Real-Time Networking for Quality of Service on TDM based Ethernet

Badri Prasad Subramanyan
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Committee:
Dr. Douglas Niehaus
Dr. David Andrews
Dr. Jerry James

Presentation Outline

- Introduction
- Related Work
- Objectives
- Background Information
- Implementation Details
- Performance Evaluation
- Conclusion
- Future Work

Introduction

- Real-time applications span across multiple systems.
- Network delays have to be predictable to enable real-time applications.
- Present technology - Ethernet
  - CSMA/CD protocol.
  - Collisions – retransmissions.
  - Not deterministic.
  - Cannot support real-time applications.

Related Work

- Hardware Solutions
  - Shared Memory Methods
  - Switched Ethernet
  - Token Passing Protocols
- Software Solutions
  - RTnet – Hard real-time network protocol stack for RTAI.
  - Rether – Real-time Ethernet protocol.
  - Traffic Shaping
  - Master/Slave Protocols

Objectives

- Support real-time applications which span across multiple systems in a LAN.
- Predictable end-to-end packet transfer time.
- Devise a software based solution which works using the present Ethernet hardware.
- Modifications should not affect existing protocols.

- Proposed Solutions
  - Provide Quality of Service for real-time processes.
  - Time Division Multiplexing to make the network deterministic.
  - Use the framework provided by KURT-Linux.

Background Information

- UTime
- DSKI/DSUI
- Netspec
- Group Scheduling Framework
- Linux Traffic Control
- Linux Network Stack
  - Transmit packet flow
  - Receive packet flow

UTime

- Periodic interrupt at a rate of once for every 10ms in Linux 2.4.x
- Timer resolution not sufficient for real-time requirements.
- One-shot mode – interrupts the kernel at specified times.
- Timer bottom half execution in the hardirq context.
- Utime timers were used for accurate control over time.

DSKI / DSUI

- Debugging kernel code is complex
  - Kernel source code is very big and complex.
  - Large amount of concurrency
  - Kernel does not/cannot provide usage of break points in the code.
- Data Stream Kernel Interface (DSKI)
  - Instrumentation points in the kernel to log an event.
  - Interface should be configured to log events as desired.
  - Post processing filters.
  - Data Stream Visualizer.
- Data Stream User Interface (DSUI)
  - Log events in user space.

Netspec

- Provides a framework to centrally control daemons running on other systems.
- Control distributed applications.
- Transfer of files to and from daemons.
- Takes a script to specify experimental parameters.
  - Scalable
  - Reproducible
- Used to control different experiments in a LAN.

Group Scheduling Framework

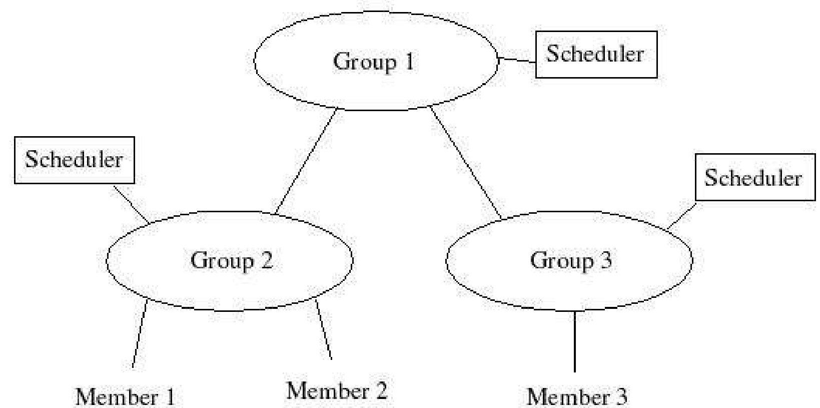
- Linux scheduler is a priority-based scheduler.
- Computational Components
  - HardIrqs – executed at the earliest.
  - SoftIrqs – deferrable functions.
  - Process – scheduled by the scheduler.
- Each process has a static and dynamic priority.
- Process scheduled based on the goodness value.
- No direct control over the scheduling policy.

Group Scheduling Framework

- Group Scheduling framework provides Unified scheduling model.
- Configurable hierarchic decision structure which decides which computation to execute.
- Explicit control of computational components.

Group Scheduling Framework

- Group – Place holder for other entities.
- Member – Computational component which can be a hardirq, softirq, process or a group.
- Scheduler – Decision routine which chooses a component for execution.

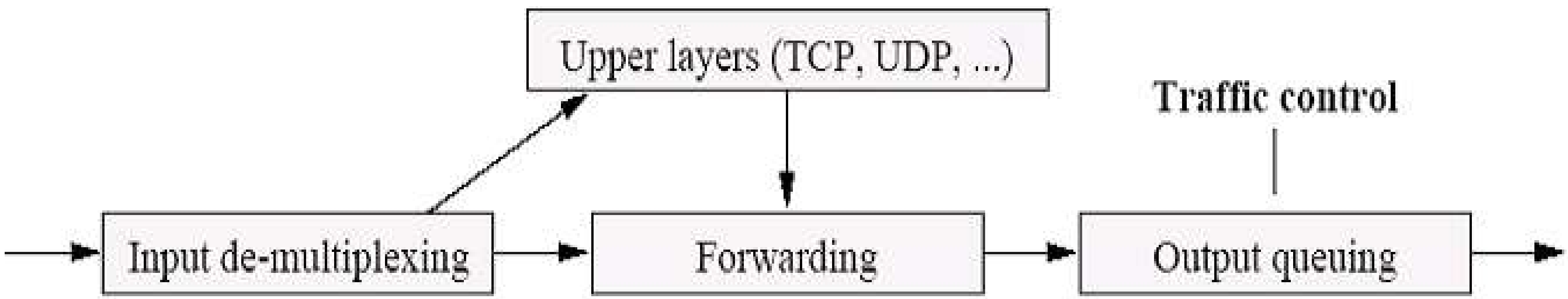


Group Scheduling Framework

- Function pointer hooks to control scheduling and execution.
- Each of the hooks point to the Vanilla Linux routines by default.
- These hooks can be mapped to other routines to define customized routines.
- Gives the flexibility to control scheduling and execution of selective computational components.

