RI2N/UDP: High bandwidth and fault-tolerant network for a PC-cluster based on multi-link Ethernet

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Outline

- Motivation and background
- Design and implementation
  - System construction
  - Protocol
- Performance evaluation
  - Throughput, fault tolerance, latency
- Related works
- Conclusion and future work

Motivation & background

- Interconnection used in clusters
  - SAN (System Area Network)
    - High bandwidth, low latency, high availability, large scalability
    - Expensive for small-scale clusters
  - Ethernet
    - High performance/cost ratio
    - Lower performance, availability and scalability

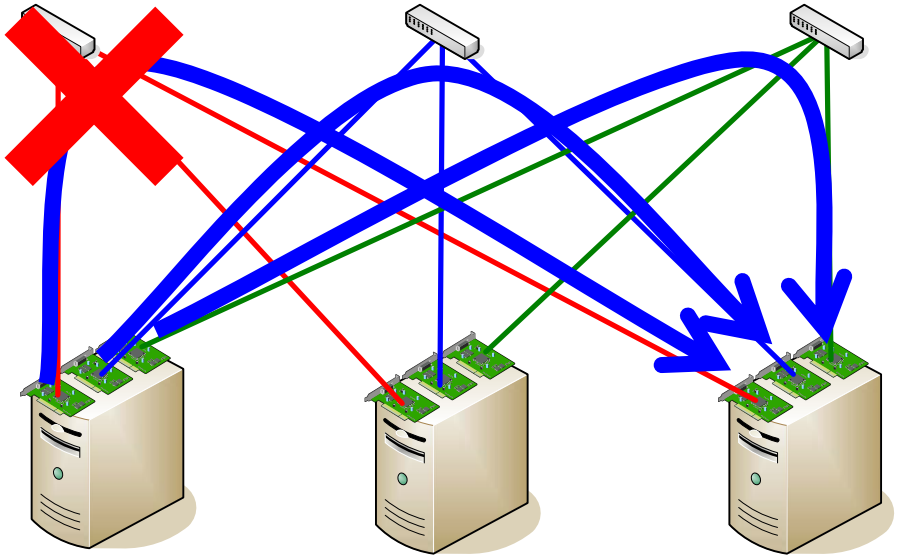
Providing high performance and high availability with multi-link Ethernet only by software

RI2N

Redundant Interconnection with Inexpensive Network

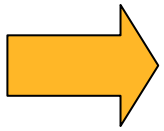
Concept of RI2N

- High bandwidth and fault-tolerant network based on multi-link Ethernet
  - High throughput between nodes
    - Data striping
  - Fault tolerant function for clusters
    - Redundant links and switches



Previous implementation of RI2N/TCP

- User level prototype with TCP/IP
  - Establishes a TCP connection on each Ethernet link
  - Achieves 230MB/s using dual links of GbE
  - Fault tolerant function was not implemented
  - Problem of TCP behavior when hardware fails
    - Old linux TCP can be blocked for a long time in select() system-call
  - Both TCP and RI2N should care about retransmission

