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Enhanced Cell Visiting Probability for QoS Provisioning in Mobile Multimedia Communications

Mohammad Mahfuzul Islam, Manzur Murshed and Laurence S Dooley
Gippsland School of Computing and Info. Tech., Monash University, Churchill VIC 3842, Australia.
E-mail: {*Mahfuzul.Islam,Manzur.Murshed,Laurence.Dooley}@infotech.monash.edu.au*

Abstract

This paper presents an enhanced Cell Visiting Probability (CVP) estimation technique by integrating both mobility parameters such as position, direction, and speed together with exponential call duration probability of mobile units. These improved CVP estimates can be used in both adaptive and non-adaptive mobile networks to enhance QoS parameters. This paper also presents a new shadow-clustering scheme based on these enhanced CVPs, which is then applied to the call admission control scheme similar to the one, called predictive mobility support QoS provisioning scheme, proposed by Aljadhai and Znati (2001). Simulation results confirm that this new shadow-clustering scheme outperforms predictive mobility support QoS provisioning scheme in terms of different QoS parameters under various different traffic conditions.

1. Introduction

Mobile wireless networks are facing extreme challenges in supporting a broad range of real time multimedia applications with diverse bandwidth requirements for audio, voice, video, and text data with *quality-of-service* (QoS) assurance, comparable with wired networks, under various traffic conditions [4][5][8]. Unlike their wired counterpart, the scarcity of bandwidth, roaming, and channel imperfections of mobile networks make QoS provision a far more challenging task. In order to support active users who are likely to visit a cell, i.e., to reduce the *call dropping probability* (CDP), its base station needs to implement a *call admission control* (CAC) scheme to reserve resources at the expense of increasing the possibility of denying new calls within the cell, i.e., increasing the *call blocking probability* (CBP) [2][12]. Reservation of *bandwidth*, the most valuable resource, is a mandatory issue in all such schemes [3][10][11][13].

From the user's perspective, dropping an ongoing call is far less desirable than blocking a new call. However, the greatest challenge in designing any CAC scheme lies in its ability to estimate resource reservation requirements as accurately as possible so the increase in CBP is minimised without unnecessarily reducing the *channel utilization*. Channel utilization is expressed as the ratio of the total bandwidth in use to the minimum of the total bandwidth requested and the total bandwidth available.

Recent studies [1][2][6][7] have clearly established the importance of incorporating *mobility parameters*, such as speed, direction, and distance of mobile units, into the decision making process at different strategic levels, including the CAC scheme. The schemes in [1][2][6][7], in general, consider mobility parameters to calculate the probability of visiting each active mobile unit from a neighboring cell to the current cell. Resource reservation requirements are then estimated based on this *cell visiting probability (CVP)*. In the *predictive mobility support CAC* (PMSCAC) scheme in [1], CVPs (referred as the *directional probabilities* [1]) are calculated based on the predicted directions of the mobile units.

In this paper, a new *mobility and survival probability based CAC* (MSCAC) scheme is developed where the cell visiting probabilities are calculated using not only the mobility parameters but also the *call survival behavior*. The basic components of this scheme are: 1) a mobility and call survival probability based CVP model to support timed-QoS guarantees; 2) a shadow clustering model, based on the probability model, to represent the cells that are most likely to be visited by an active mobile unit; and 3) a CAC model to verify the feasibility of supporting a call within the shadow cluster.

Both abovementioned mobility based CAC schemes were evaluated extensively using a large-scale simulation, comprising real world road networks and mobile units capable of exchanging multimedia data such as voice, text, audio and video. It will be shown that the new MSCAC scheme clearly outperforms the PMSCAC scheme in the simulation results.

The paper is organized as follows. Section 2 explains the mathematical concepts for defining cell-visiting probability as proposed, while the formation of a shadow cluster model based on the CVPs is presented in Section 3. Section 4 provides guidelines for calculating the time window for reserving bandwidth; with the bandwidth reservation and allocation algorithms of the new MSCAC scheme being detailed in Section 5. Section 6 describes the simulation models and parameters while Section 7 presents simulation results to evaluate the performance of the new scheme. Finally, some concluding remarks are given in Section 8.

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2. Cell visiting probability (CVP)

In order to efficiently support QoS guarantees through better utilization of bandwidth resource, it is important to measure the time-independent CVP, $P_{i,j}^{\gamma}$, of an active mobile in cell *i* to visit cell *j,* which can be calculated from the following two time-independent probabilities.

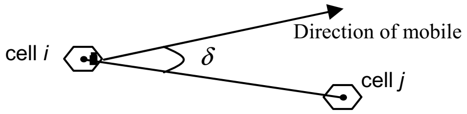

Figure 1. Graphical representation of δ.

