A Scalable Framework for Segment Routing in Service Provider Networks: The Omnipresent Ethernet Approach

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Problem in Service Provider Networks

Challenge 1 : Explosion of hand-held **devices** and **next generation data-services**

- Legacy transport networks that were built using SONET/SDH **circuit-switched paradigms**
- **Packet-based networking solution** that would be flexible, yet provide for **service-oriented communication**

Challenge 2: Operations Administration Maintenance and Provisioning (OAM&P)

- IP at the network layer and MPLS as a transport solution have been adopted
- Despite the ability to differentiate flows and provision services, the IP/MPLS layer falls short to provide full OAM&P

Background

Segment Routing SR

- IETF use source routing as an ebabler towards simplifing networks
- Segment routing facilitates implementation of source routing within a closed domain by **encoding end-to-end route information within the packet header** as a sequence of segments.

Carrier Ethernet (CE)

- CE is a service-oriented version of Ethernet with **no spanning tree protocol, no MAC learning**
- Forwarding is based exclusively on control plane defined **identifiers**
  - provider backbone bridged traffic-engineering (IEEE)
  - MPLS-TP (MPLS-transport profile) (IETF)

Introduction

- The focus of this paper is to present a pragmatic method to implement segment routing based on CE advances
- **Omnipresent Ethernet (OE)** was shown in as a **source routing+binary routing** solution for **software defined networks (SDNs)**
  - **OE as an SR framework serves providers effectively**
  - **source routing :** multi-parameter service provisioning is possible
  - **binary routing :** the lookup at a node is reduced making OE carrier-class with deterministic latency
- H-SR : improve scalability ofsegment routed networks based on a hierarchical segment routing (H-SR) framework

SR Concept

- Reduces the per-flow state maintenance, route computation complexity and is service oriented
- Nodes are labeled with globally unique identifiers (called node-segment IDs)
- Links are labeled with locally unique identifiers (called adjacency-segment IDs)

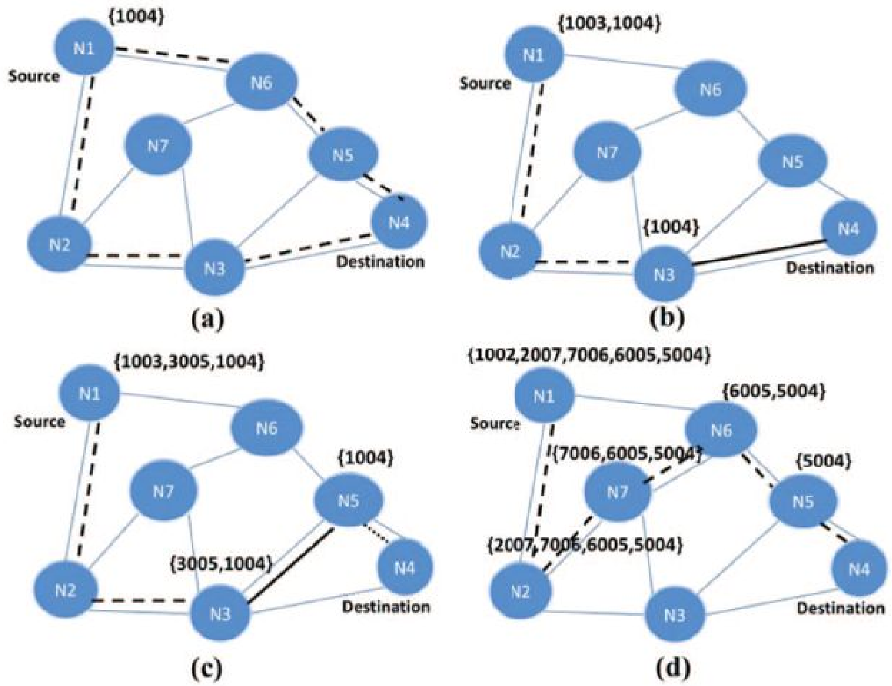
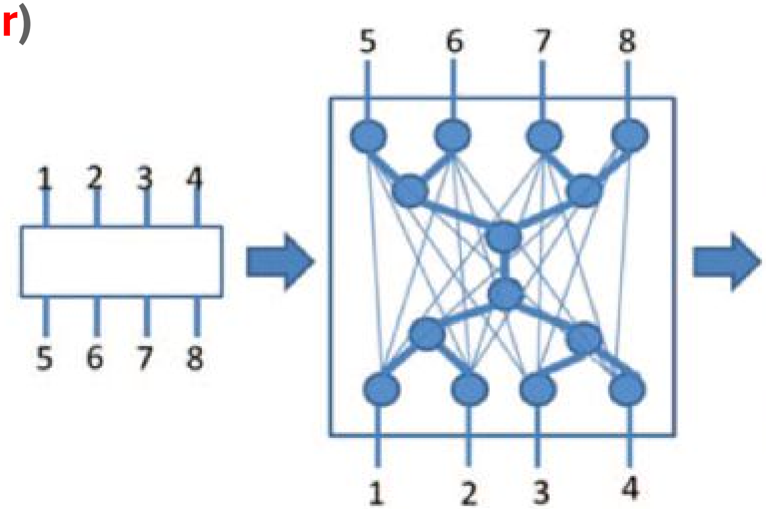


