Topology Management for Unstructured Overlay Networks

Doctoral School Day in Cloud Computing

João Leitão
INESC-ID / IST - Lisbon, Portugal

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Roadmap

Peer-to-Peer model:

- Promise to overcome the limitations of the client-server model.
- Fault-Tolerance: There is no single point of failure.
- Inherent Scalability: All nodes contribute with their resources.

Popular Examples:

- File Sharing: Napster, Emule, Gnutella, Bittorrent.
- VOIP: Skype.
- IPTV: PPLive.
- Internet Anonymity: TOR.

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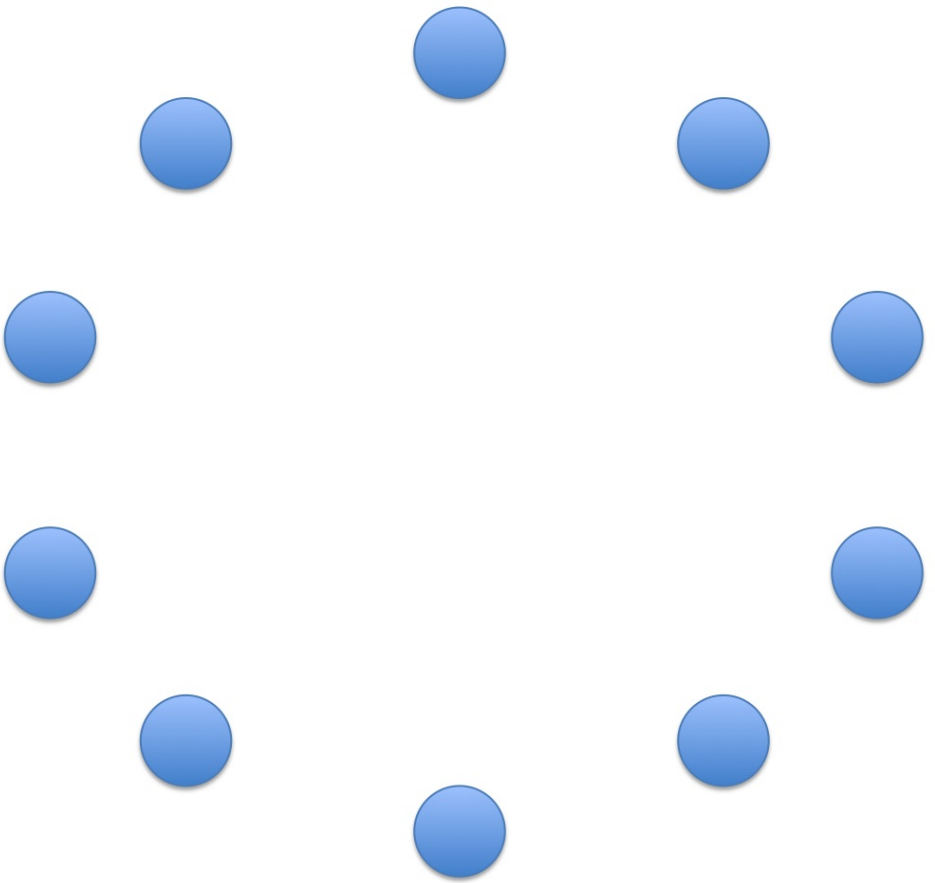
P2P Global Membeship



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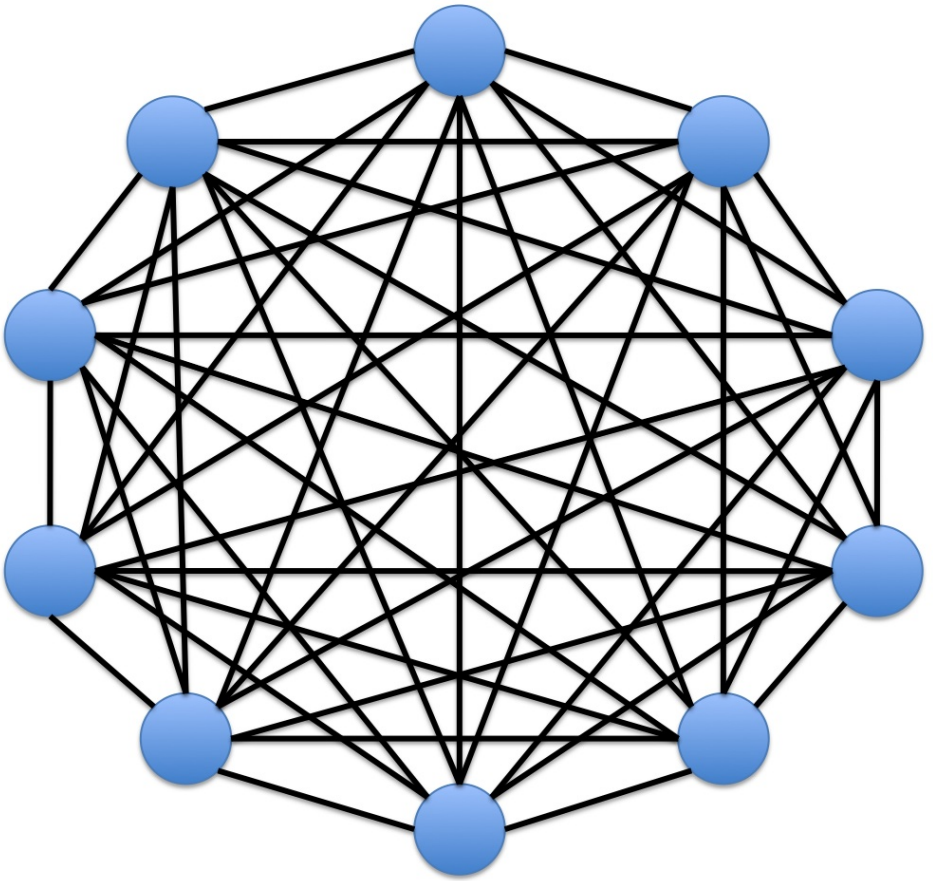

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  - High maintenance cost under high membership changes (*e.g.*, churn).
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Partial Views:

- Encodes neighboring relations across participants.
- Their closure establishes an *overlay network*.

Topology properties can affect P2P services:

- Efficiency.
- Fault-tolerance.
- Convergence.
- Latency.

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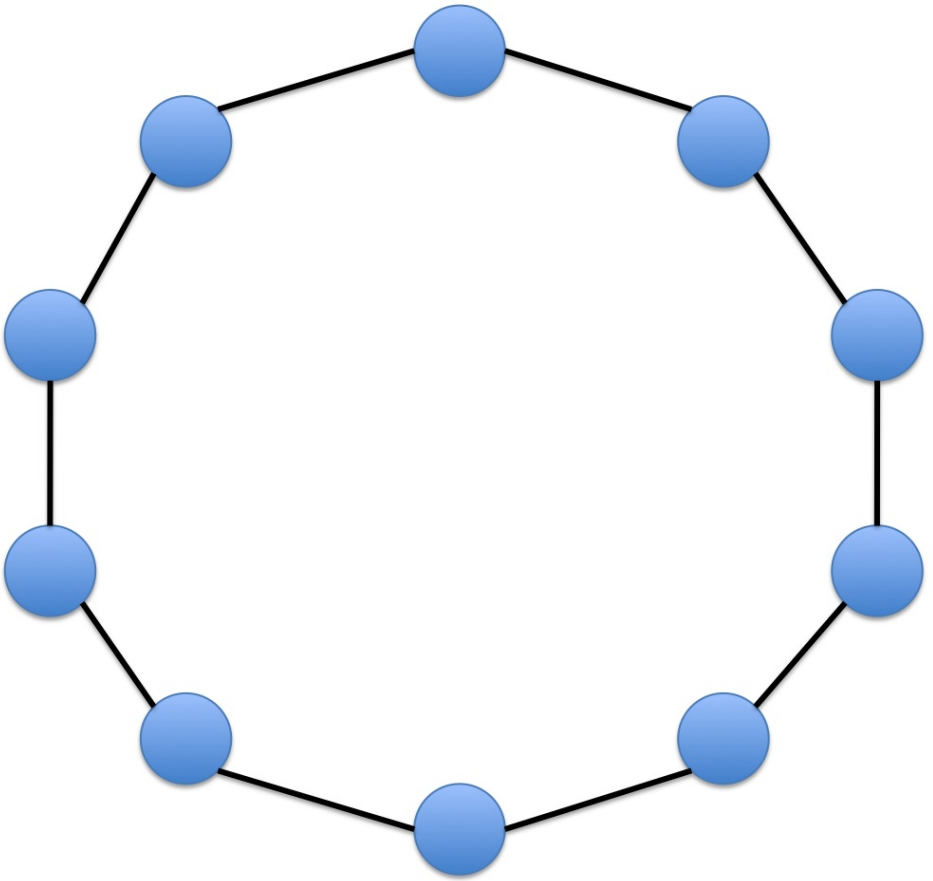
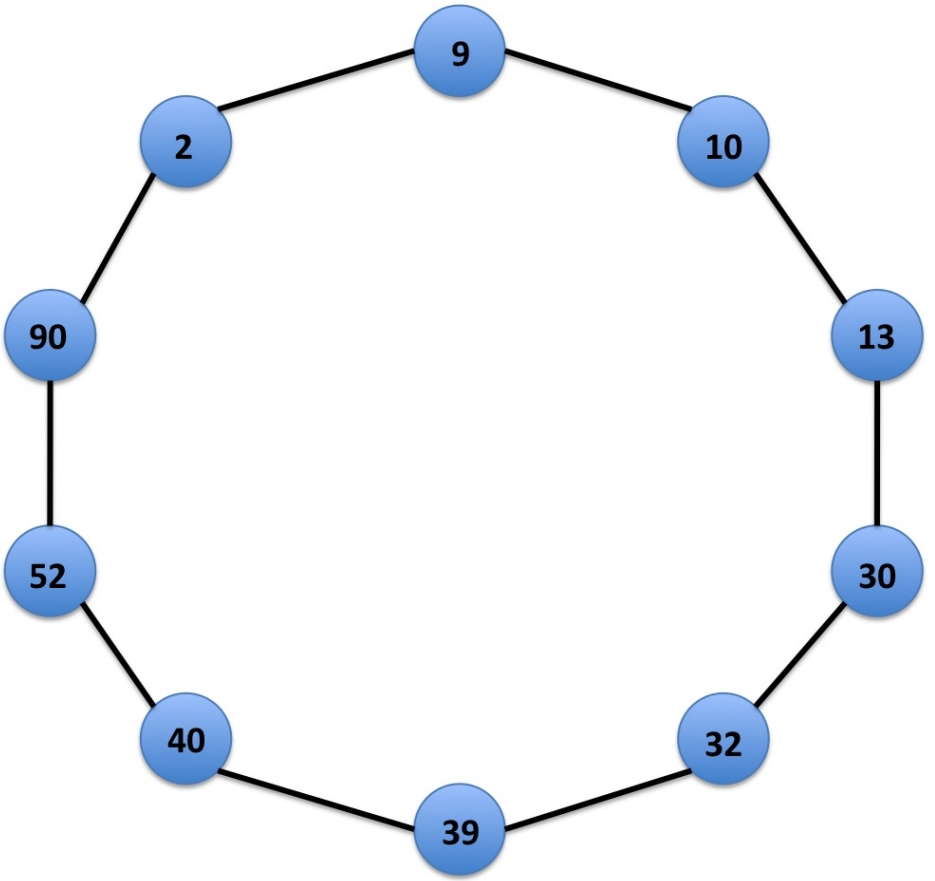
Two types of overlay networks:

- Structured Overlay Networks (*e.g.*, DHTs)
- Unstructured Overlay Networks (*i.e.*, random overlays).





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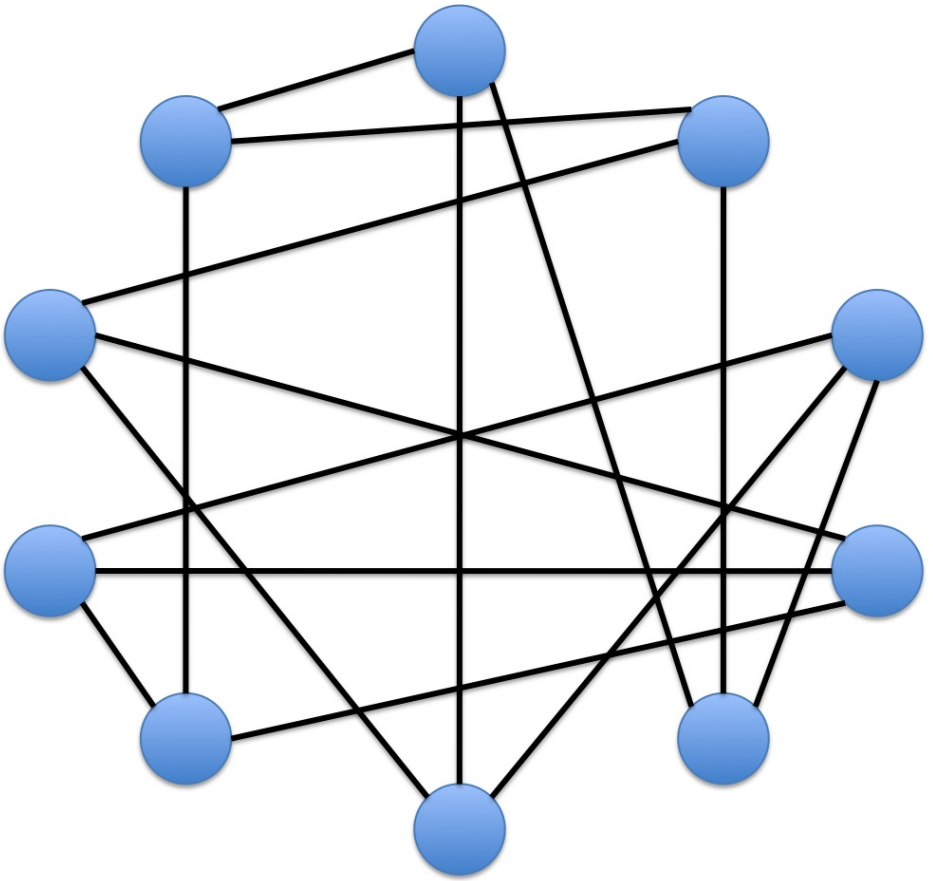

Structured Overlay Networks

- Can (easily) offer additional functionality to services.
- Complex construction and maintenance.
- More susceptible to (high) membership dynamics.

Unstructured Overlay Networks

- Lower construction and maintenance costs.
- More robust to (high) membership dynamics.
- Natural redundancy.
- Topology cannot be easily leveraged by services.

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Get the best of both worlds by imbuing some form of relaxed structure over unstructured overlay networks.

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- Offer some topology properties than can benefit and be leveraged by P2P services and applications.

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Cloud Computing??

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  - Huge number of Nodes.
  - Heterogeneous environment (Geographically disperse Datacenters).
  - Efficiency, Robustness, and Load-Balancing are key aspects of systems design.
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Roadmap

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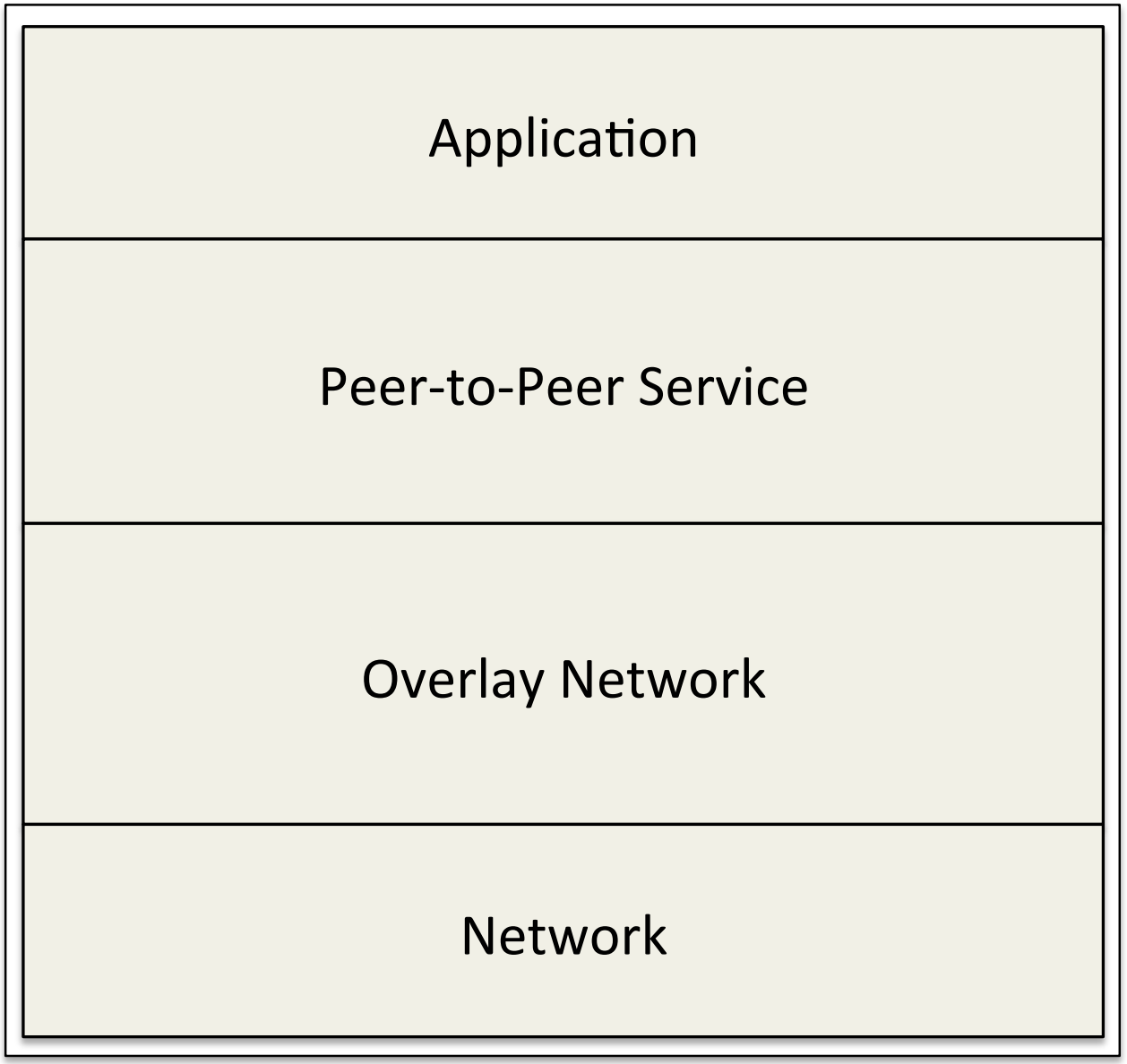

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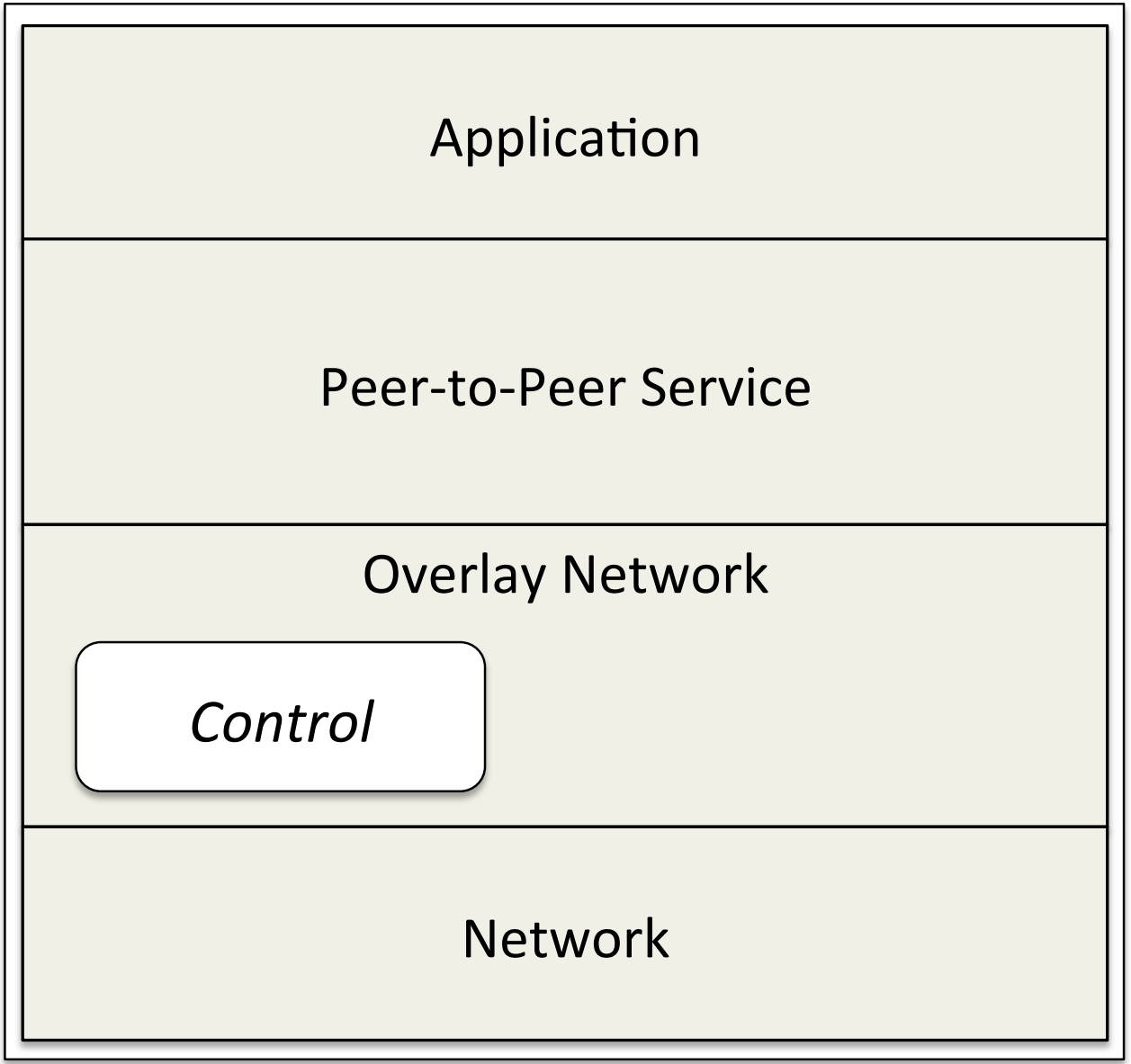
Application
Peer-to-Peer Service
Overlay Network
Control
Network

