assumed that about 30% to 40% of the active mobiles are in the soft handoff state [25].

Finding the optimal value for soft handoff parameters is not straighforward. In [5] some soft handoff parameters, which affect the performance of soft handoff, are addressed. These include:

- Add threshold: the threshold for membership in the active set.
- Drop threshold: the threshold for dropping of membership in the active set.
- Soft handoff window (SHW): the difference between the add and drop threshold.
- The ratio *a*: defined as:

$$a = \frac{area\_of\_handoff\_region}{area\_of\_a\_cell} \qquad (3)$$

which may vary, for example by adjusting the distance between base stations.

As far as the soft handoff trade-off and parameter optimization is concerned, some researches in the form of simulation study have been done. These researches have focused on the signal propagation characteristics, Bit Error Rate (BER), and resource allocation. Nevertheless, most of these researches have mainly been concentrated on analyzing, modelling, and performance of the soft handoff mechanism rather than range optimization [1-10].

In the L-SH, soft handoff parameters in terms of rage optimization or as previously mentioned (*a*) and active set parameter are set based on the mobile positioning information, including mobile location coordinates, its motion and direction.

Mobile positioning data can be utilized to optimize the active set areas. When the soft handoff rage is initialized, in addition to conventional soft handoff measurements, the positioning assistance data is valuable information for the first estimates of the soft handoff range extension. Moreover, positioning assistance data can be utilized to optimize the soft handoff configuration dynamically as the traffic and mobility aspects of the network environment vary.

Furthermore, in cases there are many mobiles camping in a cell, moving around the inner limit of the soft handoff area forward and backward to the active set and non-active set area then mobile positioning assistance data would be valuable basis for optimizing the soft handoff range changes. Otherwise, they cause soft handoff triggering too often, resulting in undesirable signalling load to the system and decreasing the system performance.

Figure 3 illustrates a case when the additional branch is added to, or the present branch is frequently dropped from the ongoing connection. The reason behind the undesirable soft handoff triggering is the mobile motion and poorly optimized soft handoff parameters, which determined the soft handoff range extension. Conventionally, the mobile may experiences handoff at points A, B, C, D, E, and F shown in the figure. These handoff events may occur even within a very short time, causing additional signalling load to the system.

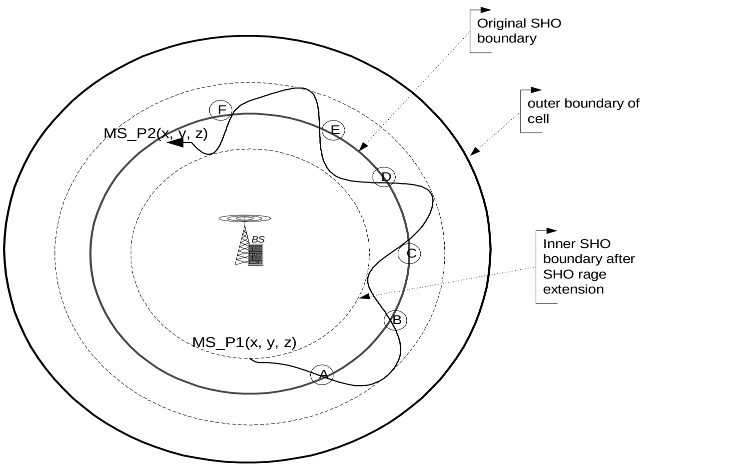

Figure 3. Soft handoff range optimization by utilizing mobile positioning assistance data

In the L-SH, the mobile positioning information is utilized in order to take into account the random trace of a mobile in a soft handoff boundary. In the case of a soft handoff, the process starts by generating soft handoff measurement and mobile positioning calculation carried out by the mobile and the network, respectively. Once the measurement result is

analyzed, the location of the mobile is compared with the location threshold which is a predefined parameter of L-SH, setting and updating based on the mobiles mobility pattern in the cell. The general algorithm of the L-SH for soft handoff application is shown in *Figure 4*. In the figure, the *threshold marging* can be defined as the distance between two consecutive turning points in and around the inner boundary of the soft hand range. Alternatively it may be set based on the dwelling time of the mobile within this distance. If this criterion is met the algorithm goes to the next step, when the signal level is compared to the *add threshold*. In this case and if the criterion is met the availability of the radio resource is analysed by close cooperation with other entities of the radio resource management. When a soft handoff is executed the new soft handoff range corresponding to the mobile's mobility and based on its positioning information is defined by the network in order to meet the real time traffic distribution and avoid performance degradation due to undesirable soft handoff events.
Concerning the positioning mechanism, and if the cellular positioning is utilised, the soft handoff range adjusting facilitate mutually the mobile positioning process in cases there is lack of branches needed for the network-based positioning. This can be reached by adding the required branch(s) and excluding the soft handoff threshold.
It should be mentioned that based on the L-SH concept, mobile positioning information may be utilised in same manner as described above when it is appropriated to shrink the soft handoff range because of the low mobility of mobiles or high signalling load in the system.

