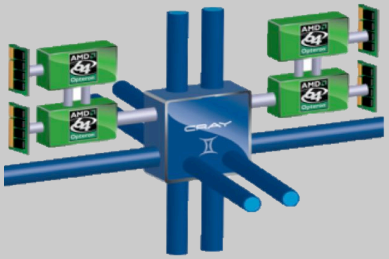

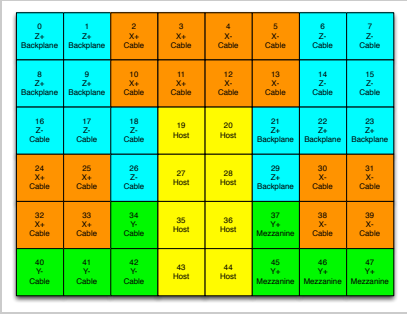

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Exceptional service in the national interest

Using the Cray Gemini Performance Counters

Cray User Group Meeting
May 8, 2013

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Outline

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- Motivation and background
- How to access
- What they measure
- Usage example: MiniGhost rank remapping
- Conclusion

Motivation

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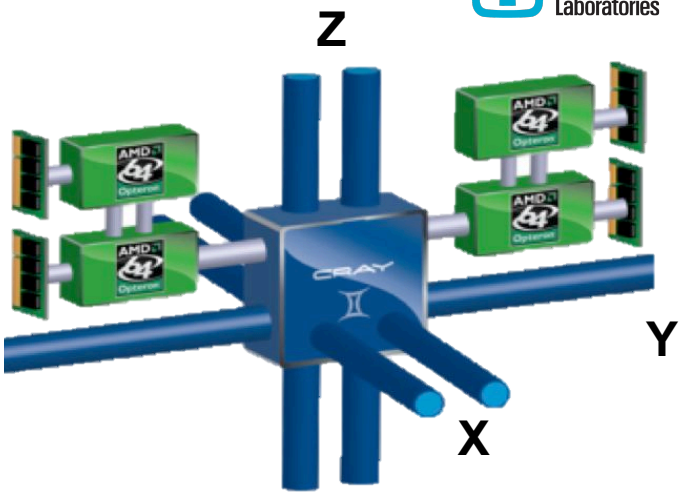
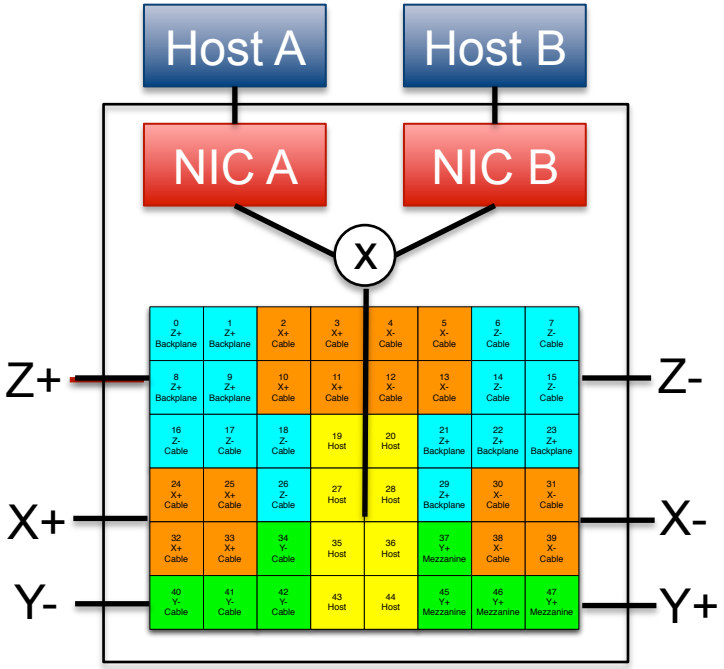
- We had an application that was scaling well to 16K processes, then poorly afterwards (weak scaling)
- We suspected network congestion/contention was becoming an issue and wanted to quantify it empirically
- We had heard the Gemini had a nice set of performance counters that could do this

➜ It turned out to be quite a bit of work to access the counters, seemed like a good topic to discuss at CUG

Cray Gemini

- Two nodes (hosts) per Gemini chip
- Gemini chip consists of:
  - Two network interfaces
  - 48 port (tile) router,
    logically organized into 7 network links
- Routers connected to form 3-D torus
  - X links between cabinets in a row
  - Y links between rows of cabinets
  - Z links within a cabinet
- Large set of performance counters
  - Cray Documentation (S-0025-10):
    Using the Cray Gemini Hardware Counters
  - This talk focuses on the router tile
    performance counters





Available Tile Counters

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- Each tile has six fixed counters:

0:	VC0_PHIT_CNT	Request VC phits
1:	VC1_PHIT_CNT	Response VC phits
2:	VC0_PKT_CNT	Request VC packets
3:	VC1_PKT_CNT	Response VC packets
4:	INQ_STALLS	Request VC input stalls
5:	CREDIT_STALLS	Request VC output stalls

- What is a phit? => 3 bytes
- What is a packet? => 8 to 32 phits (24 to 96 bytes)
- Input stalls? => Time waiting to get to output tile
- Output stalls? => Time waiting to get to next Gemini

Questions?

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- Basic
  - How can we access the tile counters from an MPI program?
  - How do we turn the individual tile counters into link counters?
  - How do we calculate the capacity of each link?
- Operational:
  - What exactly are the packet/phit counters measuring?
  - Do the counters work as expected for PUT/GET transactions?
  - Are measurements repeatable?
  - How is the system routed?
  - Do the stall counters correlate with network congestion?