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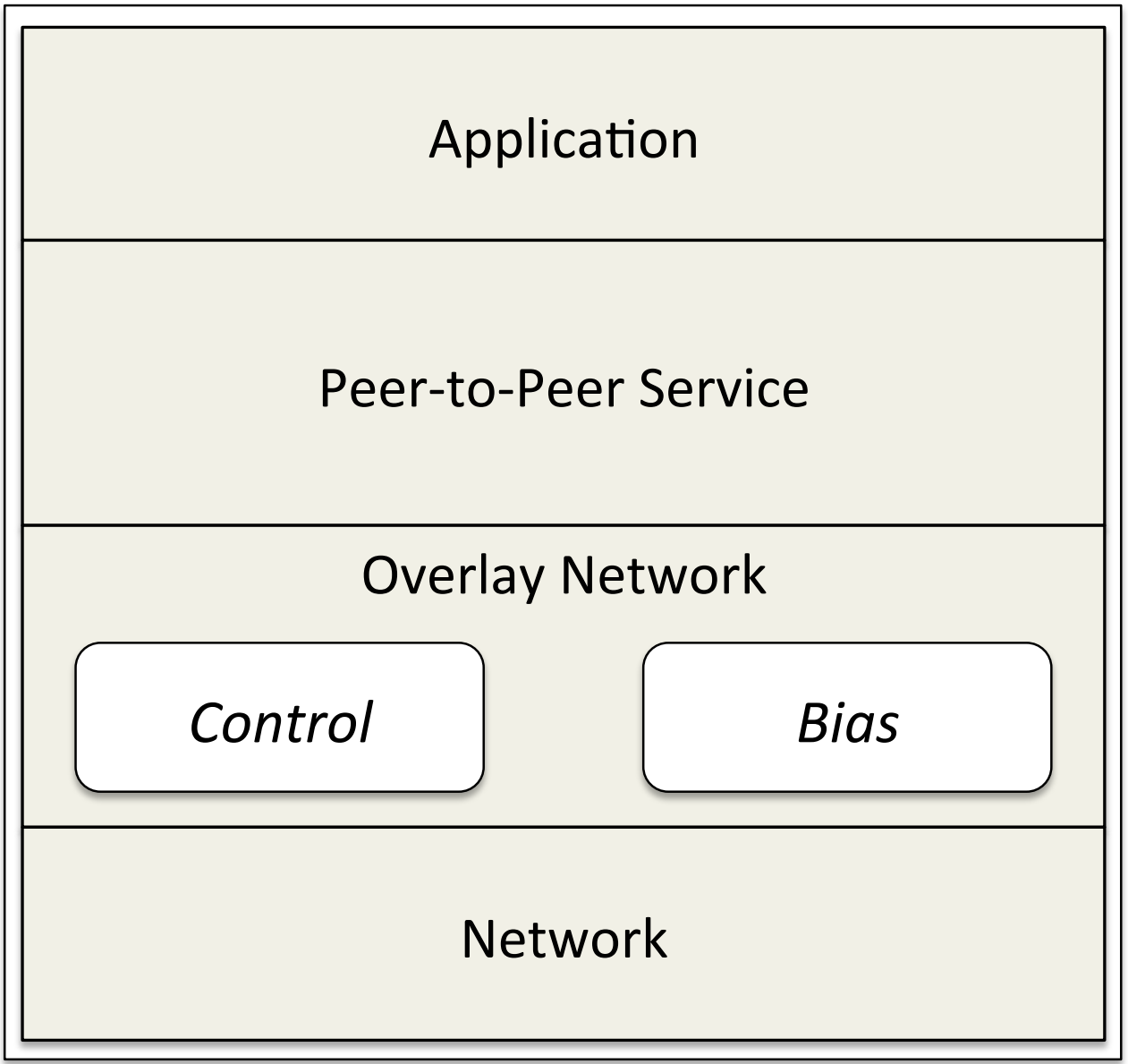
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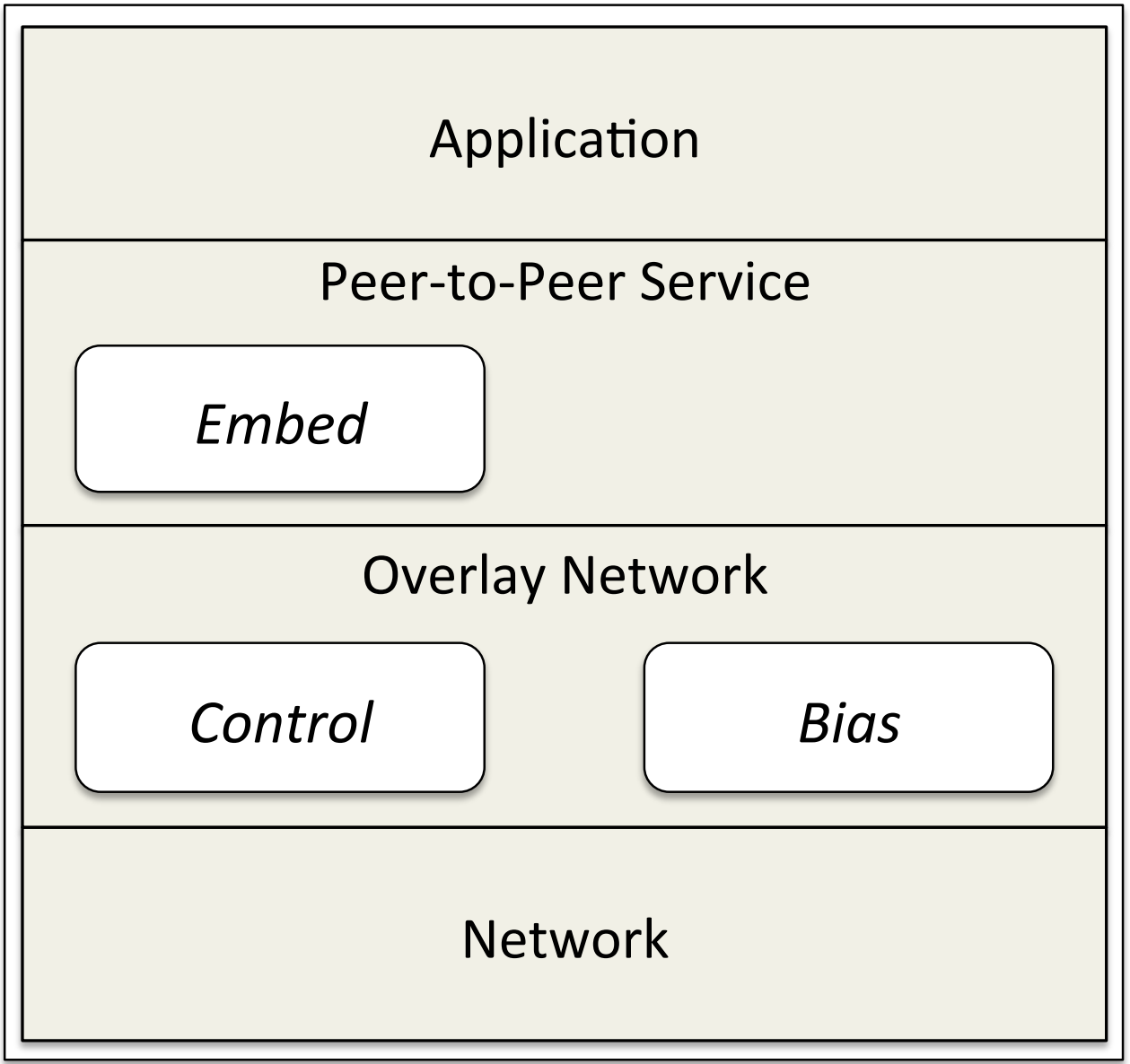
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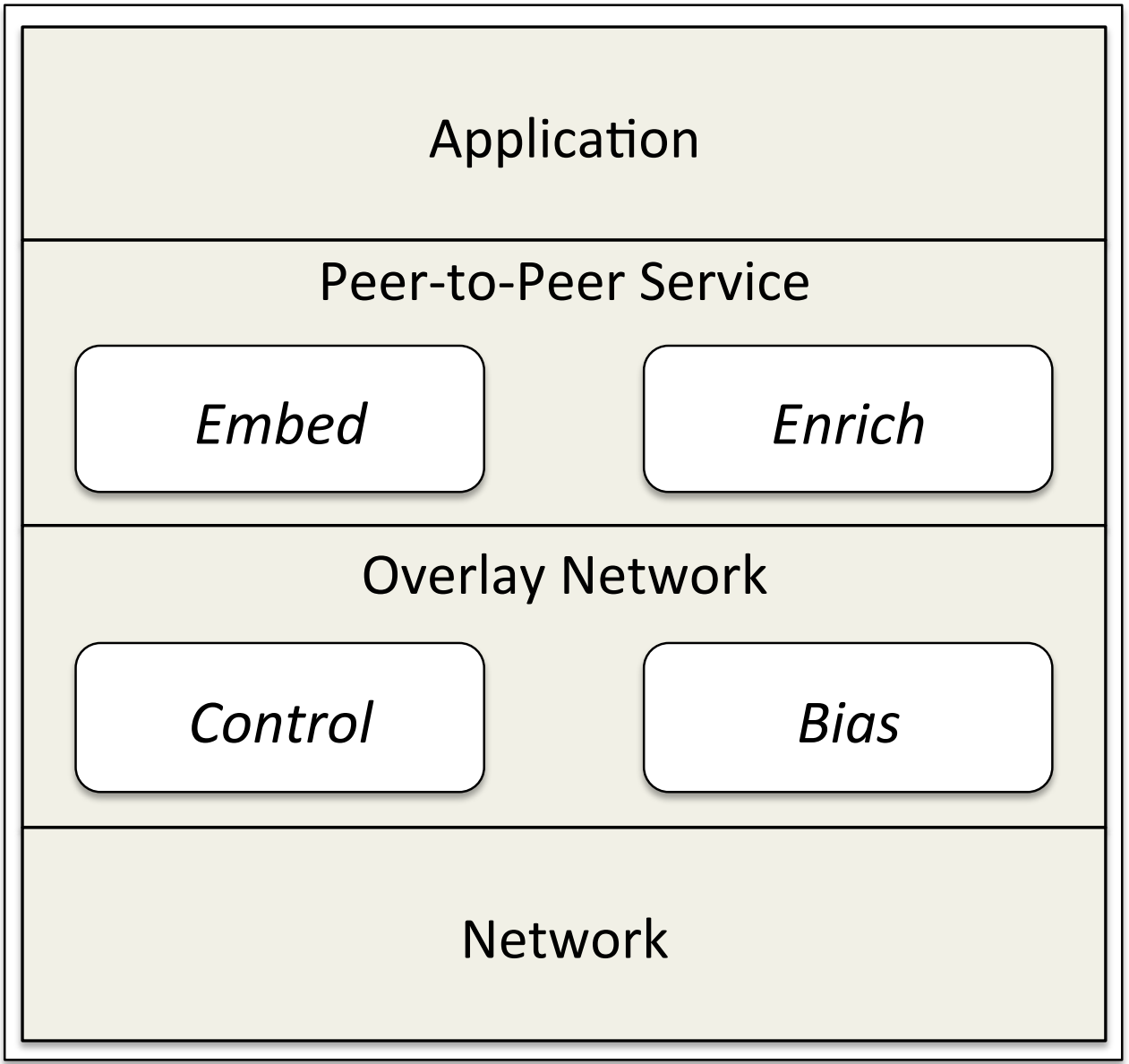
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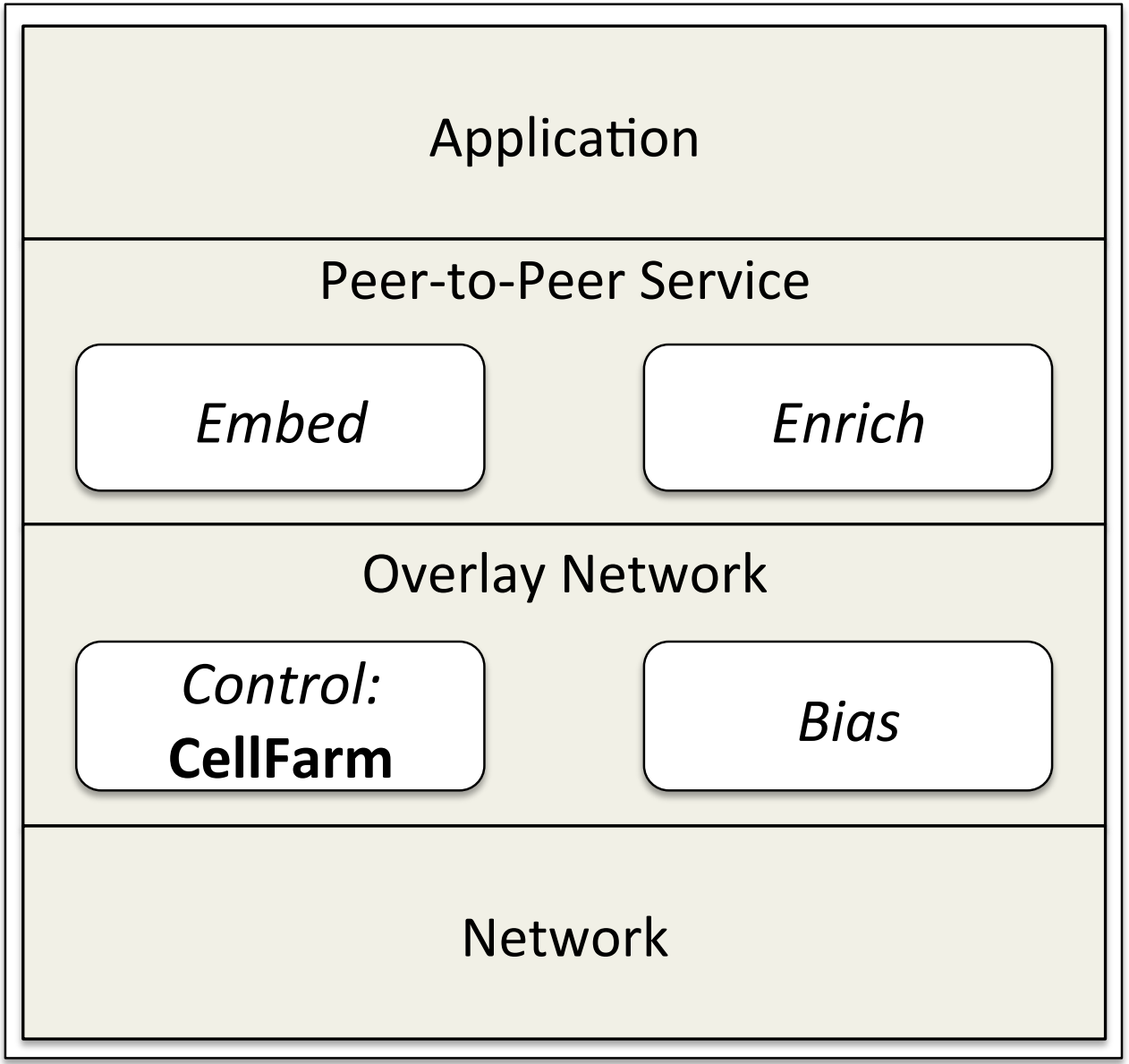
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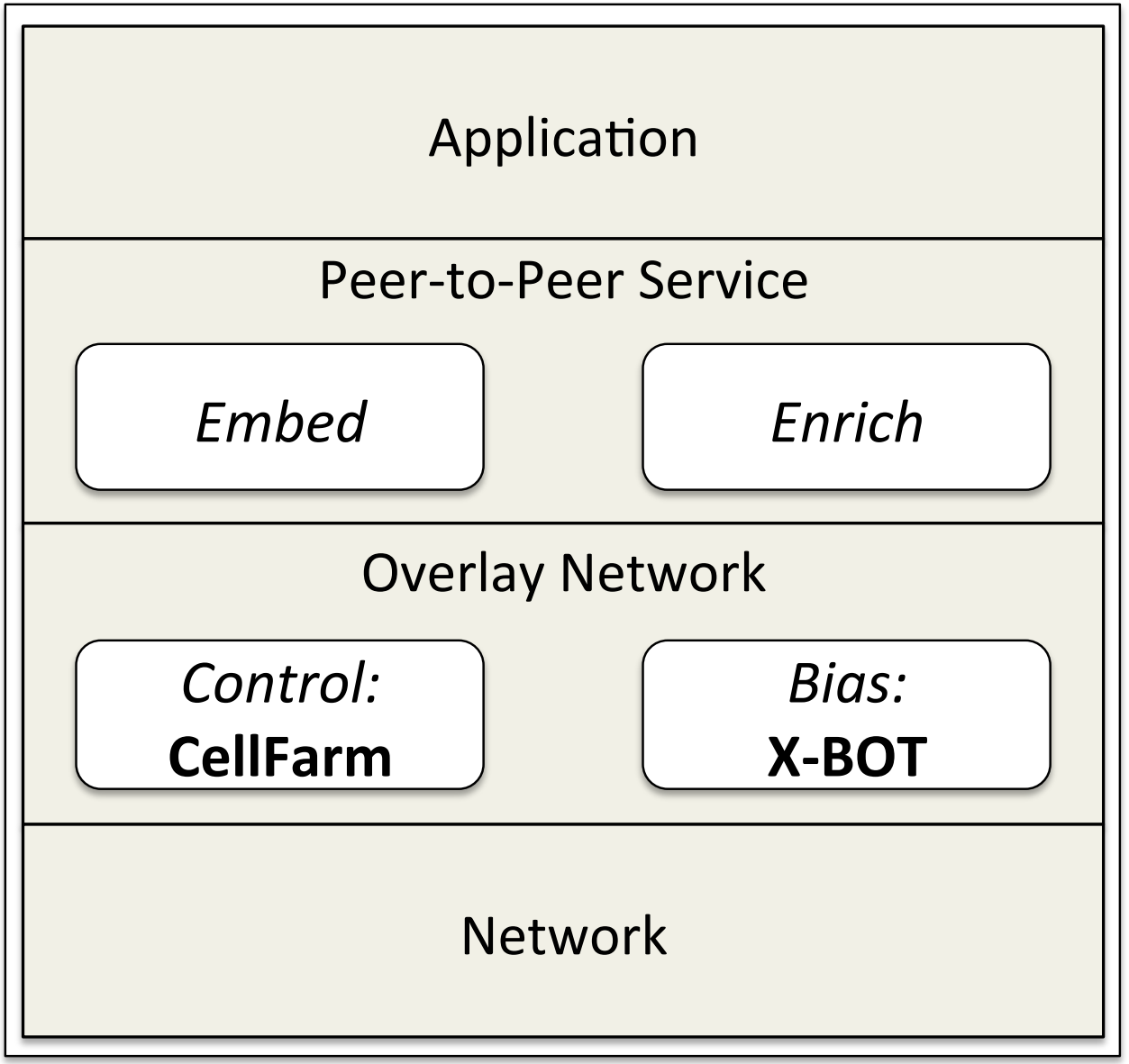
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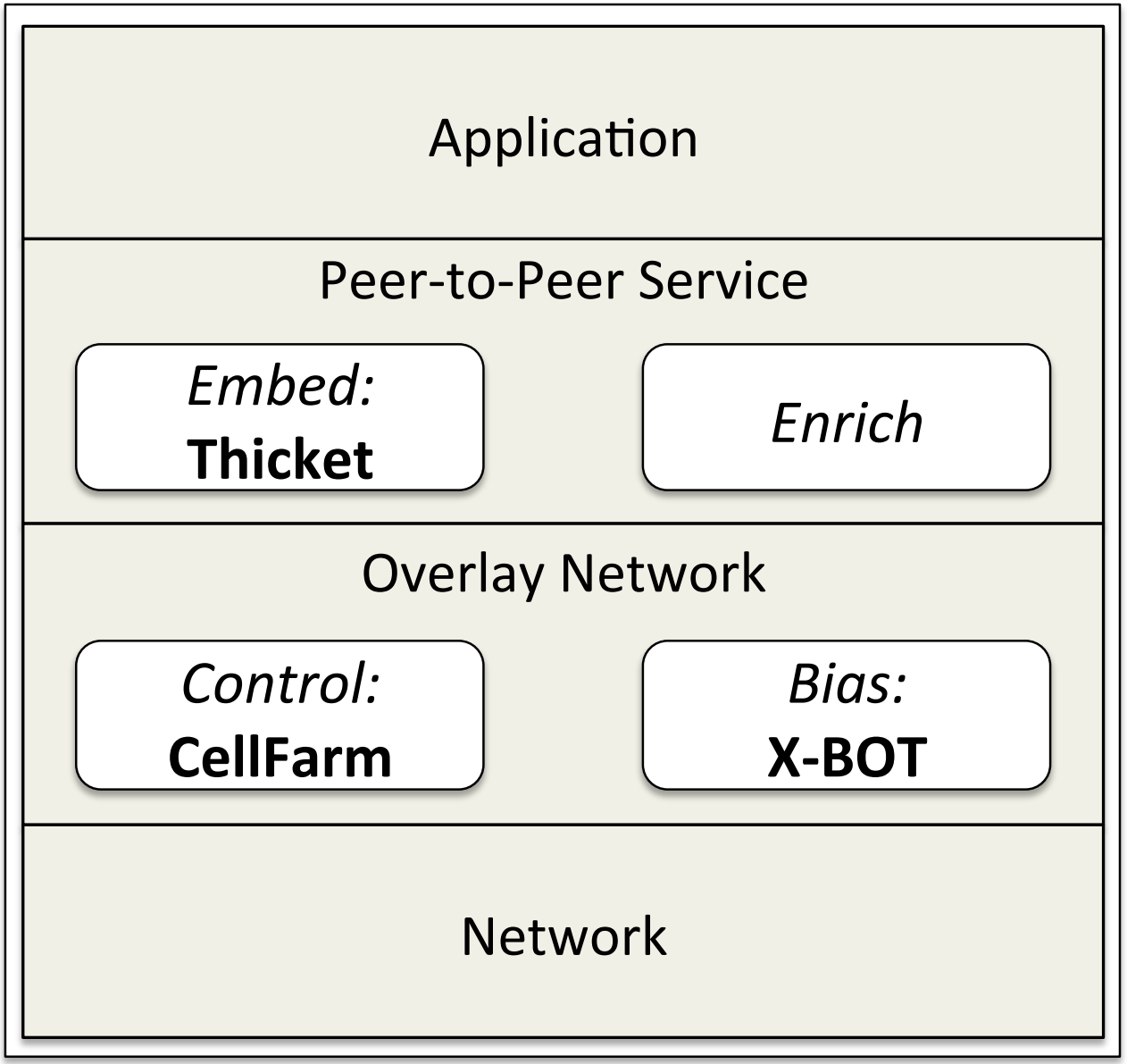
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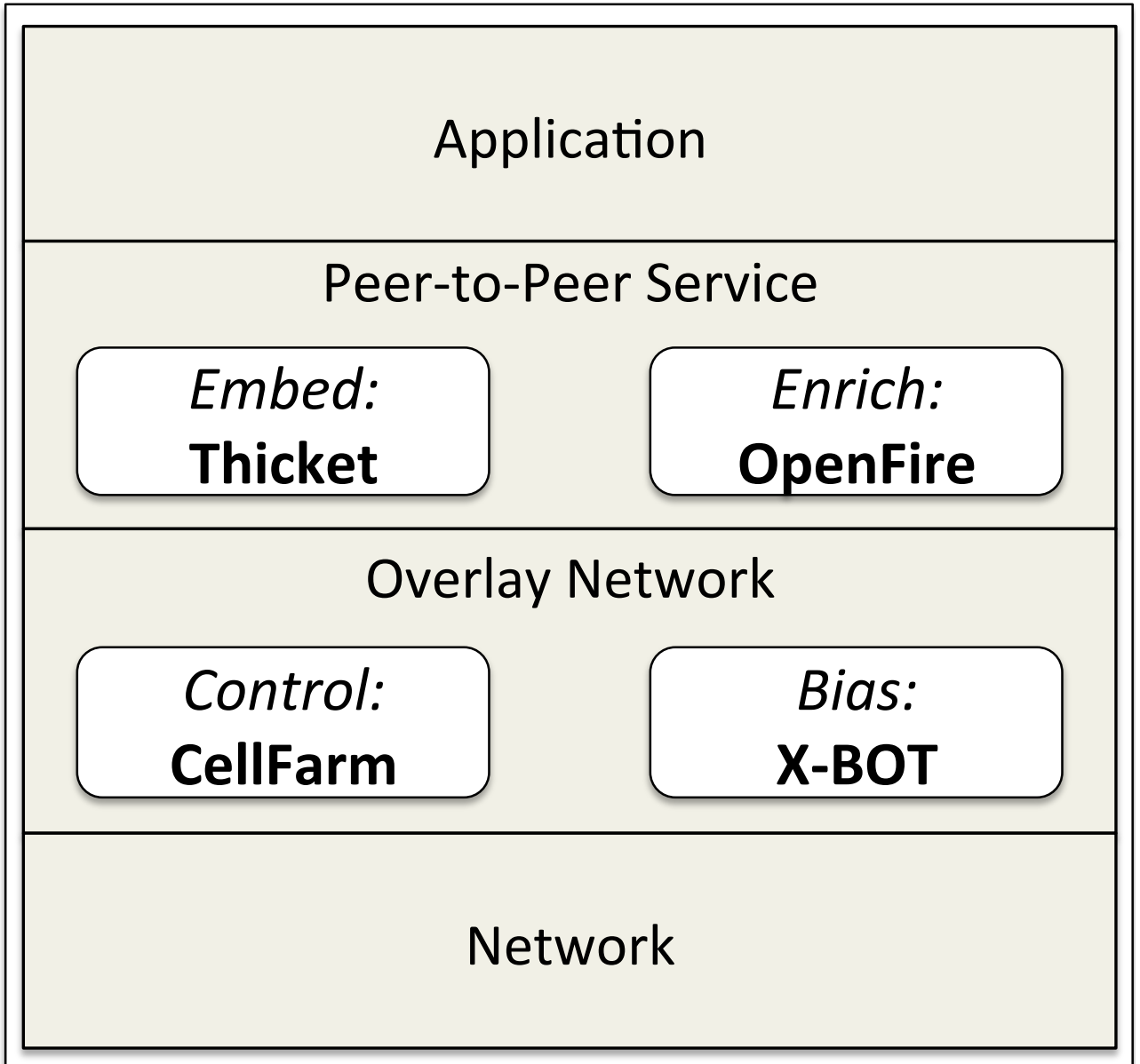
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- Motivation.
- Summary of the solution.
- Some relevant experimental results.

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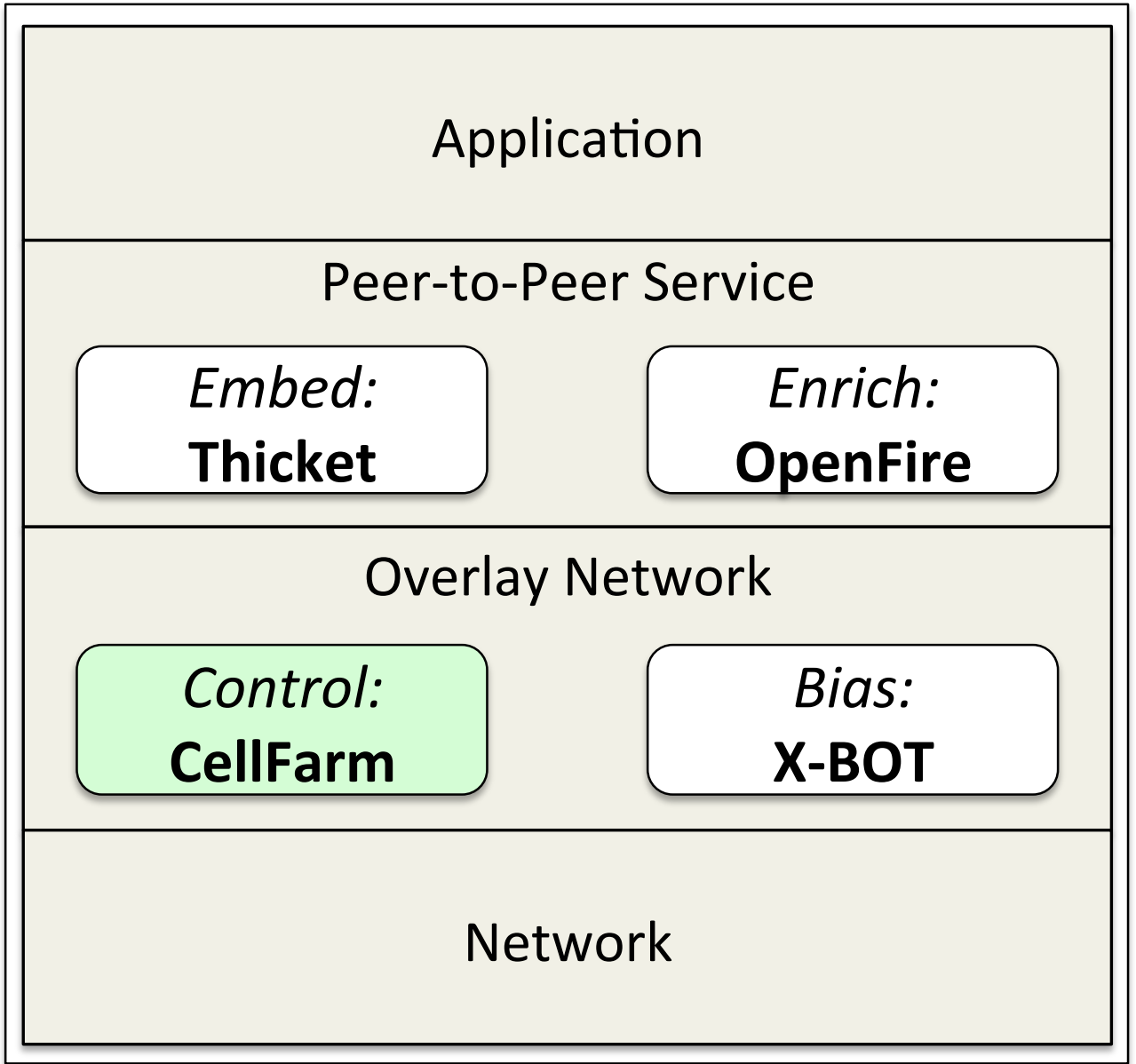
Control the Topology



Process groups:

- Well known approach to make distributed systems reliable.
- Offers the potential to improve scalability through load distribution.

CellFarm
Motivation

In the context of P2P systems the notion has been proposed to:

- Scalable P2P grid management services.
- Optimize one-hop replication schemes.
- Robust and efficient P2P streaming infrastructures.
- DHT-based key value stores.

However...

...no robust and scalable mechanism to build and maintain process groups in a P2P context has been proposed.

