Ubiquitous Networked System Lab.

Congestion-Aware Single Link Failure Recovery in Hybrid SDN Networks.

Cing-Yu Chu, Kang Xi, Min Luo and, H. Jonathan Chao, in Proc. of the IEEE INFOCOM 2015

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Paper overview

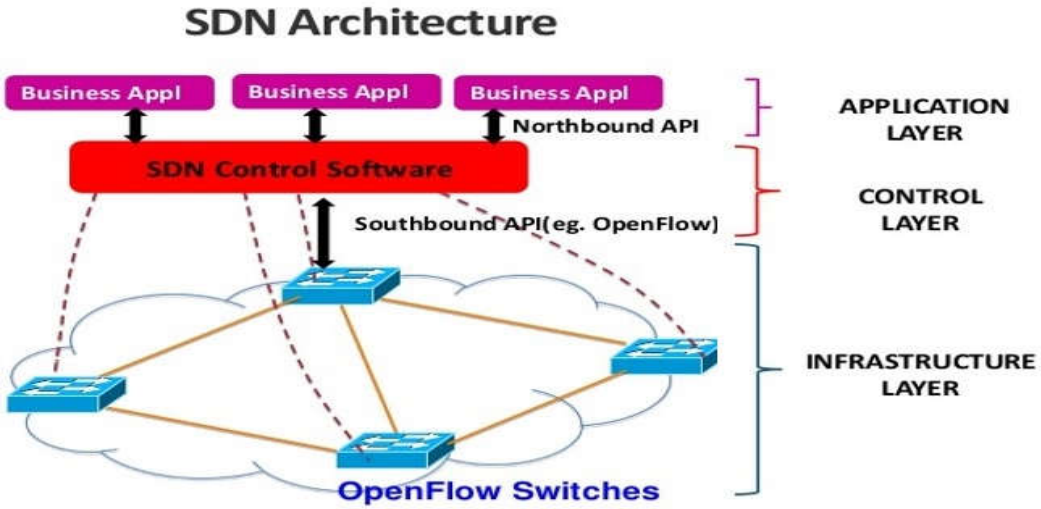
- Topic of this paper
  - Traffic reachability in the presence of single link failure.
- Proposed approach
  - Hybrid SDN network
    - Traditional IP routers and SDN switches co-exist.
  - Redirecting traffic on the failed link to SDN switch through pre-configured IP tunnels.
- Goal
  - To achieve fast failure recovery while load-balancing the post-recovery network.

Background of Software Defined Networking

Software Defined Networking (SDN)

- A new networking paradigm
  - The forwarding hardware is decoupled from control decisions

- Key features
  - **Controller based architecture**
    - Logically centralized software program to control the behavior of the entire network.
  - **Flow-based routing (forwarding)**
    - Each SDN Switch has own Flow Table that is configured by SDN controller



Advantages of SDN

- Logically centralized Network.
  1. Easy to manage network.
  2. Better load-balancing
  3. Fast failure recovery.
     - SDN controller knows entire network information. So SDN can provide multiple backup paths for the failure recovery.

Evaluating the paper in 7 steps

1. What does the paper try to solve?

- Single link failure recovery problem of traditional hybrid SDN network.
  - The current proposed hybrid SDN network schemes use fixed recovery path for any particular link failure
    - they cannot react to current network traffic.

- By redirecting traffic on the failed link to SDN switches through pre-configured IP tunnels.

2. What was the problem before?

- Legacy network
  - It requires reactive computation.
- SDN network
  - Need to lots of replacement cost and man power.
- Hybrid SDN network
  - Maintain multiple routing tables/configurations
    - When a link failure is detected, the router choose the configuration.
      - It does not considering current network traffic.

➢ It is not enough to achieve fast failure recovery while load-balancing the post-recovery network.

