Predictive and Adaptive Bandwidth Reservation for Hand-Offs in QoS-Sensitive Cellular Networks

SUNGHYUN CHOI AND KANG G. SHIN

Real-Time Computing Laboratory
Department of Electrical Engineering and Computer Science
University of Michigan
Ann Arbor, MI 48109-2122, USA
E-mail: {shchoi,kgshin}@eecs.umich.edu
URL: http://www.eecs.umich.edu/~{shchoi,kgshin}

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Talk Outline

- Introduction and Motivation
- Related Work
- System Model
- History-Based Mobility Estimation
- Bandwidth Reservation and Admission Control
- Performance Evaluation
- Conclusion and Future Work

Introduction

- Connection-level QoS: connection setup and management-related
- Hand-off drops: when the cell in the new location does not have enough bandwidth to support the connection
- To eliminate hand-off drops
  $\longrightarrow$ reservation of bandwidth for possible hand-offs
- How much bandwidth will be reserved in each cell ?
- Per-connection bandwidth reservation to have no hand-off drops ??
  By reserving each connection's bandwidth in all cells the connection might pass through
  $\longrightarrow$ Not practical, and too costly if possible

Our Approach

- Connection-level QoS parameters:
  - P_{CB}: new connection blocking probability
  - P_{HD}: hand-off dropping probability
- Design goal: bounding P_{HD} under a pre-specified target value $P_{HD,target}$ (i.e., *probabilistic* QoS guarantees)
- Predictive and adaptive bandwidth reservation for hand-offs and admission control for new requests
- Fractional bandwidths of estimated hand-offs are reserved

Related Work

- Static reservation: a portion of link bandwidth reserved permanently
- Per-connection reservation: too costly if possible
- Fractional bandwidth reservation: based on unrealistic assumptions (e.g., exponentially-distributed sojourn times in each cell and known hand-off rates)

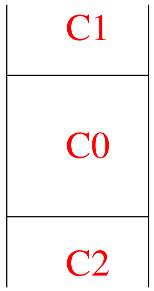
⇒ Extensive comparison of our work with three other schemes in *MobiCom'98*

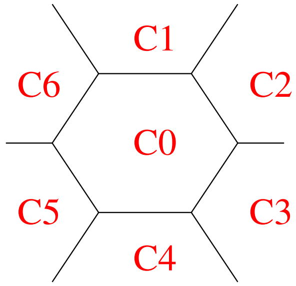
- History-based mobility estimation to estimate the next cell

⇒ Our scheme predicts both next cell and hand-off time probabilistically

System Model

- Cell indexing: (a) 1-dim. case (b) 2-dim. case





- $C_{i,j}$: connection j in cell i; $b(C_{i,j})$: its bandwidth
- $C(i)$: link capacity of cell i
- Admission control of new connection by the BS in cell i with *target reservation bandwidth* $B_{r,i}$:

$$\sum_{j \in \mathbf{C_i}} b(C_{i,j}) + b_{new} \leq C(i) - B_{r,i}$$

Mobility Estimation

- Mobility information: when and where (i.e., to which cell)
- Observations from road traffic:

O1. Traffic signals and signs (e.g., speed limits and stop signs) affect mobiles' movements and speeds significantly

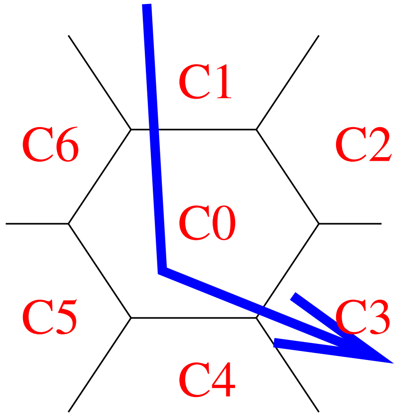
O2. During the rush hours, the speeds of all mobiles in a given geographical area are closely correlated

O3. In many cases, the direction of a mobile can be predicted from the previous path the mobile has taken so far

$\Rightarrow$ Cell-specific history-based mobility estimation

Hand-off Event Quadruplets

- Upon the departure of a mobile from cell 0 to an adjacent cell, the BS of cell 0 caches hand-off event quadruplet $(T_{event}, prev, next, T_{soj})$



- $prev = 1 \quad \rightarrow \quad \text{cell } 0 \quad \rightarrow \quad next = 3$

