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Optimal Distributed Call Admission Control for Multimedia Services in Mobile Cellular Network

Taekyoung Kwon, Yanghee Choi

Seoul National University
Seoul, Korea

Mahmoud Naghshineh

IBM T. J. Watson Research Center
Yorktown Heights, NY 10598

Abstract— **There is a growing interest in providing multimedia services in mobile/wireless communication networks. Call admission control (CAC) is a key factor in supporting successfully these services. In this paper, we propose a distributed call admission control policy which is optimal from the standpoint of service providers because it maximizes their revenue. A semi-Markov decision process is employed to determine an optimal CAC policy for multimedia services, which also satisfies the quality of service constraint to upper bound of the handoff dropping probability.**

I. Introduction

With the recent advances in mobile/wireless technologies, there is a growing interest in deploying multimedia services in mobile cellular networks (MCNs). For mobile multimedia services, the existing cellular network, which has provided voice-oriented services, needs to be adapted in numerous aspects. Call admission control (CAC) is one of the areas in need of adaptation to accommodate multimedia traffic.

The connection-level quality of service (QoS) in an MCN is usually expressed in terms of *call blocking probability* and *call dropping probability* [1], [2]. Call dropping probability is the probability that an accepted call will be terminated before the completion of its service. Call dropping probability is directly proportional to the *handoff dropping probability*, which is the probability that a handoff attempt fails [1], [5]. Therefore, we focus on the handoff dropping probability as the main QoS requirement. At the same time an attractive CAC for service providers should maximize their revenue.

CAC for multimedia services has been investigated intensively since the introduction of integrated services networks [7], [9], [11]. Hereafter, multimedia calls will be represented by multiple and different types of calls and will be referred to as *multiclass* calls.

Typical policies in multiclass networks are *complete sharing* (CS), *complete partitioning* (CP), *threshold*, etc. With the CS policy, calls of every class share the bandwidth pool. With the CP policy, bandwidth for every class is exclusively reserved. With the threshold policy, the number of calls of each class cannot be greater than a predefined threshold. It has been proven that the threshold policy is optimal in two-class networks [9]. However, the threshold policy is not optimal in general multiclass networks.

Another important policy is the *coordinate-convex policy.* The coordinate-convex policy boasts of easy tractability, thus several CAC policies are based on this policy [6], [9], [11]. However, it turns out that in certain cases coordinate-convex policies are strictly suboptimal [7], [8]. Alternatively, it is indicated that a *semi-Markov decision process* (SMDP) based CAC can maximize revenue for multiclass networks. Therefore, we employ SMDP to find an optimal CAC policy which will be described in Section III.

Several CAC policies have been proposed for mobile multimedia services [3], [4], [5], [6]. In [3], [4], class-based CACs are proposed where a real-time class is taken into account with higher priority than a non-real-time class. However, they consider only two classes. Epstein and Schwarz [5] extend distributed CAC [2] for multiclass networks and they show analytically how the handoff dropping probability can be guaranteed. Chao and Chen [6] model multiple classes of multimedia calls and analyze coordinate-convex CAC policies but only on a two-cell network. The latter two schemes, however, do not investigate the optimality of their CAC policies from a service provider perspective, i.e., maximize the revenue.

The rest of this paper is organized as follows. A model of a multiclass MCN is illustrated in Section II. Section III describes how to find out an optimal CAC policy. We illustrate the numerical results in Section IV. Finally, we conclude this paper in Section V.

II. Model Description

We consider a general model of multiclass calls with mobility characteristics; this model is found frequently in the literature. We assume that multimedia calls in MCNs can be abstracted by multiclass calls whose characteristics are as follows.

Suppose that there are K classes of calls in an MCN. Call requests of class-i, $i = 1, 2, ..., K$, are assumed to form a Poisson process with arrival rate λ_i. The holding time of a class-i call is assumed to follow an exponential distribution with mean $1/\mu_i$. The bandwidth of a class-i call, i.e., the number of channels required to accommodate the call, is given by b_i. Finally, for each on-going class-i call, revenue is accrued at rate r_i.

For the mobility characterization, we assume the following simple model. A mobile terminal (MT) moves through the whole cellular system. The *cell residence time* (CRT), i.e., the amount of time that an MT stays in a cell during a single visit to this cell, is assumed to follow an exponential distribution with mean $1/\eta$. We assume that the CRT

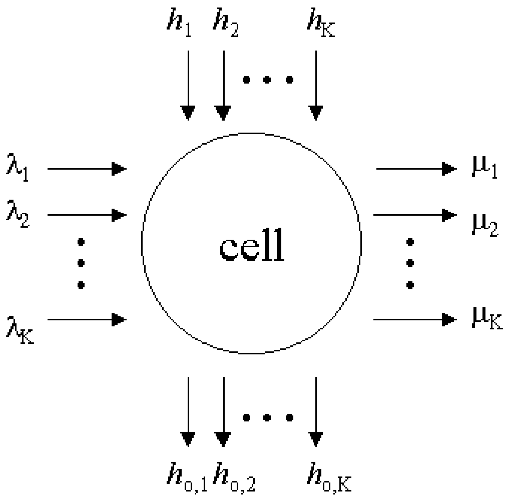

Fig. 1. Traffic in Mobile Cellular Network

is independent of class, hence, calls in any class follow the same cell residence time distribution. Note that the parameter η represents also the handoff rate. An MT is assumed to handoff to its adjacent cells with equal probability. For example, in an hexagonal cellular network, the probability that an MT will handoff to one of its adjacent cells is 1/6. As a consequence, the probability rate that a call in an adjacent cell will handoff to the given cell is $\eta/6$.

