TRAM: Improving Fine-grained Communication Performance with Topological Routing and Aggregation of Messages

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T opological

R outing and

A ggregation

M odule

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exploits physical network topology

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R outing and

determines message path

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A ggregation

combines messages

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component of a larger system

Introduction

- Charm++ library
  - Prototype: Mesh Streamer
  - Originally developed for the 2011 Charm++ HPC Challenge submission
- Aggregates fine grained messages to improve communication performance

Why Aggregation?

- Sending a message involves overhead
  - Allocating buffer
  - Serializing into buffer
  - Injecting onto the network
  - Routing
  - Receiving
  - Scheduling

Communication Overhead

- Some overhead depends on data size
  – Serialization
- Some does not
  – Scheduling
- Aggregation targets the latter, constant overhead

Two Types of Constant Overhead

- Processing overhead
  - Processing time involved in sending a message
- Bandwidth overhead
  - To send some bytes on the network you must first … send some more bytes on the network
  - What does it mean to *send* a 0-byte message?
    - Answer: in Charm++, to send at least 48 bytes

Bandwidth Overhead

- Message header
  - Charm++ envelope: 48 bytes
- Network overhead
  - Routing
  - Error checking
  - Partially filled packets

Bandwidth Methodology

- Network bandwidth is tricky to deal with
- Fundamentally, it is a property of a single link, but our tendency is to try to distill it into a single value (e.g. bisection bandwidth)
- If all links are utilized equally and link bandwidth is saturated, then each link's consumption is significant
  - We can then add up each link's utilization, and concern ourselves with this aggregate bandwidth

Fine-grained Communication

- Constant communication overhead really adds up when sending large numbers of small messages
  - What about large numbers of large messages?
- Sources of fine-grained communication
  - Control messages, acknowledgments, requests, etc.
- For strong scaling, communication becomes increasingly fine-grained with increasing processor count

Why Routing?

- By routing, we mean not selection of the links along which messages travel, but instead:
  - Selection of intermediate destination nodes or processes and delivery of the message to the runtime system at the intermediate destinations
  - Analogy: bus route
- Why does a passenger bus make stops before reaching the end of the route?

Why Routing?

- Why does a bus make stops before reaching the end of the route?
  - To serve more people along its direction of travel
    - Picking up people who want to board the bus at ANY stop along the route
    - Dropping off people whose destination is ANY subsequent stop along the route
  - Stopping at n stops serves (n-1)(n-2) separate trips (source/destination pairs)
    - This is why a relatively small number of buses can serve a large area of a city

Why Topological?

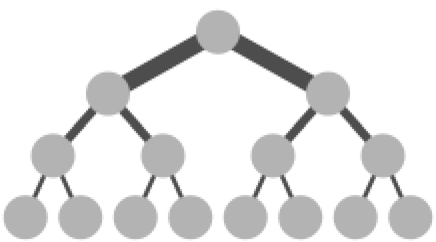
- It is infeasible to have a separate hardware network link between every pair of nodes in the system
- Consequences
  - some messages must travel through one or more intermediate nodes or switches
    - How it happens is normally invisible to the application and runtime system
  - aggregate bandwidth consumed grows linearly with every additional link along the route

Congestion

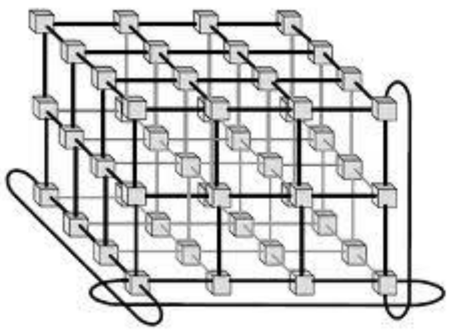
- Messages traveling concurrently along a link must split the bandwidth, leading to congestion
- Due to aggregation, TRAM messages are larger than typical, so congestion is of higher concern

