End-to-End Delay Constrained Routing and Admission Control for MPLS Networks

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NETWORKS 2008
September 28 – October 2, 2008
Budapest, Hungary

Introduction

- In this paper, we propose to tackle the joint dynamic routing and admission control (JRAC) problem for the IP traffic flows in MPLS networks without rerouting the already admitted flows.
- Two mathematical programming models are proposed for this problem.
    - Model 1 (JRAC-D) includes end-to-end Delay constraints.
    - Model 2 (JRAC-P) includes end-to-end Packet loss constraints.

  These end-to-end quality of service (QoS) constraints are imposed not only for the new traffic flow, but also for all already admitted flows in the network.
- An exact solution algorithm is proposed.
- Finally, numerical results are presented and analyzed.

Introduction (cont’d)

- Today, the network services such as the high-definition television (HDTV) over IP (IPTV) service, have severe QoS requirements (principally in terms of end-to-end delay, packet loss and jitter).
- Dynamic JRAC is a major task to prevent networks from being overloaded.
- When doing the admission control for a new request, the network has to satisfy the QoS requirements of the flows already in service.
  - The impact of the new flow on the end-to-end performance of each flow already in service should ideally be estimated before admitting it.
- In this paper, no rerouting is allowed while guaranteeing end-to-end QoS for all flows in the network.

Delay and packet loss functions

- In this paper, the $M/M/1/k$ queuing model is used to evaluate the delay and packet loss.
- Note that the proposed dynamic JRAC framework can be used with any delay and packet loss models. In fact, the delay and packet loss values are only input parameters of the proposed framework.
- Notation
  - f_{ij}, the traffic (in bits/sec) on the link (i, j);
  - c_{ij}, the capacity (in bits/sec) on the link (i, j);
  - ℓ, the packet length (in bits/paquet);
  - $\lambda_{ij} = f_{ij}/\ell$, the arrival rate (in packets/sec) on the link (i, j);
  - $\rho_{ij} = f_{ij}/c_{ij}$, the utilization of the link (i, j);
  - a_{ij}, the propagation delay (in seconds) on the link (i, j).

Delay and packet loss functions (cont'd)

- Let $d_{ij}(f_{ij})$ be the average delay (in seconds) on the link (i, j).

$$d_{ij}(f_{ij}) = \frac{\rho(1 + k\rho^{k+1} - (k+1)\rho^{k})}{\lambda(1-\rho)(1-\rho^{k})} + a_{ij}$$

- Let $p_{ij}(f_{ij})$ be the average packet loss rate on the link (i, j).

$$p_{ij}(f_{ij}) = 1 - r_{ij}(f_{ij}) = \frac{\rho^{k}(1-\rho)}{1-\rho^{k+1}}$$

where $r_{ij}(f_{ij}) = 1 - p_{ij}(f_{ij})$ is the average packet transmit rate on the link (i, j).

The model formulation: The notation

Sets:

- N, the set of nodes;
- M, the set of unidirectional links;
- L, the set of unidirectional LSPs;
- T, the set of already admitted flows
  - $O(t)$, the starting node of the flow t;
  - $D(t)$, the terminating node of the flow t;
  - α^t, the traffic demand (in bps) for the flow t;
  - β^t, the end-to-end maximum delay limit (in sec) for the flow t;
  - φ^t, the end-to-end maximum packet loss rate for the flow t.

The model formulation: The notation (cont'd)

Constants:

- y_{ij}^{t}, a 0-1 constant such that $y_{ij}^{t} = 1$ iff the flow t passes on the link (i, j);
- z_{ij}^{ab}, a 0-1 constant such that $z_{ij}^{ab} = 1$ iff the LSP (a, b) passes on the link (i, j).

Variables:

- y_{ij}, a 0-1 variable such that $y_{ij} = 1$ iff the new flow passes on the link (i, j);
- x_{ab}, a 0-1 variable such that $x_{ab} = 1$ iff the new flow passes on the LSP (a, b).

The model formulation: The preprocessing

- If the new flow does not pass on the link (i, j), the traffic on that link, F_{ij}, is given by

$$F_{ij} = \sum_{t \in T} \alpha^t y_{ij}^t$$

and the delay on that link will be $D_{ij} = d_{ij}(F_{ij})$, the packet loss rate $P_{ij} = p_{ij}(F_{ij})$ and the packet transmit rate $R_{ij} = 1 - P_{ij}$.

- Otherwise, if the new flow passes on the link (i, j), the traffic on that link will be

$$\overline{F}_{ij} = \sum_{t \in T} \alpha^t y_{ij}^t + \alpha$$

and the delay on that link will be $\overline{D}_{ij} = d_{ij}(\overline{F}_{ij}) = D_{ij} + \Delta D_{ij}$, the packet loss rate $\overline{P}_{ij} = p_{ij}(\overline{F}_{ij})$ and the packet transmit rate $\overline{R}_{ij} = 1 - \overline{P}_{ij}$.

The model formulation: The preprocessing (cont’d)

- Similarly, if the new flow does not pass on the LSP (*a*, *b*), the end-to-end delay, the transmit rate and the packet loss rate are respectively given by the following equations.

