Optimizing the Handover Call Blocking Probability in Cellular Networks With High Speed Moving Terminals

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***Abstract*—This letter presents a two-layer cellular architecture which optimizes the handoff blocking probability performance of high-speed moving terminals (HSMT) in a congested urban area. The lower layer of the proposed architecture is based on a microcellular solution, for absorbing the traffic loads of both the low-speed moving terminals (LSMT) and the new calls of HSMT. The higher layer is based on a macrocell umbrella solution, for absorbing the traffic load of the existed handoff calls of the HSMT. The results show that using the optimum number of channels in each layer, the handoff call blocking probability of the HSMT is optimized having the minimum effect on the call blocking probability of the microcellular layer.**

***Index Terms*—Call blocking probability, handoff, high and low speed moving terminals, multilayer architecture.**

I. INTRODUCTION

MOBILE communications systems experience a rapid increase in the number of subscribers, which places extra demands on their capacity. This increase leads to a new network architecture where the cells are designed to be increasingly smaller. The most serious problem that arises in this architecture is the handoff issue [1]. This problem becomes more serious, for high speed moving terminals (HSMTs) where the handoff rate increases and the probability that an ongoing call will be dropped due to the lack of a free traffic channel is high.

A great effort has been spent in order to study the handoff process and to minimize the involved handoff blocking probability [2]. The handoff blocking probability is considered to be more important than the blocking probability of new calls because the call is already active and the QoS is more sensitive for the handoff calls. The examined model adopts a traffic analysis for cellular mobile networks with prioritized handoff procedure. By taking into account that C are the available channels in every microcell and the priority technique for handoff calls is realized by assigning guard channels (C_h) exclusively for handoff calls, the remaining $(C - C_h)$ channels are shared both by new and handoff calls. The following assumptions, without affecting the results, are considered: 1) the terminals are characterized as low-speed moving terminals (LSMT) or HSMTs according to the speed they move and 2) homogenous traffic, same capacity and same mean holding time T_h, are considered in all microcells.

New and handoff calls of LSMT are generated in the area of microcell according to a Poisson point process, with mean rates of Λ_R^L, Λ_{Rh}^L, respectively, while new calls and handoff calls of HSMT are generated with mean rates of Λ_R^H, Λ_{Rh}^H per cell. The relative mobilities are defined as

$$a_L = \frac{\Lambda_{Rh}^L}{\left(\Lambda_{Rh}^L + \Lambda_R^L\right)} \text{ for LSMT} \tag{1}$$

$$a_H = \frac{\Lambda_{Rh}^H}{\left(\Lambda_{Rh}^H + \Lambda_R^H\right)} \text{ for HSMT.} \tag{2}$$

The total relative mobility for both HSMT and LSMT is given by

$$a_{HL} = \frac{\left(\Lambda_{Rh}^H + \Lambda_{Rh}^L\right)}{\left(\Lambda_{Rh}^H + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_R^L\right)}. \tag{3}$$

The offered load per cell is

$$T_{\text{off}} = \left(\Lambda_{Rh}^L + \Lambda_R^L + \Lambda_{Rh}^H + \Lambda_R^H\right) \Big/ \mu_H \tag{4}$$

where $\mu_H = 1/T_H$ and T_H is the channel holding time.

II. ANALYSIS OF THE EXISTING MODEL WITH PRIORITIZED HANDOFF PROCEDURE

Let n be the number of microcells in the microcellular area. The total offered load in the system is:

$$T_{\text{off}}^{\text{tot}} = n \cdot T_{\text{off}} \tag{5}$$

and the total number of channels in the system is

$$C_s = n \cdot C. \tag{6}$$

The steady-state probabilities that j channels are busy in every microcell, can be derived from [3]

$$P_j = \begin{cases} \dfrac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^j}{j!\mu_H^j} P_0, & \text{for } j = 1, 2, \ldots, C - C_h \\ \dfrac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{C-C_h} \left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{j-(C-C_h)}}{j!\mu_H^j} P_0, & \text{for } j = C - C_k + 1, \ldots, C \end{cases} \tag{7}$$

where P_0 is as shown in (8) at the bottom of the next page.

