Adaptive Forwarding Strategy for Hyperbolic Routing

Vince Lehman, Ashlesh Gawande, Lan Wang,
University of Memphis
Rodrigo Aldecoa, Dmitri Krioukov, *Northeastern University*
Beichuan Zhang, *University of Arizona*
Lixia Zhang, *UCLA*

THE UNIVERSITY OF MEMPHIS

Routing Scalability in NDN

- Already large number of content names in today's Internet
- Number of Forwarding Information Base (FIB) entries in NDN could grow at an unmanageable rate without viable routing protocol
- Number of routing updates (overhead) to maintain consistent FIBs may also be costly
- NDN networks must scale in terms of routing table size and routing protocol overhead

What do we want from a routing protocol?

- Small FIB size
- Low number of routing updates
- Comparable performance to shortest path routing algorithms

- In short, we want to bound the size of routing state while supporting an unbounded namespace

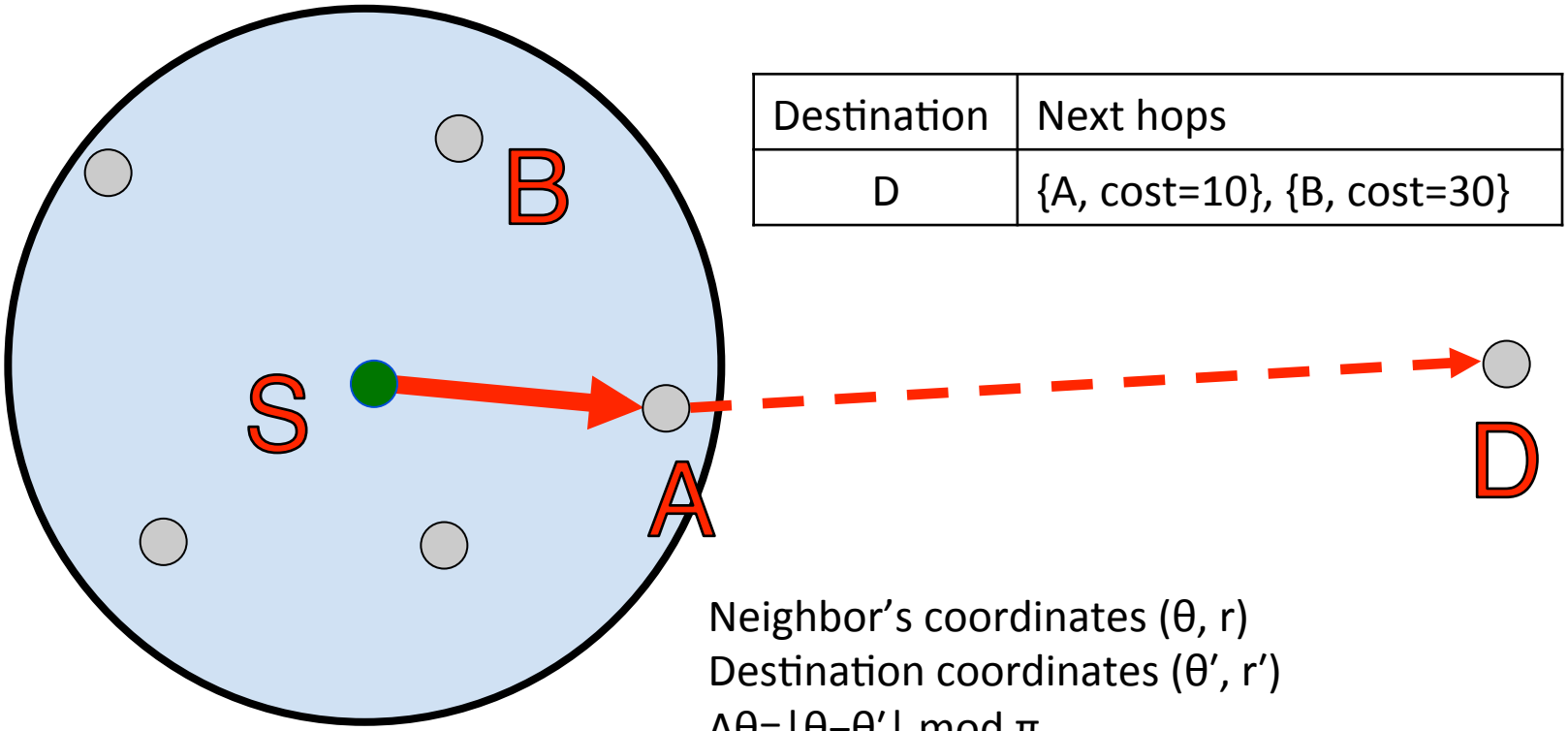
Potential of Adaptive Forwarding

- Routing can be less dynamic because of adaptive forwarding plane
- NDN Forwarding Strategy can make forwarding decisions based on routing
- Non-traditional routing schemes may become viable

Hyperbolic Routing (HR)

- Each node and name prefix has a set of hyperbolic coordinates
- Next hop ranks are calculated based on each neighbor's distance to the destination
- No need to distribute topology information or updates
- For forwarding in HR, it is necessary that:
  1. Each node knows its own hyperbolic coordinates
  2. Each node knows its neighbors' coordinates
  3. The node that is forwarding knows the coordinates of the destination

Greedy Forwarding in HR



Destination	Next hops
D	{A, cost=10}, {B, cost=30}

Neighbor's coordinates (θ, r)
Destination coordinates (θ', r')
$\Delta\theta = |\theta - \theta'| \bmod \pi$
distance = $\operatorname{acosh}(\cosh r \cosh r' - \sinh r \sinh r' \cos \Delta\theta)$

To forward a packet:

- Find the neighbor closest to the destination
- Forward the packet to that neighbor

Why Hyperbolic Routing?

- In the ideal case, no FIB is needed

  If an Interest carries the coordinates associated with the name, each node only needs to know their neighbors' coordinates

