Call Admission Control in Mobile Cellular Network based on Macroscopic Modeling of Vehicular Traffic

Taekyoung Kwon, Yanghee Choi
Dept. of Computer Engineering
Seoul National University, Seoul, Korea
{tkkwon,yhchoi}@mmlab.snu.ac.kr

abstract

This paper proposes a novel call admission control scheme which is based on macroscopic modeling of vehicular traffic. Our macroscopic model describes vehicular traffic in terms of number of vehicles, mean speed, and cell transition probability. When a new call request arrives in a cell, our call admission control scheme considers ongoing calls in the cell and its adjacent cells. Our scheme approximately estimates the handoff failure probability that is used to accept/reject the call request. Thereby it is possible to adapt to dynamically changing vehicular traffic and to guarantee the handoff failure probability of accepted calls to be less than a predetermined QoS value. Simulation reveals that our scheme shows better network utilization than trunk reservation scheme on the condition that the QoS value of the handoff failure probability is satisfied.

1 Introduction

The cellular network infrastructure is widely deployed because of efficient frequency reuse. However, the cellular network inherently accompanies handoff, that has a significant impact on the teletraffic performance of the cellular network such as call dropping probability. The call admission control(CAC) in mobile cellular network is also affected by handoff. The CAC should consider that an accepted call can be forced-terminated before completion of service, which is more unbearable to users than blocking of service. The teletraffic performance metrics, considered by CAC, are as follows.

- Carried Load : This metric represents the ratio of the bandwidth used by completely serviced calls to the total capacity of mobile cellular network. If a call is forced-terminated, the bandwidth used by the call is not taken into account.
- Call Dropping Probability : It is the probability that an accepted call is forced-terminated before it completes the service.
- Call Blocking Probability : It means the likelihood that a newly arriving call is blocked. Actually it depends on the CAC schemes.
- Call Completion Probability : It means the probability that a newly arriving call completes its service without forced termination.
- Handoff Failure Probability : It is the probability that a handoff fails because the target cell has no free channel. This is also called as forced termination probability.

The CAC for mobile cellular network can be categorized into fixed and dynamic approach. CACs in the fixed category cannot consider dynamic variation of vehicular traffic. In fixed category, there are trunk reservation[3], threshold[5], and queueing[4] schemes.

On the contrary, CACs in dynamic category react to the time-varying status of vehicular traffic. Weighting Scheme[6] considers the number of ongoing calls in the cells within some pre-defined number of hops. This scheme assigns an unequal weight to each cell to calculate the weighted average. If the weighted average number of ongoing calls in the cells is greater than the threshold, the originating call in the given cell is rejected. This scheme, however, cannot take account of a mobility pattern of vehicular traffic.

In Distributed CAC[1], CAC considers only calls in the given cell and in its adjacent cells. This scheme calculates the cell overflow probability that the number of calls after estimation period in this cell overflows. However, all the vehicles in the cells are assumed to handoff to its neighboring cells with equal probability, which ignores the unequal cell transition probability of vehicles.

Shadow Cluster[2] considers active mobile probability of each mobile terminal. Speed and direction of every vehicle is taken into account by surrounding cells and the cells reserve channels accordingly. The calculation overhead of movement parameters of every mobile terminal is under-estimated in this scheme.

Probability Index Scheme[6] proposes how to estimate the call dropping probability of an originating call when a call request arrives. However, the estimated call dropping probability is poorly justifiable and the processing complexity is too high.

When discussing the CAC in mobile cellular networks, the most important performance metric is the call dropping probability, which is highly dependent on handoff failure probability. There is a tradeoff relationship between call blocking probability and handoff failure probability. If CAC admits an originating call as much as possible and thereby lowers call blocking probability, the handoff failure probability will increase because of heavy ongoing traffic. On the contrary, if call blocking probability increases, the number of ongoing calls decreases and handoff failure probability decreases accordingly.

Therefore, the focus of CAC in mobile cellular network is how to accept/reject the originating calls in a given cell while satisfying the QoS(Quality of Service) value. For example, the handoff failure probability may be set to be less than 0.01%. In this paper, we propose a novel CAC for mobile cellular network which guarantees the QoS and maximizes the network utilization(carried load) of radio bandwidth.

