Optimal placement of Controllers in a resilient SDN Architecture

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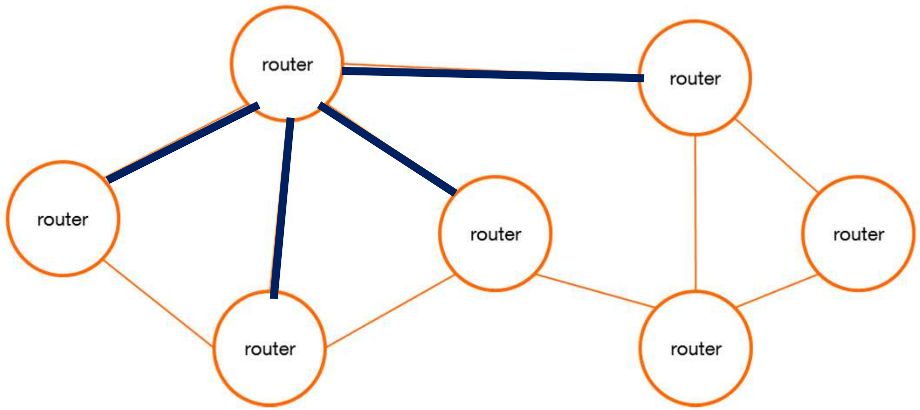
Outline

1. SDN in a few words
2. Motivation
3. Controller Placement Problem (CPP)
4. Resilient Controller Placement Problem (RCPP)
5. Conclusions and perspectives

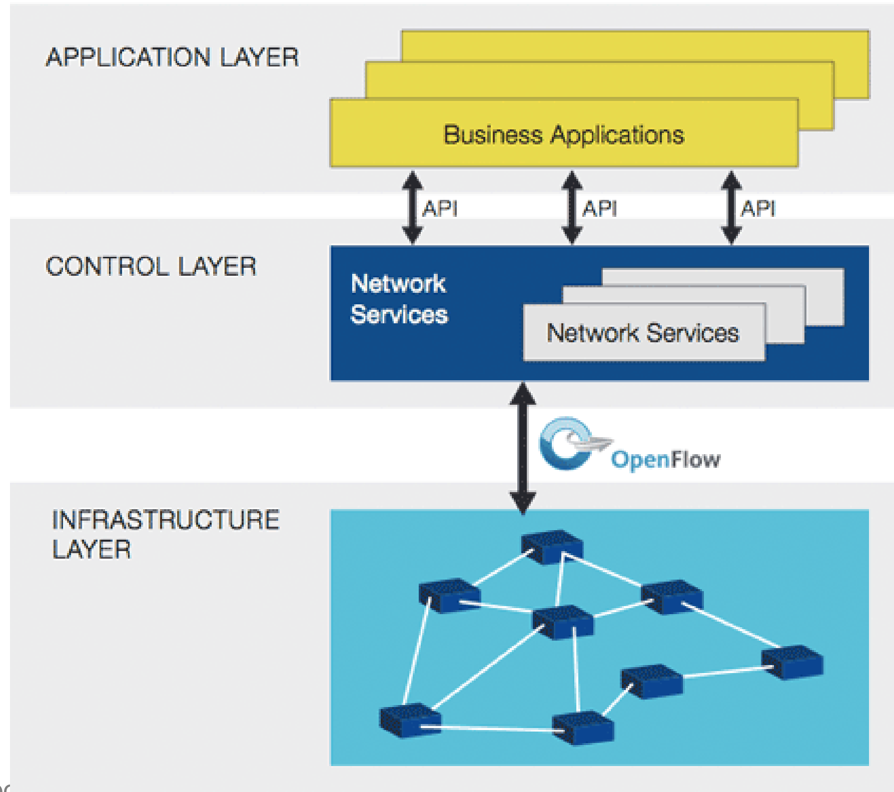
Introduction to SDN

- Data network devices (switch, router) have always been embedding three planes of operation :
  - Forwarding Plane :
    - Responsible for carrying user traffic, it moves packets from input to output
  - Control Plane :
    - Determines how packets should be forwarded
    - Responsible for signaling
  - Management plane :
    - Responsible for configuration of the control plane