Fig. 1. Different routing schemes possible using Segment Routing

OE approach SR

- OE-domain specific identifier facilitates fast transport through the OE domain
- A **logical binary graph is created at each node** such that each physical port of the node is a leaf node of the logical binary graph.
- Internal Route Map (IRM) is computed for each node using binary routing
- Entire network becomes an **interconnection of logical binary graphs** and we can reach every node from every other node using **binary routing** and **source routing (long header)**



Internal Route Map (Port 1)	
Output Port	Binary Route
2	0
3	100
4	101
...	...
8	1100

Fig. 2. Logical binary tree representation of an 8-port switch and example Internal Route Map.

Route-label

- We use MPLS-TP labels stacked in an Ethernet frame for encoding the binary route to the destination
- 16 MSBs of the route-label to encode the binary route and the remaining 4 bits as the start-bit pointer
- Node further fetches the 2log2D bits to determine the out port

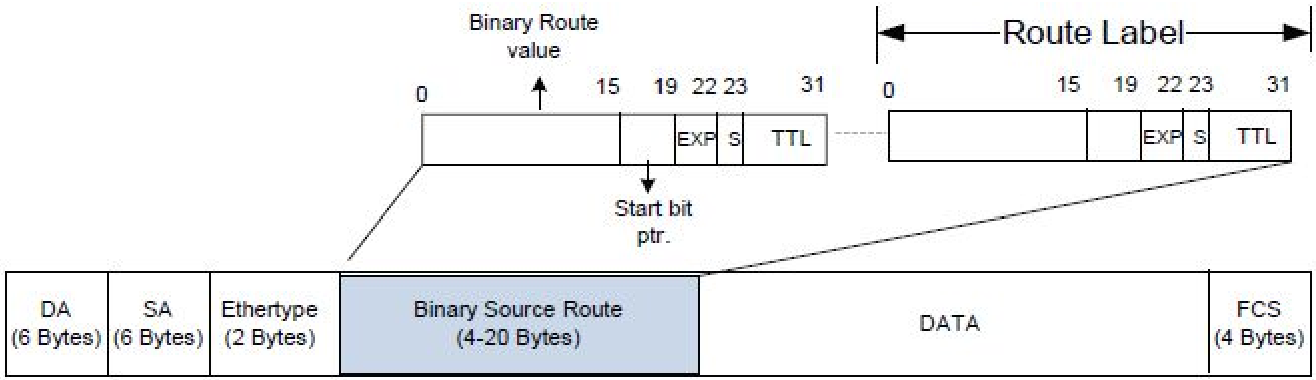
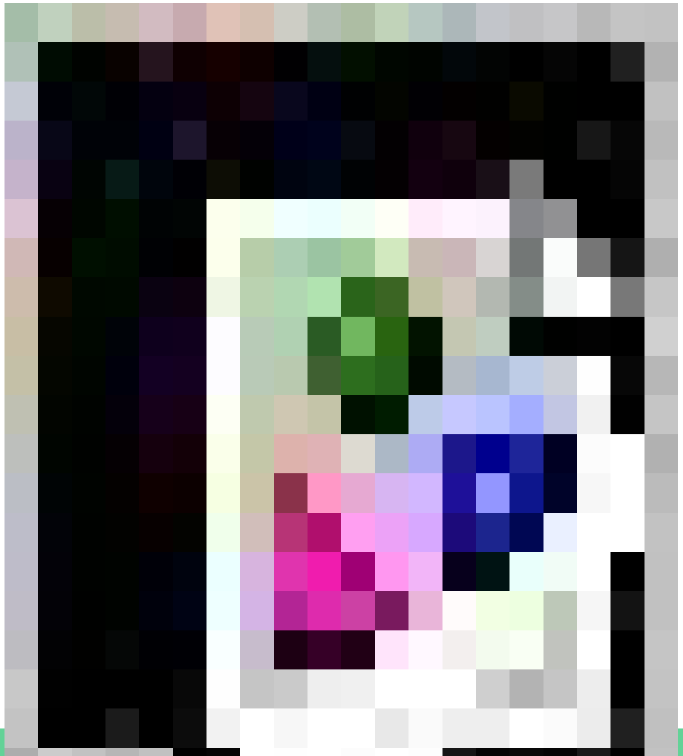