The rest of this paper is organized as follows. Section 2 explains our CAC scheme and Section 3 discusses the model and analysis of our scheme. Simulation results are shown in Section 4. Section 5 concludes the paper.

2 CAC based on Macroscopic Vehicular Traffic Modeling

In this section, we model the vehicular traffic from a macroscopic viewpoint. Based on the macroscopic model, we calculate the probability that how many mobile terminals in the neighboring cells are going to handoff to the given cell. The estimation method of the number of handoff calls is basically adopted from the distributed CAC scheme[1]. We extend the scheme by considering realistic modeling of vehicular traffic which will be described in this section. Finally we decide whether the requested new call will be accepted or not according to the above-mentioned probability.

There are two kinds of calls in mobile cellular network, related to speed : call of pedestrian and call of vehicle. As it is not likely that calls of pedestrians will invoke many handoffs because of slow moving speed, only calls of vehicles are considered in this paper. As we dynamically consider traffic of vehicles(actually mobile terminals), our proposed CAC can be classified as dynamic CAC scheme.

There are two approaches in modeling of vehicular traffic : microscopic modeling and macroscopic modeling[7]. Our CAC based on Macroscopic Vehicular Modeling(CMVM) is based on the macroscopic

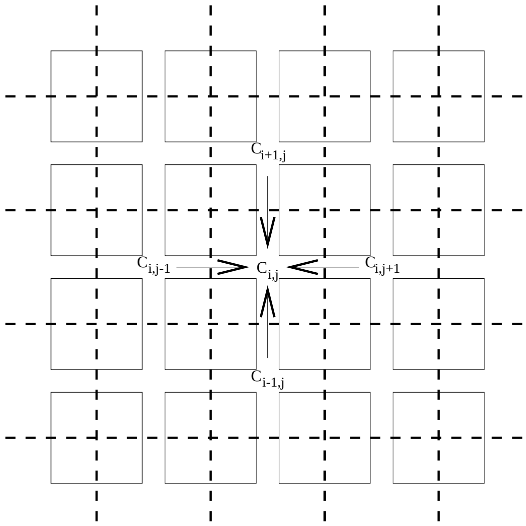

Figure 1. Model of Mobile Cellular System

modeling of vehicular traffic. Microscopic modeling considers the individual vehicle's physical movement. The movement of individual vehicle is governed by the driver's behaviour, the road geometry, the status of surrounding vehicles, and so on. Each vehicle may be described by a set of parameters such as position, actual speed, desired speed, and route choice. However, computational complexity increases rapidly with number of vehicles considered. From this point of view, Shadow Cluster[2] and Probability Index Scheme[6] are based on microscopic modeling. On the contrary, macroscopic modeling describes vehicular traffic with aggregate variables such as traffic density, mean speed, and so on. The use of such variables reduces the computation requirements which, in turn, makes real time calculation feasible.

Our CAC scheme, CMVM, considers vehicular traffic in terms of the number of vehicles carrying ongoing calls, cell transition probability, and mean vehicle speed in each cell. In addition, we assume that the cell transition probability and mean speed are dependent on each cell as it is easily expected in real traffic pattern. Here, we consider two dimensional cellular network, typical in city environment. We think that this model can be easily extended for hexagonal cellular network and the like.

If we denote two dimensional cellular network as two dimensional array, every cell can be represented by row index and colume index. Referring to Figure 1, we denote $C_{i,j}$ as the cell where a call request arrives; the corresponding location is i-th row and j-th column in the whole cellular system. Calls in neighboring cells will handoff to $C_{i,j}$ with the corresponding cell transition probability. This call is a handoff call from the viewpoint of the $C_{i,j}$. Neighboring cells of $C_{i,j}$ are $C_{i,j-1}$, $C_{i,j+1}$, $C_{i+1,j}$, $C_{i-1,j}$. These cells are

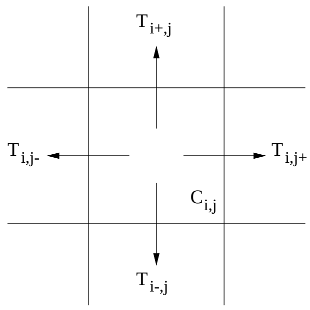

Figure 2. Cell Transition Probability

located in the left, right, upper, lower to the given cell $C_{i,j}$ respectively.

