Evaluating OSPF Convergence with ns-3 DCE

Nicolas Rybowski, Olivier Bonaventure
nicolas.rybowski@uclouvain.be

ICTEAM
UCLouvain

Workshop on ns-3 (WNS3) 2022

UCLouvain
Institute for Information
and Communication Technologies,
Electronics and Applied Mathematics

icteam

Agenda

- Background and Motivation
- BIRD Integration with DCE
- Network Model
- Micro-loops Detection Methods
- Sample Simulations
- Framework Evaluation

Agenda

- **Background and Motivation**
- BIRD Integration with DCE
- Network Model
- Micro-loops Detection Methods
- Sample Simulations
- Framework Evaluation

Classical Link-state Routing
Background

- Link-state Routing Protocols (LSR)
  1. LSR PDU (LSA/LSP) describing node's neighborhood
     - distributed by flooding
  2. Link State Database (LSDB)
  3. Shortest Path algorithm (local)

Classical Link-state Routing

Background

- Link-state Routing Protocols (LSR)
  1. LSR PDU (LSA/LSP) describing node's neighborhood
     - distributed by flooding
  2. Link State Database (LSDB)
  3. Shortest Path algorithm (local)
- Equal-Cost MultiPath (ECMP)
  - Load-balancing packets on paths with the same cost

Classical Link-state Routing

Background

- Link-state Routing Protocols (LSR)
  1. (i) LSR PDU (LSA/LSP) describing node's neighborhood
     - distributed by flooding
  2. (ii) Link State Database (LSDB)
  3. (iii) Shortest Path algorithm (local)
- Equal-Cost MultiPath (ECMP)
  - Load-balancing packets on paths with the same cost
- Bidirectional Forwarding Detection (BFD)
  - Quick link failure detection

icteam

How to measure IGP convergence duration after a failure?

Control plane is known to have slow reactions to failures

Routing Protocols Evaluation

Motivation

- Physical testbeds
  - ✓ Real world measurements
  - ✗ Timing measurement not reproducible
  - ✗ Costly for large topologies

- Physical testbeds
  - ✓ Real world measurements
  - ✗ Timing measurement not reproducible
  - ✗ Costly for large topologies
- Emulation
  - ✓ Cheap to setup on commodity hardware
  - ✗ Each node competes for resources
  - ✗ Timing measurement not reproducible

- Physical testbeds
  - ✓ Real world measurements
  - ✗ Timing measurement not reproducible
  - ✗ Costly for large topologies
- Emulation
  - ✓ Cheap to setup on commodity hardware
  - ✗ Each node competes for resources
  - ✗ Timing measurement not reproducible
- Simulation
  - ✓ Cheap to set up on commodity hardware
  - ✓ No competition for resources since no real-time
  - ✓ Reproducible timing measurement

Agenda

- Background and Motivation
- **BIRD Integration with DCE**
- Network Model
- Micro-loops Detection Methods
- Sample Simulations
- Framework Evaluation

icteam

Syscalls Interception in DCE

BIRD Integration with DCE

Native

- *ffs*
- *localtime_r*
- *longjmp*

Custom Handling in DCE

- *dce_mmap64*

☞ Support for private anonymous memory mapping

Toolchain I

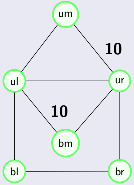
BIRD Integration with DCE

Topology Specification: Network Topology Format (NTF)

`(head, end, metric, delay)`

```
um ul 1 5
um ur 10 5
ul um 1 5
ul ur 1 5
ul bl 1 5
ul bm 10 5
bl ul 1 5
bl br 1 5
```

```
br bl 1 5
br ur 1 5
ur br 1 5
ur ul 1 5
ur um 10 5
ur bm 1 5
bm ul 10 5
bm ur 1 5
```



Toolchain I

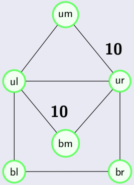
BIRD Integration with DCE

Topology Specification: Network Topology Format (NTF)

`(head, end, metric, delay)`

```
um ul 1 5
um ur 10 5
ul um 1 5
ul ur 1 5
ul bl 1 5
ul bm 10 5
bl ul 1 5
bl br 1 5
```

```
br bl 1 5
br ur 1 5
ur br 1 5
ur ul 1 5
ur um 10 5
ur bm 1 5
bm ul 10 5
bm ur 1 5
```



BIRD Module in ns-3: `dce-bird`

NTF Parser → DCE setup → Topology Generation → BIRD Configuration → ns-3 Simulation Start

