Exploiting Path/Location Information for Connection Admission Control in Cellular Networks

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Abstract — **This paper demonstrates how to utilize (1) path information, e.g., available from navigation systems of Intelligent Transportation Systems (ITS), or (2) location information, e.g., available from the Global Positioning System (GPS), for admission control in cellular networks. From the path (location) information of a mobile, its next cell can be determined (estimated accurately sometimes). By utilizing the next-cell information, we modify a 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. While both the original and modified schemes meet the design goal, the modified scheme utilizing next-cell information is shown to outperform the original scheme even with much less computational requirement.**

Index Terms — **cellular networks, bandwidth reservation for hand-offs, path/location information, QoS guarantees.**

I. 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 have proposed a scheme for bandwidth reservation and admission control in cellular networks [1]. This scheme is shown to meet the design goal under different environments including various offered loads, heterogeneous traffic types, and different mobile speeds. We also compared the scheme with other schemes including those in [3–6] while showing its superiority to the others [1,2]. 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. To this end, 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 mobiles' *next-cell* information. The next cell of a mobile can be either derived when the path of the mobile is known, e.g., from an ITS navigation system [7], or predicted with high accuracy when the location of the mobile is known, e.g., from the GPS. How to predict the next cell of a mobile from its location will be presented in Section III via the simulation environment. As will be shown later, this path/location information-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 II describes bandwidth-reservation and admission-control schemes with and without next-cell information. Section III quantitatively compares these schemes through simulations. Finally, the paper concludes with Section IV.

II. Bandwidth Reservation and Admission Control

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

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

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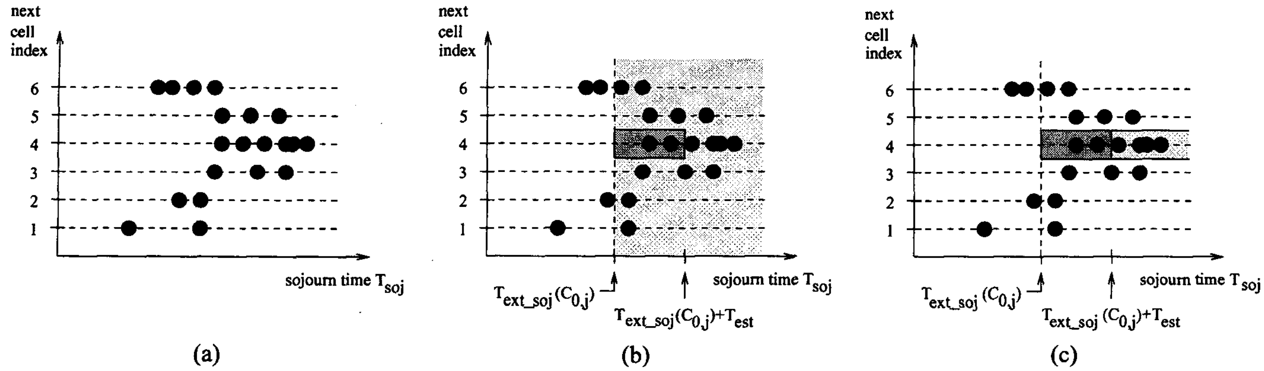

Fig. 1. (a) An example of the distribution of cached 4-tuples for $prev = 1$; and an example of calculating $p_h(C_{0,j} \to 4)$ using the cached 4-tuples (b) without and (c) with next-cell information.

our schemes, all cells around a cell A are indexed:[2] A is labeled with 0, and the others with numbers beginning 1.

A. 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 next-cell information is available, the mobility estimation can be used only to predict the hand-off time. 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.

Mobility is estimated 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. $prev = 0$ 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 most recently observed N_{quad} 4-tuples are stored and used for the mobility estimation of mobiles for each *prev*, where N_{quad} is a design parameter. 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}. $(T^i_{ho}, prev, next^i, T^i_{soj})$ represents the i-th 4-tuple for a given *prev*.

B. Target Reservation Bandwidth

Let $C_{i,j}$ be the j-th connection in cell i and $b(C_{i,j})$ be its required 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 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.

