MAKING NETWORKS ROBUST TO COMPONENT FAILURE

A Dissertation Outline presented by Daniel Gyllstrom
University of Massachusetts Amherst USA
Advisor: Jim Kurose

2/8/13

Talk Outline

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- thesis introduction

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- describe 3 technical chapters

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- outline for future work and conclusions

Thesis Problem Statement

How can networks -- the Internet and networked cyber-physical systems -- be made more robust to component failure?

3 Component Failure Problems

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1. failure of critical power grid sensors

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2. link failures in a power grid communication network

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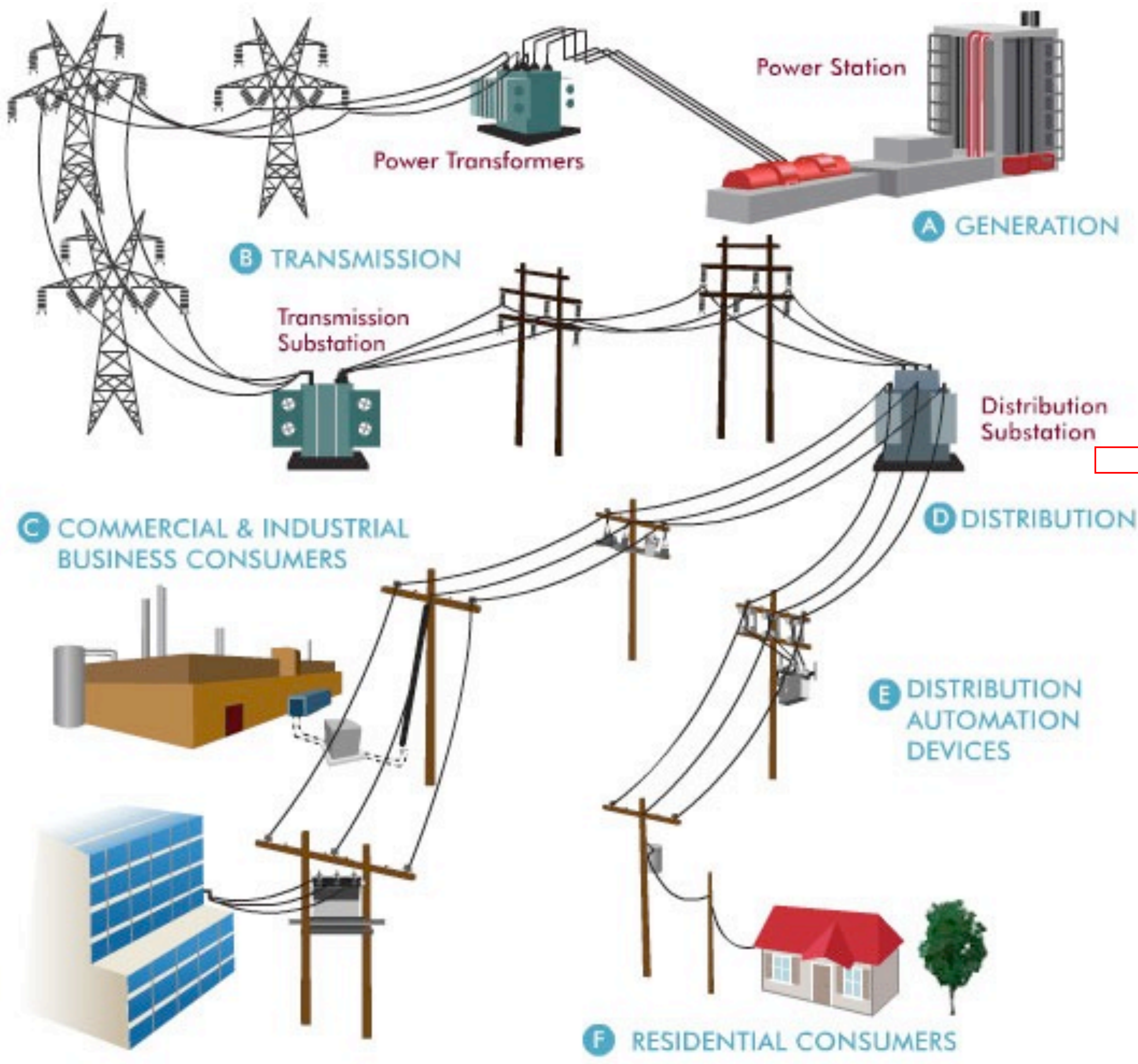
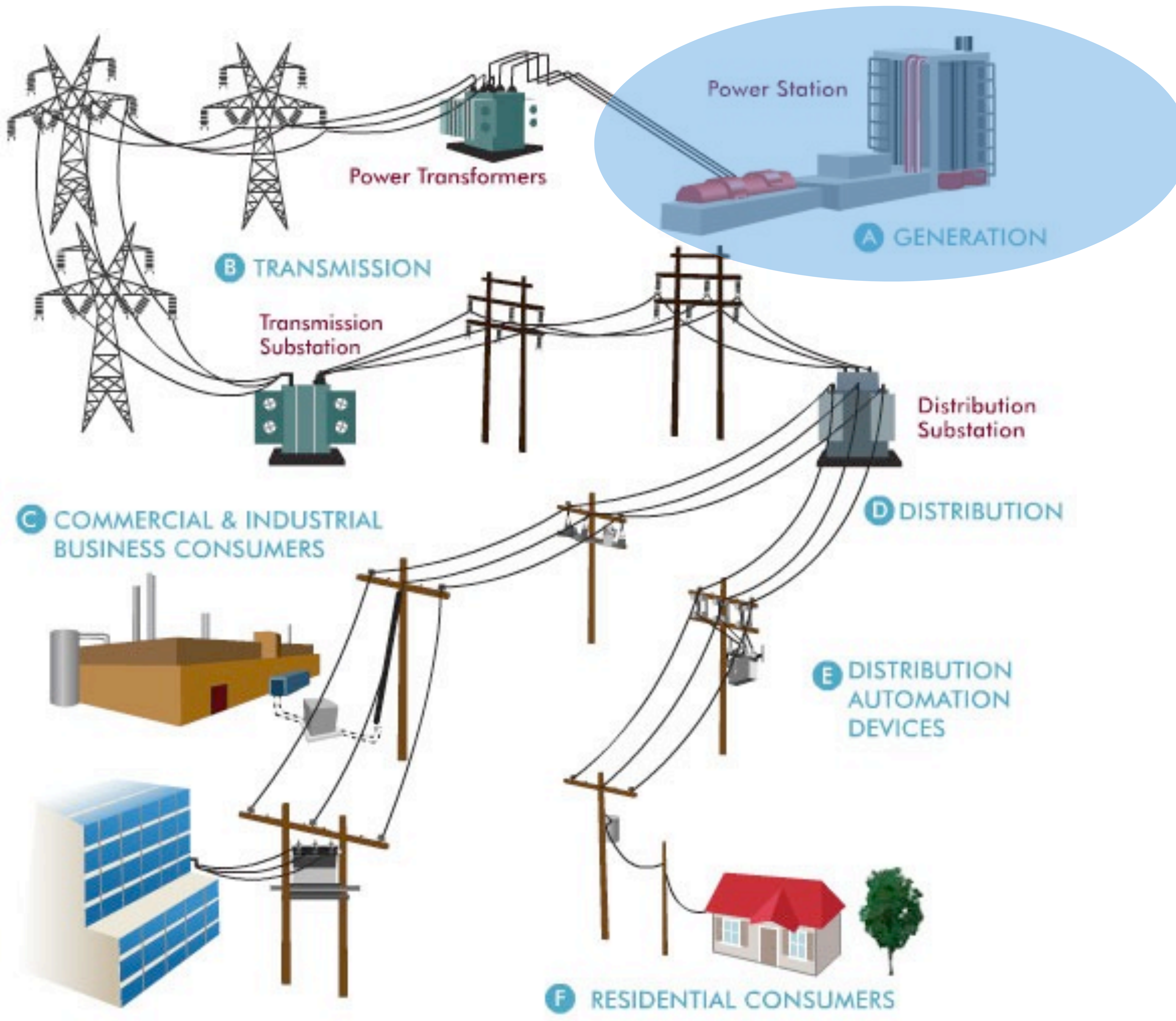
1. failure of critical power grid sensors
2. link failures in a power grid communication network
3. router failure in traditional communication networks

Power and Smart Grid Definition



THINK OF A BUS AS A NODE")

Power and Smart Grid Definition



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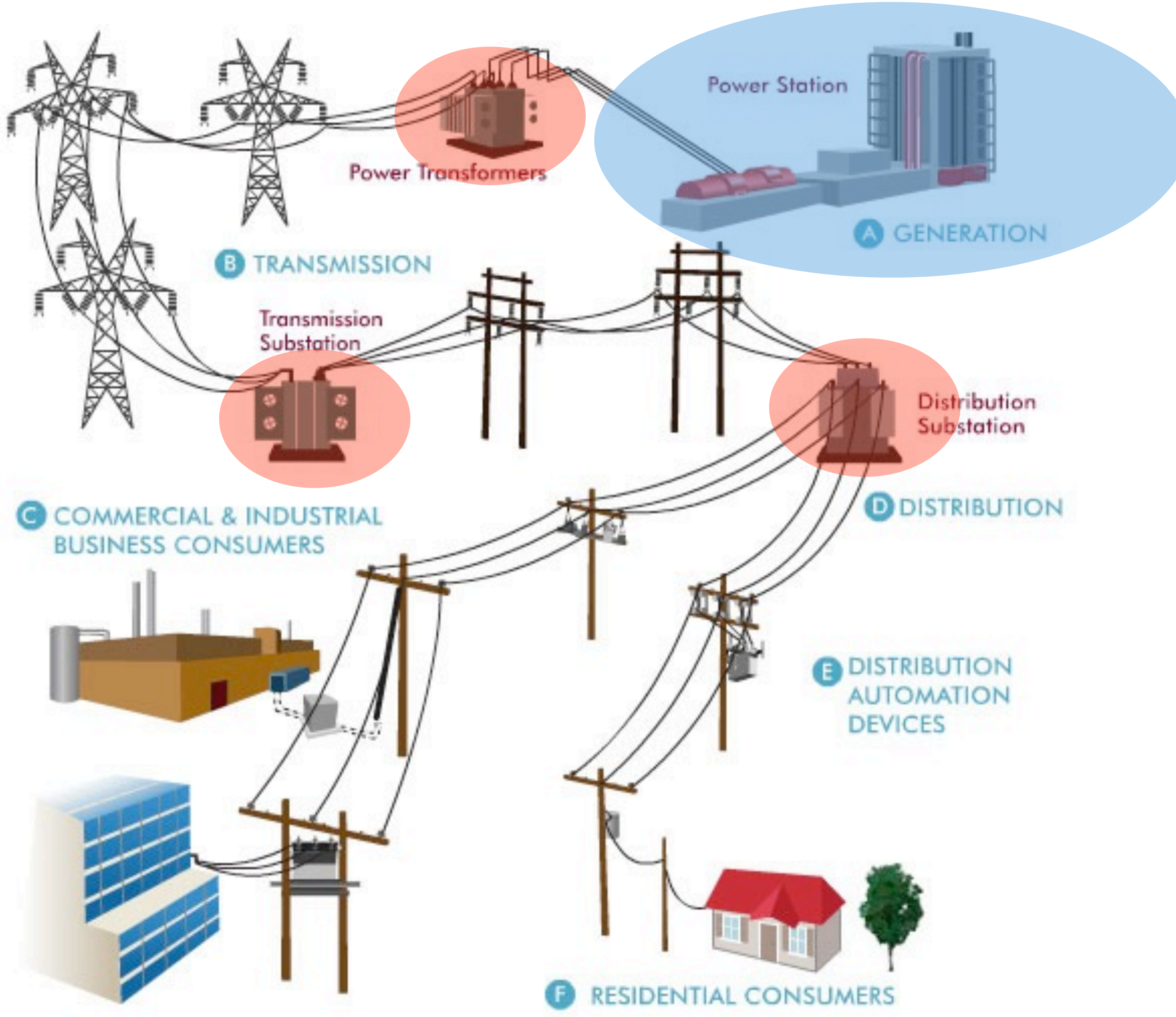

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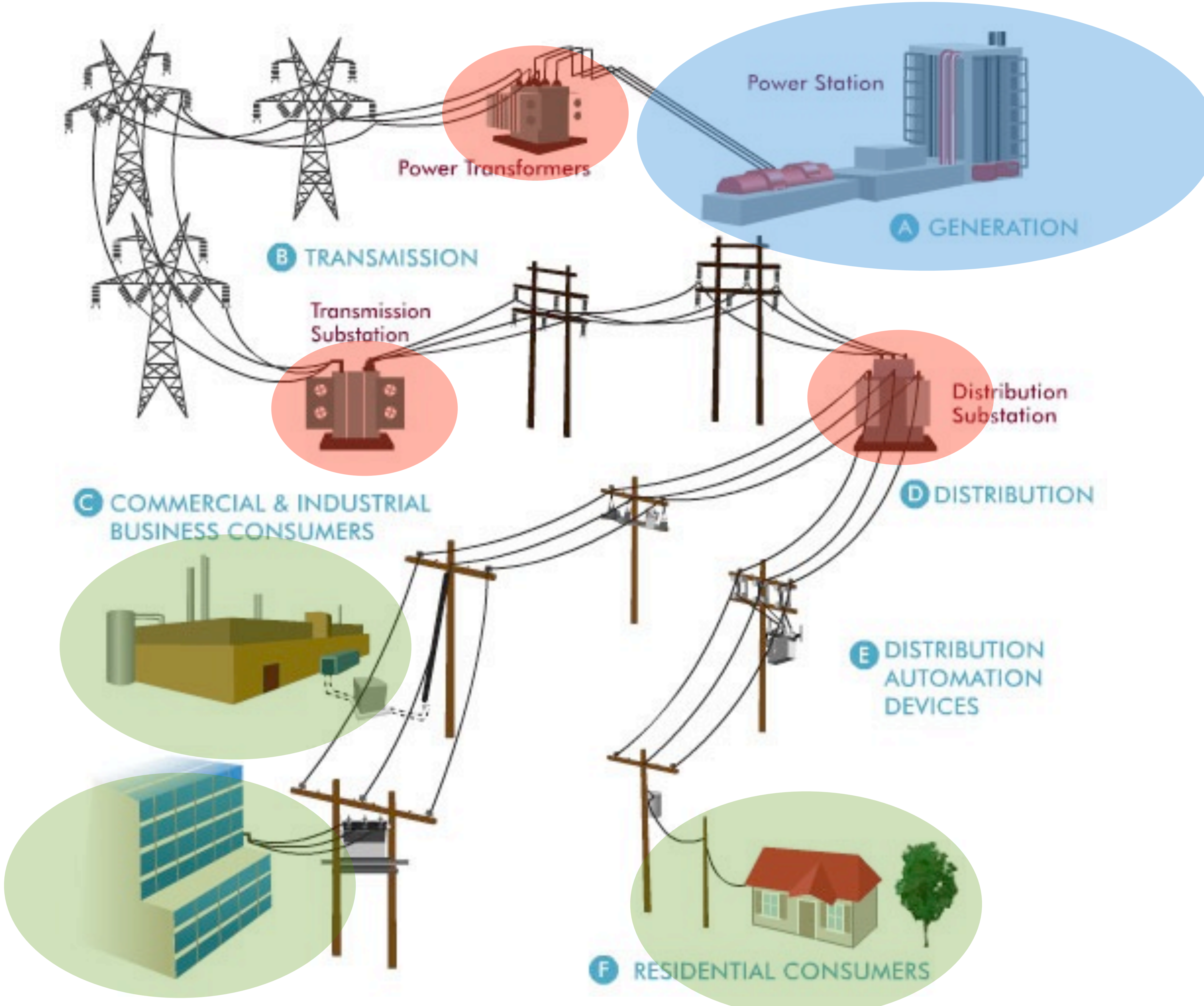

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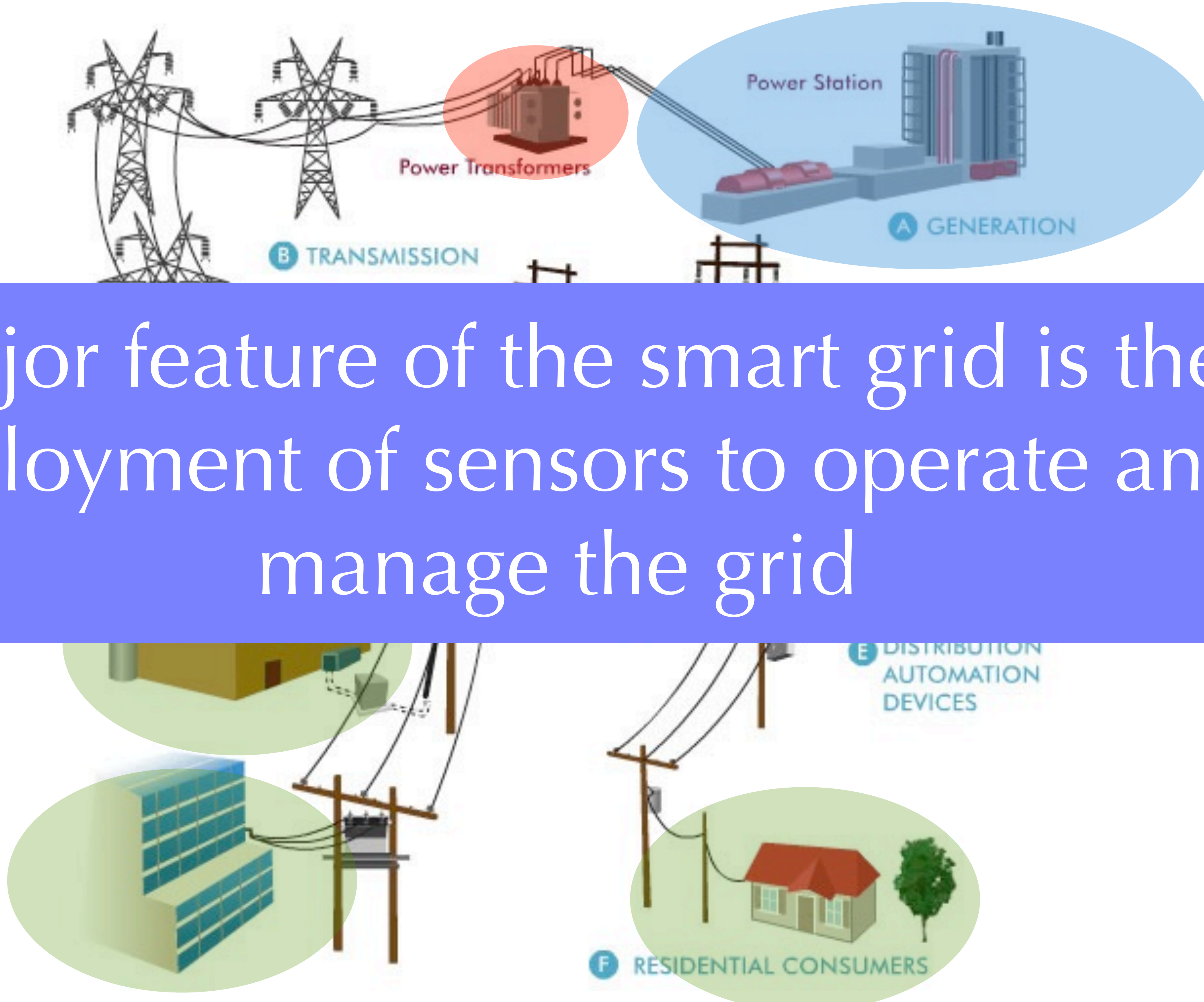

major feature of the smart grid is the deployment of sensors to operate and manage the grid

PMU: Smart Grid Sensor

- Phasor Measurement Unit (PMU)
- high frequency voltage and current measurements
  - measures the “pulse” of the power grid

Ch 1+2: Smart Grid Failures

placement and failure

- Ch 1: PMU sensor failure
- Ch 2: link failures in communication network used to disseminate PMU measurements

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- Ch 1: PMU sensor failure
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these failures can cause critical errors in smart grid applications used to operate the grid

theguardian

India blackouts leave 700 million without power

Power cuts plunge 20 of India's 28 states into darkness as energy suppliers fail to meet growing demand

Helen Pidd in Delhi
The Guardian, Tuesday 31 July 2012 10.48 EDT

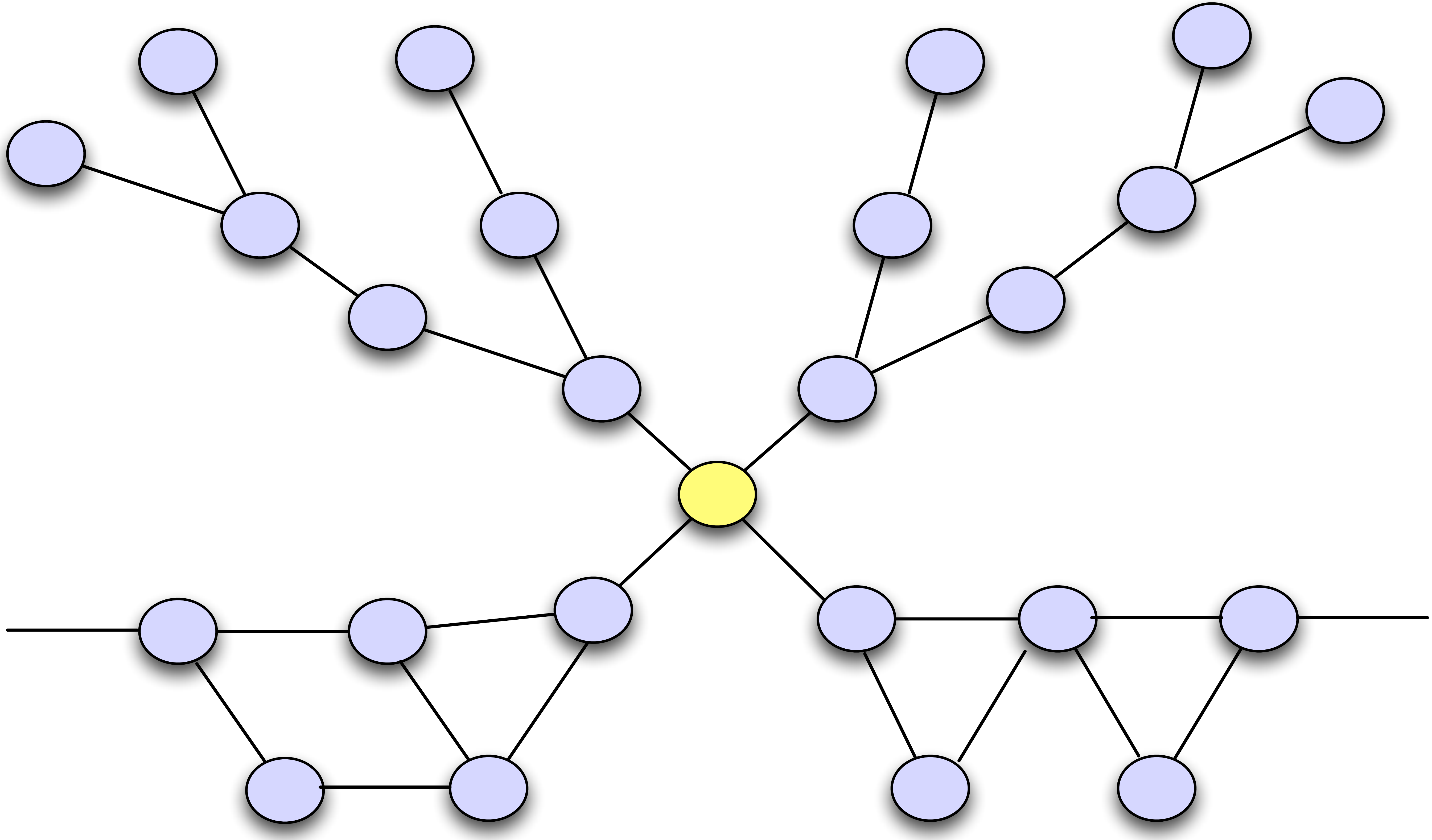
More than 700 million people in India have been left without power in the world's worst blackout of recent times, leading to fears that protests and even riots could follow if the country's electricity supply continues to fail to meet growing demand.

Twenty of India's 28 states were hit by power cuts, along with the capital, New Delhi, when three of the country's five electricity grids failed at lunchtime.

As engineers struggled for hours to fix the problem, hundreds of trains failed, leaving passengers stranded along thousands of miles of track from Kashmir in the north to Nagaland on the eastern border with Burma.

Traffic lights went out, causing jams in New Delhi, Kolkata and other cities. Surgical operations were cancelled across the country, with nurses at one hospital just outside Delhi having to operate life-saving equipment manually when back-up generators failed.

Ch 3: Network Router Failure



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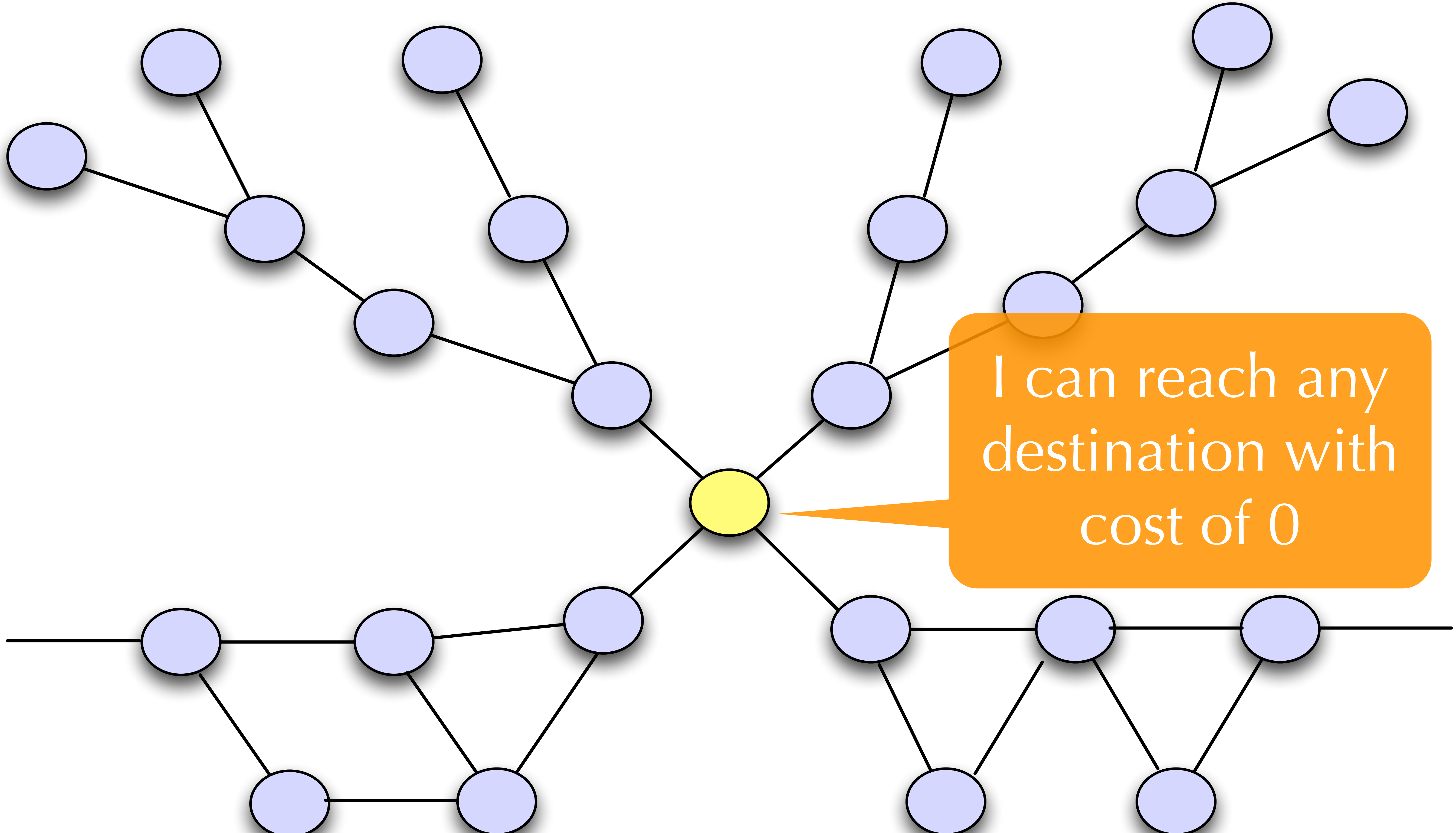