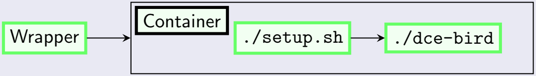
Full Toolchain

Wrapper

Toolchain II

BIRD Integration with DCE

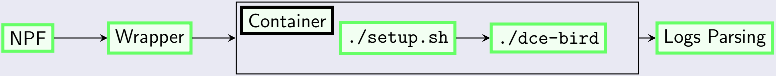
Full Toolchain



Toolchain II

BIRD Integration with DCE

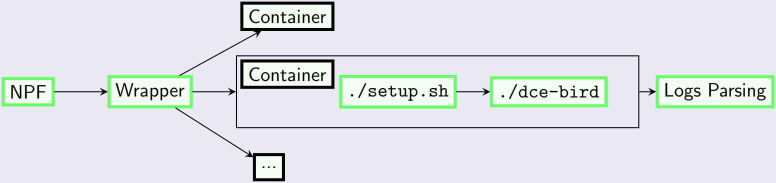
Full Toolchain



Toolchain II

BIRD Integration with DCE

Full Toolchain



☞ Workload parallelization: each container simulates a specific scenario

Agenda

- Background and Motivation
- BIRD Integration with DCE
- **Network Model**
- Micro-loops Detection Methods
- Sample Simulations
- Framework Evaluation

Convergence components

`D + O + F + SPT + FIB + DD`

D	Failure Detection
O	LSP Origination
F	LSP Flooding
SPT	SPT Computation
FIB	FIB Update
DD	Linecard Update

Convergence components

`D + O + F + SPT + FIB + DD`

D	Failure Detection
O	LSP Origination
F	LSP Flooding
SPT	SPT Computation
FIB	FIB Update
DD	Linecard Update

Internal Node's Delays Parameters

Delay source	Value
LSP processing	$[2,4]ms$
Maintenance timer	$\{10,25,50,100\}ms$
SPT computation	$[2,4]ms$
FIB prefix update	$[100, 110]\mu s/\text{prefix}$

Convergence components

D + O + F + SPT + FIB + DD

- D **Failure Detection**
- O ~~LSP Origination~~
- F **LSP Flooding**
- SPT **SPT Computation**
- FIB **FIB Update**
- DD ~~Linecard Update~~

Internal Node's Delays Parameters

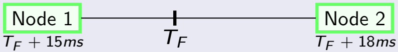
Delay source	Value
LSP processing	$[2,4]ms$
Maintenance timer	$\{10,25,50,100\}ms$
SPT computation	$[2,4]ms$
FIB prefix update	$[100, 110]\mu s/\text{prefix}$

Network Failures Model

Network Model

Single Link Failure

$D \in \{15, 18\} ms$



☞ Extended NTF: (`head`, `end`, `metric`, `delay`, T_F)

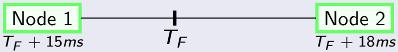
- T_F: the delay since the start of the simulation (T_0) in seconds

Network Failures Model

Network Model

Single Link Failure

$$D \in \{15, 18\}ms$$



☞ Extended NTF: `(head, end, metric, delay,` T_F`)`

- T_F: the delay since the start of the simulation (T_0) in seconds

Parallel links not supported yet

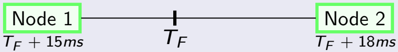
Cannot differentiate links with the same characteristics

Network Failures Model

Network Model

Single Link Failure

$$D \in \{15, 18\} ms$$



☞ Extended NTF: (`head, end, metric, delay,` T_F)

- T_F: the delay since the start of the simulation (T_0) in seconds

Parallel links not supported yet

Cannot differentiate links with the same characteristics

Node Failure

The Single Link Failure model is applied on each node's link

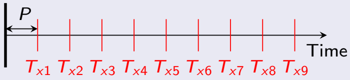
Agenda

- Background and Motivation
- BIRD Integration with DCE
- Network Model
- **Micro-loops Detection Methods**
- Sample Simulations
- Framework Evaluation

UDP Flows

Micro-loops Detection Methods

Constant bit-rate UDP flows



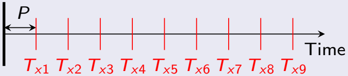
$$P = 5ms$$

- UDP payload = packet generation timestamp
- Full mesh of UDP flows
- $T_{xi} = T_{xi-1} + \text{P}$

UDP Flows

Micro-loops Detection Methods

Constant bit-rate UDP flows



$P = 5ms$

- UDP payload = packet generation timestamp
- Full mesh of UDP flows
- $T_{xi} = T_{xi-1} + \mathrm{P}$

