

SRLG-Disjoint Multi-Path Protection: When LP meets ILP



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Multi-Path Routing: Motivation

Route the traffic via multiple parallel links or paths:

- Inverse Multiplexing (ATM and MPLS)
- Ethernet “Link Aggregation” (Bundling) of 2-8 channels (in IEEE 802.3ad)
- VCat (Virtual Concatenation) in ngSDH/SONET and OTN networks (with LCAS for protection)
- Network coding (Security + Resilience)

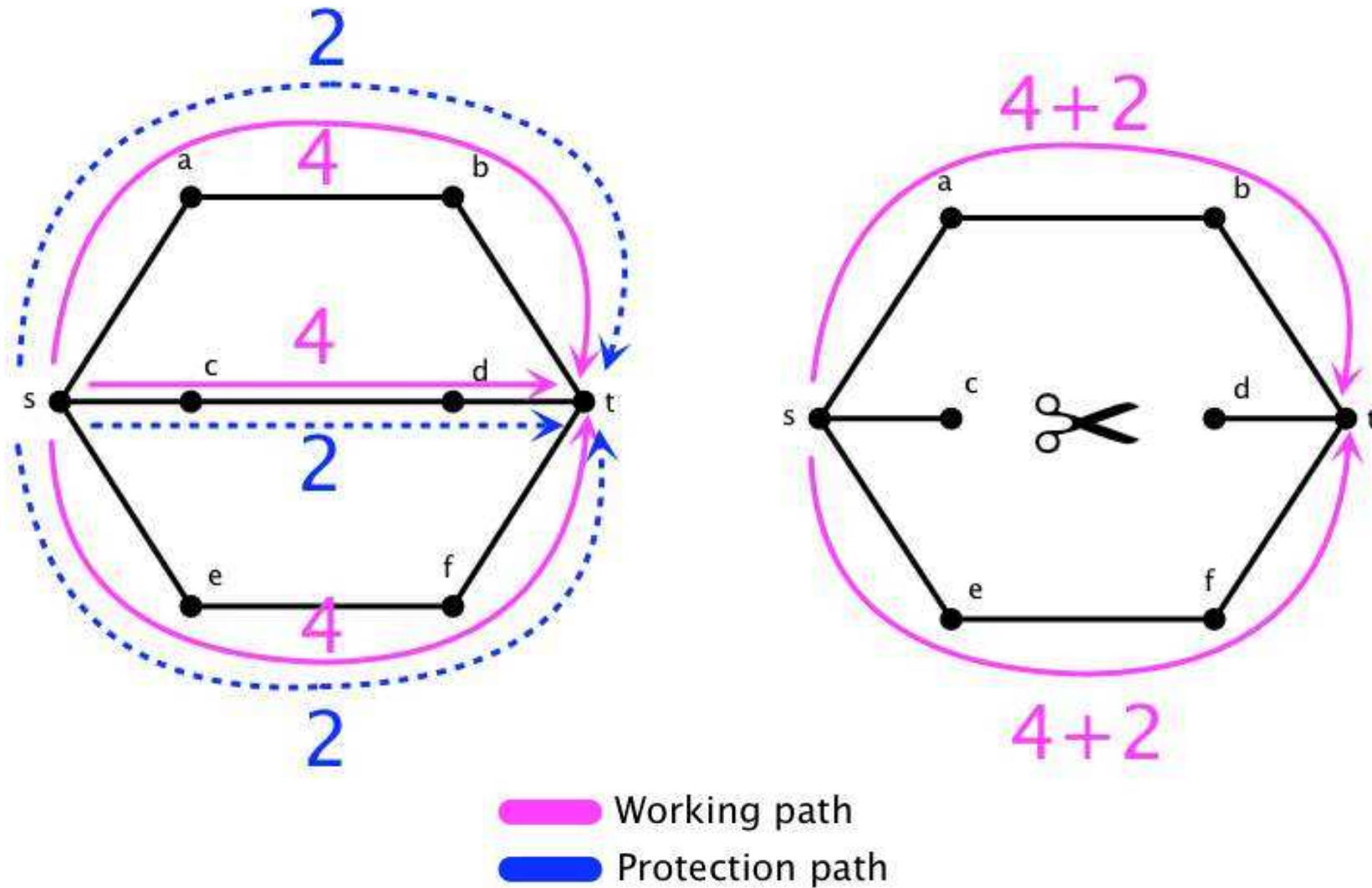
Improved version of the Multi-Path Protection resilience scheme

- *Linear Program (LP)*: the demand is routed and protected using multiple paths
- We are able to *avoid branching* of the flow between the end-nodes
- Network transformation model to *handle SRLG scenarios* (node-disjointness as well) without integer variables
- Solving the dedicated path protection problem with Multi-Path Protection
- *Fewer variables and constraints* in the LP formulation