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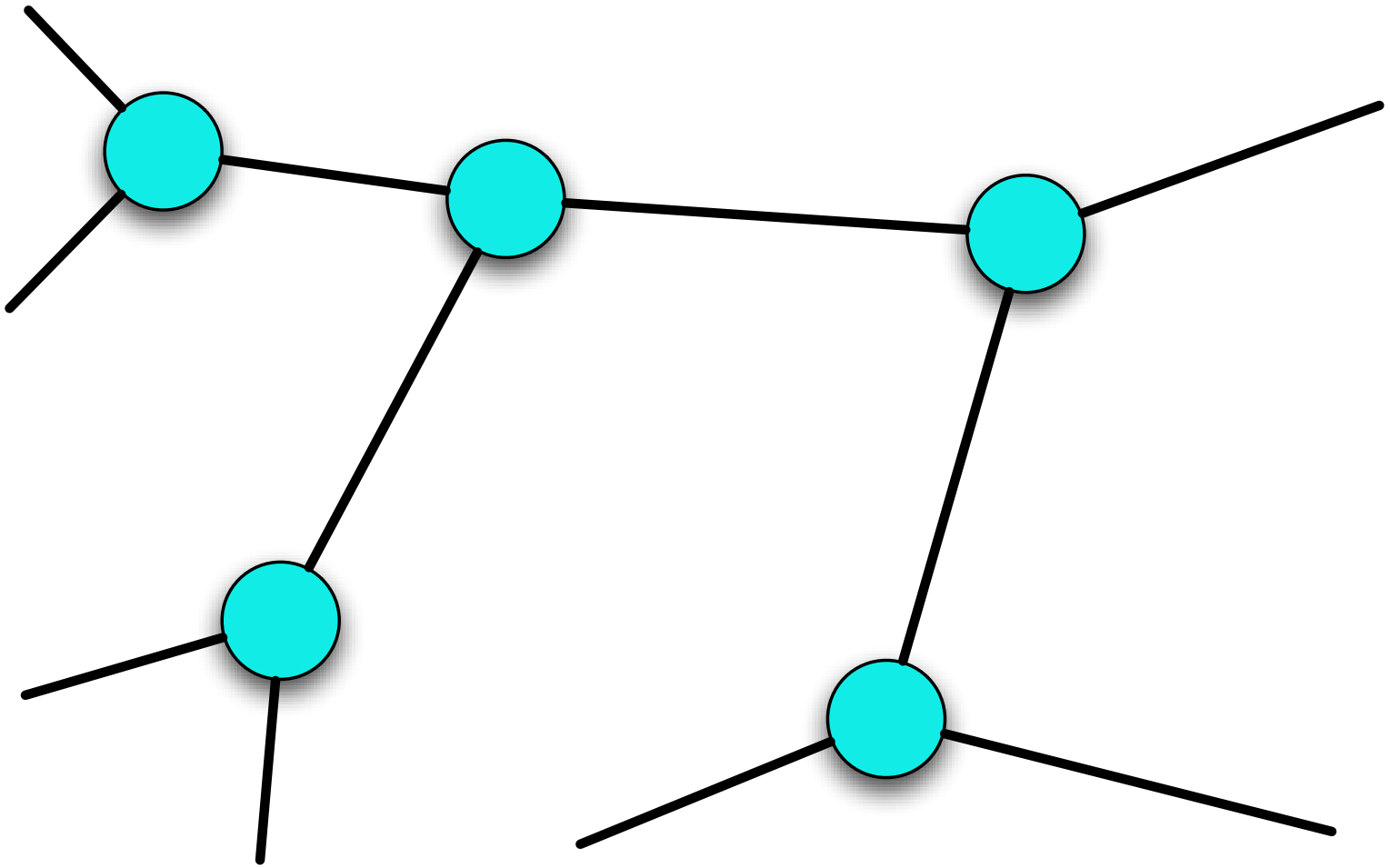

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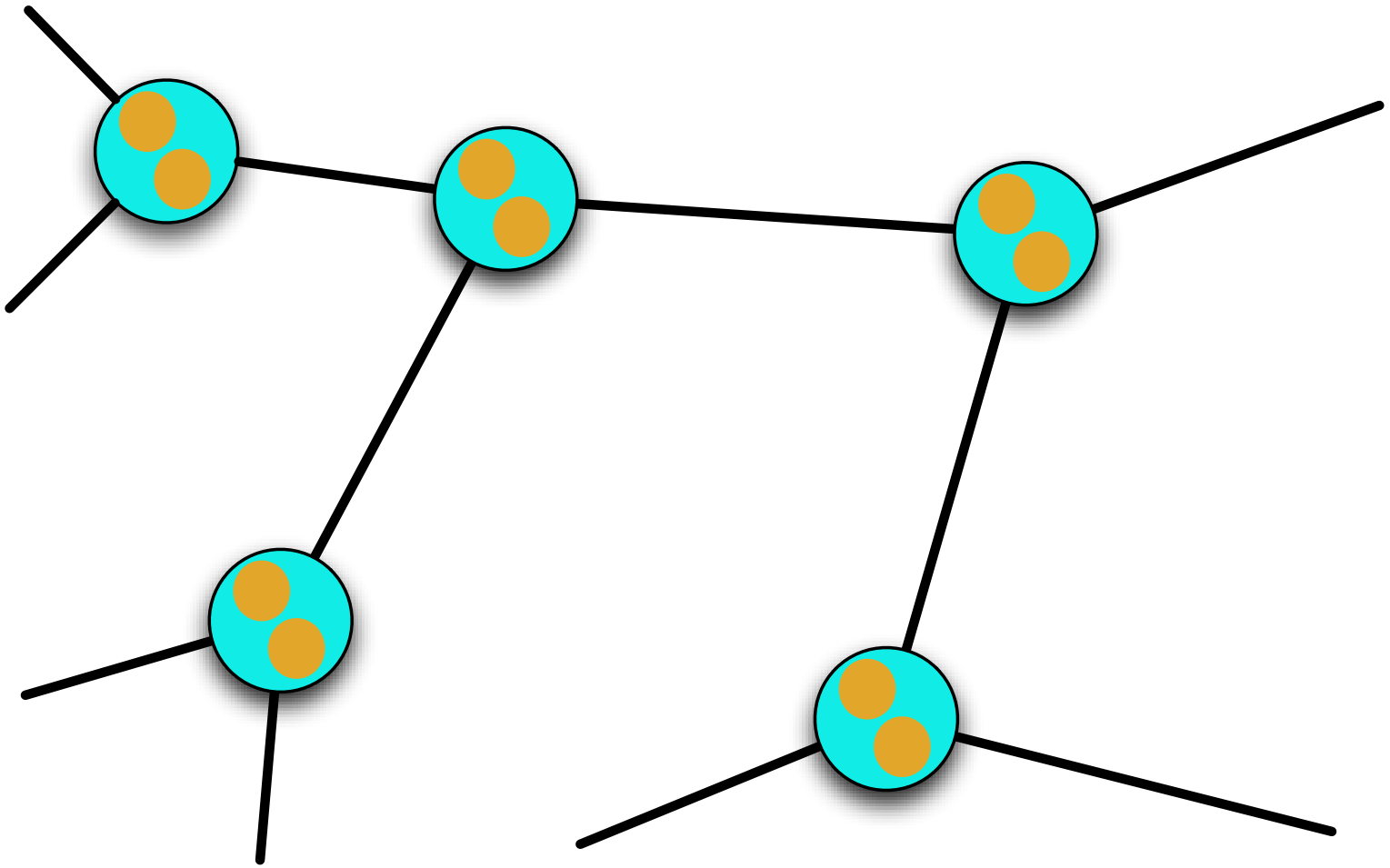

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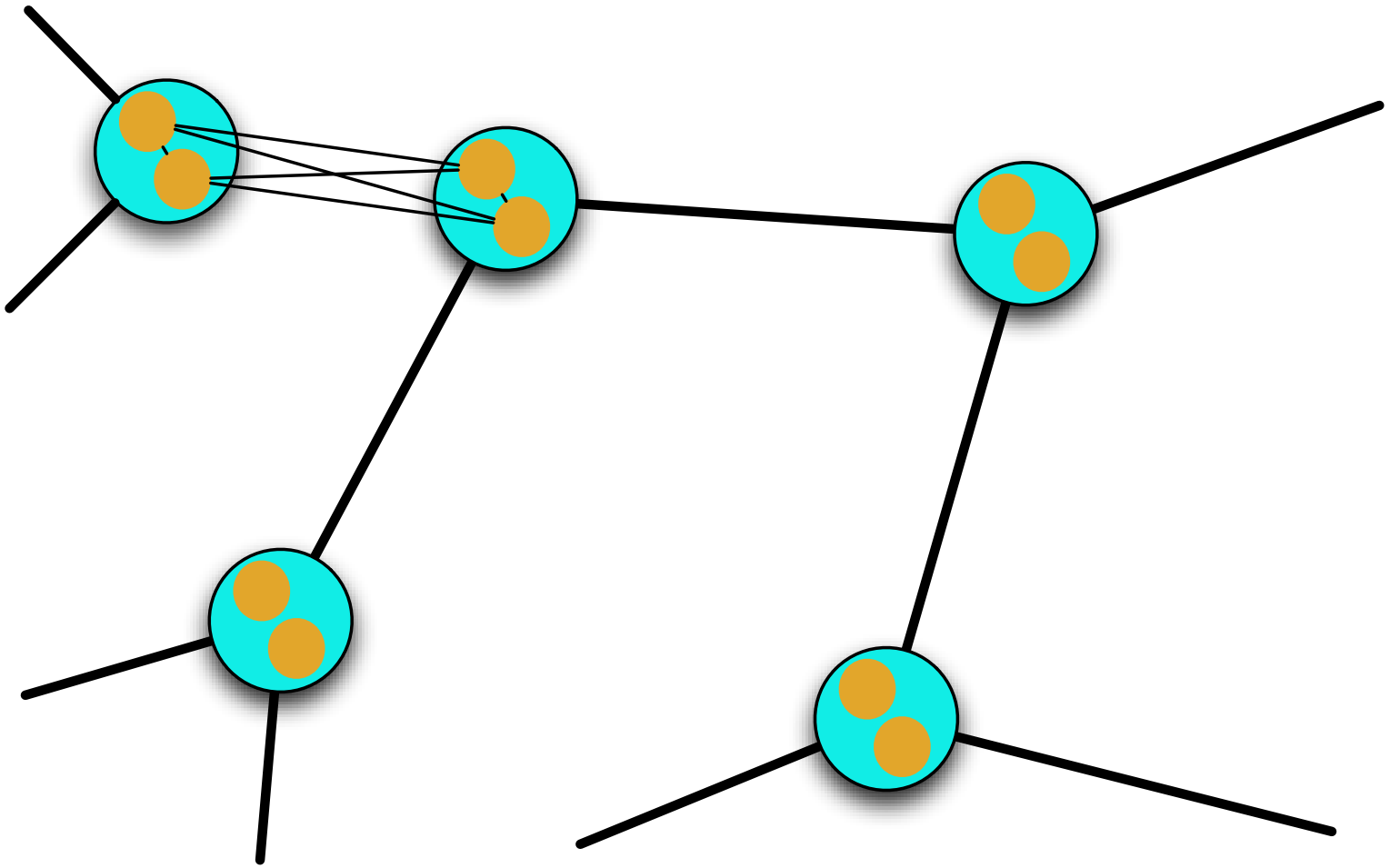

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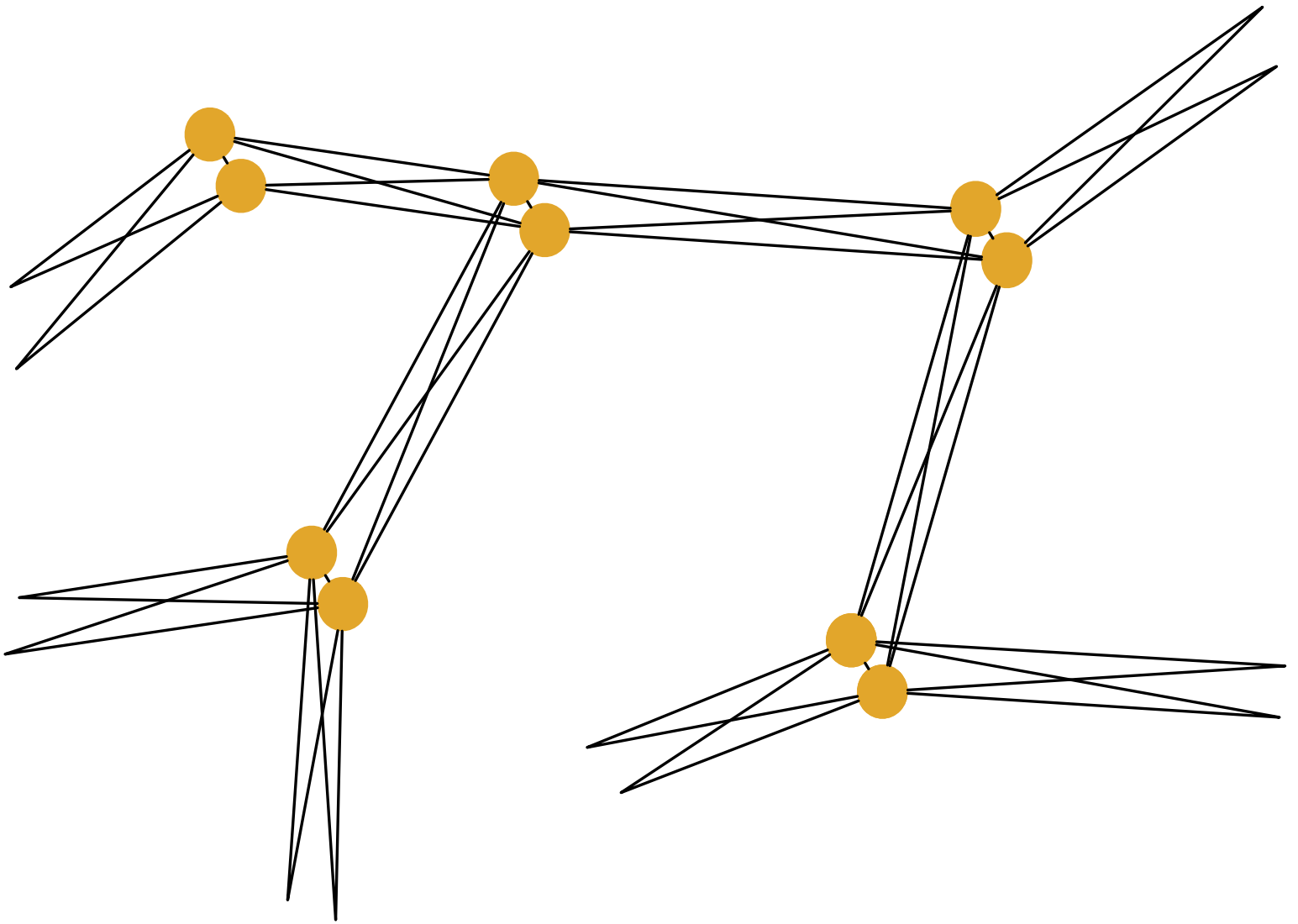

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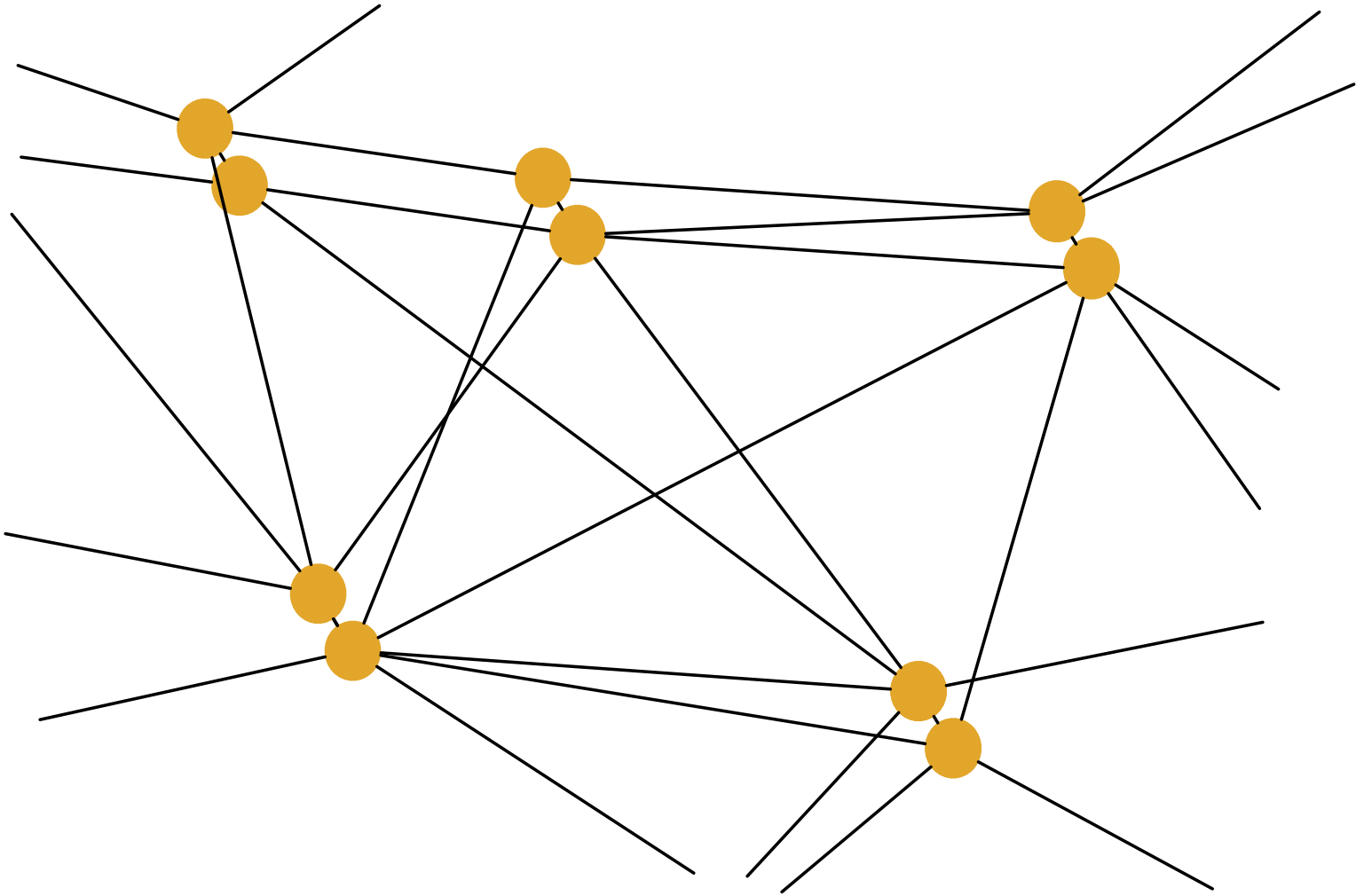

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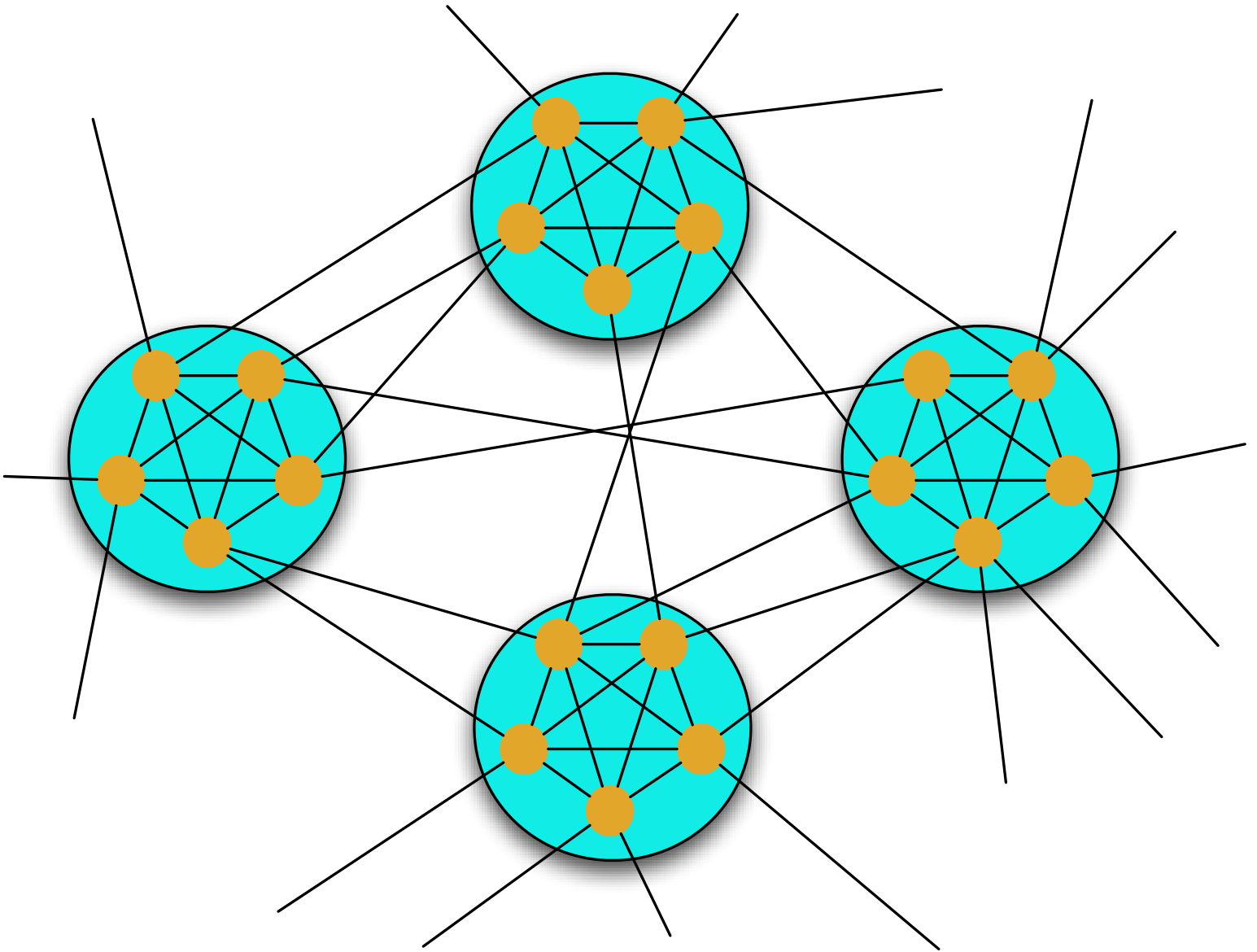

CellFarm
Solution Overview

Control Technique:

- Operates at the overlay network layer.
- Enforces *soft* constraints over the neighboring relations of peers:
  - topology retains flexibility (not based on nodes identifiers).
  - overlay topology enforces properties that can benefit of be leveraged by P2P services.

Case study:

An unstructured resource location system based on one-hop replication.

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Cell Size

- Impossible to ensure that all Cells have the same size.
- Cell sizes are governed by a set of configurable parameters:
  - Cell target size.
  - Cell maximum size.
  - Cell minimum size.

Relies of mechanisms typically employed to manage unstructured overlay networks:

- Random walks.
- Gossip protocols.

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CellFarm
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Solution is composed of 5 micro-protocols:

- Join.
- Divide.
- Collapse.
- External Neighboring.
- Anti-entropy.