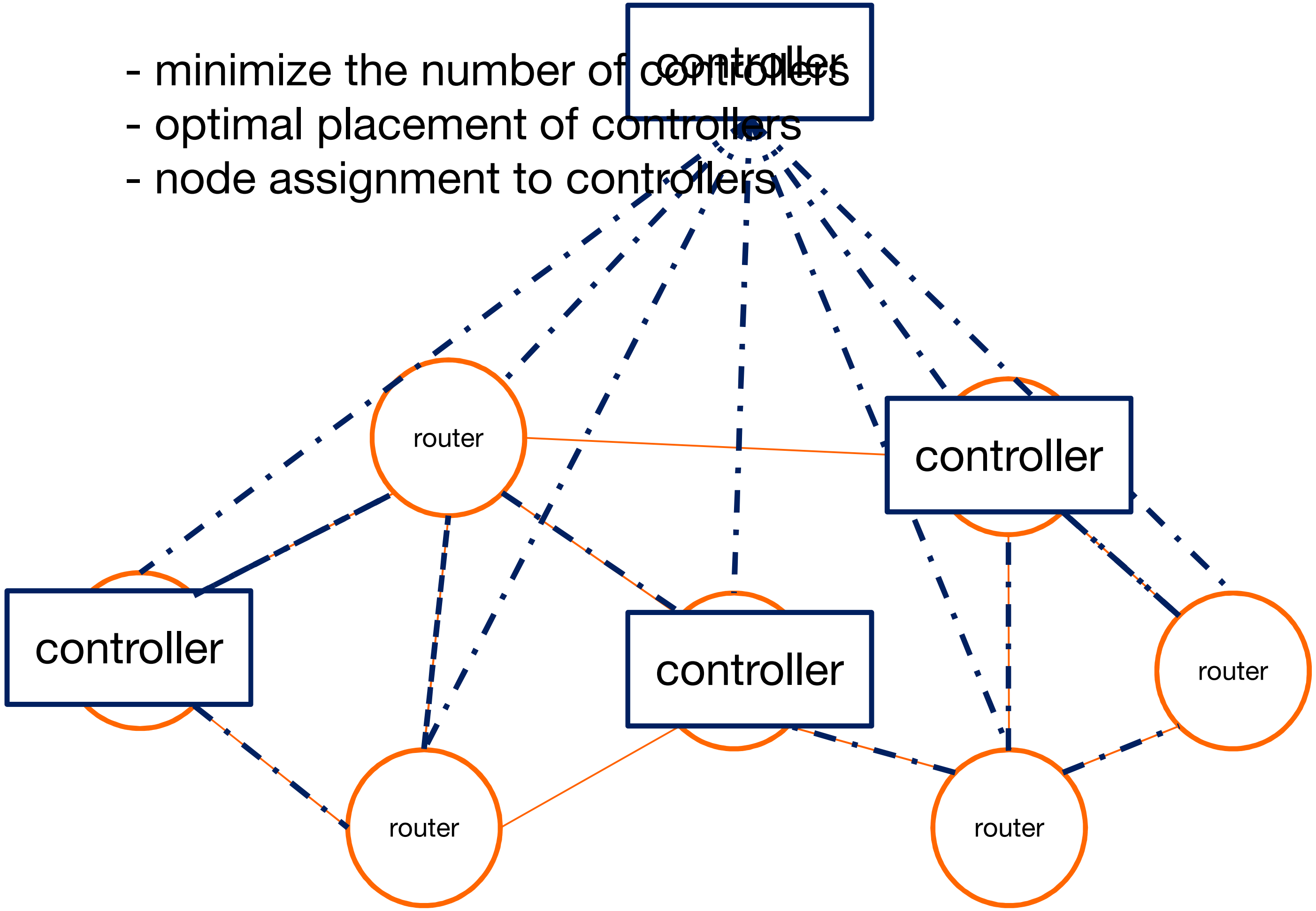
The SDN Paradigm

- SDN is the physical separation of the network control plane from the forwarding plane. The control plane controls several devices.
  - The network control becomes directly programmable
  - The underlying infrastructure is abstracted for applications and network services.



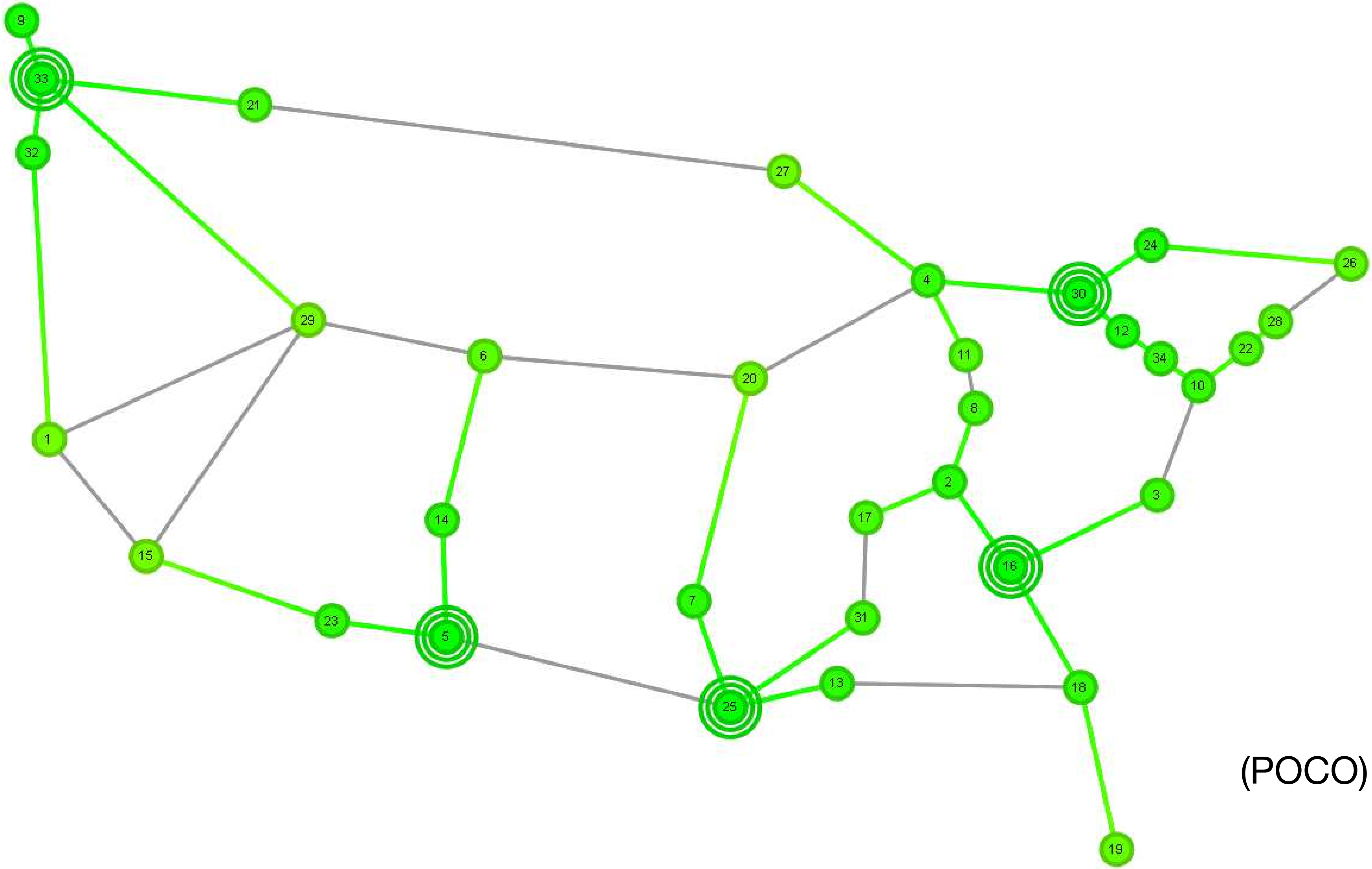
SDN in Wide Area Networks

- minimize the number of controllers
- optimal placement of controllers
- node assignment to controllers



What is a "good" placement ?

