Lossless Migrations of Link-State IGPs

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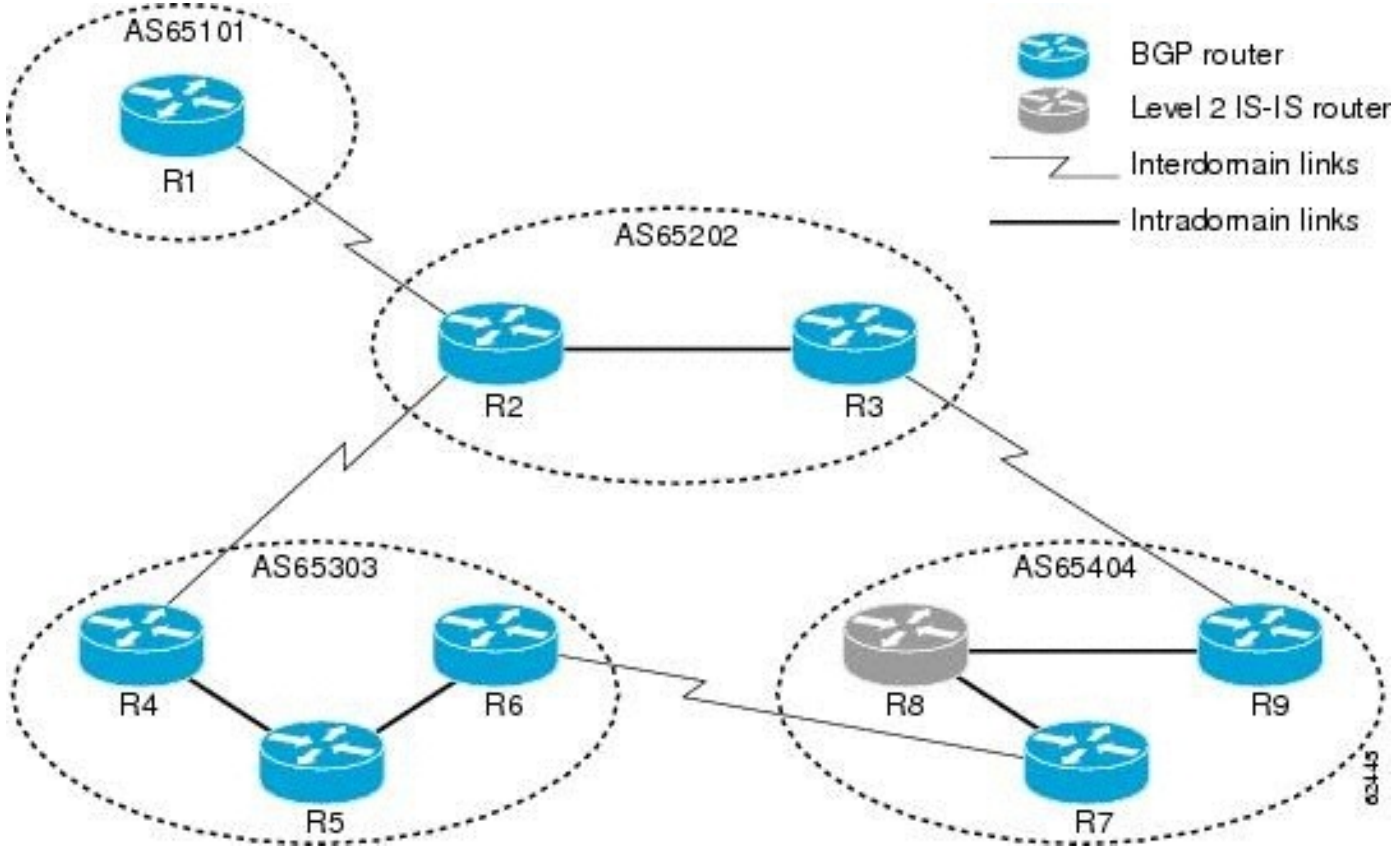
Seminar in Distributed Computing
Jochen Zehnder

Table of Contents

1. Topology of the Internet
2. Migration Problem
3. Evaluation
4. Summary
5. Q&A

Topology of the Internet

Topology of the Internet



http://www.cisco.com/c/en/us/td/docs/ios/12_2sr/12_2srb/feature/guide/tbgp_c/brbclns.html

Autonomous System (AS)

"An AS is a connected group of one or more IP prefixes run by one or more network operators which has a SINGLE and CLEARLY DEFINED routing policy." (RFC 1930)

Autonomous System (AS)

- groups of IP prefixes
  - e.g. AS559 (ETH-NET)
    - 129.132.0.0/16

Autonomous System (AS)

- groups of IP prefixes
  - e.g. AS559 (ETH-NET)
    - 129.132.0.0/16
- two types of protocols
  - Border Gateway Protocol (BGP)
  - Interior Gateway Protocol (IGP)

Interior Gateway Protocol

- flat vs. hierarchical
  - flat: forward packets along the shortest path
  - hierarchical: divided into zones

Interior Gateway Protocol

- flat vs. hierarchical
  - flat: forward packets along the shortest path
  - hierarchical: divided into zones
- route summarization
  - for hierarchical IGP
  - zone announces available prefixes and
  - length of the path

