Adaptive Robust Traffic Engineering in Software Defined Networks

Davide Sanvito[*], Ilario Filippini[*], Antonio Capone[*], Stefano Paris[▪], Jeremie Leguay[▪]

[*] Politecnico di Milano (Italy)
[▪] Huawei Technologies, France Research Center (France)

IFIP Networking - May 14-16, 2018 - Zurich, Switzerland

Traffic Engineering and Software-Defined Networks

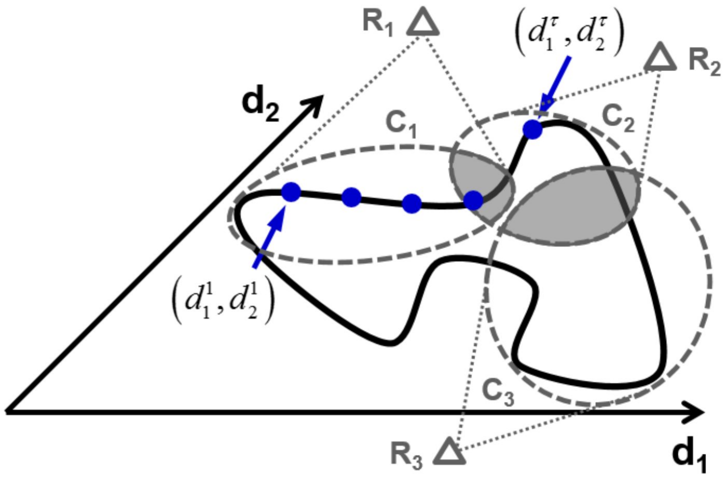
- T.E. optimizes network configuration according to traffic conditions
  - Traffic Matrix (TM)
  - Maximum Link Utilization (MLU)
- Dynamicity of traffic
  - ordinary daily fluctuations
  - unpredictable events (congestion, failures, ...)
- Software-Defined Networks
  - global view of the network status
  - traffic monitoring
  - online traffic optimization

How to cope with traffic dynamicity?

- Static TE
  - stable routing configuration
  - low optimality
- Dynamic TE
  - multiple routing configurations
  - optimal routing
  - traffic monitoring latency and processing overhead
  - routing instability (consistent update)
- Semi-static TE

Our contribution

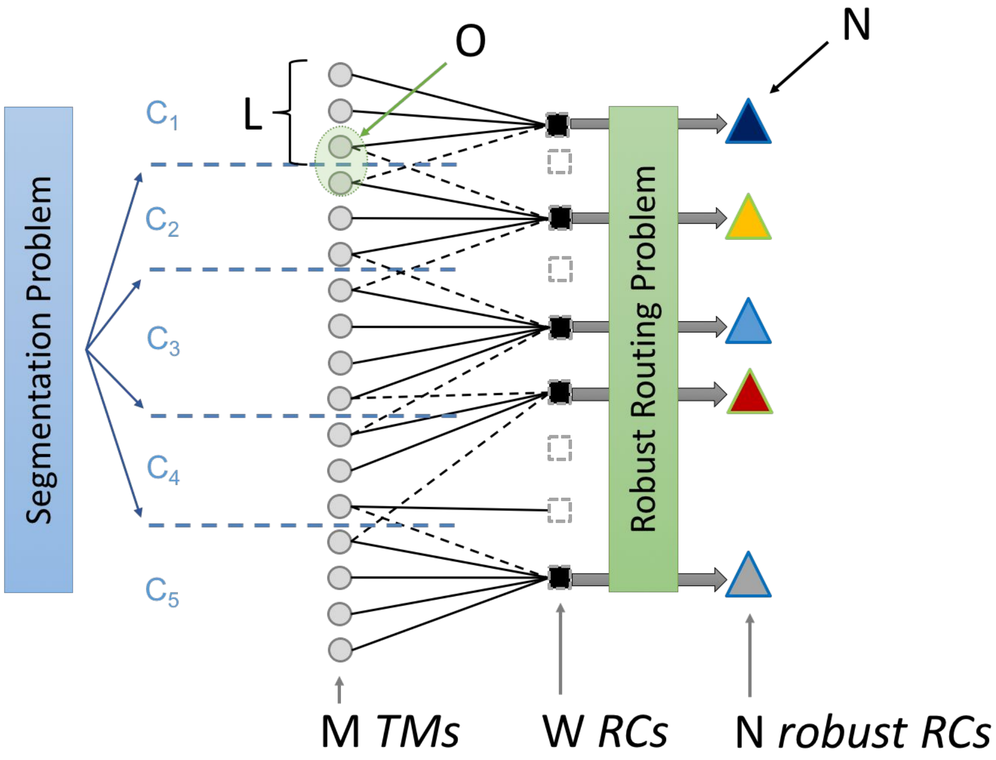
- Clustered Robust Routing (CRR)
  - Algorithm to build a set of robust routing (RR) configuration associated to clusters of TMs
  - Clustering of TM space in time, traffic and routing domains
  - Stability of configurations (guaranteed routing holding time)
- SDN controller logic
  - TM collection (e.g. for a 24h period)
  - CRR execution
  - Activation of RR config for the following 24h