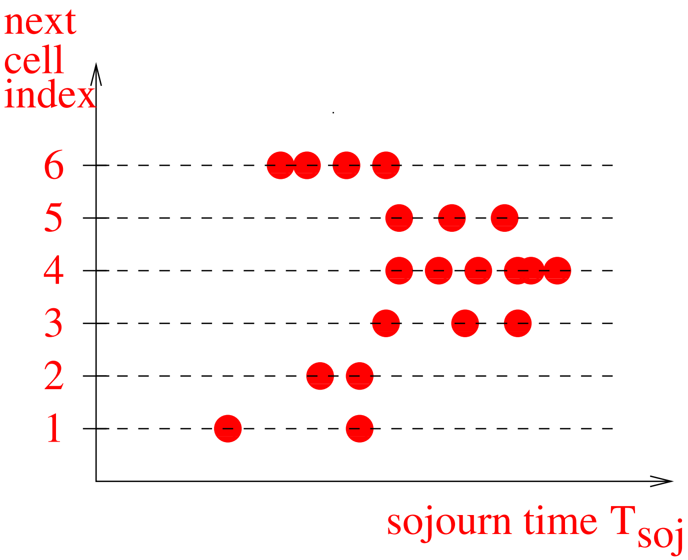
  $t = 10 \qquad t = 30$

- T_{soj}: time duration the mobile spent at cell 0, i.e., $T_{soj} = 20$

- T_{event}: the hand-off time, i.e., $T_{event} = 30$

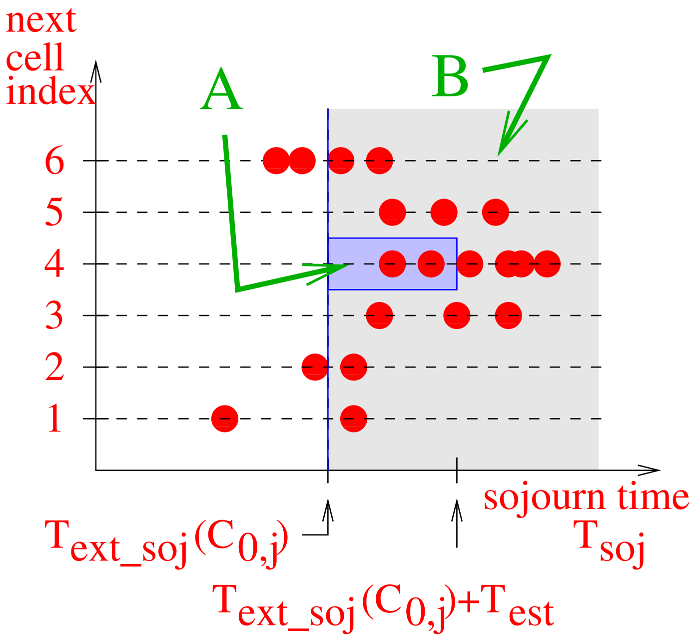
Mobility Estimation Function

- Describes the users' hand-off behaviors probabilistically
- From the cached hand-off event quadruplets $(T_{event}, prev, next, T_{soj})$ observed during the last T_{int} time (and previous days)
- Hand-off estimation function $F_{HOE}(t_o, prev, next, T_{soj}) := w_n$
- Cyclic mobility pattern $\rightarrow w_0\ (=1)$ (today), $w_1\ (<1)$ (yesterday)



Bandwidth Reservation

- Mobility estimation time window: $[t_0, t_0 + T_{est}]$
- Hand-off probability $p_h(C_{i,j} \rightarrow next)$: probability that $C_{i,j}$ hands off into cell *next* within time T_{est}
- Extant sojourn time $T_{ext\_soj}(C_{0,j})$: time elapsed since $C_{0,j}$ entered cell 0
- Example: $p_h(C_{0,j} \rightarrow 4) = A/B$



- Target reservation bandwidth at cell 0:

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

Mobility Estimation Time Window Control

⇒ The larger T_{est}, the larger p_h, the larger $B_{r,i}$

⇒ To attain our design goal more efficiently

- Reference window size w $(= \lceil 1/P_{HD,target} \rceil)$
  $(100 \text{ if } P_{HD,target} = 0.01)$
- Should be no more than n hand-off drops out of $w \cdot n$ $(= 100 \cdot n)$ observed hand-offs
- If it is violated, $T_{est} := T_{est} + 1$ to reserve more
- Otherwise, $T_{est} := T_{est} - 1$ to reserve less