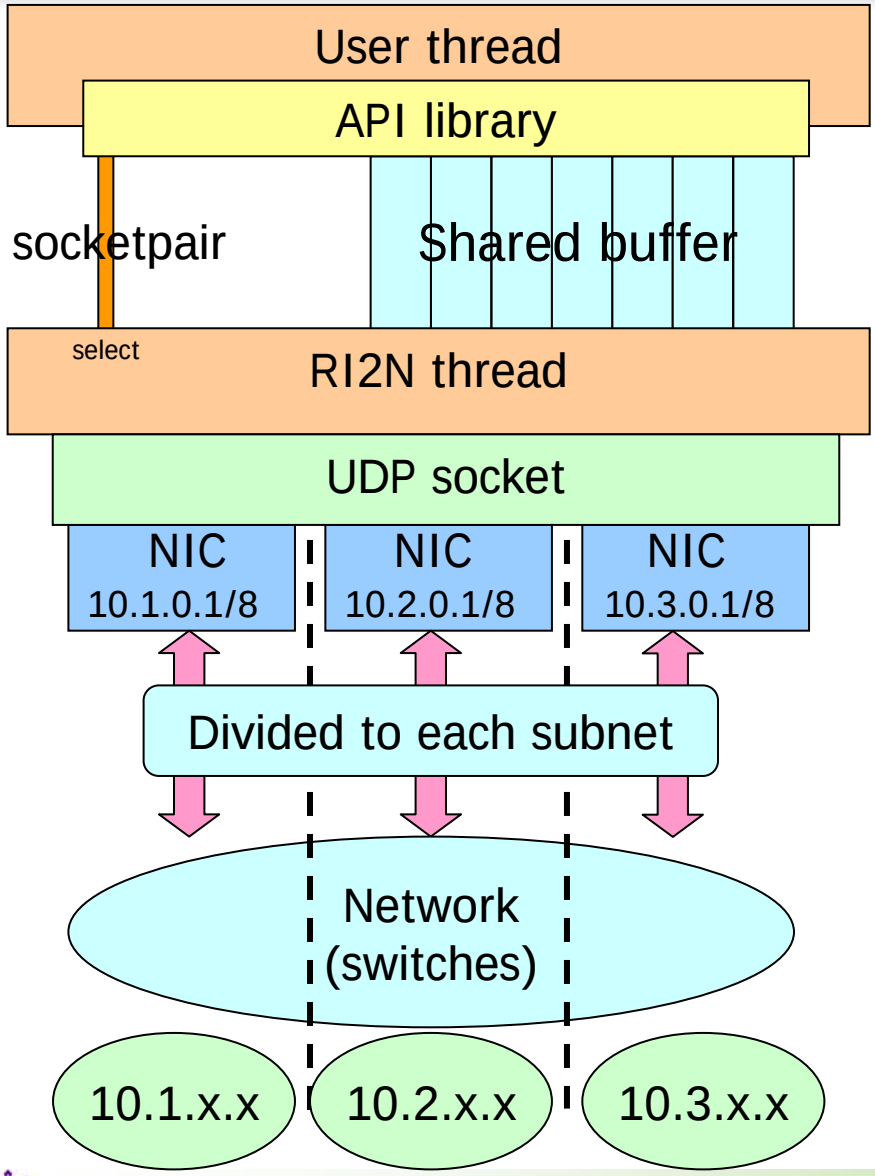


New implementation of RI2N with UDP/IP

Design of RI2N/UDP

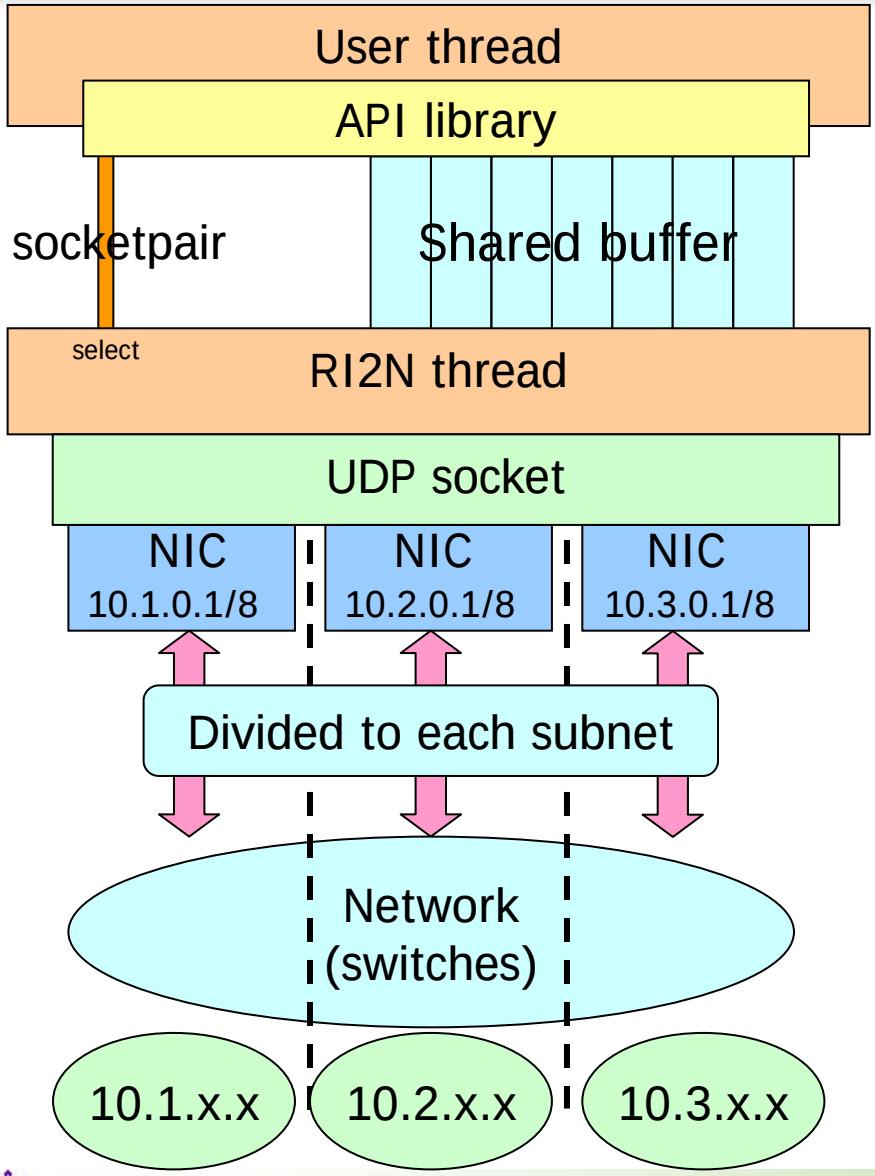
- User level implementation
  - High portability for various operating systems and hardware
- Implementation with UDP/IP
  - Using multiple subnet with private IP address space
  - Simple as like as IP, a protocol which doesn't care any packet-losses under it
  - Suitable to implement new protocols on it
- High bandwidth and fault tolerance
  - Data striping
  - Use of redundant links
- TCP compatible socket API
  - Easy to port existing applications for TCP
  - Guarantee the reliability
    - Acknowledgement, serialization, retransmission
    - Dedicated RI2N thread for asynchronous processing

System construction (1)



- TCP compatible API library
  - Called from application
- RI2N communication thread
  - created by initialization function in API library
- User thread
  - User application keeps running as user thread

System construction (2)



