# Performance evaluation of a Bayesian decisor in a multi-hop IP over WDM network scenario

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# Outline

- Motivation
- Problem statement
  - Utility functions
  - Cost function
  - Risk function
- Numerical results and discussion
  - Decisor dynamics experiment
  - On the influence of the decisor's parameters
- Contributions

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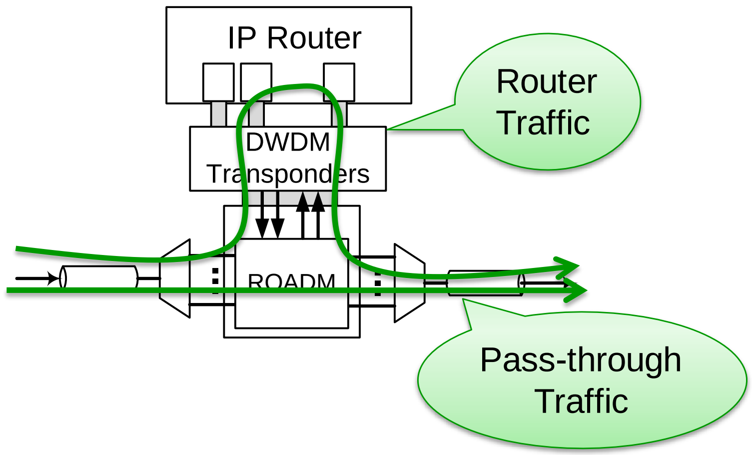
# Motivation

- Current backbone networks are migrating to an IP over WDM scenario.
- In such scenario, a multilayer-capable router has to decide whether to perform optical or electronic switching.




**Design premises**

(1) IP equipment is already deployed, so let's go to use it.

- When a proper service is not provided → establish an e2e lightpath.

(2) The longer the light-path is, the more congestion is reduced at the IP layer.

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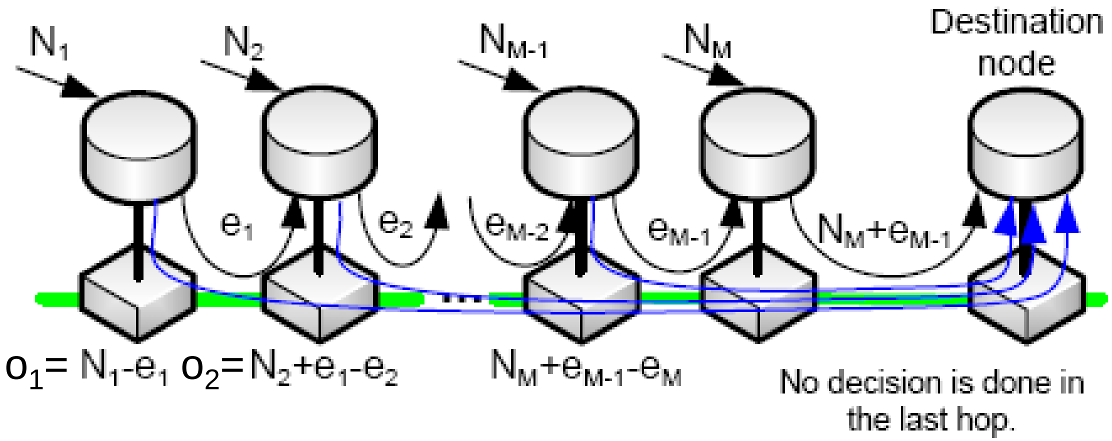
# Problem Statement

- There three key aspects in our model:
  - Utility functions
  - Cost function
  - Risk function
- The multi-hop scenario used is:




**$N_j$** → Number of incoming LSPs at node j
**$e_j$** → LSPs switched via electronic layer.
**$o_j$** → LSPs transmitted using e2e connections

# Utility function definition

- Definition:
  - Utility associated to a delay of x units of time, experienced by the electronically switched LSPs.
- Assumptions:
  - The queuing delay is assumed to be Weibull distributed. [9-11]
  - In this light the probability distribution function is [9]:

$$
\begin{aligned}
p(x) &= \frac{s}{r^s} x^{s-1} \exp\{-\left(\frac{x}{r}\right)^s\}, x \geq 0 \\
s &= 2 - 2H \\
r &= \frac{1}{C}\left(\frac{2K(H)^2 ame}{(C-me)^{2H}}\right)^{\frac{1}{2-2H}}
\end{aligned}
$$

    - Where:
      - m: input traffic mean, C: link capacity, H: Hurst parameter, $am=\sigma^2$, e number of LSPs.