Clustered Robust Routing

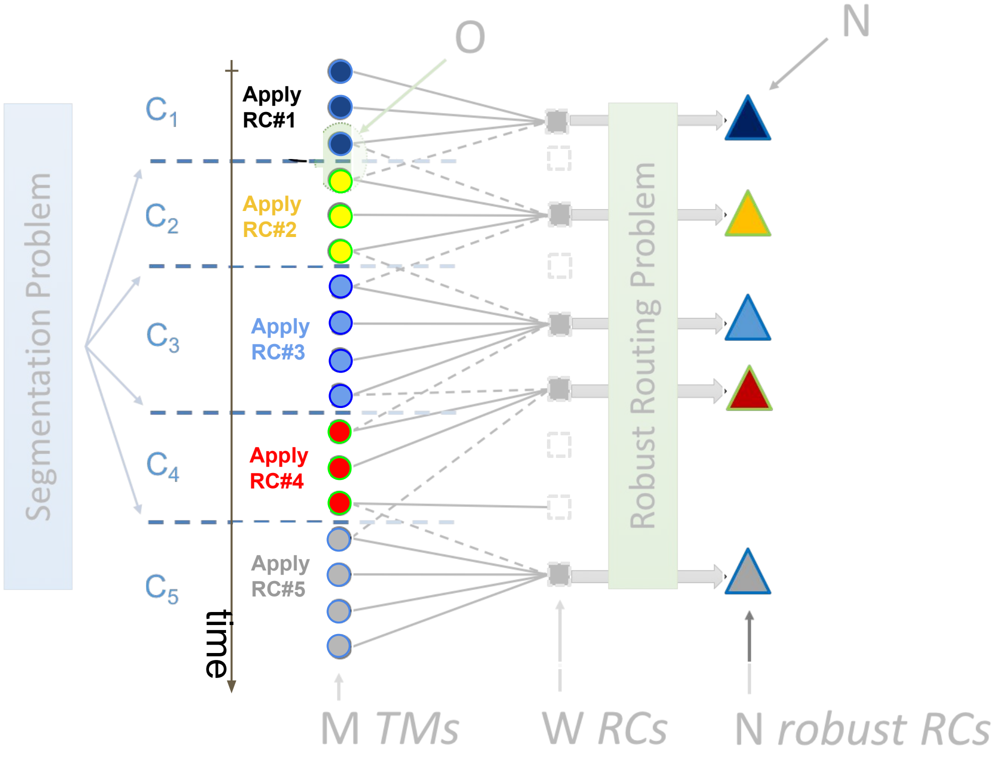
- Find the best assignment of **M** TMs to **N** robust RCs to find **N** TM clusters having minimum length of **L** TMs and an overlap of **O** TMs
- Joint optimization of routing and clusters
  - output set of RCs is required as input by the clustering logic
- Two-steps iterative algorithm
  - Segmentation Problem (**SP**)
  - Robust Routing Problem (**RRP**)