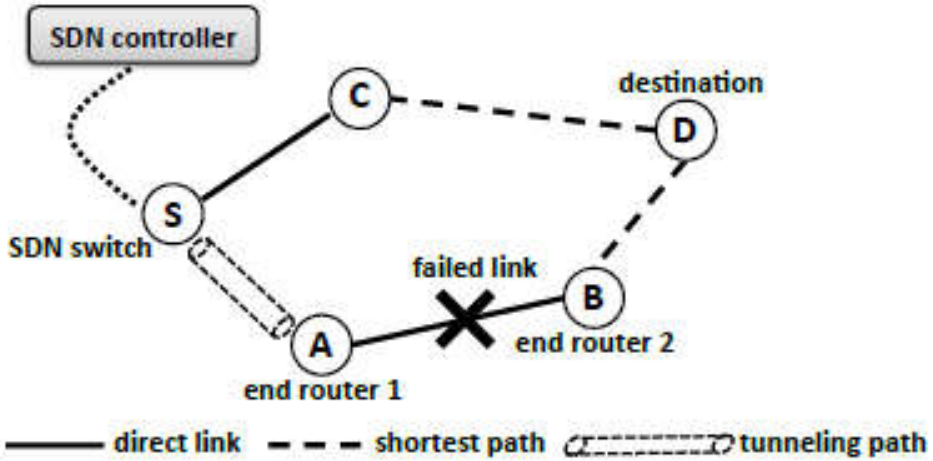
3. What are its ideas?

- Using IP tunnel between the router and a SDN switch.
  - To provide failover upon detecting a link failure on its interfaces.

- Goal and Purpose
  - To achieve fast failure recovery while load-balancing the post-recovery network.

  - Reducing the cost and man power needed to replace legacy IP routers with SDN switches.

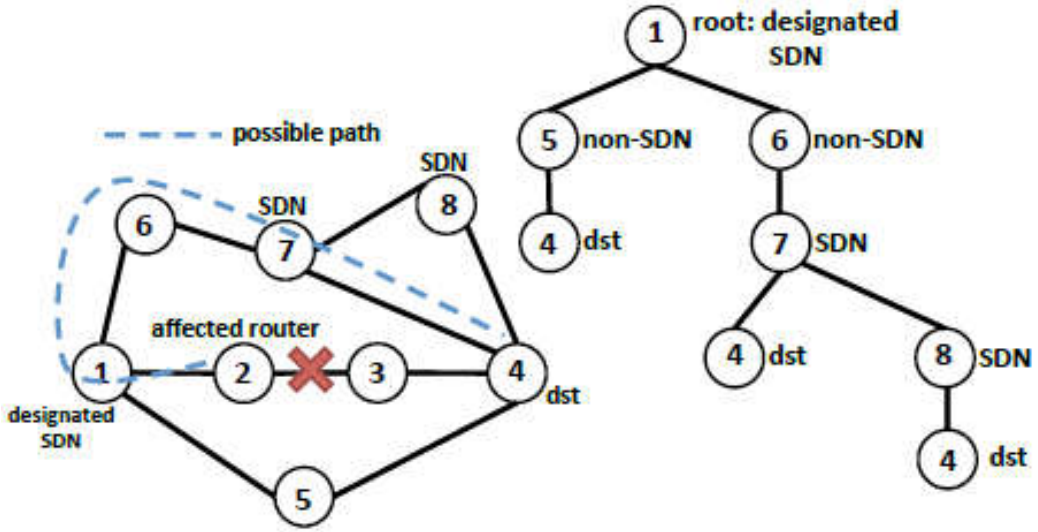
Proposed Recovery Scheme



- Single link failure recovery procedure.
  1. Router A which is directly connected to the failed link detects link failure.
  2. Router A immediately encapsulate and forward all packets that to SDN switch S through the backup IP tunnel.
  3. SDN switch S decapsulates the packets and performs table lookup.
     - Routing decision at an SDN switch is configured by the SDN controller.
  4. SDN switch sends traffic to the final destination without using the failed link.

