Seamless Network-Wide IGP Migrations

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It is not the strongest of the species
that survives, nor the most intelligent.

— Leon Megginson

(miss-attributed to Darwin)

It is not the strongest of the species
that survives, nor the most intelligent.
It is the one that is most
adaptable to change.

— Leon Megginson
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Last week on the NANOG mailing-list ...

Is there any reason to run IS-IS over OSPF in the service provider core?
Currently, we are running IS-IS but we are redesigning
our core and now would be a good time to switch.

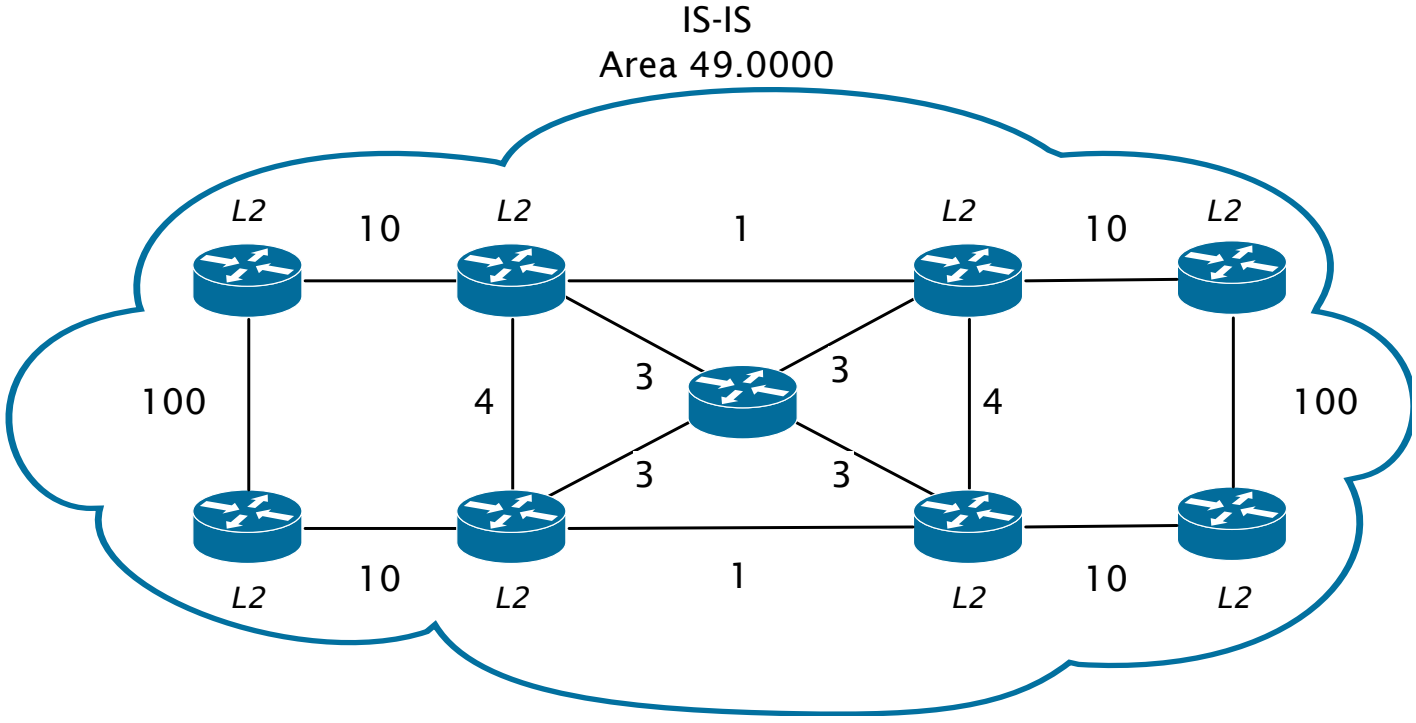
I would like to switch to OSPF, mostly because of
familiarity with OSPF over IS-IS.

What does everyone think?

NANOG thread, *OSPF vs IS-IS*, 11/08/11

Migrating the IGP is about network-wide reconfiguration

How do we get from here ...



Migrating the IGP is about network-wide reconfiguration

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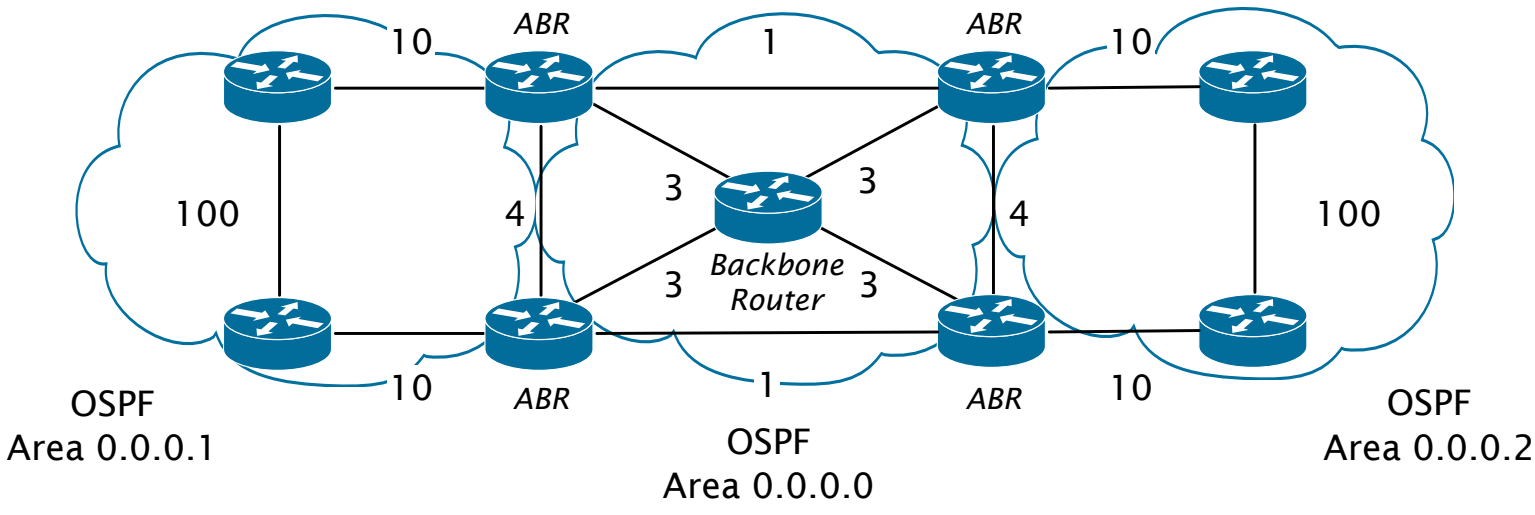


Reconfiguring the IGP can provide immediate benefits to the network

IGP reconfigurations can improve the

- manageability
- performance
- stability
- security

of the entire network

Migrating the IGP is operationally complex

Reconfigure a running network
while respecting Service Level Agreement

Make highly distributed changes
on all the routers, in a coordinated manner

Face potential routing anomalies
as non-migrated routers interact with migrated ones

Current approaches do not entirely solve the problem

Reconfigure weights/links

Disruption free topology reconfiguration [Francois et al. INFOCOMM'2007]

Loop-free updates of forwarding tables [Fu et al. IEEE TNSM 2008, Shi et al. ICC'2009]

Graceful Network Operations [Raza et al. INFOCOMM'2009]

Modify the routers

Shadow Configuration [Alimi et al. SIGCOMM'2008]

Take advantage of virtualization

VROOM [Wang et al. SIGCOMM'2008]

BGP Grafting [Keller et al. NSDI'2010]

Problem

Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies

Sub-problem 1	Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies
Current Practice	Run the two IGP configurations in parallel

Migrating the IGP usually requires running two routing planes

Abstract model of a router

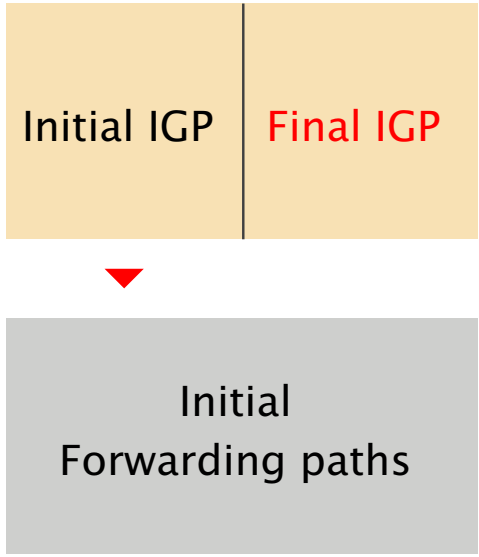
At first, the initial IGP dictates the forwarding paths being used

Migrating the IGP usually requires running two routing planes

Abstract model of a router

Control-plane

Data-plane



Then, the final IGP is introduced without changing the forwarding

Migrating the IGP usually requires running two routing planes

Abstract model of a router

Control-plane

Data-plane

After having converged, the final IGP is used by flipping the preference

Migrating the IGP usually requires running two routing planes

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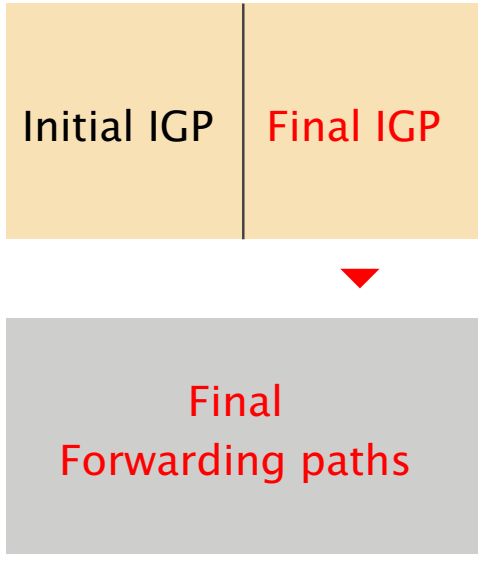

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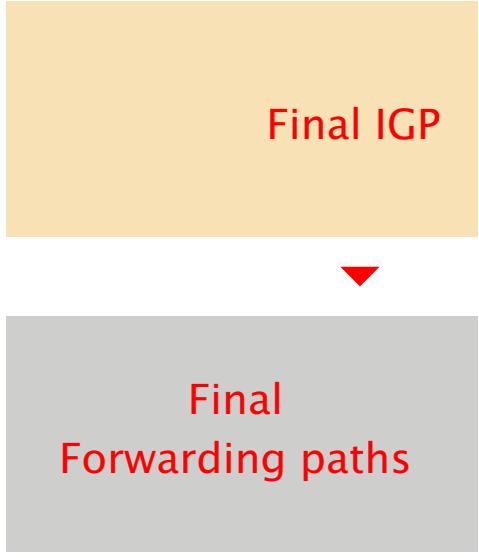
Migrating the IGP usually requires running two routing planes

