Handoff and Call Dropping Probabilities in Wireless Cellular Networks

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***Abstract*— In cellular networks, the Call Dropping Probability (CDP) is a very important connection-level QoS parameter. It represents the probability that a call is dropped due to a handoff failure. The goal of almost all admission control schemes is to limit the CDP to some target value while maintaining higher bandwidth utilization or lower blocking rates for new calls in the system. Another related parameter is the Handoff Dropping Probability (HDP). It represents the probability of a handoff failure due to insufficient available resources in the target cell. Most local admission control schemes try to limit the HDP to some target maximum and assume that this will limit the CDP too. In this paper, we show that even if the HDP is controlled to be below a maximum value in every cell in the network, the CDP experienced by the users is not controlled, independently from the admission control scheme used to control the HDP.**

***Index Terms*— Handoff Dropping Probability, Call Dropping Probability, Wireless Cellular Networks.**

I. Introduction

A. Background

As the mobile network is often merely an extension of the fixed network infrastructure from the user's perspective, mobile wireless users will demand the same level of service from each. Such demand will continue to increase with the growth of multimedia computing and collaborative networking applications. It raises new challenges to call (session) admission control (CAC) algorithms.

Call admission control schemes can be divided into two categories, local and collaborative schemes [1]. Local schemes use local information alone (e.g. local cell load) when taking the admission decision. Examples of these schemes are [1], [2], and [3]. Collaborative schemes involve more than one cell in the admission process. The cells exchange information about the ongoing sessions and about their capabilities to support these sessions. Examples of these schemes are [4], [5], [6], [7] and [8].

Handoff is a time-critical feature in wireless mobile communications that has to be addressed to provide seamless multimedia communications under changing radio resource conditions. Handoff ensures the continuity of a call, while the dedicated radio resource changes within one cell or during cell crossing. Handoff has a significant impact on system capacity and performance. Effective and reliable handoff is highly desirable from the user's point of view. The handoff is already a key process in current systems and it is foreseen to gain increasing importance in third and fourth generation cellular systems, as cell radius decreases and the number of users grows dramatically.

An important underlying aspect is the techniques used to control the handoff of users as they move between shrinking cells, at greater speeds, and with stricter requirements on both the QoS delivered to the user and the operational costs associated with a connection. The wireless network must provide the requested level of service even if the user roams among cells.

B. Motivation and contribution

A handoff could fail due to insufficient bandwidth in the new cell, and in such case, the connection is dropped. The Call Dropping Probability (CDP) is a very important connection-level QoS parameter. It represents the probability that a call is dropped due to a handoff failure. The goal of almost all admission control schemes is to limit the CDP to some target value while maintaining higher bandwidth utilization or lower blocking rates for new calls in the system.

Another related parameter is the Handoff Dropping Probability (HDP). It represents the probability of a handoff failure due to insufficient available resources in the target cell. From both the user's and service provider's perspectives, only the CDP is relevant (not directly the HDP).

Most local admission control schemes try to limit the HDP to some target maximum and assume that this will limit the CDP too. Other local schemes use both probabilities CDP and HDP to refer to the same thing, which is in this case the handoff dropping probability. Local admission control schemes benefit from the fact that they do not require an exchange of information between the cells, and base their scheme exclusively on local information. However, this prevents them from controlling an inherently global parameter like the CDP and can only control a local parameter like the HDP.

In this paper, we will demonstrate that even if the HDP is controlled to be below a maximum value in every cell in the network, the CDP experienced by the users is not controlled. And this is independent from the admission control scheme used to control the HDP. We will show that the CDP can have a wide range of values much higher than the HDP.

Our approach is to prove it by contradiction. In this case, a simple counterexample is sufficient. This means that if the hypothesis: "The CDP is controlled if the HDP is" is not true in a particular example of network, then this hypothesis is also not true in the real network.

The paper is organized as follows. In Section II, we present our investigation of the Call Dropping and the Handoff Dropping Probabilities. Section III discusses the simulations conducted and presents an analysis of the obtained results. Finally, Section IV concludes the paper.

II. Is controlling the handoff dropping probability enough?

A. Network Model

The shape of the cells in a cellular network are generally modelled as hexagons while the ideal shape of the coverage area is a disk. However, due to interference and other factors, the actual cell coverage can have a changing amoeba-like shape (see Figure 1). Another way for modelling the network is to consider square-shaped cells which is sometimes called Manhattan-like network.

