

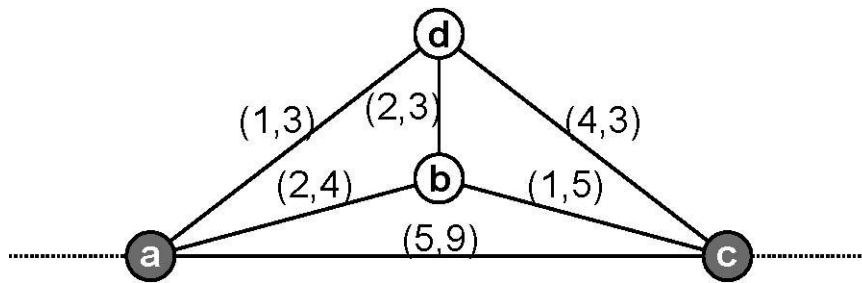


This material is partially supported by the Romanian National University Research Council under award PN-II IDEI 2412/2009.

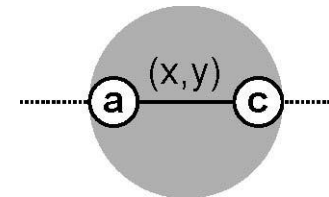
Hierarchical QoS Routing by Using Multi-Constrained Macro-Routing

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The hierarchical multi-constrained problem



(a) The physical topology

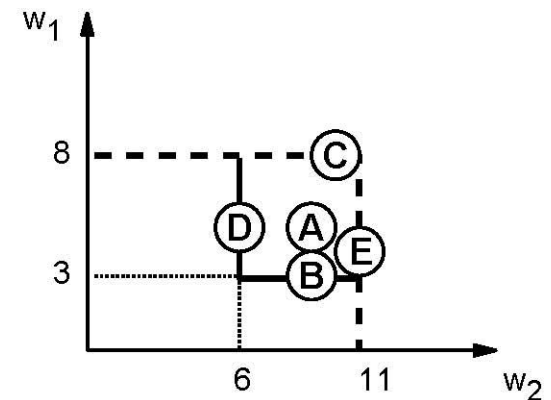


(b) The logical/aggregated link

NP-complete problem:

Finding a feasible path that satisfies multiple constraints.

- A. a-c = (5,9)
- B. a-b-c = (3,9)
- C. a-b-d-c = (8,10)
- D. a-d-c = (5,6)
- E. a-d-b-c = (4,11)



(c) Paths represented into the QoS-metric bi-dimensional space

Macro-routing

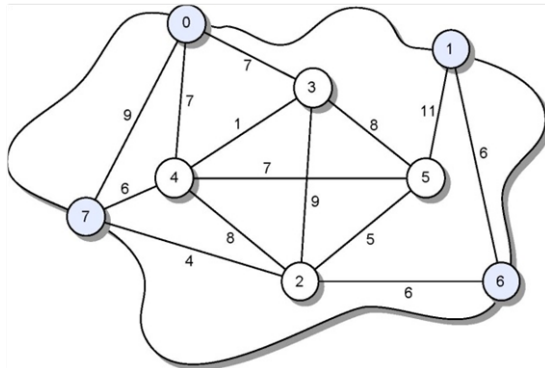
- ▶ protocol that addresses the problem of hierarchical routing within MPLS networks.
 - uses very small mobile agents (called *waves*) that are dispatched to process the state information at each node. Sample of *wave* code:

```
Falg=RP(OS(Fcost==0,A/~Fborders). A/~Fpath.Fcost<Frequired.Fpath&A.Fcost+L.#).\
Fborders=ARG1.Frequired=ARG2.Fmanaging=ARG3.\
Falg.\
Fpath&A.Fcost+L.@#Fmanaging.Npath&Fpath.Ncost&Fcost
```

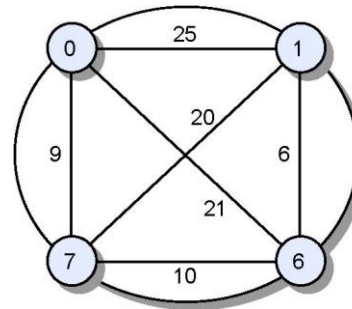
- no state information advertising is required
- the information used to compute routes can be much more detailed than in traditional link-state protocols (e.g., it can feature multiple QoS constraints, or a Full-Mesh aggregated representation).