2.1. Directional probability

Let $\delta_{i,j}$ be the angle between the direction of the mobile unit in cell *i* and the line passing through the position of the mobile unit and the centre of cell *j* as shown in Figure 1. The *directional probability*, $P_{i,j}^{\alpha}$, of an active mobile unit in cell *i* to visit cell *j* has the following properties:

- $P_{i,j_1}^{\alpha} \geq P_{i,j_2}^{\alpha}$ iff $\delta_{i,j_1} \leq \delta_{i,j_2}$.
- A mobile unit moving at a low speed has a higher tendency to change direction than a mobile unit moving at a higher speed.

Therefore, $P_{i,j}^{\alpha}$ can be defined as

$$P_{i,j}^{\alpha} = \begin{cases} \frac{k}{2}\cos k\delta_{i,j}, & \text{if } -\frac{\pi}{2k} \leq \delta_{i,j} \leq \frac{\pi}{2k} \text{ and } \frac{1}{2} \leq k \leq 2; \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where $k = \log v$ is the *speed factor* and *v* is the speed of the mobile unit. Note that

$$\int_{-\pi/2k}^{\pi/2k} P_{i,j}^{\alpha}\, \mathrm{d}\delta_{i,j} = 1. \tag{2}$$

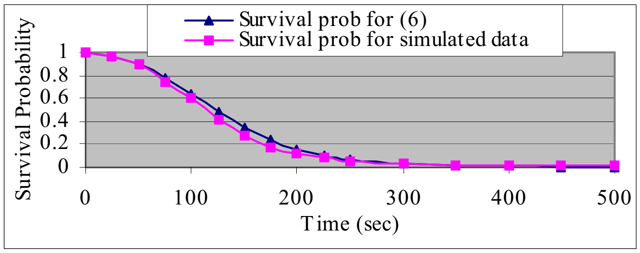

Figure 2: Survival probability for (6) and simulated data for mean talk time 105s.

2.2. Call survival probability

The *call survival probability*, $P_{i,j}^{\varsigma}$, of an active mobile unit in cell *i* to visit cell *j* assists in setting up a boundary distance from the mobile unit's current position such that only the cells within this boundary distance reserve bandwidth for the concerned active call. Call survival probability has the following properties:

- The call survival probability decreases exponentially as the distance between the mobile unit and the centre of cell *j* (proportional to traveling time) increases as is evident from the curve generated by the normally distributed simulated data in Figure 2.
- Rate of change in the call survival probability reaches the maximum at the distance, between the mobile unit and the center of cell *j*, corresponding to the mean talk time of mobile unit as observed from the curve generated by the simulated data shown in Figure 3.

Let $D_{i,j}(x) = (T_j^{\aleph}(x) - T_{i,j}^{\rho}(x))\bar{v}_{i,j}(x)$ be the *observed distance* traversed by mobile unit *x* from cell *i* to cell *j* where $T_j^{\aleph}(x)$ is the arrival time of mobile unit *x* at cell *j*, $T_{i,j}^{\rho}(x)$ is the first activation time of mobile unit *x* in cell *i*, and $\bar{v}_{i,j}(x)$ is the average speed of mobile unit *x* in that distance.

Let $\widetilde{D}_{i,j}^{S}$ be the *expected distance* traversed by any mobile unit from cell *i* to cell *j* in state *S*, which is updated every time when a mobile users move from cell *i* to cell *j* as per the following exponential averaging technique:

$$\widetilde{D}_{i,j}^{S+1} = (1-\omega_{i,j}^{S})\widetilde{D}_{i,j}^{S} + \omega_{i,j}^{S} D_{i,j}(x) \tag{3}$$

where $\widetilde{D}_{i,j}^{0}$ is the distance between the mobile unit and the center of cell *j* and $\omega_{i,j}^{S}$ is the *distance smoothing factor* in state *S* computed as

$$\omega_{i,j}^{S} = c\frac{\left(\varepsilon_{i,j}^{S}\right)^2}{\xi_{i,j}^{S}+1} \tag{4}$$

where $0 < c < 1$ is the *sensitivity parameter* set by the system administrator to handle the abrupt changes in communication system, $\varepsilon_{i,j}^{S} = (\widetilde{D}_{i,j}^{S} - \widetilde{D}_{i,j}^{S-1}) / \widetilde{D}_{i,j}^{S}$ is the normalized distance error in state *S*, and $\xi_{i,j}^{S}$ is the exponential average of the past square normalized distance errors, which is updated as follows:

$$\xi_{i,j}^{S} = c\left(\varepsilon_{i,j}^{S}\right)^2 + (1-c)\xi_{i,j}^{S-1}, \quad \xi_{i,j}^{0} = 0. \tag{5}$$