Linux Traffic Control

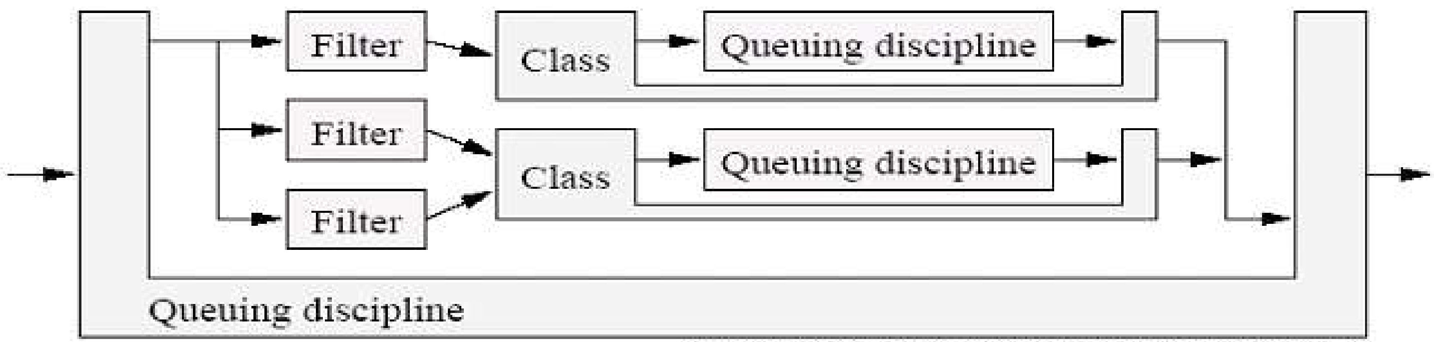
- Tools for managing & manipulating the transmission of packets.
- Net_device_layer of Linux protocol stack.



Source: http://www.almesberger.net/cv/papers/tcio8.pdf

Linux Traffic Control

- Components of Traffic Control
  - Queuing Discipline – a set of queues which are used to hold packets.
  - Classes – a class represents a class of packets and is associated with a queuing disciplines.
  - Filters – filters are used to classify packets.



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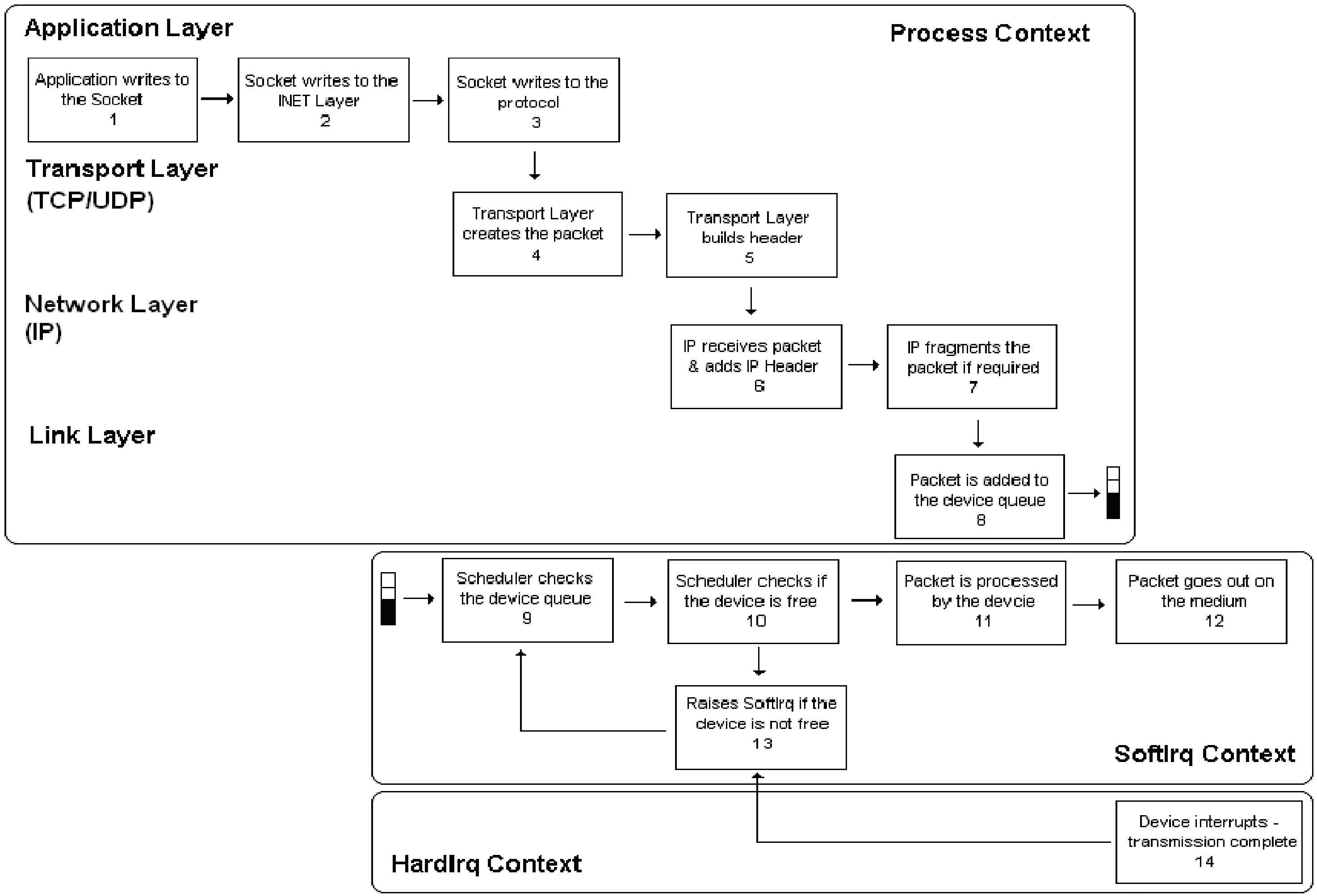
Linux Network Stack

- Explanation can be split into 2 main parts
  - Transmit side – The code which transmits the locally generated packet out of the system. This code splits the message to be transmitted, embeds it into a packet and transmit it out of the system.
  - Receive side – The code which processes a packet received by the system. This code de-fragments the received packet and sends it to the appropriate user-level process.
- DSKI instrumentations were used to understand the packet flow through the Linux network stack.

Transmit Packet flow

- The Application layer uses a system call to transmit a packet.
- The Transport layer (TCP/UDP) protocol stores the message in the sk_buff structure.
- The Network layer (IP) protocol does a route lookup based on the destination IP address.
- The Data Link layer transmits the packet out of the device.

