A Stable Broadcast Algorithm

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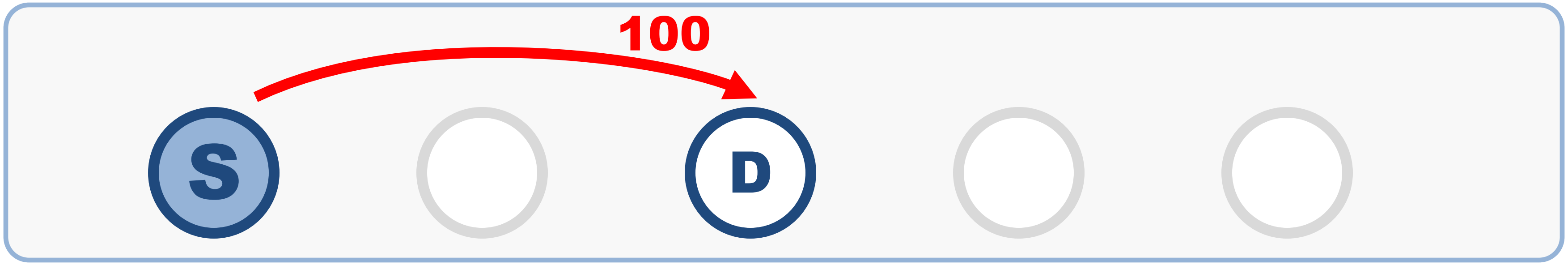
Broadcasting Large Messages

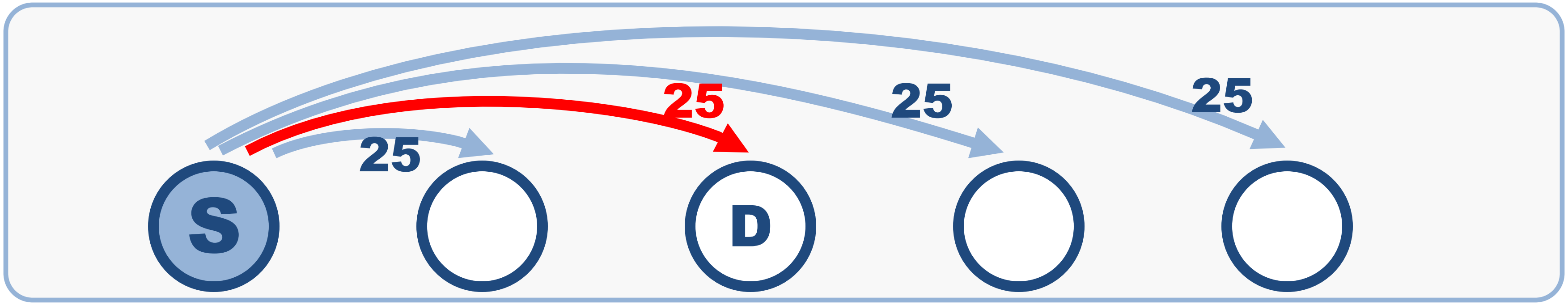
- To distribute the same, but large data to many nodes
  - Ex: content delivery

- Widely used in parallel processing

Problem of Broadcast

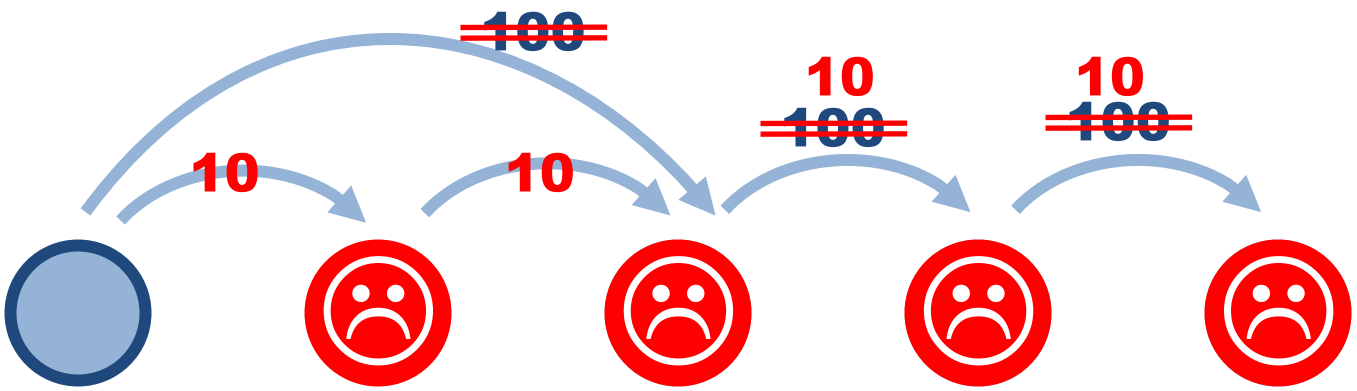
- Usually, in a broadcast transfer, the source can deliver **much less** data than a single transfer from the source





Problem of Slow Nodes

- Pipeline-manner transfers improve the performance
- Even in a pipeline transfer, nodes with small bandwidth (**slow nodes**) may degrade receiving bandwidth of all other nodes



Contributions

1. Propose an idea of **Stable Broadcast**

   In a stable broadcast:

   - Slow nodes **never** degrade receiving bandwidth to other nodes

   - **All nodes** receive the **maximum** possible amount of data

Contributions (cont.)

2. Propose a **stable** broadcast algorithm for tree topologies
   - **Proved** to be stable in a theoretical model
   - Improve performances in general graph networks
3. In a real-machine experiment, our algorithm achieved **2.5 times** the aggregate bandwidth than the previous algorithm (FPFR)