Fig. 3. Protocol Data Unit of OE.

Scalability challenges of Omnipresent Ethernet

- The binary routing and source routing principles of OE facilitate **low-latency switching** by **eliminating lookup operations** at intermediate nodes
- segment mapping table (SMT) maintains the mapping of service identifiers to binary routes
- With network size, the average number of hops between a source and destination increases.
- hierarchical segment routing (H-SR)



Hierarchical segment routing (H-SR)

- neighborhood (NH) of a swap node as the set of nodes that are **within connection proximity** of a swap node and may have similar address prefixes
- For simplicity, the NH of a swap node is analogous to an **Autonomous System** (AS)
- Internal Segment Mapping Table (I- SMT)
  - stores the routing information of all the nodes within a NH
- External Segment Mapping Table (E-SMT)
  - stores the routing information of all the other swap nodes in the network at a swap-node

Communication

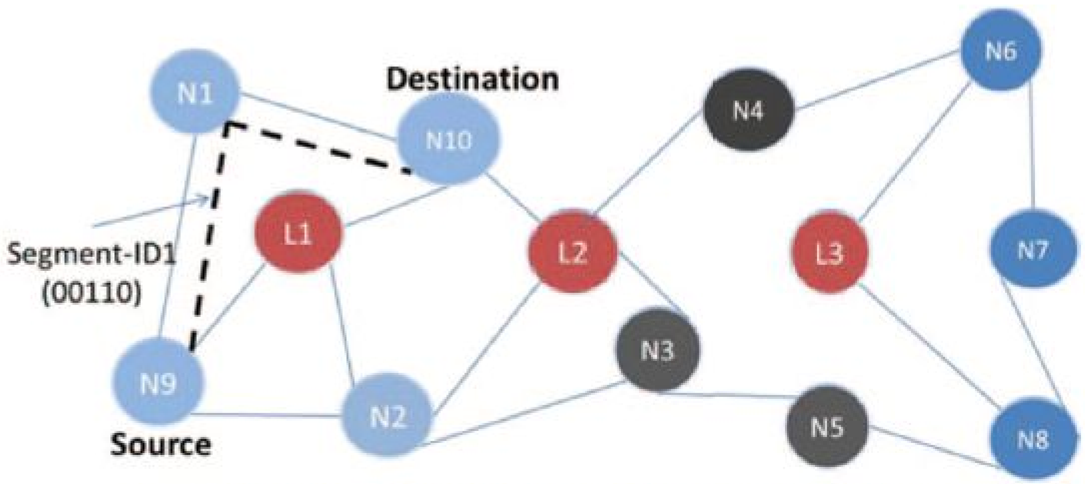
- Intra-NH Communication
- 

Fig. 4. H-SR policy for intra-NH communication.