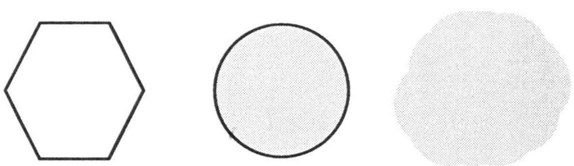

Fig. 1. Theoretical, ideal and actual cell coverage shapes

B. Mobility Model

Mobility modelling is an important research area in cellular networks, as most resource management schemes base their approach on some mobility model. The mobility model can range from simple random motion models like the Random Waypoint model and the Road Topology model [9] to more sophisticated purposeful motion models like the Travelling Salesman Model [10], the Three Dimensional Model [11] and the Activity Based Model [12]. These and other works agree that the real user mobility is much more complicated than the traditionally used models. In fact it has been shown that some models can even be harmful [13]. These facts make it difficult to link the handoff dropping probability with the call dropping probability as most of the assumptions about call related distributions in time and space do not hold anymore. To the contrary of what most local admission control schemes claim, it is not clear how to compute the CDP based on local information when there is no specific distribution model for handoffs.

C. Investigating the Call Dropping Probability

In this section we will consider a network of square-shaped cells as presented in Figure 2. We will show that even in this simple network model the CDP is not controlled even if the HDP is kept bellow some maximum value in each cell.

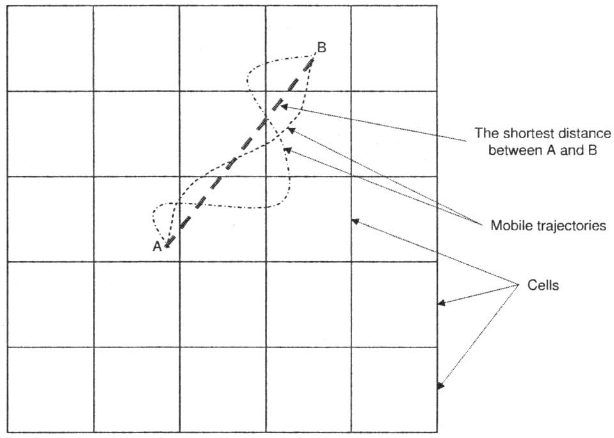

Fig. 2. The considered network model

Assume that a mobile user (for a duration of a call) moves from one point, say A, to another point, say B, as shown in Figure 2. We notice that the minimum number of handoffs, that the user can experience, is the one that he will experience if he follows the trajectory with the shortest distance between the two points (indicated by the ticker dashed line in the figure). Following any other trajectory between the two points will result in a higher or equal number of handoffs. Note that this is true only in the considered model (where the cells have square-like shapes.) This will not always be the case, for example, if the cells had hexagonal shapes.

In the remaining of the paper, only this minimum number of handoffs experienced by a user during a call will be considered independent of the user trajectory between the two points A and B (i.e. independent from the mobility model). This means that we are only interested in the point where the call starts and the point where it ends. Note that our goal is to demonstrate that the CDP is not controlled by the fact that the HDP is, even with these simplistic assumptions.

Let d be the side of the square. Assume that the point $(0, 0)$ of the coordinates is set to be the bottom left corner of the cell where point A is. Point A has the coordinates (A_x, A_y) and point B has the coordinates (B_x, B_y). Without loss of generality we assume that $A_x <= B_x$ and $A_y <= B_y$ (i.e. point A is always to the bottom left side of point B[1].) Let r be the distance between the two points A and B and let θ be the angle between the segment $[A, B]$ and the horizontal line as indicated in Figure 3. Let

$$X = |r\cos(\theta)| \quad , \quad Y = |r\sin(\theta)|$$
$$\alpha_x = \lfloor \frac{X}{d} \rfloor \quad , \quad \alpha_y = \lfloor \frac{Y}{d} \rfloor \tag{1}$$

and let X_p and Y_p so that

$$X = d\alpha_x + X_p \; and \; Y = d\alpha_y + Y_p \tag{2}$$

[1] A similar approach can be used to compute the number of handoffs in the other cases.

