On-Demand Routing for Scalable Name-Based Forwarding

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Outline

- **Background**
- On-demand Routing
- Routing Information Discovery
- Evaluation
- Conclusions

Background – Routing Scalability Problem

- As part of its original design, **CCN/NDN overloads Interest names with the functionality of network location and content identifiers.**
  - **Route-by-name.**
- Route-by-name involves resolving a **location** from a **content name**, i.e., **name resolution,** in a hop-by-hop manner.

PROBLEM:
Conventional wisdom dictates that routing and forwarding information are pre-computed and stored for ~O(10^9) name prefixes!

Background – A well-known solution: Location-identity split!

- Map content identifiers to network location names, i.e., locators.
  - Route-by-locator as opposed to route-by-name.
- Location-identity split in NDN:
  - Interests contain **a content identifier and (optionally) a locator**.
  - Locator is used as a **fallback**, only in case of a FIB miss during route-by-name.
- NDN terminology: **forwarding hints, i.e., Link objects** in interest packets.
  - Obtained out-of-band from a resolution service.
  - a la NDNS.

Background – Location-identity split in NDN

- **Problem:** Malicious hosts can place a victim's locator along with non-existent content names in the Interests to launch targeted attacks.
- ***NDN's solution:*** *Link objects carry a secure binding (i.e., signature) between content identifiers and the corresponding locators.*

A possible show stopper for NDN's use of Link objects:

- **Verification of Link object binding is very difficult to perform in the middle of the network!**

Background – Secure binding of locators and content identifiers

- **Signature verification is not sufficient!**
  - **Need to check the legitimacy of the signing key for a given prefix-to-locator binding!**
  - Must execute **trust policies** in the middle of the network.
    - *Possibly verify a chain of certificates.*

PROBLEM: Forwarding hints are obtained ***out-of-band*** and placed in the Interests by **untrusted** *end-users!*

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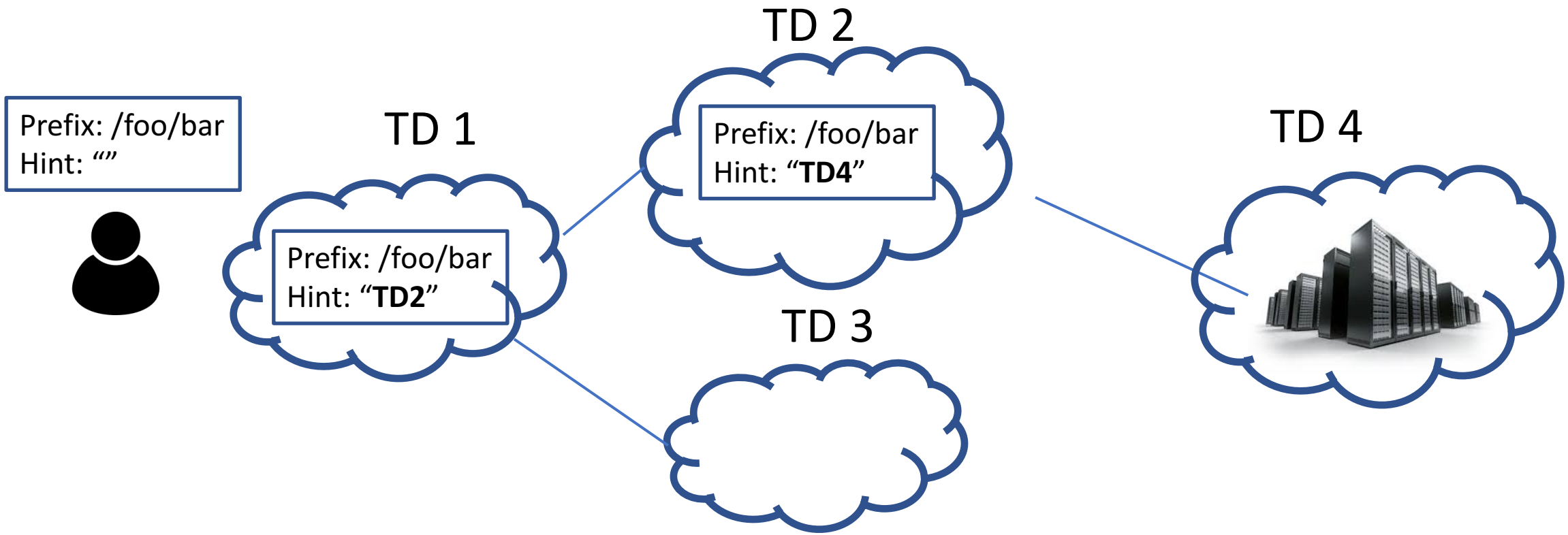
On-Demand Routing

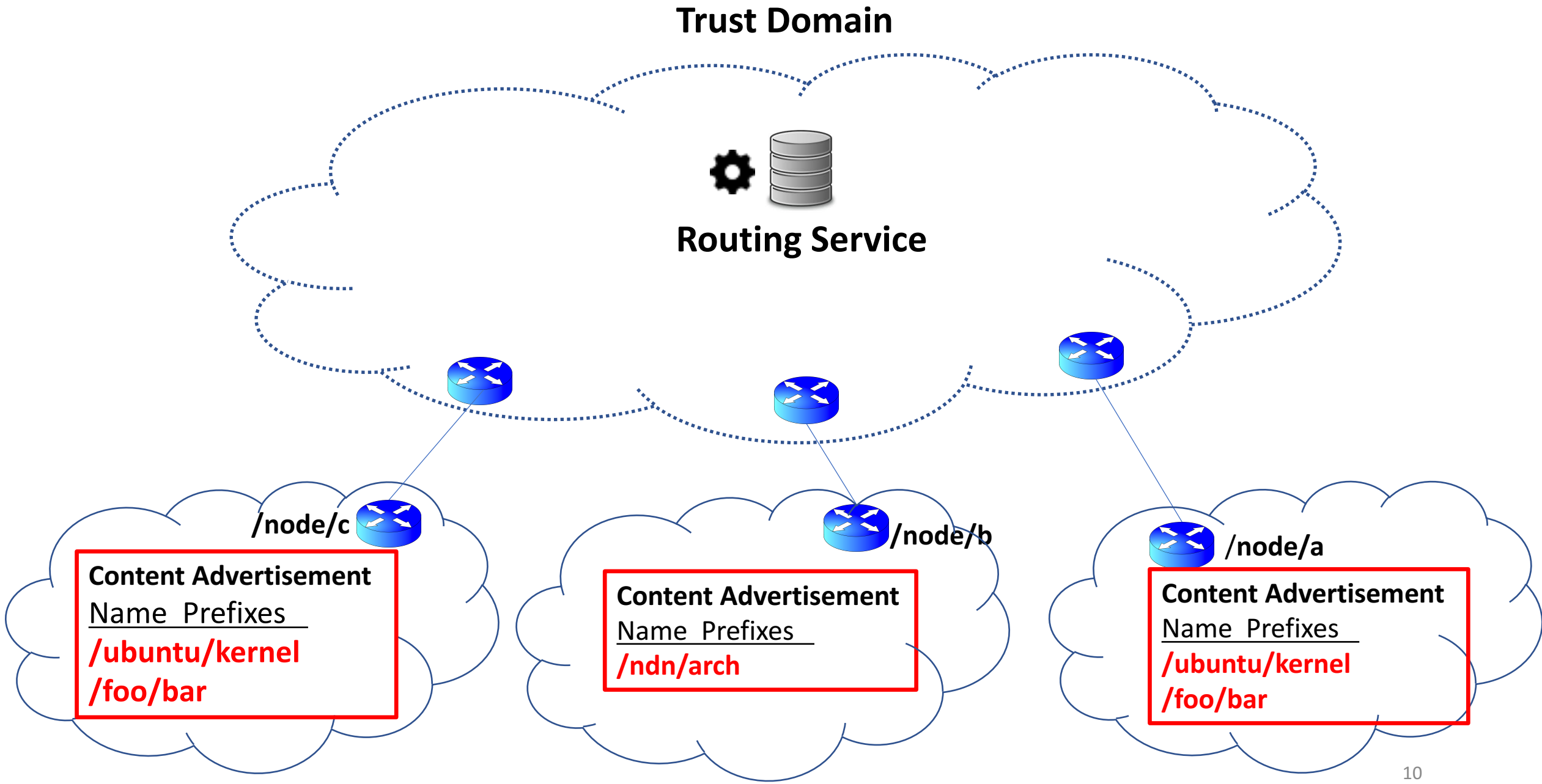
- **Trust Domains (TDs)** perform name resolution individually.
  - In-band solution.
  - **On-demand** routing mechanism.
  - Compute forwarding hints with TD-specific scope.

