The Design and Implementation of an Asynchronous Communication Mechanism for the MPI Communication Model

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Background (1)

- Large scale commodity clusters (1,000 nodes)
  - Linux + TCP/IP + Ethernet is variable
    - Ethernet: Large scale non-blocking switches
    - TCP/IP: Processing overhead is modest now
  - Good MPI implementation is needed
- Demand for asynchronous handling of messages
  - MPI has new applications in wide-area communication
    - Read operation only takes a small amount of data each time from a slow link
- Old Socket API
  - Polling-based API (behavior is synchronous/serialized)
  - Overhead proportional to #connections

Background (2)

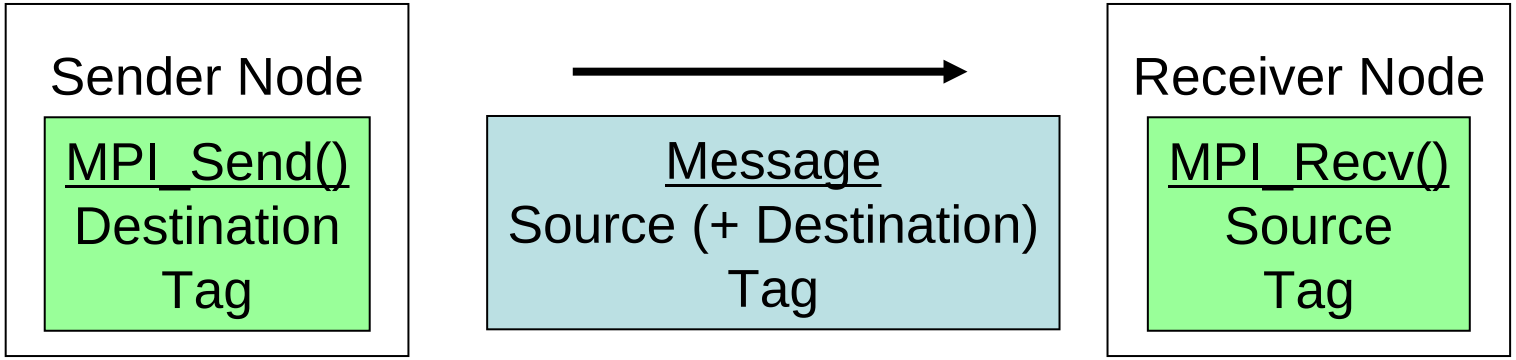
- Problems of Sockets in implementing MPI library
  - Frequent system calls
    - Loop with a pair of **select** and **read**
    - Serialize receive processing
  - Large overhead on large scale clusters
- <u>Design a simple kernel module for MPI</u>
  - MPI message handling in the interrupt handler
    - Bypass Socket API
    - No changes to TCP/IP layers and NIC drivers
  - Loadable driver module of Linux
    - No kernel reconfiguration, no rebooting needed

Outline

- Basics: MPI Communication Model and Typical MPI Implementation
- Issues on Socket API
- Design and Implementation of O2G Driver
- Performance Evaluation
- Related Work (brief)
- Summary

MPI Communication Model

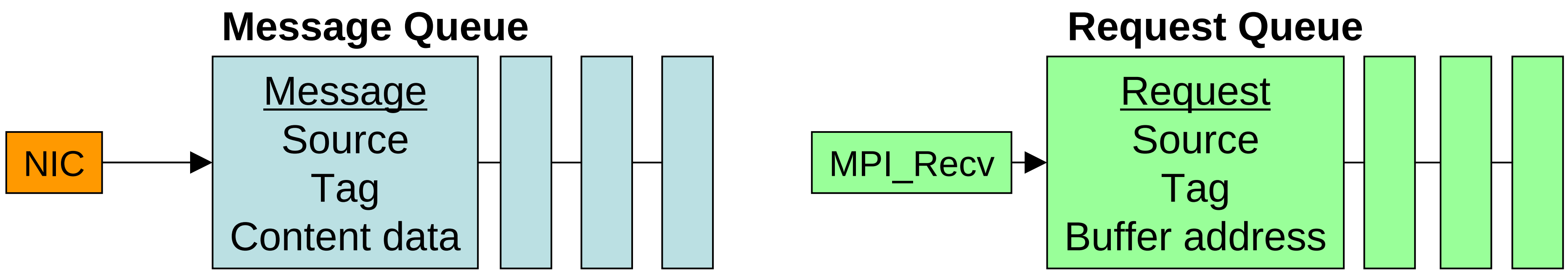
- Basic operations of MPI
  - MPI_Send(buf, size, datatype, **destination**, **tag**, comm)
  - MPI_Recv(buf, size, datatype, **source**, **tag**, comm, status)
- Matching of messages
  - Sender: specify destination process and tag
  - Receiver: specify source process and tag



Message Matching: Messages are exchanged between MPI_Send and MPI_Recv when a source and destination and a tag match