Reordering

$\{T_{x1};\ T_{x2};\ \boldsymbol{T_{x5}};\ \boldsymbol{T_{x3}};\ \boldsymbol{T_{x4}};\ T_{x6};\ T_{x7};\ T_{x8};\ T_{x9};\ \ldots\}$

☞ Estimated loop duration: $15ms$

UDP Flows

Micro-loops Detection Methods

Constant bit-rate UDP flows

$P = 5ms$

- UDP payload = packet generation timestamp
- Full mesh of UDP flows
- $T_{xi} = T_{xi-1} + \mathrm{P}$

Reordering

$\{T_{x1};\ T_{x2};\ \boldsymbol{T_{x5}};\ \boldsymbol{T_{x3}};\ \boldsymbol{T_{x4}};\ T_{x6};\ T_{x7};\ T_{x8};\ T_{x9};\ \ldots\}$

☞ Estimated loop duration: $15ms$

Black-hole

$\{T_{x1};\ T_{x2};\ T_{x6};\ T_{x7};\ T_{x8};\ T_{x9};\ \ldots\}$

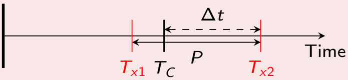
☞ Estimated loop duration: $15ms$

- No route to host
- TTL reached 0

UDP Flows Limitations I

Micro-loops Detection Methods

Timing Overestimation

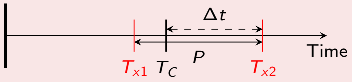


- Node converged at T_C
- T_{x1} is lost
- Next timestamp sent at T_{x2}
- ☞ Convergence overestimated by Δt

UDP Flows Limitations I

Micro-loops Detection Methods

Timing Overestimation



- Node converged at T_C
- T_{x1} is lost
- Next timestamp sent at T_{x2}
- ☞ Convergence overestimated by Δt

Solution?

Increasing the granularity (flow rate) by lowering P?

- ☞ No: highly increases simulation duration
- ☞ Trade-off: Timing accuracy vs simulation overhead

UDP Flows Limitations II

Micro-loops Detection Methods

ECMP Reordering

- IGP metrics are dimensionless
  - They may reflect the link latency
  - If not, ECMP load-balancing could provoke packet reordering
  - ☞ False positive for micro-loop detection

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

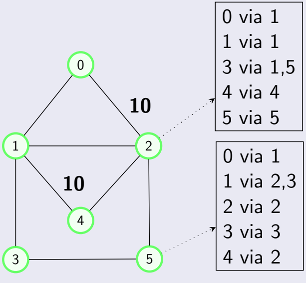
FIB Traversal

Micro-loops Detection Methods

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



T_x

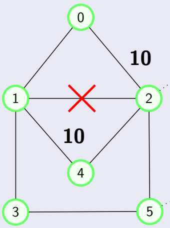
FIB Traversal

Micro-loops Detection Methods

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



T_x (node 2):

0 via 1	
1 via 1	
3 via 1,5	
4 via 4	
5 via 5	

T_{x1} (node 2):

0 via 5	
1 via 5	
3 via 1	
4 via 4	
5 via 5	

T_x (node 5):

0 via 1	
1 via 2,3	
2 via 2	
3 via 3	
4 via 2	

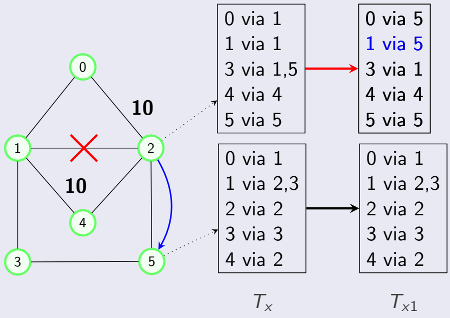
T_{x1} (node 5):

0 via 1	
1 via 2,3	
2 via 2	
3 via 3	
4 via 2	

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



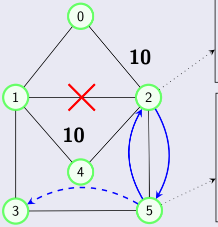
FIB Traversal

Micro-loops Detection Methods

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



0 via 1	0 via 5
1 via 1	1 via 5
3 via 1,5	3 via 1
4 via 4	4 via 4
5 via 5	5 via 5

0 via 1	0 via 1
1 via 2,3	1 via 2,3
2 via 2	2 via 2
3 via 3	3 via 3
4 via 2	4 via 2
T_x	T_{x1}