$$D_{ab} = \sum_{(i,j)\in M} D_{ij} z_{ij}^{ab}$$

$$R_{ab} = \prod_{(i,j)\in M : z_{ij}^{ab}=1} R_{ij}$$

$$P_{ab} = 1 - R_{ab}$$

- Otherwise, if the new flow passes on the LSP (*a*, *b*),

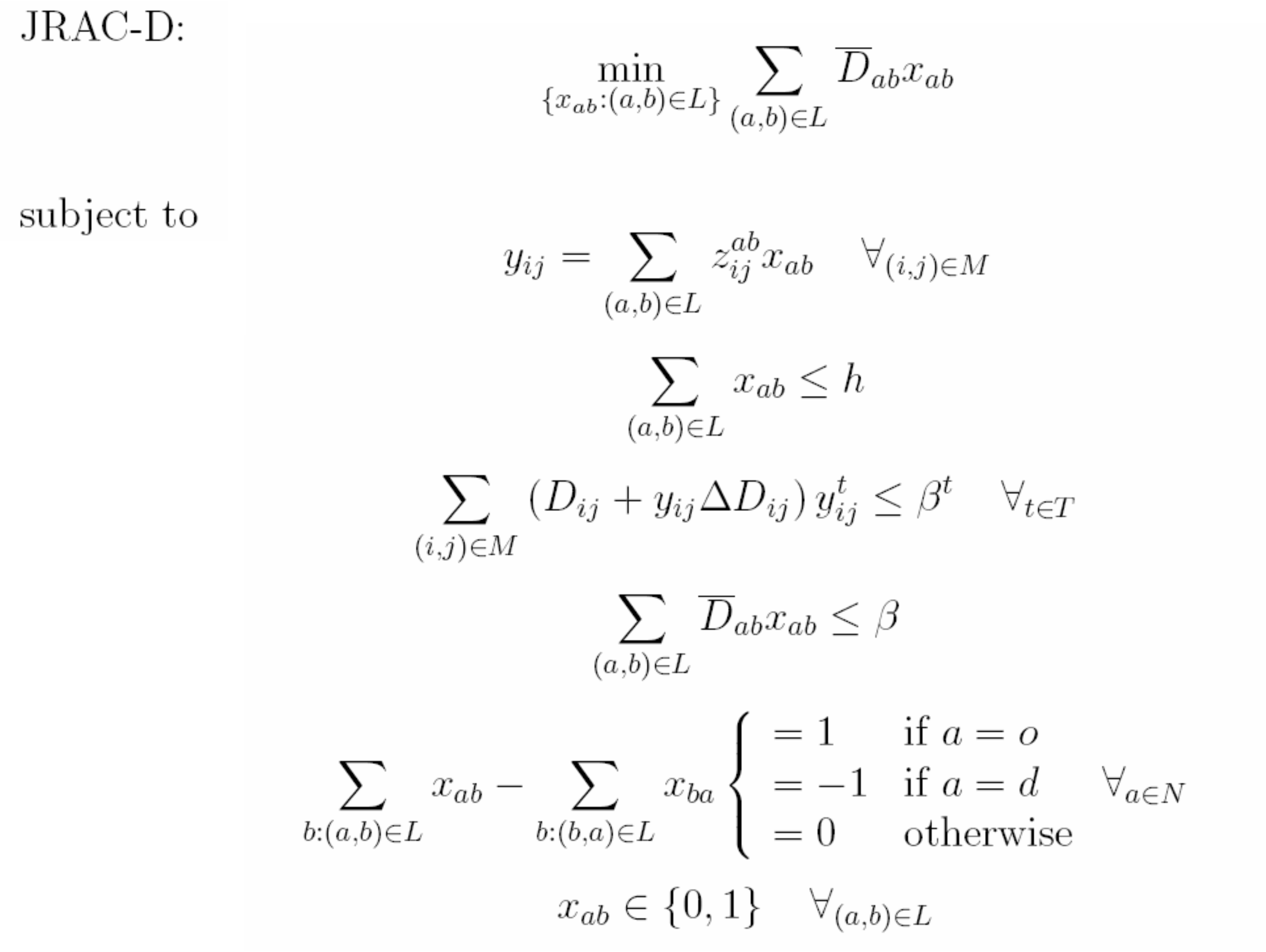
$$\overline{D}_{ab} = \sum_{(i,j)\in M} \overline{D}_{ij} z_{ij}^{ab} = D_{ab} + \Delta D_{ab}$$

$$\overline{R}_{ab} = \prod_{(i,j)\in M : z_{ij}^{ab}=1} \overline{R}_{ij}$$

$$\overline{P}_{ab} = 1 - \overline{R}_{ab}.$$

The model formulation: The model 1

- End-to-end delay constraints.



JRAC-D:

$$\min_{\{x_{ab}:(a,b)\in L\}} \sum_{(a,b)\in L} \overline{D}_{ab} x_{ab}$$

subject to

$$y_{ij} = \sum_{(a,b)\in L} z_{ij}^{ab} x_{ab} \quad \forall_{(i,j)\in M}$$

$$\sum_{(a,b)\in L} x_{ab} \leq h$$

$$\sum_{(i,j)\in M} \left(D_{ij} + y_{ij}\Delta D_{ij}\right) y_{ij}^{t} \leq \beta^{t} \quad \forall_{t\in T}$$