We assume that probabilities are known a priori with which a vehicle in $C_{i,j}$ move to adjacent cells. and these probabilities are called as cell transition probability. Cell transition probability of $C_{i,j}$ is denoted as $T_{i,j}$. For example, $T_{2,4} = (0.4, 0.3, 0.2, 0.1)$ means that a mobile terminal in $C_{2,4}$ will move to its left cell($C_{2,3}$), right cell($C_{2,5}$), upper cell($C_{3,4}$), lower cell($C_{1,4}$) with probabilities of 0.4, 0.3, 0.2, and 0.1 respectively. We define the specfic cell transition probability as $T_{i,j-}$, which means the probability that a mobile terminal in $C_{i,j}$ will move to its left cell, $C_{i,j-1}$. Likewise $T_{i,j+}$, $T_{i+,j}$, $T_{i-,j}$ denote the probability that a call in $C_{i,j}$ will move to its right cell, upper cell, and lower cell respectively(Figure 2). The cell residence time is dependent on each cell.

When there comes a new call request in $C_{i,j}$, the CAC scheme considers not only the current calls in $C_{i,j}$, but also calls in its neighboring cells. CMVM calculates the cell overflow probability that the number of calls in $C_{i,j}$ after estimation period T is greater than the total number of channels on the condition that the currently requested call is accepted. If the calculated cell overflow probability is greater than the predefined QoS value P_{QoS}, the arriving call request is rejected. Therefore, the handoff failure probability of handoff calls from neighboring cells to this cell $C_{i,j}$ will be maintainted below P_{QoS}. The estimation of cell overflow probability is performed not only in the given cell but also in its neighboring cells.

3 Model

First, we adopt the infrastructure of mobile cellular network based on Manhattan street network(MSN). MSN configures itself with two dimensional array of rectangular blocks. With this in mind, we regard an area which centers an intersection as a cell (an area whose boundaries are drawn in dashed lines in Figure 1). We also assume that a mobile terminal in a cell can handoff to only four neighboring cells. Moreover, we assume that call arrival follows a Poisson process with mean rate λ and call service time is exponentially distributed with mean $1/\mu$. The cell residence time in $C_{i,j}$, $r_{i,j}$, is assumed to follow exponential distribution with mean $1/\eta_{i,j}$. Let $n_{i,j}$ be the current number of mobile terminals in $C_{i,j}$.

Note that the channel holding time(CHT) is different from the cell residence time. The CHT is a fraction of the total call duration in each cell. Since the CHT is the minimum of the cell residence time and call service time, the CHT in $C_{i,j}$ is distributed exponentially with mean $1/(\mu + \eta_{i,j})$.

$$P[CHT_{i,j} \le t] = 1 - \exp^{-(\mu+\eta_{i,j})t} \qquad (1)$$

In the above situation, the probability that a mobile terminal in a neighboring cell will handoff to the given cell within T(estimation period) can be calculated by the product of cell transition probability of the corresponding cell and the probability that cell residence time is shorter than T. We ignore the probability that a mobile terminal performs handoff more than once within T because T is set to sufficiently smaller value than average cell residence time.

Let us denote the probability that a mobile terminal in $C_{i,j}$ will handoff to its adjacent cells within T as $H_{i,j}$. Here, $H_{i,j}$ is handoff probability and means the probability that the CHT is less than $T(P[CHT_{i,j} \le T])$.

We denote the product of cell transition probability and handoff probability as a single term $p_{i,j}$ with its direction. For example, $p_{i,(j-1)+}$ represents the probability that a mobile terminal in cell $C_{i,j-1}$ will handoff to cell $C_{i,j}$ within T. We denote $p_{i,j}$ as handoff transition probability for convenience.

