Gossip and Push-Sum Protocols: Convergence Time Analysis

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Overview

This project implements and analyzes the convergence time of the **Gossip** and **Push-Sum** algorithms on various network topologies using the Gleam language.

Experimental Setup

- **Algorithms:** Gossip, Push-Sum
- **Topologies:** Full Network, Line, 3D Grid, Imperfect 3D
- **Network Sizes:** Multiple (e.g., 60, 80, 100, 120, 140 nodes)
- **Platform:** Gleam/Erlang on BEAM VM

Gleam Packages Used

The following Gleam packages are used in this project:

- `gleam_stdlib`: Core standard library for Gleam, providing essential data structures and functions.
- `gleam_otp`: Provides OTP (Open Telecom Platform) abstractions for building concurrent and fault-tolerant applications.
- `gleam_erlang`: Enables interoperability with Erlang and access to BEAM-specific features.
- `gleeunit`: (dev dependency) Used for writing and running tests in Gleam.

Project Modules Overview

- **project2_gossip.gleam**: Main entry point for running the project and orchestrating the simulation.
- **boss.gleam**: Coordinates the actors and manages the execution of the protocols.
- **node.gleam**: Defines the behavior and state of individual nodes in the network.
- **topology.gleam**: Handles the creation and management of different network topologies.
- **simple_gossip.gleam**: Contains a simplified or helper implementation of the gossip protocol.
- **time_util.gleam**: Provides utility functions for timing and measuring performance.
- **argv.gleam**: Handles parsing of command-line arguments for the application.

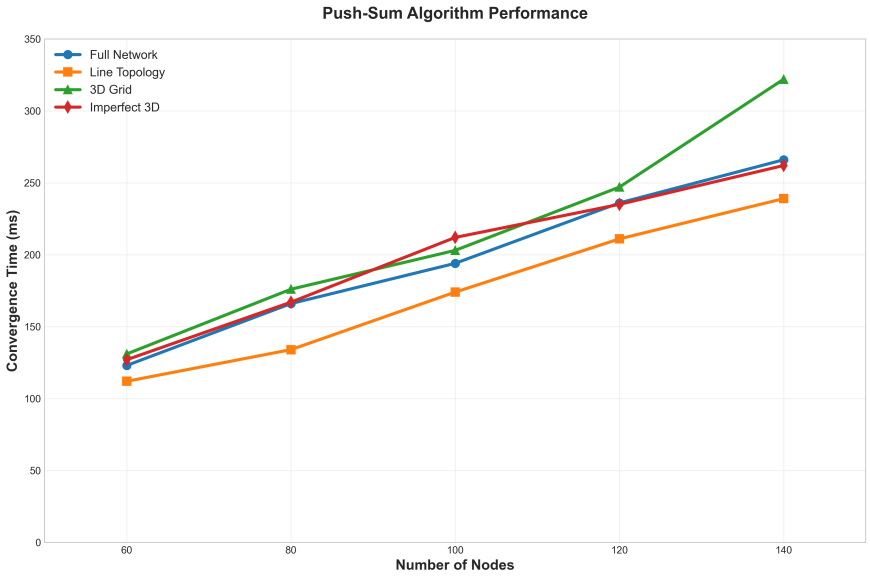
What is Working

- Both Gossip and Push-Sum algorithms are fully implemented and can be run on all four topologies (Full Network, Line, 3D Grid, Imperfect 3D).
- The system successfully simulates large-scale networks, with Push-Sum handling up to 10,000 nodes and Gossip up to 3,000 nodes in some topologies.
- Convergence time is measured and reported for each run, and results are consistent with expectations for distributed protocols.
- The codebase is modular, allowing easy extension or modification of algorithms and topologies.