Abstract model of a router



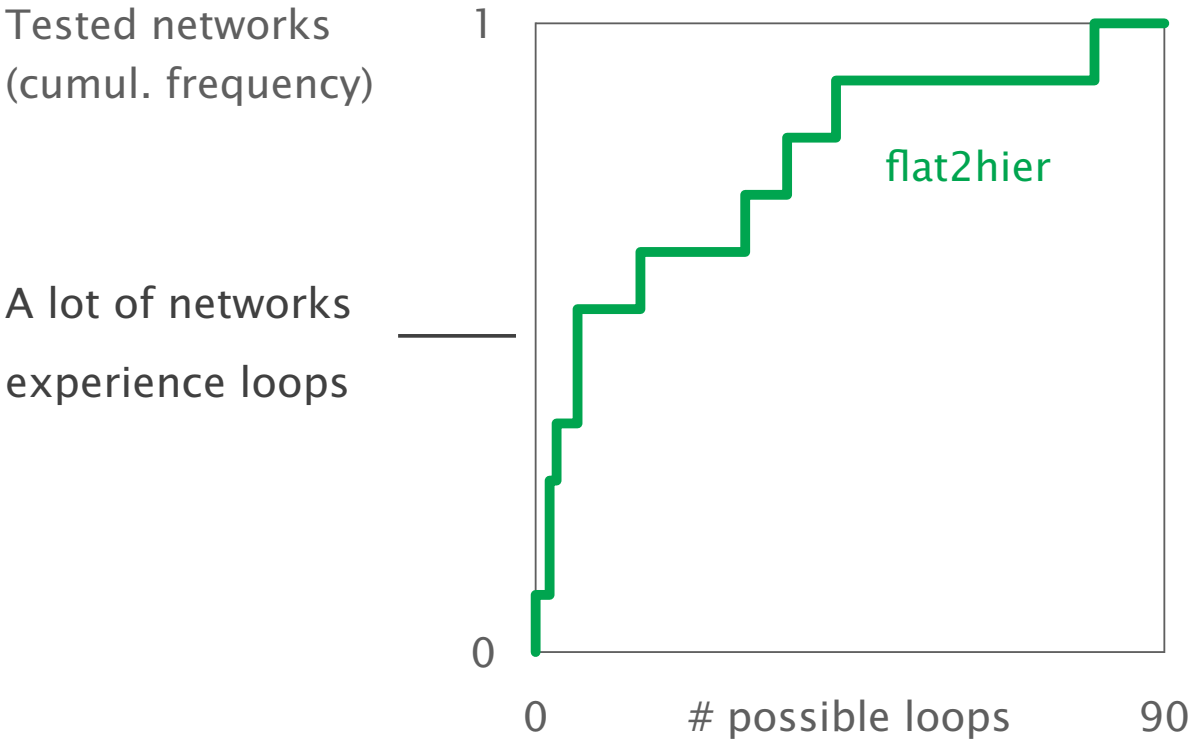
The initial IGP is removed as it is not used anymore

Sub-problem 1

Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies

Sub-problem 2 Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies

Migrating the IGP can create *migration loops*



Up to 90 *migration loops* can arise during an IGP migration

Sub-problem 2 Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies

Sub-problem 2	Replace the anomaly-free IGP configuration of a running network, router-by-router, without causing any routing anomalies
Contributions	Seamless IGP migration is possible as long as the reconfiguration process follows a strict ordering

Contributions

Seamless IGP migration is possible as long as the reconfiguration process follows a strict ordering

which one ?

Contributions

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4. Provide fallback solutions when no ordering exists

Contributions

1. Seamless IGP migration is possible as long as the reconfiguration process follows a strict ordering
2. Decide if an ordering exists is NP-complete
3. Develop an exponential algorithm as well as a heuristic to compute the ordering
4. Provide fallback solutions when no ordering exists
5. Outline solutions for link failures and congestion

Seamless IGP migration is possible as long as the reconfiguration process follows a strict ordering

which one ?

Seamless Network-Wide IGP Migrations

1. Identify the ordering
   Avoid anomalies
2. Compute the ordering
   Manage complexity
3. Apply the ordering
   Stable, efficient

Seamless Network-Wide IGP Migrations

1 Identify the ordering

Avoid anomalies

Compute the ordering

Manage complexity

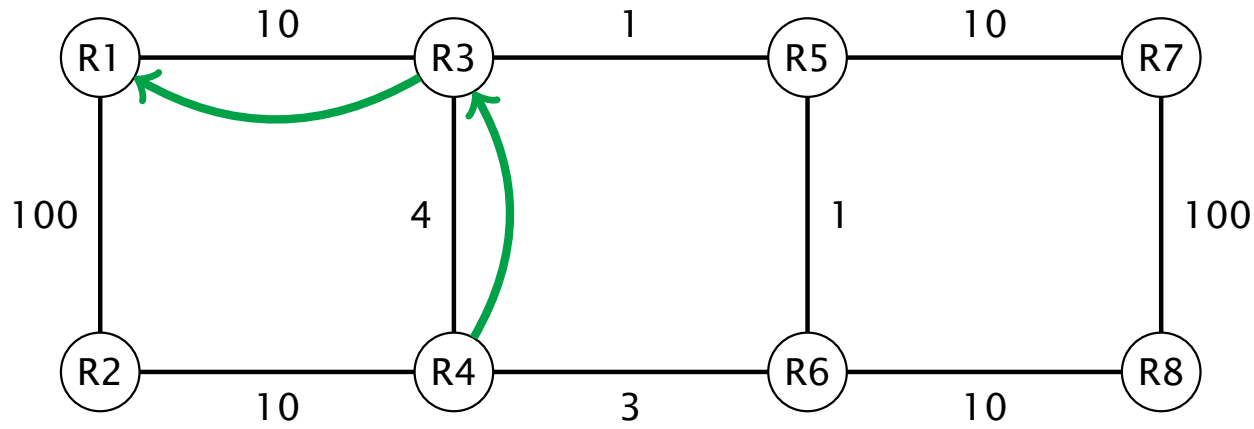
Apply the ordering

Stable, efficient

Reconfiguring the IGP might change the forwarding paths being used

In a flat IGP, routers forward traffic according to the shortest-path towards the destination.

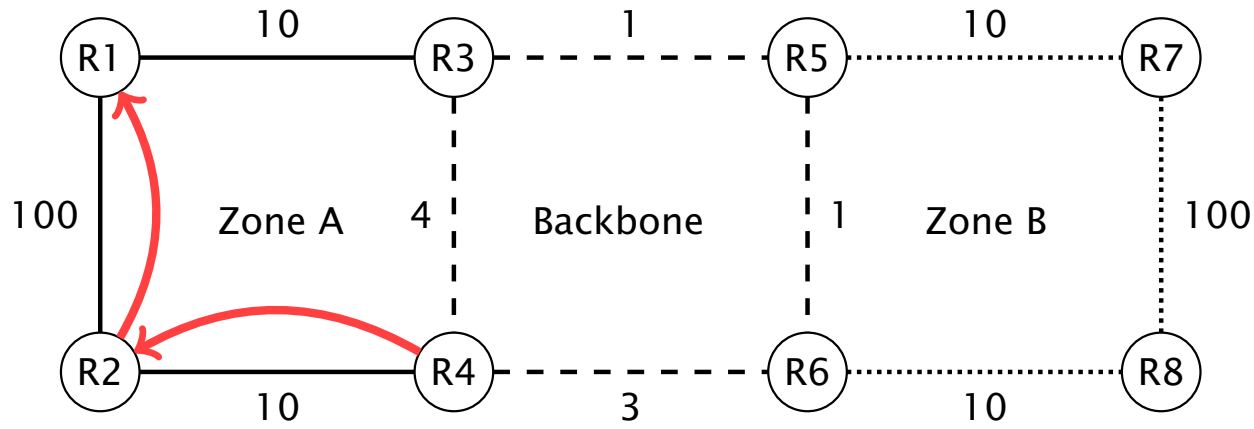
In a flat IGP, R4 reaches R1 via R3



Reconfiguring the IGP might change the forwarding paths being used

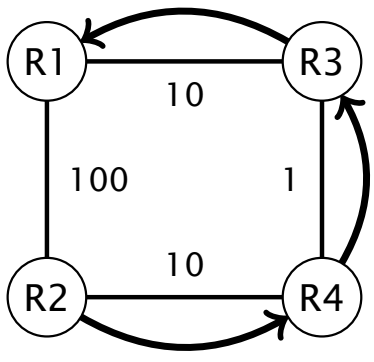
In a hierarchical IGP, routers prefer paths contained within a single zone over the ones crossing several zones

In a hierarchical IGP, R4 reaches R1 via R2



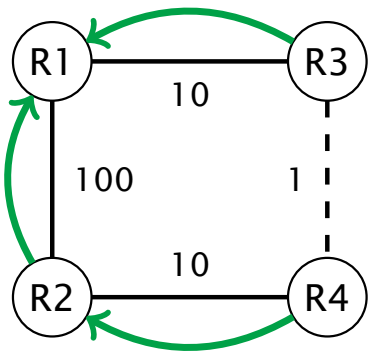
Whenever the forwarding paths change, forwarding loops can be created

initial paths



flat IS-IS

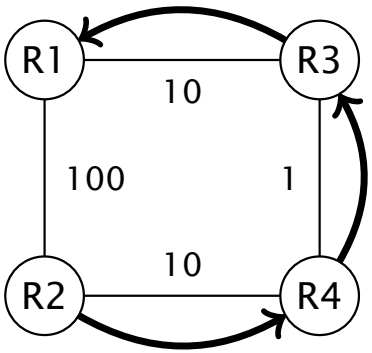
final paths



hierarchical OSPF

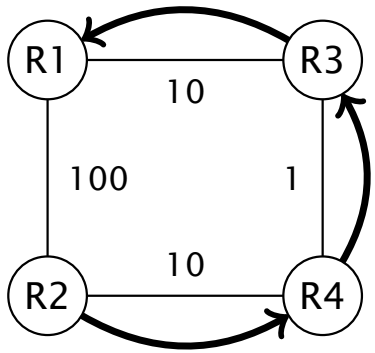
Forwarding paths towards R1

initial paths



flat IS-IS

intermediate paths



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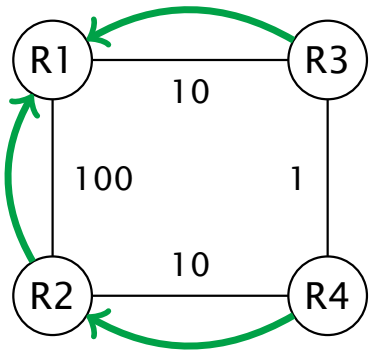
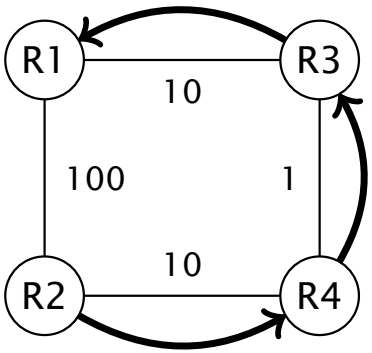


hierarchical OSPF

Forwarding paths towards R1

First, we migrate R3

initial paths



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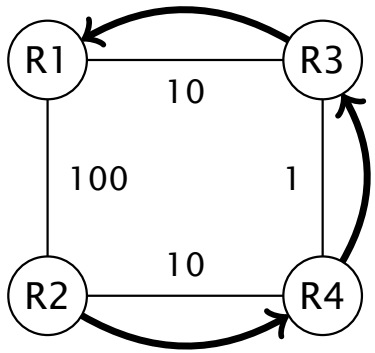