The extended Full-Mesh (EFM) aggregation

- extends the Full-Mesh by allowing not only one “best” path between any two border nodes but multiple satisfactory paths.

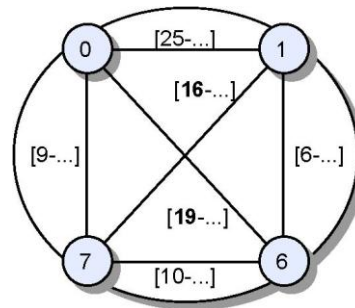


(a) The physical topology



(b) Full-Mesh aggregation

ingress node	egress node	list of traversing nodes	path cost
0	1	4, 5	25
0	6	4, 2	21
0	7	-	9
1	6	-	6
1	7	2, 5	20
6	7	2	10



(c) Extended Full-Mesh aggregation

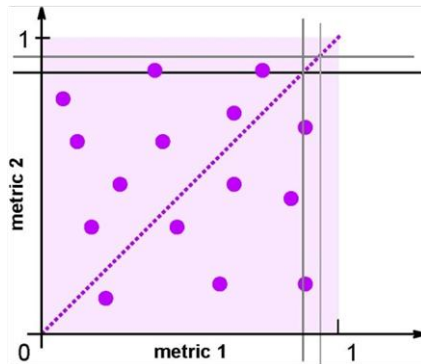
from node to node	ordered path costs
from 0 to 1	25, 26, 27, 28, 29 , 31, 32, 33, 40 , 42, 43, ...
from 0 to 6	19 , 21, 22, 23, 26, 27, 29, 31, 32, 33 , 36, ...
from 0 to 7	9, 13, 14, 19, 20, 21, 23, 24, 25, 28, 30, 31 , ...
from 1 to 6	6, 22, 32, 34, 47 , ...
from 1 to 7	16 , 20, 24, 26, 28 , 30, 32, 34, 35, 36 , 42, ...
from 6 to 7	10, 20, 22, 24, 26, 30, 32 , 36, 38 , ...

- The upper limit of number of paths in an EFM representation is T (used to fine-tune the thoroughness of the search).

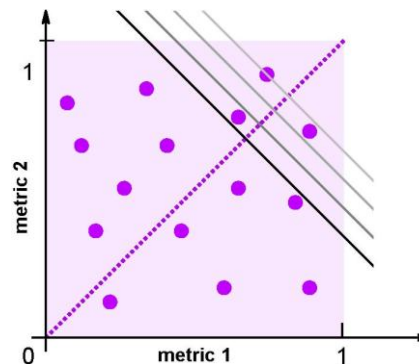
Building EFM. Keeping only T paths

▶ 3 classes of techniques to reduce the number of EFM paths:

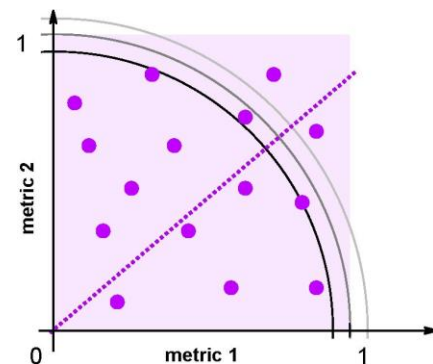
1. **Truncation** – the best resources are occupied first;



(a) *Simple method*



(b) *Normal method*



(c) *Radius method*

2. **Dispersal** – keep a larger spectrum of alternative paths; impractical: require a lot of computation;

- Random selection: true randomness is difficult to implement
- Quasi random: cyclic selection

3. **Practical** – simpler methods/algorithms.