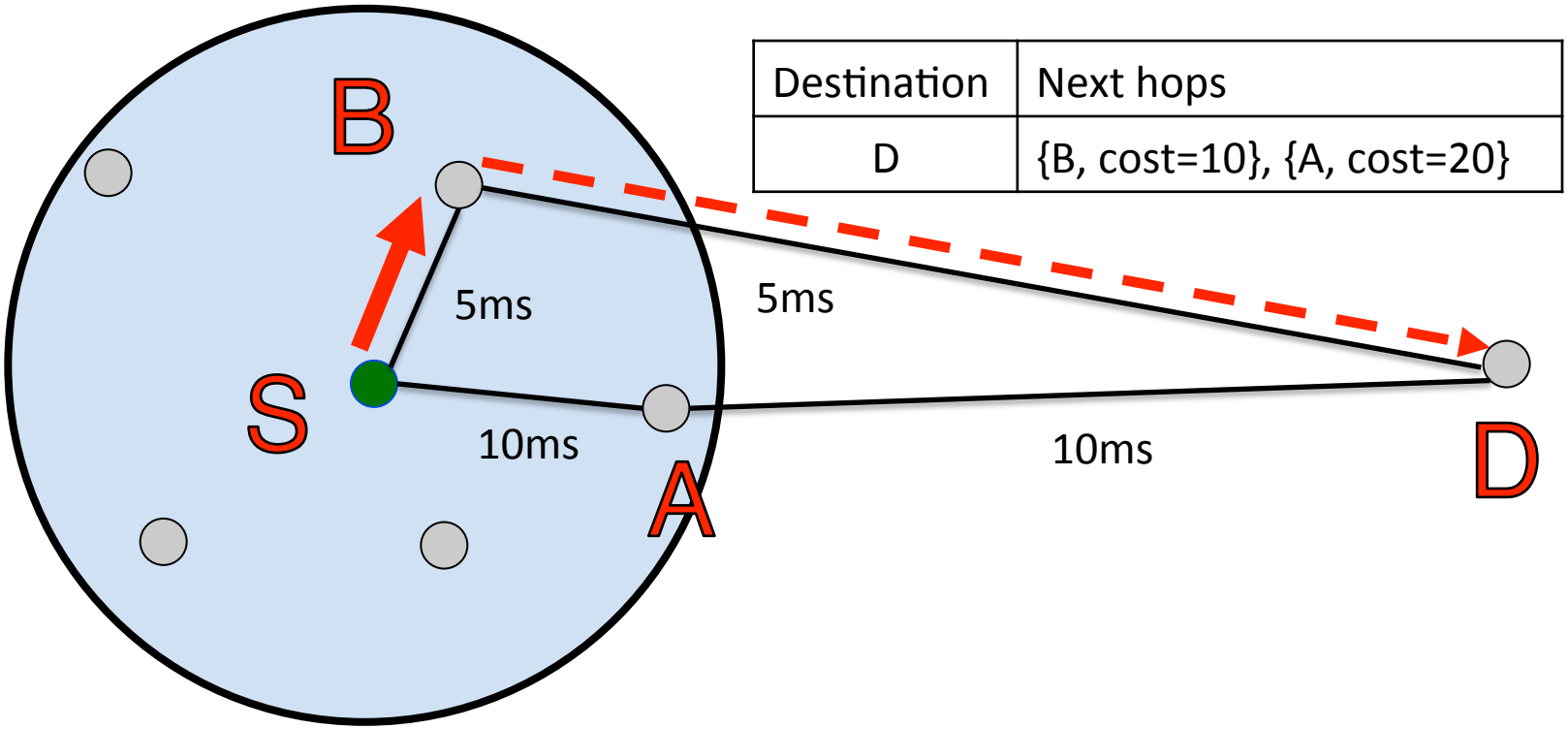
- Low communication cost

  Few routing updates, as coordinates rarely change

Drawbacks of HR

- Is there additional delay?
- Is packet forwarding performance comparable to a