Related Work

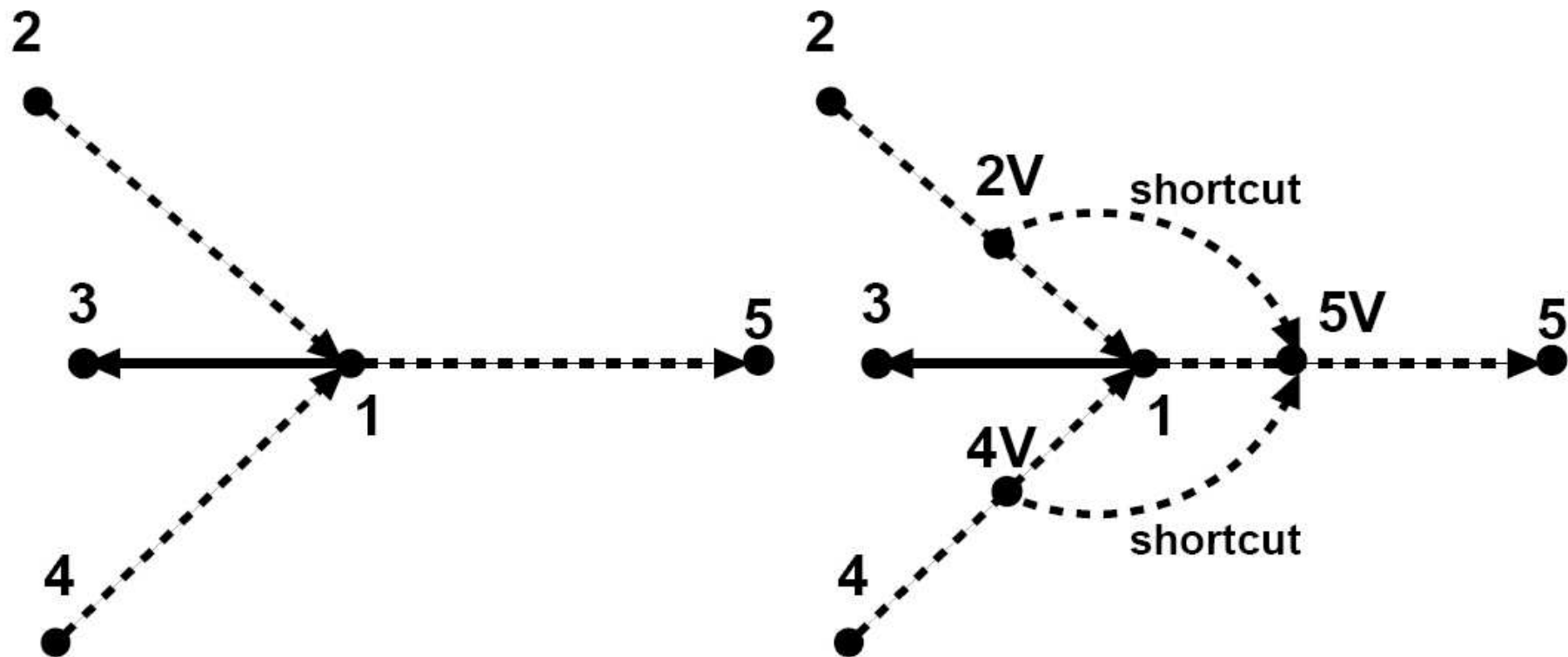
- First proposal of the idea of routing using multiple paths:
 - R. Bhandari, *Survivable Networks: Algorithms for Diverse Routing*, Norwell, MA, USA: Kluwer Academic Publishers, 1998.
- DSP: Demand-wise Shared Protection
 - The first proposal of DSP: Arie M.C.A. Koster, Adrian Zymolka, Monika Jäger, Ralf Hülsermann, Christoph Gerlach: *Demand-wise Shared Protection for Meshed Optical Networks*, DRCN 2003
 - An improved computational model for DSP and it's comparison with 1+1 and shared protection (path formulation with column generation): C. G. Gruber, A. M. C. A. Koster, S. Orłowski, R. Wessäly, A. Zymolka: *A Computational Study for Demand-wise Shared Protection*, DRCN 2005
- SPM: Self-Protecting Multipaths
 - Michael Menth, Andreas Reifert, Jens Milbrandt, “Self-Protecting Multipaths: A Simple and Resource-Efficient Protection Switching Mechanism for MPLS Networks,” in *NETWORKING 2004*, Apr 2004, pp. 526–537.