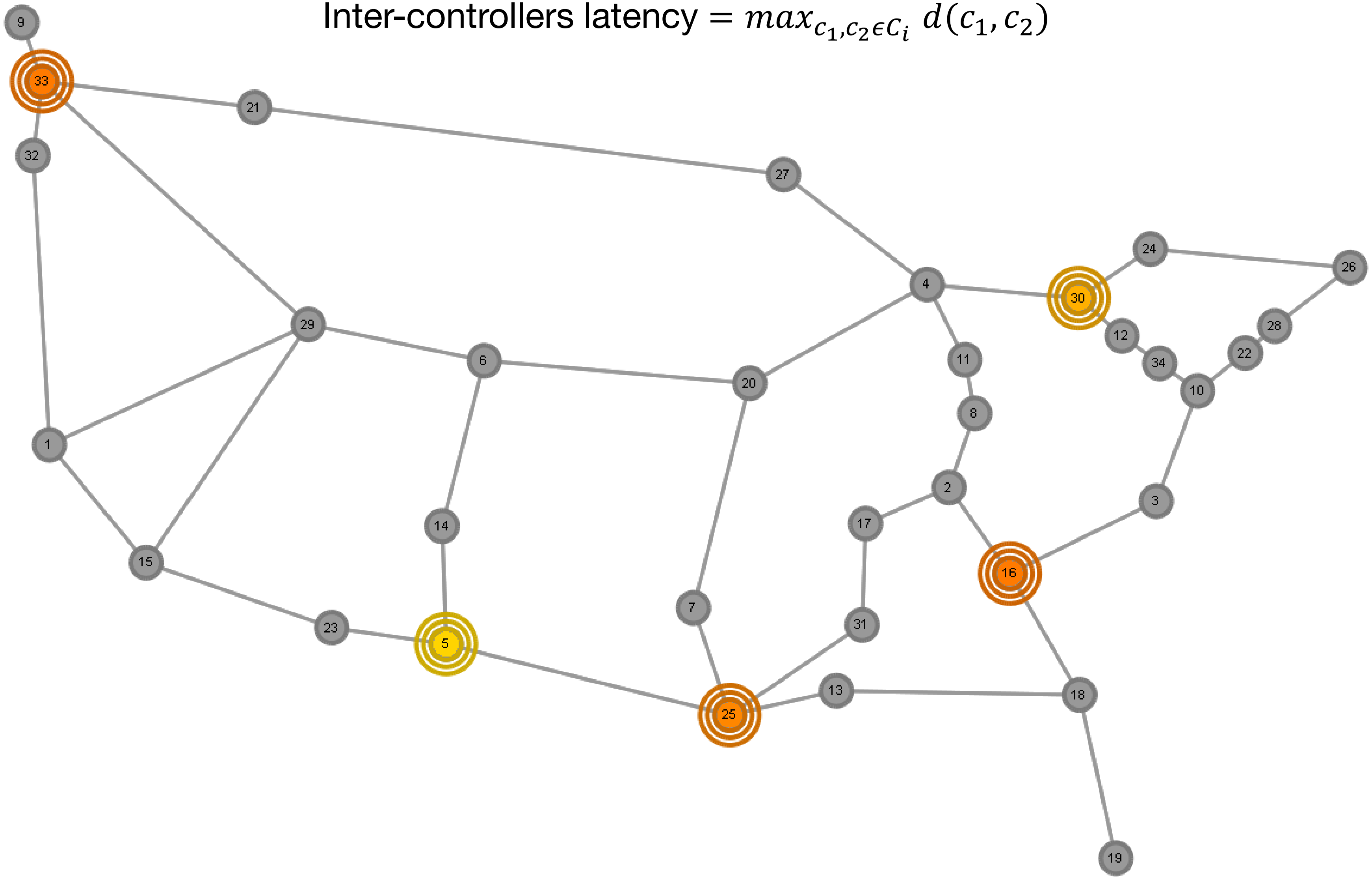
maximal latency = $max_{v \epsilon V} min_{c \epsilon C_i} d(v, c)$



(POCO)

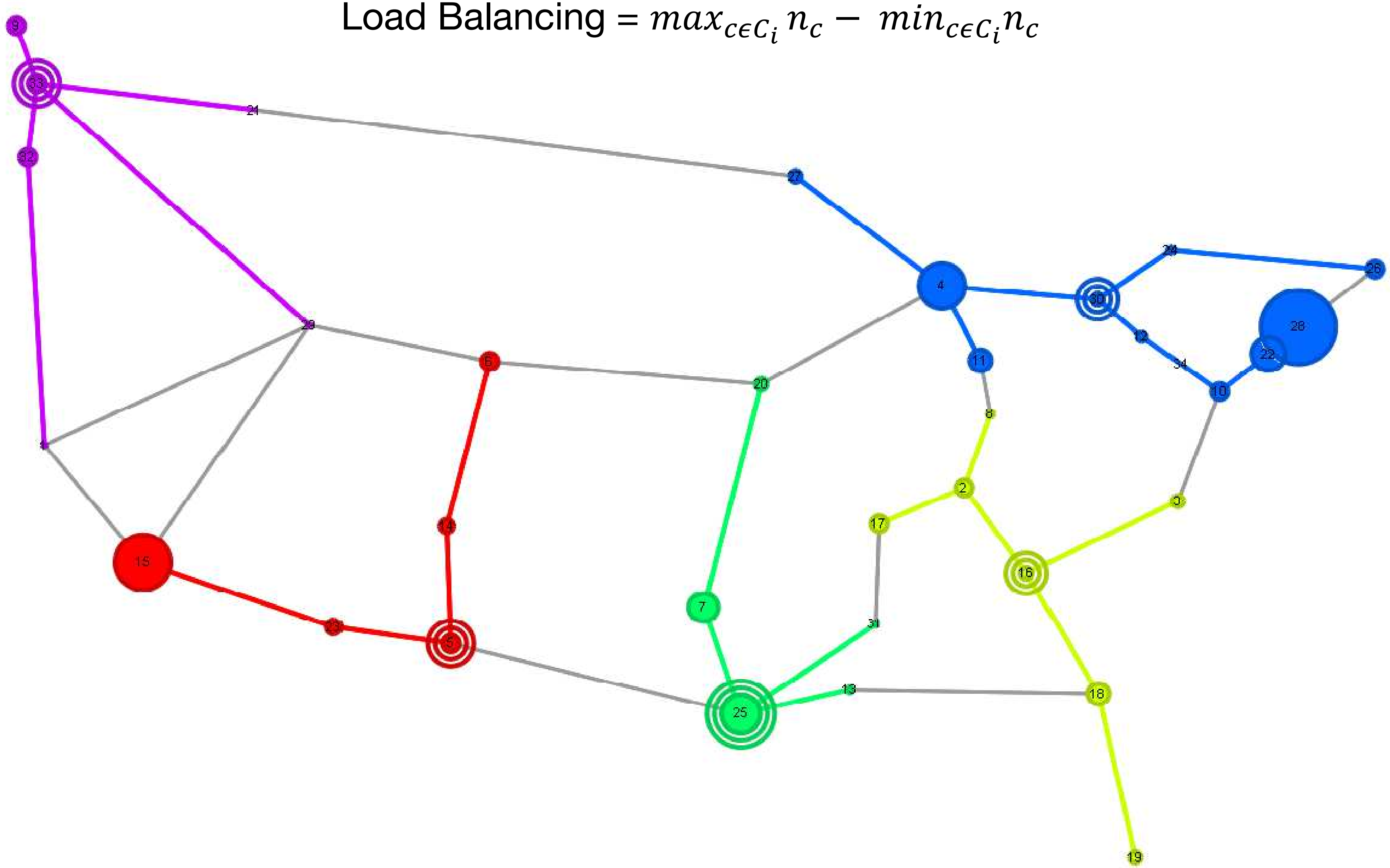
What is a “good” placement ?