CellFarm

Main Results: Cell Size Distribution

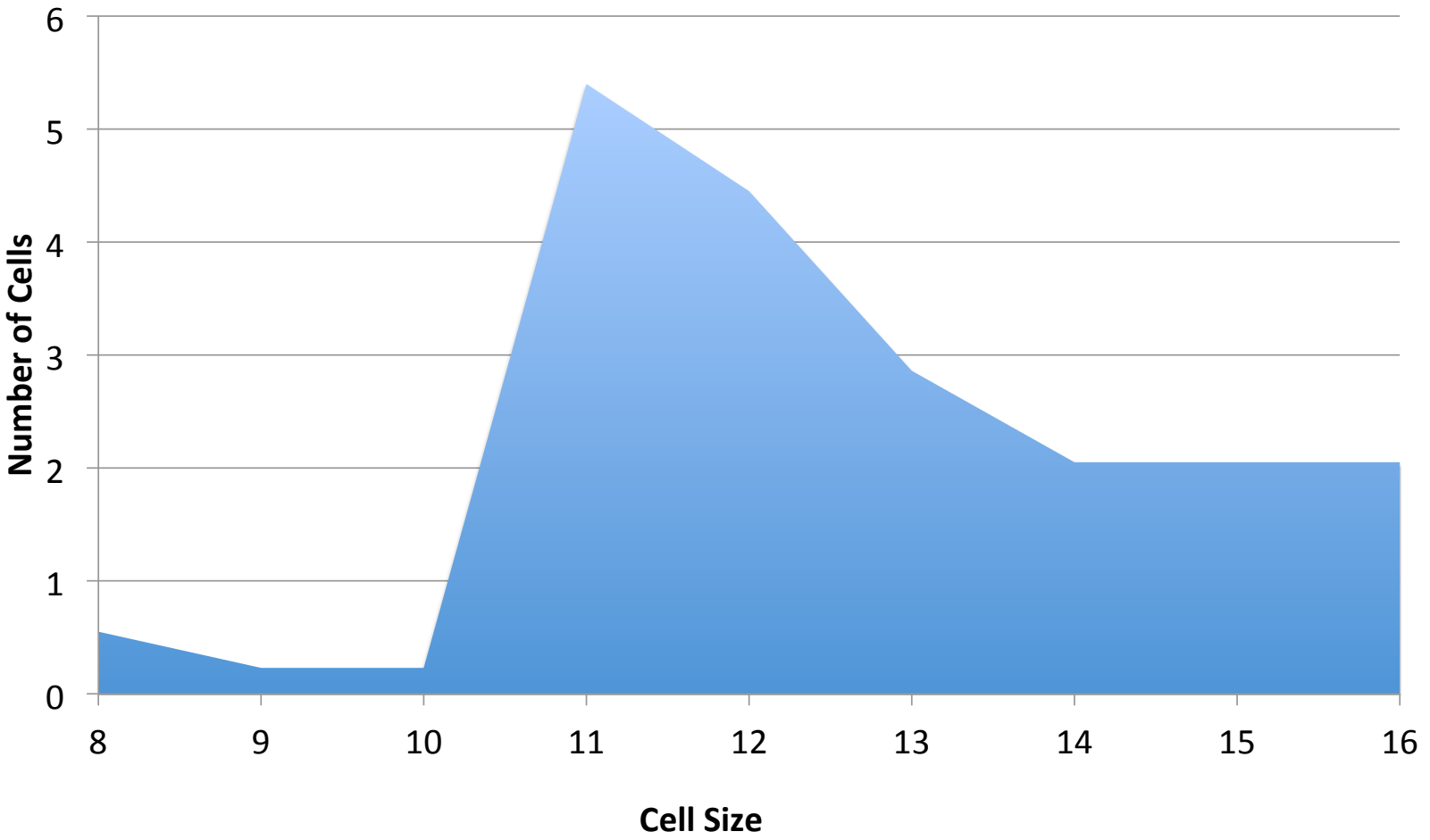
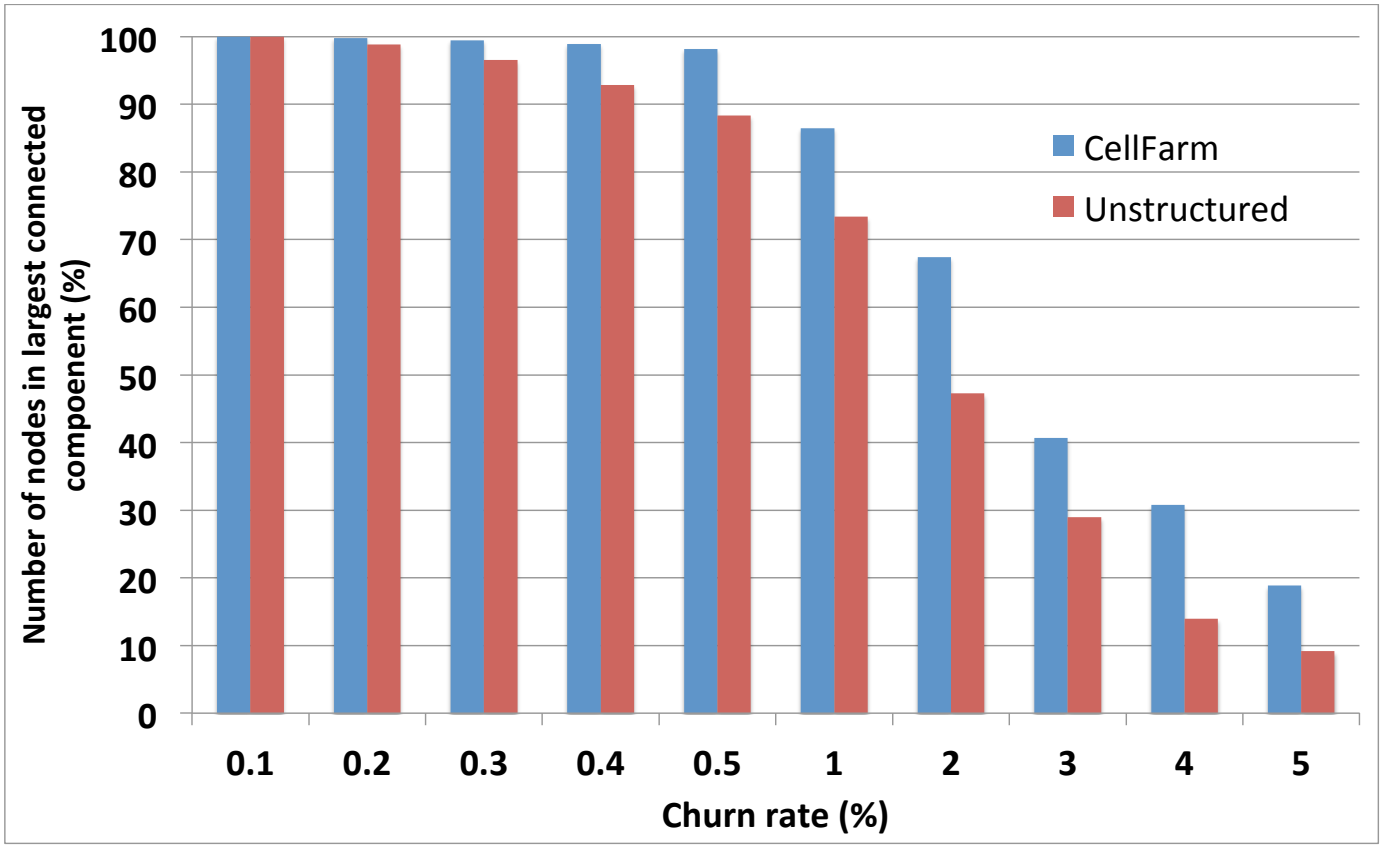


Figure : Distribution of Cells size in the PlanetLab deployment.

CellFarm
Main Results: Robustness to Churn



CellFarm
Summary

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- Control technique allows to build and maintain robust and flexible overlays with pre-determined topological properties.
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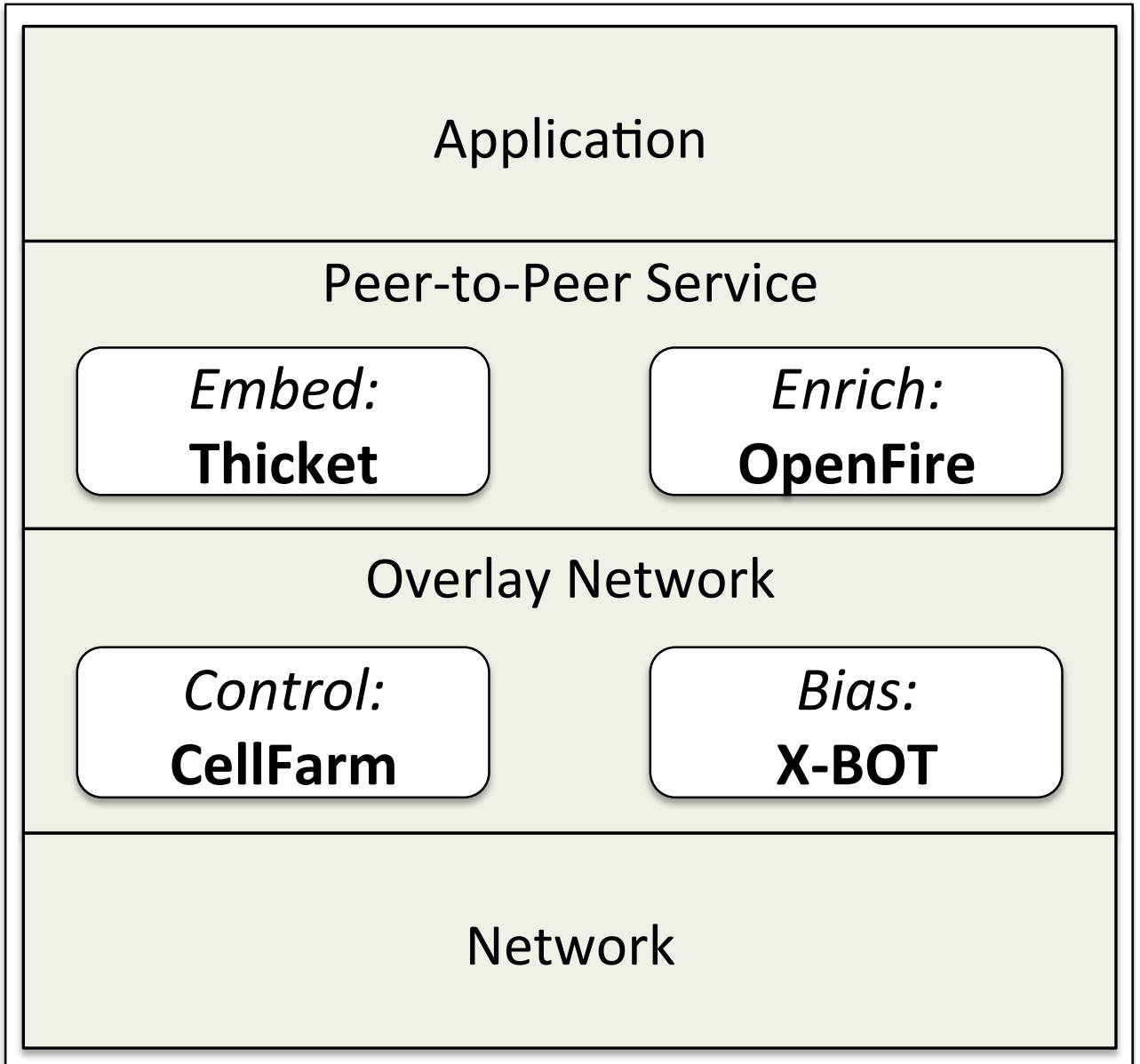
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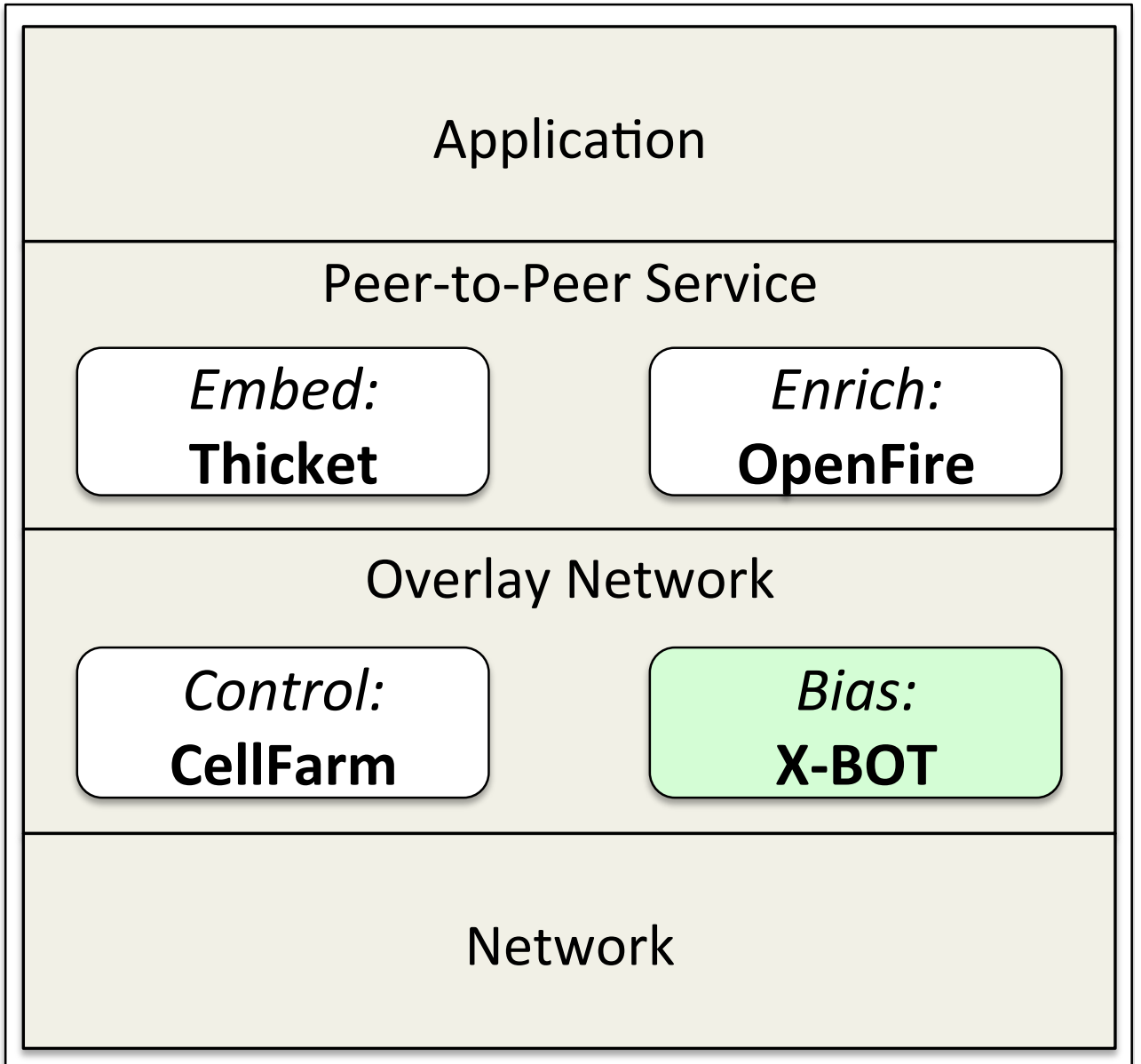
Bias the Topology



X-BOT
Motivation

Unstructured Overlay Networks:

- Simple.
- Low overhead.
- Highly resilient.

Disadvantages:

- Random neighboring relations are not able to capture efficiency criteria.
- Most overlay links may be suboptimal.
- Negative impact in service and applications.

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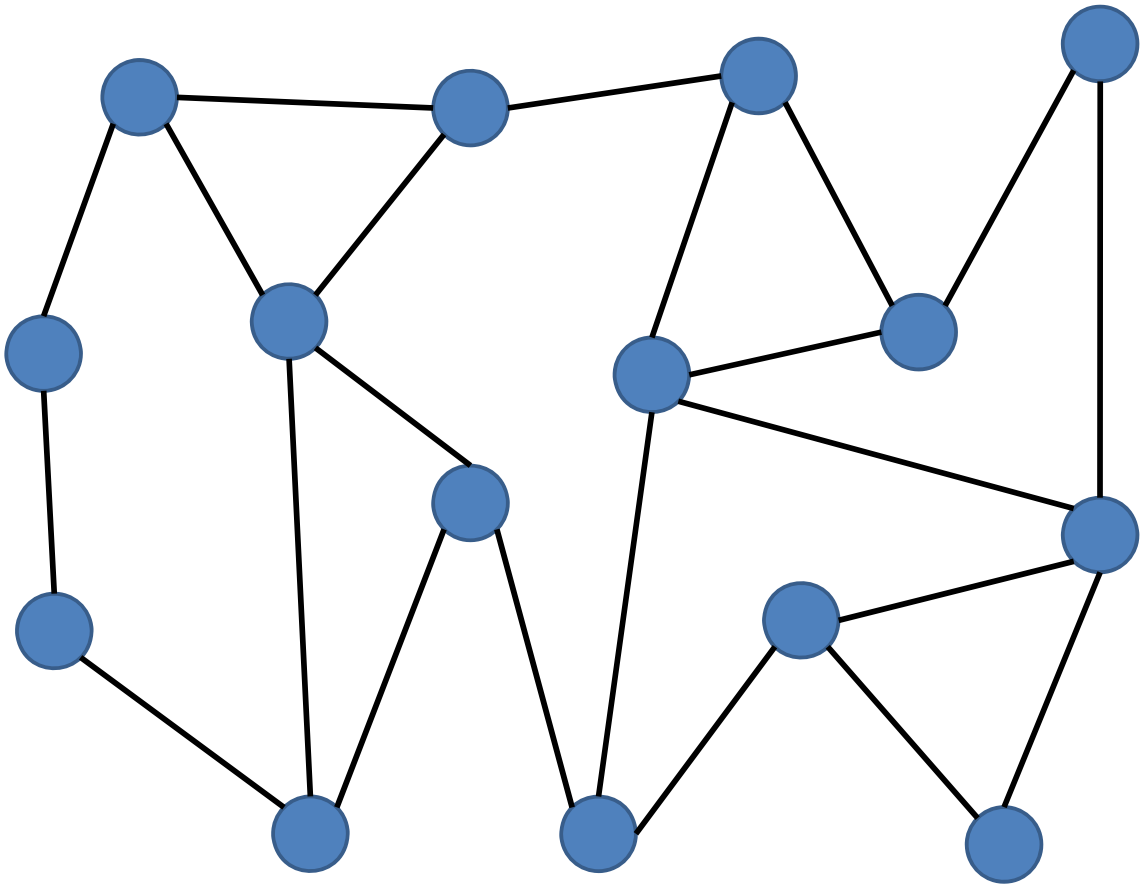
Particular example:

The topology mismatch problem.

X-BOT
Motivation: Topology Mismatch



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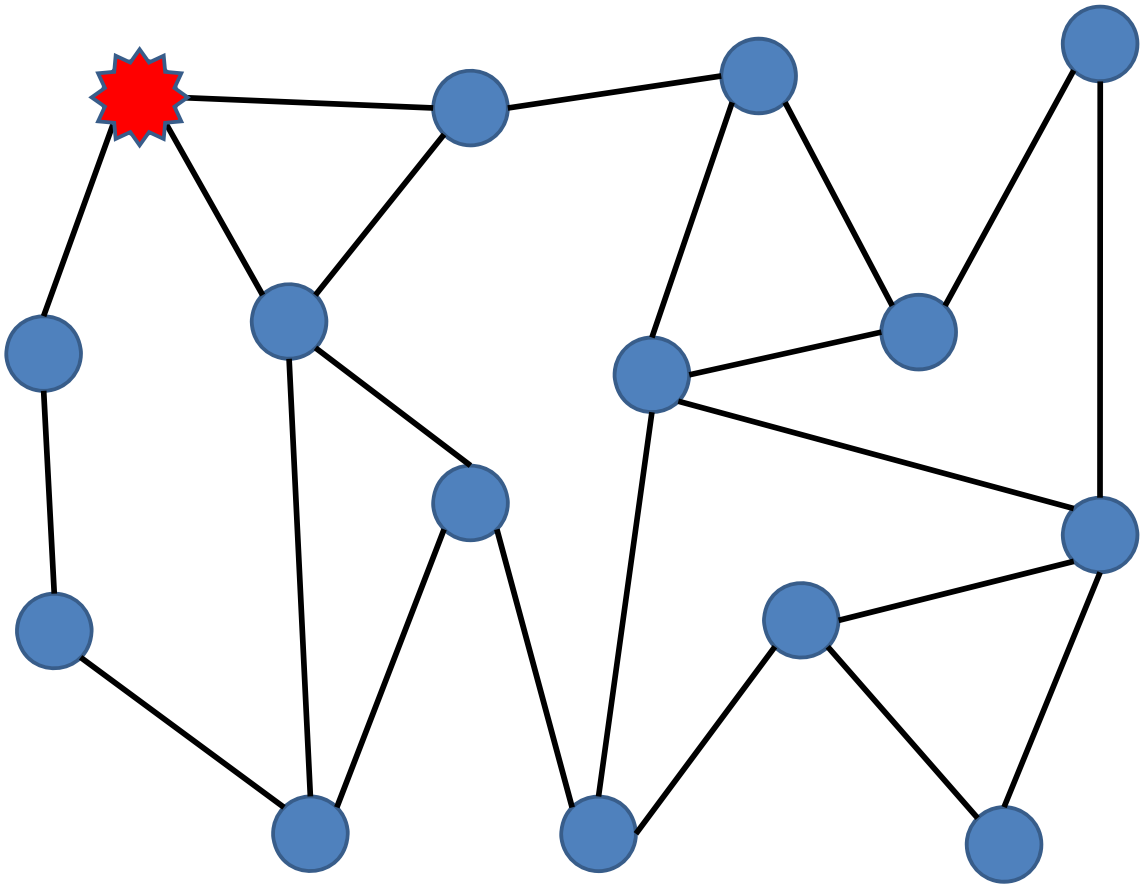

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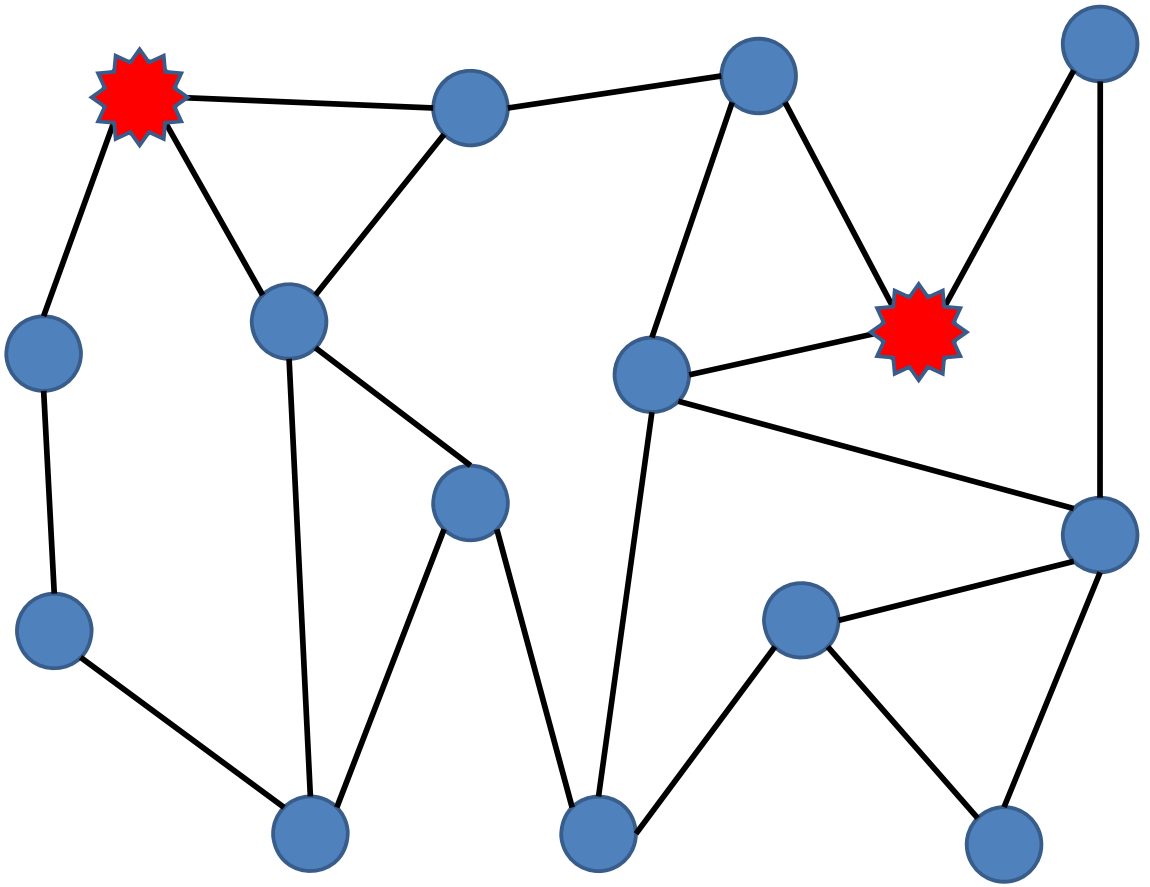

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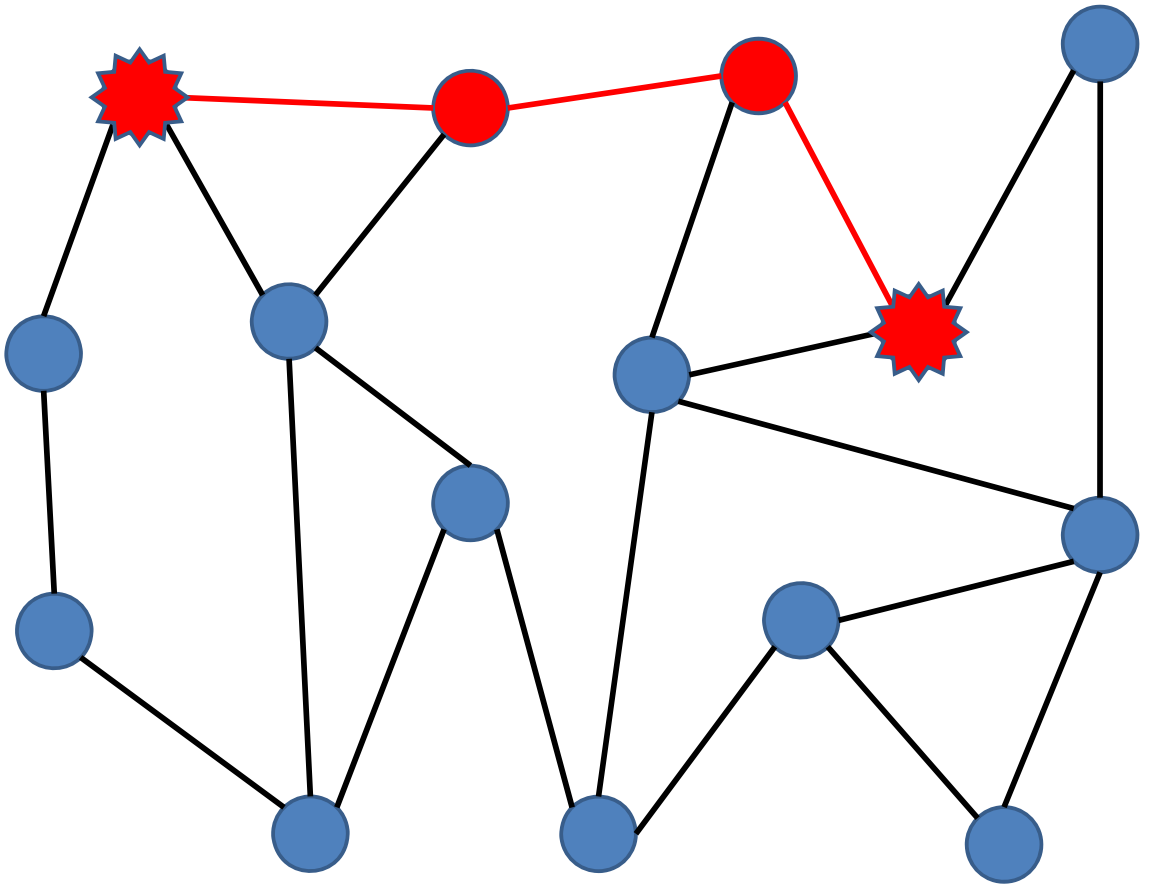