Network Topology

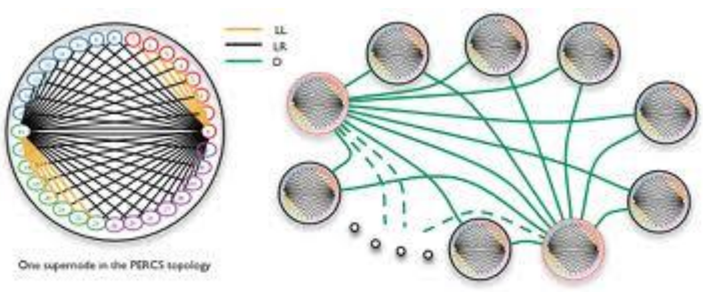
- No single network topology for supercomputers is accepted as best, so in practice several are in use



Source: en.wikipedia.org



Source: wiki.ci.uchicago.edu



Source: Bhatele et al., SC '11

Virtual Topology

- The nodes of a physical topology can be mapped onto a virtual topology
- The same virtual topology can be reused for various physical topologies
- TRAM employs a mesh virtual topology

Topological Routing

- Most messages pass across multiple links to reach the destination
- We can try combining messages, taking advantage of intermediate destinations analogously to bus stops
- But hardware-level routing is transparent to the runtime system
  - Solution: lift routing into software, at the level of the runtime system
  - Possible pitfall: routing will still happen independently in hardware

Minimal Routing

- Routing is minimal if every message sent travels over the minimum number of links possible to reach its destination
- Our goal with TRAM is to preserve minimal routing if possible
  - Reason: non-minimal routing consumes additional aggregate bandwidth

Virtual to Physical Topology Mapping

- Simplest and often best: make virtual topology identical to physical
  - Using Charm++ Topology Manager
- For high dimensional meshes, tori
  - Reduce number of dimensions while preserving minimal routing
- Fat trees
  - 2D within/across nodes

Data Item

- Unit of fine-grained communication to be sent by TRAM
- Sent for a particular destination
- Submitted using a local library call instead of the regular Charm++ syntax for a message send