Transmit Packet Flow

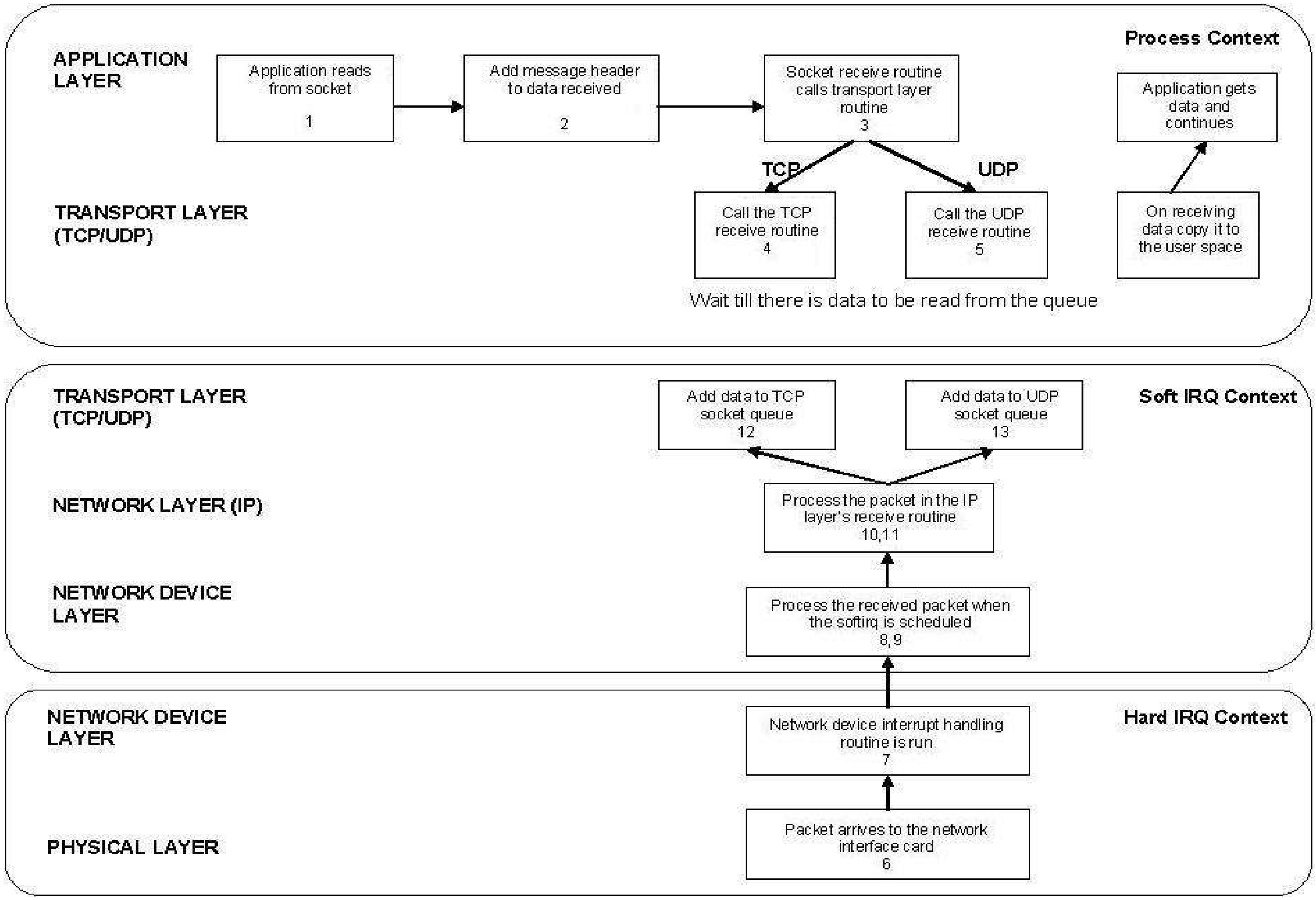


Receive Packet Flow

- The Application layer uses a system call to receive a packet. The process waits in the Transport layer queue till the packet arrives.

- The Data Link layer receives a packet.
- The Network layer (IP) protocol verifies that the packet is destined to this system.
- The Transport layer (TCP/UDP) protocol adds the packet to the Transport layer queue and schedules the process which is waiting for this packet.

Receive Packet Flow



Implementation Details

- Transmit side
  - Classification of packets
  - Processing of real-time packets
- Receive side
  - Classification of packets
  - Processing of real-time packets
- User Interface
  - Setting priority on Transmit side
  - Setting priority on Receive side
  - Adding/Removing real-time processes

Linux Softirqs

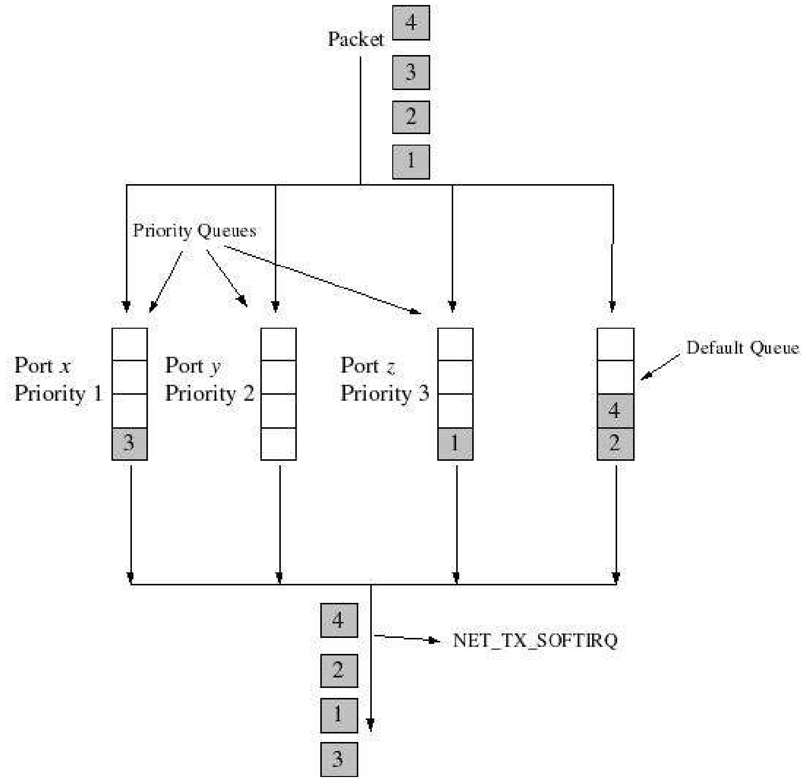
- Softirqs in Linux 2.4.x
  - HI_SOFTIRQ – processes the high priority bottom halves and tasklets.
  - NET_TX_SOFTIRQ – transmits a packet out of the system.
  - NET_RX_SOFTIRQ – processes a packet which is received on the system.
  - TASKLET_SOFTIRQ – processes the low priority tasklets.