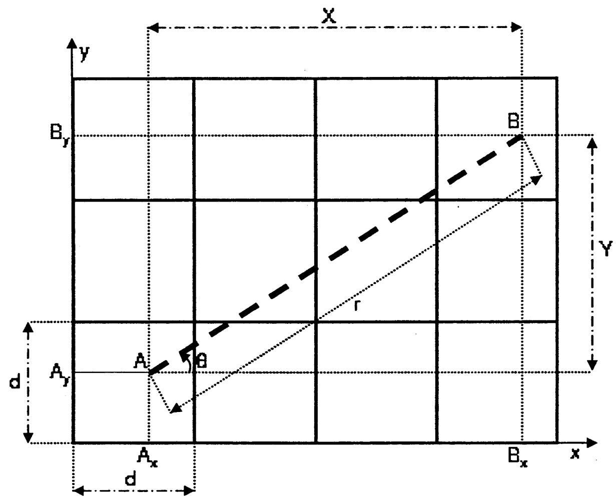

Fig. 3. Computing the number of handoffs

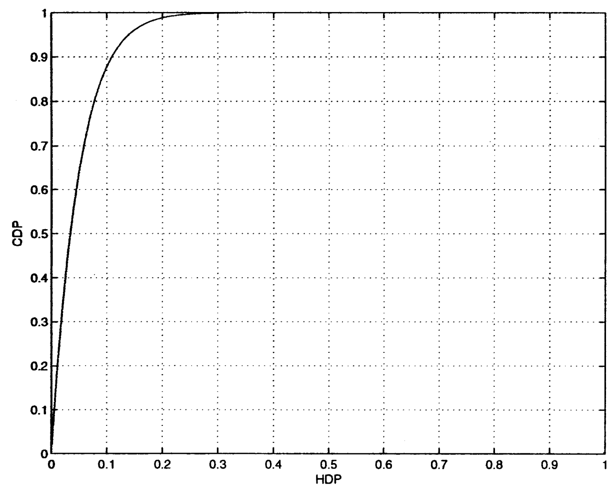

Fig. 4. CDP according to HDP for $h^{MAX} = 20$

α_x represents the minimum number of times the user has to cross a vertical border before reaching point B. α_y represents the minimum number of times the user has to cross a horizontal border before reaching point B. The exact number of times the user will cross a cell border will depend on the values of X_p and Y_p and the initial position within the cell (i.e. A_x and A_y). It can easily be shown that the exact number of times h_x^{AB} the user will cross a vertical border before reaching point B is as follows:

$$\begin{cases} h_x^{AB} = \alpha_x & if\ A_x < d - X_p \\ h_x^{AB} = \alpha_x + 1 & otherwise \end{cases} \quad (3)$$

and that the exact number of times h_y^{AB} the user will cross a horizontal border before reaching point B is as follows:

$$\begin{cases} h_y^{AB} = \alpha_y & if\ A_y < d - Y_p \\ h_y^{AB} = \alpha_y + 1 & otherwise \end{cases} \quad (4)$$

hence the total number of handoffs[2] that the user will experience, while travelling from A to B, is given by

$$h^{AB} = h_x^{AB} + h_y^{AB} \quad (5)$$

Now, if we assume that the HDP is set to some fixed value throughout the network, the CDP, experienced by the user going from A to B, can be computed using the following equation:

$$\begin{aligned} CDP^{AB} &= \sum_{i=1}^{h^{AB}} HDP \times (1 - HDP)^{i-1} \\ &= 1 - (1 - HDP)^{h^{AB}} \end{aligned} \quad (6)$$

where h^{AB} is computed using (5). This is just the probability that the call is dropped due to a handoff failure. Note that $HDP \times (1 - HDP)^{i-1}$ is the probability that the i^{th} handoff fails while all other previous handoffs succeeded.

According to (1), α_x and α_y depend on the value of $\frac{r}{d}$. This is the ration of the distance between the two points A and B and the cell side. In the real world, the distance between the two points A and B depends on the mobility model of the users (e.g. speed, direction.) as well as on the call duration. d depends on the cell size. According to (1), (3) and (4), only the ratio between r and d affects the number of handoffs experienced by the users.

Even if we assume that somehow we know what is the maximum number of handoffs h^{MAX} for any call (an assumption that is difficult to justify), using (6), we can compute the expected CDP. However, the way the CDP and HDP are linked makes it very challenging to control the CDP using the HDP.

Indeed, the first derivative of (6) at HDP is

$$\frac{\partial(1-(1-HDP)^{h^{MAX}})}{\partial HDP} = \frac{(1-HDP)^{h^{MAX}} h^{MAX}}{1-HDP}$$

and its value at HDP=0 is

$$\frac{\partial(1-(1-HDP)^{h^{MAX}})}{\partial HDP}(HDP = 0) = h^{MAX}$$

This means that the higher the maximum number of handoffs, the higher the first derivative at HDP=0 will be[3].

For example, if the maximum number of handoffs experienced by any call is 20, then, to achieve a CDP of $\frac{1}{100}$, we should have a HDP of $\frac{5}{10000}$. If we allow for 10^{-3} error on controlling the CDP, then the error for the HDP should be 5×10^{-5}. This is shown in figure 4 where the curve near zero is very steep.

In general, for values of CDP very close to zero, if the allowed variation of CDP of δ, then the allowed variation for the HDP is $\frac{\delta}{h^{MAX}}$.

Achieving this level of control on the value of HDP is very

[2]We assume that handoffs occur only at cell borders. We do not consider signal constraints and other effects. Note that the goal is to show that the CDP is not controlled. If this is the case in this simple model, it will also be the case in a real world network.