Typical MPI Implementation

- Two queues
  - **Message Queue** (Unexpected Queue)
    - Hold received messages, whose matching MPI_Recv is not yet issued
  - **Request Queue** (Expected Queue)
    - Hold MPI_Recv requests, which is pending for an unreceived message
- MPI_Recv only receives matching messages
  - Unmatched messages/requests are queued



Issues on Sockets (1)

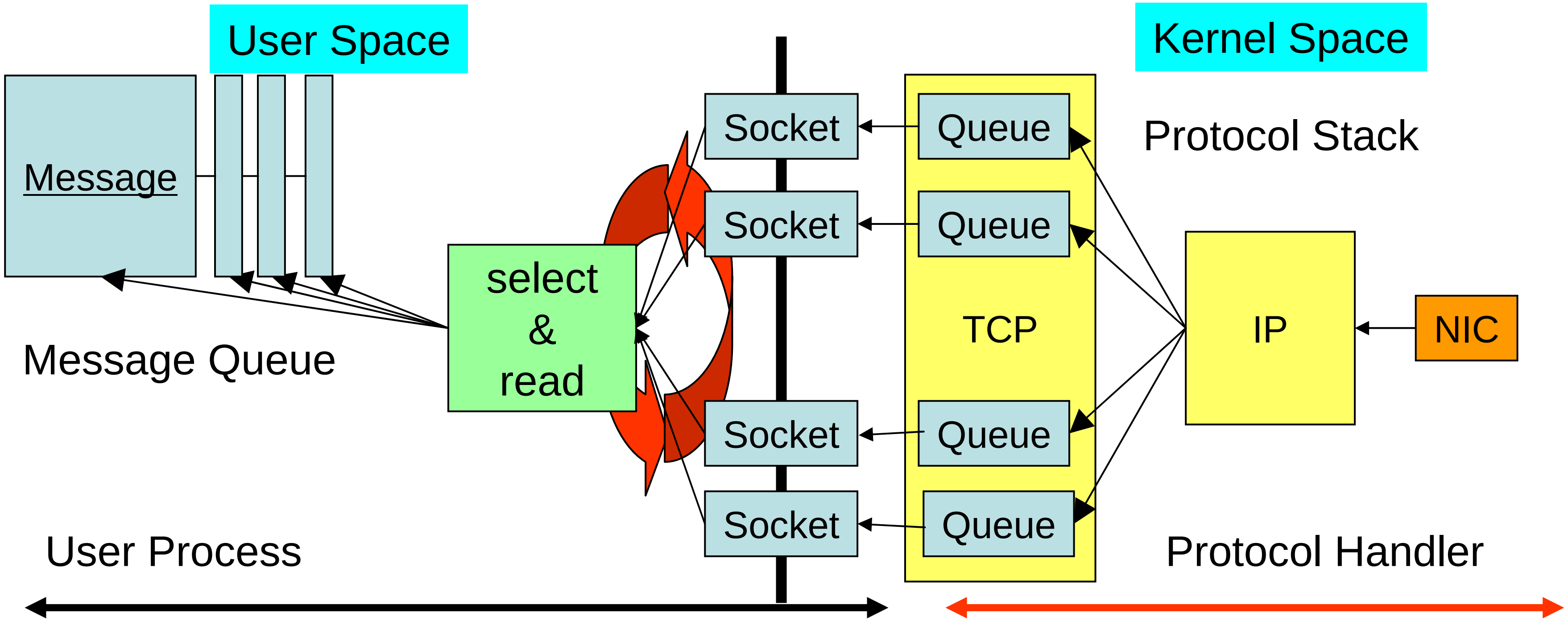
- Socket: Communication end-point
  - Communication API of OSes: Linux, Unix, (Windows)
  - Connection oriented stream (over TCP/IP)
- Receiver should repeatedly read out communication stream for matching messages
  - Search for a message whose tag matches
  - Need asynchronous receive of messages
    - Sometimes independent from program specification
  - Delay of receive operation affects TCP/IP flow control
    - Sensitive to latency, because of end-to-end control
- Socket API is not designed for MPI

Issues on Sockets (2)

- Loop with **select** and **read** for asynchronous receive
  - Polling results in frequent system calls
    - Serialize processing on each Socket
    - Serialize header decoding followed by body receive
  - Sockets are set to *non-blocking mode*
    - Read finishes prematurely, still increases system calls
- Implementations do not support large number of Sockets
  - Overhead is proportional to #connections
  - Overhead is for connected connections (not active ones)