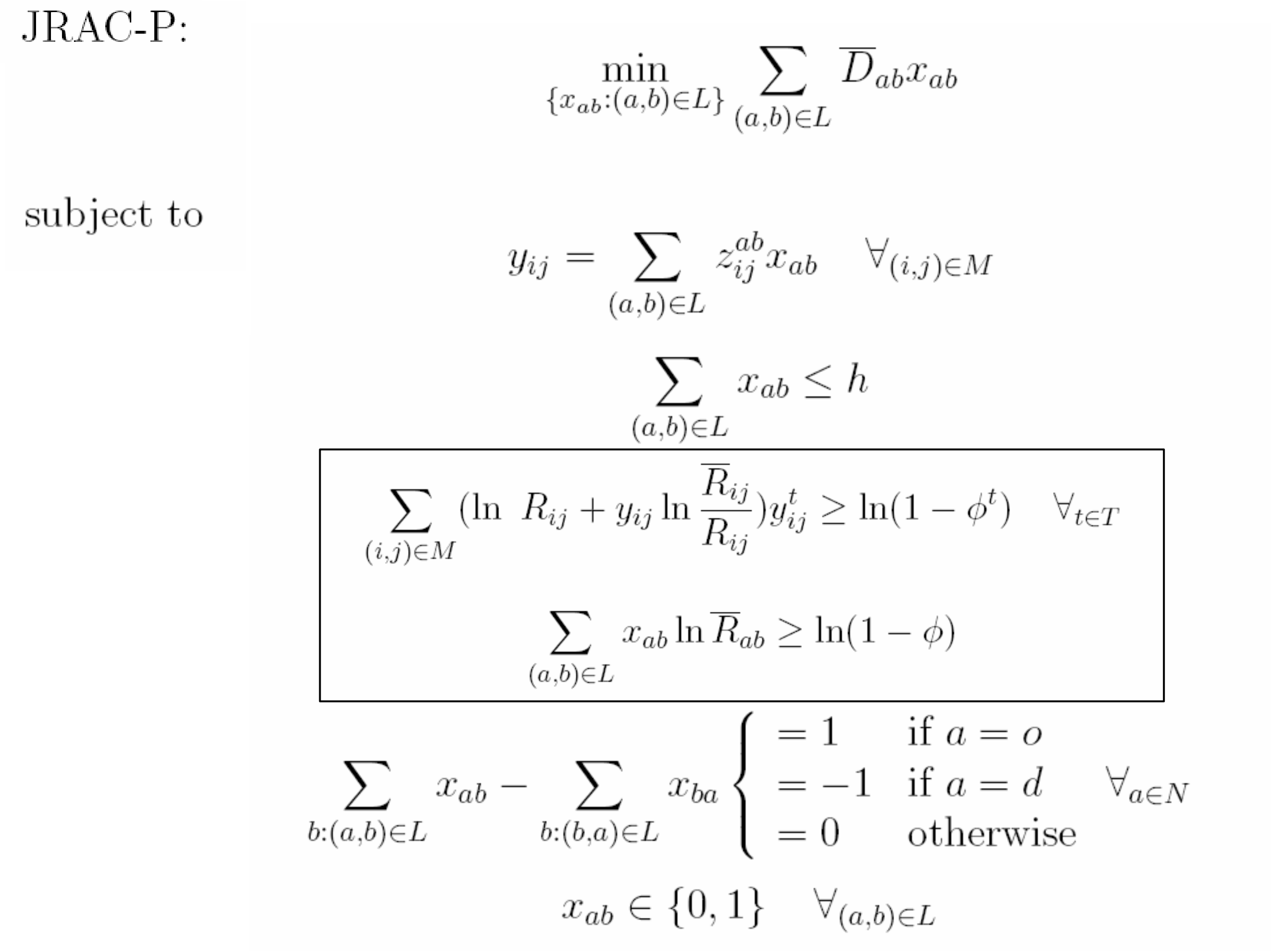
$$\sum_{(a,b)\in L} \overline{D}_{ab} x_{ab} \leq \beta$$

$$\sum_{b:(a,b)\in L} x_{ab} - \sum_{b:(b,a)\in L} x_{ba} \begin{cases} = 1 & \text{if } a = o \\ = -1 & \text{if } a = d \\ = 0 & \text{otherwise} \end{cases} \quad \forall_{a\in N}$$

$$x_{ab} \in \{0,1\} \quad \forall_{(a,b)\in L}$$

The model formulation: The model 2

- End-to-end packet loss constraints.



JRAC-P:

$$\min_{\{x_{ab}:(a,b)\in L\}} \sum_{(a,b)\in L} \overline{D}_{ab} x_{ab}$$

subject to

$$y_{ij} = \sum_{(a,b)\in L} z_{ij}^{ab} x_{ab} \quad \forall_{(i,j)\in M}$$

$$\sum_{(a,b)\in L} x_{ab} \le h$$

$$\boxed{\begin{gathered} \sum_{(i,j)\in M} (\ln\ R_{ij} + y_{ij} \ln \frac{\overline{R}_{ij}}{R_{ij}}) y_{ij}^{t} \ge \ln(1-\phi^{t}) \quad \forall_{t\in T} \\ \sum_{(a,b)\in L} x_{ab} \ln \overline{R}_{ab} \ge \ln(1-\phi) \end{gathered}}$$

$$\sum_{b:(a,b)\in L} x_{ab} - \sum_{b:(b,a)\in L} x_{ba} \begin{cases} = 1 & \text{if } a = o \\ = -1 & \text{if } a = d \\ = 0 & \text{otherwise} \end{cases} \quad \forall_{a\in N}$$

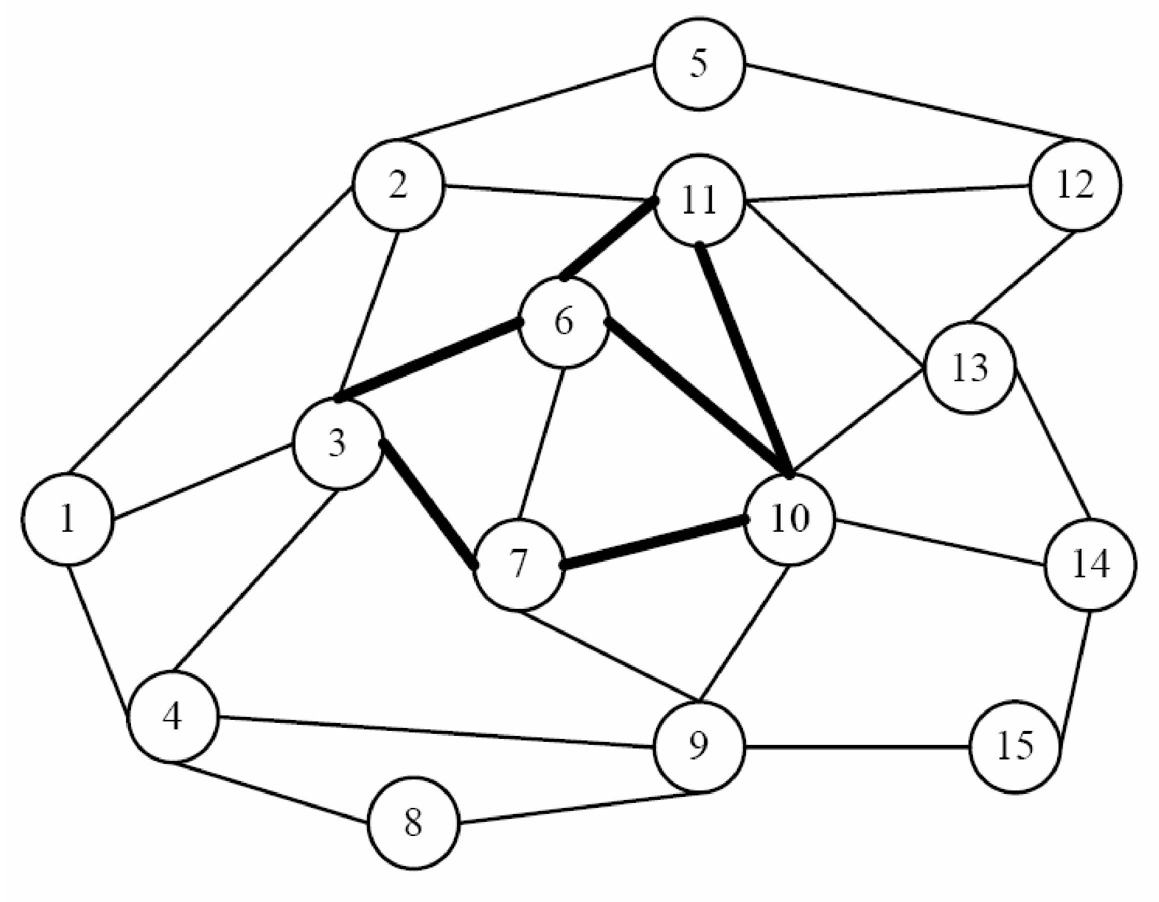
$$x_{ab} \in \{0,1\} \quad \forall_{(a,b)\in L}$$