Communication

- Intra-NH Communication

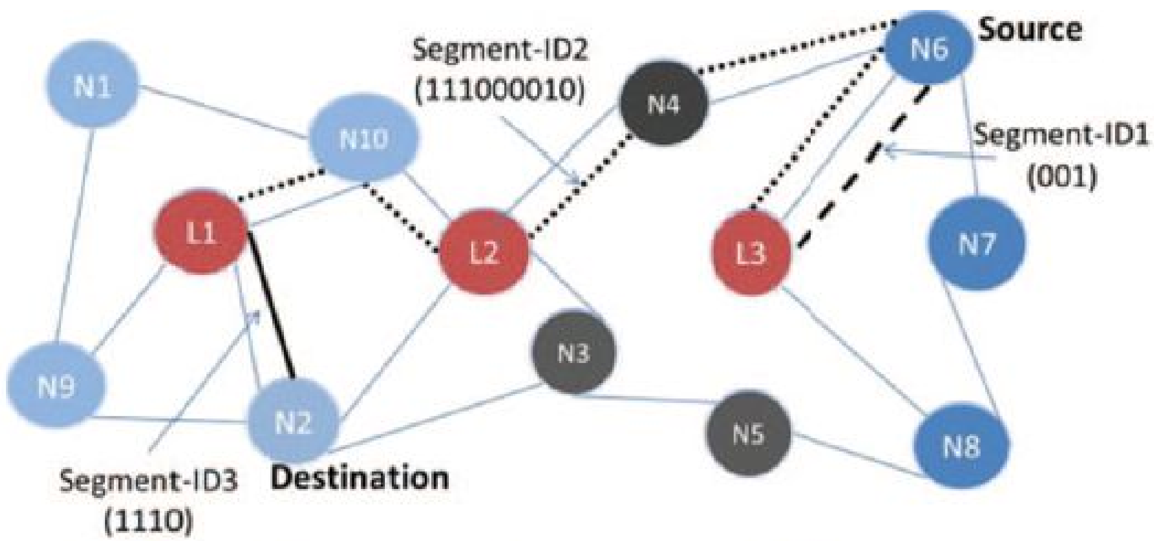


Fig. 5. H-SR routing policy for inter-NH communication.

Swap node selection techniques

- H-SR routing scheme for the inter-NH communication can potentially obtain a longer path than shortest path routing.
- To evaluate routing schemes a well- known metric called stretch is defined as:

$$\text{stretch} = \frac{\text{routing scheme (H−SR) path distance}}{\text{shortest path distance}}$$

- minimize the stretch of each path and hence the aspects related to formation of the NH

Swap node selection scheme

- Our swap node selectioon schemes are based on the **centrality indices of nodes** in a graph
- Three types of centrality indexs are defined:
  - Degree Centrality: Degree centrality index is the normalized degree of a node in a network

$$C_D(v) = D_v / \sum D_j$$

  - Betweenness Centrality: Betweenness centrality index is proportional to **the number of shortest paths in the network that pass through a particular node**

$$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

  - Closeness Centrality: Closeness centrality index is a measure of how close a node is to all other nodes in the n twork

Testbed

- A test-bed is built using OE supporting routers designed by us
- 22 nodes and 23 fiber links (RailTel Cop. India)
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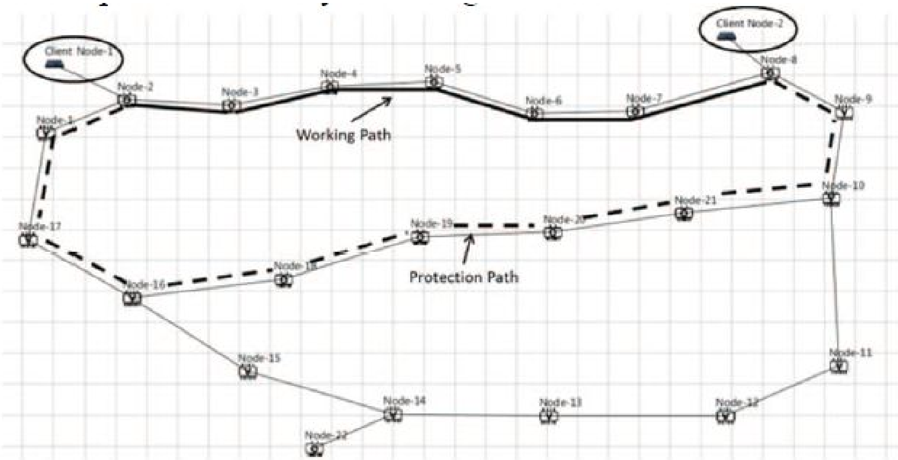