CRR = SP + RRP



- INPUT
  - TM history/prediction
  - Set of W RCs
- PARAMETERS
  - N = # of RCs
  - L = cluster size
  - O = cluster overlap amount
- OBJECTIVE FUNCTION:
  - Minimizing the sum of MLU of each TM over its assigned configuration
- OUTPUT
  - Set of N robust RCs
  - RCs activation times

CRR = SP + RRP

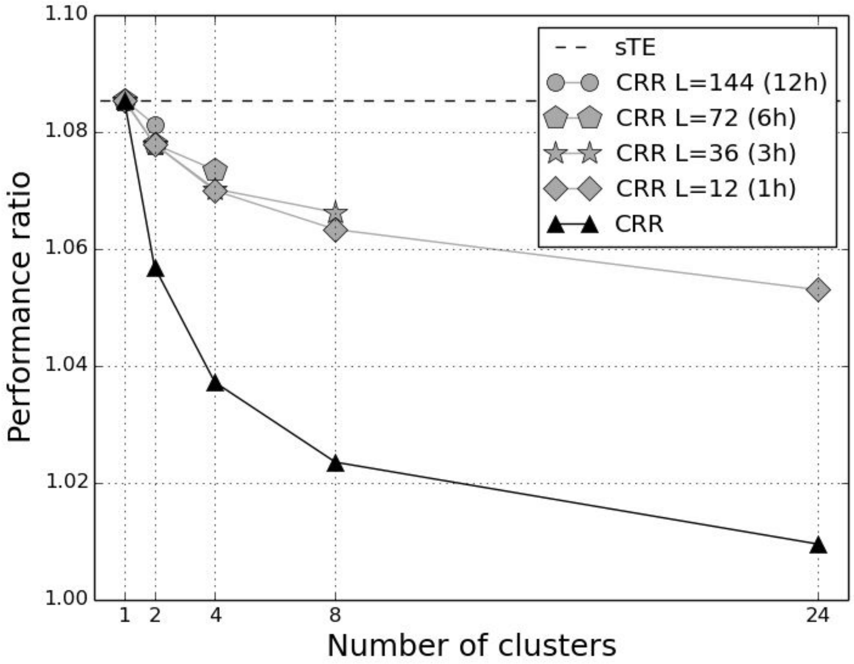


- INPUT
  - TM history/prediction
  - Set of W RCs
- PARAMETERS
  - N = # of RCs
  - L = cluster size
  - O = cluster overlap amount
- OBJECTIVE FUNCTION:
  - Minimizing the sum of MLU of each TM over its assigned configuration
- OUTPUT
  - Set of N robust RCs
  - RCs activation times

Numerical evaluation

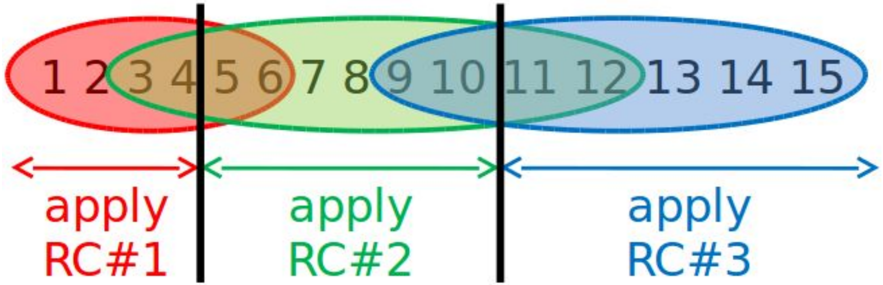
- Abilene backbone network
- 11 nodes
- 5-min granularity TMs
- CRR objective:
  minimize TM-averaged MLU
- Performance ratio with respect to Dynamic TE
- Results are averaged over 7 days