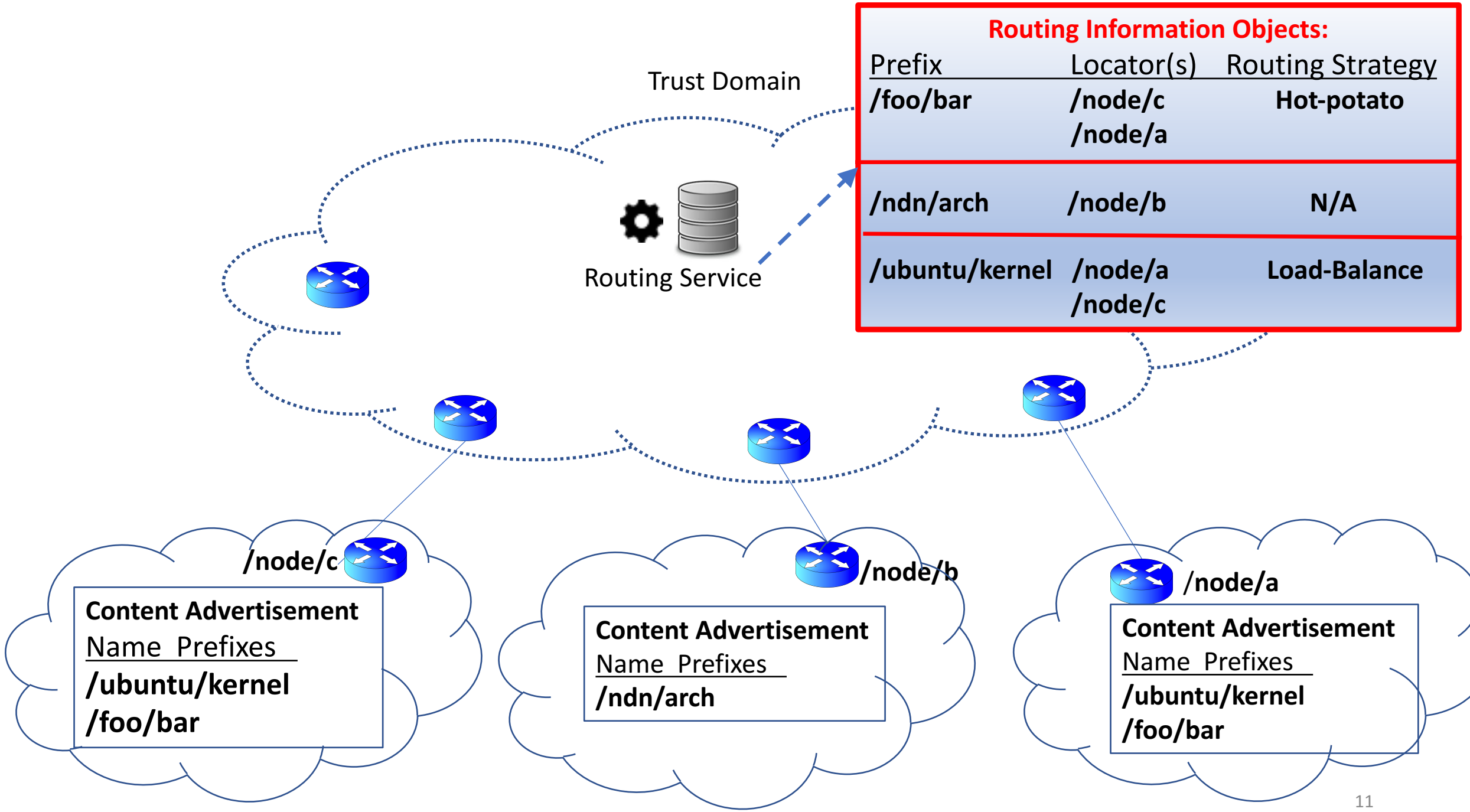


On-Demand Routing (cont'd)

- A way for **routers** to obtain and scale the storage of routing information in the form of:
  - TD-specific "instructions on how to route packets".
  - We store these routing instructions as ***Routing information Objects (RIOs).***
- Routing information is shareable across nodes in the same TD.
- **A Routing Strategy** component at each forwarding node performs on-demand routing using an RIO.

Main idea: Treat Routing Information Objects (RIOs) similar to content:
use caching and content discovery mechanisms to scale name-based forwarding.


Trust Domain
Routing Service
/node/c
Content Advertisement
Name Prefixes
/ubuntu/kernel
/foo/bar
/node/b
Content Advertisement
Name Prefixes
/ndn/arch
/node/a
Content Advertisement
Name Prefixes
/ubuntu/kernel
/foo/bar