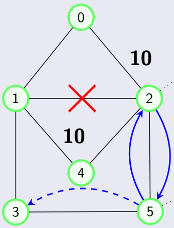
FIB Traversal

Micro-loops Detection Methods

FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



0 via 1	0 via 5
1 via 1	1 via 5
3 via 1,5	3 via 1
4 via 4	4 via 4
5 via 5	5 via 5

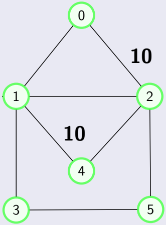
0 via 1	0 via 1
1 via 2,3	1 via 2,3
2 via 2	2 via 2
3 via 3	3 via 3
4 via 2	4 via 2

T_x T_{x1}

Black-hole

0 via 0
2 via 2
3 via 3
4 via 2
5 via 2,3

T_x



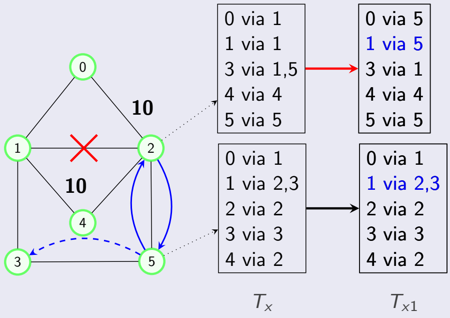
FIB Traversal

Micro-loops Detection Methods

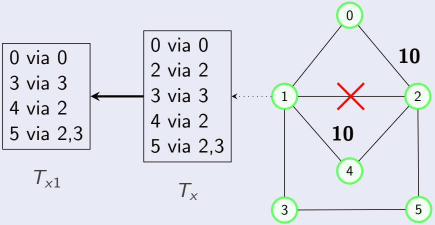
FIB Snapshots

- Capture FIB of each node upon FIB update of a single node
- For each snapshot, rebuild routes for each (*source, destination*)

Micro-loop



Black-hole



Agenda

- Background and Motivation
- BIRD Integration with DCE
- Network Model
- Micro-loops Detection Methods
- **Sample Simulations**
- Framework Evaluation

House Topology: Toy Example I

Sample Simulations

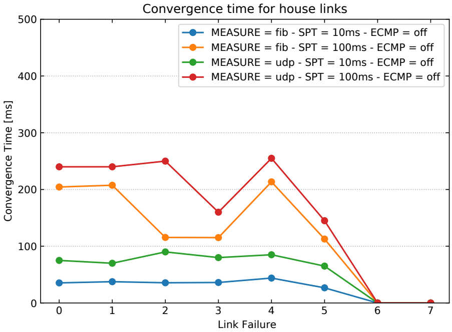


Figure: Link failures - ECMP off

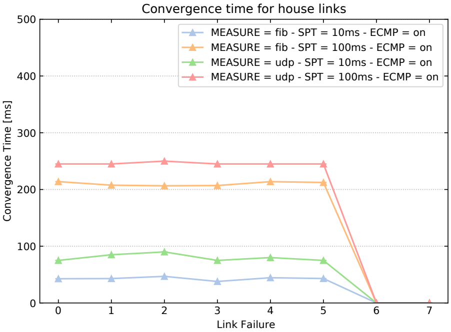


Figure: Link failures - ECMP on

House Topology: Toy Example II

Sample Simulations

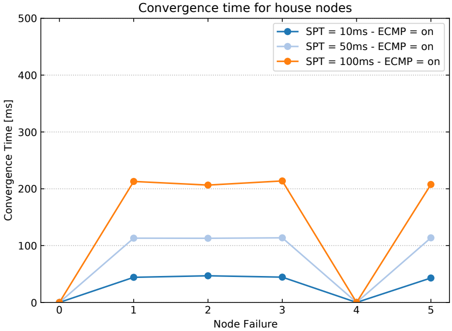


Figure: Node failures - ECMP on

GEANT Topology: Real World Network

Sample Simulations

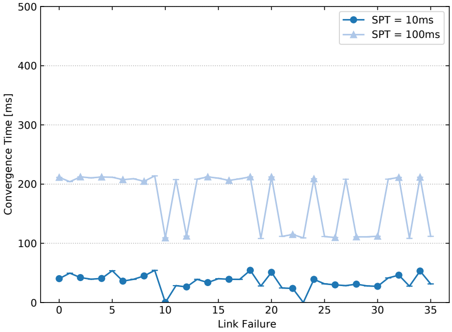


Figure: Link failures - ECMP on

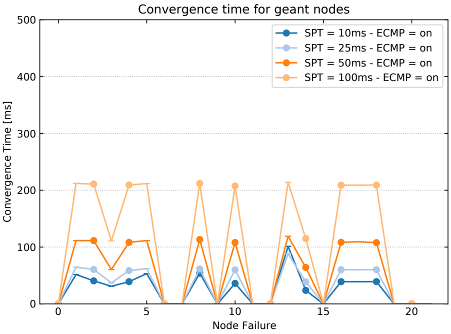


Figure: Node failures - ECMP on

Agenda

- Background and Motivation
- BIRD Integration with DCE
- Network Model
- Micro-loops Detection Methods
- Sample Simulations
- **Framework Evaluation**

Scalability I

Framework Evaluation

Does BIRD over DCE scale?