Numerical results

- A Sun Java workstation under Linux with an AMD Opteron 150 CPU and 2GB of RAM was used for the tests.
- For solving the models, the CPLEX Mixed Integer Optimizer 9.0 was used. Note that the algorithm used by the CPLEX is a branch-and-bound algorithm. The default settings of CPLEX are used.
- A LSP is set up between each pair of edge routers.
- The traffic flows are randomly generated. For each request, we randomly choose a pair of origin-destination edge nodes. We have generated sets of 5000, 6000, 7000 and 8000 connections.
- The bandwidth of each flow is randomly taken (with equal probability) from the set {10, 20, 30, 40} kbps.

Numerical results (cont'd)

- The MIRA network was used for the simulations: The dark lines are 48 Mbps links and the light lines are 12 Mbps links.
- The nodes not connected to dark lines are the edge nodes.



Numerical results (cont'd)

- JRAC-D is compared to three algorithms.

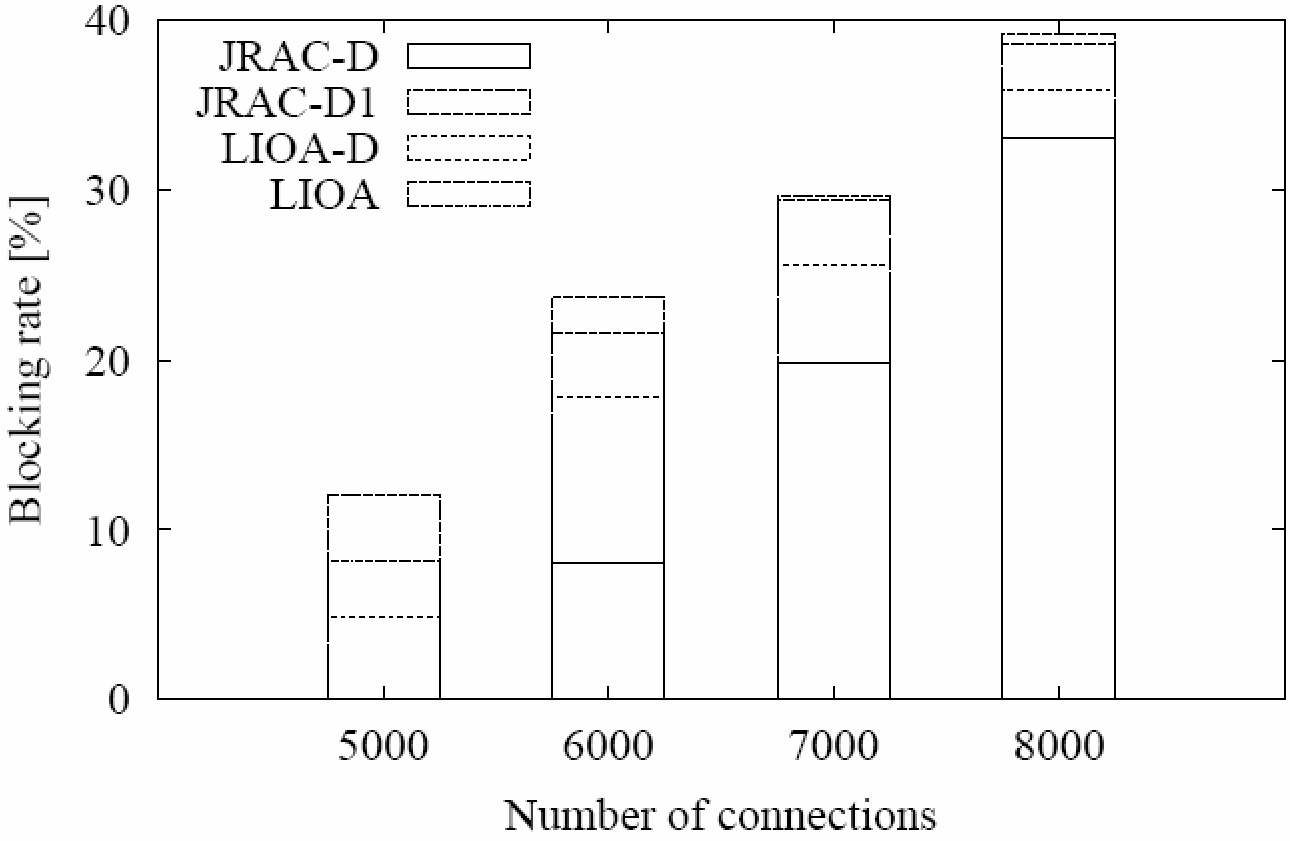
1. LIOA with an additional end-to-end delay constraint for the new flow.