Classification on Transmit side

- Packet classification was done in the Linux Traffic Control.
- Connection or flow was identified uniquely using port numbers.
- A new queuing discipline – TDM queue was developed.
  - Contains a single FIFO queue by default.
  - Can be configured to contain more than one queue.
  - Each queue is associated with a particular priority.
  - Each queue enqueues packets pertaining to a connection.

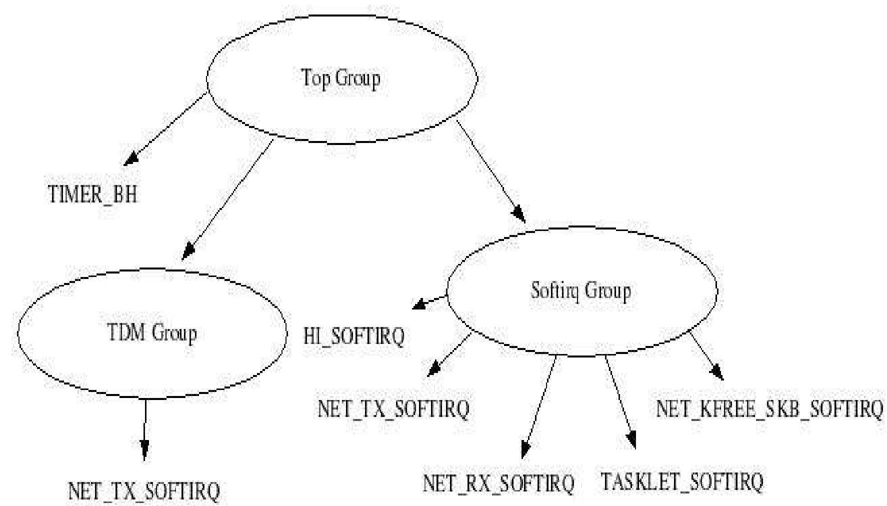
TDM queue

- Packets are enqueued in different queues based on their priority.
- Dequeueing of packet starts from the queue with the highest priority.
- The default queue is the last queue to be processed.



Group Scheduling Framework - TDM

- Timer_BH is processed first.
- NET_TX_SOFTIRQ has the highest priority during transmission time slot.
- Other softirqs are processed sequentially
- NET_KFREE_SKB_SOFTIRQ frees the packet after transmission.



Receive side

- Classification of packets.
- Reduce the real-time packet processing time.
  - Processing the real-time packets before the non real-time packets.
  - Reduce the wait time for a real-time packets in the Transport layer queue.

Classification on Receive side

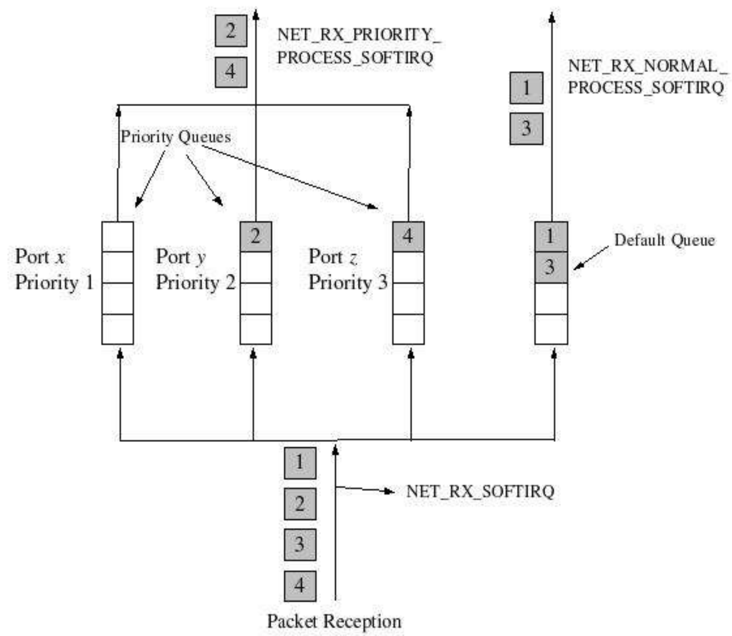
- Packet classification was done using a queuing discipline on the receive side.
- Connection or flow was identified using the port numbers.
- The queuing discipline on receive side
  - Contains a single FIFO queue by default.
  - Can be configured to contain more than one queue.
  - Each queue is associated with a particular priority.
  - Each queue enqueues packets pertaining to a connection.

Modifications to Receive Softirq

- NET_RX_SOFTIRQ was split into 3 parts
  - NET_RX_SOFTIRQ – responsible for classifying a packet and enqueuing it appropriate queue.
  - NET_RX_PRIORITY_PROCESS_SOFTIRQ – responsible for processing the priority packets present in the priority queues.
  - NET_RX_NORMAL_PROCESS_SOFTIRQ – responsible for processing the non-priority packets present in the default queue.