Fig. 6. Snapshot of the network topology of the test-bed.

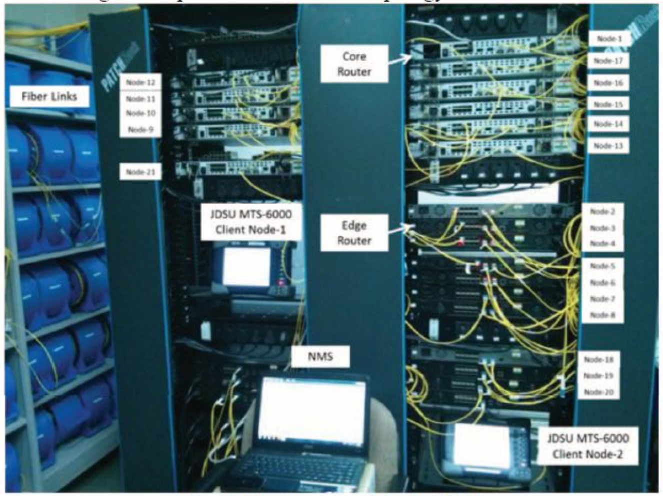

Fig. 7. Photograph of the test-bed.

Results

- throughput remains 100% for loads up to 90% and then reduces to around 90-91% for 100% load.
- This change in throughput is due to the **OE encapsulation** of the native Ethernet packet

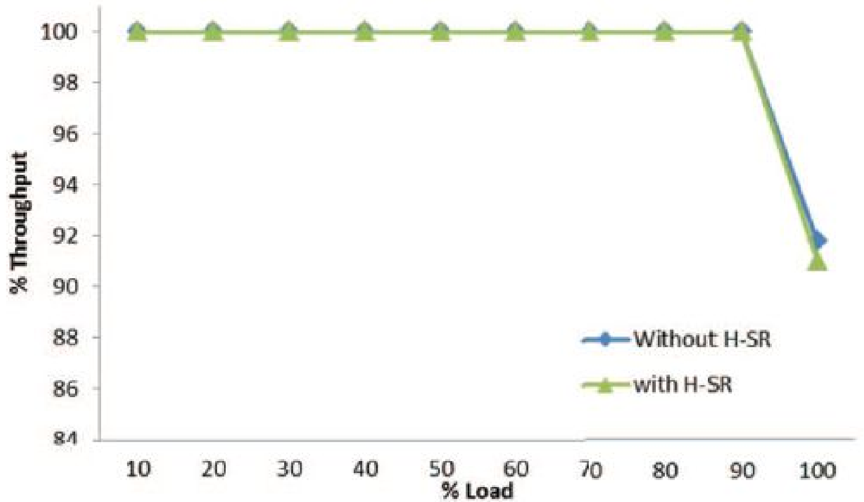

Fig. 8. Throughput of 1Gbps service for different load values.

