Comparative analysis of path computation techniques for MPLS traffic engineering

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Outline

- Introduction
- TE-Q-metrics constrained path computation
  - TE objectives
  - TE-B-constrained path computation
  - TE-DB-constrained path computation
- Performance Studies
- Conclusion

Introduction

- Adding more bandwidth to networks is not the solution to all congestion problems
- QoS-constrained routing (MCP problem)
  - Single QoS constraint
  - Multiple QoS constraints
- TE path computation (MCOP problem): optimize TE objectives while satisfying QoS constraints
  - To solve the TE-Q-metrics constrained path computation problem
  - TE-B and TE-DB heuristics are proposed

TE-Q-metrics constrained path computation

- Assume
  - Requests arrive online and no priori knowledge of future requests
  - Two QoS metrics: bandwidth and delay
  - Two forms of QoS requests are considered
    - (*A*, *B*, *Bw*): from *A* to *B* with minimum bandwidth *Bw*
    - (*A*, *B*, *Bw*, *D*): adds end-to-end delay tolerance *D*
  - The requested bandwidth units are reserved by TE signaling mechanism like RESV or CR-LDP

TE objectives (1/2)

- Minimize blocking of future requests
  - By the approach of routing requests along the least flow-blocking path
  - $f(i,j)$: max-flow reduction weight of link $l(i,j)$, max-flow reduction weight of path P is defined as $\text{path\_flow\_reduction}(P) = \sum f(i,j),\ \forall\ l(i,j) \in P$
- Minimize the overall cost of paths
  - $u(i,j)$: link cost for link $l(i,j)$, cost of P is defined $\text{path\_cost}(P) = \sum u(i,j),\ \forall\ l(i,j) \in P$

TE objectives (2/2)

- Distribute the loading on paths
  - link_load$_{(l)}$= (Reserved Bw on l)/(Total reservable Bw on l) x 100
  - link_critical$_{(l)}$ = 0 if $link_load_{(l)} \leq$U
    = $f(link\_load_{(l)})$ otherwise
  - path_critical$(P) = \sum link_critical_{(l)}, \forall\, l \in P$
- TE-Q-metrics problem statement → NP-complete
  - Minimize path_flow_reduction(P)
    Minimize path_cost(P)
    Minimize path_critical(P)

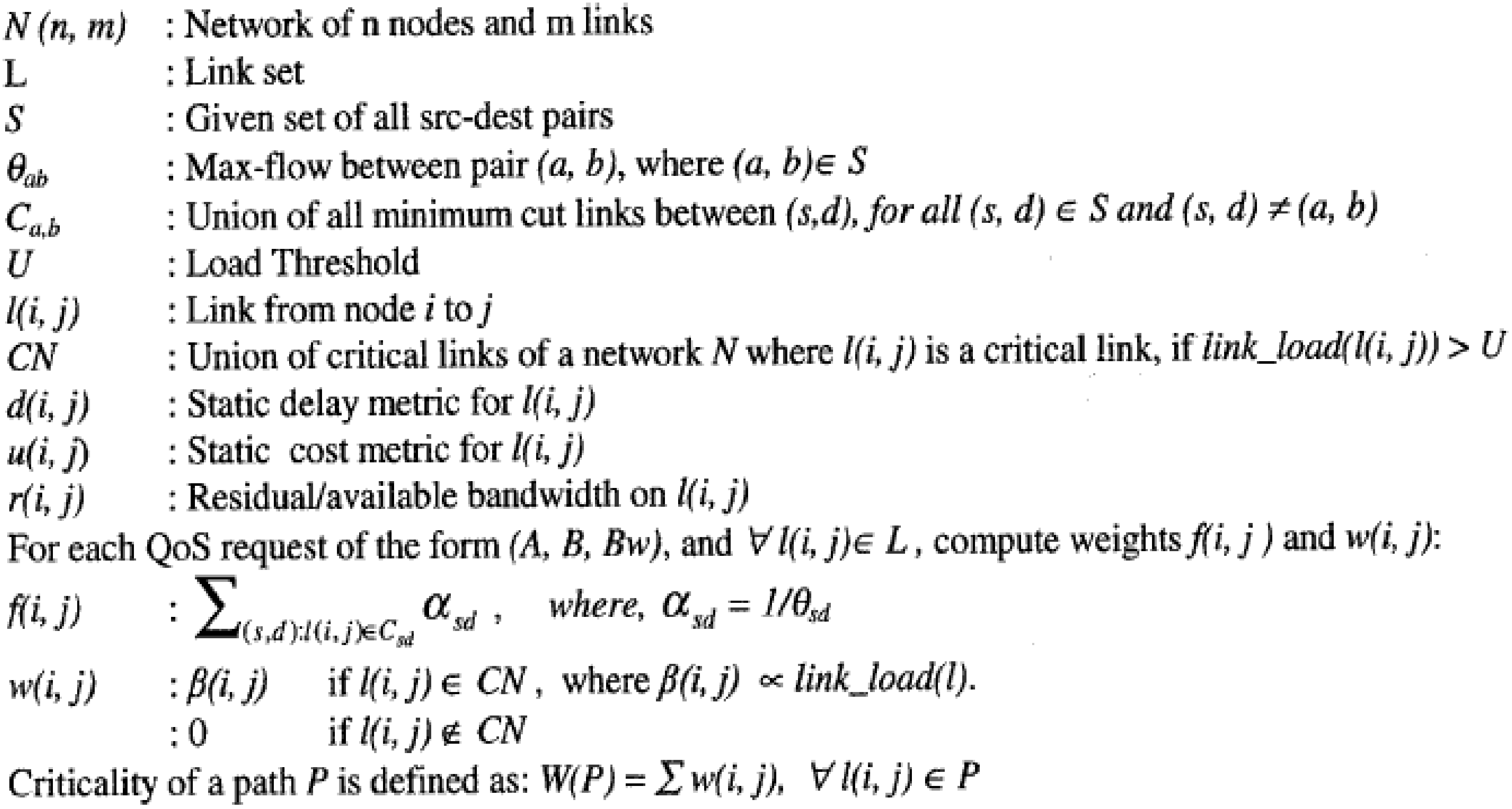
    Subject to constraints:

    1. delay(P) $\leq D$,
    2. bandwidth(P) $\geq Bw$

Existing TE-B constrained heuristic

- MIRA: minimum interference routing algorithm
  - Find a path that blocks the smallest available max-flow between all other src-dest node pairs
- WID-SHORT: widest shortest path algorithm
  - If several shortest paths exist, select the widest one
- Shortest-widest
- LCKS: least-critical-K-shortest path algorithm
  - From k shortest paths, select the least critical path

Definitions & terminology



$N(n, m)$: Network of n nodes and m links

L : Link set

S : Given set of all src-dest pairs

θ_{ab} : Max-flow between pair (a, b), where $(a, b) \in S$

$C_{a,b}$: Union of all minimum cut links between (s,d), *for all* $(s, d) \in S$ *and* $(s, d) \neq (a, b)$

U : Load Threshold

$l(i, j)$: Link from node i to j

CN : Union of critical links of a network N where $l(i, j)$ is a critical link, if $link\_load(l(i, j)) > U$

$d(i, j)$: Static delay metric for $l(i, j)$

$u(i, j)$: Static cost metric for $l(i, j)$

$r(i, j)$: Residual/available bandwidth on $l(i, j)$

For each QoS request of the form (A, B, Bw), and $\forall\, l(i, j) \in L$, compute weights $f(i, j)$ and $w(i, j)$:

$f(i, j)$: $\sum_{(s,d):l(i,j)\in C_{sd}} \alpha_{sd}$, where, $\alpha_{sd} = 1/\theta_{sd}$

$w(i, j)$: $\beta(i, j)$ if $l(i, j) \in CN$, where $\beta(i, j) \propto link\_load(l)$.

: 0 if $l(i, j) \notin CN$

Criticality of a path P is defined as: $W(P) = \sum w(i, j)$, $\forall\, l(i, j) \in P$

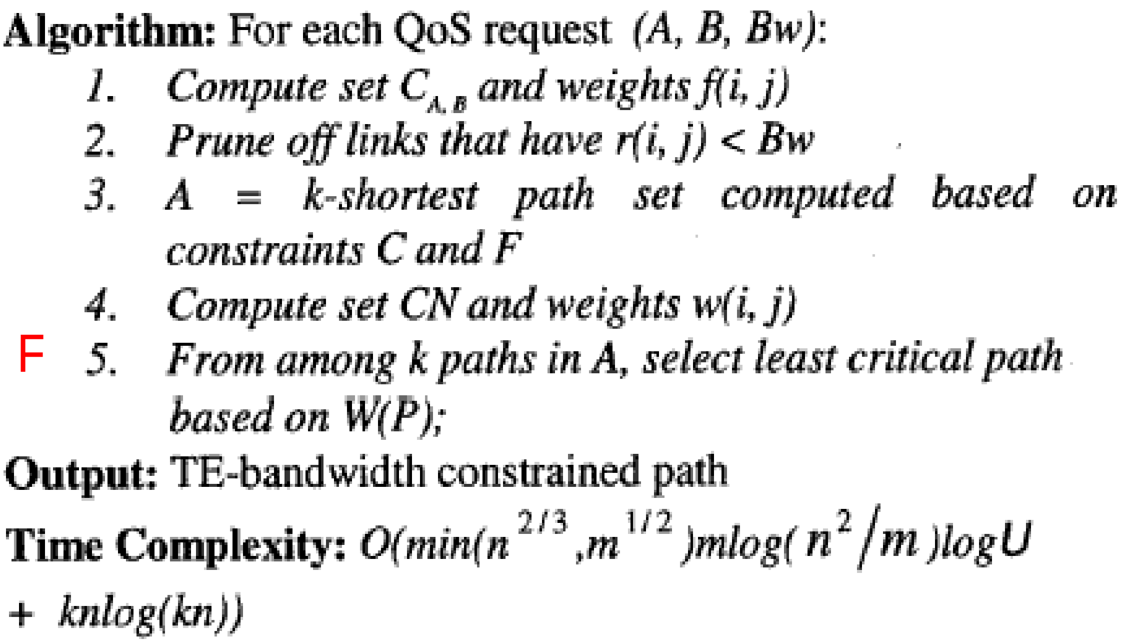
TE-B-constrained path computation

- Rewrite problem as

  Minimize path_critical(P)

  Subject to

  1. bandwidth(P) $\geq Bw$
  2. path_flow_reduction(P) $\leq$ F
  3. path_cost(P) $\leq$ C