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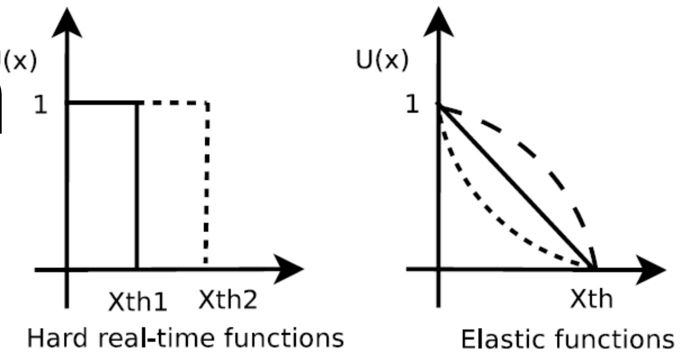
# Utility function definition




- We define three utility functions:
  - **Average delay based utility**
    - The utility function is opposite to the end to end delay from the node *j*: $x_j^{e2e}$.

$$U_{mean}(x_j^{e2e}) = -x_j^{e2e}$$

  - **Hard real-time utility**
    - Hard real-time applications are those which tolerate a $T_{max}$ delay.
      - » ITU-T Y.1541 [12] and 3GPP S.R0035 [13] defined service classes based on thresholds.

$$U_{\text{step}}(x_j^{e2e}) = \begin{cases} 1, & \text{if } x_j^{e2e} < T_{\max} \\ 0, & \text{otherwise} \end{cases}$$

  - **Elastic utility**
    - Services, which are degraded little by little, till they reach $T_{max}$.
      - » Exponential function used to describe the degradation of elastic services.
      - » G.107 "E model" [14], for voice service degradation.

$$U_{\exp}(x_j^{e2e}) = \lambda e^{-\lambda x_j^{e2e}}$$

$$\lambda = \frac{1}{T_{\max} \log(1-\alpha)}$$

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# Cost function definition

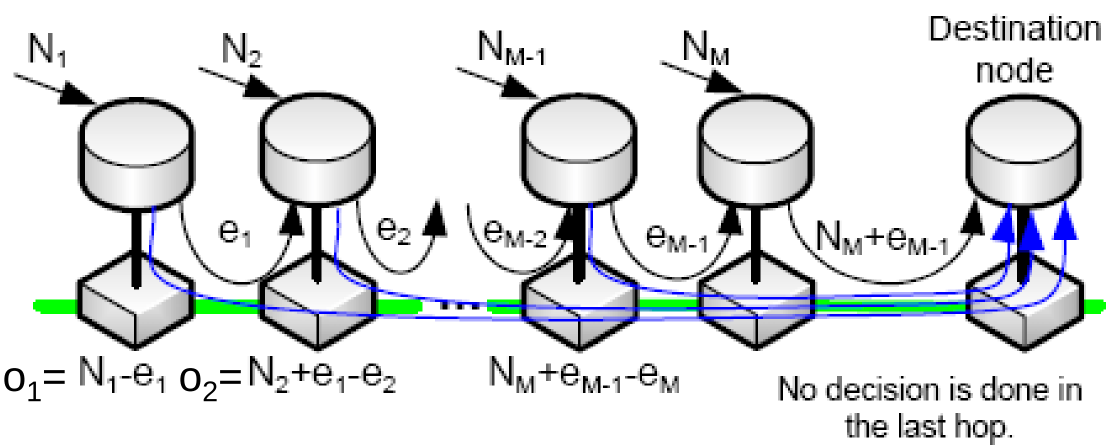
- Definition: $C_T(\vec{e}) \quad = \quad C_e(\vec{e}) + R_{\text{cost}} C_o(\vec{e})$
  - $C_e(e)$ and $C_o(e)$ represent the cost associated to switching $e$ LSPs in the electronic domain and $N - e$ in the optical domain.
    - where $R_{cost}$ is the relative utilization cost of the optical and electronic resources.
  - The cost of transmitting a LSP per hop is $\frac{(k+1)}{k}$
    - Where $k$ is the path length. $\frac{k+1}{k} > \frac{l+1}{l}, \forall k < l$
    - If M is the maximum number of nodes, the cheapest hop is $\frac{M+1}{M}$
      - » Design premise (2)
  - To firstly route at the IP layer → $R_{\text{cost}} > \frac{2 \cdot M}{M+1}$
      - » Design premise (1)