   This algorithm computes the least interference path. The link cost of the link (*i*, *j*) is

   $$u_{ij} = I_{ij}^{\omega} / S_{ij}^{1-\omega},$$

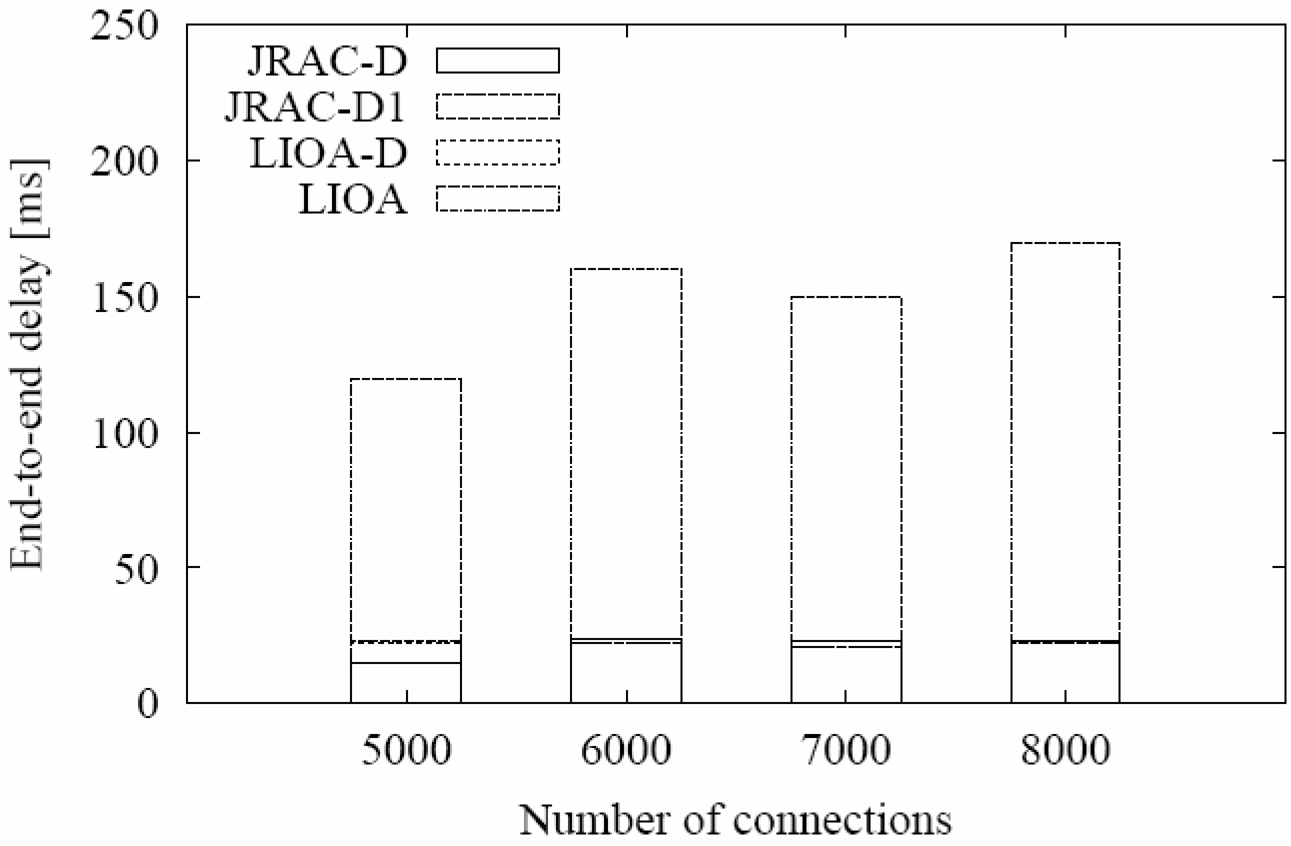
   where I_{ij} is the number of flows and S_{ij} the remaining bandwidth that can be reserved on the link (*i*, *j*).
2. LIOA-D: LIOA with additional end-to-end delay constraints for all flows.
3. JRAC-D1: JRAC-D with one LSP (i.e, h=1).

Numerical results (cont'd)