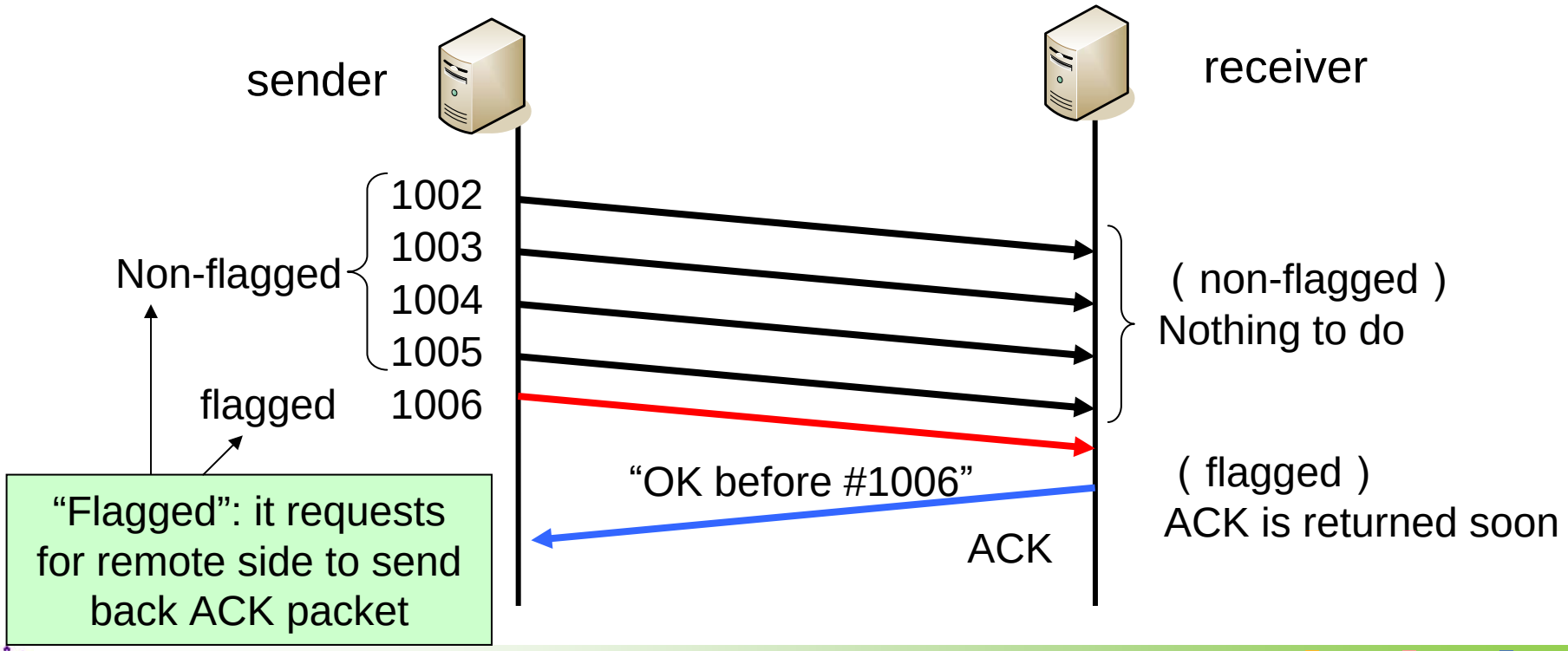
- Two data streams
  - Data sharing with user thread
  - UDP stream on multiple NICs
- Efficient handling and high throughput
  - select() for thread synchronization with socketpair
  - Shared buffer for data transfer with high throughput

RI2N/UDP protocol

- Packet transmission to multilink
  - Using data striping with round-robin manner
  - Assuming: a homogeneous multi-link
- Retransmission control
  - Multi-ACK packing to reduce the number of packets
  - Selective acknowledgement by bitmap
- Flow control
  - Simple window control
- Fault tolerance
  - Failure and recovery detection

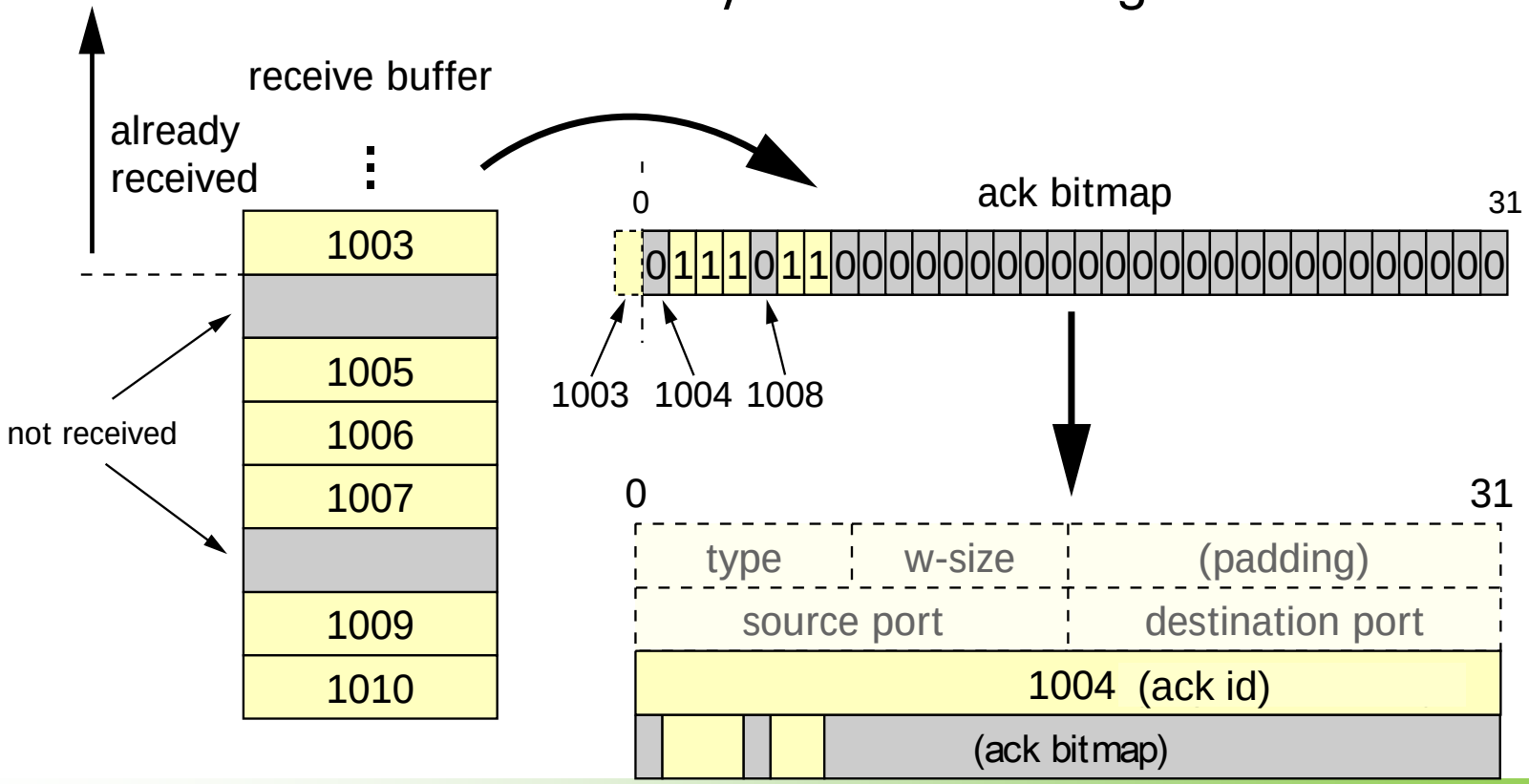
Retransmission control (1)