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Directly Accessing Gemini Counters

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```
1  gpcd_context_t *ctx;
2  gpcd_mmr_desc_t *desc;
3  gpcd_mmr_list_t *p;
4  int i, j, k;
5  char name[128];
6
7  // Create a counter group, all tile counters
8  ctx = gpcd_create_context();
9  for (i = 0; i < 6; i++)       // TILE_ROWS
10   for (j = 0; j < 8; j++)     // TILE_COLS
11     for (k = 0; k < 6; k++) // TILE_COUNTERS
12     {
13       sprintf(name,
14         "GM_%d_%d_TILE_PERFORMANCE_COUNTERS_%d",
15         i, j, k);
16       desc = gpcd_lookup_mmr_byname(name);
17       gpcd_context_add_mmr(ctx, desc);
18     }
19
20 // Sample the tile counters
21 gpcd_context_read_mmr_vals(ctx);
22
23 // Print the counter values
24 for (p = ctx->list; p; p = p->next)
25   printf("Counter %s: Value=%lu\n",
26          p->item->name, p->value);
```

- GPCD Library available in Gemini Kernel driver source code (GPLv2)
- Code sets up to sample the 288 tile counters, 48 tiles * 6 counters
- Traps to kernel to read counters, driver ioctl()
- Benchmark, time to sample all 288 tile counters:

Average:	159 us
Min:	154 us
Max:	305 us

- => **Slow Operation!**

  Use with care

Aggregating to Link Counters

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- Tile counters are just an implementation detail
  - Really care about the logical network links
  - Need to figure out which tiles make up each network link
- No obvious way to get the mapping from compute nodes
  - Instead, use Cray's rtr tool available on the SMW to dump map
  - Our tools depend on this text file, parse at startup

```
rtr --interconnect > interconnect.txt
```

Source Gemini Tile		Destination Gemini Tile	Type of Link
c0-0c0s0g0l00[(0,0,0)]	Z+ ->	c0-0c0s1g0l32[(0,0,1)]	LinkType: backplane
c0-0c0s0g0l01[(0,0,0)]	Z+ ->	c0-0c0s1g0l21[(0,0,1)]	LinkType: backplane
c0-0c0s0g0l02[(0,0,0)]	X+ ->	c1-0c0s0g0l02[(1,0,0)]	LinkType: cable11x
c0-0c0s0g0l03[(0,0,0)]	X+ ->	c1-0c0s0g0l03[(1,0,0)]	LinkType: cable11x
c0-0c0s0g0l04[(0,0,0)]	X- ->	c2-0c0s0g0l41[(15,0,0)]	LinkType: cable18x
c0-0c0s0g0l05[(0,0,0)]	X- ->	c2-0c0s0g0l31[(15,0,0)]	LinkType: cable18x
c0-0c0s0g0l06[(0,0,0)]	Z- ->	c0-0c2s7g0l26[(0,0,23)]	LinkType: cable15z
c0-0c0s0g0l07[(0,0,0)]	Z- ->	c0-0c2s7g0l35[(0,0,23)]	LinkType: cable15z

Example Tile to Logical Link Mapping For LANL/SNL Cielo Cray XE6

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0 Z+ Backplane	1 Z+ Backplane	2 X+ Cable	3 X+ Cable	4 X- Cable	5 X- Cable	6 Z- Cable	7 Z- Cable
8 Z+ Backplane	9 Z+ Backplane	10 X+ Cable	11 X+ Cable	12 X- Cable	13 X- Cable	14 Z- Cable	15 Z- Cable
16 Z- Cable	17 Z- Cable	18 Z- Cable	19 Host	20 Host	21 Z+ Backplane	22 Z+ Backplane	23 Z+ Backplane
24 X+ Cable	25 X+ Cable	26 Z- Cable	27 Host	28 Host	29 Z+ Backplane	30 X- Cable	31 X- Cable
32 X+ Cable	33 X+ Cable	34 Y- Cable	35 Host	36 Host	37 Y+ Mezzanine	38 X- Cable	39 X- Cable
40 Y- Cable	41 Y- Cable	42 Y- Cable	43 Host	44 Host	45 Y+ Mezzanine	46 Y+ Mezzanine	47 Y+ Mezzanine

Link Type	Bandwidth
Mezzanine	2.34 GB/s
Backplane	1.88 GB/s
Cable	1.17 GB/s
Host	1.33 GB/s (est.)

Unidirectional Bandwidths

X Links, all:

8 * 1.17 = 9.4 GB/s

Y Links, alternate every other:

4 * 2.34 = 9.4 GB/s (mezz)

4 * 1.17 = 4.7 GB/s

Z Links, every eighth slower:

8 * 1.88 = 15 GB/s (backpl)

8 * 1.17 = 9.4 GB/s

Gathering Job Wide Information

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```
// Initialize the library
gemini_init_state(comm, &state)

// Sample the gemini counters
gemini_read_counters(comm, &state)

// Output delta of last two samples
gemini_print_counters(comm, &state)
```

```
# DEST_COORD
#    SRC_COORD  GB/s   VC0_PHITS  VC1_PHITS VC0_PKTS  VC1_PKTS   INQ_STALLS OUTQ_STALLS

( 0, 1, 1 )
 X+ ( 1, 1, 1)  9.38   1626452284 304999266 101662806 101666422  3533598961  2689080952
 X- (15, 1, 1)  9.38       100506     38796      9780     12932          83           0
 Y+ ( 0, 2, 1)  4.69   1627257610 305156760 101726643 101718920  1702270109           0
 Y- ( 0, 0, 1)  9.38   1153554135 216313236  72105559  72104412  1925883229  2366983378
 Z+ ( 0, 1, 2) 15.00    815234359 152948952  50988260  50982984   133047991   776502961
 Z- ( 0, 1, 0) 15.00      1743043    378399    156635    126133         580   992022669
 HH ( 0, 1, 1) 10.40   1834489368 344019696 114672167 114673232 10585723107  2263990777

( 0, 0, 1 )
 X+ ( 1, 0, 1)  9.38   1966685020 368797209 122929393 122932403  3317929506  3063532486
 X- (15, 0, 1)  9.38       122194     43005     11983     14335           9           0
 Y+ ( 0, 1, 1)  9.38   1154016206 216417552  72141025  72139184  3589170400  1097189607
 Y- ( 0,11, 1)  4.69        96911     20538      9646      6846       56244           0
 Z+ ( 0, 0, 2) 15.00   2477453033 458007486 153779007 152669162   952487628  2209098748
 Z- ( 0, 0, 0) 15.00      2071415   3684912    128723   1228304      464902   387186094
 HH ( 0, 0, 1) 10.40   2174662127 407809092 135934105 135936364 10604254673  2216827070
```