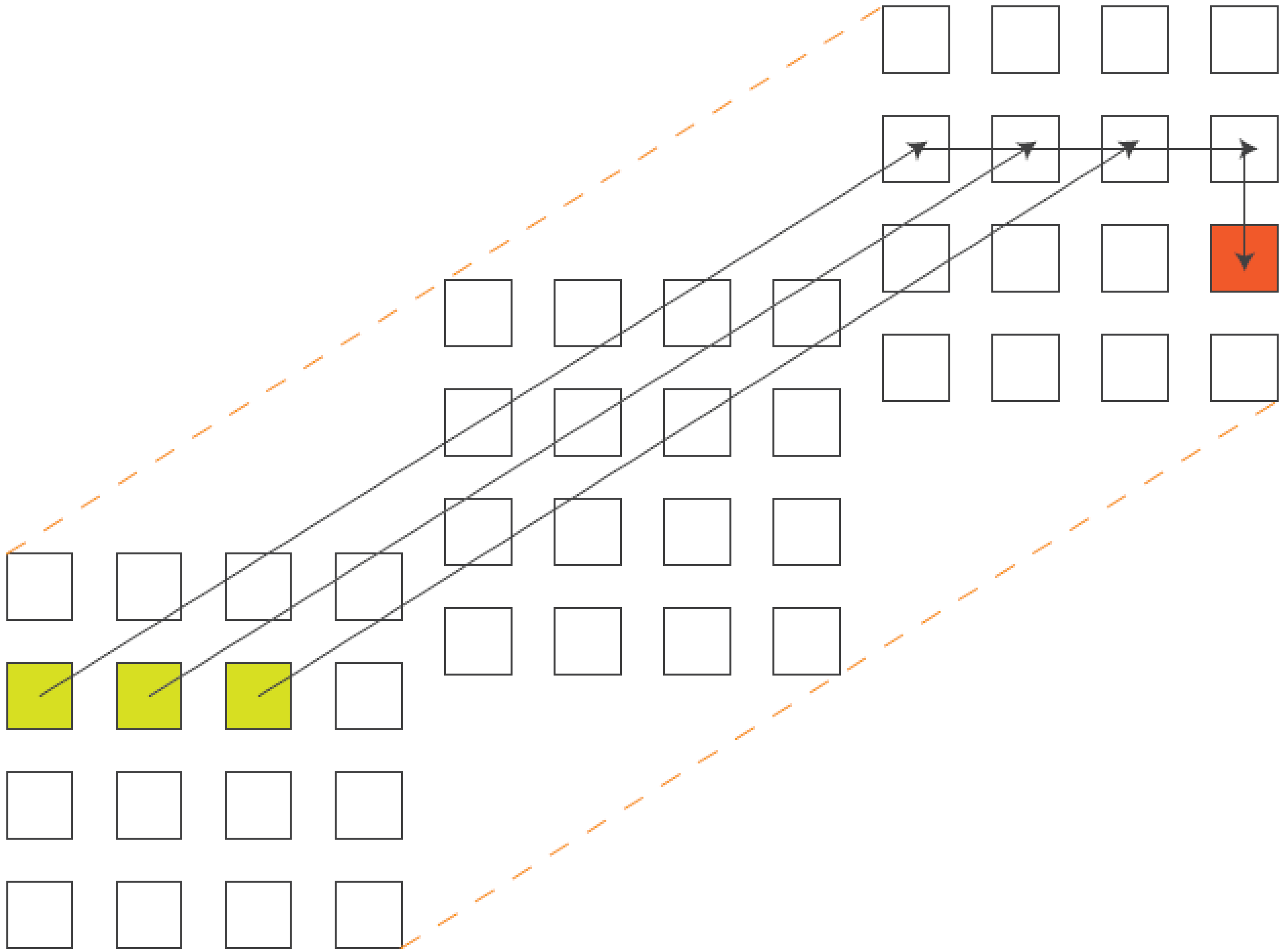
TRAM Peers

- In the context of TRAM, a process is allowed to communicate only with its peers
  - peers are all the processes that can be reached from it by moving arbitrarily far strictly along a single dimension

Mesh Routing Algorithm

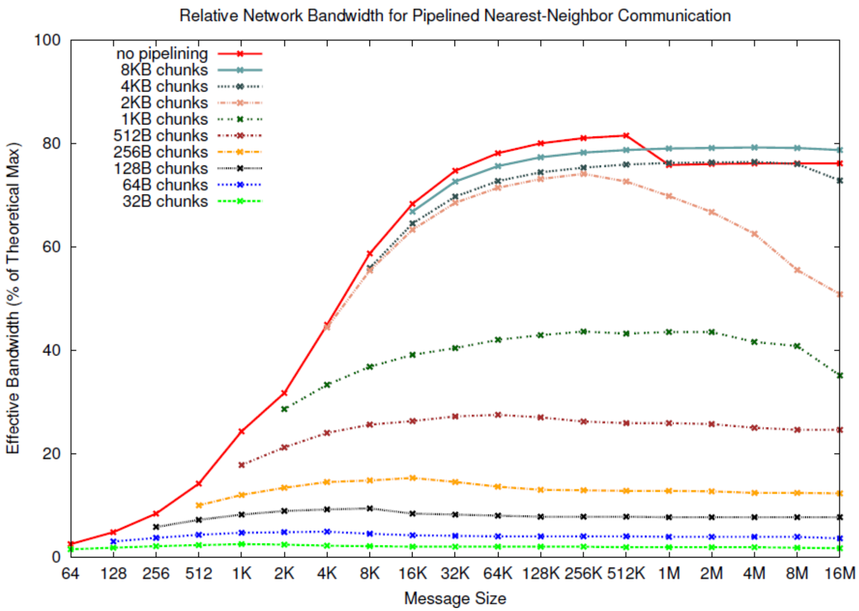
- Order the N dimensions in the virtual topology
- According to the order, send data items along the highest dimension whose index does not match the destination’s
  - to the peer whose index does match the final destination’s index along that dimension
- Aggregate at the source and each intermediate destination

Mesh Routing and Aggregation



Aggregation Buffer Size

- Buffers should be large enough to give good bandwidth utilization, but no larger
  - Buffering time should be relatively low
- On Blue Gene/P Buffers of size 4 KB or more are sufficient to almost saturate the bandwidth