Queue on Receive Side

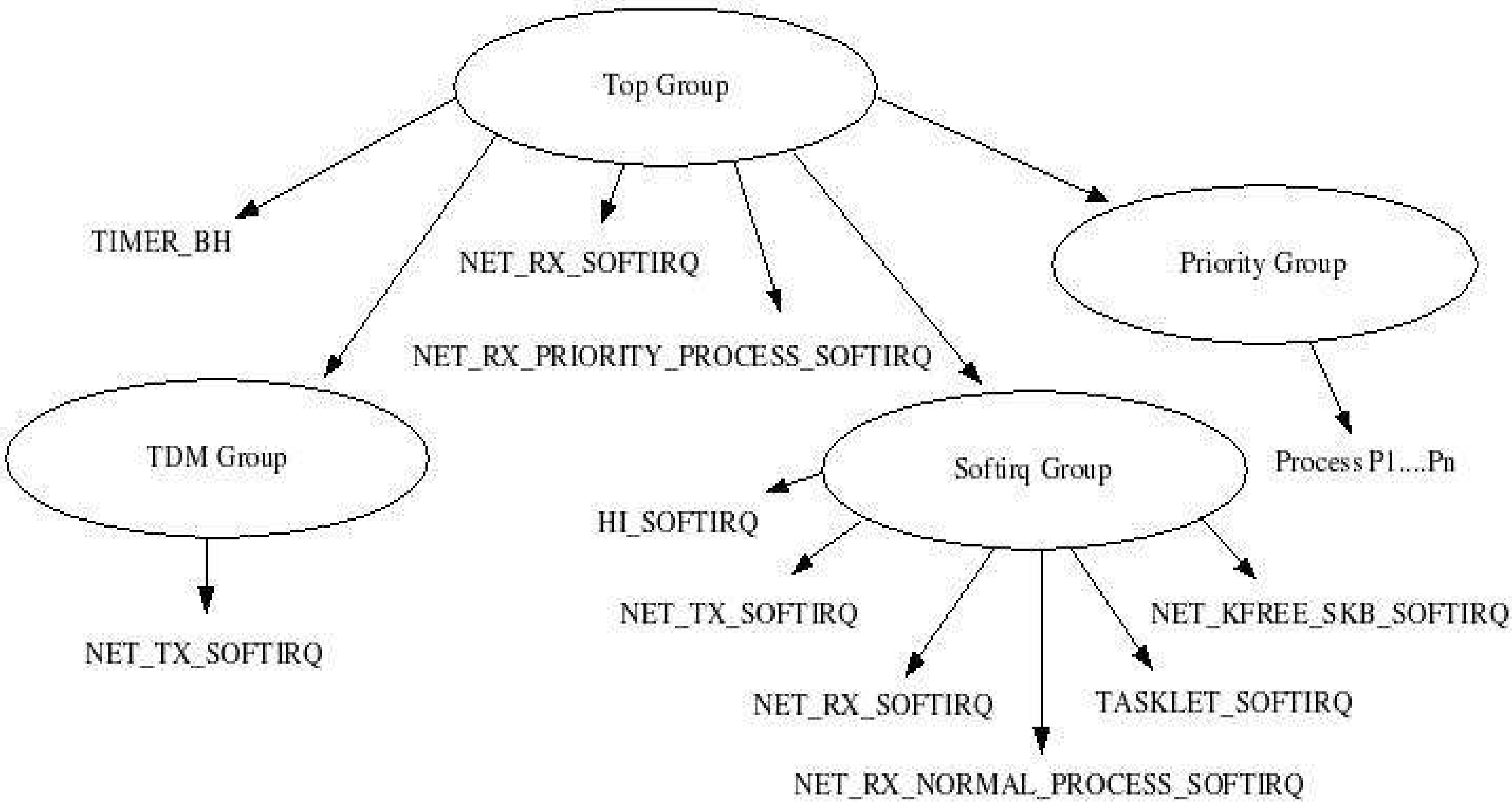
- Packets are enqueued in different queues based on their priority.
- Dequeueing takes place based on the priority of the queue – NET_RX_PRIORITY_PROCESS_SOFTIRQ.
- The default queue is scheduled to be processed after all the priority queues are processed – NET_RX_NORMAL_PROCESS_SOFTIRQ.



Priority Group

- Reduce the wait time in the Transport layer queue.
- Addition of Priority Group to the Group Scheduling Framework.
- Contains all real-time processes.
- A process in the ‘Priority’ group is scheduled once the packet corresponding to this process reaches the transport layer queue.

Real-Time Networking Model



User Interface

- User interface in TDM
  - /dev/tdm_controller – pseudo device.
  - The loadable module to interface with the device.
- This module was enhanced to configure the device for QoS changes.
- User-level program with command line options.
  - Set priority on the transmit side.
  - Set priority on the receive side.
  - Add/remove processes from the Priority group.

Setting Priority on Transmit/Receive side

- Command:

```
tdm send <# of queues> <list of (port# priority)>
tdm recv <# of queues> <list of (port# priority)>
```

- tdm – user-level routine.
- send/recv – set the transmit/receive queues.
- # of queues - Number of queues to create on the transmit side.
- Port# - the port number which needs to be prioritized.
- Priority – the priority of the port number. (Smaller number has higher priority)

Add/Remove prioritized process

- Command:

```
tdm add process <list of process Ids>
tdm remove process <list of member Ids>
```

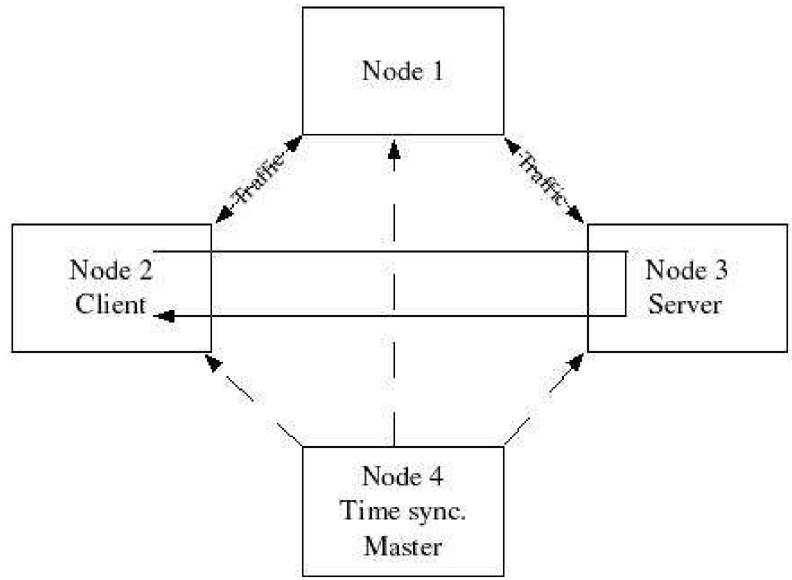
- Tdm – user-level routine.
- Add process – adds a process to the ‘Priority’ group.
- Remove process – removes a process from the ‘Priority’ group.
- Process ID – Unique identifier for each process on Linux.
- Member ID – Unique identifier for a Group Scheduling member.

Performance Evaluation

- End-to-End packet transfer time for a single real-time process.
- End-to-End packet transfer time for a single real-time process with background processes.
- End-to-End packet transfer time for different TDM schedules.
- Packet processing time on the transmit and receive side of the network stack.
- Visualization of the output.