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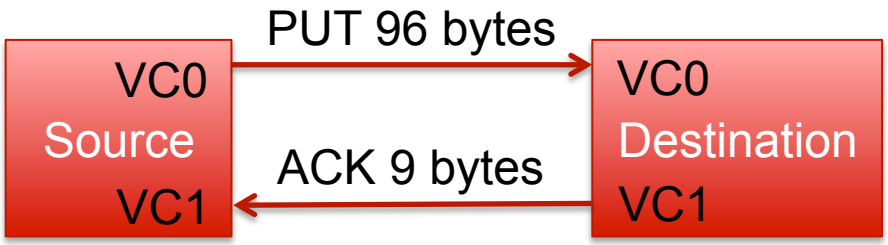
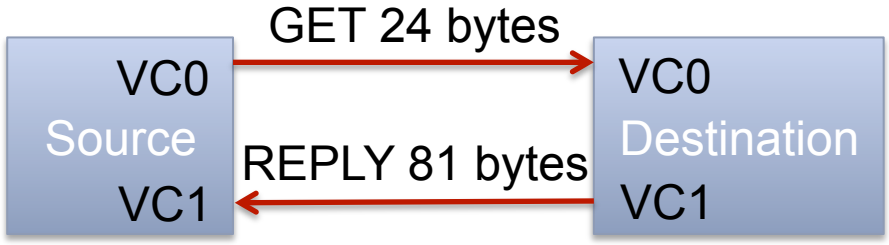
“Sonar” Experiments

- Basic Idea: Send out a known ping, observe tile counters to figure out what happened
- First test, send a 1 MB MPI message between two nodes
- Expect either PUT or GET transactions
  - Both transaction types move up to 64 bytes of user data
  - PUT transactions consist of 32 phit (96 byte) request packet on VC0 followed by a 3 phit (9 byte) response packet on VC1 (the ACK)
  - GET transactions consist of 8 phit (24 byte) request packet on VC0 followed by a 27 phit (81 byte) response packet on VC1 (the REPLY)





1 MB Point-to-Point MPI Test

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- Original counts from sender's perspective:
  - Packets: TX = 16,407 RX = 16,407 (Expected 16,384)
  - Phits: TX = **262,565** RX = 49,221 (Expected TX 524,288 RX 49,152)
- Packet counters make sense, phit counters too low by 2x
- After discussing with Cray, due to compression (!)
  - Our test was sending a zero'ed message
  - The Gemini compresses runs of zeros and ones
- After initializing buffer to random bits, phit counters made sense ☺
  - Phits: TX = **524,709** RX = 49,221

Tile Counter Directionality (1)

