Name-Based Content Routing in Information Centric Networks Using Distance Information

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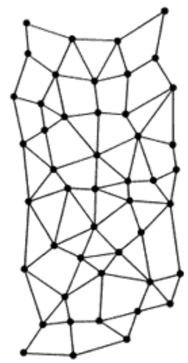
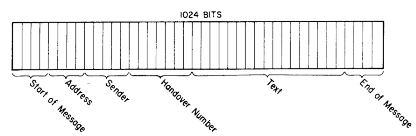
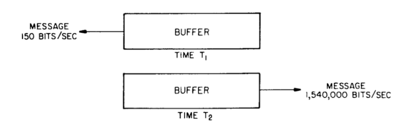
Origins of Routing for Packet Switching

Original documents: Paul Baran's "On Distributed Communications Series," RAND Corporation, **1960-62**.

- Packet headers, store-and-forward operation, statistical multiplexing of links.
- **"Hot-potato heuristic routing doctrine":** Primordial distance-vector routing.
- Addresses for sender and destination of packet.
- Routing of packets is based on destination-based routing tables using *node addresses*.
- **Destinations are routers that originate routing updates.**





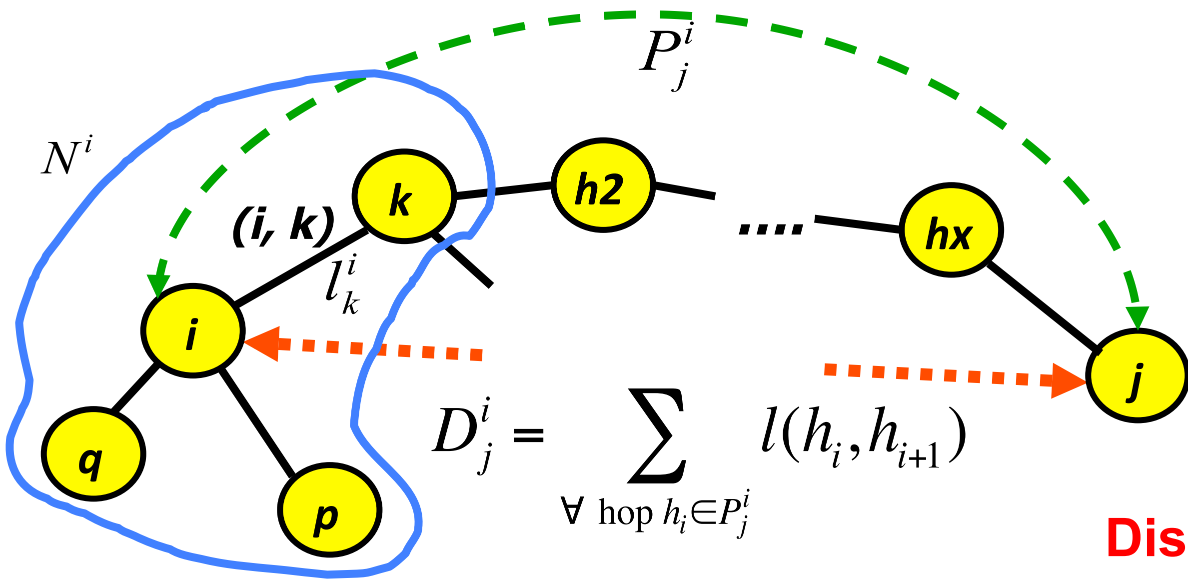


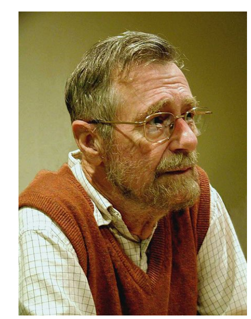
	LINK NUMBER							
	1	2	3	4	5	6	7	8
	HANDOVER NUMBER ENTRIES							
A	22	∞	12	10	9	9	8	13
B	5	3	2	2	4	5	12	2
C	7	8	13	9	22	10	7	8
D	21	23	19	21	12	10	12	13
E	7	10	12	14	12	13	13	15
F	7	10	12	13	14	[illegible]		
G	6	4	[illegible]					
…								
Z	15	20	7	3	10	8	5	10