- Multi-ACK packing to reduce the number of ACK
  - Same technique as TCP acknowledgement
  - Each packet has an *ACK-id* pointing the packet which should be received next
  - Frequent packet racing causes a lot of retransmission



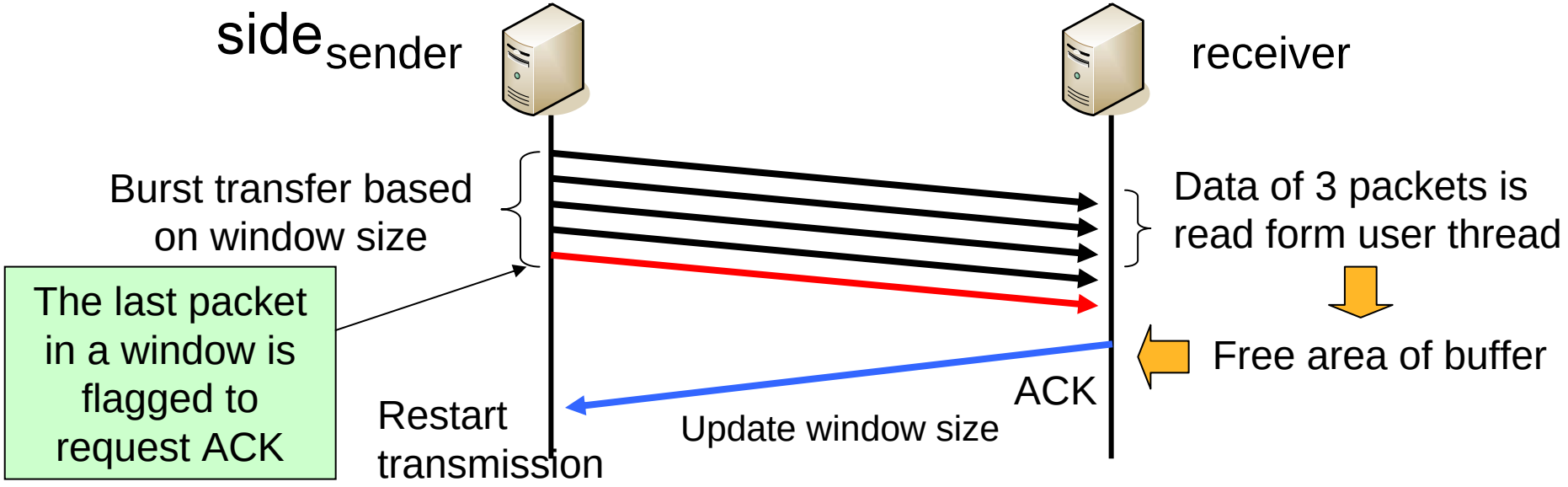
Retransmission control (2)

- Large buffer for serialization
- Selective acknowledgement
  - Bitmap represents the packets which have been already received and whose *seq number* are larger than *ack id*



Flow control

- Simple window base flow control
  - Less packet losses on cluster network
  - To utilize the max throughput of hardware
  - Receiver publishes the window-size
  - Window size = buffer size remained on receive side