# Cost function definition

- The cost expresion yields:

$$C_e(\vec{e}) = \sum_{j=1}^{M} 2e_j$$

$$C_o(\vec{e}) = \Big((M+1)(N_1 - e_1) + \sum_{j=2}^{M-1} (M-j+2)(N_j - e_j + e_{j-1})\Big)$$

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# Risk function definition

- The Bayes risk is defined as:

$$R(\vec{e}, x_j^{e2e}) \quad = \quad K_c C_T(\vec{e}) - K_u \sum_{j=1}^{M} \mathbb{E}_x \left[ U(x_j^{e2e}) \right],$$
$$x_j^{e2e} \geq 0$$

- Where $C_T(\vec{e})$ is the cost function and $U(x_j^{e2e})$ is the utility function.
- $K_c$ and $K_u$ are normalization constants to define the decision when the system operates at maximum network load ($N_{max}=C/m$).

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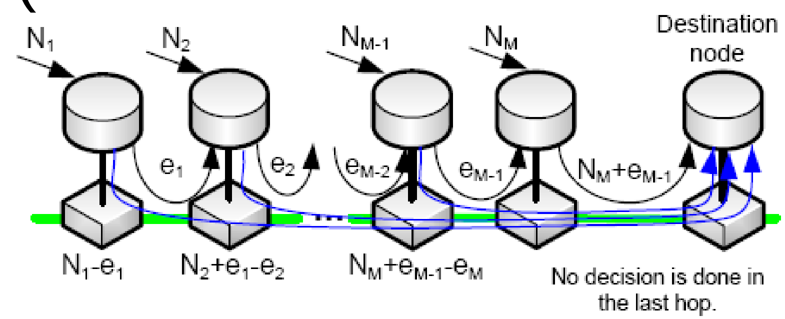
# Scenario definition

- M=3 (number of hops)
- 2.5 Gbps network link.
- Demands standard VC-3 LSPs ($m$ = 34.358 Mbps).
  - $N_{max}$ = 72
- Hurst parameter: $H$ = 0.6 [15]
- $\sigma/m$ = 0.3.
- $R_{cost}$=2
- $T_{max}$= 80ms ($U_{exp}$) and 5ms ($U_{step}$)




- Normalization:
  - When $N_{max}$ incoming LSPs, the hop-by-hop electronic connection transmits 70% of the traffic, that is 50 LSPs.
  - This policy can be adjusted by the network operator as necessary.