- First Come First Selected (FCFS)

Multi-Constrained Macro-Routing

- ▶ extends *Macro-routing* to find *multi-constraint* paths by using the EFM aggregate representation

- ▶ **Determination of participant domains**

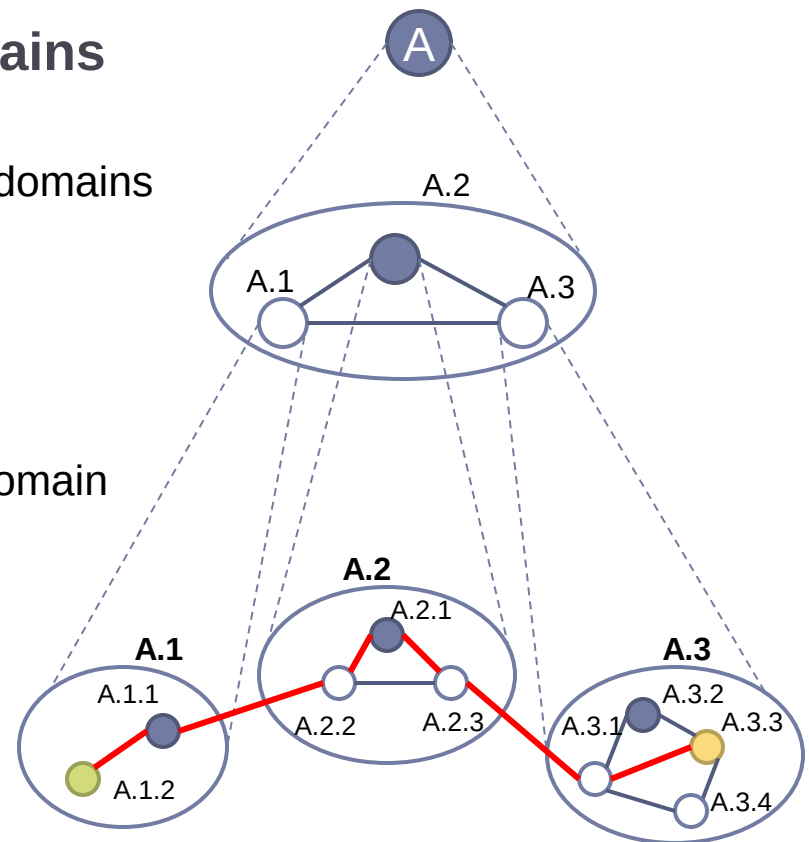
- ☐ Upwards search for the root
- ☐ Downwards search for the participant domains

- ▶ **Path computation**

- ☐ Create EFM for every domain
- ☐ Build the next hierarchical level
- ☐ Repeat the process until having one domain

- ▶ **Path reservation and set up**

- ☐ Reserve the resources
- ☐ Set the Label Switched Paths (LSPs)



