

2.2 Reverse Path Calculation

As the packets traverse the defined path, the reverse path can be calculated by changing the output interface number in the path packet header with the input interface number at each intermediate node. For example, before *SwitchB* forwards the packet to Interface 3, the entry “3” in the path header can be changed with the input interface number “1”, and so on at *SwitchD* and *SwitchE*. The sequence {2,3,3,3} will be changed to {1,1,1,2} by the time it reaches *SwitchE* and can be stored for future use with flows from *NodeY* to *NodeX* without the need for the ingress node to contact the controller, i.e., achieving a 50% reduction in the burden of the controller.

2.3 Link Failure Recovery

Link failure conditions can be handled locally in this approach as the intermediate nodes don’t hold state information about the network and rely on the path packet header in forwarding. During network initialization, the controller can push information to nodes regarding alternative routes to the next hop. For example, In *Figure 1*, if packet reaches *SwitchB* and Interface 3 is found down, the switch can change the entry “3” in the path sequence with {2,3} to reach *SwitchD* but through *SwitchC*, based on pre-stored information. As the failure is being handled locally temporarily, a notification would be sent to the controller about the failure condition.

3. ANALYSIS OF INTERNET2 OS3E

Internet2 is developing a 34-node SDN called the Open Science, Scholarship and Services Exchange (OS3E) across the US to support advanced global scientific research [4].

3.1 State Distribution

The OS3E network was analyzed considering the state distribution, assuming one controller is deployed. *Table 1* shows results relating the average number of links in the shortest paths from three main cities to the rest of the network to the reduction in state distribution if the Source Routing approach is in effect.

Table 1. State Reduction in OS3E’s three main cities.

City	Avg # Links in Shortest Path	% of Distributed State Reduction
Seattle	4.5	77.8 %
Chicago	3.2	69.2 %
New York	5.4	81.5 %

Averaging the results obtained from the rest of the 34 nodes in the network yields a 77.6% reduction in the state that has to be distributed to achieve network convergence. Applying the extra 50% state reduction that the reverse path calculation brings to the results above yields a total of 88.8% reduction in state distribution in the OS3E network, if the Source Routing approach is used. This significant state reduction directly improves the network convergence time.

3.2 Controller Placement

In Software-Defined WANs, the node-to-controller propagation latency bounds the ability to respond to network events. The best controller placement is the one that minimizes propagation delays, and consequently improves performance and fault tolerance [2]. The research in [2] finds that to minimize worst case latency in the OS3E network, the controller should be placed close to the geographic center of the network in Kansas City, while minimizing the average

latency requires a placement in Chicago close to the high density areas in the network, *Figure 3*.

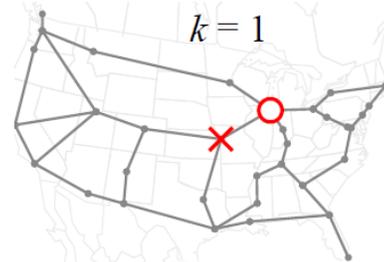


Figure 3. OSE3 Optimal Controller Placements, (K=1, one controller used), ‘X’ is Kansas City and ‘O’ is Chicago. [2]

Using the Source Routing approach adds new dimensions to this problem. In the Source Routing approach the controller sends state information to ingress nodes only. Therefore, not all node-to-controller latencies have to be considered for optimizing the controller placement. Furthermore, not all the ingress nodes will communicate to the controller at the same rate, in particular with the use of the reverse path calculation approach. As a result, taking network traffic patterns into consideration, an optimal placement can be achieved based on the geographical distribution of the ingress nodes with the highest traffic demands, possibly with lower latency bounds than found in [2].

4. CONCLUSION AND FUTURE WORK

In this paper, we presented a new approach for routing in SDN that leverages variations of Source Routing and aims to open new possibilities for improvements in controllers’ scalability, availability, and placement optimizations. Unlike previous source routing attempts, the proposed approach is simple, strict and orthogonal to IP, like MPLS tunneling. In addition, the approach utilizes the controller’s knowledge of the network topology and adapts to the Software defined networks architecture.

Currently a model for Source-Routing-enabled OpenFlow switches is being developed to be used in NS3 simulation environment, to conduct performance analysis comparing the new approach to traditional OpenFlow. Our objective is to utilize the advantages that the Source Routing approach has in (1) Improving controller’s scalability and network convergence time by reducing the state to be distributed in the network, (2) Improving controller’s availability by locally handling link failures in real time, (3) Optimizing controller(s) placements to reduce the effects of propagation latencies in WANs.

5. REFERENCES

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