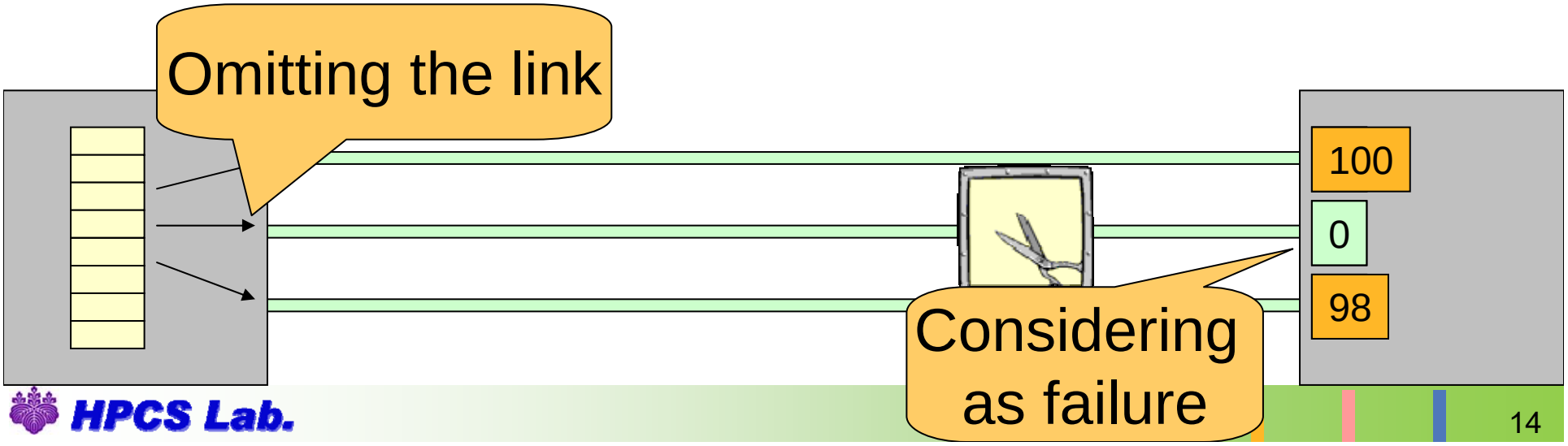


Policy of failure and recovery detection

- Failure detection
  - Significant degradation of throughput
    - Throughput falls to 1 to 10% of max throughput
  - Failure should be detected **as soon as possible**
- Recovery detection
  - Throughput keeps certain throughput after recovery
  - Recovery requires reconnection or replacement which takes few minute at least
  - Recovery does not have to be detected within seconds

Failure detection

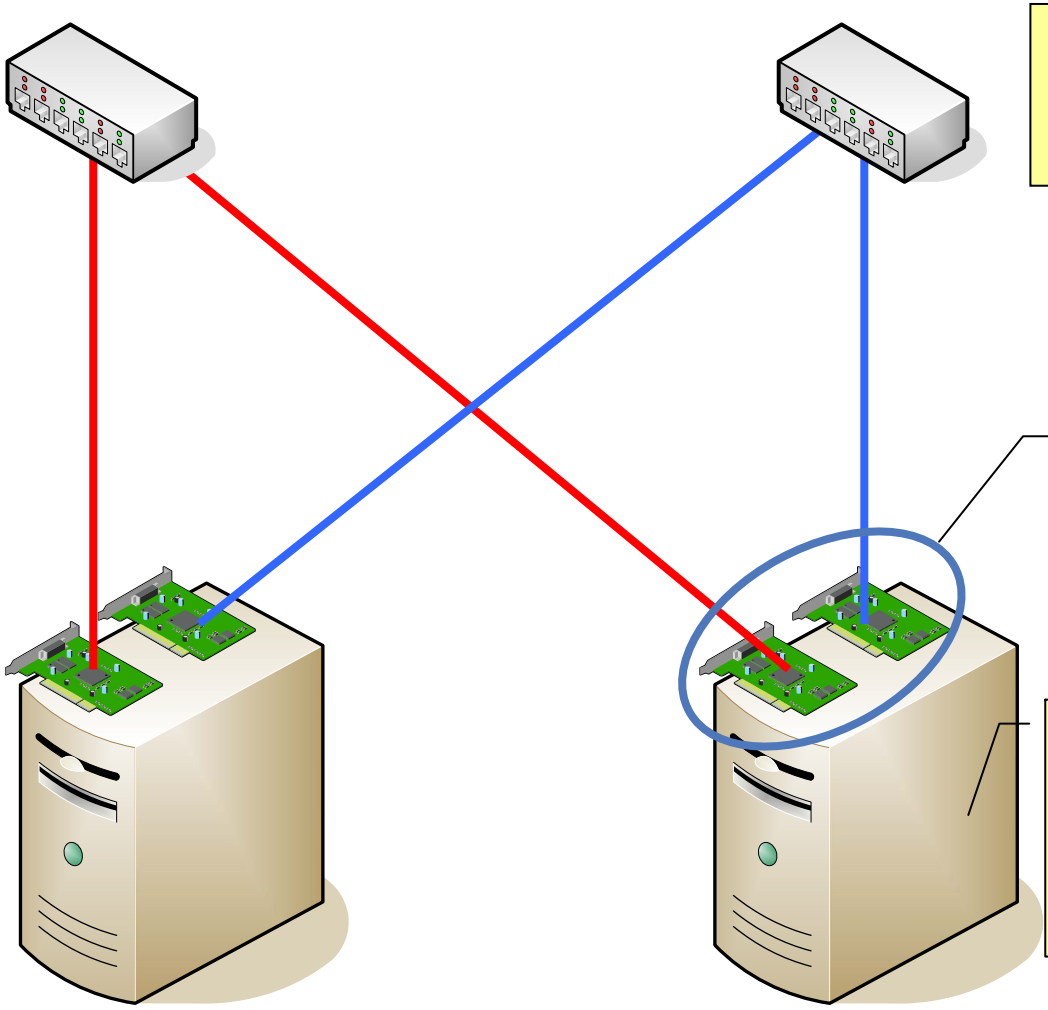
- Comparing the number of received packets
  - If the count of packets is largely differ from the others, the link can be considered as failure
  - Sharing the information between a pair of RI2N sockets
  - Omitting the failed link from the target list



Recovery detection

- Sending heartbeat packets on all links at an interval of few seconds
  - If a heartbeat is received at the link marked as “failed”, the link can be considered to be recovered
  - Adding the link to the target list

