Path Vector Face Routing: Geographic Routing with Local Face Information

Ben Leong, Sayan Mitra, and Barbara Liskov
MIT CSAIL

Geographic Routing

- Geographic routing algorithms
  - leverage physical location information
  - scale better than other ad hoc routing algorithms (Karp, 2001)
  - state proportional to network density, not size
  - can be applied using virtual coordinates (Rao et al., 2003)

Geographic Routing

- Existing geographic routing algorithms
  - GPSR (Karp, 2001)
    GFG (Bose, 2001)
  - GOAFR+ (Kuhn, 2003)
  - nodes know only about immediate neighbors
- Can we do better if nodes have more information?

Geographic Routing

- Existing geographic routing algorithms
  - GPSR (Karp, 2001)
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  - nodes know only about immediate neighbors
- Can we do better if nodes have more information? **Yes!**

Greedy Path Vector Face Routing

- Our new algorithm (GPVFR):
  - stores small amount of additional local information (< 200 bytes)
  - improve maximum routing stretch over GPSR by 35 to 40%
  - improve maximum routing stretch over GOAFR+ by 20 to 25%

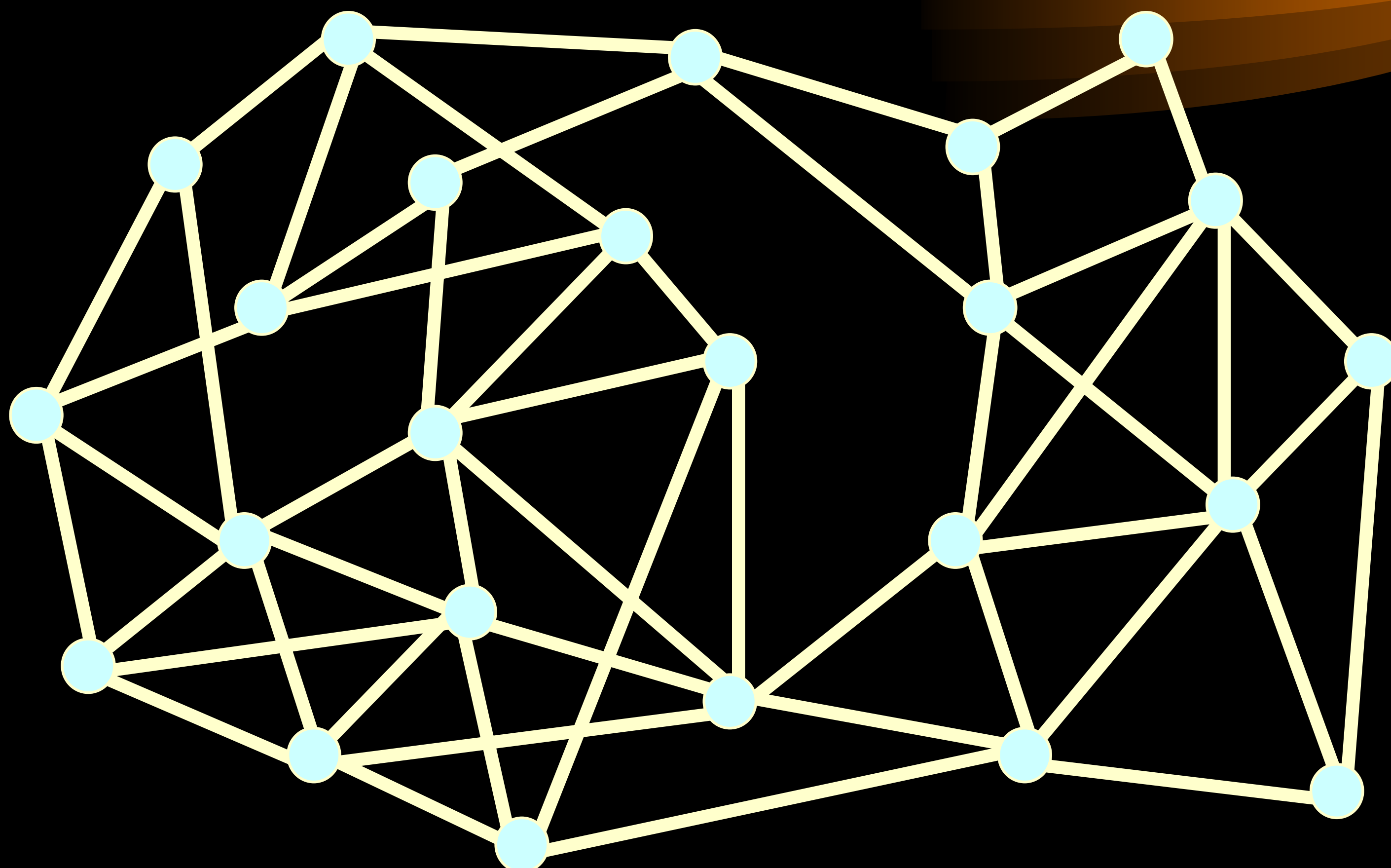
Overview

- Problem
- Approach
- Simulation Results
- Conclusion

Geographic Routing

- Nodes have *x*-*y* coordinates
- Nodes know coordinates of immediate neighbors
- Packet destinations specified with *x*-*y* coordinates
- In general, forward packets greedily

Example



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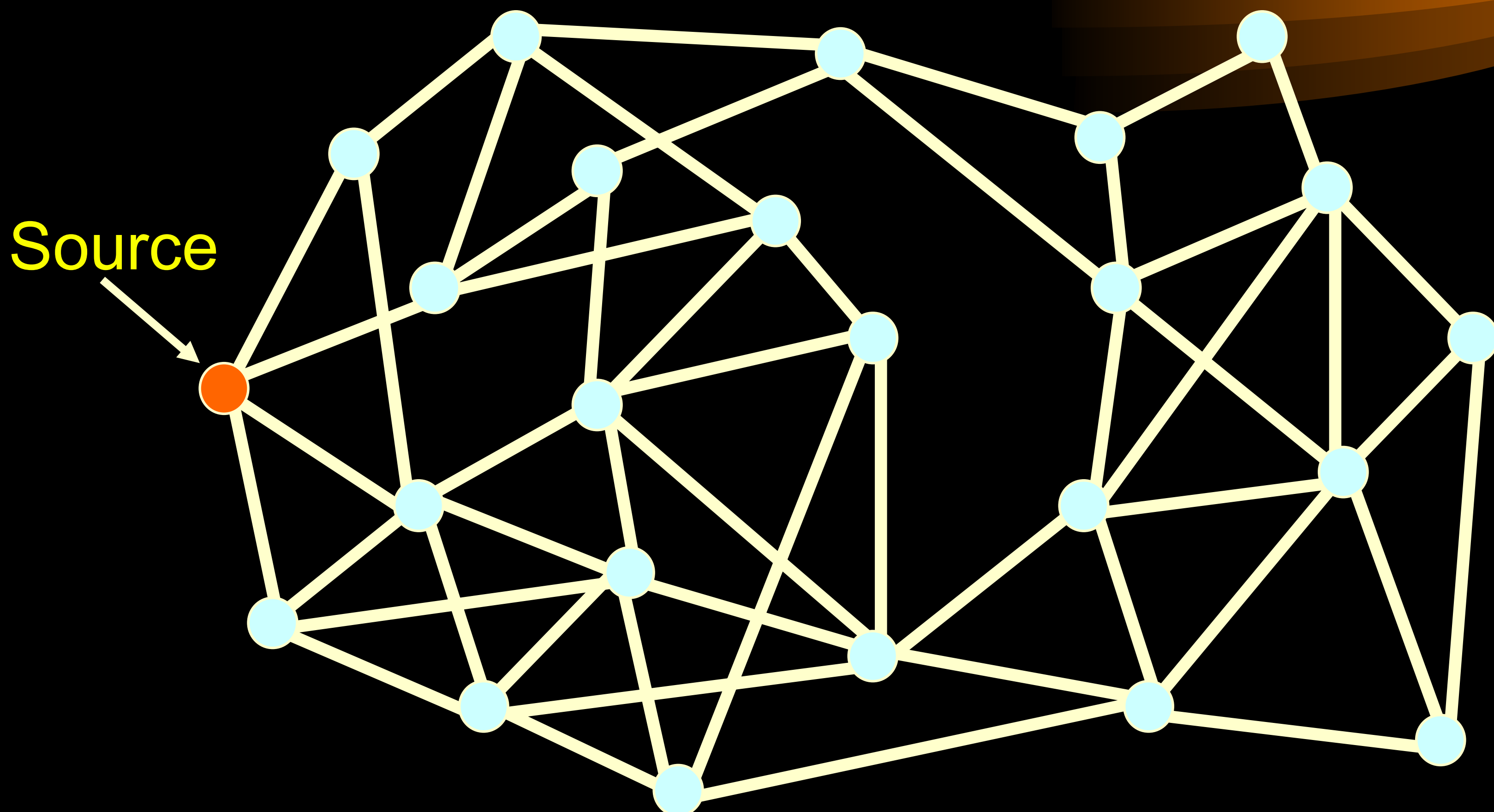

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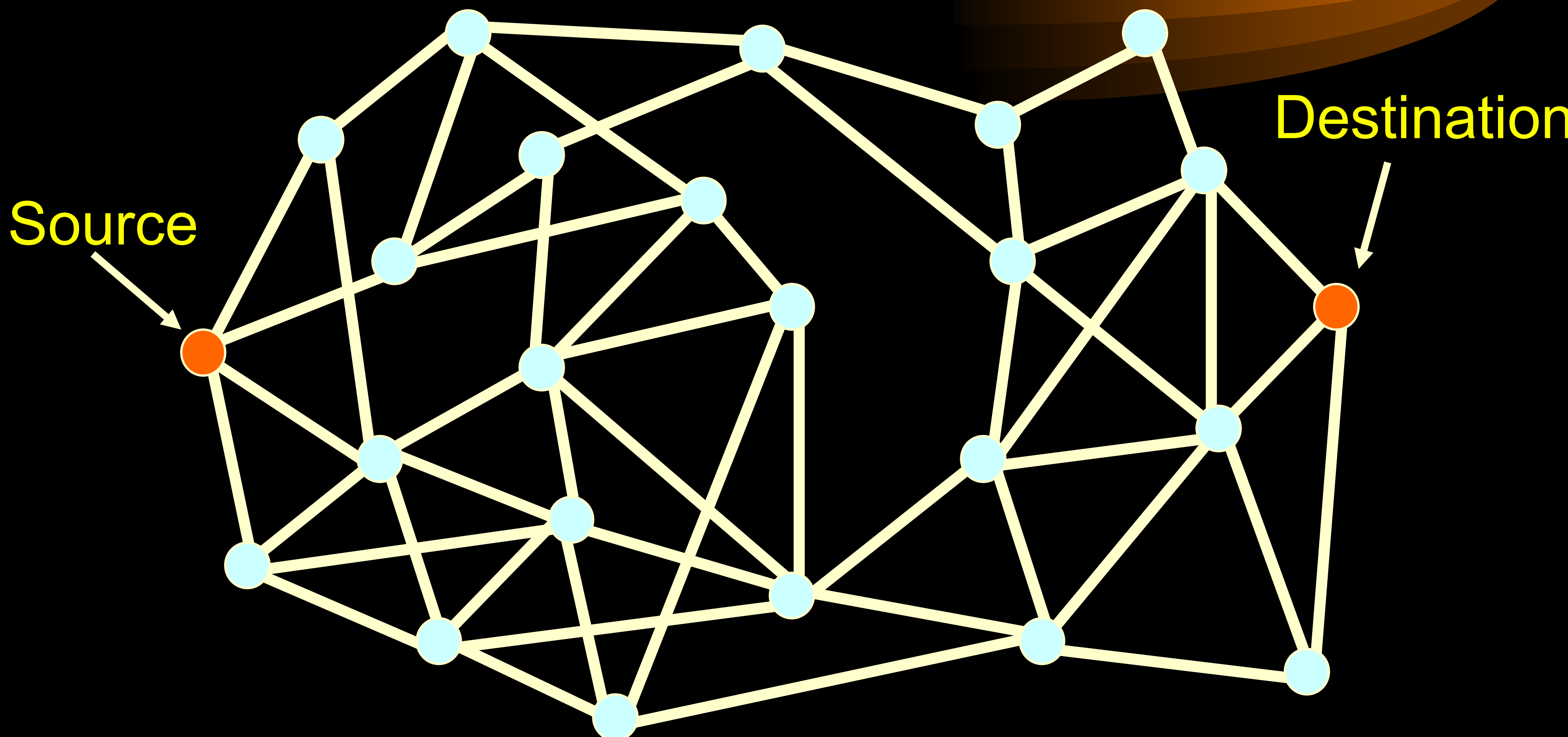

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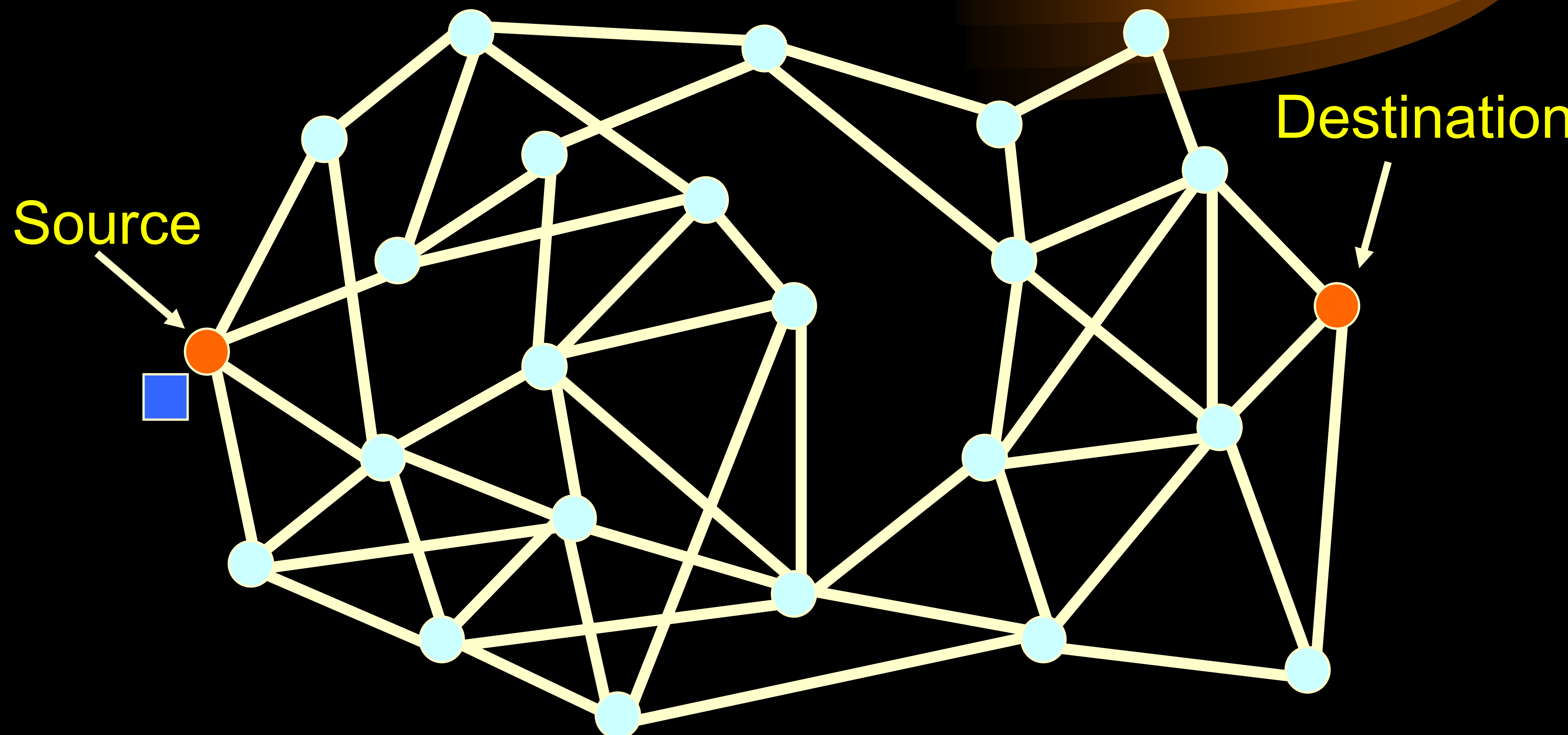

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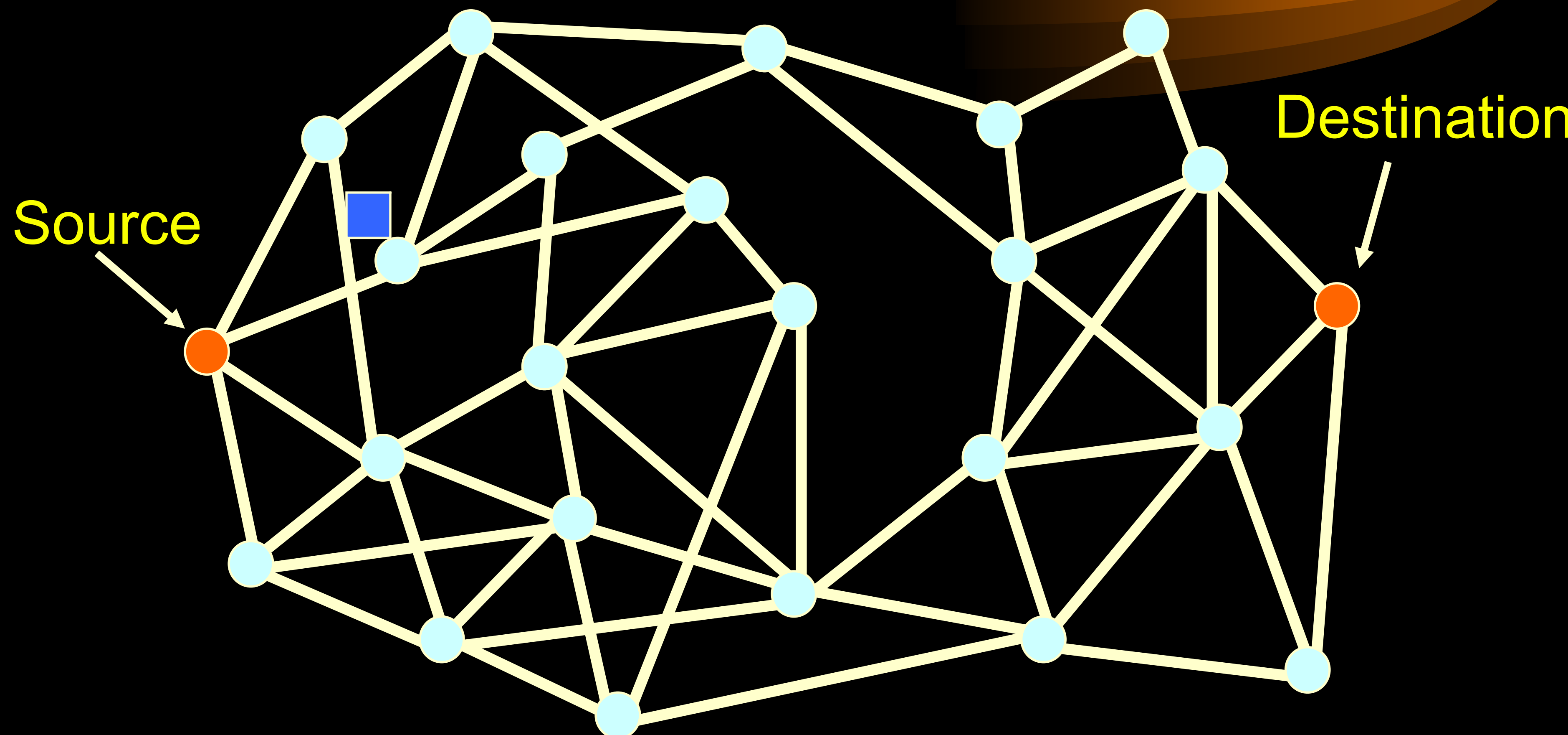