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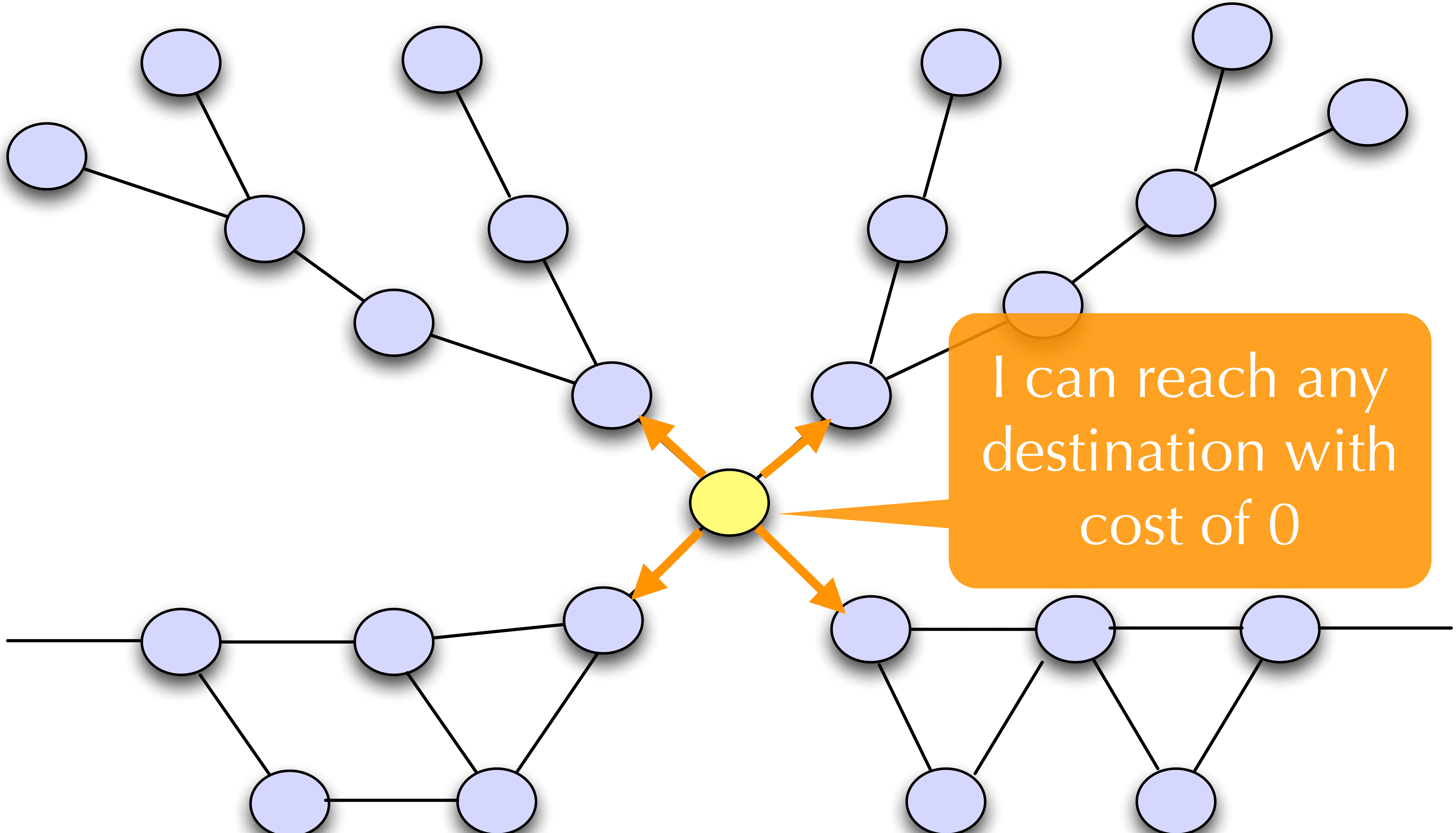

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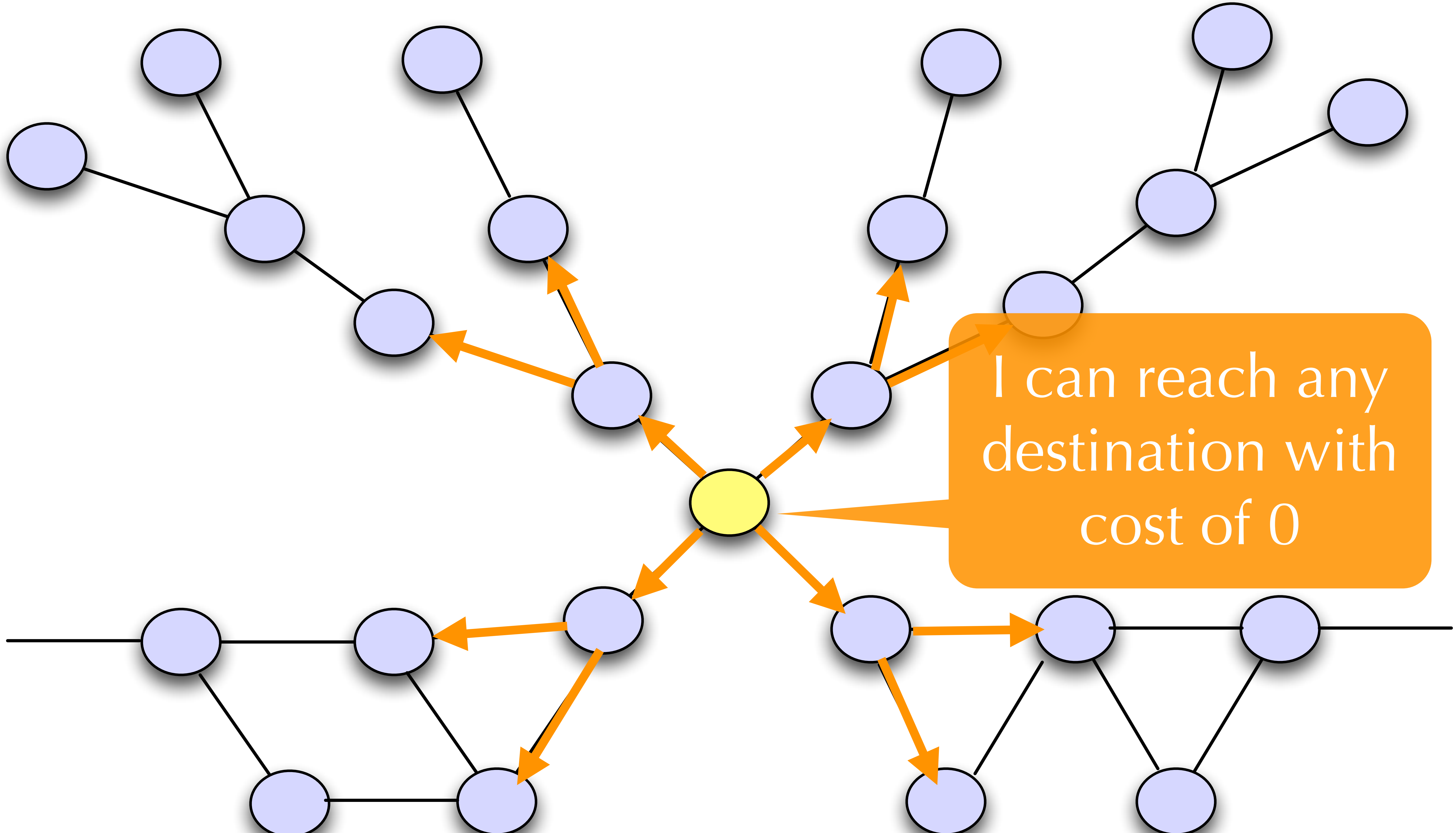

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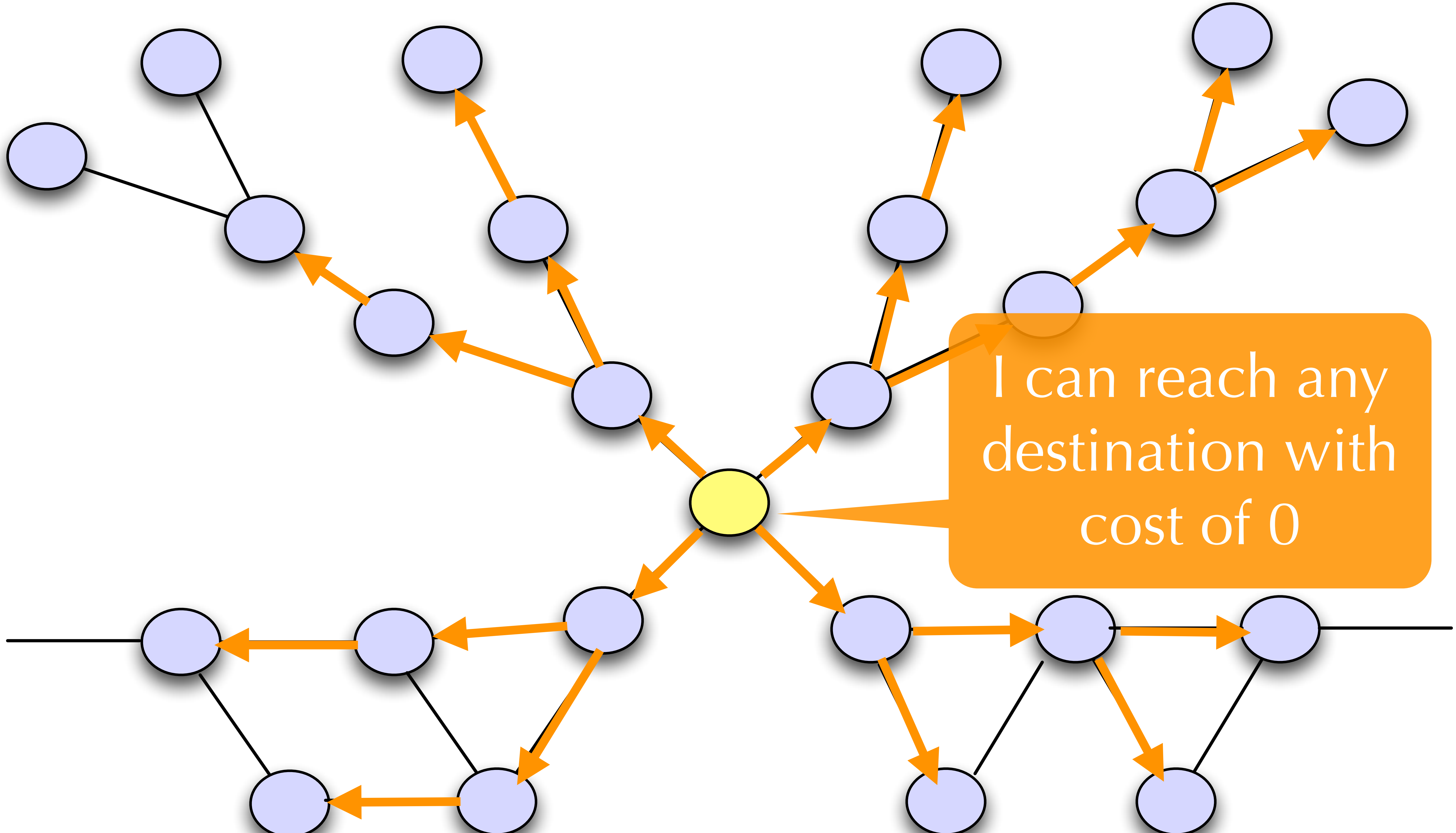

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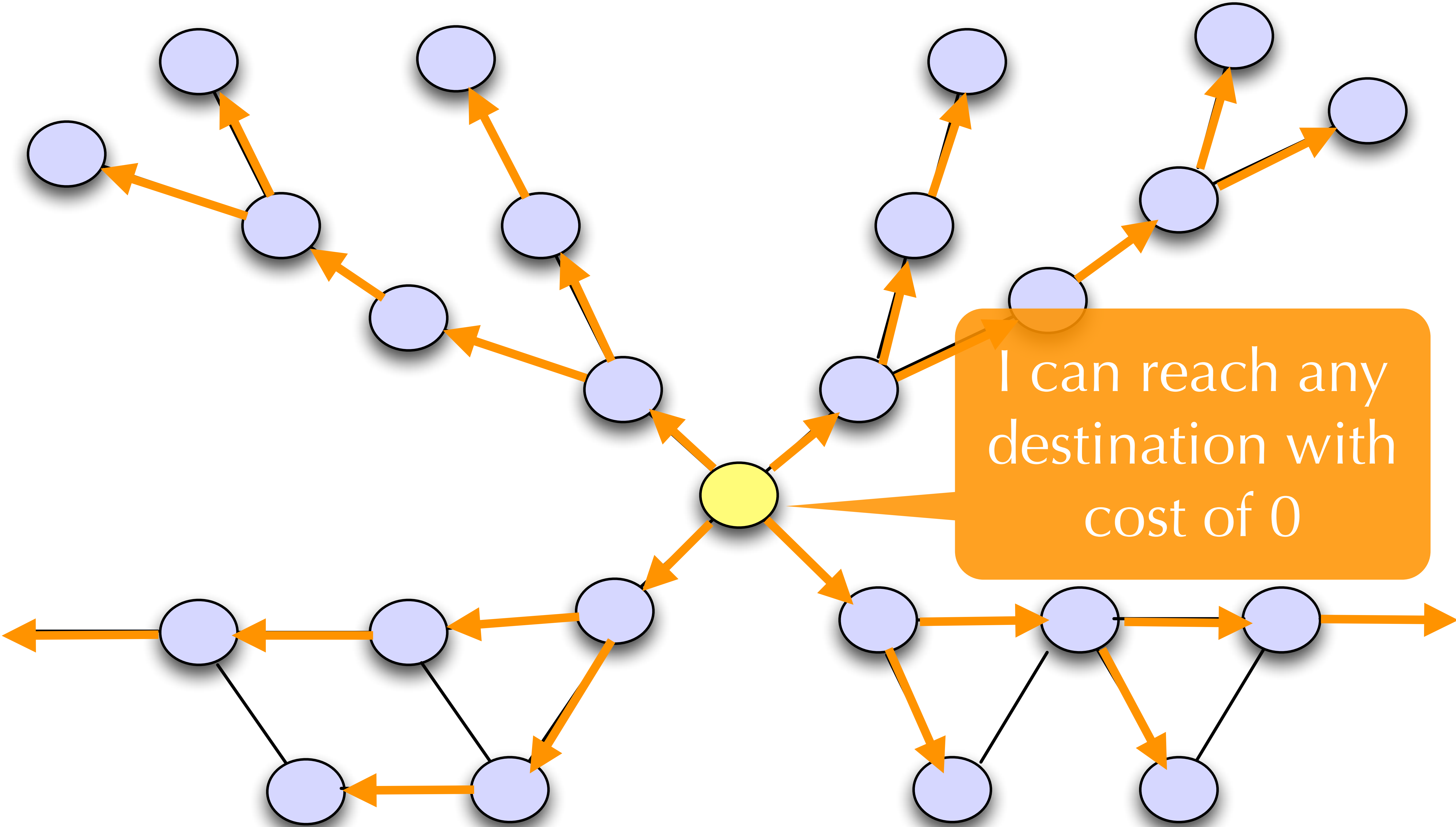

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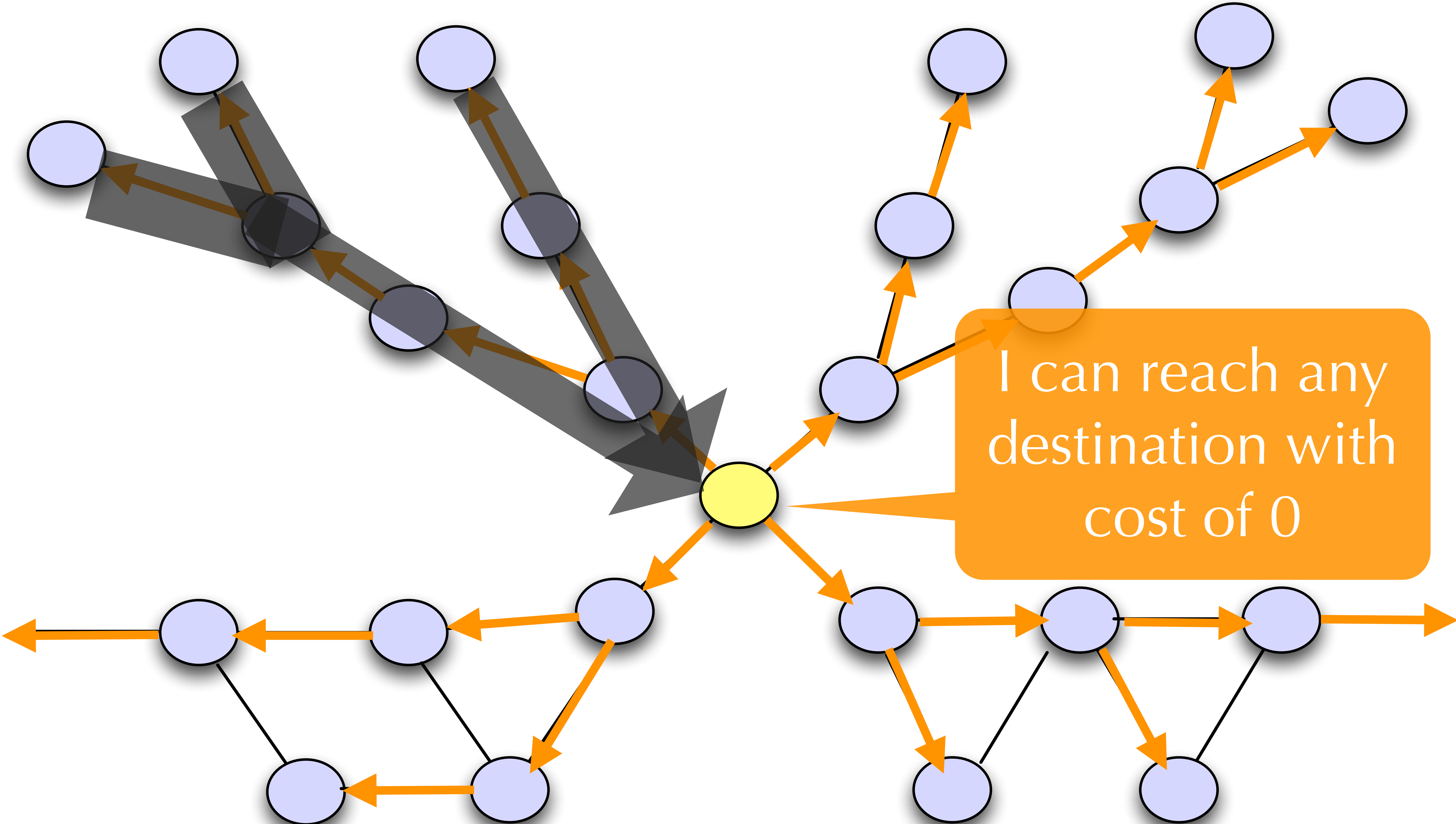

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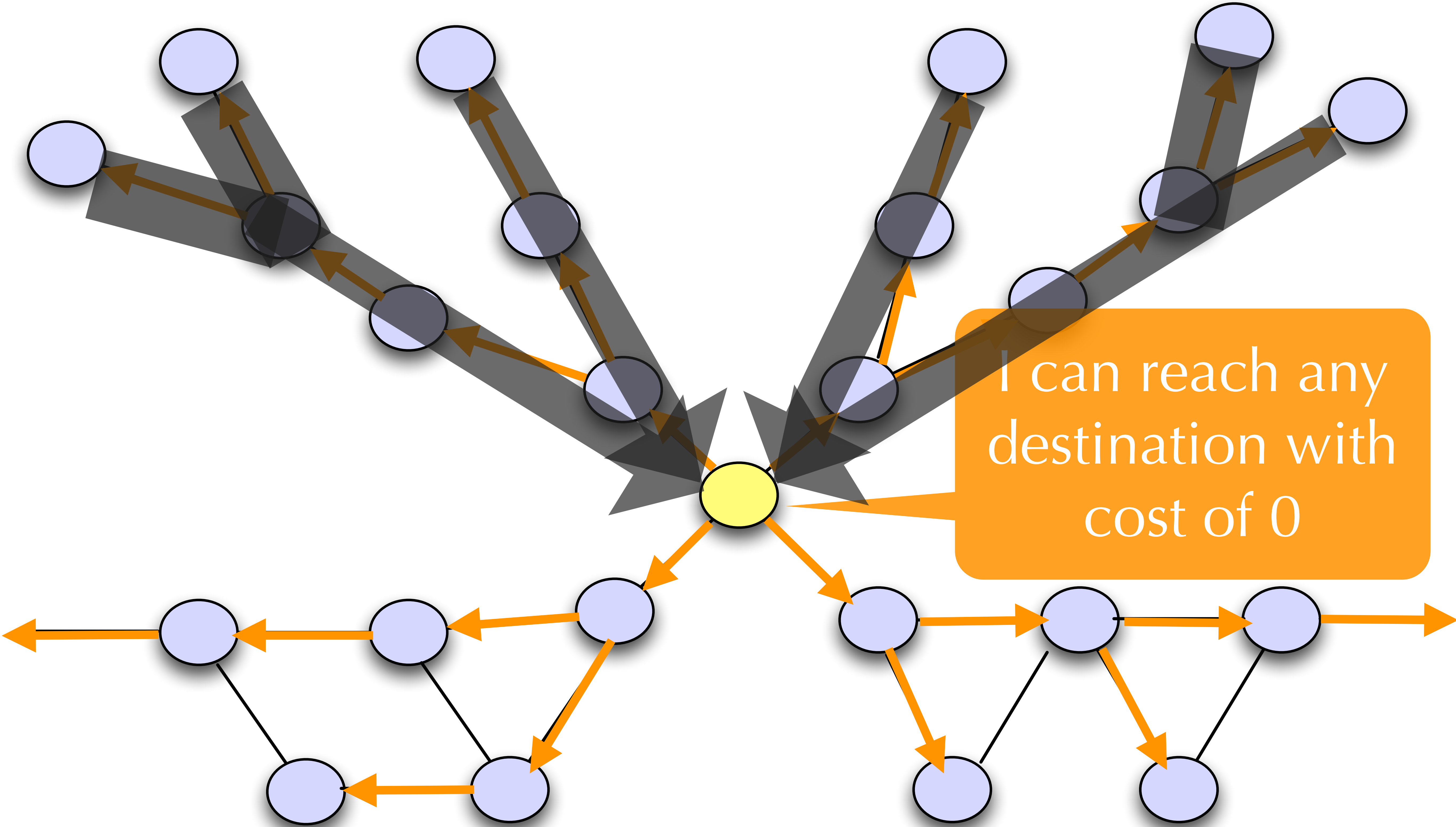

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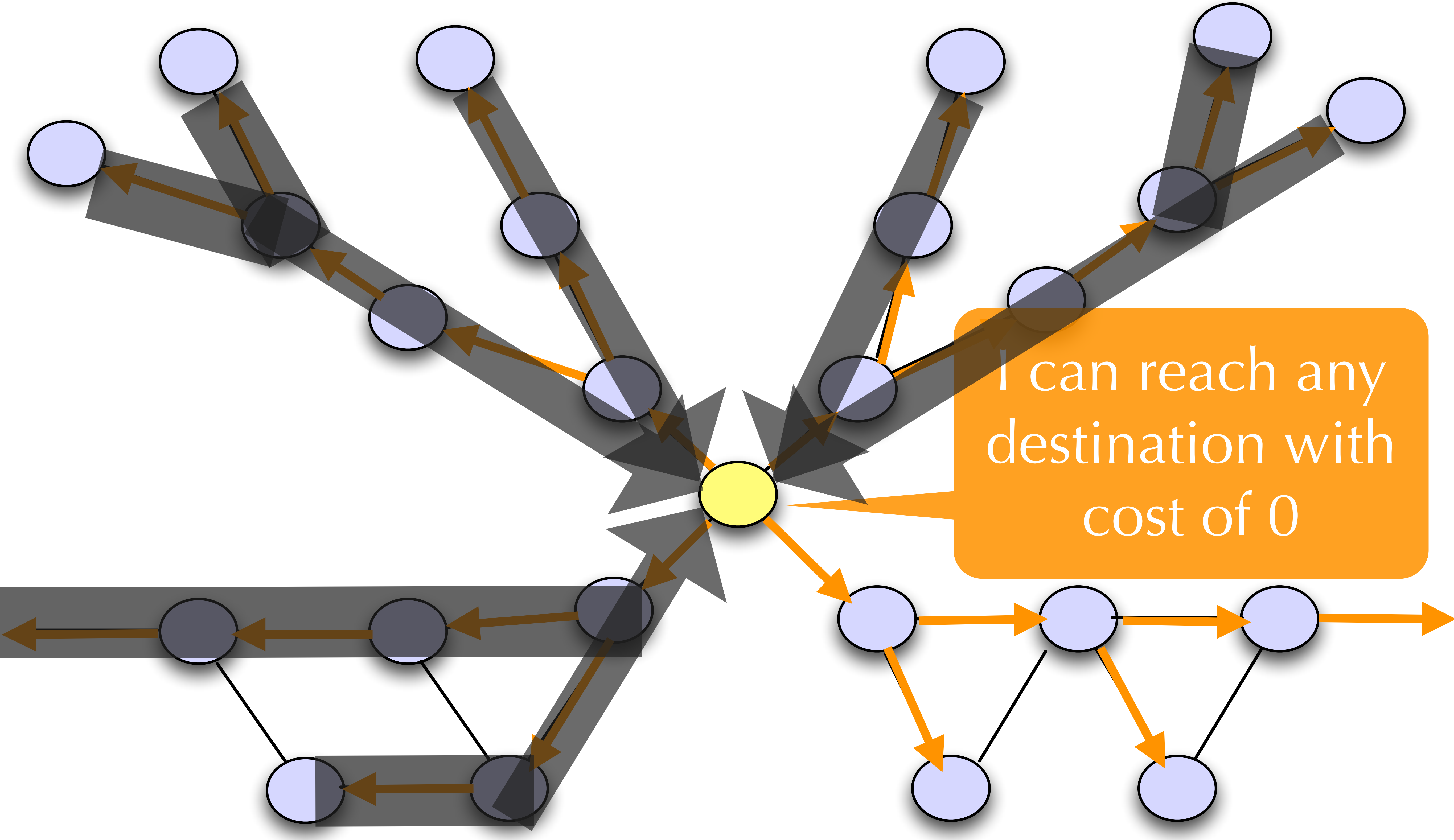

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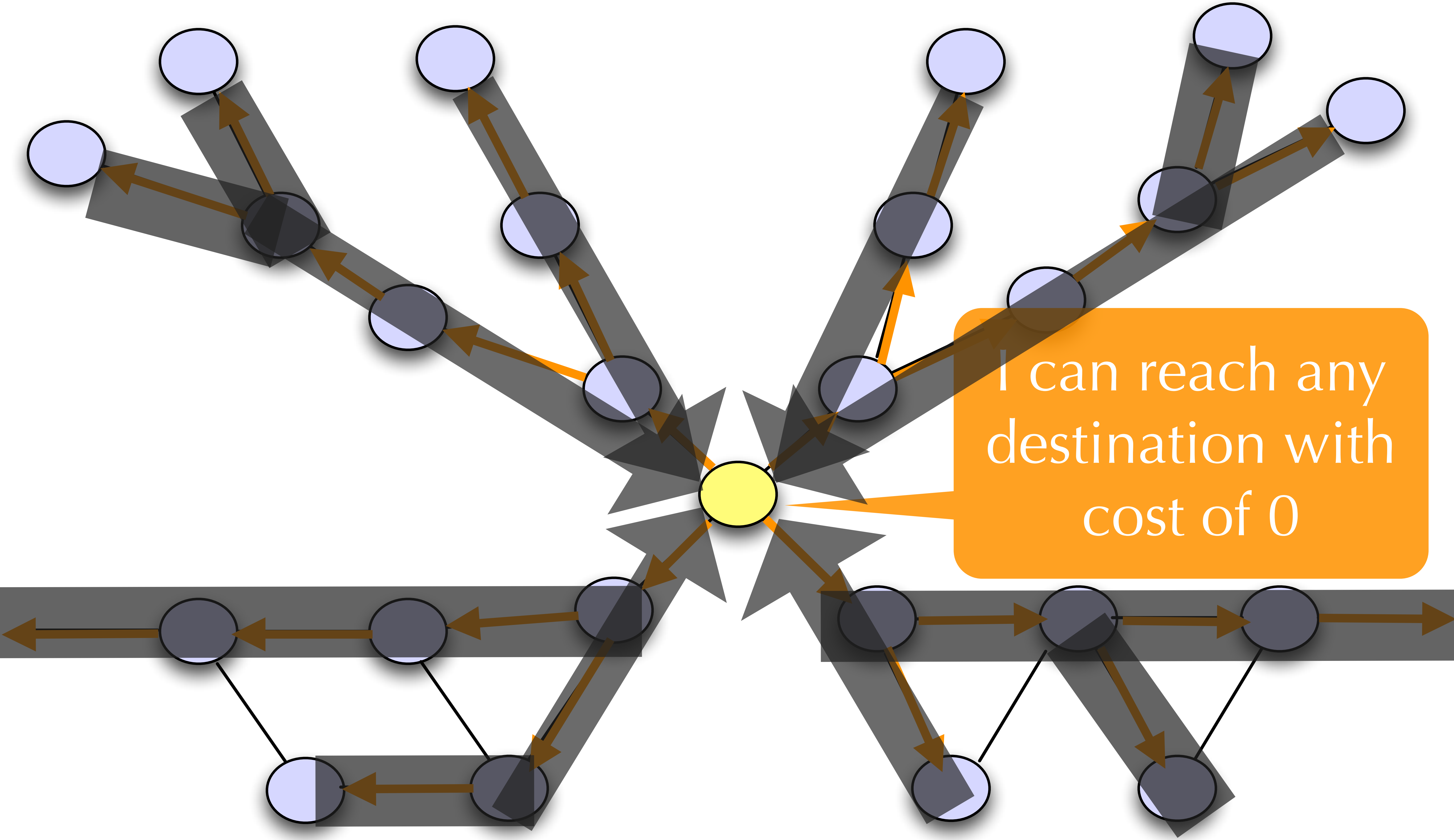

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April 25, 1997 7:00 PM PDT

Router glitch cuts Net access

By CNET News.com Staff
Staff Writer, CNET News

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What started out as a router glitch at a small Internet service provider in Virginia today triggered a major outage in Internet access across the country, lasting more than two hours in some places.

