Modeling a Million-Node Slim Fly Network Using Parallel Discrete-Event Simulation

Noah Wolfe, Christopher Carothers
Rensselaer Polytechnic Institute

Misbah Mubarak, Robert Ross, Philip Carns
Argonne National Laboratory

July 12, 2016
Outline

▪ Background/Motivation
▪ Slim Fly Network Topology Model
▪ Discrete-Event Model Implementation
▪ Model Verification
▪ Large-Scale Network Performance
▪ Simulation Performance
▪ Conclusion and Future Work
### Supercomputing Systems

<table>
<thead>
<tr>
<th></th>
<th>Current System</th>
<th>Future System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANL</strong></td>
<td>Mira: 49,152 nodes 5D Torus</td>
<td>Aurora: &gt;50,000 nodes Dragonfly?</td>
</tr>
<tr>
<td><strong>ORNL</strong></td>
<td>Titan: 18,688 nodes 3D Torus</td>
<td>Summit: &gt;3,400 nodes Fat Tree</td>
</tr>
<tr>
<td><strong>LLNL</strong></td>
<td>Sequoia: 98,304 nodes 5D Torus</td>
<td>Sierra: &gt;3,400 nodes Fat Tree</td>
</tr>
</tbody>
</table>
The Dragonfly Network Topology

- A two level directly connected topology
- Uses high-radix routers
  - Large number of ports per router
  - Each port has moderate bandwidth

\[ k = a + p + h - 1 \]

\[ a = 2p = 2h \] (Recommended configuration)
Slim Fly Network Topology

- Built on MMS graphs
- Uses high-radix routers
- Max network diameter of 2
- Complex layout and connectivity

Network Parameters:
- $q$: number of routers per group and number of global connections per router
- $p$: number of terminal connections per router, $p = \text{floor}(k'/2)$
- $k$: router radix
- $k'$: router network radix
router(0, x, y) is connected to (0, x, y') iff \( y - y' \in X \); (1)

router(1, m, c) is connected to (1, m, c') iff \( c - c' \in X^k \); (2)

router(0, x, y) is connected to (1, m, c) iff \( y = mx + c \); (3)
Layout Visualization
Model Configuration

- **Minimal Routing**
  - Messages take path of maximum 2 hops

- **Non-minimal routing**
  - Messages are routed minimally to a random intermediate router and then minimally to the destination

- **Adaptive routing**
  - Chooses between minimal and non-minimal by sensing the traffic conditions on the message’s source router

- **Virtual channels**
  - To avoid deadlocks

- **Credit based flow control**
  - Upstream nodes/routers keep track of buffer slots
Synthetic Application Workloads

- **Uniform Random (UR)**
  - Terminals send to random destination terminal

- **Worst-Case (WC)**
  - Simulates an application that is communicating in a manner that fully saturates links in the network creating a bottleneck for minimal routing

![Diagram](image-url)
PDES Implementation

Co-Design of Exascale Storage (CODES)
- Storage systems
- HPC network systems

Rensselaer Optimistic Simulation System (ROSS)
- Event Scheduling
  - Conservative
  - Optimistic
- Logical Processes (LPs)
  - MPI processes
  - Terminals/compute nodes
  - Routers/switches
PDES Implementation
Slim Fly Verification

- Comparison with published Slim Fly network results by Kathareios et al. [1]
- Slim Fly Configuration:
  - 3,042 nodes
  - 338 routers
  - $q=13$
  - $k=28$
- Simulation Configuration
  - link bandwidth: 100Gbps
  - link latency: 50ns
  - buffer space: 100KB
  - router delay: 100ns
  - Simulated time: 200us

Minimal/Non-minimal Routing

**Minimal Routing**

- **Observed (UR)**
- **IBM Paper (UR)**
- **Observed (WC)**
- **IBM Paper (WC)**

**Non-minimal Routing**

- **Observed (UR)**
- **IBM Paper (UR)**
- **Observed (WC)**
- **IBM Paper (WC)**
Adaptive Routing

Adaptive Routing

Throughput (%)

Load

- Observed (UR)
- IBM Paper (UR)
- Observed (WC)
- IBM Paper (WC)
Slim Fly Network Model Results
4. LARGE-SCALE PERFORMANCE

To show the full capabilities of the ROSS discrete event Slim Fly model simulator, we constructed and analyzed large-scale Slim Fly model configurations. The analysis includes discrete-event compute statistics and strong scaling on the Intel cluster at the Center for Computational Innovations at RPI to emphasize the efficiency of the new Slim Fly simulator. Following the same simulation parameters as in Section 3, we use 100 Gbps link bandwidth with a latency of 50 ns. Routers utilize virtual channels, a buffer space of 100 KB per port, and a 100 ns traversal delay. Each message consists of 256-byte packets. In all the adaptive routing cases, we set the number of indirect routes, $n_i = 3$, and $c = 1 \mu s$.$^\dagger$

The increased model sizes result in much larger end-to-end runtimes (the time including the initial configuration of LPs in addition to the simulation processing time). However, we still maintain the simulated time of 220 $\mu s$, as in section 3.