Performance evaluation

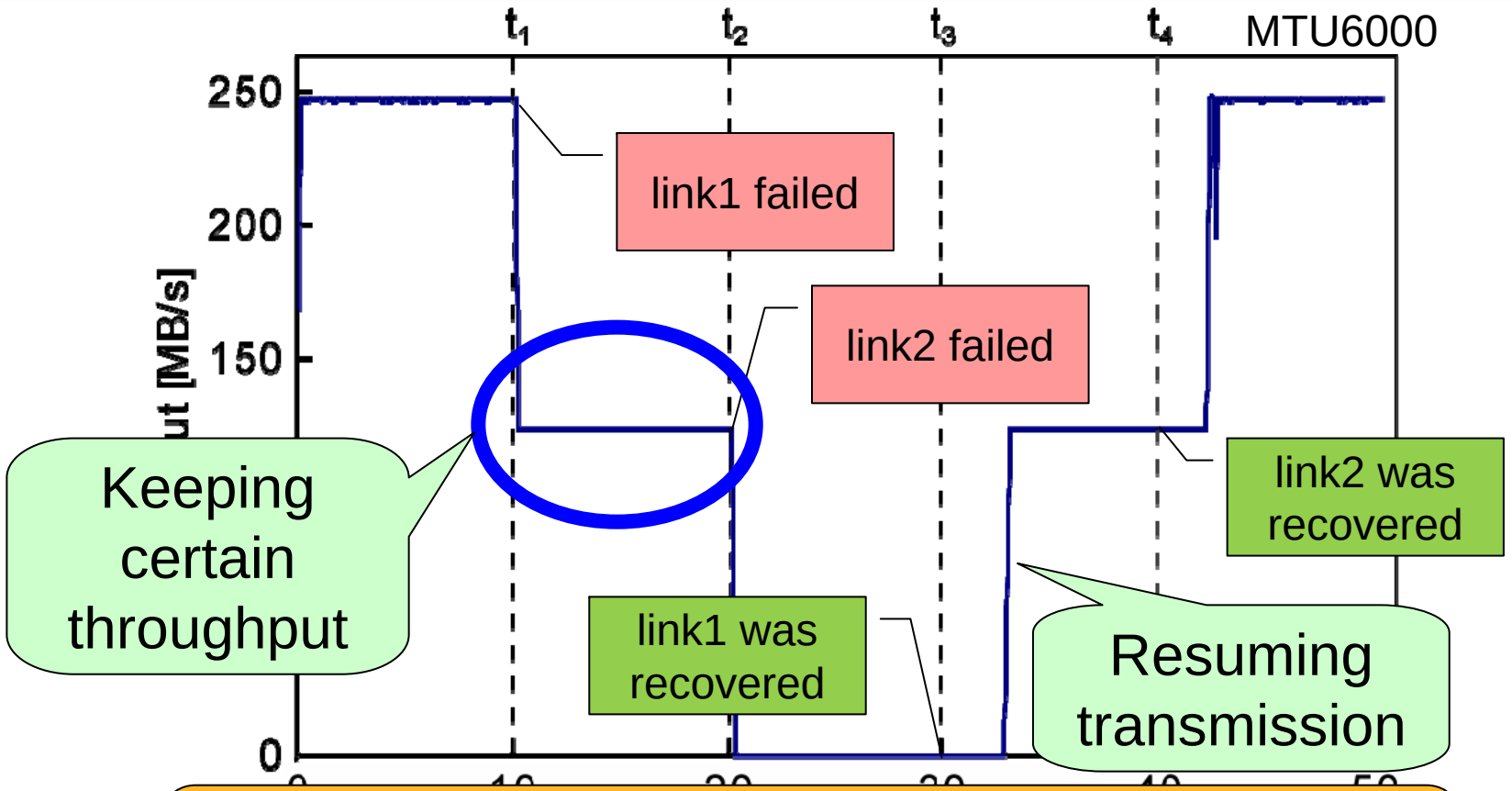


Dell PowerConnect 5224
(24ports GbE-switch)

Intel PRO/1000 MT
dual port

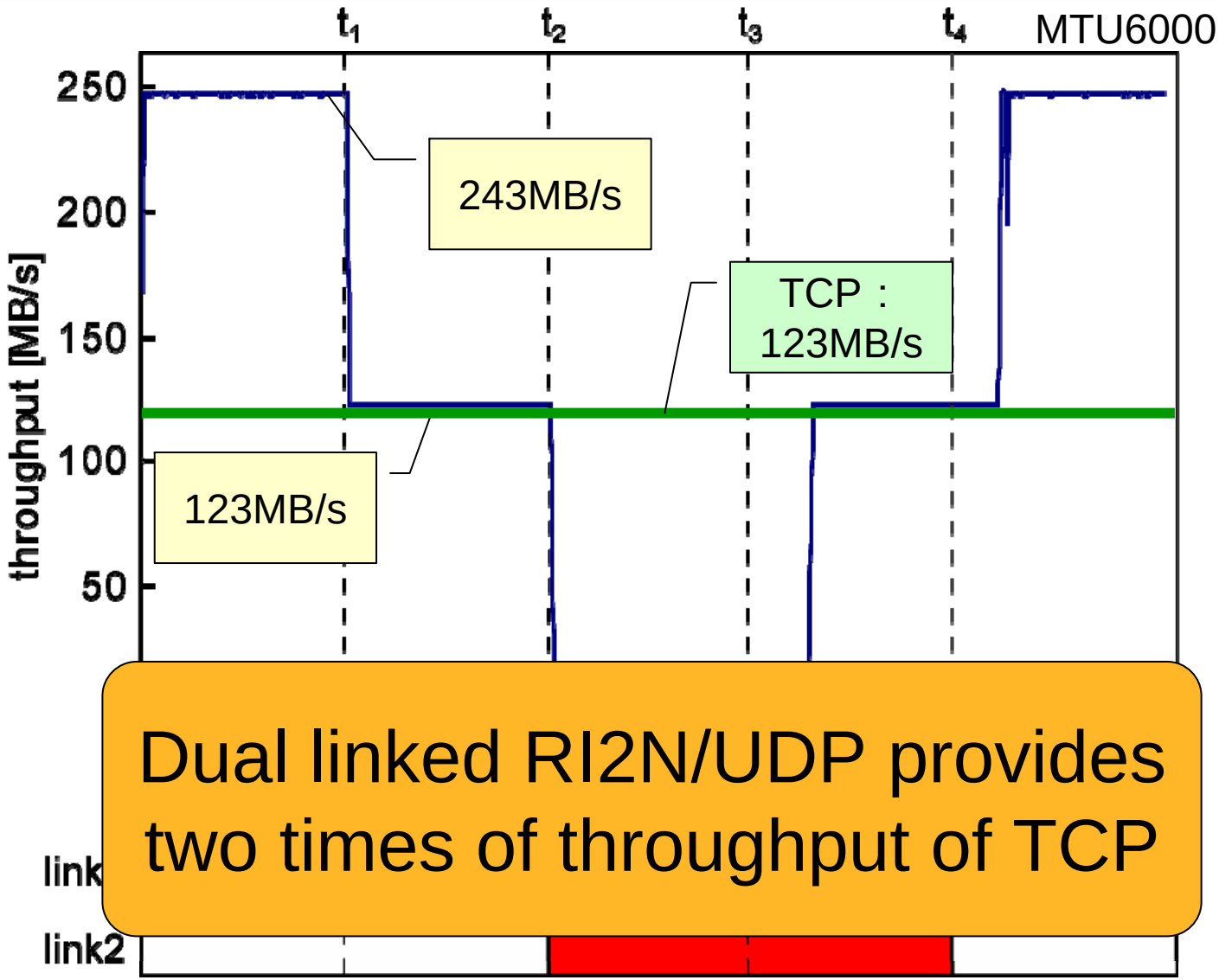
Intel-Xeon 3.0GHz
dual-channel DDR2-400 1GB
Linux 2.6.17
NIC driver e1000 7.0.33