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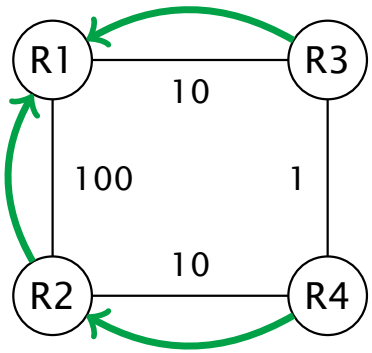

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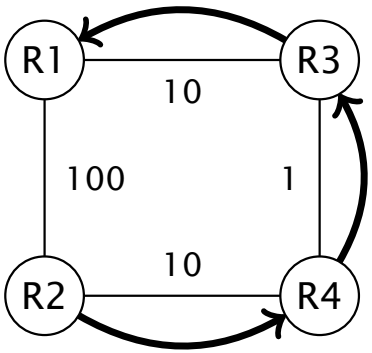

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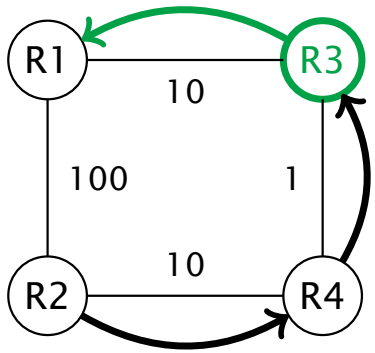

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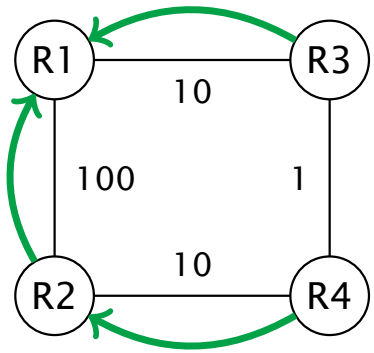

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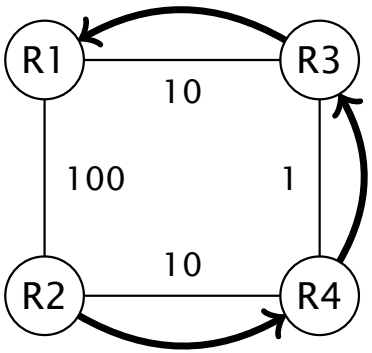
Forwarding paths towards R1

Then, we migrate R4

initial paths



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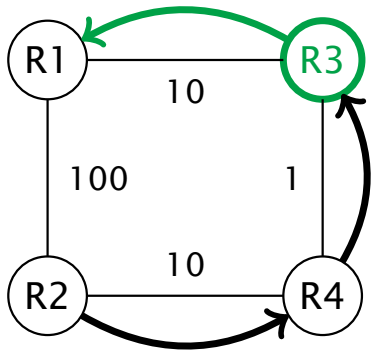

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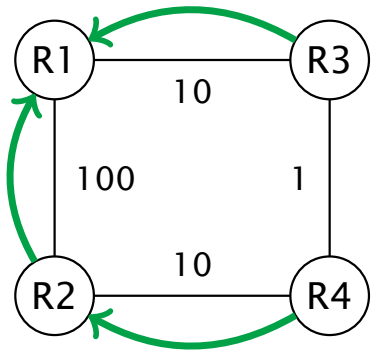

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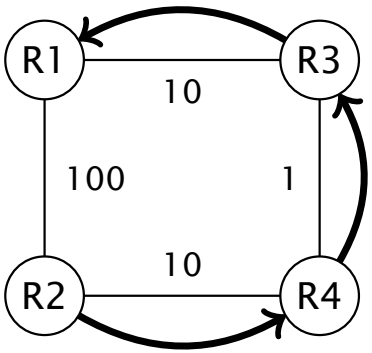

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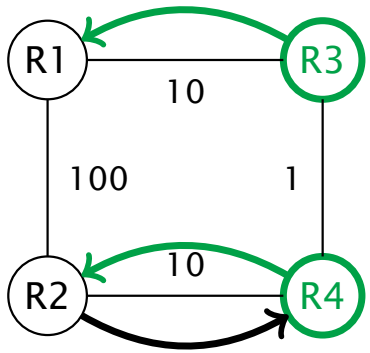

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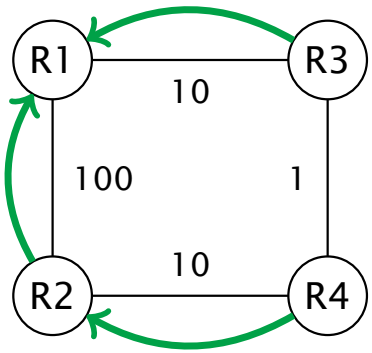

hierarchical OSPF

Forwarding paths towards R1

Whenever the forwarding paths change, forwarding loops can be created

A loop is created if R4 is migrated before R2

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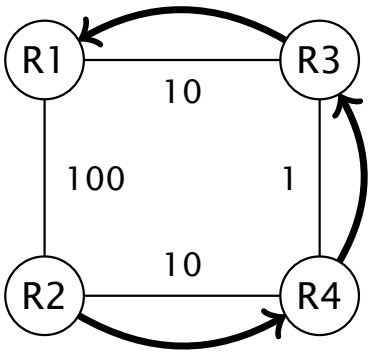

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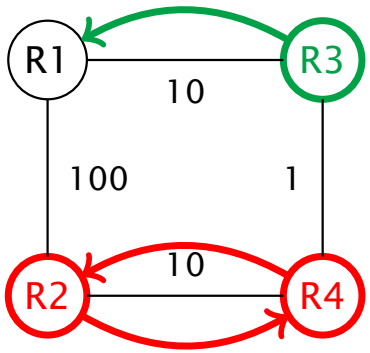

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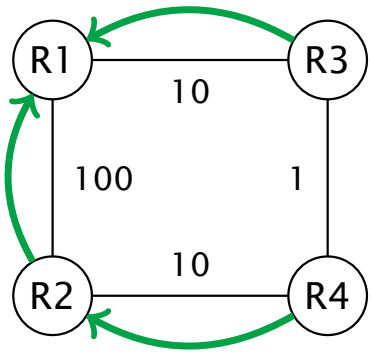


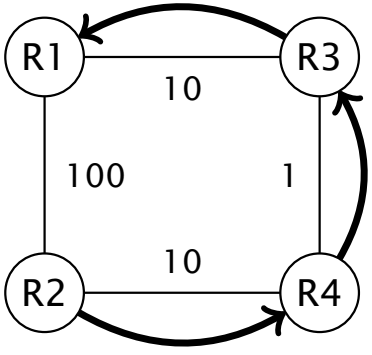
hierarchical OSPF

Forwarding paths towards R1

Migrations have to be performed following a precise ordering

No loop arises if R2 is migrated before R4

initial paths



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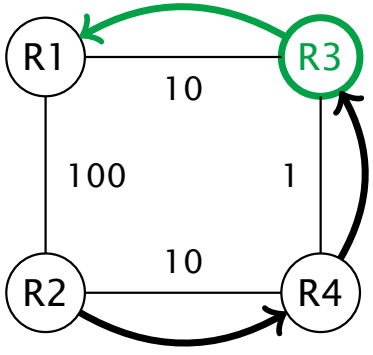

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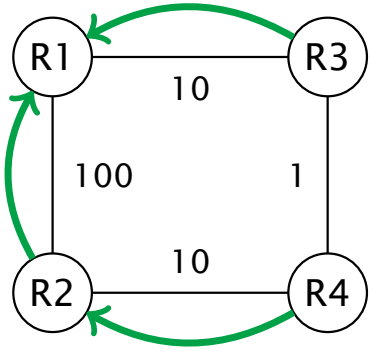

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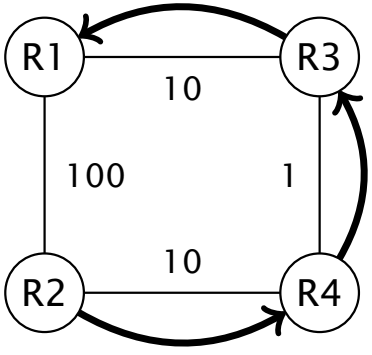

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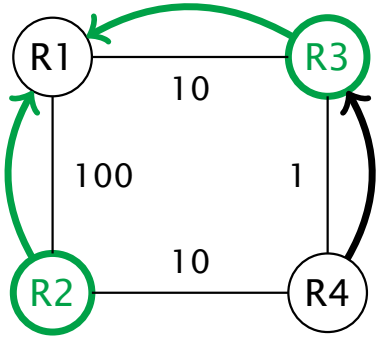

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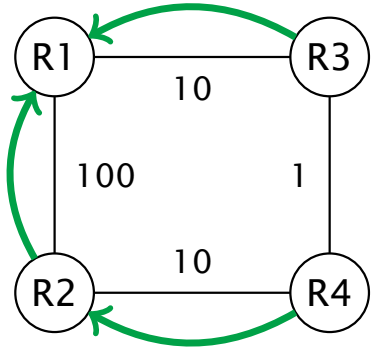

hierarchical OSPF

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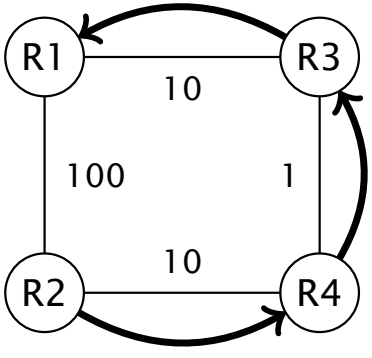

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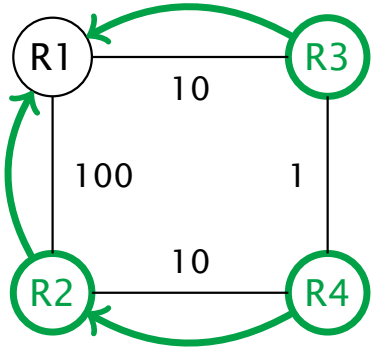

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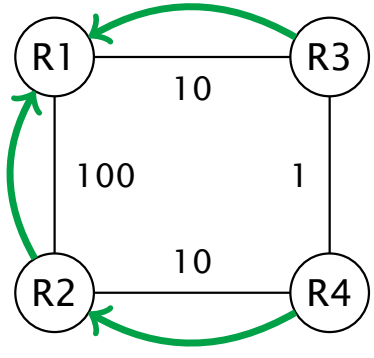


hierarchical OSPF

Forwarding paths towards R1

Seamless Network-Wide IGP Migrations

Identify the ordering

Avoid anomalies

2 Compute the ordering

Manage complexity

Apply the ordering

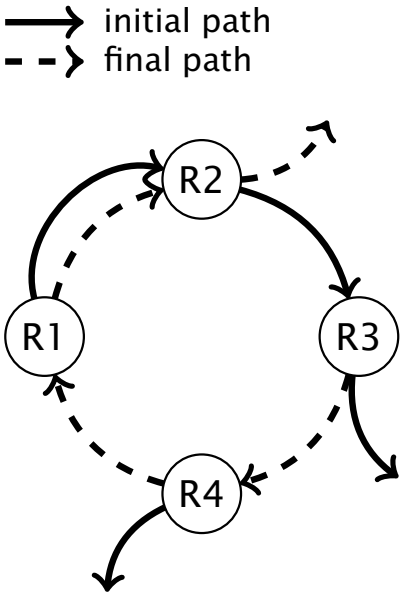
Stable, efficient

Finding and even deciding if an ordering exists is NP-complete

The Enumeration Algorithm [correct & complete]

