ProgrammabilityMedic: Predictable Path Programmability Recovery under Multiple Controller Failures in SD-WANs

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School of Automation
Beijing Institute of Technology

ICDCS'21 (July 8, 2021)

Outline

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Outline

Software-Defined Networking (SDN)

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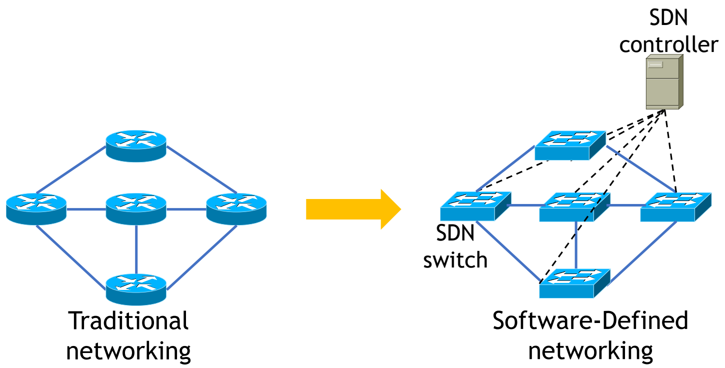

Advantages of SDN (e.g., path programmability).

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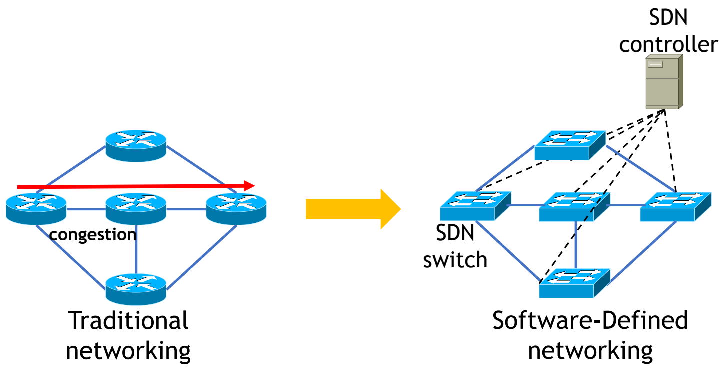

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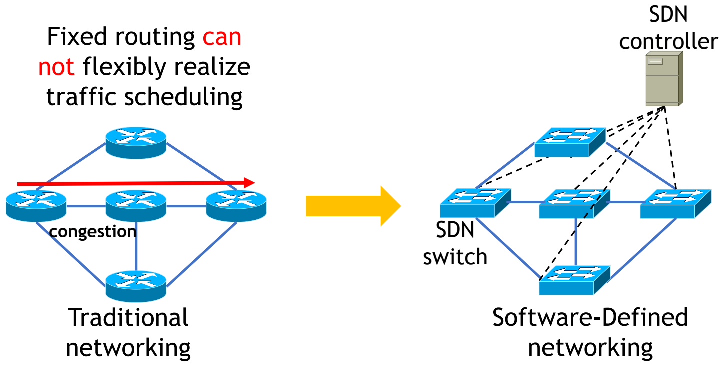

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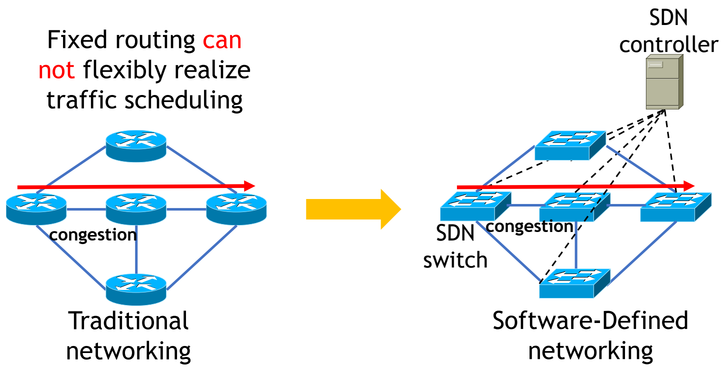

