Application Performance in the QLinux Multimedia Operating System

Sundaram, A. Chandra, P. Goyal,
P. Shenoy, J. Sahni and H. Vin

Umass Amherst, U of Texas Austin

ACM Multimedia, 2000

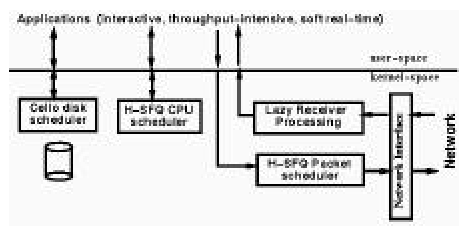
Introduction

- General purpose operating systems handline diverse set of tasks
  - Conventional best-effort with low response time
    - Ex: word processor
  - Throughput intensive applications
    - Ex: compilation
  - Soft real-time applications
    - Ex: streaming media
- Many studies show can do one at a time, but when do two or more grossly inadequate
  - MPEG-2 when compiling has a lot of jitter

Introduction

- Reason? Lack of service differentiation
  - Provide 'best-effort' to all
- Special-purpose operating systems are similarly inadequate for other mixes
- Need OS that:
  - Multiplexes resources in a predictable manner
  - Service differentiation to meet individual application requirements

Solution: QLinux



- Solution: QLinux (the Q is for Quality)
  - Enhance standard Linux
  - Hierarchical schedulers
    - classes of applications or individual applications
  - CPU, Network, Disk

Outline

- QLinux philosophy
- CPU Scheduler
  - Evaluation
- Packet Scheduler
  - Evaluation
- Disk Scheduler
  - Evaluation
- Lazy Receiver Processing
  - Evaluation
- Conclusion

QLinux Design Principles

- Support for Multiple Service Classes
  - Interactive, Throughput-Intensive, Soft Real-time
  - Low average response times, high aggregate throughput, performance guarantees
- Predictable Resource Allocation
  - Priority not enough (starvation of others)
  - Ex: mpeg_decoder at highest can starve kernel
  - QLinux uses rate-based rather than priority based
    - Weight based on rate for each: $w_i / \Sigma_j w_j$
  - Not static partitioning since unused can be used by others

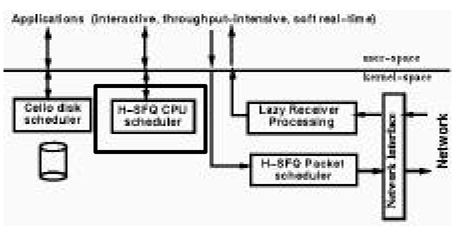
QLinux Design Principles

- Service Differentiation
  - Within a class, applications treated differently
  - Uses hierarchical schedulers
  - Top level gives resources to class
  - In each class, can allocate resources appropriately among all applications
- Support for Legacy Applications
  - Support binaries of all existing applications (no special system calls required)
  - No worse performance (but may be better)

QLinux Design Principles

- Proper Accounting of Resource Usage
  - Application level CPU easy
  - Kernel resources hard
    - + Load from interrupts difficult to charge to process
    - + Many kernel tasks are system-wide
  - *Lazy receiver processing*
    - + Defer packet processing when receiver asks
  - CPU scheduler allocation holds even when kernel uses up various amounts of CPU

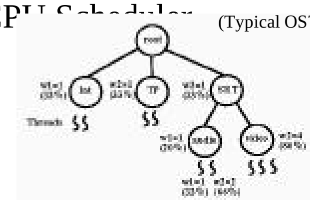
QLinux Components



Hierarchical Start-time Fair Queuing (H-SFQ) CPU Scheduler

(Typical OS?)

- Uses a tree
- Each thread belongs to 1 leaf
- Each leaf is an application class
- Weights are of parent class



$$B_i = \left(\frac{w_i}{\sum_j w_j} \right) * B$$

- Each node has own scheduler
- Uses Start-Time Fair Queuing at top for time for each

H-SFQ CPU Scheduler

- Nodes can be created on the fly
- Threads can move from node to node

System call	Purpose
hsfq_mknod	create a new node in the scheduling hierarchy
hsfq_rmnod	delete an existing node from the hierarchy
hsfq_join_nod	attach the current process to a leaf node
hsfq_move	move a process to a specified child node
hsfq_parse	parse a pathname in the scheduling hierarchy
hsfq_admin	administer a node (e.g., change weights)

