Bandwidth Reservation in Mobile Cellular Networks Using ITS Navigation Systems *

Sunghyun Choi and Kang G. Shin
Real-Time Computing Laboratory
Department of Electrical Engineering and Computer Science
The University of Michigan, Ann Arbor, Michigan, USA
E-mail: {shchoi,kgshin}@eecs.umich.edu

Abstract

We demonstrate how to utilize the path information available from ITS navigation systems for bandwidth reservation for hand-offs and admission control of new connections in mobile cellular networks. By utilizing the path information, we modify a recently-proposed bandwidth reservation and admission control scheme with a design goal to keep the hand-off dropping probability below a pre-specified target. While the original scheme utilized a history-based mobility estimation, the modified scheme uses only part of it. Since both the original and modified schemes meet the design goal, the problem is to determine which of the two can admit more new connections for a given traffic condition. Using simulations, the modified scheme aided by the navigation system is shown to outperform the original scheme even with much less computational requirement.

1 Introduction

Mobile users in cellular networks are expected to move around, making connection hand-offs between cells during a communication session. The current trend of shrinking cell size to accommodate more mobiles[1] in a given geographical area causes even more frequent hand-offs. A hand-off could fail due to insufficient bandwidth available in the new cell, and in such a case, a *connection hand-off drop* occurs. For example, we often experience abrupt disconnection of cellular phone calls while driving through a populated downtown area.

To eliminate such undesirable hand-off drops, it is necessary for the network to reserve a certain amount of bandwidth in each cell for hand-offs. Two important parameters are the probability P_{CB} of blocking newly-requested connections and the probability P_{HD} of dropping hand-offs due to the unavailability of enough bandwidth in the new cell. Basically, the more bandwidth reserved, the smaller P_{HD}, and the larger P_{CB}. We consider how to keep the hand-off dropping probability of connections under a pre-specified target value $P_{HD,target}$ (which is referred to as the *design goal*.) Since it is practically impossible to completely eliminate hand-off drops, the best one can do is to provide some form of *probabilistic* Quality-of-Service (QoS) guarantees.

Recently, we proposed a scheme for bandwidth reservation and admission control in cellular networks [1]. This scheme was shown to meet the design goal under different environments including various offered loads, heterogeneous traffic types, and different mobile speeds. In [1, 2], the scheme was shown to be superior to the other schemes in [3–6]. The basic principle of this bandwidth reservation is to reserve, in the current cell, fractional bandwidths of all the connections in adjacent cells, which are estimated to hand off into the current cell. The network needs to know where each mobile is moving to.

The original scheme in [1] used mobility estimation based on the hand-off events observed in each cell. In this paper, we consider a variation of the original scheme so as to utilize *path* (or next-cell) information which is readily available from an ITS navigation system [7]. As will be shown later, this navigation system-aided scheme will meet the design goal while admitting more new connections into the system even with much less computational complexity than the original scheme.

The paper is organized as follows. Section 2 states the system specifications and assumptions. Section 3 describes bandwidth-reservation and admission-control schemes with and without path information. Section 4 quantitatively compares these schemes through simulations. Finally, the paper concludes with Section 5.

2 System Specifications

We consider a wireless/mobile network with a cellular infrastructure, comprising a wired backbone and a (possibly large) number of base stations (BSs). The ge-

*The work reported in this paper was supported in part by the US Department of Transportation under Grant No. DTFH61-93-X-00017. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the funding agency.

[1] We use the term "mobiles" to refer to mobile or portable devices.

0-7803-4975-X/98/$10.00

ographical area covered by a BS is called a *cell.* A mobile, while staying in a cell, communicates with another party, which may be a node connected to the wired network or another mobile, through the BS in the same cell. When a mobile moves into an adjacent cell in the middle of a communication session, a hand-off will enable the mobile to maintain connectivity to its communication partner, i.e., the mobile will start to communicate through the new BS, hopefully without noticing any difference. Insufficient bandwidth in the new cell results in a connection hand-off drop. Since hand-off drops are not desirable, we consider how to limit these, and how the path information can be exploited for this purpose.