Routing Information Objects:
Prefix
Locator(s)
Routing Strategy
/foo/bar
/node/c
/node/a
Hot-potato
/ndn/arch
/node/b
N/A
/ubuntu/kernel
/node/a
/node/c
Load-Balance
Trust Domain
Routing Service
/node/c
Content Advertisement
Name Prefixes
/ubuntu/kernel
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Content Advertisement
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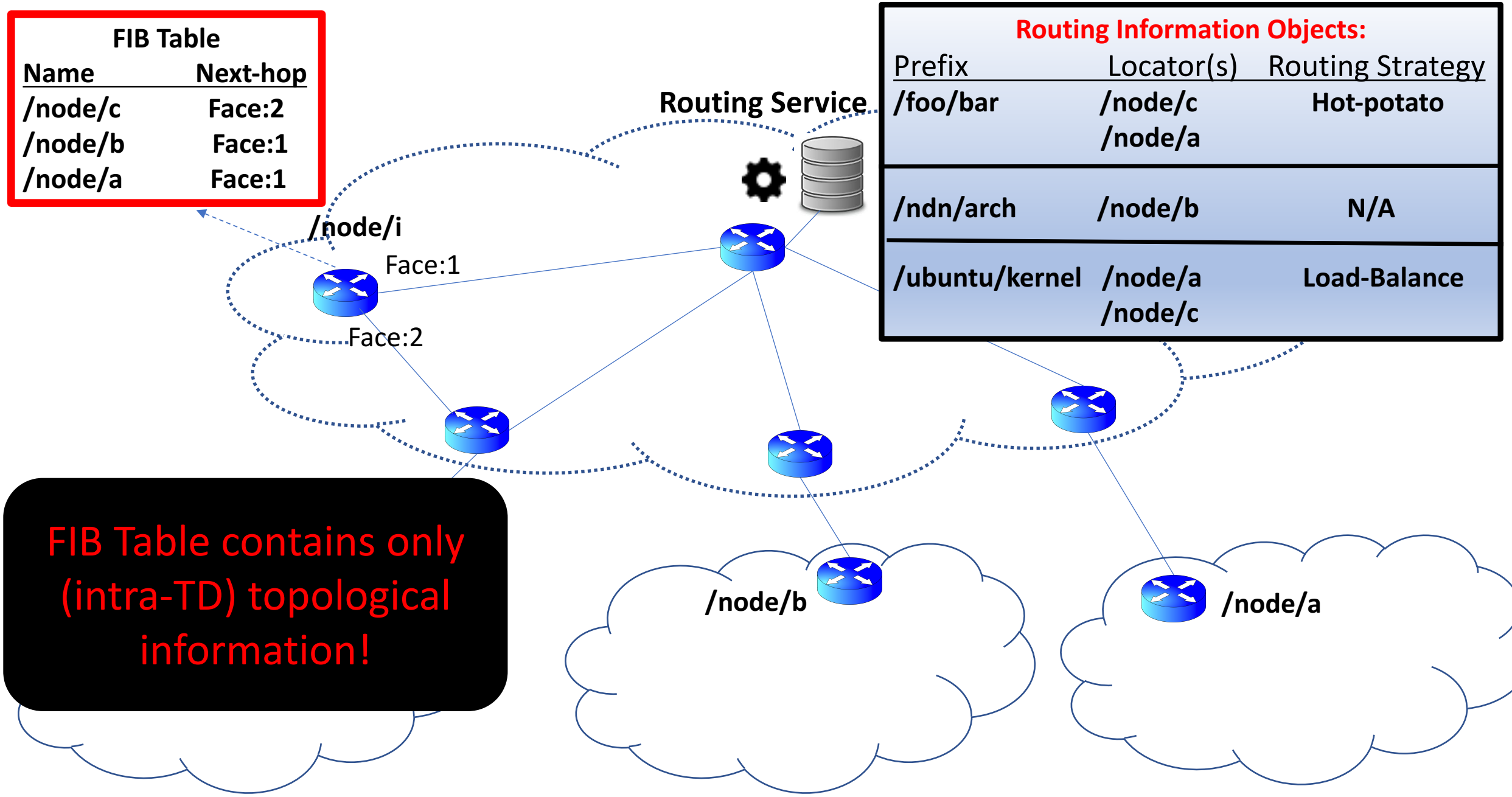
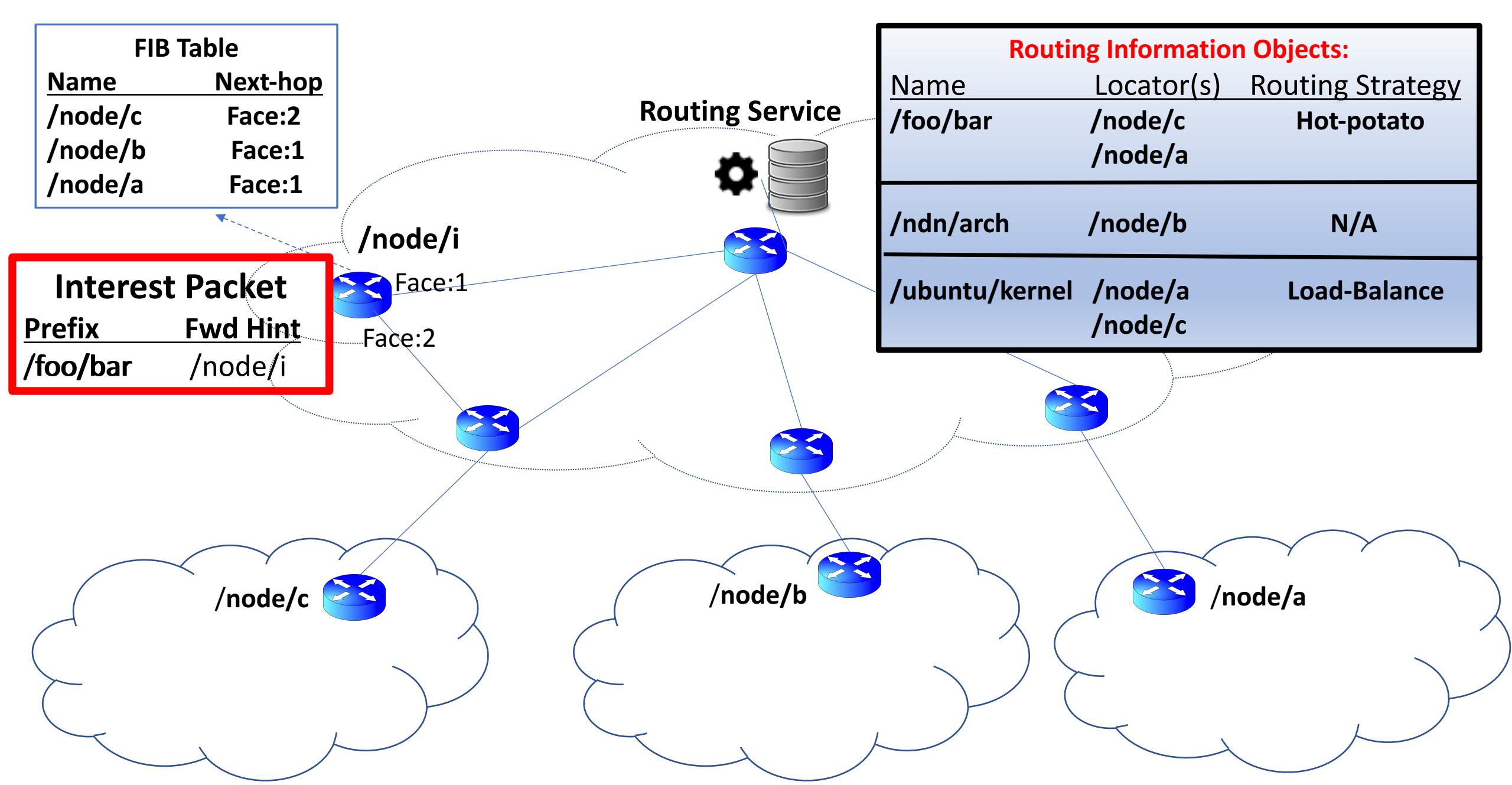
/foo/bar


FIB Table
Name Next-hop
/node/c Face:2
/node/b Face:1
/node/a Face:1
Routing Service
Routing Information Objects:
Prefix Locator(s) Routing Strategy
/foo/bar /node/c /node/a Hot-potato
/ndn/arch /node/b N/A
/ubuntu/kernel /node/a /node/c Load-Balance
/node/i
Face:1
Face:2
/node/b
/node/a
FIB Table contains only (intra-TD) topological information!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/ubuntu/kernel /node/a /node/c Load-Balance
/node/i
Face:1
Face:2
Interest Packet
Prefix Fwd Hint
/foo/bar /node/i
/node/c
/node/b
/node/a

FIB Table

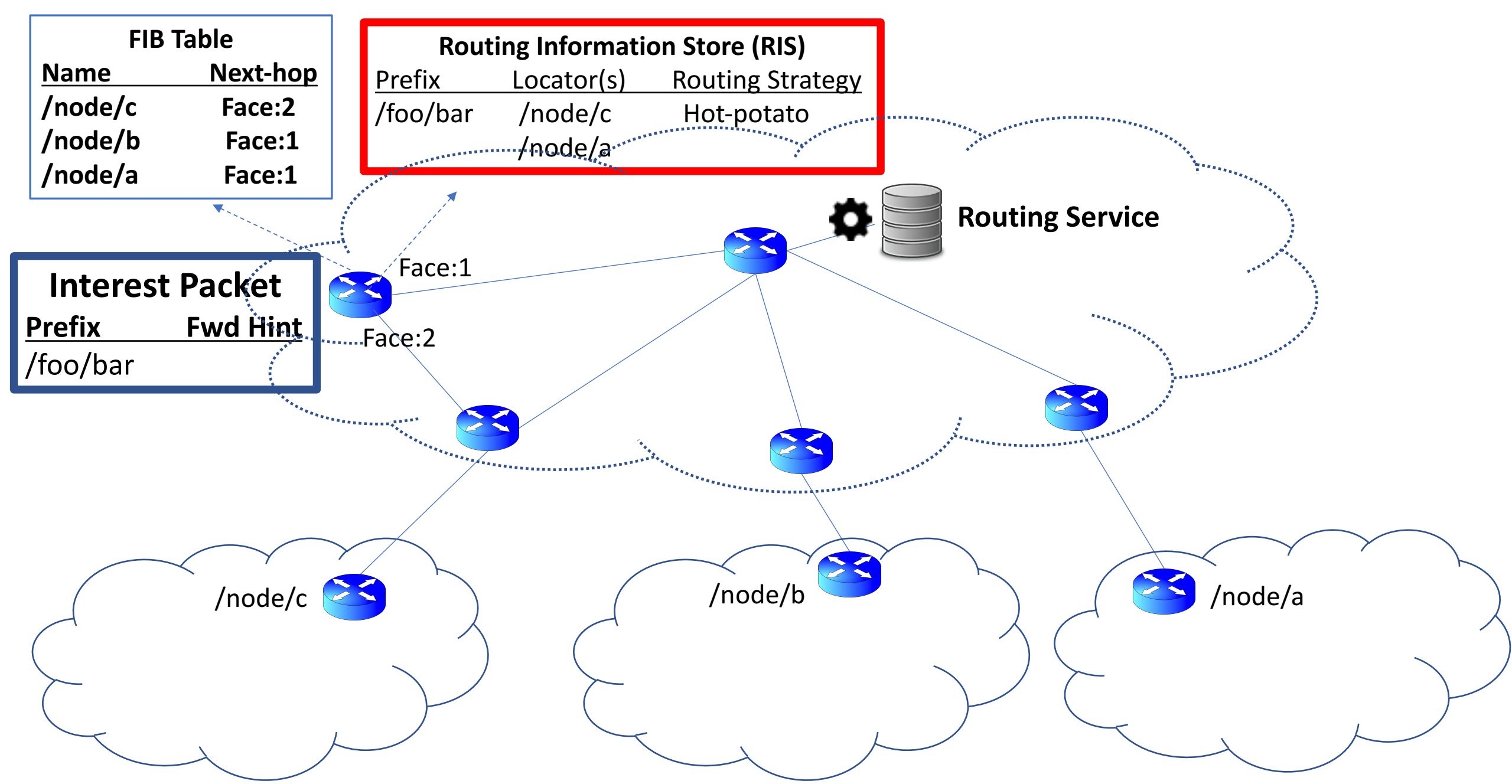
Name	Next-hop
/node/c	Face:2
/node/b	Face:1
/node/a	Face:1