- Defaults to top-level fair scheduler if not specified
- Utilities to do external from application

→ Allow support of legacy apps without modifying source

Experimental Setup (for all)

- Cluster of PCs
  - P2-350 MHz
  - 64 MB RAM
  - RedHat 6.1
  - QLinux based on Linux 2.2.0
- Network
  - 100 Mb/s 3-Com Ethernet
  - 3Com Superstack II switch (100 Mb/s)
- "Assume" machines and net lightly loaded

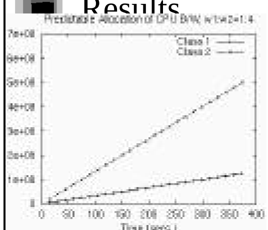
Experimental Workloads

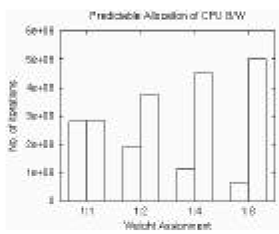
- *Inf*: executes infinite loop
  - Compute-intensive, Best effort
- *Mpeg_play*: Berkeley MPEG-1 decoder
  - Compute-intensive, Soft real-time
- *Apache Web Server and Client*
  - I/O intensive, Best effort
- *Streaming media server*
  - I/O intensive, Soft real-time
- *Net_Inf*: send UDP as fast as possible
  - I/O instensive, Best effort
- *Dhrystone*: measure CPU performance
  - Compute-instensive, Best effort
- *Lmbench*: measure I/O, cache, memory … perf

CPU Scheduler Evaluation-1

- Two classes, run *Inf* for each
- Assign weights to each (ex: 1:1, 1:2, 1:4)
- Count the number of loops

CPU Scheduler Evaluation-1 Results



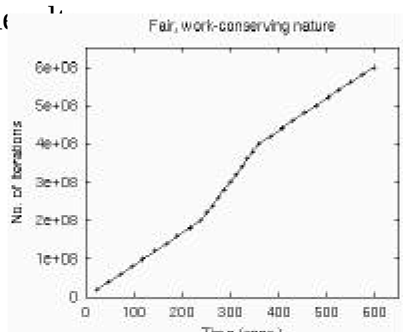


"count" is proportional to CPU bandwidth allocated

CPU Scheduler Evaluation-2

- Two classes, equal weights (1:1)
- Run two *Inf*
- Suspend one at t=250 seconds
- Restart at t=330 seconds
- Note count

CPU Scheduler Evaluation-2 Results

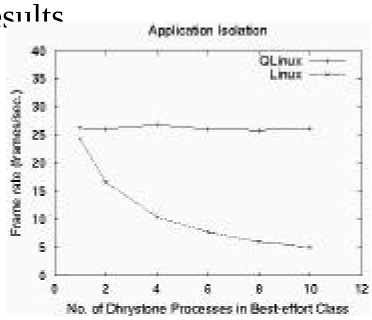


(Counts twice as fast when other suspended)

CPU Scheduler Evaluation-3

- Two classes: soft real-time & best effort (1:1)
- Run:
  - *MPEG_PLAY* in real-time (1.49 Mbps)
  - *Dhrystone* in best effort
- Increase Dhrystone's from 1 to 2 to 3 …
  - Note MPEG bandwidth
- Re-run experiment with Vanilla Linux

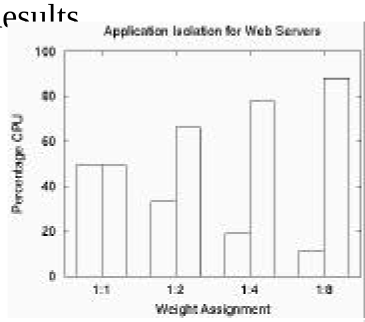
CPU Scheduler Evaluation-3 Results



CPU Scheduler Evaluation-4

- Explore another best-effort case
- Run two *Web servers* (representing, say 2 different domains)
- Have clients generate many requests
- See if CPU bandwidth allocation is proportional