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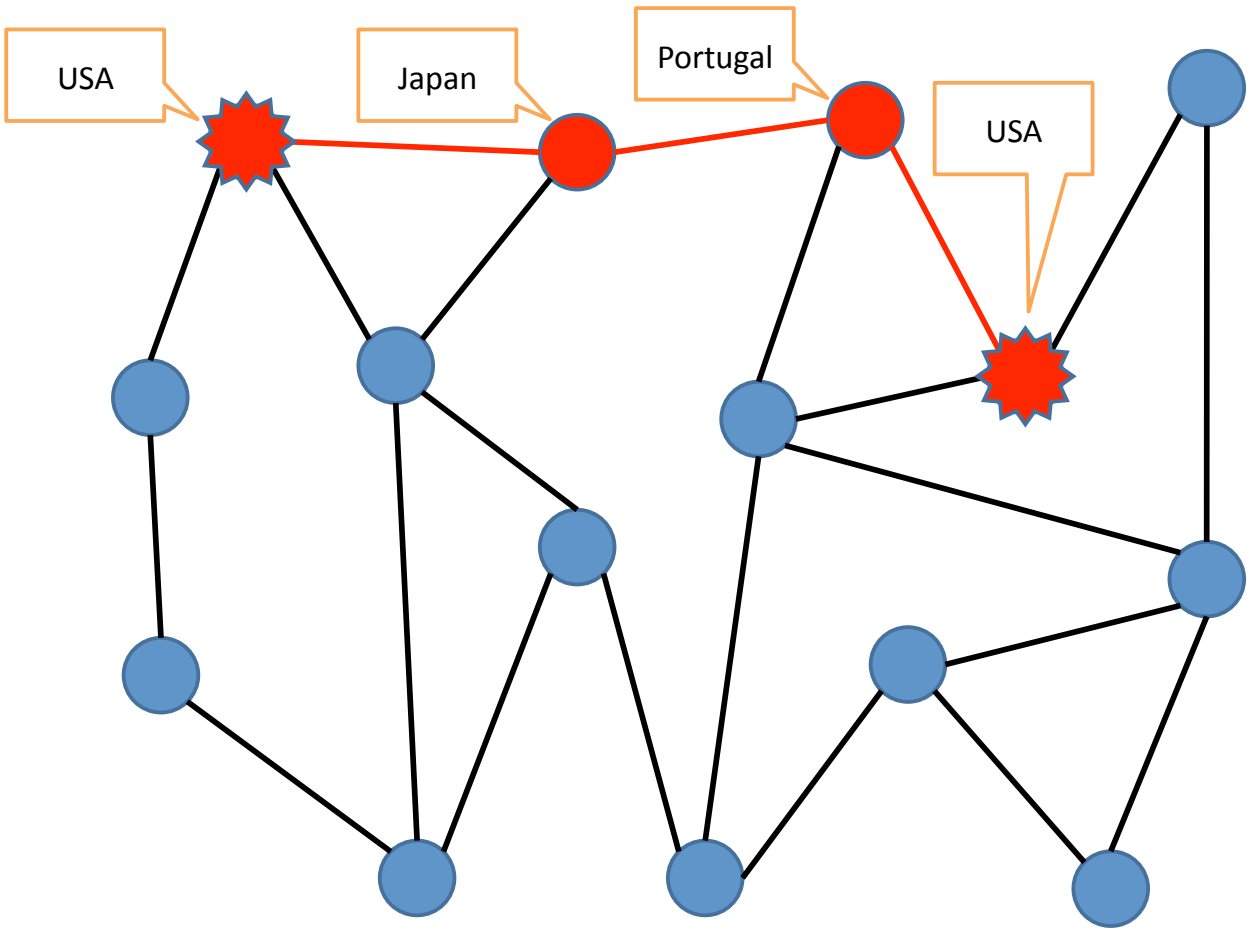
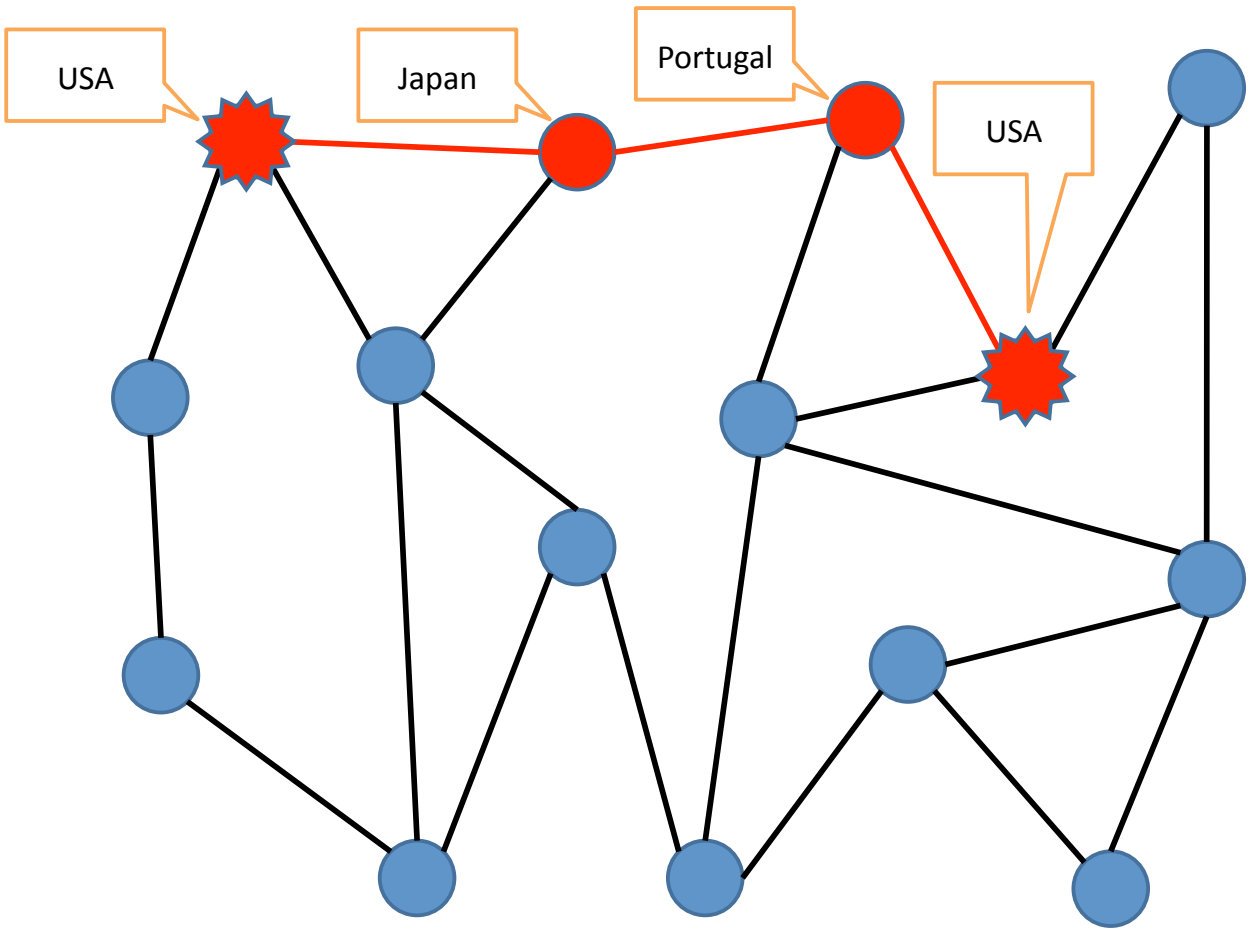


X-BOT
Motivation

- The topology mismatch problem is only an example.
- We can further generalize this to other performance criteria:
  - Link Latency.
  - Link Bandwidth.
  - Node Stored Content Similarity.
  - Node Internet Service Provider.
  - ...

X-BOT
Intuition



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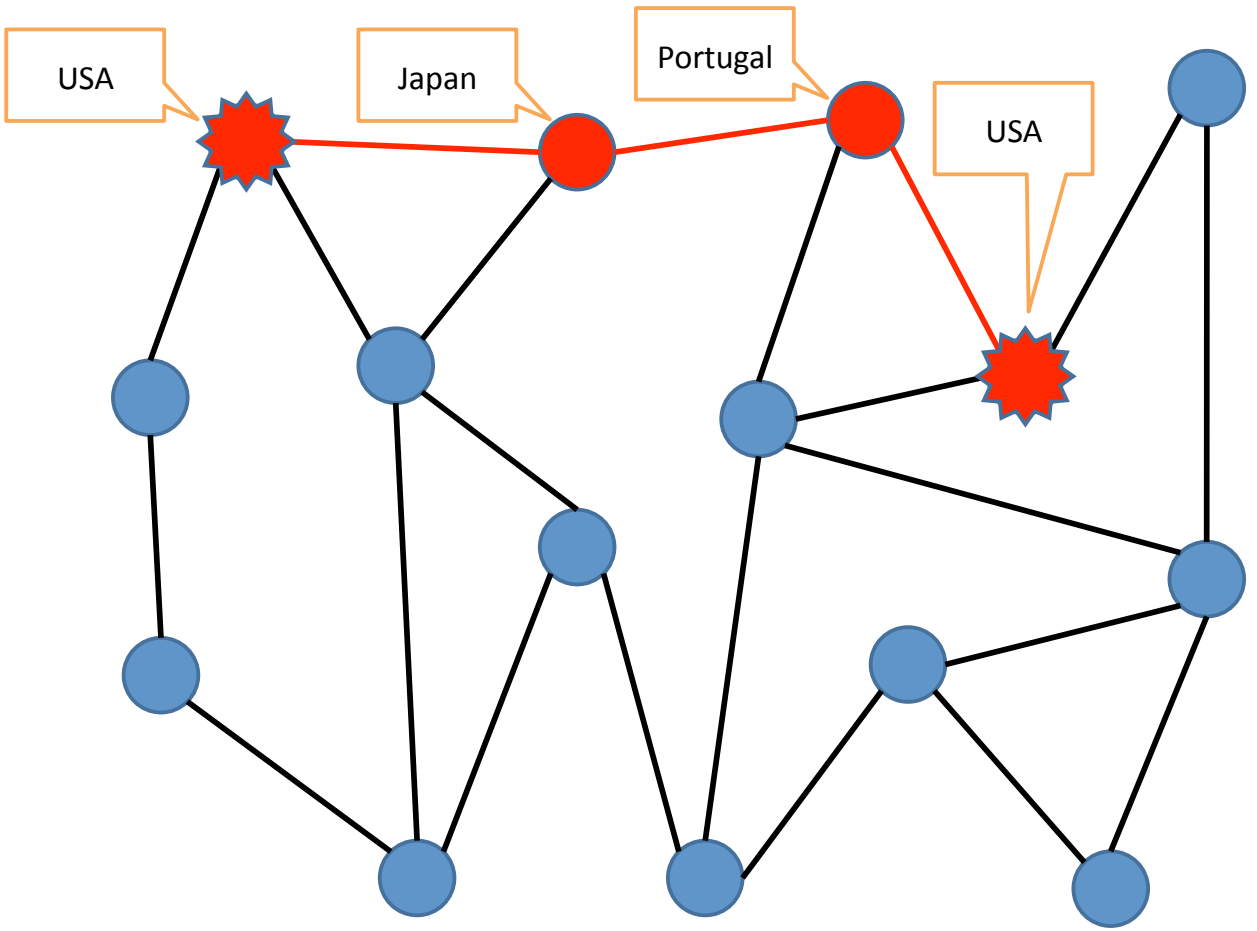

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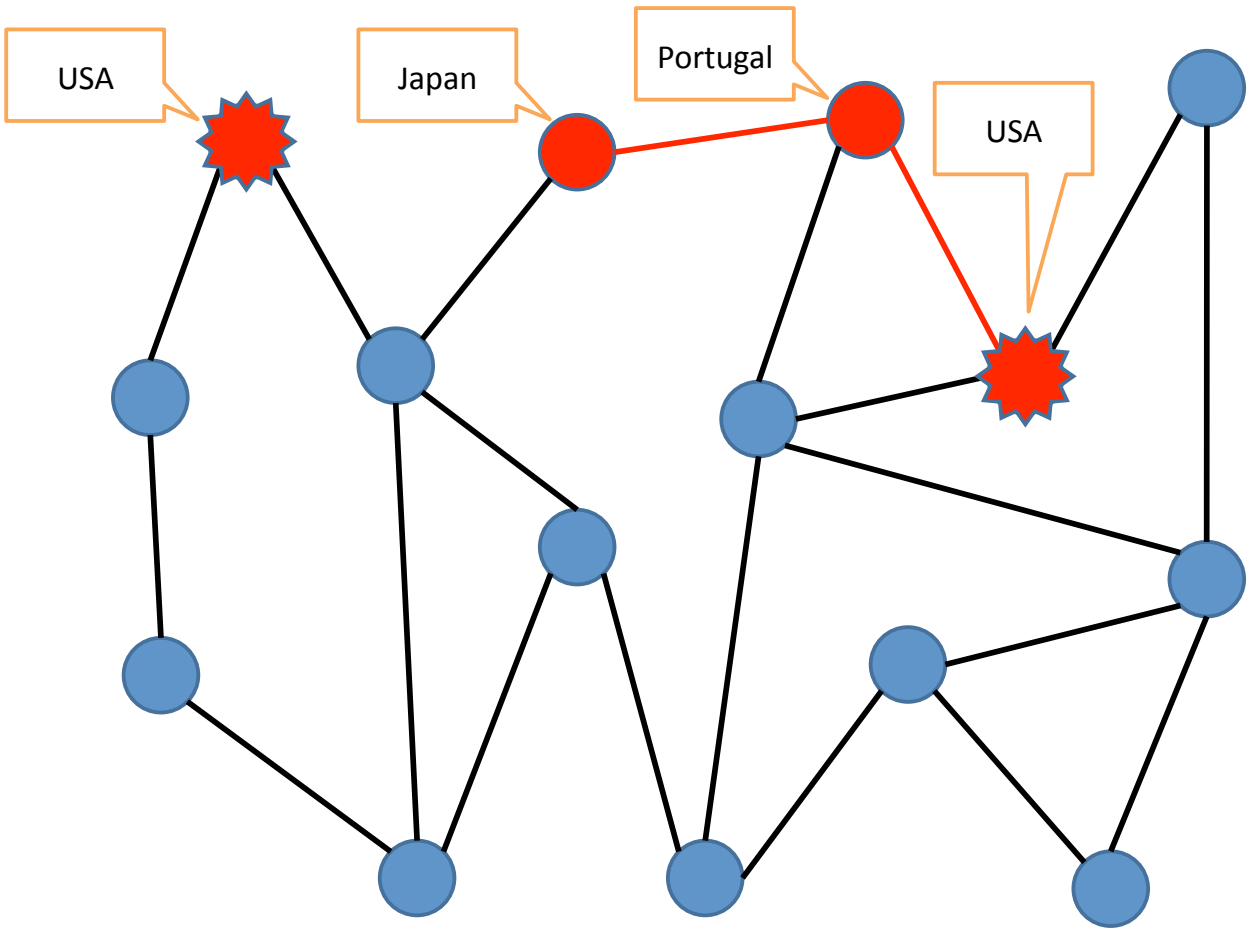

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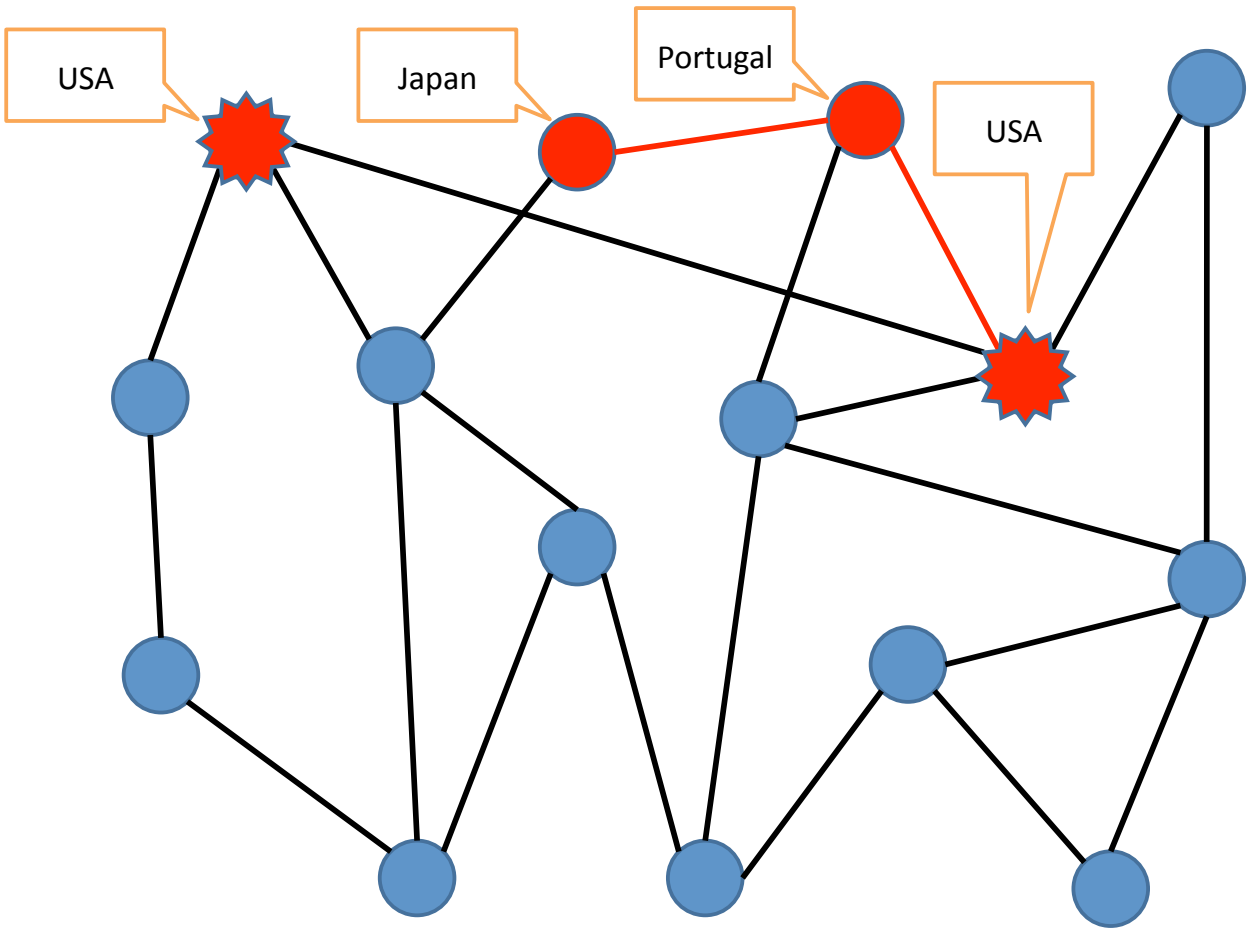

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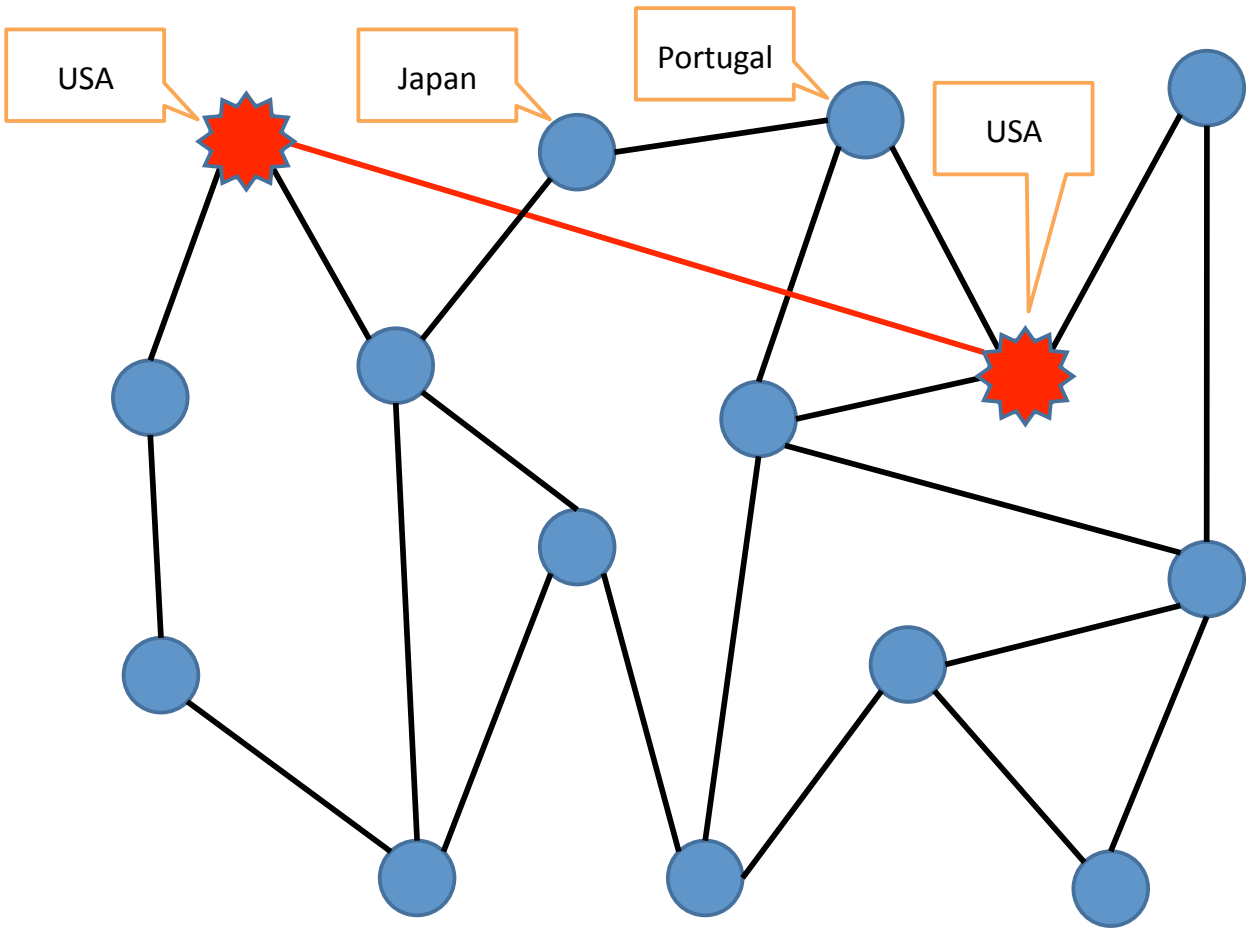
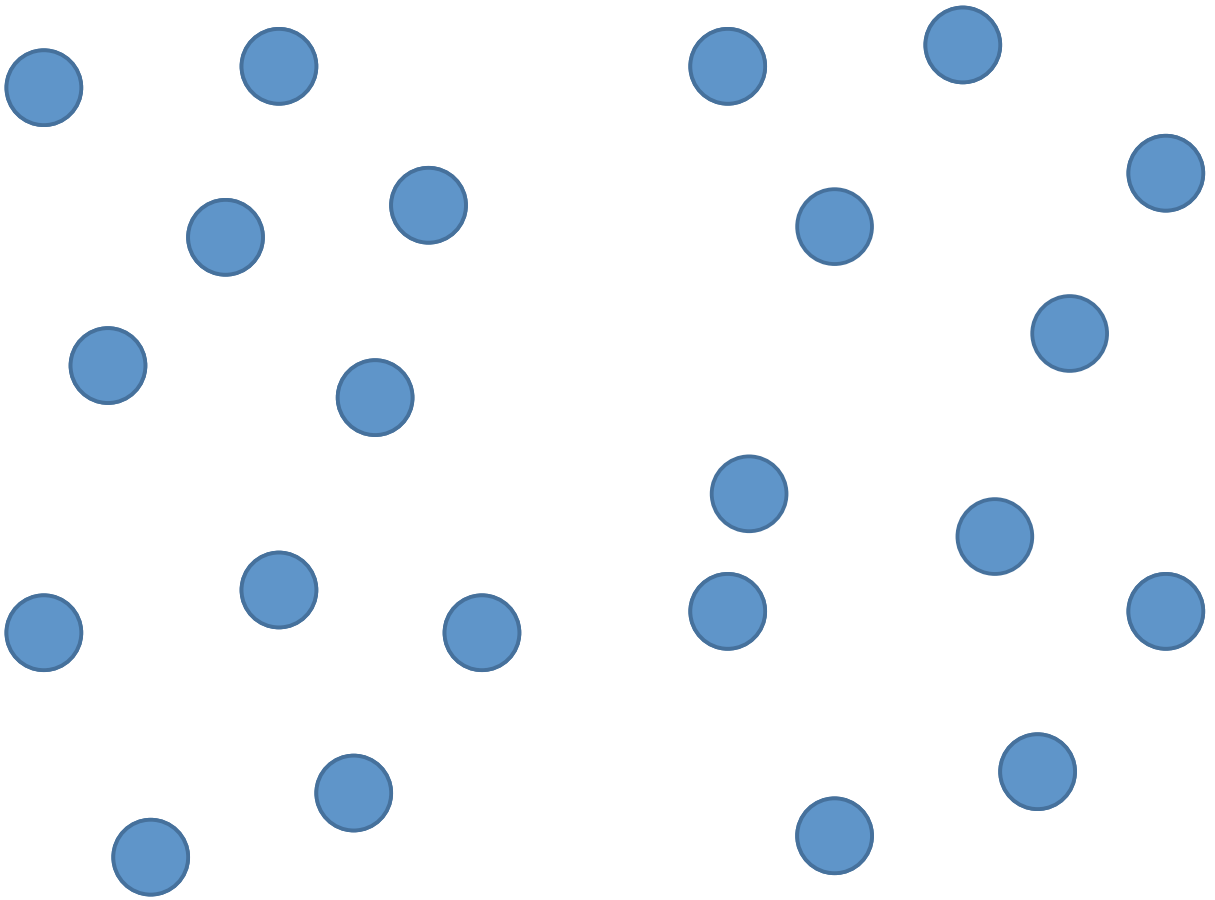


X-BOT
Intuition

However doing this may compromise some key properties of the unstructured overlay:

- Low clustering coefficient & Overlay diameter.
- Constant node degree & Connectivity.