[3]we are interested in the values of HDP very close to 0, so the first derivative at 0 will give a good estimate of the first derivative at values very close to 0.

challenging and requires reserving a large amount of bandwidth which will lead to poor resource utilization throughout the network.

III. Performance Evaluation

To evaluate the CDP experienced by users in a system where the HDP is controlled, we simulate a system where the value of $\frac{r}{d}$ can take any value between the minimum value 5 and the maximum value 10 (i.e. $5 \leq \frac{r}{d} \leq 10$).[4] The HDP is set to 2% in all the cells of the system. 1000 values of $\frac{r}{d}$ were chosen randomly between 5 and 10. For each value of $\frac{r}{d}$, we generated 10000 random values for θ, A_x and A_y for which we computed the number of handoffs experienced by the user using (5). We then computed the CDP according to (6).

Figure 5 depicts the obtained CDP distribution. The experienced CDP values range from a minimum of 7.76% to a maximum of 27.62% with a mean of 17.37% and a standard deviation of 3.63%. Note that the HDP was set to 2% in every cell in the network. This clearly shows that any local scheme that aims at controlling the HDP to a particular value will fail to control the CDP as this later has an inherently global aspect. In the considered simulations, the obtained minimum number of handoffs was 4 and the maximum number was 16 with a mean of 9.445 handoffs.

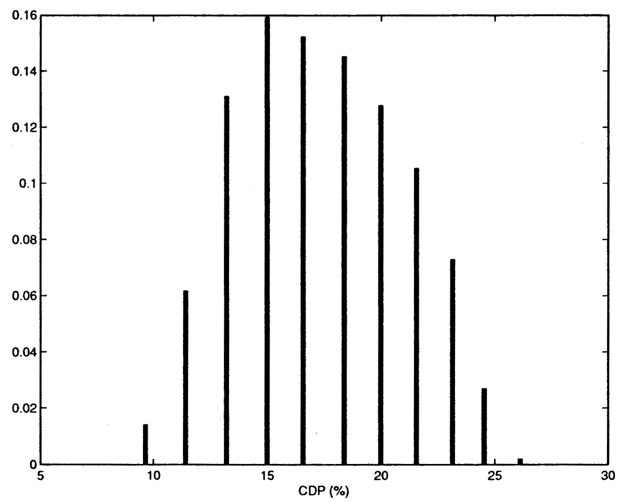

Fig. 5. CDP distribution for HDP=2%

Figure 6 depicts the obtained cumulative distribution function of the CDP. This shows that the CDP has a wider range and a higher values than the HDP.

The range of the CDP will depend on the range of $\frac{r}{d}$ and the value of the HDP. We have simulated other ranges of $\frac{r}{d}$ and HDP, and we arrived to the same conclusion, namely that the CDP is not controlled even if the HDP is.

IV. Conclusion

In this paper, we show that it is not possible to control the Call Dropping Probability by controlling the Handoff

[4]Other ranges of values have been considered and led to similar conclusions.

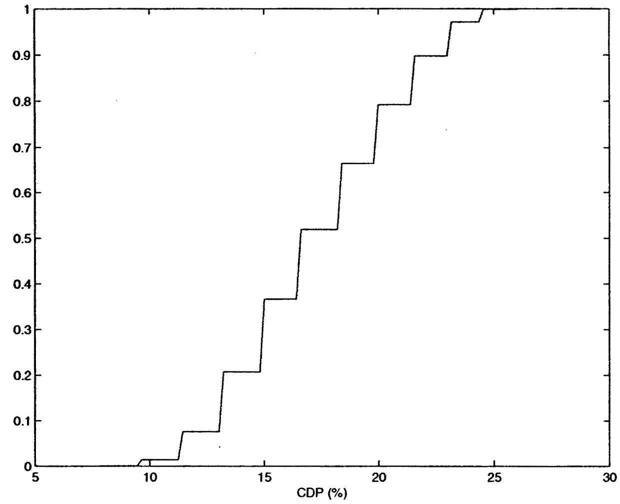

Fig. 6. CDP cumulative distribution function for HDP=2%

Dropping Probability locally. It is not clear how to compute the CDP based on local information when there is no specific distribution model for handoffs. The complex and still not fully comprehended user mobility makes it almost impossible to predict what will be the CDP. In addition, real networks have cells of different sizes and shapes, which further complicate the control of the CDP at a local (i.e. cell) level. If any CDP value is to be guaranteed, resource management schemes should not base their decisions on local information alone. Some form of information exchange is needed to control this inherently global QoS parameter. This is not to say that all proposed local admission control schemes are not useful. However, from a practical point of view (user's and provider's points of view), controlling the HDP is not enough. This paper aims at pointing out this important issue that is often overlooked.

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