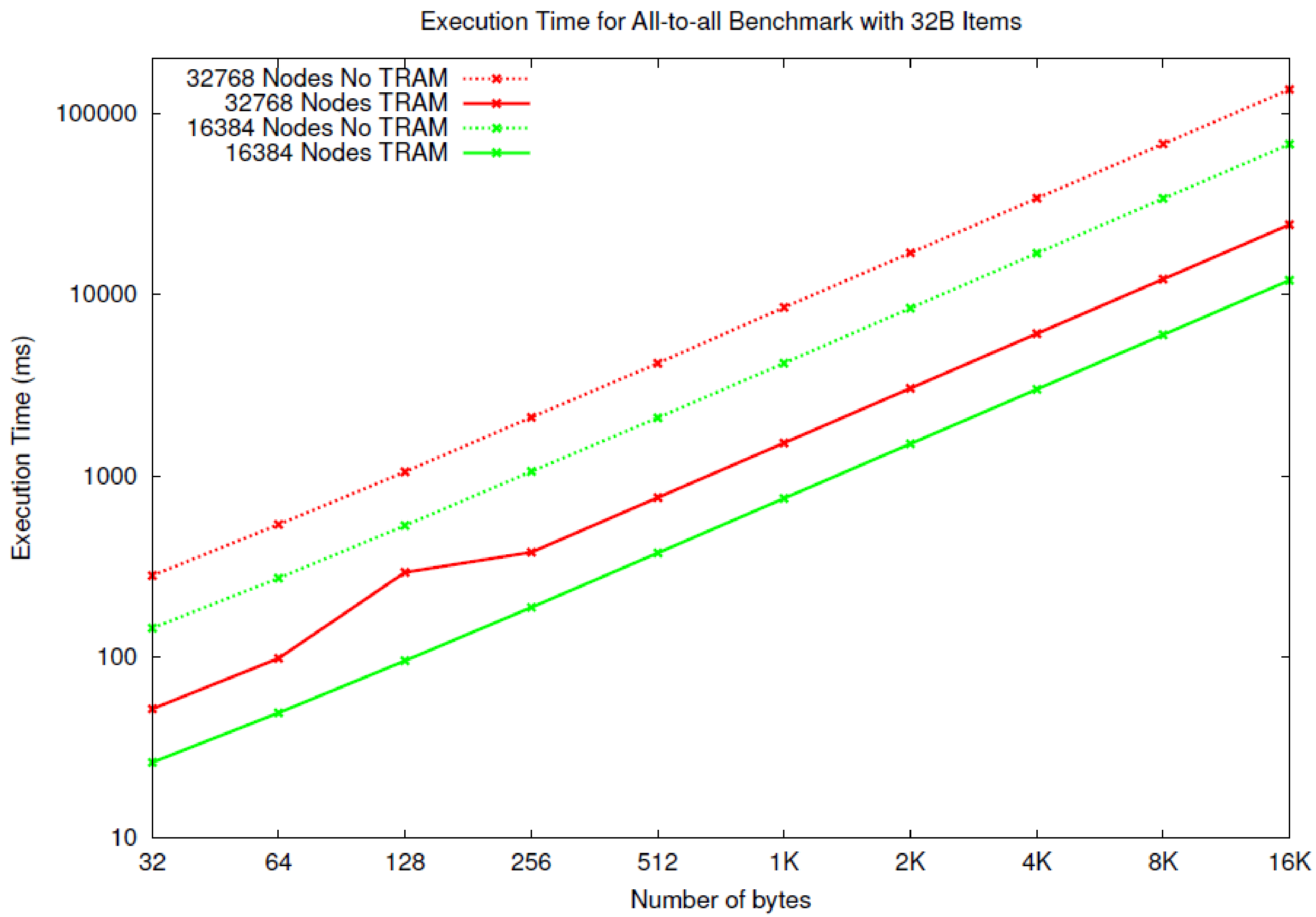
TRAM Memory Footprint

- Number of peers is typically a small fraction of all the processes in the run
  – For example, 32 x 32 x 32 topology
    - 32768 processes
    - 93 peers
- This allows TRAM's memory footprint to remain relatively small
  – Small enough for lower level cache

