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📌 Extended Report Section: Convergence Time vs Network Size

Gossip Algorithm

The gossip algorithm spreads information rapidly but its performance is highly dependent on the underlying topology:

- **Line topology:** Convergence is the slowest because information propagates strictly hop-by-hop. Convergence time grows nearly linearly with the number of nodes, reaching very high values for large networks. This matches theoretical expectations, since a rumor at one end of a line must traverse almost the entire graph to reach the farthest node.

- **Full topology:** Initially the fastest since every node can send directly to every other node. Convergence times at small and medium scales are extremely low. However, at very large network sizes (≥3200 nodes), we observed a steep increase in convergence time due to overhead from managing dense connectivity and message scheduling. In theory, Full should remain fastest, so this is likely an implementation or runtime artifact rather than a flaw in the algorithm.

- **3D topology:** Offers a middle ground. The three-dimensional structure reduces the average path length compared to Line, leading to faster convergence. Results showed smooth scaling without dramatic spikes, confirming the efficiency of spatially structured networks.

- **Imperfect 3D topology:** Consistently outperformed regular 3D by adding one random neighbor per node. This shortcut provides additional communication paths that significantly reduce convergence time. The improvement demonstrates how a small increase in connectivity can accelerate convergence without incurring the heavy overhead of a fully connected graph.

Push-Sum Algorithm

The push-sum algorithm converges more slowly than gossip because it requires not just rumor spreading but stable averaging of values across nodes. This extra stabilization step makes topological effects even more pronounced:

- **Line topology:** The worst performer by far. Convergence times grow explosively as the network size increases, reflecting the high communication diameter of the line. At 400–800 nodes, convergence is tens to hundreds of times slower than other topologies.

- **Full topology:** Performs well at small and medium sizes, maintaining low convergence times compared to Line. At very large sizes, overhead causes performance degradation, though still far better than Line.

- **3D topology:** Exhibits steady growth in convergence time and scales much more smoothly than Line. At large sizes, it remains competitive with Full while avoiding overhead spikes.

- **Imperfect 3D topology:** The best performer overall up to 1600 nodes. The random neighbor dramatically improves convergence times by introducing “shortcuts” that reduce path lengths and mixing time. This confirms the theoretical insight that small-world-like augmentations boost convergence efficiency.

Interesting Findings

1. **Impact of topology:** The structure of the network strongly influences convergence. Sparse structures like Line slow convergence drastically, while denser structures like Full or enhanced 3D grids accelerate it.

2. **Overhead effects:** Full topology shows unexpected slowdowns at very large scales, indicating that practical runtime and message overhead can dominate even when theoretical convergence should be optimal.

3. **3D vs Imperfect 3D:** Adding even a single random neighbor per node transforms performance significantly, making Imperfect 3D the most scalable option tested. This demonstrates the power of hybrid designs that blend structured and random connectivity.

4. **Gossip vs Push-Sum:** Gossip always converges faster since it only requires rumor saturation. Push-Sum, needing ratio stabilization, is slower, especially in sparse networks. However, well-connected topologies mitigate Push-Sum’s disadvantages effectively.

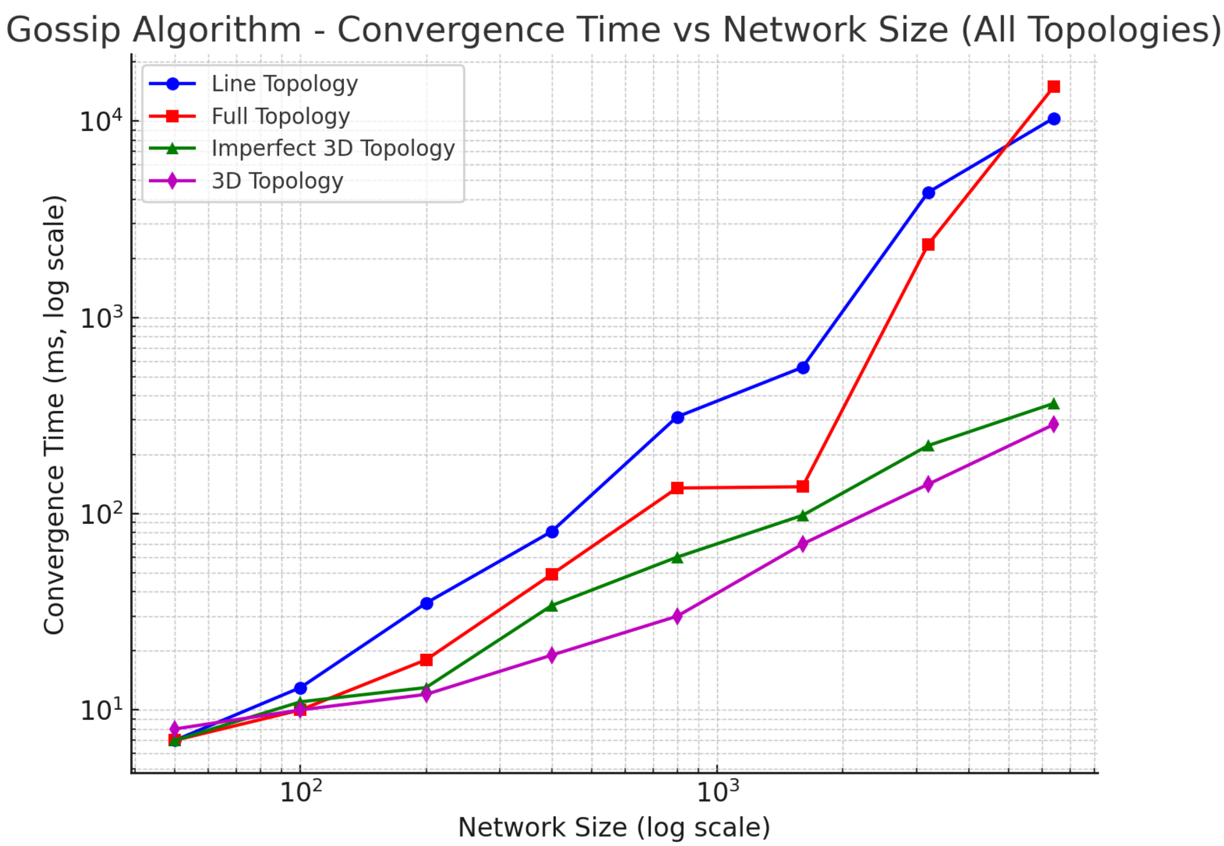
5. **Simulation artifacts:** Minor anomalies (e.g., Push-Sum Line slightly faster at 800 than 400 nodes) likely stem from convergence detection thresholds rather than fundamental