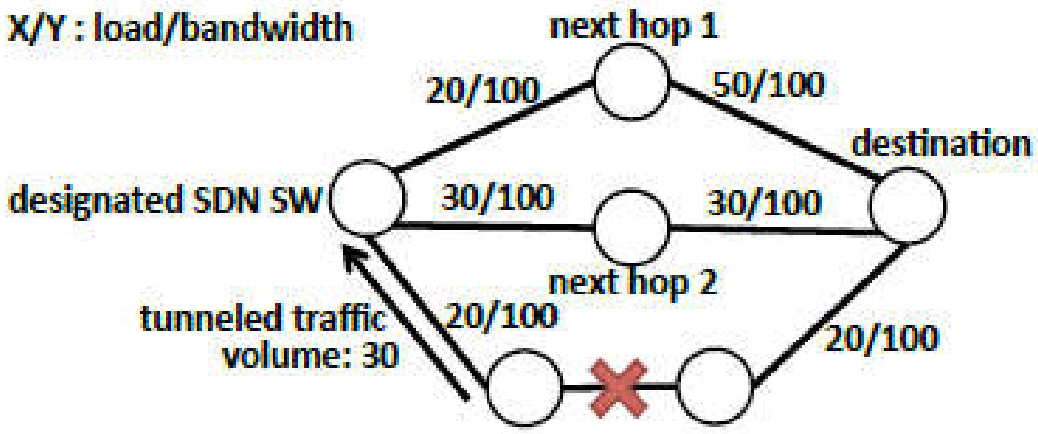
Paths Construction

- Node type
  - SDN node
    - It is allowed to have multiple children which are the neighbors of this SDN node.
      - SDN node can select next hop considering load-balancing
  - Non-SDN node
    - It is only allowed to have one child which is the next hop on the shortest path from the current node to the final destination.



Path selection

- There are multiple next hops that can be used to forward traffic
- The controller chooses the path
  - The maximal link utilization after redirecting all the affected traffic is minimized.



Notations for Reachability

NOTATIONS FOR REACHABILITY

(**V**, **E**)	A network with node set **V** and link set **E**
β_x^e	Binary, $\beta_x^e = 1$ if node x is an end node of link e; 0, otherwise.
$\delta_{i,j}^e$	Binary, $\delta_{i,j}^e = 1$ if link e is on the shortest path from node i to node j; 0 otherwise.
$b_{x,i}^e$	Binary, $b_{x,i}^e = 1$ if node i is chosen as node x's designated SDN switch when link e fails; 0, otherwise.
$N_{i,m}$	Binary, $N_{i,m} = 1$ if node i and node m are neighbors with only one hop; 0, otherwise
u_i	Binary, $u_i = 1$ if node i is chosen to be a SDN switch; 0, otherwise.
	$e \in \mathbf{E}$ and $i, j, x, m \in \mathbf{V}$

The formulation for minimize the number of SDN switches.

- Proposed scheme's basic requirements
  - For each single link failure, an affected router has at least one candidate designated SDN switch which is destination independent
  - For every SDN switch, there exists at least one next hop for each possible destination.

$$\sum_i b^e_{x,i}(1-\delta^e_{x,i})[\sum_m N_{i,m}(1-\delta^e_{i,m})(1-\delta^e_{m,d})] \geq \beta^e_x \delta^e_{x,d} \quad (1)$$

$$\sum_i b^e_{x,i} \leq \beta^e_x \quad (2)$$

$$b^e_{x,i} \leq u_i \quad (3)$$

1) (1) ensures that for every affected router x can at least find one designated SDN switch *I* and reach it with out using the failed link e.

2) (2) ensures that only one designated SDN switch is used for an affected router x when link e fails.

3) (3) ensures that a router has to be replaced by a SDN switch if any affected router x chooses it as its designated SDN switch.

Notations for Load Balancing

NOTATIONS FOR LOAD BALANCING

l_e	Traffic load on link e without redirected traffic
c_e	Capacity of link e
$\lambda^s_{e,d,p}$	Binary, $\lambda^s_{e,d,p} = 1$ if link e is on the path p from an affected router s to destination d; 0, otherwise
t^s_d	Traffic volume from an affected router s to destination d
$\alpha^s_{d,p}$	Binary, $\alpha^s_{d,p} = 1$ if path p is chosen for the affected router s and destination d to deliver traffic to destination d; 0, otherwise
y_e	Traffic load on link e after redirection
γ	Upper bound of link utilization

The formulation for minimizing maximal link utilization

- To achieves load balancing by using multiple next hops and the coordination among SDN switches.

$$\sum_p \alpha^s_{d,p} = 1 \quad (4)$$

$$\sum_s \sum_d \sum_p \lambda^s_{e,d,p} \alpha^s_{d,p} t^s_d + l_e = y_e \quad (5)$$

$$y_e \leq \gamma c_e \quad (6)$$

1. (4) ensures that for each affected router and destination pair, it uses only one path to reach each destination.