X-BOT
Intuition



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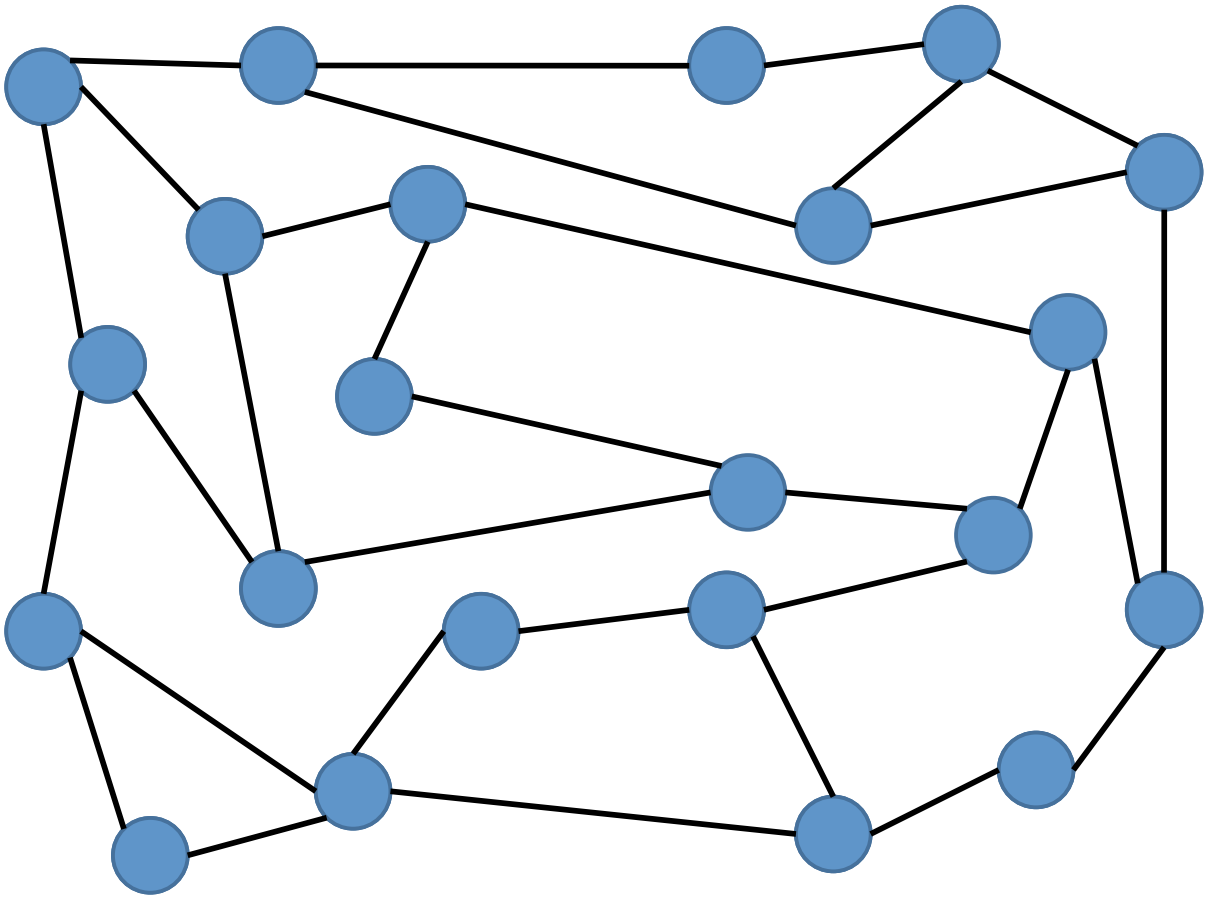

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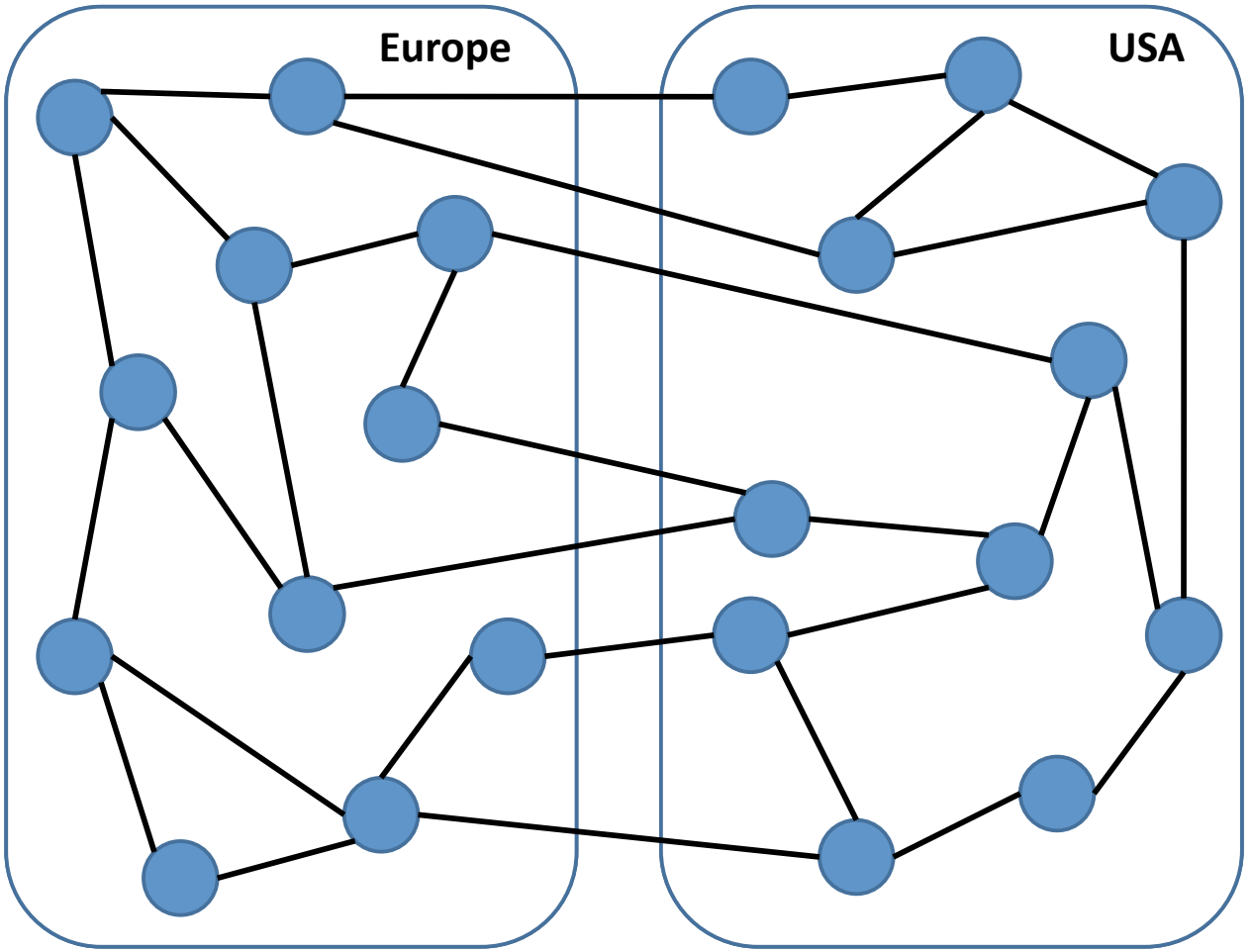

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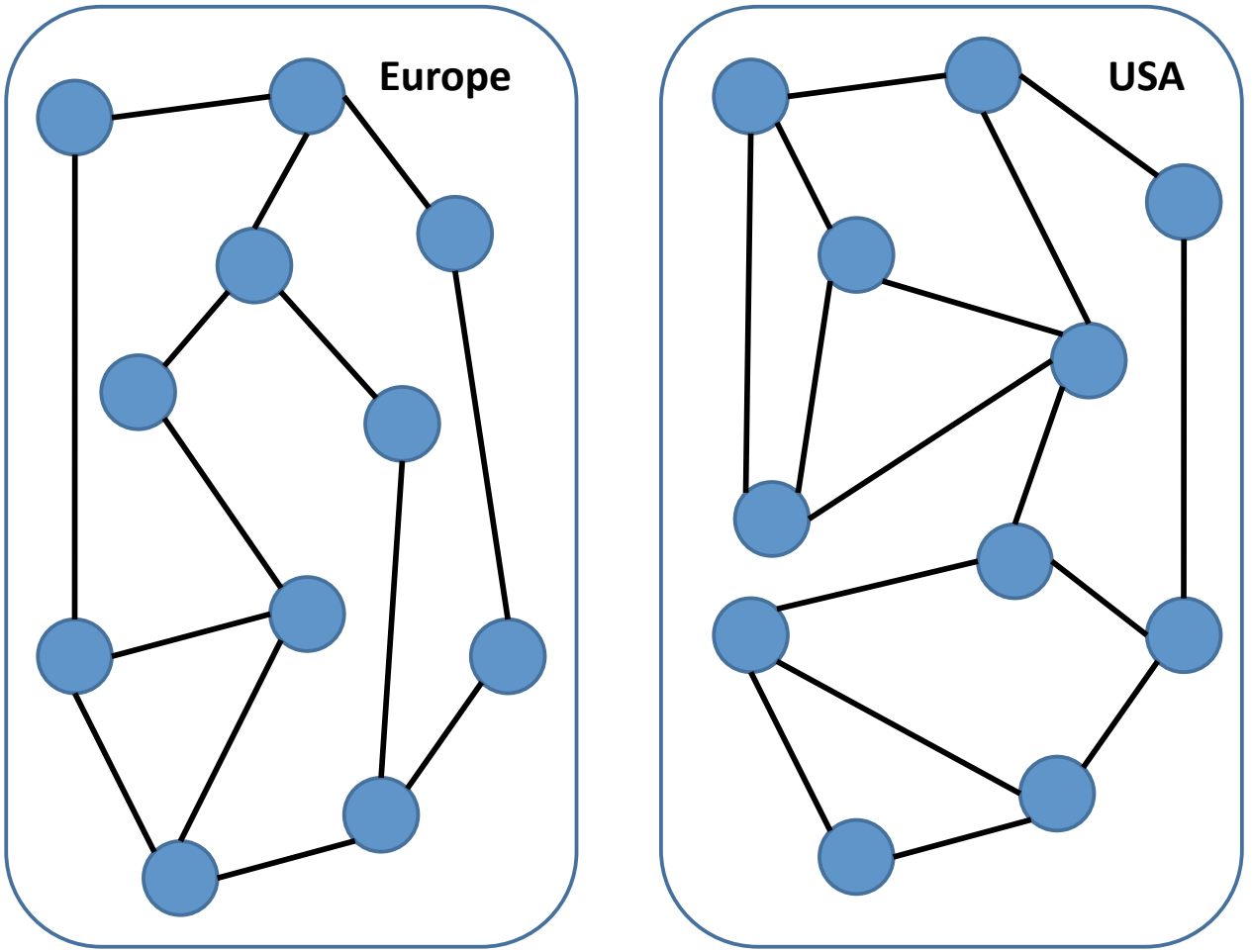

X-BOT
Solution Overview

Bias Technique:

- Operates at the overlay network layer.
- Allows node to interactively replace existing overlay links by new and *better* overlay links to other neighbors:
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  - trying to avoid to disrupt the relevant properties of the original unstructured overlay.

Case study:

Gossip-based application-level broadcast application.

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4-node coordination technique:

- 4 nodes coordinate among themselves to replace 2 existing overlay links by two new and *better* links.
- Maintains node degree.
- Helps to protect overlay connectivity.

Highly flexible:

- Relies on a companion *Oracle*.
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X-BOT
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- Each node maintains a set of unbiased links to avoid compromising the overlay connectivity.
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X-BOT
Main Results: Overlay Cost

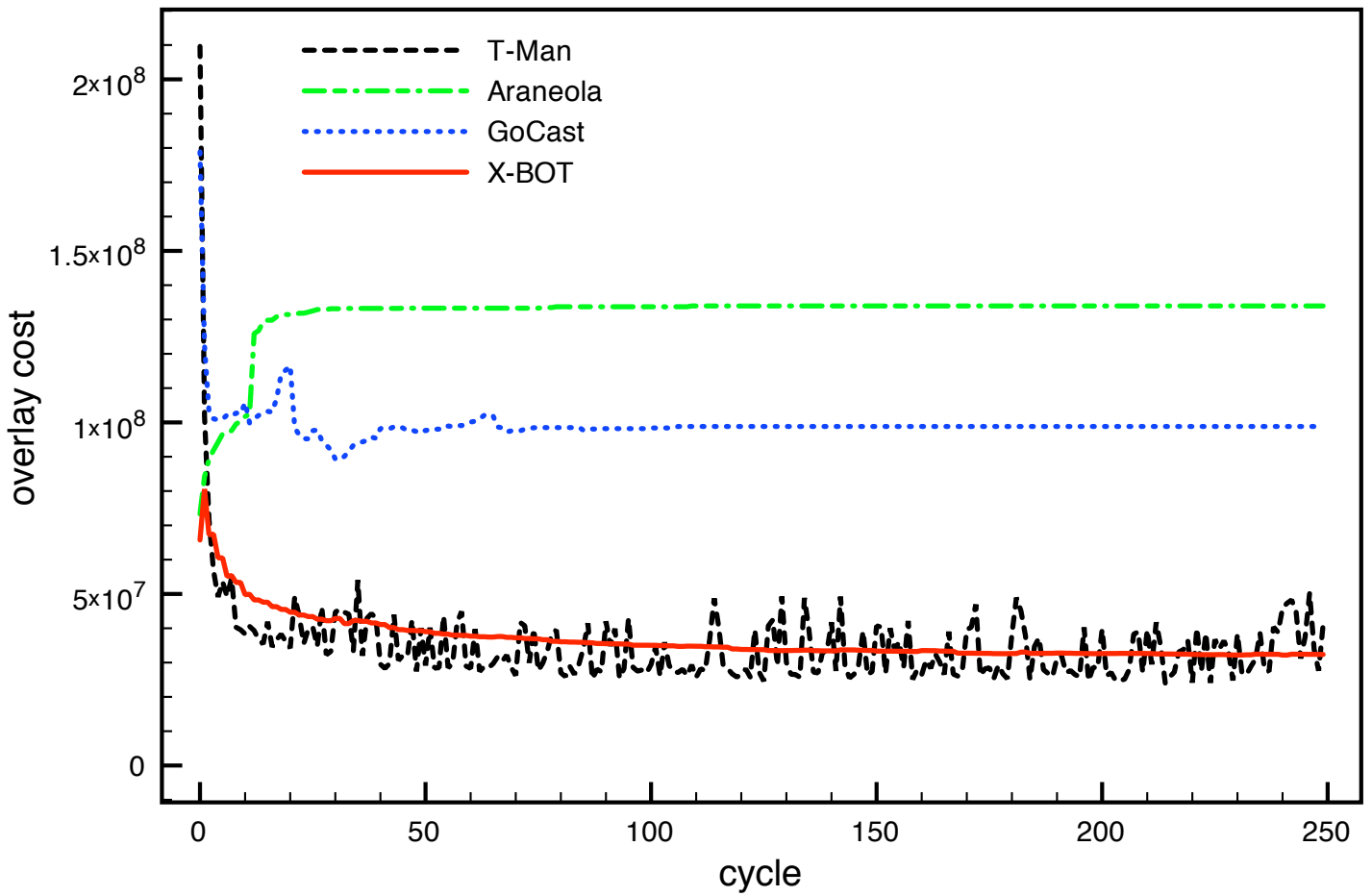

Figure : Overlay cost in Inet-3.0 scenario.

X-BOT
Main Results: Broadcast Latency

	Inet-3.0 Scenario	
	Latency (ms)	Reliability (%)
Araneola	3517.0	100.00000
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- X-BOT, based on the bias technique operating at the overlay network layer.
- Bias technique allows to achieve improved overlay topologies that can better match the requirements of services executing on top of them.
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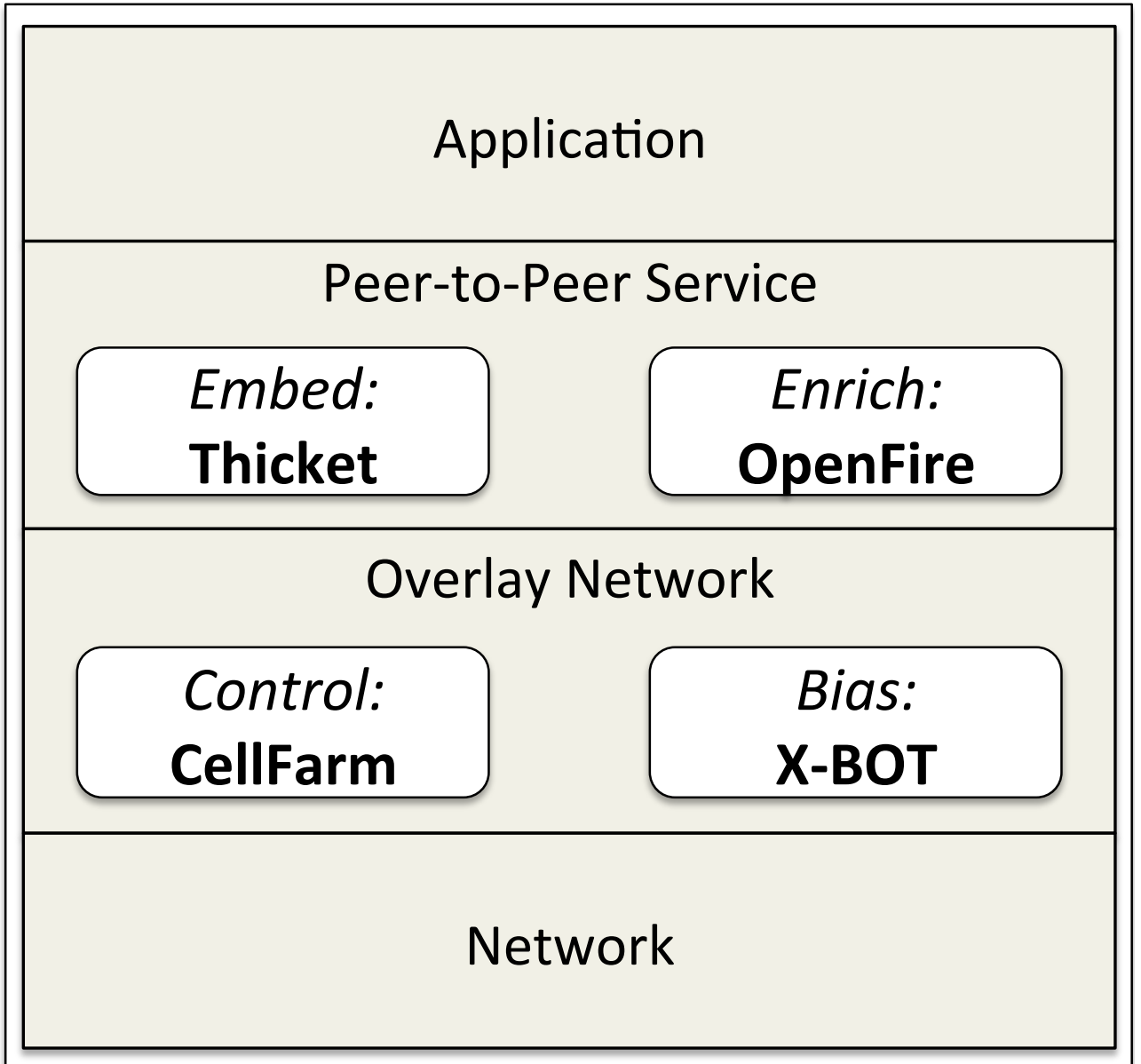

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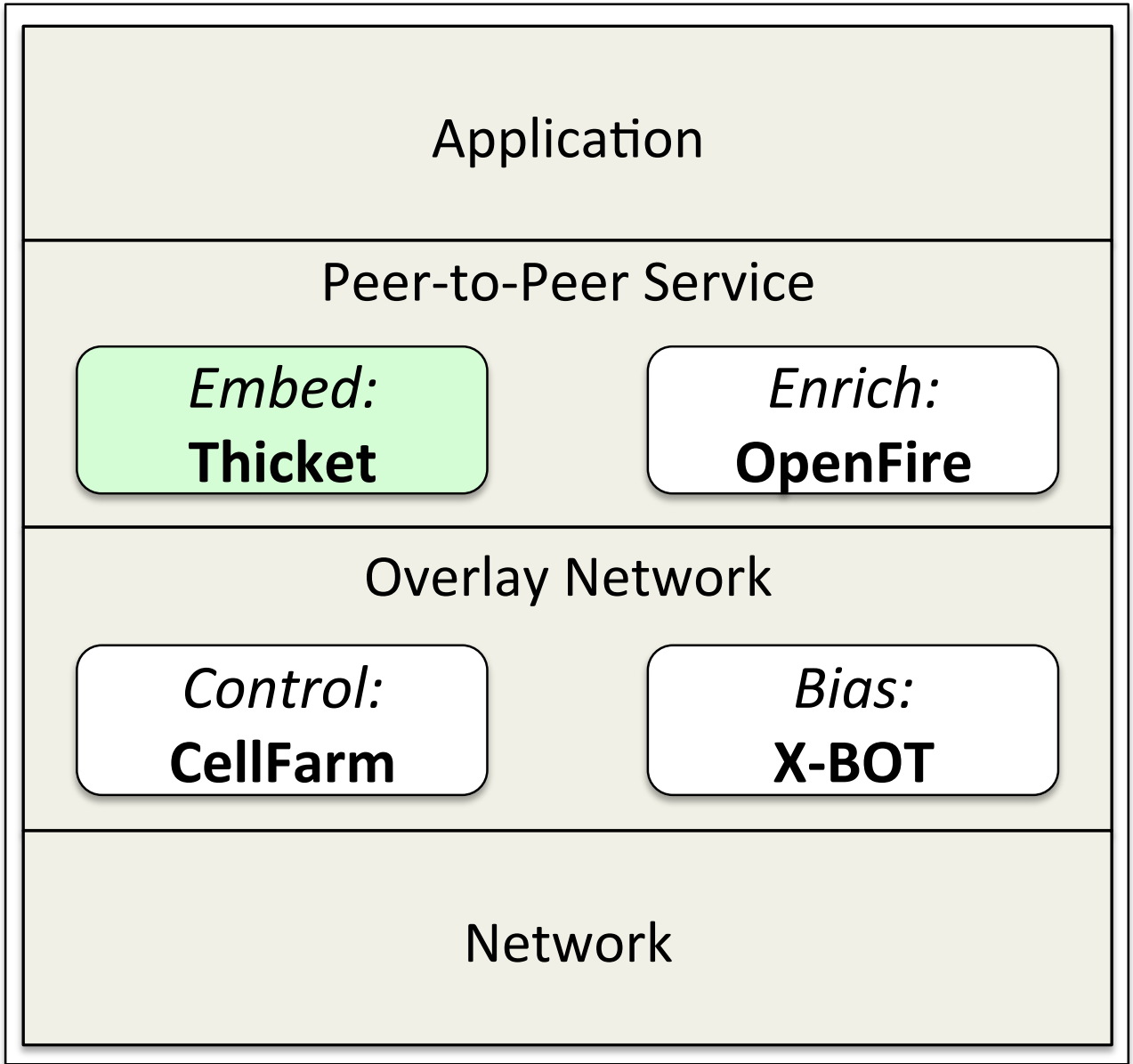

Thicket
Motivation

- P2P-based approaches to support efficient, scalable, and robust data dissemination:
  - Gossip-based approaches.
  - Tree-based approaches.

Gossip-based approaches:

- Very Robust.
- Simple to implement.
- Excessive communication overhead (due to the intrinsic redundancy of gossip).

Tree-based approaches:

- Low communication overhead.
- Complex to build and maintain the topology.
- A single node failure can disrupt a large fraction of the system.

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Plumtree protocol.

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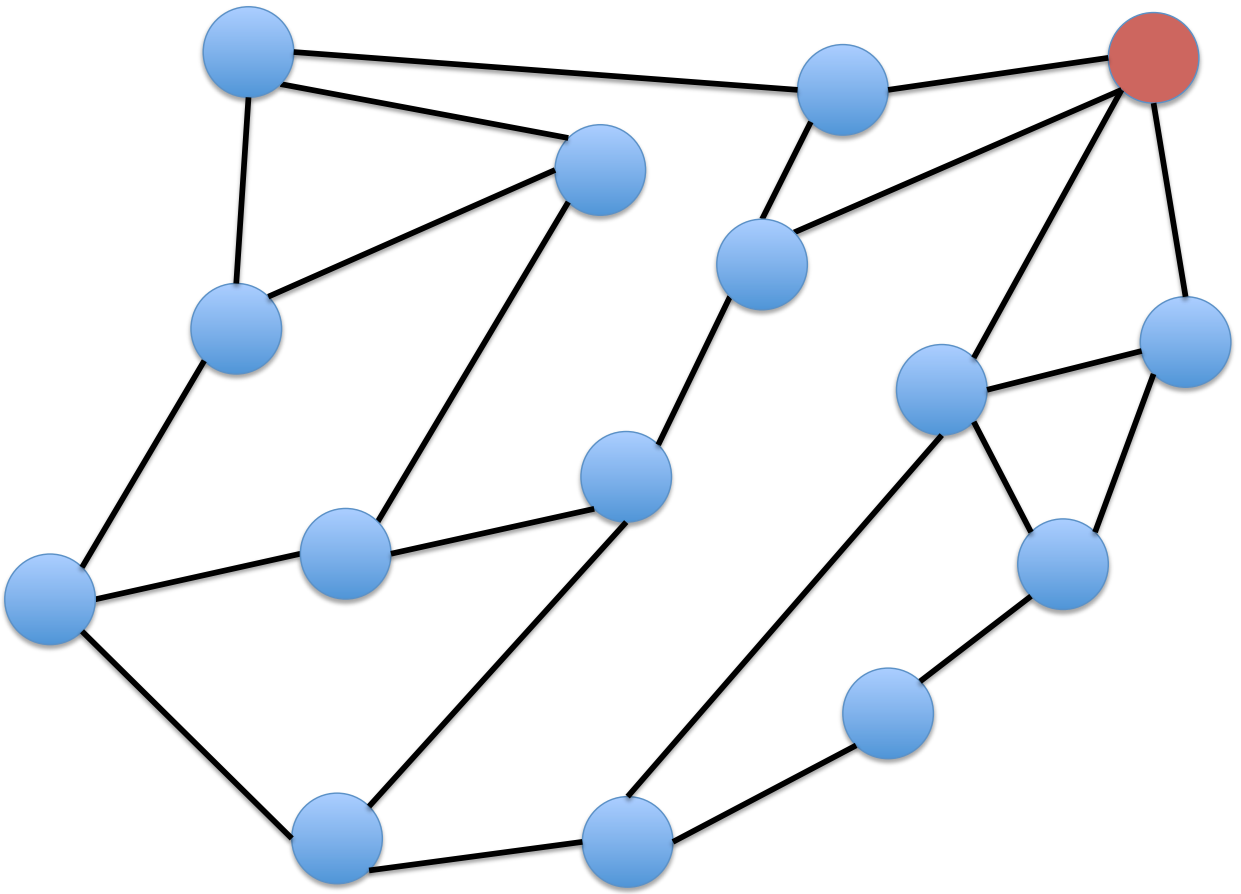