The path information can be made available to the network (or BSs) when a mobile user is driving a car equipped with a combined cellular communication and ITS navigation system, and the navigation system communicates with the current cell's BS to inform the next cell the user is supposed to move to. Specifically, the locations of the adjacent cells are informed to the navigation system first, which will then determine the next cell according to the guided route of the car. This next cell will be finally informed to the current cell's BS. The driver may sometimes not follow the direction by the navigation system. However, we don't consider these accidental cases, and assume that the mobile follows the route which is known to the BS in order to support/refute the advantage of path information.

We assume that BSs can communicate through wired links, and the admission control considered in this paper is performed by each BS, which receives a new connection request from a mobile in its cell. All cells around a cell A are indexed:[2] A is labeled with 0, and the others with numbers beginning 1. Let $C_{i,j}$ be the j-th connection in cell i and $b(C_{i,j})$ be its required bandwidth. For simplicity, we assume that a mobile doesn't have multiple simultaneous connections, so that by an *active mobile*, we mean a mobile with one existing connection. The cellular system uses a fixed channel allocation (FCA) scheme, and a wireless link capacity is C. The unit of bandwidth is BU, which is the required bandwidth to support one *voice* connection.

3 Bandwidth Reservation and Admission Control

This section describes how to reserve bandwidth for hand-offs and how to control the admission of new connections.

3.1 Mobility Estimation

We briefly describe the mobility-estimation scheme in [1] that is based on a history of hand-offs observed in each cell. Originally, this mobility estimation was developed to probabilistically predict the next-cell and hand-off time of mobiles. When the path information is available, the mobility estimation is used only to predict the hand-off time since the next cell of a mobile is already known.

This scheme is motivated by road traffic: the mobility in terms of a mobile's speed and direction in a cell is probabilistically similar to that of those mobiles that came from the same previous cell and are now residing in the same cell. The rationale behind this scheme is the existence of the traffic signals and/or signs (e.g., speed limits) and the possible correlation between mobiles' previous and future paths. It might not produce very accurate mobility estimation due to its dependency on the observation, but is feasible in practice, and was found to work well with the original scheme [1].

Mobility is estimated and predicted by the BS of each cell in a distributed manner. Let's consider cell 0 without loss of generality. For each mobile which moves into an adjacent cell from cell 0, the BS caches a 4-tuple $(T_{ho}, prev, next, T_{soj})$, where T_{ho} is the time the mobile departed from cell 0, $prev$ is the index of the previous cell the mobile had resided in before entering cell 0, $next$ is the index of the cell the mobile entered after departing from cell 0, and T_{soj} is the sojourn time of the mobile in cell 0, i.e., the time span between the entry into and departure from cell 0. Note that $prev = 0$ means that the departed mobile started its connection in cell 0.

In order to reduce the memory and computation complexity (as will be clear later), the number of cached 4-tuples is limited by a design parameter N_{quad} for each $prev$, i.e., the most recently observed N_{quad} 4-tuples are stored and used for the mobility estimation of mobiles for each $prev$. The effect of changing N_{quad} was examined in [2]. Figure 1 (a) shows an example of a collection of cached 4-tuples (represented by dots) which are located according to $(T_{soj}, next)$ for $prev = 1$. The number of dots in the distribution is bounded by N_{quad}. Note that this distribution for a given $prev$ can generate a probability mass function for a two-dimensional random vector $(next, T_{soj})$, where $next$ is the predicted next cell and T_{soj} is the estimated sojourn time in cell 0. $(T^i_{ho}, prev, next^i, T^i_{soj})$ represents the i-th 4-tuple for a given $prev$.