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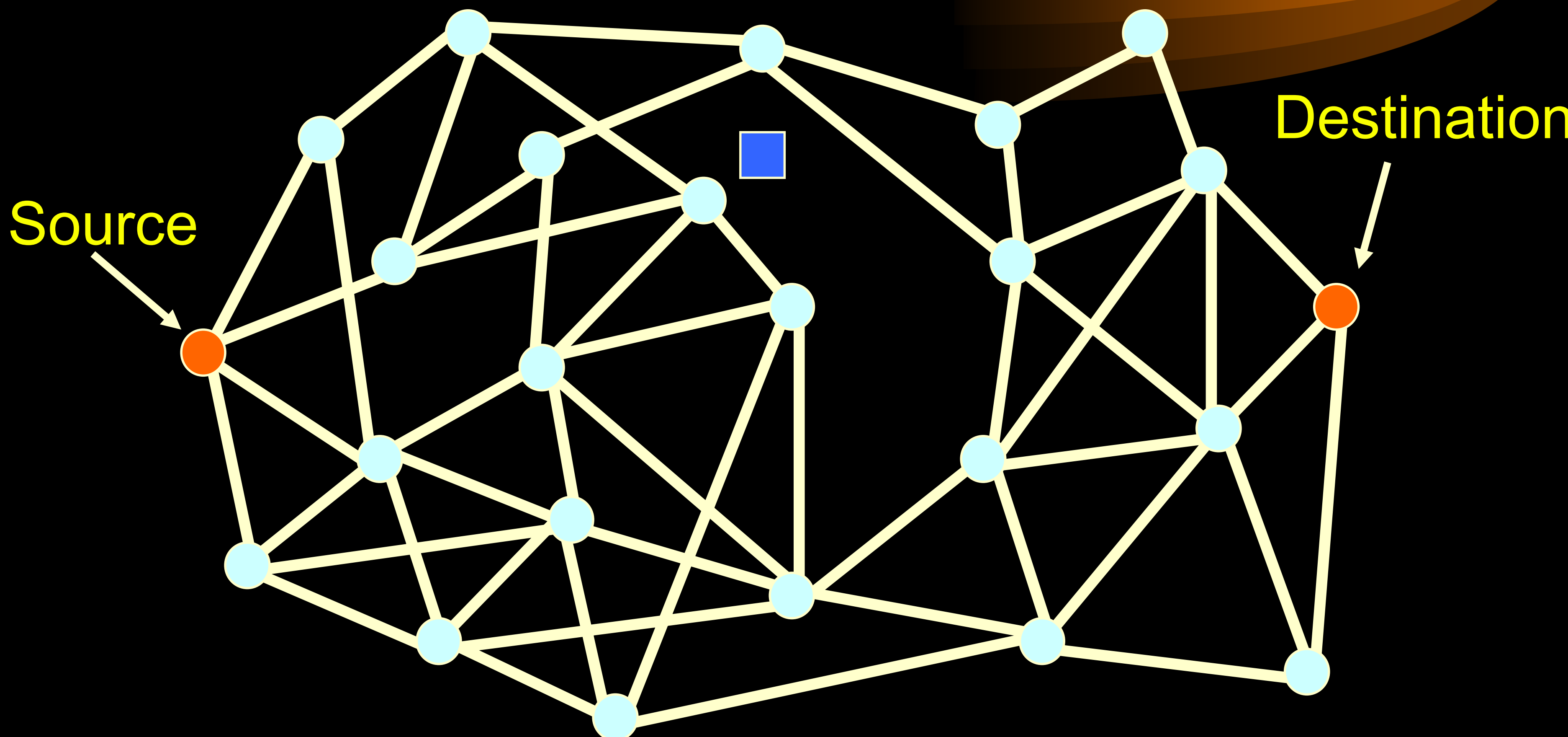

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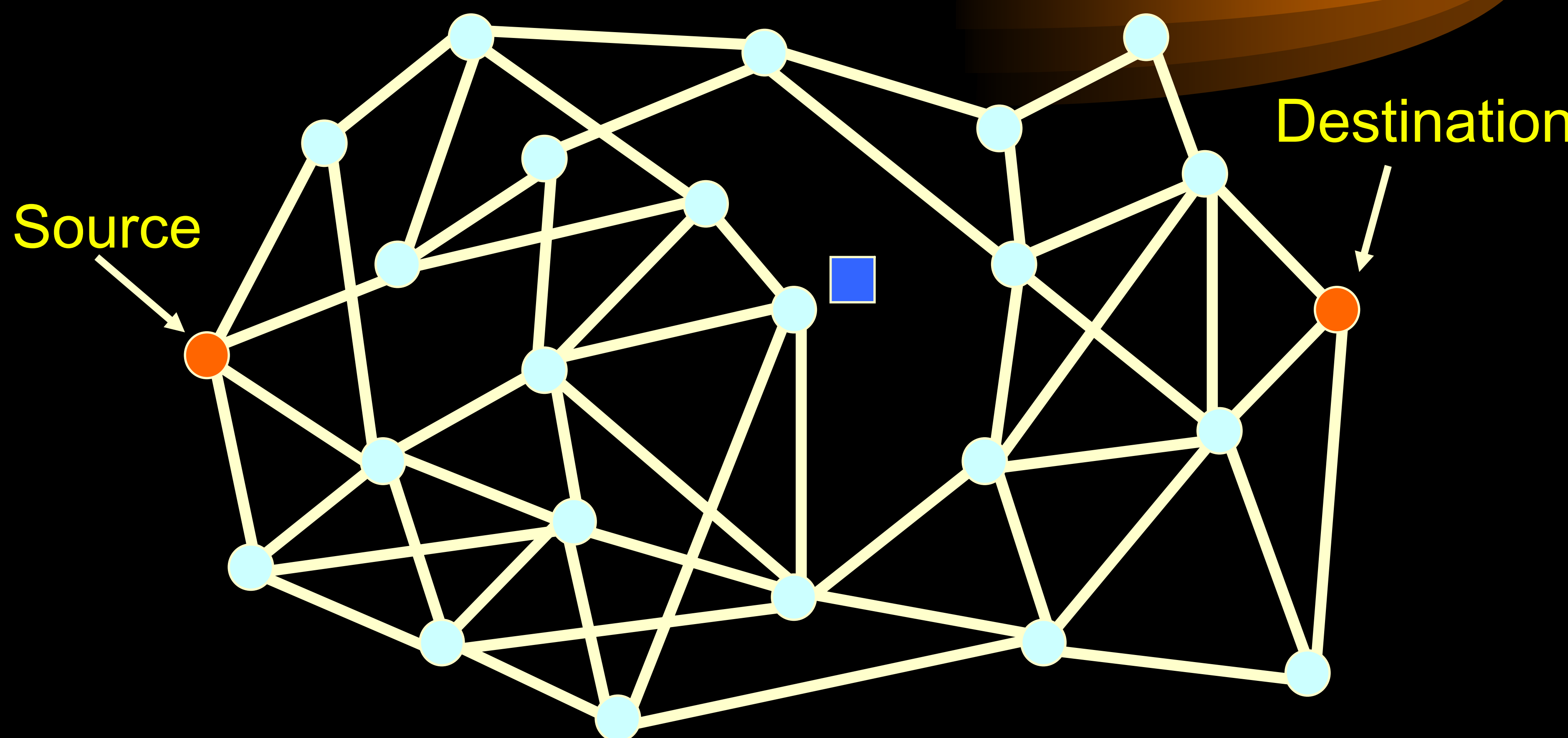
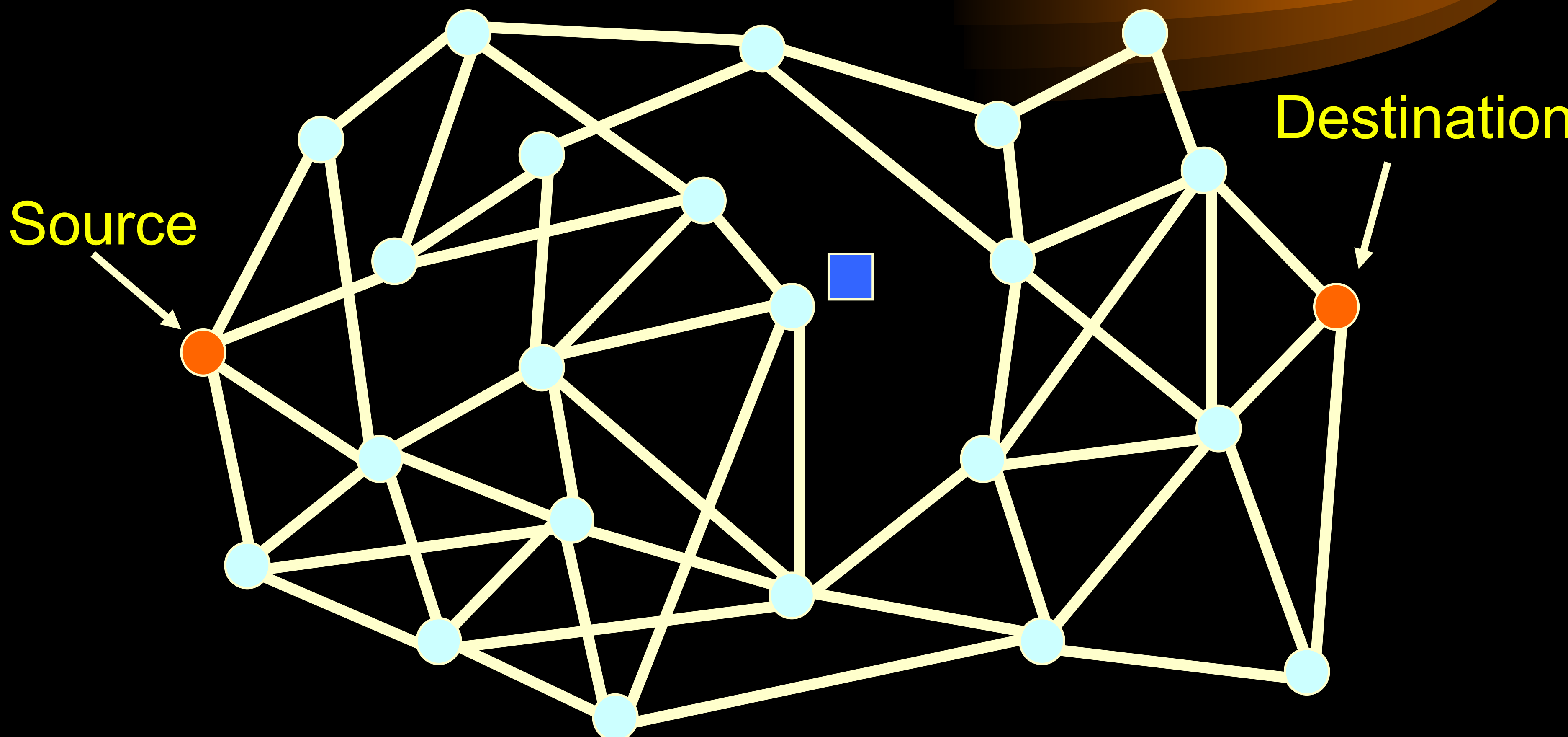


Geographic Face Routing

- Problem: sometimes a packet ends up at a local minimum.
- Face routing – route packet along faces of a planar subgraph
- Planarization:
  - Relative Neighborhood Graph (RNG)
  - Gabriel Graph (GG)
  - Cross Link Detection Protocol (CLDP) (Kim et al., NSDI 2005)

Example



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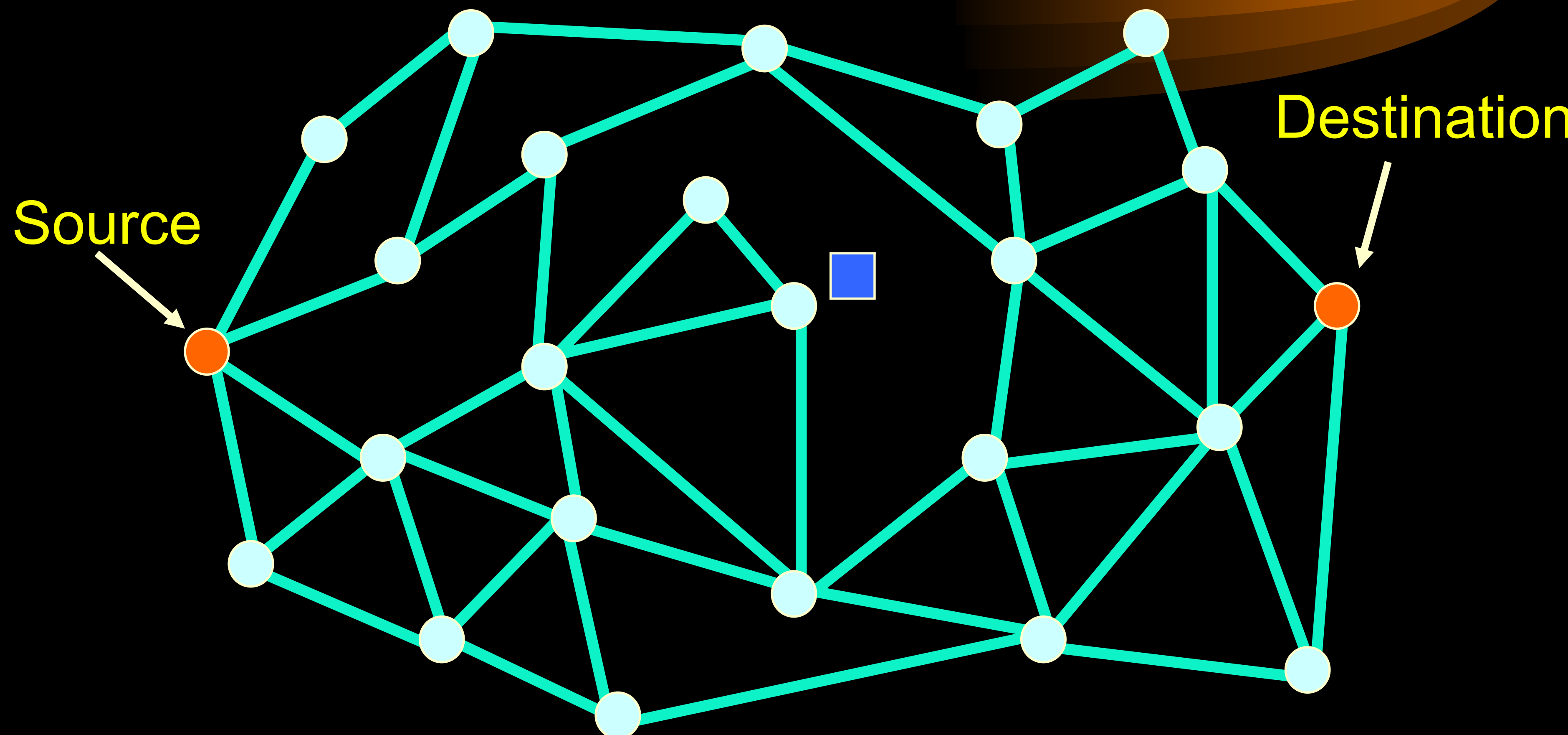

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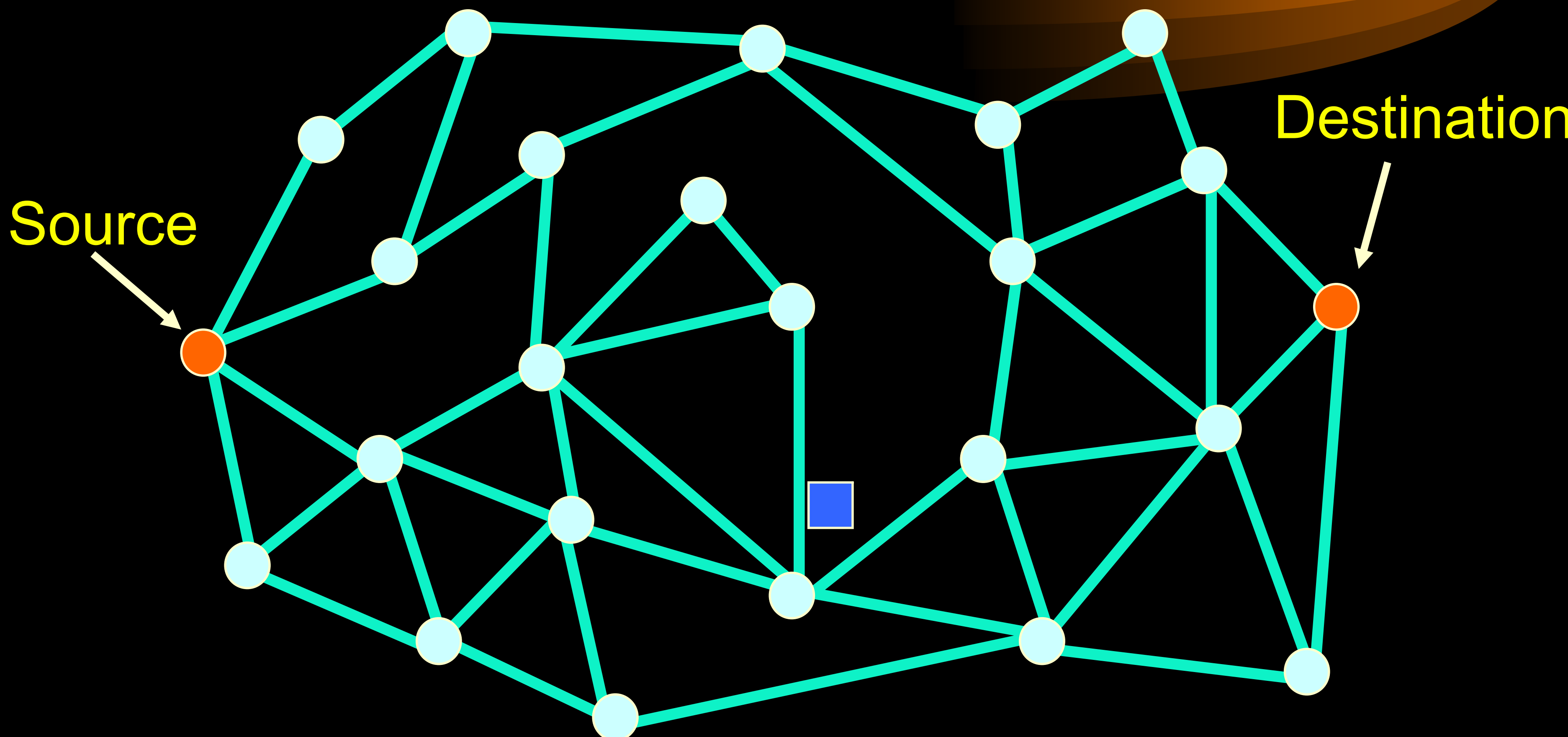

