Central Control over Distributed Routing

fibbing.net

Stefano Vissicchio

UCLouvain

SIGCOMM

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Joint work with

O. Tilmans (UCLouvain), L. Vanbever (ETH Zurich) and J. Rexford (Princeton)
SDN is based on antithetical architecture with respect to traditional networking

Traditional
(e.g., IGP, distributed MPLS)

SDN
(e.g., OpenFlow, Segment Routing)
Centralization improves network management, but *sacrifices* robustness of distributed protocols.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Traditional</th>
<th>SDN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manageability</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Flexibility</td>
<td>low</td>
<td>highest</td>
</tr>
<tr>
<td>Scalability</td>
<td><em>by design</em></td>
<td>ad hoc</td>
</tr>
<tr>
<td>Robustness</td>
<td>high</td>
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We propose Fibbing, a hybrid SDN architecture

Fibbing
central control over link-state IGPs
Fibbing *combines* advantages of SDN and traditional networking.

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Fibbing *combines* advantages of SDN and traditional networking.

- Manageability: high
- Flexibility: high
- Scalability: high (by design)
- Robustness: high

same as SDN
per-destination full control
some function are distributed
thanks to partial distribution
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1. Manageability
2. Flexibility
3. Scalability
4. Robustness
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1. Manageability
2. Flexibility
3. Scalability
4. Robustness
SDN achieves high manageability by centralizing both computation and installation.

- **Requirements**: e.g., OpenFlow controller or RCP
- **Computes paths**
- **Derives FIB entries**
- **Installs FIB entries**
Fibbing is as manageable as SDN, but centralizes only high-level decisions.
Fibbing keeps installation distributed, relying on distributed protocols.
Distributed installation is controlled by injecting carefully-computed information.
We study which messages to inject for controlling intra-domain routing protocols.
The output of the controlled protocol is specified by operators’ requirements.

**link-state IGP**

**input**
- weighted topology

**function**
- shortest-path computation

**output**
- forwarding paths

provided by operators or controller optimizers (e.g., DEFO)
To control IGP output, the Fibbing controller inverts the shortest-path function.
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1. Manageability
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Consider this simple network (implemented with Cisco routers)
An IGP control-plane computes shortest paths on a shared weighted topology.
IGP shortest paths are translated into forwarding paths on the data-plane
In Fibbing, operators can ask the controller to modify forwarding paths.
The Fibbing controller injects information on fake nodes and links to the IGP control-plane.

requirement \((C,A,B,X,D2)\)

node V1, link \((V1,C)\), map \((V1,C)\) to \((C,A)\)
Informations are flooded to all IGP routers in the network.
Fibbing messages *augment* the topology seen by all IGP routers.

**Diagram:**

- Node V1
- Link (V1, C)
- Map (V1, C) to (C, A)

**Requirement:** (C, A, B, X, D2)

**Notes:**
- Node V1, link (V1, C), map (V1, C) to (C, A)
Augmented topologies translate into new control-plane paths

requirement $(C,A,B,X,D_2)$

node $V_1$, link $(V_1,C)$, map $(V_1,C)$ to $(C,A)$
Augmented topologies translate into new data-plane paths.
Fibbing can program arbitrary per-destination paths

Theorem Any set of forwarding DAGs can be enforced by Fibbing
Fibbing can program arbitrary per-destination paths.

Theorem: Any set of forwarding DAGs can be enforced by Fibbing.

paths to the same destination do not create loops.
By achieving full per-destination control, Fibbing is highly flexible.