The problem started this morning at 8:30 a.m. PT when MAI Network Services, an ISP headquartered in a McLean, Virginia, unwittingly passed some bad router information from one of its customers onto Sprint, one of the largest Internet backbone operators in North America. Because Sprint's backbone is used by so many other smaller ISPs, the router problem was echoed, causing temporary network outages across the country and, perhaps, internationally.

The outage underscored the fragility of the infrastructure that underlies the global network and how easily a problem with one small ISP can be amplified throughout the Internet. Even so, the Net displayed a remarkable resilience that seems to disprove its doomsayers, who have predicted that the network is on the verge of collapse.

"This particular thing was a confluence of two or three things happening--human error, bug, and some policy problems--that all came together on the same day," said Jack Rickard, publisher of *BoardWatch* magazine.

"There are probably a hundred guys in back rooms keeping this stuff together, just barely," Ricard said of the Internet.

Automated Recovery Is Needed

- automated recovery needed to reduce
  - short-term disruption
  - increase long-term network survivability

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thesis designs algorithms to make networks robust to these component failures

Unifying The 3 Subproblems

- each problem considers network robustness in the face of component failure
- our solutions
  - preplanned recovery for smart grid apps where reliability is key
  - on-demand recovery for distributed network algorithms

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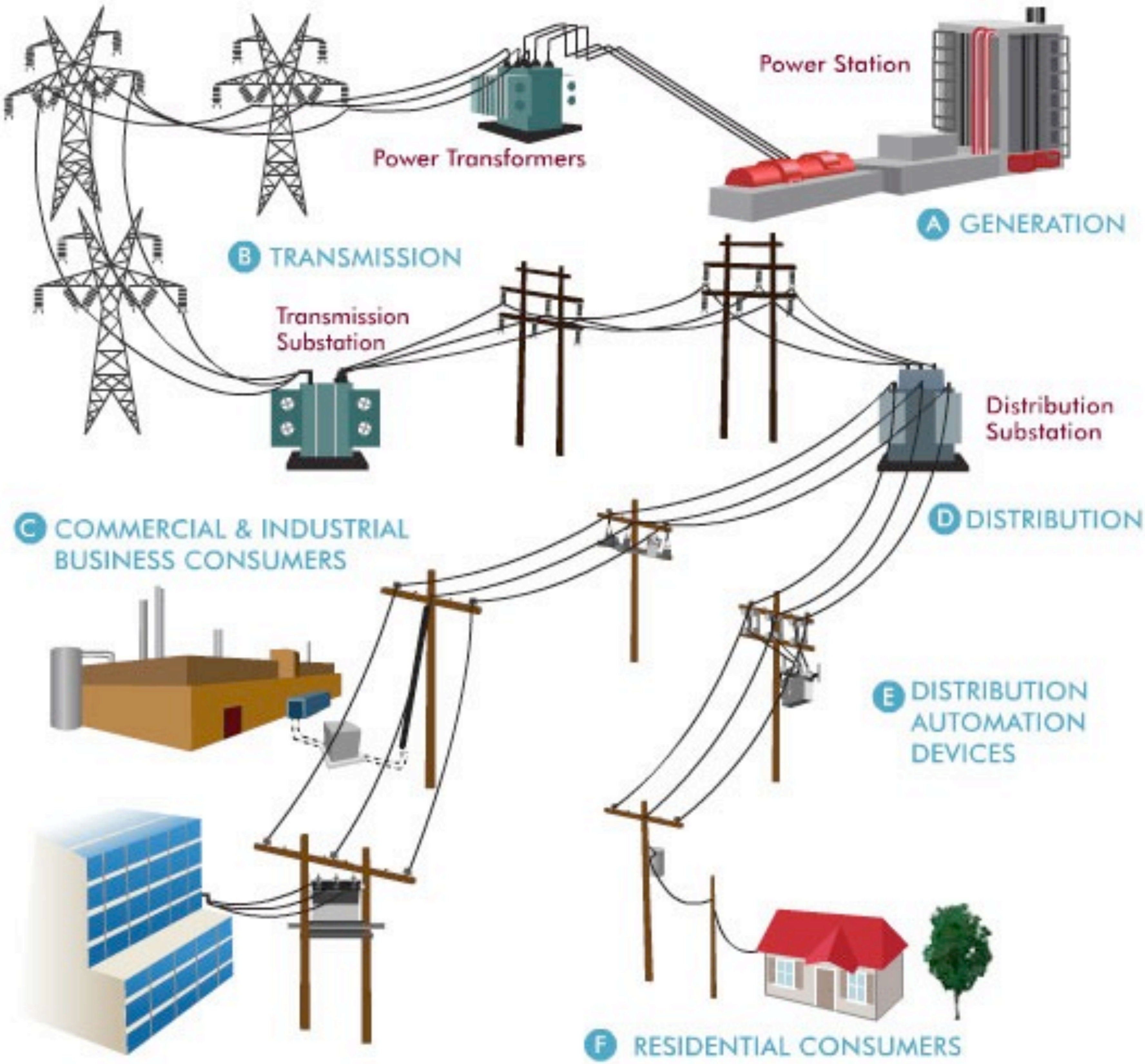

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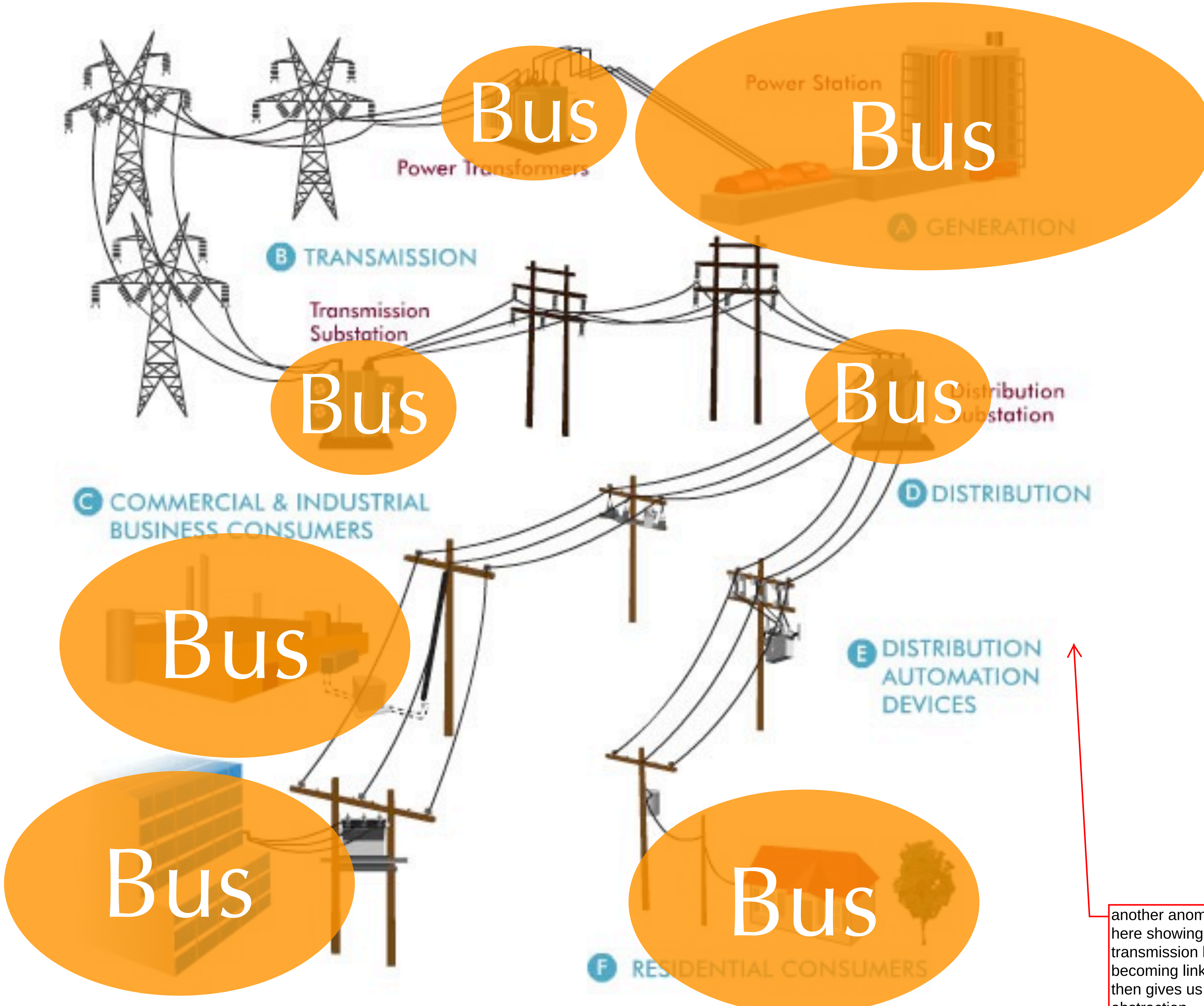
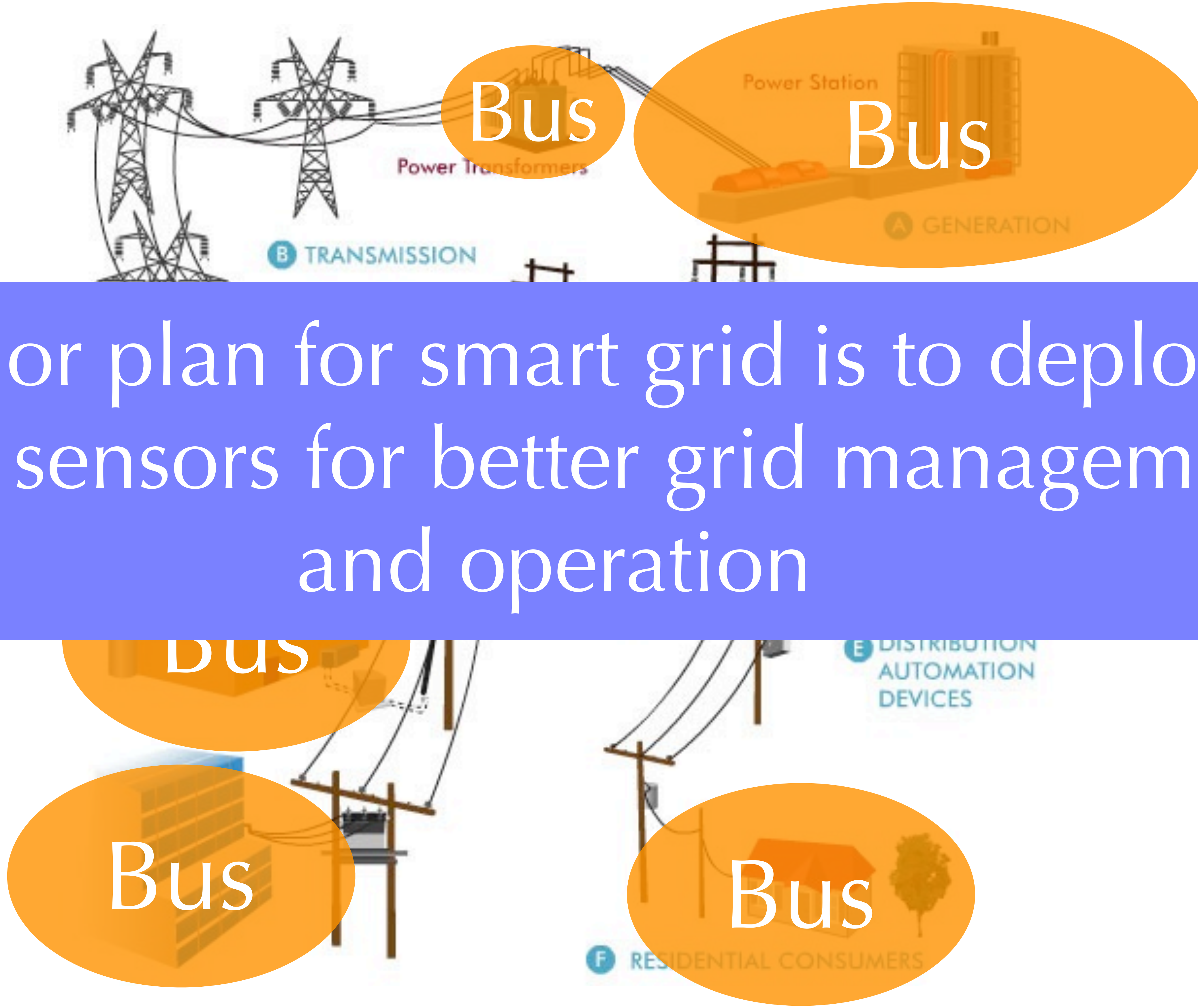


another anomiation here showing transmission lines becoming links. THis then gives us the graph abstraction

Refresher: Power Grid Definition



major plan for smart grid is to deploy PMU sensors for better grid management and operation

More on PMU Sensors

- deployed at system buses
- measure voltage and current of system bus and transmission lines
  - high sampling rate (60 samples/sec)
  - measurements synchronized with GPS clock
- instantaneous snapshot of grid

Grid Measurement + Monitoring

where to place PMUs to maximize observability?

D. Brueni and L. Heath. The PMU Placement Problem. SIAM Journal on Discrete Math, 2005

Grid Measurement + Monitoring

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you need to say what it means to be "observable" !!!!!!!

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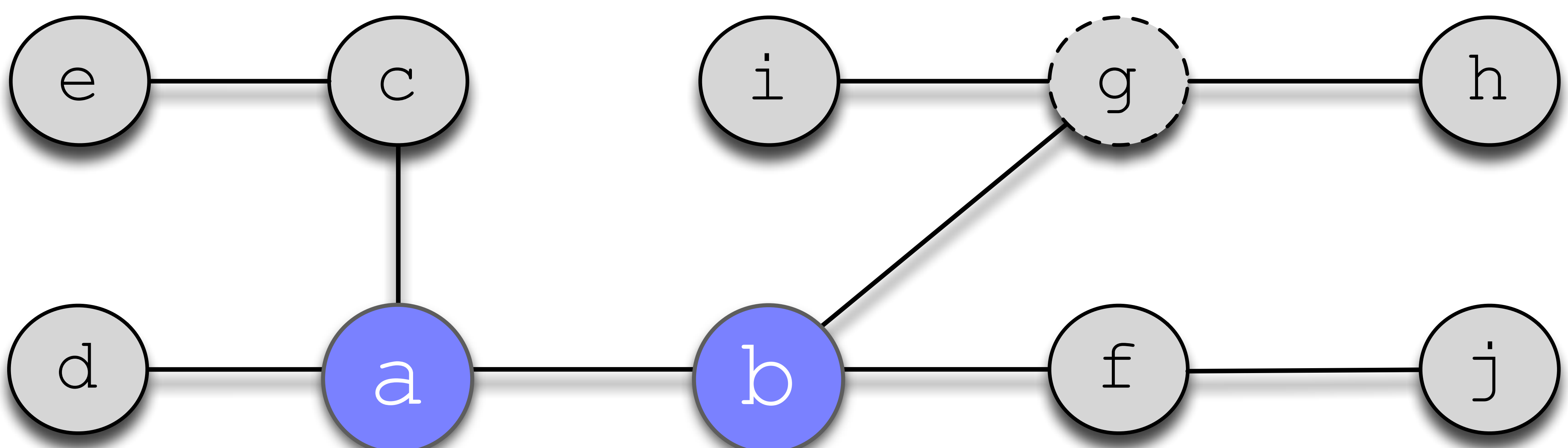

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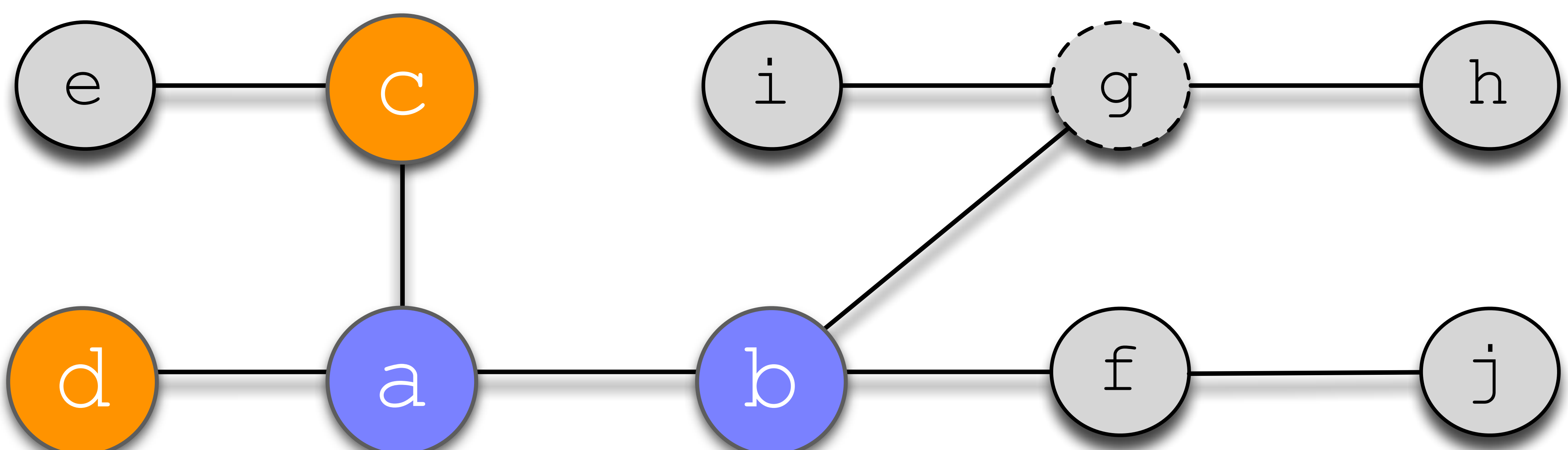

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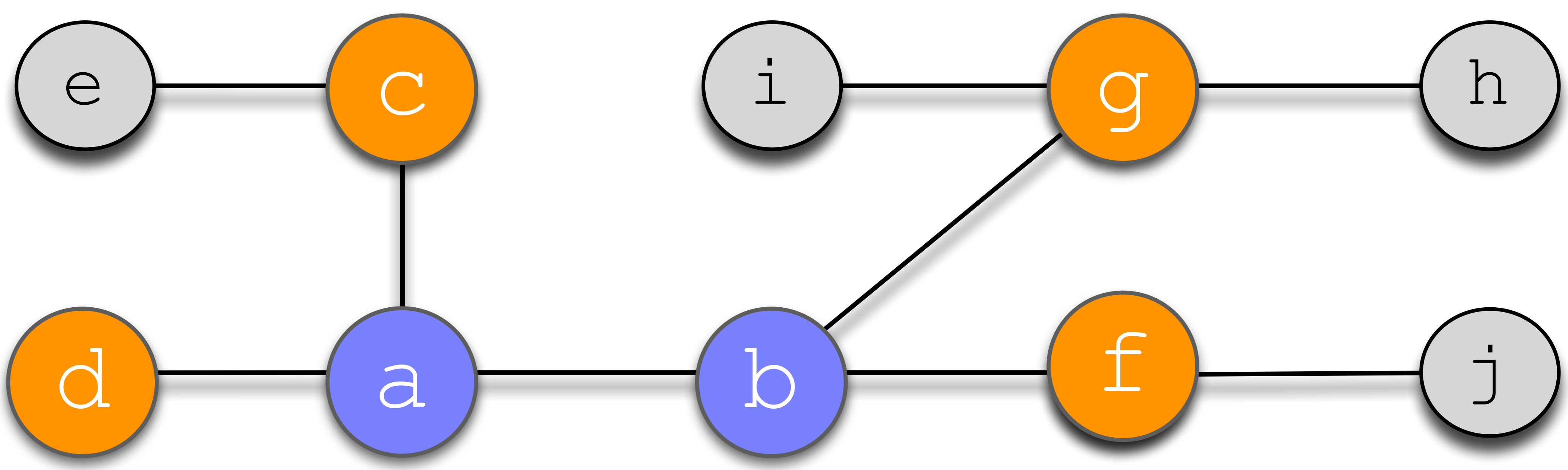

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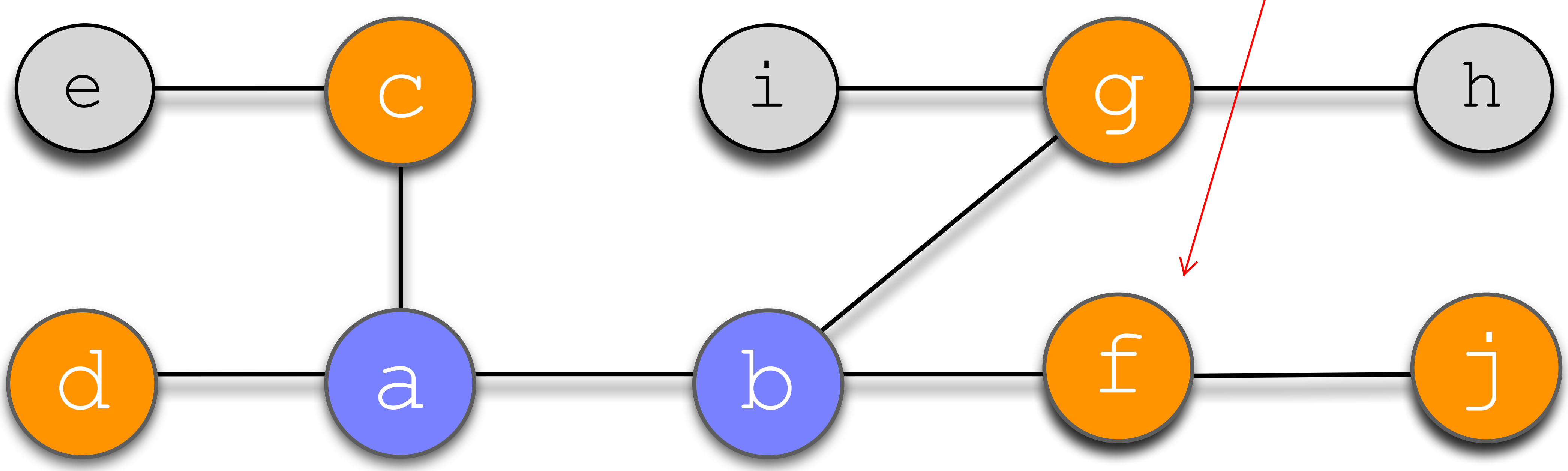
you should point to these as you're going along. (i.e., physicall ypoint). You're a bit "flat" in your talk here - not moving, not pointing. I am guessing you are tired.



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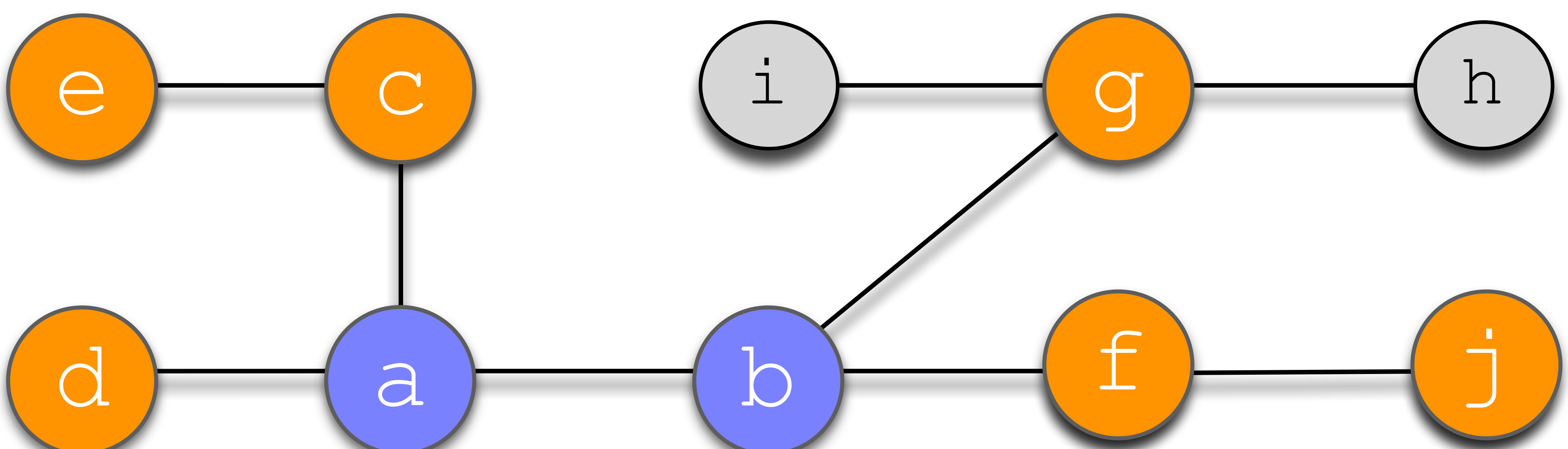

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MAX-OBSERVE Problem

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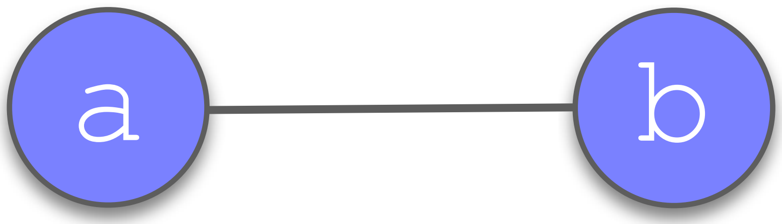

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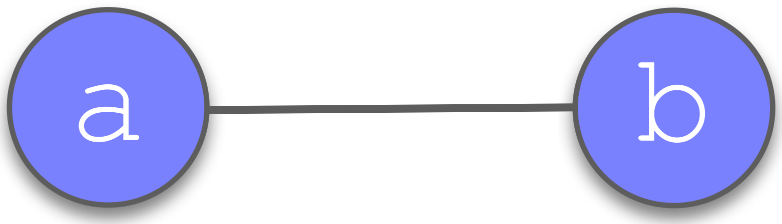
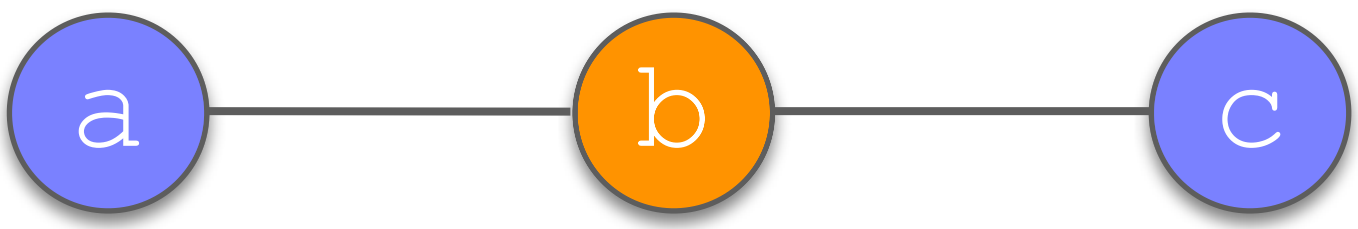


- cross-validation rule 2: if two PMUs share a common neighbor, they cross-validate each other



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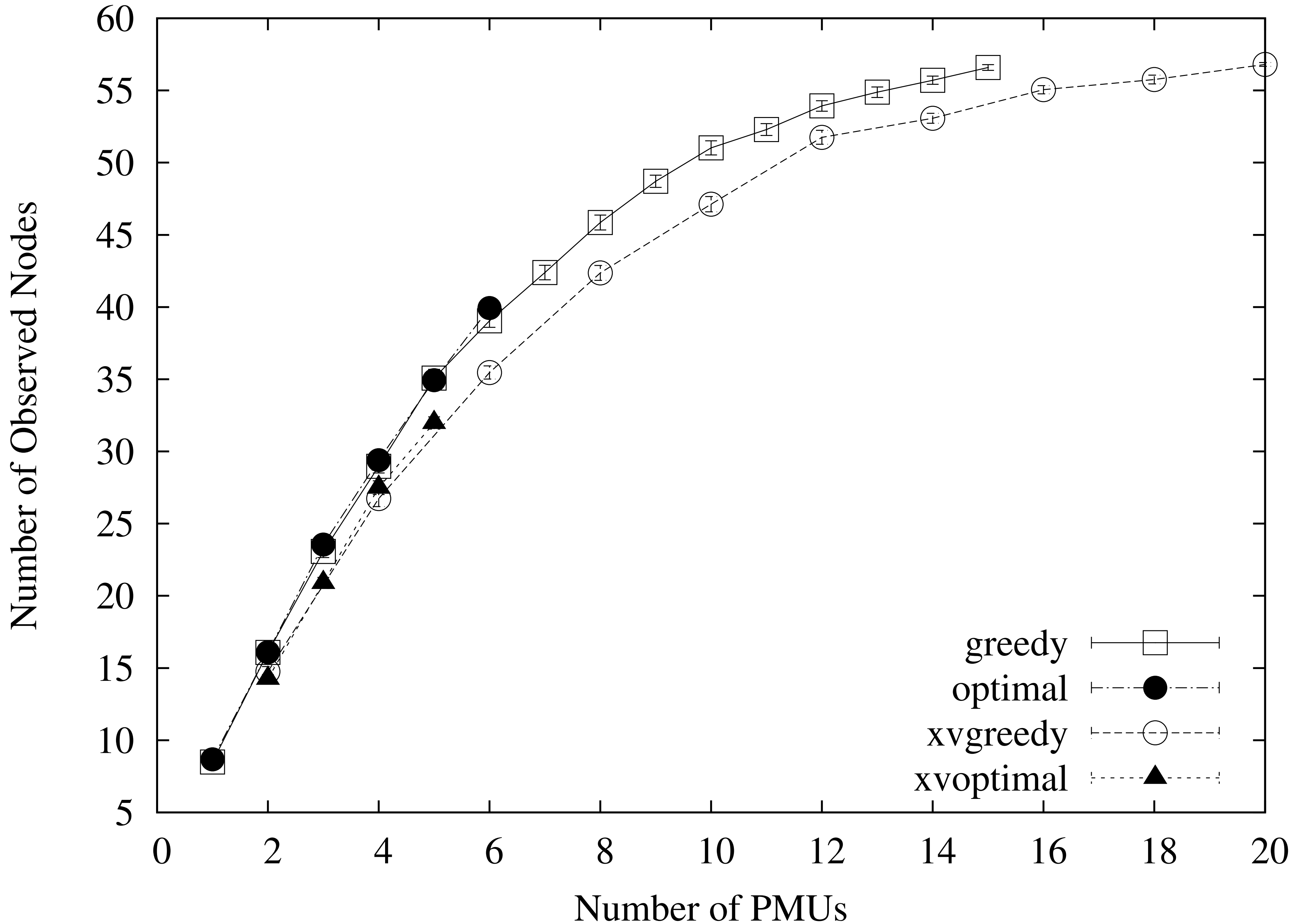
GREEDY-XV:

- iteratively place PMU pairs at nodes `{u,v}` such that `u` and `v` are cross-validated and results in the observation of max # of nodes

Simulation Setup

- generate grid networks with same degree distribution as IEEE bus systems
  - show results for synthetic topologies based on IEEE Bus 57
- compare with brute-force optimal solution by enumeration with small # of PMUs

Simulation Results



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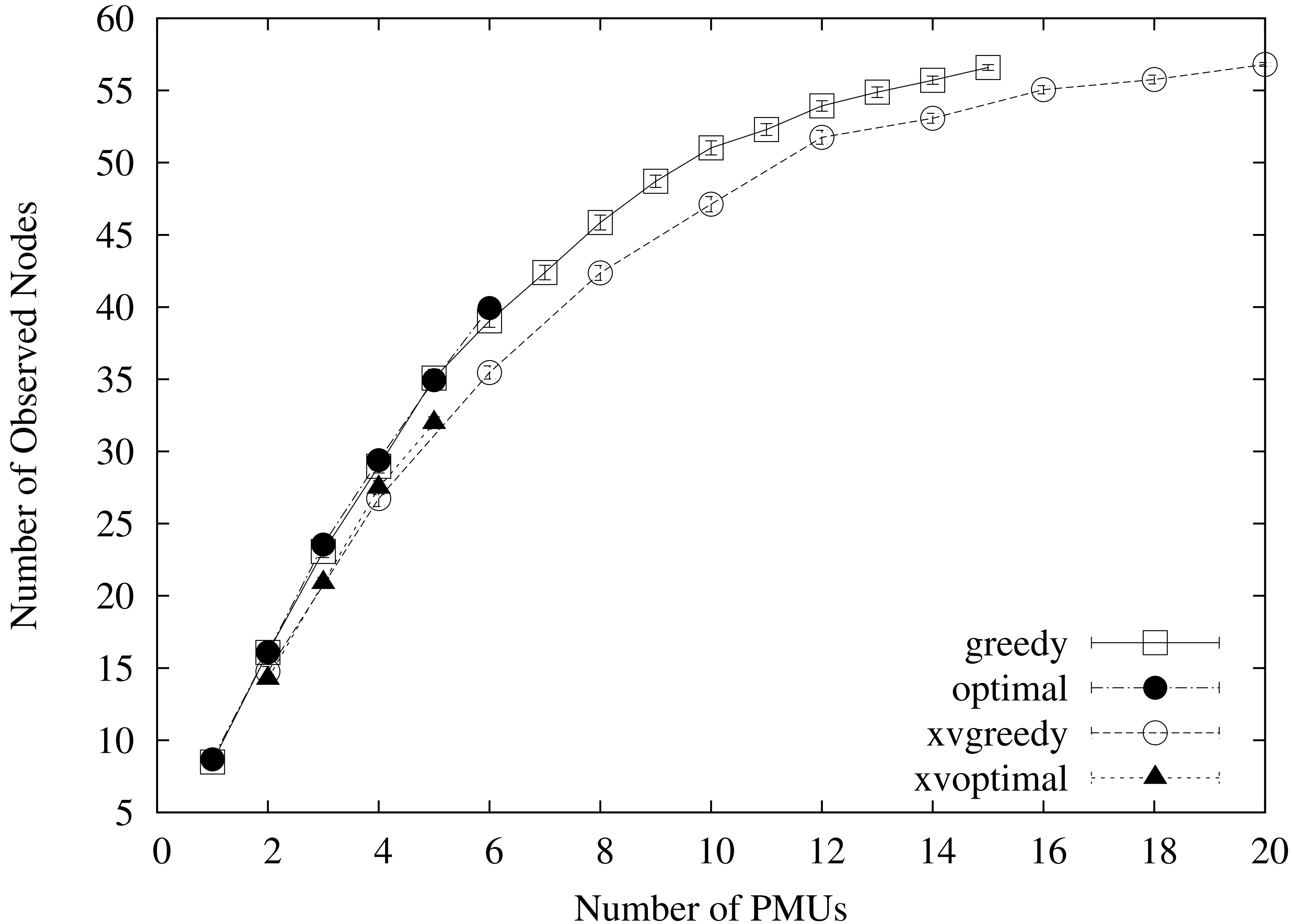

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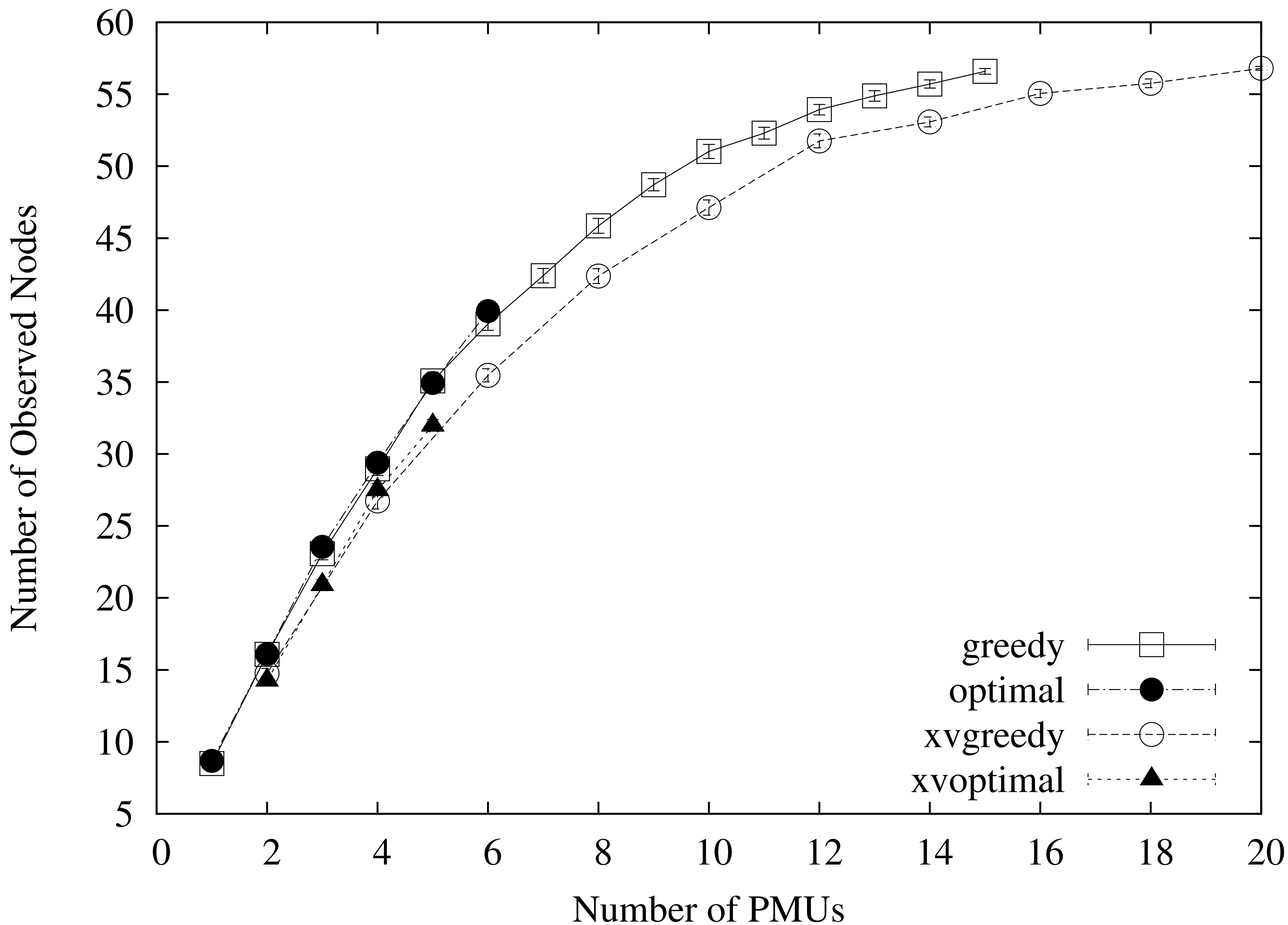

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<u>result 2</u>: cross-validation decreases # observed by ~ 5%

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wide-area data dissemination will enable more efficient ways to operate and manage the grid

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focus: recovery from comm. link failures in smart grid
=> precompute backup MTs offline in case link fails

Smart Grid App QoS Requirements

- focus on QoS requirements for critical smart applications (e.g., real-time control)
- stringent and challenge QoS
    - low latency
        - ex. 8-16 ms per packet for real-time control
    - low tolerance for packet loss

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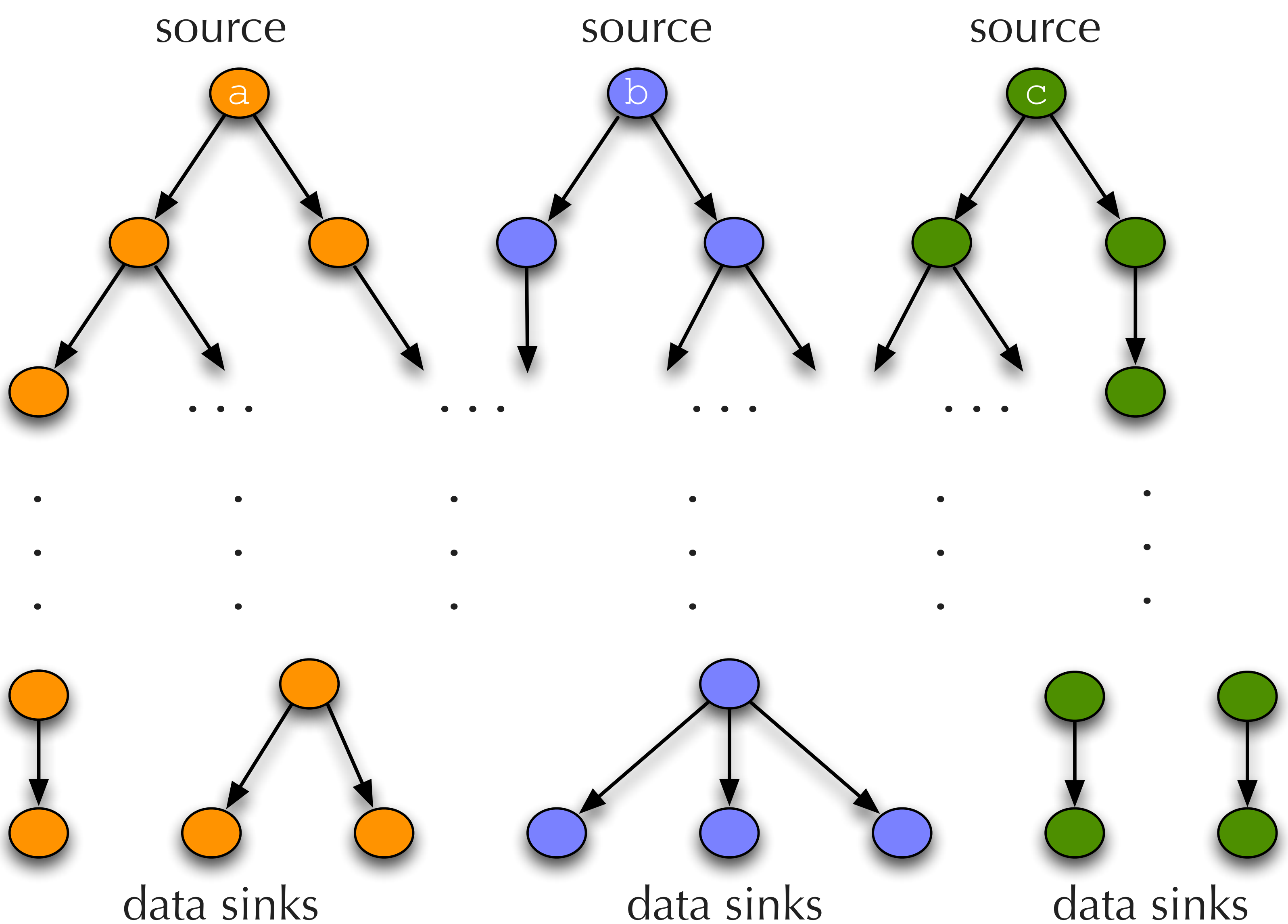
hard E2E delivery guarantees are needed!

Problem Description



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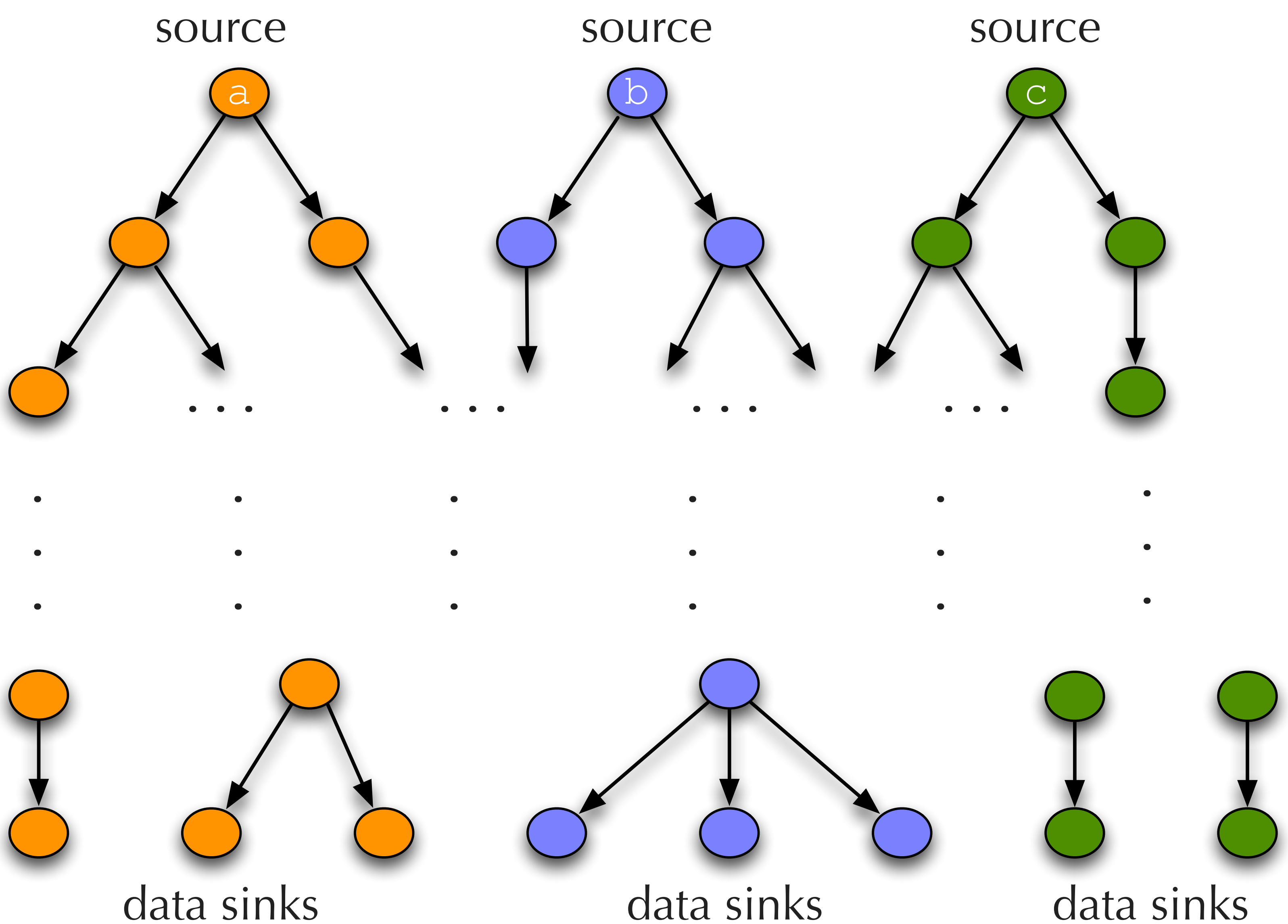

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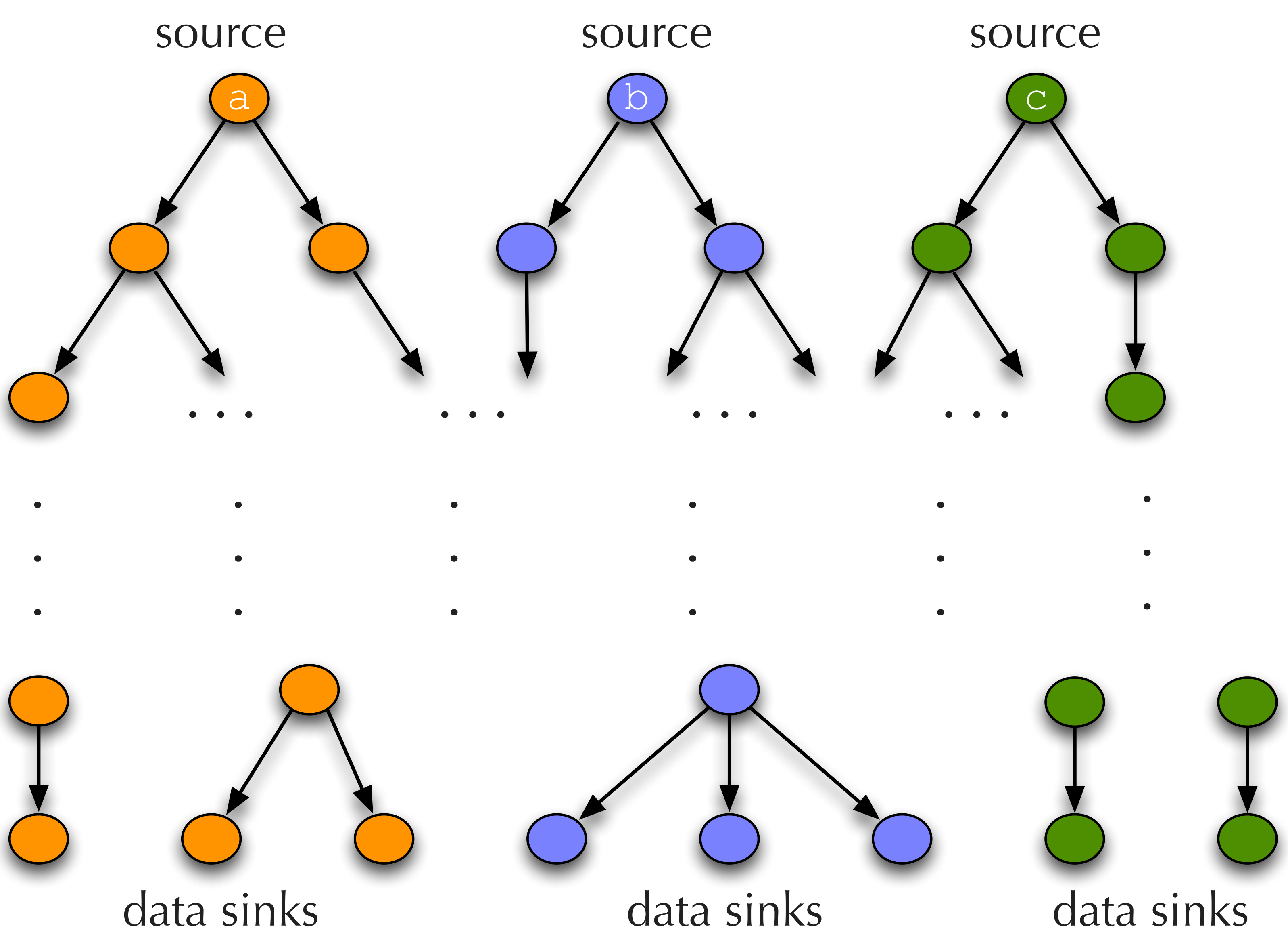

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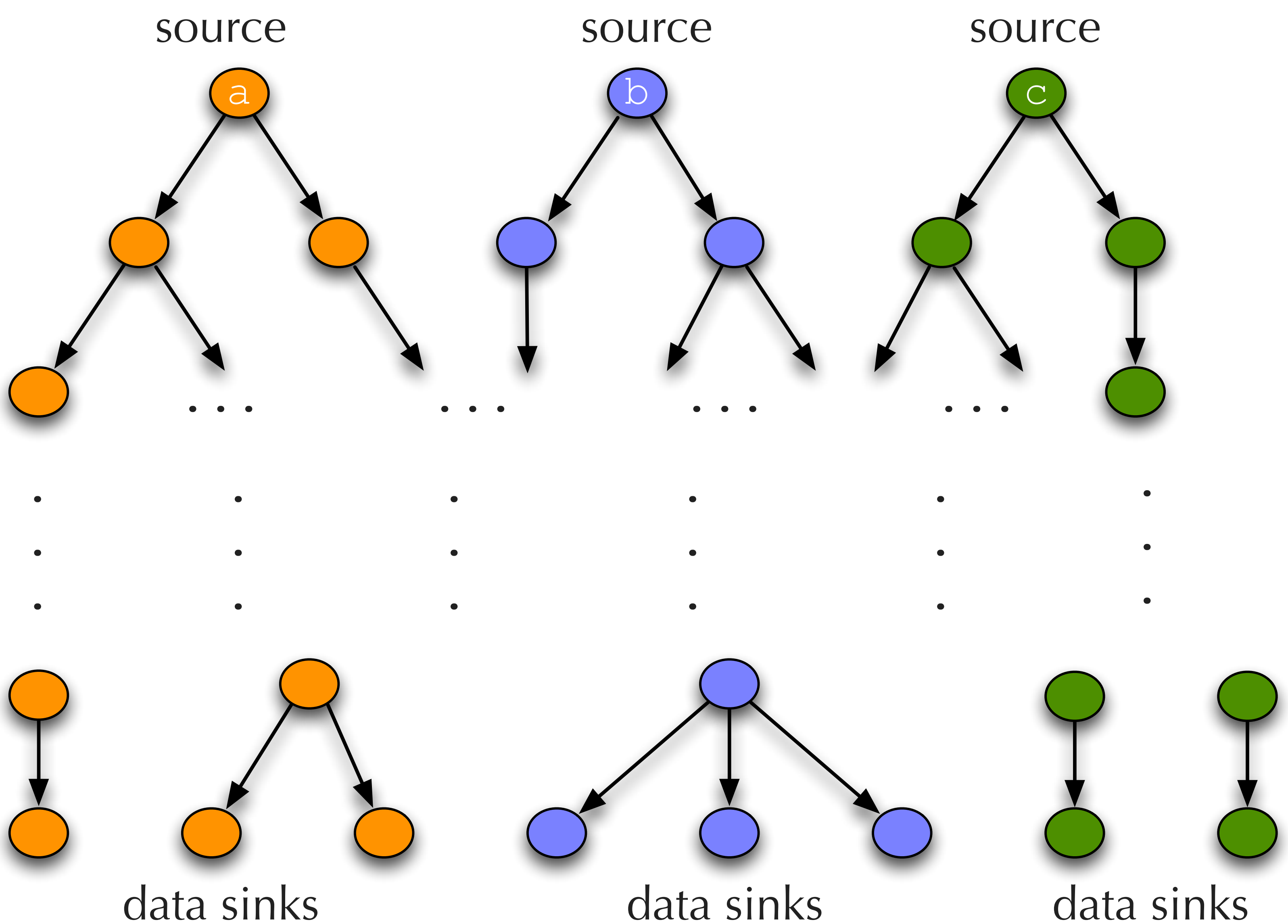

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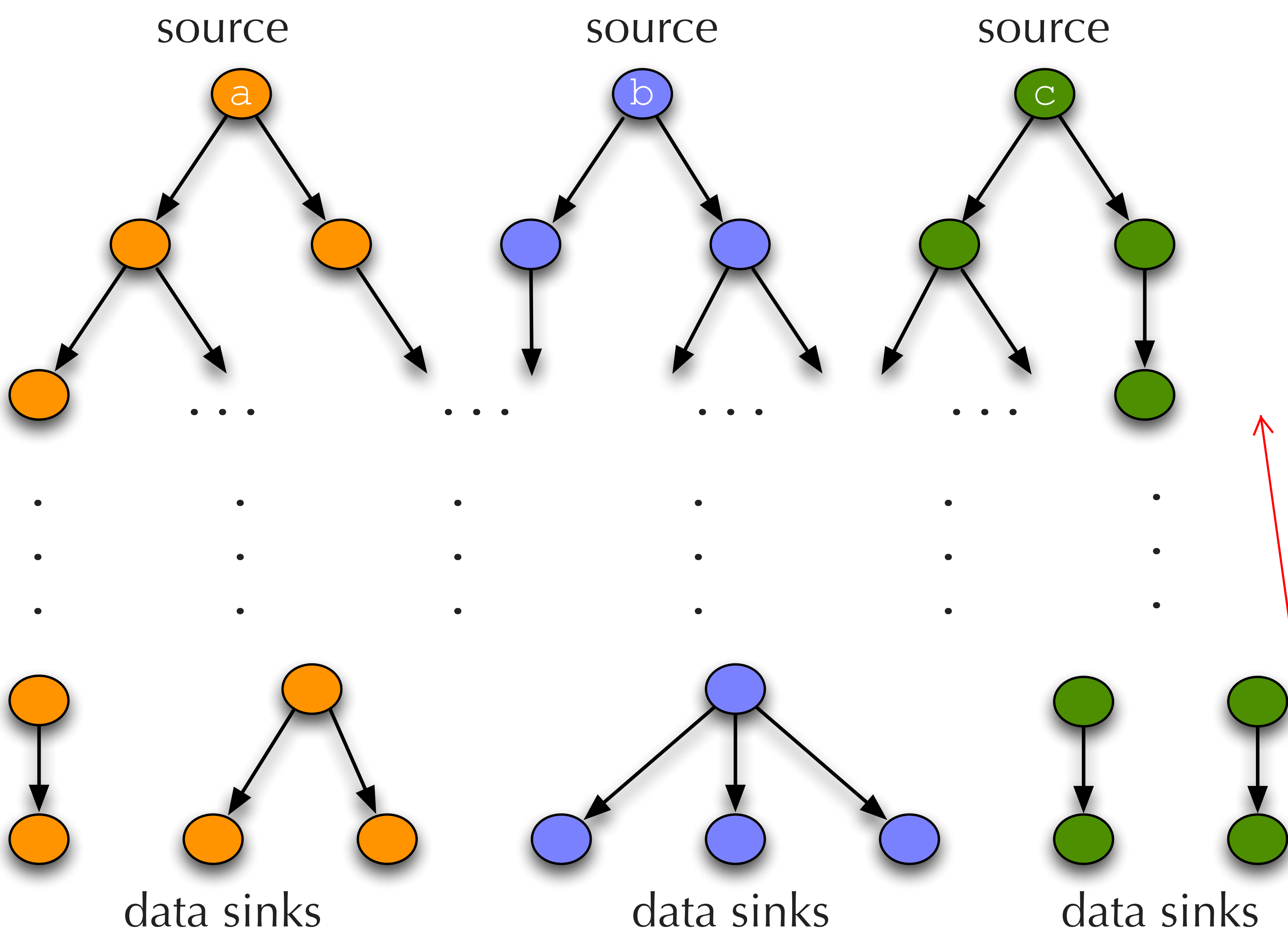

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- fixed sender and receiver set => predictable traffic

let's discuss this figure.
I think you want to overlay different colored trees on one graph (and in particular showing multiple strees crossing the same link). the three different colors each being saprate here doesn't get the idea across