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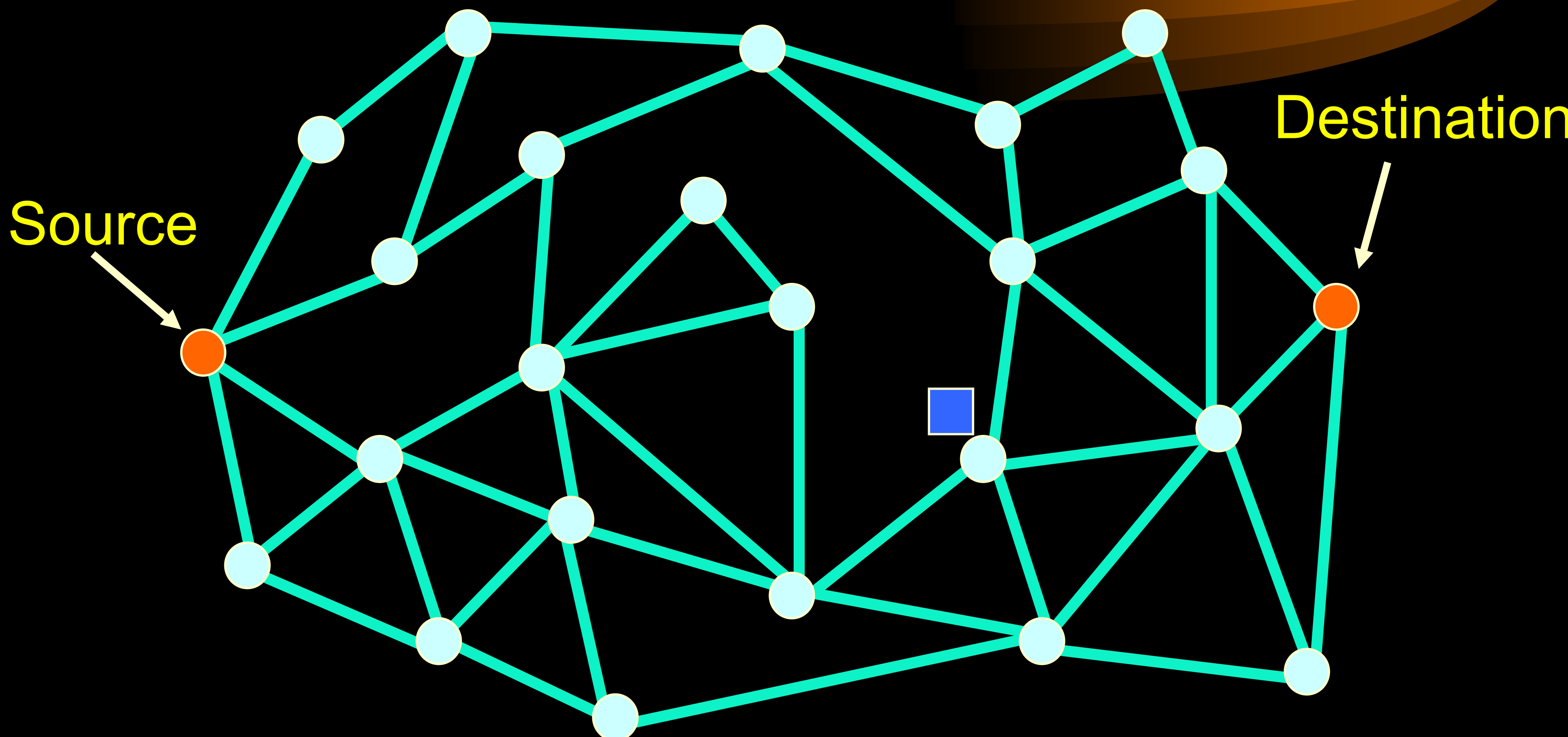

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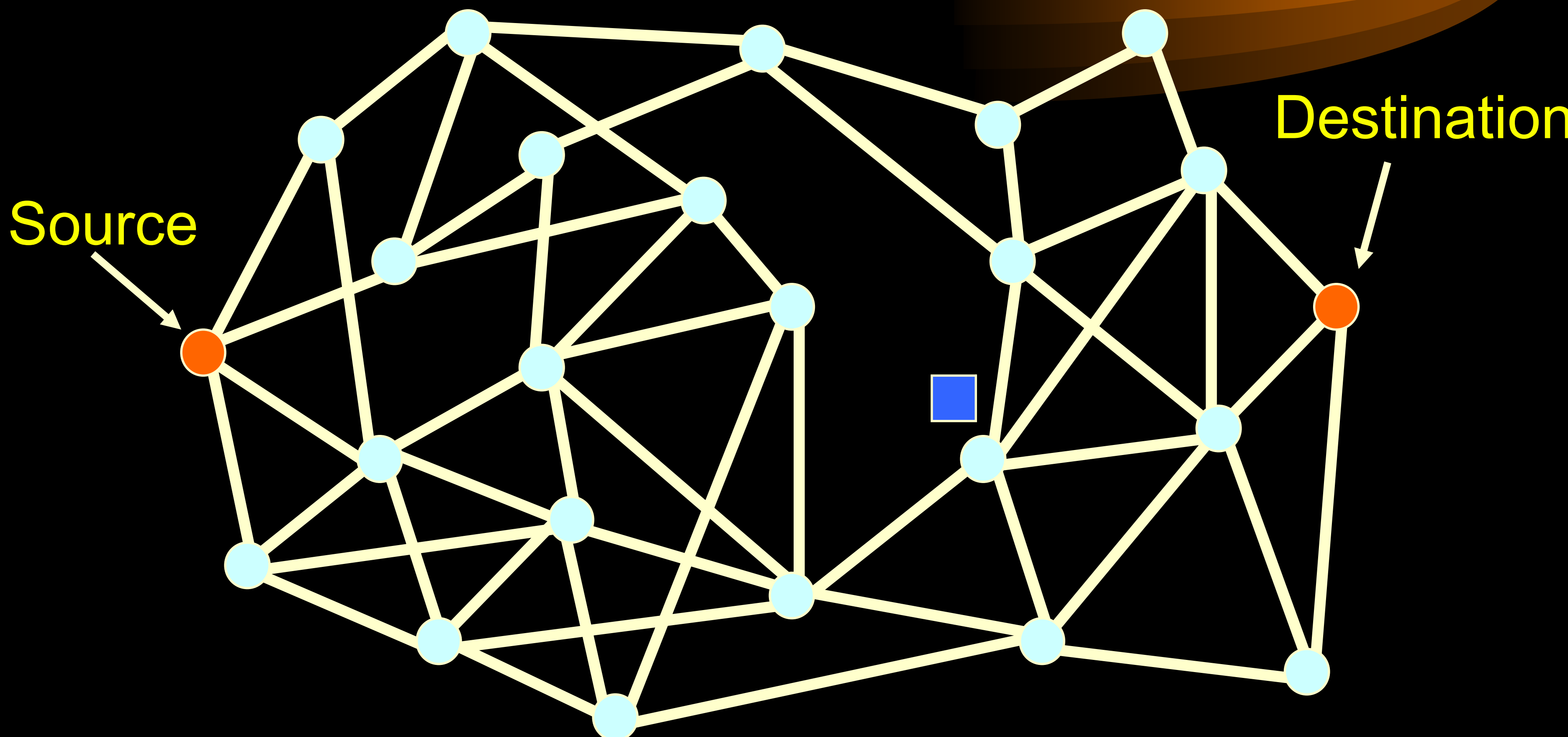

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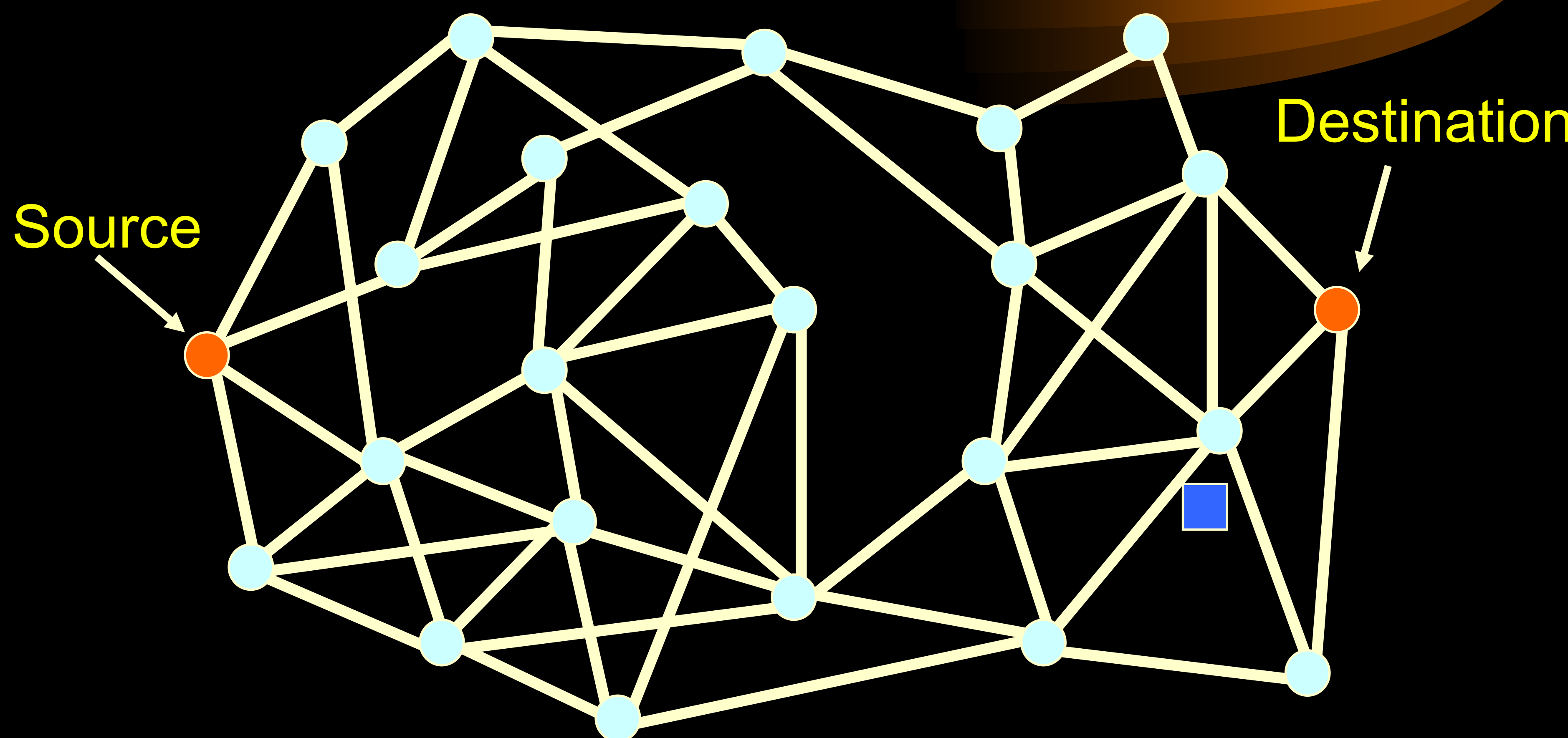

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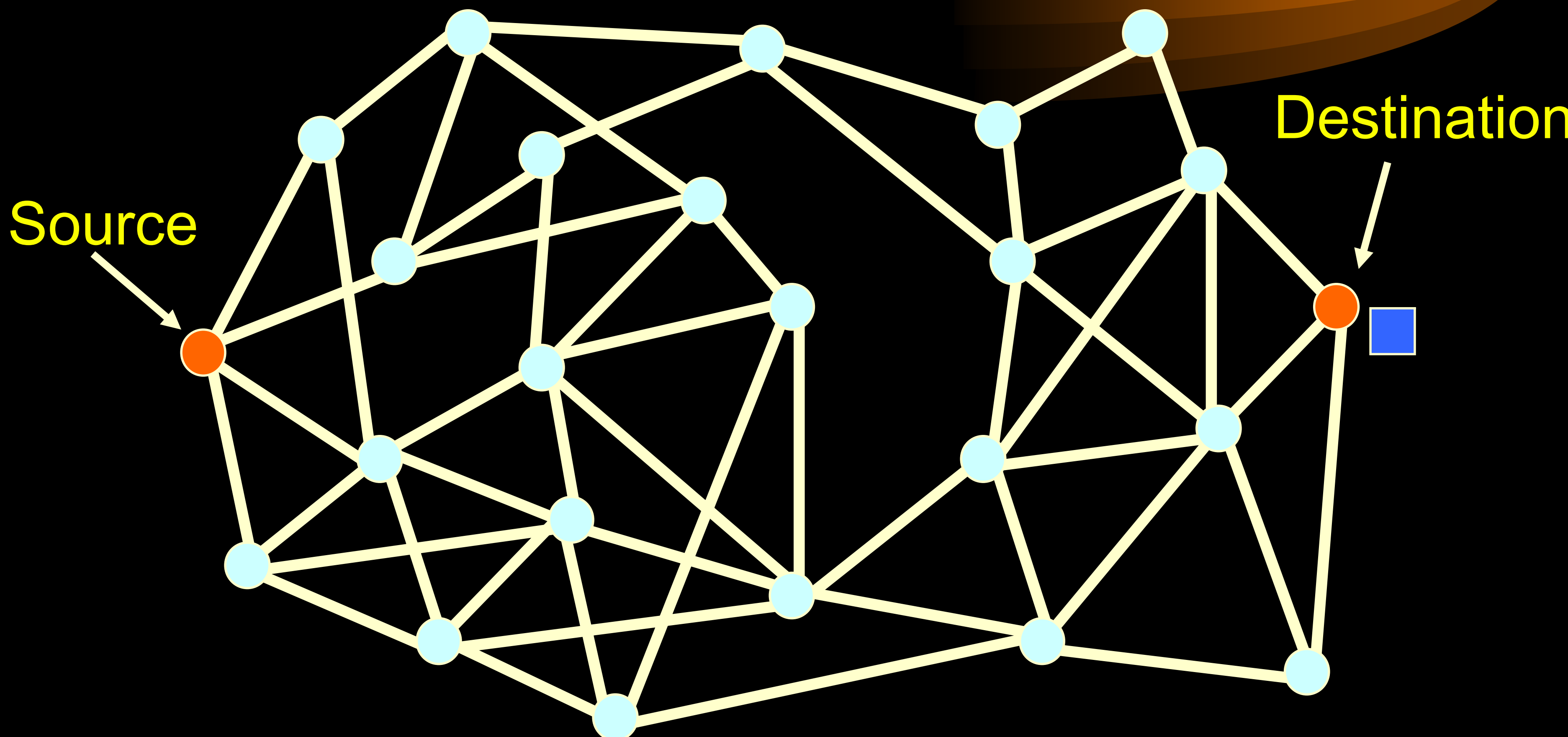
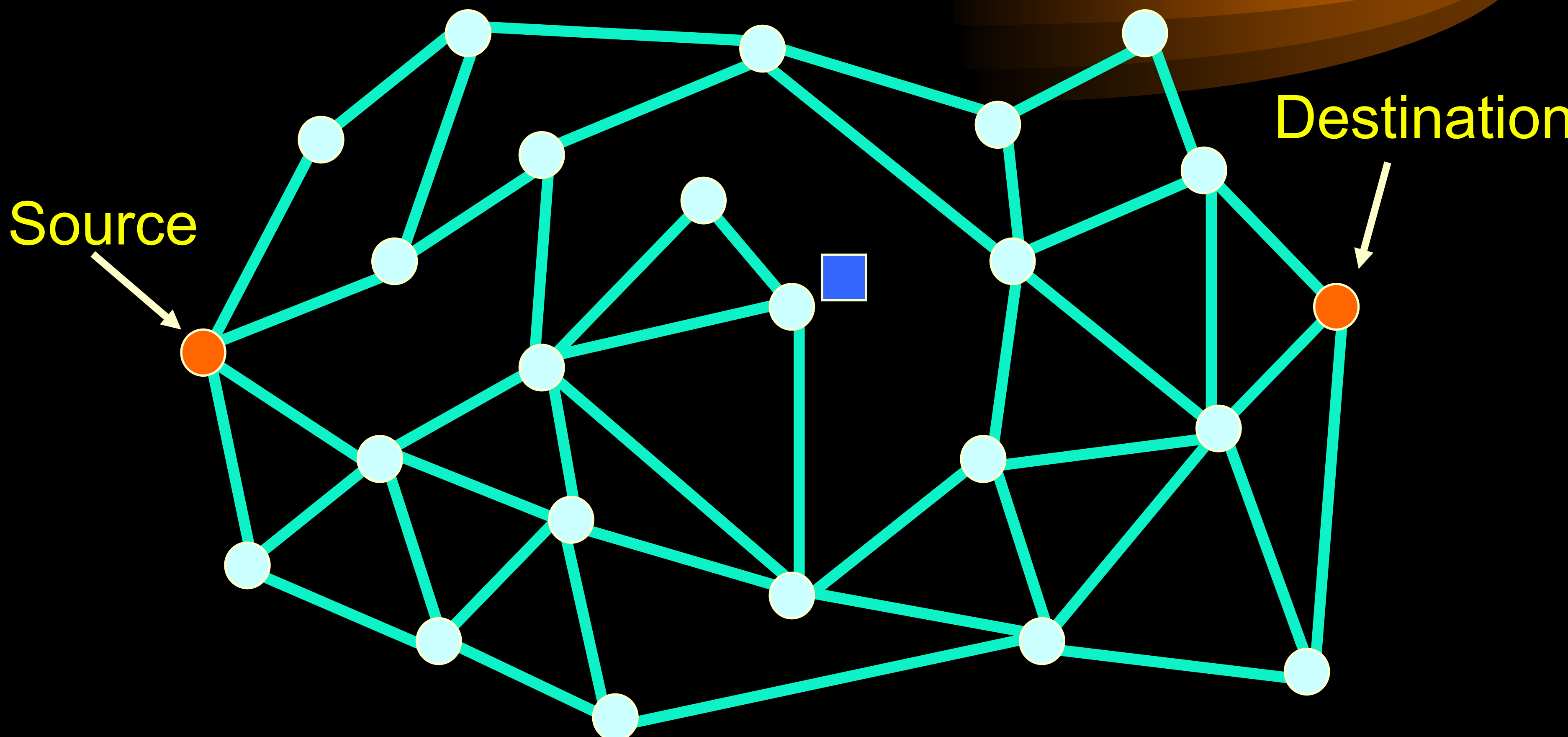


Problem

Nodes do not know enough to determine the "correct" forwarding direction.