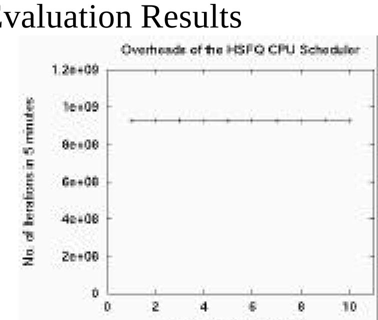
CPU Scheduler Evaluation-4 Results



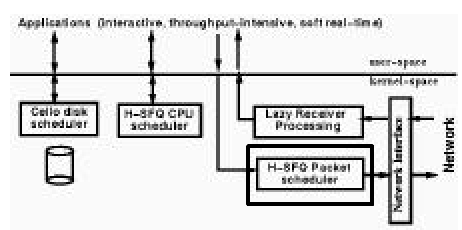
CPU Scheduler Overhead Evaluation

- Scheduler takes some overhead since recursively called
- Run *Inf* at increasing depth in scheduler hierarchy tree
- Record count for 300 seconds

CPU Scheduler Overhead Evaluation Results

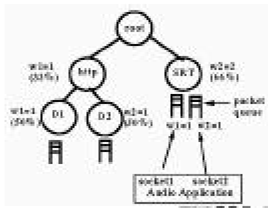


QLinux Components



H-SFQ Packet Scheduler

- Typical OS uses FIFO scheduler for outgoing packets
- Use H-SFQ (Fair Queue) to schedule
- Each leaf is one or more queues of packets
- Weights for queues
- Unused bandwidth to others



H-SFQ Packet Scheduler

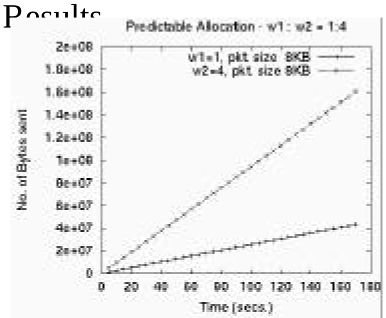
- Operations on the fly
- Associate with queue via setsockopt()

System call	Purpose
hsfq_qdisc_install	Install HSFQ queuing discipline on a network interface
hsfq_link_mknod	create a node in the scheduling hierarchy
hsfq_link_createq	create a packet queue
hsfq_link_attachq	attach a queue to a leaf node
hsfq_link_moveq	move a queue between schedulers
hsfq_link_rmnod	delete the specified node
hsfq_link_rmq	delete the specified queue
hsfq_link_modify	change the weight of a node/queue
hsfq_link_parsenode	parse a pathname in the scheduling hierarchy
hsfq_link_getroot	get the ID of the root node at a particular network interface
hsfq_link_status	display the scheduling tree
setsockopt	attach a socket to a queue

Packet Scheduler Evaluation-1

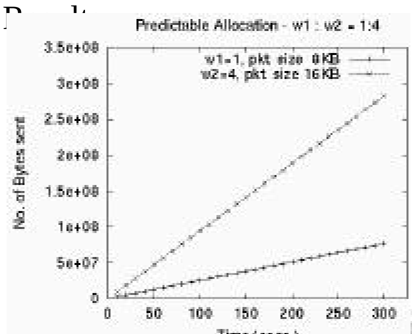
- Two classes using *Net_inf*
- Run two receivers to count received packets
- 8KB packets

Packet Scheduler Evaluation-1 Results



(Different packets sizes?)

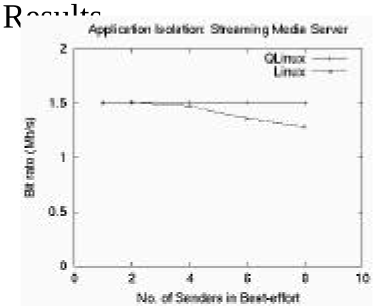
Packet Scheduler Evaluation-2 Results



Packet Scheduler Evaluation-3

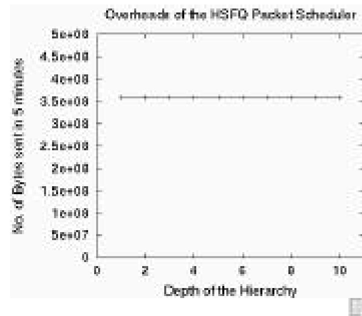
- Real-world applicatis
- *Streaming media server* in soft real-time class
- Increasing number of *Net_inf* apps
- Compare QLinux with Vanilla Linux

Packet Scheduler Evaluation-3 Results



(Me … note, degradation not linear)