1. Merge the initial and the final forwarding paths
2. For each migration loop in the merged graph,
   Output ordering constraints such that
   at least one router in the initial state
   is migrated before at least one in the final
3. Solve the system by using Linear Programming

Finding and even deciding if an ordering exists is NP-complete



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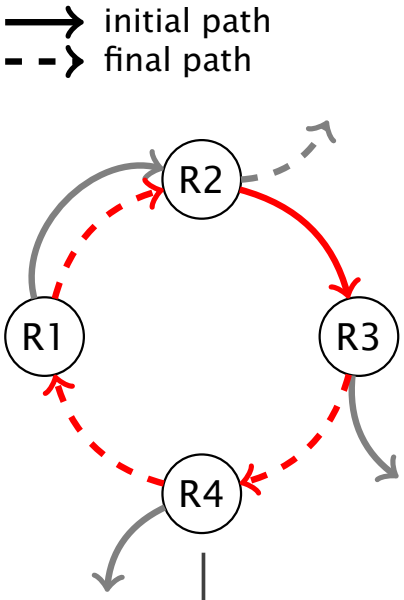

In every migration loop, at least one router is not migrated (R2) while at least one is migrated (R4, R3)

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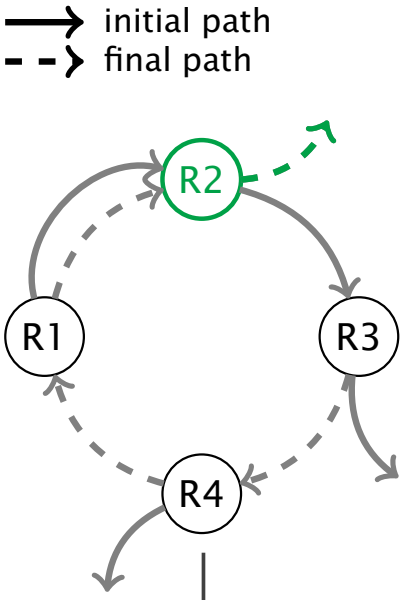

Migrate R2 before R3 or R4 avoids the loop

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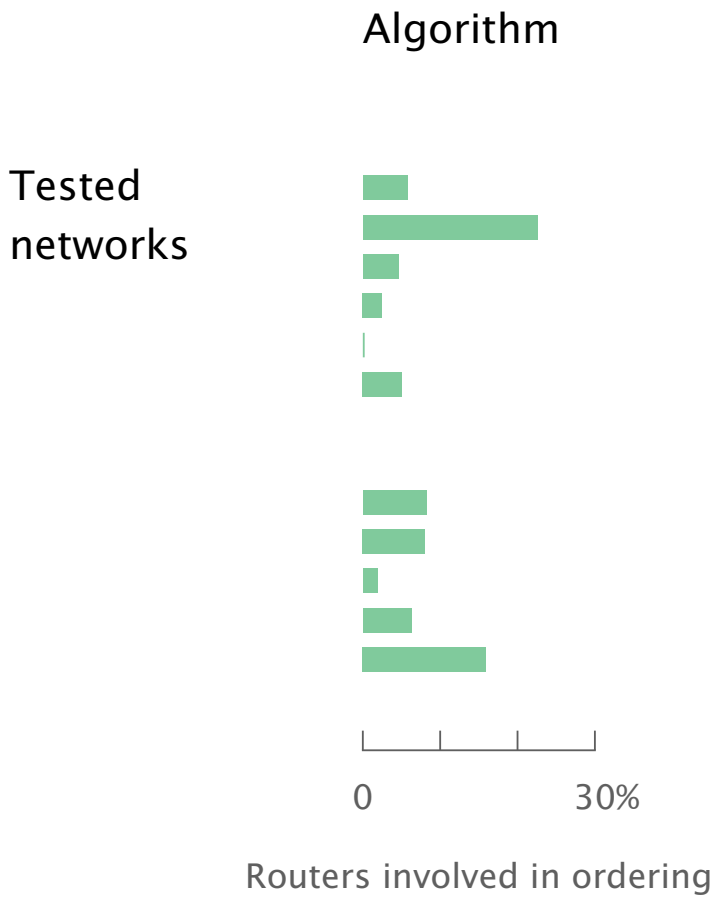
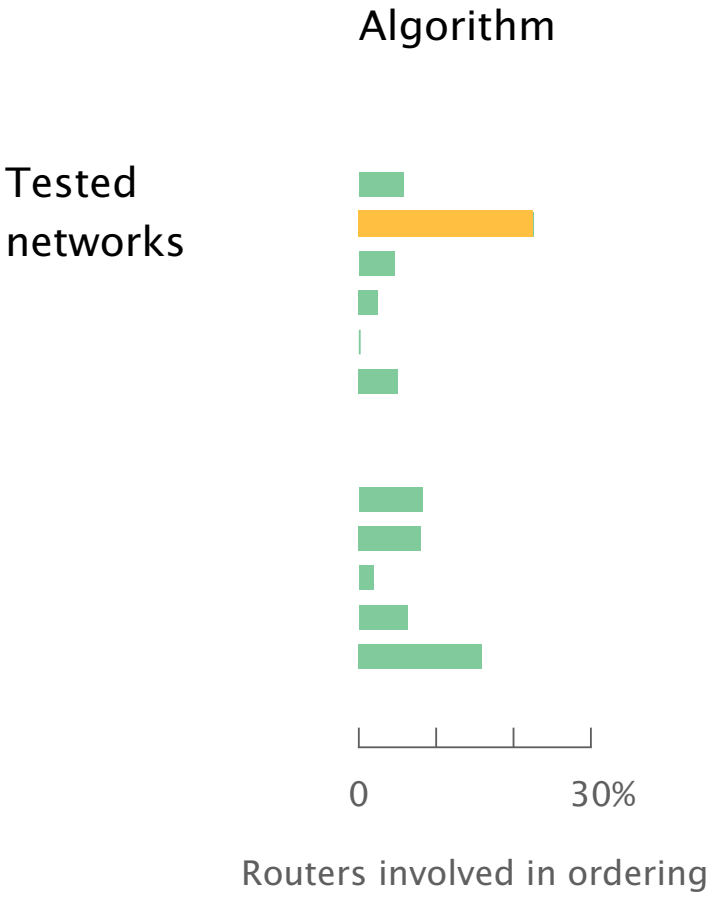
3. Solve the system by using Linear Programming

In all the tested scenarios, the algorithm has found a solution



More than 20% of the routers might be involved in the ordering



To deal with failures during the migration, time-efficient techniques are needed

Failures can change the computed ordering

as they modify the underlying IGP topology

Solutions

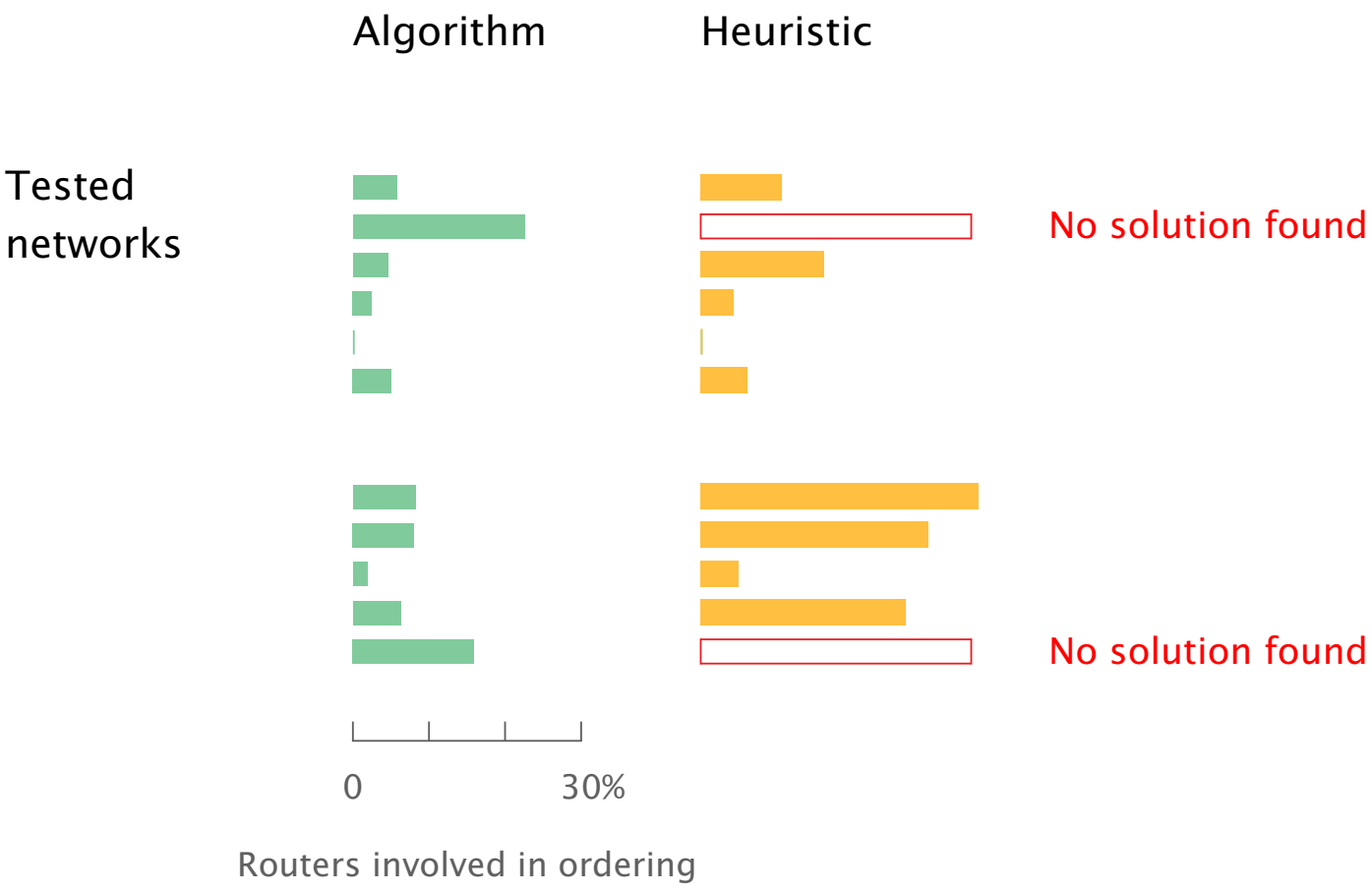
- Precompute failover orderings
- Compute a new ordering when a failure is detected