Migration Problem

next-hop function

- next-hop function $nh(u, d)$
  - u : router
  - d : destination

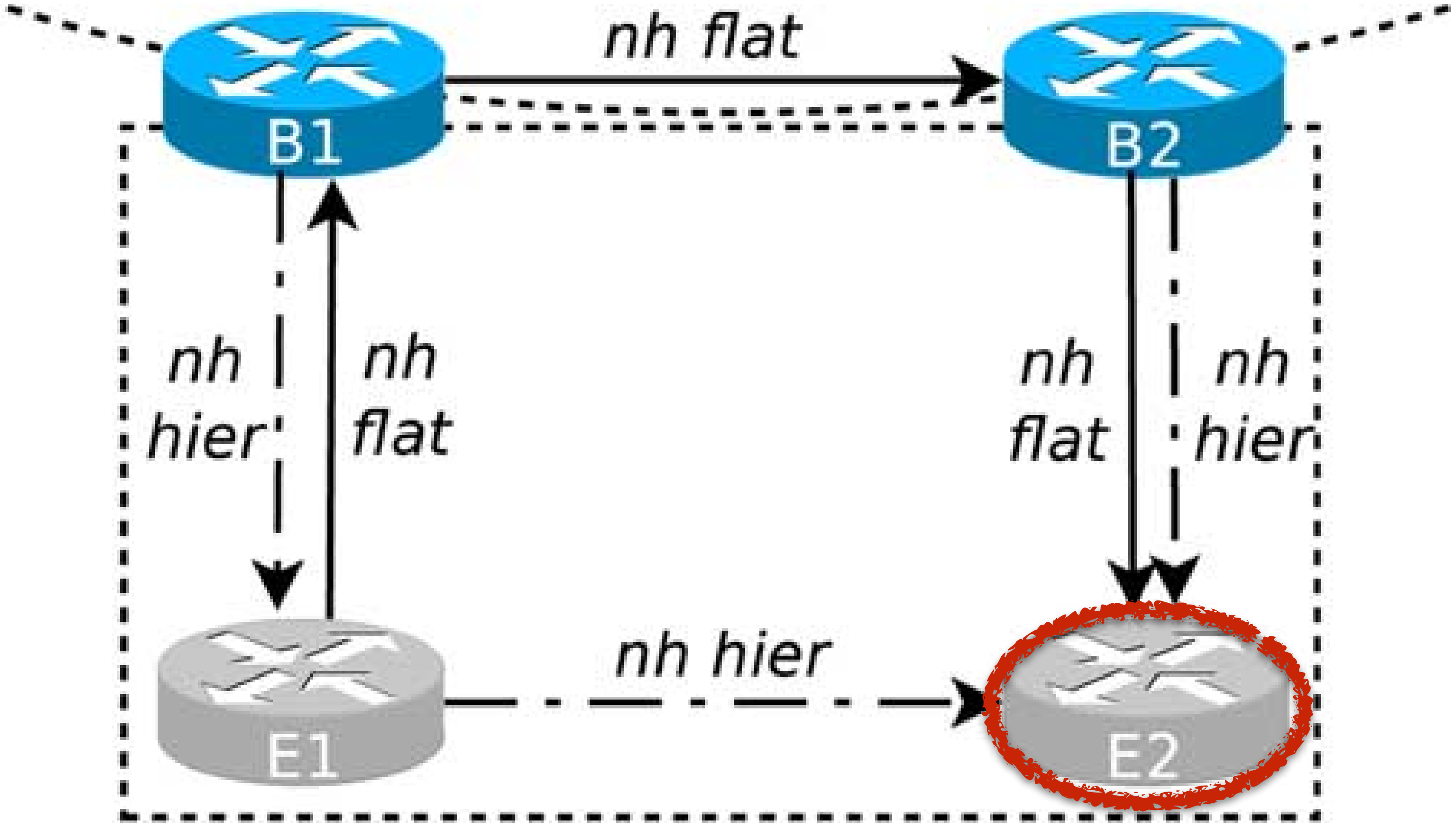
next-hop function

- next-hop function $nh(u, d)$
  - u : router
  - d : destination
- next router towards d

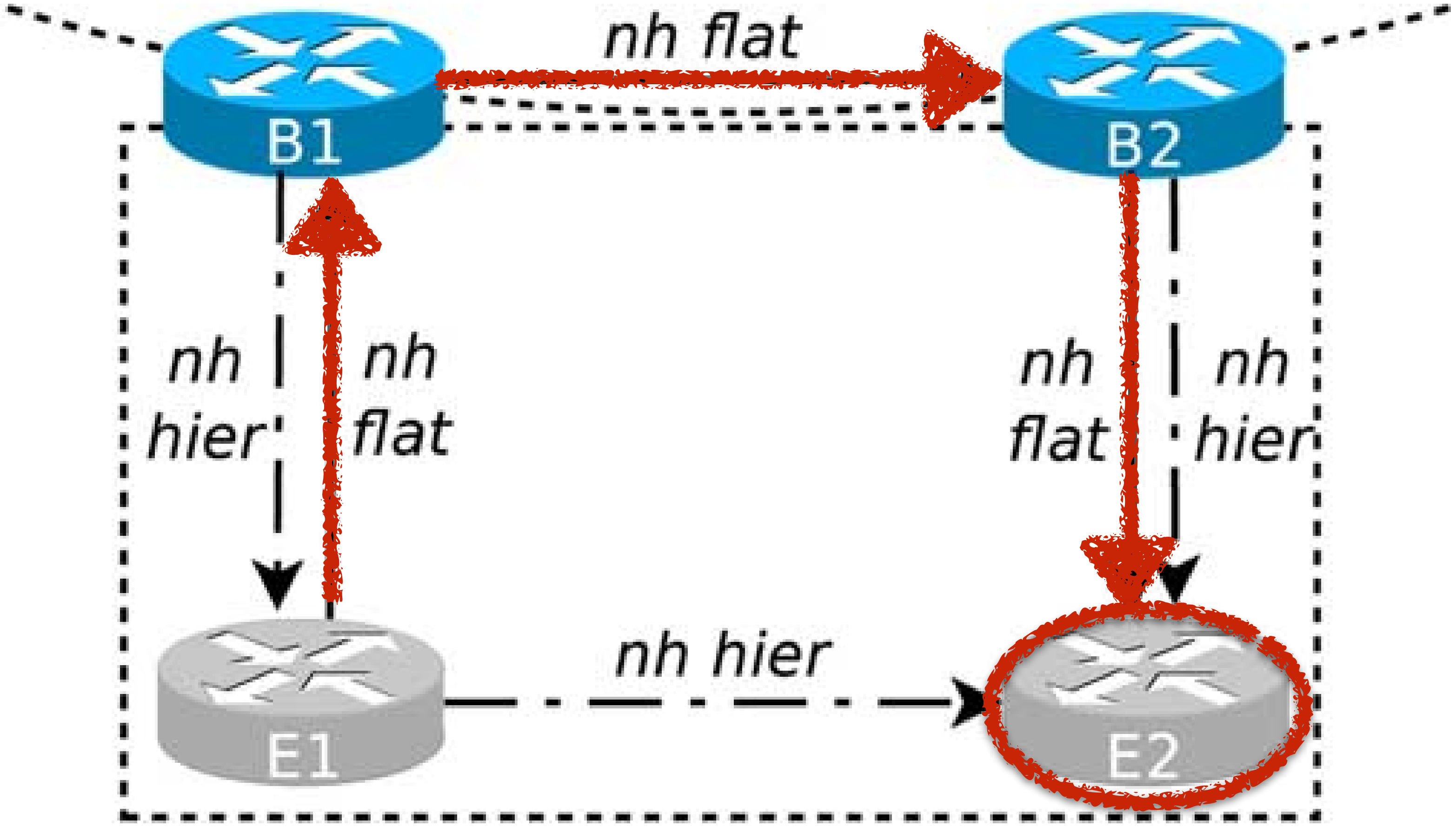
next-hop function

- next-hop function $nh(u, d)$
  - u : router
  - d : destination
- next router towards d
- $|nh(u, d)|$ does not have to be 1