⇒ Robust to (1) inaccurate mobility estimation; and (2) time-varying traffic/mobility

Admission Control

- Target reservation bandwidth is calculated during the admission control phase of a new request
- The current cell and some adjacent cells participate in the admission control
- With current target reservation bandwidth $B_{r,i}^{curr}$

T1. For all $i \in \mathbf{A}_0$ such that $\sum_{j \in \mathbf{C}_i} b(C_{i,j}) + B_{r,i}^{curr} > C(i)$,
calculate $B_{r,i}$ newly, set $B_{r,i}^{curr} := B_{r,i}$, and
check if $\sum_{j \in \mathbf{C}_i} b(C_{i,j}) \leq C(i) - B_{r,i}$;

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

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

Performance Evaluation

A1. 10 linearly-arranged cells (the diameter of each cell 1 km)

A2. Connection requests generated from a Poisson process with rate λ (connections/second/cell) in each cell, anywhere in the cell

A3. Voice (1 BU) or video (4 BUs) connections with probabilities R_{vo} and $1 - R_{vo}$, respectively, where the *voice ratio* $R_{vo} \leq 1$

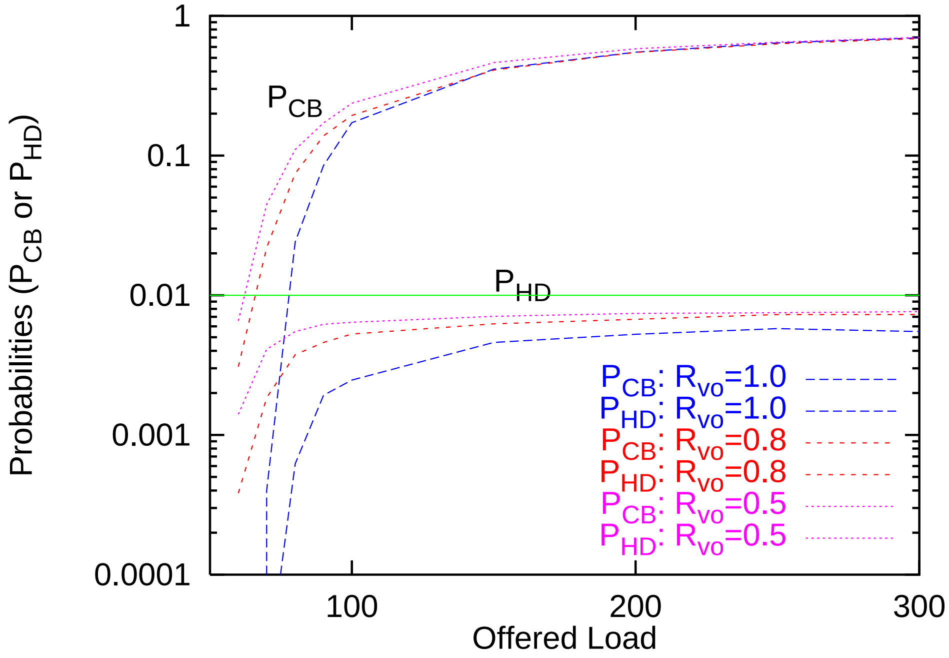
A4. Mobiles travel in either of two directions with an equal probability with a speed range $[SP_{min}, SP_{max}] = [80, 120]$ (km/hour)

A5. Exponentially-distributed connection lifetime with mean 120 (seconds)

