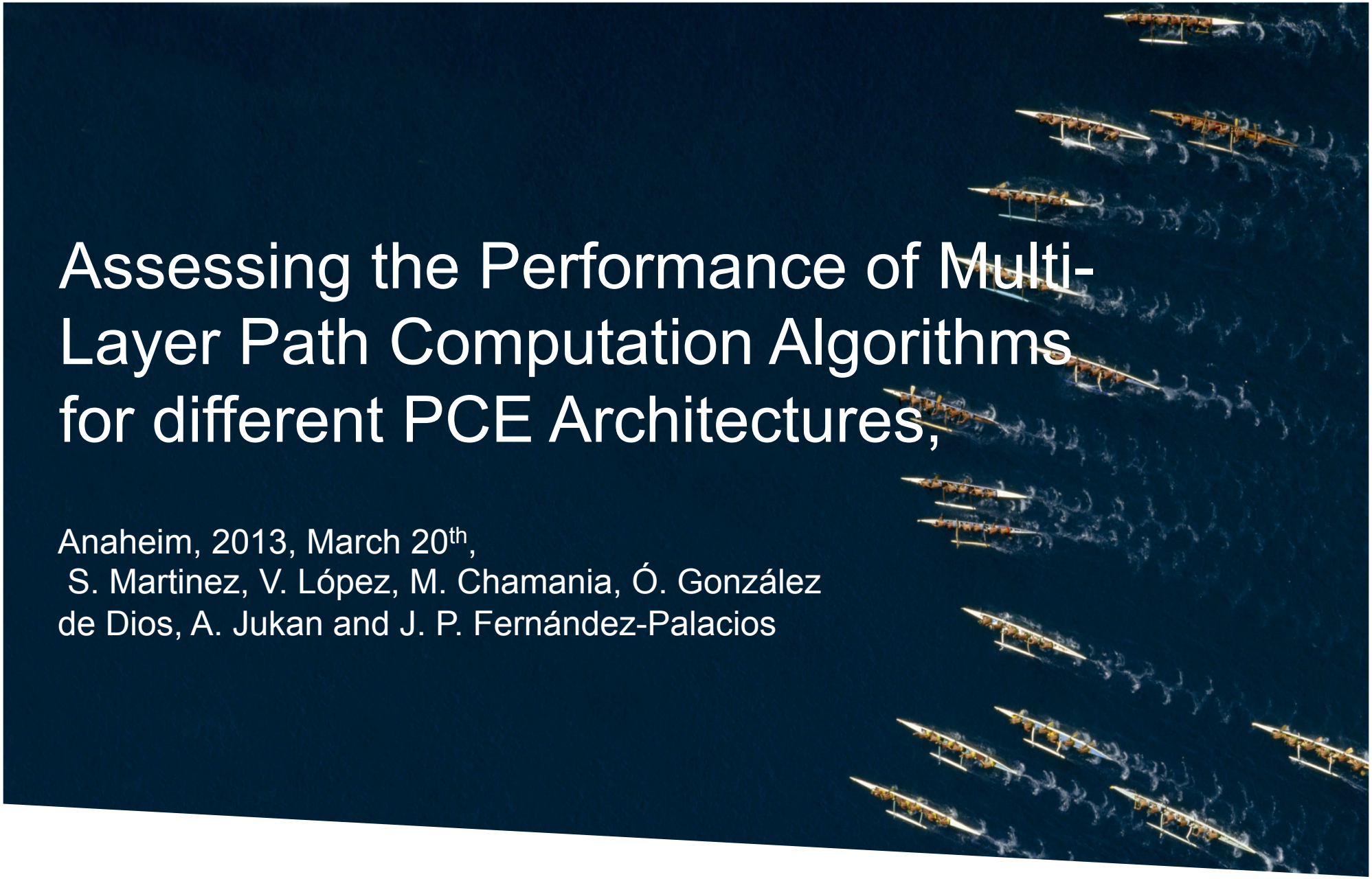

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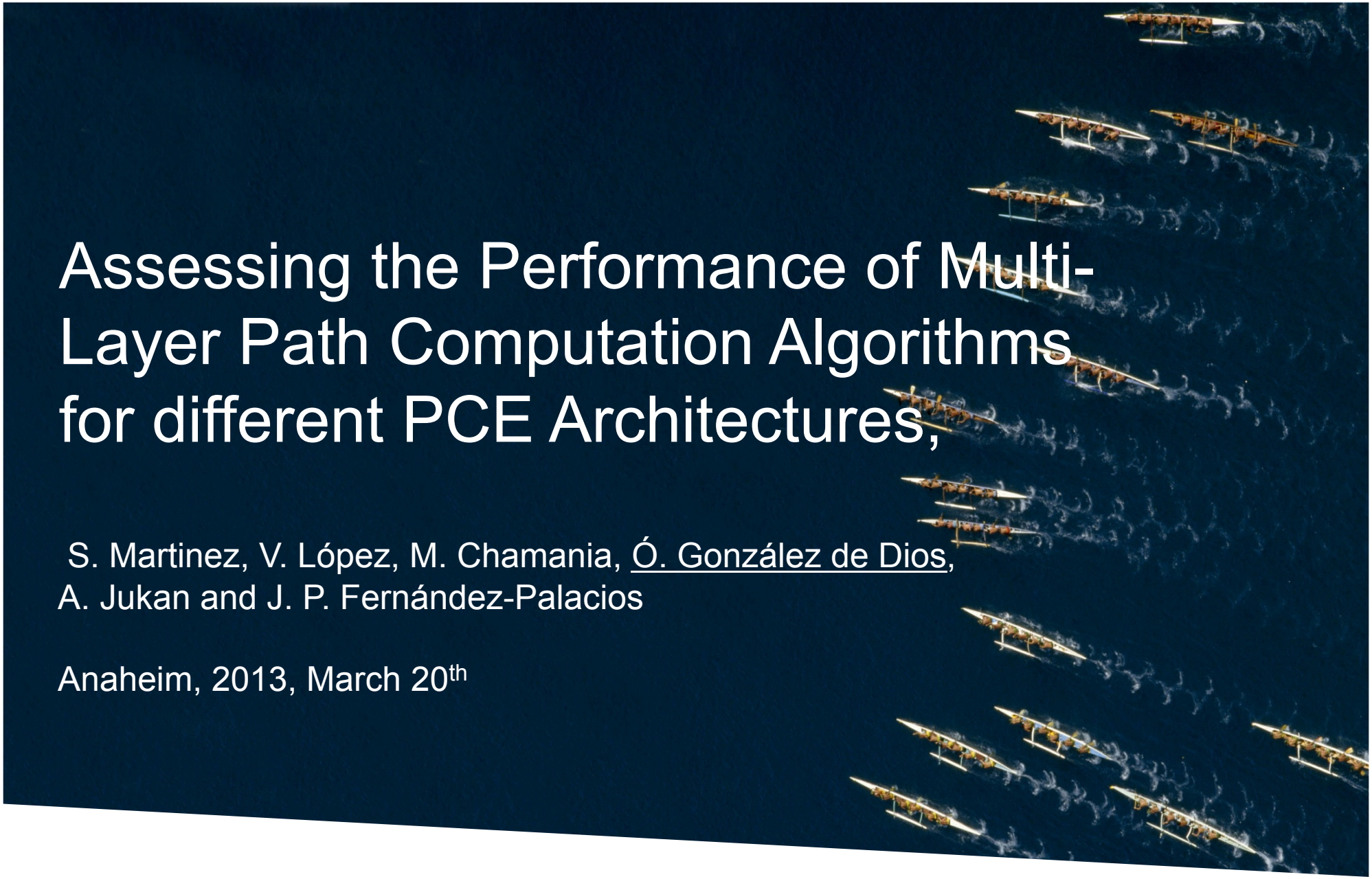