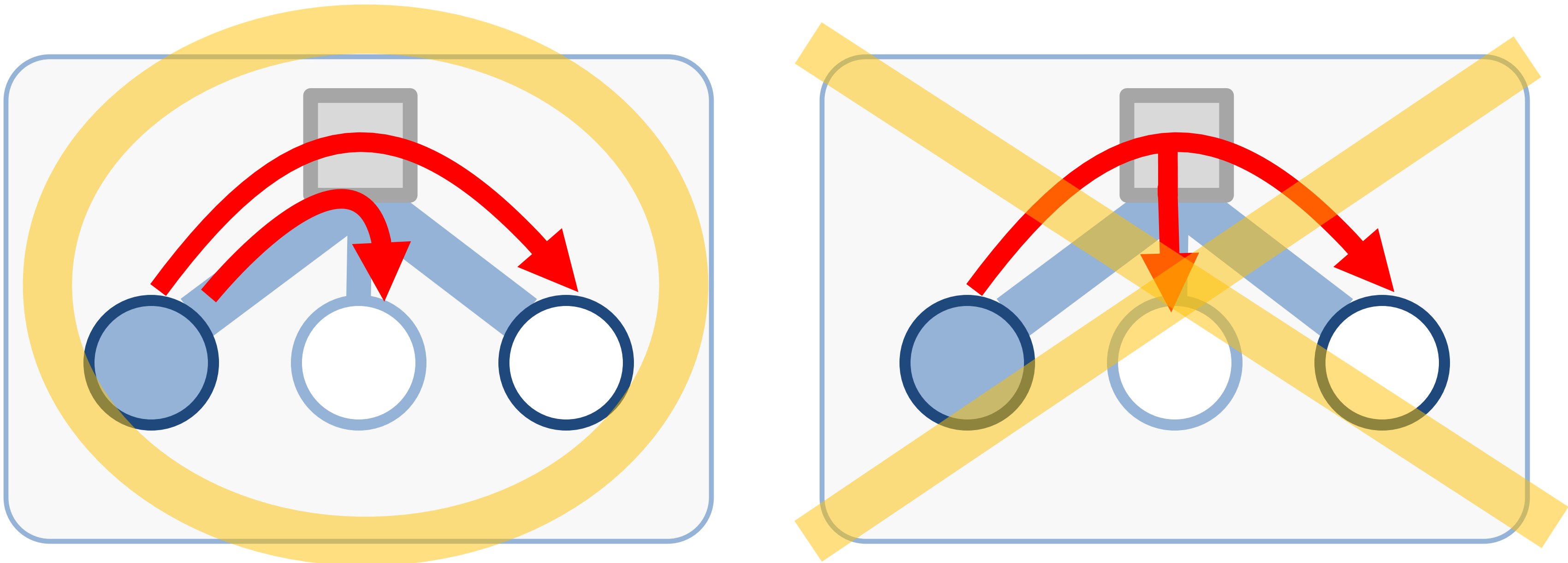
Agenda

- Introduction
- **Problem Settings**
- Related Work
- Proposed Algorithm
- Evaluation
- Conclusion

Problem Settings

1. Target: large message broadcast

2. Only computational nodes handle messages



Problem Settings (cont.)

3. Only bandwidth matters for large messages
   - $$(\text{Transfer time}) = (\text{Latency}) + \frac{(\text{Message Size})}{(\text{Bandwidth})}$$

     50msec

     1GB

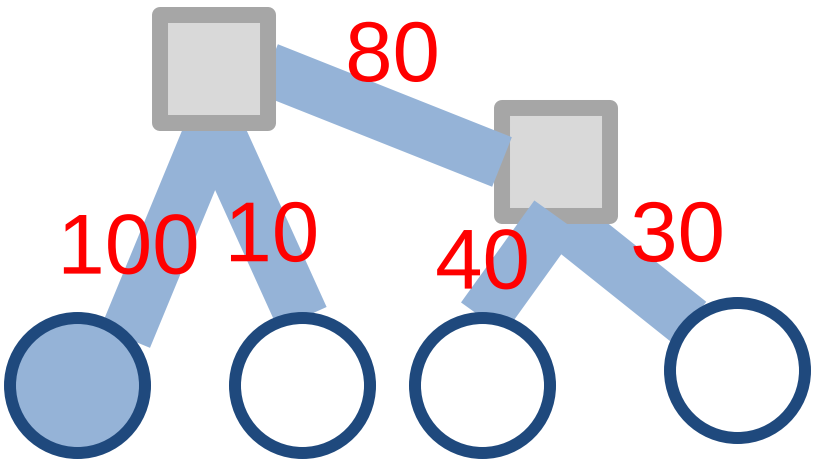
     1Gbps

     99%

4. Bandwidth is only limited by link capacities
   - Assume that nodes and switches have enough processing throughput

Problem Settings (cont.)

5. Bandwidth-annotated topologies are given in advance
   - Bandwidth and topologies can be rapidly inferred
     - Shirai et al. A Fast Topology Inference - A building block for network-aware parallel computing. (HPDC 2007)
     - Naganuma et al. Improving Efficiency of Network Bandwidth Estimation Using Topology Information (SACSIS 2008, Tsukuba, Japan)

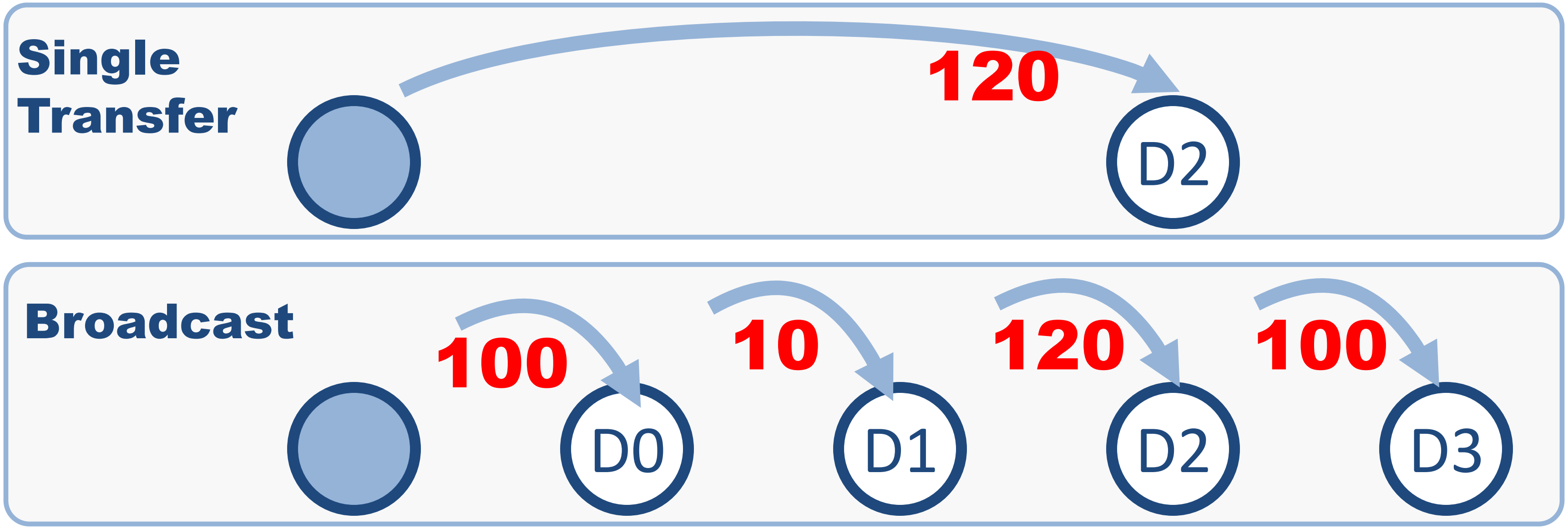


Evaluation of Broadcast

- Previous algorithms evaluated broadcast by completion time
- However, it cannot evaluate the effect of slowly receiving nodes
  - It is desirable that each node receives as much data as possible
- **Aggregate Bandwidth** is a more reasonable evaluation criterion in many cases