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Algorithm: For each QoS request (A, B, Bw):
    1. Compute set $C_{A,B}$ and weights $f(i, j)$
    2. Prune off links that have $r(i, j) < Bw$
    3. A = k-shortest path set computed based on constraints C and F
    4. Compute set CN and weights $w(i, j)$
    5. From among k paths in A, select least critical path based on $W(P)$;
Output: TE-bandwidth constrained path
Time Complexity: $O(\min(n^{2/3}, m^{1/2}) m \log(n^2/m) \log U + kn\log(kn))$
```

Existing TE-DB constrained heuristic

- MIN-DELAY: minimum delay algorithm
  - Prune links that do not satisfy bandwidth requirement
  - Find the shortest path w.r.t. delay
- TAMCRA: tunable accurate multiple constrained routing algorithm
  - Use a non-linear weight function
  - Find a candidate set of k paths whose metrics are far from the constraint bounds

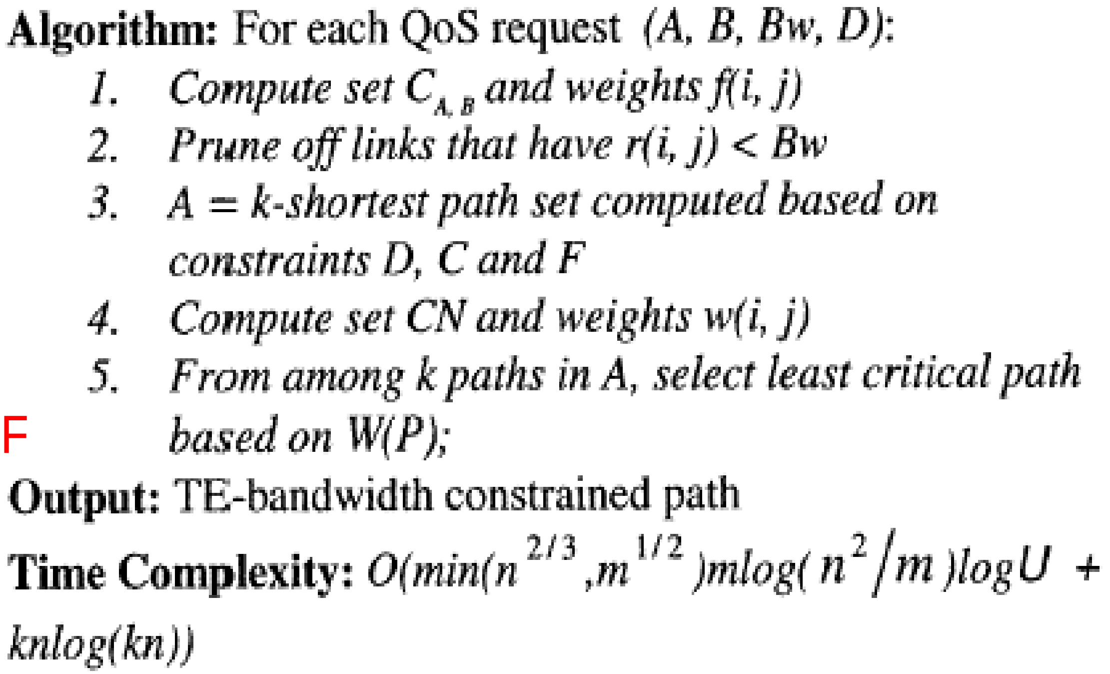
TE-DB-constrained path computation

- Rewrite problem as

  Minimize path_critical(P)

  Subject to

  1. bandwidth(P) $\geq Bw$
  2. delay(P) $\leq D$
  3. path_flow_reduction(P) $\leq$ F
  4. path_cost(P) $\leq$ C



Algorithm: For each QoS request *(A, B, Bw, D)*:

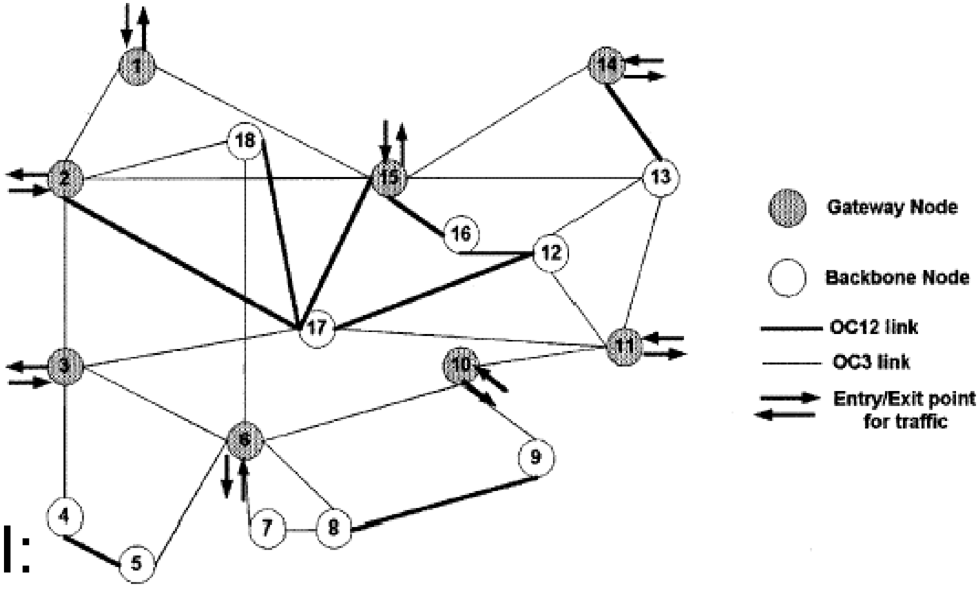
```
1. Compute set $C_{A,B}$ and weights $f(i, j)$
2. Prune off links that have $r(i, j) < Bw$
3. A = k-shortest path set computed based on