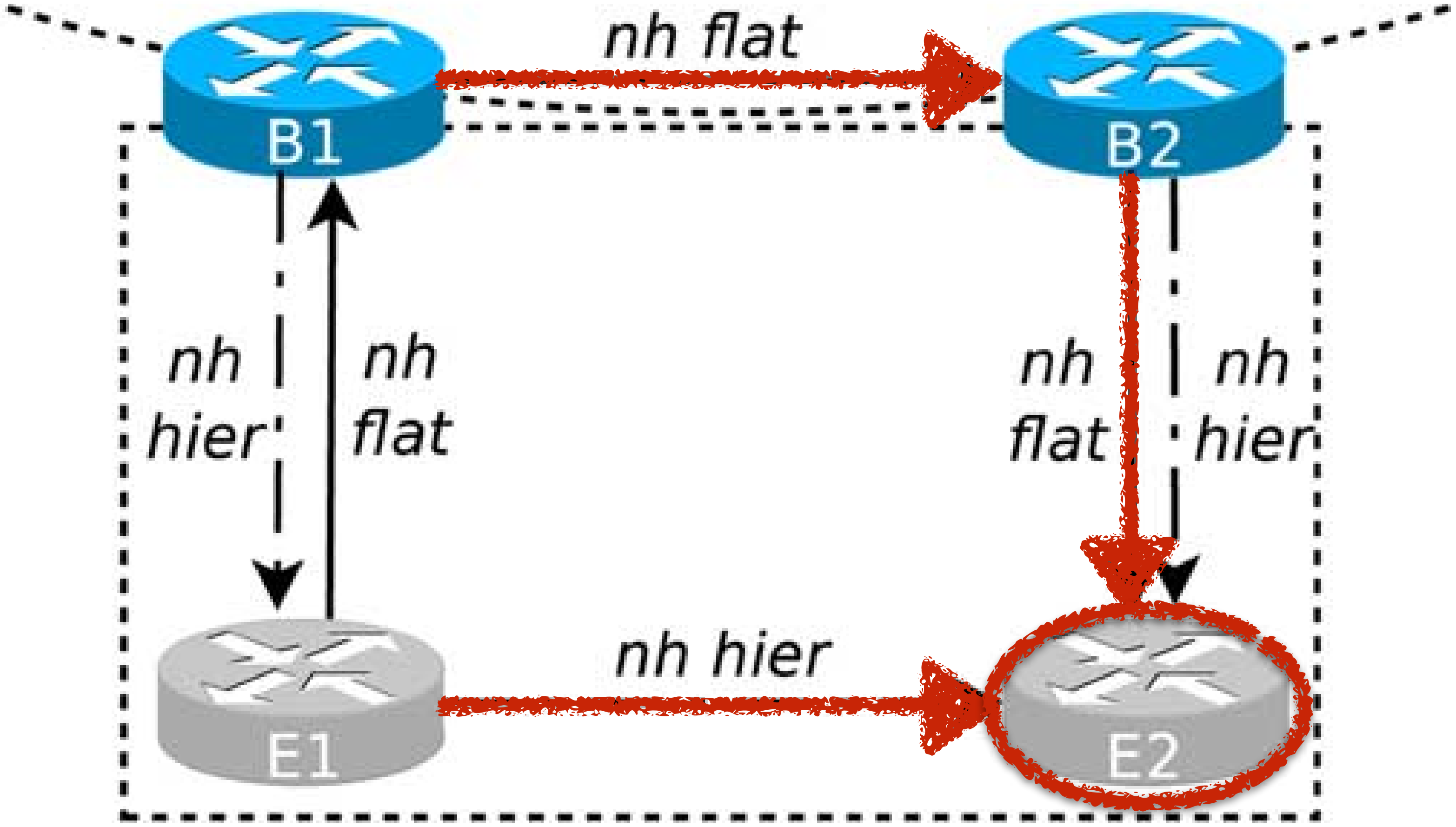
Migration Loop



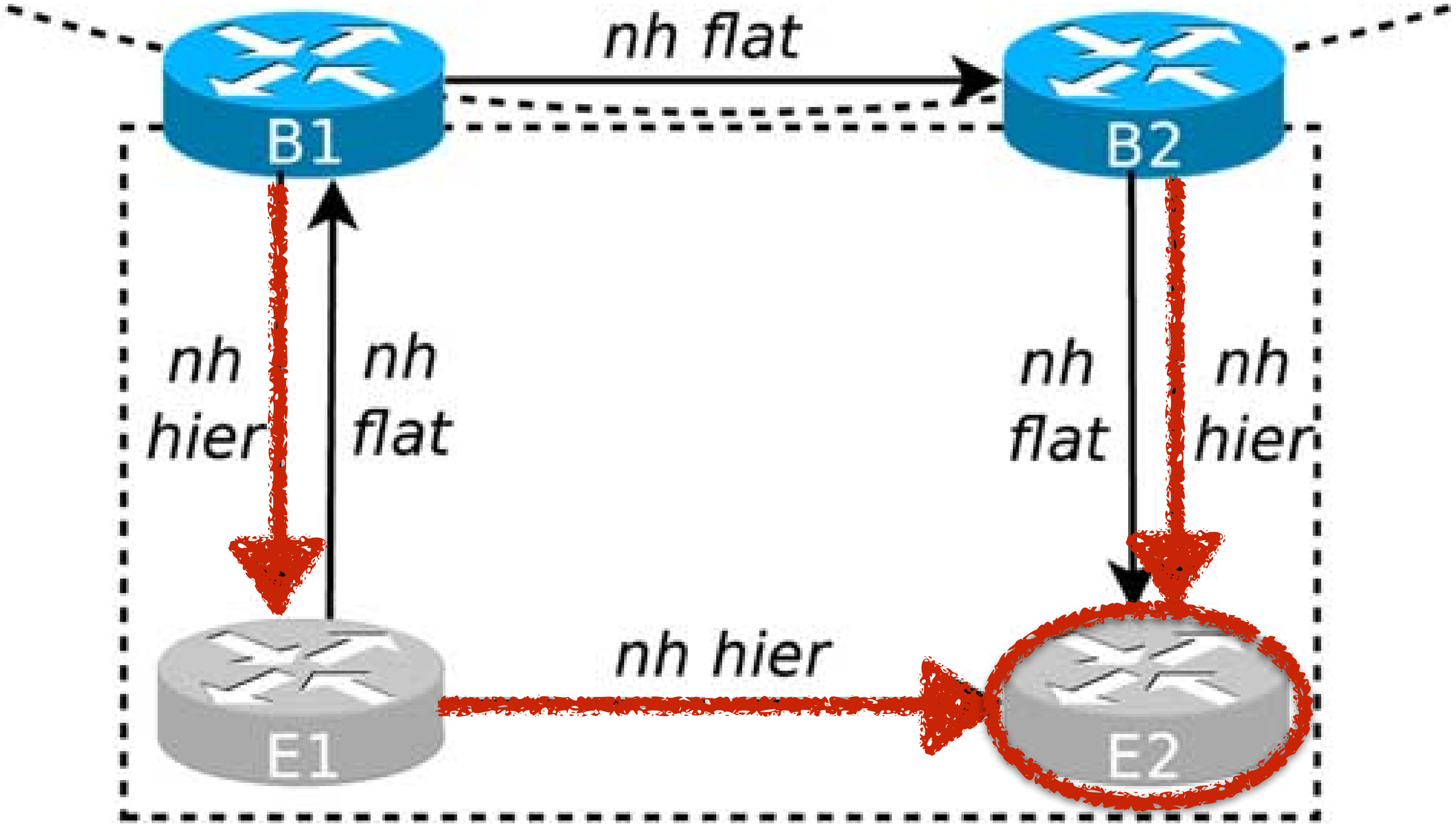
Migration Loop



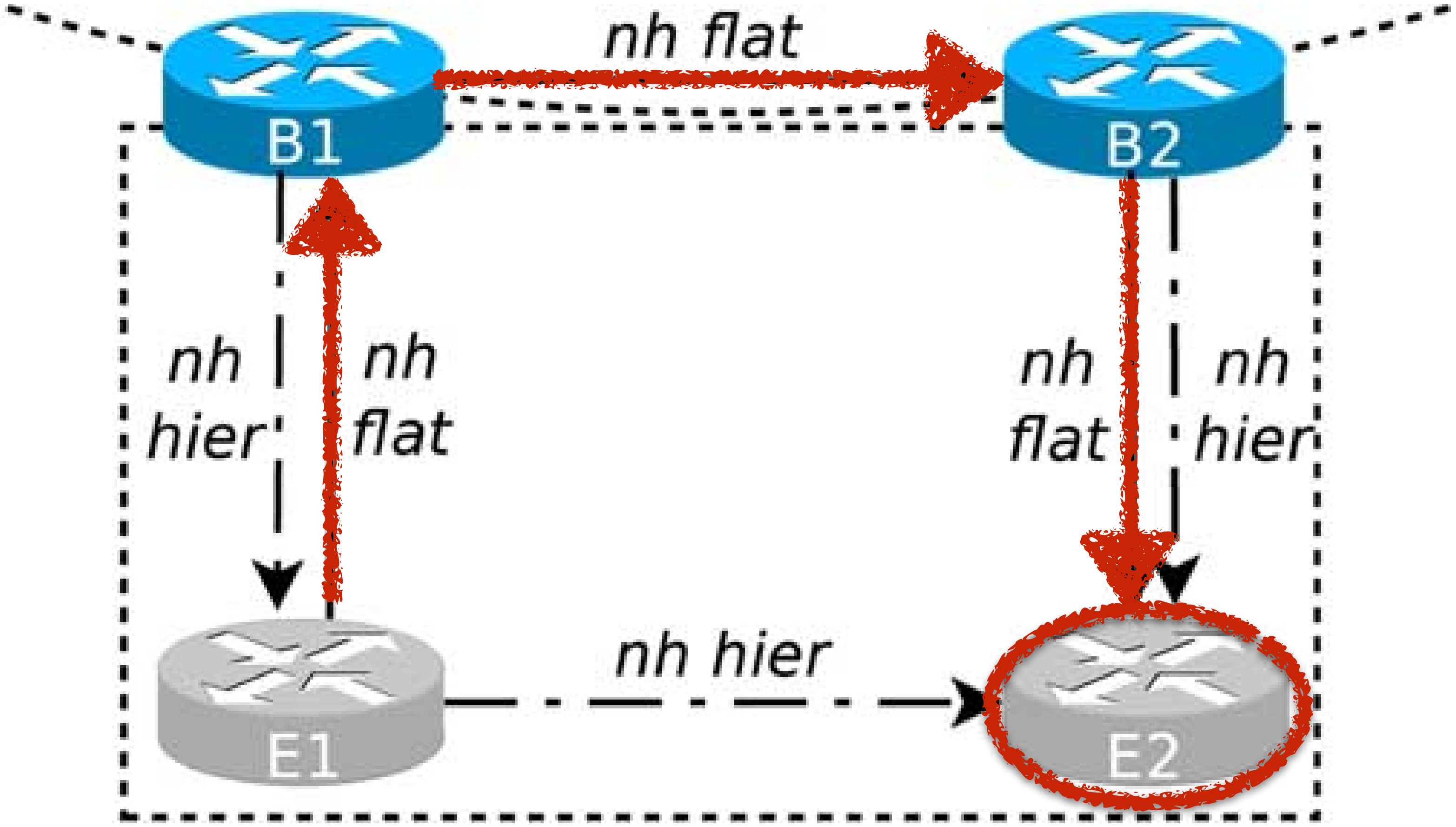
Migration Loop



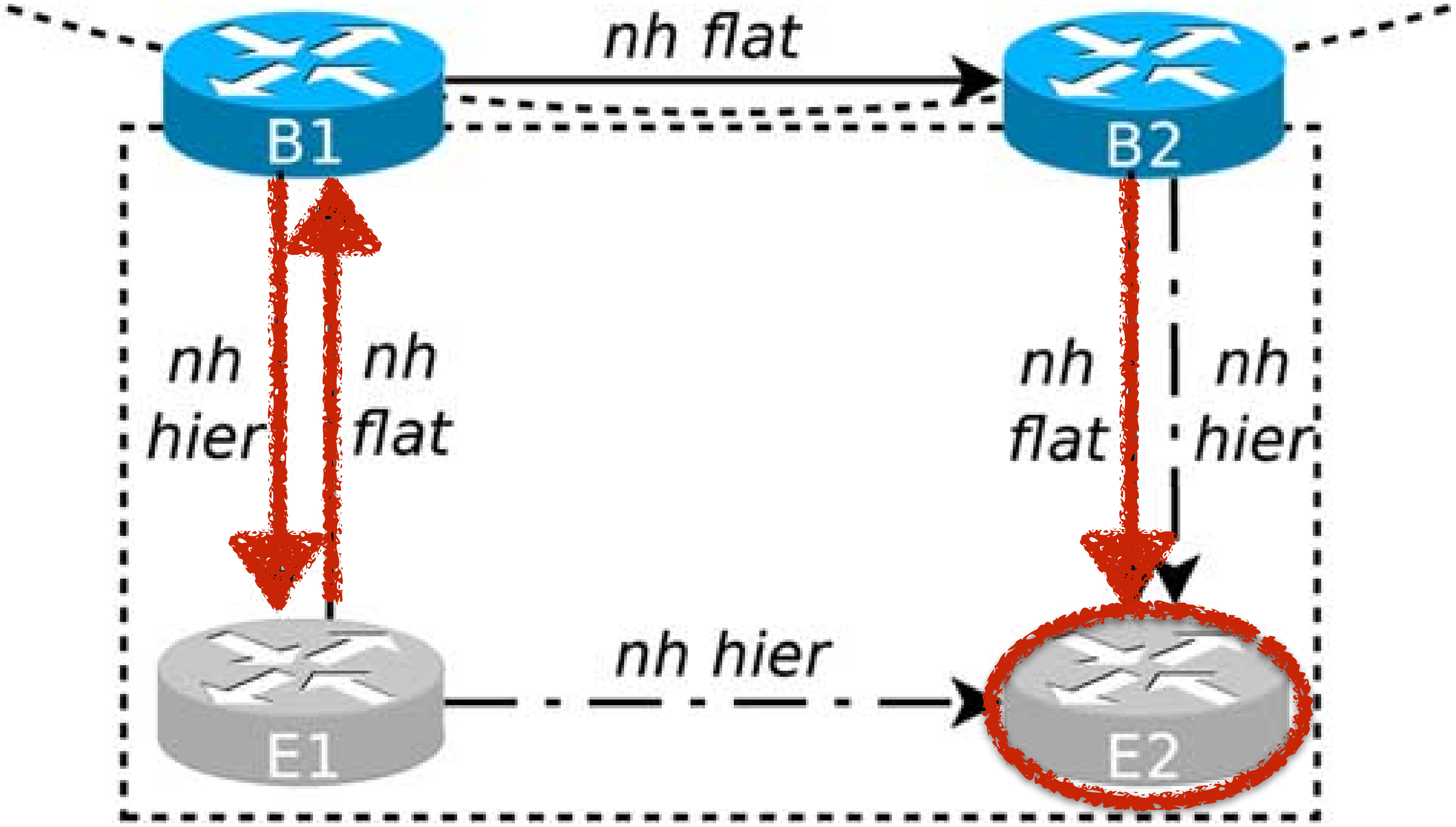
Migration Loop



Migration Loop



Migration Loop



Migration Problem

- given unicast IP network

Migration Problem

- given unicast IP network
- replace IGP configuration
    - from nh_{init} to nh_{final}

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- minimal configuration changes

Migration Problem

- given unicast IP network
- replace IGP configuration
  - from nh_{init} to nh_{final}
- minimal configuration changes
- no migration loops

Migration Scenarios

scenario	**IGP configuration changes**
protocol	protocol replacement
flat2hier	zone introduction
hier2flat	zone removal
hier2hier	zone reshaping
summarization	summarization introduction/removal

ships-in-the-night

- run separate routing protocols on one router

ships-in-the-night

- run separate routing protocols on one router
- share hardware and software resources

ships-in-the-night

- run separate routing protocols on one router
- share hardware and software resources
- but do not interact on a protocol level

Proposed methodology

- Seamless IGP Migration Methodology

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    1. Compute a lossless router migration order

Proposed methodology

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    2. Introduce the final IGP configuration