Definition of **Stable Broadcast**

- **All nodes** receive **maximum** possible bandwidth
  - Receiving bandwidth for each node does not lessen by adding other nodes to the broadcast



Properties of **Stable broadcast**

- **Maximize** aggregate bandwidth
- **Minimize** completion time

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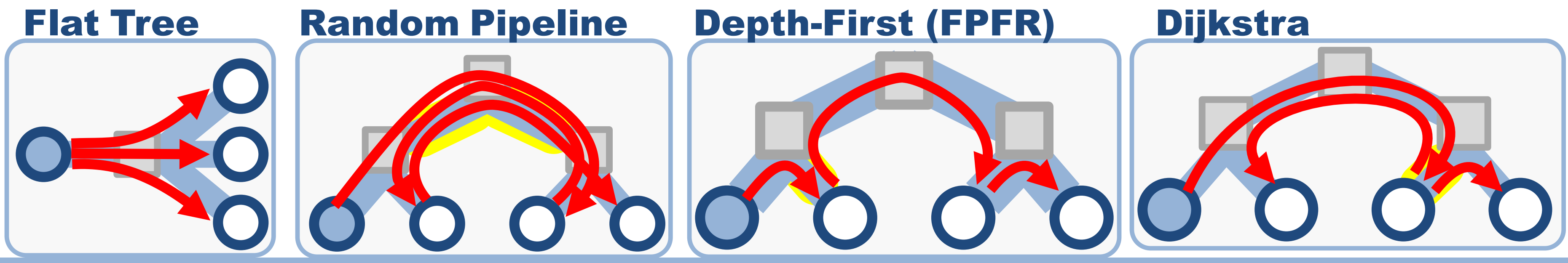
Single-Tree Algorithms

- Flat tree:
  - The outgoing link from the source becomes a bottleneck
- Random Pipeline:
  - Some links used many times become bottlenecks
- Depth-first Pipeline:
  - Each link is only used once, but fast nodes suffer from slow nodes
- Dijkstra:
  - Fast nodes do not suffer from slow nodes, but some link are used many times



FPFR Algorithm [†]

- *FPFR* (Fast Parallel File Replication) has improved the aggregate bandwidth from algorithms that use only one tree

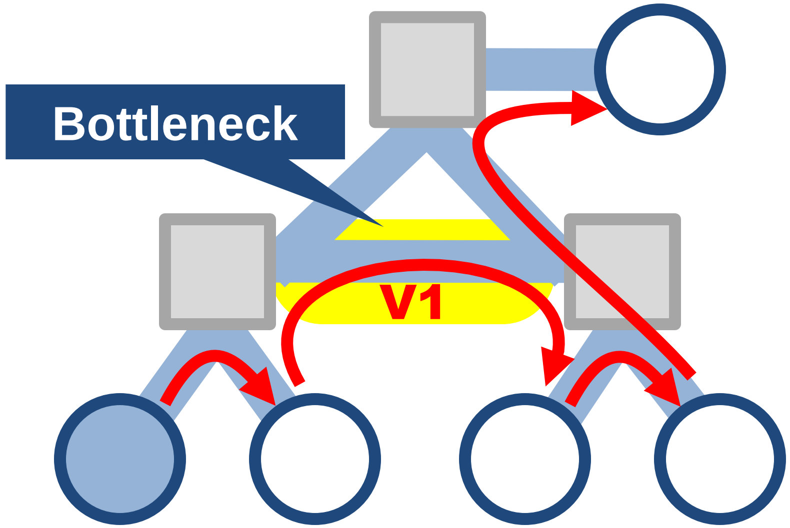
- Idea:
  (1) Construct **multiple** spanning trees
  (2) Use these trees **in parallel**

[†] Izmailov et al. Fast Parallel File Replication in Data Grid. (GGF-10, March 2004.)

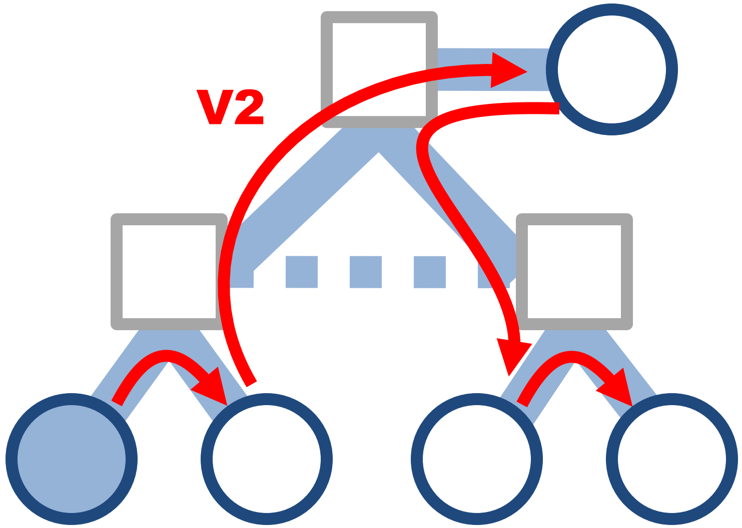
Tree constructions in FPFR

- Iteratively construct spanning trees
  - Create a spanning tree (**Tn**) by tracing every destination
  - Set the throughput (**Vn**) to the bottleneck bandwidth in **Tn**
  - Subtract **Vn** from the remaining bandwidth of each link

First Tree (T1)