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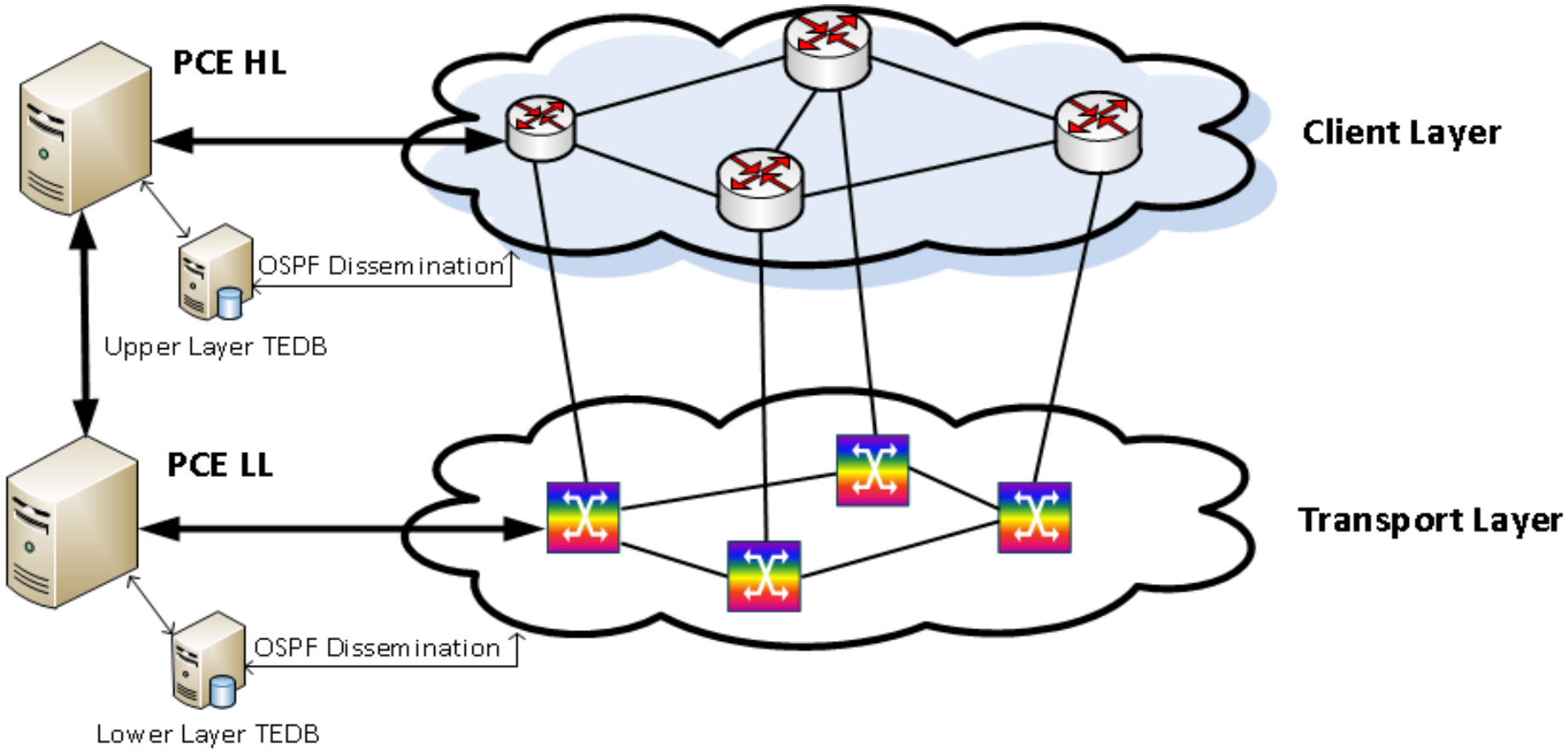
01