B.1 Without next-cell information

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

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

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 $(T^k_{ho}, prev, next^k, T^k_{soj})$ with the previous cell index *prev* is defined by

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

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

B.2 With next-cell information

With the next-cell information of a mobile, the BS knows of the mobile's next cell, and hence, the mobility estimation can be 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

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

Figure 1 (b) and (c) show an example of calculating $p_h(C_{0,j} \to 4)$ (b) without and (c) with next-cell 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

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

where $\mathbf{C}_i$ is the set of indices of the connections in cell i. The hand-off probability $p_h(C_{i,j} \to 0)$ is calculated using Eq. (1) or (3) depending on the availability of the next-cell 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., $\sum_{j \in \mathbf{C}_0} b(C_{0,j}) + B_{r,0} > C$.

C. 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 I 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).

TABLE I

A PSEUDOCODE OF THE ALGORITHM TO ADJUST T_{est}.

```
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;
   }
}
```

D. 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 next-cell 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 $next$, $B_{r,next}^{curr}$, 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 next-cell information.

D.1 Without next-cell 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 $\sum_{j \in \mathbf{C}_i} b(C_{i,j}) + B_{r,i}^{curr} > C$, check if $\sum_{j \in \mathbf{C}_i} b(C_{i,j}) \leq C - B_{r,i}$,

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

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

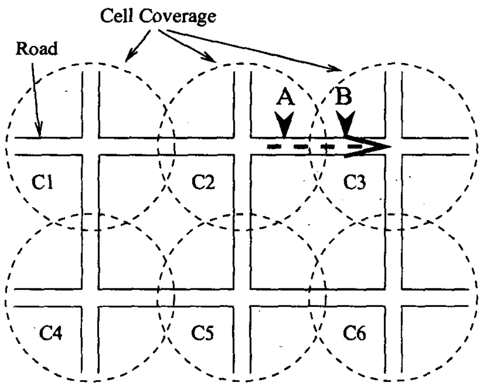

Fig. 2. A cellular structure.

where b_{new} is the bandwidth of the new connection.

D.2 With next-cell information

With the next-cell information of the new connection-requesting mobile, the admission test can be simplified to

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

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

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

III. Comparative Performance Evaluation

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

A. Assumptions

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 2. This cellular structure can typically be seen in a metropolitan downtown area. We make the following assumptions for our simulations:

A1. The cellular system is composed of 25 cells (i.e., a 5 $\times$ 5 mesh), and each cell's diameter is 300 m.

A2. New connections are generated according to a Poisson process with rate λ (connections/sec/cell) in each cell, and can appear anywhere on the roads.

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

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.

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 2, 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, *offered load L* per cell, is defined by

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

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

B. Next-Cell Prediction

We first consider how to predict the next cell from the location information of a mobile using an example. In Figure 2, a mobile was in cell $C2$, and eventually moves into cell $C3$. When the mobile is at location A, the next cell can be predicted with probability 1 assuming that the direction of the mobile is also known. Note that GPS gives both location and direction information. However, the next cell cannot be predicted when the mobile is at location B even if its direction is known since the mobile can change its direction at the intersection. When the direction is not available somehow, the next cell can be predicted only for some cases even at location A depending on the previous cell of the mobile, i.e., only when the mobile's previous cell is neither $C3$ nor $C2$, it can be predicted. Note that this next-cell prediction will depend on the cellular environment such as the road topology and traffic signals/signs in each cell.

C. Results and Discussion

In the real world, the path/location information will be available to only a subset of mobiles. However, we compare three extreme cases to evaluate the advantages of the information: (1) next-cell information is not available for any mobile (referred to as **ORG**); (2) location/direction information is available for every mobile (referred to as **LOC**); and (3) path information is available for every mobile (referred to as **PATH**). Figure 3 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, the performance in terms of P_{CB} is shown in the order of **PATH**, **LOC**, and **ORG**, i.e., more new connections can be admitted in that order. Even though the differences are not significant, we can determine that location/path information is 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 4 shows the average numbers of numerical operations and comparisons for an admission decision for three cases. We observe the complexity gap between **ORG/LOC** and **PATH** is significant while **LOC** is about 20% (30%) better than **ORG** in terms of the number of operations (comparisons.)