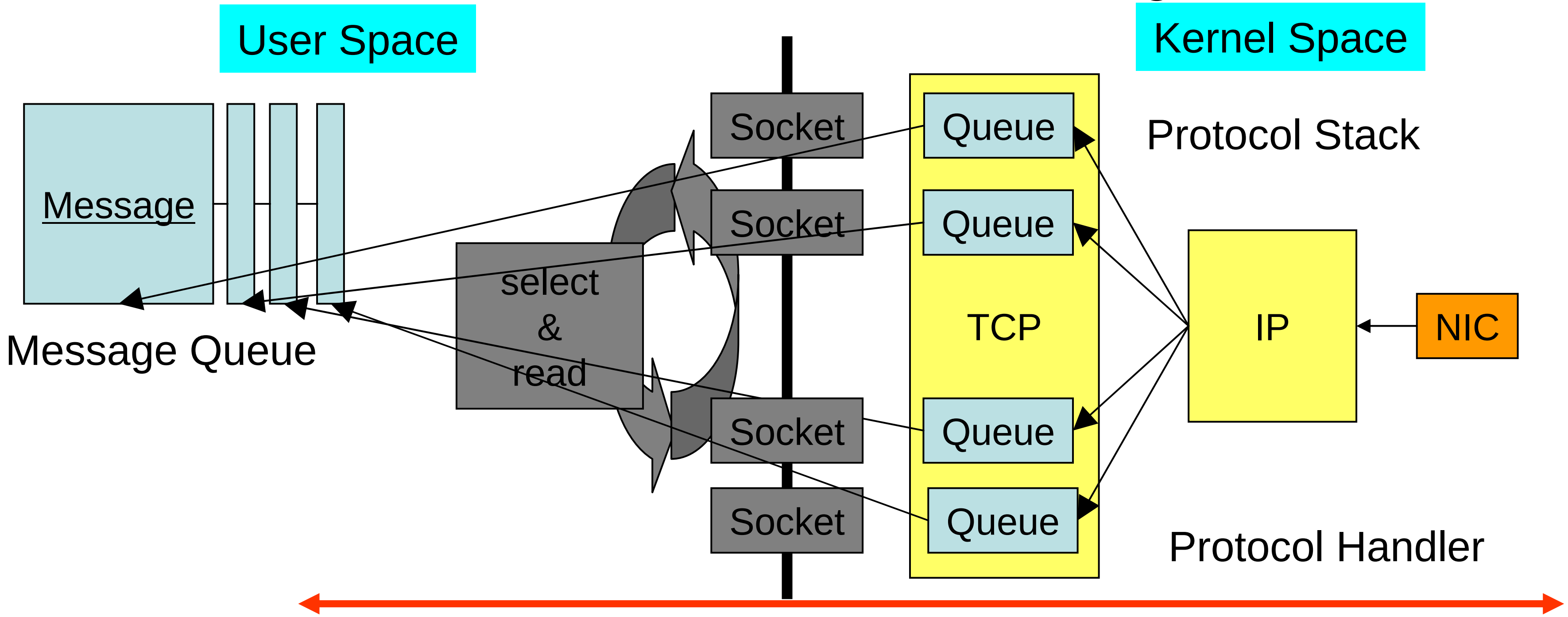
MPI Implementation with Sockets

- Loops with **select** and **read** system calls
  - **select** detects a socket with receive data
  - **read** extracts data from kernel space to user space
- Source/destination and tag matching is done in user space



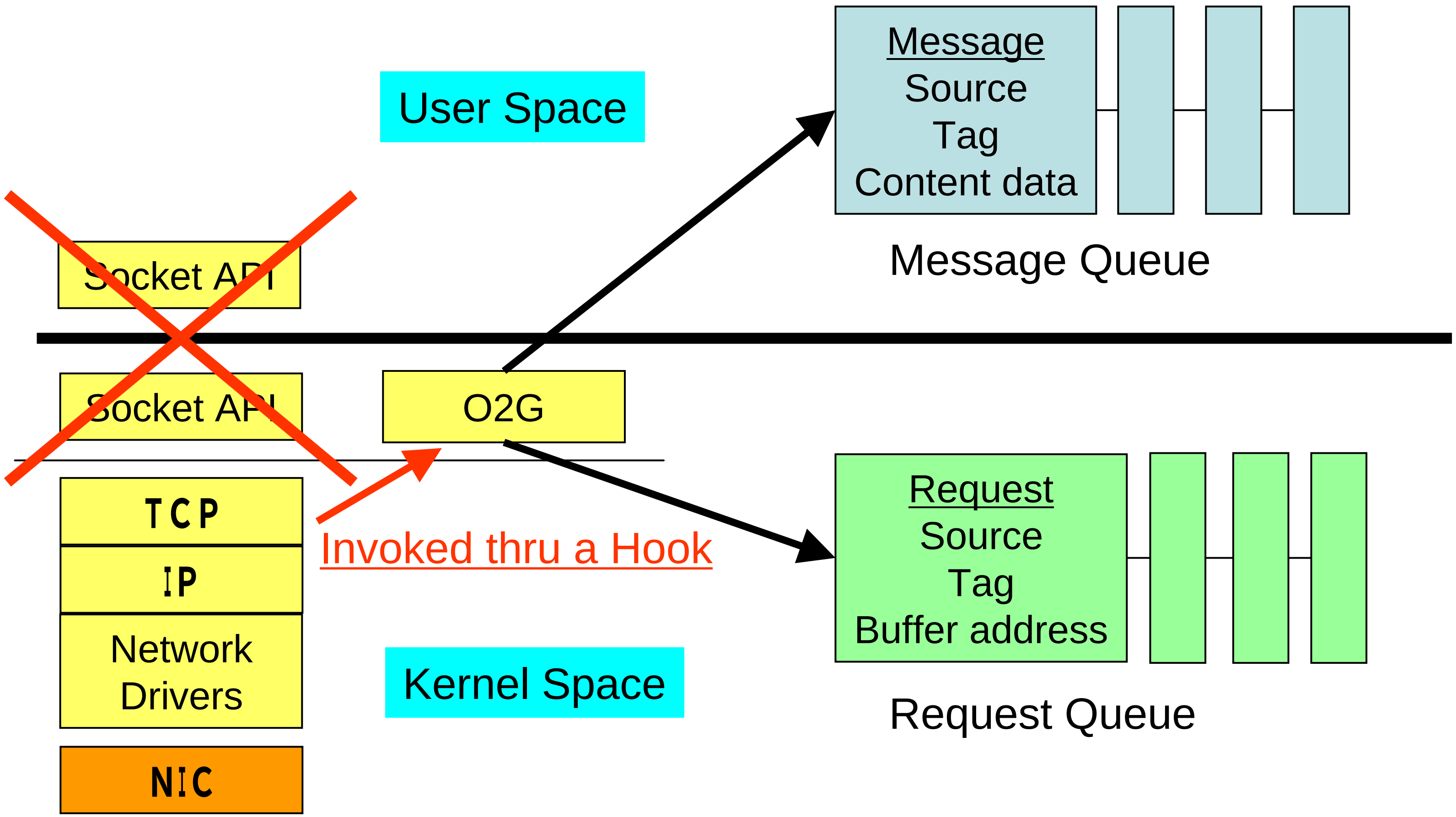
Design of O2G Driver (1)