The path selection techniques used for simulation tests

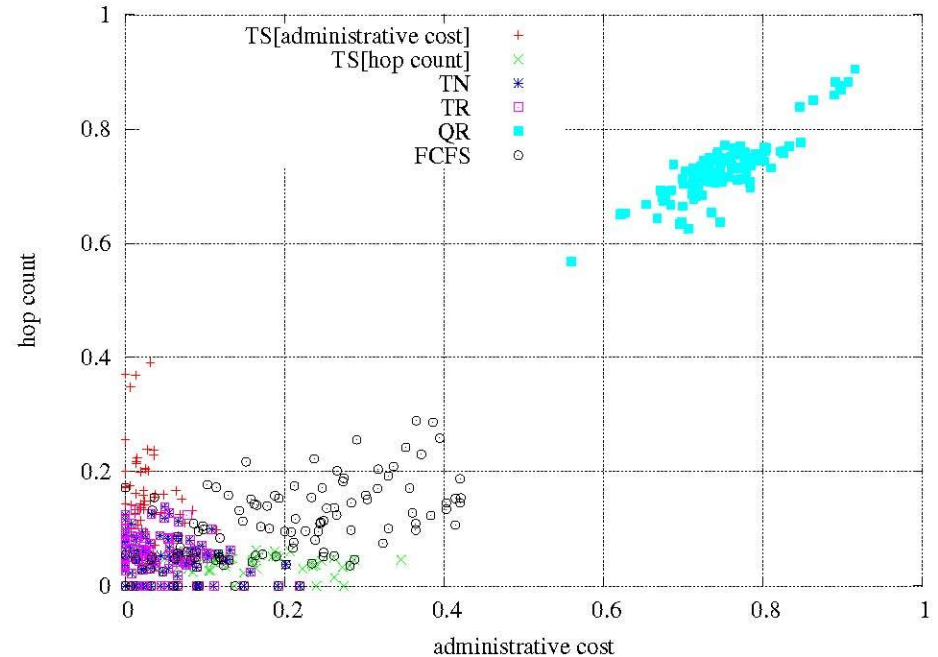
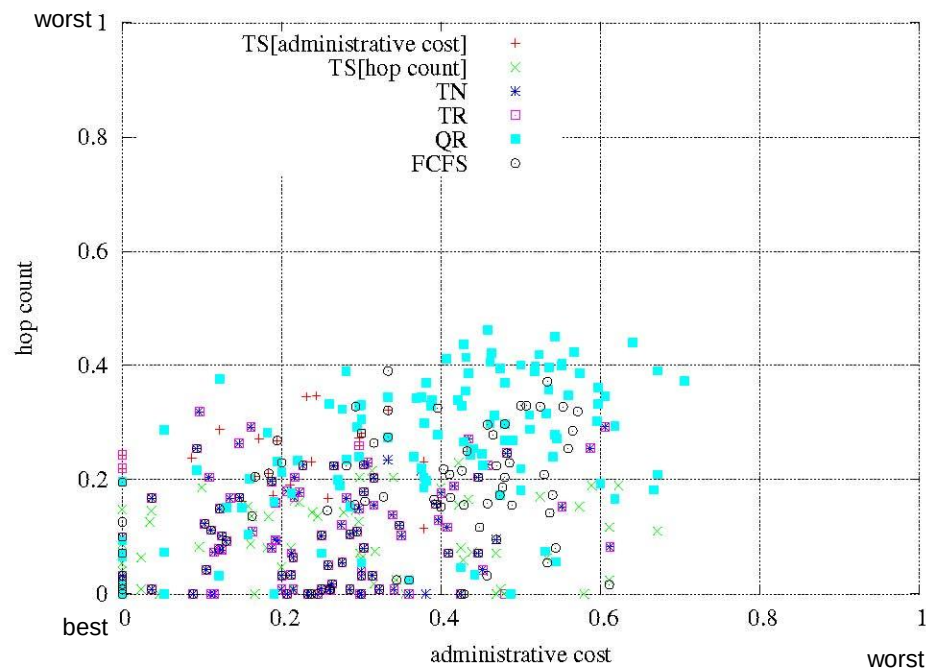
► candidate path selection technique acronym

1. TRUNCATE SINGLE using metric j _____ $TS[j]$
- this is truncate simple but only for one metric
2. TRUNCATE NORMAL _____ TN
3. TRUNCATE RADIUS _____ TR
4. QUASI RANDOM _____ QR
5. FIRST COME FIRST SELECTED _____ $FCFS$

EFM's simulation results

▼ On a 4 x 4 network:

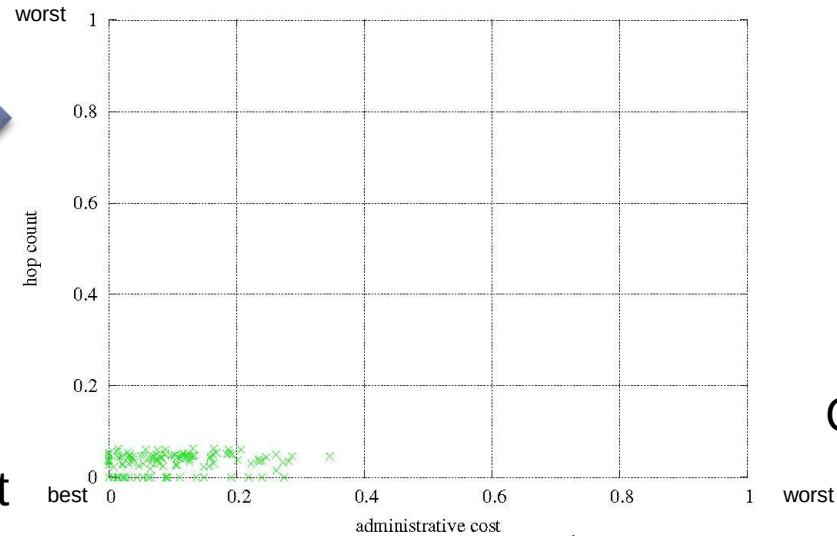
There is no significant difference between the 5 methods