Bad Choice Example



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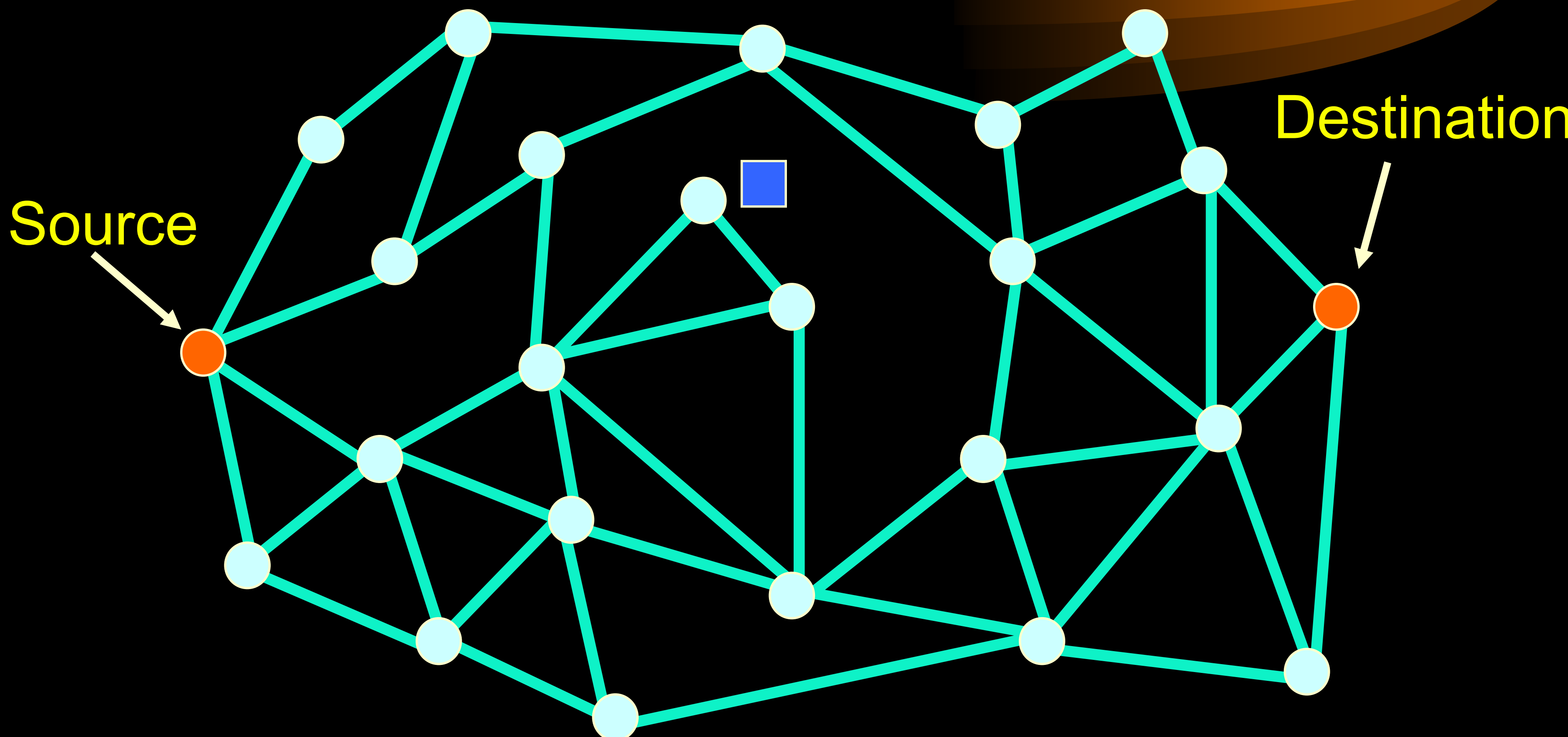

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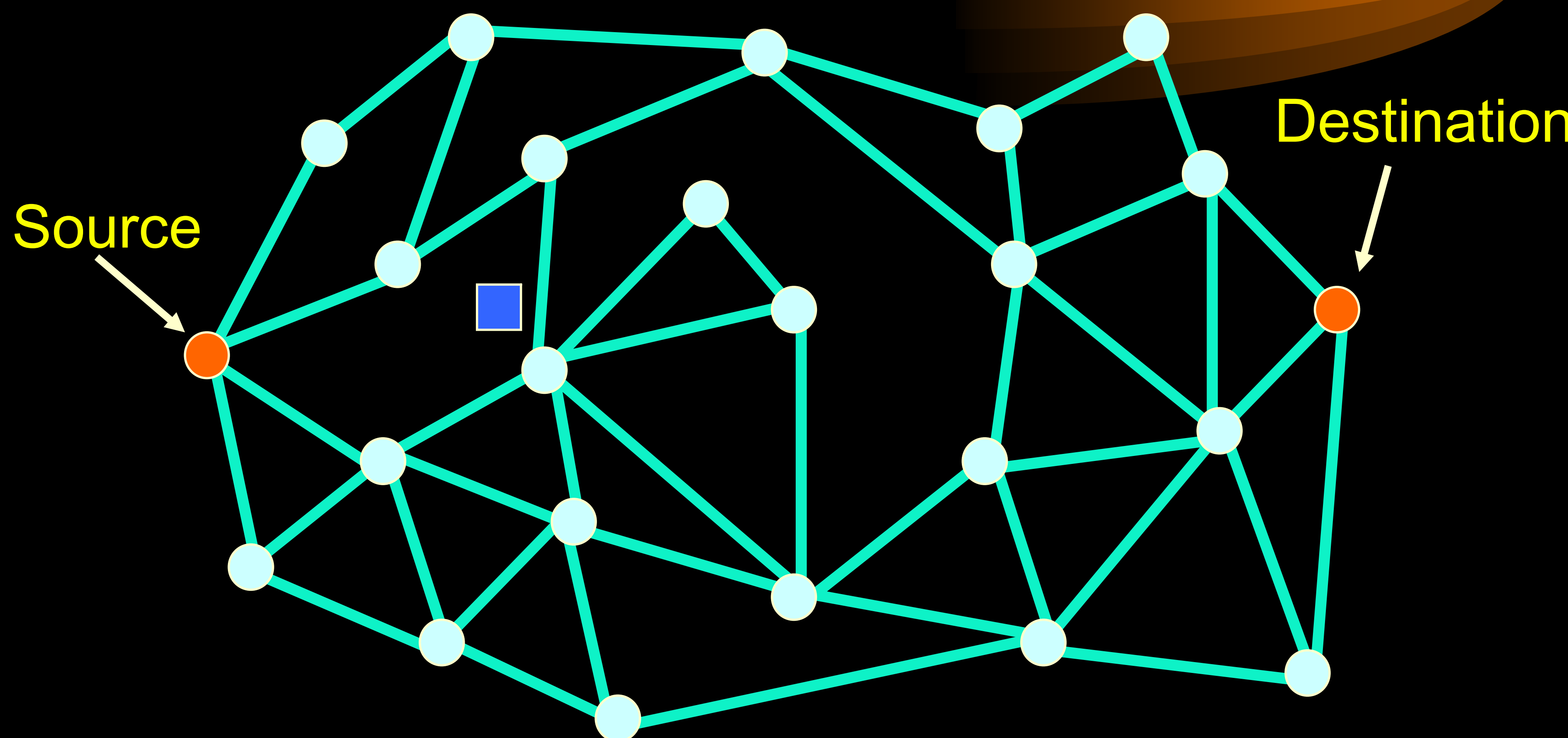


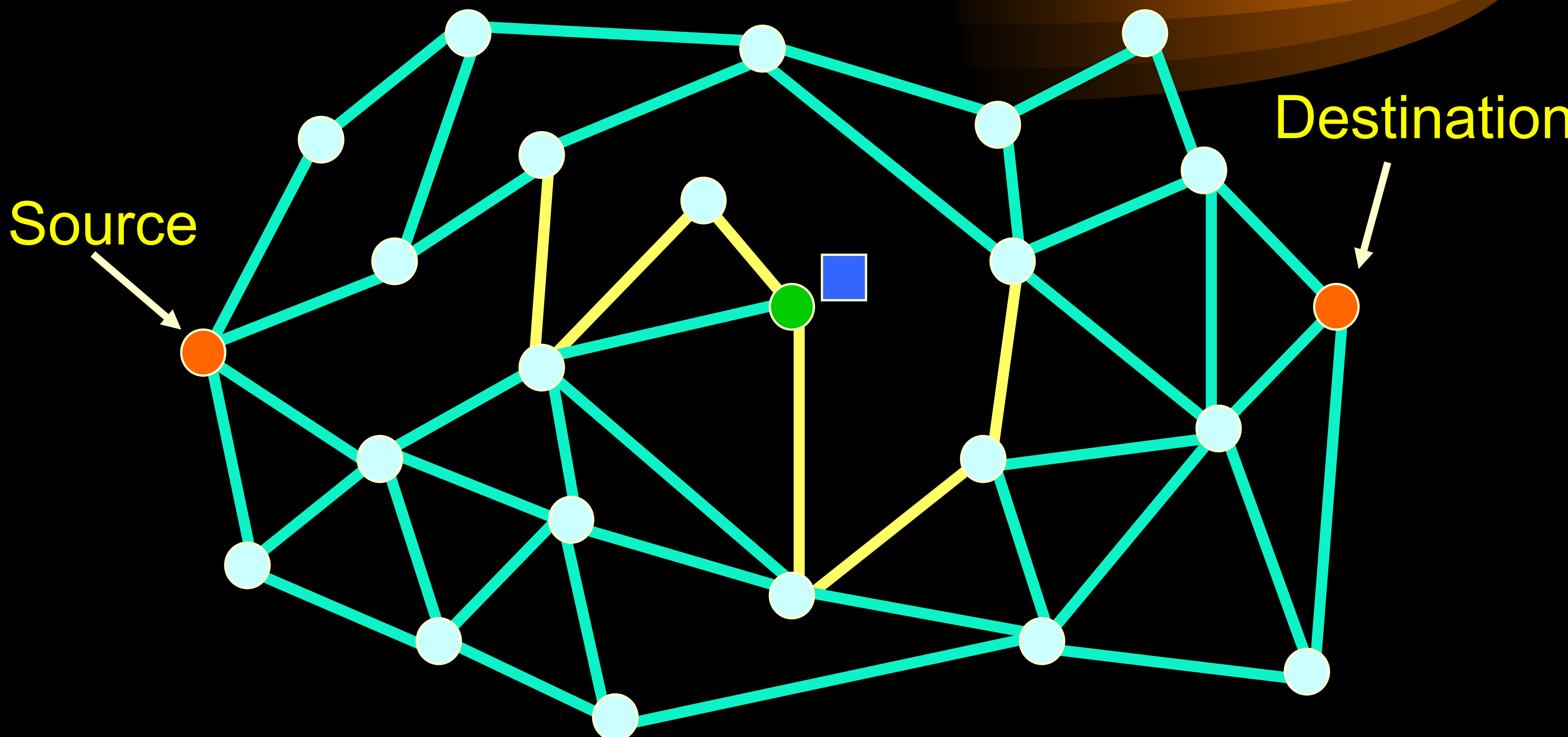
Hypothesis

By maintaining several hops of information along each planar face, we can make a better choice when deciding how to traverse a face

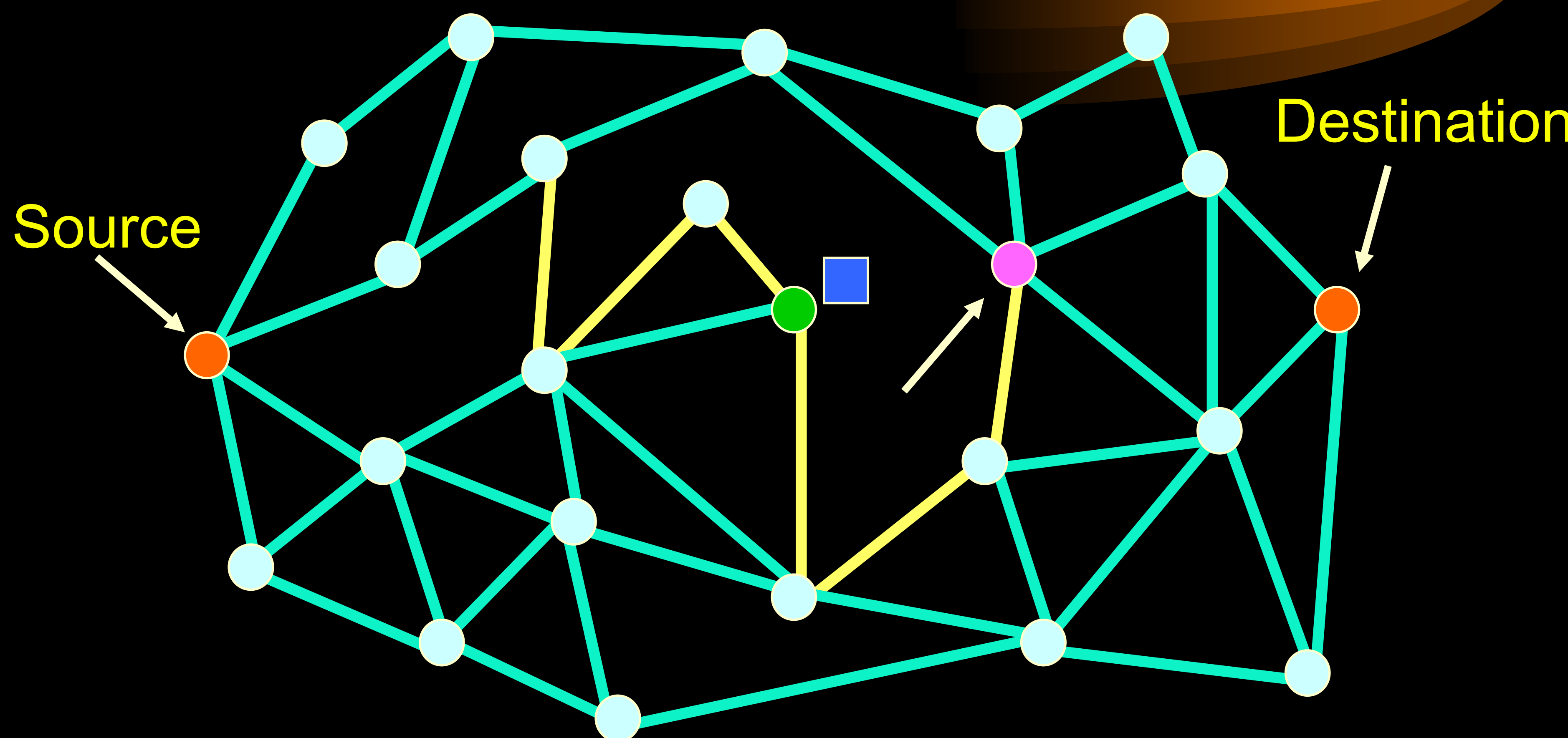
Greedy Path Vector Face Routing (GPVFR)

- Three modes:
  1. Forward greedily if possible.
  2. Use face information to forward along existing face
  3. Fallback on face traversal (GPSR)
- Revert to greedy forwarding as soon as it is feasible