Throughput before and after failure



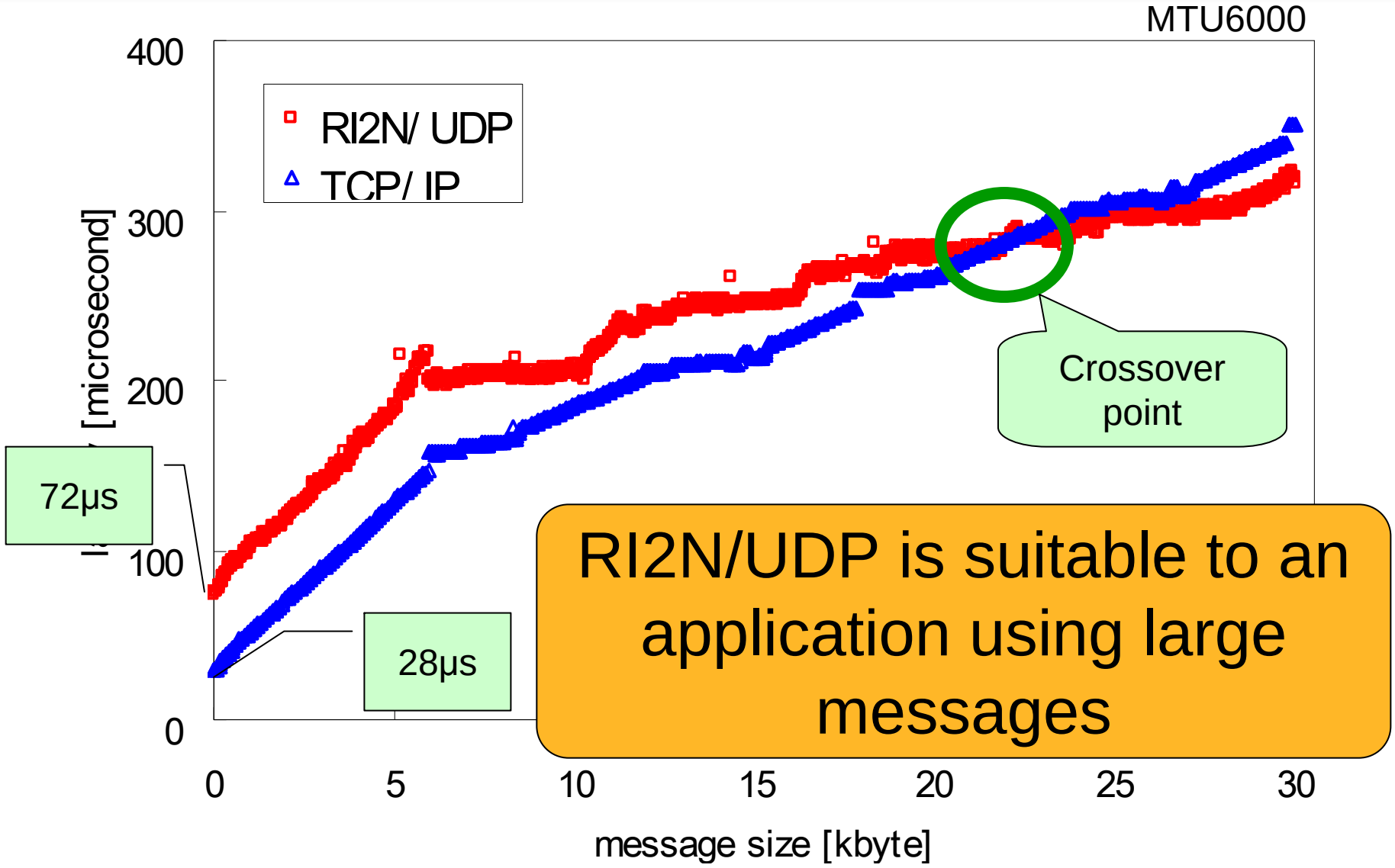
RI2N/UDP can keep communication on a partial link failure