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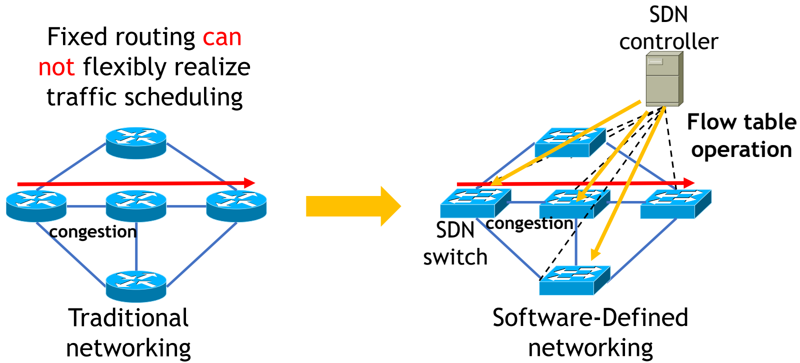

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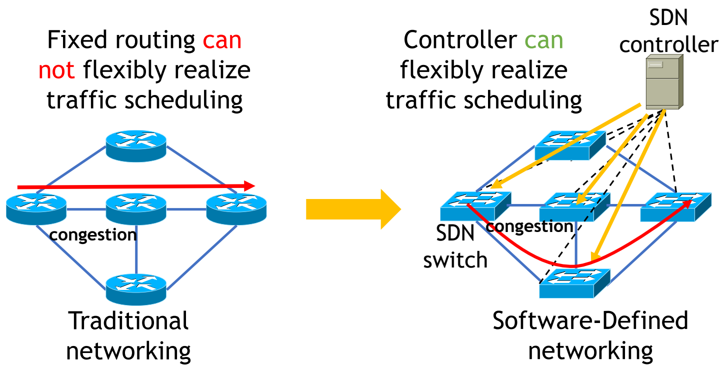

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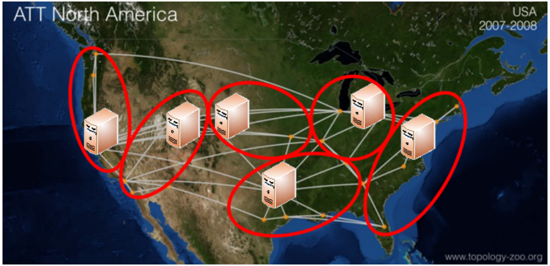
Software-Defined Wide Area Networks (SD-WANs)

- Large scale with many devices
- Partitioning the network into domains
- Distributed control plane
  1. Quick response
  2. Control resiliency
  3. Controller synchronization



AT&T topology.

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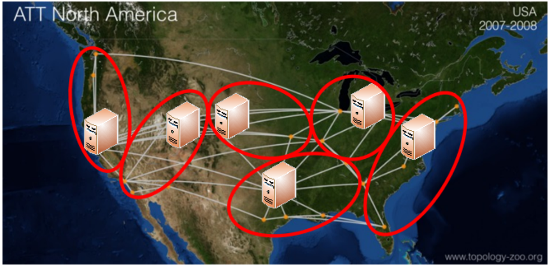

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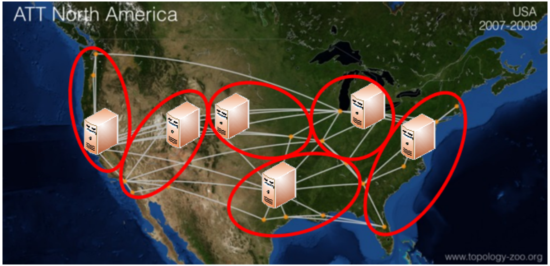

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Controller failure problem in SD-WANs

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Controller failure

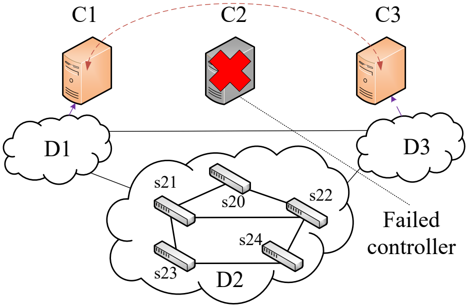
- Software bugs, Hardware failure, Power outage

Maintaining path programmability

- Offline switches remapping

Challenges

- Limited control resource
- Path programmability recovery
- Multiple failures



An example of controller failure.