Introduction

Introduction

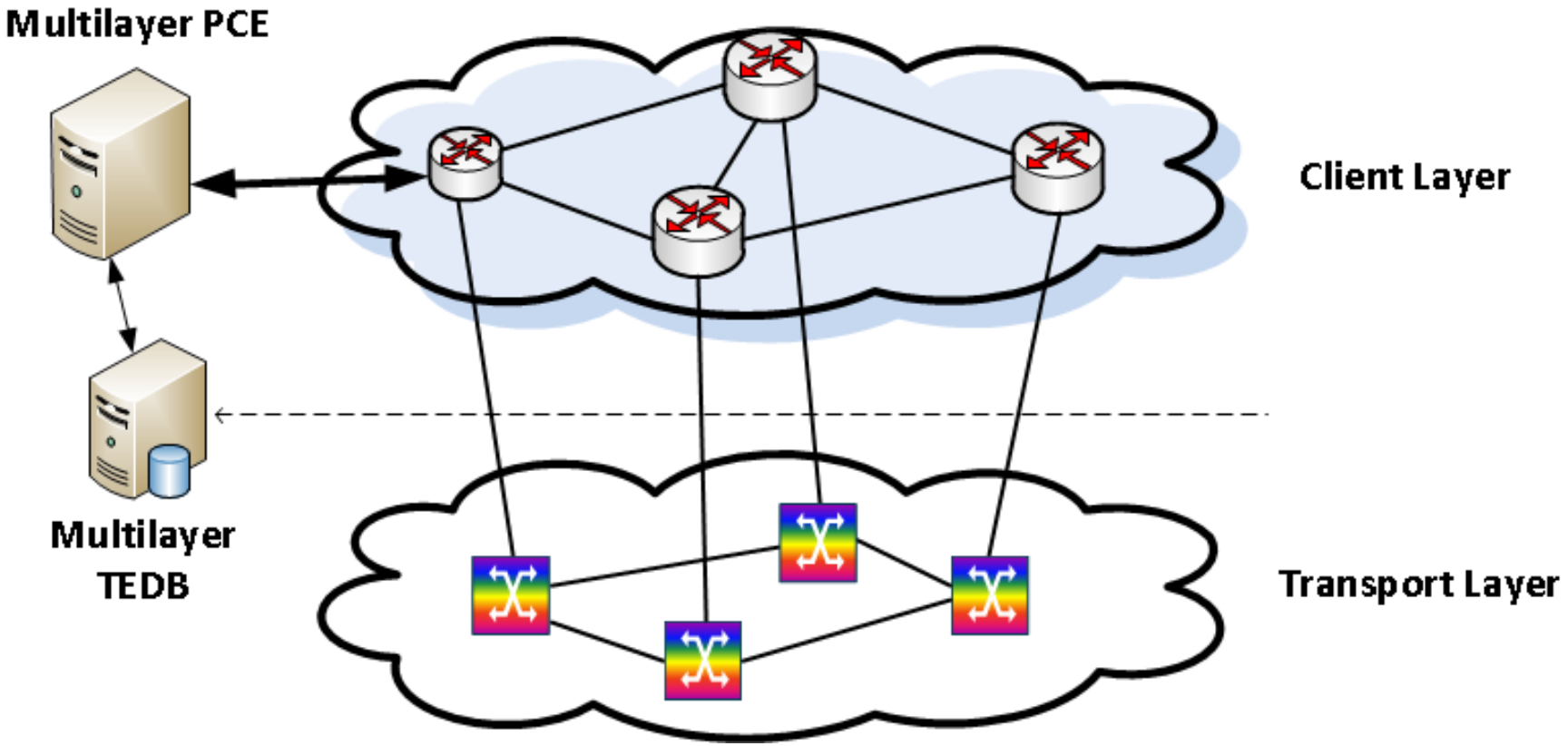
- A typical core network is based on an IP/MPLS network designed over a transport network (e.g. Wavelength-Switched Optical Network).
- Multi-layer interworking is considered to increase efficiency.
- Joint computation (IP/MPLS+WSON) is key.
- Path Computation Element: standard approach to solve the computation
- Two PCE-based schemes proposed to compute multi-layer paths:
  - Coordinated (multiple) PCEs solution: each layer has its own PCE.
  - Integrated(single) multi-layer PCE where a unique PCE has the complete multi-layer topology information.
- We have implemented PCE-based schemes and several algorithms.
- Performance is assessed in terms of blocking and computation delay

Cooperating PCEs scheme



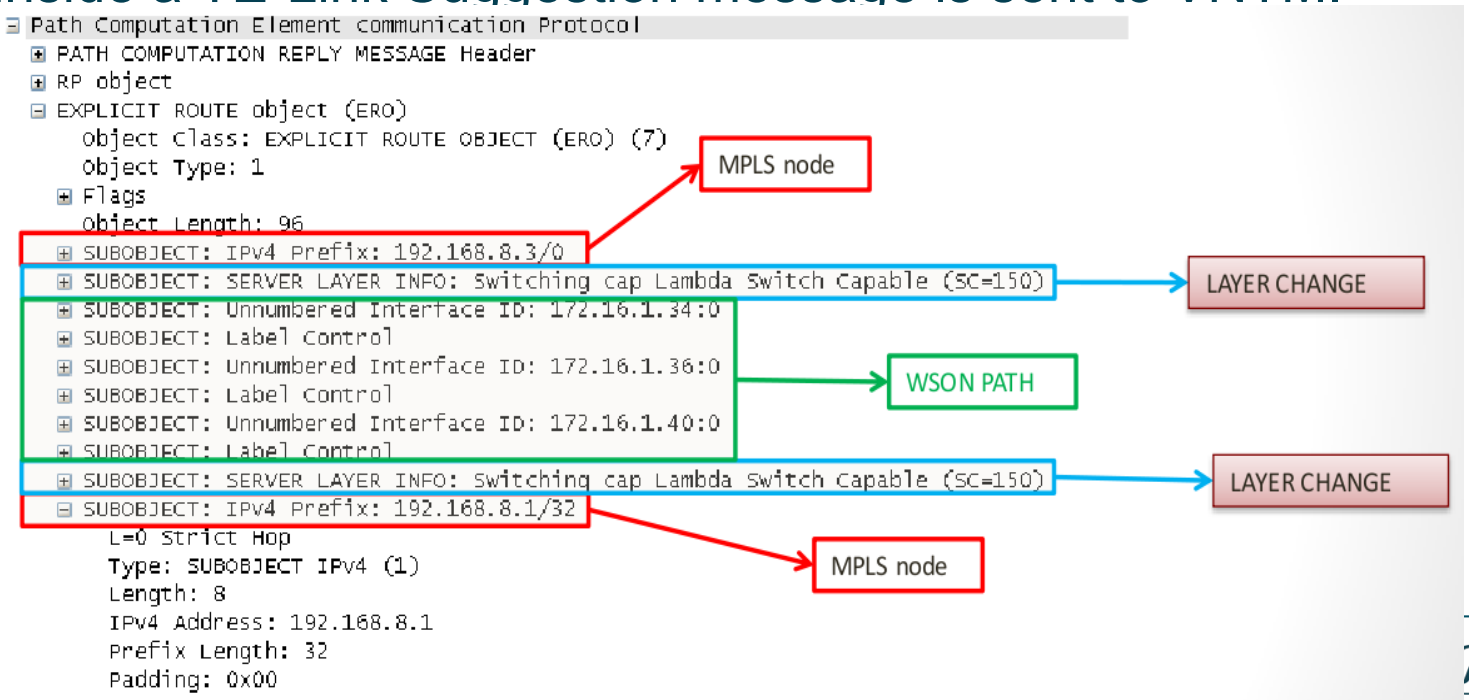
Multilayer PCE scheme

- Single multilayer graph to compute all the requests.