3.2 Target Reservation Bandwidth

Our bandwidth reservation is based on the estimated incoming hand-offs during the time window $[t_o, t_o+T_{est}]$, where t_o is the current time. Let's consider the behavior of a mobile in cell 0. The mobility of connection $C_{0,j}$ is estimated with $p_h(C_{0,j} \to i)$, the probability that $C_{0,j}$ hands off into cell i within T_{est}. This probability can be computed using the cached 4-tuples as follows. The BS of each cell keeps track of each active mobile in its cell via the mobile's *extant sojourn time*. The extant sojourn time $T_{e\_soj}(C_{0,j})$ of connection $C_{0,j}$ is the time elapsed since connection $C_{0,j}$ handed off to cell 0. Without path

[2] This is the cell A's (or its base station's) view.

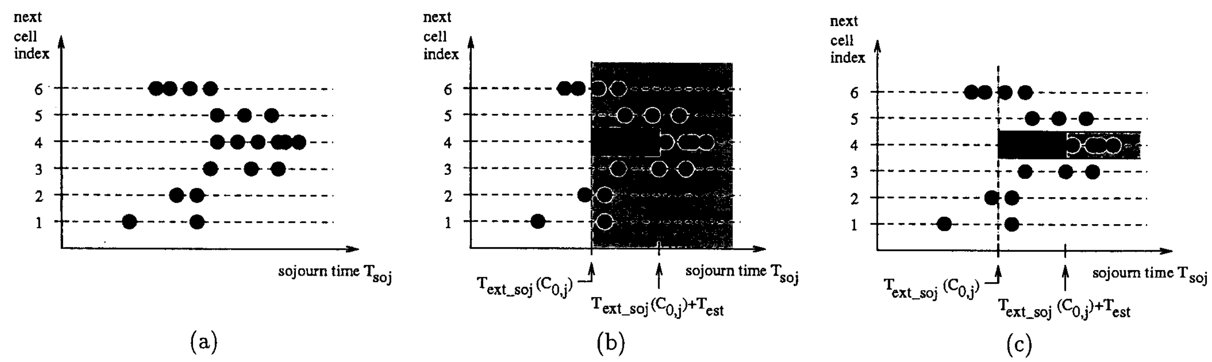


Figure 1. (a) An example of the distribution of cached 4-tuples for *prev* = 1; and an example of calculating $p_h(C_{0,j} \to 4)$ using the cached 4-tuples (b) without and (c) with path information.

information, using the Bayes' theorem, $p_h(C_{0,j} \to next)$, where $C_{0,j}$ stayed in cell *prev* before entering cell 0, is calculated by

$$p_h(C_{0,j} \to next) := \begin{cases} \frac{\sum_{k=1}^{N_{quad}} I_k(\{next\},T_{est})}{\sum_{k=1}^{N_{quad}} I_k(\mathbf{A}_0,\infty)}, & \text{if } \sum_{k=1}^{N_{quad}} I_k(\mathbf{A}_0,\infty) \neq 0, \\ 0, & \text{otherwise,} \end{cases} \tag{1}$$

where $\mathbf{A}_i$ is the set of indices of cell i's adjacent cells, and the index $I_k(\mathbf{S},t)$ of the k-th 4-tuple $(T_{ho}^k, prev, next^k, T_{soj}^k)$ with the previous cell index *prev* is defined by

$$I_k(\mathbf{S},t) := \begin{cases} 1, & \text{if } next^k \in \mathbf{S} \text{ and} \\ & T_{e\_soj}(C_{0,j}) < T_{soj}^k \leq T_{e\_soj}(C_{0,j}) + t, \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

With the path information of a mobile, the BS knows of the mobile's next cell, and hence, the mobility estimation is used to estimate the hand-off time of the mobile only. Suppose the mobile with connection $C_{0,j}$ will leave for cell $next'$, then $p_h(C_{0,j} \to next)$ at time t_o is calculated by

$$p_h(C_{0,j} \to next) := \begin{cases} \frac{\sum_{i=k}^{N_{quad}} I_k(\{next\},T_{est})}{\sum_{i=k}^{N_{quad}} I_k(\{next'\},\infty)}, & \text{if } next = next' \text{ and} \\ & \sum_{i=k}^{N_{quad}} I_k(\{next'\},\infty) \neq 0, \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