Maximum throughput



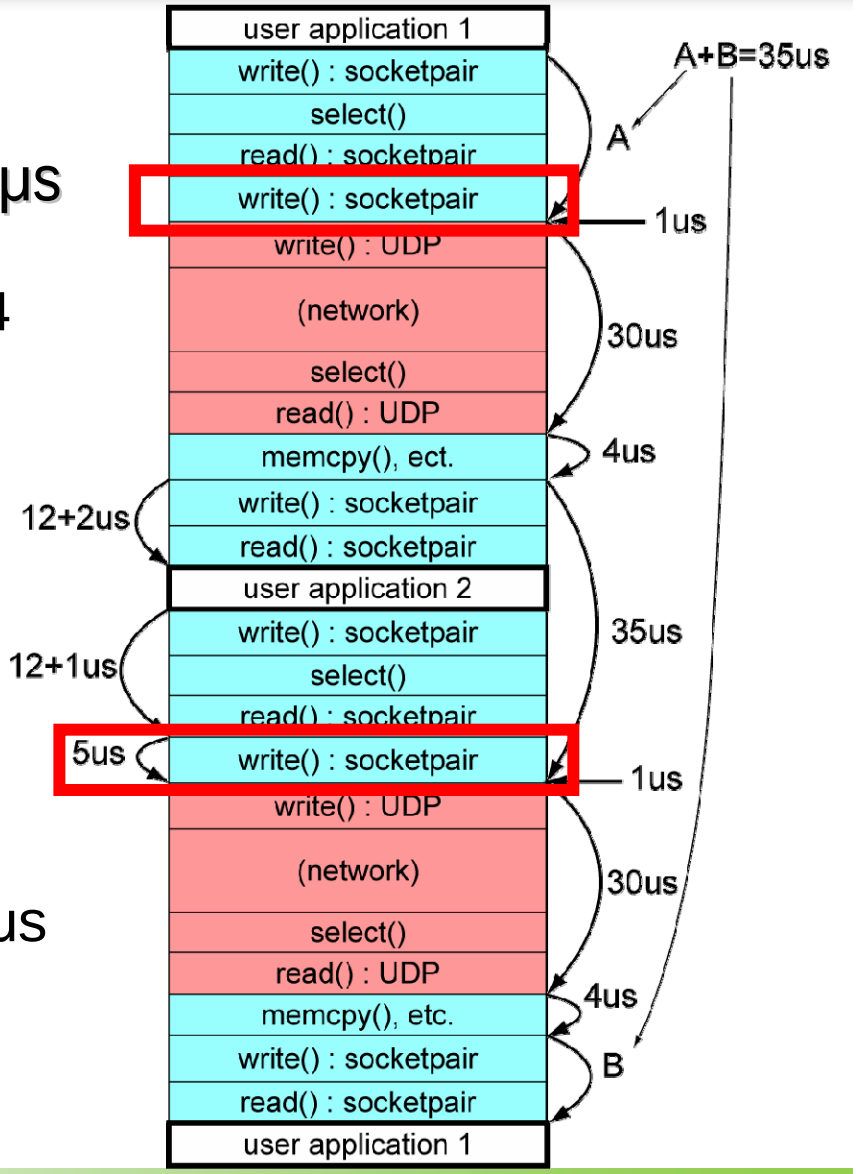
Dual linked RI2N/UDP provides two times of throughput of TCP

Latency


MTU6000
RI2N/ UDP
TCP/ IP
Crossover point
72µs
28µs
RI2N/UDP is suitable to an application using large messages
400
300
200
100
0
0
5
10
15
20
25
30
message size [kbyte]

An analysis of latency

- Detailed time required for RI2N/UDP processing
- Latency (a half of RTT) was 72μs
  - Inter-node : 30μs (red) = 30
  - Intra-node : 40μs (blue) = 35+1+4
  - 30+40 = 70≒72μs



Comm. between threads dominates the latency

Changing the inter-thread comm. method to use only socketpair → –5μs

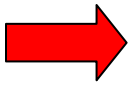
Considering “non-thread” implementation⇒ “Driver”

Related works

- Link Aggregation (IEEE802.3ad) – driver level
  - Provides high bandwidth and fault tolerance based on multilink Ethernet
  - Single switch pair → non-scalable, non-supporting for switch failure
  - RI2N/UDP supports multi-paths & multi-switches
- VMI2.0 – socket level
  - A socket layer supporting multilink network
  - Supports some heterogeneous interfaces for fault tolerance
  - RI2N/UDP also provides data striping to increase the bandwidth
- Open MPI, LA-MPI – library level
  - An MPI implementation supporting multilink network
  - Fault tolerance will be available in Open MPI v1.2
  - RI2N/UDP provides a socket level interface → wide applications

Conclusion

- Implementing RI2N on UDP/IP
  - An user level library for high bandwidth and fault tolerance
  - Just using commodity network (Ethernet) and software
- Performance Evaluation
  - Higher bandwidth
    - Dual linked RI2N/UDP achieved exactly two times of throughput for GbE
  - Fault tolerance
    - Keeping the communication while a part of links failed
    - Automatically detecting the recovery and restarting



RI2N/UDP provides high bandwidth and fault tolerance for PC cluster only with commodity network and software

Future works

- To improve the flow control algorithm
  - Current algorithm is too simple to be used for multi-point comm. on a network which has a bottleneck on the path
- RI2N/UDP under MPI
  - We will use MPICH/ch_p4
  - Practical evaluation with some MPI applications is required
    - Especially with an application hiding the communication time by computing time
- To restrict the comm. method between thread only with socketpair
  - Reduces the latency between threads
  - Provides higher compatibility to TCP socket
    - It is easy to implement some socket functions (etc. select(), poll())
- Another implementation in pseudo device driver level
  - Provides the latency as same as TCP/IP