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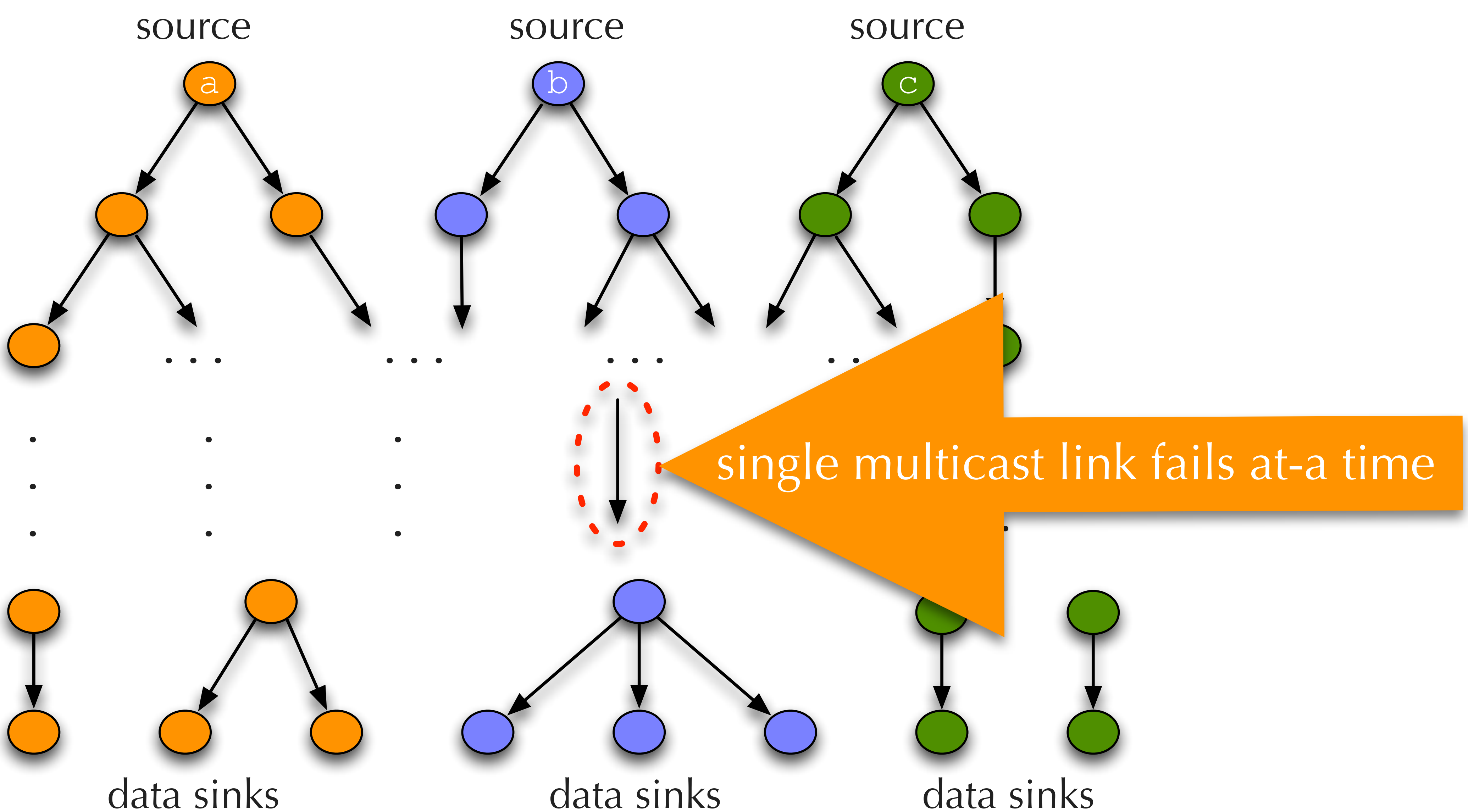

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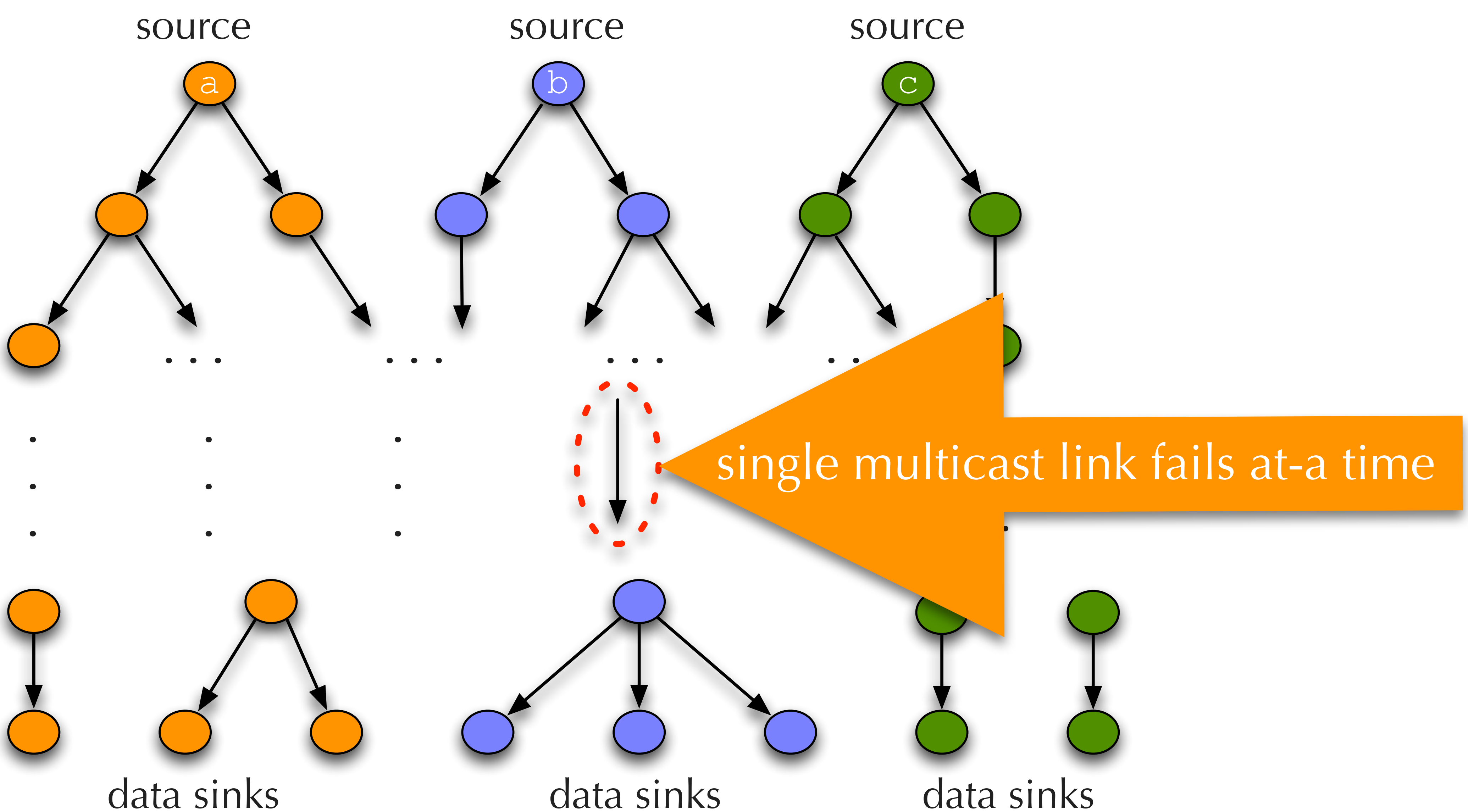

how to detect MT link failure + recover such that E2E packet loss and delay is minimized?

- fixed sender and receiver set => predictable traffic

2 Step Solution

add a hyphen

- two steps to provide link failure robustness
  1. fast detection of link failures
     - detect link failure inside network
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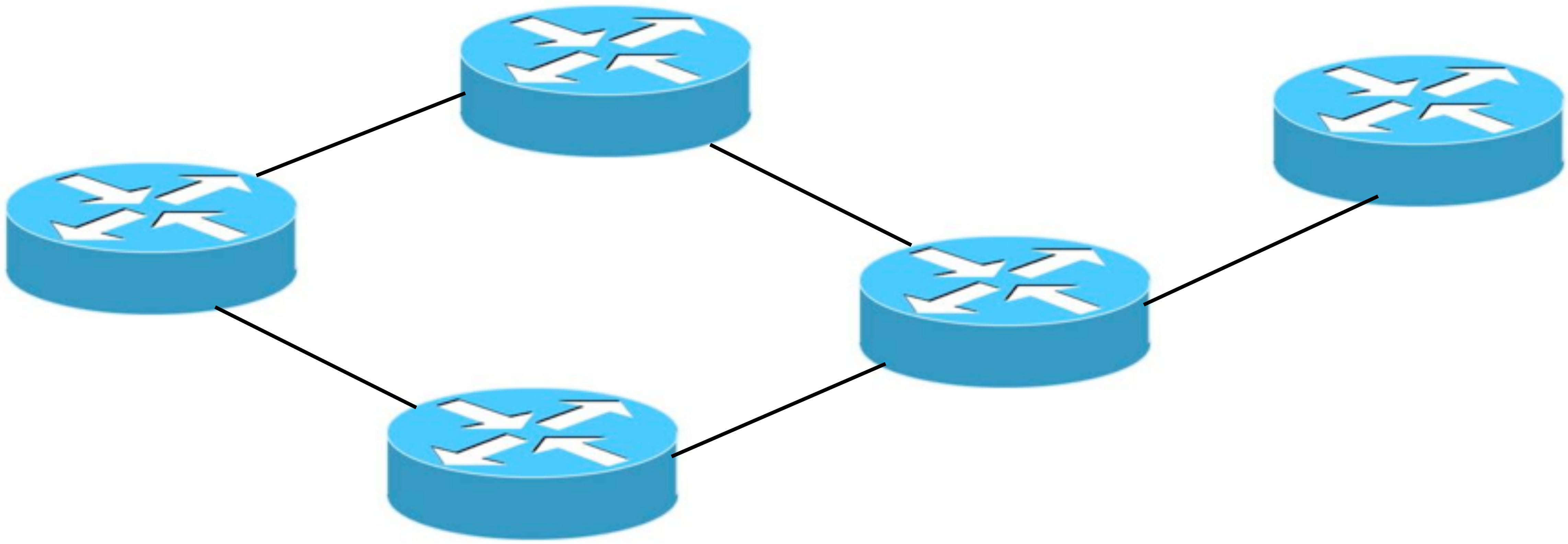
requires changes to existing routers ... how?

OpenFlow: Open Network Control Plane



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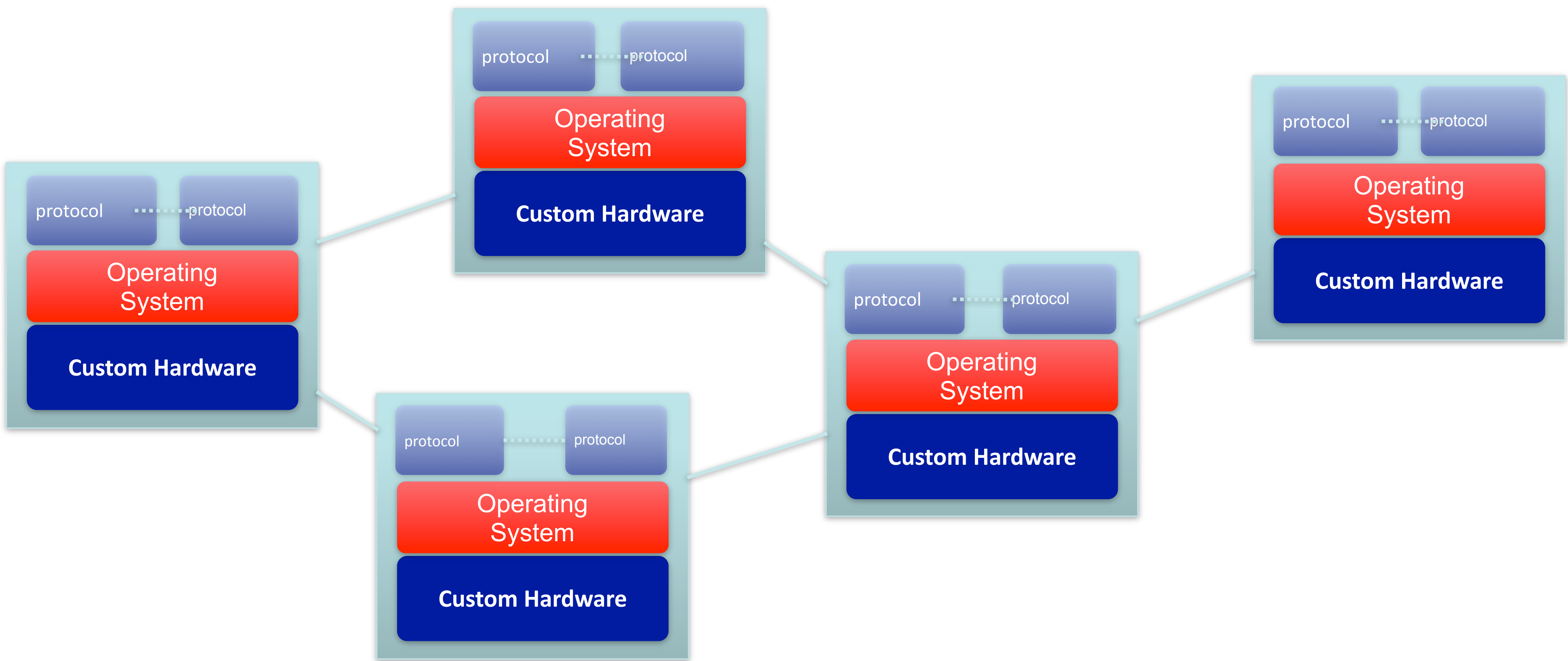

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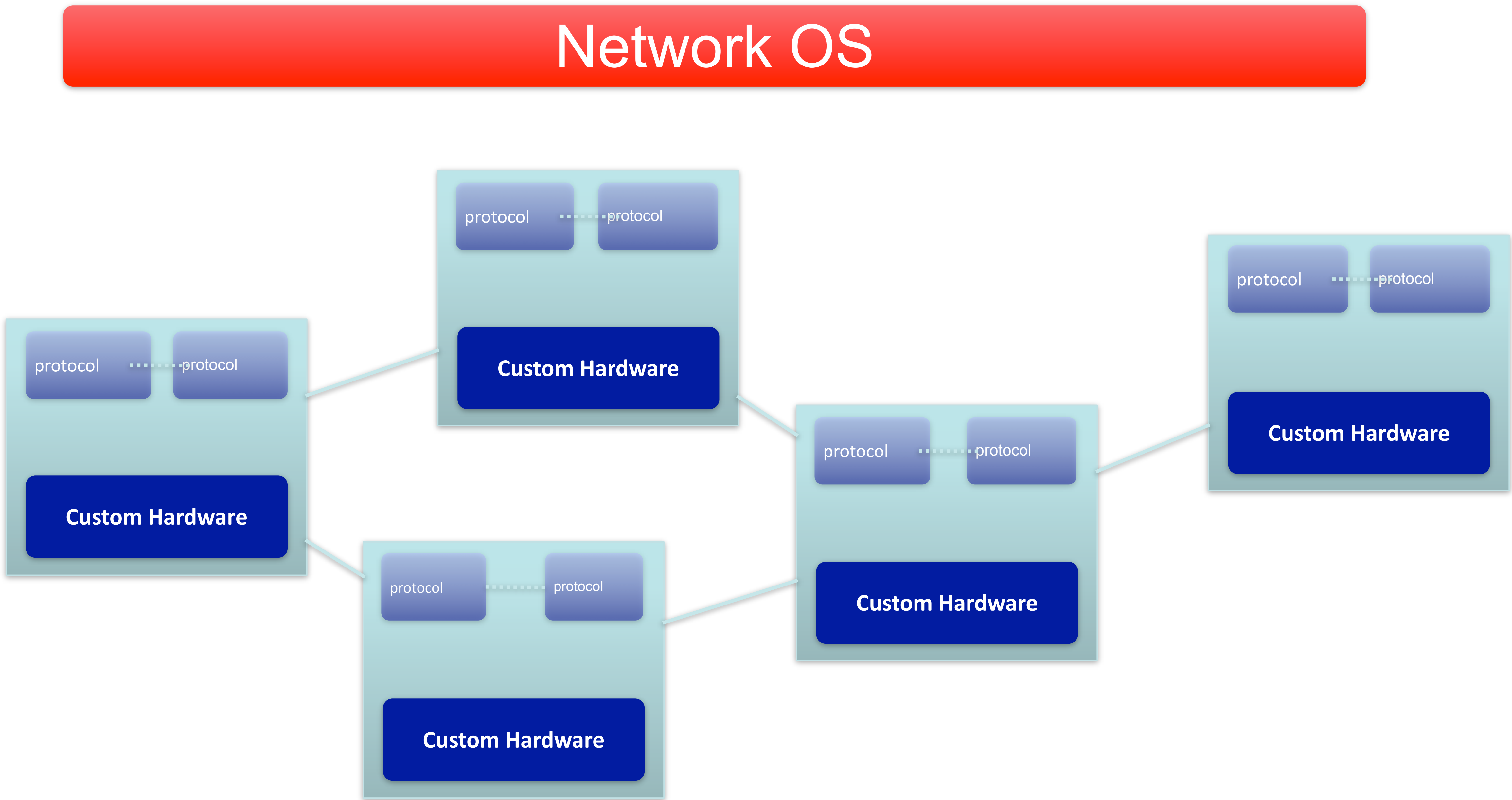

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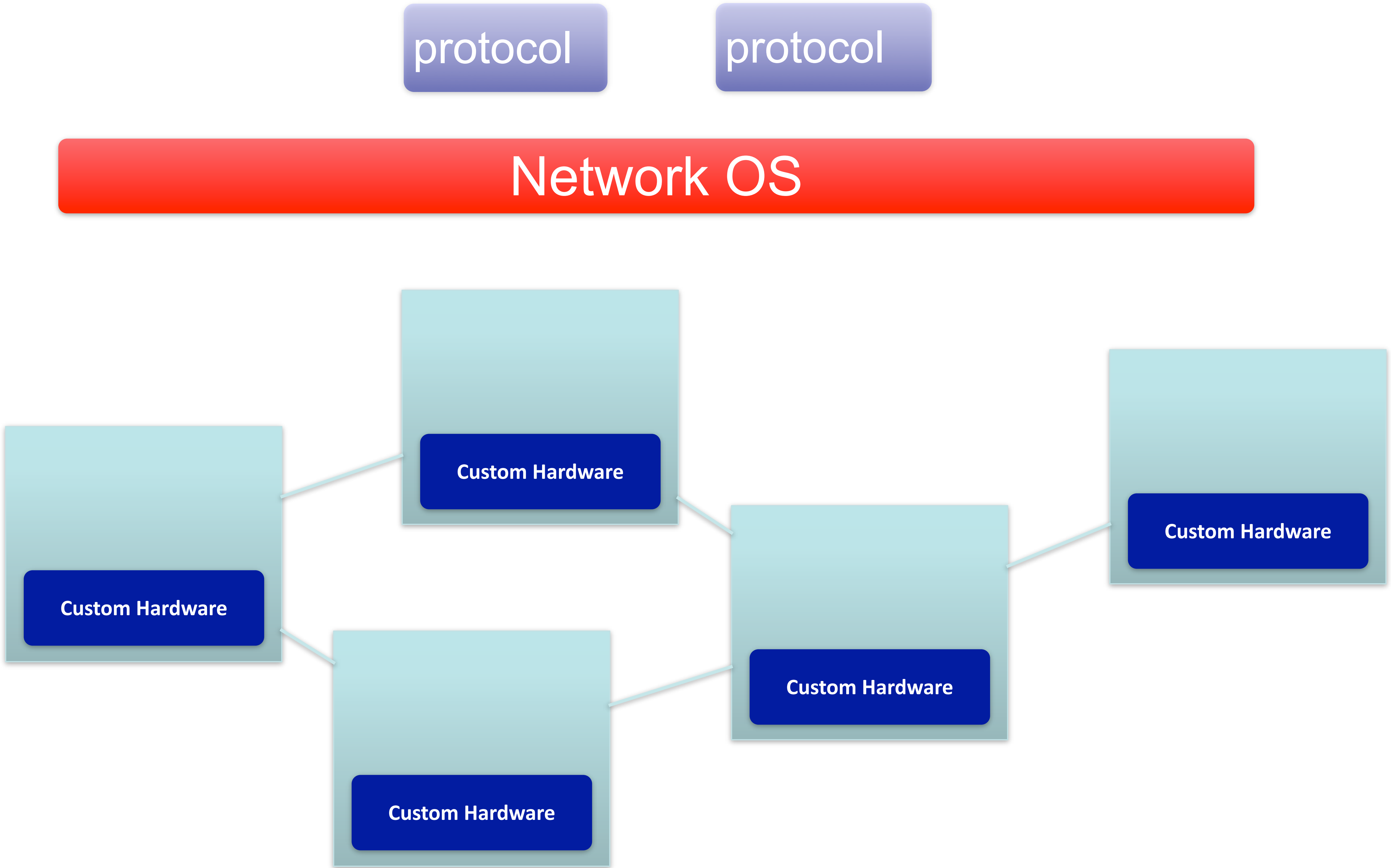
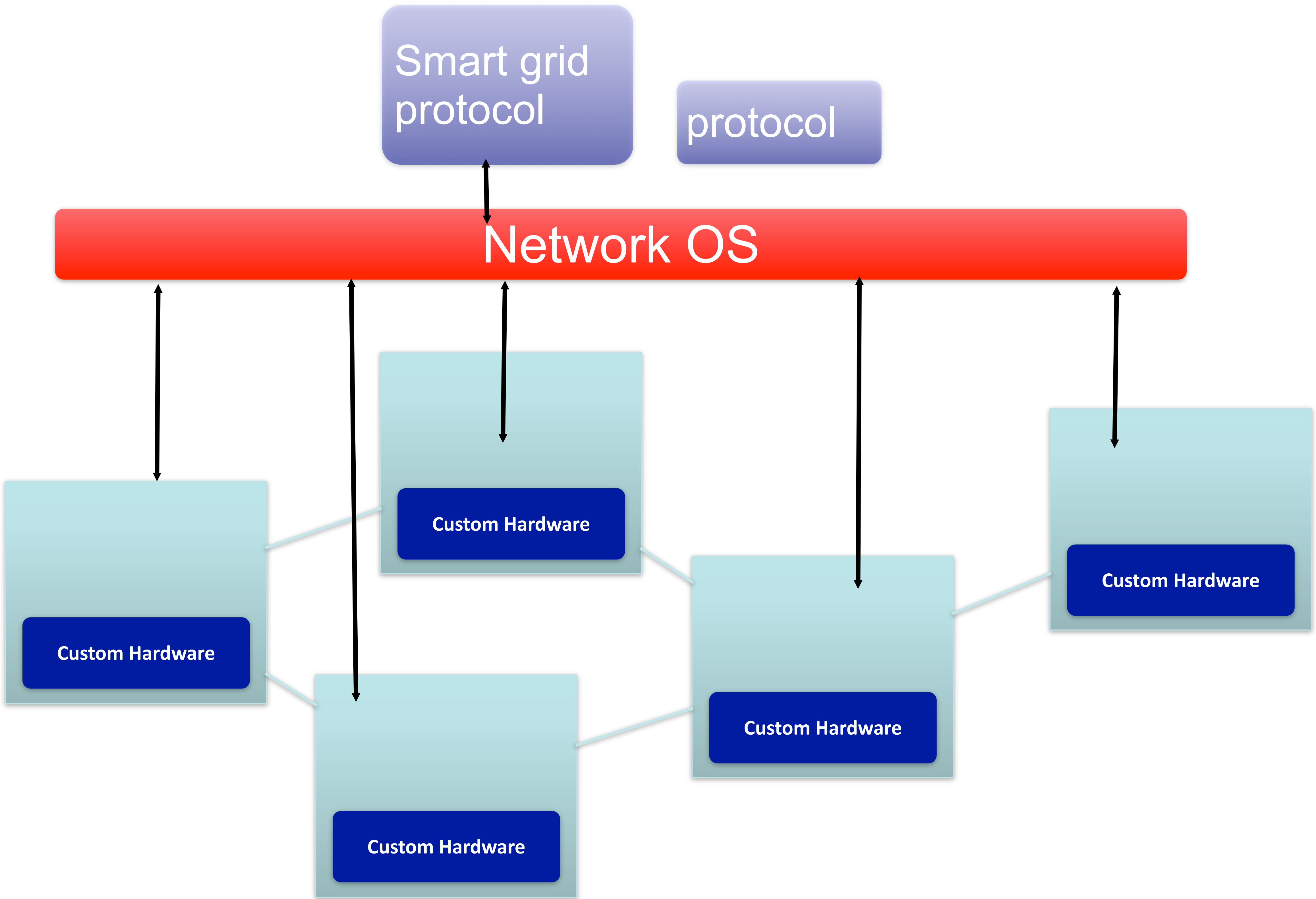


OpenFlow: Open Smart Grid Control Plane



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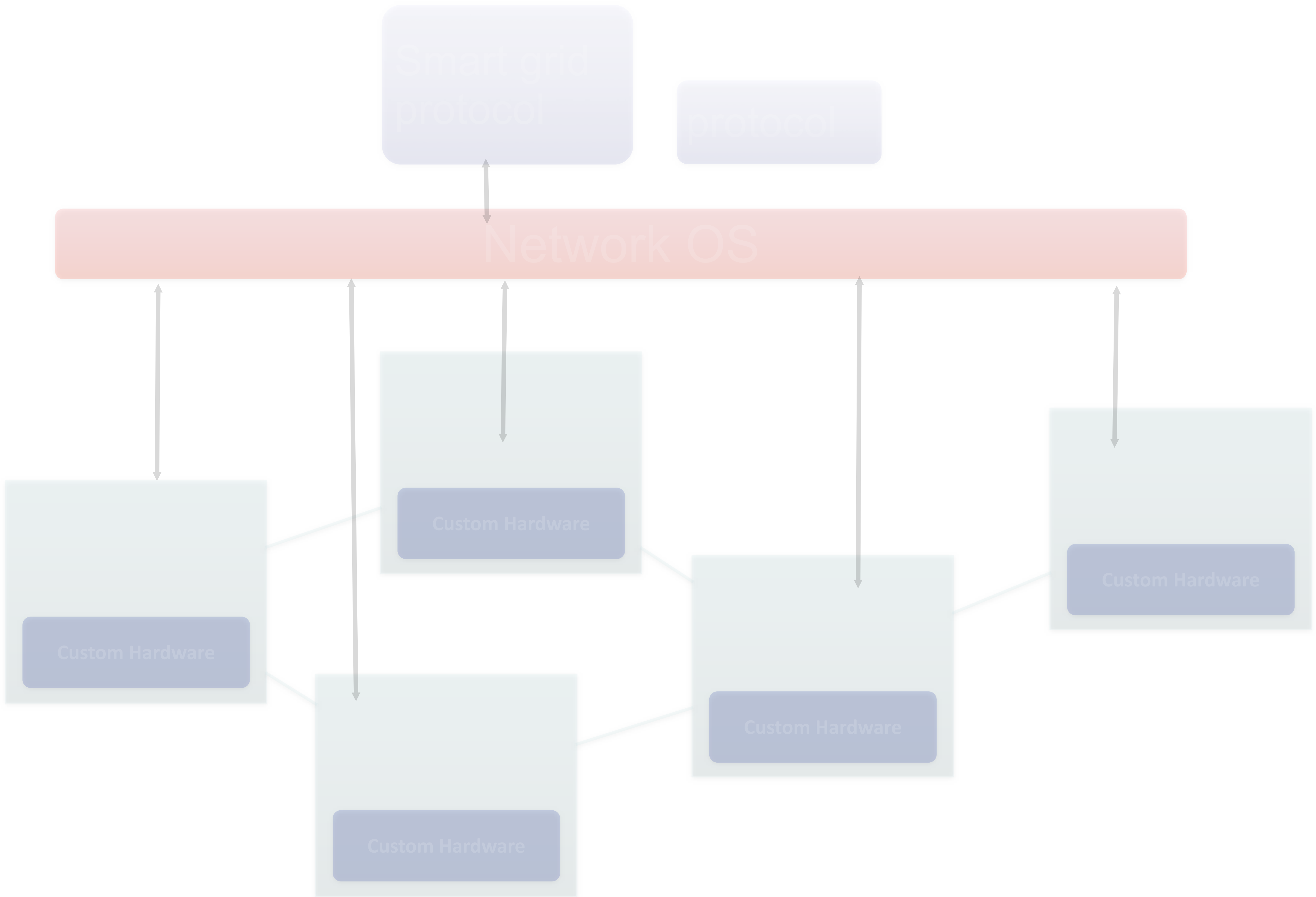

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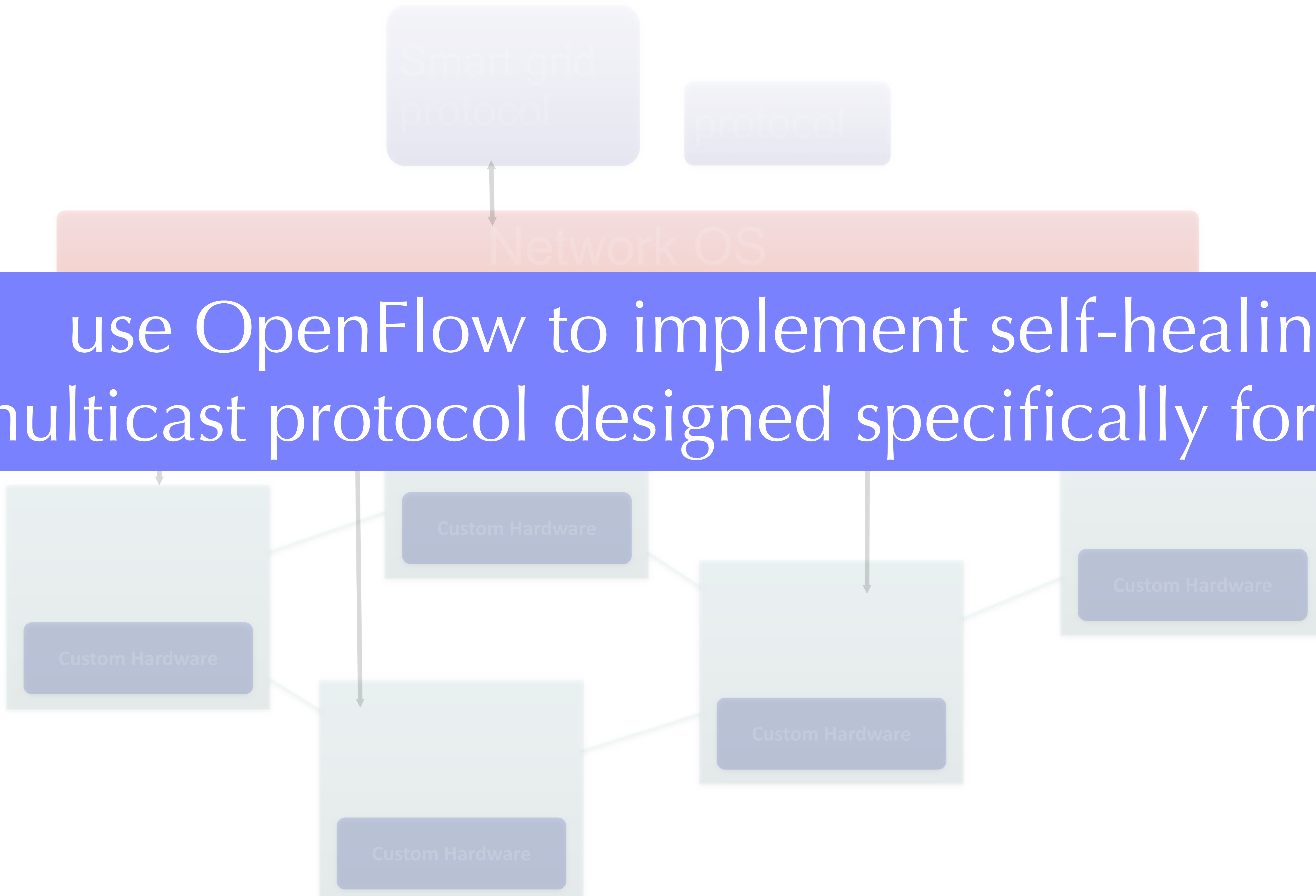

use OpenFlow to implement self-healing multicast protocol designed specifically for grid

Why Develop a New Solution?