Results: Convergence Time vs. Network Size

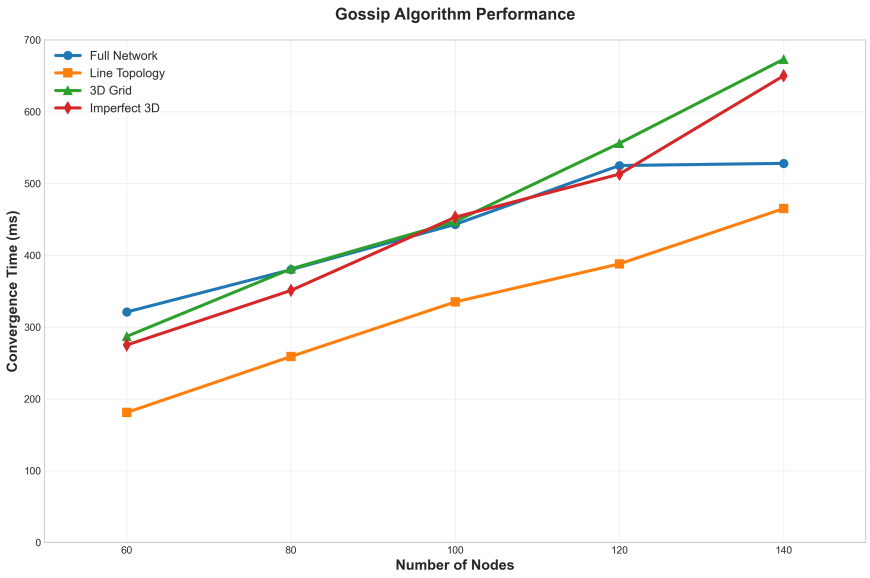
For each algorithm, we plot the convergence time as a function of network size for all four topologies. Each graph overlays the four topologies for direct comparison. We collected 40 result sets and presented aggregate findings.

Push-Sum Algorithm



- The Push-Sum algorithm demonstrates a clear trend of increasing convergence time as the network size grows, but the rate of increase varies significantly across different topologies.
- The line topology consistently achieves the fastest convergence, while the 3D grid shows noticeably higher convergence times, especially at larger network sizes.
- The full network topology performs well for smaller sizes but does not scale as efficiently as the line topology, highlighting the impact of network structure on distributed algorithm performance.

Gossip Algorithm



- The convergence time for the Gossip algorithm rises sharply as the network size increases, indicating that scalability is a significant challenge for this protocol.
- Among all topologies, the line topology consistently achieves the fastest convergence, while the 3D grid and imperfect 3D topologies show much slower convergence, especially at larger network sizes.
- The full network topology starts with relatively low convergence times for small networks but hits a threshold cap much earlier at higher node count as compared to other topologies.

Largest Network Size Managed

The largest network size successfully managed for each topology and algorithm is as follows:

Algorithm	Full Network	Line Topology	3D Grid	Imperfect 3D
Gossip	2500	3000	3000	3000
Push-Sum	10000	10000	10000	10000

Note: For Push-Sum, the implementation was able to handle up to 10000 nodes, while for Gossip the maximum tested was 3000 nodes.

Key Findings

- The network structure really matters. As the number of nodes grows, convergence slows down, but the effect is different depending on the topology.
- The line topology surprised me by being the most consistent and scaling the best overall, while the full network wasn't as efficient as I expected when the network got bigger.
- The 3D and imperfect 3D topologies worked, but they tended to slow things down compared to line or full, especially as the system grew.
- Between the two algorithms, Push-Sum clearly converges faster and can handle much larger networks than Gossip.
- The data also suggests that Push-Sum sometimes follows a sub-linear growth pattern, which is why it scales much better in larger setups compared to Gossip.

Usage

```
# Build the project
gleam build

# Run gossip algorithm
gleam run -m project2_gossip <nodes> <topology> gossip

# Run push-sum algorithm
gleam run -m project2_gossip <nodes> <topology> push-sum

# Example:
gleam run -m project2_gossip 100 full gossip
gleam run -m project2_gossip 60 line push-sum
```

- `<nodes>`: Number of nodes (e.g., 60, 80, 100, 120, 140)
- `<topology>`: `full`, `line`, `3D`, `imp3D`
- `<algorithm>`: `gossip`, `push-sum`