To manage complexity, we implemented a correct, but not complete heuristic

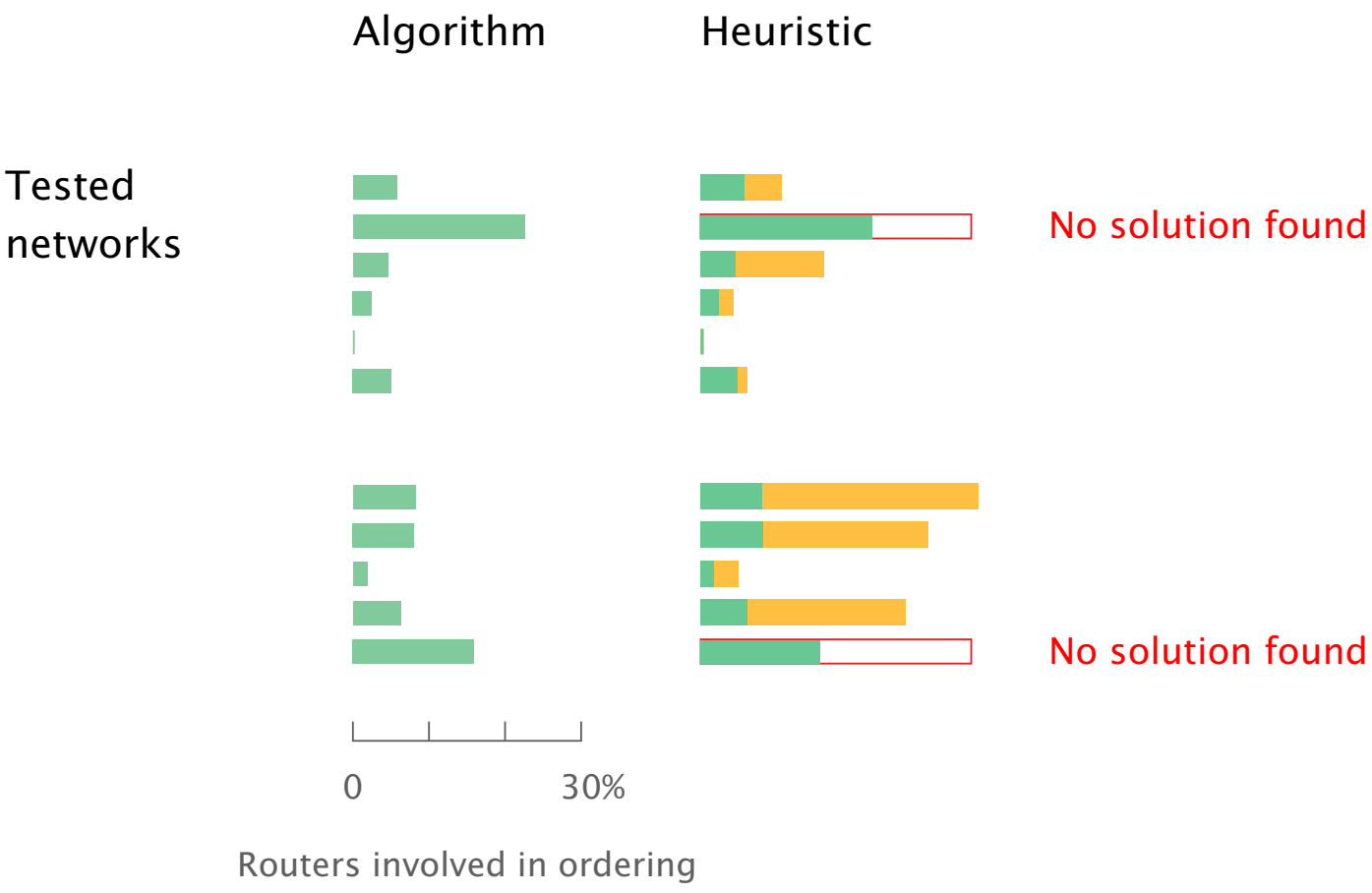
The heuristic is

- based on sufficient, but not necessary condition ▶ migrate each router after all its successors
- one order of magnitude faster than the complete algorithm

The heuristic may not find a solution, even if it exists



The heuristic involves more routers in the ordering than needed



Seamless Network-Wide IGP Migrations

Identify the ordering

Avoid anomalies

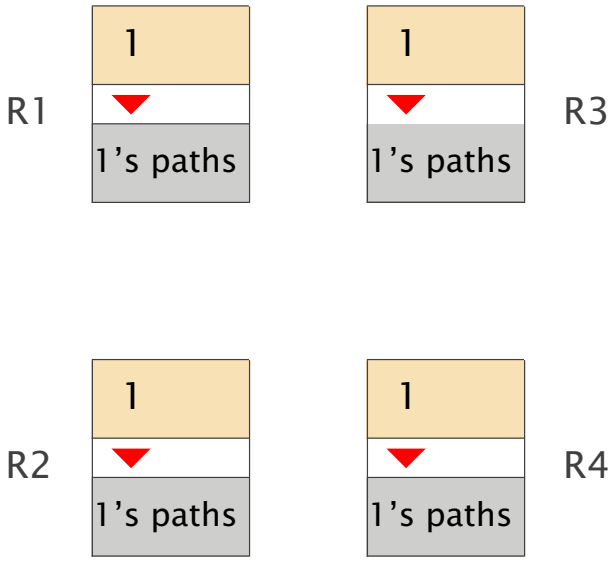
Compute the ordering

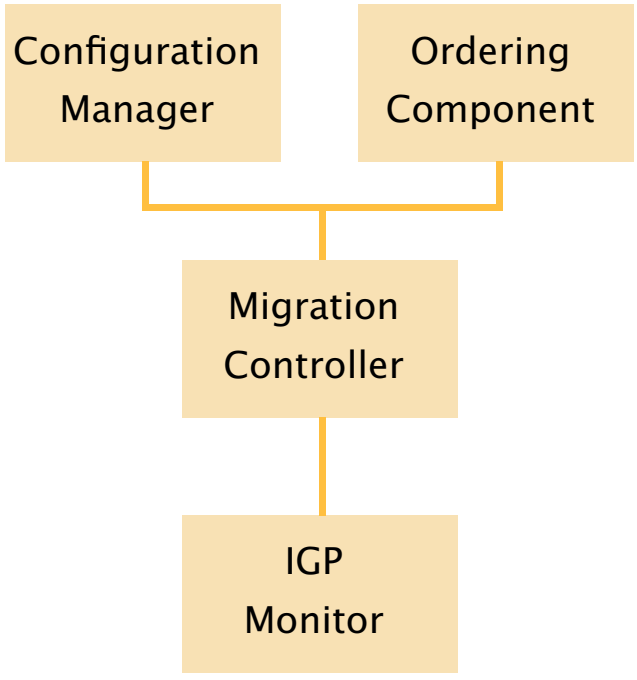
Manage complexity

3 Apply the ordering

Stable, efficient

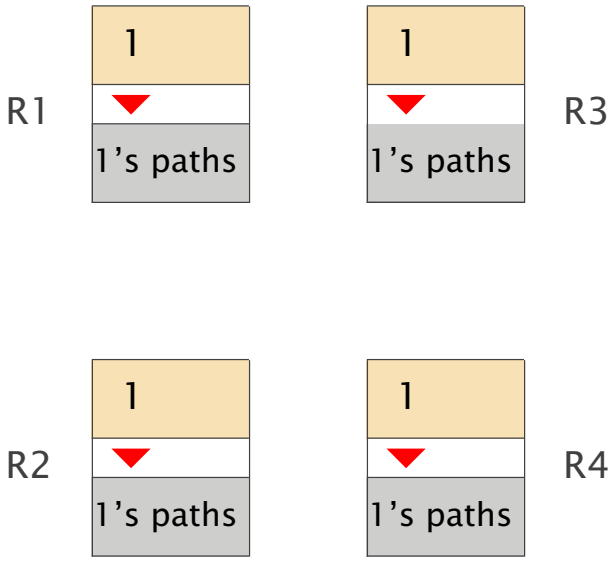
We implemented a provisioning system which automates the process

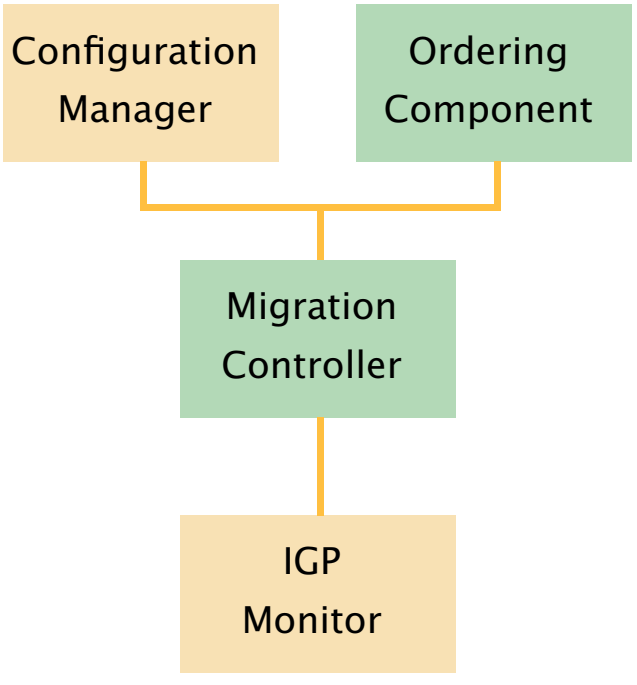




Network in which IGP 1 is replaced by IGP 2

First, the *Ordering Component* computes the ordering (if any)