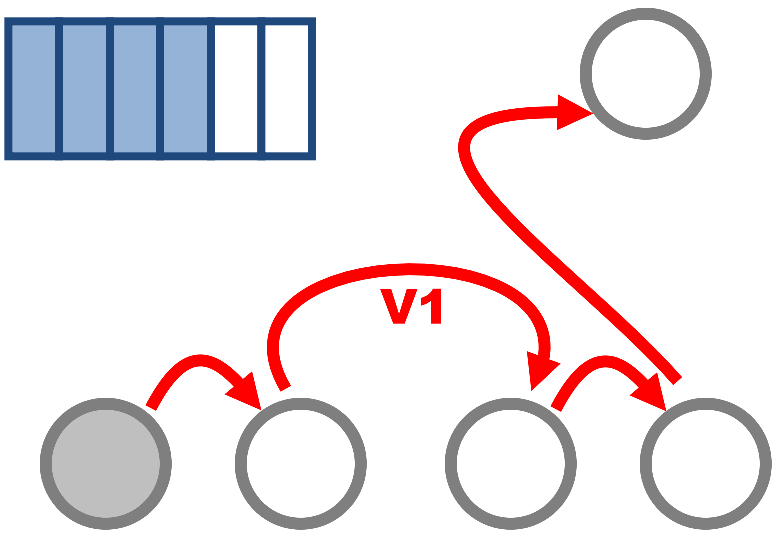
Second Tree (T2)



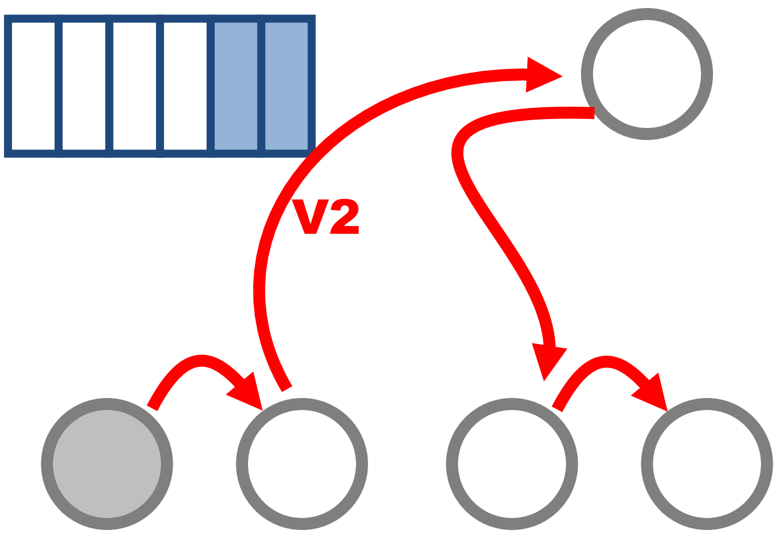
Data transfer with FPFR

- Each tree sends different fractions of data in parallel
  - The proportion of data sent through each tree may be optimized by linear programming (*Balanced Multicasting*[†])

T1: Sends the former part

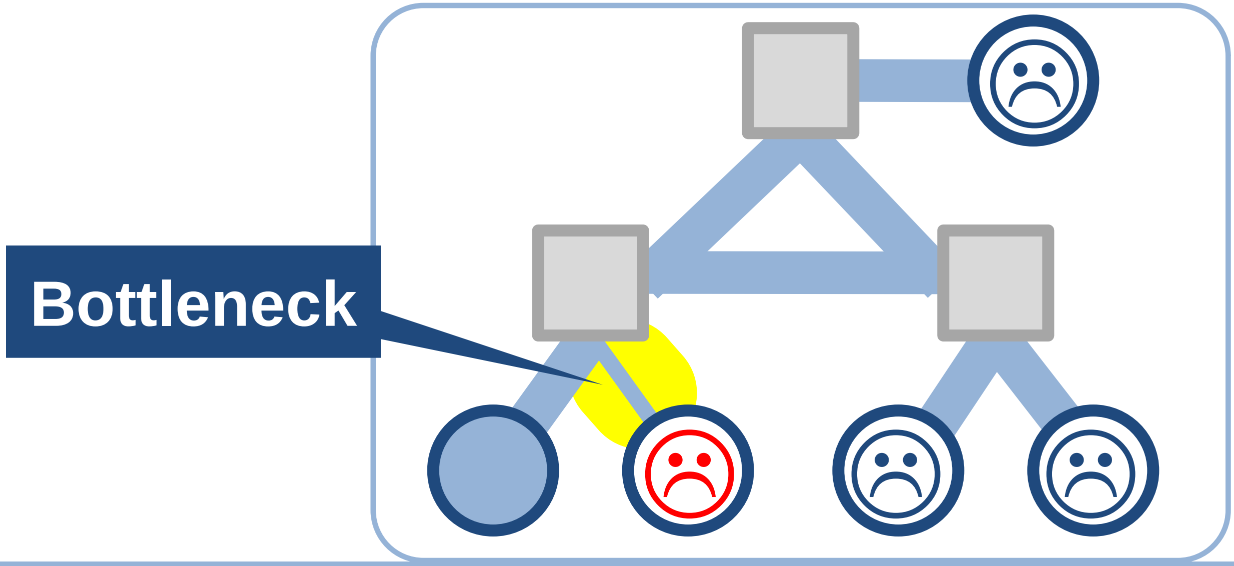


T2: sends the latter part



Problems of FPFR

- In FPFR, slow nodes degrade receiving bandwidth to other nodes
- For tree topologies, FPFR only outputs one depth-first pipeline, which cannot utilize the potential network performance



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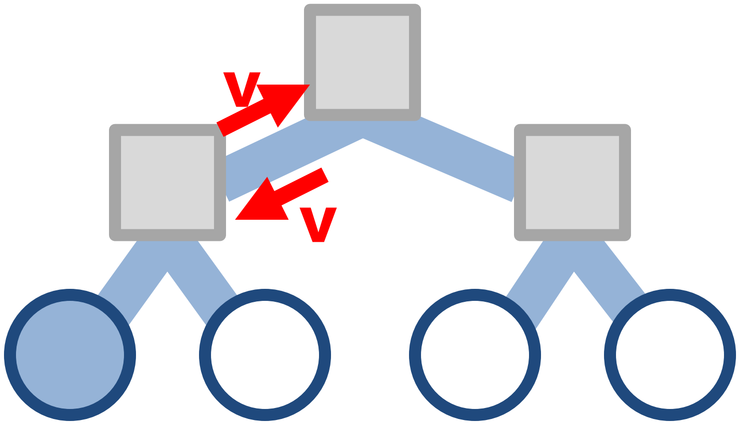
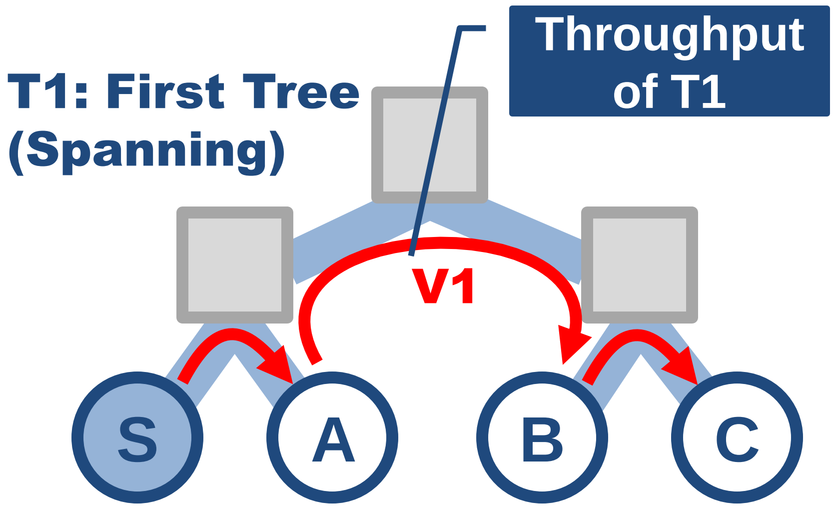
Our Algorithm