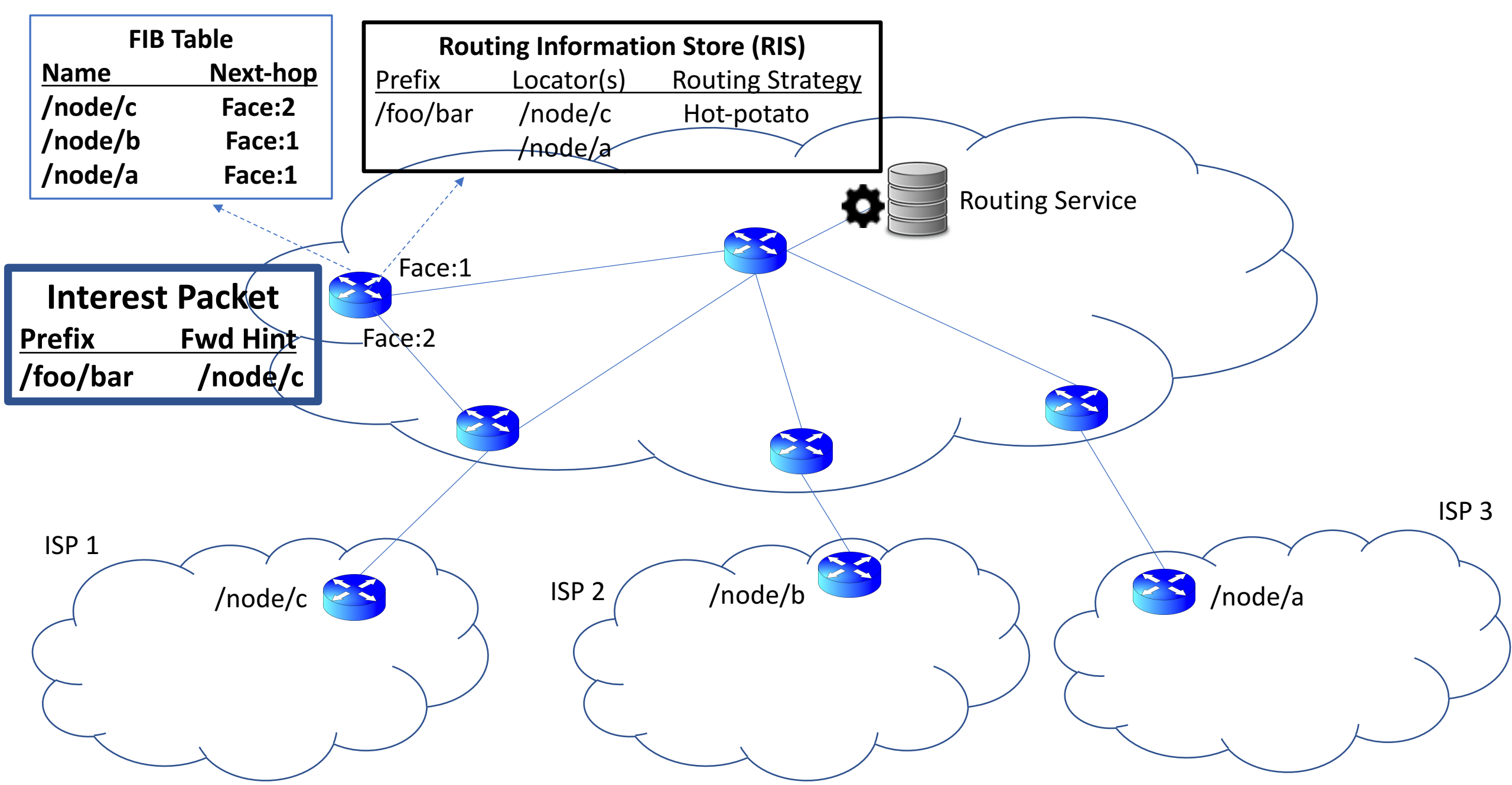
Routing Information Store (RIS)

Prefix	Locator(s)	Routing Strategy
/foo/bar	/node/c /node/a	Hot-potato

Interest Packet

Prefix	Fwd Hint
/foo/bar	

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Prefix Locator(s) Routing Strategy
/foo/bar /node/c Hot-potato
/node/a
Routing Service
Interest Packet
Prefix Fwd Hint
/foo/bar /node/c
Face:1
Face:2
ISP 1
/node/c
ISP 2
/node/b
ISP 3
/node/a