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- public Internet
  - best-effort model unsuitable to meeting hard E2E delay requirements
  - not optimized for power grid conditions
    - small scale, traffic is known

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- MPLS fast reroute: similar to our approach but
  - optimization criteria specified over single MT, we consider criteria across multiple MTs
- Gridstat: does not address link failures

Link Failure Detection

are packets being lost at a given network link?

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- algorithm ensures that upstream and downstream switches consider the same set of packets

MIN-FLOWS Backup Multicast Trees

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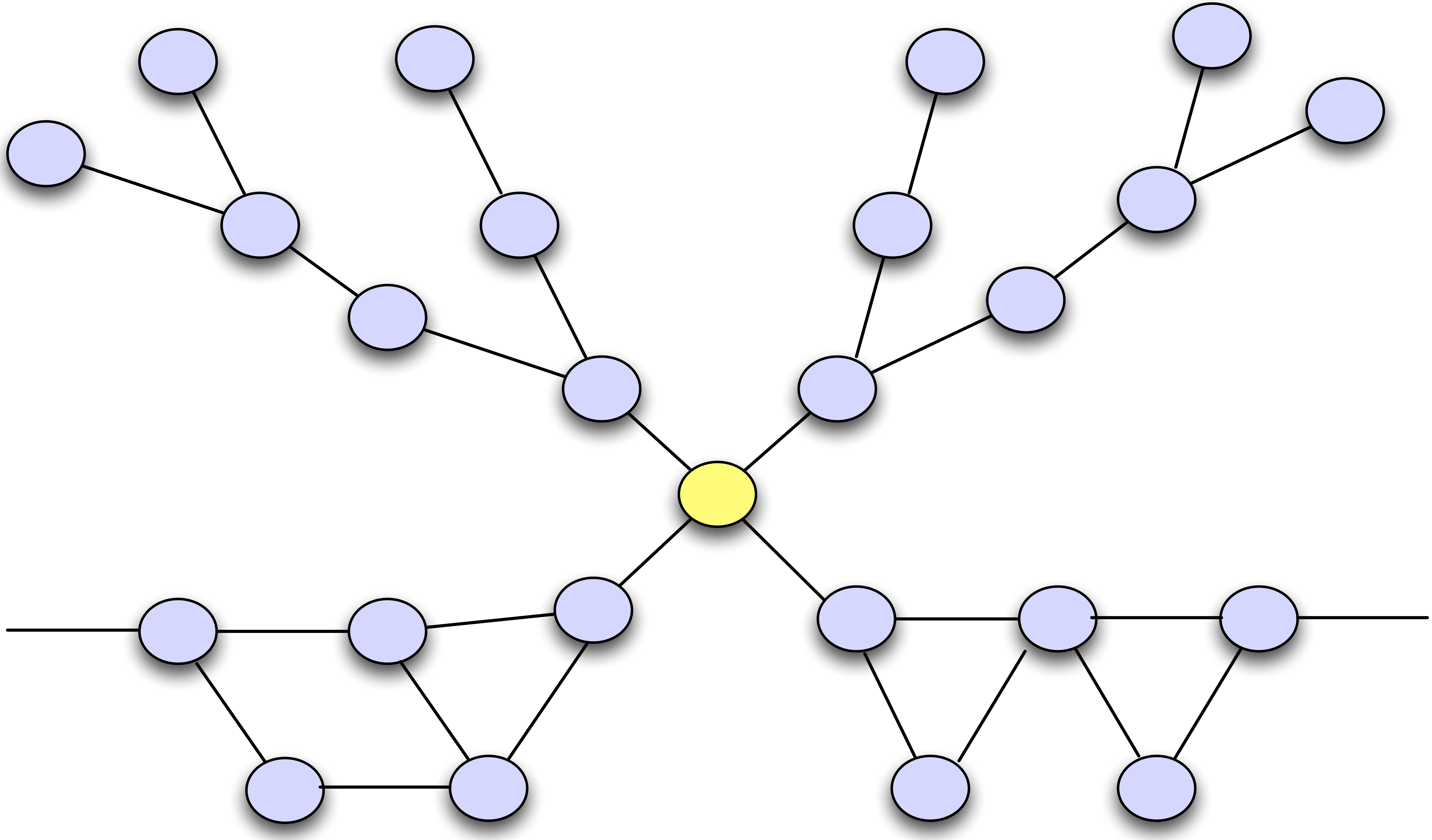
INTUITION: quick installation of backup multicast trees because fewer switches to signal

delay requirements are met using T_l

Talk Outline

- thesis introduction
- placement of smart grid sensors to enable measurement error detection
- recovery from failed communication links in a smart grid
- recovery from malicious nodes injecting false routing state
- outline for future work and conclusions

Ch 3: Network Router Failure



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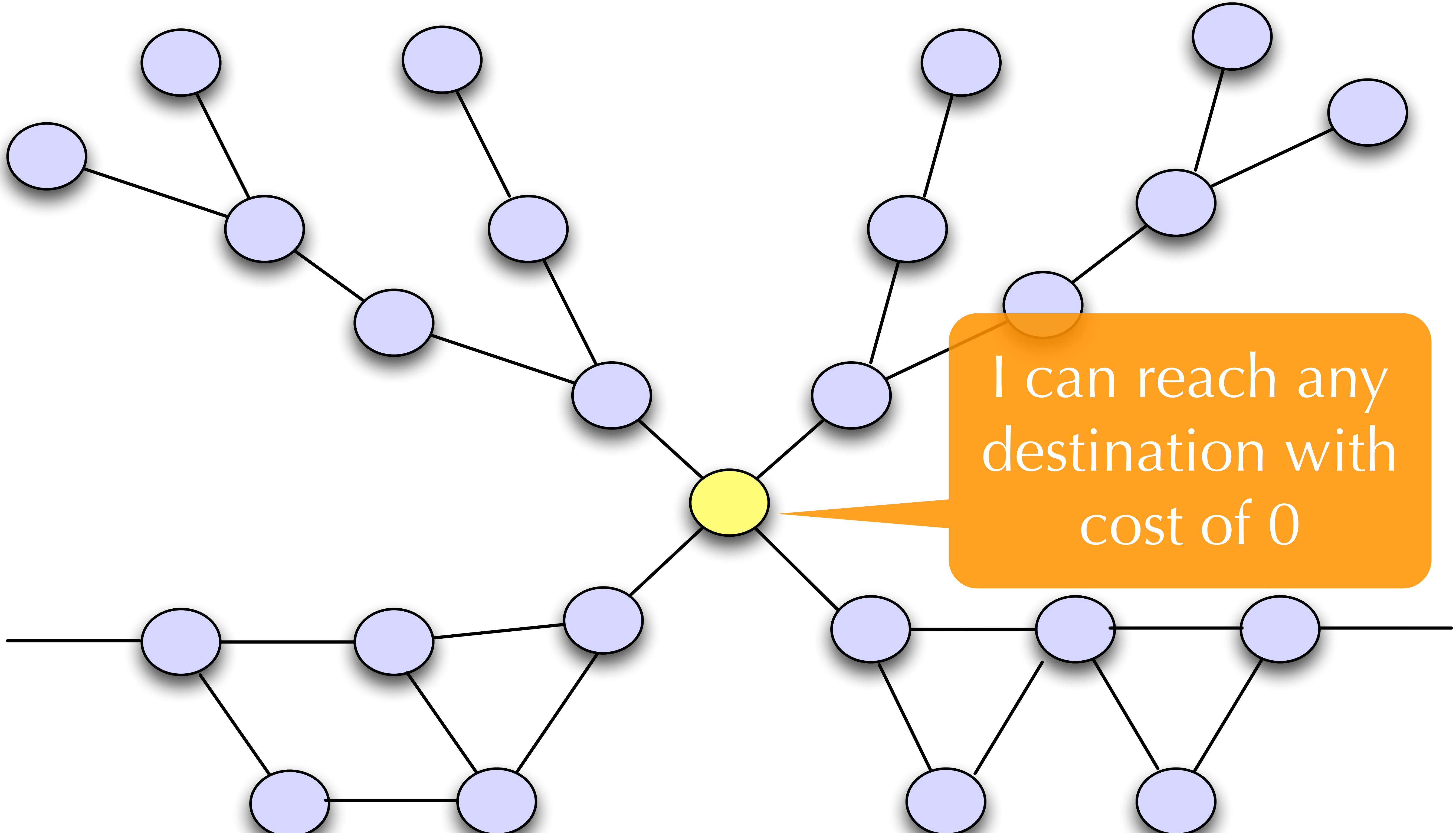

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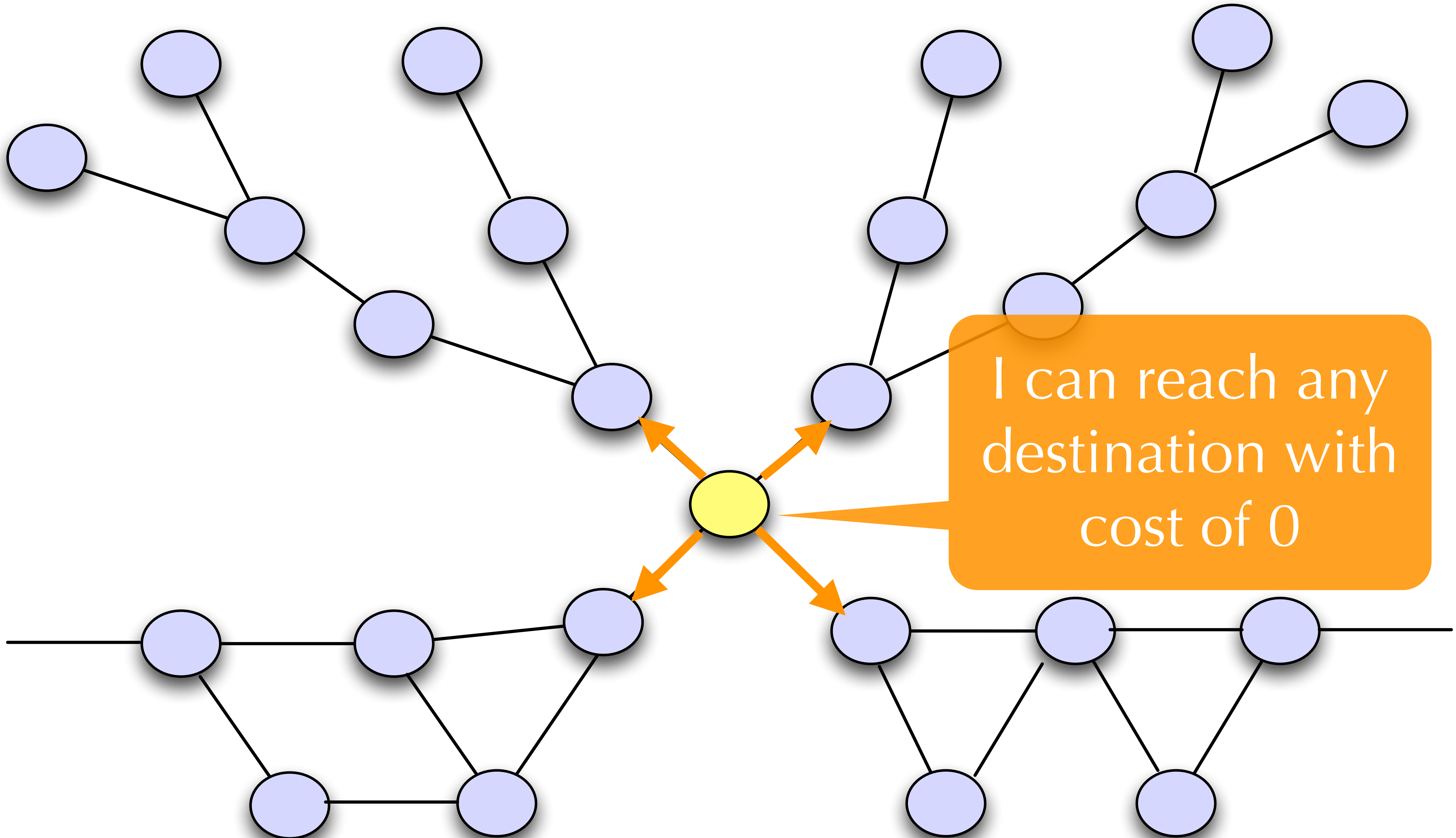

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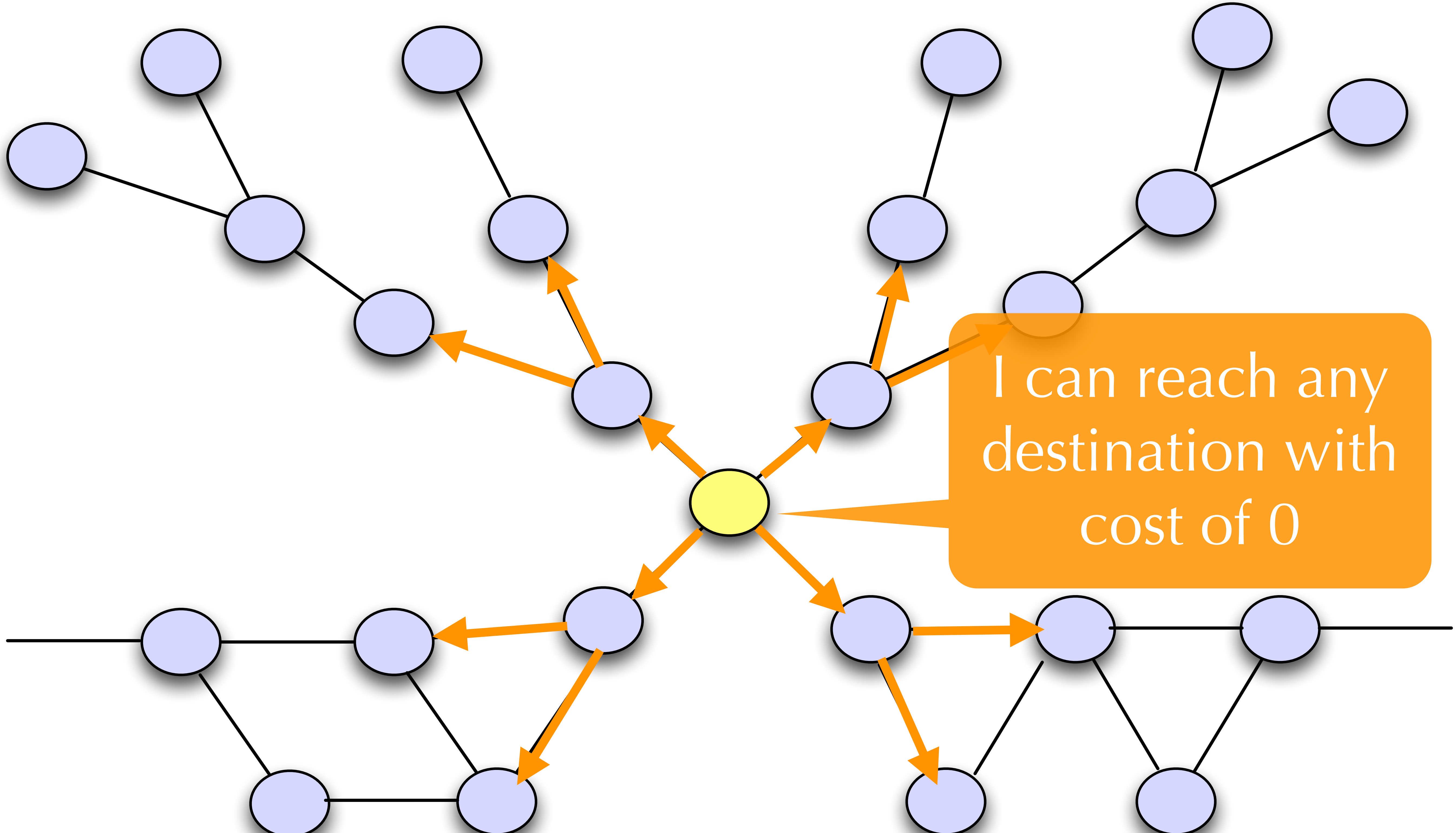

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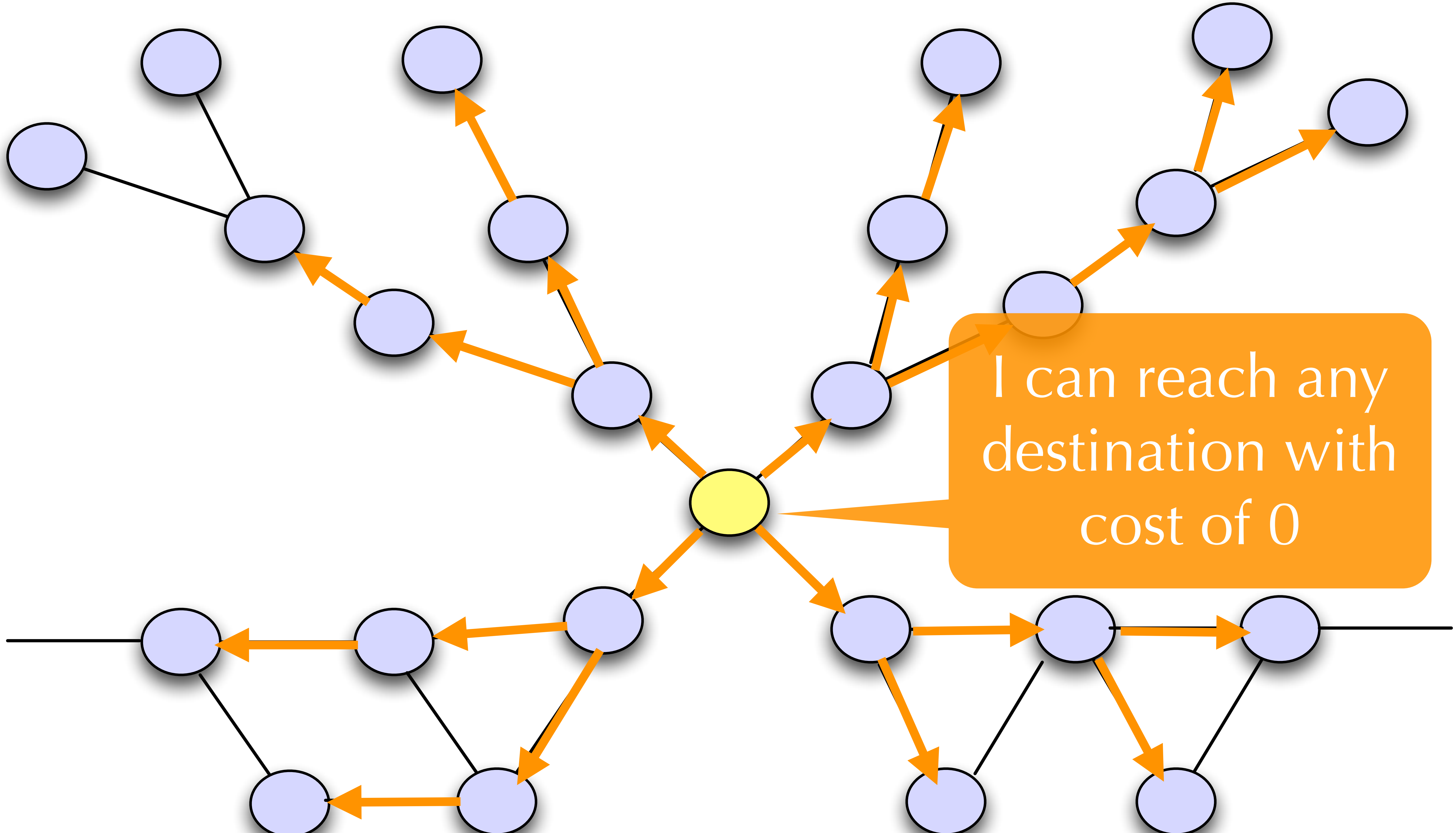

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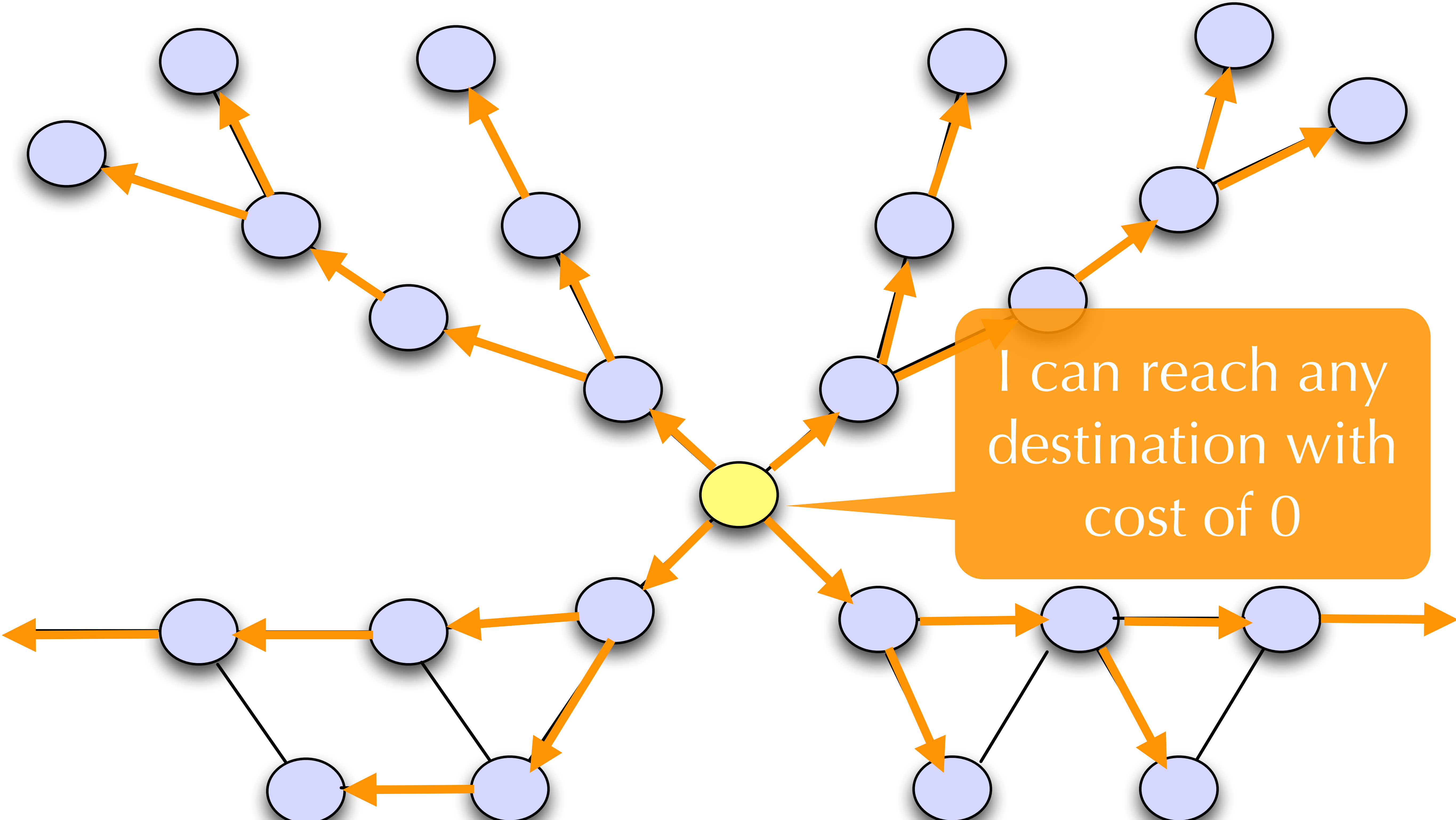

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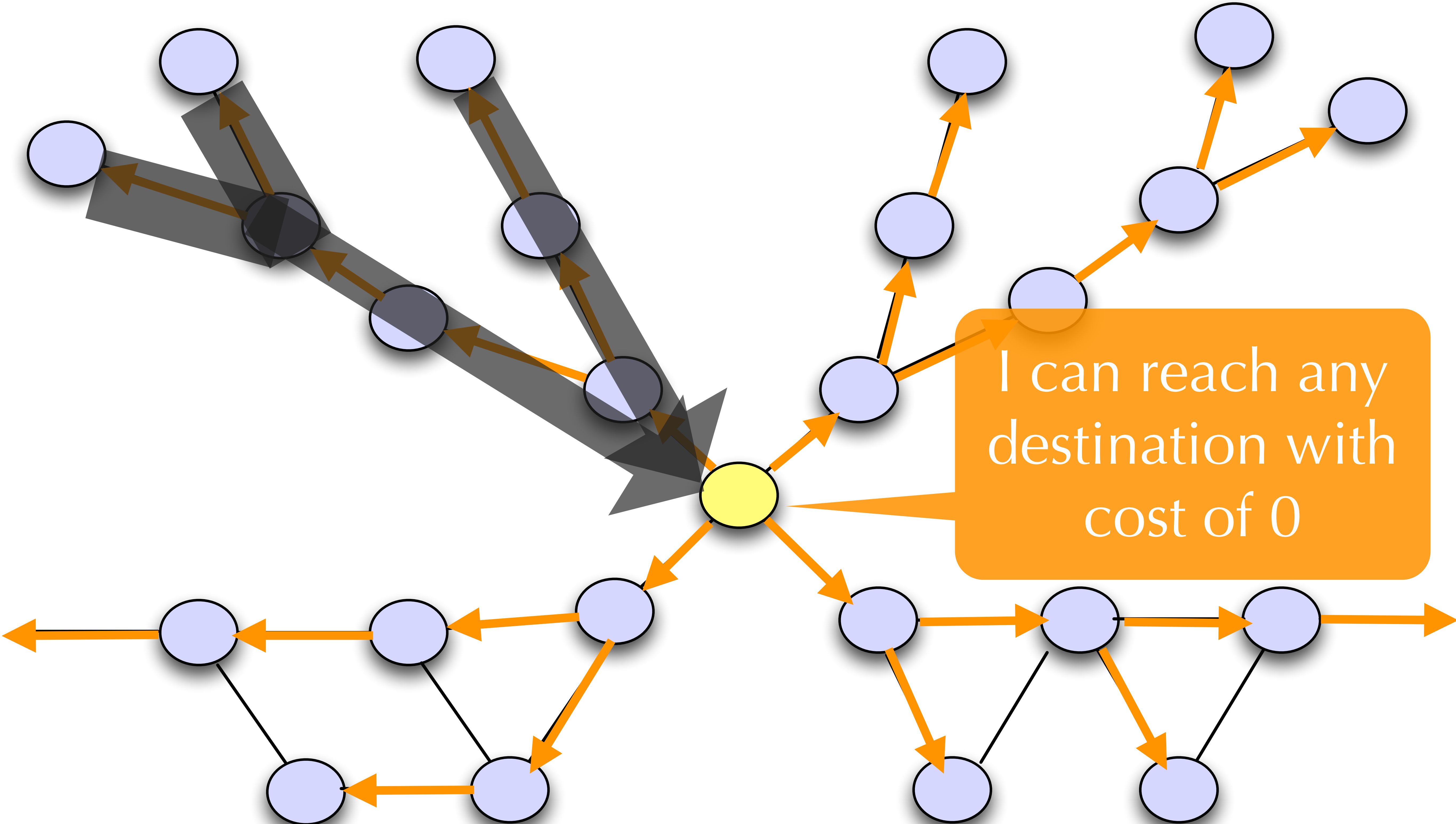