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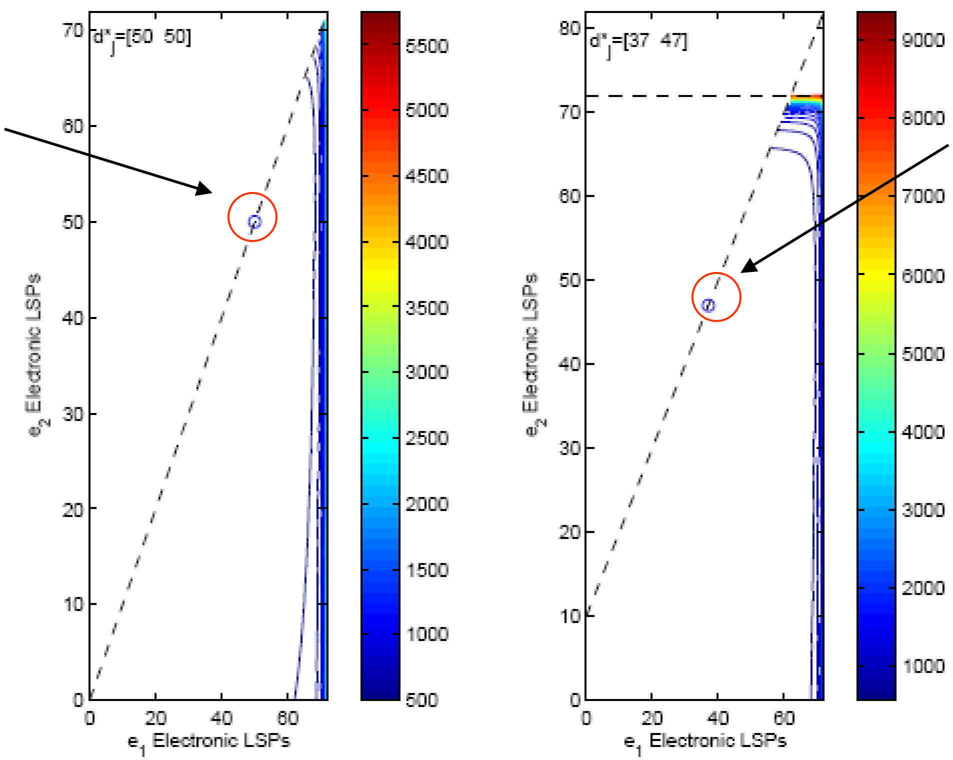
# Decisor dynamics experiment

- Risk level curves

$N_1$=72, $N_2$=0 $N_1$=72, $N_2$=10

Without cross-traffic the solution is $e_1$=50, $e_2$=50, thus is the normalization point.




With cross-traffic the decisor sends less traffic at the first hop ($e_1$=37)

$U_{mean}$

**The other utility functions are not shown for lack of time**

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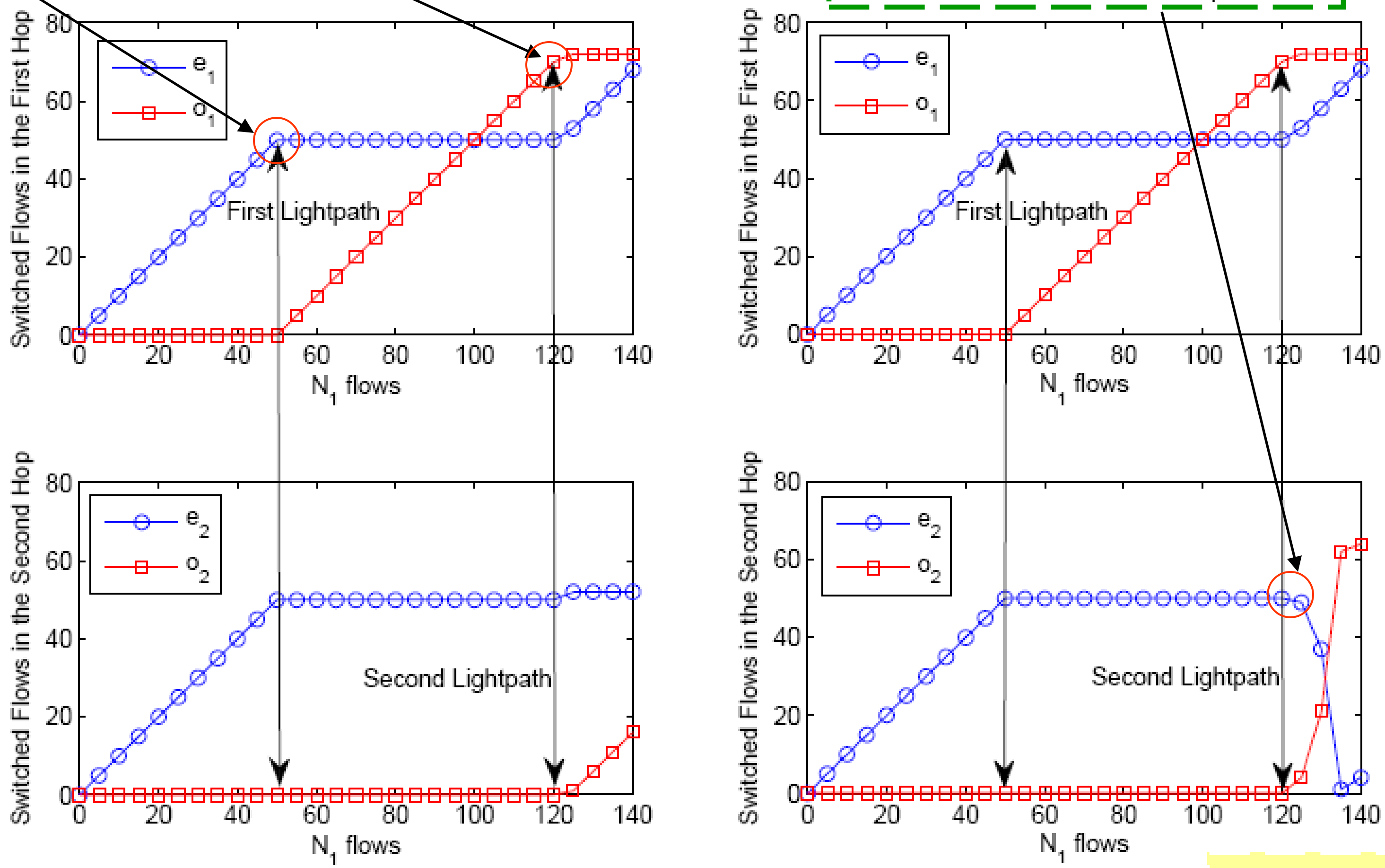
# Traffic increment in the first node