Multi-Path Protection: Example



Modeling Shared Risk Link Groups

Optimal allocation, where the edges in SRLG are connected at least one node



(a) Part of the original network

(b) The constructed network

Linear Program of Improved MPP

Variables:

$x_{ij} \geq 0$ flow over edge $ij \in E$
 x_{max} the maximum of x_{ij} over $\forall ij \in E$

Objective:

$$\min \sum_{\forall ij \in E} c_{ij} x_{ij} \quad (1)$$

Subject to:

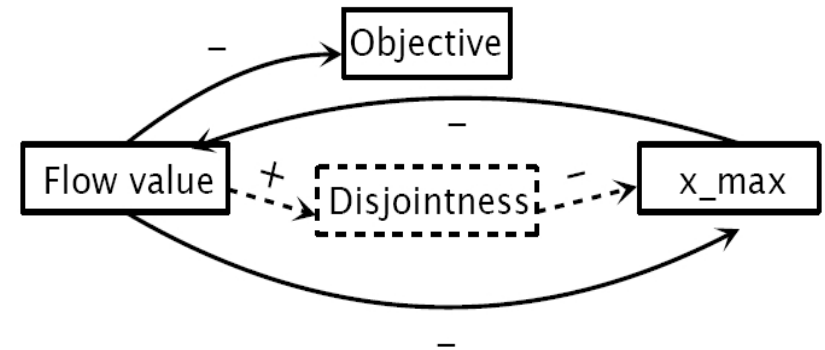
$$\sum_{\forall i \in E \rightarrow j} x_{ij} - \sum_{\forall k \in E^j \rightarrow} x_{jk} = \begin{cases} -b - x_{max} & \text{if } j = s \\ 0 & \text{otherwise} \\ b + x_{max} & \text{if } j = t \end{cases} \quad \forall j \in V$$

$$x_{ij} \leq x_{max} \quad \forall ij \in E \quad (3)$$

$$x_{ij} \leq B'_{ij} \quad \forall ij \in E \quad (4)$$

$$\sum_{\forall ij \in S} s_{ij} \cdot x_{ij} \leq x_{max} \quad \forall S \quad (5)$$

$$b \leq x_{max} \quad (6)$$

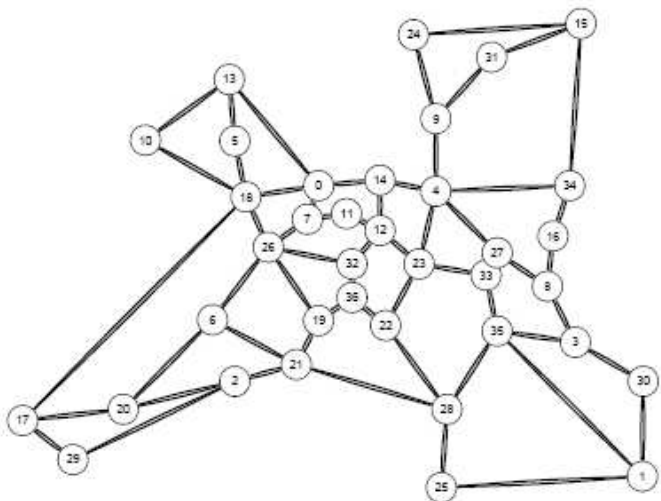


Properties of IMPP

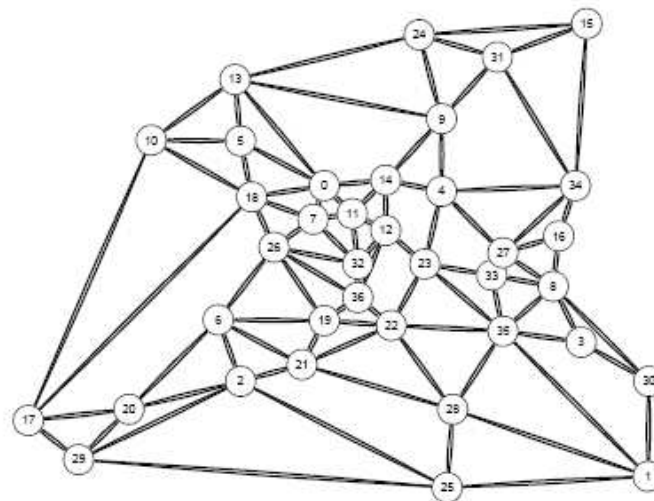
- LP instead of ILP!
- Low complexity
- Disjoint paths
- Handle a group of SRLG scenarios
- Fewer variables and constraints: common variable for working and protection capacities
- The number of the paths can be controlled