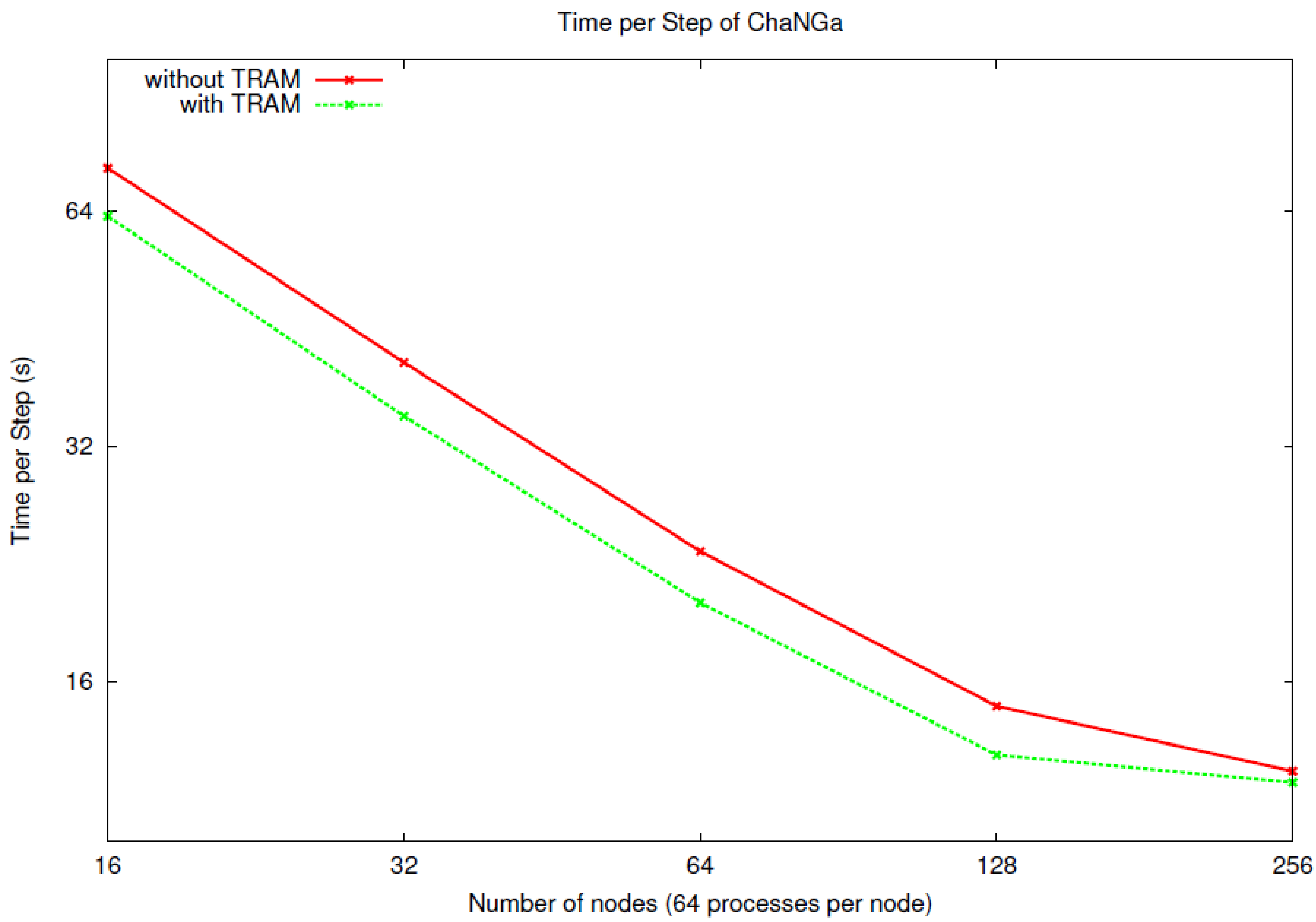
TRAM Usage Pattern

- Start-up
- Initialization
- Sending and receiving
- Termination
- Re-initialization