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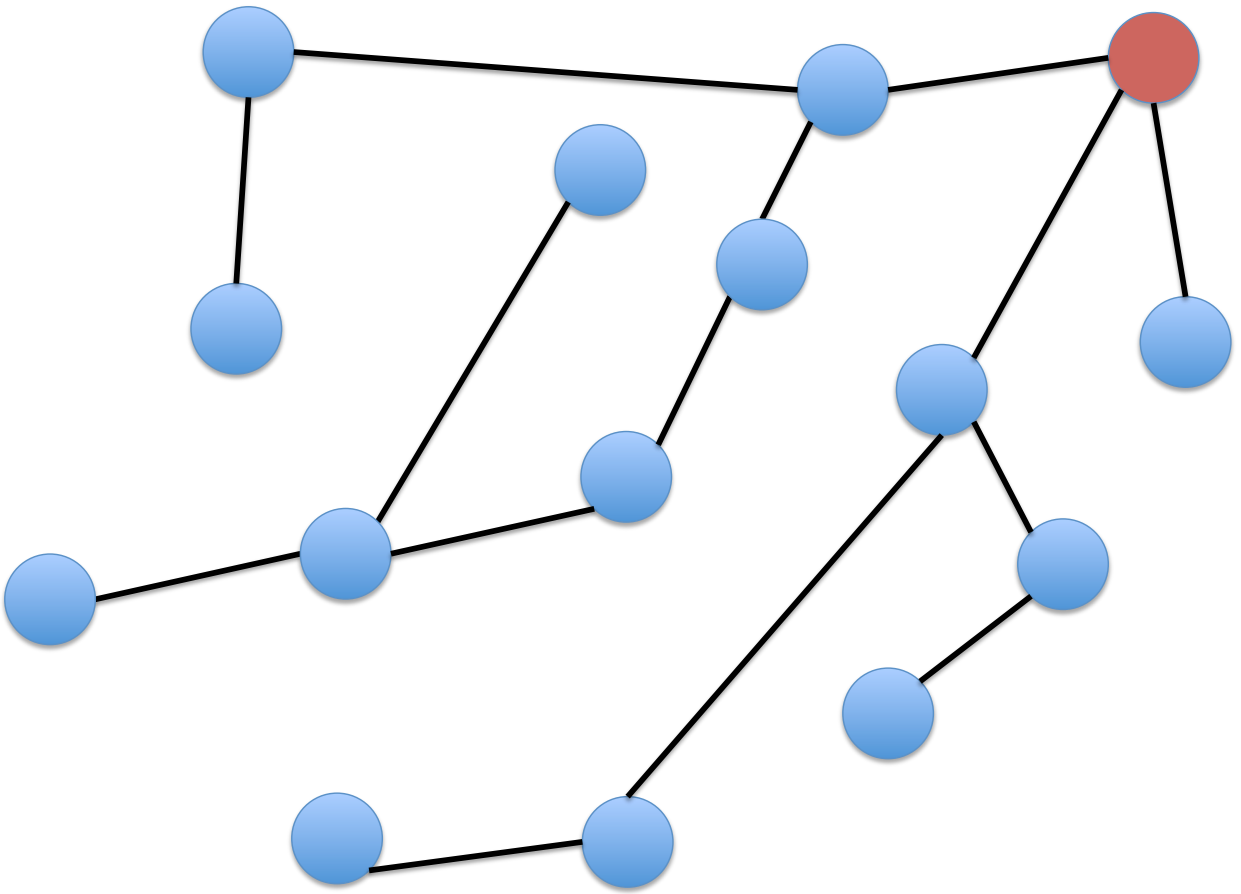

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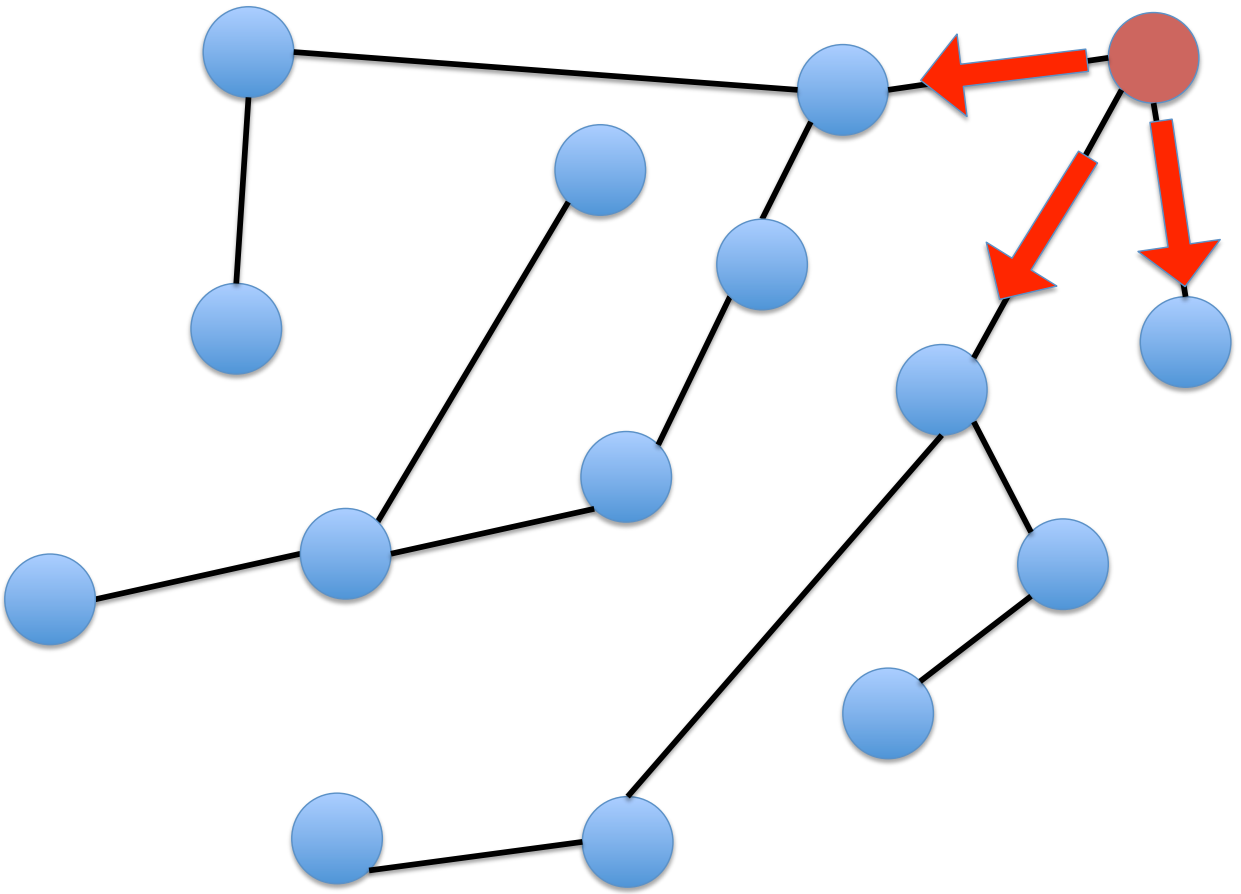

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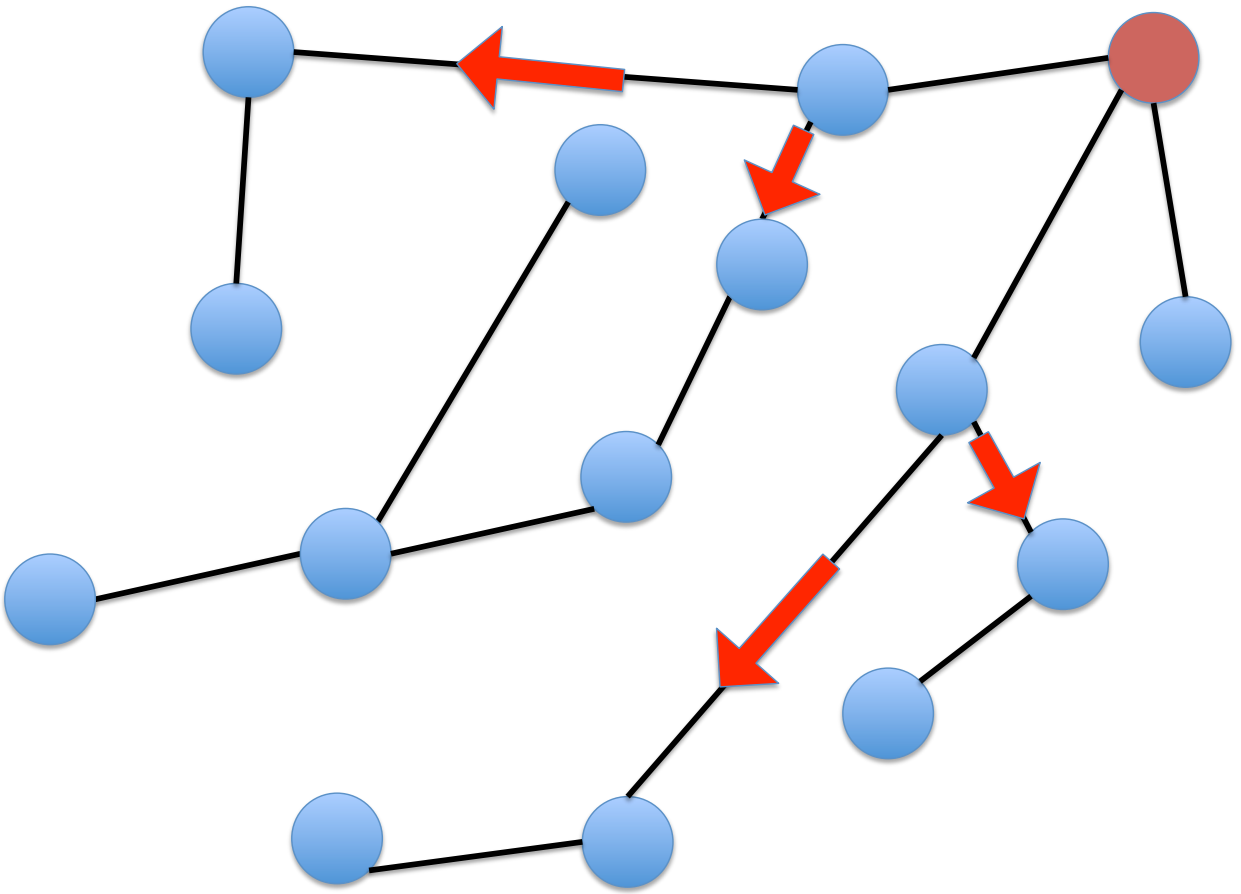

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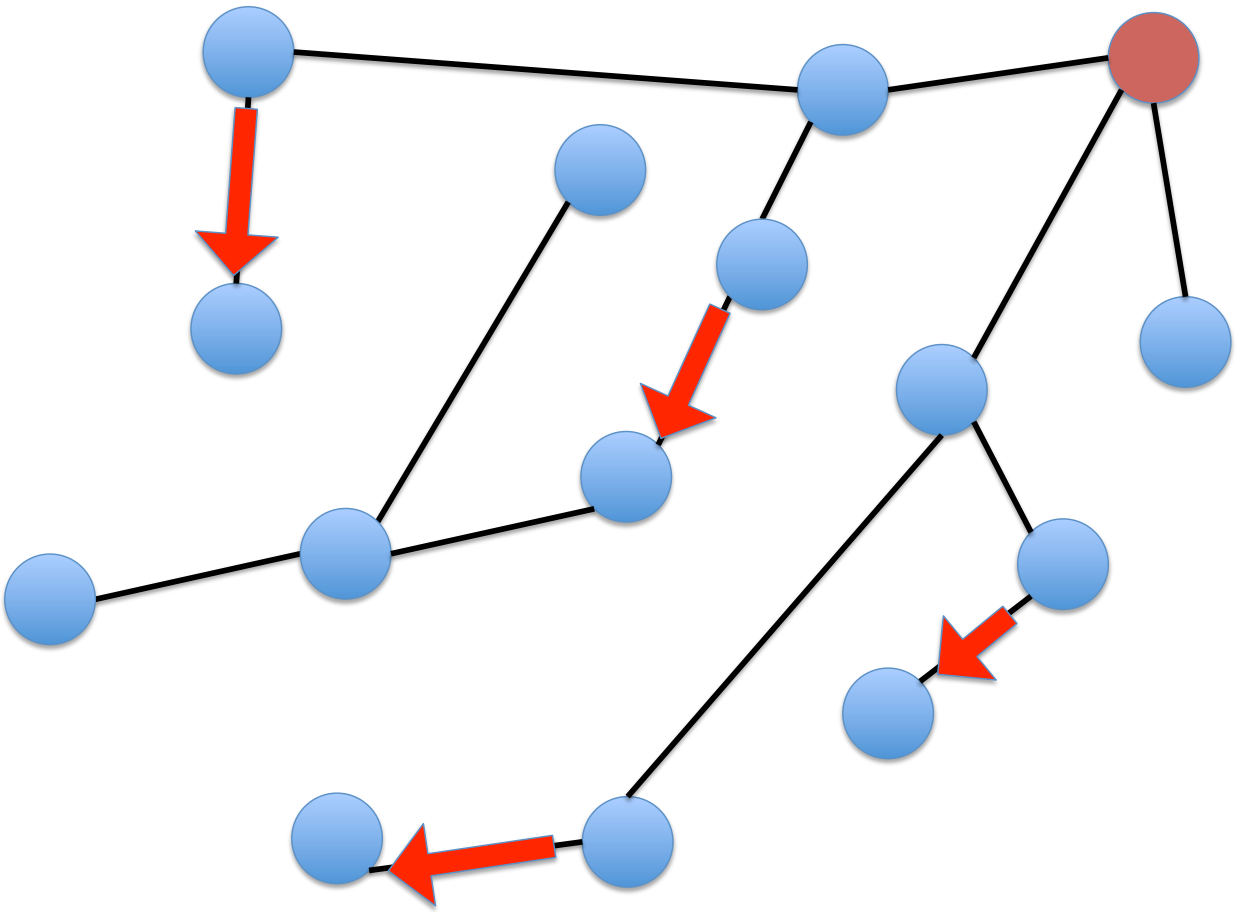

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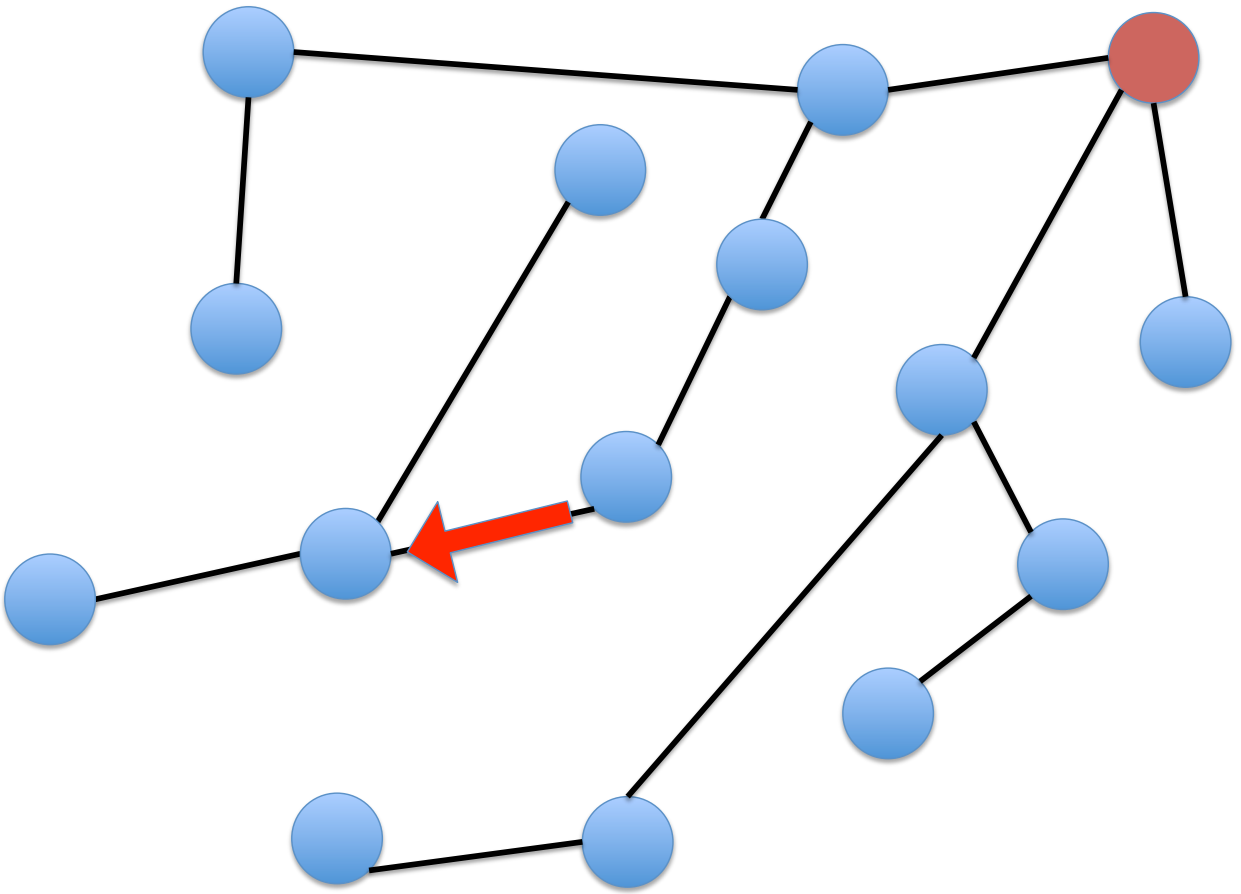

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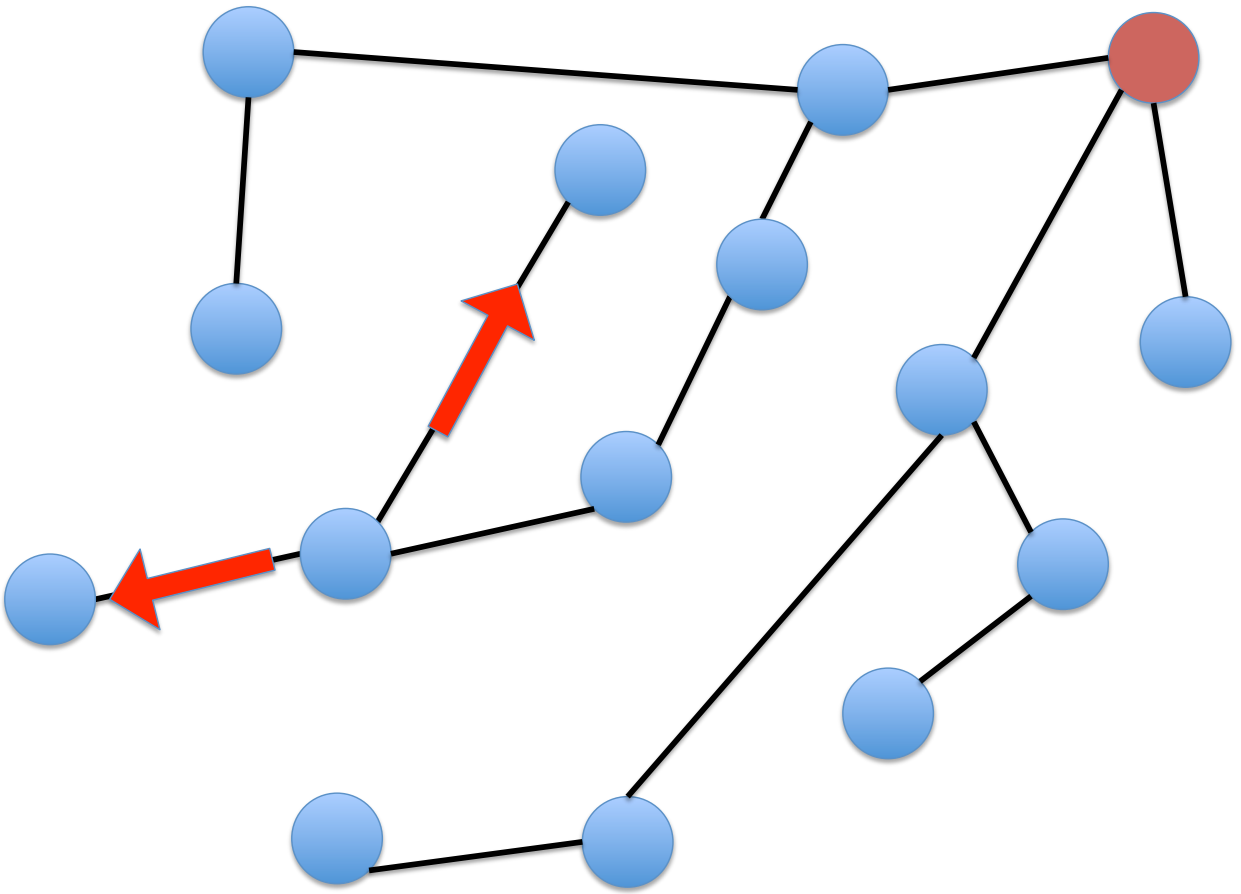

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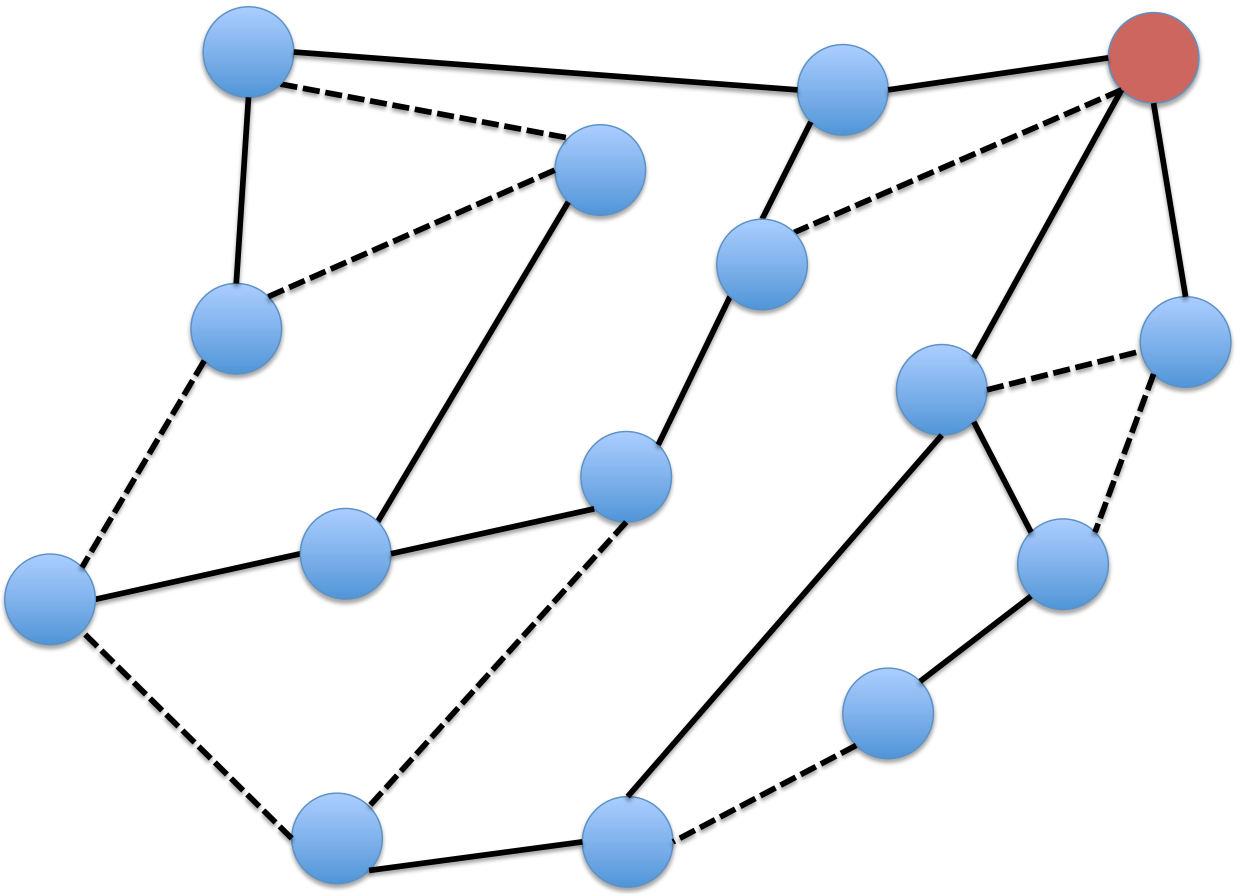

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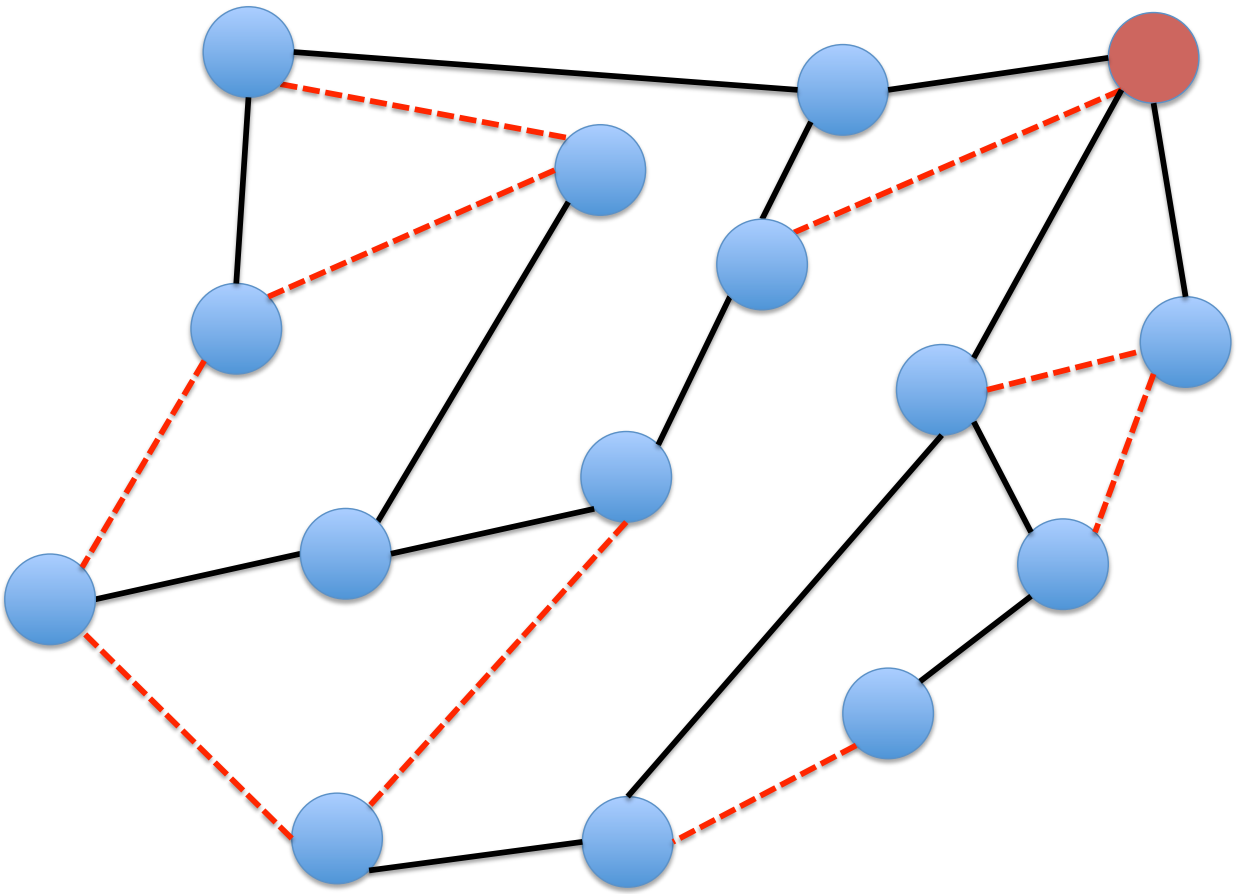