The total bandwidth (in number of channels) in each cell is the same and denoted by C. In this paper, we assume a fixed channel allocation (FCA) environment. Furthermore, it is assumed that the bandwidth of wideband call can be scattered across the bandwidth pool as in [5], [6], [7].

For our CAC, we consider both the incoming handoff traffic to and the ongoing traffic in a given cell. We do so because we want to guarantee a restricted handoff dropping probability by taking the calls in adjacent cells into account.

Our traffic model is summarized in Figure 1. The rate of class-i calls that originate in a given cell is denoted by λ_i. The rate of class-i calls that depart from the cell due to service completion is denoted by μ_i. The rate of class-i calls that handoff to the cell from all adjacent cells is denoted by h_i, while the rate of class-i calls that handoff from the cell to all adjacent cells is denoted by $h_{o,i}$.

The current state of a cell is represented by the vector $x = (x_1, x_2, ..., x_K)$, where x_i denotes the number of class-i calls in the cell. In the absence of any control, the set Λ of possible states is given by

$$\Lambda = \{x : x \geq 0; \sum_{i=1}^{K} b_i x_i \leq C\}. \qquad (1)$$

Ultimately, for each state x, a CAC policy in an MCN should find out an "accept/reject" decision rule for all kinds of traffic in Figure 1.

III. SMDP Approach to Our CAC

A. SMDP Overview

The original semi-Markov decision process (SMDP) model considers a dynamic system which, at random points in time, is observed and classified into one of several possible states. After observing the state, a decision has to be made and the corresponding revenue for each state is gained. For each state x, a set of actions is available. This controlled dynamic system is called an SMDP when the following Markovian properties are satisfied: if at a decision epoch the action a is chosen in state x, then the time until, and the state at, the next decision epoch depend only on the present state x.

Consequently, we focus in finding an optimal decision for each state. There are many methods to solve an SMDP-formulated problem [10]; also, additional constraints can be easily incorporated by using a linear programming (LP) formulation. Using the LP approach, we can enforce the upper bound on the handoff dropping probability in terms of an additional constraint. Ultimately, we apply the LP approach in the SMDP problem to solve for an optimal CAC policy in an MCN, which aims at both maximum revenue and QoS guarantee.

B. Our SMDP Approach

We adopt the SMDP approach in [7]. Decisions are made before, rather than after, the occurrence of an event. The SMDP state of the system (a cell) at a decision epoch is given by the vector $s = (x, e)$, where x is the vector of class-i calls from Section II. The variable e, $e \in \{a_1, ..., a_K, a_{K+1}, ..., a_{2K}\}$, represents the event type of an arrival; the indicator a_i, $a_i \in \{0, 1\}$, denotes the origination of a class-i call within the cell when $i \leq K$, while it denotes the arrival of a class-i call due to handoff from an adjacent cell when $i \geq K + 1$.

In this case, when the system is in state x, an accept/reject decision must be made for each type of possible arrival. Thus, the action space B can be expressed as follows:

$$B = \{(a_1, a_2, ...a_{2K}) : a_i \in \{0, 1\}, i = 1, 2, ..., 2K\}. \qquad (2)$$

For example, when $K = 2$ and $(a_1, a_2, a_3, a_4) = (1, 0, 1, 1)$, if the next event type is an arrival, then only calls of class-2 originating within the cell would be rejected. The action space is actually a state-dependent subset of B denoted by

$$B_x = \{a \in B : a_i = 0 \; if \; x + e_i \notin \Lambda\}, \qquad (3)$$

where e_i is a vector of zeros, except for an one in the i-th position.

If the system is in state $x \in \Lambda$ and the action $a \in B_x$ is chosen, then the expected time, $\tau(x, a)$, until a new state is entered is given by

$$\tau(x, a) = [\sum_{i=1}^{K} (\lambda_i a_i + x_i \mu_i + x_i \eta + \eta E[x_i] a_{K+i})]^{-1} \qquad (4)$$

On the right hand side of (4), the first two terms represent the rate at which calls originate from and terminate at a given cell, respectively. The third term represents the rate of outgoing handoffs from the cell, while the fourth term represents the rate of incoming handoffs from the adjacent cells to this cell. Also, $h_{o,i}$ and h_i in Figure 1 represent the latter two terms in order.