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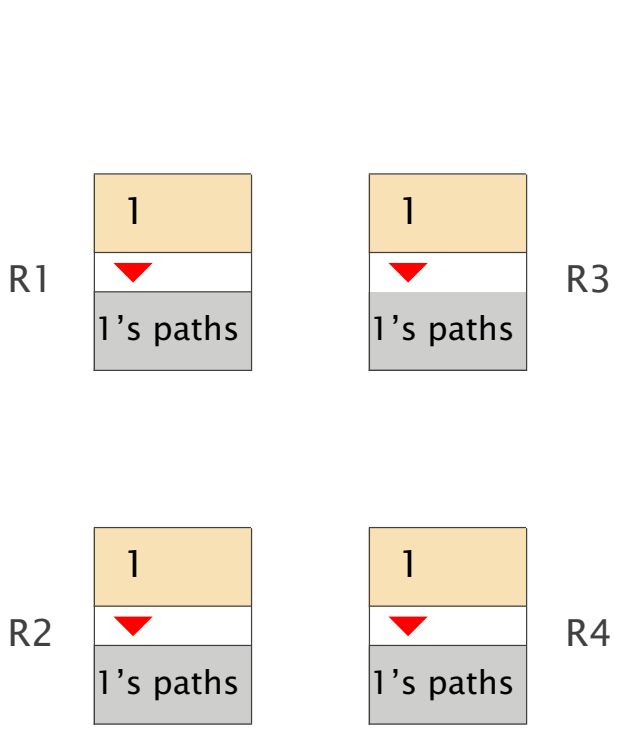
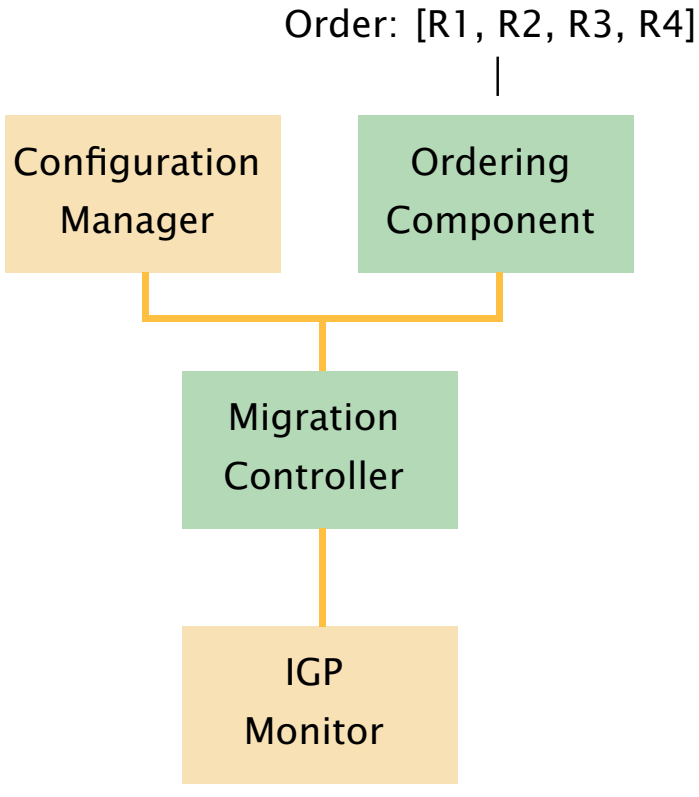
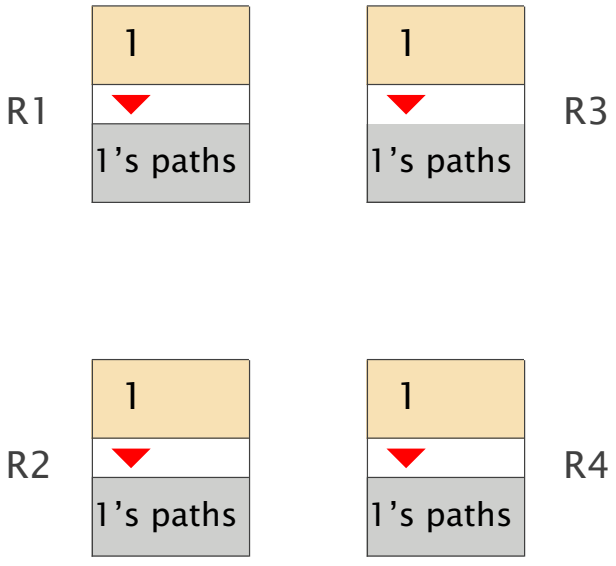
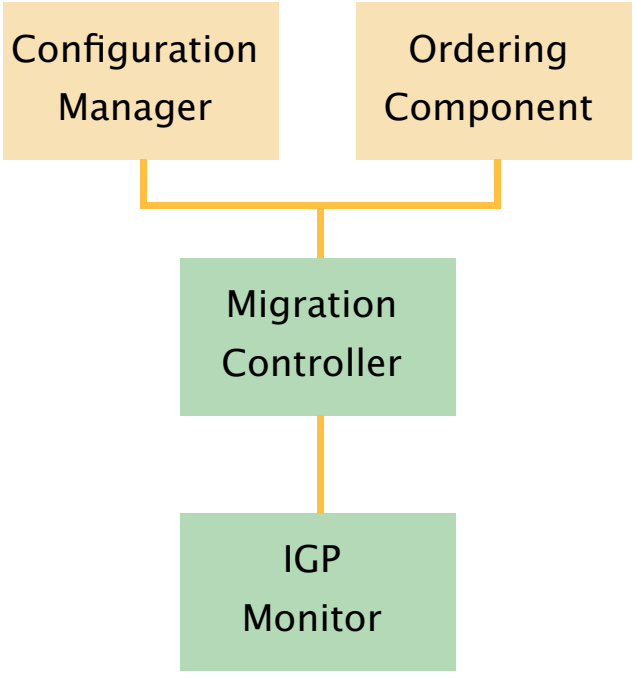




Network in which IGP 1 is replaced by IGP 2

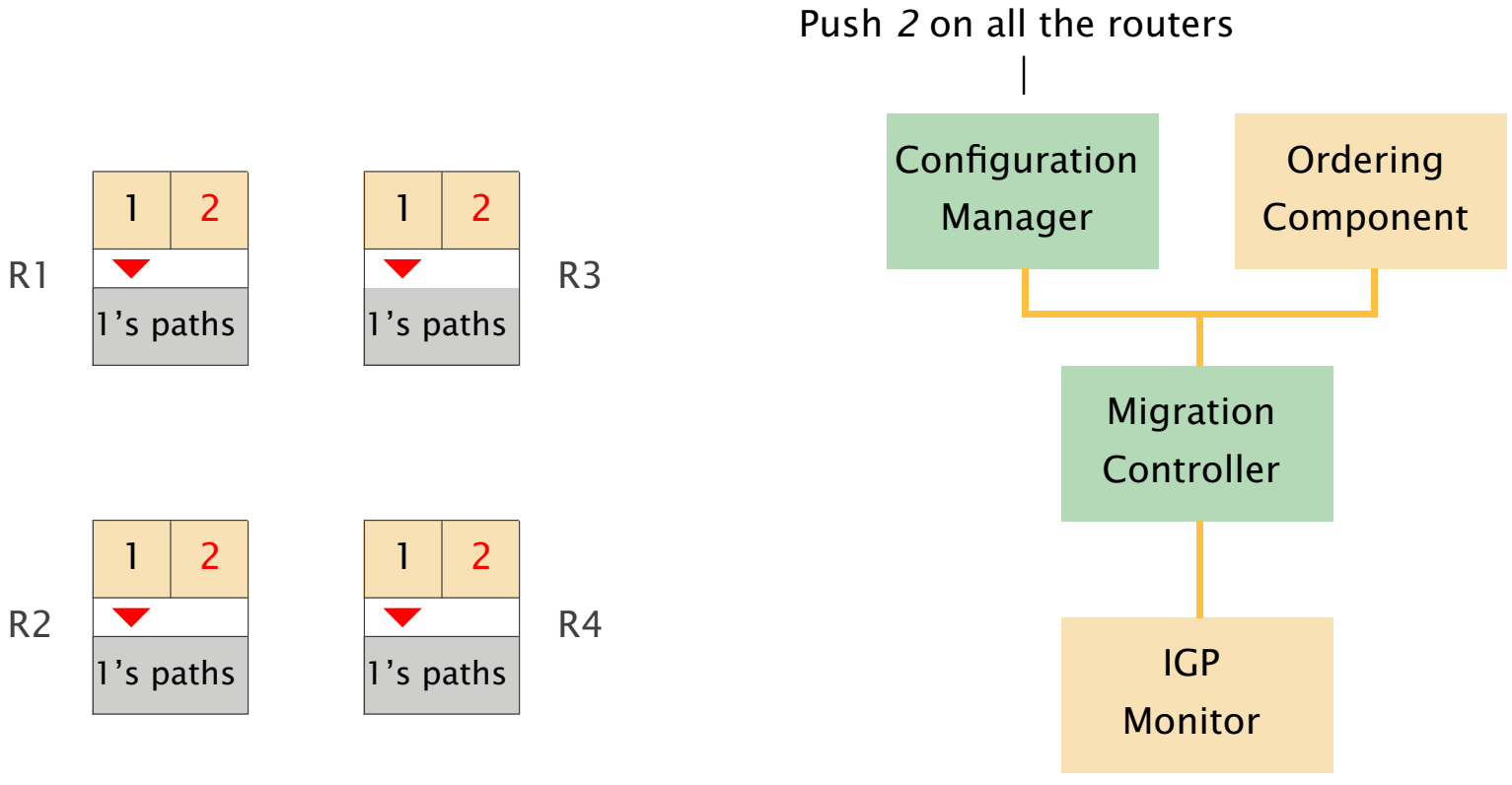
Second, the *IGP Monitor* builds a dynamic view of the IGP and assesses its stability





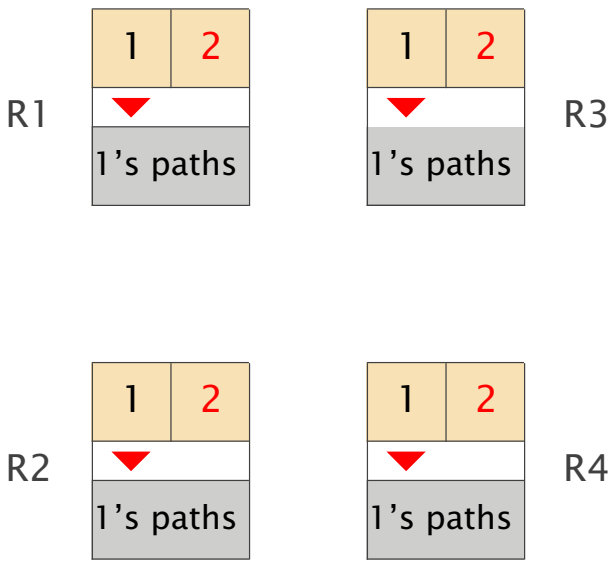
Network in which IGP 1 is replaced by IGP 2

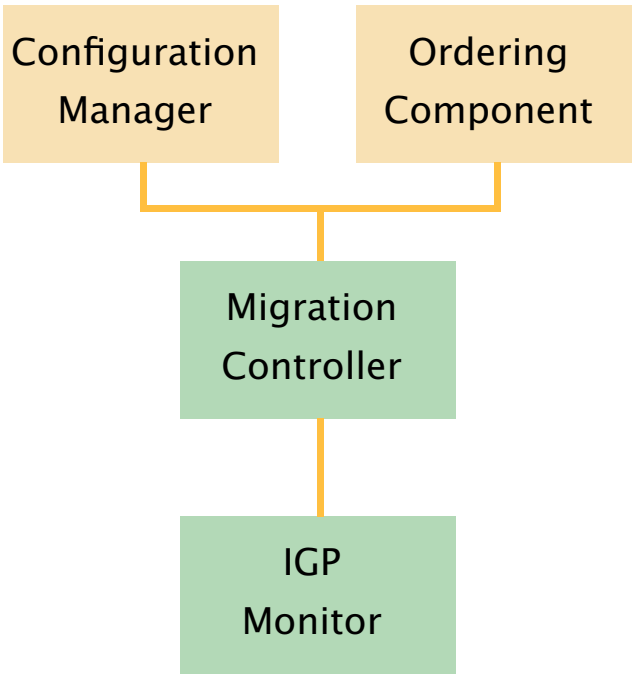
Third, the *Configuration Manager* introduces the, final configuration (not yet used) on all the routers



Network in which IGP 1 is replaced by IGP 2

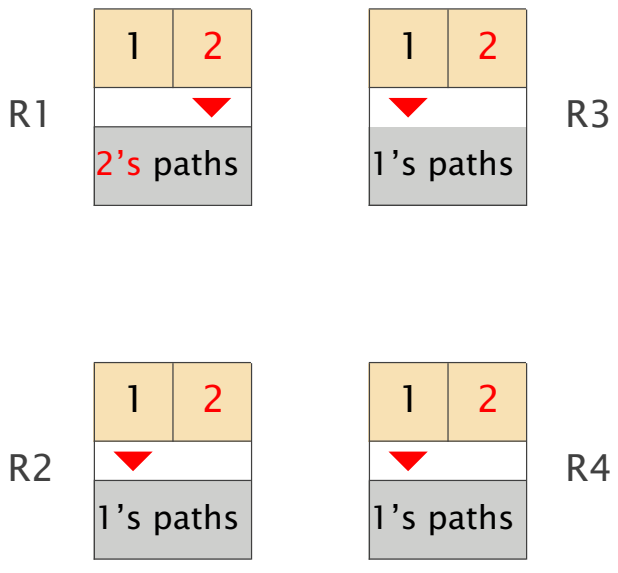
Fourth, the final IGP's completeness and stability are verified by the *IGP Monitor*