shortest path protocol such as link-state?
- Can packets become “lost” in HR with greedy forwarding?

Sub-Optimal Paths in HR



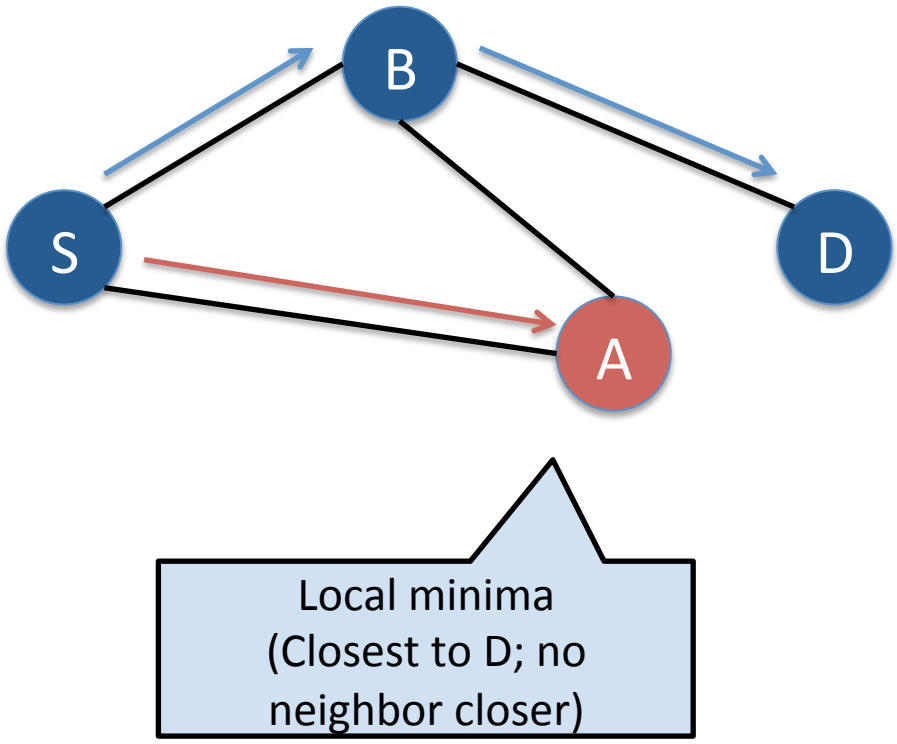
Destination	Next hops
D	{B, cost=10}, {A, cost=20}