Eqs. (1) and (3) represent the expected probability that $C_{0,j}$ hands off into cell *next* with the sojourn time which is less than, or equal to, $T_{e\_soj}(C_{0,j}) + T_{est}$ given the condition that $t_{soj} > T_{e\_soj}(C_{0,j})$. Figure 1 (b) and (c) show an example of calculating $p_h(C_{0,j} \to 4)$ (b) without and (c) with path information, respectively, when $C_{0,j}$ entered cell 0 from cell 1 and will leave for cell 4, using the distribution of the cached 4-tuples in Figure 1 (a). In both figures, all points in both dark and light shaded regions are summed to obtain the denominators in Eqs. (1) and (3) while two points in the dark-shaded region are summed to obtain the numerators. We can then complete the calculation of $p_h(C_{0,j} \to 4)$.

Now, using the hand-off probabilities of all the connections in the adjacent cells, the *target reservation bandwidth* $B_{r,0}$ in cell 0, which is the aggregate bandwidth to be reserved in cell 0 for the expected hand-offs from adjacent cells within T_{est}, is calculated as

$$B_{r,0} = \sum_{i \in \mathbf{A}_0} \sum_{j \in \mathbf{C}_i} b(C_{i,j}) p_h(C_{i,j} \to 0), \tag{4}$$

where $\mathbf{A}_i$ is the set of indices of cell i's neighbors, $\mathbf{C}_i$ is the set of indices of the connections in cell i and $b(C_{i,j})$ is connection $C_{i,j}$'s bandwidth. The hand-off probability $p_h(C_{i,j} \to 0)$ is calculated using Eq. (1) or (3) depending on the availability of the path information of connection $C_{i,j}$. Note that $B_{r,0}$ is a target, not the actual reserved bandwidth, since cell 0 may not be able to reserve the target bandwidth, i.e., $\sum_{j \in \mathbf{C}_0} b(C_{0,j}) + B_{r,0} > C$.

3.3 Mobility Estimation Time Control

Note that $B_{r,0}$ is a non-decreasing function of T_{est} as $p_h(C_{i,j} \to 0)$ is a non-decreasing function of T_{est}. There might be an optimal value of T_{est} for given traffic/mobility status in the sense of giving the smallest P_{CB} while keeping P_{HD} below the target. However, traffic/mobility status is time-varying, and the history-based mobility estimation itself might not be accurate. In our schemes, the estimation time is adjusted adaptively in each cell independently of others, depending on the hand-off dropping events so as to approximate the optimal T_{est} over time [1]. Figure 2 shows the algorithm executed by the BS in each cell to adjust the value of T_{est}. The basic idea of the algorithm is that there should not be more than $1, 2, 3, \ldots$ hand-off drops out of $w, 2w, 3w, \ldots$ observed hand-offs, where the reference window size $w = \lceil 1/P_{HD,target} \rceil$. Whenever this condition is violated, T_{est} is increased by 1 (sec).

```
if (w = ⌈1/P_{HD,target}⌉), then w_obs := w;
T_est := T_start;  n_H := 0;  n_HD := 0;
while (time increases) {
    if (hand-off into the current cell happens) then
        n_H := n_H + 1;
    if (it is dropped) then {
        n_HD := n_HD + 1;
        if (n_HD > w_obs/w) then {
            w_obs := w_obs + w;
            if (T_est < T_soj,max) then T_est := T_est + 1;
        }
    }
    else if (n_H ≥ w_obs) then {
        if (n_HD ≤ w_obs/w and T_est > 1) then
            T_est := T_est − 1;
        w_obs := w;  n_H := 0;  n_HD := 0;
    }
}
```

Figure 2. A pseudocode of the algorithm to adjust T_{est}.

3.4 Admission-Control Schemes

We now establish admission-control schemes by utilizing the target reservation bandwidth. The basic idea of the admission decision is to check if there is enough bandwidth left unused after reserving the target reservation bandwidth. However, for the admission control of a newly-requested connection in a cell, sometimes it is required to check the reservation bandwidth in some adjacent cells as well (in the next cell if the path information is available). Otherwise, continual connection admissions in a cell may result in continual hand-off drops in adjacent cells, thus violating the design goal.