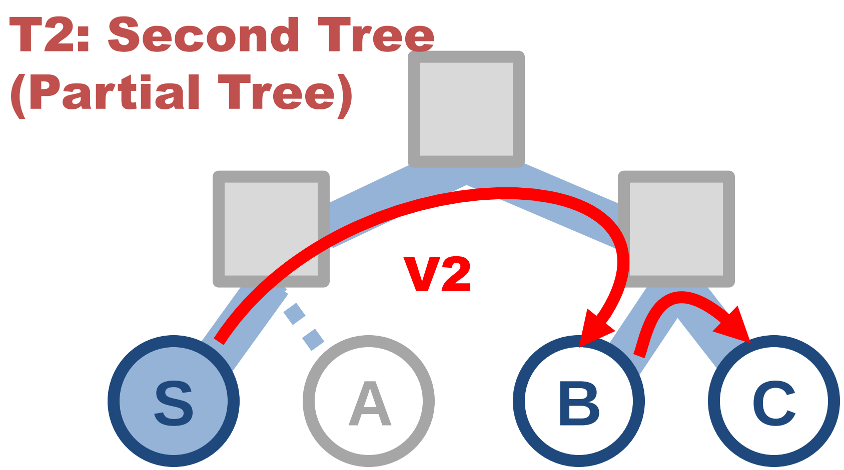
- **Modify FPFR algorithm**
  - Create both **spanning** trees and **partial trees**
- **Stable** for tree topologies whose links have the same bandwidth in both directions

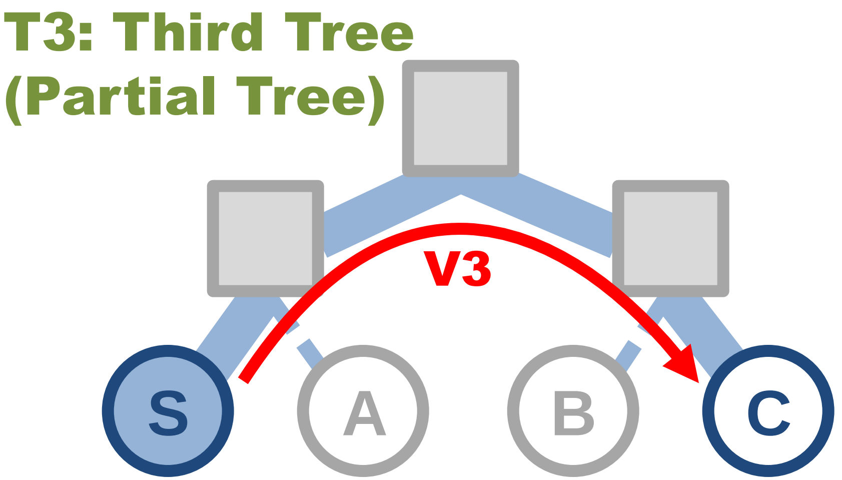


Tree Constructions

- Iteratively construct trees
  - Create a tree **Tn** by tracing every destination
  - Set the throughput **Vn** to the bottleneck in **Tn**
  - Subtract **Vn** from the remaining capacities

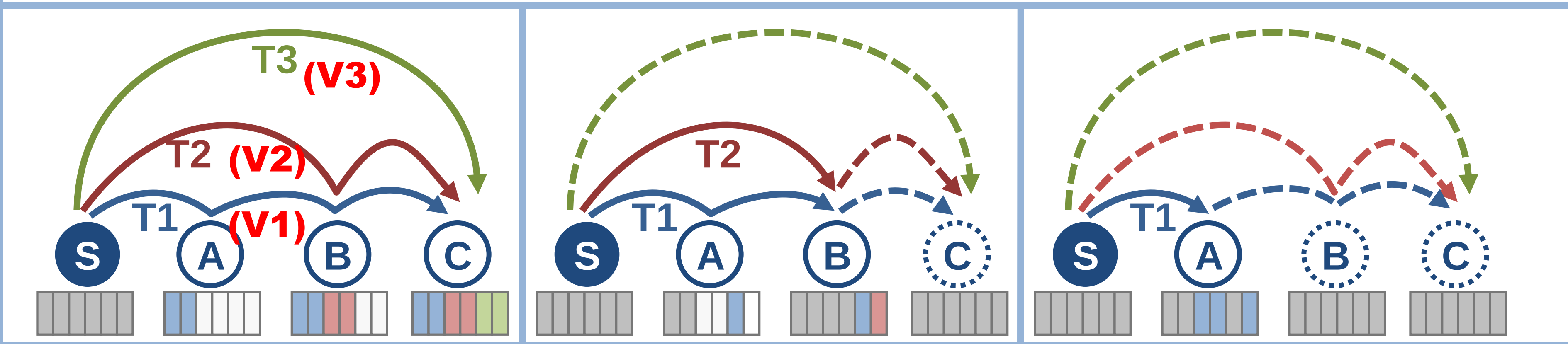






Data Transfer

- Send data proportional to the tree throughput **Vn**
- Example:
  - Stage1: use T1, T2 and T3
  - Stage2: use T1 and T2 to send data previously sent by T3
  - Stage3: use T1 to send data previously sent by T2