Networks used for simulations

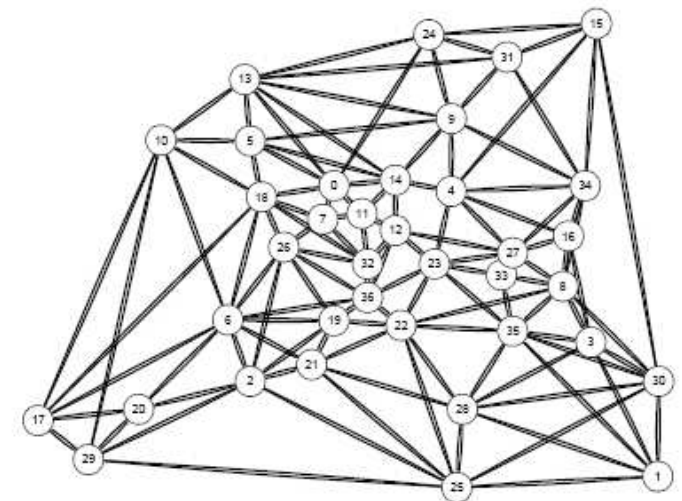
- COST 266 Large topology and derived topologies (37 nodes, 57 bidirectional edges)
- USA networks



(a) The COST266 LT Reference Network (RN).



(b) The COST266 LT RN extended by 30 links.

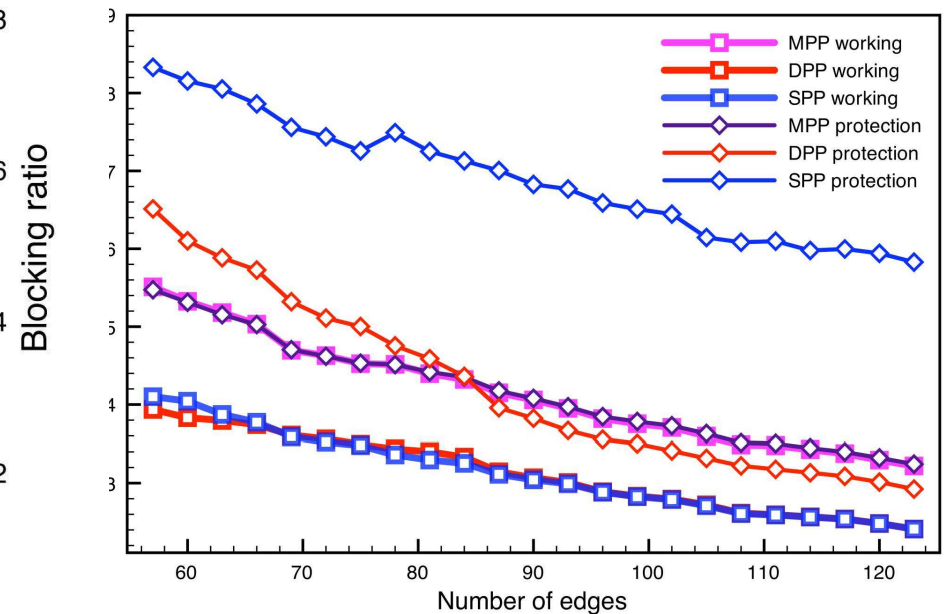
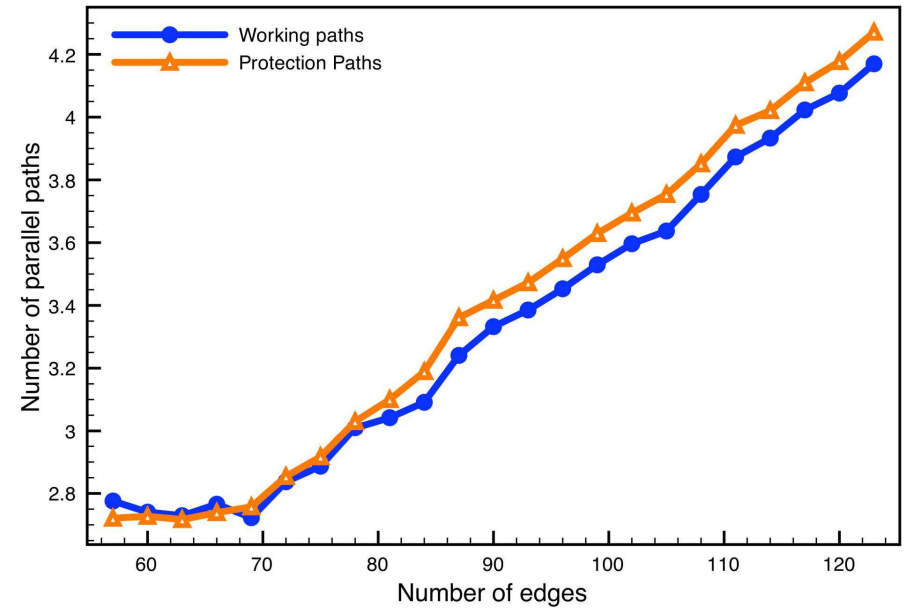
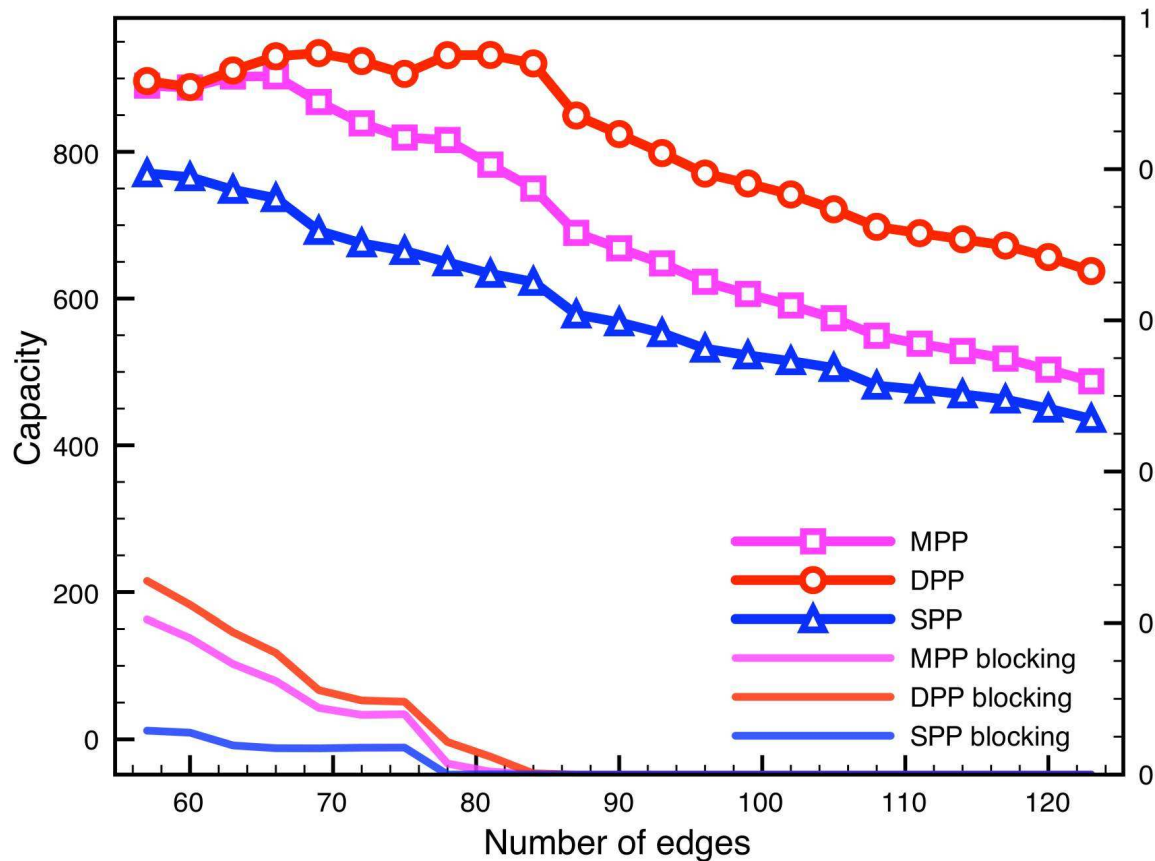