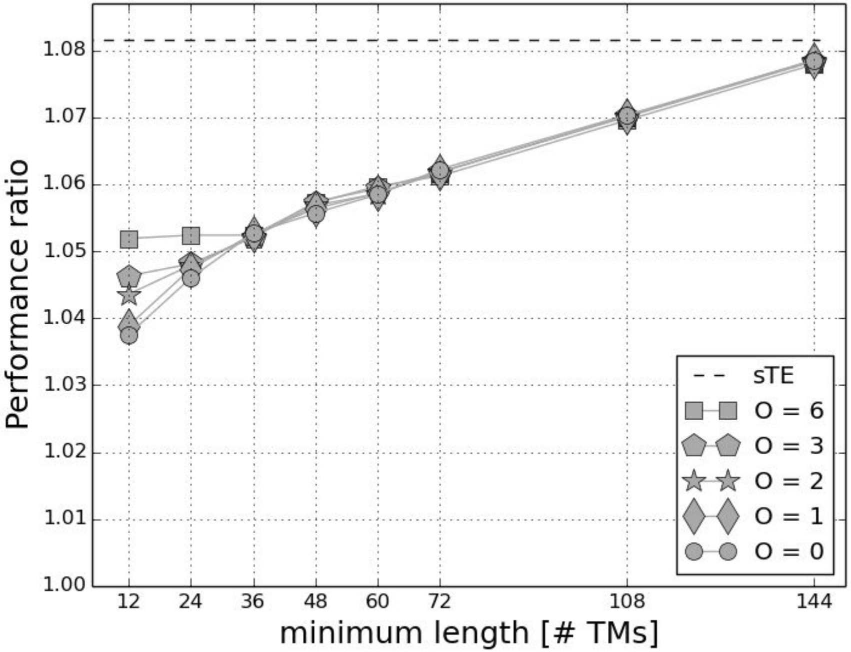
Minimum cluster length



- Parameter **L** defines the minimum cluster size
    - translates in a guaranteed routing configuration duration
- It allows to tune the tradeoff between Stable TE and Dynamic TE

Overlapping clusters





- Network reconfiguration is not instantaneous
  - Consistent updates mechanisms
- Clusters can be overlapped
  - Routing configurations take into account **O** TMs before/after the boundaries of the clusters
- Overlaps help slow consistent updates mechanism
- Negligible impact as **L** >> **O**

Impact of TM prediction error

- We run the CRR over a noisy version of the TMs and applied its output to the original set of TMs
- Table reports % increase of objective function w.r.t. Dynamic TE
  - different levels of noise (α)
  - different levels of robustness (L)
- Performance decrease
  - But limited to 10-12% wrt DynTE
- Larger clusters are better as noise increases
  - Resort to sTE if prediction quality is low

cluster \ α		0	15	30	45	60
sTE		6.52	7.02	8.19	9.25	**10.52**
CRR	L=72	4.07	5.13	6.93	**8.94**	11.09
	L=60	4.04	5.23	7.24	9.44	11.19
	L=48	3.76	5.06	7.12	9.61	11.79
	L=36	3.17	4.55	**6.74**	9.04	11.33
	L=24	2.84	4.50	6.85	9.35	11.93
	L=12	**2.06**	**4.29**	7.04	10.08	12.28

Role of the SDN controller

- Offline
    - TM collection (e.g. for a 24h period)
    - CRR execution (e.g. during night)
- Online
    - estimation of current traffic scenario
    - activation of the proper RR configuration
    - handling of unexpected events
        - big traffic changes wrt planned scenarios
        - network failures