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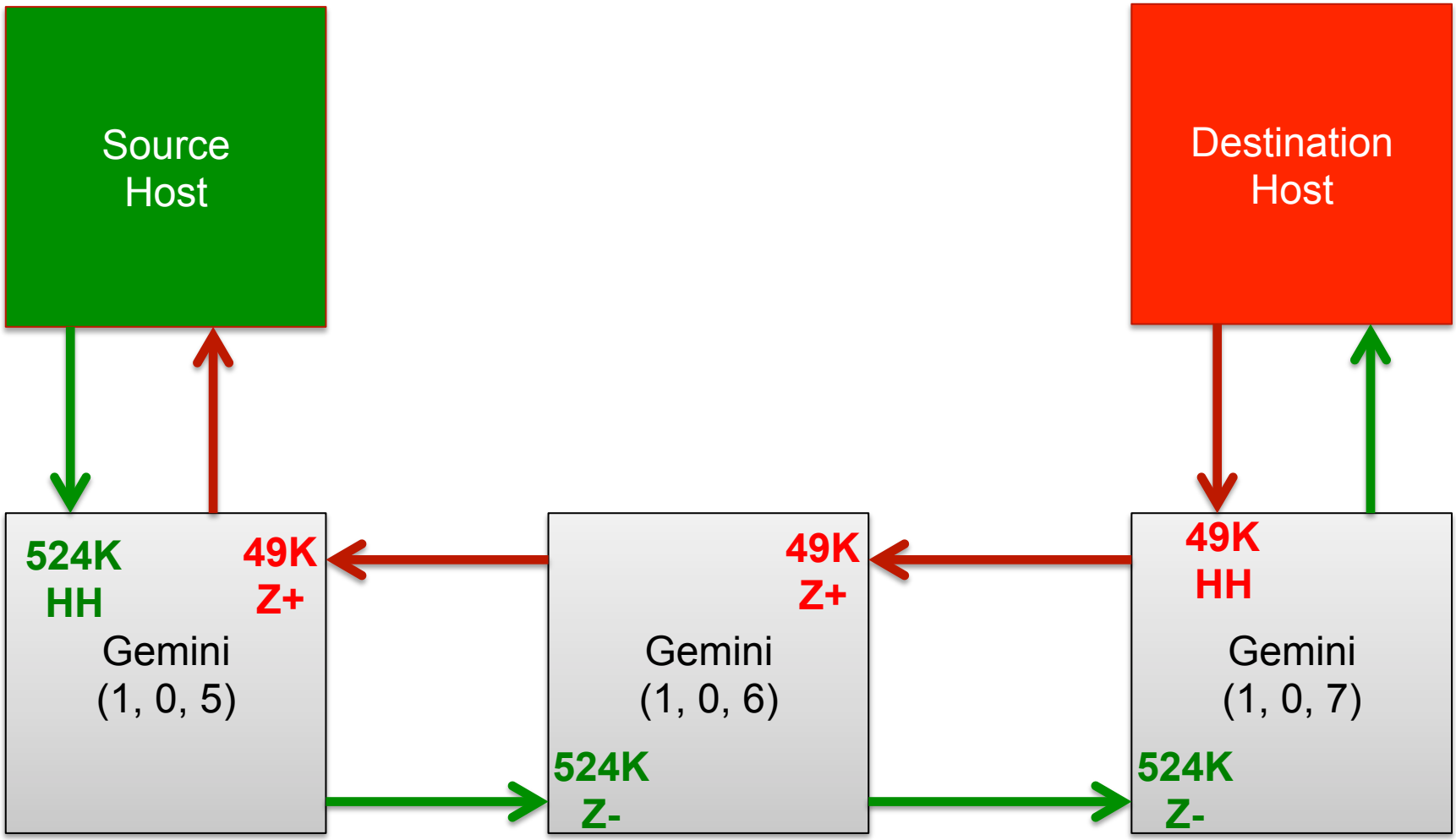
- Packet and Phit counters measure input into tile, not output

```
src=0, dst=2
================================================================================
(1, 0, 5) SOURCE
  X- (0, 0, 5) 18.75            0            0            0            0            0            0
  Y+ (1, 1, 5) 14.06            0            0            0            0            0            0
  Z+ (1, 0, 6) 15.00          278        49203           14        16401            0       141274
  Z- (1, 0, 4) 15.00            0            0            0            0            0            0
  HH (1, 0, 5) 10.40       524580           42        16401           14       817252            0
(1, 0, 6)
  X- (0, 0, 6) 18.75            0            0            0            0            0            0
  Y+ (1, 1, 6) 14.06            0            0            0            0            0            0
  Z+ (1, 0, 7) 15.00          278        49203           14        16401            0            0
  Z- (1, 0, 5) 15.00       524580           42        16401           14            0            0
  HH (1, 0, 6) 10.40          156           24            8            8            0            0
(1, 0, 7) DESTINATION
  X- (0, 0, 7) 18.75            0            0            0            0            0            0
  Y+ (1, 1, 7) 14.06            0            0            0            0            0            0
  Z+ (1, 0, 0)  9.38            0            0            0            0            0            0
  Z- (1, 0, 6) 15.00       524584           42        16401           14        57659            0
  HH (1, 0, 7) 10.40          278        49203           14        16401            0            0
```

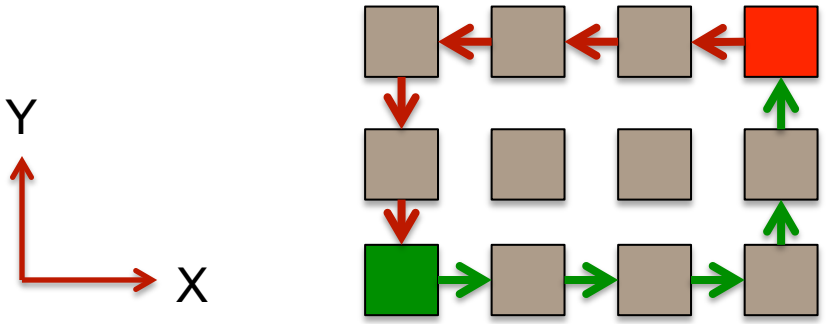
Tile Counter Directionality (2)