Proposed methodology

- Seamless IGP Migration Methodology
  1. Compute a lossless router migration order
  2. Introduce the final IGP configuration
  3. Monitor the final IGP status

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  1. Compute a lossless router migration order
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  4. Progressively migrate routers

Proposed methodology

- Seamless IGP Migration Methodology

  1. Compute a lossless router migration order

  2. Introduce the final IGP configuration

  3. Monitor the final IGP status

  4. Progressively migrate routers

  5. Remove initial IGP configuration

Router migration ordering

- Given
  - initial and final next-hop functions
  - logical graph *G*
  - set of destinations *D*

Router migration ordering

- Given
  - initial and final next-hop functions
  - logical graph *G*
  - set of destinations *D*
- Compute router migration
  - no forwarding loops in *G* for $d \in D$

Router migration ordering

- Router Migration Ordering Problem is NP-complete

Router migration ordering

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  - is in NP

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        - e.g. $F = (x_1 \lor \bar{x}_2 \lor x_3) \land (\bar{x}_1 \lor \bar{x}_2 \lor x_3)$

Router migration ordering

- Router Migration Ordering Problem is NP-complete
  - is in NP
  - Reduction from 3-SAT
    - e.g. $F = (x_1 \vee \bar{x}_2 \vee x_3) \wedge (\bar{x}_1 \vee \bar{x}_2 \vee x_3)$
    - is F satisfiable?