To forward a packet:

- Find the neighbor closest to the destination
- Forward the packet to that neighbor

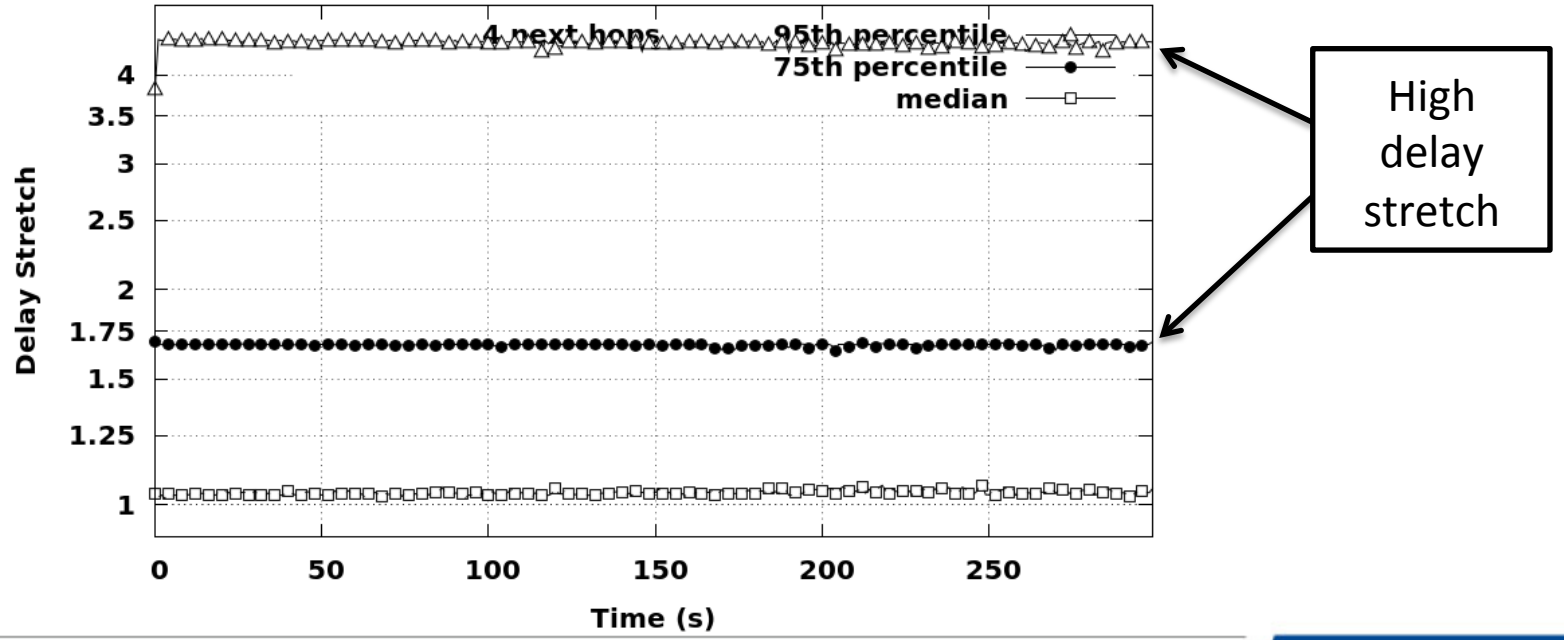
Local Minima in HR

- Occurs when a node does not have a neighbor closer to the destination coordinates than itself
- Forwarding in HR can hit a dead-end
- NDN can use multiple next hops per prefix and adaptive forwarding to avoid this problem
- Number of next hops per prefix can be limited to reduce overhead (multipath factor)