- Graphical view of data on previous slide

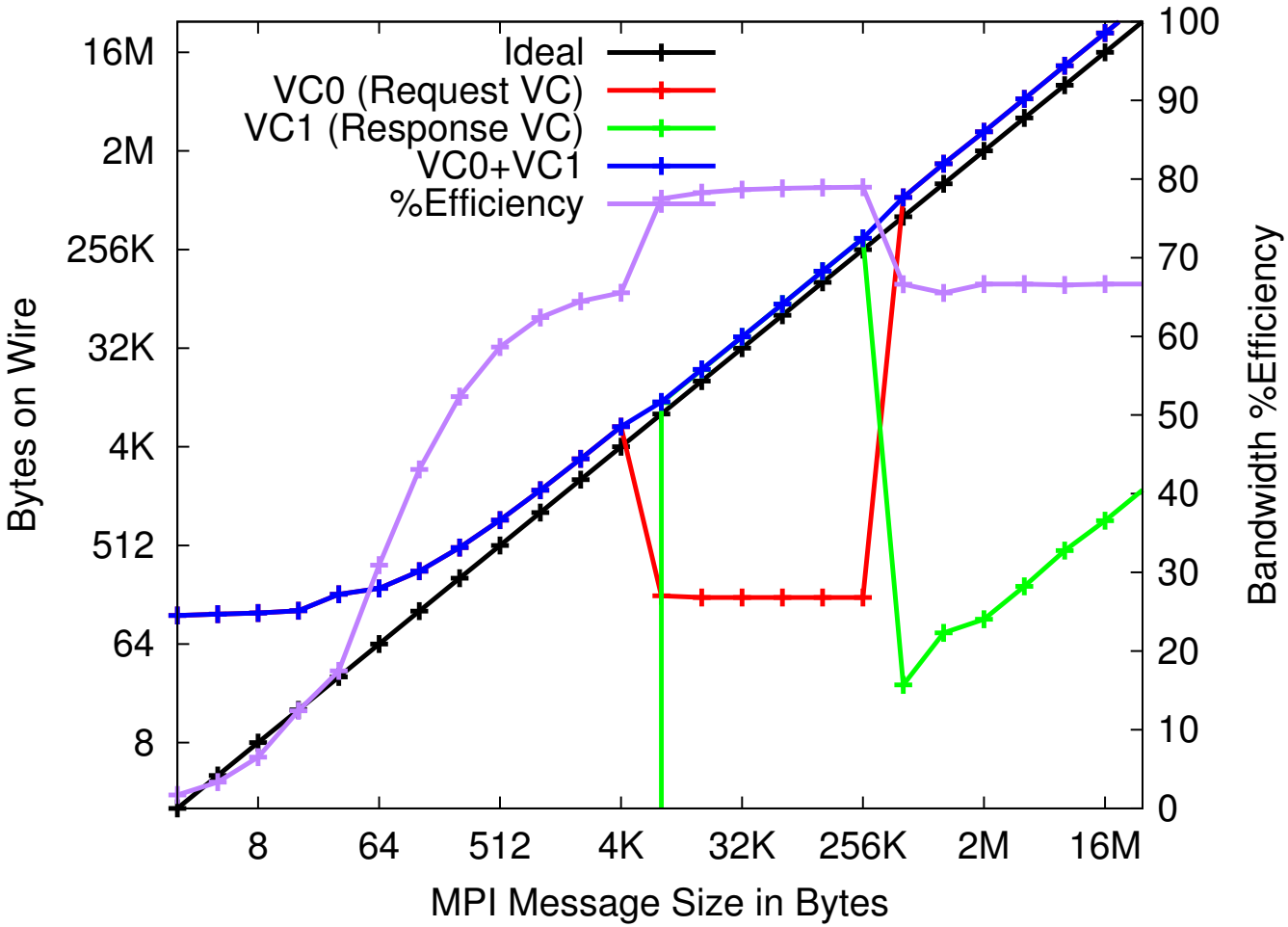


Routing

- Performed experiments to verify empirical counters matched routes output by “rtr --logical-routes” command
- Static routing
  - All packets from a given src to dst always travels the same path
  - The path from (src to dst) not the same as (dst to src) in general
    - Request and response packets follow different paths
- All routes completely traverse the X dimension, then completely traverse Y dimension, then Z last
  - More flexible routing if there are link failures, didn’t verify
  - Should consider PUT ACK + GET REPLY backflows in system models



MPI Point-to-Point BW Efficiency (Initiator Transmit Only)



- Observing VC0 and VC1 traffic reveals the MPI protocols, PUT push vs. GET pull based
- Purple curve plots bandwidth efficiency, uses scale on right Y axis
- Lower bandwidth efficiency for small messages, due to ~64 byte MPI header
- Results highly repeatable, appear accurate even for zero byte messages

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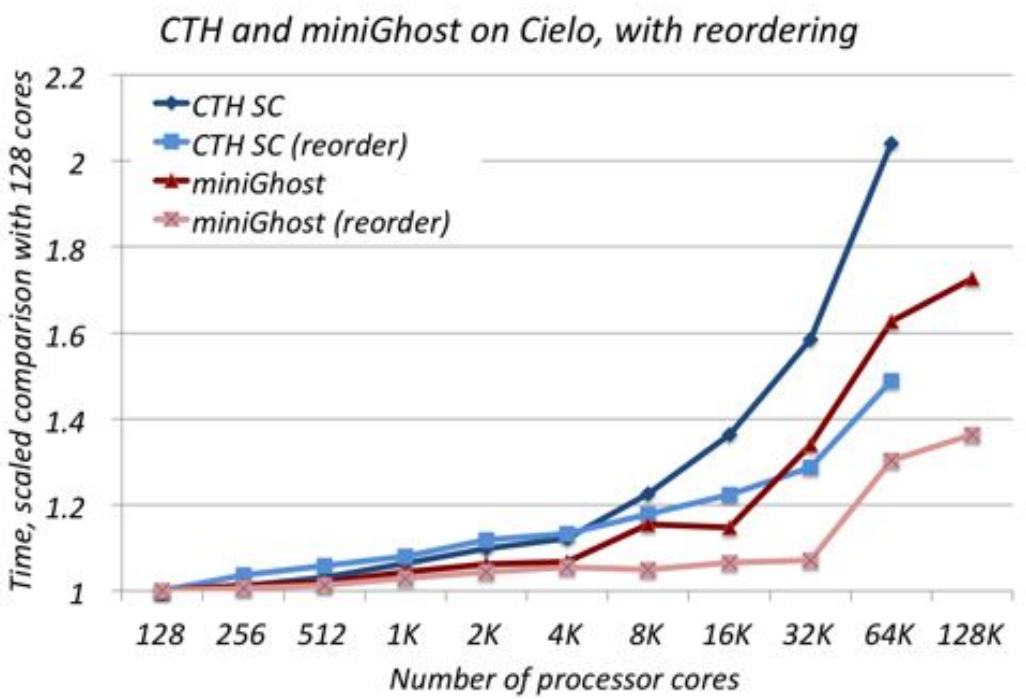
Large-scale MiniGhost Experiments