BEST CHOICE				
1st	2nd	3rd	4th	[illegible]
LINK NUMBER for DECISION CHOICE				
7	5	6	4	[illegible]
3	4	8	2	[illegible]
1	7	2	8	[illegible]
6	5	7	8	[illegible]
1	2	3	5	[illegible]
1	2	3	4	[illegible]
5	2	1	6	
…				
4	7	3	6	[illegible]

State of The Art in Shortest-Path Routing Algorithms

- ***Problem:*** Compute the path of minimum length from each router to each destination node in the network
- ***G(N, E) is the network of |N| nodes and |E| links***





Each destination node has a single instance in the graph

Distances: Node starts by sending distance to itself

Link-state: Node shares the state of adjacent links

The Brave New World of Information Centric Networks (ICN)

- Many papers have stated that routing in ICNs is inherently different than routing in the "old" IP Internet.
  - Content objects are copied opportunistically in the network.
  - Multiple instances of the same destination.
- However, existing proposals for routing in ICNs assume routing algorithms designed for single-instance destinations.

Remembering Multi-Homing and John McQuillan

- McQuillan worked on the "old" and the "new" ARPANET routing protocols:
  - McQuillan J. M., et. al., "The New Routing Algorithm for the ARPANET," *IEEE Trans. Comm*. 1980.
- He and others also studied multi-homed destinations:
  - J.M. McQuillan, "Enhanced Message Addressing Capabilities for Computer Networks", *Proc. IEEE*, Vol. 66, No. 11, Nov. **1978**.
- **Same routing algorithms for single-instance destinations.**
- **A <u>directory</u> is used to map identifier of "group" to identifier of each instance.**

How Can We Route to Multiple Instances of The Same Thing with Today's Routing Algorithms?

- Source does not know all instances
- Source knows all instances
- Something in between

How Can We Route to Multiple Instances of The Same Thing with Today's Routing Algorithms?

- **Source does not know all instances**
  - Flood the network towards instances and prune as needed
- **Source knows all instances**
  - Have each node know the topology and the location of each instance. Instances flood the network.
  - Source can compute source trees to instances
- **Something in between**
  - Designate a representative node between sources and destination instances
  - Compute a routing tree rooted at the representative

Prior Results in ICN Routing

- **No information:**
  - Intanagonwiwat et al., [**Directed Diffusion** (Trans. Networking 2002)]; many DTN routing schemes.
- **All information:**
  - Mahmudul-Hoque et al., [**NLSR** (ACM ICN ‘13)].
  - DHT approaches need an underlay to build the DHT.
- **Representative:**
  - Carzaniga, Rosenblum, and Wolf [**Content-Based Networking** (Infocom 04)].

Distance-based Content Routing (DCR): Basic Approach

- Establish a lexicographic ordering of distances to instances of destination.
- The name of a router "speaking for" a destination instance (called **anchor**) is an attribute that must be used in the ordering.
- Routers choose what information to share with their peers to preserve ordering

  (e.g., "the best distance to any instance of content").
- Lexicographic ordering among all instances determines which instance can be the root of a DAG spanning all instances.

DCR

Routing to nearest instances of destination:

- N^i = set of neighbors of node i
- S^i = set of neighbors of node i that are closer to destination (next hops).
- A^i = set of known anchors of destination at node i.

- An update from i about a destination states $[d^i, a^i, sn^i]$:
  - distance (d^i), an anchor (a^i), a seq. number created by the anchor (sn^i).
- $d^i = \mathrm{Min}\{d^i_k + l^i_k \mid k \in S^i\}$
  - d^i_k = distance reported by k; l^i_k = cost of link to k

DCR

Routing to nearest instances of destination:

- **Successor-Set Ordering Condition (SOC) used by node i to select a next hop k for destination:**
  - ✓ Node k reports up-to-date information