Each mobile terminal in neighboring cells will handoff to the given cell with the corresponding handoff transition probability, each of which will follow Bernoulli distribution. Therefore, the number of handoff calls from neighboring cells can be regarded as a binomial random variable. For example, the number of mobile terminals which will handoff to the given cell $C_{i,j}$ from left cell $C_{i,j-1}$ will have binomial probability distribution with $B(n_{i,j-1}, p_{i,(j-1)+})$. Therefore, random variable X_l which denotes the number of handoff calls from left cell will have this probability distribution. It is obvious that the numbers of handoff calls from right, upper, and lower cell also follow the binomial distribution.

Not only the number of the ongoing calls in neighboring cell, but also the number of the ongoing calls in the given cell should be considered. That is, we should calculate the probability that the CHT in the given cell is greater than T. A mobile terminal will stay in the given cell until T with probability $s_{i,j}$ as in the Equation 2.

$$s_{i,j} = P[CHT_{i,j} > T] = \exp^{-(\eta_{i,j}+\mu)T} \qquad (2)$$

Equation 2 represents the probability that both call service time and cell residence time of a mobile terminal will be greater than T. Therefore, random variable X_s, the number of calls which will stay in the given cell, will have binomial distribution.

Let X be a random variable which represents the expected number of handoff calls in the given cell after $t_0 + T$, when a call request is made at t_0. We can find the probability distribution of X by the convolution sum of $B(n_{i,j-1}, p_{i,(j-1)+})$, $B(n_{i,j+1}, p_{i,(j+1)-})$, $B(n_{i+1,j}, p_{(i+1)-,j})$, $B(n_{i-1,j}, p_{(i-1)+,j})$, and $B(n_{i,j}, s_{i,j})$. Therefore, we can calculate the expected number of mobile terminals after T by summing the handoff calls from the adjacent cells and the remaining calls in the given cell.

As the direct calculation of distribution of X is of great complexity, we approximate the convolution of binomial distributions by normal distribution. It is well known that binomial distribution with $B(n, p)$ can be approximated by normal distribution with $G(np, \sqrt{np(1-p)})$. Here, np is mean and $\sqrt{np(1-p)}$ is standard deviation.

In the above situation, the sum of four binomial distributions(in the adjacent cells) and one binomial distribution(in the given cell) can be approximated by the following normal distribution $G(E(X), \sigma(X))$ with mean($E(X)$) and standard deviation($\sigma(X)$).

$$\begin{aligned} E(X) &= n_{i,j-1}p_{i,(j-1)+} + n_{i,j+1}p_{i,(j+1)-} + n_{i+1,j}p_{(i+1)-,j} \\ &\quad + n_{i-1,j}p_{(i-1)+,j} + n_{i,j}s_{i,j} \end{aligned} \tag{3}$$

$$\begin{aligned} \sigma^2(X) &= n_{i,j-1}p_{i,(j-1)+}(1 - p_{i,(j-1)+}) \\ &\quad + n_{i,j+1}p_{i,(j+1)-}(1 - p_{i,(j+1)-}) \\ &\quad + n_{i+1,j}p_{(i+1)-,j}(1 - p_{(i+1)-,j}) \\ &\quad + n_{i-1,j}p_{(i-1)+,j}(1 - p_{(i-1)+,j}) \\ &\quad + n_{i,j}s_{i,j}(1 - s_{i,j}) \end{aligned} \tag{4}$$

As a result, we can get the probability distribution of the number of calls in the given cell after time T. We denote $X(i)$ as the probability that X is i. Let P_O be the probability that X will exceed the total number of channels in the given cell. Then, the probability that an handoff call will produce an overflow in the given cell can be calculated by Equation 5. Here, N is the total number of channels in a cell and FCA(Fixed Channel Allocation) is assumed in this paper.

$$P_O = \sum_{i=N+1}^{n_{all}} X(i) \approx Q(\frac{N - E(X)}{\sigma(X)}) \tag{5}$$

Here, n_{all} is the total number of the ongoing calls in the given cell and in its adjacet cells. And the function $Q(x)$ is a integral of tail distribution of standard normal distribution function and can be represented by Equation 6.

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp^{-t^2/2} dt \tag{6}$$

If calculated P_O is greater than the predefined QoS value P_{QoS}, the call request in the given cell is rejected. Therefore, we can enforce the handoff failure probability to be less than P_{QoS}.