Now, $P_{i,j}^{\varsigma}$ can be defined as

$$P_{i,j}^{\varsigma} = e^{-\frac{1}{2}\left(\frac{\widetilde{D}_{i,j}^{S}}{D_m}\right)^2} \tag{6}$$

where $D_m = \bar{v}_{i,j}(x)T_m(x)$ is the average remaining distance to be traversed by the mobile unit *x* under consideration and $T_m(x)$ is the average talk time minus the call age of mobile unit *x*. It can be readily established from Figures 2 and 3 that the definition of the call survival probability in (6) is a close fit to the simulated real world data.

2.3. Combining the probabilities

The directional and call survival probabilities are correlated as both the probabilities are calculated using the speed of the mobile unit. Therefore, these two probabilities can be combined to calculate CVP, $P_{i,j}^{\gamma}$, as follows:

$$P_{i,j}^{\gamma} = \left(P_{i,j}^{\varsigma}\right)^{\tau}\left(P_{i,j}^{\alpha}\right)^{1-\tau} \tag{7}$$

where $0 < \tau < 1$ is the *tuning parameter* to adjust the dependencies between the directional and call survival probabilities.

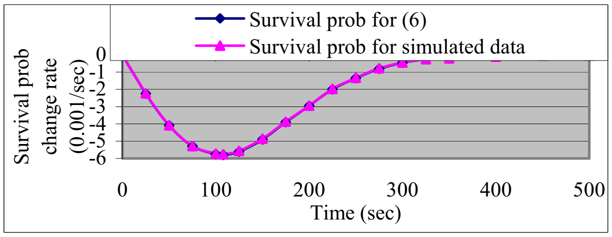

Figure 3. Survival probability changing rate for (6) and simulated data for mean talk time 105s.

3. Formation of a shadow cluster

For an active mobile unit, the directional probability distribution forms a conical shape as shown in Figure 4, with the direction of the mobile unit acting as the major axis of the cone, where only the cells inside this shape should consider reserving any bandwidth for the mobile unit. The angle of any of the cone's two sides with the direction of the mobile unit for CVP threshold, ψ, can be measured from (1) as

$$\delta_m = \frac{1}{k}\cos^{-1}\frac{2\psi}{k}. \tag{8}$$

Clearly, as the speed v of a mobile unit increases, the angle δ_m decreases, and therefore, the area of the conical shape is reduced.

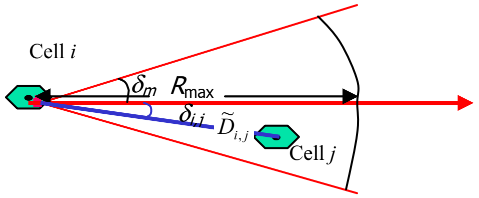

Figure 4. Conical shaped shadow cluster.

Within this conical shape, defining a *cut-off radial distance*, $R_{\max}$, as shown in Figure 4, forms a *shadow cluster* such that only the cells within this cluster will be reserving bandwidth for the mobile unit. By assuming a *radial threshold,* η, for the call survival probability, as shown in Figure 5, the value of $R_{\max}$ can be calculated from (6) as follows:

$$R_{\max} = D_m\sqrt{\ln\left(\frac{1}{\eta^2}\right)}. \tag{9}$$

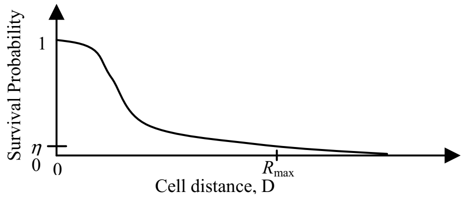

Figure 5. Maximum boundary distance, $R_{\max}$ for survival probability threshold, η

4. Reservation time slot estimation

To estimate the reservation time slot in cell j of an active mobile x currently in cell i to visit cell j in its shadow cluster, the *standard deviation of expected distance*, $\sigma_{i,j}^{S}$, is measured as follows:

$$\left(\sigma_{i,j}^{S}\right)^2 = (1-\omega_{i,j}^{S})\left(\sigma_{i,j}^{S-1}\right)^2 + \omega_{i,j}^{S}\left(D_{i,j}(x) - \widetilde{D}i,j\right)^2 \tag{10}$$

assuming $\sigma_{i,j}^{0} = 0$.