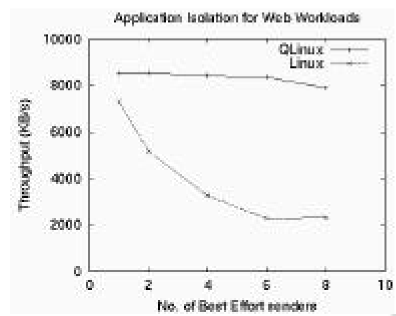
Packet Scheduler Overhead Evaluation Results



Combined Packet and Scheduler Evaluation

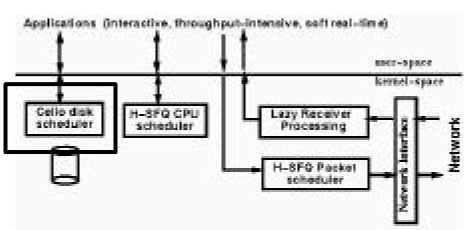
- Web server and several I/O intensive apps
- Two classes in CPU and Packet scheduler
  - *Web server* in one
  - All I/O intensive *Net_inf* in other
- *Web server* driven by trace (ClarkNet)
- Increase number of *Net_inf*
- Compare to Vanilla Linux

Packet/CPU Evaluation Results



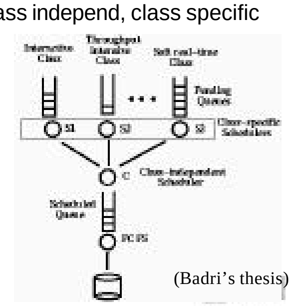
Qlinux degrades at 8 … ideas why?

QLinux Components



Cello Disk Scheduler

- Typical OS uses SCAN for disk
- Cello 2 levels: class independ, class specific
- 3 classes
- Class specific decides when and how many to move
- Class ind puts where
- Lastly moved FCFS

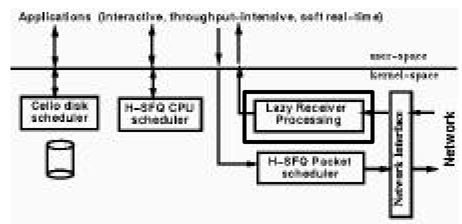


(Badri's thesis)

Cello Disk Scheduler Evaluation

- (None in this paper)
- (Previous paper at SIGMetrics)

QLinux Components



Lazy Receiver Processing (LRP)

- Process *A* running
- Packet arrives for process *B*
  - Interrupt, IP, TCP, Enqueue gets charged to *A*!
- LRP postpones until process does a read
- Tricky! Some steps, e.g. TCP ack, requires it to happen right away
  - Special thread for each process for packets
- QLinux uses special queues, decodes only as far as needed
  - Special queue for ICMP, ARP …

LRP Evaluation and Results

- Run 2 Apache Web Servers
  - Lightly loaded, retrieve 2KB file in 51ms
- Bombard 1 server with DoS by sending 300 requests/sec
  - Other server load went to 70ms
- Re-run with Vanilla Linux
  - Other server load went to 80ms

QLinux Total System Evaluation

- Run lmbench
  - System call overhead
  - Context switch times
  - Network I/O
  - File I/O
  - Memory perofrmance
- QLinux vs. Vanilla Linux

QLinux Total System Evaluation Results

Table 4: Lmbench Results

Test	QLinux	Linux
syscall overhead	1 μs	1 μs
`fork()`	400 μs	400 μs
`exec()`	2 ms	2 ms
Context switch (2 proc/ 0KB)	4 μs	1 μs
Context switch (16 proc/ 64KB)	286 μs	283 μs
Local UDP latency	47 μs	53 μs
Local TCP latency	83 μs	82 μs
File create (0 KB file)	21 μs	21 μs
File delete (0 KB file)	2 μs	2 μs

- Not much overall.
- Context switch overhead, but 100 ms time slice
- QLinux untuned, so could be better

Conclusion

- Qlinux provides
  - CPU scheduler
  - Packet scheduler
  - Disk scheduler
  - Proper I/O processing
- Provide fair and predictable allocation
- Multimedia and Web applications can benefit
- Overhead is low
- All conventional operating systems should incorporate

Future Work?

Future Work

- Disk scheduler results
- Multiprocessors
- Fair allocation of other I/O interrupts
- Other devices since Cello disk specific
  - RAID, tape,