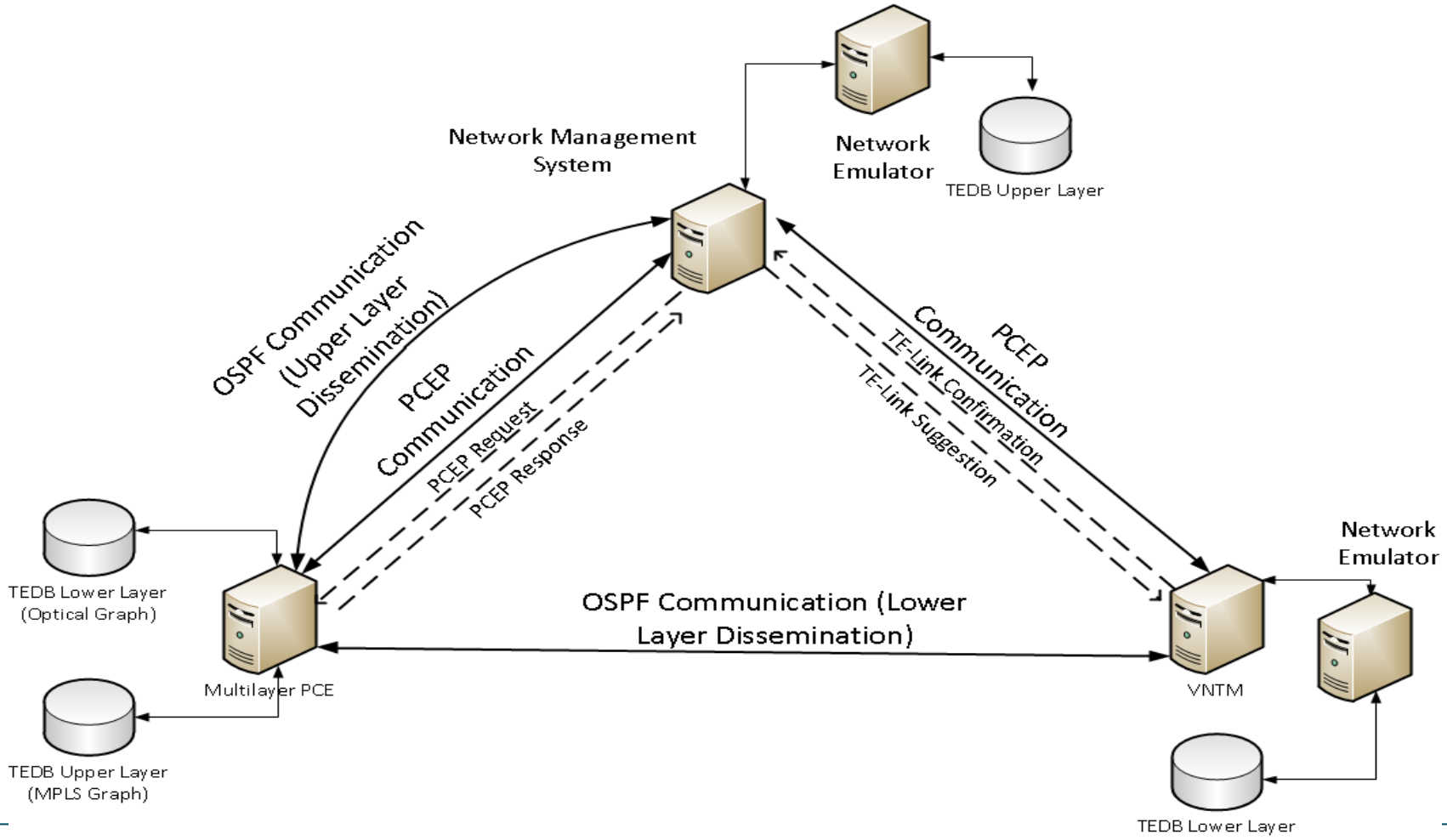
Multi-layer Paths

- ERO: Standard representation of a path.
- Multi-layer Path includes path in upper layer and paths in lower layer
- Multi-layer ERO: standard RSVP ERO subobjects and use the SERVER_LAYER_INFO sub-object to indicate a layer change.
- Virtual Network Topology Manager (VNTM) takes care of the establishment of lower layer paths
- ERO inside a TE-Link Suggestion message is sent to VNTM.