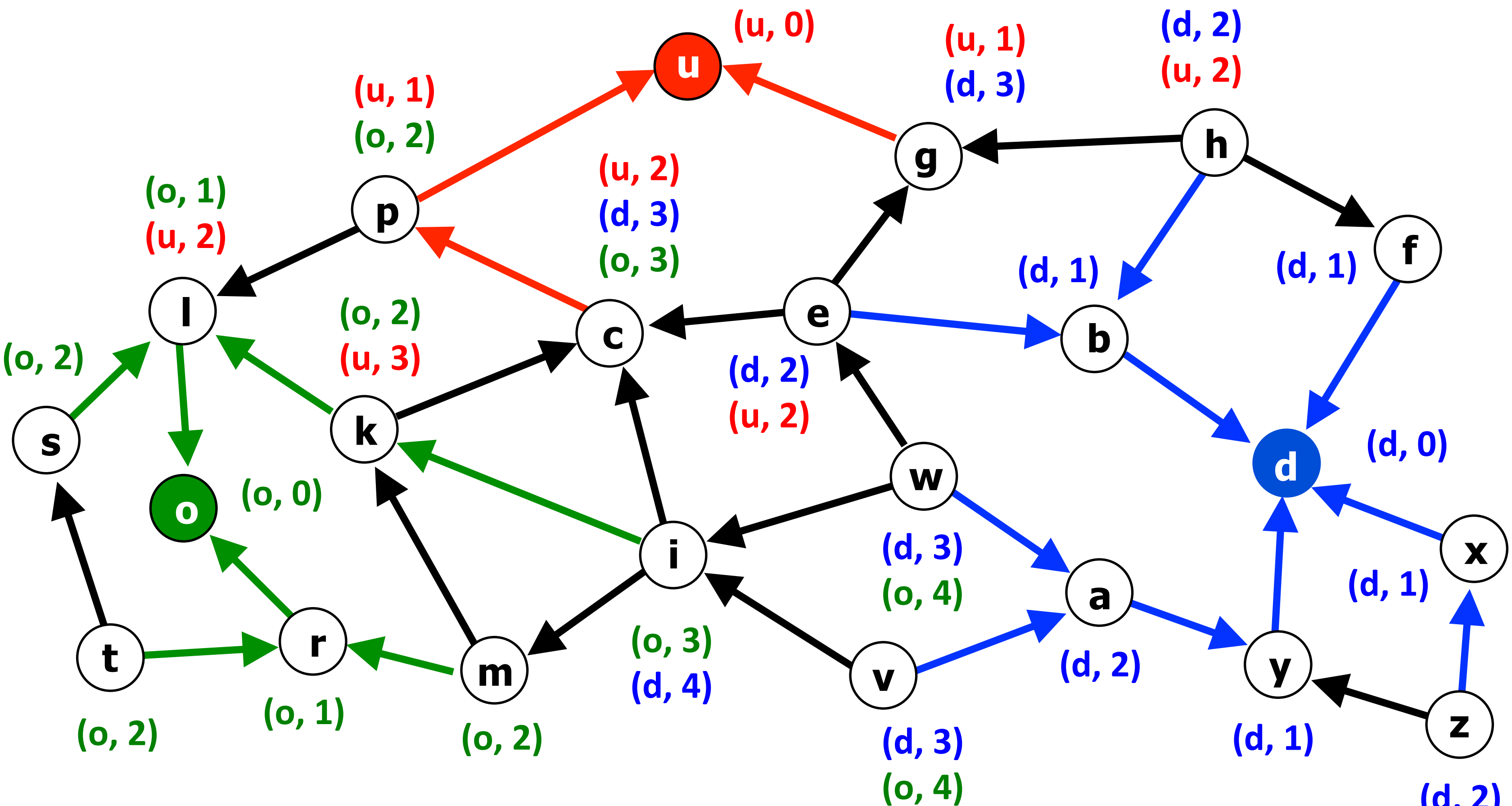
    $(\forall m \in A^i \, (a^i_k \neq m \vee s^i_k \geq sn(m) \,)$
  - ✓ If node i has a finite distance:

    Node k is <u>closer</u> $(d^i_k < d^i \,)$ <u>or</u> is at the <u>same distance and has a smaller name</u> $(d^i_k = d^i \wedge |k| < |i| \,)$
  - ✓ If node i does not have a finite distance:

    Node k offers the <u>smallest distance or has smallest name</u> among neighbors offering the same smallest distance

    $(\forall q \in N^i - \{k\}(d^i_k < d^i_q \;\vee (\, d^i_k = d^i_q \wedge |k| < |i| \,)\,)$

DCR



- Three instances (at **d**, **o**, and **u**)
- Lexicographic ordering based on: hop count to instance, ID of instance's anchor, and sequence number from anchor.
- **Route to nearest instance w/o knowing all.**