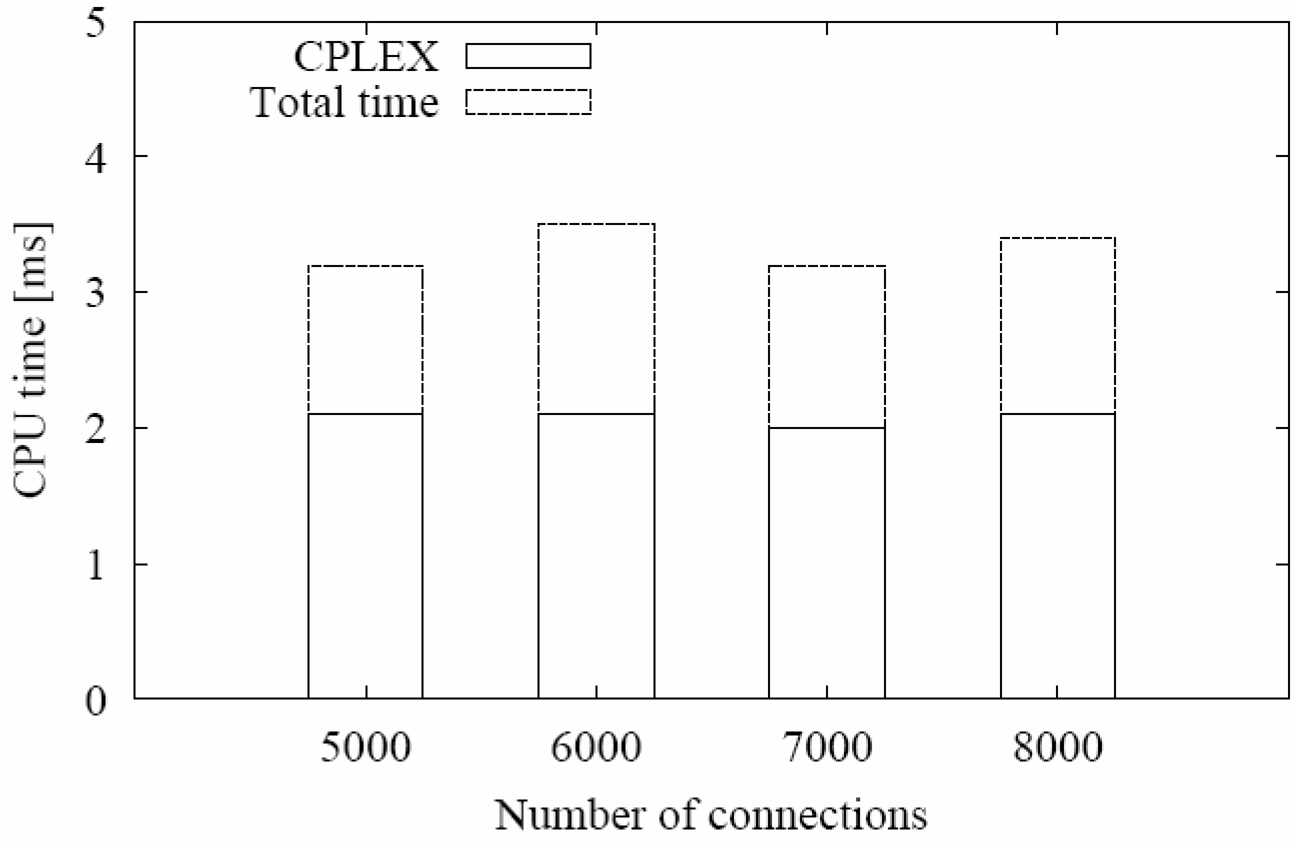
Flow blocking rate for $k = 288$ (MIRA network)

Numerical results (cont'd)



End-to-end delay for $k = 288$ (MIRA network)

Numerical results (cont'd)

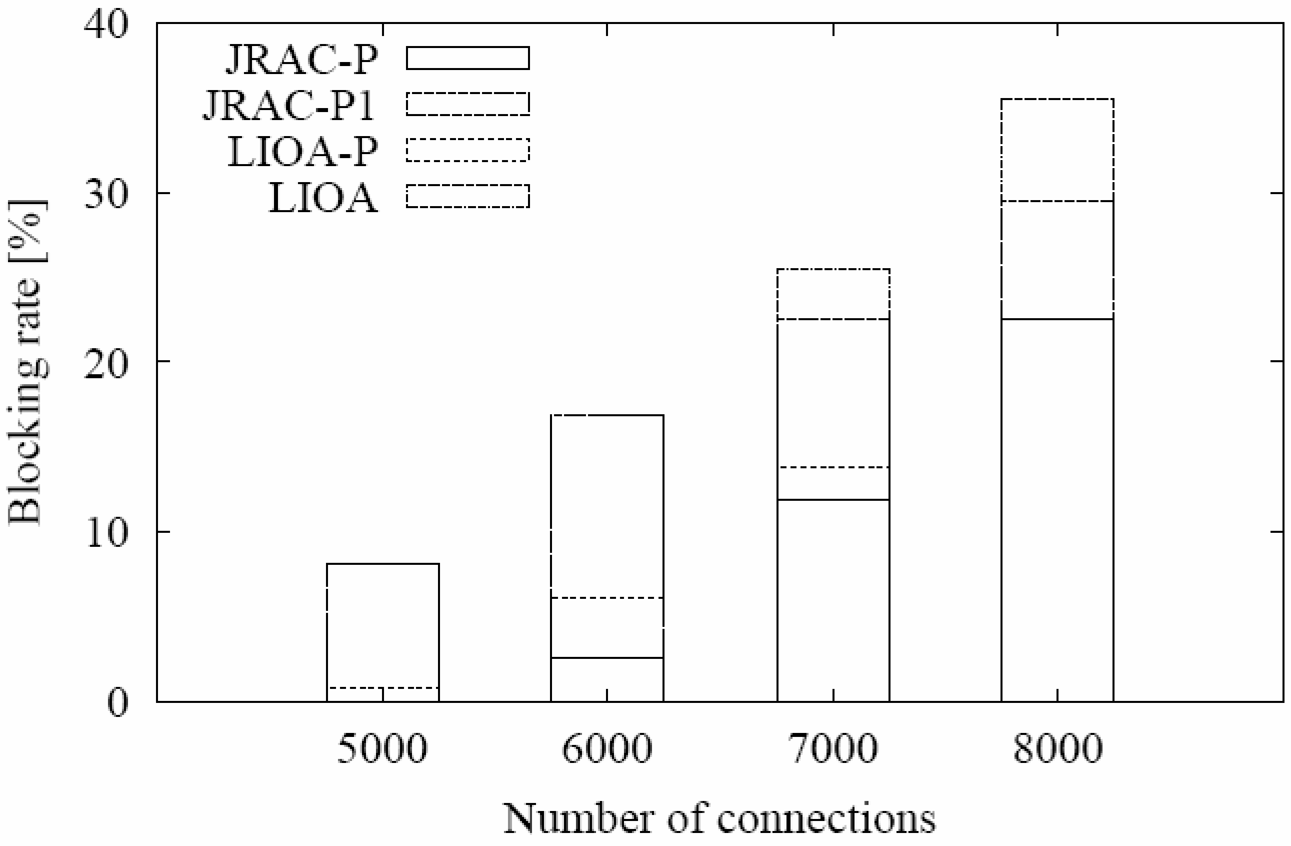


CPU execution time for JRAC-D ($k = 800$, MIRA network)