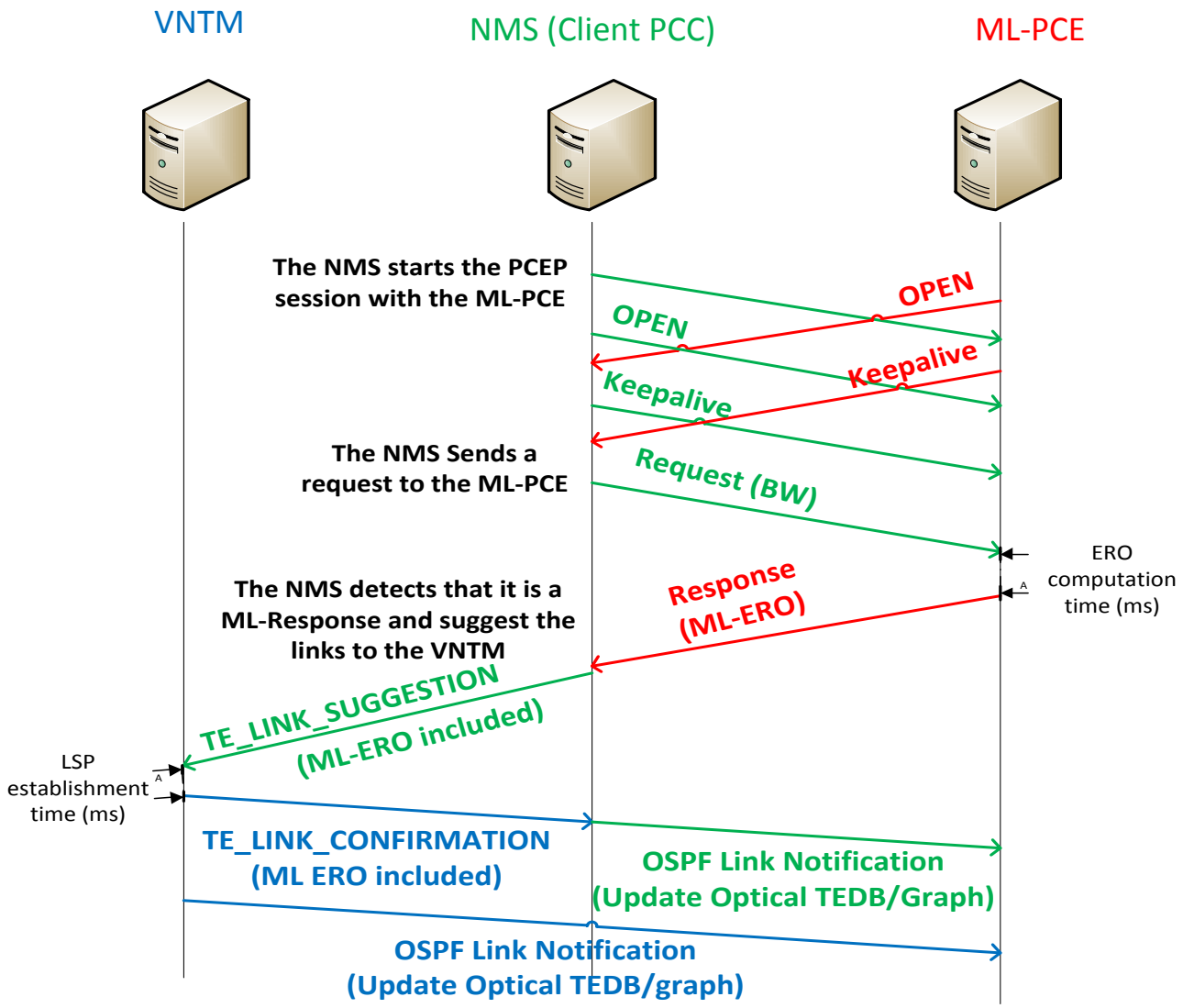


Emulated Setup

- Multi-layer PCE emulates the 2 modes (integrated and cooperation).
- Cooperation between PCEs demonstrated in Chamania *et al*. ICC 2012.



Message Exchange



02

Implemented ML Algorithms

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Implemented Algorithms: Two TEDBs Architecture

- Multi-layer path computation for a request in the client network can be reduced to a combination of one or more of four different operations:
  - **Operation 1:** Route the traffic onto an existing light-path directly connecting the source and the destination .
  - **Operation 2:** Route the traffic through multiple existing light-paths.
  - **Operation 3:** Set up a new light-path directly between the source and the destination and route the traffic onto this light-path.
  - **Operation 4:** Set up one or more light-paths that do not directly connect the source and the destination , and route the traffic onto these light-paths and/ or some existing light-paths.

H. Zhu, *et al*, "A novel generic graph model for traffic grooming in heterogeneous WDM mesh networks," IEEE/ACM Trans. , 2003.

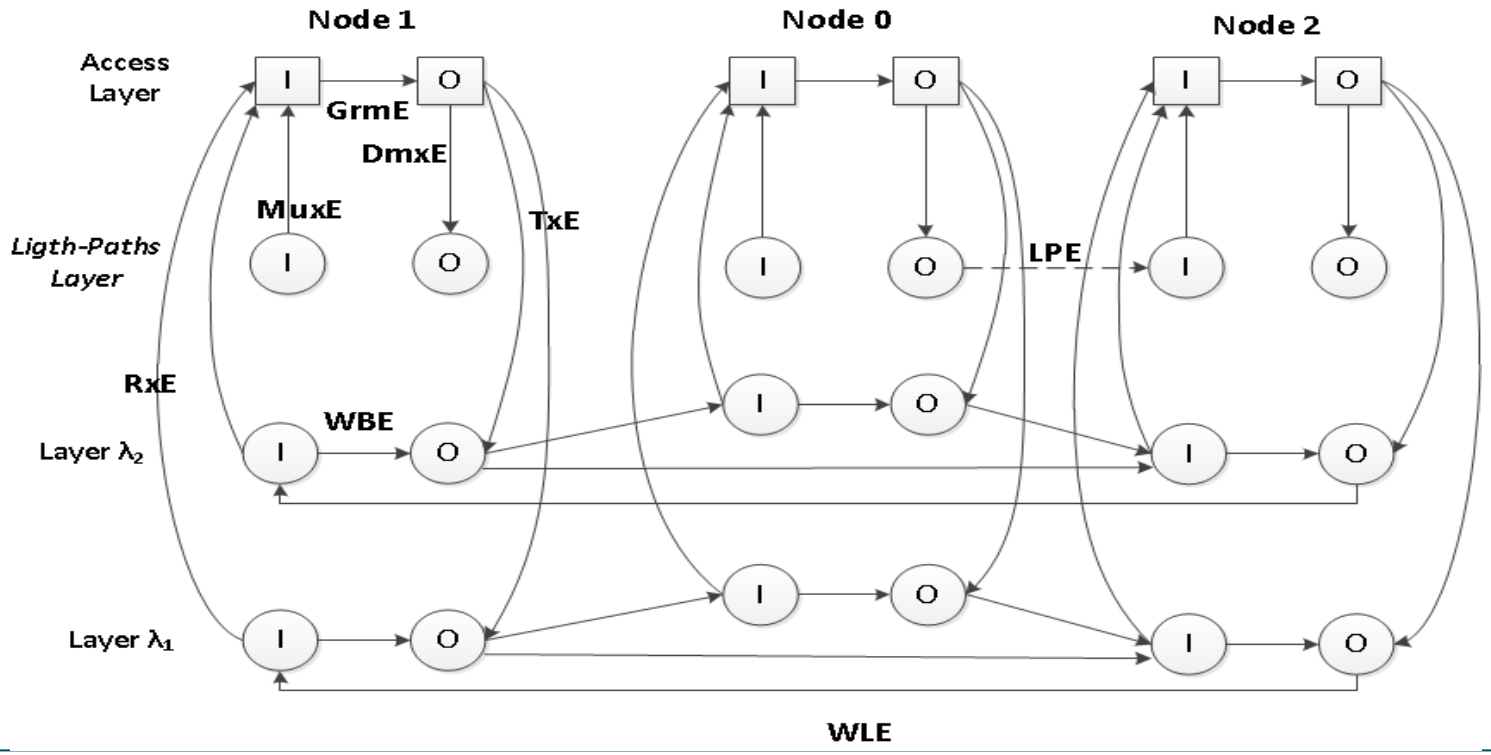
Implemented Algorithms : Two TEDBs Architecture