Properties of Our Algorithm

1. Our algorithm is **Stable** for tree topologies (whose links have the same capacities in both directions)
   - Every node receives **maximum** bandwidth
2. For any topology, it achieves **greater aggregate bandwidth** than the baseline algorithm (FPFR)
   - Fully utilize link capacity by using **partial trees**
3. It has small calculation cost to create a broadcast plan

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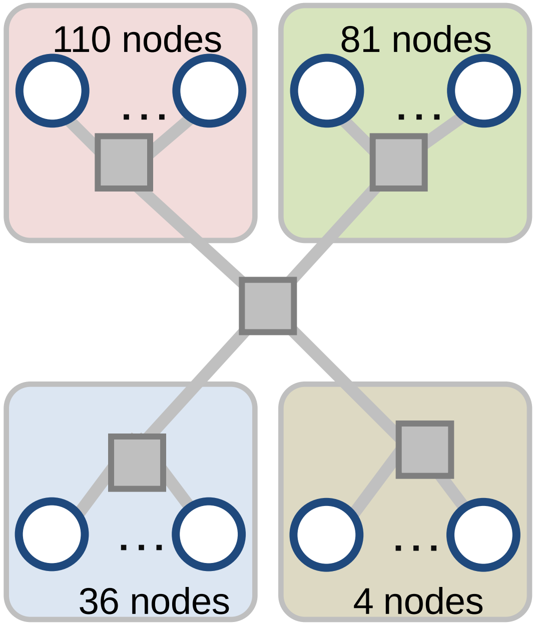
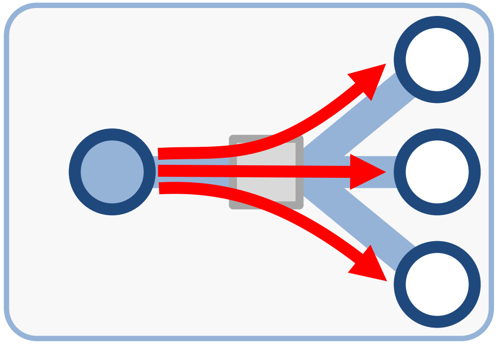
(1) Simulations

- Simulated 5 broadcast algorithms using a real topology
- Compared the aggregate bandwidth of each method
  - Many bandwidth distributions
  - Broadcast to 10, 50, and 100 nodes
  - 10 kinds of conditions (src, dest)

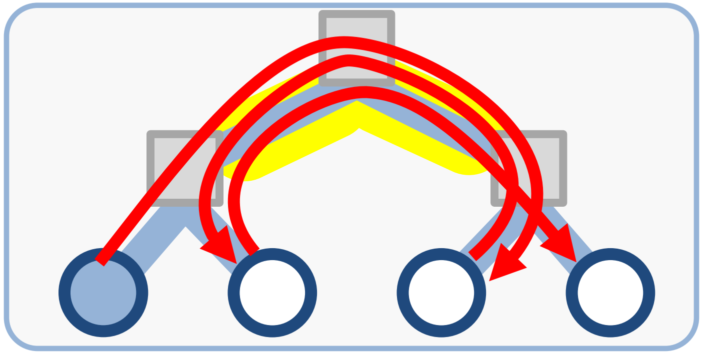


Compared Algorithms

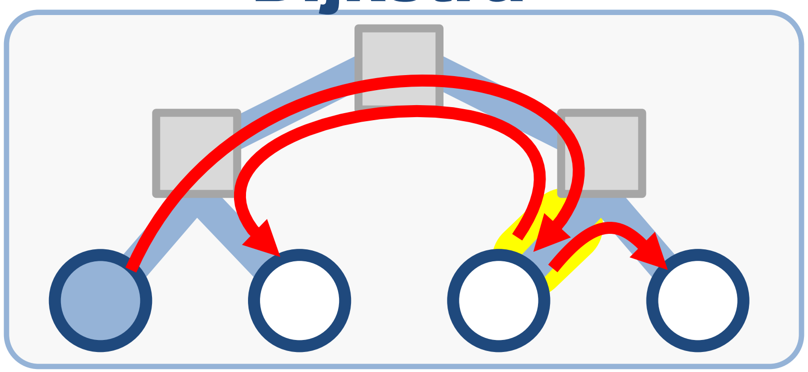
Flat Tree



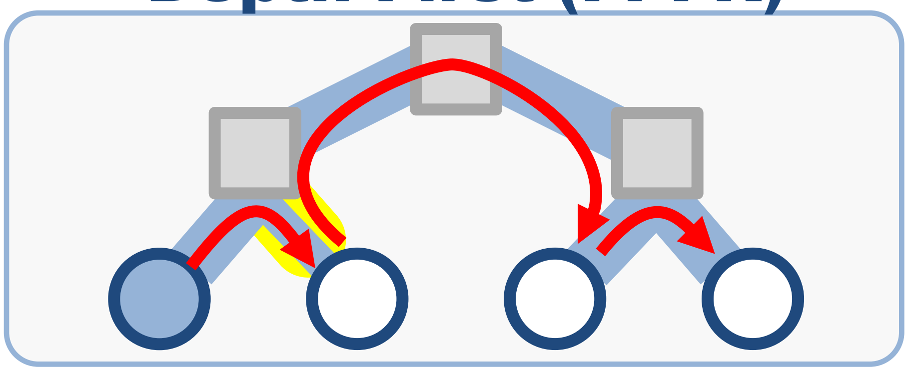
Random



Dijkstra



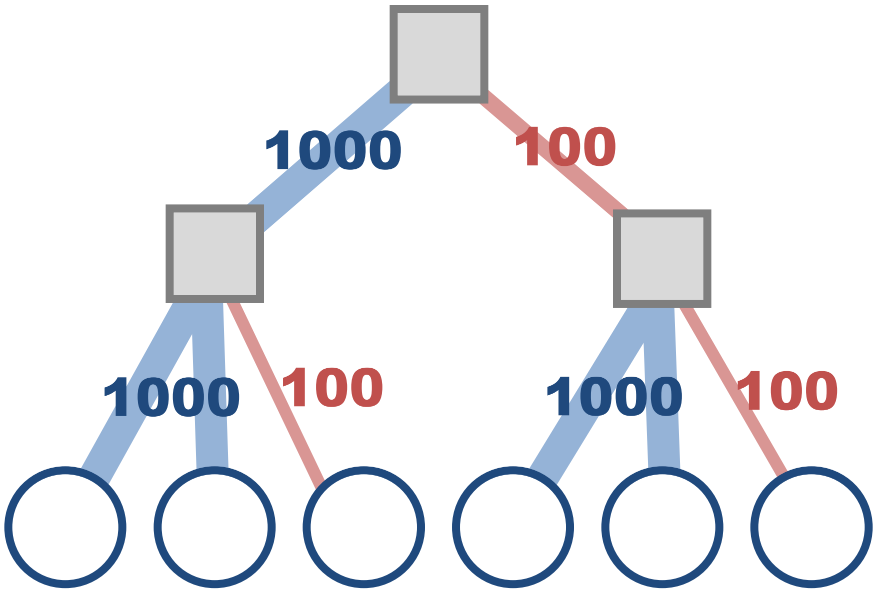
Depth-First (FPFR)