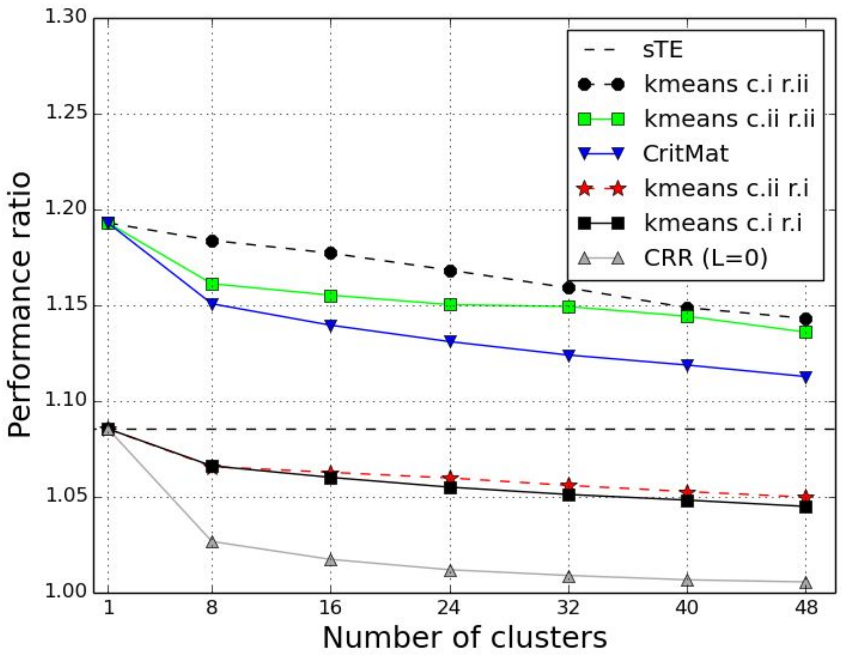
Conclusion

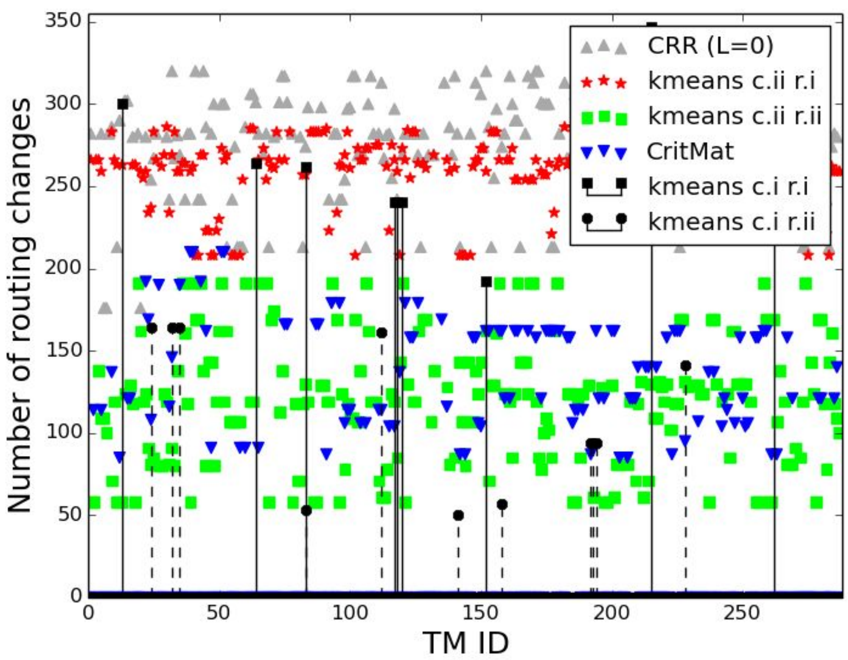
- Clustered Robust Routing (CRR)
  - reduced number of routing configuration
  - guaranteed routing holding time
- SDN controller plays a key role
  - a-posteriori evaluation of TM prediction error
  - adaptive selection of the best level of robustness

Thanks!

davide.sanvito@polimi.it

TM clustering and routing changes





SP

$$
\begin{aligned}
\min \quad & \sum_{i\in\mathcal{T}, j\in\mathcal{R}} x_{ij}\delta_{i,j} + \\
& \frac{1}{2}\sum_{i\in\mathcal{T}, j\in\mathcal{R}} y_{ij}\left(\sum_{(i-O<k\leq i)_{|\mathcal{T}|}} \delta_{k,j} - \sum_{(i+1\leq k\leq i+O)_{|\mathcal{T}|}} \delta_{k,j}\right) + \\
& \frac{1}{2}\sum_{i\in\mathcal{T}, j\in\mathcal{R}} w_{ij}\left(\sum_{(i\leq k<i+O)_{|\mathcal{T}|}} \delta_{k,j} - \sum_{(i-O\leq k<i)_{|\mathcal{T}|}} \delta_{k,j}\right)
\end{aligned} \tag{1}
$$

$$y_{ij} \geq x_{(i+1)_{|\mathcal{T}|}j} - x_{ij}, \qquad \forall i\in\mathcal{T}, j\in\mathcal{R} \tag{2}$$

$$\sum_{i\in\mathcal{T}} y_{ij} \leq z_j, \qquad \forall j\in\mathcal{R} \tag{3}$$