- O2G driver bypasses Socket layer
- Queue operations are in protocol handler
  - Match tag and source/destination
  - Write message data directly to user space
  - Internal work is similar to **read**, matching is extra



Design of O2G Driver (2)

- Linux driver module
  - Data is immediately handled by the interrupt handler
  - Data is written to user space directly



Implementation of O2G (hook function)

- O2G driver is invoked thru a hook function
  - Hook is for Kernel NFS (Network File System) in Linux
  - Hook is set per socket, called for each packet
- Hook usage example:

```
{
    /* Register a hook */
    struct sock *sk = ...;
    sk->data_ready = data_ready_fn;
}
void data_ready_fn(struct sock *sk, int len) {
    tcp_read_sock(sk, ..., data_recv_fn);
}
int data_recv_fn(..., struct sk_buff *skb, int off, int len) {
    char *buf=...;
    skb_copy_bits(skb, off, buf, len);
}
```

Implementation of O2G (API)

- API of O2G
  - Library API to wrap IOCTL of the driver
  - Initialization
  - Receive request queue operation

```
/* Initialization */
o2g_init(int n_socks);
o2g_register_socket(int sock, int rank);
o2g_set_dump_area(void *area, int size);
o2g_start_dumper_thread(int n_thrds);

/* Request entry API */
o2g_put_entry(struct queue_entry *e);
o2g_cancel_entry(struct queue_entry *e);
o2g_free_entry(struct queue_entry *e);
o2g_poll(void);
```

Subtle Issues on O2G Driver

- Process context mismatch handling
  - Interrupt handlers sometimes cannot write user space
    - Delegate write processing to a pre-started user thread
    - Handle page fault in user space in the same way
- Race condition avoidance
  - Request queue is processed from both user process and interrupt handler
    - Race condition is detected by recording last few messages
    - O2G driver returns EAGAIN at detecting race condition
    - o2g_put_entry, o2g_cancel_entry

Evaluation: Base MPI Library

- Base MPI System: **YAMPII**
  - Developed at Univ. of Tokyo
  - Full MPI-1.2 (MPI-2.0 under development)
  - Full scratch, LGPL license
  - Supported communication layers
    - Socket (TCP/IP)
    - Myrinet (SCore-PM cluster system)
- Queue management code is modified for O2G
  - "YAMPII/Sock": Socket version (original code)
  - "YAMPII/O2G": O2G version