Router migration ordering

- given formula F

Router migration ordering

- given formula F
- transform into migration ordering instance

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Router migration ordering

- given formula F
- transform into migration ordering instance
- show that
    - F satisfiable ⇒ loop free migration ordering
    - F not satisfiable ⇒ no loop free migration ordering

Router migration ordering

- central vertex P

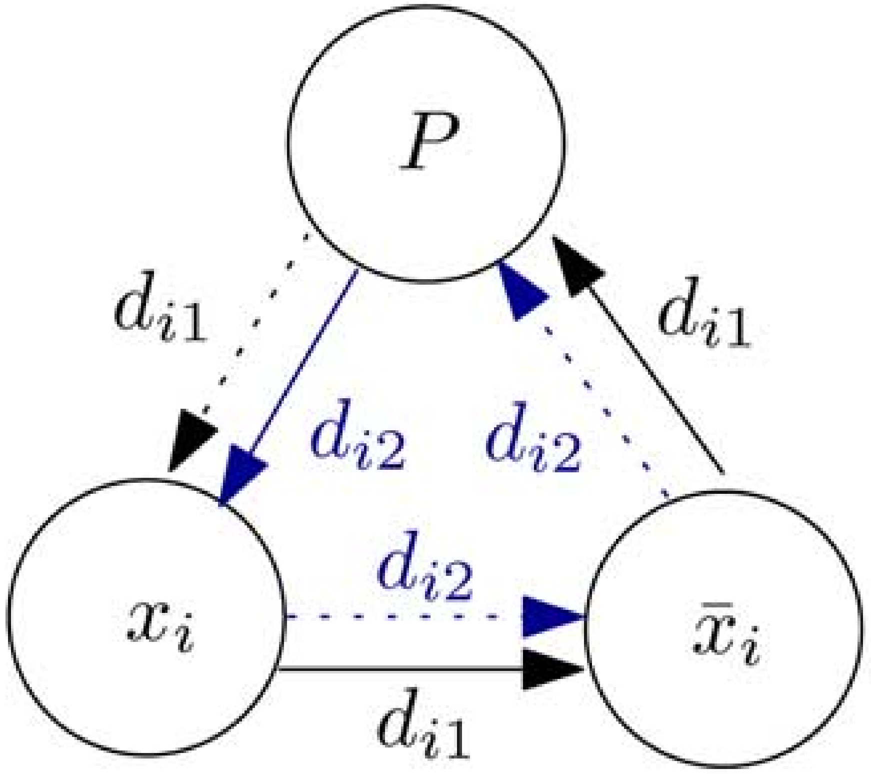
Router migration ordering

- central vertex P
- true: x_i migrated before P

Router migration ordering

- central vertex P
- true: x_i migrated before P
- false: x_i migrated after P

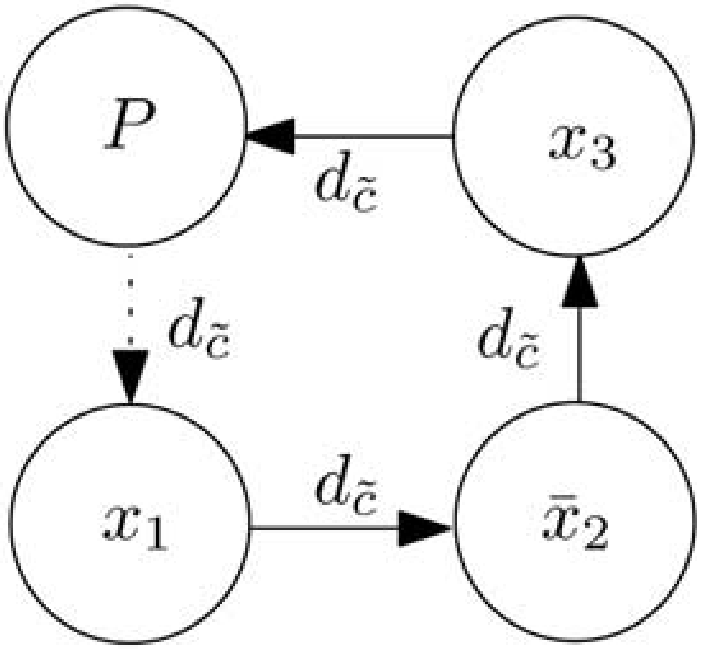
Router migration ordering



(a)