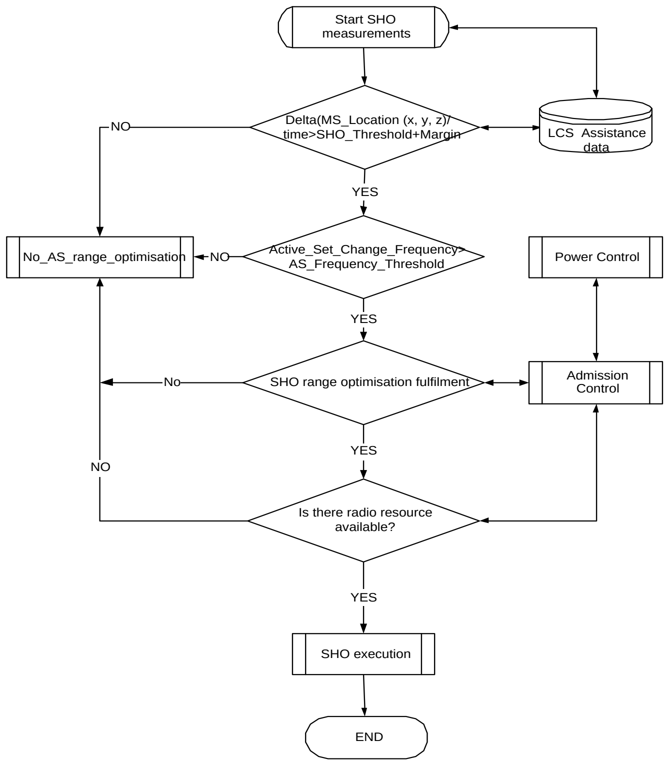

Figure 4. General algorithm of the L-SH for soft handoff application

3. DISSCUSION AND RESULTS

In order to evaluate the cost of the L-SH in terms of signalling load, we investigated the effects of mobile speed (change of its coordinates during a specific time) and cell area on the handoff signalling load, including switching and routing cost for a two-tier network layout (*Figure 1*). We further investigated the cost of mobile positioning in terms of signalling load in third-generation cellular system. The reference system model was based on the basic radio access architecture defined for the third-generation WCDMA [26]. The key parameters of our simulation are summarized in *Table 1*. The mobility model was based on [4]:

$$\lambda = \frac{\rho V_m L}{\pi} \qquad (4)$$

where λ depicts the average outgoing handoff rate from a cell, ρ represents the mobile density, *Vm*

is the mean speed of a mobile, and *L* is the perimeter of the cell.
In this model it is assumed that the density of mobiles is constant, the speed of mobiles are random in direction, the mobiles maintain their original directions, and the region border is smooth.

Table 1. The key parameters for the simulation

Parameter	Value
Number of cells/base stations	60
Traffic Model	
Mean holding time	120s
Mobile originated calls	50%
Mobile terminated calls	50%
Real time traffic	0.33 kps per subscriber
None real time traffic	0.80 kbps per subscriber
Mobility Modelling	
Number of mobiles	50000
Cell area (perimeter *L*)	3.5 and 12 km^2
Speed of mobile (V_m)	1-50 km/h
Number of cells in location area	16
Positioning	
Positioning per total number of handsets	67%
Positioning frequency	1…8, 20, 30/h

Figure 5 demonstrates the dependency of the mobile speed and the cell area on the handoff cost in terms of signalling load. As shown, the signalling load is remarkably increasing when mobile's speed increases both for micro-cell with 3.5 km^2 area and macro-cell with 12 km^2. However, in the case of micro-cell the handoff-signalling load increases more rapidly than that of macro-cell for the same time varying differentiation of two consecutive coordinates of the mobiles. For instance, when a mobile moves with a speed of 40 km/h the handoff signalling is approximately 1250 kbps for a macro-cell hence it is nearly 1650 kbps for the micro-cell structure.
Based on the results it is evident that the number of handoffs is straightly dependent on the speed of the mobile. The higher the mobiles' speed the more is the undesirable signalling load to the system. Therefore, it is reasonable to hand over those mobiles whose location changes rapidly from the micro-cells to the macro-cells, avoiding undesirable signalling load to the system. In the case of low speed mobiles, on the other hand, they can be handed over from macro-cells to micro-cells to improve the radio signal strength, saving in battery consumption.