A6. A fixed link capacity 100 BUs for each cell

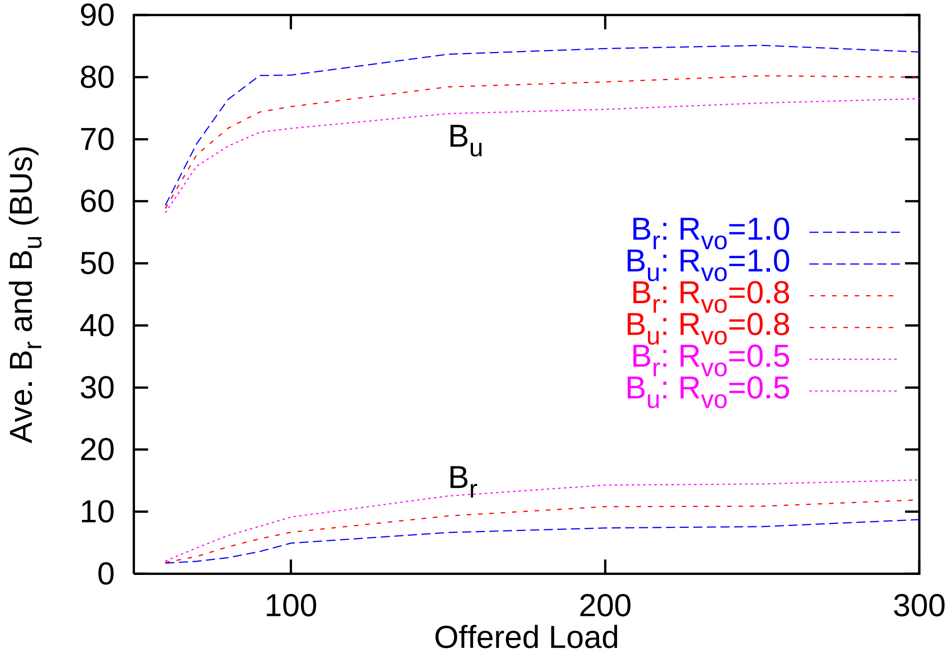
$\Rightarrow P_{HD,target} = 0.01$

P_{CB} and P_{HD} vs. Offered Load



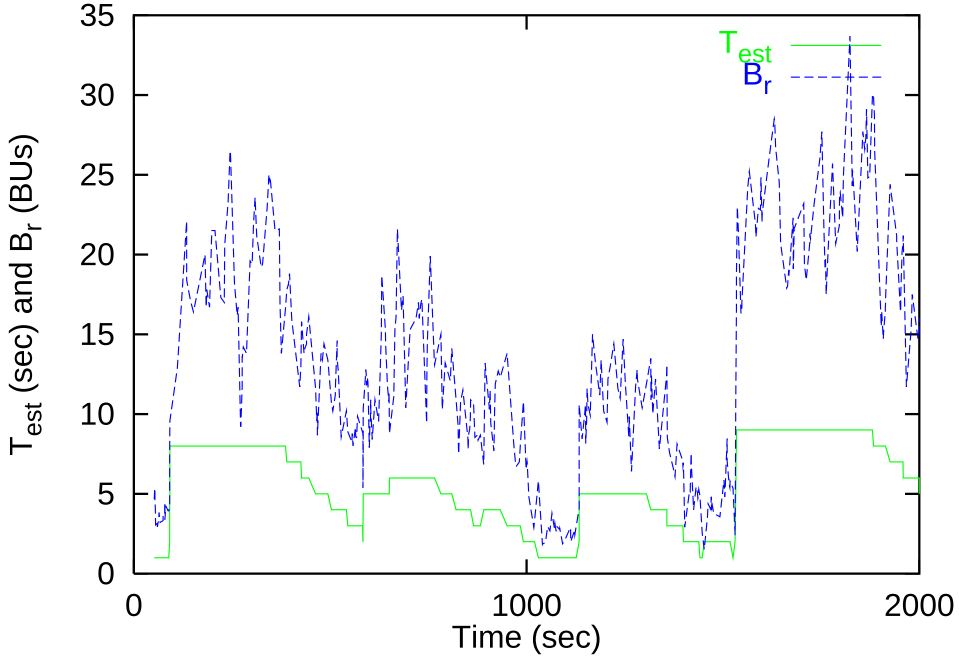
- Target $P_{HD,target} = 0.01$
- Design goal is achieved irrespective of offered load, voice ratio, and speed range

B_r and B_u vs. Offered Load



- B_u: ave. bandwidth used by on-going connections in each cell
- The lower R_{vo}, the larger B_r
- Saturation of B_r and B_u in heavily-loaded region

T_{est} and B_r over Time



- Offered load $L = 300$ and voice ratio $R_{vo} = 1.0$
- Increases of T_{est} from hand-off drops

Conclusions

- Mobility estimation based on observed history in each cell
- Predictive and adaptive bandwidth reservation and admission control to limit P_{HD} below $P_{HD,target}$
- Performance evaluation via simulations

Future Work

- Computational complexity will be reported in *MobiCom'98* as part of the comparison with three other schemes
- Extension to utilize the mobiles' mobility information from ITS route guidance system
- Extension to CDMA systems (soft capacity and hand-off)