Inter-controllers latency $= max_{c_1,c_2 \epsilon C_i}\ d(c_1, c_2)$



What is a “good” placement ?

Load Balancing = $max_{c \epsilon C_i} n_c - min_{c \epsilon C_i} n_c$



The Controller Placement Problem

- A Facility Location Problem with
  - maximal latency between the controller and its assigned nodes l_{max}
  - maximal latency between two controllers l_{cc-max}
  - load balancing constraints

- The binary variables are
  - assignment variables : $x_{ij} \in \{0,1\}$
  - active controller variables : $y_i \in \{0,1\}$
  - linearization variables : $t_{ii'} = y_i y_{i'} \in \{0,1\}$

- $\mathrm{d}_{(\mathrm{i,j})}$ shortest path between router j and controller i
- covering matrix
  - $a_{ij} = \begin{cases} 1 & \text{iff } d_{ij} \le l_{max} \\ 0 & otherwise \end{cases}$

- objective : $\min \sum_{i \in C} y_i$

The CPP - explicit formulation

- each router j must be covered by at least one controller within the latency bound :

$$\sum_{i \in C} a_{ij} y_i \geq 1 \quad \forall j \in R$$

- each router j must be assigned to the nearest active controller i :

$$\begin{cases} \sum_{i \in C} x_{ij} = 1 & \forall j \in R \\ x_{ij} \leq y_i & \forall i \in C, \forall j \in R \\ y_{\sigma_{jq}} \leq \sum_{m=1}^{q} x_{j \sigma_{jm}} & \forall j \in R,\ \forall q \in [1, |C| - 1] \end{cases}$$

- all pairs of controllers must respect the allowed inter-controllers latency

$$t_{ii'} d_{ii'} \leq l_{cc-max} \qquad \forall i, i' \in C$$

The CPP - explicit formulation

- the difference of load between all pairs of controllers must be at most δ *:*

$$-\delta - (|R| - \delta)(1 - t_{ii'}) \leq \sum_{j \in R} \left(x_{ij} - x_{i'j}\right) \leq \delta + (|R| - \delta)(1 - t_{ii'}) \quad \forall i, i' \in C$$

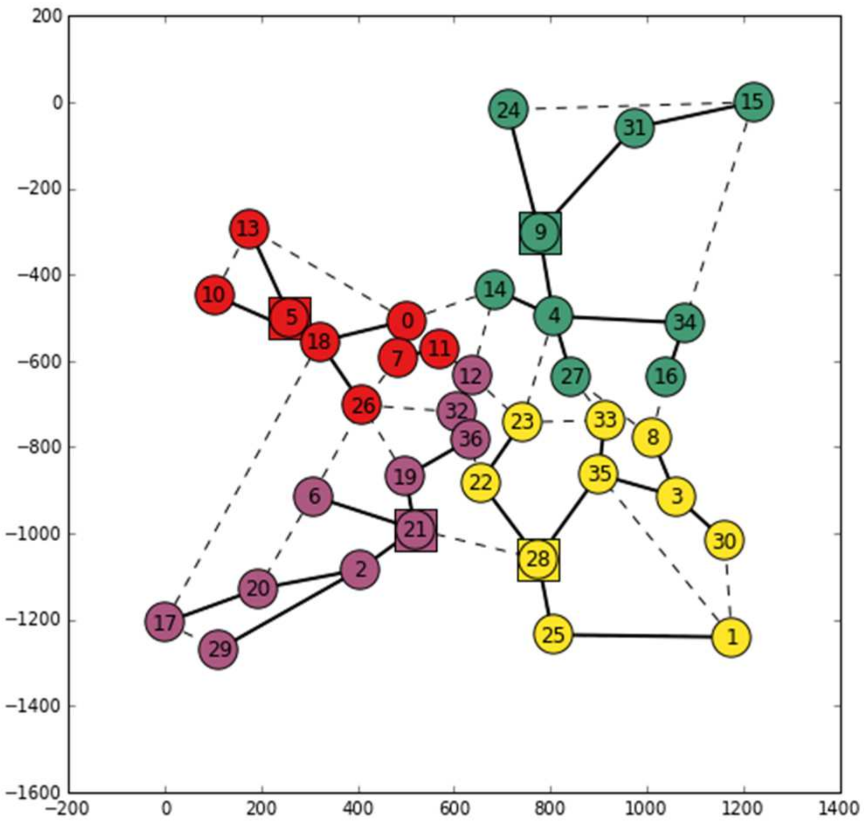
- linking variables constraints :

$$t_{ii'} \geq y_i + y_{i'} - 1 \quad \forall i, i' \in C$$
$$t_{ii'} \leq y_i \quad \forall i, i' \in C$$
$$t_{ii'} \leq y_{i'} \quad \forall i, i' \in C$$