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The blocking probability (P_B) for a new call (either HSMT or LSMT) per microcell is the sum of probabilities that the state number (j) of the microcell is $\geq (C - C_h)$. Hence:

$$P_B = \sum_{j=C-C_h}^{C} P_j. \tag{9}$$

The probability of handoff attempt failure P_{fh} is the probability that the state number of the microcell is equal to C. Thus

$$P_{fh} = P_C. \tag{10}$$

The P_{fh} of HSMT is

$$P_{fh}^{\text{HSMT}} = \left(\frac{\Lambda_{Rh}^H}{\left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)} \right) P_{fh}. \tag{11}$$

The mean call blocking probability (P_{nl}) for the microcellular layer (n microcells), considering new and handoff calls of LSMT and HSMT, is defined as

$$P_{nl} = \frac{\sum_{i=1}^{n} \left(\left(\Lambda_R^H(i) + \Lambda_R^L(i)\right) P_B^m(i) + \left(\Lambda_{Rh}^H(i) + \Lambda_{Rh}^L(i)\right) P_{fh}(i) \right)}{\sum_{i=1}^{n} \left(\Lambda_R^L(i) + \Lambda_R^H(i) + \Lambda_{Rh}^H(i) + \Lambda_{Rh}^L(i)\right)}. \tag{12}$$

III. Proposed Multilayer Cellular Architecture

The proposed two-layer architecture is introduced in order to dedicate different layers to different types of subscribers according to their speed and the type of call (new or handoff) in the same geographical area. This approximation that has been recommended for Mobile Networks by Nokia [4], introduces a two-layer architecture, the lower microcellular layer and the higher, the "Umbrella layer", which is implemented by an "Umbrella cell" [4], [5]. In addition, the umbrella cell layer services only handoff calls of HSMT, homogeneous traffic is considered in all microcells and umbrella cell, and the T_h is the same for the mircrocells and the umbrella cell.

Let n be the number of microcells that consist the microcellular layer. Let C_S be the total number of channels in the system. In the microcellular layer, priority is given to handoff attempts by assigning guard channels (C_h) exclusively for handoff calls of LSMT among the C channels in a cell. The remaining $(C - C_h)$ channels are shared by both new calls of HSMT and LSMT and handoff calls of LSMT [3]. Let C_u be the channels assigned to umbrella cell to serve only handoff calls of HSMT. Hence:

$$C_S = nC + C_u. \tag{13}$$

The mean rate of generation of handoff calls of HSMT is Λ_{Rh}^H per cell, so the mean rate generated in the umbrella is $n \cdot \Lambda_{Rh}^H$.

The proposed architecture, assigns a ratio C_u/C_S, according to α_L, α_H, α_{HL} and $T_{\text{off}}^{\text{tot}}$, contributing to the improvement of handoff call blocking probability of HSMT (blocking probability of the higher layer), with the smallest possible effect on the mean call blocking probability of microcellular layer.

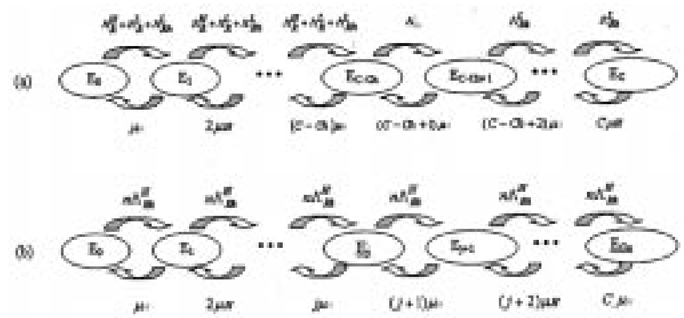

Fig. 1. State Transition diagram for: (a) every microcell and (b) umbrella cell of proposed architecture.