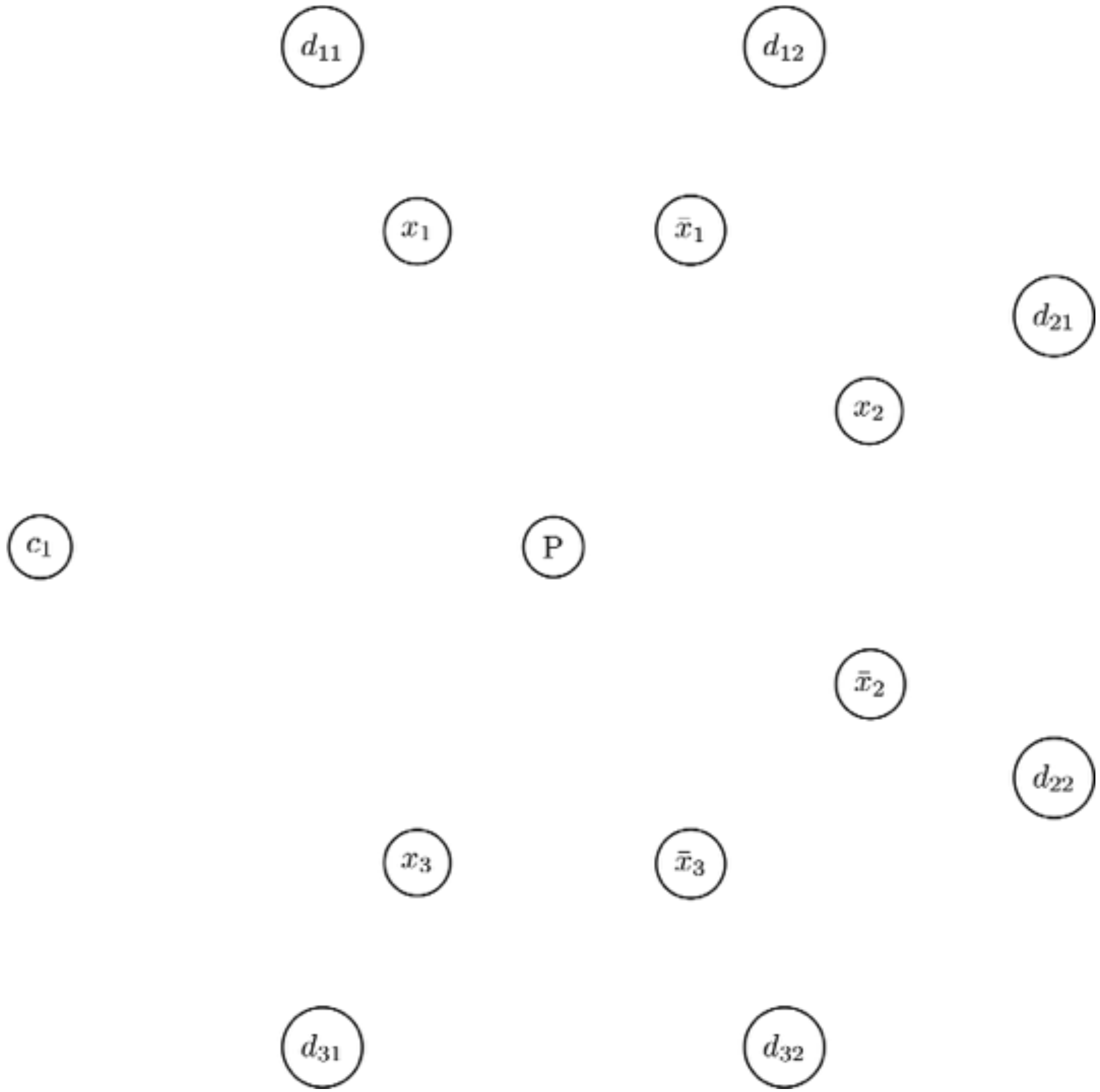
Router migration ordering

$$\tilde{C} = (X_1 \vee \bar{X}_2 \vee X_3)$$

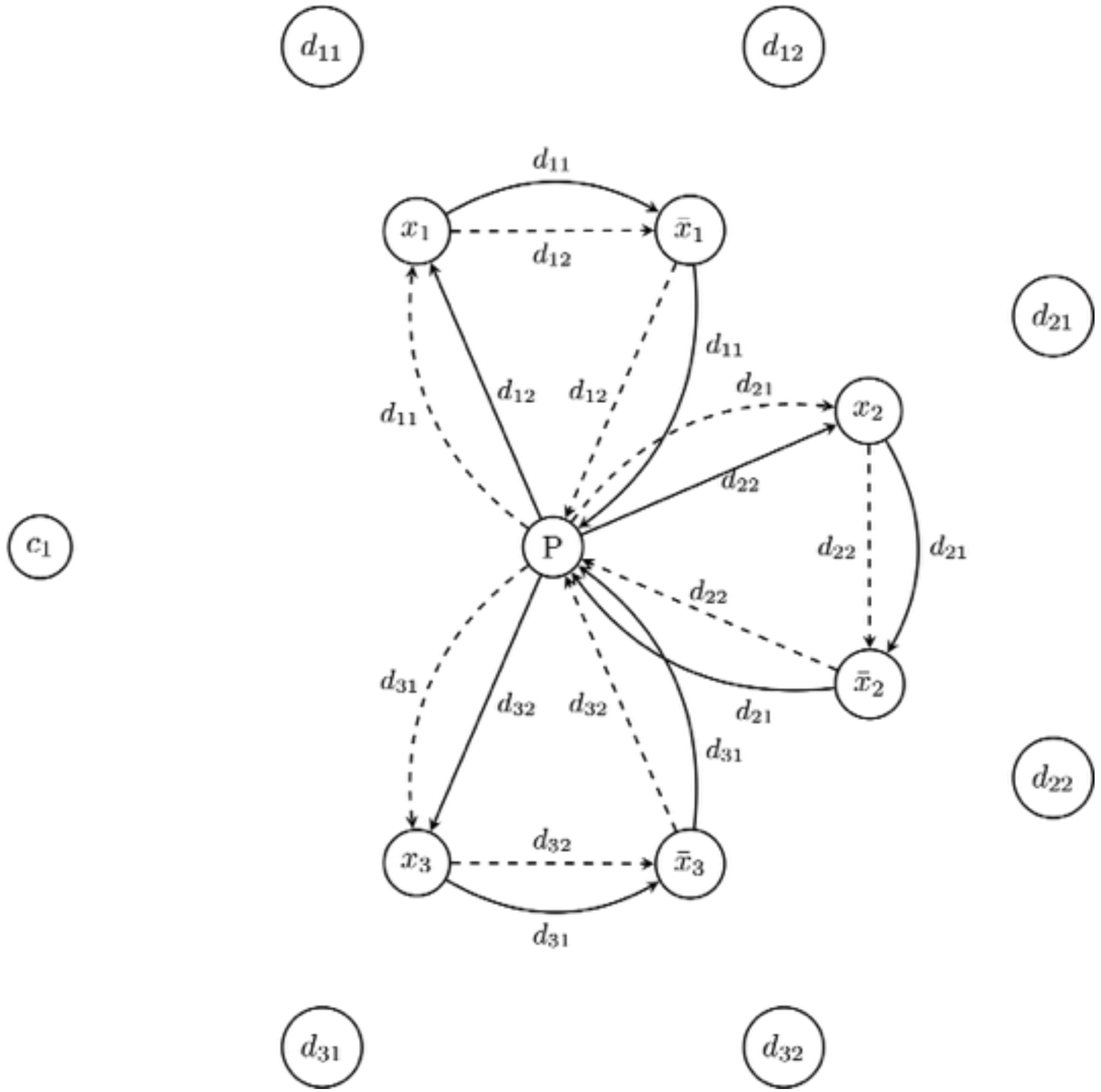


(b)