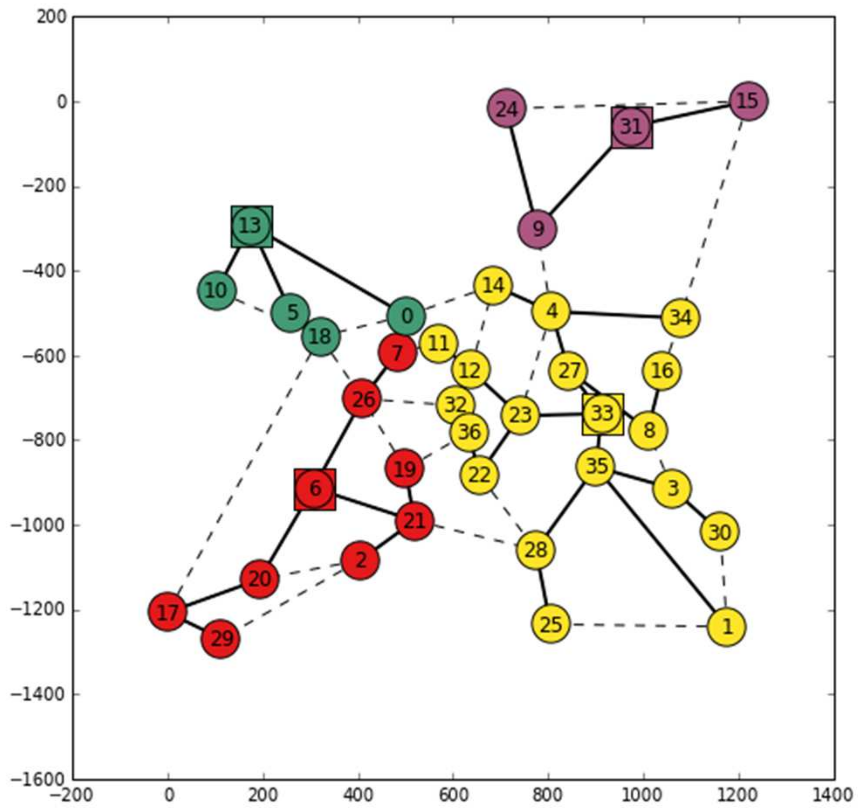
- $x_{ij}, y_i, z_j, t_{ii'} \in \{0,1\}$

The Controller Placement Problem

Effect of load balancing constraints on COST topology



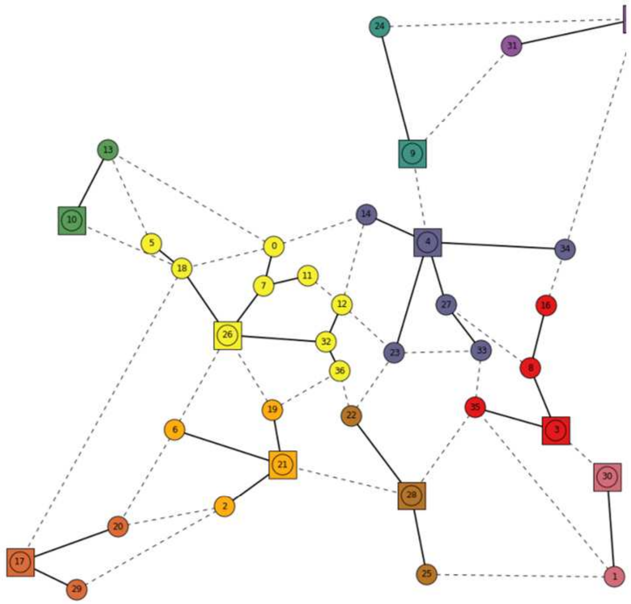
optimal solution with δ=3



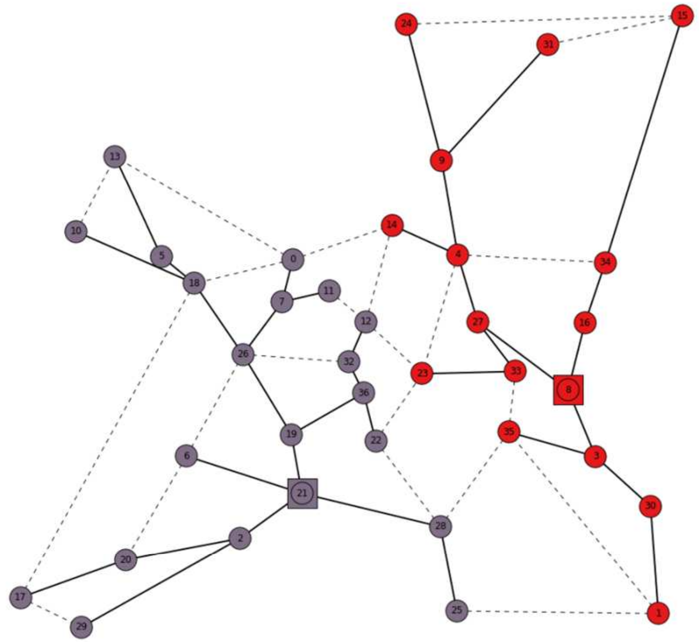
relaxation of load balancing constraints