Normalization point.

$N_{max}$ limit is reached.

The first hop is so congested that no more delay is possible a real time service ($U_{step}$)



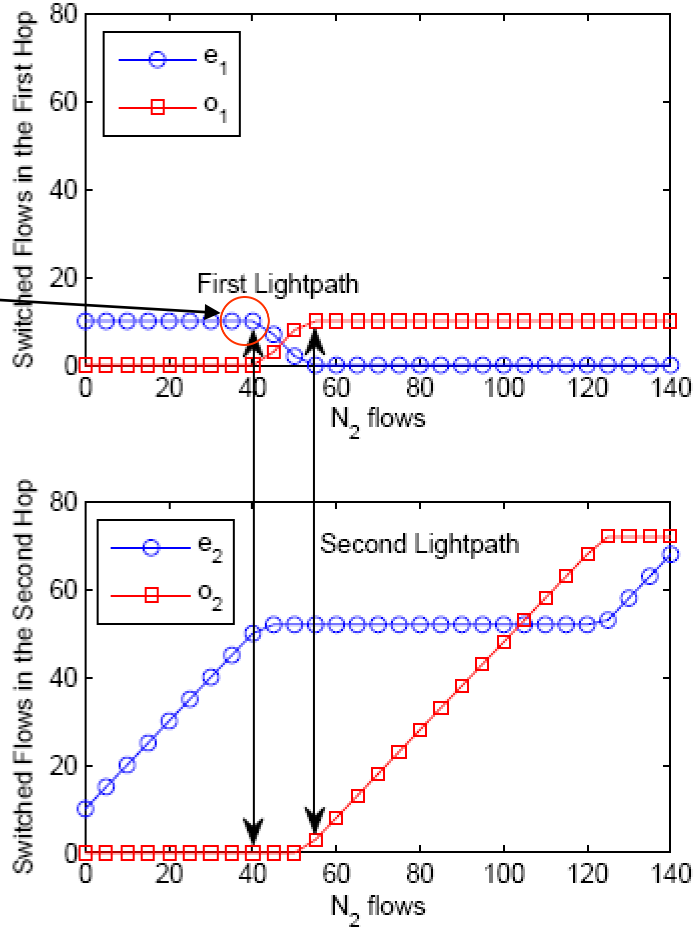

(a) *U*mean (b) *U*step

**Uexp similar to Umean results in the article**

# Traffic increment in the second node

- The first node injects $N_1$=10 and the second node increases its load.

As the second node is congested, so an e2e connection is used.