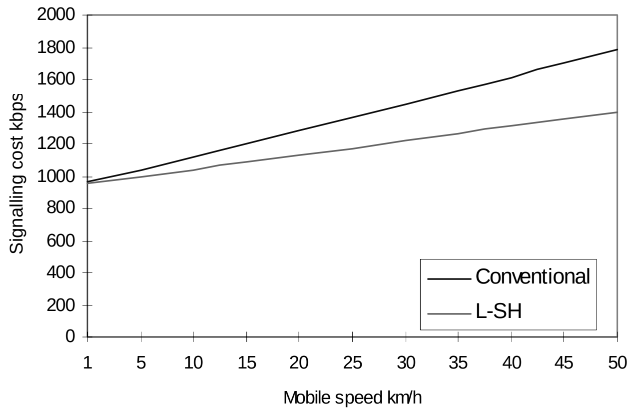

Figure 5. Dependency between mobile speed and the cost of signalling

If we assume that in order to utilise the L-SH approach the location information on the mobiles may be extracted by the radio network system or more specifically by the SMLC then it also causes additional signalling load to the system. Indeed, this is the worst case because in future cellular systems it is likely to have the location information at the radio access system, also otherwise, for location-based services such as navigation services. Nevertheless, let us consider the worst case scenario for figuring out the maximum drawback of the mobile positioning, imposing to the system in connection with L-SH execution.
Figure 6 demonstrates the dependency of the mobile based Positioning Frequency (PF/h) and the cost of signalling load. The simulation results are based on the networked-based Idle Period Downlink-Observed Time Difference of Arrival (IPDL-OTDOA) positioning method specified for third-generation application [27]. In this case the mobiles mean speed was 1 km/h and 67% of the active mobiles were positioned simultaneously. As illustrated, the cost of positioning in terms of signalling load is strictly dependent upon the positioning frequency. The background signalling load - when positioning frequency is equal to zero - is due to the basic signalling at the time of connection that otherwise exists.

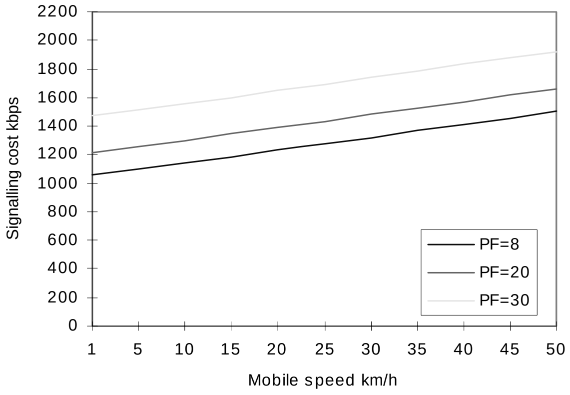

Figure 6. Dependency btewen positioning frequency and the cost of on signalling

Figure 7 on the other hand, illustrates the total cost of L-SH handoff, including positioning mechanism in terms of signalling load for positioning frequency of 8/h, 20/h, and 30/h, respectively. The mean speed of mobiles vary from 1 to 50 km/h and the cell area is 12 km^2 as was assumed for the macro-cell case. As shown, the total cost of combined handoff and positioning increases as the positioning frequency increases. As it can be expected the signalling load of combined positioning and handoff is considerably higher than that of load caused by solely handoff mechanism. Nevertheless, the signalling load is still less than that of conventional scheme for the moderate positioning frequency.

These results show that even if the pure network-based positioning is utilized for assisting the handoff purposes the performance of positioning-base handoff up to moderate PF, is quite acceptable. It should be emphasized that in this association we assumed that the macro-cell radio link meets the minimum signal quality required for handling the connection. Another important point is that the pure network-based positioning causes more signalling load to the network than that of stand-alone approaches. Therefore, the results of this simulation may carry the worst case in terms of imposed signalling load in association with combined positioning-handoff mechanism.

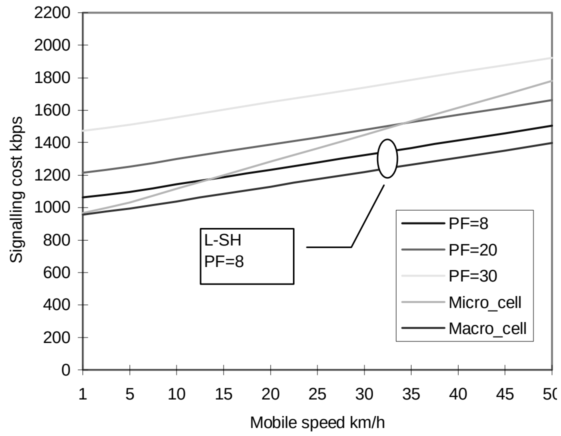

Figure 7. The signalling cost of the L-SH in association with mobile positioning process.

4. CONCLUSION

Handoff control was discussed as an important component of the radio resource management in any mobile system. Handoff is necessary to support the user mobility in the mobile networks. Nevertheless, its cost should be optimized to avoid degrading the system performance especially in terms of signalling load and radio resource reservation. A novel location-sensitive handoff approach, L-SH, was presented and its performance in terms of signalling cost, including switching and routing cost was evaluated. We conclude that mobile positioning will provide valuable information to improve the intelligence of the handoff mechanism in the cellular system by optimizing of connection routs as well as radio resource policy. However, this information should be utilized in association with signal measurements in order to ensure the minimum QoS of the connections involved in the handoff process. Another important point is that invoking the network-based positioning mechanism very frequently in conjunction with the handoff mechanism may increase the cost of signalling, compensating the superiority of the L-SH. This paper can be concluded by emphasizing that:

- Mobile positioning will bring considerable benefits to the intelligence of the radio resource management in the future mobile systems.

- It seems that it mostly brings benefits especially to the handoff mechanism rather to the other components of radio resource management.

More research is needed to verify the performance of location assisted handoff in terms of spectrum efficiency. It is also necessary to investigate thoroughly the benefits of positioning assistance data to the other components of radio resource management like power control and admission control.

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