The Controller Placement Problem

Effect of the maximal delay on the COST topology



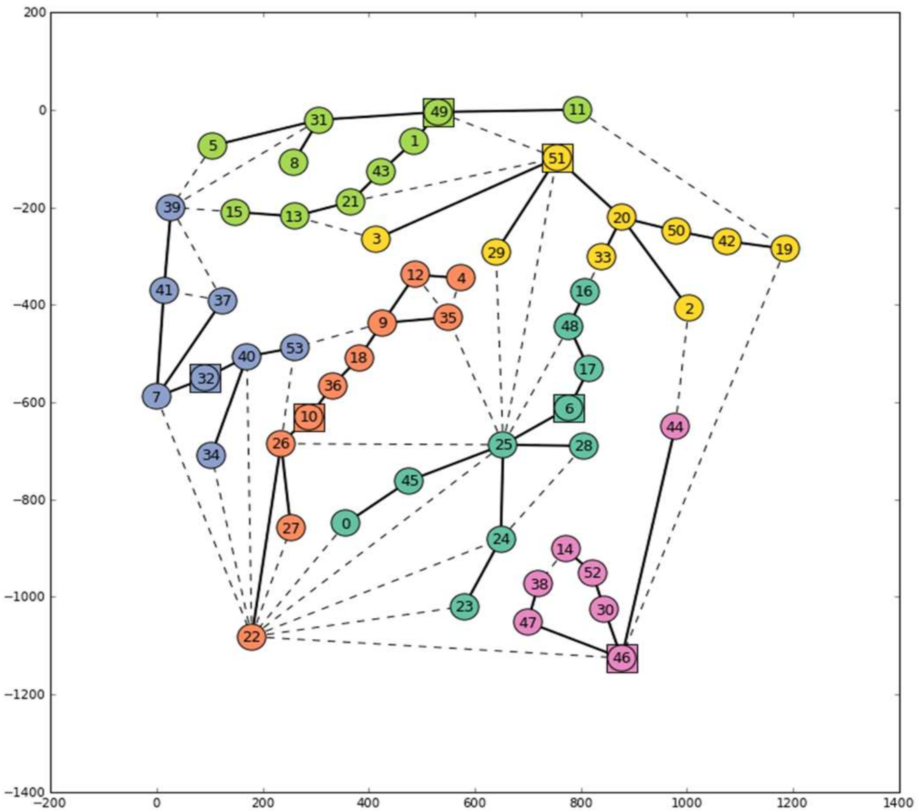
delay max is 15% of graph diameter

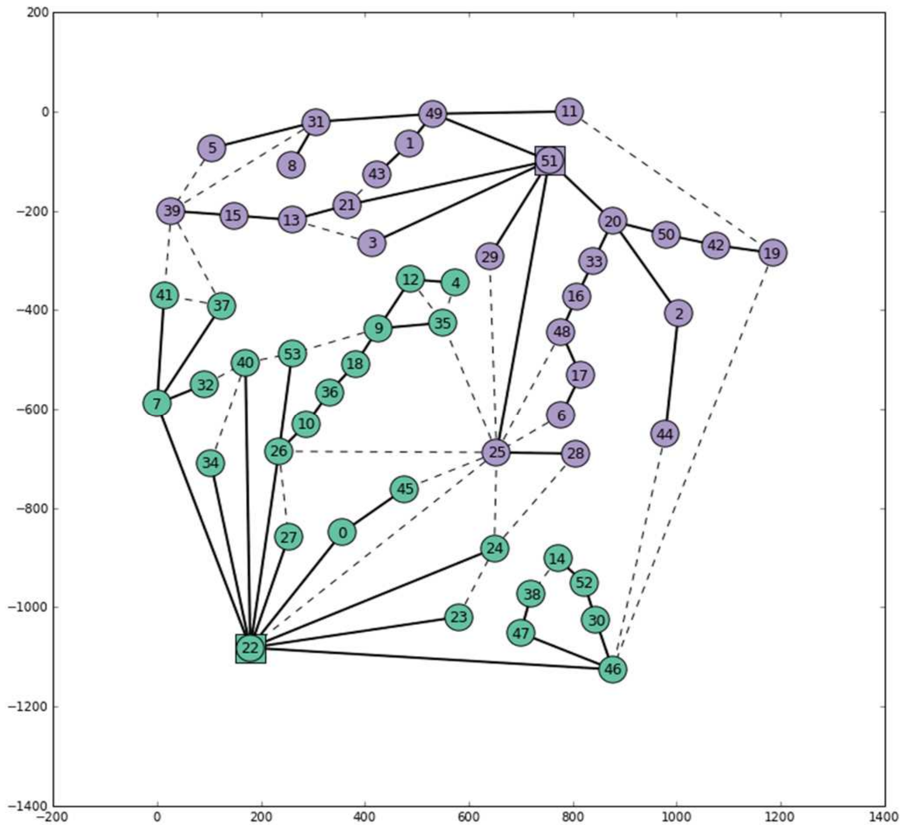


delay max is 39% of graph diameter

The Controller Placement Problem

Effect of the maximal delay on Zib topology



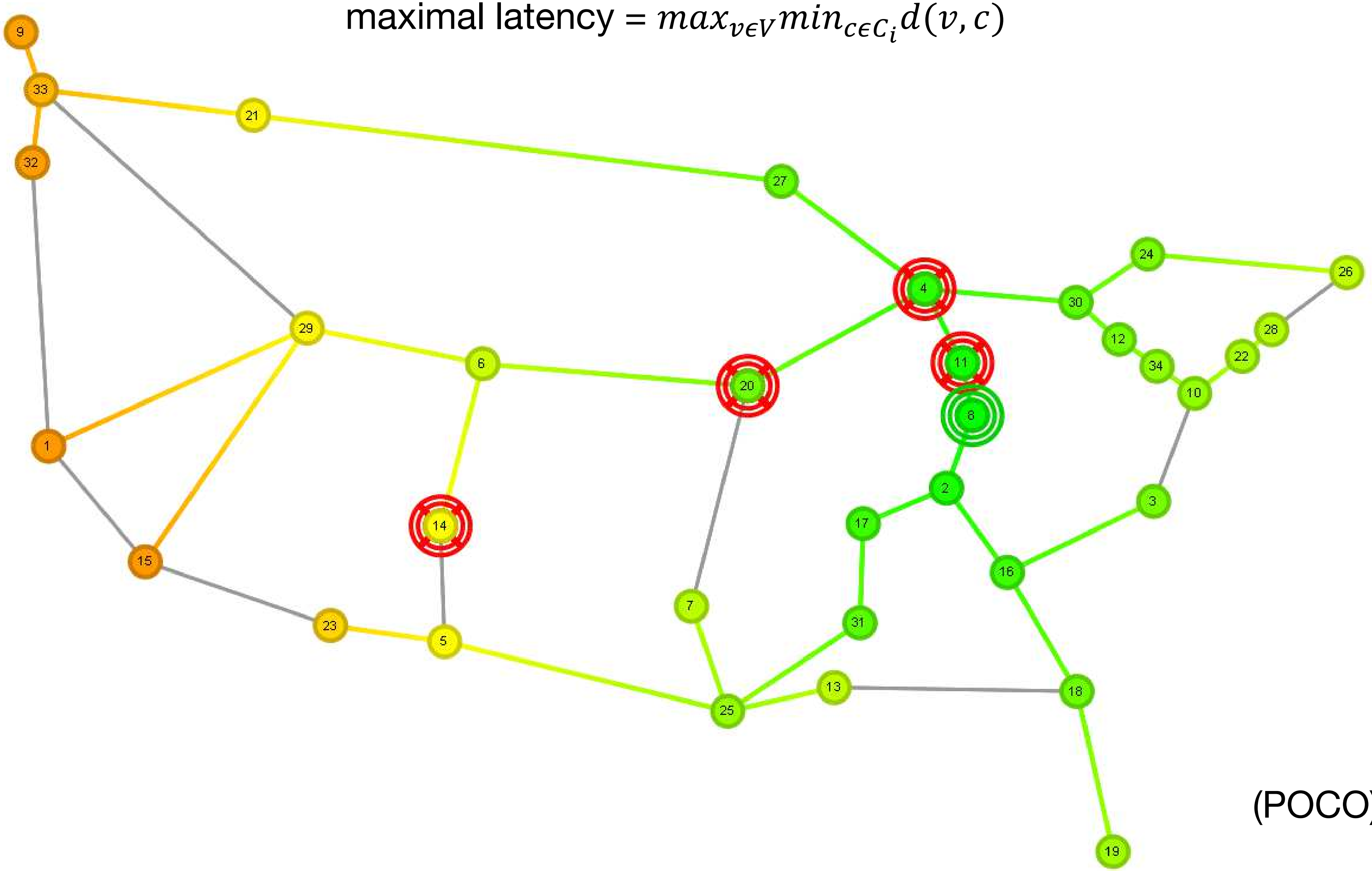


max latency is 30%

max latency is 50%

What is a “good” placement ?

maximal latency = $max_{v \epsilon V} min_{c \epsilon C_i} d(v, c)$



(POCO)

The Resilient Controller Placement Problem

- If a controller fails ? the nodes are assigned to another one
  – increases the latency between routers and controller
  – unbalanced domains (especially if the secondary controller takes the management of all the routers of the failed controller)

- we consider simultaneously *k* levels of controller failures.

- let *p* be the failure probability of a controller