2. (5) ensures that the workload on each link after traffic redirection is the summation of current workload of each link and the traffic volume from the designated SDN switches.

3. (6) ensures that the workload of each link after traffic redirection is bounded by the maximal link utilization.

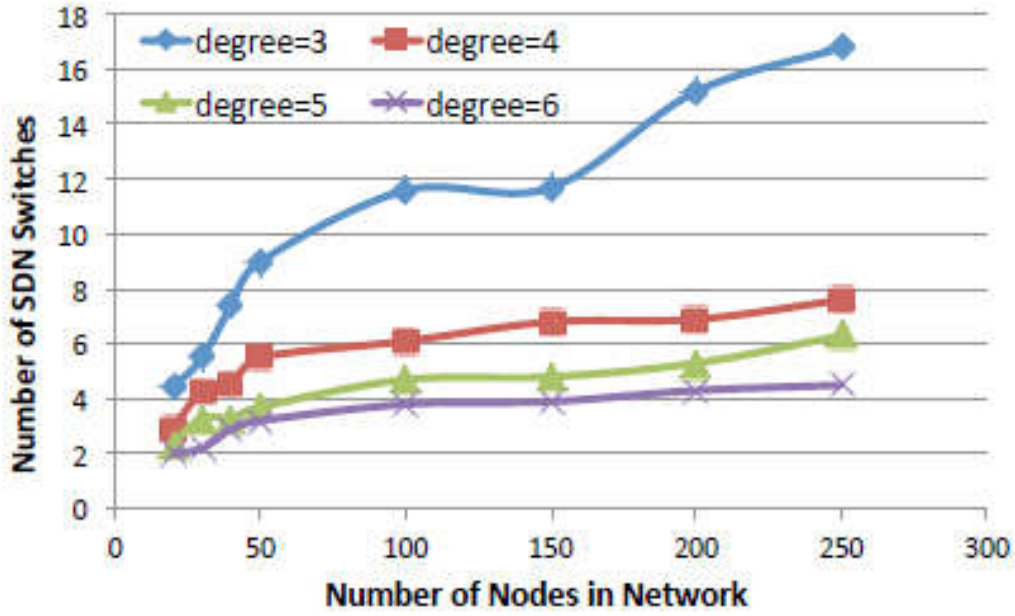
4. How does the paper evaluate?

- Investigate two properties
  - The number of SDN switches needed
  - The maximal link utilization in the post-recovery network.

- Evaluation environments

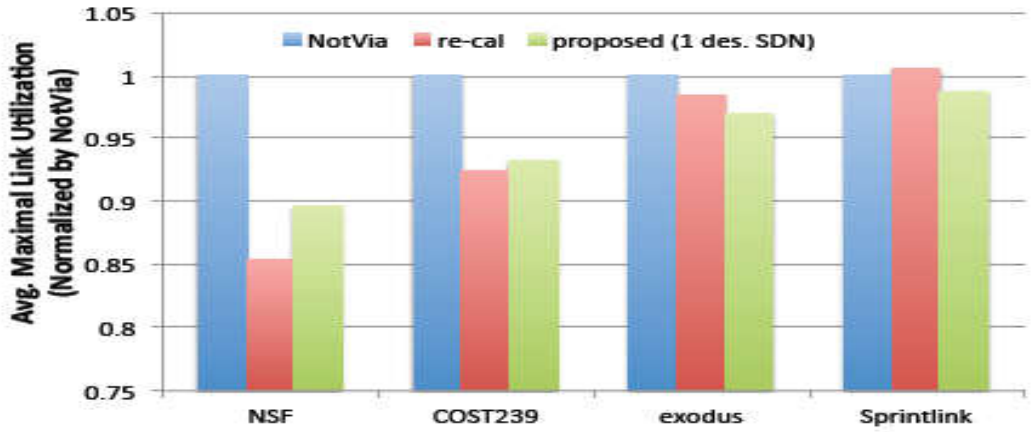
Dataset	Number of Nodes	Number of Links	Degree
COST239	11	26	4.7
NSFNET	14	21	3
Exodus	22	38	3.5
Sprintlink	44	97	4.4

Number of SDN Switches



- Number of SDN switches needed
  - The number of SDN switches needed generally increases with the number of nodes in a network
  - When a network has very dense connections, this increase is slower.