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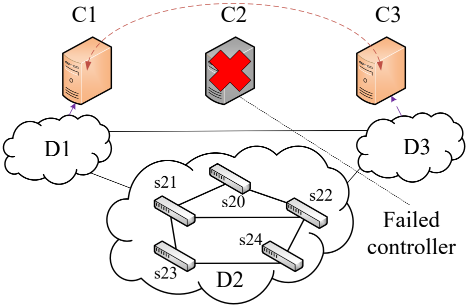

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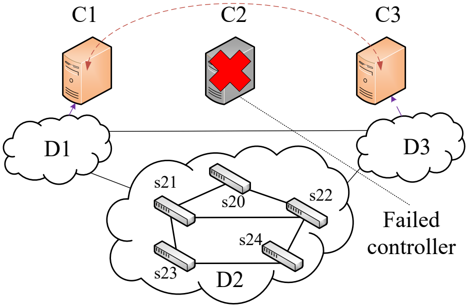

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Switch-level mapping solution

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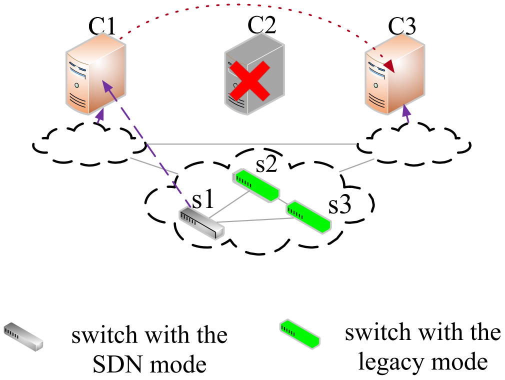
Switch-level mapping solution

RetroFlow*

- Some offline switches work under the **legacy routing mode** without the controllers
- The rest offline switches with the SDN routing mode

Limitations

- Fixed control cost of switches
- Per-switch mapping



An example of switch-level solution.

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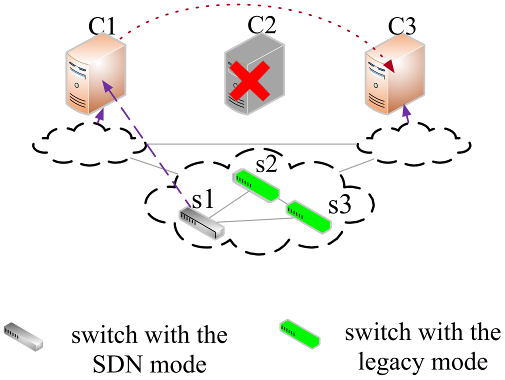

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Flow-level mapping solution

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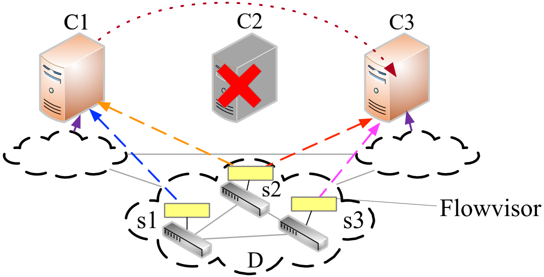
Switch-level mapping solution

ProgrammabilityGuardian†

- Introducing a middle layer between controller and switches using **Flowvisor**
- Fine-grained per-flow mapping

Limitations

- Increasing the processing delay
- Bringing new unreliability



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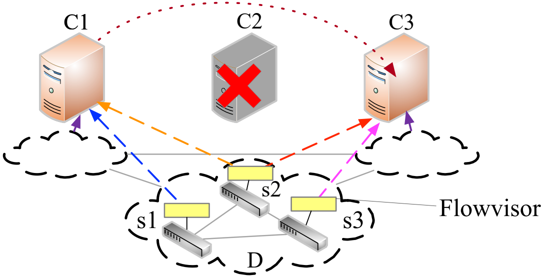

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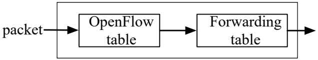
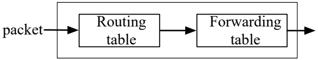
Opportunity

Hybrid SDN/legacy routing mode

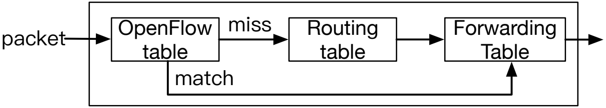
- Specifically hybrid OpenFlow/OSPF routing mode
- Selectively deciding the routing mode for each offline flows
- Dynamically changing the control cost of offline flows



SDN routing mode.