▲ On a 20 x 20 network: each method develops patterns

EFM's simulation results on a 20 x 20 network

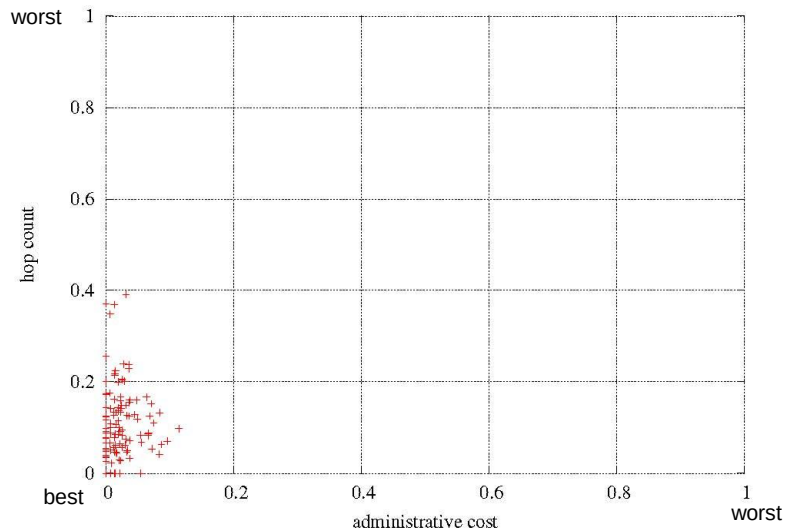
TS using hop count



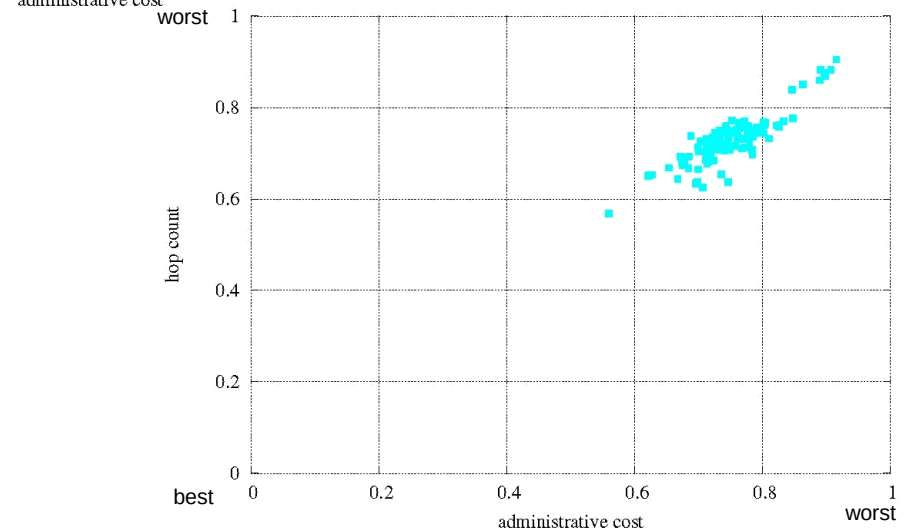
TS using



administrative cost

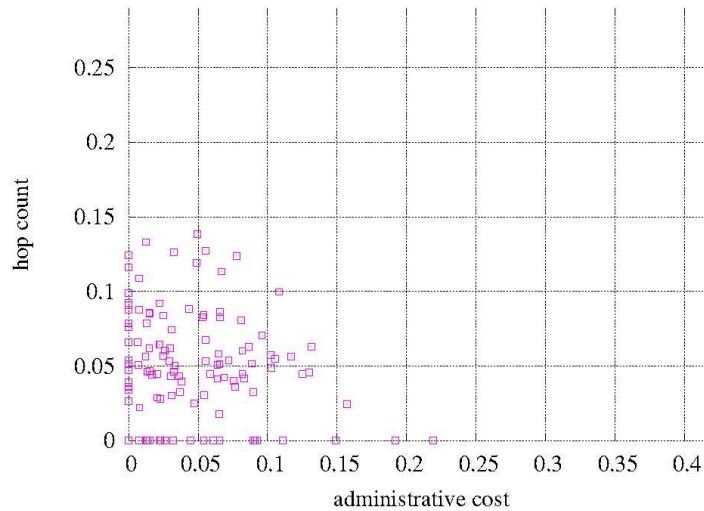


Quasi random

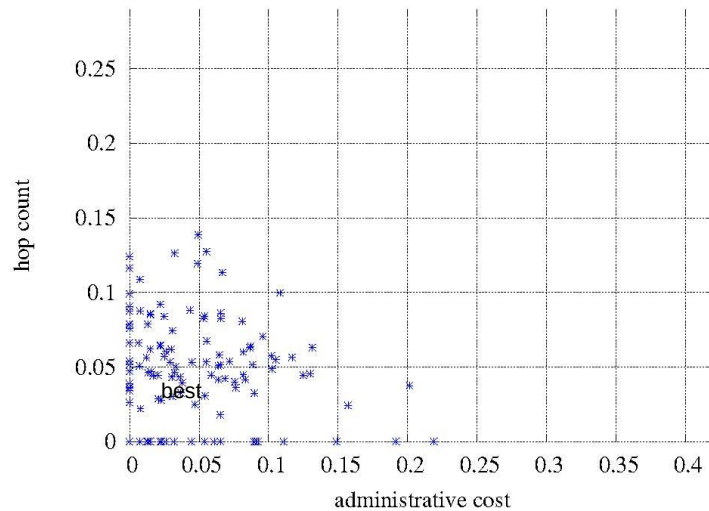


EFM's simulation results on a 20 x 20 network