Table 1. Cellular System Parameters

Parameter	Value
mean call service time	180 seconds
mean cell residence time	20 seconds
estimation period(T)	5 seconds
number of channels per cell(N)	20
cell transition probability	(0.7,0.1,0.1,0.1)
P_{QoS}	0.01%

4 Numerical Results

We adopt two performance measures to evaluate the CAC in mobile cellular network: handoff failure probability and carried load. The comprehensive simulation has been carried out to evaluate our CMVM scheme and trunk reservation(TR) scheme. In the TR scheme, a handoff call is admitted only if there are free radio channels. However, a new arriving call cannot be accepted if the number of free radio channels is below than specific value. This value is also called as guard channel.

The system parameters for the experiment are as in Table 1. Considering that recent cell size becomes smaller, we can take a example where cell diameter is 200 meter and vehicle speed is 10 m/s, and the cell residence time becomes 20 seconds. Cell transition probability of every cell is set to $(0.7, 0.1, 0.1, 0.1)$, which reflects a mobility pattern that most vehicles move from right to left.

Figure 3 and Figure 4 show the handoff failure probability and carried load respectively. Here, the offered load is $\lambda/(N\mu)$. From the simulation results, TR scheme with 9 guard channels violates the bound of handoff failure probability so severely that we can exclude this from the graph. In that case, our CMVM scheme shows better utilization than TR scheme with 10 guard channels.

5 Conclusion

The QoS requirement of mobile communications becomes more and more important and complicated.

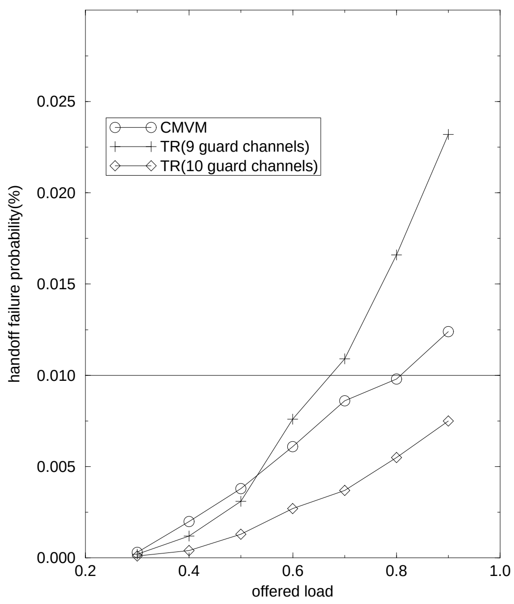

Figure 3: Handoff Failure Probability vs. Offered Load

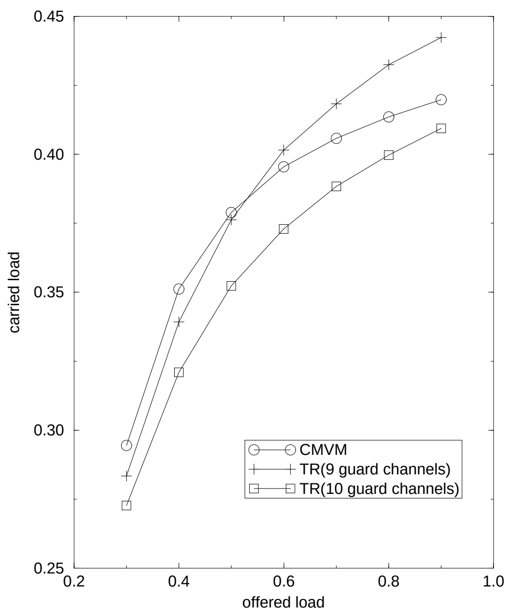

Figure 4. Carried Load vs. Offered Load

Therefore CAC in mobile communcations which can guarantee QoS has been an significant research issue. In this paper, we proposed the novel modeling of vehicular traffic. This macroscopic model considers the average speed of vehicle, cell transition probability, and the average cell residence time. Our CAC scheme based on that model approximately estimates the handoff failure probability and rejects the originating call request if estimated cell overflow probability is greater than predetermined value. According to the simulation results, CMVM scheme shows better network utilization than trunk reservation scheme while satisfying the requirement of handoff failure probability.

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