Legacy routing mode.



Hybrid SDN/legacy routing mode.

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Design considerations

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Consideration 1:

- Recovering offline flows as many as possible

Consideration 2:

- Balancing path programmability

Consideration 3:

- Fully utilizing controllers' control resource

Design considerations

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Flow Mode Selection and Switch Mapping problem

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Switch-controller mapping constraint

- Each switch can be mapped to at most one controller

$$\sum_{j=1}^{M} x_{ij} \leq 1, \forall\ i. \quad (1)$$

Controller resource constraint

- The control load of a controller should not exceed the controller's available control resource

$$\sum_{l=1}^{L} \sum_{i=1}^{N} (x_{ij} * \beta_i^l * y_i^l) \leq A_j^{rest}, \forall\ j. \quad (2)$$

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Flow Mode Selection and Switch Mapping problem

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Flow programmability constraint

- r is used to denote the least programmability of all offline flows

$$pro^l = \sum_{i=1}^{N} \sum_{j=1}^{M} (\bar{p}_i^l * x_{ij}^l * y_i^l) \geq r, \forall\ l. \quad (3)$$

Propagation delay constraint

- Total propagation delay should not exceed the propagation delay of the ideal recovering case

$$G = \sum_{j=1}^{M} \sum_{i=1}^{N} (\alpha_{ij} * \gamma_i * D_{ij}). \quad (4)$$

$$\sum_{l=1}^{L} \sum_{j=1}^{M} \sum_{i=1}^{N} (x_{ij} * \beta_i^l * y_i^l * D_{ij}) \leq G. \quad (5)$$

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Flow Mode Selection and Switch Mapping problem

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Objective function

- To recover offline flows as many as possible and let them have similar programmability

$$obj_1 = r. \tag{6}$$

- To make full use of the control resource of active controllers

$$obj_2 = \sum_{l=1}^{L} pro^l. \tag{7}$$

Problem formulation

$$\max_{r,x,y} r + \lambda \sum_{l=1}^{L} pro^l \tag{P}$$

subject to

Eqs. (1)(2)(3)(4)(5)

$$r \geq 0, x_{ij}, y_i^l \in \{0,1\}, \forall\, i, \forall\, j, \forall\, l.$$

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Heuristic solution: ProgrammabilityMedic

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Preferably recovering offline flows, which have the least programmability

- Finding switch s_{i_0} to recover
- Mapping switch s_{i_0} to controller C_{j_0}
- Selecting the routing mode for flows at switch s_{i_0}

Making full use of available control resource to improve the total programmability