HR with Best-Route Strategy

- Best Route Strategy simply uses the next hop ranked highest by the routing protocol
- Delay stretch – Packet delay ratio of RTT in HR over RTT in shortest path routing



Forwarding Strategy Design

- Goal: Find and use optimal paths
- Approaches:
  - Test different paths by periodically forwarding Interest to different Face using new nonce
  - Maintain SRTT measurement for each Face to determine best Face for forwarding
  - Probabilistically choose Faces to probe; weighted towards better performing Faces

Adaptive SRTT-Based Forwarding

- Consider Round Trip Time (RTT) when choosing next hop in HR
  - Use Smoothed RTT (SRTT) to allow variation
- Best SRTT-Based Forwarding
  - Choose next hop for each FIB entry based on SRTT
- Probabilistic SRTT-Based Probing
  - Periodically probe unused next hops to learn RTT
  - Next hops that performed well previously have higher probability

Choosing Best Face for Forwarding

- For a FIB entry:
  - Sort available Faces into groups:
    1. Faces with SRTT measurements and no timeouts are sorted by SRTT; a lower SRTT is better
    2. Faces without SRTT measurements and no timeouts are sorted by routing cost
    3. Faces with SRTT measurements and their last Interest timed-out are sorted by routing cost
  - Choose the first Face from 1, else 2, else 3

Probabilistic SRTT-Based Probing

- Want to learn RTT of next hops other than the one being used for forwarding
- Schedule first probe for a FIB entry on first matching Interest in interval [0, T1]
- When an Interest is forwarded that matches a FIB entry and the FIB entry is due for probing:
  - Pick Face to probe and forward probe Interest with new nonce
- After each probe, next probe is scheduled in T2 seconds

Probabilistic SRTT-Based Probing

- Selecting a next hop to probe:
  - Use same grouping and sorting for next hops as in forwarding (exclude primary next hop)
  - Choose the lowest cost next hop with no measurements (Group 2) immediately if one exists
  - Otherwise, combine Group 1 and Group 3 and assign each next hop a probing probability
  - Next hops that performed well previously are assigned a higher probability

Probabilistic SRTT-Based Probing

- Compute probability:
  - N = Number of next hops in combined list
  - X = Sum of indices in combined list; n (n + 1)/2
  - $P(Nexthop_i) = (N + 1 - i)/X;$
- Select next hop to probe based on probability

Probing Probability Example

Sorted Interfaces

ID: 128 Rank: 1 HasTimedOut = false SRTT = 50	ID: 256 Rank: 2 HasTimedOut = false SRTT = 100	ID: 512 Rank: 3 HasTimedOut = true SRTT = 75

Assign Probability:
P(ID: 128) = (3 + 1 – 1)/6 = 0.5
P(ID: 256) = (3 + 1 – 2)/6 = 0.334
P(ID: 512) = (3 + 1 – 3)/6 = 0.166

Select uniformly random number over [0, 1)

e.g.) random number = 0.75
Select Face with ID: 256 to probe

NACKs

- All Incoming NACKs are handled by setting the timeout flag in the corresponding face's measurements
- NACKs do not contribute to SRTT calculation
- If strategy cannot forward to any next hops, send NO_ROUTE NACK

Retransmissions

- Consumer retransmissions
  - Suppress in same manner as BestRouteStrategy2
  - Interest is suppressed if within minimum interval
  - Otherwise, pick best next hop to forward to based on sorted groups
- Router retransmissions
  - Router retransmissions are not performed

HR with ASF Strategy