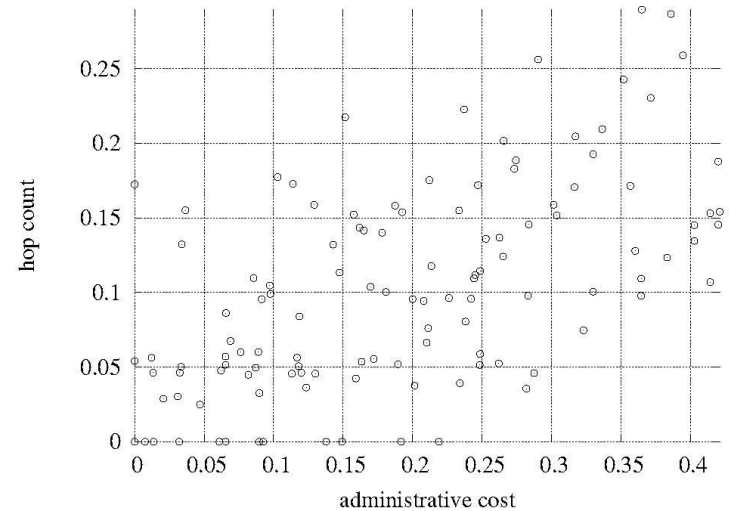
TR



TN

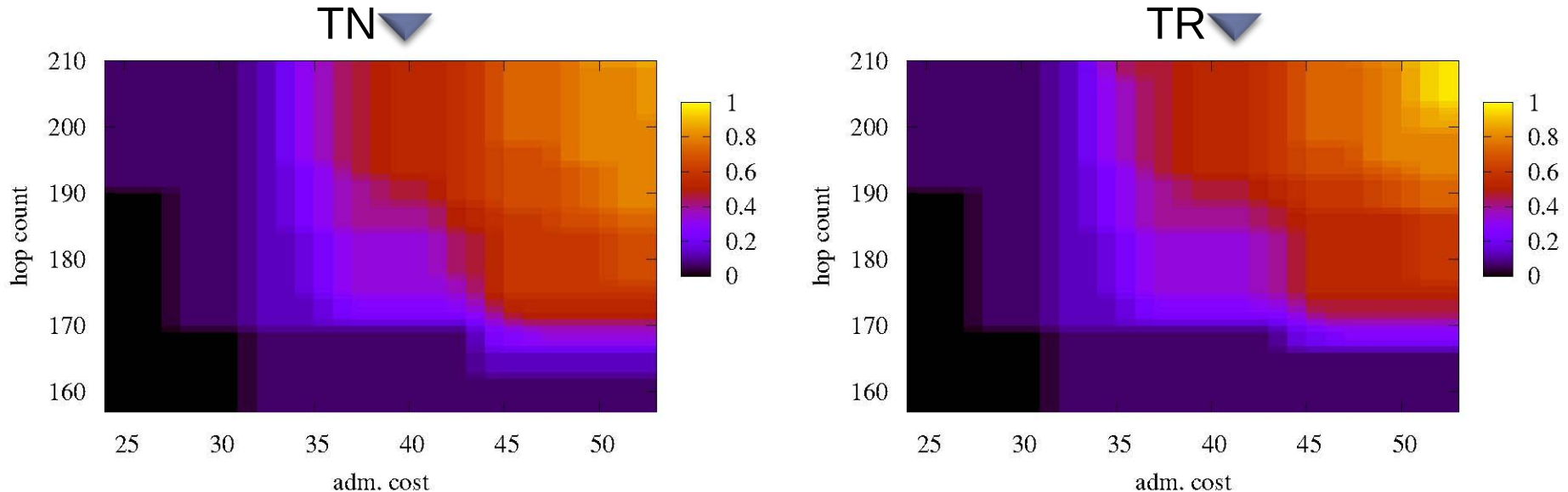


FCFS



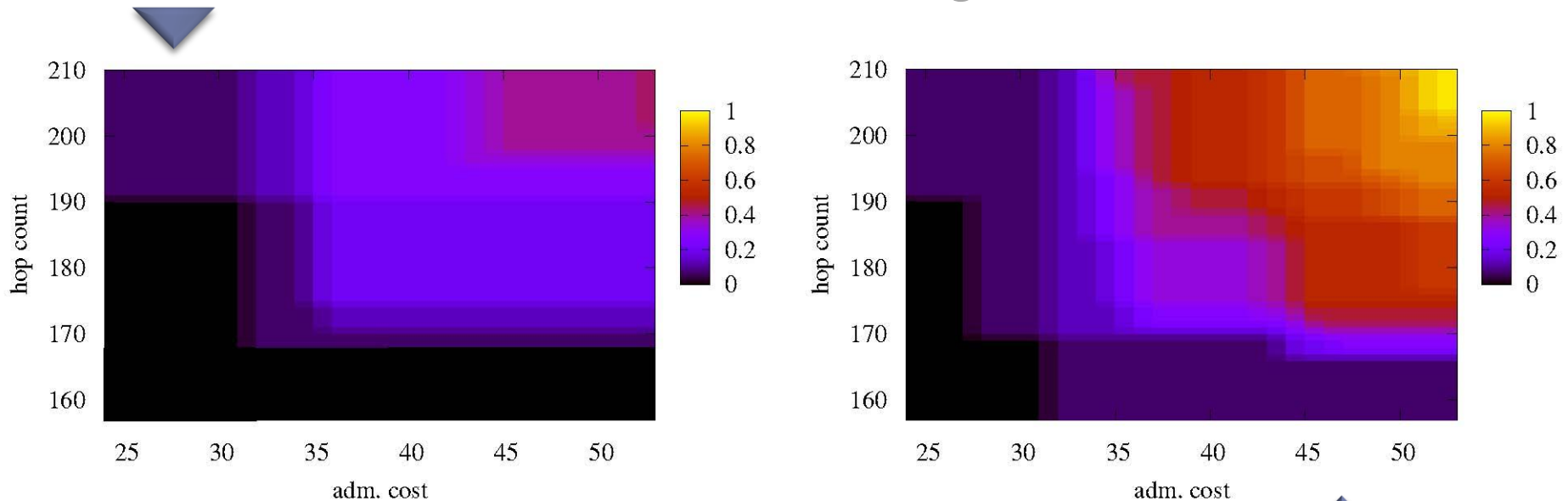
Compare TRUNCATE NORMAL and TRUNCATE RADIUS

- ❖ Previous tests show that TR and TN obtain the best methods
- ❖ To differentiate TR and TN, they were tested on 12×12 networks with higher connectivity ($c_d \in [5, 5.3]$) and $T = 4$
- ❖ Next tests count the proportion of TN/TR paths satisfying the constraints: $\text{administrative_cost} < 54$, $\text{hop_count} < 210$



Compare with another protocol

Lagrangian-based linear composition + Full Mesh
or *Multi-constraint Macro-routing* with TR and $T = 1$



Multi-constraint Macro-routing with TR and $T = 4$