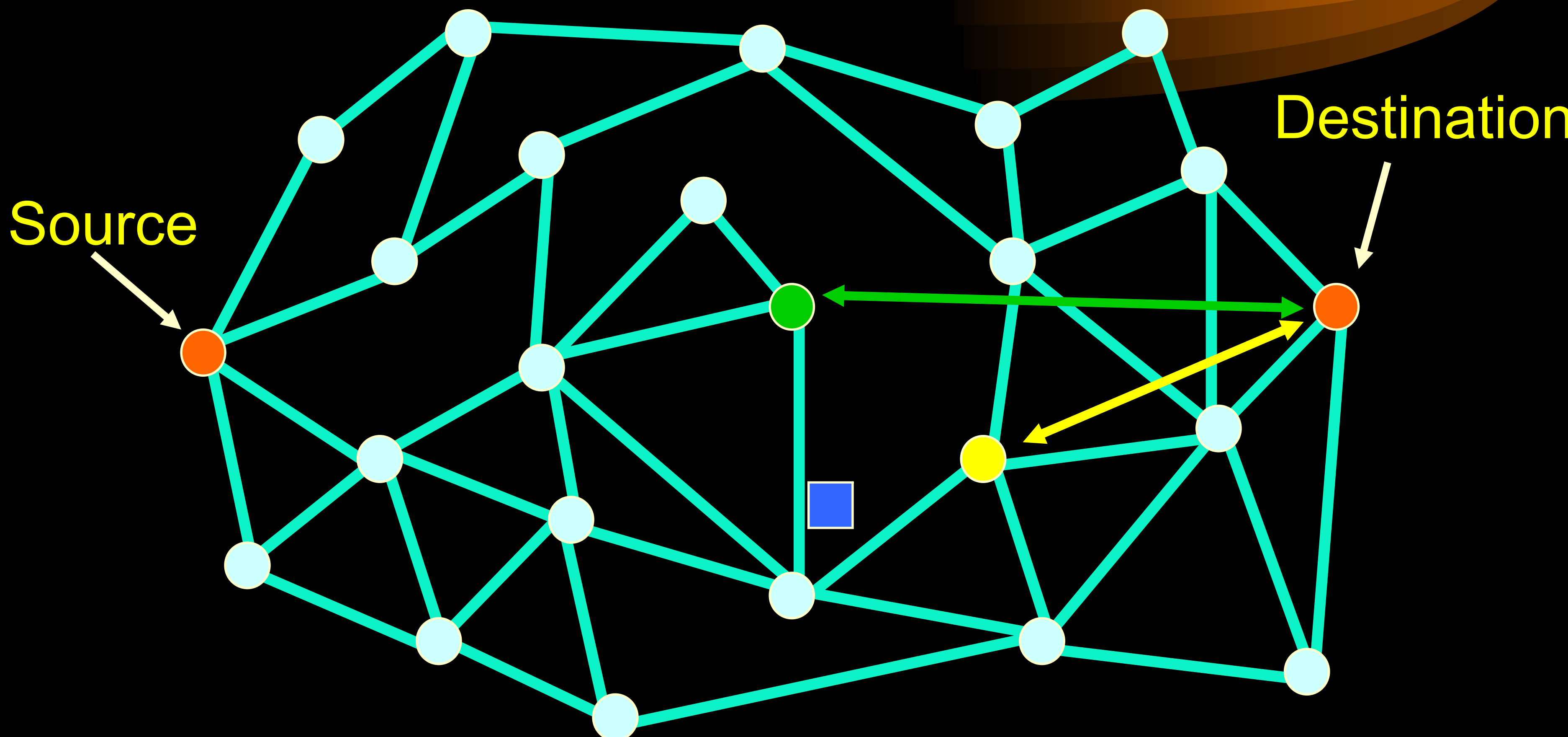
Using Face Information



Using Face Information



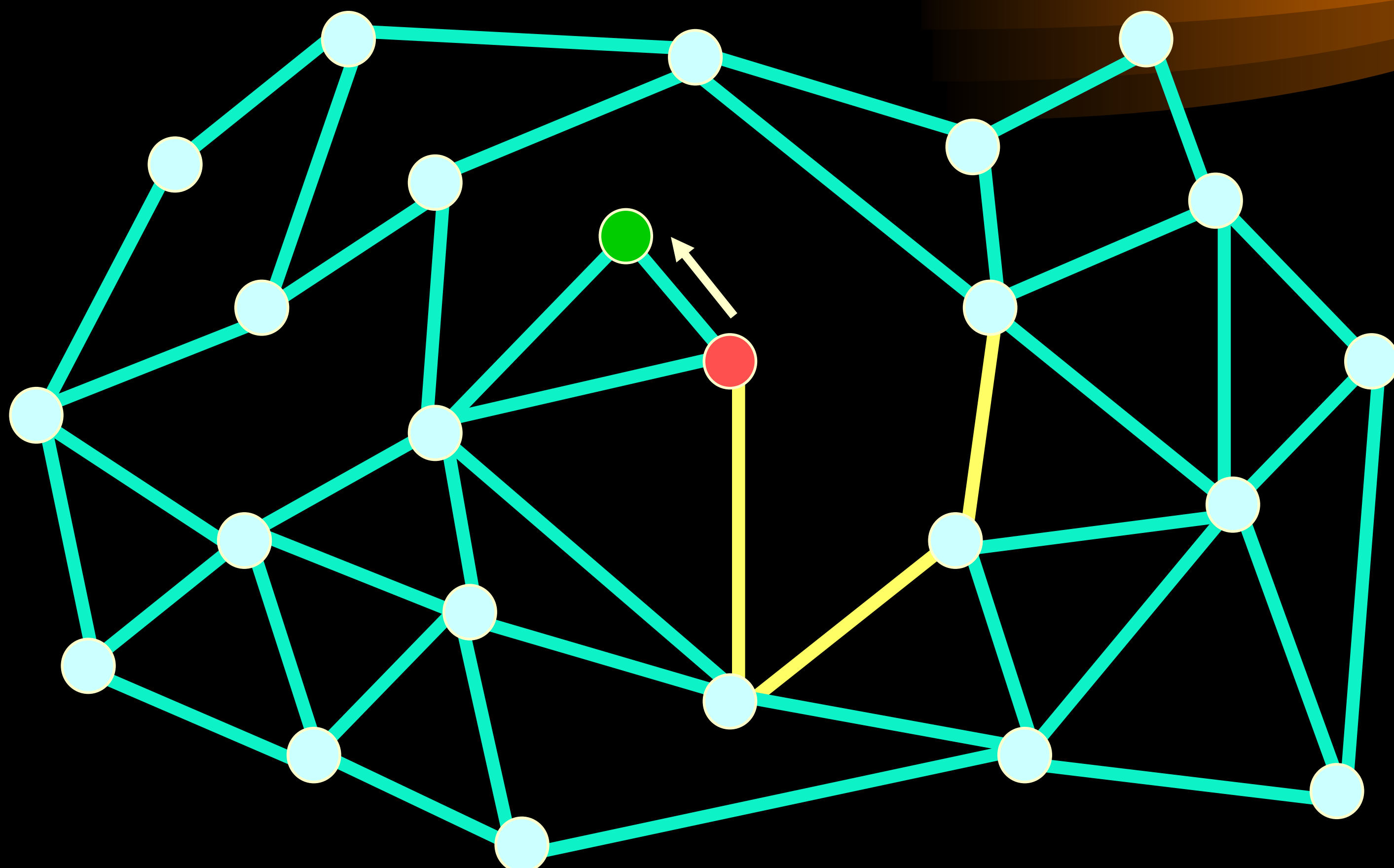
Revert to Greedy Mode



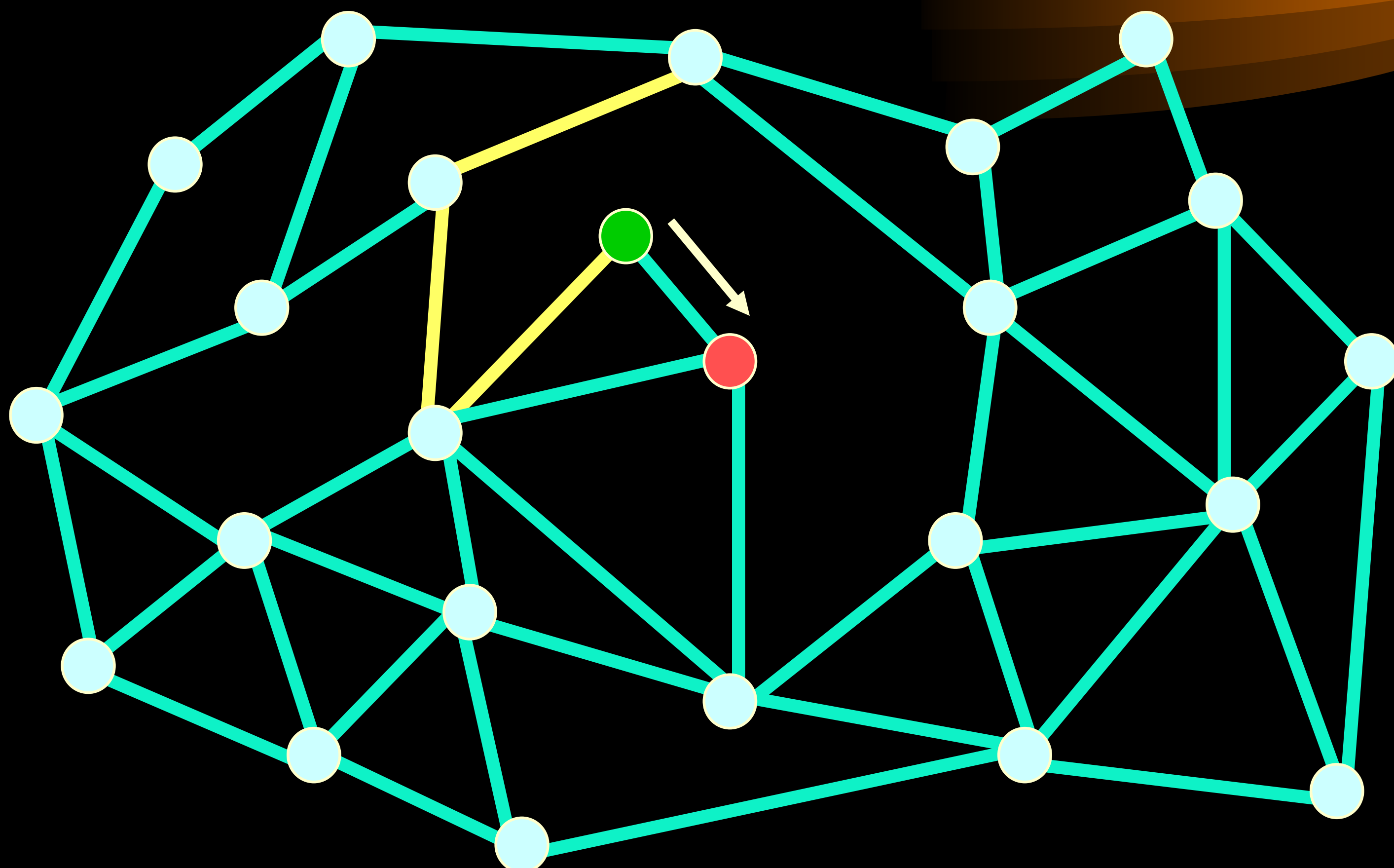
Path Vector Exchange (PVEX)

- Protocol for maintaining face information
- Nodes periodically exchange path vectors with planar neighbors
  - *h* hops of information
- Information is piggybacked on *keepalive* messages

Maintaining Face Information



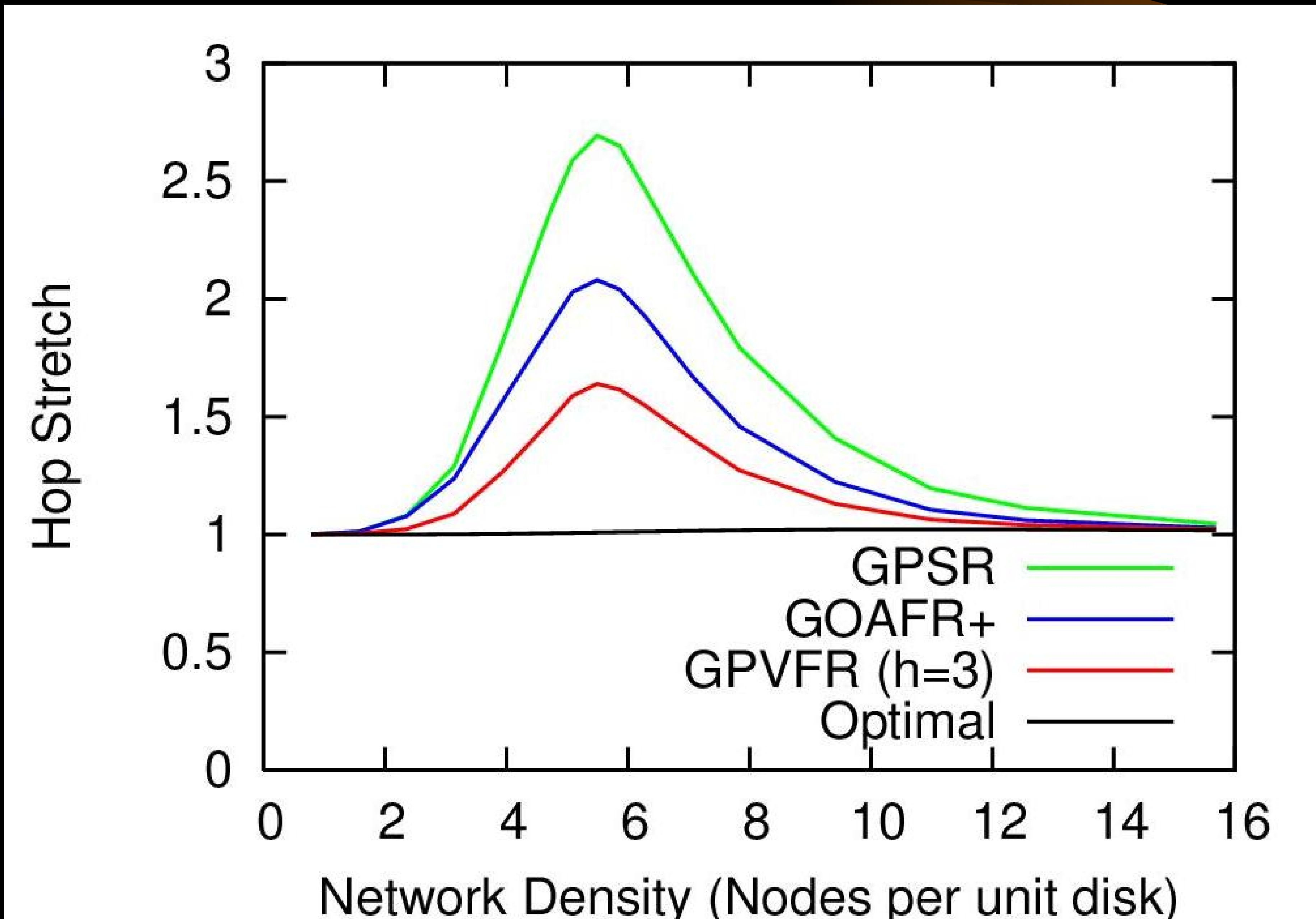
Maintaining Face Information



Simulation Results

- Measured 2 routing metrics:
  - Path Stretch
  - Hop Stretch
- Random networks over a range of network densities
- Compare to GPSR (Karp, 2001) and GOAFR+ (Kuhn, 2003)
- Results for RNG and GG planarization in paper

Hop Stretch (CLDP Planarization)



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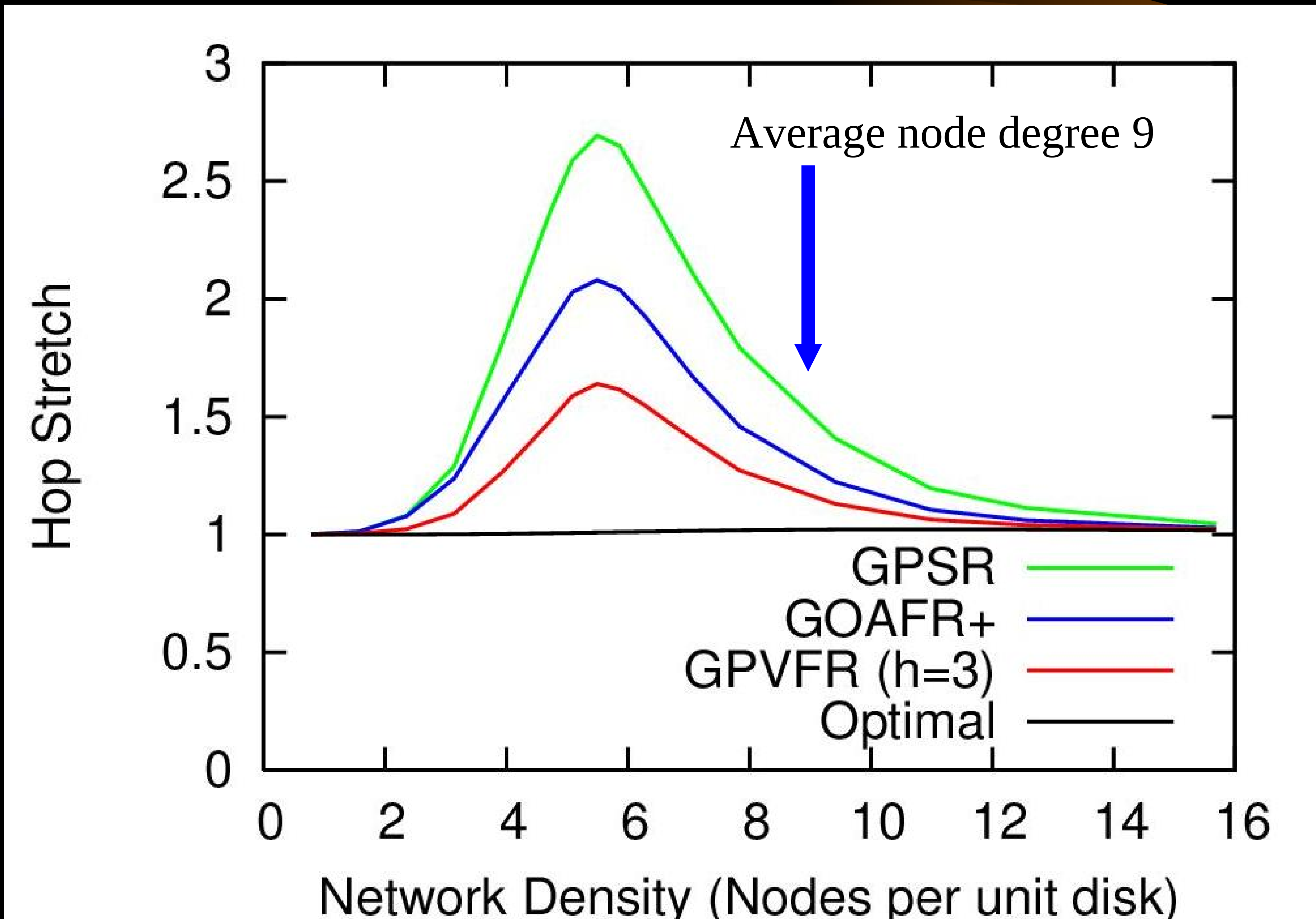
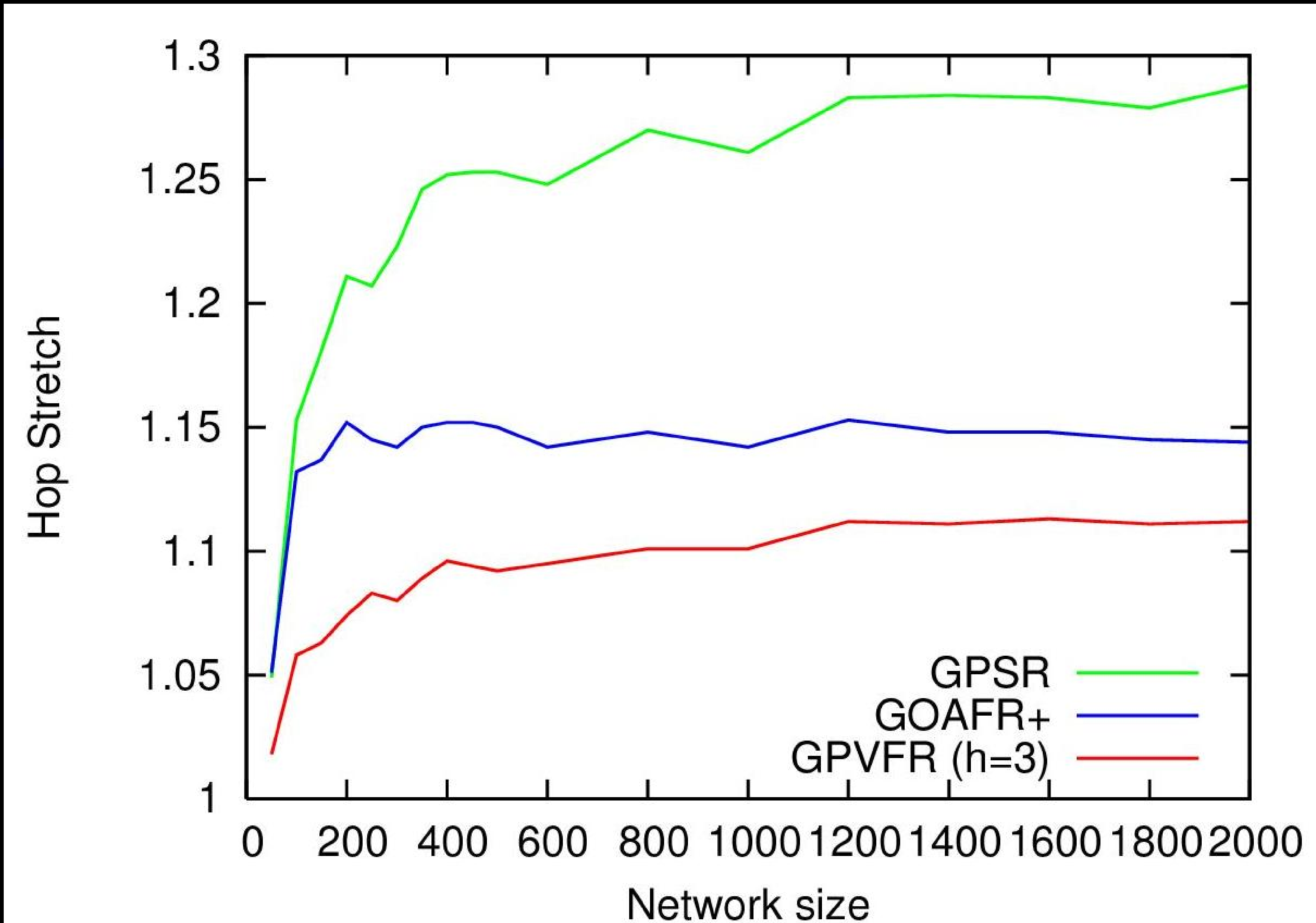
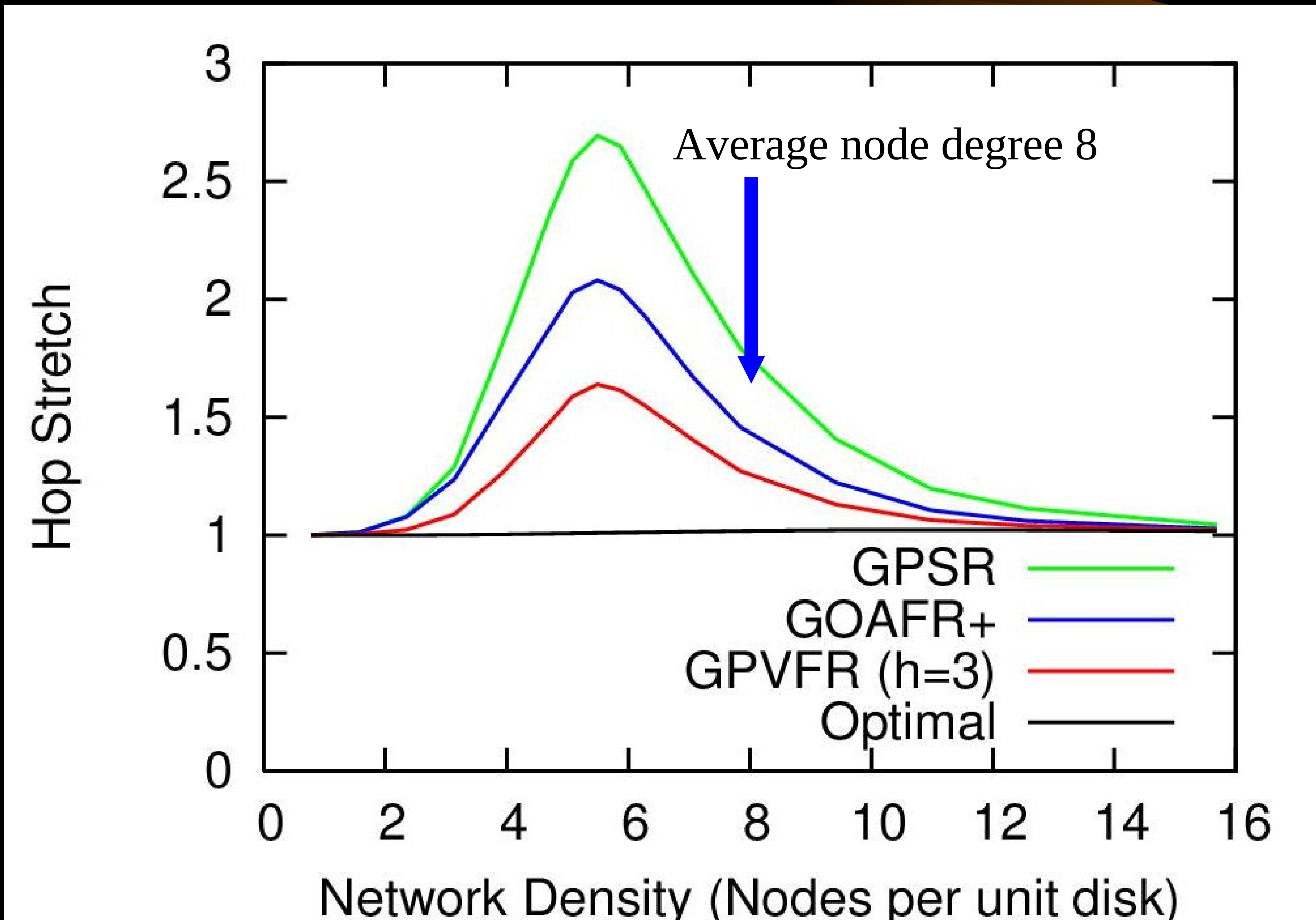