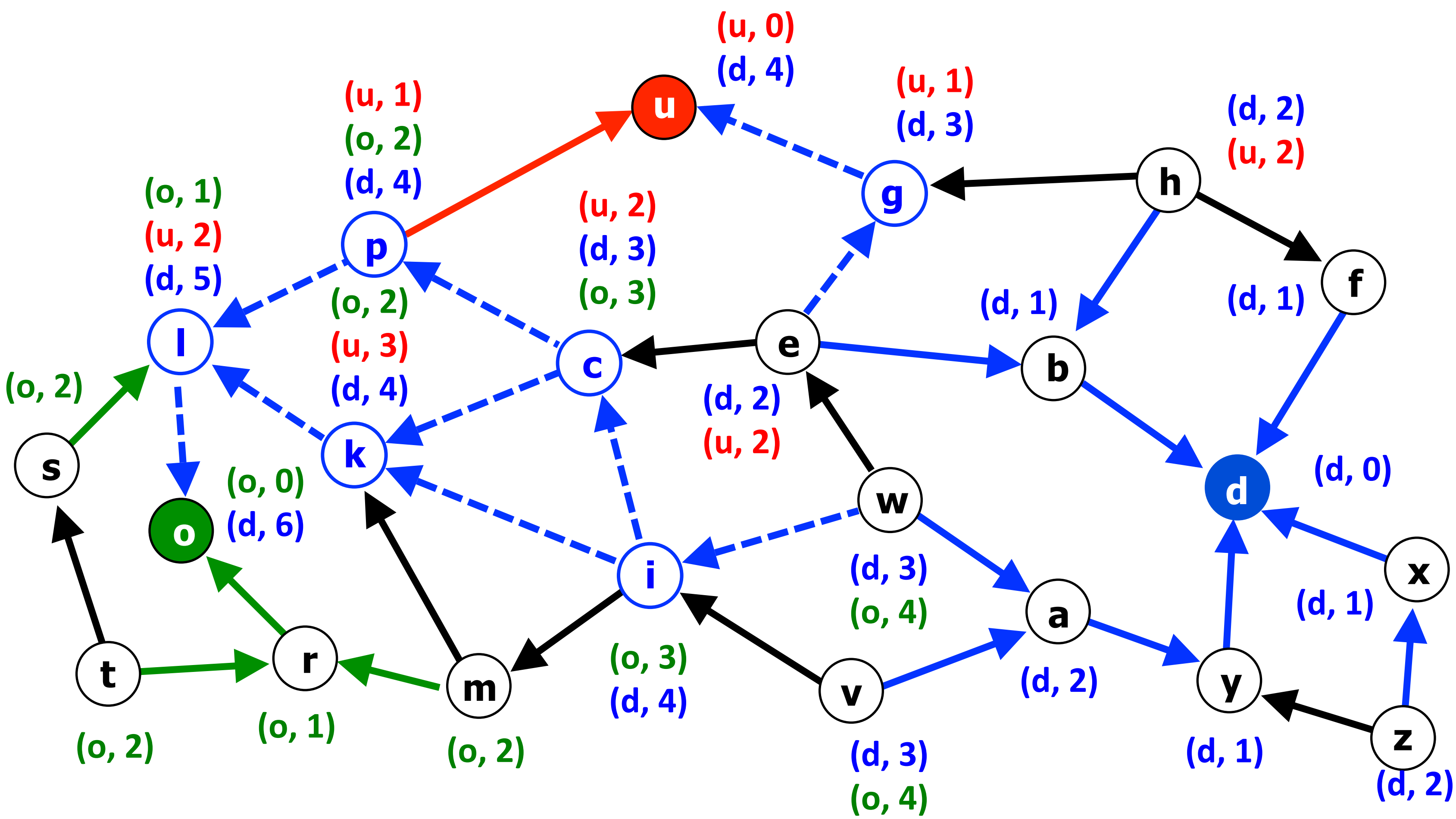
DCR

Routing to some or all instances of destination:

1. Select the anchor with the smallest identifier as the root anchor (ra) of the destination.
2. Select neighbor k as next hop to root anchor if node k:
   - ✓ Reports up-to-date anchor information
   - ✓ Has the smallest sequence number for ra or is closest to ra among all neighbors with a valid sequence number for ra.
3. Ensure that *root anchor* information is known by all anchors of destination:
   - ✓ Node i sends update about ra to neighbor q if i is an anchor or q is the lexicographically smallest way to reach *another* anchor:

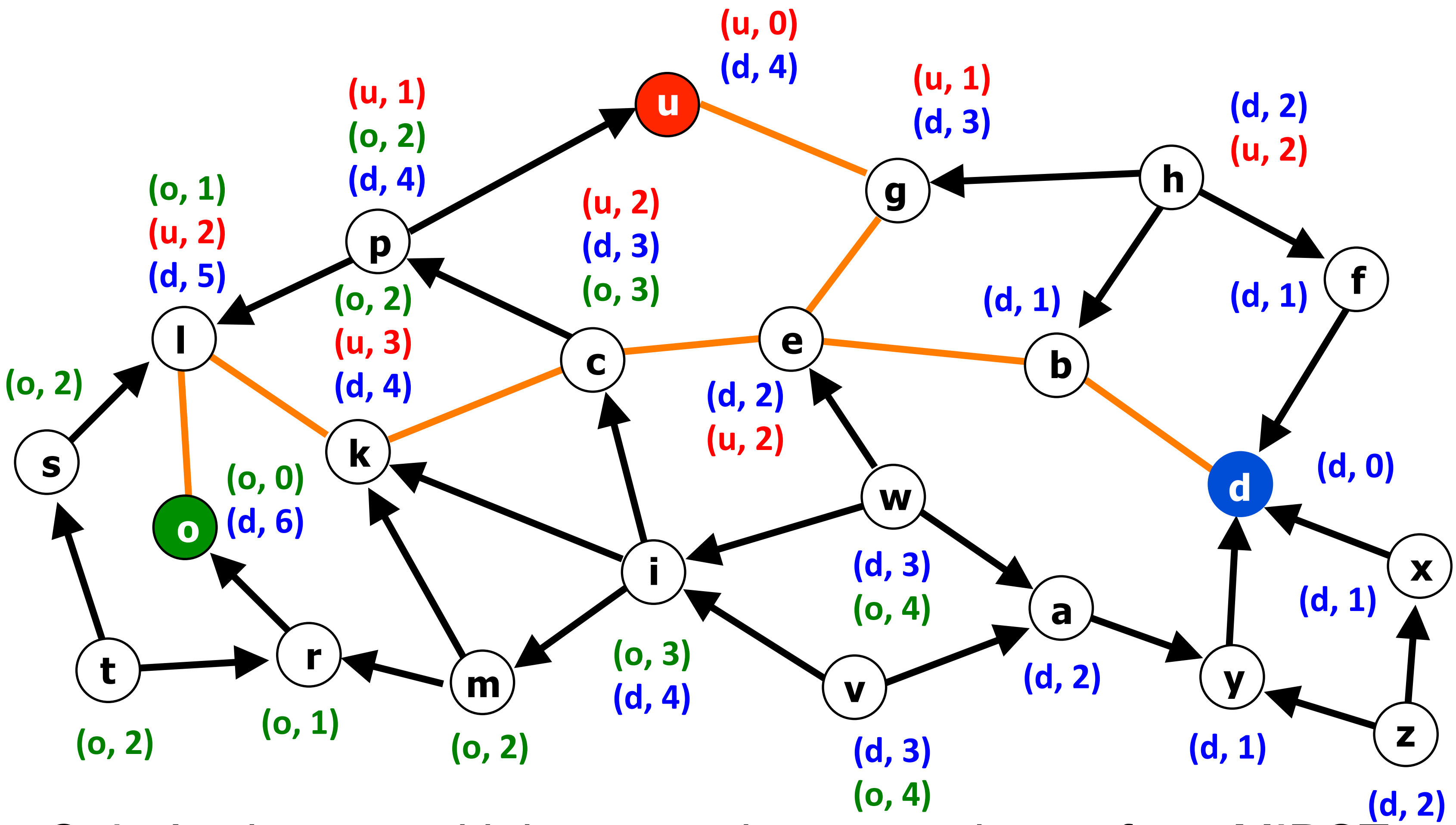
$$a^i_q \neq ra^i_j \;\wedge\; |ra^i_q| > |ra^i| \;\wedge$$
$$\forall k \in N^i - \{i\} \; [\; a^i_k = i \vee$$
$$(a^i_k \neq ra^i_q \vee (d^i_q < d^i_k \vee [d^i_q = d^i_k \wedge |\, q \,| < |\, k \,|\,]\,)\,)\,]$$

DCR



- One instance is "best" and hence is known by other instances (**d** < **o** < **u**).
- Updates about *d* are sent only along the best paths between *d* and *o* and between *d* and *u*.