Note that $B_{r,i}$ is a time-varying function, and updated upon admission test. Upon arrival of a new connection request at cell 0, if the current target reservation bandwidth of the next cell *next*, $B^{curr}_{r,next}$, which was calculated for a previous admission test, is not reserved fully, this cell will re-calculate $B_{r,next}$, and participate in the admission test. The admission test will differ depending on the availability of the new connection-requesting mobile's path information. First, without the path information, the BS needs to check all the adjacent cells for admission tests. Then, the admission test is given by

T1. For all $i \in \mathbf{A}_0$ such that $\sum_{j\in\mathbf{C}_i} b(C_{i,j}) + B^{curr}_{r,i} > C$, check if $\sum_{j\in\mathbf{C}_i} b(C_{i,j}) \le C - B_{r,i}$,

T2. Check if $\sum_{j\in\mathbf{C}_0} b(C_{0,j}) + b_{new} \le C - B_{r,0}$,

T3. If all the above tests are positive then the connection is admitted,

where b_{new} is the bandwidth of the new connection, and $\mathbf{A}_i$ is the set of indices of cell i's neighbors. Second, the admission test with the path information is given by

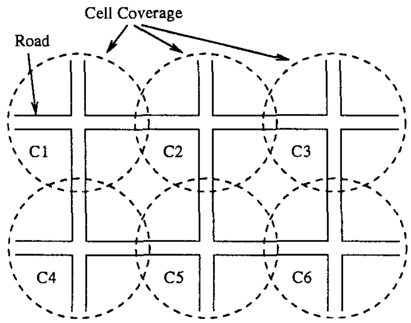


Figure 3. A cellular structure.

T1. If $next \ne 0$ and $\sum_{j\in\mathbf{C}_{next}} b(C_{next,j}) + B^{curr}_{r,next} > C$, then check if $\sum_{j\in\mathbf{C}_{next}} b(C_{next,j}) \le C - B_{r,next}$,

T2. Check if $\sum_{j\in\mathbf{C}_i} b(C_{i,j}) + b_{new} \le C - B_{r,0}$,

T3. If the above two tests are positive then the connection is admitted.

4 Comparative Performance Evaluation

This section presents and discusses the evaluation results of the schemes described thus far.

4.1 Assumptions

For our simulation environment, we consider two dimensionally-arranged cells, in which the roads are arranged in a mesh shape, and a BS is located at each intersection of two crossing roads as shown in Figure 3. This cellular structure can typically be seen in a metropolitan downtown area. We make the following assumptions for our simulations:

A1. The whole cellular system is composed of 25 two dimensionally-arranged cells (i.e., a 5 × 5 mesh), for which the diameter of each cell is 300 m.

A2. Connections are generated according to a Poisson process with rate λ (connections/sec/cell) in each cell. A new connection can appear anywhere on the roads with an equal probability.

A3. A connection is either for voice (requiring 1 BU of bandwidth) or for video (requiring 4 BUs) with probabilities R_{vo} and $1 - R_{vo}$, respectively, where the *voice ratio* $R_{vo} \le 1$.

A4. Each connection's lifetime is exponentially distributed with mean 120 (sec).

A5. The link capacity C is 50 BUs.

There are further assumptions regarding the user mobility pattern:

M1. Mobiles can travel in either of two directions along a road with an equal probability at a speed chosen randomly from [40, 60] (km/hour).

M2. At the intersection of two roads, a mobile might continue to go straight, or turn left, right, or around with probabilities 0.55, 0.2, 0.2, and 0.05, respectively.

M3. If a mobile chooses to go straight or turn right at the center of a cell, it might need to stop there with probability 0.5 for a random time between 0 and 30 (sec) due to a red traffic light. The probability 0.5 roughly represents the fact that one of two crossing roads will see the green light at a time, and the time 30 (sec) represents the duration of a traffic signal light.

M4. If a mobile chooses to turn left or around, it needs to stop there for a random time between 0 and 60 (sec) due to the traffic signal.