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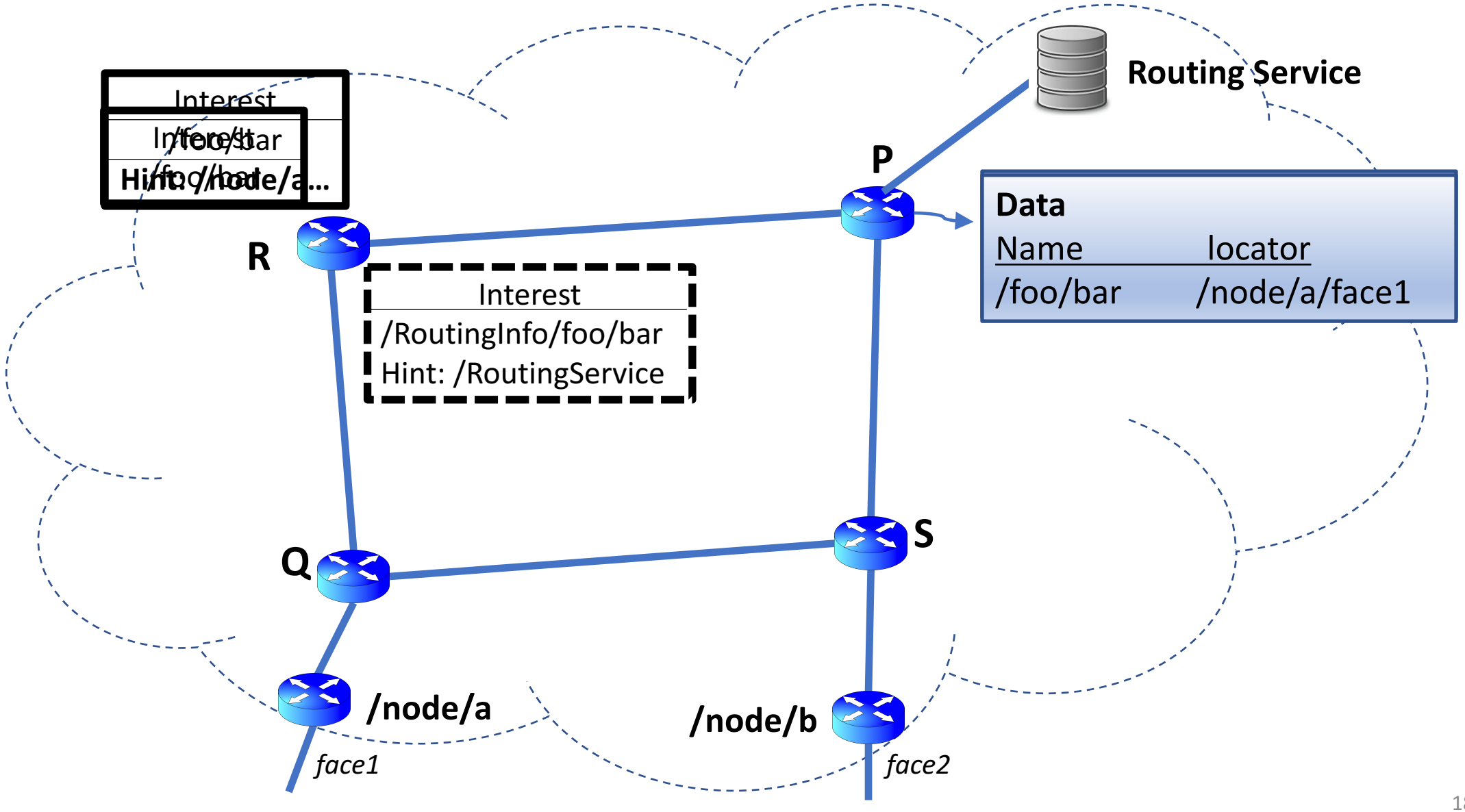
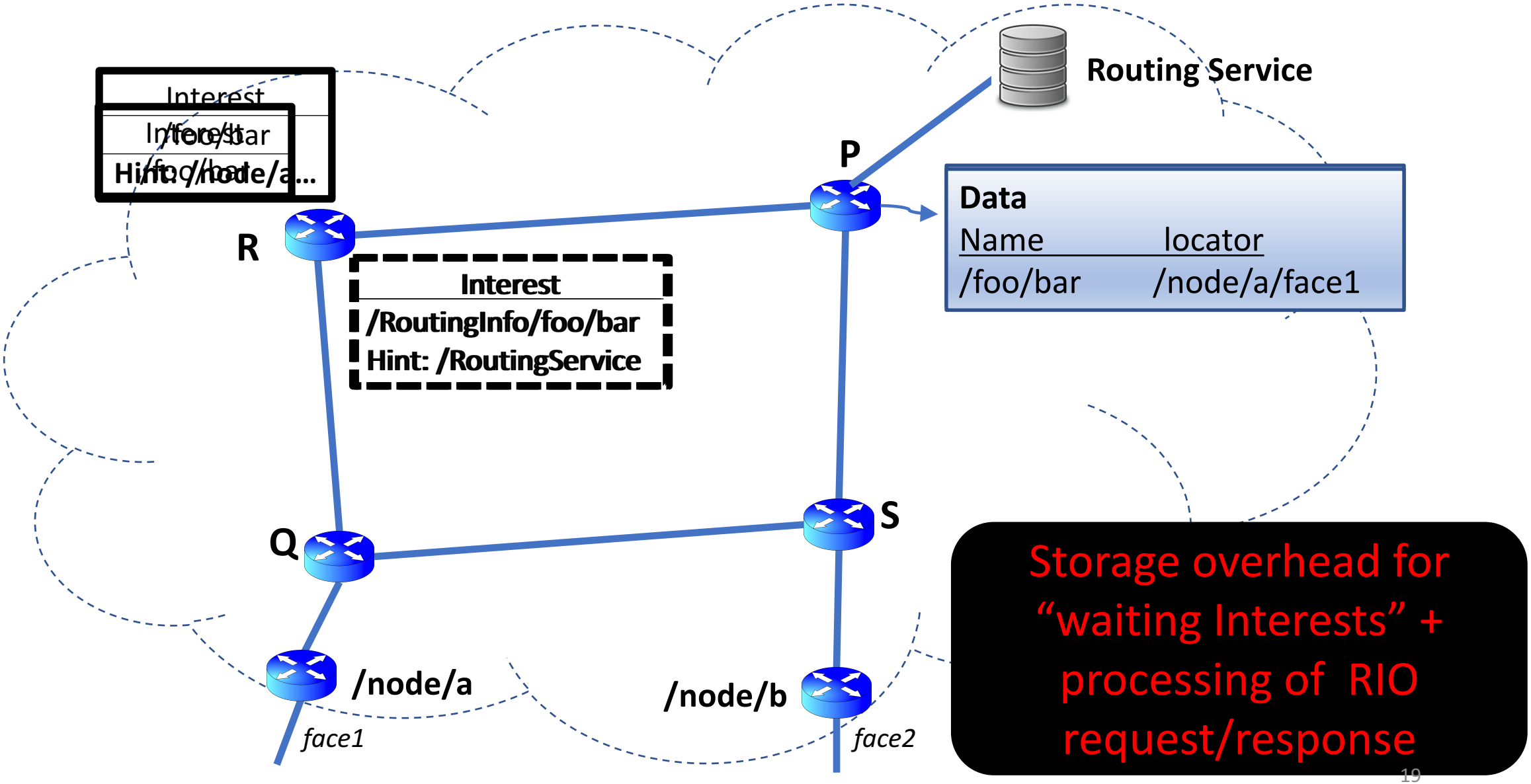
Routing Information Discovery and Caching

- **Passive Discovery:**
  - Simply observing passing-by Interests carrying Forwarding Hints.
- **Active (on-demand) Discovery – in case of a RIO miss:**
  - Search nearby or nodes along a path
  - Forward the Interest towards a neighbor with higher likelihood of RIO hit.
    - **Any node on the path with the RIO can perform routing and divert the packet along the policy-compliant route..**
- Discovered information is cached locally at the forwarders.
  - Different caching strategies are possible (probabilistic, LCE, etc.)

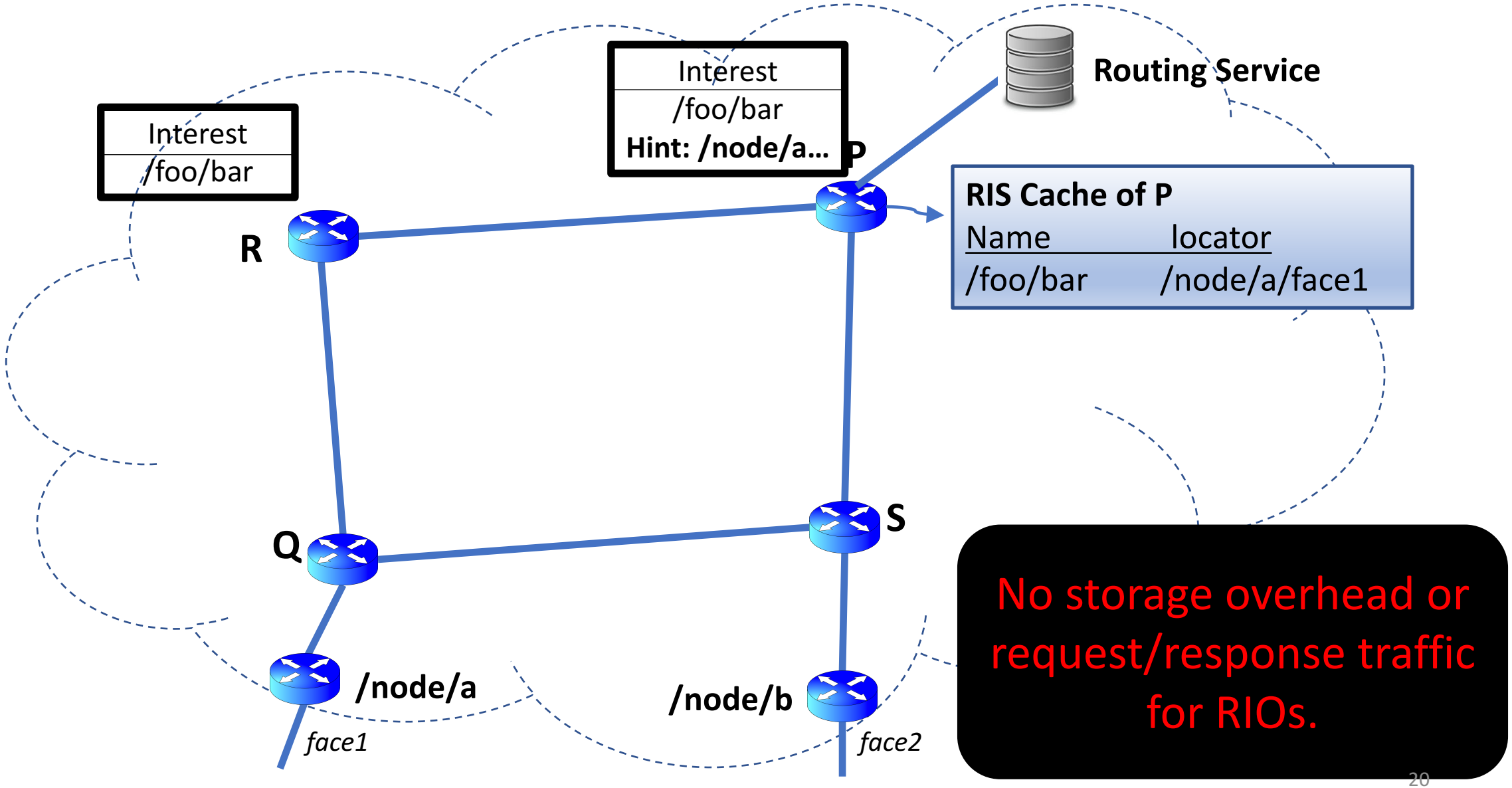
Routing Information Discovery: Search on-path