Evaluation: Setting

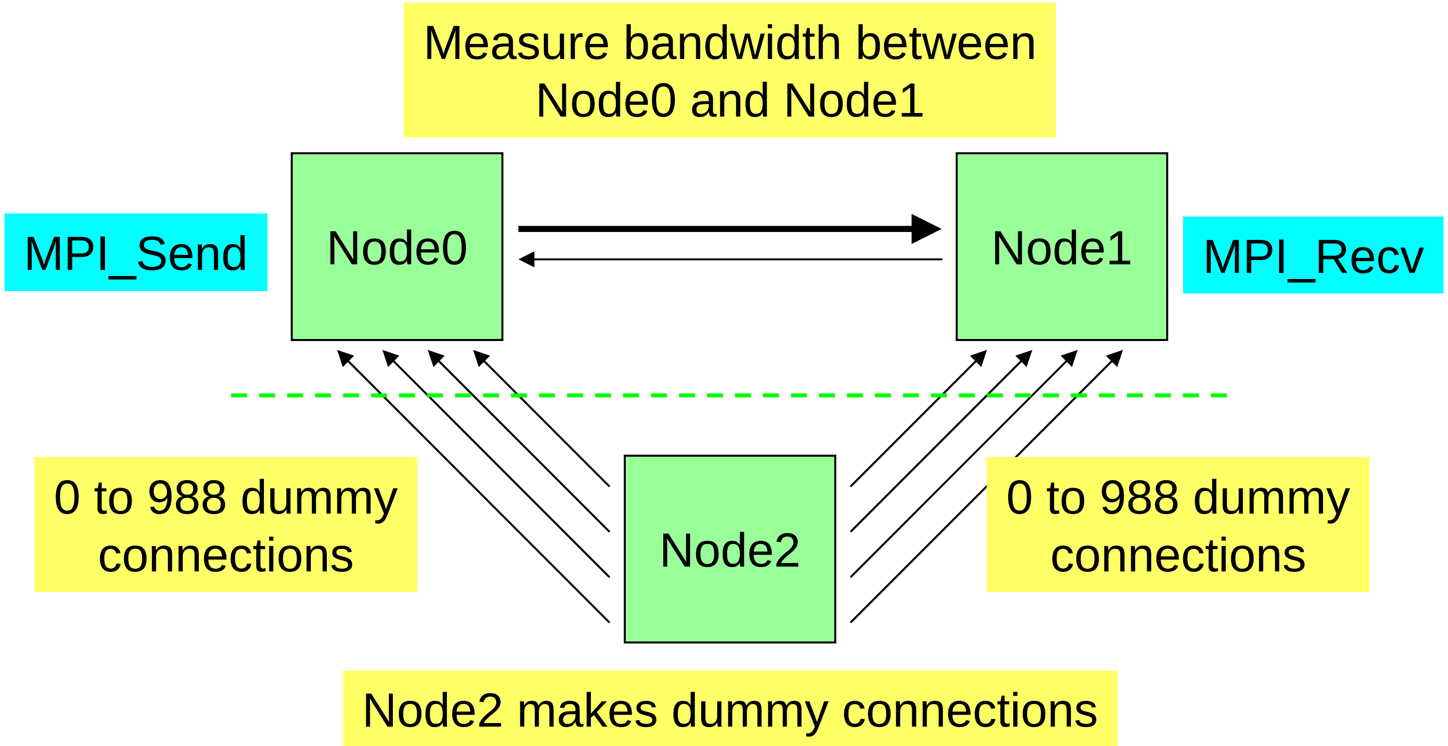
- Overhead reduction
  - Point-to-point bandwidth
  - Time spent in **select** system call
  - NPB (NAS Parallel Benchmarks)

Benchmark Setting

AIST Super Cluster (F32 Cluster, 256 Node)	
Node (use 1CPU each node)	CPU: Xeon 3.06GHz, 512KB L2 (Dual) Chipset: Intel E7501 Memory: DDR266, 4GB
OS	Linux-2.4.24
Network (Non-blocking switch)	NIC: Intel 82546EB (Driver: e1000 5.2.2) Switch: Force10 Networks E1200
Compiler	GCC (ver 3.3.3) -O3

Evaluation: Bandwidth (1)

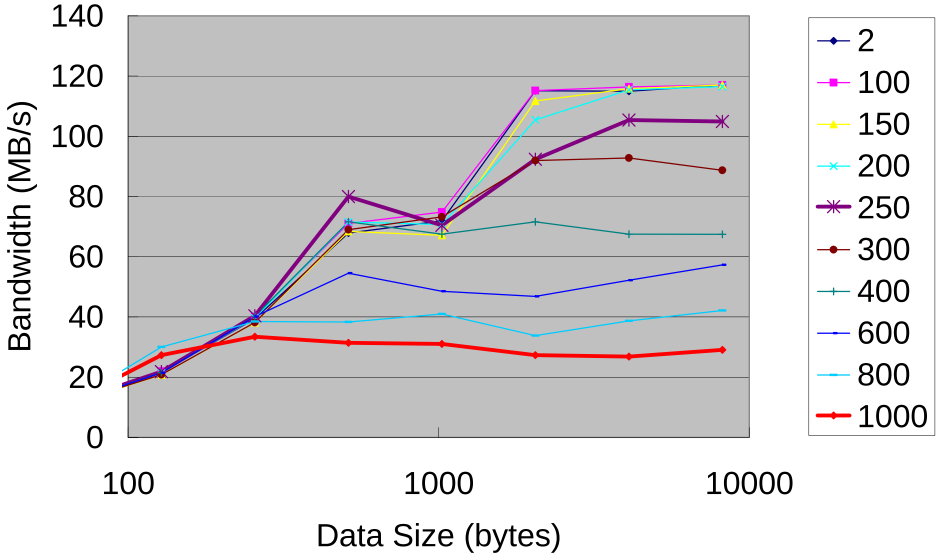
- Bandwidth varying #connections
  - Artificially add connections
  - Vary #connection from 2 to 1,000
  - Third node (Node#2) makes dummy connections, but does not perform any communication