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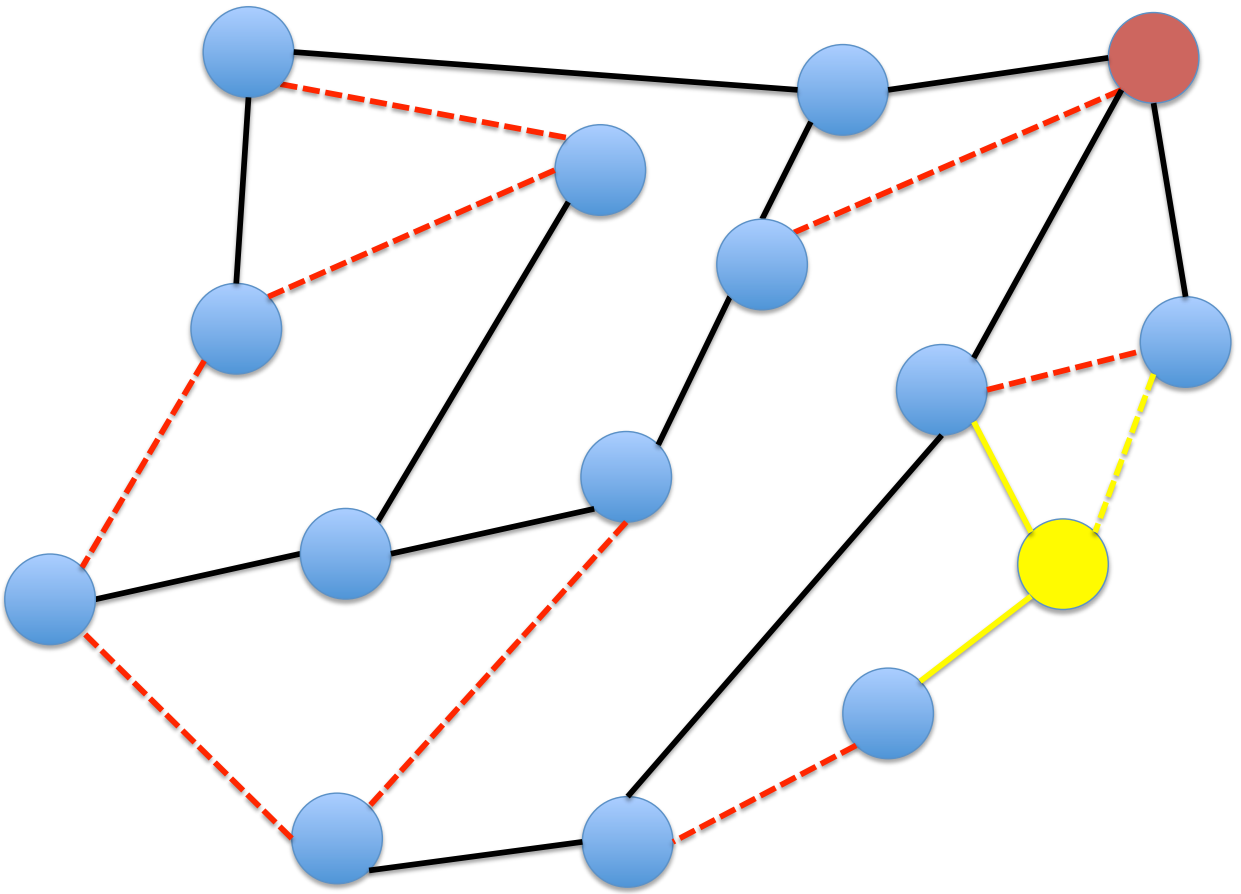

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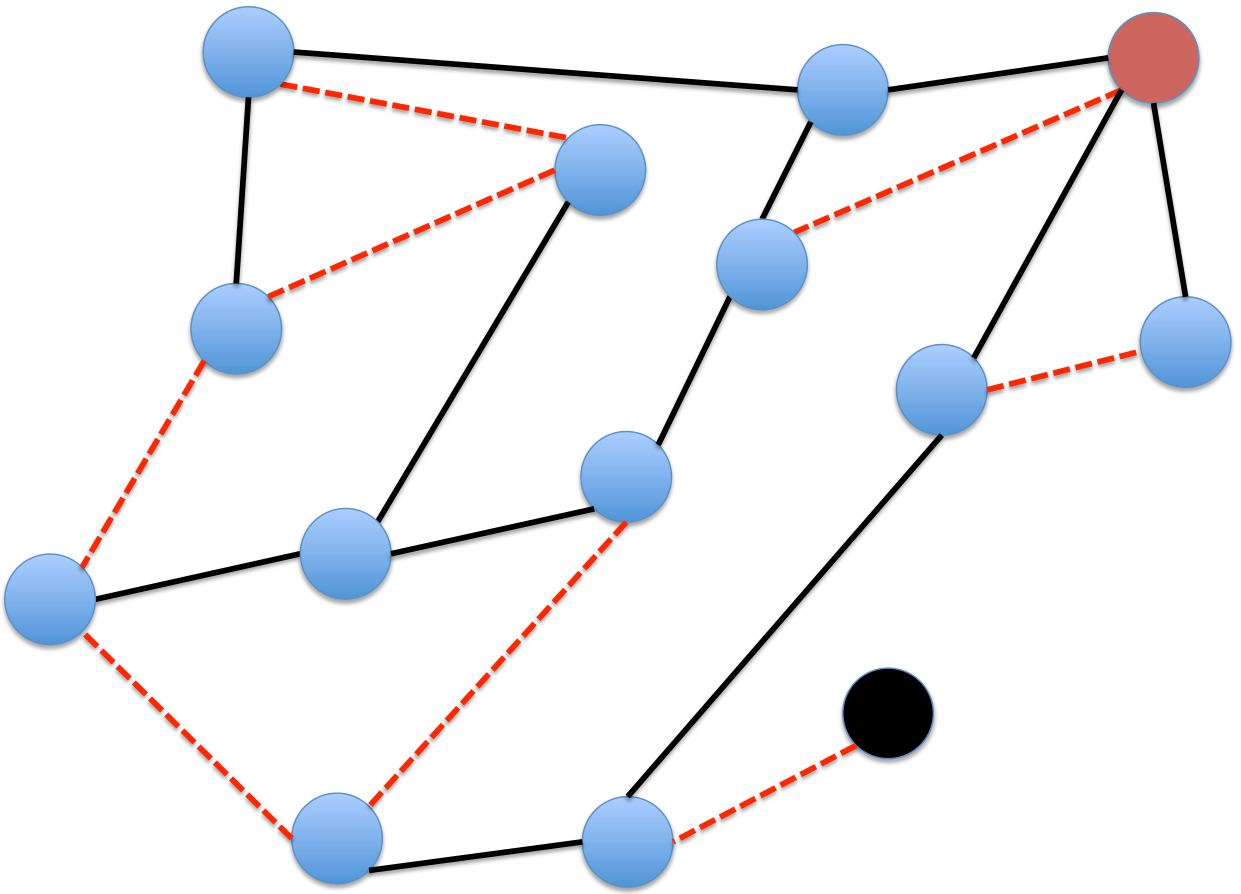

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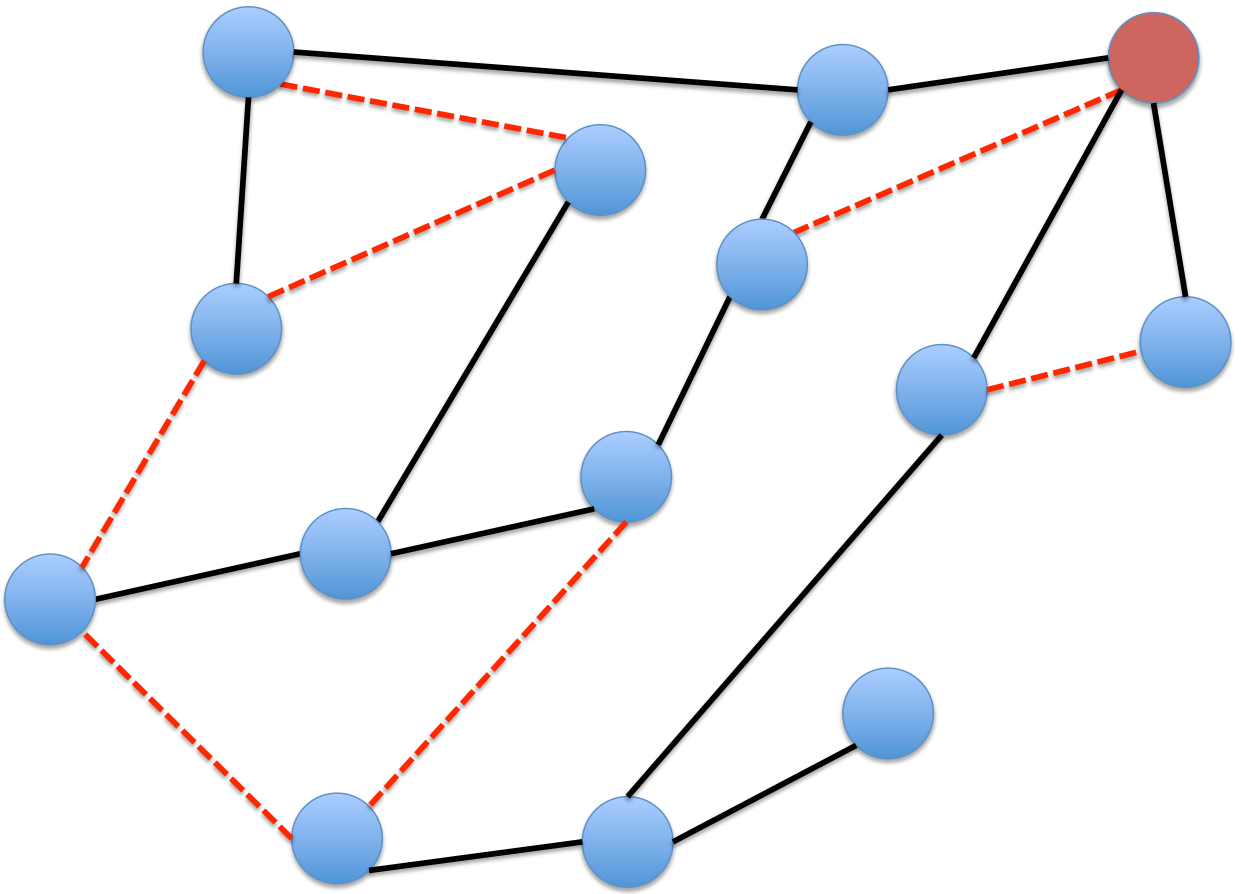

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Plumtree:

- Combines gossip-based and tree-based solutions by embedding a spanning tree on top of a low-cost unstructured overlay network.
- Efficient (from the point of view of communication overhead).
- Robust to node failures.

However...

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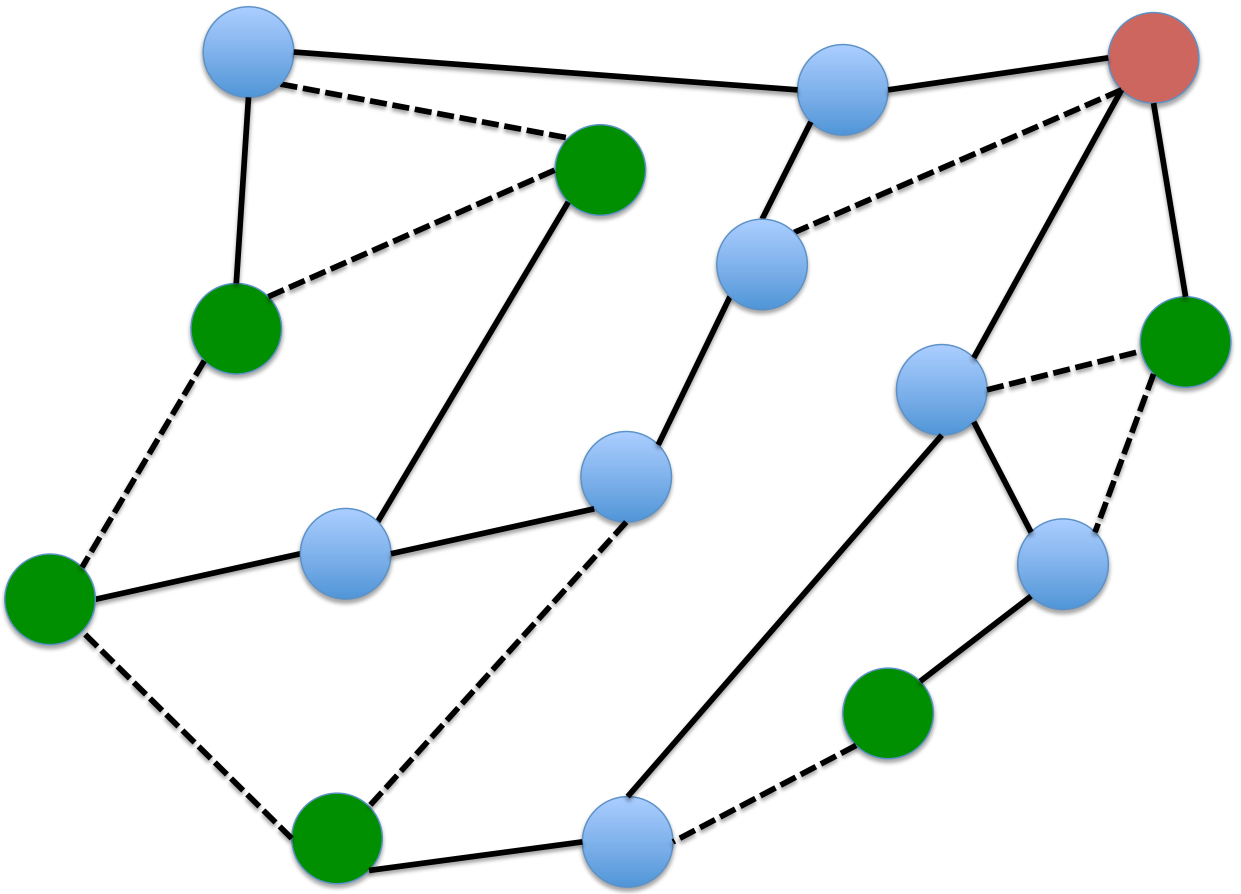

Thicket
Solution Overview

Embed Technique:

- Operates at the peer-to-peer service layer.
- Use feedback from the operation of a P2P service to use overlay links with different properties for distinct purposes:
  - use a subset of available overlay links to establish spanning trees.
  - remaining links are used to convey control information to support tree recovery and reconfiguration.

Case Study:

Gossip-based streaming application.

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- Embed several spanning trees over a single unstructured overlay:
  - most nodes are interior in a single tree.
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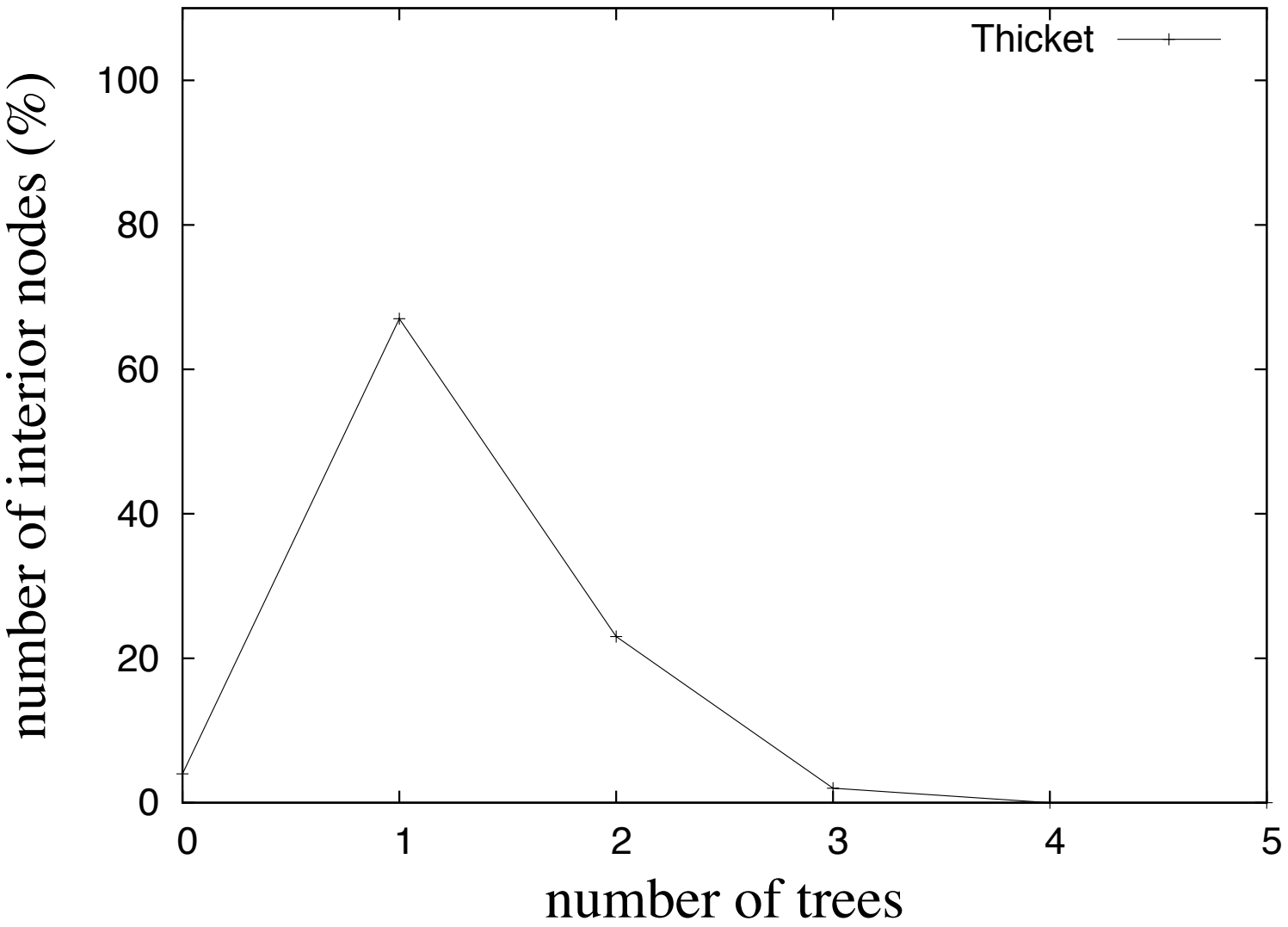

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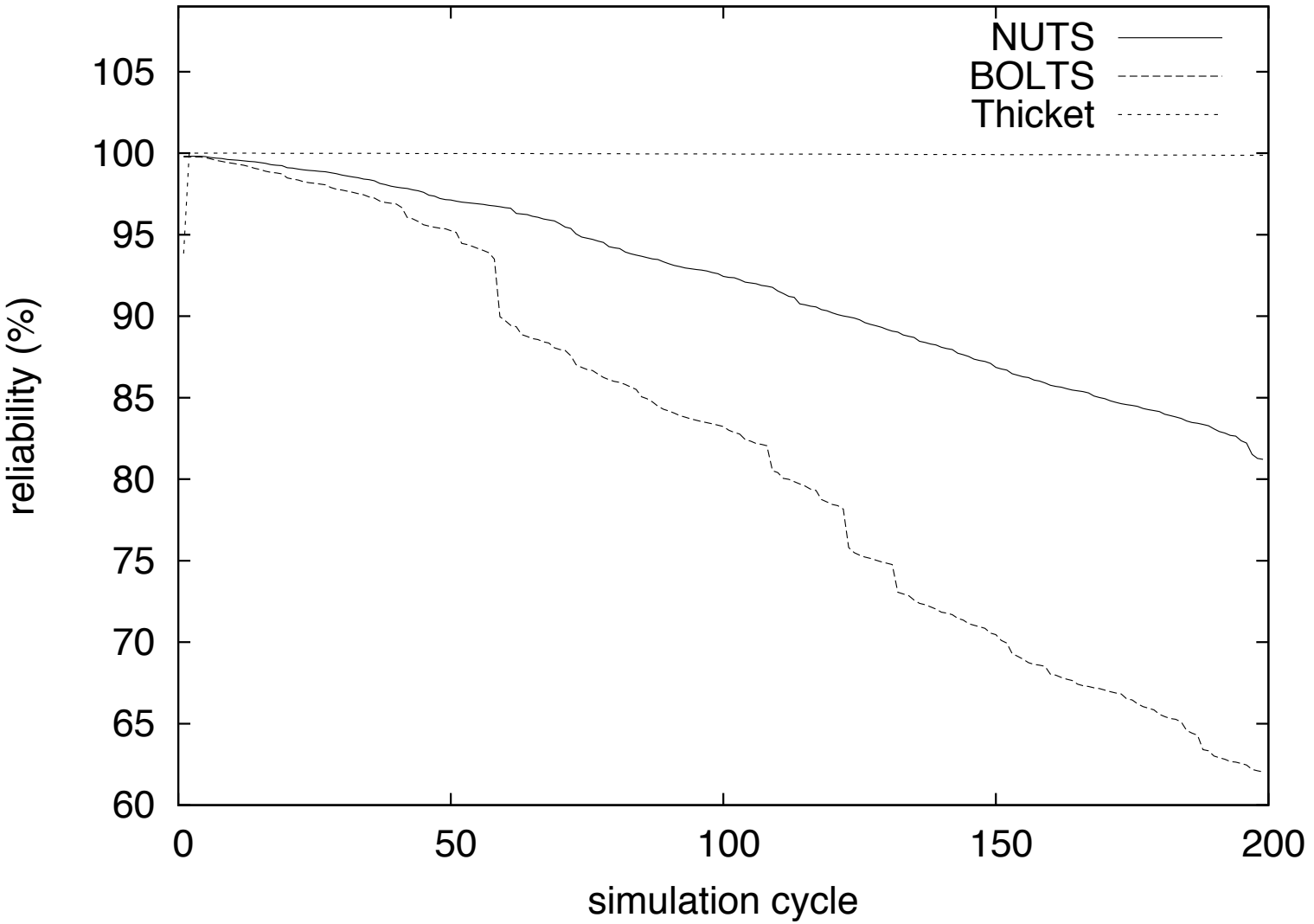
Main Results: Streaming service robustness in face of targeted node failures



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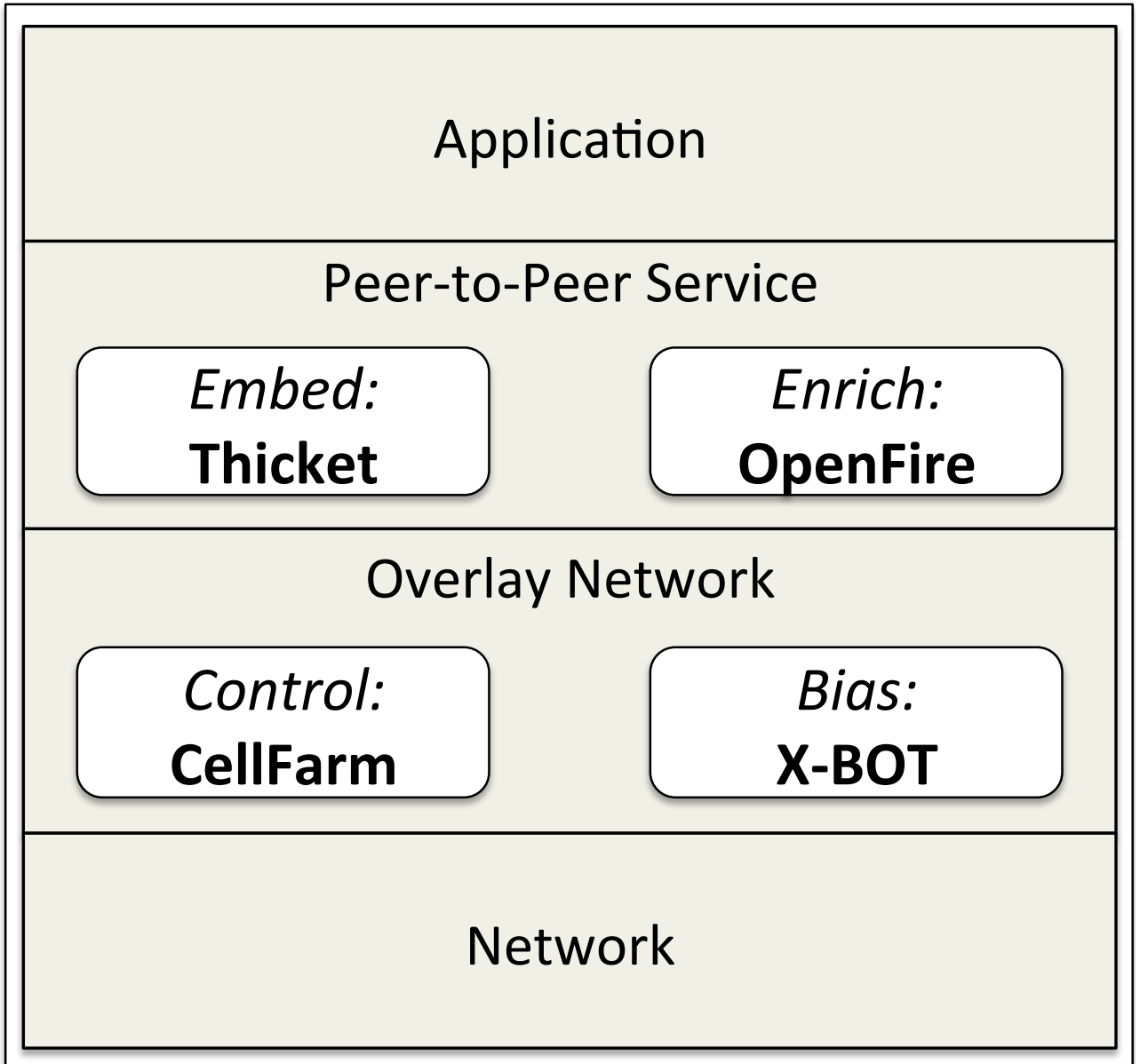

Roadmap

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- João P. Marques, INESC-ID/IST, Portugal.
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Final Remarks

My point:

Designing large-scale distributed protocols is a complex task. However it can be highly simplified by relying on overlay networks that deal with some of the inherent complexity of the environment.

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- The applicability of these solutions will be studied in the near future in the context of the European Project: *CloudSpaces: Open Service Platform for the Next Generation of Personal Clouds*.
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Thanks for your attention.

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(On December 2012 search in the website of the Eurecom Institute on Sophia Antipolis, France)