The scheme without next-cell 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.

IV. Concluding Remarks

In this paper, we explored how to utilize path/location information readily available from ITS navigation systems or GPS for bandwidth reservation and admission control. Path/location 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 less computational complexity for admission decisions. In practice, path/location information considered in this paper will be available to certain mobiles only since not every mobile is expected to be equipped with a navigation system or GPS. Depending on the fraction of mobiles with path/location information, system performance lies between **ORG** and the other two cases.

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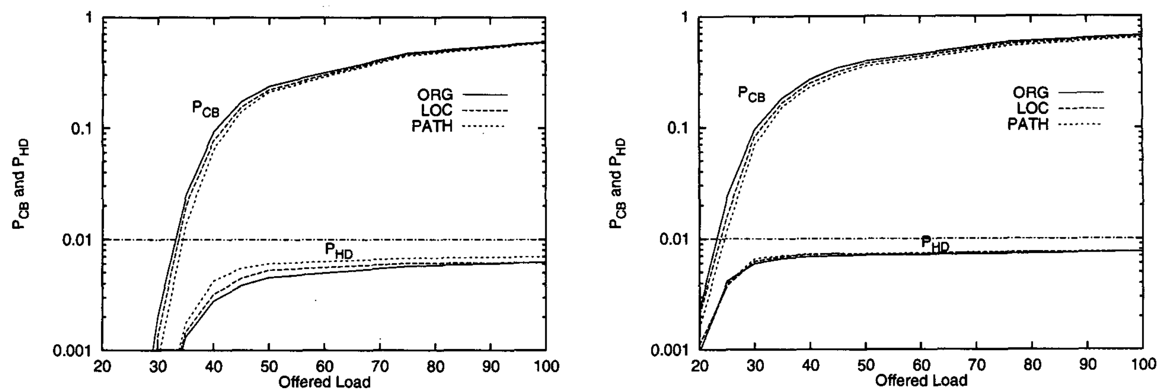
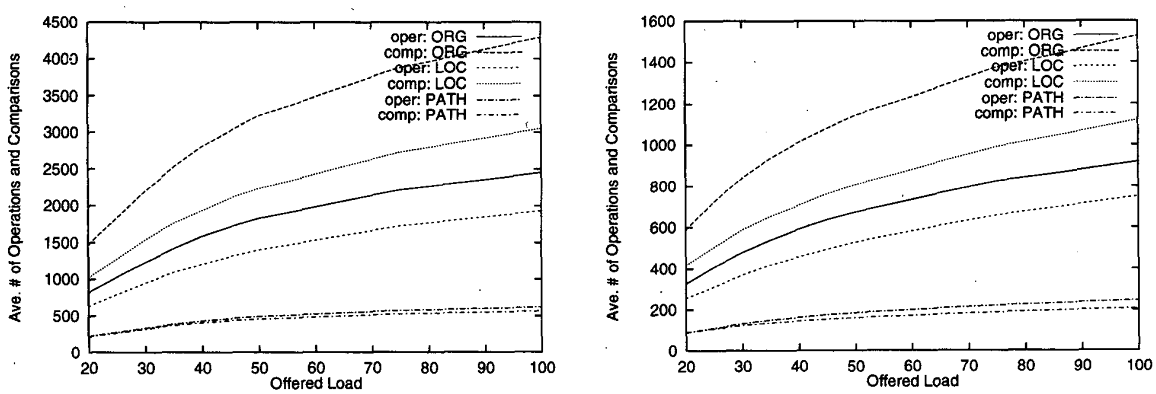


(a) $R_{vo} = 1.0$ (b) $R_{vo} = 0.5$

Fig. 3. Comparison of three cases: P_{CB} and P_{HD} vs. offered load.



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

Fig. 4. Comparison of three cases: average number of numerical operations and comparisons vs. offered load.