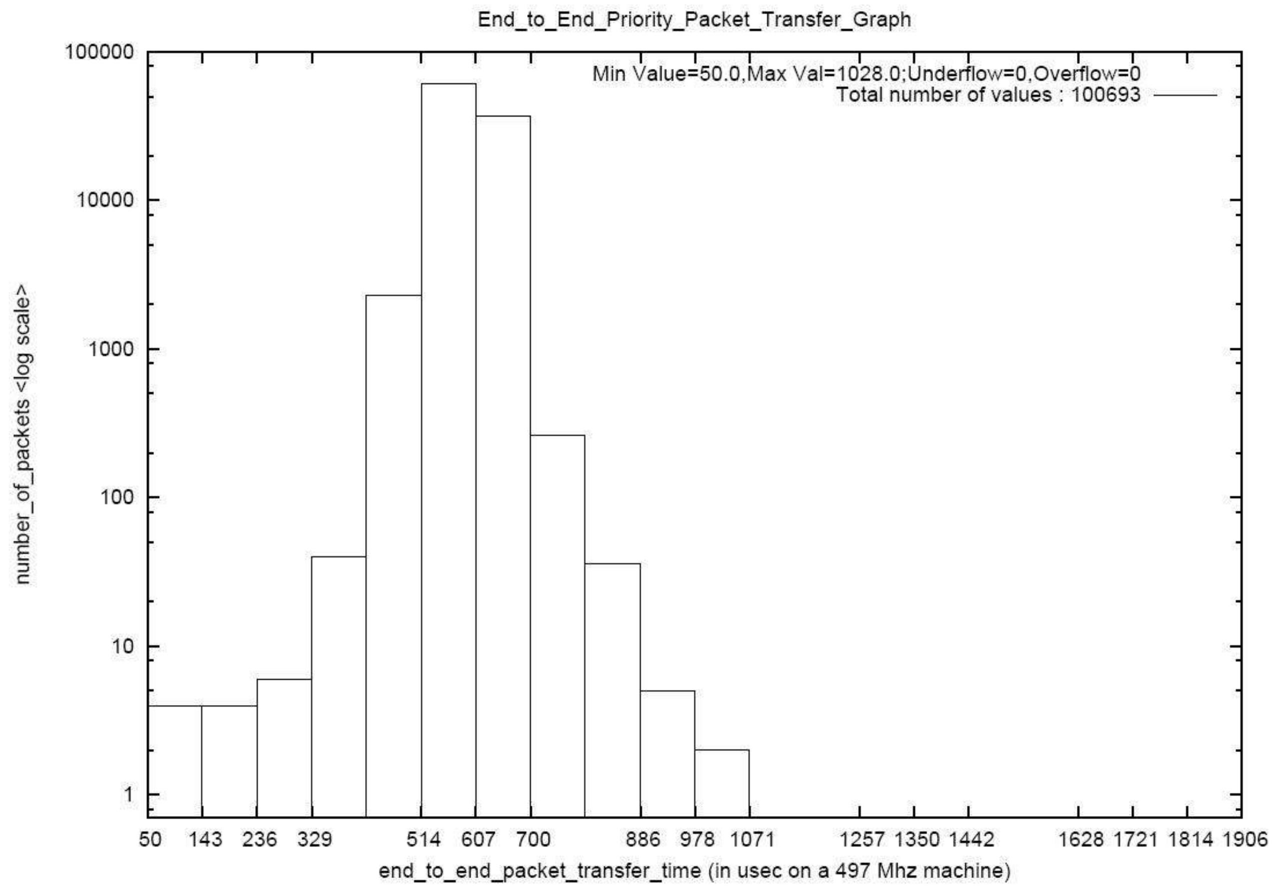
Test Setup

- LAN with 4 systems connected using a 100 Mbps hub.
- Time synchronization master.
- Transmission slot time – 260s (220 s transmission time + 40 s buffer time).
- Total transmission cycle of 1040 s.
- 64 bytes of data.