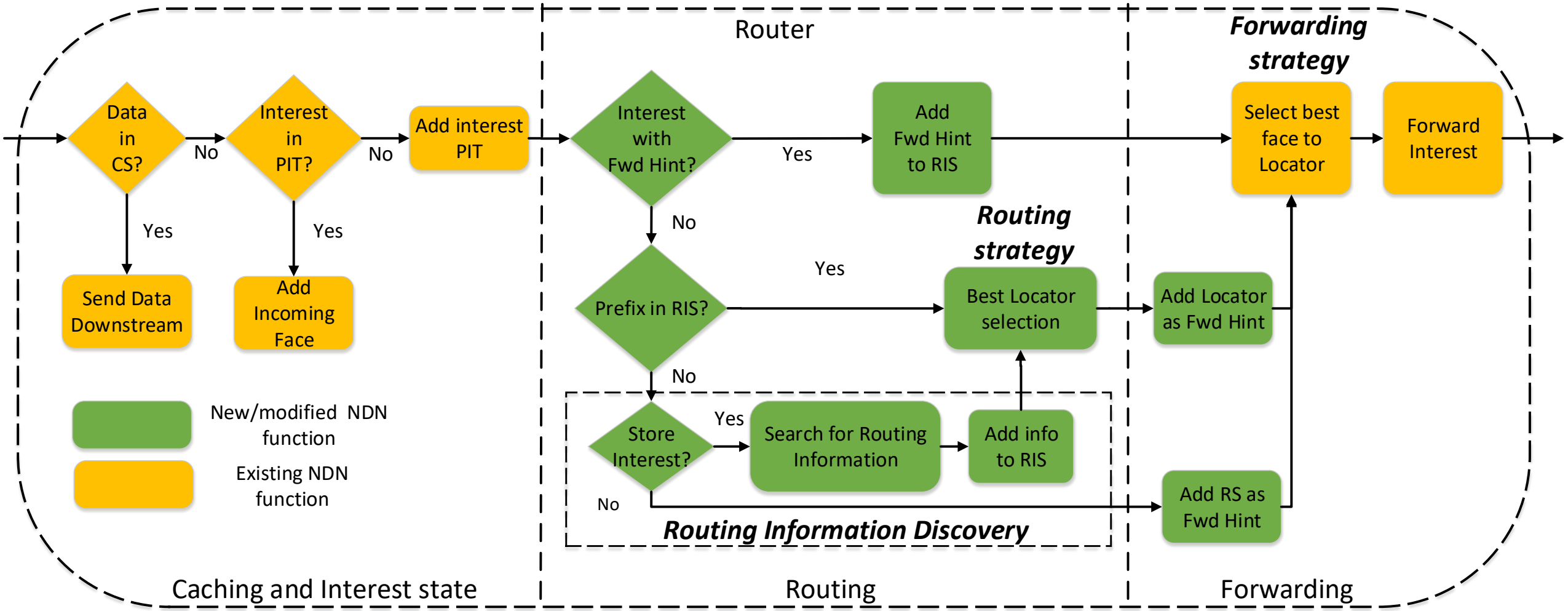
Routing Information Discovery: Search nearby



Routing Information Discovery: Forward to RS



Interest Packet Processing



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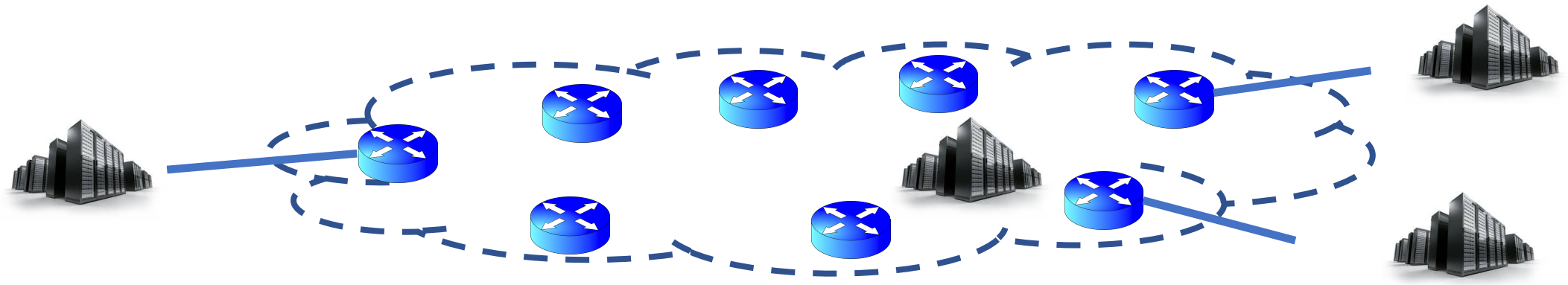
- **Conclusions**

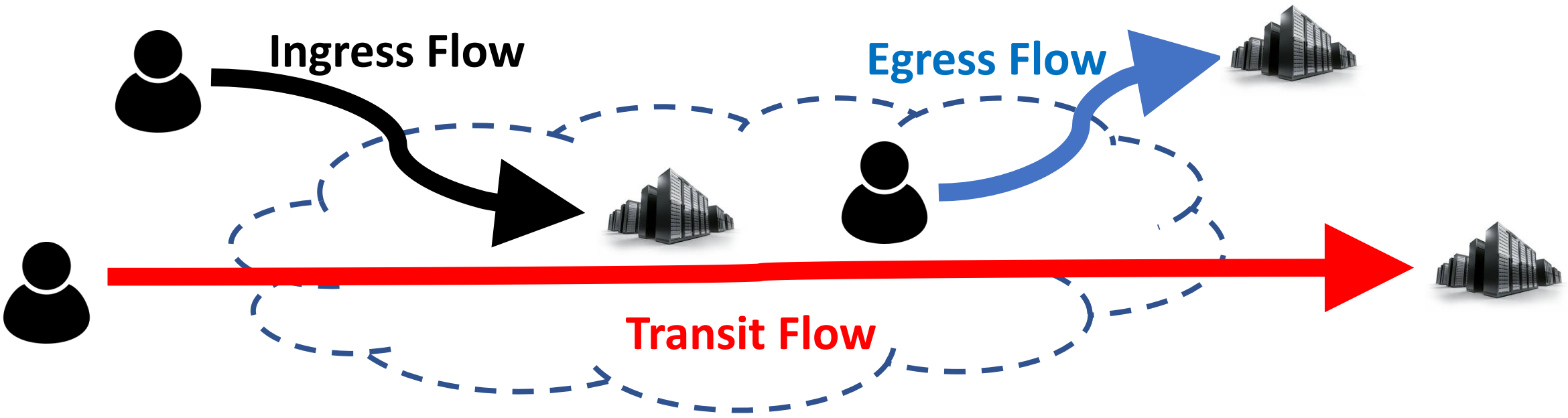
Evaluation – Experiment Setup

- **Platform**: Icarus – a Python based simulator for ICN.
- **Topology:** ISP topology (TISCALI) from Rocketfuel dataset.
  - Prefix categories: Internal vs. External. 90% have *external* producers.
    - Randomly picked ***three*** locators per external name prefix.
    - One locator per internal prefixes.



Evaluation – Experiment Setup

- **Workload**: 100 flows per msec – Scalability limit of the simulator
  - Flow Categories – Ingress, Egress, Transit Flows.
  - 90% of flows are transit – as in a carrier ISP.