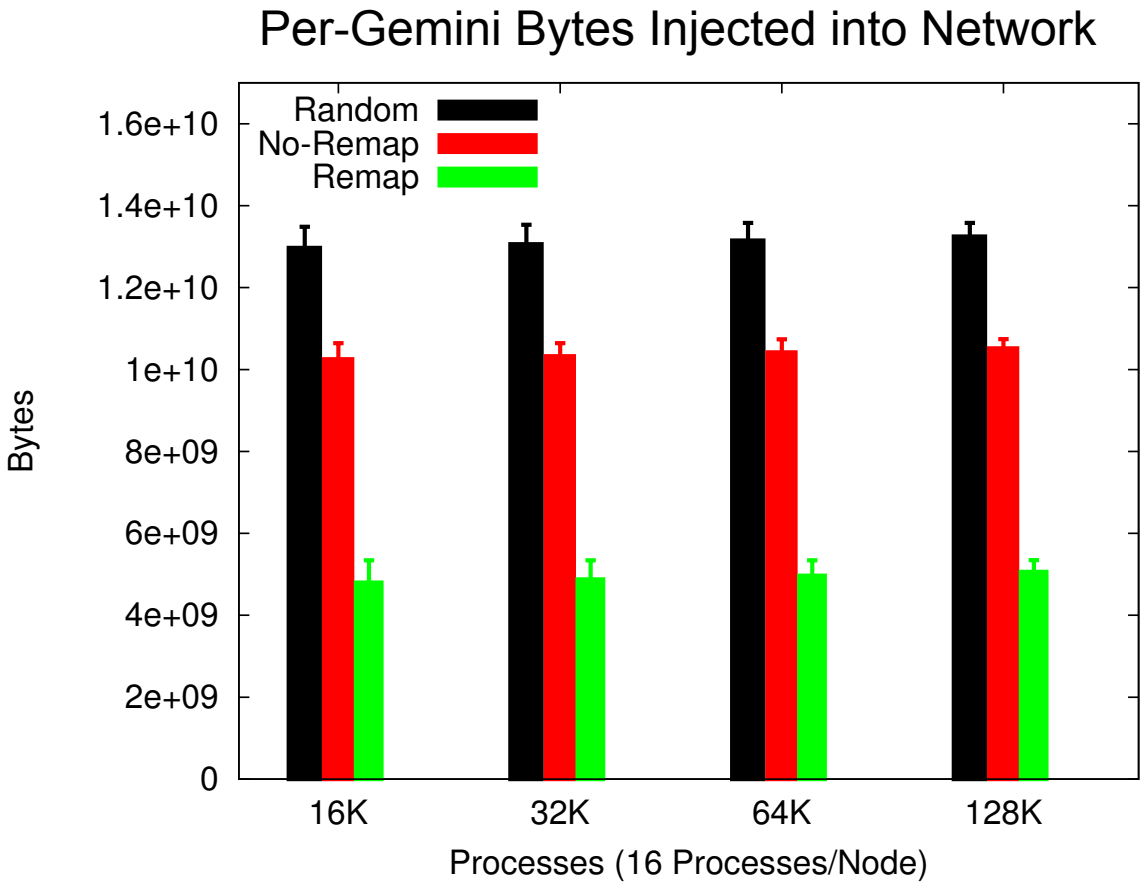


- MiniGhost is a proxy application, represents CTH full application
- Explicit time-stepping, synchronous communication, 27-point stencil across 3-D grid
- Dark Red Curve:
  Original configuration
  scaled poorly after 16K cores
  (1024 nodes, 512 Geminis)
- Light Red Curve:
  Reorder MPI rank to node mapping to reduce off-node communication