The *maximum expected distance*, $\widetilde{D}_{i,j}^{\max}$ and the *minimum expected distance*, $\widetilde{D}_{i,j}^{\min}$ are then measured from the standard normal distribution curve with mean and standard deviation as $\widetilde{D}_{i,j}^{S}$ and $\sigma_{i,j}^{S}$ respectively for a specific confidence level β. The *expected earliest arrival time*, $\widetilde{T}_{i,j}^{EA}(x)$, and the *expected latest departure time*, $\widetilde{T}_{i,j}^{LD}(x)$, of mobile unit x to cell j are then calculated as follows:

$$\widetilde{T}_{i,j}^{EA}(x) = \frac{\widetilde{D}_{i,j}^{\min}}{\bar{v}_{i,j}(x)} \text{ and } \widetilde{T}_{i,j}^{LD}(x) = \frac{\widetilde{D}_{i,j}^{\max} + 2R_j}{\bar{v}_{i,j}(x)}. \tag{11}$$

where R_j is the radius of cell j.

5. Proposed CAC algorithms

The following steps are executed in reserving bandwidth for the proposed MSCAC scheme:

1. Whenever a mobile unit is activated in a cell (say cell *i*), a shadow cluster is calculated in the cell's base station and appropriate bandwidth reserve request messages are transmitted to the base stations of all the cells in the shadow cluster. Each request message carries the value of corresponding $P_{i,j}^{\gamma}$ and the reservation time slot.

2. After receiving the request, each base station in the shadow cluster then calculates bandwidth reservation requirements for this mobile unit based on the received probability value and the free bandwidth available in the requested time slot. If sufficient bandwidth is available to be reserved for the requested call, the reservation is permitted with probability $P_{i,j}^{\gamma}$.
3. However, if there is insufficient bandwidth, then the remaining available free bandwidth is reserved, provided $P_{i,j}^{\gamma} > 0$.

The steps involved in allocating bandwidth for the proposed MSCAC scheme is as follows:

1. If the incoming call is new, both the allocated bandwidth and the reserved bandwidth are subtracted from the cell capacity to calculate the bandwidth available for allocation.
2. Otherwise, only the allocated bandwidth is subtracted from cell capacity to calculate the bandwidth available for allocation.
3. If the requested bandwidth is less than or equal to the available bandwidth, the call (new or handoff) is accepted by allocating the required bandwidth.
4. Otherwise, the call is rejected.

Table I: Simulation parameters.

Parameter	Value	Description
N	39	Number of cells in system
R	13	Number of country roads and freeways
J	10	Number of road junctions
C	30 BU	Cell capacity
M	Var	Number of mobiles in system
P_{dc}	0.15	Probability of traveling on a country road
P_{df}	0.1	Probability of traveling on a freeway
P_{walk}	0.4	Walking probability
P_{s2m}	0.4	From stopping to moving probability
P_{m2s}	0.4	From moving to stopping probability
G_{out}	0.0001	Going out of network probability
S_t	Var	Received signal strength
R_c	Var	Radius of the cell
V_{maxc}	28	Max speed (m/s) on a country road
V_{maxf}	35	Max speed (m/s) on a freeway
V_{maxr}	18	Max speed (m/s) on local/city roads
V_{maxw}	3	Max walking speed (m/s)
λ	Var	Mean call arrival rate
$/\mu$	Var	Mean talk time
G_{off}	0.01	Mobile off probability
V_s	0.1	Velocity sensitivity of MT
$1/\mu_{off}$	Var	Mean off time
$1/\mu_{out}$	Var	Mean out of network staying time
β	0.9	Confidence level
τ	0.5	Tuning parameter
η	0.3	Radial Threshold
ψ	0.2	CVP Threshold

6. Simulation model description

A real time wireless environment, comprising of local, city, local/city roads, country roads, and freeways, was simulated for both the proposed MSCAC scheme and the PMSCAC scheme [1]. The simulation was developed in Java using a general-purpose *discrete event simulation* library SimJava [9].

Each simulation was carried out for 24 hours of real time mobile communications within 39 cells of equal radius to analyze the effects on QoS parameters and the number of overhead message transmission caused by the underlying CAC scheme. The mobile units were allowed to travel at predefined speeds associated with the current locality or road with ±10% variations. The arrival rate of the new calls was assumed to have a *Poisson distribution* with an arrival rate of λ, while the call duration time was assumed to be exponentially *distributed* with mean $1/\mu$. Mobile units are considered capable of transmitting four different types of traffic—voice, text, audio, and video with respective probabilities of 0.5, 0.2, 0.2, and 0.1 and *Bandwidth Unit* (BU) requirement by each call 1, 2, 5, and 10 respectively.