Scaling up

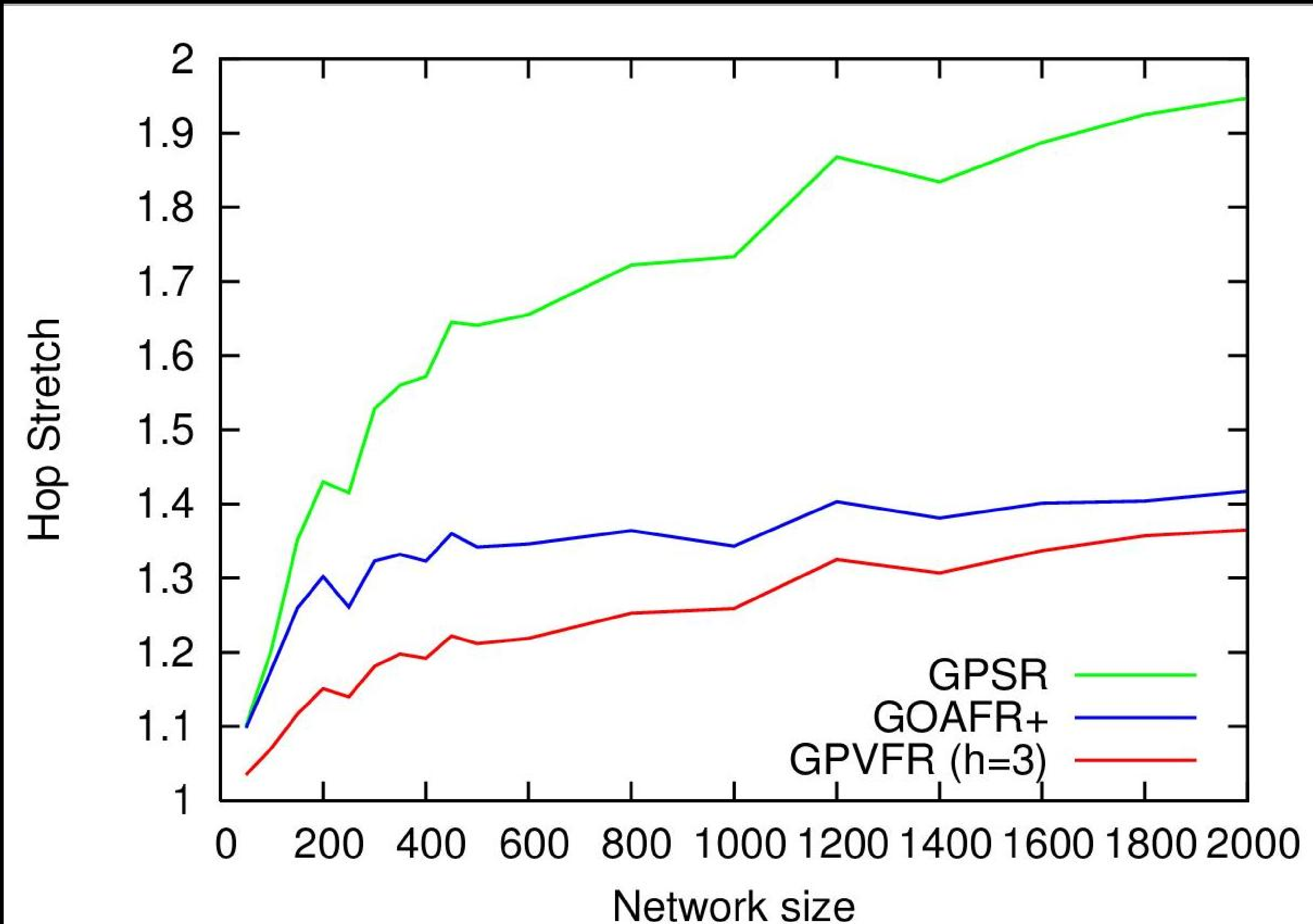


Average node density = 9

Hop Stretch (CLDP Planarization)

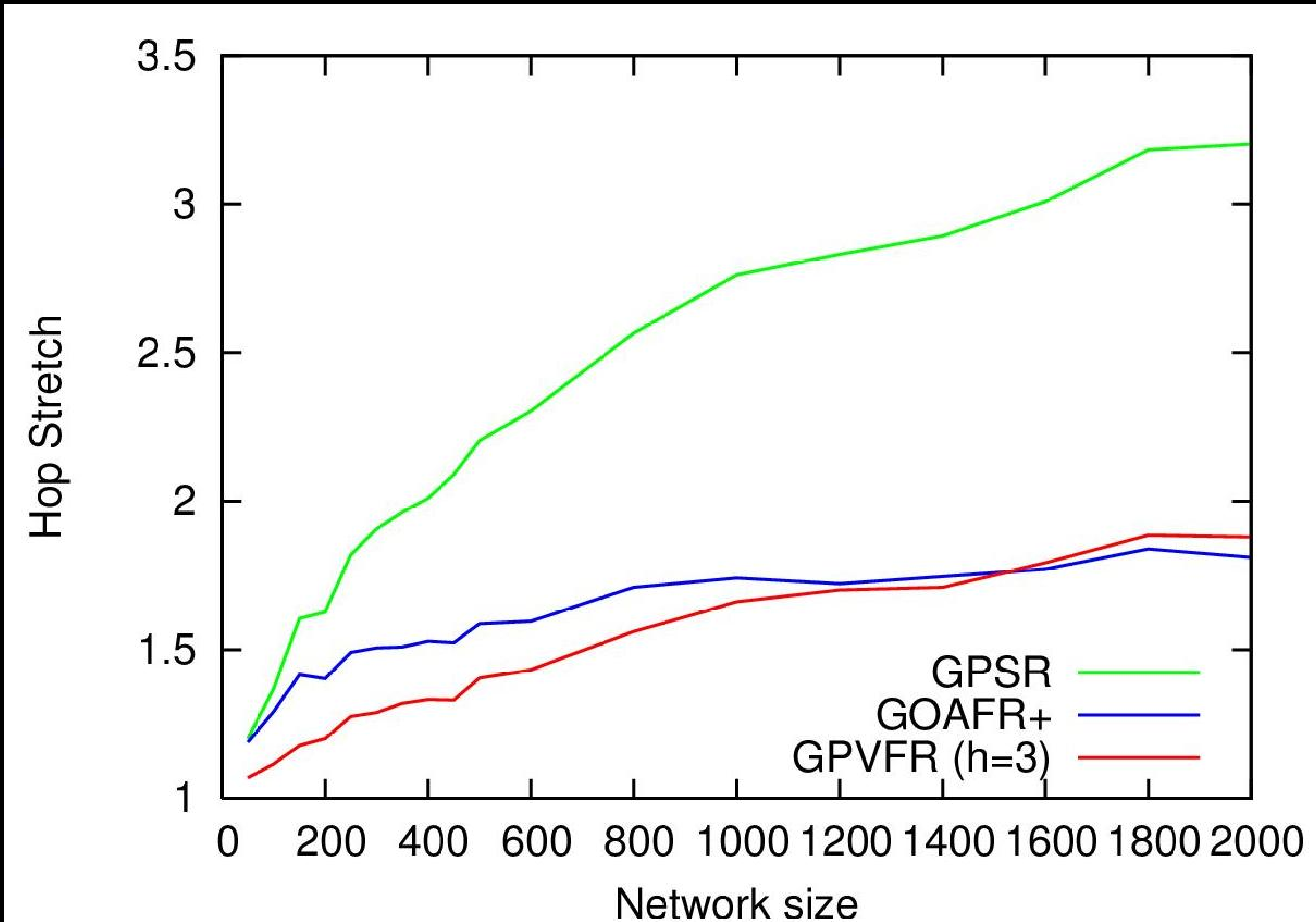


Scaling up



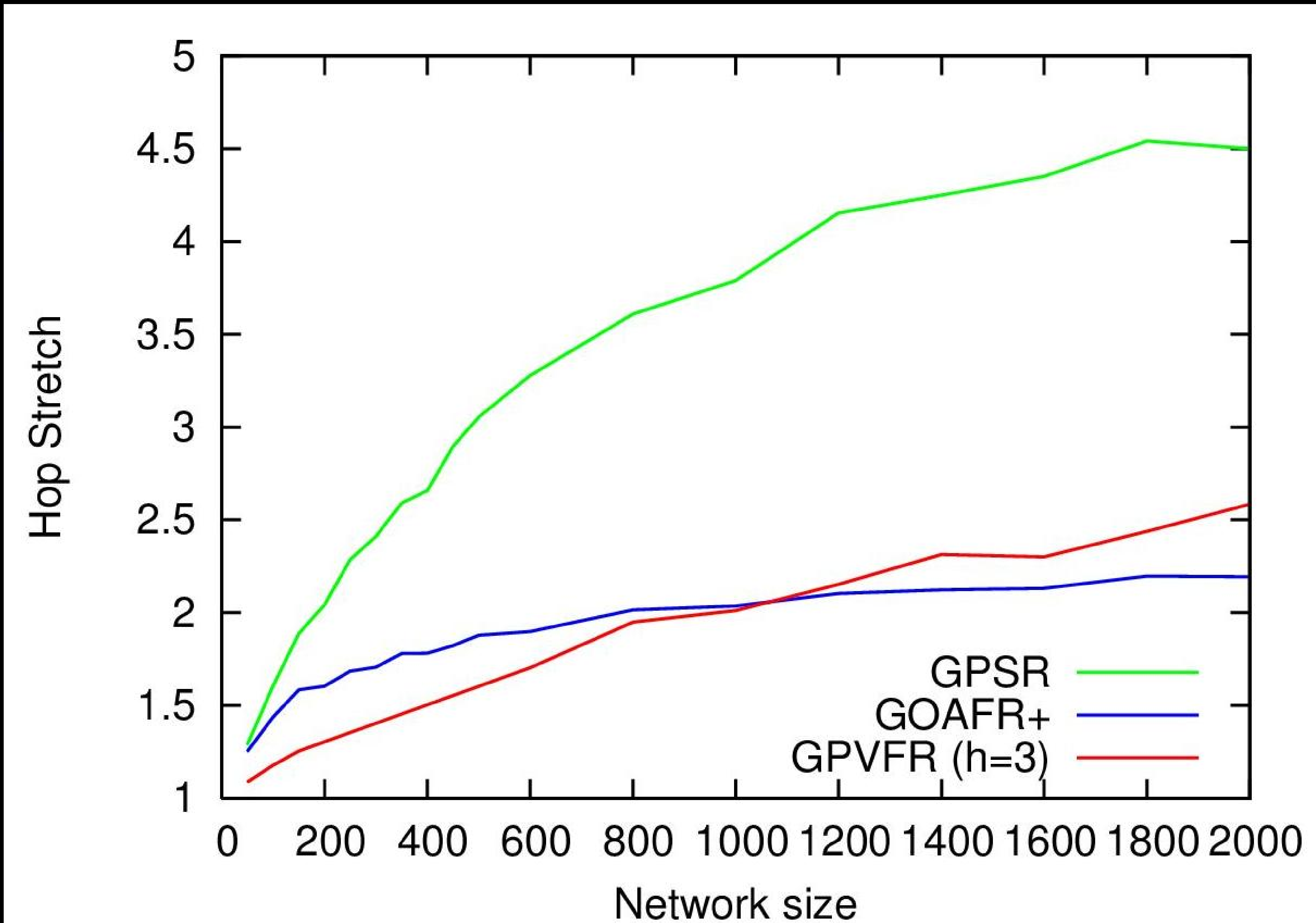
Average node density = 8

Scaling up



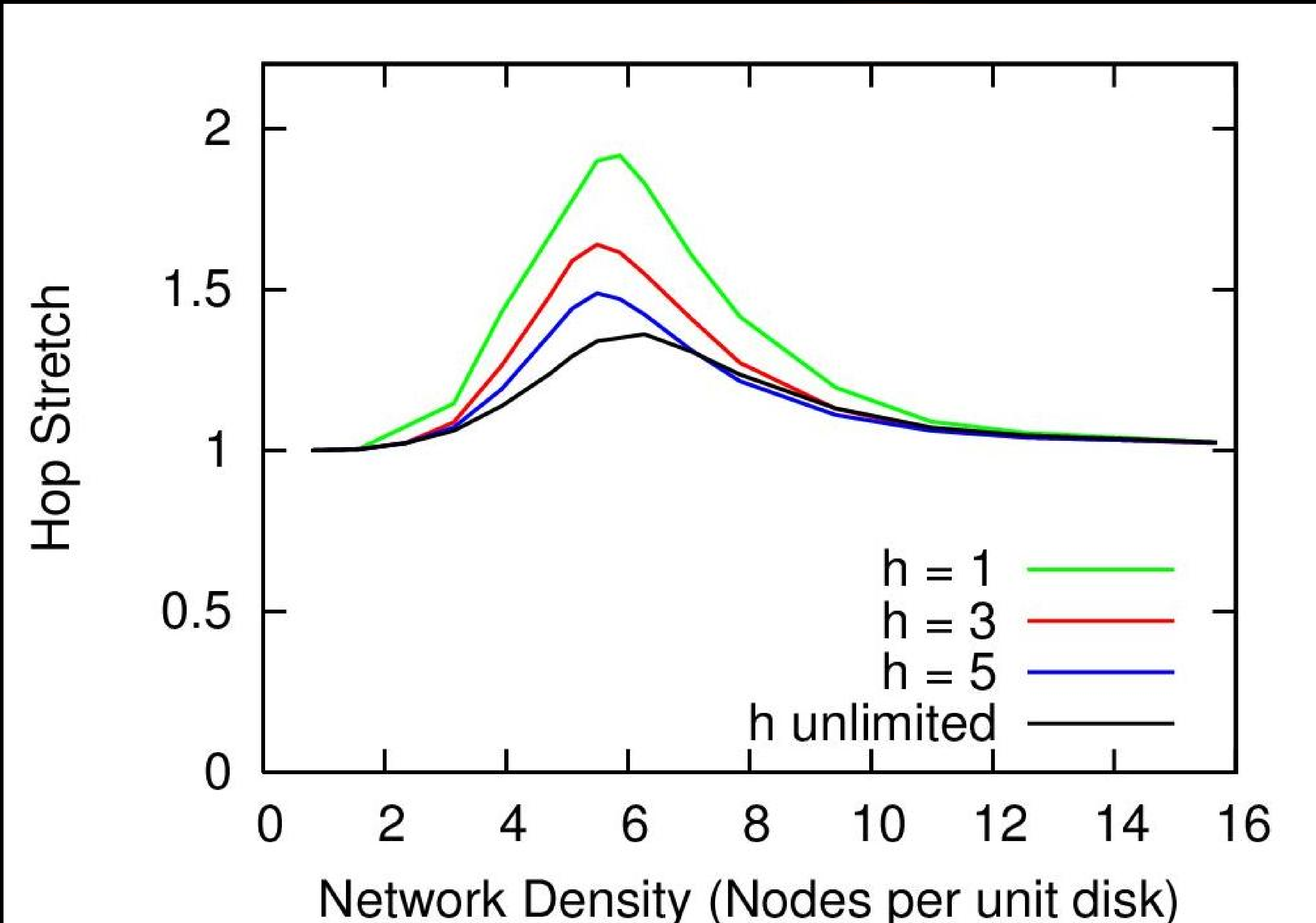
Average node density = 7

Scaling up



Average node density = 6.5

Varying Path Vector Length



Maintenance Cost

- Additional storage:
  - Small (15 to 20 extra nodes on average, < 200 bytes)
  - proportional to number of planar neighbors
  - independent of network density
- Additional bandwidth:
  - *h* message exchanges (each < 200 bytes)
- Planarization cost >> PVEX cost

Theoretical results

1. With full face information, we can route obliviously;
2. Without full face information, it is impossible to route obliviously.

Conclusion

- Forwarding direction is critical for good performance
- GPVFR achieves significantly improved routing stretch with a little extra storage.

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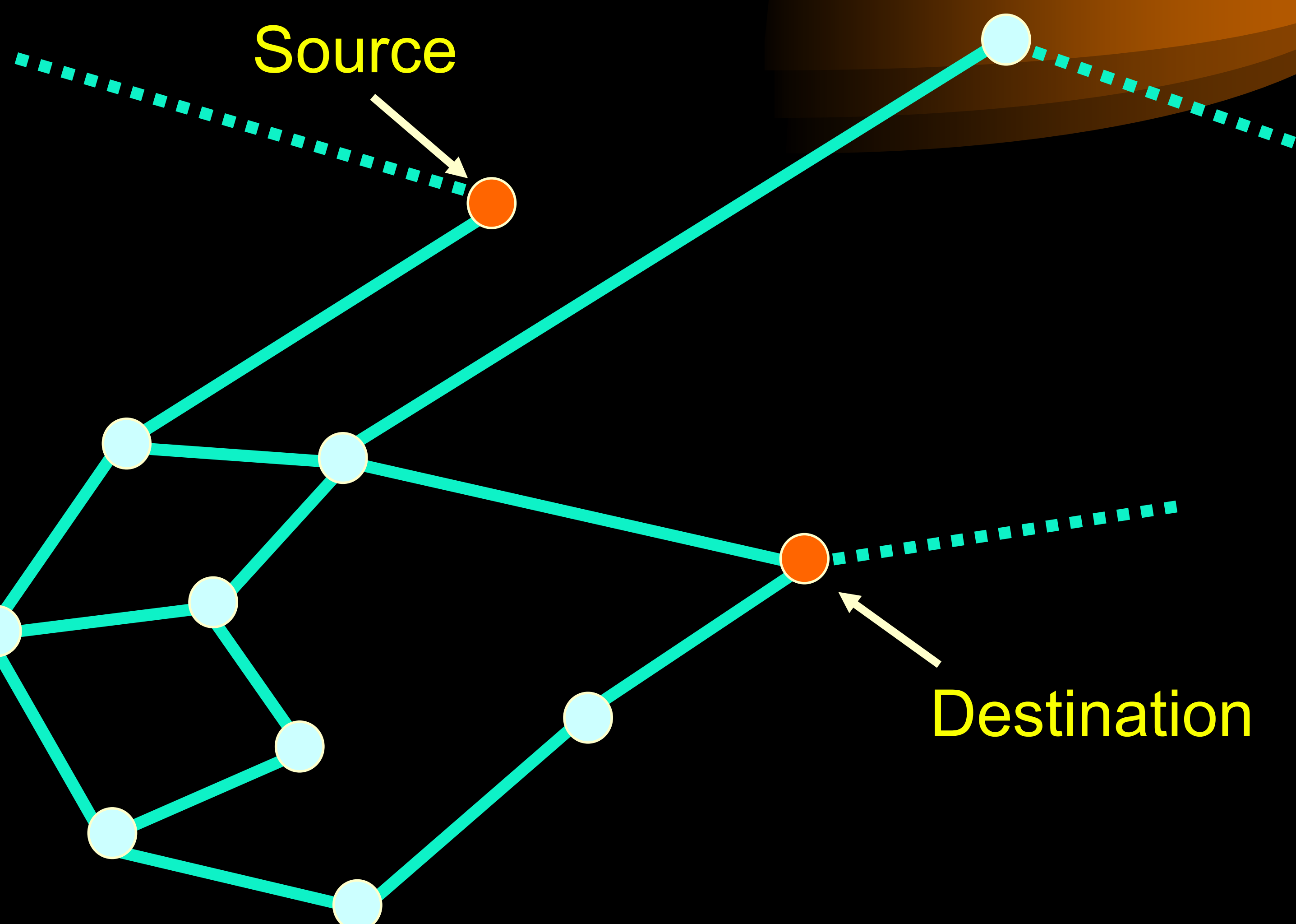
Why unlimited face information can be bad