  Original: 1x1x16 ranks/node

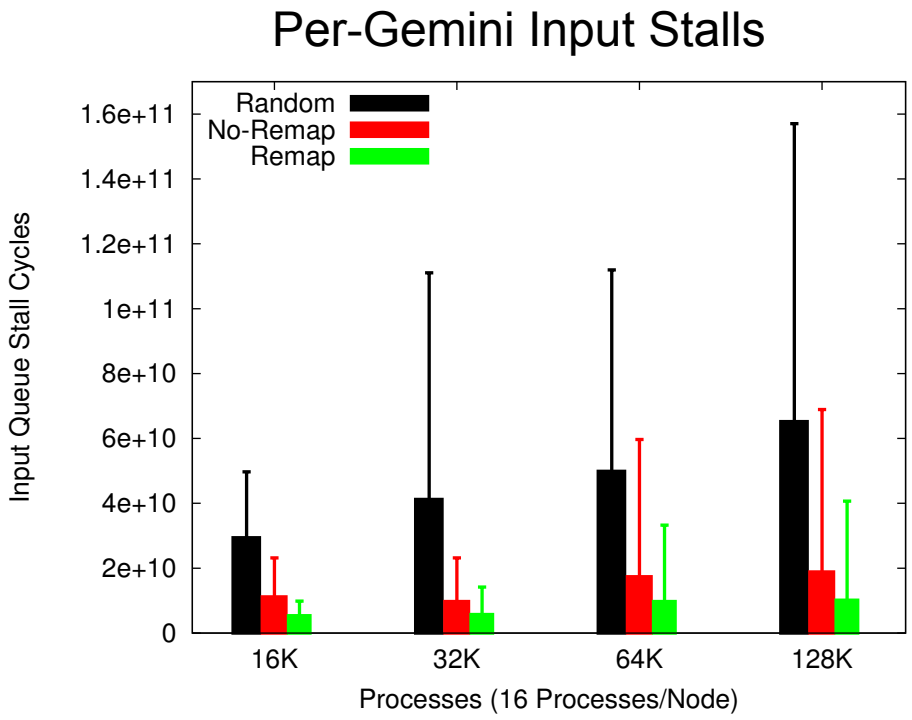
  Reorder: 2x2x4 ranks/node

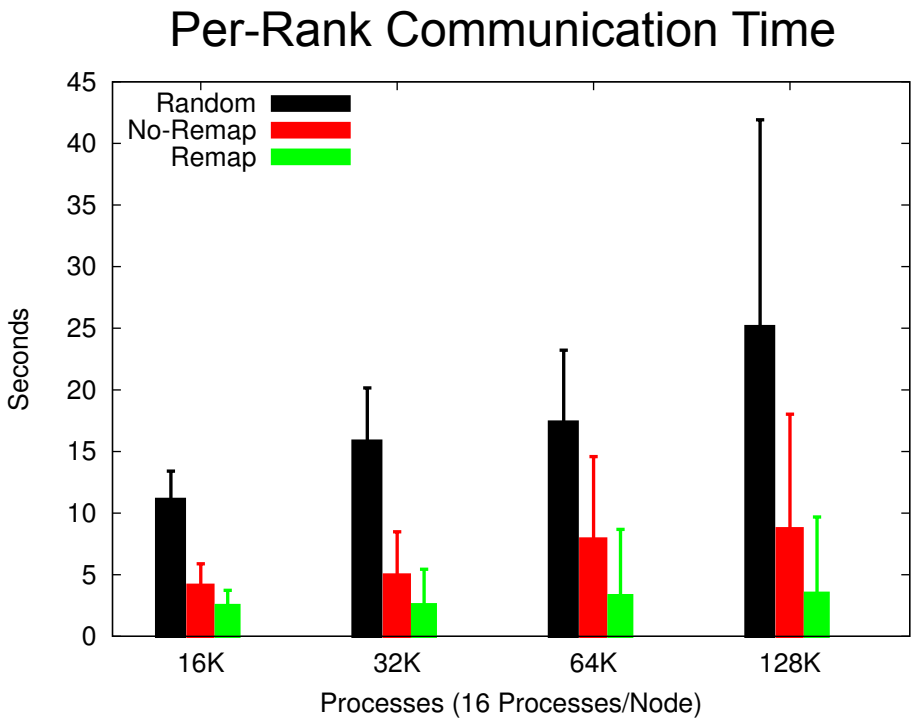
Reducing Off-node Communication



- Changing the mapping of MPI processes to nodes affects off-node communication
- Used Gemini tile counters to measure traffic injected on the host links
- The reordered "Remap" scheme (2x2x4) reduces off-node communication by more than a factor of 2x compared to the original "No-Remap" scheme (1x1x16)

Stalls Correlate with Communication Time





Per-Link Input and Output Stalls 128K Process Runs (4K Geminis)

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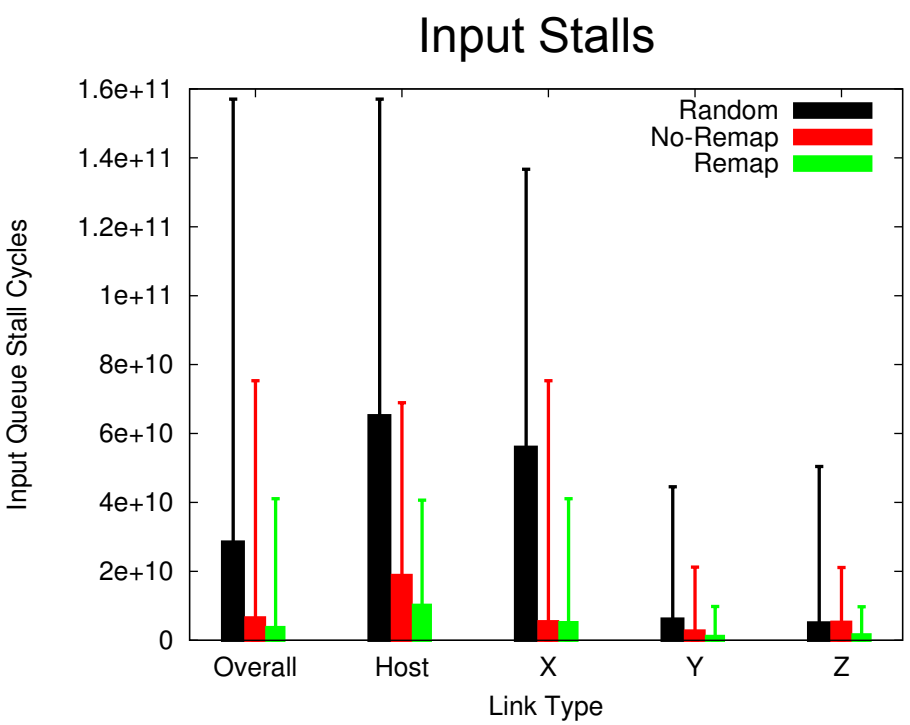
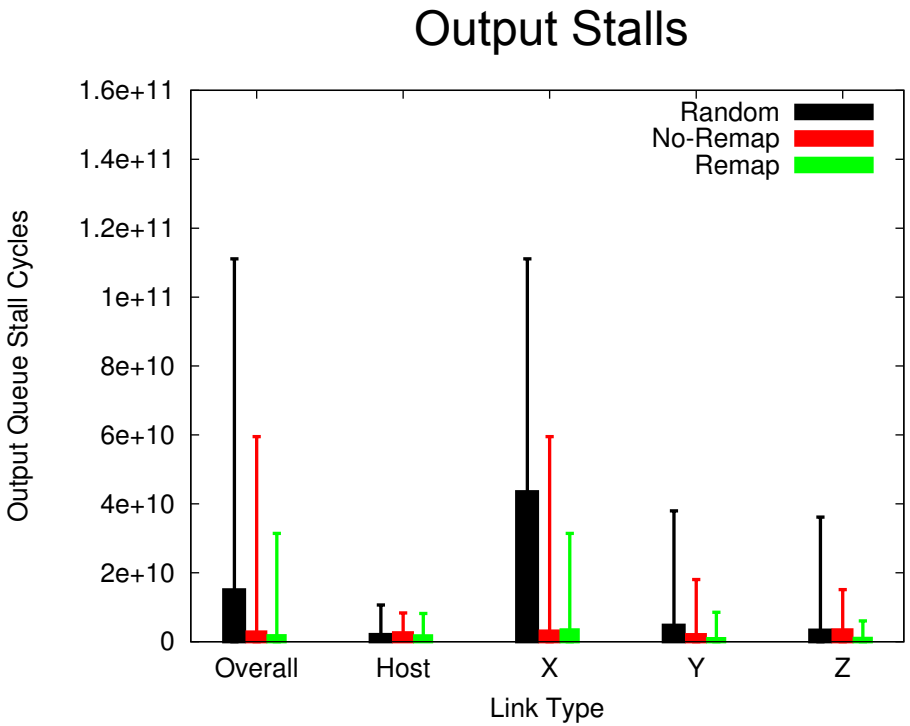
- Remap scheme reduces maximum load on any link (error bars)
- X-dimension has highest congestion, likely due to routing alg.