   constraints D, C and F
4. Compute set CN and weights $w(i, j)$
5. From among k paths in A, select least critical path
   based on $W(P)$;
```

Output: TE-bandwidth constrained path

Time Complexity: $O(min(n^{2/3}, m^{1/2}) m log(n^2/m) log U +$ $knlog(kn))$

Performance studies

- All links are symmetric and link weights and link delays are assigned randomly
- Size of candidate set of paths, k=4



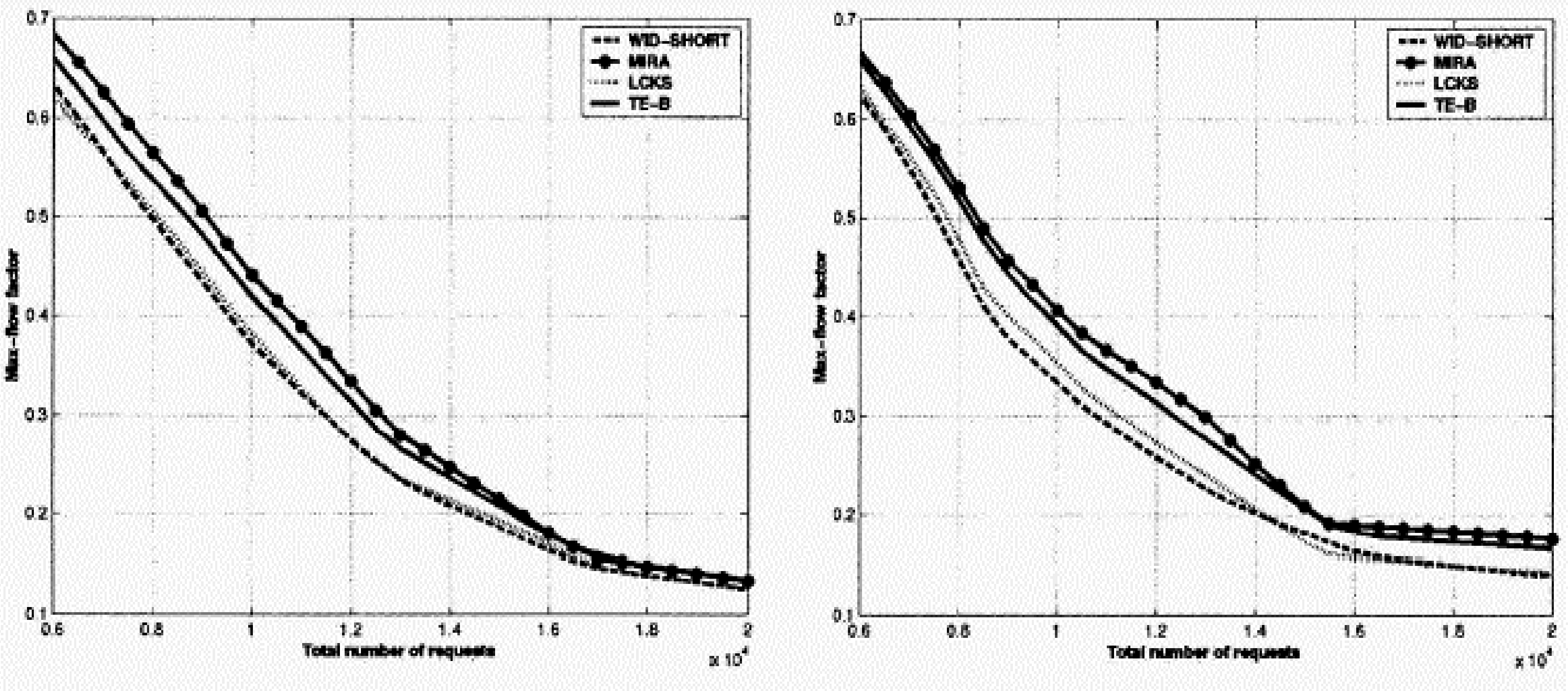
- Request generation model:
  - Uniform: requests are uniformly distributed between all pairs
  - Non-uniform: with hot & cold pairs
    - Hot and cold pairs are evenly distributed
    - Hot pairs are very high in number compared to cold