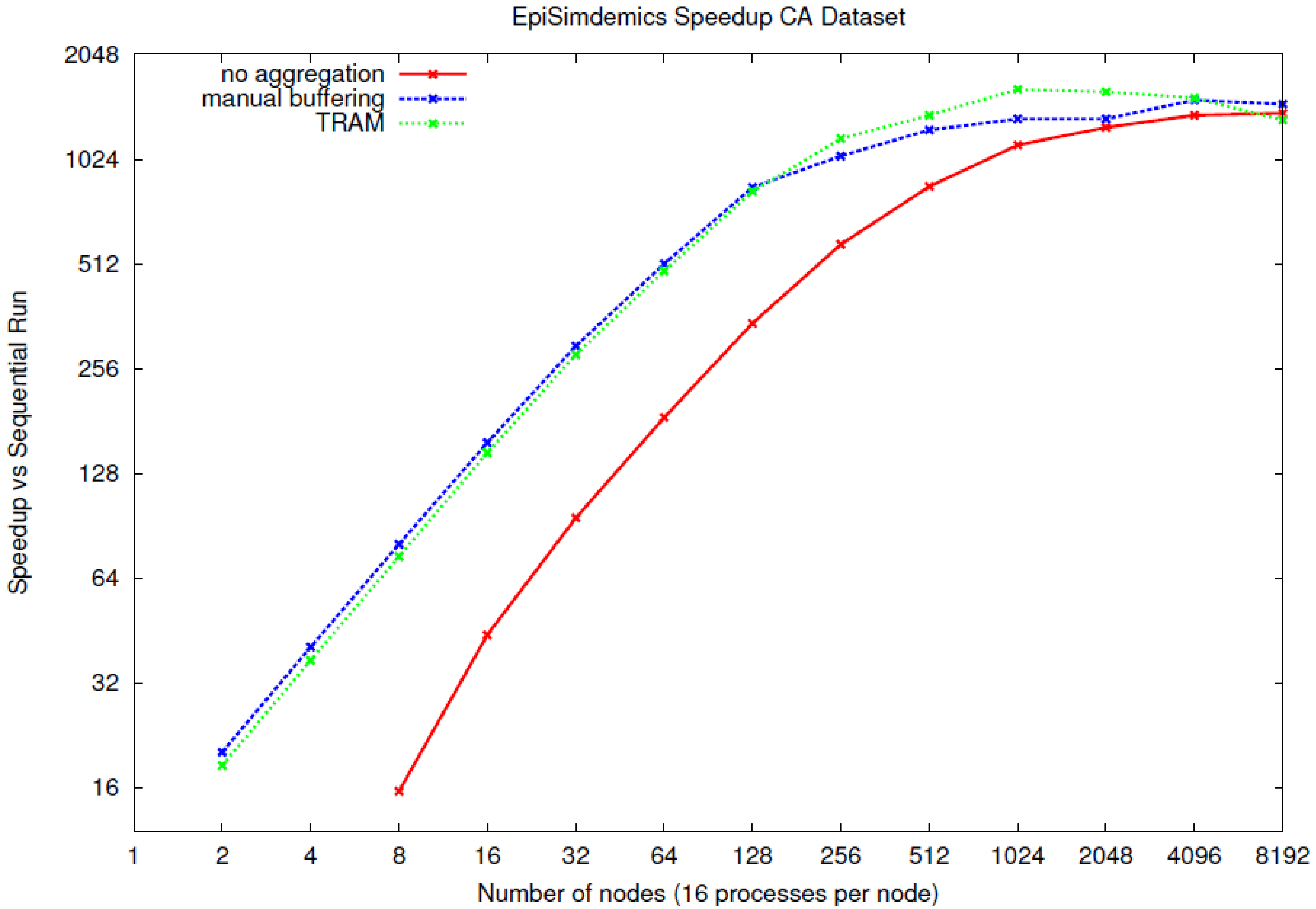
Alltoall Performance on Blue Gene/P



ChaNGa on Blue Gene/Q



EpiSimdemics on Blue Waters



Future Plans

- Develop alternative virtual topologies for non-mesh networks
- Generalize
  - First within Charm++
  - Then to other communication models
- Automate
  - Library parameter selection
  - Virtual topology dimensions
  - Choice of which messages to aggregate

Acknowledgements

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Thank You