(c) The COST266 LT RN extended by 60 links.

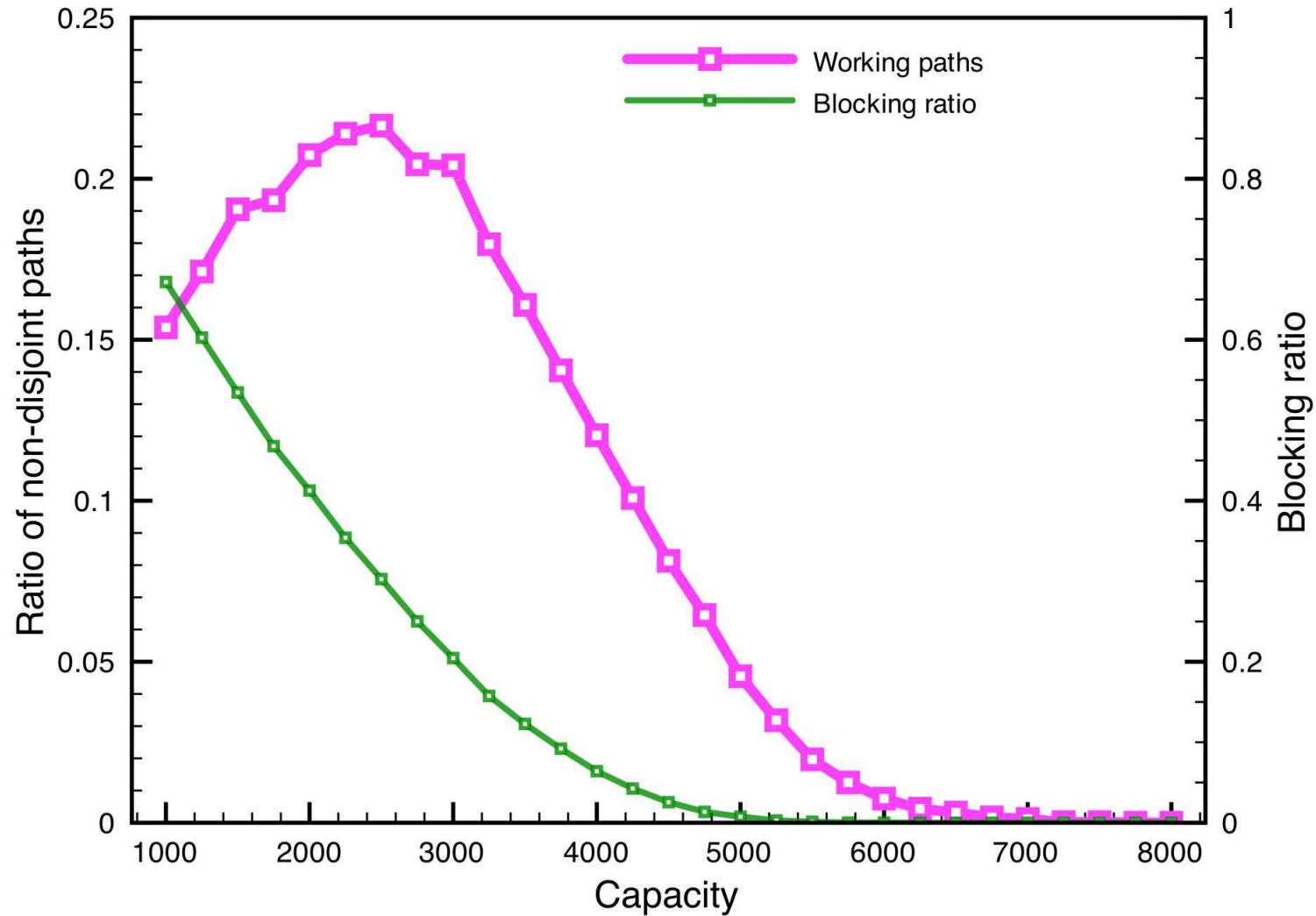
Simulation Results

- Trade-off
- Properties of the paths
- Dedicated Path Protection (DPP) problem
- Different SRLG scenarios