    - Hot pairs are very high in number compared to cold

Performance metrics

- Available max-flow
  - Max-flow factor = (Current available max-flow between all src-dest pairs) / (Initial available max-flow between all src-dest pairs)
- Reducing network cost
  - Path cost: determined by path length
- Distributing load
  - Path load: maximum link load on the component links of a path

Max-flow factor (1 QoS constraint)

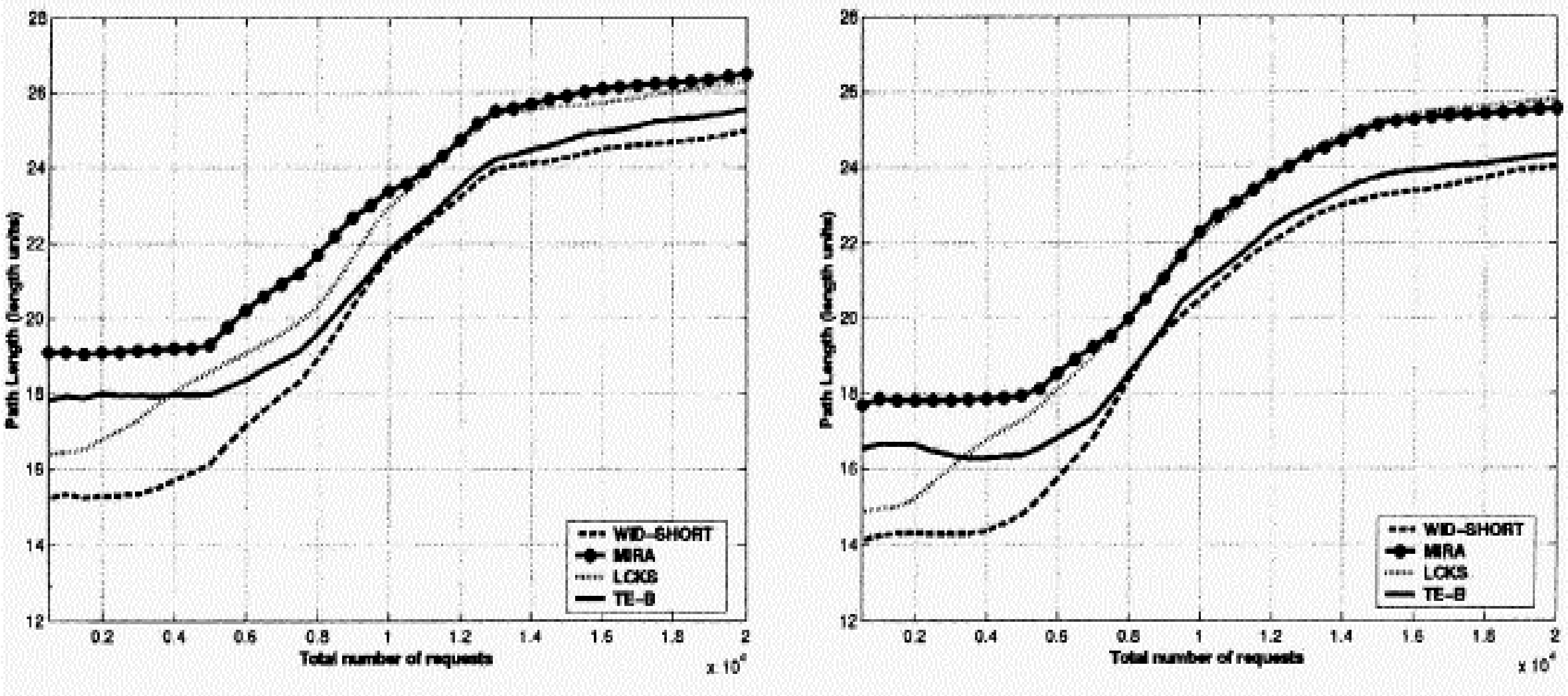
- Higher is better



I. Uniform model

II. Non-uniform model (c)

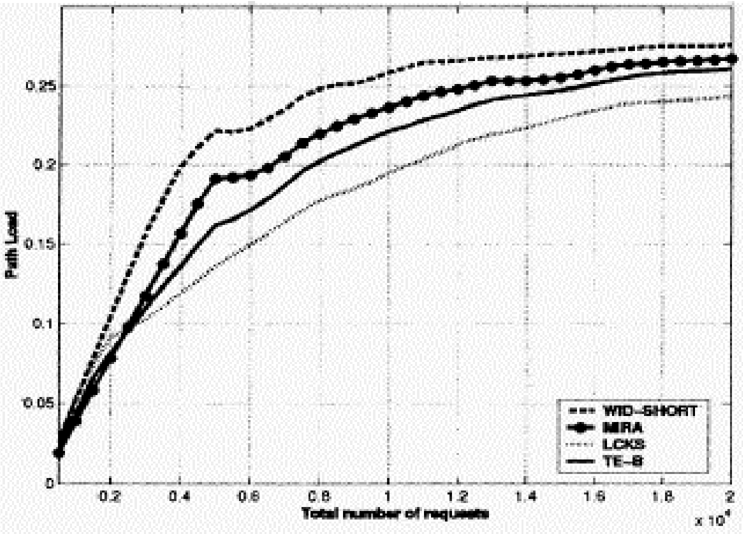
Path length (1 QoS constraint)



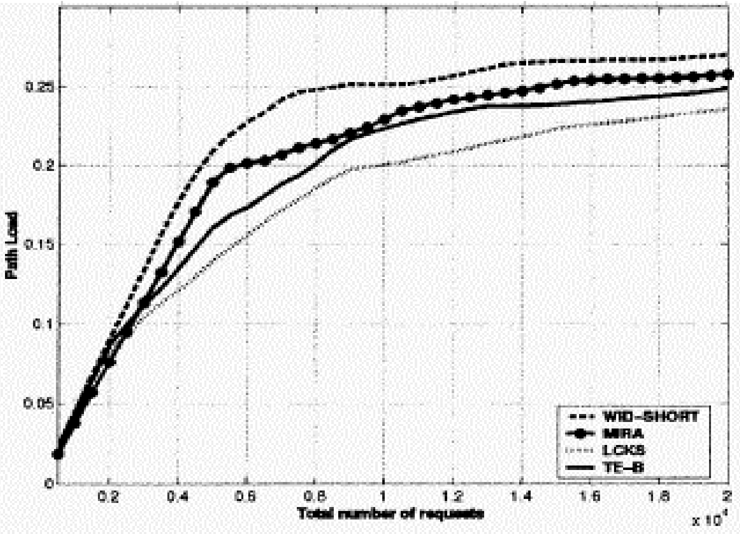
I. Uniform model