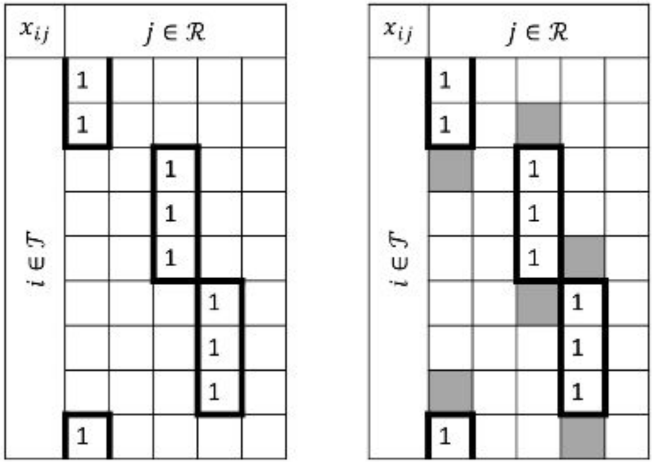
$$\sum_{i\in\mathcal{T}, j\in\mathcal{R}} y_{ij} \leq \sum_{j\in\mathcal{R}} z_j \tag{4}$$

$$\sum_{j\in\mathcal{R}} x_{ij} = 1, \qquad \forall i\in\mathcal{T} \tag{5}$$

$$\sum_{i\in\mathcal{T}} x_{ij} \geq L\cdot z_j, \qquad \forall j\in\mathcal{R} \tag{6}$$

$$\sum_{j\in\mathcal{R}} z_j \leq N \tag{7}$$

$$x_{ij}, y_{ij}, z_j \in \{0,1\}, \qquad \forall i\in\mathcal{T}, j\in\mathcal{R} \tag{8}$$



(a) Segmentation with no overlap

(b) Segmentation with $O = 1$

$$w_{ij} \geq x_{(i-1)_{|\mathcal{T}|}j} - x_{ij}, \qquad \forall i\in\mathcal{T}, j\in\mathcal{R} \tag{9}$$

$$\sum_{i\in\mathcal{T}} w_{ij} \leq z_j, \qquad \forall j\in\mathcal{R} \tag{10}$$

$$\sum_{i\in\mathcal{T}, j\in\mathcal{R}} w_{ij} \leq \sum_{j\in\mathcal{R}} z_j \tag{11}$$

RRP

$$[\mathbf{RR}] : \text{min. } \gamma_{max} \qquad \text{s. t.:} \tag{13}$$

$$\sum_{(i,j)\in\mathcal{L}} f_{ij}^h - \sum_{(j,i)\in\mathcal{L}} f_{ji}^h = \begin{cases} 1 & \text{if } i = O_h \\ -1 & \text{if } i = D_h \\ 0 & \text{otherwise} \end{cases}$$

$$\forall i \in \mathcal{N}, h \in \mathcal{H} \tag{14}$$

$$\sum_{h\in\mathcal{H}} d_h^m \cdot f_{ij}^h \leq c_{ij}, \forall m \in \mathcal{T}_c, (i,j) \in \mathcal{L} \tag{15}$$

$$\gamma_{max} \geq \frac{\sum_{h\in\mathcal{H}} d_h^m f_{ij}^h}{c_{ij}}, \forall m \in \mathcal{T}_c, (i,j) \in \mathcal{L} \tag{16}$$

$$0 \leq f_{ij}^h \leq 1, \qquad \forall h \in \mathcal{H}, (i,j) \in \mathcal{L} \tag{17}$$