The steady-state probabilities that j channels are busy in a microcell can be derived from Fig. 1 [2], [3]

$$P_j^m = \begin{cases} \dfrac{\left(\Lambda_R^H + \Lambda_R^L + \Lambda_{Rh}^L\right)^j}{j!\mu_H^j} P_0^m, & j = 1, 2, \ldots, C - C_h \\ \dfrac{\left(\Lambda_R^H + \Lambda_R^L + \Lambda_{Rh}^L\right)^{C-C_h} \Lambda_{Rh}^{L\, j-(C-C_h)}}{j!\mu_H^j} P_0^m, & j = C - C_h + 1, \ldots, C \end{cases} \tag{14}$$

where

$$P_0^m = \left[\sum_{k=0}^{C-C_h} \frac{\left(\Lambda_R^H + \Lambda_R^L + \Lambda_{Rh}^L\right)^k}{k!\mu_H^k} + \sum_{k=C-C_h+1}^{C} \frac{\left(\Lambda_R^H + \Lambda_R^L + \Lambda_{Rh}^L\right)^{C-C_h} \Lambda_{Rh}^{L\, k-(C-C_h)}}{k!\mu_H^k} \right]^{-1}. \tag{15}$$

The blocking probability for a new call (either for HSMT or LSMT) per microcell is the sum of probabilities that the state number of the microcell is $\geq C - C_h$. Hence

$$P_B^m = \sum_{j=C-C_h}^{C} P_j^m. \tag{16}$$

The probability of handoff attempt failure P_{fh}^m is the probability that the state number of the microcell is equal to C. Thus

$$P_{fh}^m = P_C^m. \tag{17}$$

For the umbrella cell, the steady-state probabilities that j channels are busy can be derived from Fig. 1 [2], [3]

$$P_j^u = \frac{\left(n \cdot \Lambda_{Rh}^H\right)^j}{j!\mu_H^j} P_0^u, \qquad j = 1, 2, \ldots, C_u \tag{18}$$

where

$$P_0^u = \left[\sum_{k=0}^{C_u} \frac{\left(n \cdot \Lambda_{Rh}^H\right)^k}{k!\mu_H^k} \right]^{-1}. \tag{19}$$

$$P_0 = \left[\sum_{k=0}^{C-C_h} \frac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^k}{k!\mu_H^k} + \sum_{k=C-C_h+1}^{C} \frac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{C-C_h} \left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{k-(C-C_h)}}{k!\mu_H^k} \right]^{-1}. \tag{8}$$

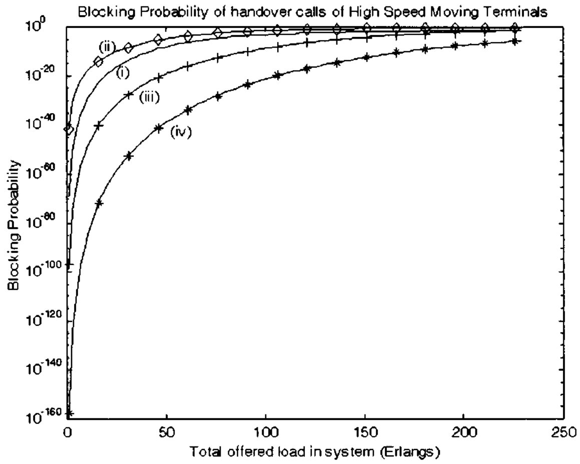

Fig. 2. Handoff blocking probability of HSMT against total offered traffic load in the system. (i) Architecture with no Umbrella Layer and $C_s = 120, C = 40$. (ii) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 24, C = 32$. (iii) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 48, C = 24$. (iv) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 72, C = 16$.