- x_{ij}^{k} are re–assignment variables for each level of failure : 1 if controller i is the k^{th} backup controller of router j
- z_j^k = 1 if j has a $(k-1)^{th}$ backup controller but not a k^{th} backup controller

delay = $d_{ij} x_{ij}^{k} \, (1-p) p^{k-1}$

penalty cost = $l_{max} \, z_j^k p^{k-1}$

Resilient Controller Placement Problem

- bi-objective problem
- first objective

$$\min \sum_{i \in C} y_i$$

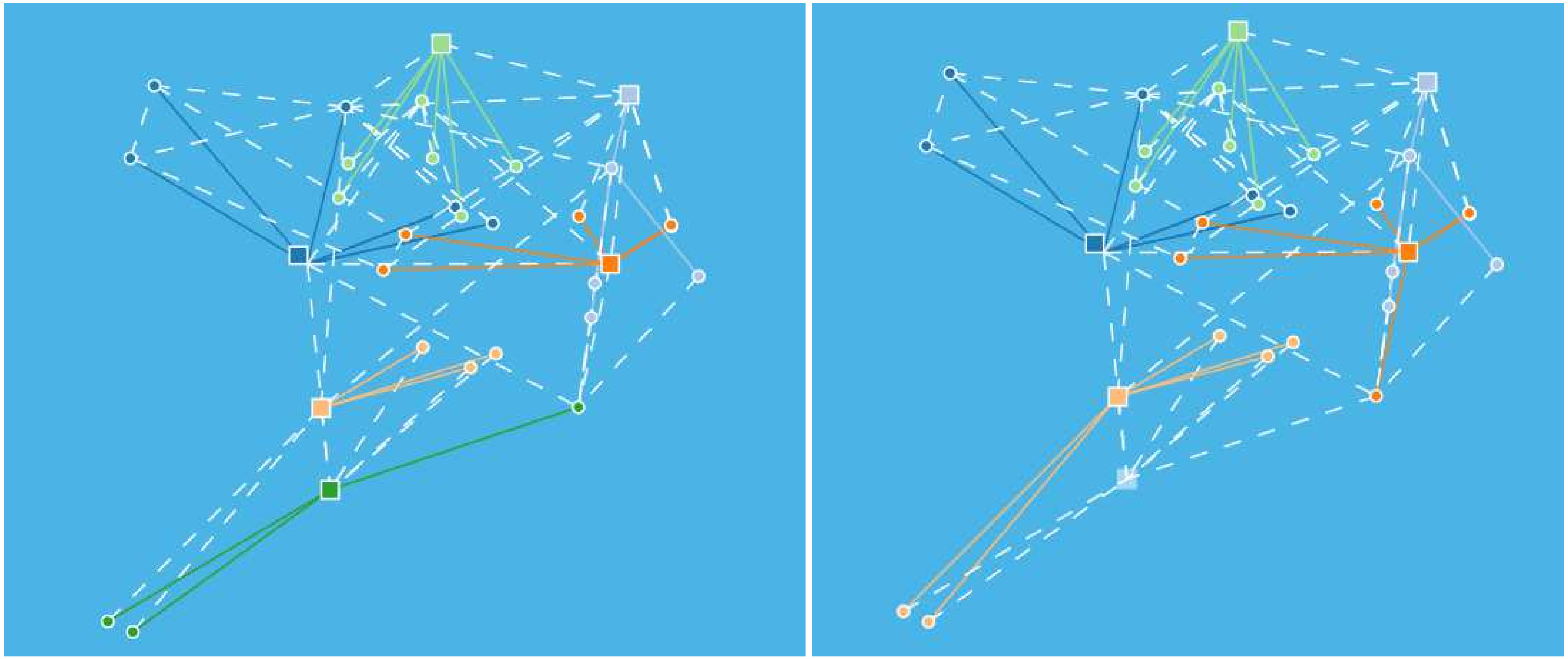
- second objective

$$\min \sum_{j \in R} \sum_{k=1}^{|C|} \sum_{i \in C} d_{ij} x_{ij}^k (1-p) p^{k-1} + l_{max} \sum_{j \in R} \sum_{k=1}^{|C|+1} p^{k-1} z_j^k$$

\+ the same block of constraints than for CPP for all back-up levels k

- The solution consists of
  - the minimum number of controllers,
  - their placement among the candidate network nodes,
  - the assignment of network elements to controllers,
  - the re assignement in case of multiple failures of any controller with minimal degradation of QoS.