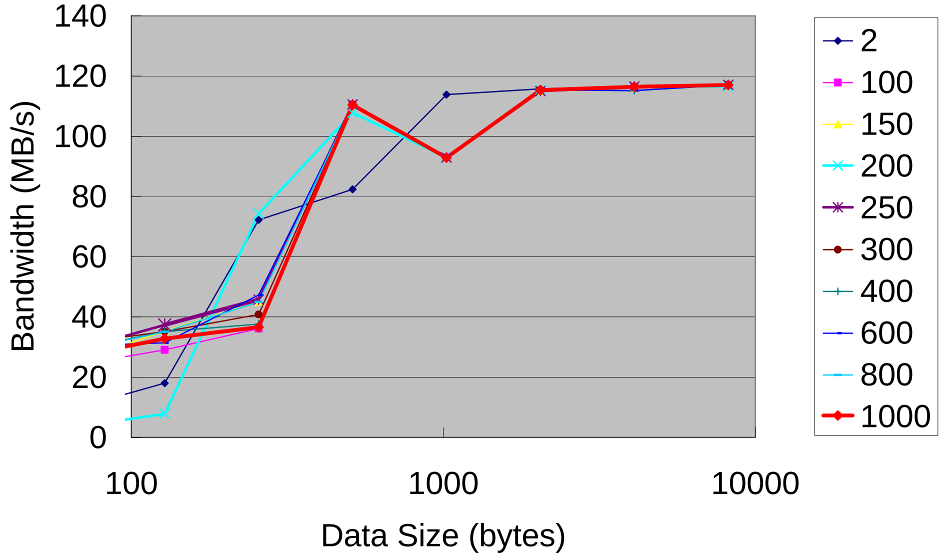
Evaluation: Bandwidth (2)

- Point-to-point, uni-directional
  - Message size: 64B to 8KB (X-axis log-scale)
  - O2G is not affected by #connections
  - Socket also performs well upto 200 connections

