Loss Formulas and Their Application to Optimization for Cellular Networks

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***Abstract*—In this paper, we develop a performance model of a cell in a wireless communication network where the effect of handoff arrival and the use of guard channels is inlcuded. Fast recursive formulas for the loss probabilities of new calls and handoff calls are developed. Monotonicity properties of the loss probabilities are proven. Algorithms to determine the optimal number of guard channels and the optimal number of channels are given. Finally, a fixed-point iteration scheme is developed in order to determine the handoff arrival rate into a cell. The uniqueness of the fixed point is shown.**

***Index Terms*—Channel allocation, Markov models, optimization, performance modeling, wireless cellular networks.**

I. Introduction

THE Erlang-B formula has been normally used to compute the loss probability in wireline networks. This formula cannot be used in cellular wireless networks due to the phenomenon of handoff. When a mobile station moves across a cell boundary the channel in the earlier cell is released and an idle channel is required in the target cell. This phenomenon is called handoff. If an idle channel is available in the target cell the handoff call is resumed nearly transparently to the user. Otherwise the handoff call is dropped. The dropping of a handoff call is generally considered more serious than blocking of a new call [2]. One way of reducing the dropping probability of a handoff call is to reserve a fixed number of channels (called guard channels) exclusively for the handoff calls [1], [3]. As a result, separate formulas for the dropping probability of handoff calls and the blocking probability of the new calls are required. Furthermore, as the number of guard channels is increased the dropping probability will be reduced while the blocking probability will increase. Thus, it is possible to derive an optimal number of guard channels subject to given constraints on the dropping and blocking probabilities.

Earlier efforts in this direction have been in the context of performability models including the effects of channel failures and recovery [4]. The objective of this paper is to derive the blocking and dropping probability formulas for a pure performance model. We also consider the optimal number of guard channels. We use a homogeneous continuous time Markov chain model for our derivations.

In Section II, we discuss the basic model and in Section III we consider the computational aspects. In Section IV we discuss properties of loss probabilities while in Section V we consider the optimization of the number of guard channels. In Section VI we discuss the use of fixed-point iteration to determine handoff call arrival rate. Finally, in Section VII we provide the conclusions.

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II. Basic Model

We consider the performance model of a single cell in a cellular wireless communication network. Consider Poisson arrival stream of new calls at the rate λ_1 and the Poisson stream of handoff arrivals at the rate λ_2. An ongoing call (new or handoff) completes service at the rate μ_1 and the mobile engaged in the call departs the cell at the rate μ_2. There is a limited number of channels, N, in the channel pool. When a handoff call arrives and an idle channel is available in the channel pool, the call is accepted and a channel is assigned to it. Otherwise, the handoff call is dropped. When a new call arrives, it is accepted provided that $g+1$ or more idle channels are available in the channel pool; otherwise, the new call is blocked. Here, g is the number of guard channels. We assume that $g < N$ in order not to exclude new calls altogether.

Let $C(t)$ denote the number of busy channels at time t, then $\{C(t), t \geq 0\}$ is a birth–death process as shown in Fig. 1. We define $\lambda = \lambda_1 + \lambda_2$, $\mu = \mu_1 + \mu_2$. The state-dependent arrival and departure rates in the birth–death process are given by

$$\Lambda(n) = \begin{cases} \lambda, & n = 0, 1, \ldots, N-g-1 \\ \lambda_2, & n = N-g, \ldots, N-1; \quad g > 0 \end{cases}$$

and $M(n) = n\mu$, $n = 1, \ldots, N$.

Because of the structure of the Markov chain we can readily write down the solution to the steady–state balance equations as follows. Define the steady–state probability

$$p_n = \lim_{t \to \infty} \text{Prob}(C(t) = n), \quad C = 0, 1, 2, \ldots, N.$$

Let $A = \lambda/\mu$, $A_1 = \lambda_2/(\mu_1 + \mu_2)$. Then we have an expression for p_n

$$p_n = p_0 \begin{cases} \frac{A^n}{n!}, & n \leq N-g \\ \frac{A^{N-g}}{n!} A_1^{n-(N-g)}, & n \geq N-g \end{cases}$$