- The combination of the four operations leads us to the following algorithms for multilayer routing:

  - **Minimizing the Number of Traffic Hops (MinTH)**.
  - **Minimizing the Number of Light-paths (MinLP)**.
  - **Minimizing the Number of Wavelength-Links (MinWL).**

Algorithms Implemented: One TEDBs Architecture

- Multilayer auxiliary graph
- Different weights to the edges in order to reach the different grooming policies by applying K-shortest-paths to this graph.

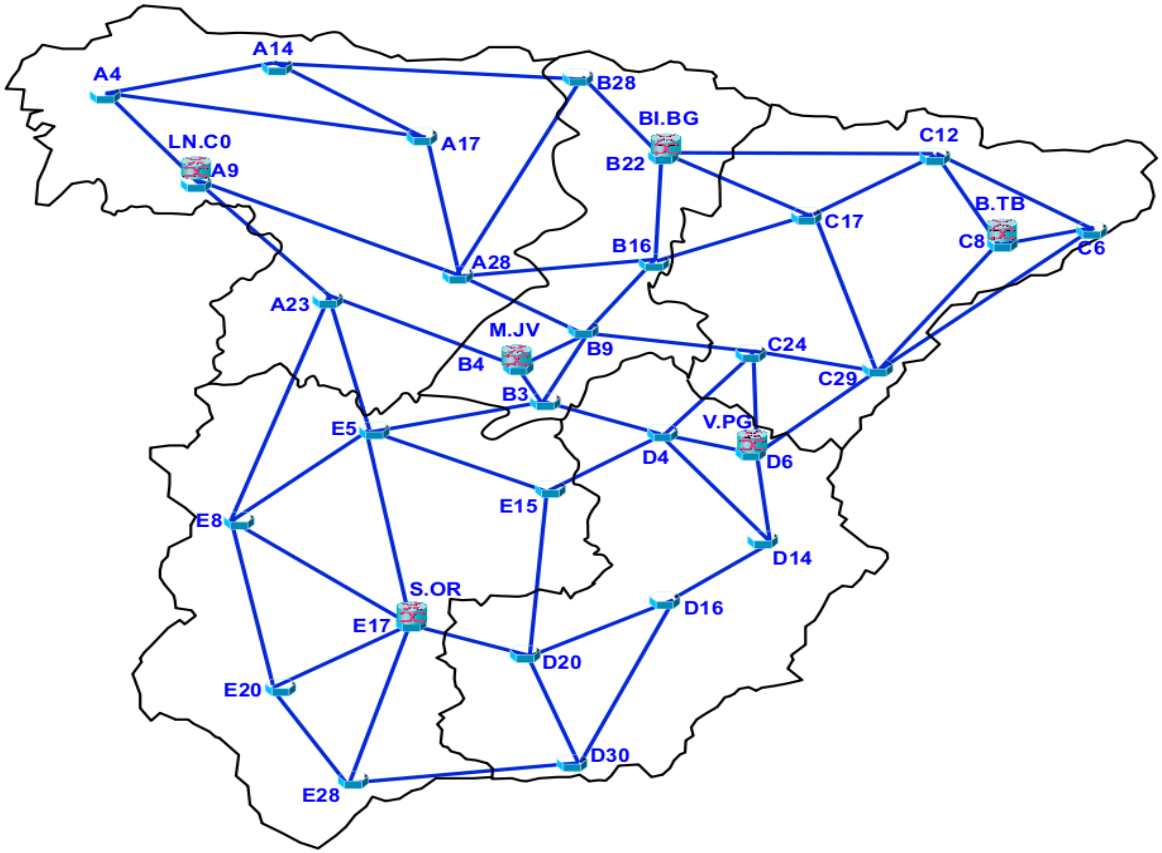


03

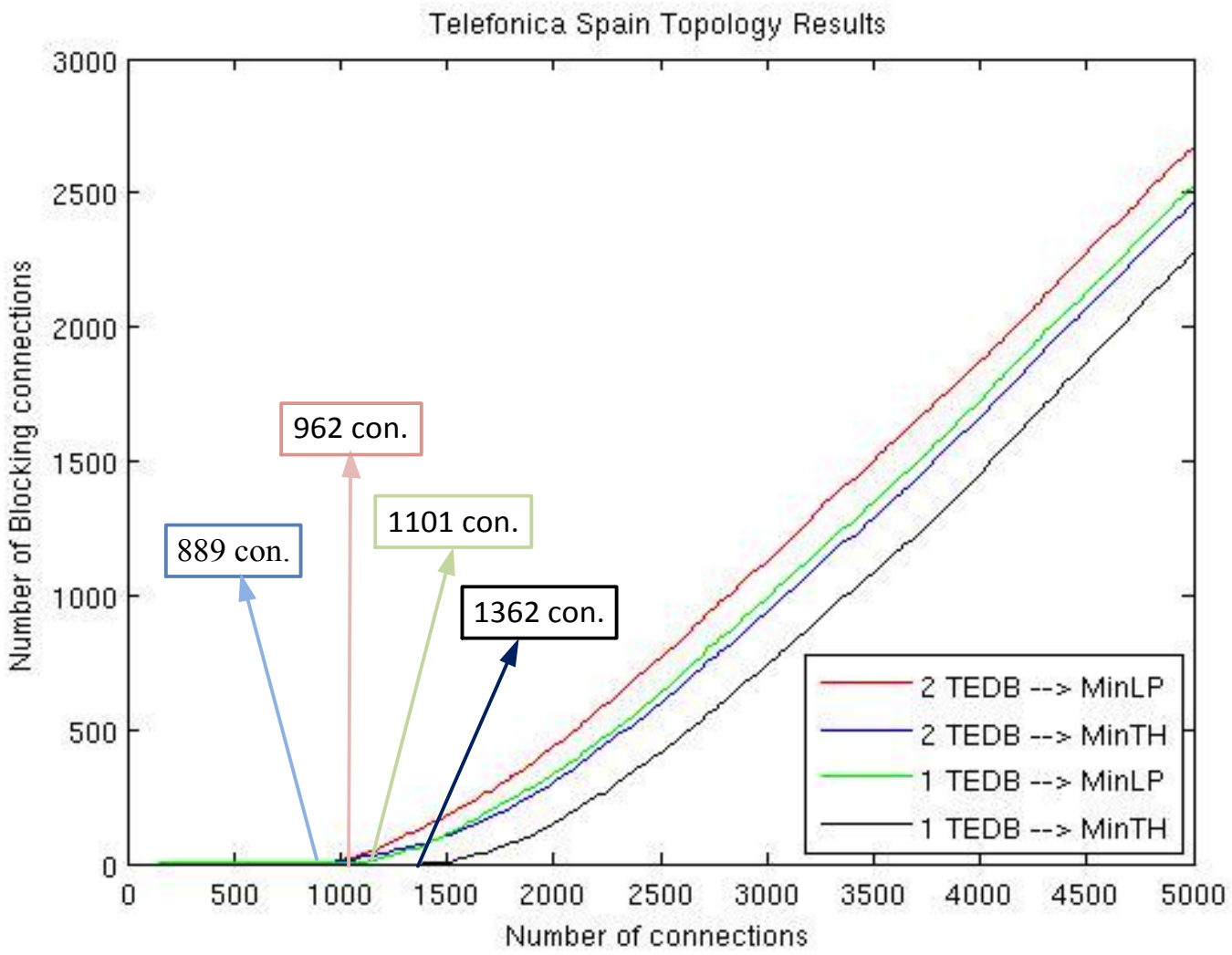
Results

Validation scenario

- Telefonica core Network Scenario:
  - Client Layer: MPLS (PSC).
  - Transport Layer: Optical/Lambdas (LSC).
    - 80 lambdas/fiber.
- Bandwidth requests:
  - 1-10 Gbps at MPLS layer.
  - Sequential requests.
  - Random order.

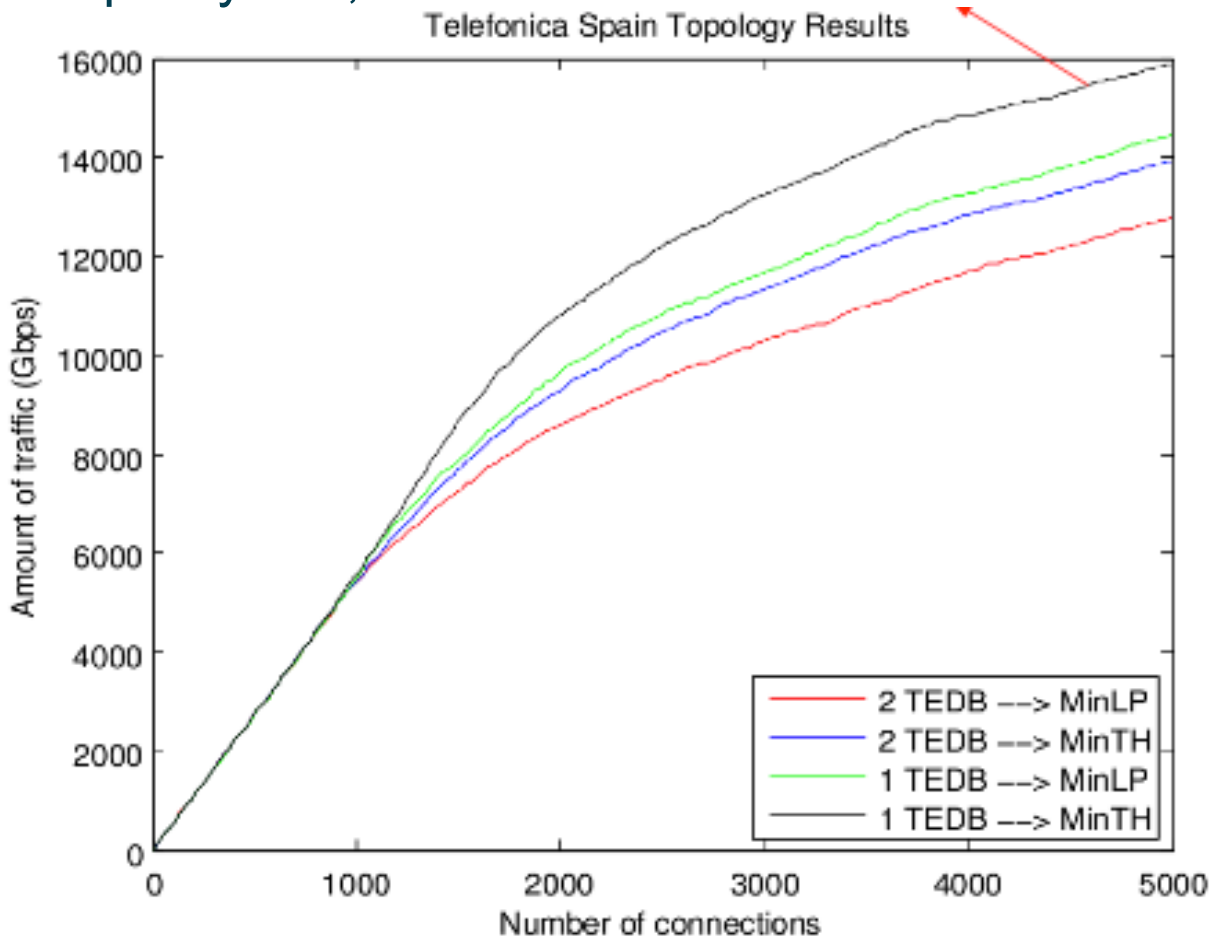


Evaluation of ML algorithms



Evaluation of ML algorithms (II)