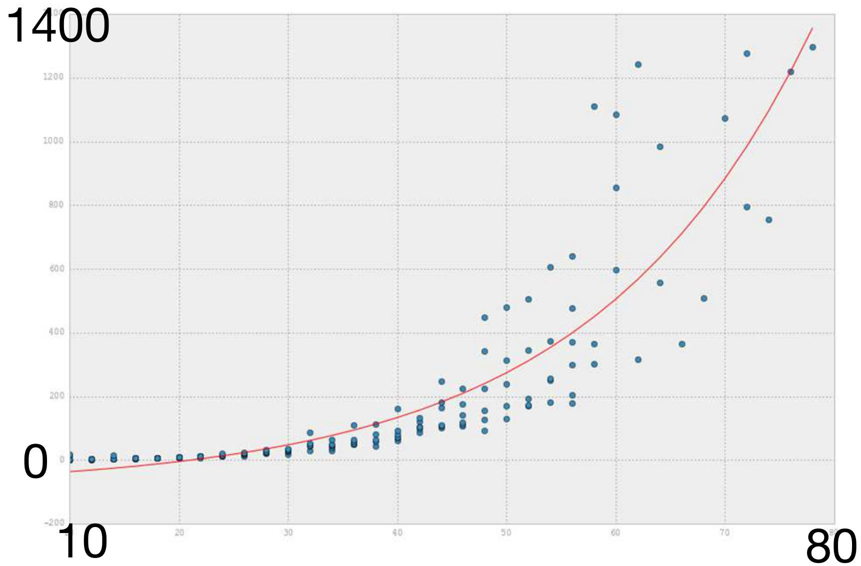
Resilient Controller Placement Problem



Simulation results

Parameters	Value
Number of nodes	[10, 80]
l_{max}	{3 000, 5 000, 7 000}
l_{cc-max}	7 000
δ	3
back-up levels	2

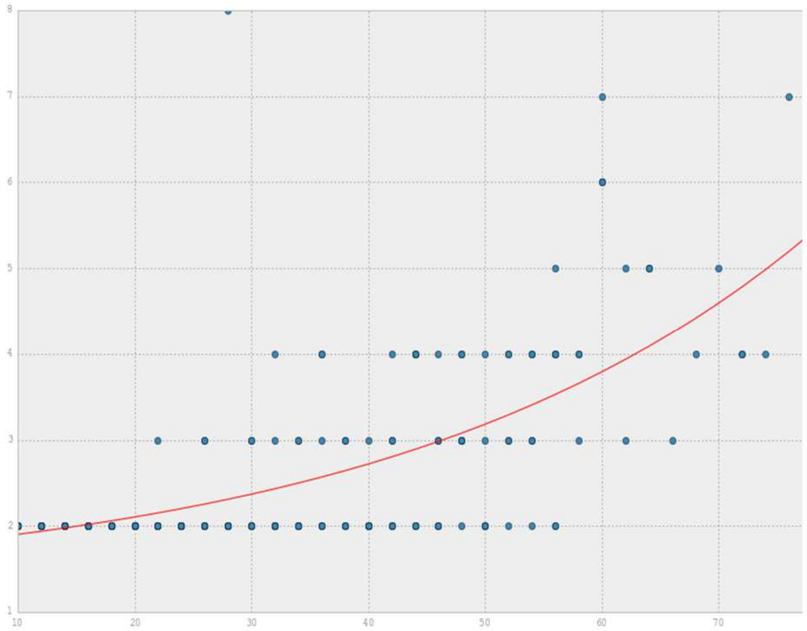
3 000 random graphs



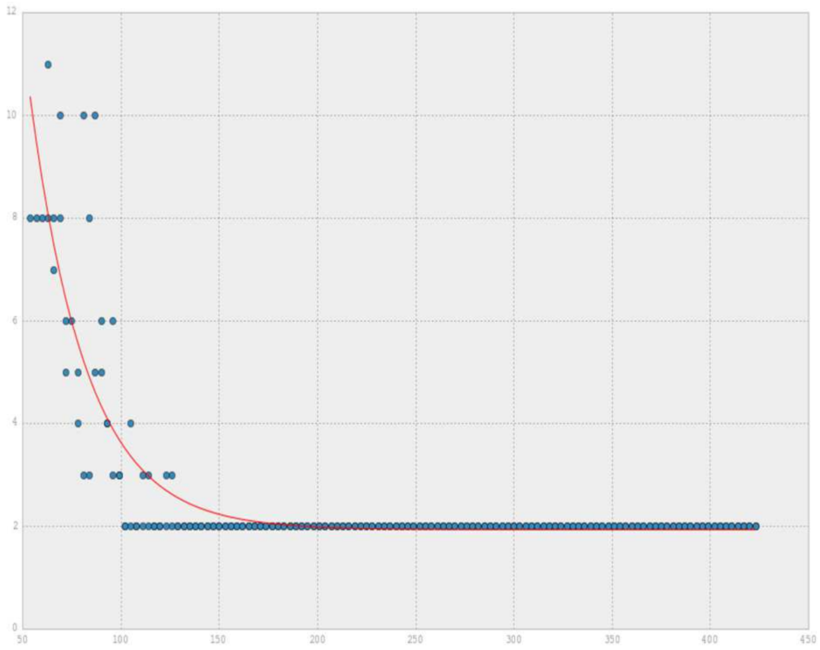
- CPU time on number of nodes

Simulation results

- Evolution of the number of controllers depending on the graph size/density.



Number of controllers on the number of nodes



Number of controllers on the number of arcs

Conclusions and Perspectives

- These formulations have been implemented in a decision-aid tool to simulate deployment scenario.

- Huge network instances : spectral clustering, relaxation-based heuristic.

- Study of dynamic ressources re-assignment will depend on real use cases.