The rationale behind the assumed mobile's delay at the intersection is that there are four traffic signals at the intersection for mobiles arriving from the four directions, respectively. A traffic signal will have the red (for stop), left-turn, green (for going straight and turning right) lights in order, then returning to the red light. The whole period from red light to the next red is $60 + \epsilon$ seconds in which the red light will last for 30 seconds, then the left-turn light will turn on for a very short time ϵ, then, finally, the green light will last for 30 seconds.

Two end roads in the border cells at the boundary of the cellular structure are connected. For example, in Figure 3, the left-most (upper-most) road in cell $C1$ is connected to the right-most (lower-most) road in cell $C3$ ($C4$). This is because the border cells will face more mobiles than cells near the center otherwise, and this uneven traffic load can affect the performance evaluation of our proposed schemes, hence making it difficult to assess their operations correctly. With the same reasoning, a cellular architecture forming a ring shape was considered in [1,4].

The parameters used include: $P_{HD,target} = 0.01$, $T_{start} = 1$ (sec), and $N_{quad} = 10$. A frequently-used measure is the *offered load* per cell, L, which is defined by

$$L = (1 \cdot R_{vo} + 4 \cdot (R_{vo} - 1)) \cdot \lambda \cdot 120, \qquad (5)$$

under the above-described assumptions. The physical meaning of the offered load per cell is the total bandwidth required on average to support all existing connections in a cell.

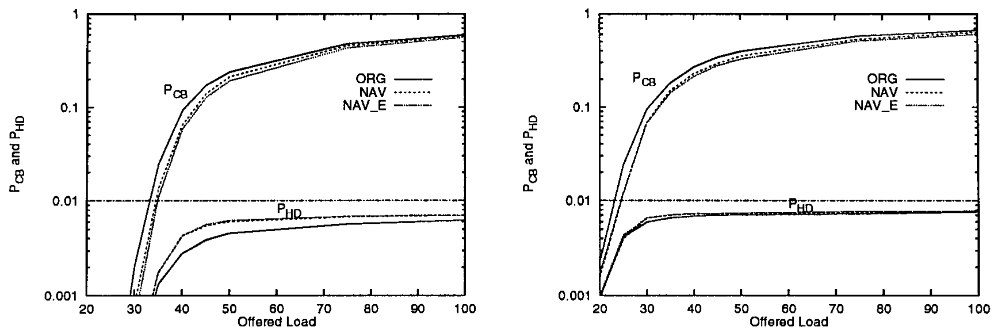
4.2 Results and Discussion

In the real world, only a subset of mobiles will be equipped with navigation systems. However, we compare three extreme cases to evaluate the advantages of path information: (1) path information is not available for any mobile (referred to as **ORG**); (2) path information is available for every mobile (referred to as **NAV**); and (3) path plus *end-cell* information is available for every mobile (referred to as **NAV_E**). The next cell of a mobile determined by the navigation system can be wrong when the mobile user ends the connection before entering the guided next cell. By end-cell information, we imply that whether a connection will end in the current cell or not is also known to the BS. By knowing this, some redundant bandwidth reservation can be saved when a connection ends in the current cell. This information can be available only when each connection ends at the final destination of the mobile with the connection, which is not always true. The end-cell information can be considered as a special case of path information. Figure 4 shows P_{CB} and P_{HD} of three cases as the offered load increases. First of all, P_{HD} is bounded for all three cases, thus achieving the design goal. As expected, **NAV** outperforms **ORG** in terms of P_{CB} while **NAV_E** is slightly better than **NAV**, i.e., more new connections can be admitted into the network for in the order of **NAV_E**, **NAV**, and **ORG**. Even though the differences are not significant, we can determine that path and end-cell information are quite advantageous.