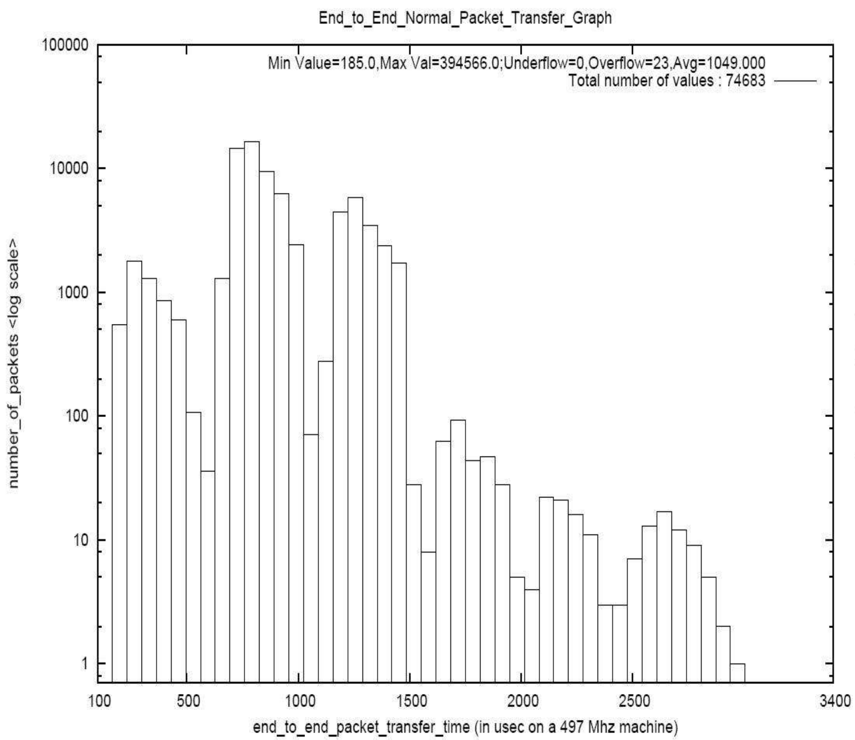
End-to-End Packet Transfer Time

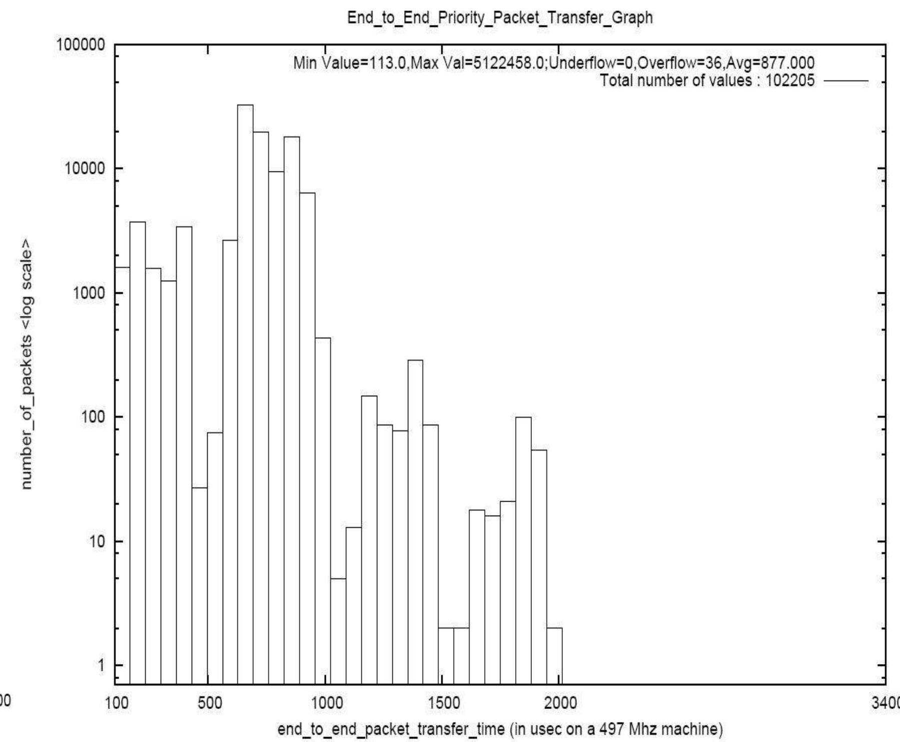
- Single real-time application.



End-to-End Packet Transfer Time

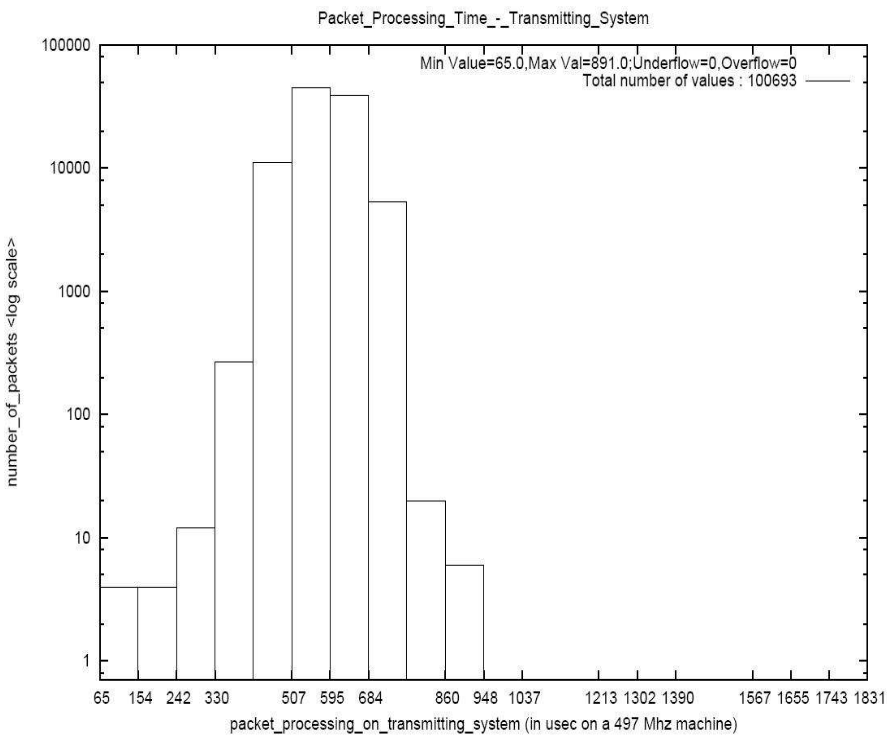
- Real-time/non real-time process with other background processes.