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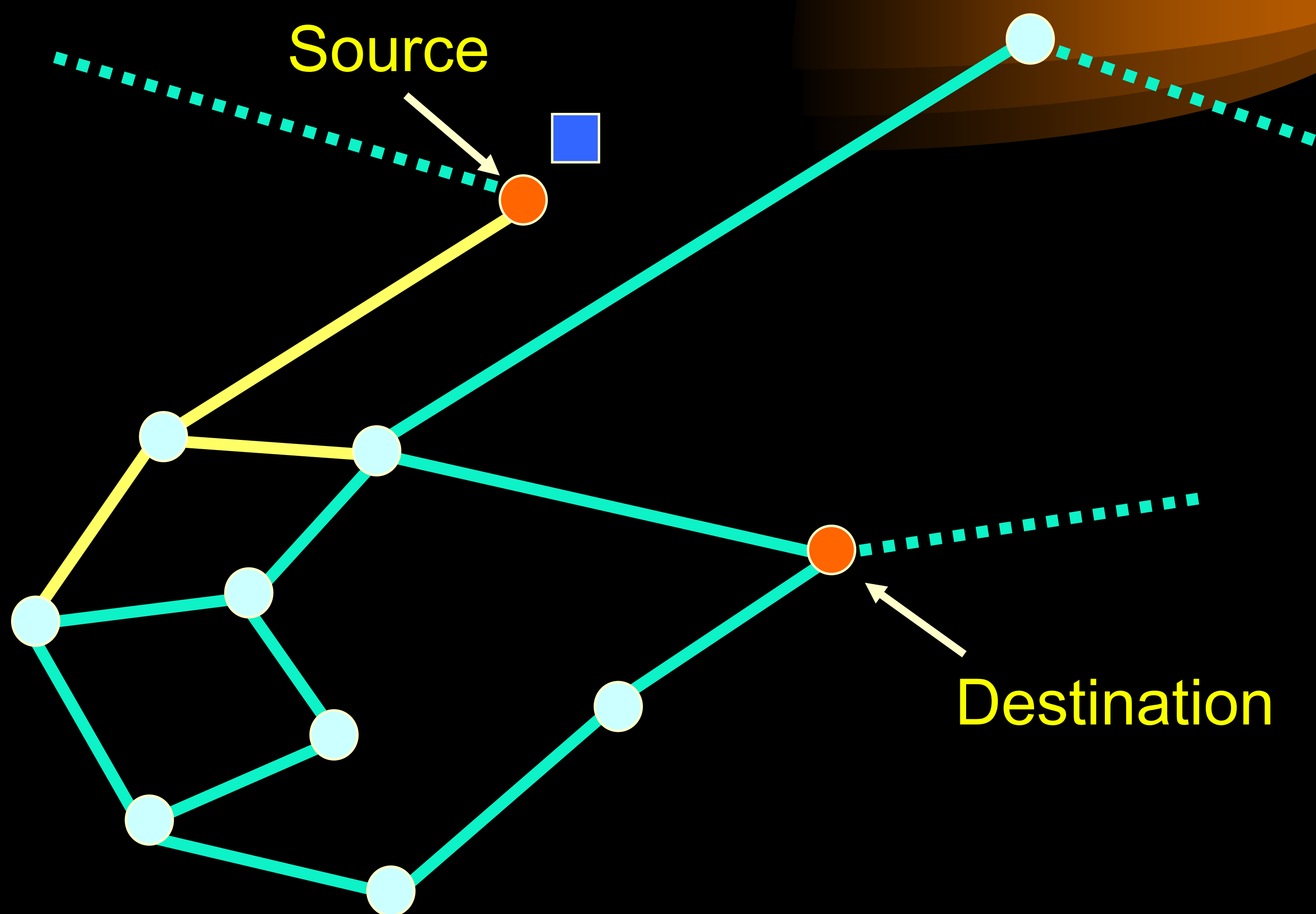

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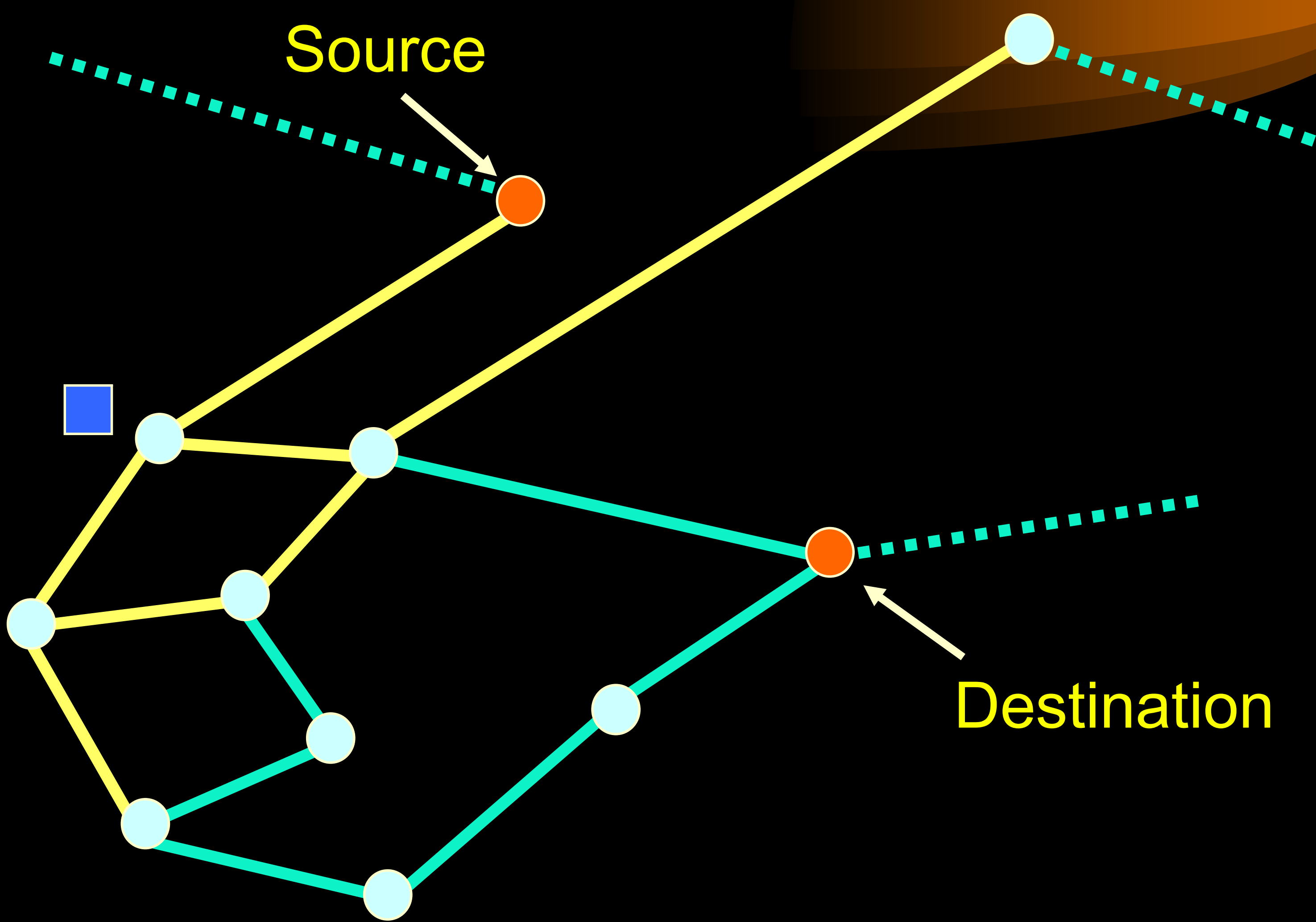

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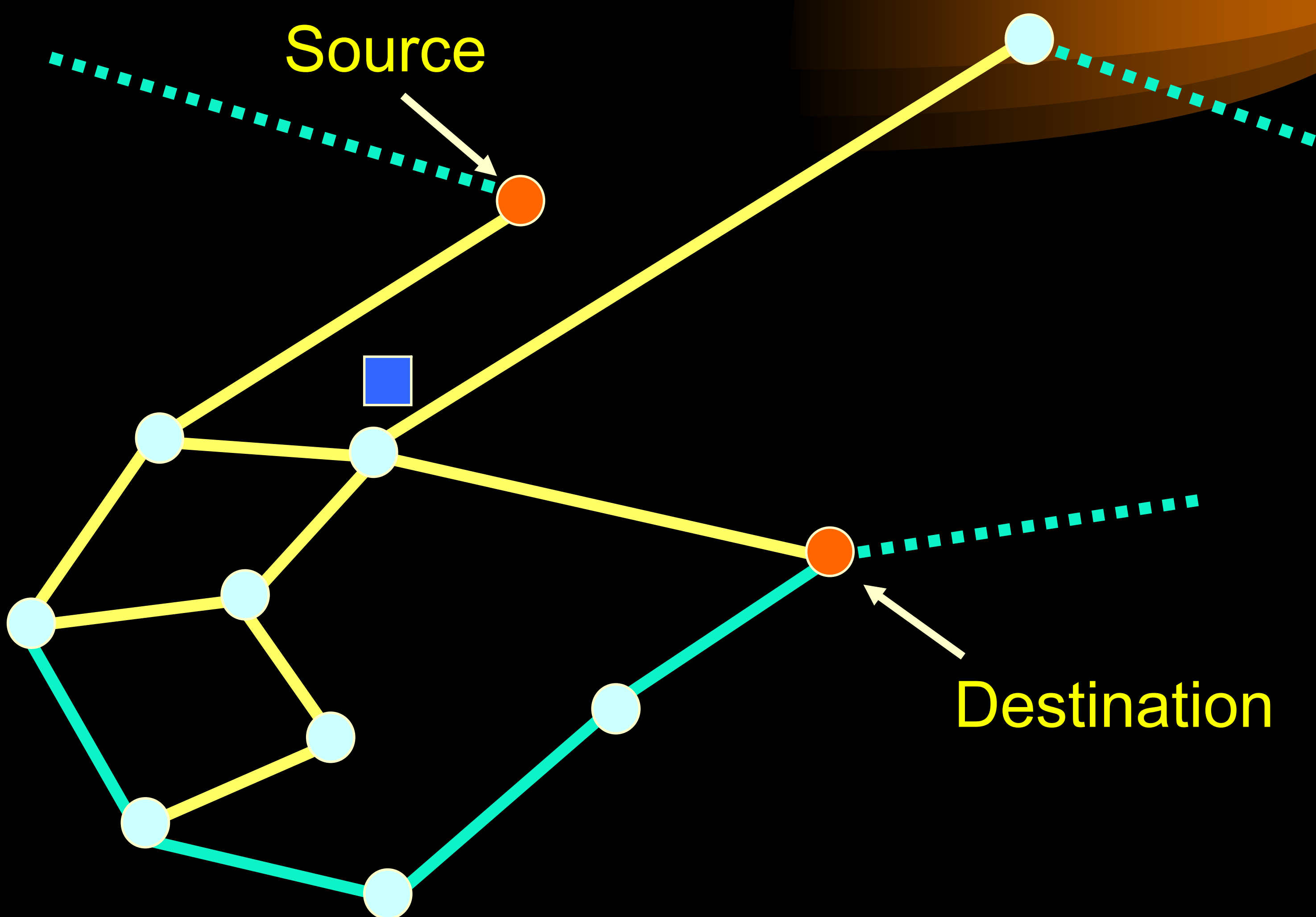

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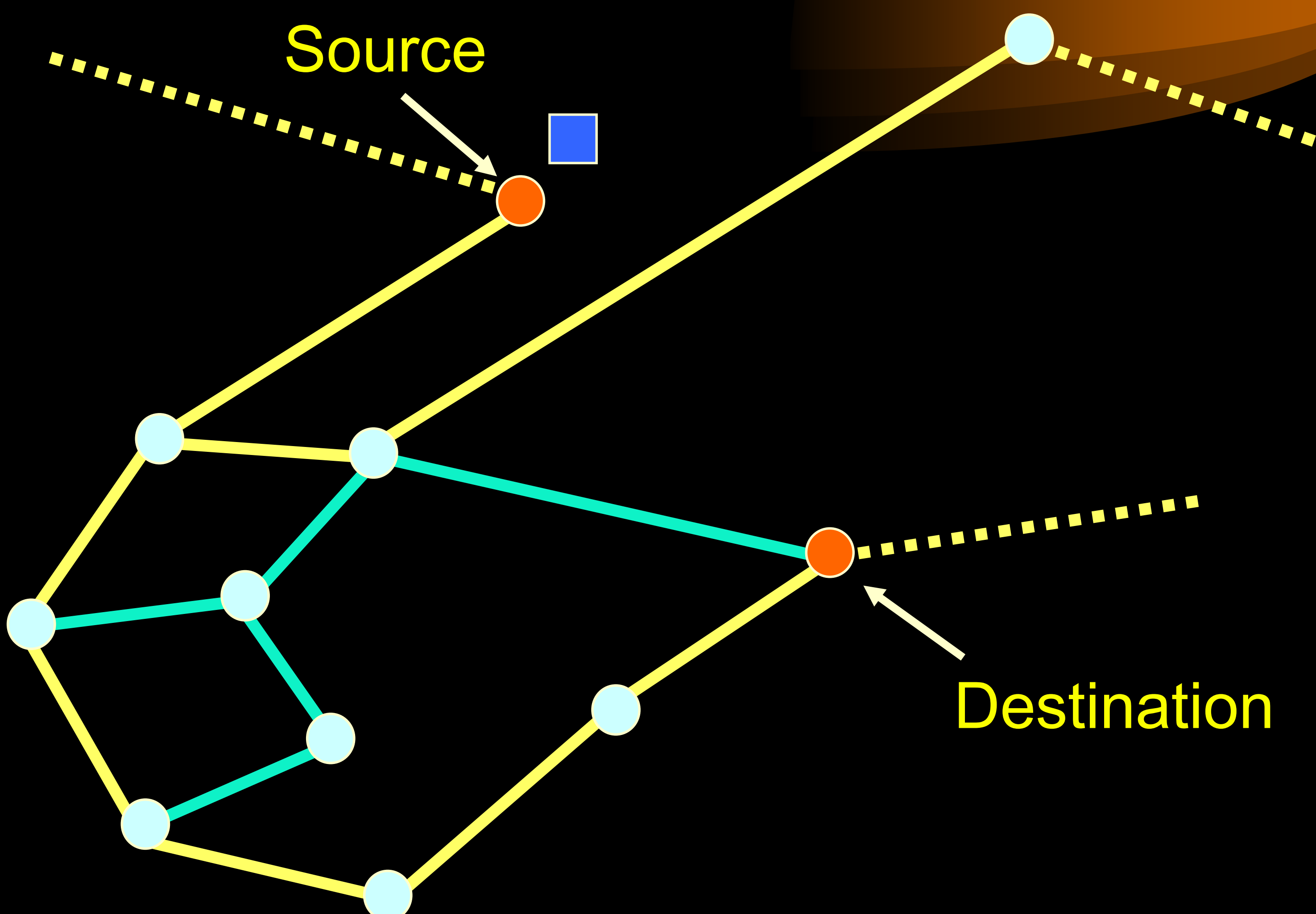

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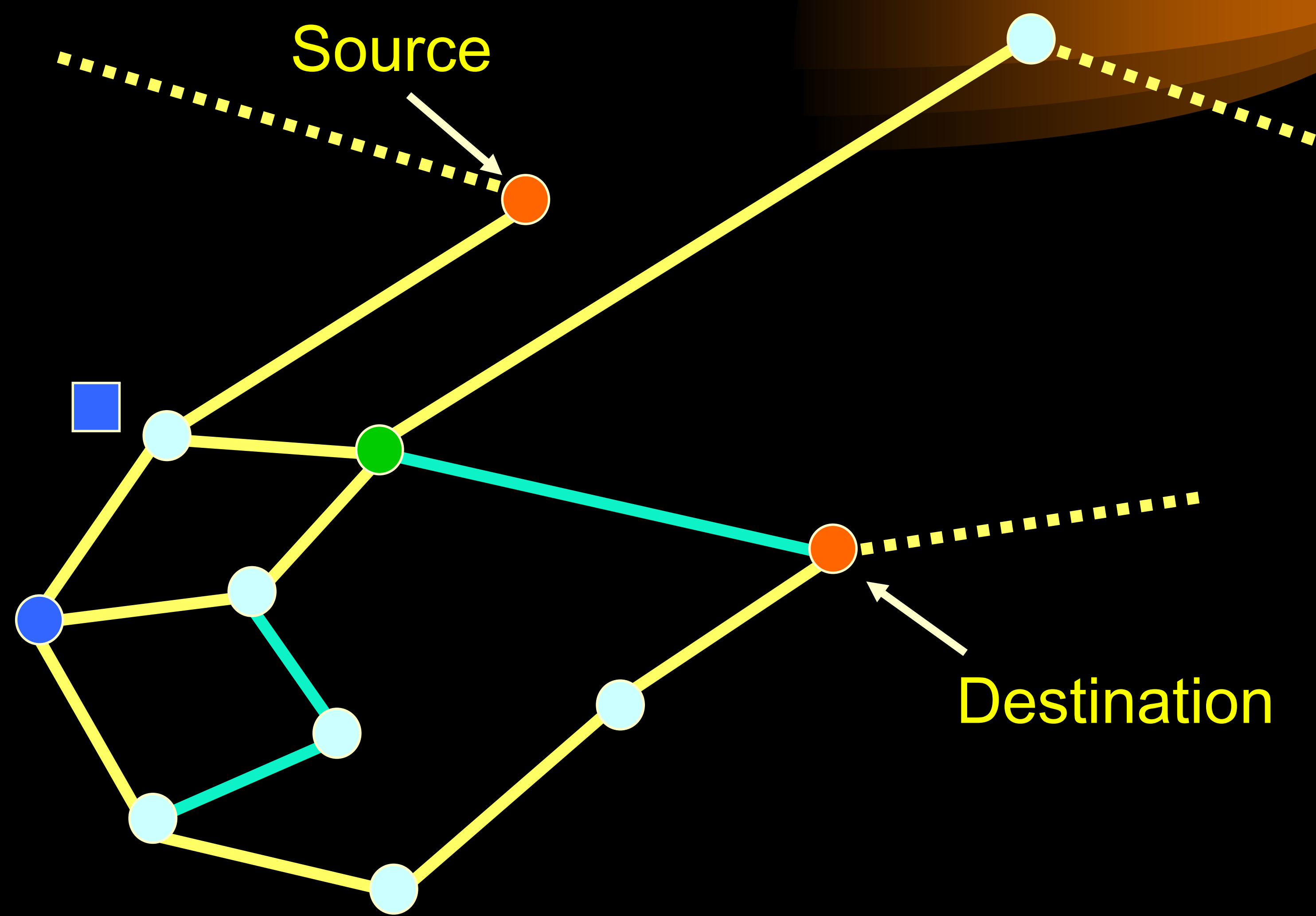