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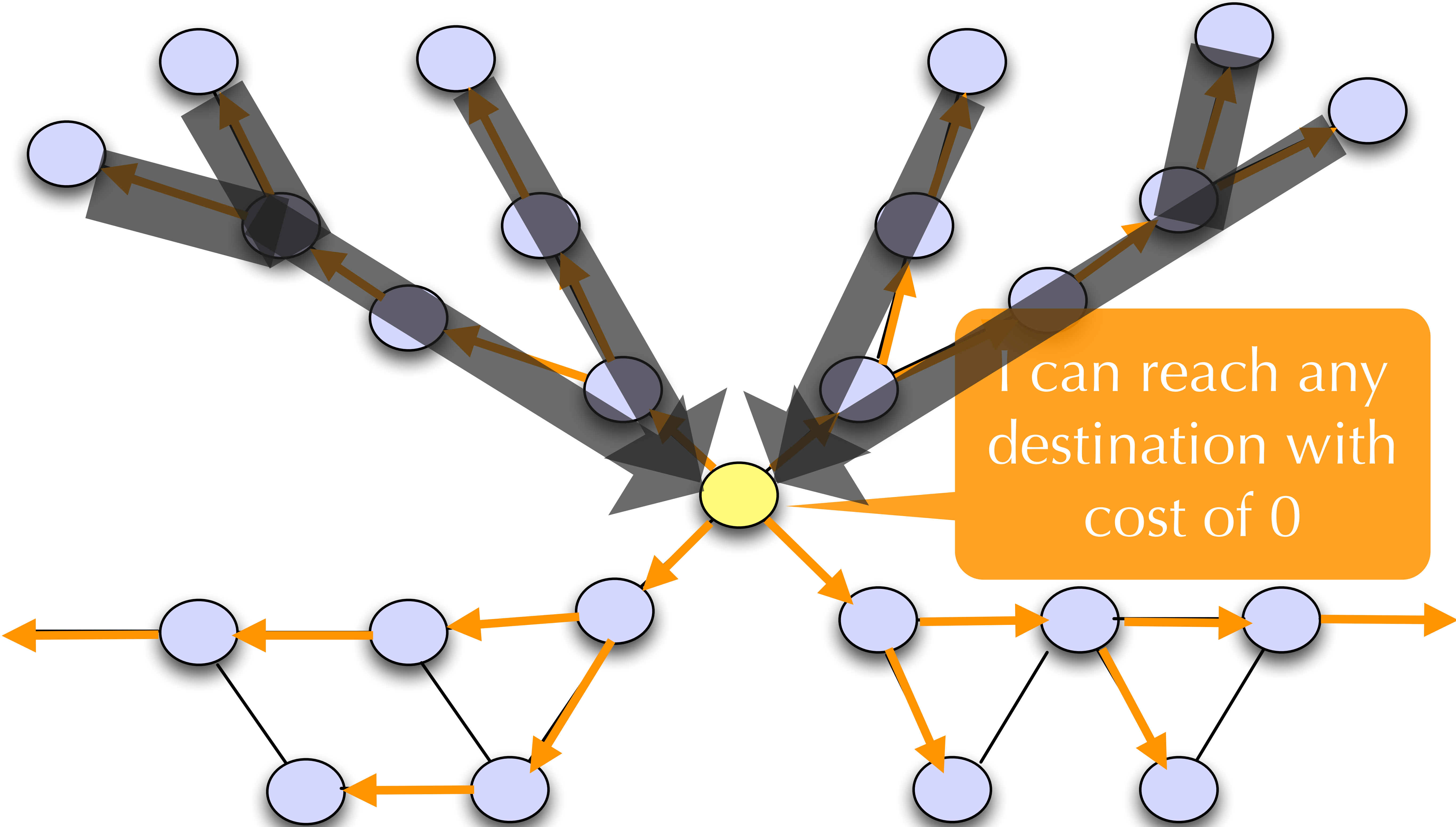

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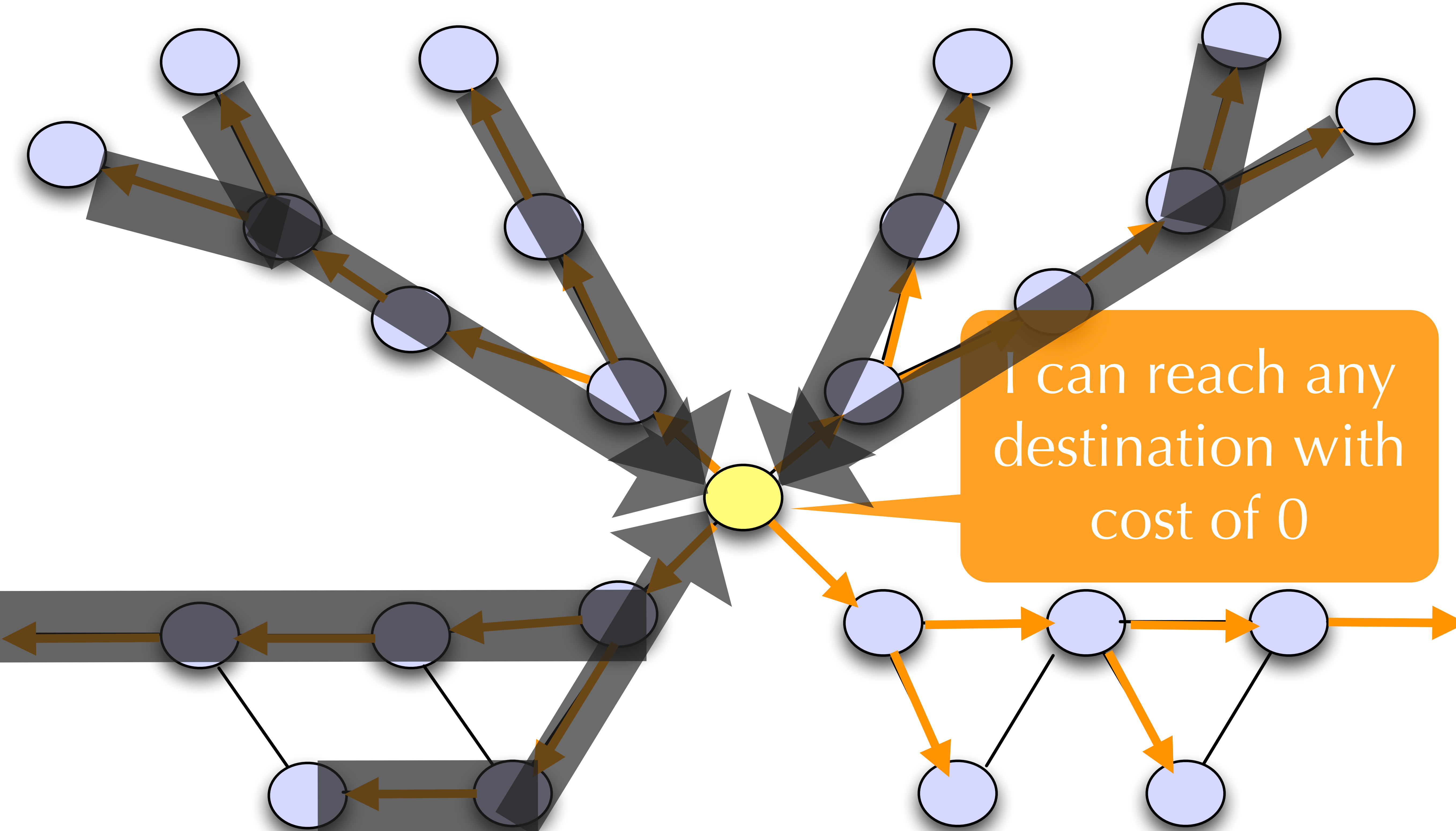

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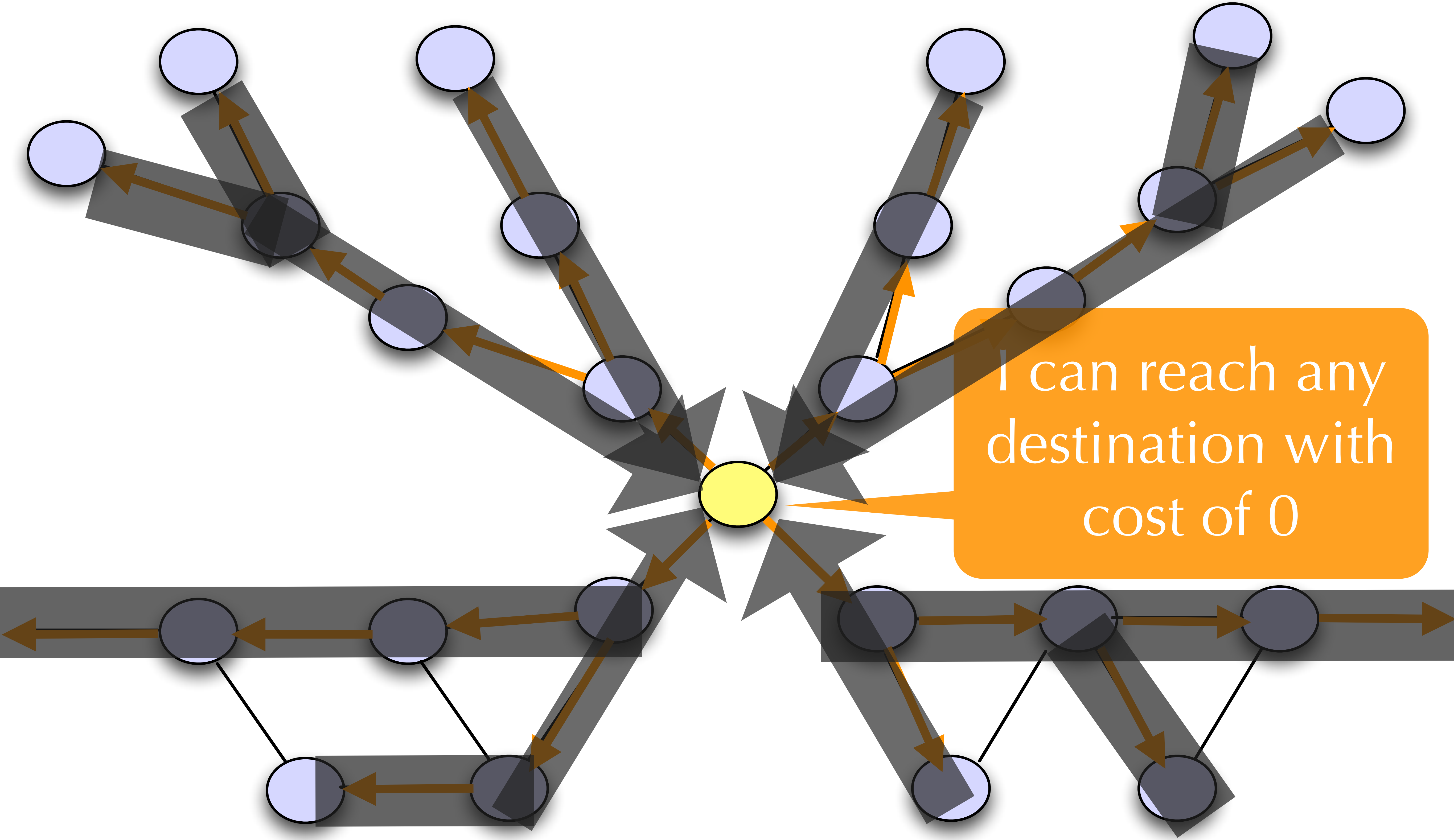

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    a. remove compromised nodes from graph

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1. nodes share false routing state
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3. recover
    a. remove compromised nodes from graph
    b. compute least cost paths that route around compromised nodes

2nd BEST Recovery Algorithm

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1. locally remove false routing state

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2. initiate new distance vector computation to recompute new least cost paths that route around compromised node

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(+) simple, (−) risk of routing loops

PURGE Recovery Algorithm

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1. globally remove false routing state

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(+) removes all routing loops

CPR Recovery Algorithm

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CPR (**C**heck**P**oint and **R**ollback)

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1. Each node rolls back to checkpoint taken before node is compromised
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   - computes new least cost paths that route around compromised node + updates any

(+) remove stale state w/ rollback, (–) requires synchronized clocks, (–) storage overhead

Related Work

- PURGE is similar to Garcia-Luna-Aceves DUAL algorithm for loop-free routing
  - both use diffusing computations
- CPR borrows ideas from
  - database crash recovery
  - recovery from malicious but committed database transactions

Simulation Scenario

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1. all nodes correctly compute least cost paths

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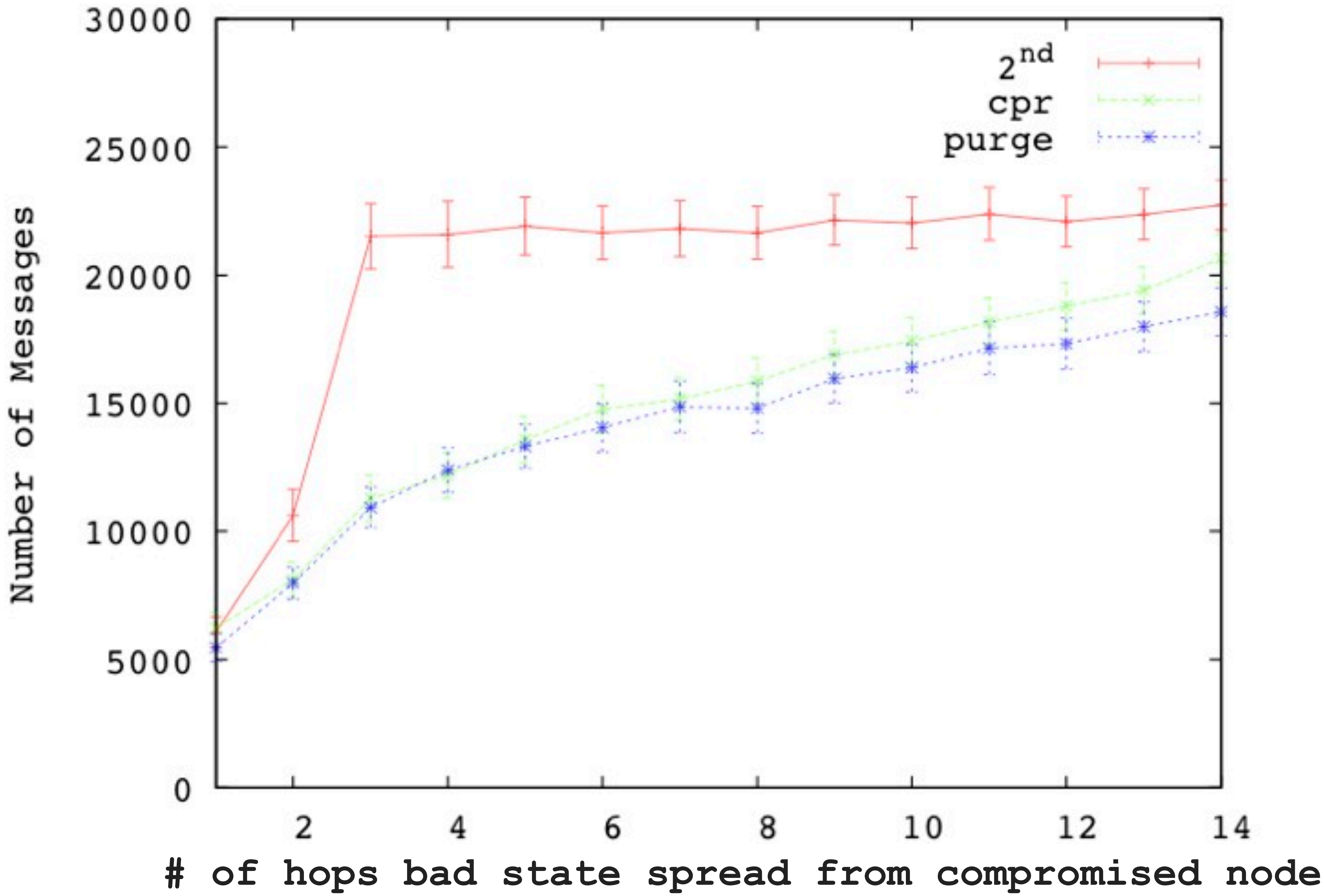
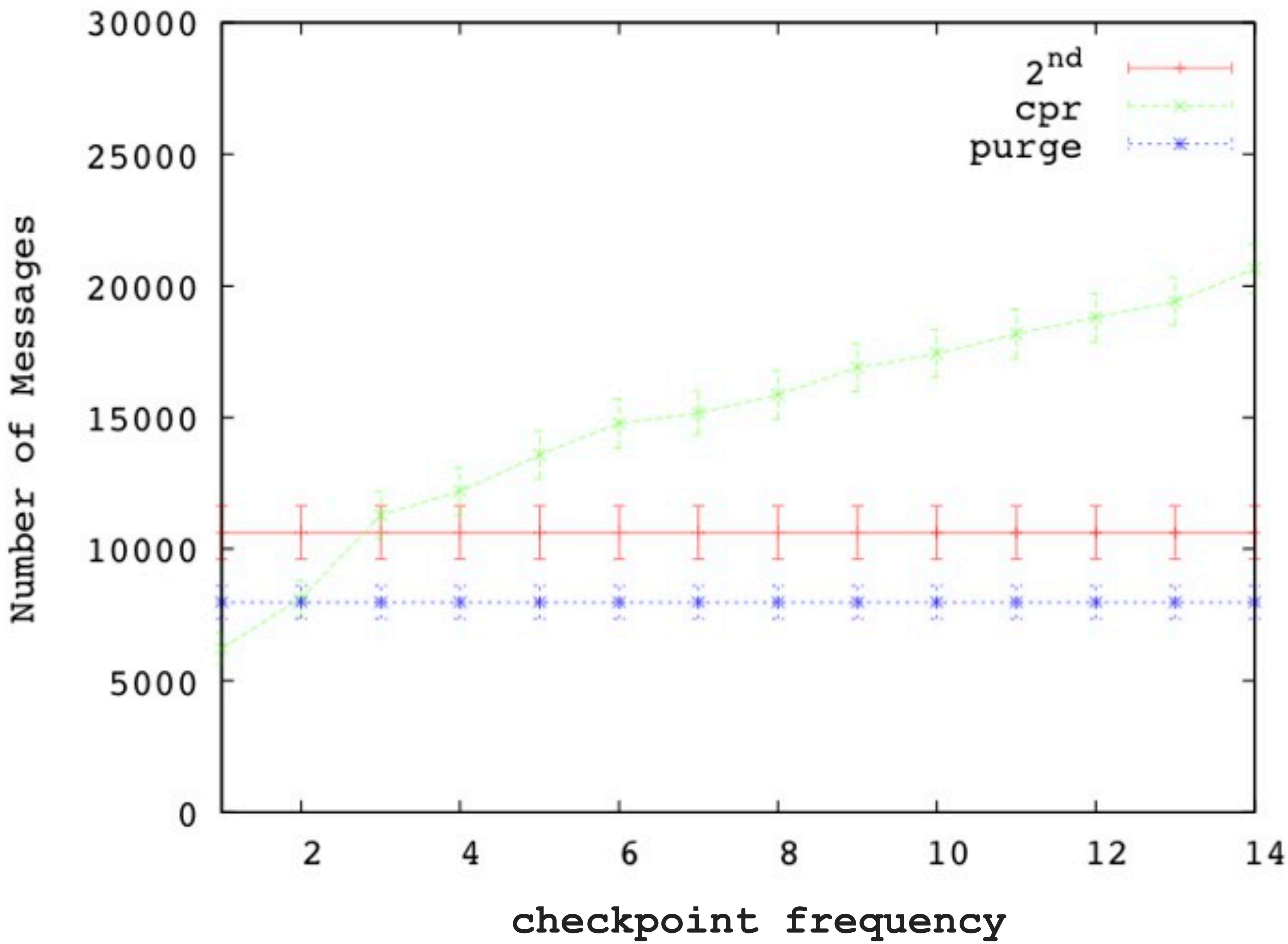
- show results for Erdos-Renyi graphs
  - `n=100`, link weights between `[1,100]`

msgs vs # hops bad state spreads



- 2ND BEST: many routing loops
- CPR: has stale state after rollback + assumes synch clocks
- PURGE: no routing loops + no stale state during recovery

How to Set Checkpoint Frequency?



- CPR: less frequent checkpoints => more overhead
- 2ND BEST and PURGE: constant overhead b/c neither algorithm checkpoints

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Thesis Timeline: Completed Work

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- Ch 1: “Recovery from False Routing State in Distributed Routing Algorithms”
  - published in *IFIP Networking 2010 Conference*
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- Ch 2: “PMU Sensor Placement for Measurement Error Detection in the Smart Grid”
    - published in *e-Energy 2012*
    - done (unless committee has suggestions)

Thesis Timeline: Work in Progress

- Ch. 3: "Recovery from Link Failures in Smart Grid Communication Network"
  - problem well-defined
  - algorithms, implementation, analysis, and evaluation yet to be completed

Thesis Timeline: Work In Progress

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- Ch. 3 milestones

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    2 weeks - May
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    3 weeks - June

Thesis Summary

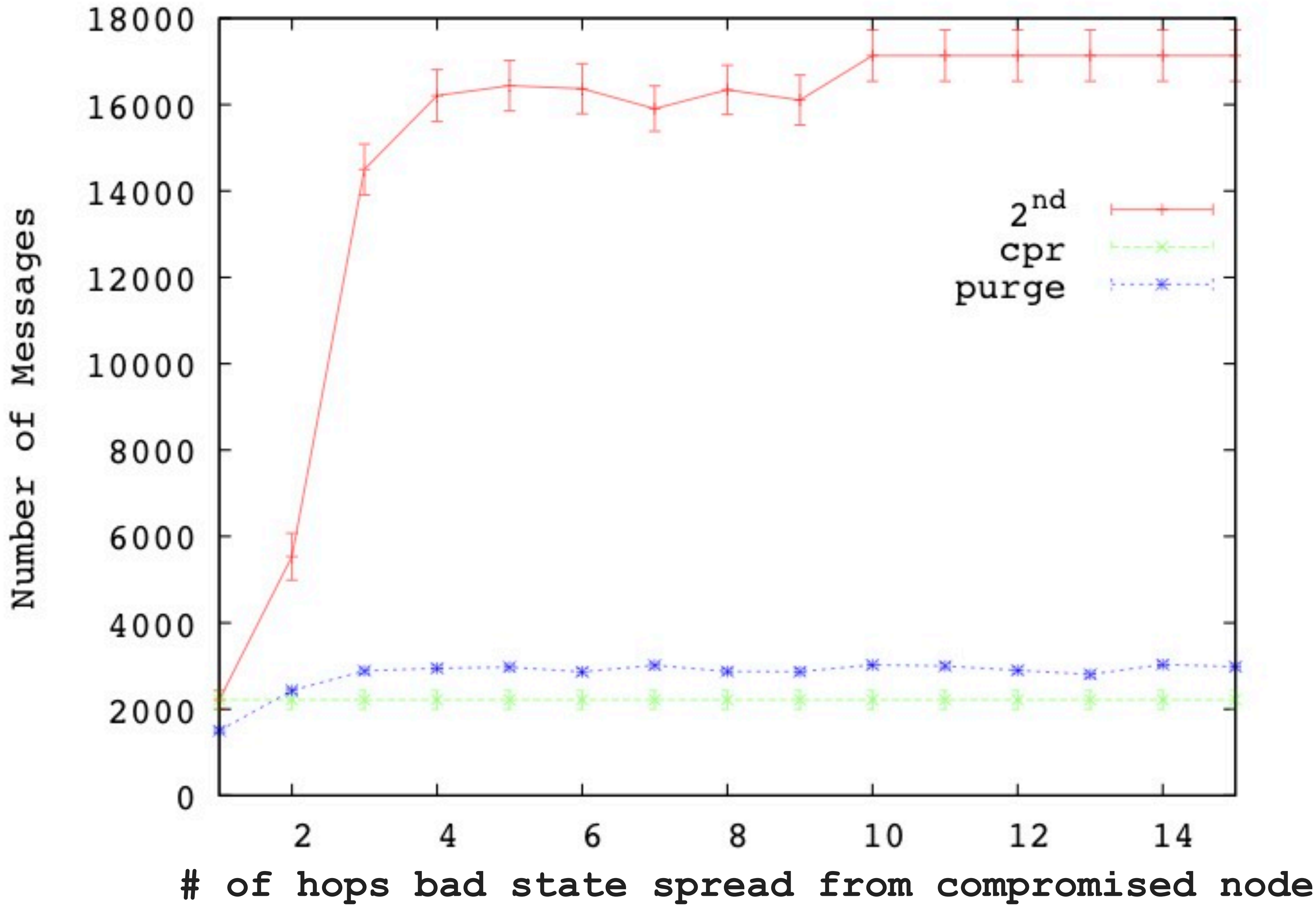
- consider failure of network components
  - router spreading false routing state
  - smart grid sensor measurement error
  - link failures in smart grid communication network
- proposed algorithms for automated recovery

Thank you.

Questions/Comments?

Backup Slides

Sim 1: Fixed Link Cost Graphs

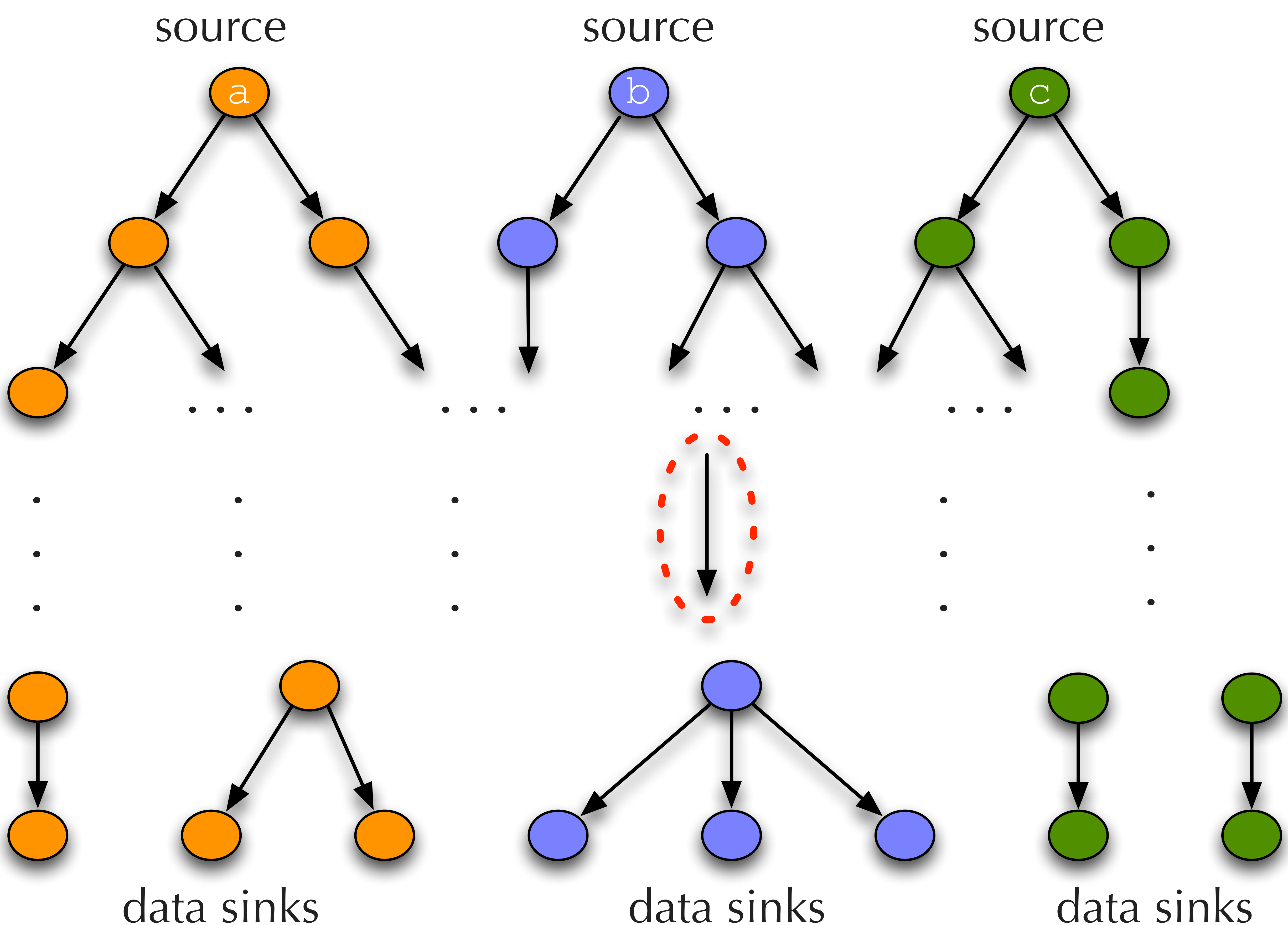


- 2ND BEST: many routing loops
- CPR: removes state with checkpoint and rollback
- 2ND BEST and PURGE: use iterative distance vector

Summary of Simulation Results

- 2ND BEST suffers from routing loops
- CPR is effective because rolling back quickly removes false routing state
- CPR assumes synchronized clocks
- PURGE removes routing loops and has no stale state

Communication Link Failures



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- many data sources
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- many sinks with interests in subset of data
  - utility companies, balancing authorites