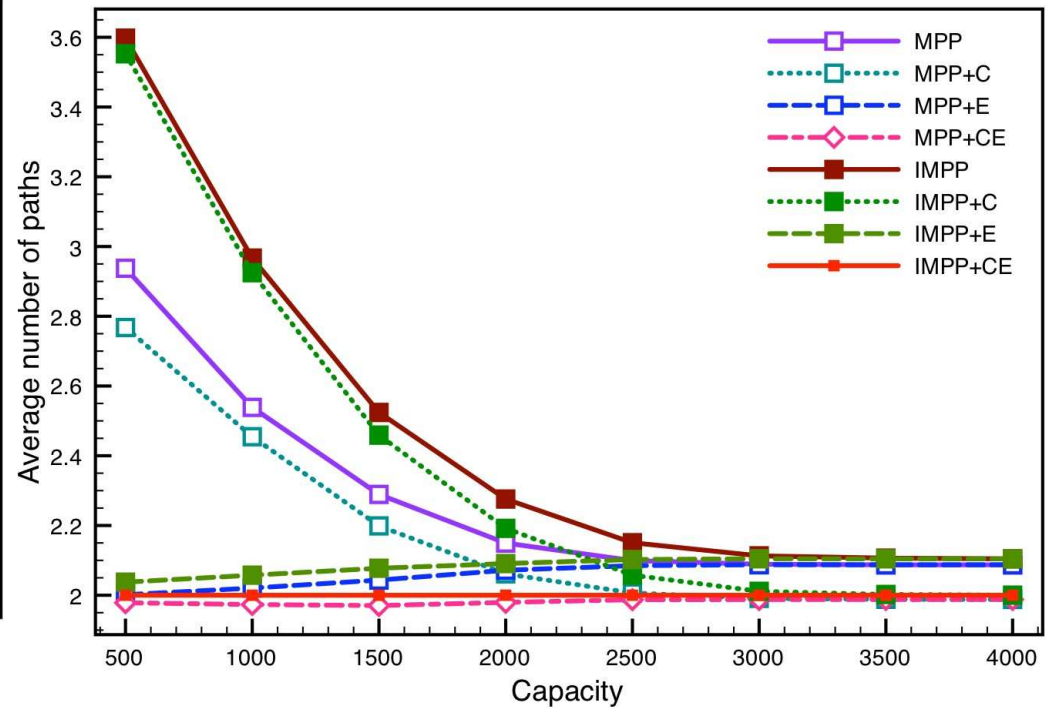
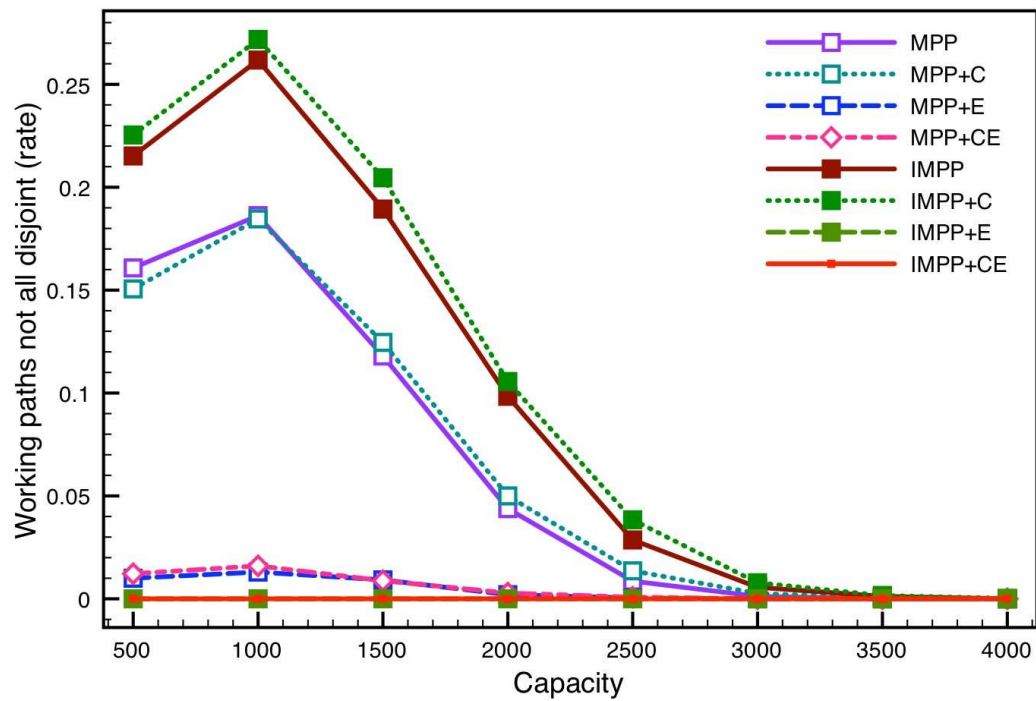
Trade-off between the bandwidth, the number and the length of paths as the density of the network grows