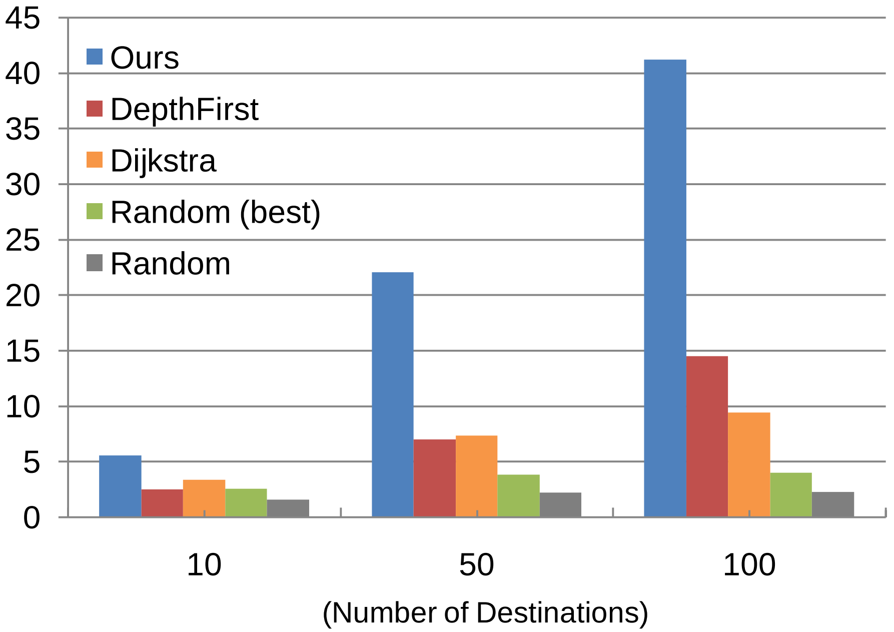


… and OURS

Result of Simulations

- Mixed two kinds of Links (100 and 1000)
  - Vertical axis: speedup from *FlatTree*
  - 40 times more than *random*,
    3 times more than *depth-first* (FPFR) with 100 nodes





Result of Simulations (cont.)

- Tested 8 bandwidth distributions
  - Uniform distribution (500-1000)
  - Uniform distribution (100-1000)
  - Mixed 100 and 1000 links
  - Uniform distribution (500-100) between switches

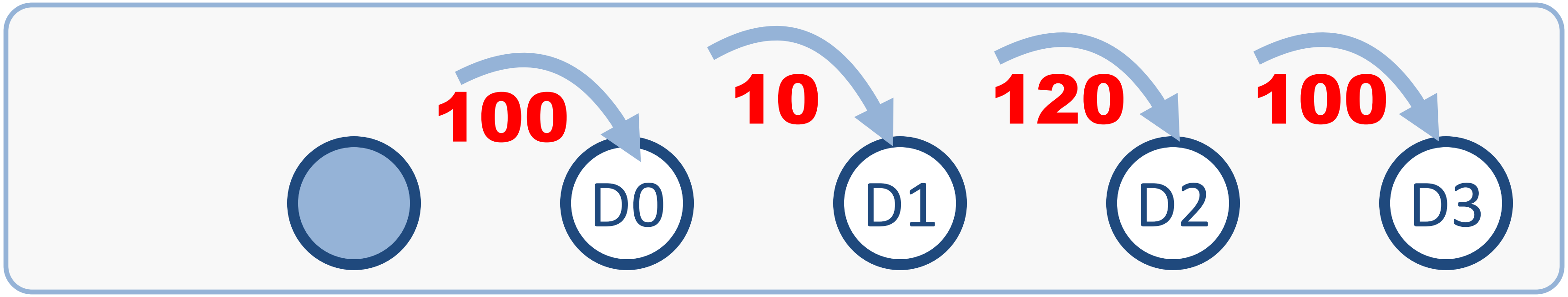
  (for each distribution, tested two conditions
  that bandwidth of both directions are the **same** and **different**)
- Our method achieved the largest bandwidth in 7/8 cases
  - Large improvement especially in large bandwidth variance
  - In a uniform distribution (100-1000) and link bandwidth in two directions are different, *Dijkstra* achieved 2% more aggregate bandwidth

(2) Real Machine Experiment

- Performed broadcasts in 4 clusters
  - Number of destinations:10, 47 and 105 nodes
  - Bandwidths of each link: (10M - 1Gbps)
- Compared the aggregate bandwidth in 4 algorithms
  1. Our algorithm
  2. Depth-first (FPFR)
  3. Dijkstra
  4. Random (Best among 100 trials)

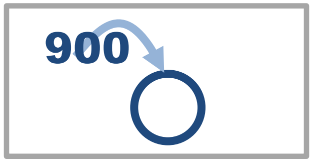
Theoretical Maximum Aggregate Bandwidth

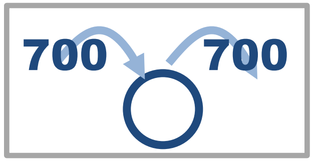
- Also, we calculated the theoretical maximum aggregate bandwidth
  - The total of the receiving bandwidth in a case of separate direct transfer from the source to each destination