Numerical results (cont'd)

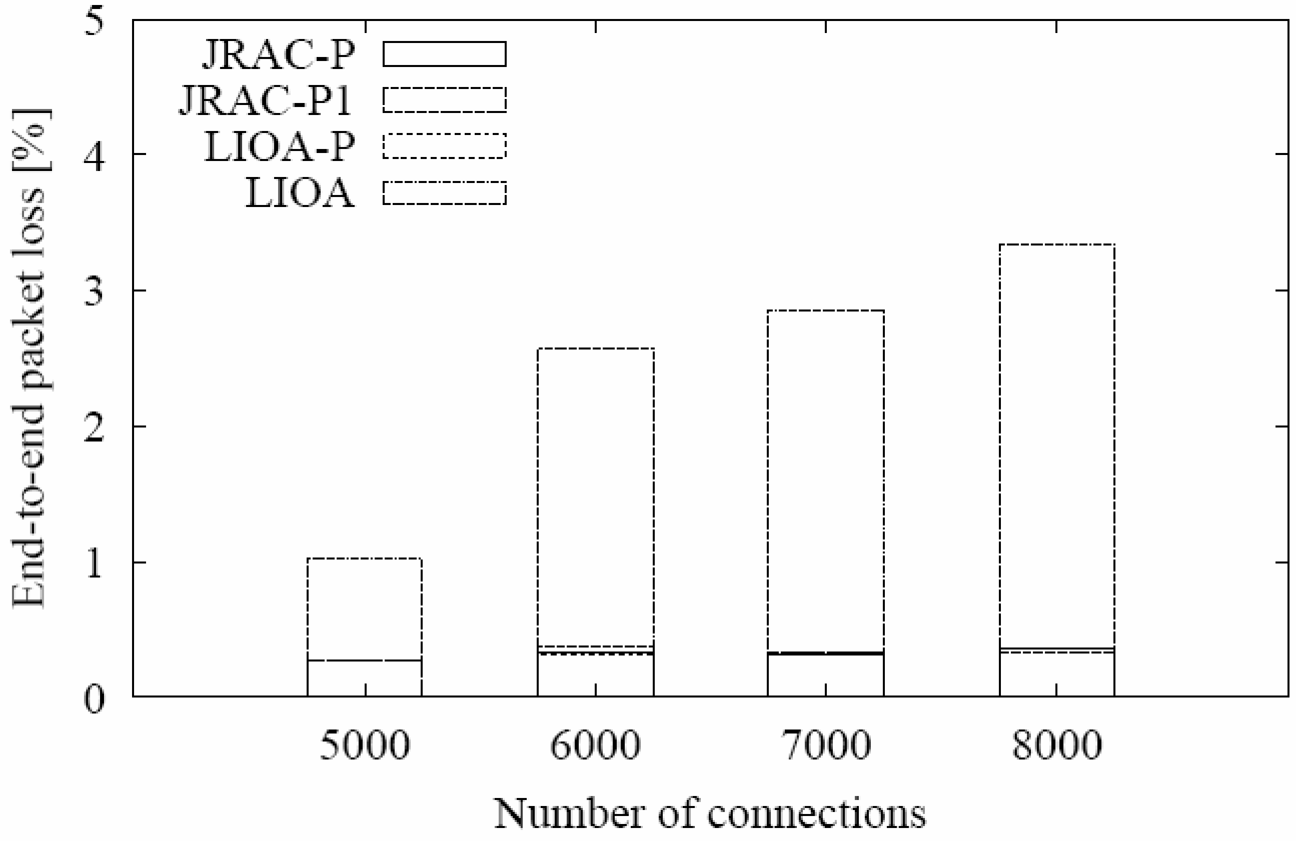
- JRAC-P is compared to three algorithms.
  - LIOA with an additional end-to-end packet loss constraint for the new flow.
  - LIOA-P: LIOA with additional end-to-end packet loss constraints for all flows;
  - JRAC-P1: JRAC-P with one LSP (i.e, h=1).

Numerical results (cont'd)