**Similar results for the other utilities**

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# $R_{cost}$ variation

- $R_{cost}$ variation 1.6, 2 and 3.
  - The higher $R_{cost}$ is the less number of LSPs are switched optically.
  - $U_{step}$ optimal working point does not depends on $R_{cost}$, but on the QoS

| | | $N_1 = 60, N_2 = 0$ | | | $N_1 = 60, N_2 = 10$ | | |
|---|---|---|---|---|---|---|---|
| | | $U_{\mathrm{mean}}$ | $U_{\mathrm{step}}$ | $U_{\mathrm{exp}}$ | $U_{\mathrm{mean}}$ | $U_{\mathrm{step}}$ | $U_{\mathrm{exp}}$ |
| $R_{\mathrm{cost}} = 1.6$ | $e_1^*$ | 33 | 50 | 32 | 17 | 41 | 16 |
| | $e_2^*$ | 33 | 50 | 32 | 27 | 51 | 26 |
| $R_{\mathrm{cost}} = 2$ | $e_1^*$ | 50 | 50 | 50 | 37 | 42 | 37 |
| | $e_2^*$ | 50 | 50 | 50 | 47 | 52 | 47 |
| $R_{\mathrm{cost}} = 3$ | $e_1^*$ | 58 | 51 | 58 | 54 | 49 | 54 |
| | $e_2^*$ | 58 | 51 | 58 | 55 | 52 | 55 |

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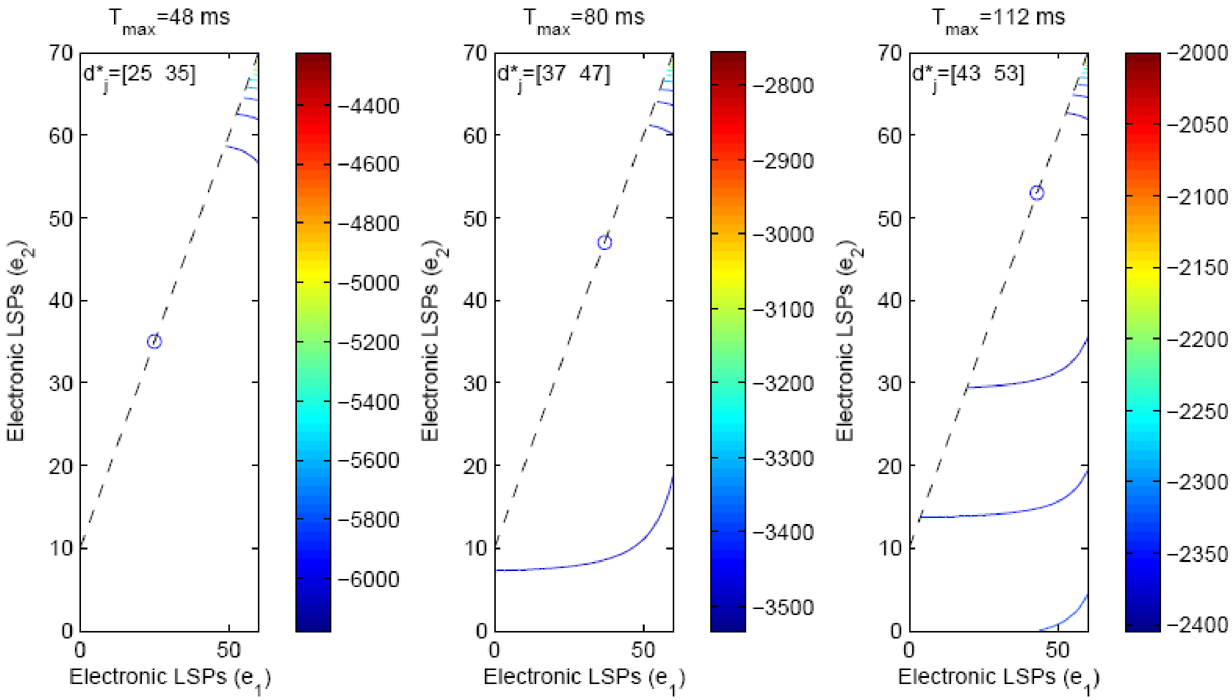
# $T_{max}$ variation