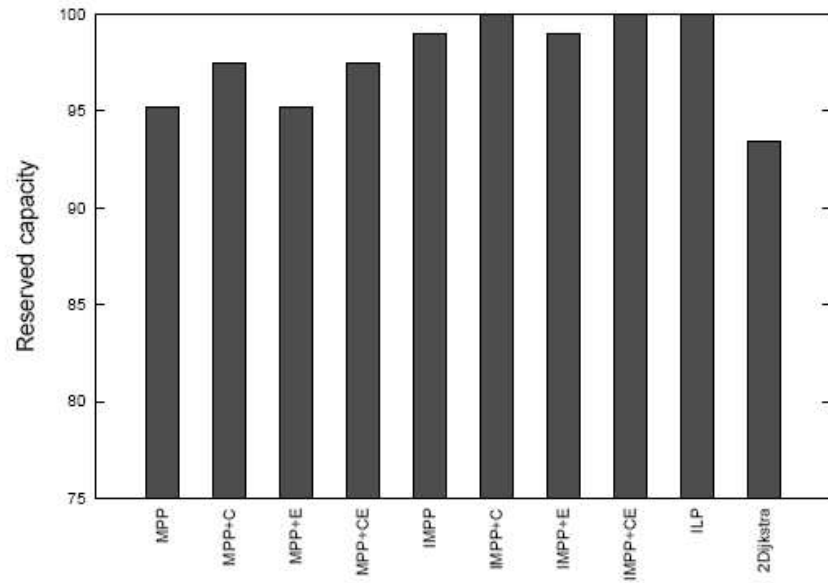
Properties of the paths



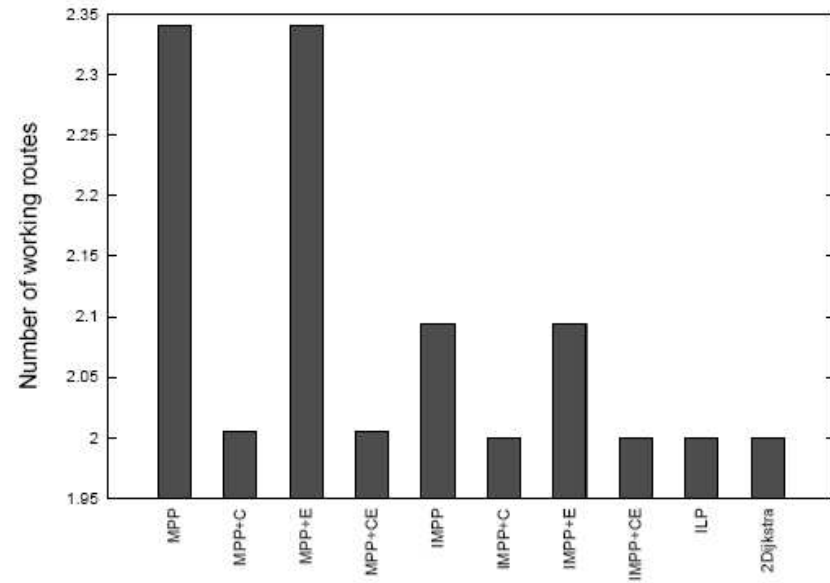
Dedicated Path Protection Problem



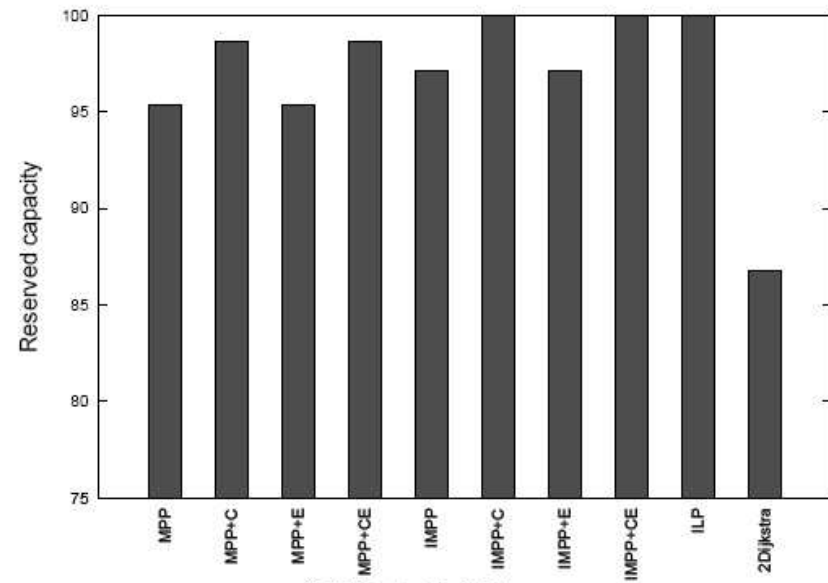
Results at different SRLG scenarios



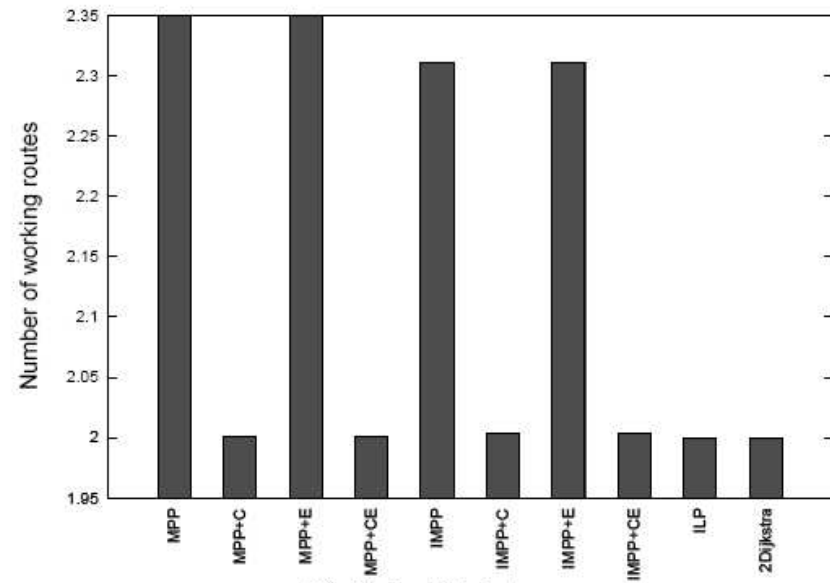
(a) "50-50" case.



(b) "50-50" case.



(c) Node-disjoint case.



(d) Node-disjoint case.

Conclusion

- IMPP formulated with LP -> polynomial runtime
- Disjoint paths, avoid flow branching between the end-nodes
- IMPP can handle a group of SRLG scenarios optimally
- The number of paths can be controlled
- Applicable in multi-domain environment