Now, we consider the computation complexity of the admission control schemes by comparing the numbers of numerical operations (including summations and multiplications) and comparisons for an admission decision. Comparisons include decisions such as if t_{soj} is larger than a value in summations of Eqs. (1) and (3). We did not include the complexity and cost for the interface between the navigation systems and the network. Figure 5 shows the average numbers of numerical operations and comparisons for an admission decision for three cases. We observe the complexity gap between **ORG** and the others is significant. The scheme without path information appears to be too complicated to be useful. Note, however, that the operations and comparisons are distributed over a number of cells since five cells participate in the B_r calculation in a cell and more than one B_r are calculated for an admission decision. This complexity number will also drop if a smaller N_{quad} is used. Interestingly, the complexity for $R_{vo} = 0.5$ is much smaller than that for $R_{vo} = 1.0$. This is because the admission decision complexity depends on the number of existing connections in the current and adjacent cells, but for $R_{vo} = 0.5$, there are fewer existing connections in the system on average for a given offered load.

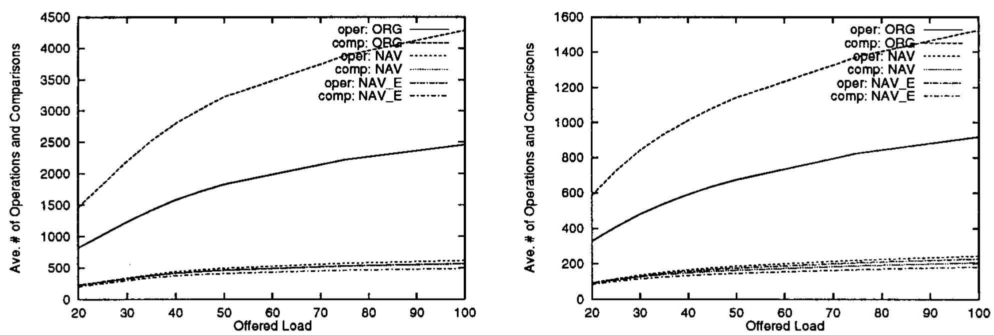
5 Concluding Remarks

In this paper, we extended a recently-proposed scheme for bandwidth reservation and admission control to utilize path information by the ITS navigation system. Path and end-cell information is found to be useful in the sense of (1) admitting more new connections by reserving bandwidth for hand-offs more efficiently, and (2) requiring much less computational complexity for admission decisions. In practice, the path and end-cell informa-



(a) $R_{vo} = 1.0$ (b) $R_{vo} = 0.5$

Figure 4. Comparison of three cases: P_{CB} and P_{HD} vs. offered load.



(a) $R_{vo} = 1.0$ (b) $R_{vo} = 0.5$

Figure 5. Comparison of three cases: average number of numerical operations and comparisons vs. offered load.

tion considered in this paper will be available to certain mobiles only since not every mobile is expected to be equipped with a navigation system. Especially, the end-cell information will be available for some special cases only as discussed earlier. Depending on the fraction of mobiles with path and end-cell information, system performance lies between **ORG** and the other two cases.

References

[1] S. Choi and K. G. Shin, "Predictive and adaptive bandwidth reservation for hand-offs in QoS-sensitive cellular networks," in *Proc. ACM SIGCOMM'98*, pp. 155–166, September 1998.

[2] S. Choi and K. G. Shin, "Comparison of connection-admission control schemes in the presence of hand-offs in cellular networks," in *Proc. ACM/IEEE MobiCom'98*, pp. 264–275, October 1998.

[3] D. Hong and S. S. Rappaport, "Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and nonprioritized procedures," *IEEE Trans. on Vehicular Technology*, vol. 35, pp. 77–92, August 1986.

[4] M. Naghshineh and M. Schwartz, "Distributed call admission control in mobile/wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 14, no. 4, pp. 711–717, May 1996.

[5] A. K. Talukdar, B. R. Badrinath, and A. Acharya, "On accommodating mobile hosts in an integrated services packet network," in *Proc. IEEE INFOCOM'97*, pp. 1048–1055, April 1997.

[6] S. Lu and V. Bharghavan, "Adaptive resource management algorithms for indoor mobile computing environments," in *Proc. ACM SIGCOMM'96*, pp. 231–242, August 1996.

[7] Y. Zhao, *Vehicle Location and Navigation Systems*, Artech House, 1997.