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Future Work

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- Investigate Cray PAPI support for Gemini and Aries
  - *Using the PAPI Cray NPU Component,* Cray Inc., Mar. 2013. Available: http://docs.cray.com/books/S-0046-10/

- Evaluating topology mapping strategies
- Dynamic (re)partitioning based on real-time counter info
- Investigate Aries network

Conclusion

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- Direct access to Gemini tile performance counters
- Convert tile counters to logical network link counters
- Gemini counter operation
  - Put and Get transactions
  - Counter directionality (count incoming packets/phits)
  - Routing
  - MPI bandwidth efficiency
- Used counters to quantify MiniGhost rank remapping scheme

- Plan to release Gemini Monitor library as open source, email ktpedre@sandia.gov in the meantime

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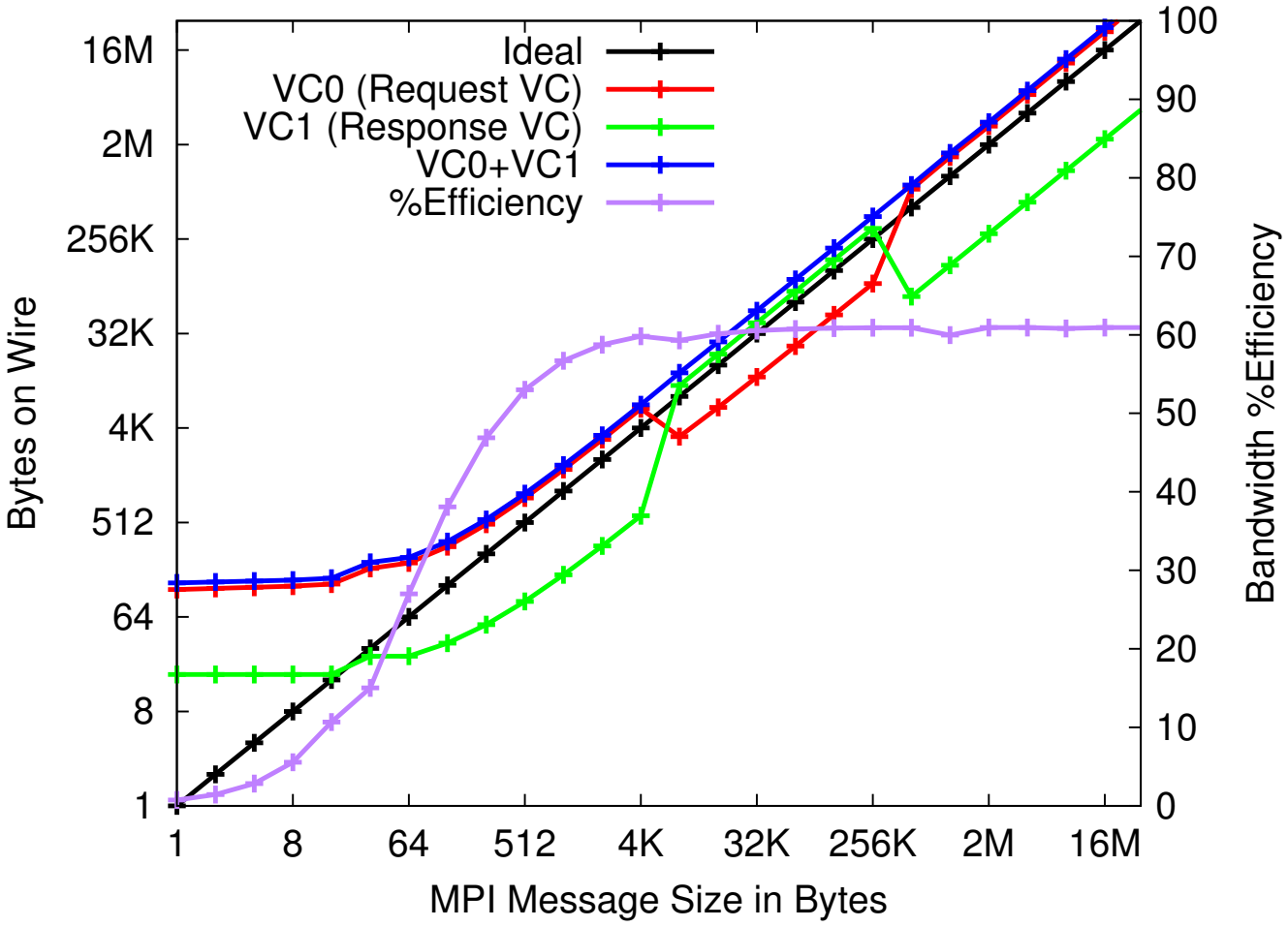
Backup Slides

MPI Point-to-Point BW Efficiency (Overall, Transmit + Receive)



- This plot includes all traffic on the wire, including response traffic (PUT ACK and GET REPLY)
- Large messages achieve ~60% bandwidth efficiency, larger max packet size would help