Evaluation – Experiment Setup & Metrics

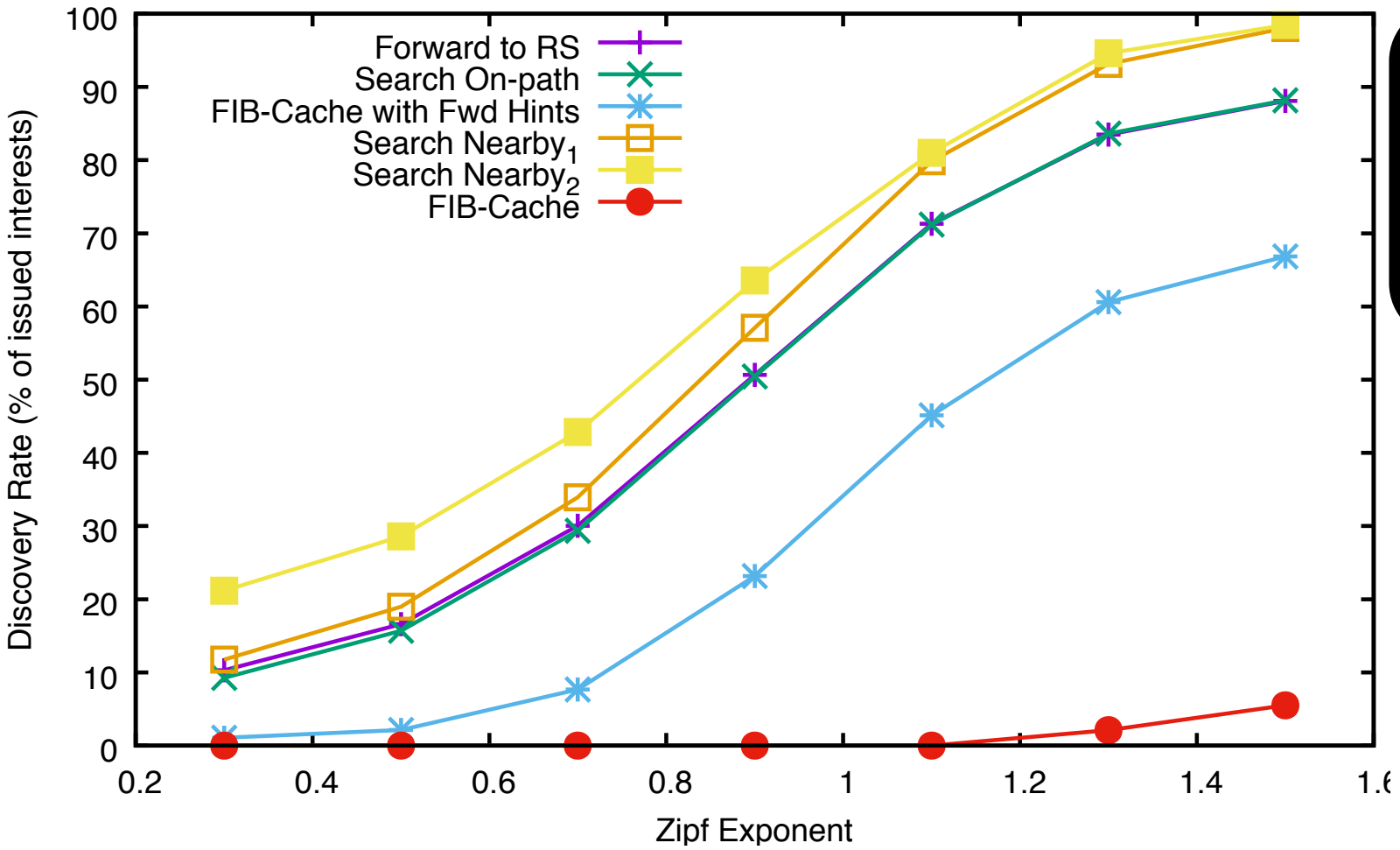
- **Scalability Parameters:**
  - |RIS| / |Prefixes| = 0.0075 – Based on BGP router fast memory size.
  - Routing Service Replicas = 10 – RIOs are sharded onto RS instances.
  - Name Prefix Popularity Zipf Exponent = 1.0 – based on web
- **Performance Metrics:**
  - **Discovery Rate:** Percentage of Interests whose routing information is obtained from the RIS cache of a forwarder (as opposed to an RS node).
    - Measure of the load on RS and impacts latency.
  - **Latency:** This metric measures the average round-trip time (RTT) delay in retrieving content.
    - Caching of regular content is disabled.
  - **Overhead:** Average number of hops that routing information and Interests for routing information travel in the network per issued interest.

Evaluation – Benchmarks for comparison

- **FIB-as-a-cache:** Store forwarding information (as opposed to routing information) in the FIB that is used as a cache.
  - Based on the work by Detti et al. [1]
  - A centralised controller (similar to SDN controller) pushes forwarding information to nodes in case of a FIB miss.
  - **Forwarding information has local significance as opposed to RIOs.**
- **FIB-Cache with Forwarding Hints:** Store forwarding information along with forwarding hint in the FIB.
  - Hints are specific to a node.

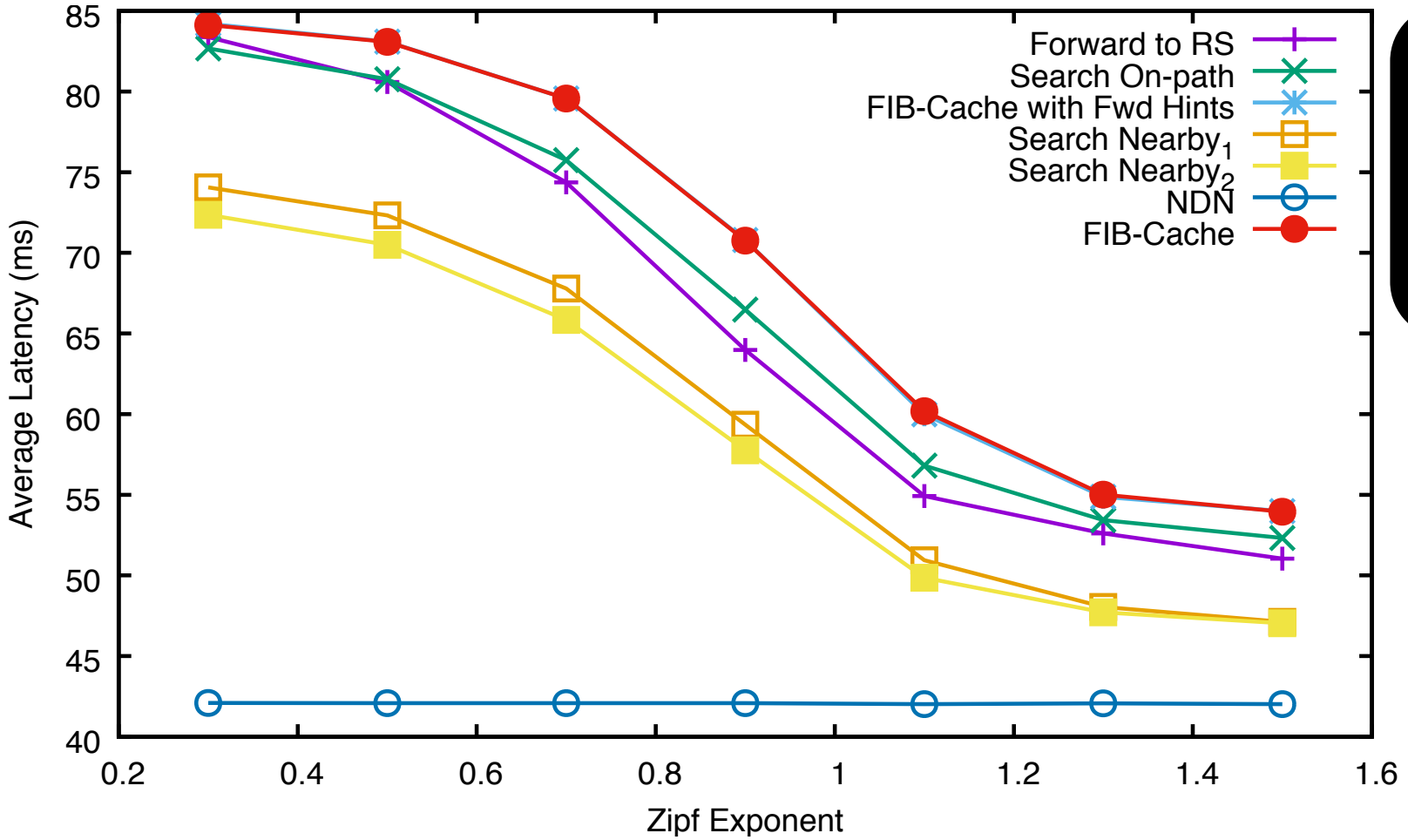
- [1] Detti, A., Pomposini, M., Blefari-Melazzi, N. and Salsano, S., 2012. *Supporting the web with an information centric network that routes by name*. Computer Networks, 56(17), pp.3705-3722.