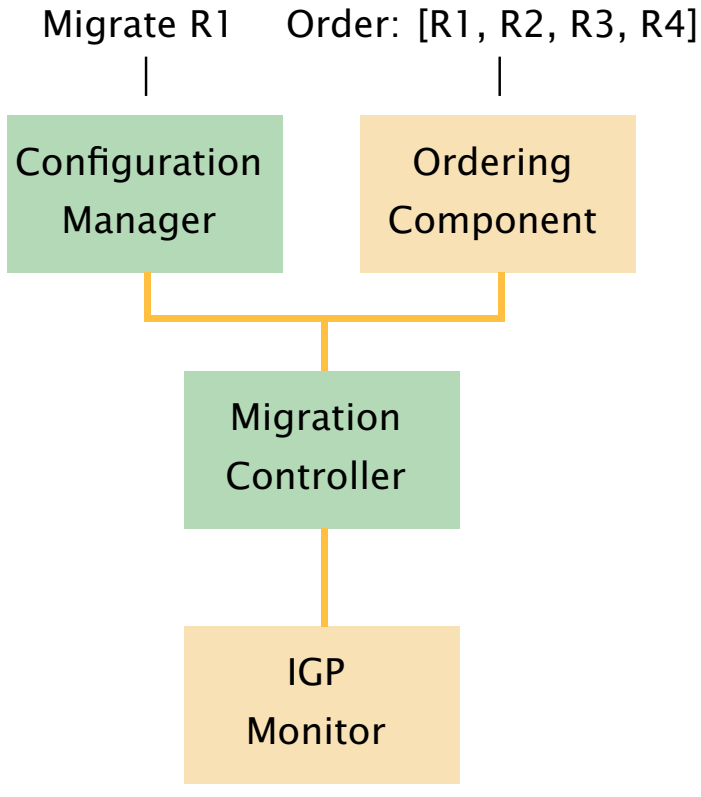




Network in which IGP 1 is replaced by IGP 2

Fifth, the *Configuration Manager* reconfigures each router – according to the ordering — so that it uses the final IGP





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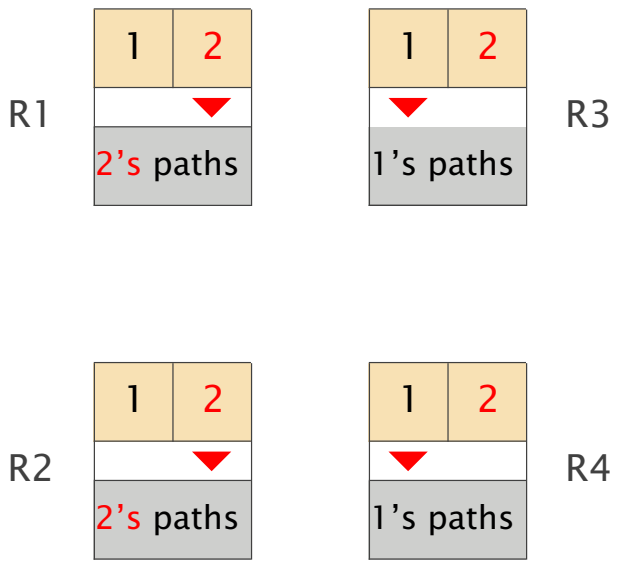

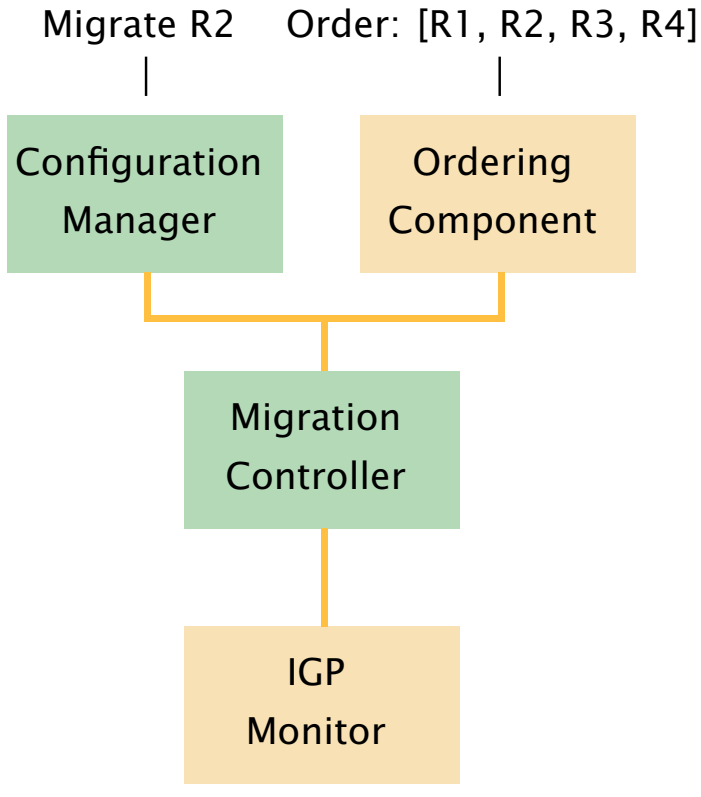

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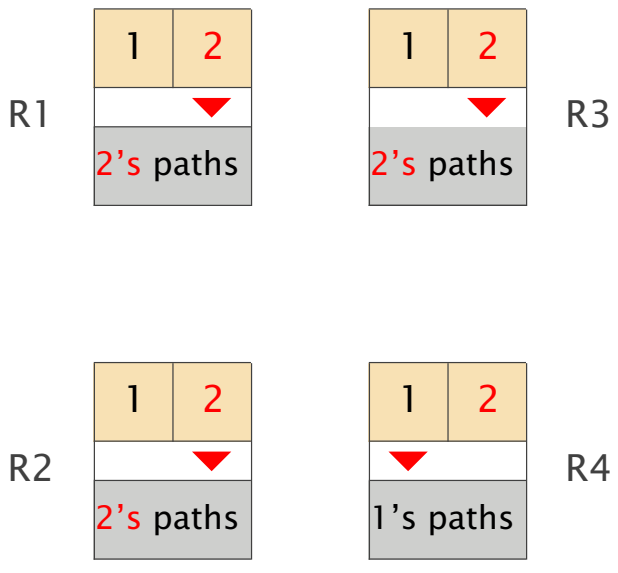

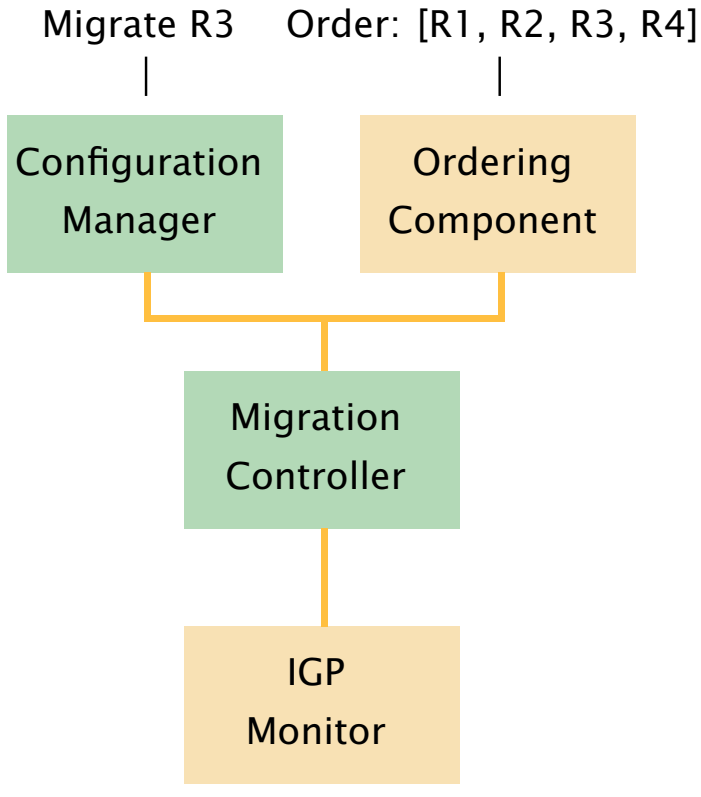

Network in which IGP 1 is replaced by IGP 2

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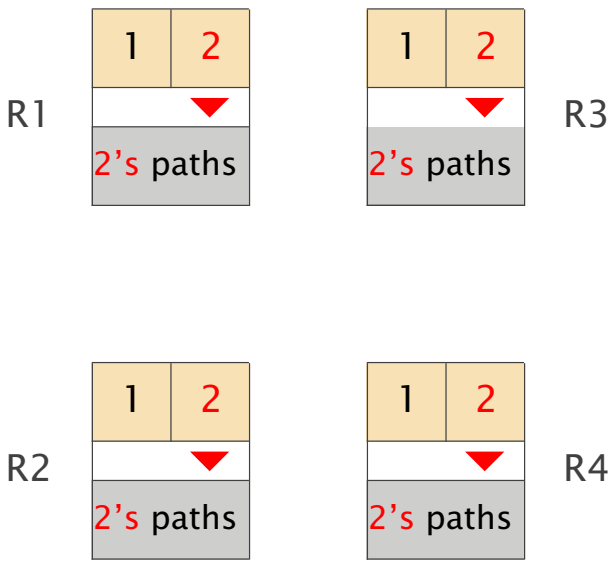
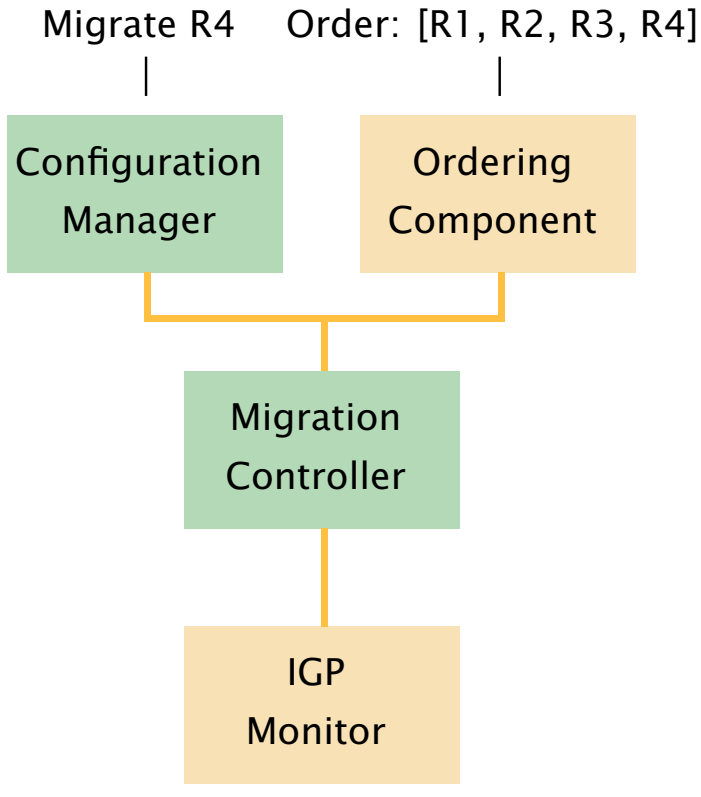
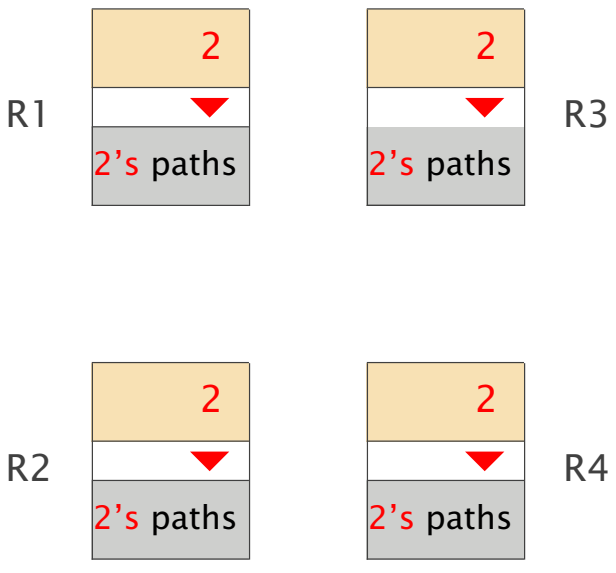
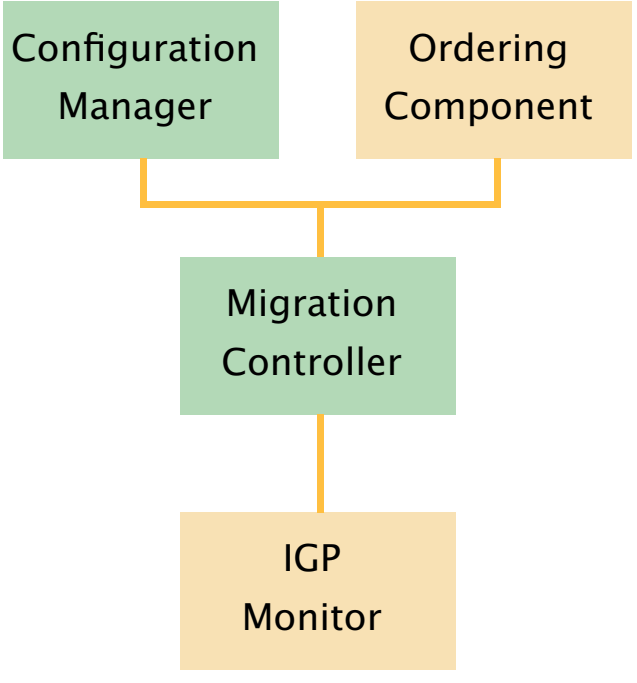