II. Non-uniform model (b)

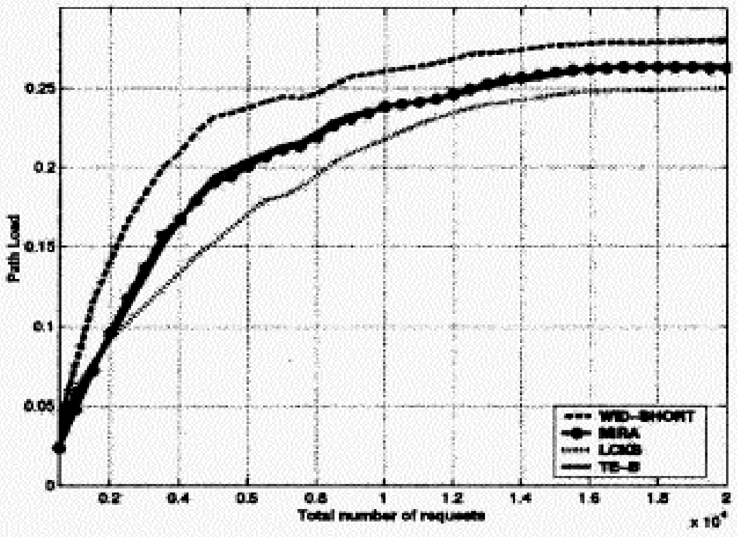
Path load (1 QoS constraint)



I. Uniform model

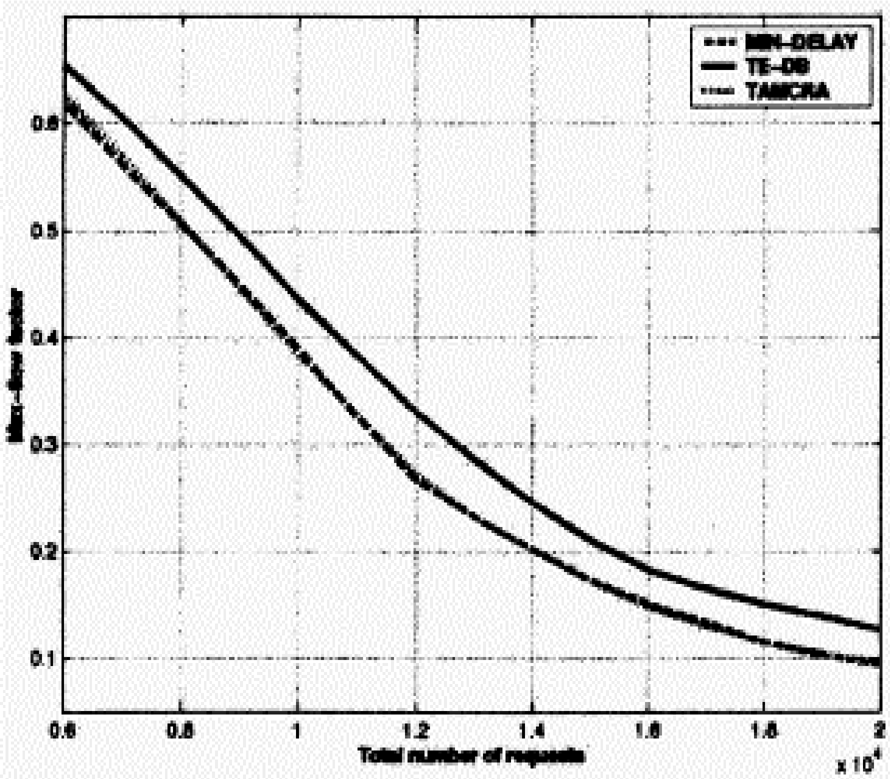


II. Non-uniform model (a)

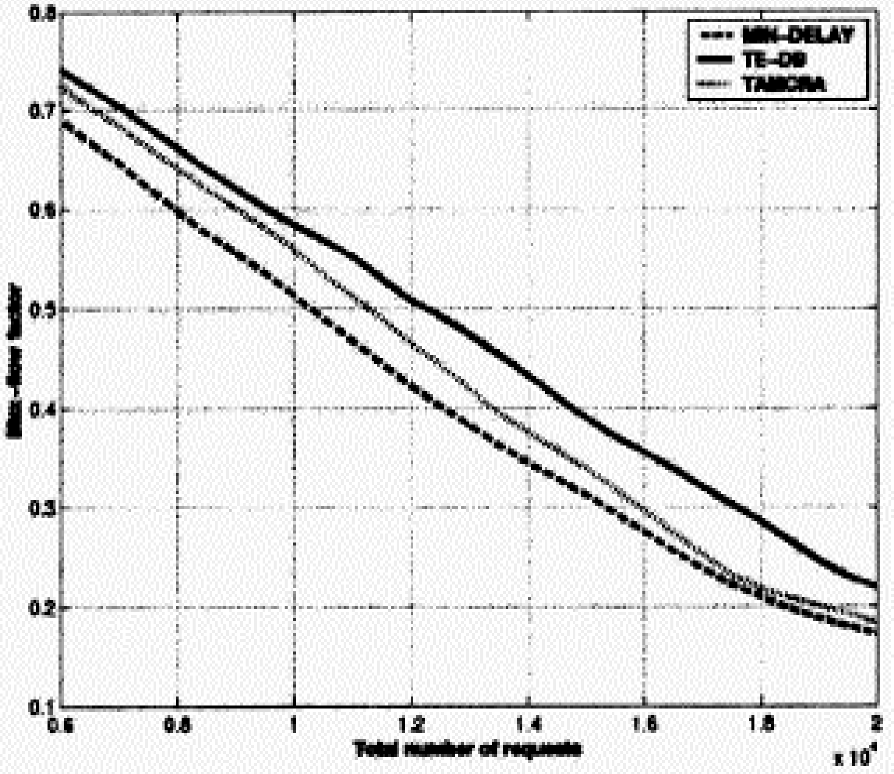


III. Non-uniform model (c)

Max-flow factor (2 QoS constraints)

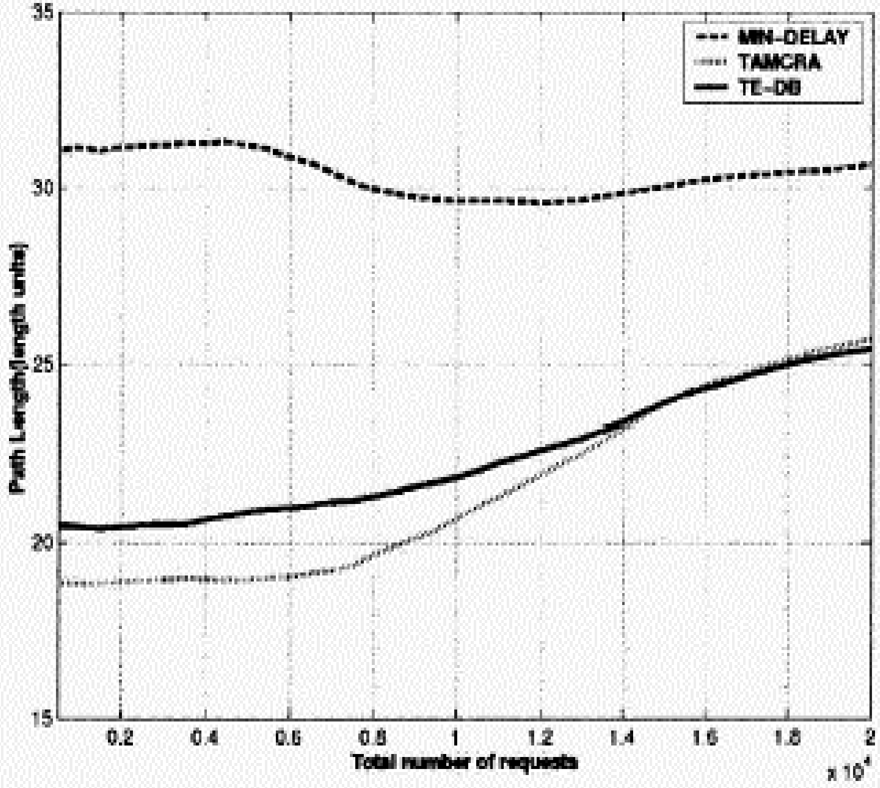


I. Uniform model

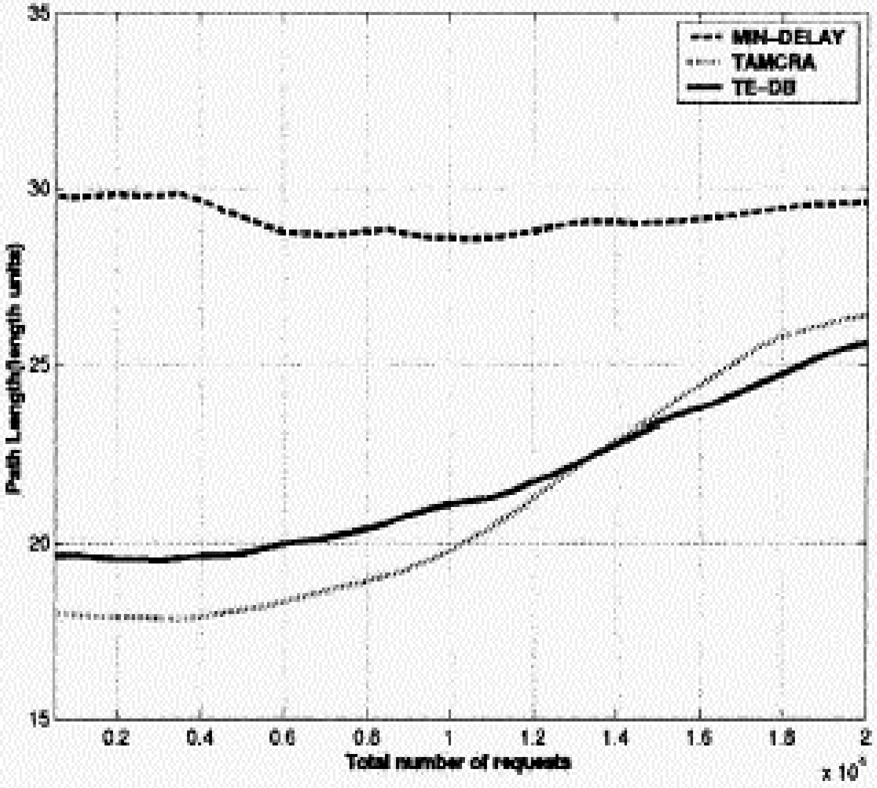


II. Non-uniform model (a)

Path length (2 QoS constraints)

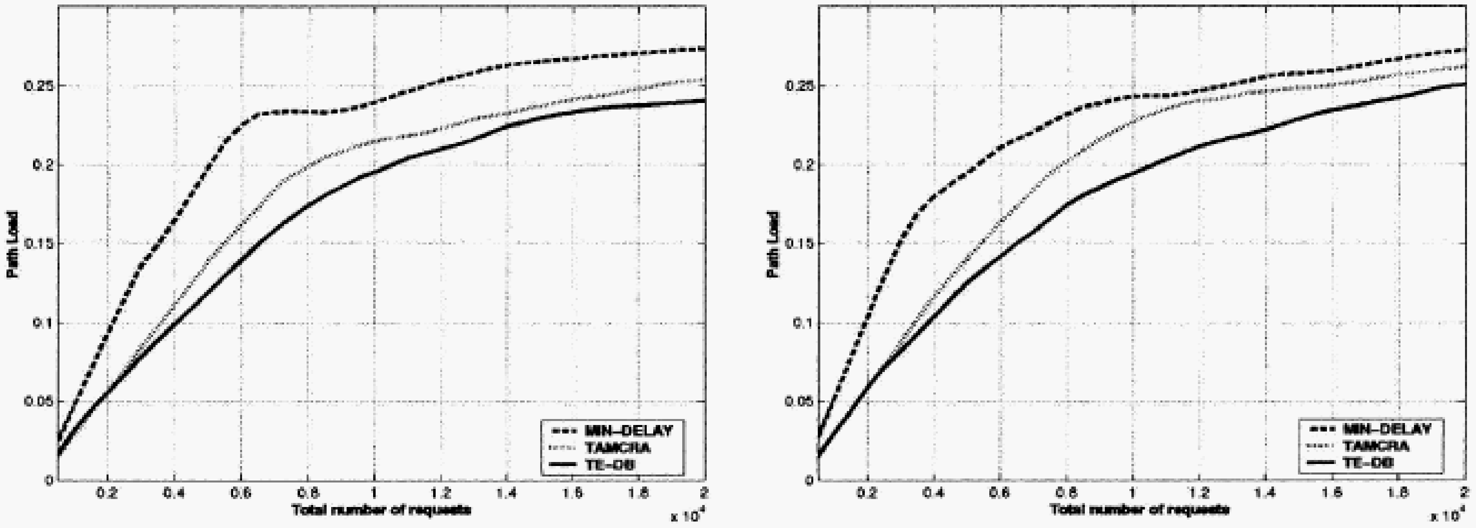


I. Uniform model



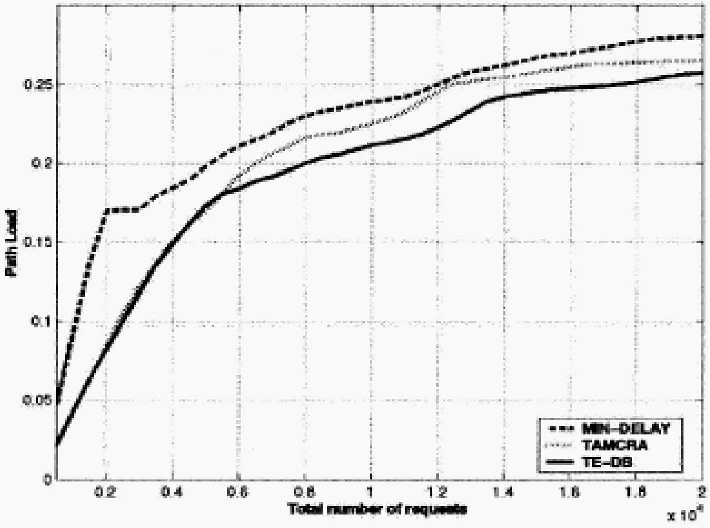
II. Non-uniform model (a)

Path load (2 QoS constraints)



I. Uniform model

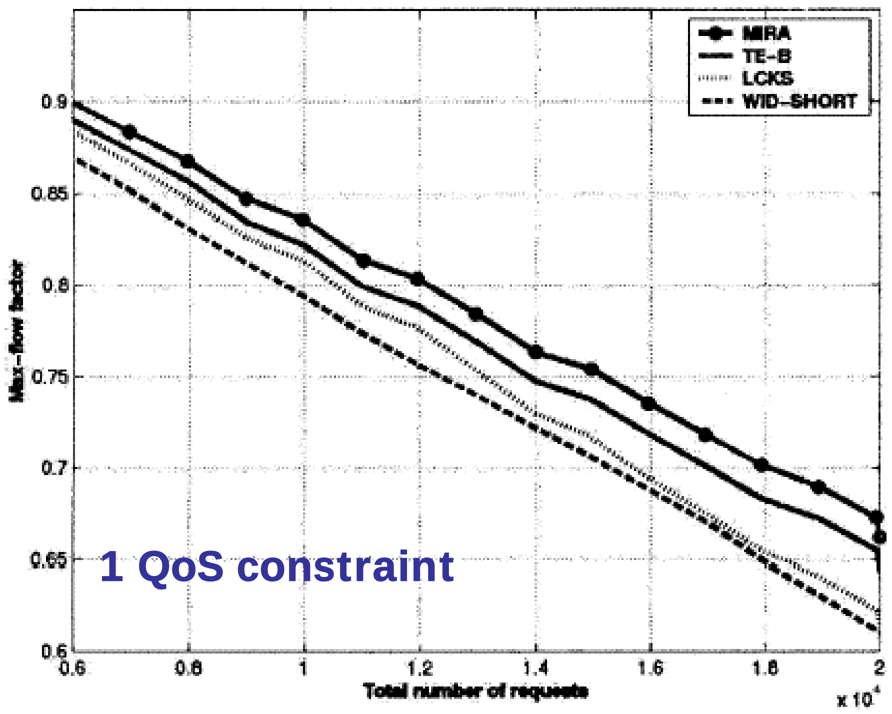