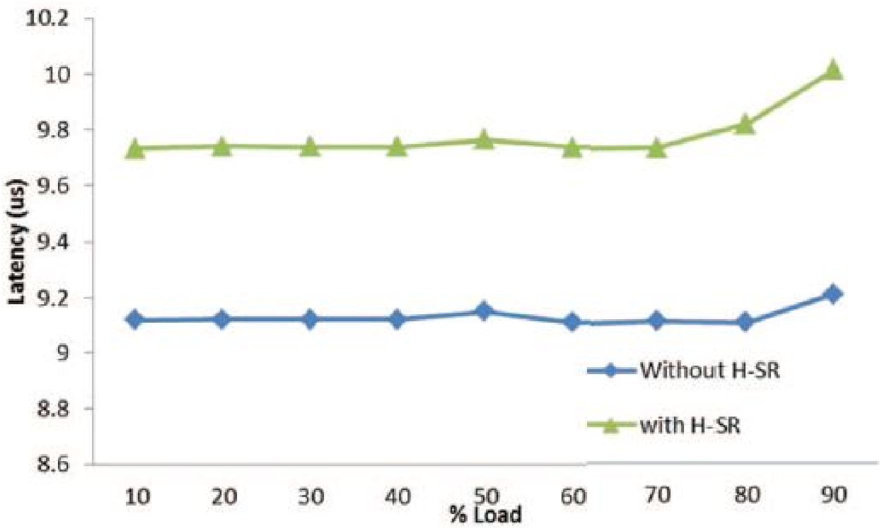

Fig. 9. Latency of 1Gbps service for different load values.

- latency is almost constant for load up to 70%

Simulation setup and results

- Network sizes with nodes ranging from 1000-10000 in the increments of 1000
- Highest Degree 1-Swap” in all subsequent graphs represents key results from compact routing which prefers highest degree nodes as swap node
- Average stretch values for betweenness centrality based swap node selection scheme is close to 1

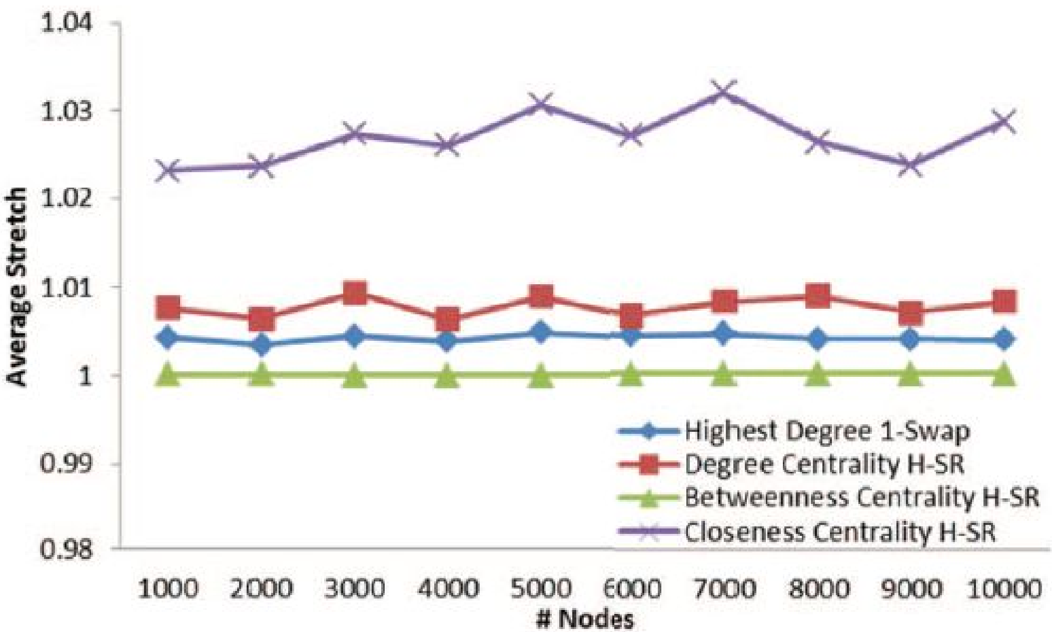

Fig. 10. Average stretch.