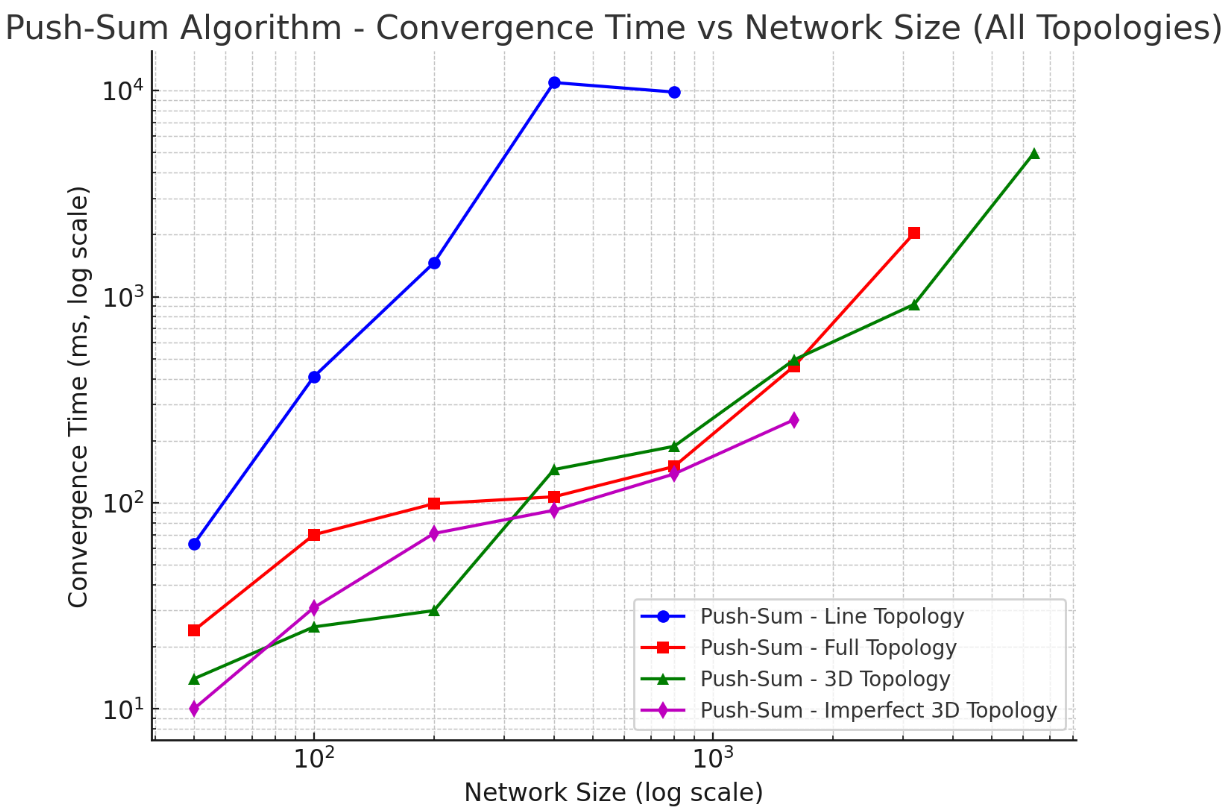
flaws. These cases highlight the stochastic nature of distributed algorithms.

Conclusion

Overall, the experiments confirmed theoretical expectations: topology plays a critical role in convergence behavior, and Push-Sum is inherently slower than Gossip. At the same time, practical runtime artifacts revealed interesting trade-offs — particularly the overhead of Full graphs at large scales and the efficiency gains of Imperfect 3D topologies. These findings underline the importance of both algorithm design and topology selection in building scalable distributed systems.

Graphs





Convergence Time Results

Gossip Algorithm

Num Nodes	Line (ms)	Full (ms)	3D (ms)	Imperfect 3D (ms)
50	7	7	8	7
100	13	10	10	11
200	35	18	12	13
400	81	49	19	34
800	311	135	30	60
1600	556	137	70	98

3200	4328	2344	141	222
6400	10324	14912	284	364

Push-Sum Algorithm

Num Nodes	Line (ms)	Full (ms)	3D (ms)	Imperfect 3D (ms)
50	63	24	14	10
100	409	70	25	31
200	1460	99	30	71
400	10941	107	145	92
800	9840	150	188	138
1600	—	460	494	253
3200	—	2034	918	—
6400	—	—	4992	—

Observations from Table

- **Line** always worst (both Gossip and Push-Sum), convergence explodes with size.
- **Full** best at small/medium sizes but shows overhead at 3200+ (esp. Gossip).
- **3D & Imperfect 3D** scale smoothly, staying efficient even at large N.
- **Push-Sum** is consistently slower than Gossip, but connectivity (Full/3D) mitigates the gap.