II. Non-uniform model (a)



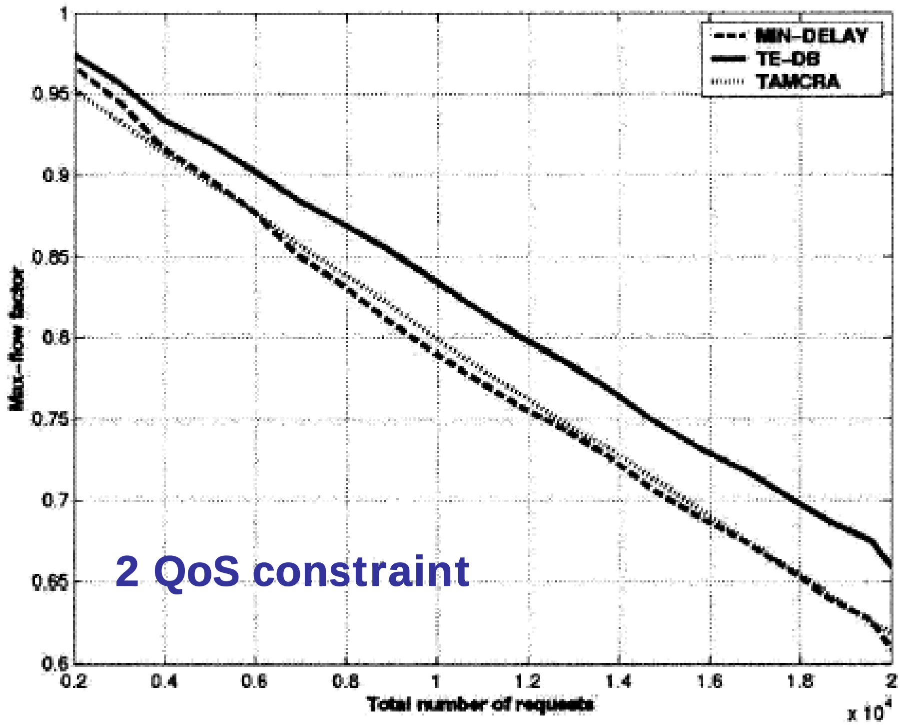
III. Non-uniform model (c)

Max-flow factor (dynamic environment)

- 30% of flows are assumed indefinitely long
- The rest of them have a mean holding time of 250 s

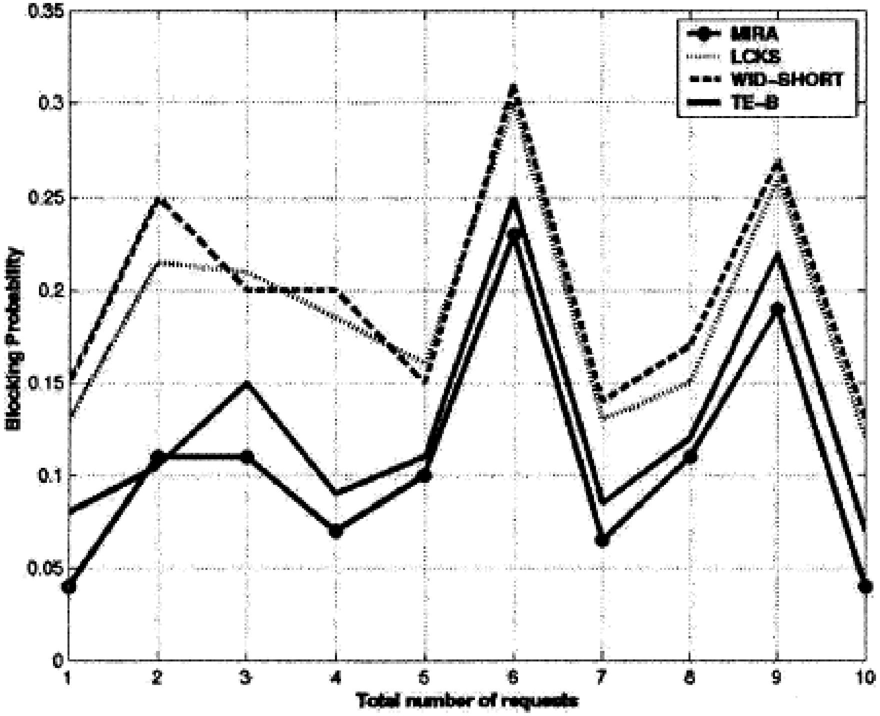


1 QoS constraint

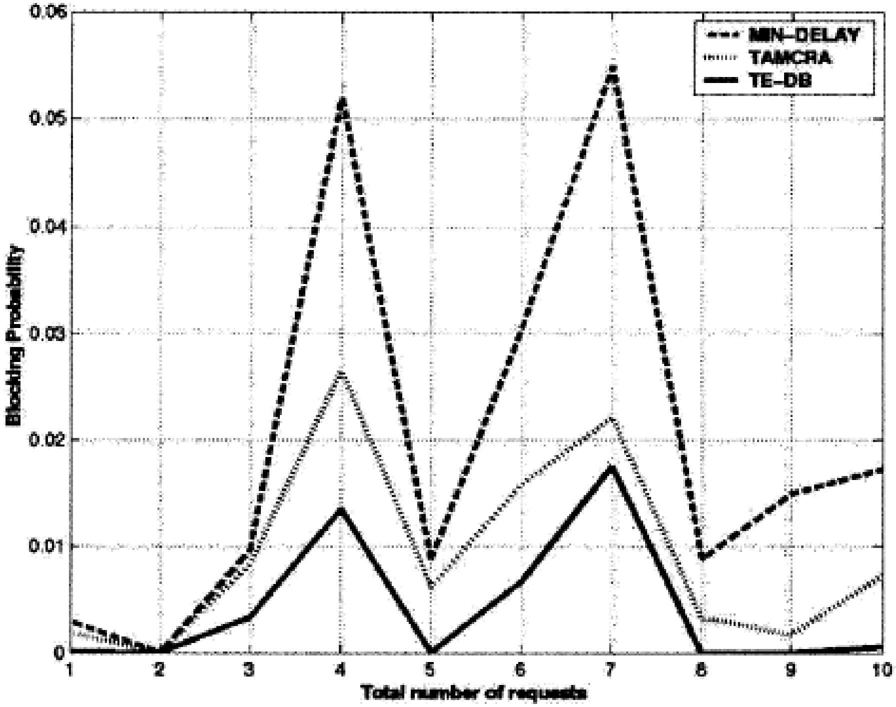


2 QoS constraint

Blocking probability



1 QoS constraint



2 QoS constraint

Conclusion

- Two TE path computation algorithms, TE-B and TE-DB, are proposed to maintain three TE objectives:
  - Increase network revenue
  - Limiting network cost
  - Distributing network load
- TE-B and TE-DB achieve considerable performance enhancements