- Improving the total programmability

```
X = ∅, Y = ∅, S* = S, σ = 0, test_count = 0;
while test_count ≤ TOTAL_ITERATIONS do
    δ = 0, i_0 = NULL, j_0 = NULL;
    //find switch s_{i_0} to recover
    for s_i ∈ S* do
        TEST_NUM = 0;
        for l ∈ {β_i^l = 1, l ∈ [1, L]} do
            if h^l == σ then
                TEST_NUM = TEST_NUM + 1;
            end if
        end for
        if TEST_NUM > δ then
            δ = TEST_NUM, i_0 = i;
        end if
    end for
    //map switch s_{i_0} to controller C_{j_0}
    if (i_0, *) ∈ X then
        use i_0 to find j_0 from X;
    else
        for C_j ∈ C(i_0) do
            if A_j^{rest} ≥ γ_{i_0} then
                j_0 = j;
            end if
        end for
        if j_0 == NULL then
            A_j^{rest} = max(A), j_0 = j;
        end if
    end if
    X ← X ∪ (i_0, j_0), S* ← S* \ s_{i_0};
    //select the routing mode for flows at switch s_{i_0}
    for l_0 ∈ {β_{i_0}^l = 1, l ∈ [1, L]} do
        if h^{l_0} ≤ σ and (i_0, l_0) ∉ Y and A_{j_0}^{rest} > 0 then
            A_{j_0}^{rest} = A_{j_0}^{rest} − 1, h^{l_0} = h^{l_0} + pro_{i_0}^{l_0};
            Y ← Y ∪ (i_0, l_0);
        end if
    end for
    if |S*| == ∅ then
        S* = S, test_count++, σ = min(H);
    end if
end while
//improve the total programmability
for (i_0, l_0) ∈ {β_i^l = 1, i ∈ [1, M], l ∈ [1, L]} do
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Evaluation

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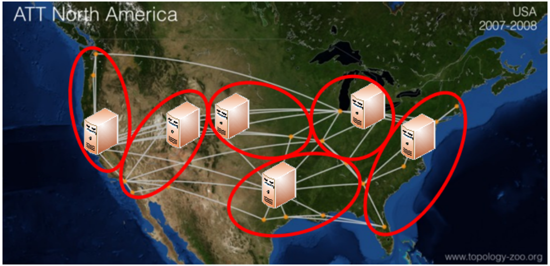
Simulation setup

- AT&T topology with 25 nodes and 112 (56*2) links
- 6 controllers
- Any two nodes have a flow

Comparison algorithms

- RetroFlow
- ProgrammabilityMedic
- Optimal
- ProgrammabilityGurdian



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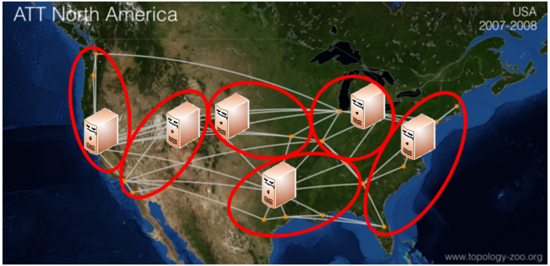

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Evaluation

Simulation scenarios

- Scenario 1. One controller failure
- Scenario 2. Two controllers failure
- Scenario 3. Three controllers failure

Performance metrics

- **Path programmability** of flows
- Percentage of **total path programmability** of recovered flows to RetroFlow
- Percentage of **recovered programmable flows** from offline switches
- Number of **recovered offline switches**
- **Control resource** of active controllers
- Per-flow **communication overhead**

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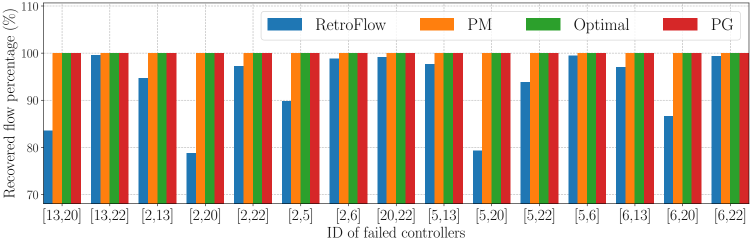
Two controllers failure

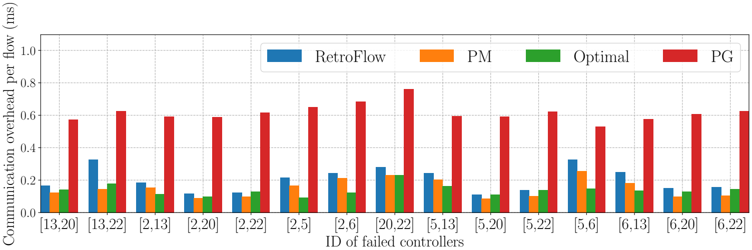
Recovered programmable flows

- PM, Optimal, and PG recover all offline flows
- RetroFlow: 78-99% to PM



Communication overhead

- The lower, the better
- PG performs the worst because the middle layer's processing time significantly increases the overhead



More results in paper

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Summary

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New idea

- We propose to recover path programmability of offline flows by approximately realizing flow-controller mappings using **hybrid SDN/legacy routing** supported by high-end commercial SDN switches.

New problem and solution

- We formulate the **Flow Mode Selection and Switch Mapping (FMSSM) problem**, which is a mix integer programming with high computation complexity. To efficiently solve the problem, we reformulate the problem with linear techniques and solve the problem with the proposed efficient **heuristic algorithm** named PM.

Good performance

- We evaluate the performance of PM under different controller failure scenarios. The results show that PM outperforms existing switch-level solutions by maintaining balanced programmability and increasing the total programmability under multiple controller failures.

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Good performance

- We evaluate the performance of PM under different controller failure scenarios. The results show that PM outperforms existing switch-level solutions by maintaining balanced programmability and increasing the total programmability under multiple controller failures.

Thank you for your attention!

Q&A

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