The MIDST of a Destination: Multiple Instance Destination Spanning Tree



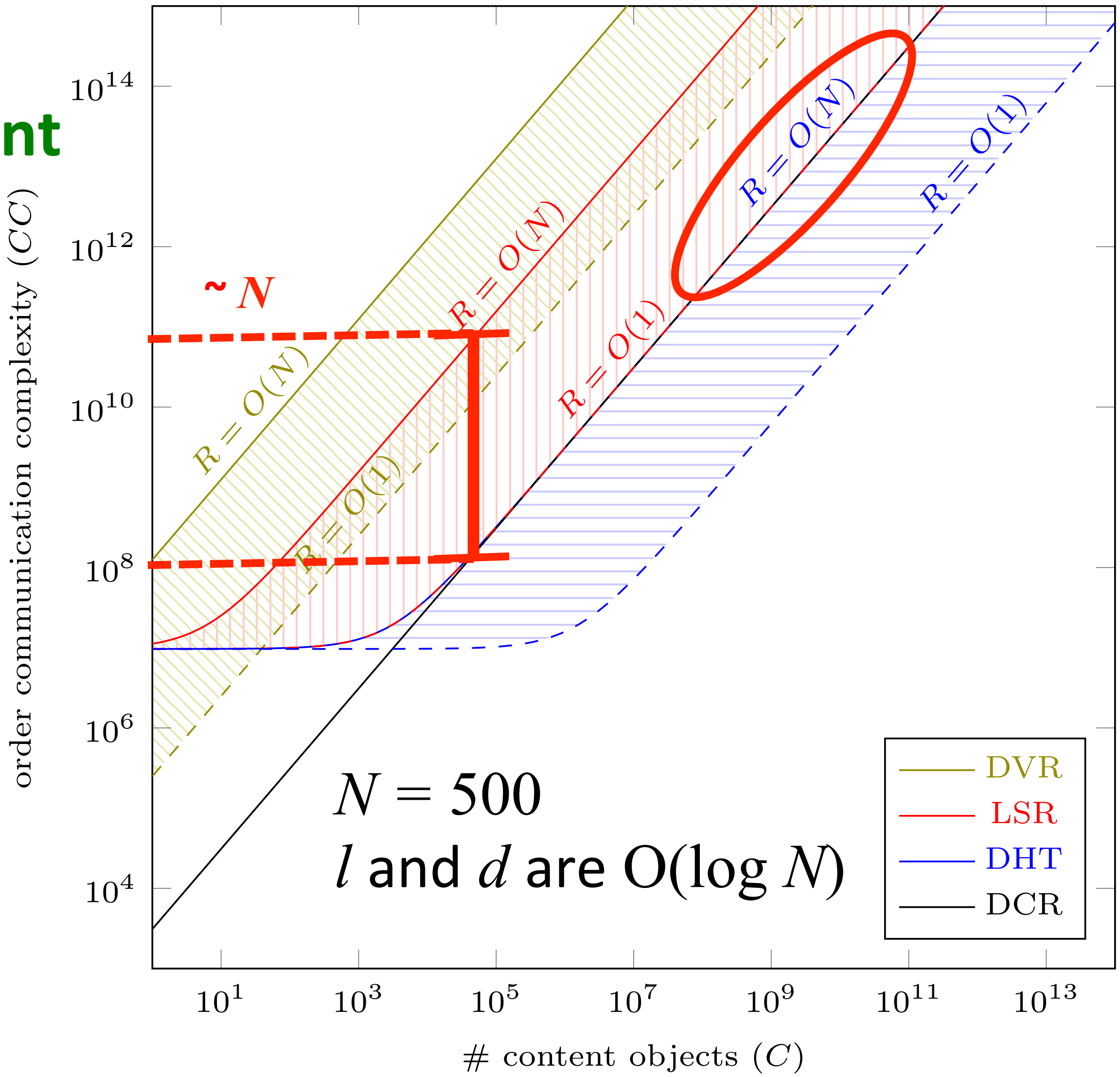
- Only Anchors send joins towards root anchor to form MIDST.
- Messages sent towards nearest instance, broadcast over MIDST to reach all or some instances.