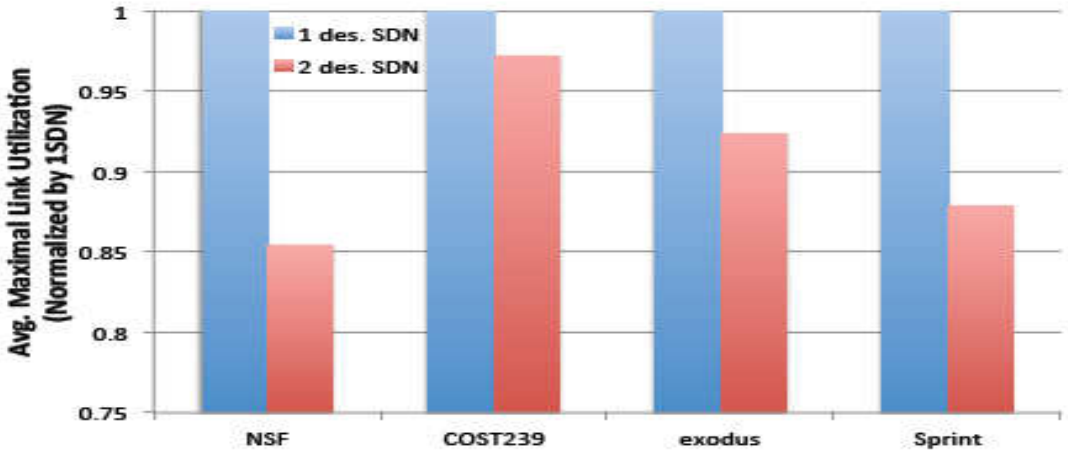
Normalized Maximal Link utilization



Averaged Maximal Link Utilization (Normalized).

- NotVia
  - IP Fast Reroute
  - The tunneling path is computed using shortest path by excluding link A-B
- Re-cal
  - Shortest path recalculation.
  - widely used to deal with link failures in today's IP network

Normalized Maximal Link utilization



Normalized Maximal Link Utilization: Multiple Designated SDN switches.

- The reduction depends on the link distribution and locations of SDN switches.
- Sometimes it is inevitable for a router to have multiple tunneling paths that share same links

The Number of additional Entries

NUMBER OF SDN SWITCHES NEEDED FOR SINGLE LINK FAILURES

	Number of Designated SDN Switches	
Dataset	ONE	TWO
COST239	2	3
NSFNet	3	5
Exodus	4	9
Sprintlink	5	10

AVG. NUMBER OF FLOW TABLE ENTRIES REQUIRED AT EACH SDN SWITCH

	Avg. Number of Additional Entries				
SDN SW ID	1	2	3	4	5
COST239	61	55	N/A	N/A	N/A
NSFNet	49	60	35	N/A	N/A
Exodus	75	25	79	24	N/A
Sprintlink	42	142	25	34	78

- The additional flow table entries needed at each SDN switch.
  - To cover all the possible single link failures.
- Distribution of number of additional entries is uneven.
  - It is because when we try to minimize the number of SDN switches in the network, we tend to choose nodes that are the traffic hubs in the network.

5. What can we expect in the future?

- Applying proposed approach to other networks
  - resource-constrained network
    - Applying Hybrid SDN architecture
      - Most SDN studies in resource-constrained network assume that every node is replaced by SDN switches.
  - Wireless ad-hoc network
    - Applying node failure recovery

6/7. Limitation & Opinion

- Limitation
  - No consistent in topology environment.
    - It is hard to know relationship between number of Nodes and Number of Links.
  - Paper does not consider Link failure recovery time.

- Opinion
  - Proposed scheme seems to be achieved good load-balancing performance
    - Paper does not shows link failure recovery time
      - Is It finished in reasonable time?

Thank you for your attention!

Any Questions ?