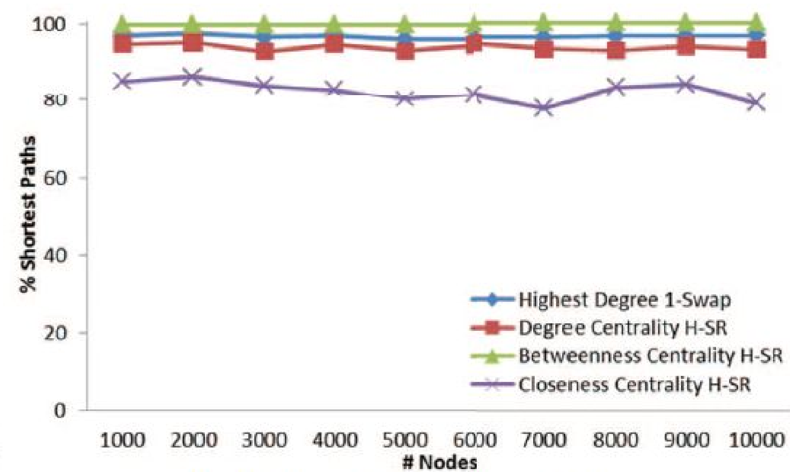

Fig. 12. Percentage of shortest paths.

number of routing table entries

- There is no comparable difference in the schemes for number of routing table entries
  - the same neighborhood formation approach for each scheme

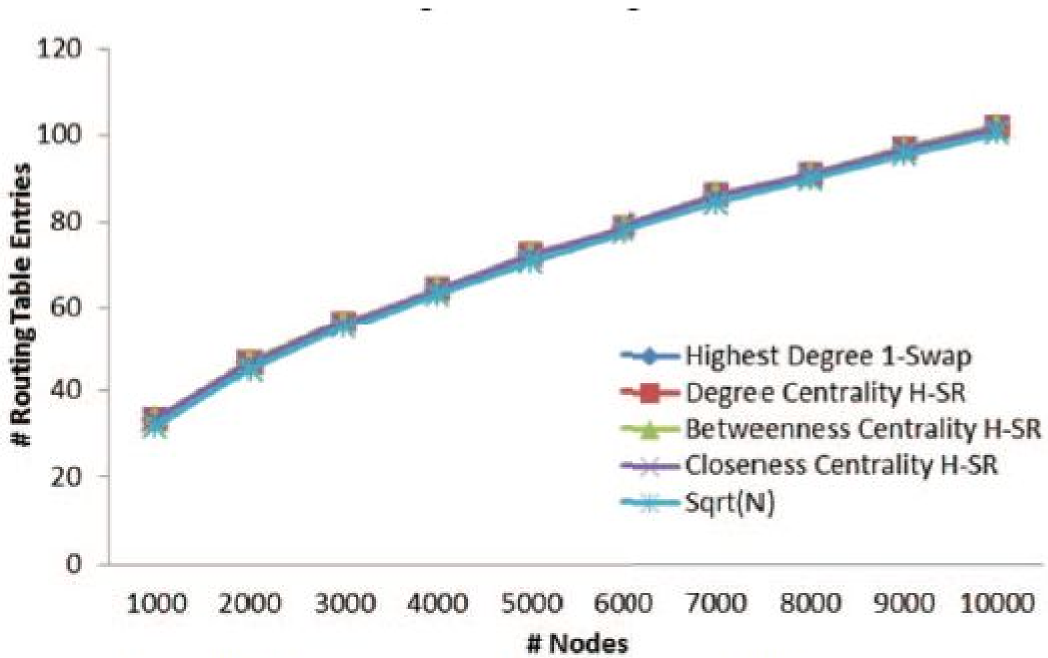

Fig. 11. Average number of routing table entries.

- propose a new metric called “Latency-Stretch” (LS) which is the product of **average end-to-end latency** and the **average path stretch** for a routing scheme
- In service oriented environments, **low-latency paths with deterministic latency but more hops are favorable** than the high-latency shortest paths with probabilistic latency