**Theorem**

Any set of forwarding DAGs can be enforced by Fibbing

- fine-grained traffic steering *(middleboxing)*
- per-destination load balancing *(traffic engineering)*
- backup paths provisioning *(failure recovery)*
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1. Manageability
2. Flexibility
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4. Robustness
We implemented a Fibbing controller
We also propose algorithms to compute augmented topologies of limited size.
For our Fibbing controller, we propose algorithms to be run in sequence:

1. **Compilation**
   - per-destination augmentation
2. **Augmentation**
   - cross-destination optimization
3. **Optimization**
   - running network

**Compilation**
- path reqs.
- network topology
- per-destination forwarding DAGs

**Augmentation**
- augmented topology

**Optimization**
- reduced topology

**Injection/Monitoring**
- running network

**Compilation Heuristics**
- simple
- merger
Consider the following example, with a drastic forwarding path change.

- Original shortest-path: “down and to the right”
- Desired shortest-path: “up and to the right”
Simple adds one fake node for every router that has to change next-hop.
Merger iteratively merges fake nodes (starting from Simple’s output)
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This way, Merger programs multiple next-hop changes with a single fake node.
This way, Merger programs multiple next-hop changes with a single fake node.
Simple and Merger achieve different trade-offs in terms of time and optimization efficiency

We ran experiments on Rocketfuel topologies, with at least 25% of nodes changing next-hops

- Simple runs in milliseconds
  Merger takes 0.1 seconds

- Merger reduces fake nodes by up to 50%
  and up to 90% with cross-destination optimization
We implemented the machinery to listen to OSPF and augment the topology.
Experiments on real routers show that Fibbing has very limited impact on routers

<table>
<thead>
<tr>
<th># fake nodes</th>
<th>router memory (MB)</th>
</tr>
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<tbody>
<tr>
<td>1,000</td>
<td>0.7</td>
</tr>
<tr>
<td>5,000</td>
<td>6.8</td>
</tr>
<tr>
<td>10,000</td>
<td>14.5</td>
</tr>
<tr>
<td>50,000</td>
<td>76.0</td>
</tr>
<tr>
<td>100,000</td>
<td>153</td>
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DRAM is cheap

>> # real routers
Experiments on real routers show that Fibbing has very limited impact on routers.

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DRAM is cheap.

CPU utilization always under 4%
Experiments on real routers show that Fibbing does not impact IGP convergence.

Upon link failure, we registered *no difference* in the (sub-second) IGP convergence with

- no fake nodes
- up to 100,000 fake nodes and destinations
Experiments on real routers show that Fibbing achieves fast forwarding changes

<table>
<thead>
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<th># fake nodes</th>
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<tbody>
<tr>
<td>1 000</td>
<td>0.9</td>
</tr>
<tr>
<td>5 000</td>
<td>4.5</td>
</tr>
<tr>
<td>10 000</td>
<td>8.9</td>
</tr>
<tr>
<td>50 000</td>
<td>44.7</td>
</tr>
<tr>
<td>100 000</td>
<td>89.50</td>
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1. Manageability
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Fibbing improves robustness by relying on the underlying IGP

- no controller action needed in some cases
  IGPs re-converge quickly [Filsfils07]

- IGP provides fast failure detection and control-plane sync thanks to its shared topology

- Fibbing supports fail-open and fail-close semantics
  see paper
We ran a failure recovery case study, with distributed Fibbing controller.

```prolog
(fail-close(D1));
(fail-open(D2));
```
Fibbing survives replica failures with no impact on forwarding.

( fail-close(D1) );
( fail-open(D2) );
Fibbing reacts to network failures quickly re-optimizing forwarding

( fail-close(D1) );
( fail-open(D2) );
Fibbing reacts to partitions, respecting fail-close and fail-open semantics.

( fail-close(D1) );
( fail-open(D2) );
Fibbing recovers correctly
(as soon as failures are fixed)
Fibbing shows the *benefits* of central control over distributed protocols

- Realizes SDN management model
  network-wide automated control

- Simplify controllers and improves robustness
  heavy work is still done by routers

- Works today, on existing networks
  avoids SDN deployment hurdles
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Tell me lies, tell me sweet little lies
— Fleetwood Mac

Stefano Vissicchio
stefano.vissicchio@uclouvain.be