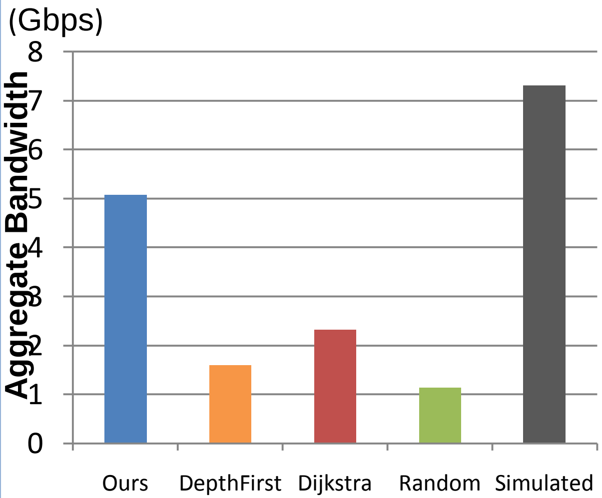


Evaluation of Aggregate Bandwidth

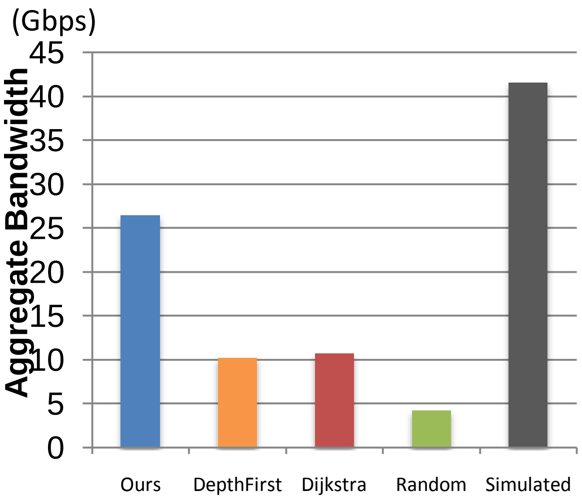
- For 105 nodes broadcast, **2.5 times** more bandwidth than the baseline algorithm *DepthFirst (FPFR)*
- However, our algorithm stayed 50-70% the aggregate bandwidth compared to the theoretical maximum
  - Computational nodes cannot fully utilize up/down network



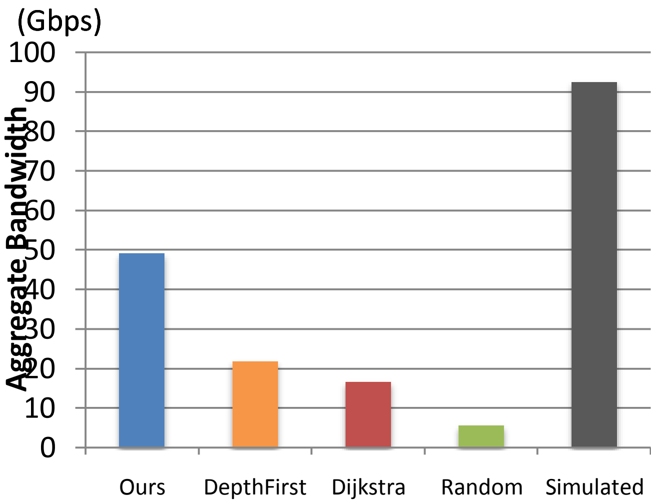




(a) Broadcast (10 Nodes)



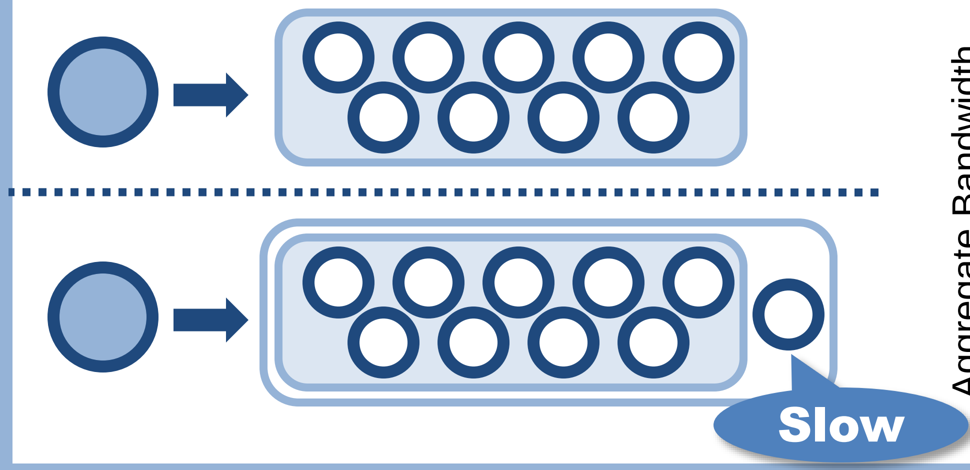
(b) Broadcast (47 Nodes)

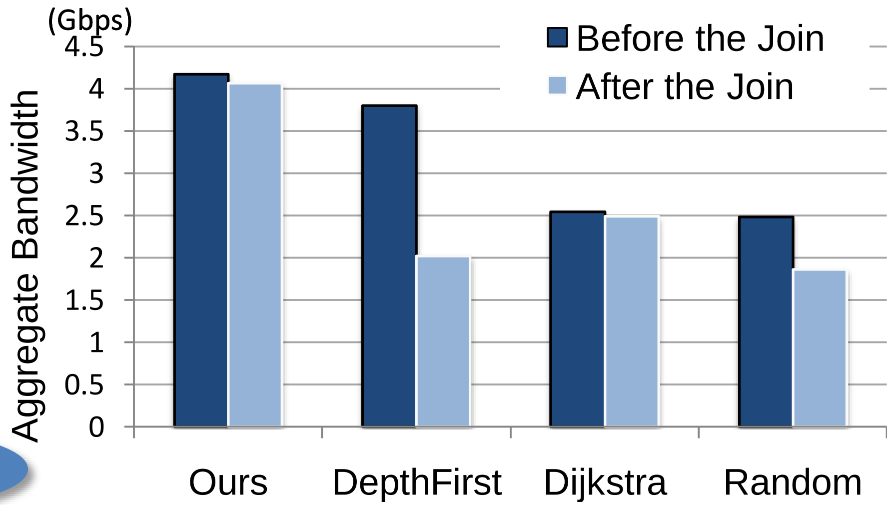


(c) Broadcast (105 Nodes)

Evaluation of Stability

- Compared aggregate bandwidth of 9 nodes before/after adding one slow node
  - Unlike *DepthFirst*(*FPFR*), existing nodes do not suffer from adding a slow node in our algorithm
  - Achieved 1.6 times bandwidth than *Dijkstra*





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Conclusion

- Introduced the notion of **Stable Broadcast**
  - Slow nodes **never** degrade receiving bandwidth of fast nodes
- Proposed a stable broadcast algorithm for tree topologies
  - Theoretically proved
  - **2.5 times** the aggregate bandwidth in real machine experiments
  - Confirmed speedup in simulations with many different conditions

Future Work

- Algorithm that maximizes aggregate bandwidth in general graph topologies

- Algorithm that changes relay schedule by detecting bandwidth fluctuations