YAMPII/Sock

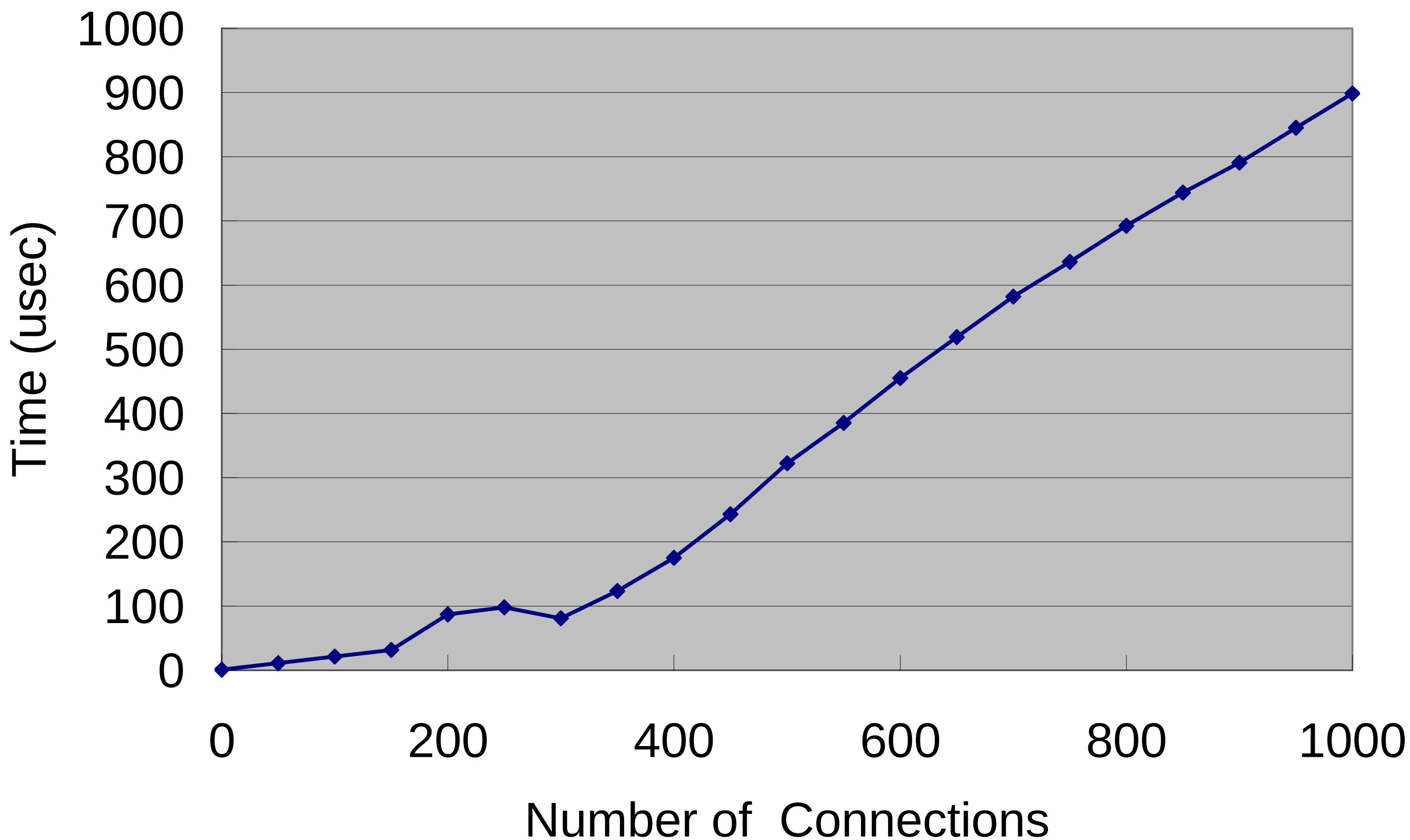


YAMPII/O2G



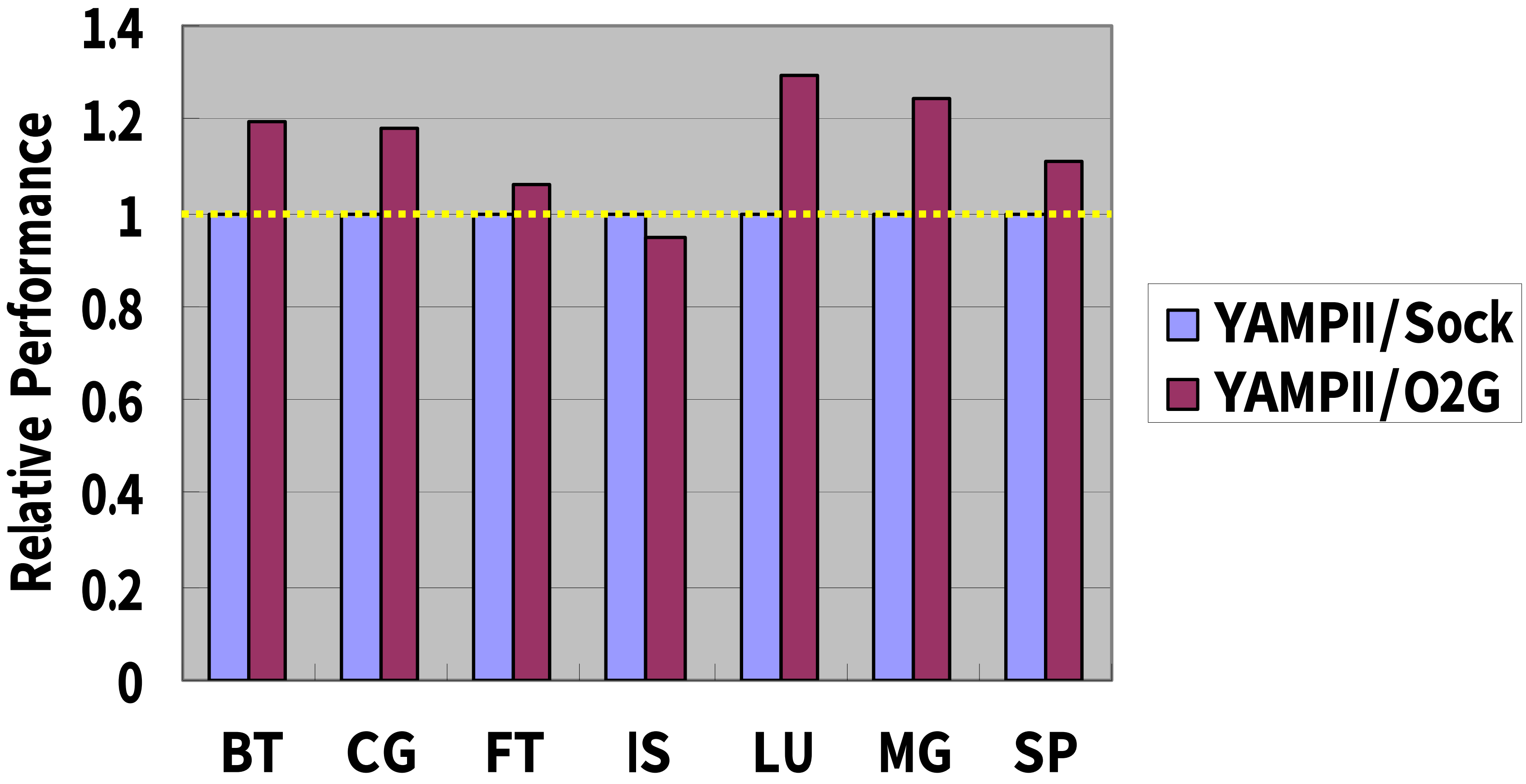
Evaluation: Select Time

- Time spent in **select** system calls
  - Vary #connections, no message data
  - Measurement by CPU clock counter (min from 10 trials)