The probability that the next state is $y \in \Lambda$ is given by

$$P_{xay} = \begin{cases} (\lambda_i a_i + \eta E[x_i] a_{K+i})\tau(x,a) & y = x + e_i, \\ x_i(\mu_i + \eta)\tau(x,a) & y = x - e_i, \\ 0 & \text{otherwise,} \end{cases} \quad (5)$$

where $E[x_i]$, $i = 1, ..., K$, is the average number of class-i calls in a cell. Later on, we approximate the value of $E[x_i]$ by the outcome of simulations of coordinate-convex CAC policies which demonstrate maximum utilization while satisfying the QoS bound on handoff dropping probability.

Let $r(x,a)$ be the revenue rate when the cell is in state x and action a has been chosen. If r_i is the revenue rate of class-i call, then the total revenue rate for the cell is calculated by:

$$r(x,a) = \sum_{i=1}^{K} r_i x_i. \quad (6)$$

The utilization of the system is given by replacing r_i with b_i in (6). Strictly speaking, we should also consider the effect of call dropping into the definition of revenue rate. However, we assume that the effect of bandwidth used by forced-terminated calls can be ignored in our LP formulation.

C. LP Algorithm

The LP associated with the SMDP for maximum revenue is given below with decision variables z_{xa}, $x \in \Lambda$, $a \in B_x$:

$$\begin{aligned} \text{maximize} \ & \sum_{x\in\Lambda}\sum_{a\in B_x} r(x,a)\tau(x,a) z_{xa} \\ \text{s.t.} \ & \sum_{x\in\Lambda}\sum_{a\in B_x} \tau(x,a) z_{xa} = 1, \\ \sum_{a\in B_y} z_{ya} = & \sum_{x\in\Lambda}\sum_{a\in B_x} P_{xay} z_{xa}, \ y \in \Lambda, \\ & z_{xa} \geq 0, \ x \in \Lambda, \ a \in B_x. \end{aligned} \quad (7)$$

In (7), the decision variable z_{xa} represents "the long-run fraction of decision epochs at which the system is in state x and action a is taken."

Based on the LP formulation in (7), we can obtain an optimal CAC policy. However, we also need to consider the QoS requirement to upper-bound the handoff dropping probability. Let D_i denote the maximum tolerable handoff dropping probability of a class-i call. Then the following constraint needs to be added also to the LP formulation in (7) to satisfy the QoS requirement:

$$\sum_{x\in\Lambda}\sum_{a\in B_x} (1 - a_{K+i})\tau(x,a) z_{xa} \leq D_i, \quad \text{for } i = 1, 2, ..., K. \quad (8)$$

TABLE I

Parameters of the Simulation

C	5
mean service time ($1/\mu_1 = 1/\mu_2$)	500 sec
mean CRT ($1/\eta$)	100 sec
K	2
λ_1/μ_1	0.4
λ_2/μ_2	0.4
b_1	1
b_2	2
D_1	1%
D_2	2%

TABLE II

Results of the Simulation

	SMDP	Coordinate-convex
utilization	0.160286	0.152198
H_1	0.004377	0.003748
H_2	0.019921	0.016829

IV. Numerical Results

Our aim here is to indicate that SMDP approach can find an optimal CAC policy in an MCN. As the number of bandwidth units (channels) increases, the complexity of the corresponding LP formulation increases exponentially [7]. Therefore, we illustrate the advantage of our CAC policy in the case of small bandwidth capacity. We believe that the advantage of the SMDP-based policy can increase accordingly as the bandwidth capacity increases.

The coordinate-convex CAC policy to compare against in the experiment has a threshold t_i for a class-i call originating in a cell. For example, for a two-class case, the coordinate-convex policy with threshold (2,1) blocks a new class-1 call originating in a cell if there are already at least two class-1 calls in the cell. Also, it blocks a new class-2 call originating in the cell if there is already at least one class-2 call in the cell. An incoming handoff call is accepted only if there are enough available channels for the call.

The experimental results here are based on the simulation of a system consisting of ten cells arranged on a circle. A call, that handoffs from one cell to another, handoffs with equal probability to any of the adjacent cells. We compare our SMDP CAC policy with the coordinate-convex policy where the parameters for the simulation are as in Table I.

The utilization of a cell is a main performance metric in the above simulation experiment. The results of the simulation experiment are shown in Table II. In Table II, H_i represents the measured handoff dropping probability of class-i calls in the simulation experiment. The coordinate-convex CAC policy used for comparison has a threshold (1,1). Coordinate-convex CAC policies with other thresholds cannot satisfy the upper bound of handoff dropping probability, or they show less utilization.

V. Conclusion

It is anticipated that demands for multimedia services will grow for future mobile cellular networks. Optimal CAC is essential for the efficient utilization of scarce radio bandwidth. We have proposed a CAC policy, and a corresponding mathematical formulation framework, which can both guarantee the QoS requirements and maximize revenue. Our CAC policy makes a decision (accept/reject) for each call arriving to a cell during any state of this cell by means of a semi-Markov decision process. The linear programming method for solving the semi-Markov decision process is employed to find out the optimal CAC policy. A simulation has been carried out to show that performance of our CAC policy is better than that of the coordinate-convex policy.

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