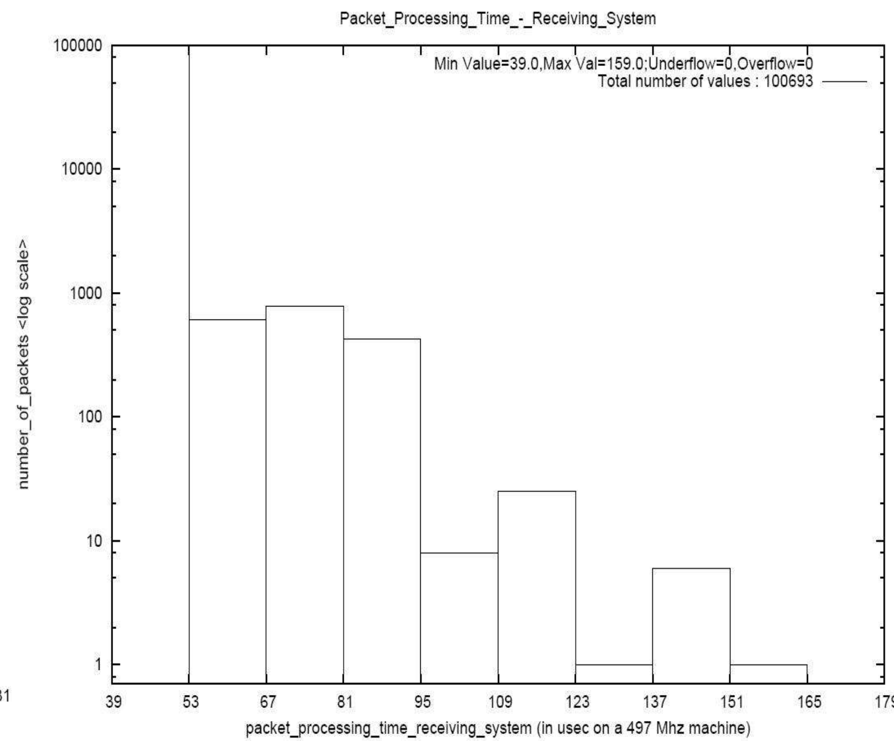




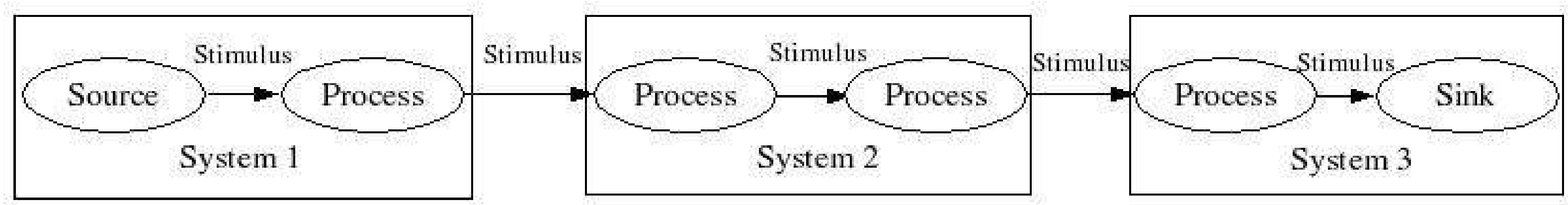
Packet Processing Time

- Packet processing time in the kernel.



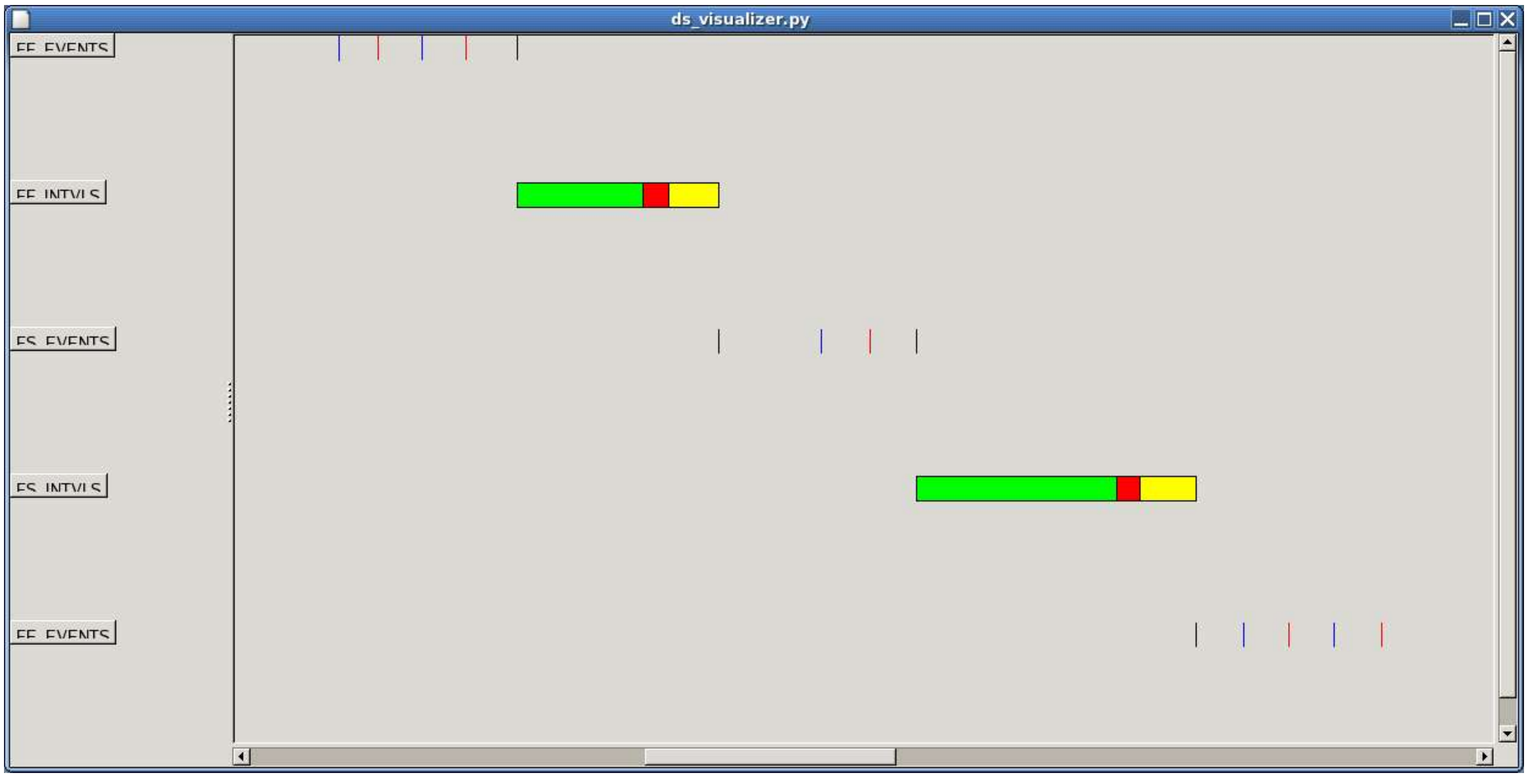


Pipeline Computation



- 3-stage pipeline computation.
- LAN with 4 systems using a 100 Mbps hub.
- Time synchronization master.
- Transmission slot time – 260s (220 s transmission time + 40 s buffer time)
- Total transmission cycle of 1040 s.

Pipeline Computation Visualization



Packet processing on the transmit side.

Packet propogation time.

Packet processing on the receive side.

Pipeline Computation

- Pipeline computation gives a real-world distributed application scenario.
- The packet processing time on the transmit side varies depending on the availability of the transmission time slot.
- The packet processing time on the receive side does not vary much.
- The end-to-end packet transfer time is comparable to half total transmission time cycle.

Table 5.2: Packet processing time

	Average Time (μs)
Packet processing time on Transmit side	492
Packet processing time on receive side	41
End-to-End transfer time	537

Conclusion

- Differentiation of real-time and non real-time packets in the network stack was achieved.
- Predictable end-to-end transfer time was achieved in a LAN.
- This software solutions was implemented on the standard Ethernet hardware.
- The changes do not require any modifications to the protocols used in Linux.

Future Work

- Time Constraint in Quality of Service
  - Each process has a set of QoS parameters.
  - Each process should negotiate QoS with the system based on its QoS parameters.
  - System should commit to provide desired QoS only when it has the resources.
- Resource Reservation Protocol (RSVP)
  - Extend QoS beyond a single LAN.
  - RSVP reserves resources in the intermediate nodes for an Internet connection.
  - The real-time networking module can interact with the RSVP protocol to reserve resources on nodes beyond the LAN.

Thank you