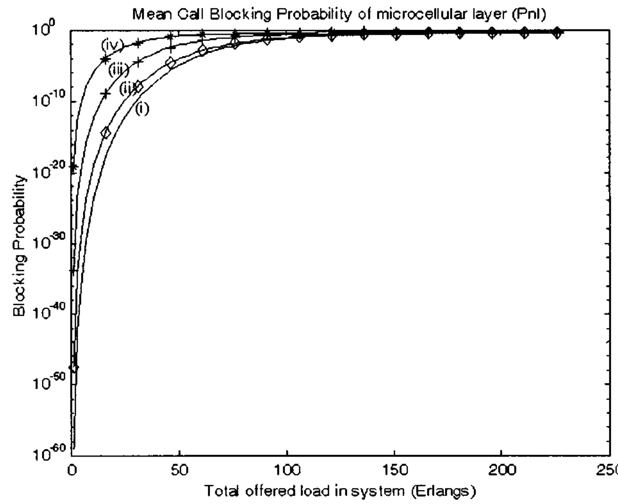

Fig. 3. Mean call blocking probability of the microcellular layer (P_{nl}), against total offered traffic load in the system. (i) Architecture with no Umbrella Layer and $C_s = 120, C = 40$. (ii) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 24, C = 32$. (iii) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 48, C = 24$. (iv) Proposed Architecture with Umbrella Layer and $C_s = 120, C_u = 72, C = 16$.

The probability that a handoff call will be blocked in the umbrella cell is P_{fh}^u and is the probability that state number of the cell is equal to C_u. Thus

$$P_{fh}^u = P_{C_u}. \tag{20}$$

The mean call blocking probability (P_{nl}^m) for the microcellular layer (n microcells), considering new calls of LSMT and HSMT and handoff calls of LSMT is defined as

$$P_{nl}^m = \frac{\sum_{i=1}^{n} \left(\left(\Lambda_R^H(i) + \Lambda_R^L(i) \right) \cdot P_B^m(i) + \Lambda_{Rh}^L(i) \cdot P_{fh}^m(i) \right)}{\sum_{i=1}^{n} \left(\Lambda_R^H(i) + \Lambda_{Rh}^L(i) + \Lambda_R^L(i) \right)}. \tag{21}$$

Therefore, the QoS for handoff calls especially for HSMT must be guaranteed while allowing high utilization of channels. The objective of the proposed architecture is to guarantee the required handoff blocking probability for HSMT.

IV. Results

Fig. 2 shows the handoff blocking probability of HSMT against $T_{\text{off}}^{\text{tot}}$. Fig. 3 shows the mean call blocking probability of the microcellular layer (P_{nl}), respectively as a function of the $T_{\text{off}}^{\text{tot}}$. In both figures, curve (i) represents the performance of a typical cellular system for $C_s = 120$ (according to a traffic model analysis with prioritized handoff procedure). In this case, there is no umbrella layer and all the involved calls are served by microcells. Curves (ii), (iii), and (iv) show the performance of a Cellular system with the proposed architecture for $C_s = 120$, where handoff calls of HSMT are served by the umbrella layer and the new calls of HSMT and LSMT, and the handoff calls of LSMT by the microcellular layer. In Curve (ii) $C_u = 24$, $C = 32$, in Curve (iii) $C_u = 48$, $C = 24$ and in Curve (iv) $C_u = 72$, $C = 16$.

In the performed simulation, the number of microcells is considered to be $n = 3$, without affecting the generality of the model. The following parameters are also considered: $C_h = 0.1$ C, $T_H = 80$ s, $\alpha_L = 0.4$, $\alpha_H = 0.6$ and $\alpha_{HL} = 0.46$. Using these values and $0 \leq T_{\text{off}}^{\text{tot}}$ erlangs, the Λ_R^L, Λ_{Rh}^L, Λ_R^H, Λ_{Rh}^H are calculated.

Curves of Figs. 2 and 3 show an improvement in the handoff call blocking probability of HSMT as a result of using the proposed architecture, as well as adjusting the ratio C_u/C_S, according to the $T_{\text{off}}^{\text{tot}}$, α_L, α_H and α_{HL}. This improvement depends on the number of channels that are assigned to the umbrella cell. Figs. 2 and 3, show that $C_u/C_S = 48/120$ optimizes the umbrella layer with the minimum effect on the lower layer. This optimization refers to a decrease in blocking probability of the umbrella layer with the minimum increase in blocking probability of microcellular layer. The optimal ratio C_u/C_S is not always the same with different C_s.

V. Conclusion

A new two-layer architecture has been proposed to achieve low handoff call blocking probability. In this architecture, the umbrella cell philosophy has been introduced to serve handoff calls of HSMT. Moreover, according to the obtained results, the handoff call blocking probability of the HSMT has been optimized having a minimum effect on the call blocking probability of the microcellular layer.

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