- Tested on small topologies
- Search lower and upper bounds for
  - Memory consumption
  - CPU time consumption

Scalability I

Framework Evaluation

Does BIRD over DCE scale?

- Tested on small topologies
- Search lower and upper bounds for
  - Memory consumption
  - CPU time consumption

How?

- What?
  - Initial convergence (5 simulated minutes)
- Which topology?
  - Simplest topology for LSR: Ring
  - Worst topology for LSR: Full Mesh
- Which size?
  - Number of nodes (n) linearly increased by 10 up to 100

Scalability II

Framework Evaluation

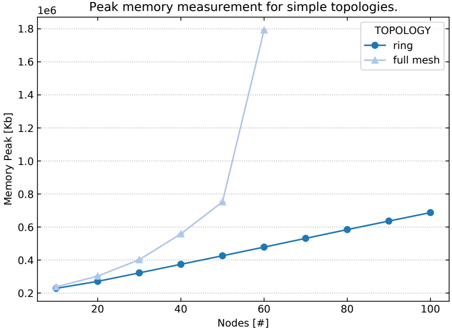


Figure: Peak memory usage

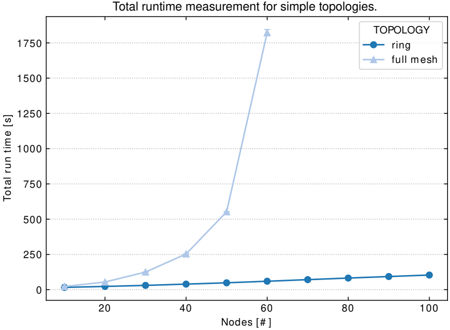


Figure: Total runtime

Code is available

`https://github.com/nrybowski/ns3-sim/tree/wns3-22`

- `C++` ns-3 modules
  - NTF Toplogy generator
  - BIRD daemon configurator
- Dockerfiles with patched ns-3
- RUST wrapper to launch the simulations
- NPF scripts to reproduce the figures

Questions?

- Background and Motivation
- BIRD Integration with DCE
- Network Model
- Micro-loops Detection Methods
- Sample Simulations
- Framework Evaluation

Why BIRD?

Backup Slide

Requirements

- Implement ISIS and/or OSPF
- Open-Source
  - Must recompile with DCE flags
  - Must be able to modify the code
    - Internal delays model
    - Implement new LSR extensions (Future Work)
- C/C++ code to run in DCE
- Actively maintained
  - Implement recent extensions
  - Community Support
  - Used in real-world deployments

Why BIRD?

Backup Slide

Why BIRD?

Backup Slide

FRRouting

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ C code
- ✓ Actively maintained: last update from June 2022
- ✗ Many DCE modifications

Why BIRD?

Backup Slide

FRRouting

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ `C` code
- ✓ Actively maintained: last update from June 2022
- ✗ Many DCE modifications

Quagga

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ `C` code
- ✗ Actively maintained: last update from 2018

Why BIRD?

Backup Slide

FRRouting

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ C code
- ✓ Actively maintained: last update from June 2022
- ✗ Many DCE modifications

XORP

- ✓ Implement ~~ISIS~~ or OSPF
- ✓ Open-Source
- ✓ C++ code
- ✗ Actively maintained: last update from 2012

Quagga

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ C code
- ✗ Actively maintained: last update from 2018

icteam

Why BIRD?

Backup Slide

FRRouting

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ `C` code
- ✓ Actively maintained: last update from June 2022
- ✗ Many DCE modifications

XORP

- ✓ Implement ~~ISIS~~ or OSPF
- ✓ Open-Source
- ✓ `C++` code
- ✗ Actively maintained: last update from 2012

Quagga

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✓ `C` code
- ✗ Actively maintained: last update from 2018

FreeRtr

- ✓ Implement ISIS **and** OSPF
- ✓ Open-Source
- ✗ `Java` code
- ✓ Actively maintained: last update from June 2022