Table I summarizes the simulation parameters whose values were empirically selected to represent a realistic simulation scenario.

7. Simulation results

To avoid errors introduced due to unrealistic initial conditions, simulation results were collected only after the first 12 real-time hours when the simulation reached a quiescent state.

The new proposed MSCAC scheme is compared with the PMSCAC scheme [1] for call dropping rate, call blocking rate, and channel utilization under different traffic conditions.

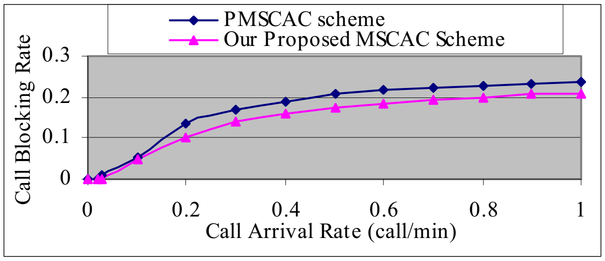

Figure 6. Comparisons of call blocking rates at different traffic conditions.

7.1. Call blocking rate

The comparative plots in Figure 6 show that the call blocking rate is nearly zero at very low traffic, but increases steadily with the increasing traffic loads for both PMSCAC and MSCAC so that at 1.0 call/min, the respective call blocking rate values are 0.24 and 0.21. This improvement continues up to a call arrival rate of 0.2 call/min and then remains approximately constant at 0.03.

7.2. Call dropping rate

From the comparison in Figure 7, we observe that the call-dropping rate of the new MSCAC scheme is lower than PMSCAC scheme throughout the study. While the call dropping rate is zero at very low traffic, it soon increases for traffic loads of 0.16 call/min or higher in both cases, but the rate of increase for the PMSCAC scheme is higher than that of MSCAC before traffic loads 0.4 call/min and the difference remains almost constant at 0.014 thereafter.

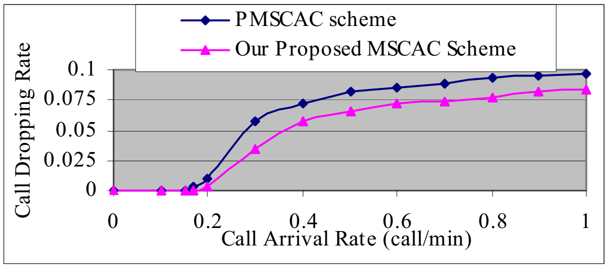

Figure 7. Comparison of call dropping rates at different traffic conditions.

7.3. Channel utilization

The impact of bandwidth utilization in both cases is plotted in Figure 8, which confirms the better bandwidth utilization of the MSCAC scheme compared with PMSCAC scheme. At very low traffic loads, there is no problem since the level of bandwidth used is almost equal to the amount of bandwidth requested which leads to 100% utilization. However, as traffic loads increase, some requests are denied for both schemes, which reduce the overall channel utilization. It is clear that channel utilization for PMSCAC decreases at a higher rate than that in the MSCAC scheme as traffic loads increase.

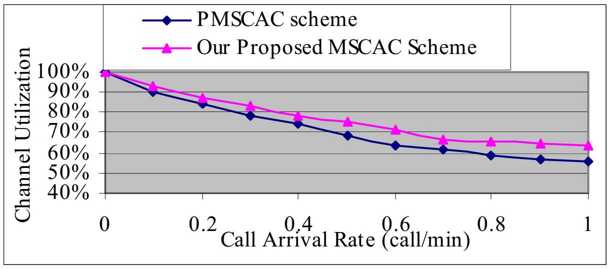

Figure 8. Comparison of channel utilization at different traffic conditions.

8. Conclusions

This paper presented an enhanced *cell visiting probability* (CVP) model by integrating mobility parameters and the call survival behaviors of mobile units. Moreover, a *mobility and call survival probability based* call admission control (MSCAC) scheme is presented based on the CVPs estimated through this model to support increased timed-QoS guarantees for resource-demand multimedia communication applications. The scheme uses directional probabilities, in terms of direction and speed, and the call survival probabilities, in terms of the call survival behavior and distance, to estimate the CVPs and the resource reservation time slots. A shadow-clustering model has been implemented using the estimated CVPs to identify the most likely cells that an active mobile unit will visit. The scheme's bandwidth reservation and allocation algorithms have then been developed based on the shadow clusters and the reservation time slots. Using a simulation, the performance of this scheme was compared with the PMSCAC scheme [1]. Results have shown that the MSCAC scheme consistently outperforms the PMSCAC approach as the network traffic loads increase.

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