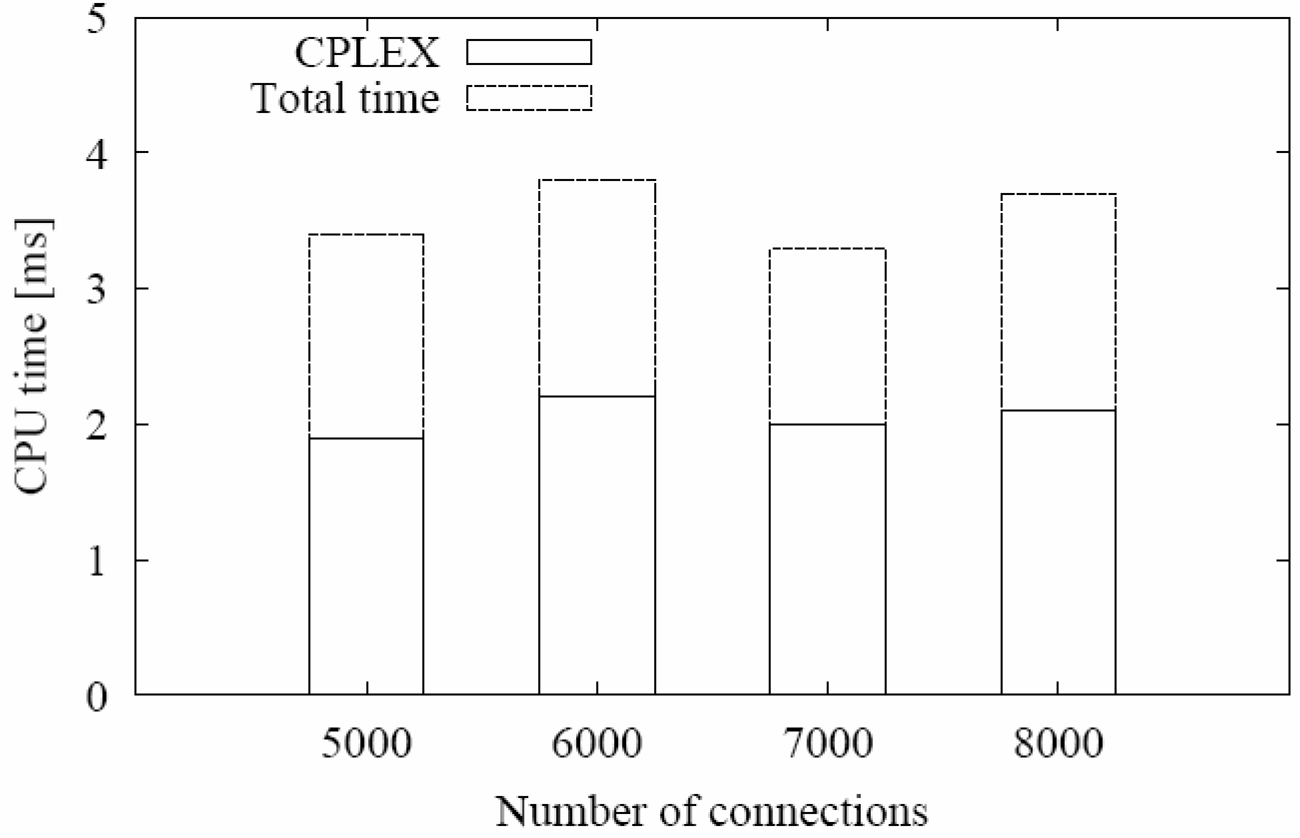
Flow blocking rate for $k = 288$ (MIRA network)

Numerical results (cont'd)



End-to-end packet loss for $k = 288$ (MIRA network)

Numerical results (cont'd)

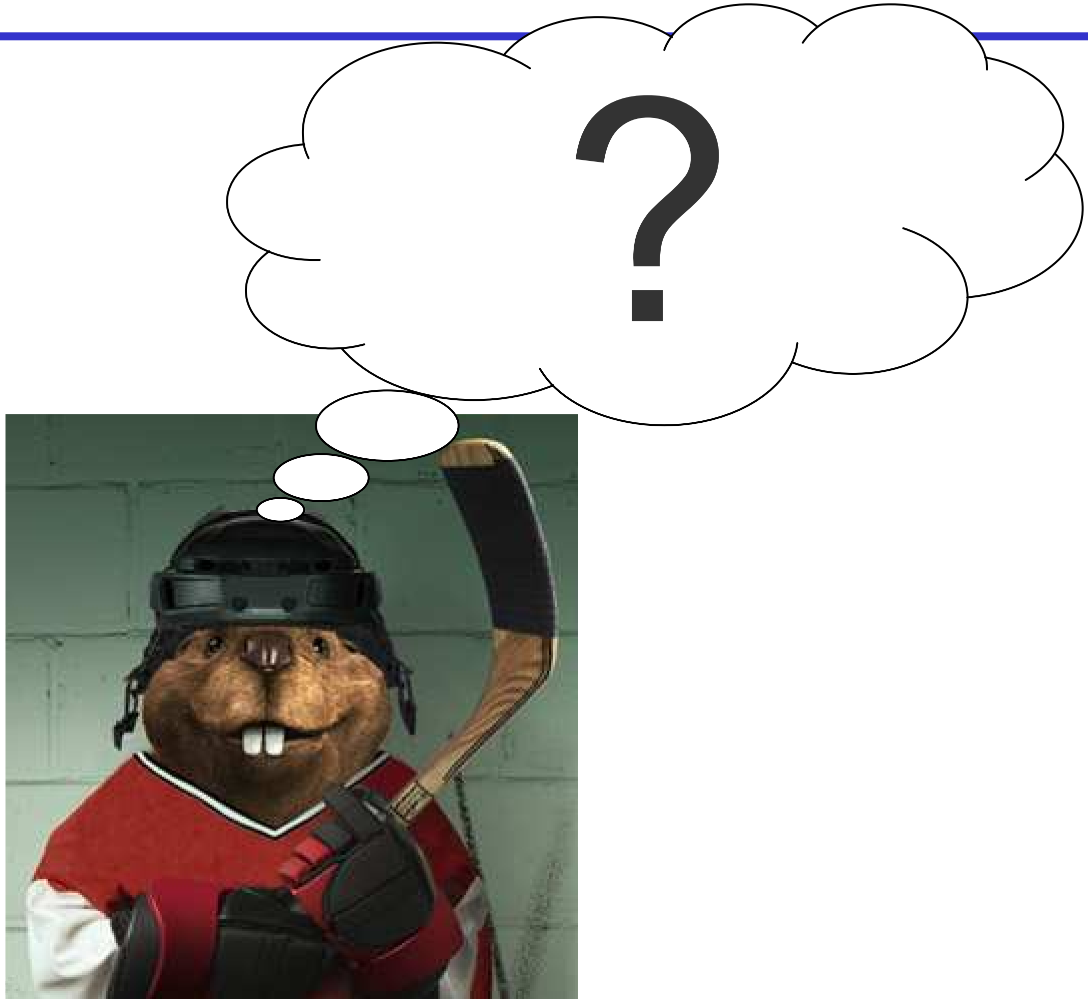


CPU execution time for JRAC-P ($k = 800$) (MIRA network)

Conclusions

- In this paper, we have proposed to solve the dynamic JRAC for the IP traffic flows in MPLS networks without rerouting the already admitted flows.
- Two models have been proposed for this problem.
- The numerical results have demonstrated that the proposed approach can offer less flow blocking rate and reduce significantly the mean end-to-end delay (or the mean end-to-end packet loss rate).
- The proposed approach is able to make the decision to admit or not a new flow rapidly (a few milliseconds).

Questions



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