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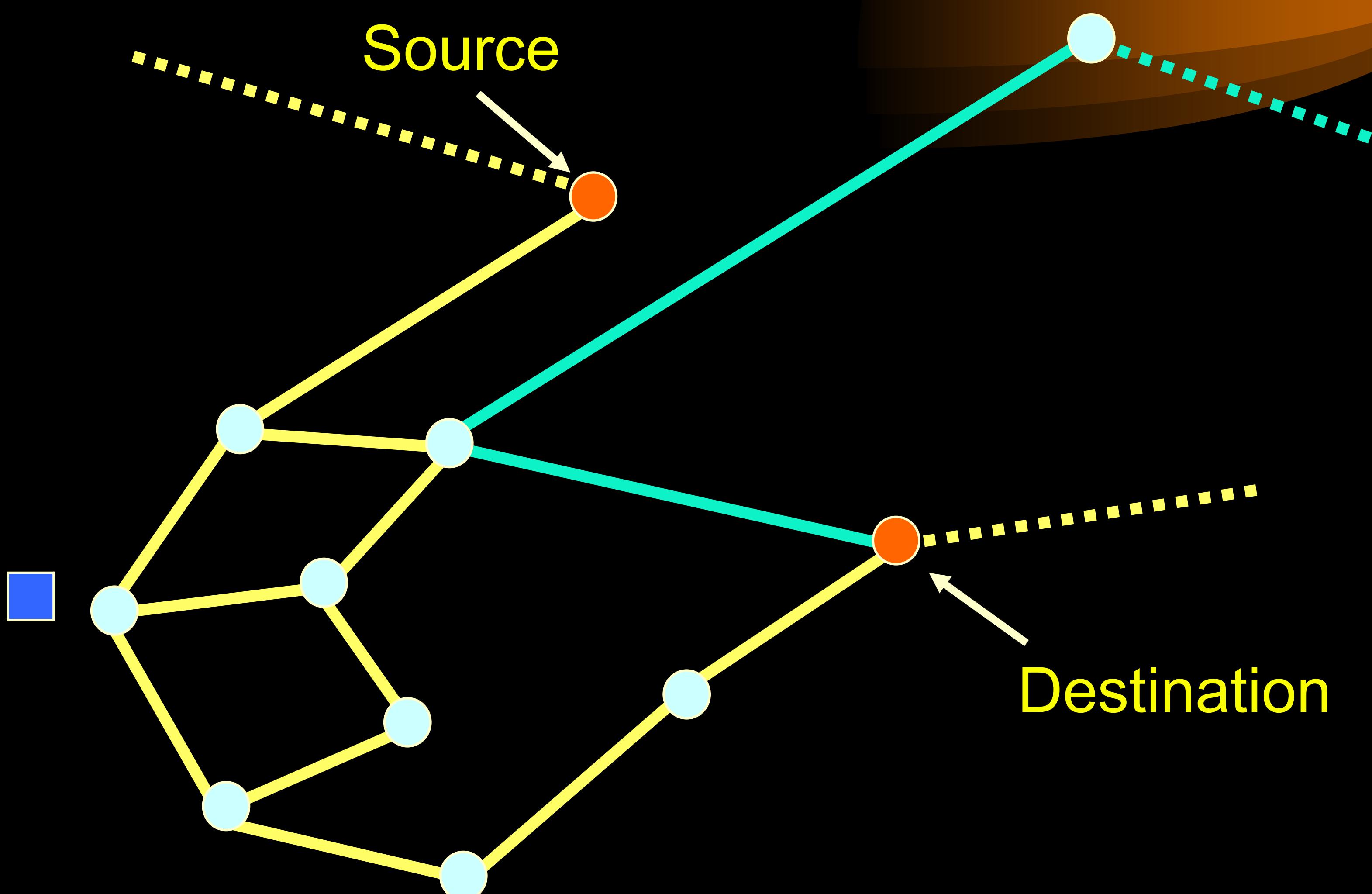

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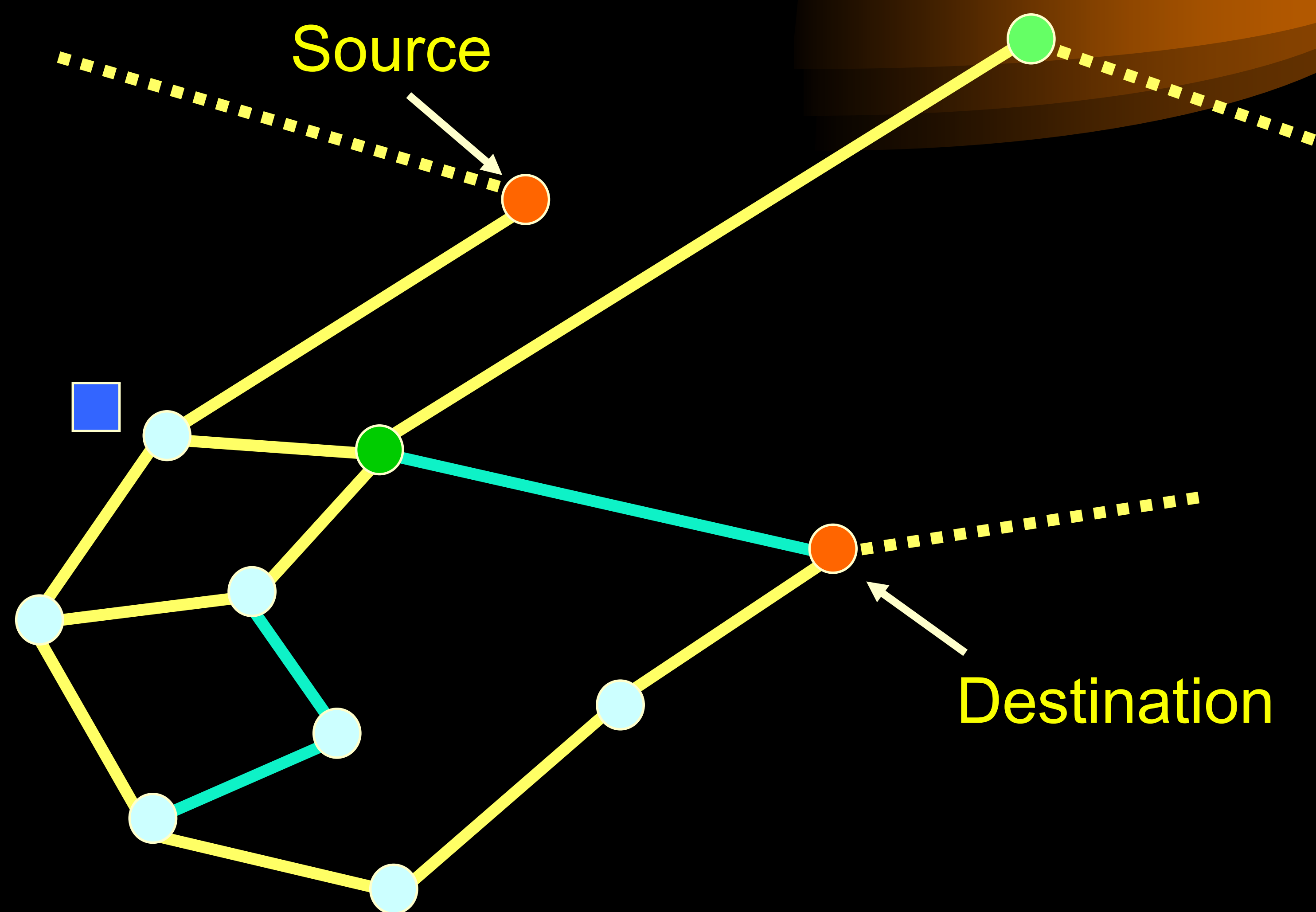

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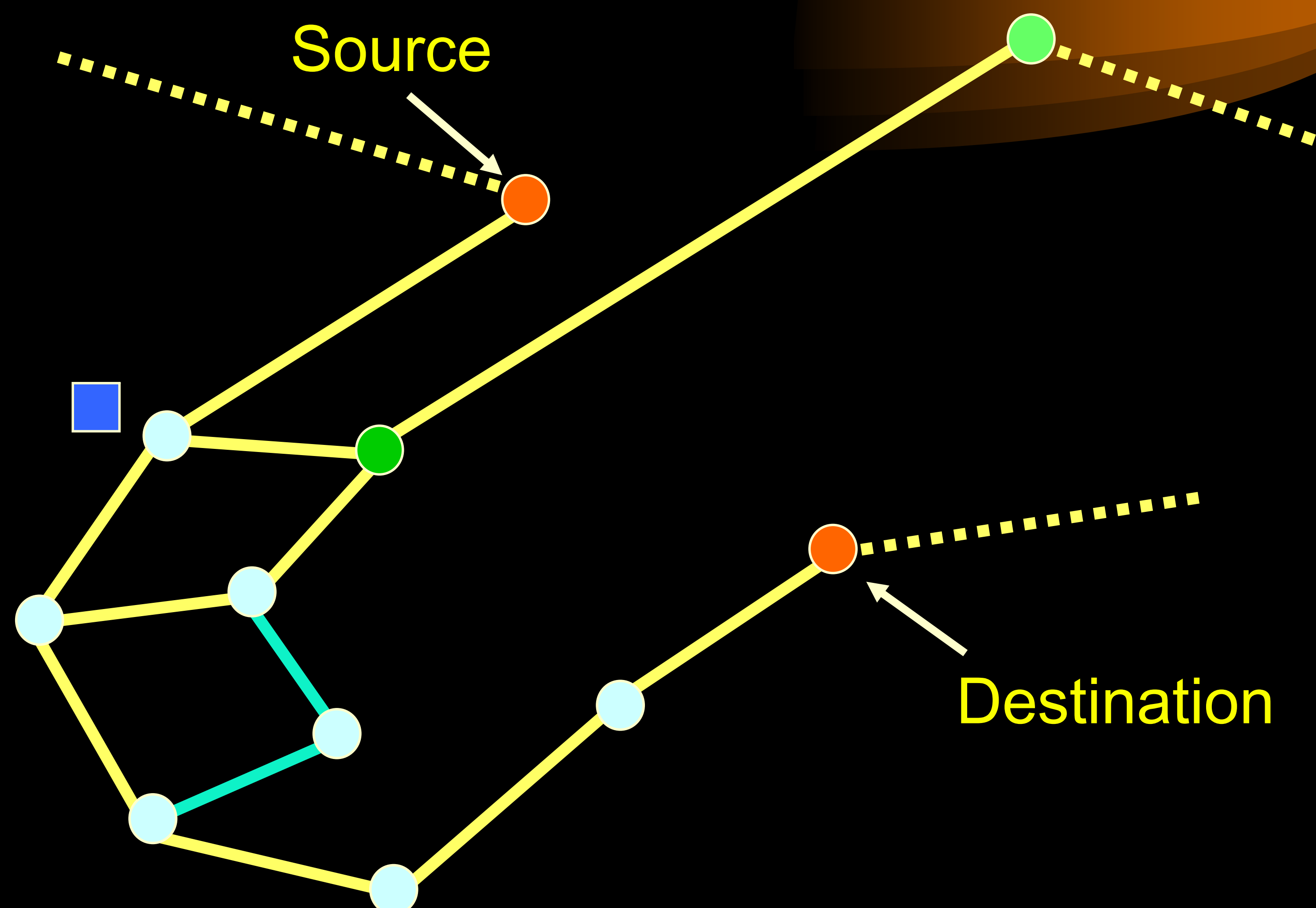


Theorem 1

Given a connected pair of nodes v and t in a planar graph G, assuming that every node in G completely knows all its faces, we can route from v to t obliviously

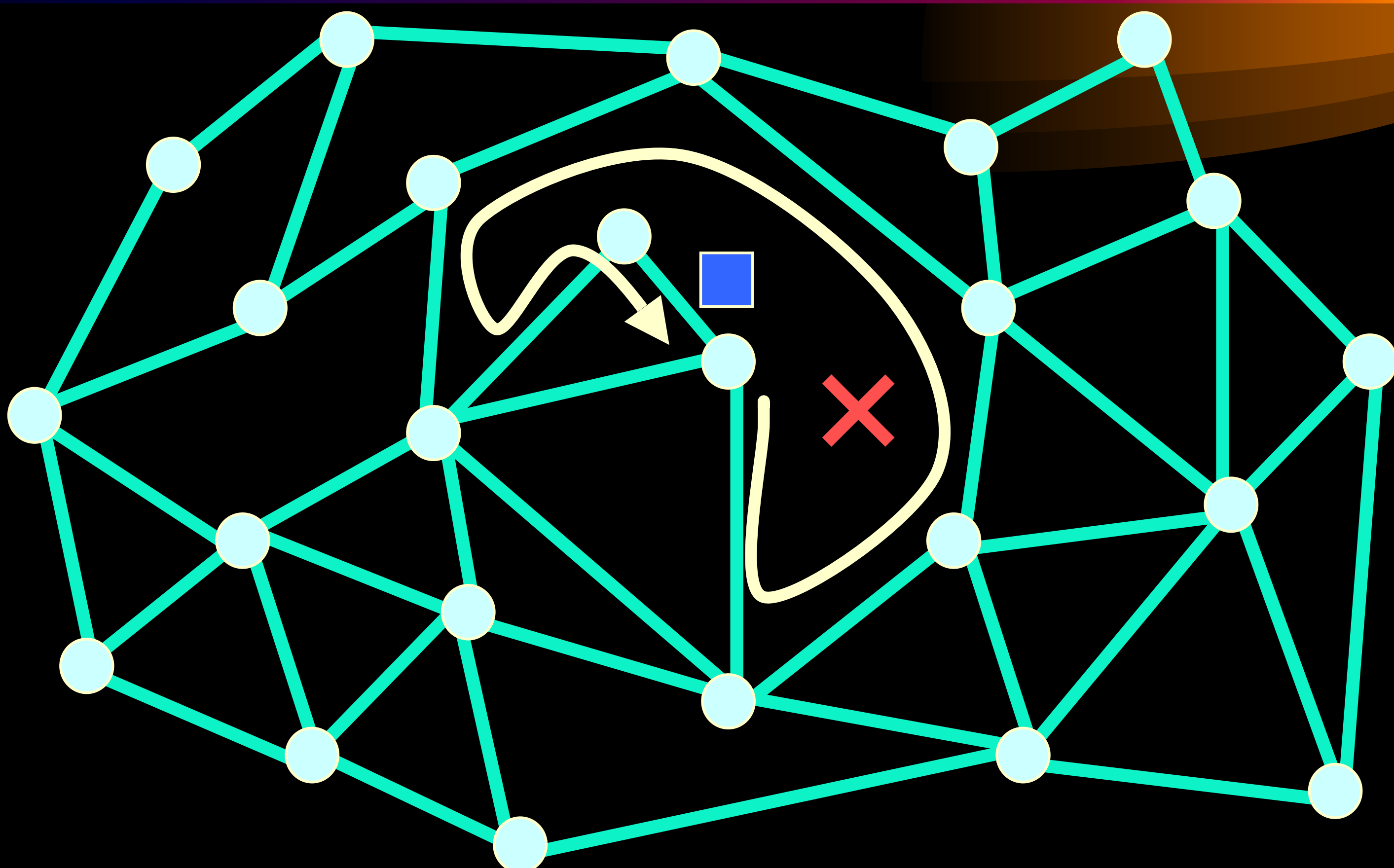
Theorem 1 Paraphrased

With full face information at each node, we can route without storing state in the packets

Oblivious Routing with Full Face Information (OPVFR)

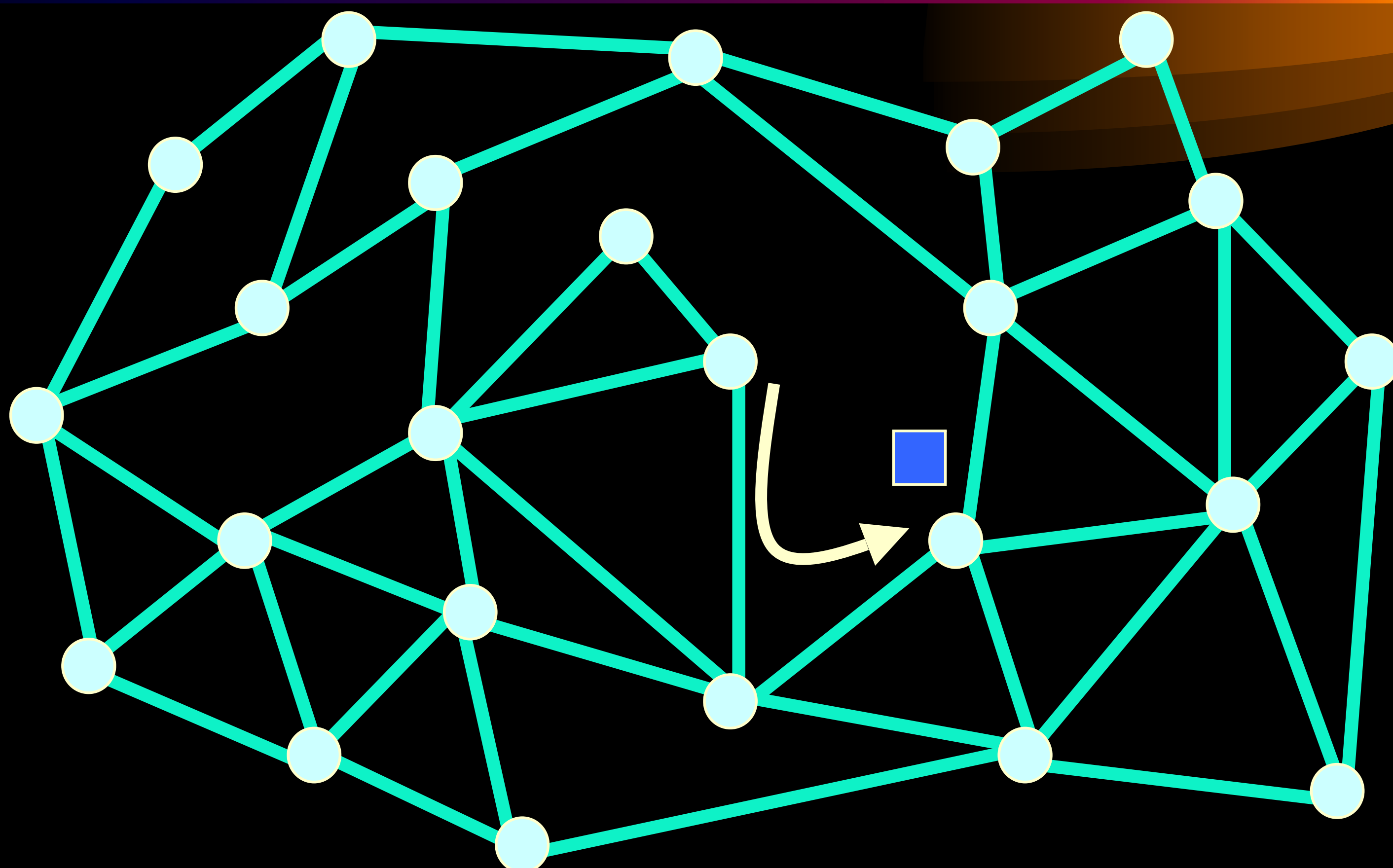
- Suppose all nodes have full face information
- Do:
  - Find **target node** and route towards it.
  - To find **target node**: find edge that is nearest to destination node among all faces. Node on edge that is nearer destination is target node.
- Break ties in some consistent way.

Non-oblivious Routing



- Need to know when we come back to the same node!

Non-oblivious Routing



- Need to know when to switch back to greedy

Theorem 2

For any given non-negative integer h, there does not exist a deterministic oblivious routing algorithm that guarantees packet delivery for all planar graphs if nodes are limited to knowing only about nodes that are up to h hops away

Theorem 2 Paraphrased

If nodes do not have full face information, it is impossible to always route correctly without storing some state in the packets.