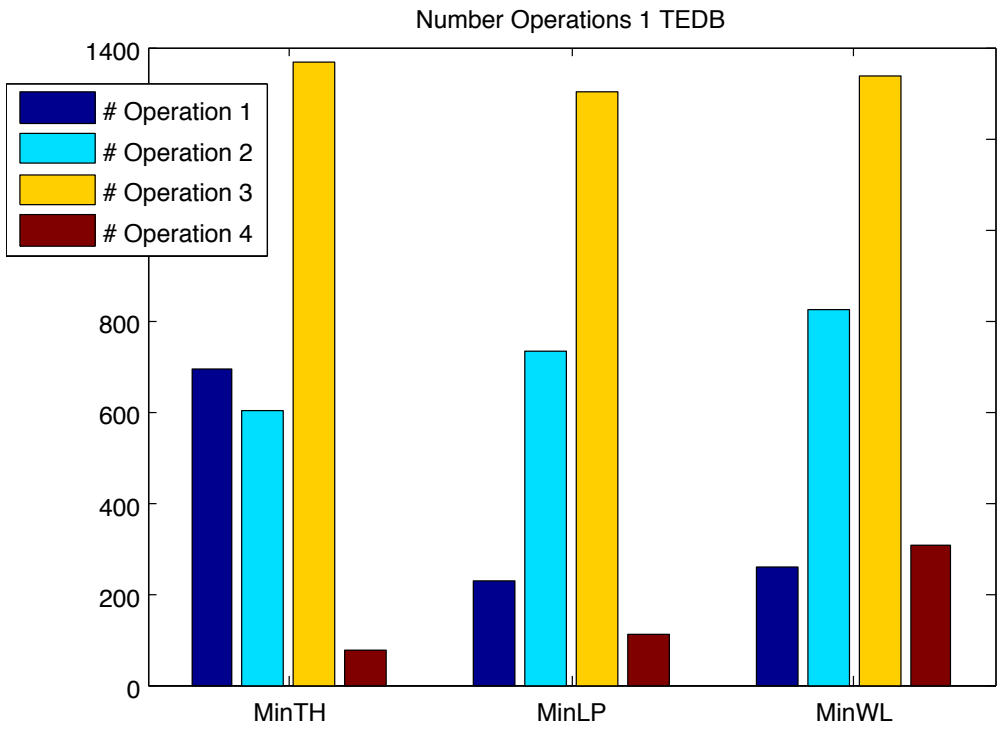
- MinTH policy can improve total capacity allocation by 13.91% when using a single PCE as compared to multiple PCEs while the increase in the MinLP policy is 9,97%.

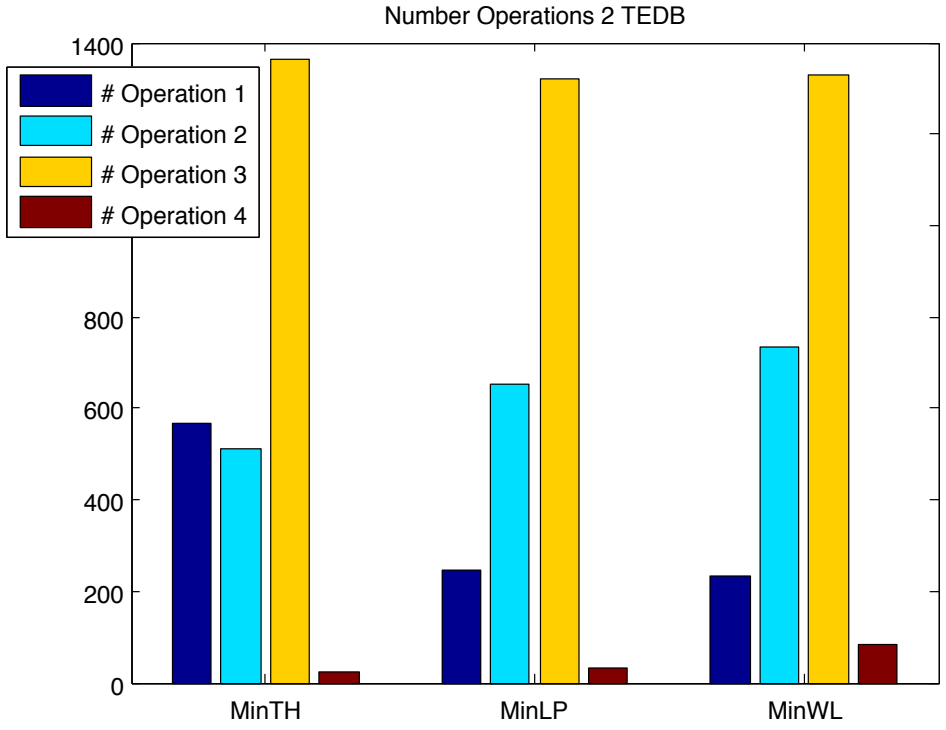


Computation time Evaluation

- Mean Computation time on Single ML PCE:
  - 54.32 ms MinLP, 53.57 ms MinTH
- Multiple PCE solution:
  - 29.15 ms MinLP, 27.19 ms MinTH
  - Additionally, delay between PCEs per each query (0 in this setup)
- Multi-layer PCE solution computation time bigger due to size of graph.
  - the PCE is running KSP in a large graph with N+1 layers (81 in this case).
  - KSP complexity increases linearly with number of arcs and nodes the computation time for this algorithm is much higher than in the case of
- Multiple PCE
  - Each PCEs runs their own KSP+First Fit.

Number of operations





- **In two TEDB case, interactions between PCEs is limited to one.**

05

Conclusions and Next Steps

Conclusions

- Multi-layer coordination is becoming an important requirement in network operators, due to its potential to reduce carrier's investments, network interventions and thus cost of operations.
- Multi-layer PCE is a key technology for multi-layer coordination and interworking.
- This work shows the performance achieved with full topological information or with partial information.
- Results show that integrated TED PCE can increase 13,91% bandwidth utilization in Spanish topology, but its computational time increases 49,24% in comparison with two coordinated TEDs per layer.

Algorithms Evaluation

- Use of resources in the network for the different algorithms in a non blocking static scenario (results for 400 requests):