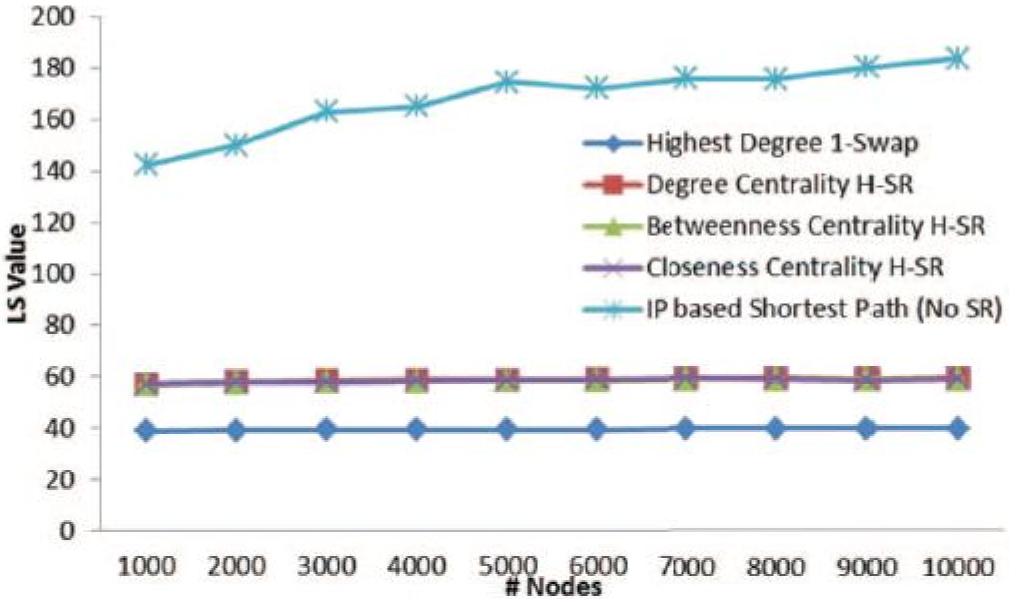

Fig. 13. Latency Stretch value as a function of network size.

label size

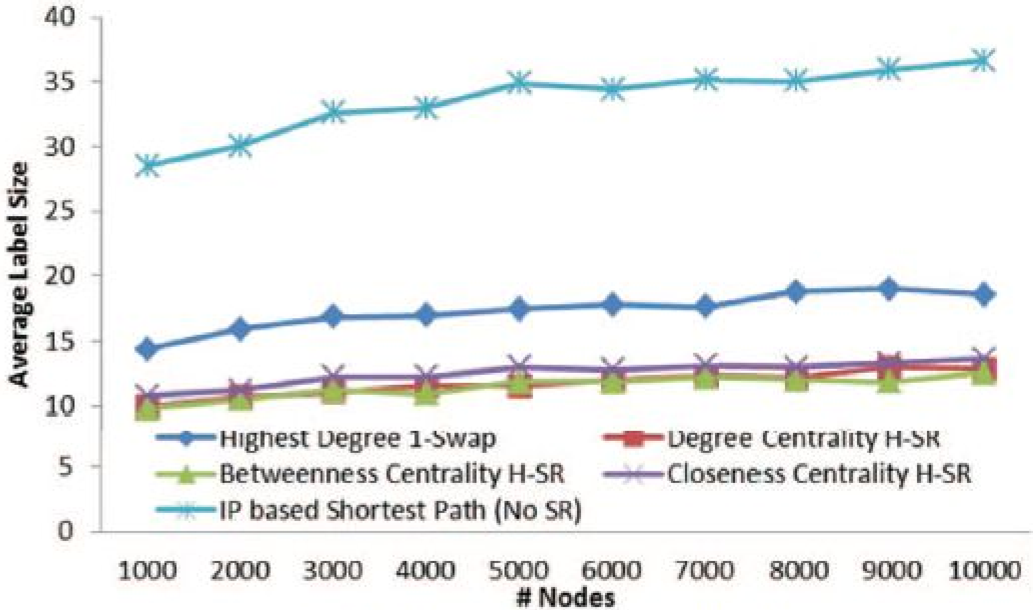

Fig. 14. Label size in the header.

CONCLUSION

- Integrated SR concepts with our recently proposed paradigm of Omnipresent Ethernet within the realm of Carrier Ethernet
- Allows providers to implement a packet-based carrier-class core network
- hierarchical-SR , three techniques for swap nodes, selection