4.1 74K-Node Slim Fly Model

In this section, we simulate the Slim Fly model at the scale of Aurora, the future supercomputer to be deployed at Argonne National Laboratory. Aurora is stated to have more than 50,000 nodes, which is significantly larger than Summit [13]. Assuming that the Knights Hill version of the Intel Xeon Phi, which will be the compute architecture for the system, is released with 3 TFLOPs, the future Aurora supercomputer will need to have 60,000 nodes in order to reach the quoted 180 PFLOPS of system performance. A network the size of the future Aurora supercomputing system results in a Slim Fly topology with the following configuration:

- $q = 3$, $p = 2^7$, $N_n = 73, 926$, $N_r = 2^{23} 8$, $k = 82$.
Virtual Channel Occupancy

Figure 8: Router occupancy comparison for simulations using UR traffic and minimal routing with increasing injection load. Figures are best viewed in color.

(a) VC0 50% Load  
(b) VC0 90% Load  
(c) VC0 95% Load  
(d) VC0 100% Load  
(e) VC1 50% Load  
(f) VC1 90% Load  
(g) VC1 95% Load  
(h) VC1 100% Load

Figure 9: Messages sent and received over time for the simulation using UR traffic and minimal routing using 100% load. Figures 9a and 9b show the number of sends and receives sampled over the simulation run time for all the compute nodes. Figures 9c and 9d show the same for all routers in the simulation.

4. LARGE-SCALE PERFORMANCE

To show the full capabilities of the ROSS discrete event Slim Fly model simulator, we constructed and analyzed large-scale Slim Fly model configurations. The analysis includes discrete-event compute statistics and strong scaling on the Intel cluster at the Center for Computational Innovations at RPI to emphasize the efficiency of the new Slim Fly simulator. Following the same simulation parameters as in Section 3, we use 100 Gbps link bandwidth with a latency of 50 ns. Routers utilize virtual channels, a buffer space of 100 KB per port, and a 100 ns traversal delay. Each message consists of 256-byte packets. In all the adaptive routing cases, we set the number of indirect routes, \( n_i = 3 \), and \( \text{SF} \) = 1 µs.

The increased model sizes result in much larger end-to-end runtimes (the time including the initial configuration of LPs in addition to the simulation processing time). However, we still maintain the simulated time of 220 µs, as in section 3.

4.1 74K-Node Slim Fly Model

In this section, we simulate the Slim Fly model at the scale of Aurora, the future supercomputer to be deployed at Argonne National Laboratory. Aurora is stated to have more than 50,000 nodes, which is significantly larger than Summit [13]. Assuming that the Knights Hill version of the Intel Xeon Phi, which will be the compute architecture for the system, is released with 3 TFLOPs, the future Aurora supercomputer will need to have 60,000 nodes in order to reach the quoted 180 PFlOPS of system performance. A network the size of the future Aurora supercomputing system results in a Slim Fly topology with the following configuration:

- \( q = 3 \), \( p = 2 \), \( N_n = 73926 \), \( N_r = 2738 \), \( k = 82 \).
Large-Scale Performance

- 74K node (Aurora) system
  - 2,738 routers
  - q=37, k=82

- 1M node system
  - 53,178 routers
  - q=163, k=255
ROSS PDES Results
Performance Parameters

▪ Evaluation System
  ▪ Center for Computational Innovations (CCI) RSA Intel cluster
  ▪ 34 nodes, 2x 4-core Intel Xeon E5-2643 3.3 GHz processors

▪ Execution Parameters
  ▪ 1M-node model: 4 MPI tasks per node
  ▪ 74K-node model: 8 MPI tasks per node

▪ Performance metrics
  ▪ Committed event rate
  ▪ Total events
  ▪ ROSS event efficiency
  ▪ Simulation run time

▪ Event Schedulers
  ▪ Optimisitic
  ▪ Conservative
Scaling Analysis

- **74K Node Model:**
  - 43 million events per second
  - 543 million events processed

- **1M Node Model:**
  - 36 million events per second
  - 7 billion events processed
PDES Analysis

- Distribution of simulation time scales linearly in Optimistic event scheduling indicating a uniform distribution of work among all processing elements (MPI ranks).
Future Work

- Future work
  - Compare the slim fly network model with other candidate topology models for exascale computing
  - Integrate slim fly simulator with NeMo simulator to investigate the possibility of a hybrid supercomputing system incorporating neuromorphic hardware such as IBM’s TrueNorth processor
Questions?