Power Grid Data Dissemination

- SCADA currently used
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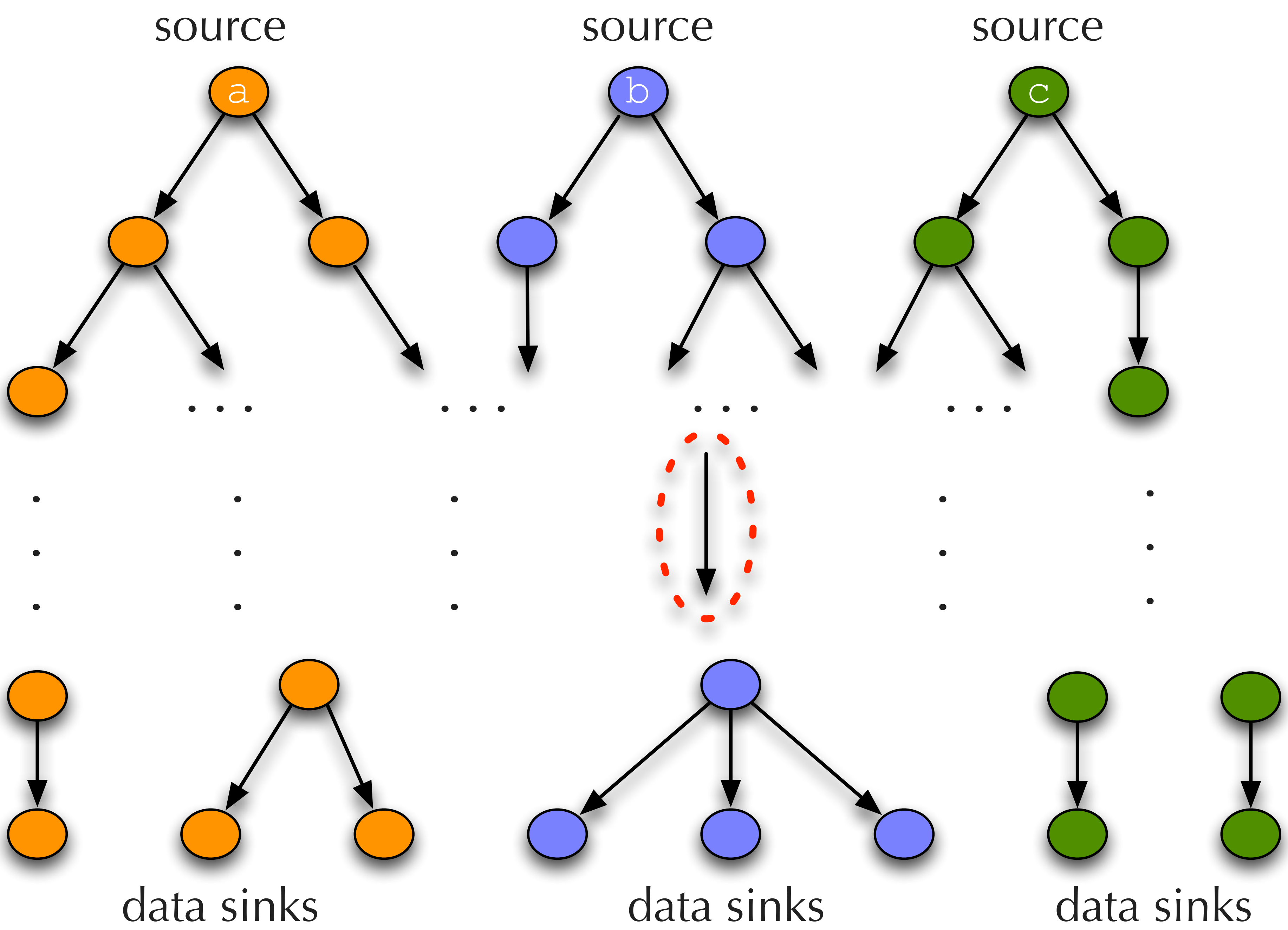
  - no wide-area dissemination
- many data sources
  - PMUs, IEDs, fault recording devices, ...
- many sinks with interests in subset of data

great opportunity for richer wide-area data dissemination (big reason for the smart grid)

Problem Description



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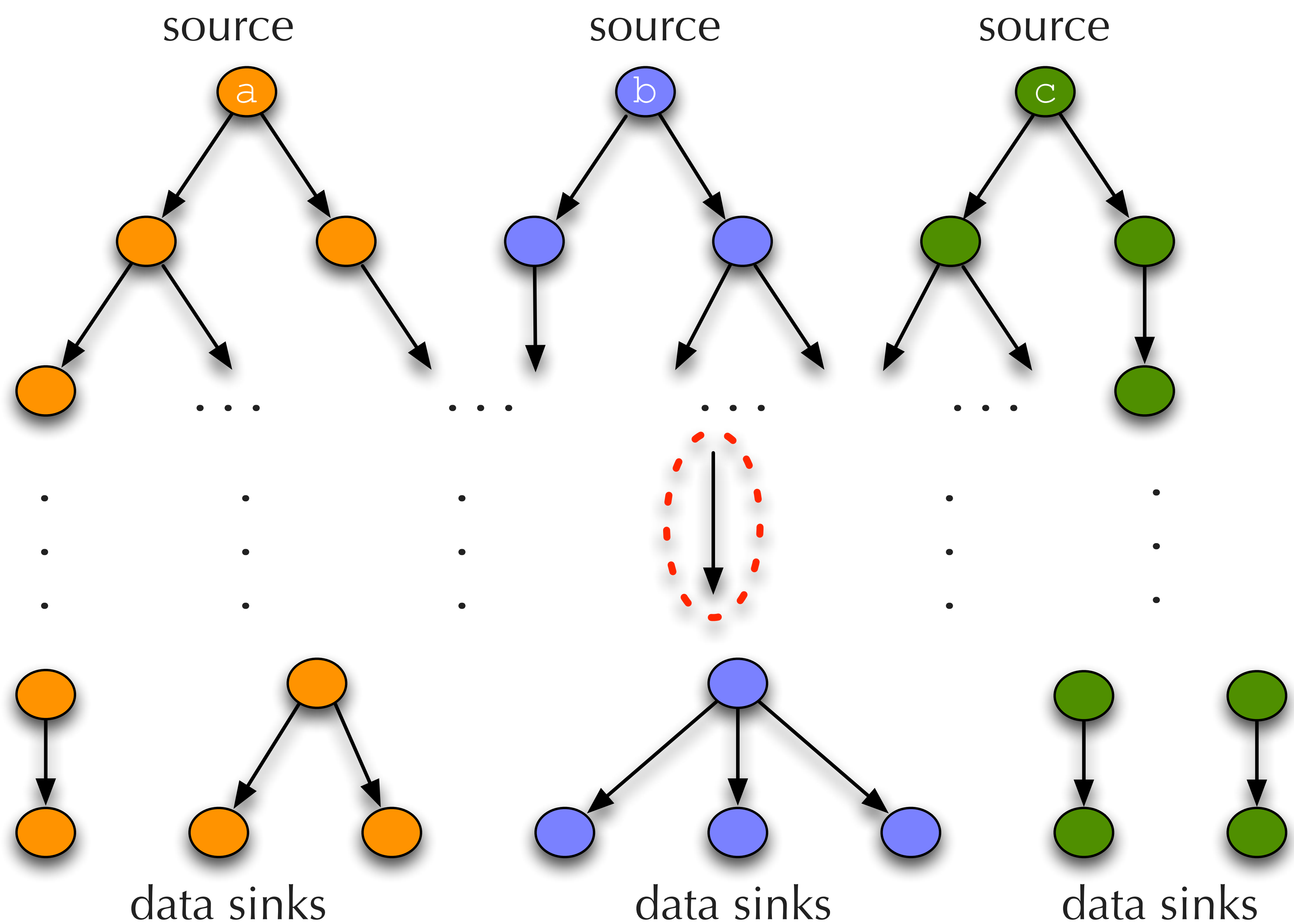
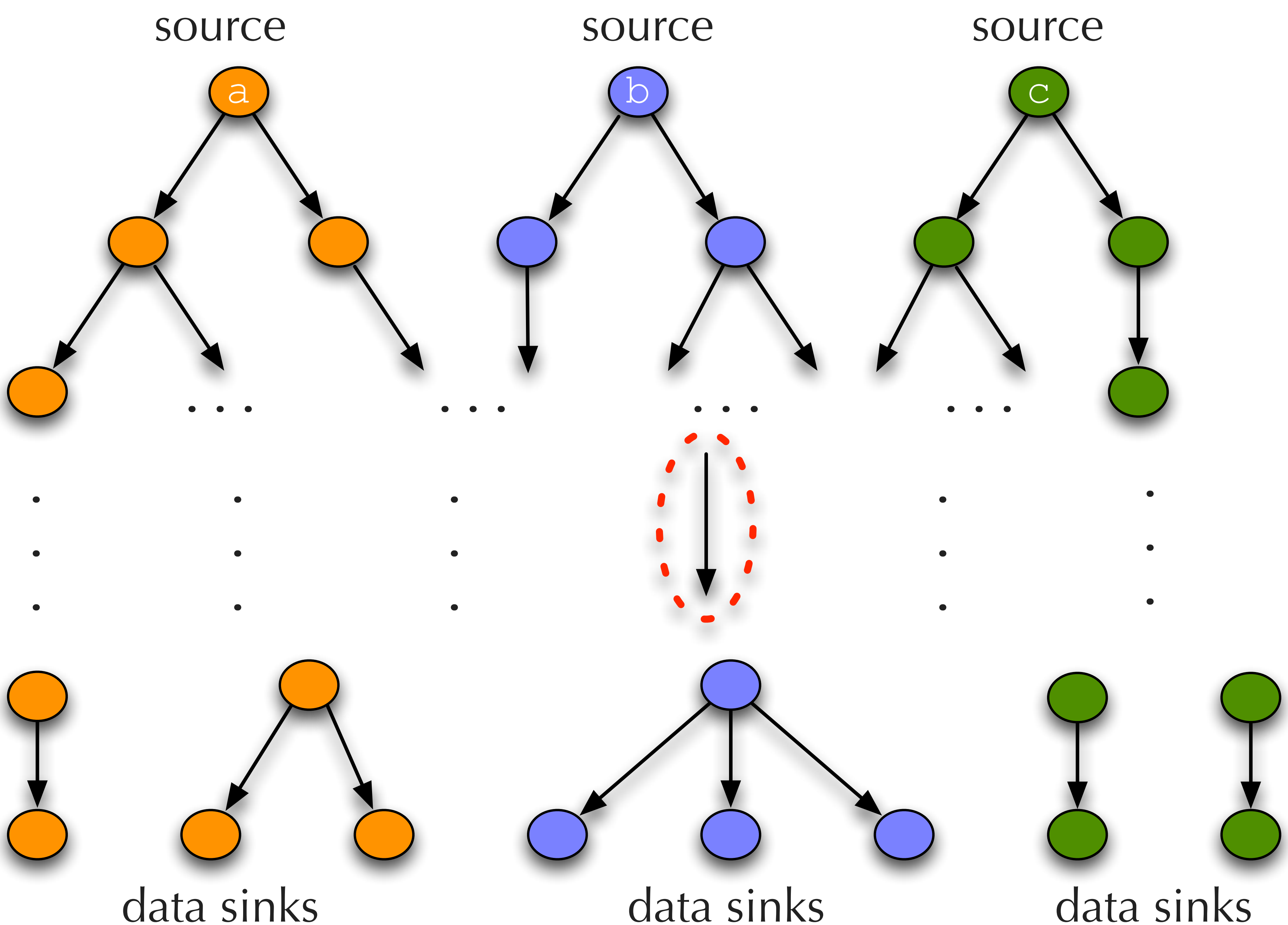


- multiple source-based MTs

Problem Description



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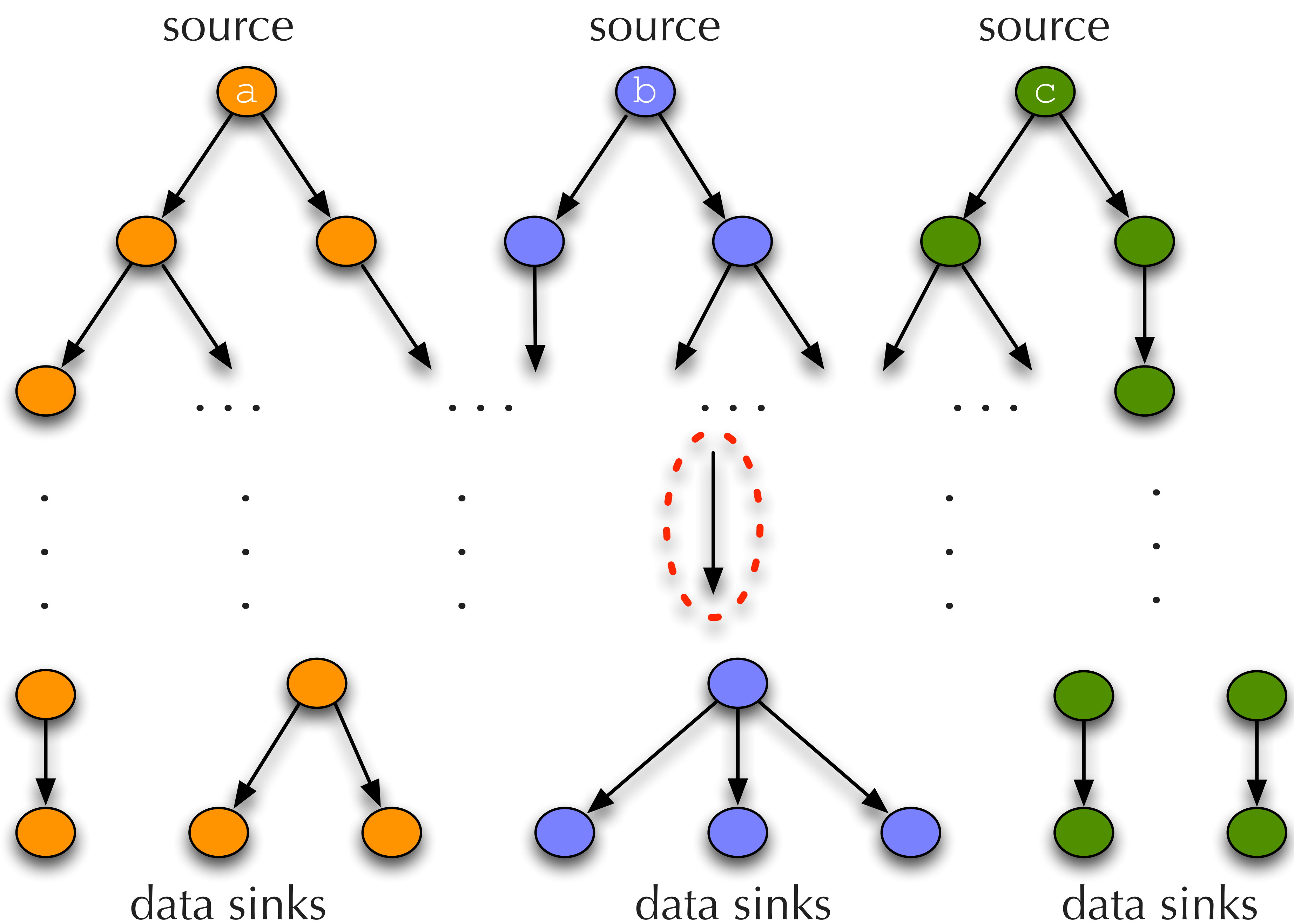

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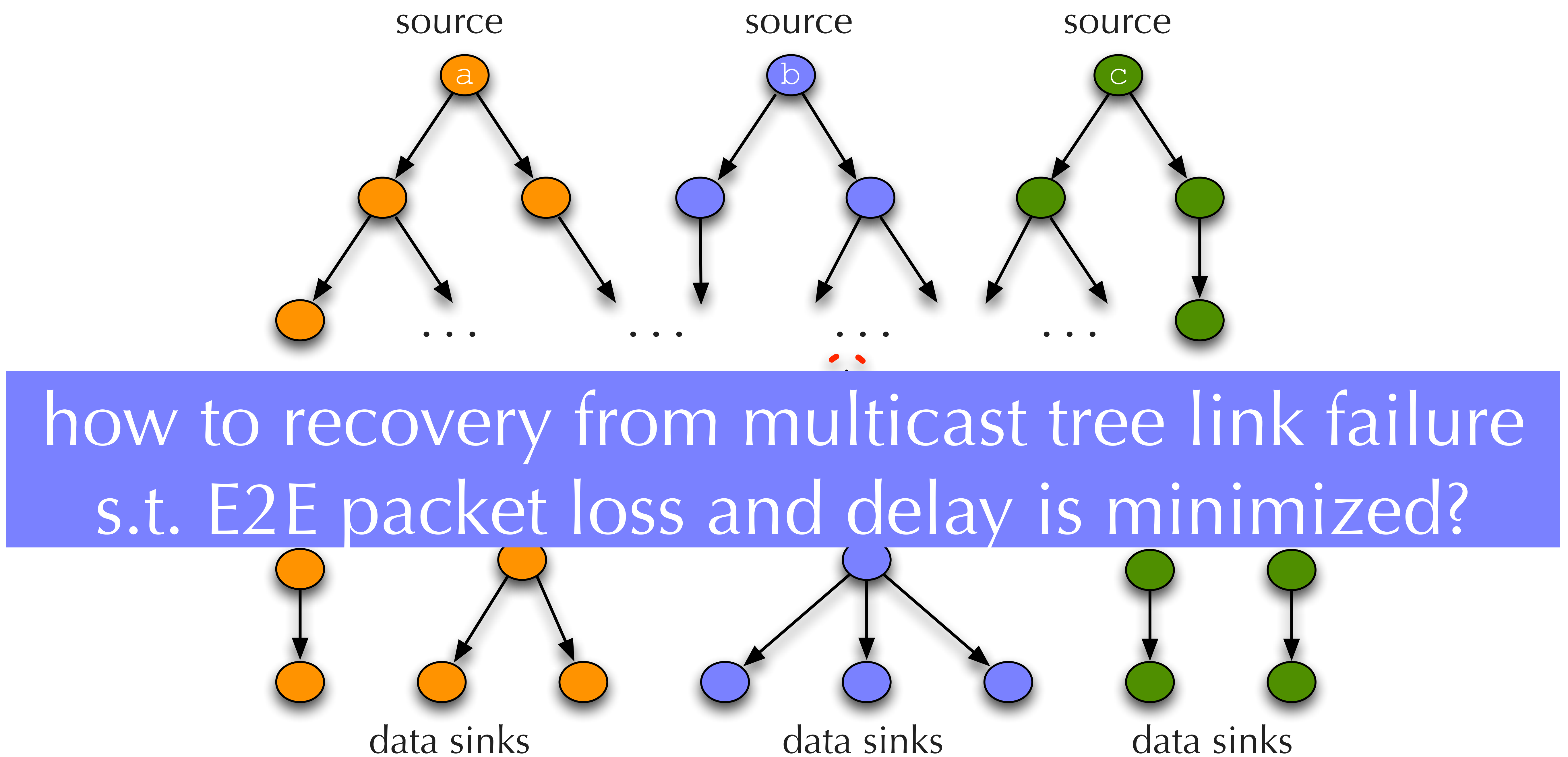

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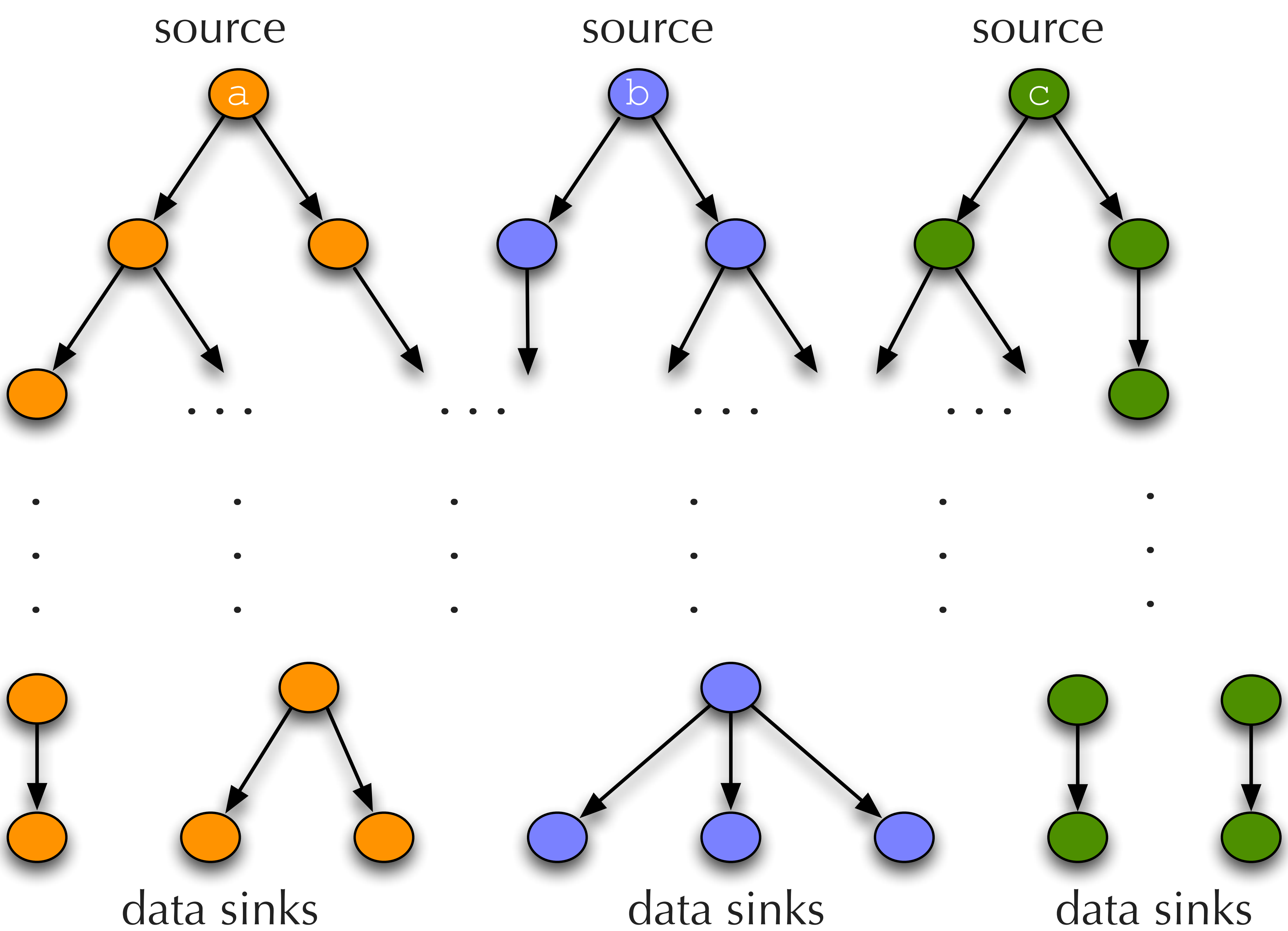

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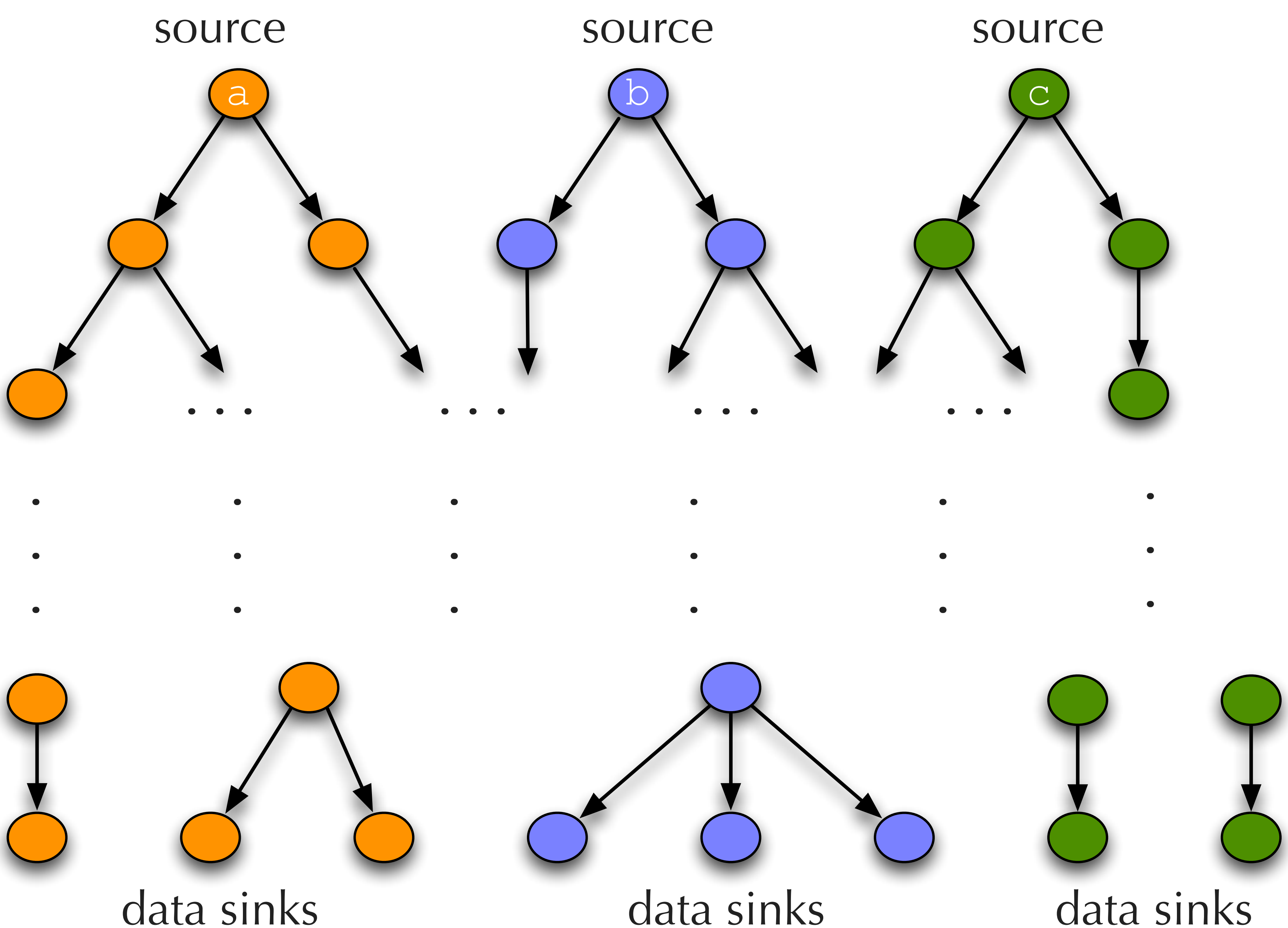

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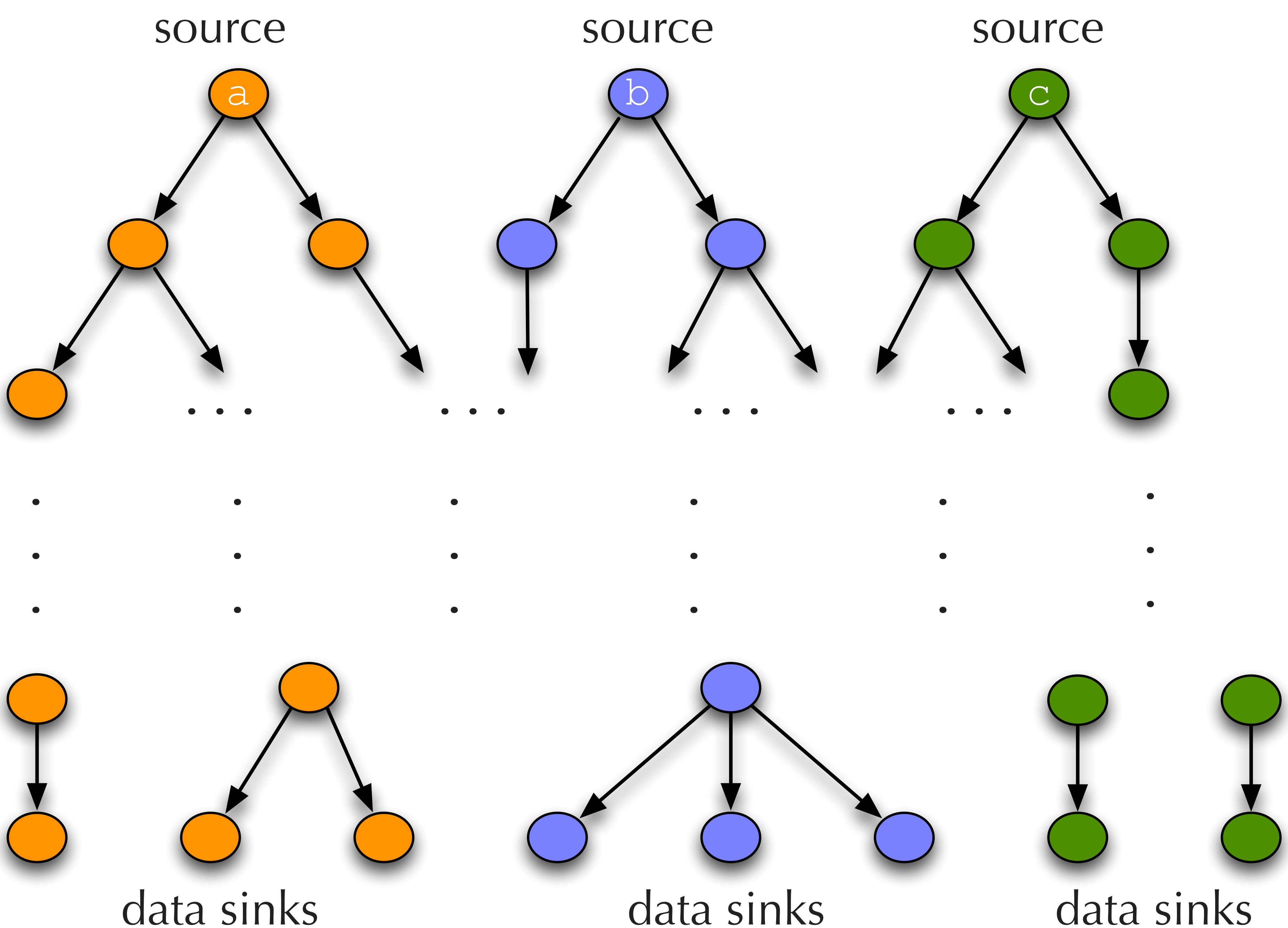

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