Network in which IGP 1 is replaced by IGP 2

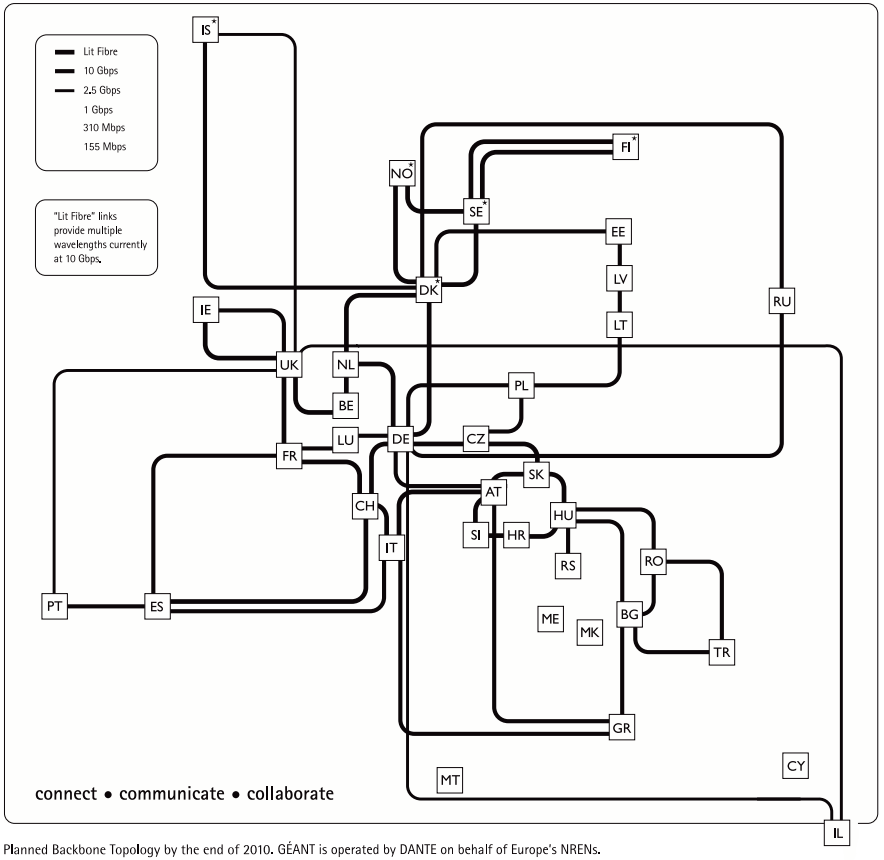
Sixth, the IGP migration is over. The *Configuration Manager* removes the initial IGP configuration from each router





Network in which IGP 1 is replaced by IGP 2

Let's reconfigure an existing network from a *flat* IGP ...



Planned Backbone Topology by the end of 2010. GÉANT is operated by DANTE on behalf of Europe's NRENs.

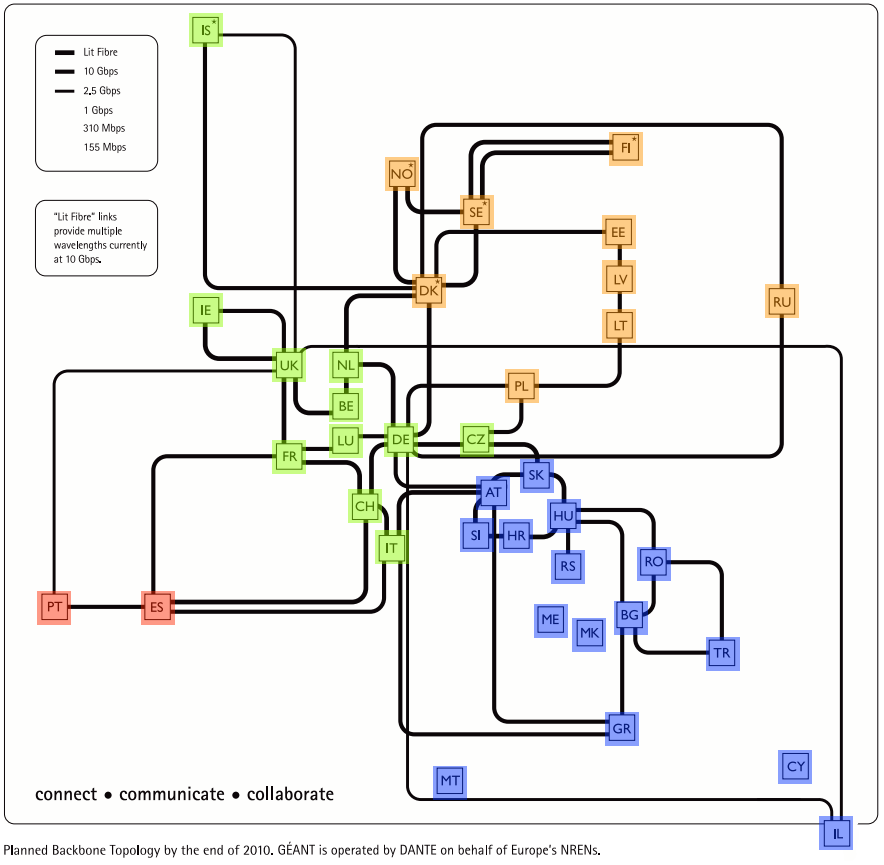
GEANT

European research network

36 routers

53 links

Let's reconfigure an existing network from a *flat* IGP to a *hierarchical* IGP



Planned Backbone Topology by the end of 2010. GÉANT is operated by DANTE on behalf of Europe's NRENs.

GEANT

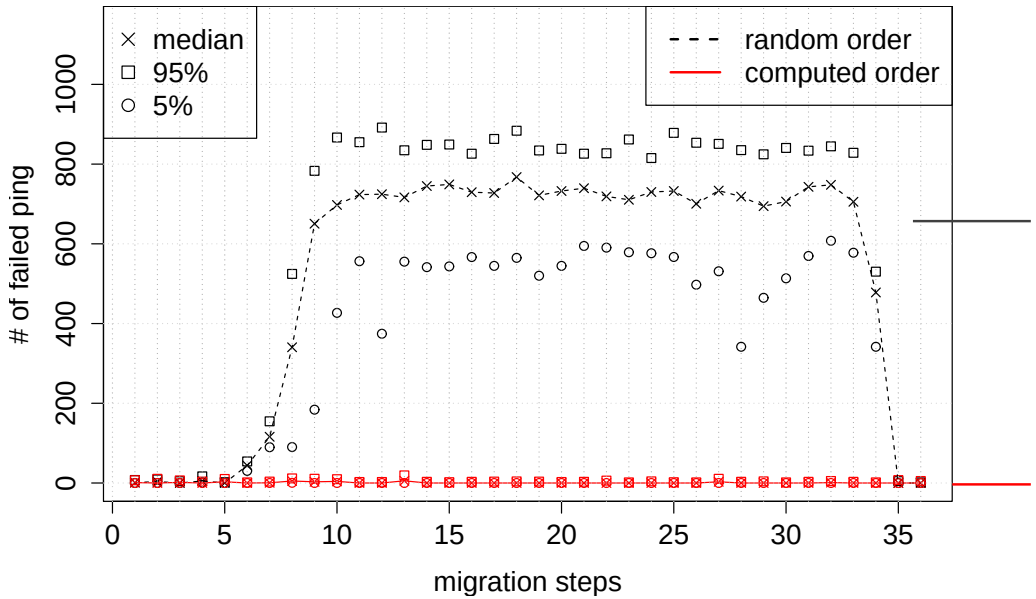
European research network

36 routers

53 links

- Backbone zone
- South-west zone
- South-east zone
- North-east zone

Lossless reconfiguration is possible, by following the precomputed ordering



Traffic gets lost during more than *80%* of the process

No loss occurs with proper ordering

Average results (50 repetitions) computed on 700+ pings per step from every router to 5 problematic destinations

Seamless Network-Wide IGP Migrations

1. Identify the ordering
   Avoid anomalies
2. Compute the ordering
   Manage complexity
3. Apply the ordering
   Stable, efficient

Don’t fear network reconfiguration, adapt the network to its environment

Add flexibility in network management

seamlessly move to the current best configuration

Apply to other types of network migrations

that translate to a change of forwarding paths

Introduce a whole new family of problems

How do you reconfigure BGP, MPLS, multicast, etc.

Seamless Network-Wide IGP Migrations

Laurent Vanbever, Stefano Vissicchio,
Cristel Pelsser, Pierre Francois,
and Olivier Bonaventure
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SIGCOMM
August 18, 2011

Seamless Network-Wide IGP Migrations
towards more agile networking