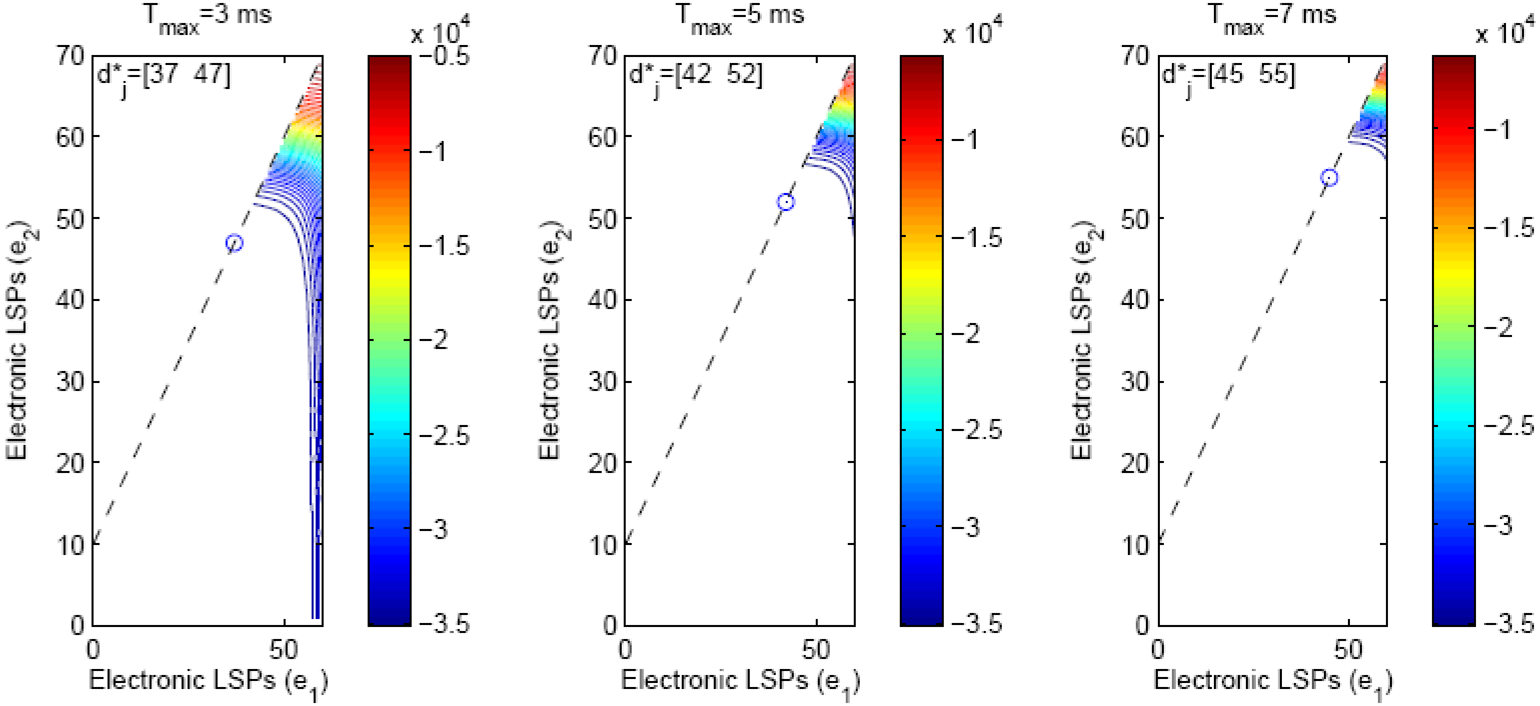
- Coarser QoS constraints → the more LSPs over the electronic layer.




$U_{exp}$

# $T_{max}$ variation

- $U_{step}$ has the same behavior than $U_{exp}$
- This parameter is related to the e2e QoS performance experienced by the LSPs




$U_{step}$

**Umean does not have any QoS parameter**

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# Contributions

- Novel methodology to deal with the utilization of the electronic and optical layers in a multihop scenario with multi-layer capable routers.
- Thanks to the $T_{max}$ and $R_{cost}$ parameters, the decisors dynamically can change its behaviour.
- Future work:
  - To define a full risk-oriented routing mechanism.
  - The provisioning of multiple services in the same network scenario

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# Thank you!!
# Questions?

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