$$F = (x_1 \vee x_2 \vee x_3)$$



$$F = (x_1 \vee x_2 \vee x_3)$$



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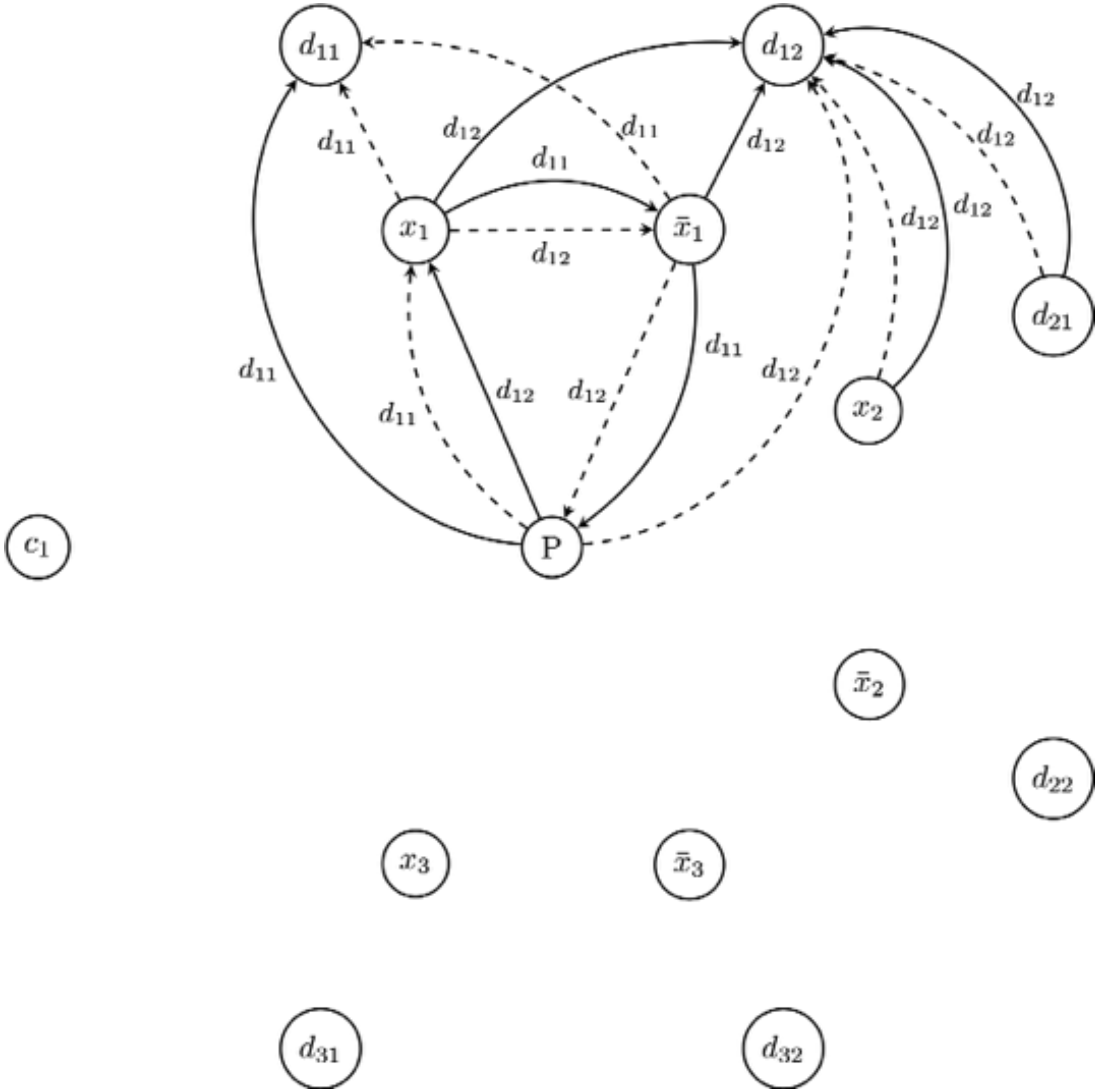
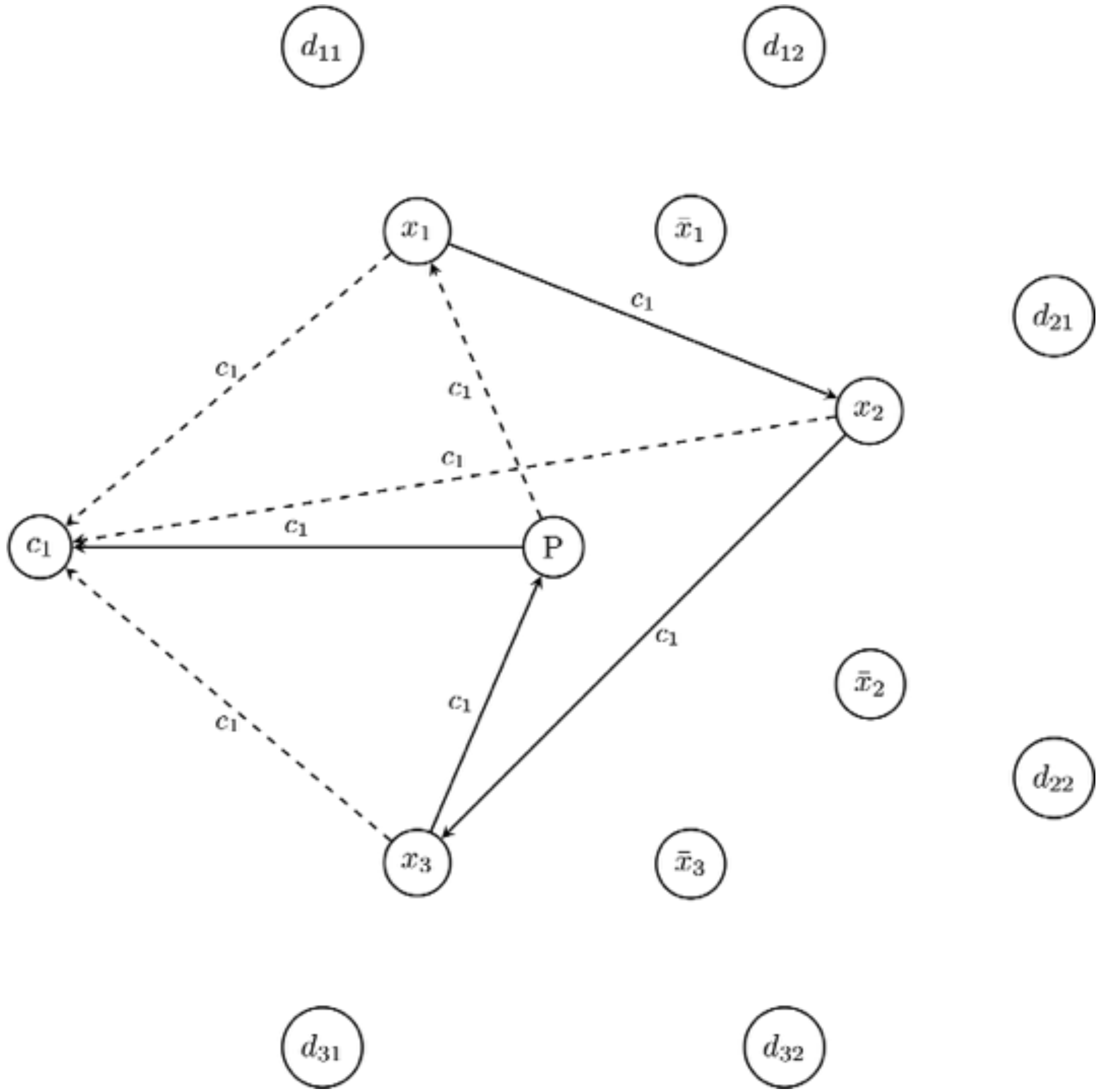


$$F = (x_1 \lor x_2 \lor x_3)$$



Loop enumeration Algorithm

Loop enumeration Algorithm

- inefficient algorithm

Loop enumeration Algorithm

- inefficient algorithm
- requires exponential time
  - cycles can be exponential in the number of nodes

Loop enumeration Algorithm

1. for each destination d

Loop enumeration Algorithm

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    1. Build graph G_d

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Loop enumeration Algorithm

1. for each destination d
    1. Build graph G_d
        - initial and final next hops for destination *d*
    2. for each loop in G_d create ordering constraint
2. solve the problem using a Linear Programm

Routing Tree Heuristic

Routing Tree Heuristic

- computes constraints for each destination
    - migrate next-hop changing routers after
    - forwarding path is established

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Routing Tree Heuristic

- computes constraints for each destination
  - migrate next-hop changing routers after
  - forwarding path is established
- polynomial respect to input size
- not guaranteed to find a solution
  - rare in carefully designed networks

Routing Tree Heuristic

1. for each destination d

Routing Tree Heuristic

1. for each destination d
    1. greedy run to generate set S_d

Routing Tree Heuristic

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    2. generate set V_d

Routing Tree Heuristic

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    4. constraints: migrate router after all its successors

Routing Tree Heuristic

1. for each destination d
    1. greedy run to generate set S_d
    2. generate set V_d
    3. build graph G_d
    4. constraints: migrate router after all its successors
2. topological sort of the final graph

Per-Destination Ordering

- per-router ordering does not exist or

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- Routing Tree Heuristic does not find a solution

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- applied to problematic destinations only

Per-Destination Ordering

- per-router ordering does not exist or
- Routing Tree Heuristic does not find a solution
- applied to problematic destinations only
- use constraints generated in Routing Tree Heuristic

Method discussion

- always migrate one router after the other
  - why not migrate a subset of routers?
  - why not migrate only part of the routers?

Method discussion

- always migrate one router after the other
  - why not migrate a subset of routers?
  - why not migrate only part of the routers?
- other approach introducing version numbers
  - packets need to be adapted
  - when can I delete old configurations?