Evaluation – Results: Impact of Prefix Popularity



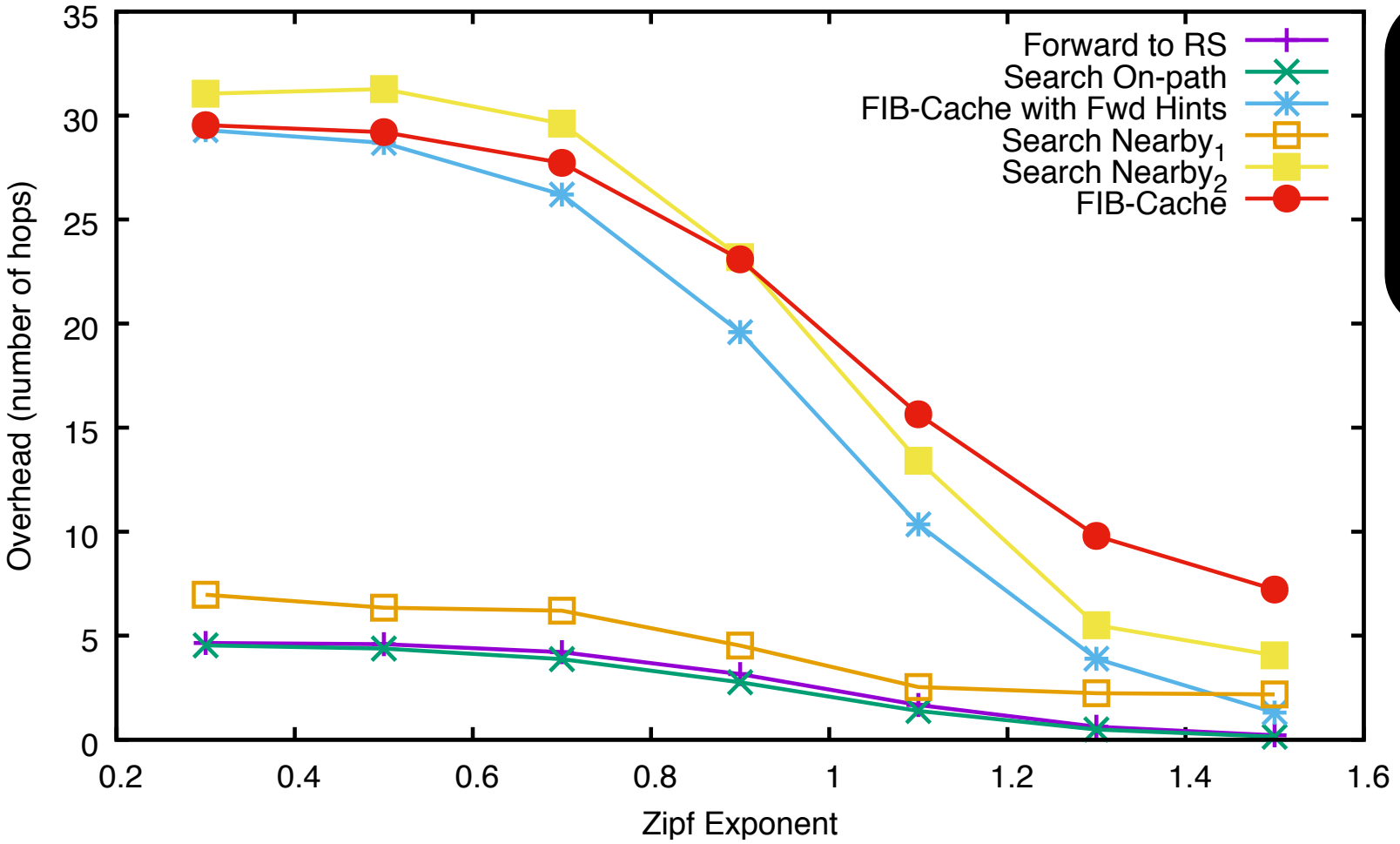
Performance of Forward-to-RS is close to Search-Nearby.

Evaluation – Results: Impact of Prefix Popularity



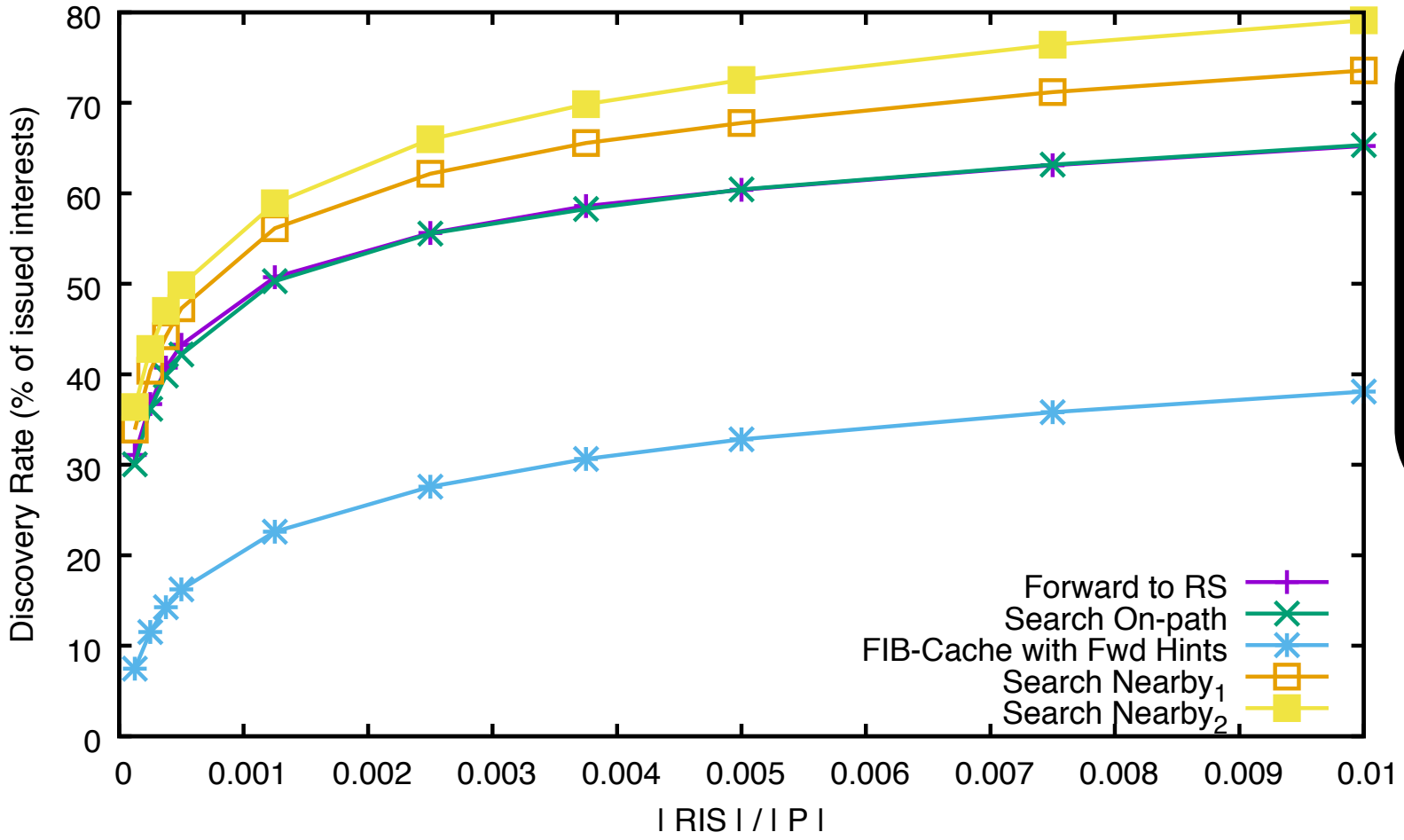
Additional latency drops to 5msec for realistic popularity distributions.

Evaluation – Results: Impact of Prefix Popularity



Retrieving node-specific FIB information is much more costly!

Evaluation – Results: Impact of RIS Size



Less than 30% of traffic requires involvement of Routing Service for realistic RIS sizes

Conclusions

- **Scale name-based forwarding through caching and information discovery mechanisms.**
  - Allow per-prefix, AS-specific “routing instructions” (RIOs) to be treated as data objects.
- RIOs are maintained by resourceful servers – i.e., Routing Service.
- Routing is performed on-demand.
  - Forwarding Hints are inserted in packets and used within Trust Domains.
- Acceptable performance in comparison to pre-computed FIB approach.
  - Routing Stretch.
  - Additional Traffic to fetch routing information.
- Secure name resolution within Trust domains.