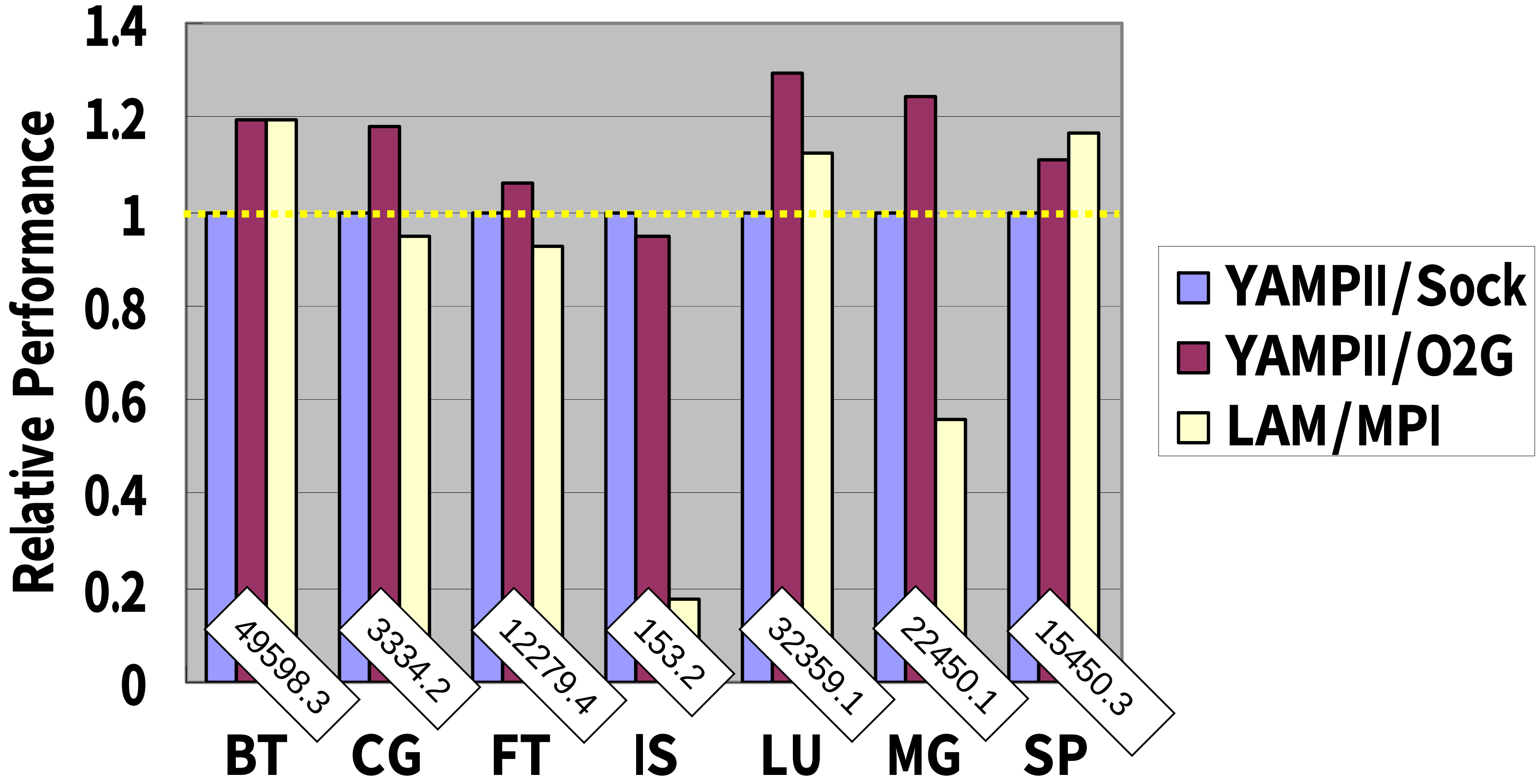
Evaluation: NPB Benchmarks (1)

- NPB (NAS Parallel Benchmarks, Ver 2.3)
  - 256 Nodes NPROCS=256, Data set size CLASS=B
  - Relative Performance to YAMPII/Sock (Mops/total)



Evaluation: NPB Benchmarks (2)

- NPB (NAS Parallel Benchmarks, Ver 2.3)
  - 256 Nodes NPROCS=256, Data set size CLASS=B
  - Add LAM/MPI performance for comparison



Related Work

- Overhead reduction of **select**
  - **kqueue** (FreeBSD)
    - Filter events (eventlist filter)
  - **devpoll** (Solaris) (**epoll** in Linux kernel 2.6)
    - Confines sockets to check, with a device /dev/poll
- Asynchronous I/O (aio_read/aio_write)
  - Large data I/O in background processing
- O2G advantage
  - devpoll (kqueue) needs as many as system calls
    - Behavior is still polling based
  - Asynchronous I/O needs as many as system calls
    - Body read can be issued after header decode

Summary

- MPI optimizing driver for large scale commodity clusters
  - Simple & straightforward O2G driver module
  - Overhead reduction of system calls
  - Asynchronous behavior
  - No changes to TCP/IP layers and NIC drivers
  - Most queue operations of MPI done in interrupt hander
- Evaluation in middle scale cluster with Ethernet
  - Performance independent to #connections
  - Observe 10% to 20% speed up in 256 nodes
- Future work
  - Evaluation of merit of asynchronous behavior
  - Design of an abstract interface, currently most part is YAMPII specific

END