Evaluation

Dataset

- Rocketfuel project

Dataset

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  - AS of different sizes

Dataset

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  - AS of different sizes
  - smallest: 79 nodes and 294 edges

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  - 36 routers and 53 links

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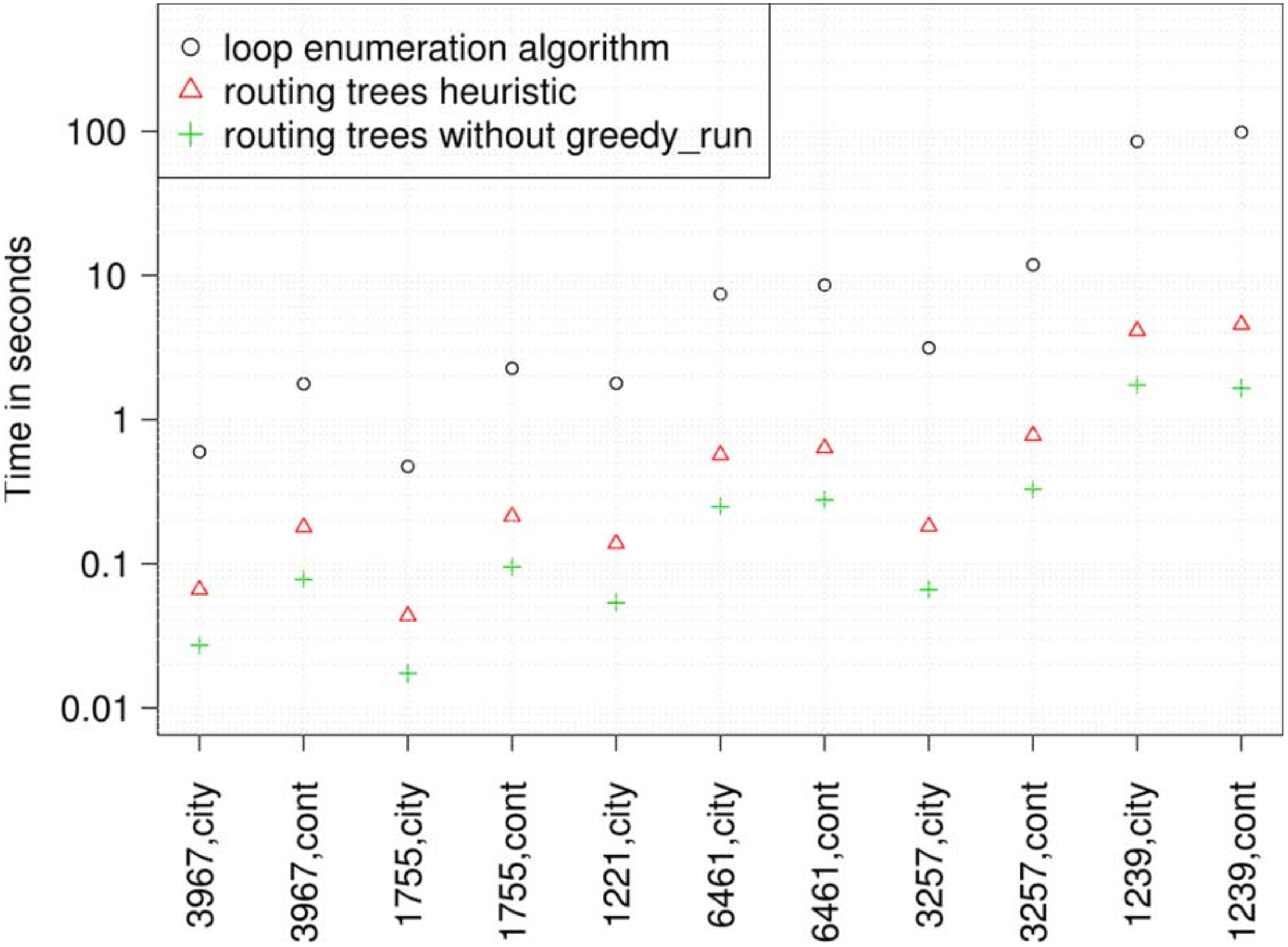
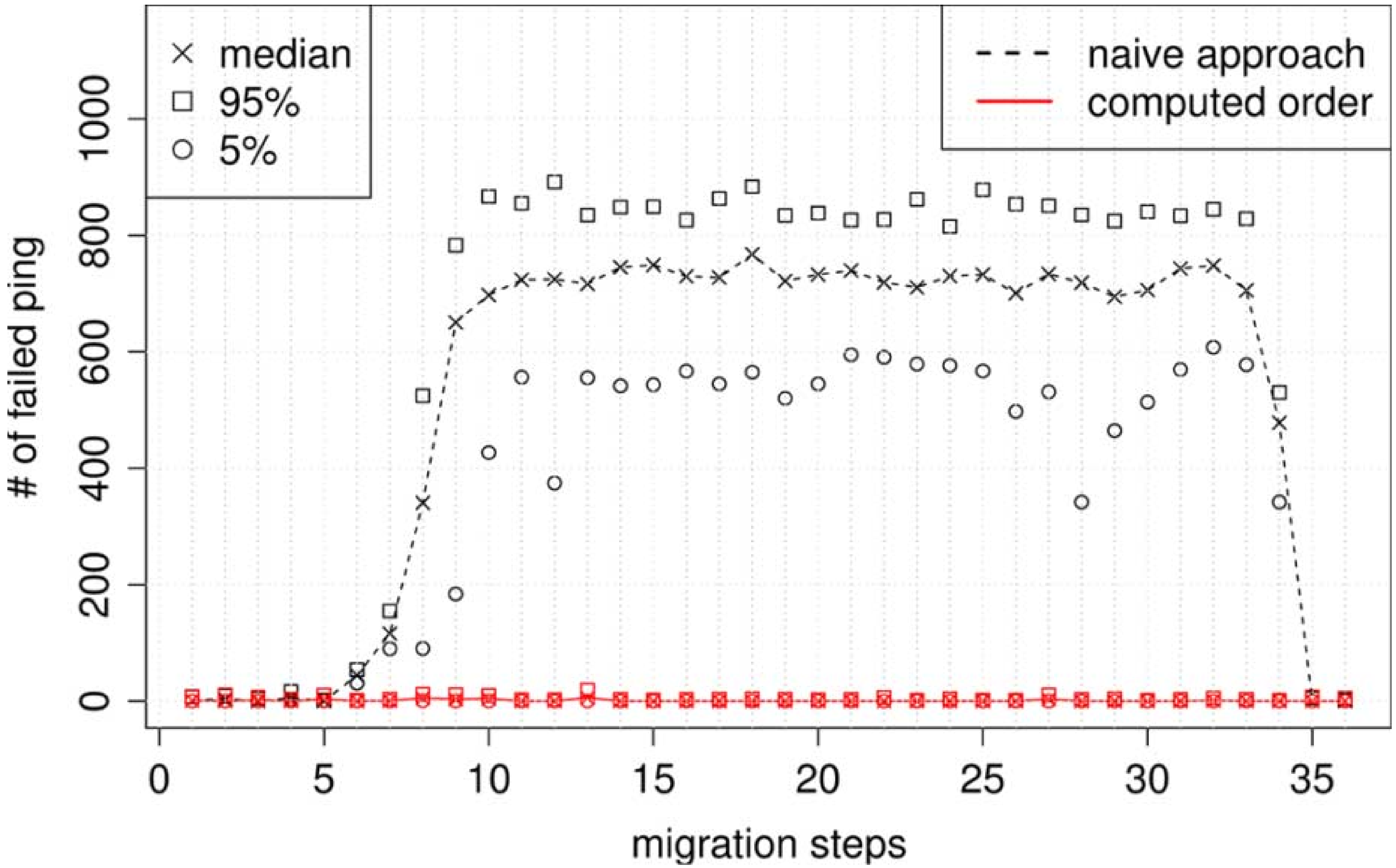
- pan-European research network (Geant)
  - 36 routers and 53 links
  - emulation

Algorithms compared



Time taken to compute an ordering in flat2hier (Rocketfuel topologie)

Packet loss



Packet loss during flat2hier migration (Geant topology)

Summary

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- proposed a methodology
    - router migration ordering

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Q&A