Why Is This Important?

Attain orders of magnitude improvement in the control plane

$CC_{LSR} = O(ERC + lNE)$
$SC_{LSR} = O(RC + E)$
$CC_{DHT} = O(dRC + lNE)$
$CC_{DHT} = O(C + E)$
$CC_{DCR} = O(EC)$;
$SC_{DCR} = O(C)$

C: # destinations
R: # replicas
E: # edges; N: # nodes
d: diameter; l: node degree



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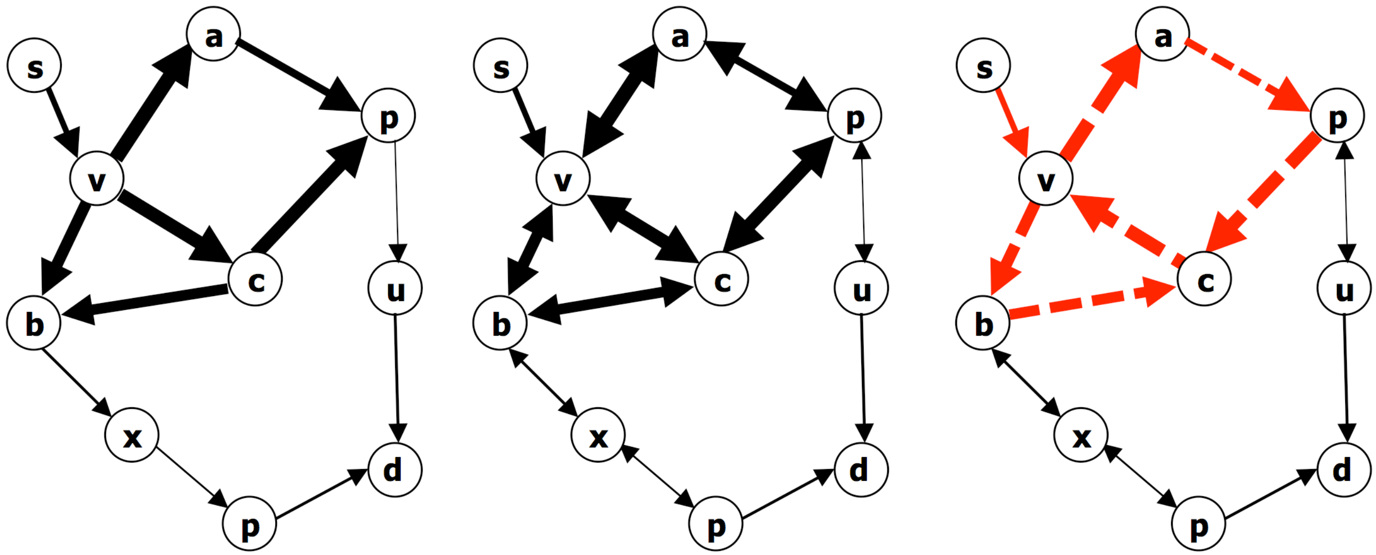

Loop-Free FIBs Loop-Prone FIBs Interest looping

More efficient data plane!

Looping with multi-path routing leads to searching for paths in $O(N)$ steps w/o guarantees (DFS) and Interest timers of order $O(N)$ to avoid loops not being detected!

Loop-free FIBs allow searching for paths in $O(x)$ steps and Interest timers of order $O(d)$, with $x < d << N$

Summary

- **Just a start!** Many more results are needed:
  - DCR simulations in ns3 soon
  - Real implementation after that
  - Multipoint applications (e.g., multicast)
  - QoS, policies, other types of termination detection.

- Change the way we think about destinations for *all* types of routing; assume any destination can have multiple instances.

- Integrate unicast, multicast, and anycast routing.

- Need solutions that scale *better* than O(*C*).
  It can be done using distances.

THANK YOU!

ANY QUESTIONS?