Hard Real-Time Linux

(or: How to Get RT Performances Using Linux)

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Linux Kernel Hacking Free Course IV Edition

What is a “Real-Time” System

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What about the consequences of a malfunctioning?

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3. Probabilistic considerations

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Some possible criteria to draw their definitions:

1. Criticality of consequences of a failure (on both system and environment)
   - What is a generally acceptable definition of critical failure?
2. Usefulness of late work completion (job tardiness)
   - How to evaluate the usefulness of a late completion?
3. Probabilistic considerations
   - No accounting of possible consequences

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These definitions do not fully cover the complexity of the field though.

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- Is it so easy to prove (100%) a system to behave correctly?
  - Various methodologies: WCET Analysis, formal proofs, exhaustive testing (not always applicable)

Real-Time Applications Features

Distinctive features:

Real-Time side

Embedded side

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- Resource allocation policies (Prio Inheritance, Prio Ceiling . . .)

Linux as RTOS

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Sometimes . . .

Linux as (S)RTOS

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It is optimized to provide:

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Suitable for:

- Multimedia Applications
- VoIP
- Video / Audio Streaming

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. . . and what about predictability?

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Furthermore:

5. Quite high (w.r.t. HRT performances) scheduling latency for user mode processes

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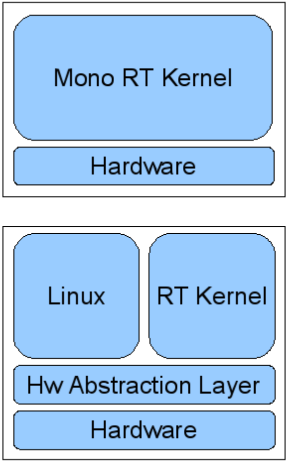
- *Dual Kernel Approach*
  - Changes are done locally: simplified porting
  - New (and complex) intermediate layer between Hardware and OS
  - Mostly Open Source: *RTAI*, *RTLinuxFree - PaRTiKle*, *Xenomai*
  - But some commercial as well: *Wind River Real-Time Core Linux*

Dual Kernel Approach

Ideas:

- Insert an *Hardware Abstraction Layer* between HW and OSes
- Run Linux as a "normal" *low priority* process on top of a real-time scheduler



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- Ad-hoc synchronization mechanisms

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- Generally limited interprocess communication with Linux standard applications

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- Positive aspects generally counterbalance negative ones
  - We can afford the extra programming effort and limitations
- In some cases though, dual kernel disadvantages are unacceptable
  - It would be great to (1) have a way to “do real-time” using the standard kernel and (2) to be able to obtain good performances staying in User Mode

Kernel's native support to Hard Real-Time

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- Cpusets and `sched_domain`

Scheduler and Scheduling Classes

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- Introduction of *Completely Fair Scheduling* (for conventional processes), which models "an ideal, precise multi-tasking CPU"
- Introduction of *Scheduling Classes*:
  - *Hierarchy* of scheduler modules that *incapsulate* the details of their scheduling policy
  - Clean interface between the scheduler core and scheduler modules
  - Clear scheduler modules separation: one file per class (`sched_rt.c`, `sched_fair.c`, `sched_idletask.c`)

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  - RT tasks management completely distinct from conventional processes one
  - Single runqueue with 100 priority levels
  - O(1) task selection bitmap-based

Scheduler and SMP management

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- Selection of processes to move is done through iterators (provided by each class)
- Scheduler core is *unaware* of strategies chosen by classes to balance tasks
- Different classes may implement different strategies

CPU Affinity

The idea:

- Use affinity mechanisms provided in the kernel to *bind* a real-time task and *its relative interrupts* on a CPU
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2. Low system overhead
3. High performances and responsiveness

CPU Affinity and Cpusets

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Cpusets offer more flexibility:

- Cpuset provides a mechanism to *associate* a set of CPUs (and of Memory Nodes) with a set of tasks
- All task's children are automatically executed in the same *set* of their parent

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- Cpusets allow to easily control tasks distribution (and isolation) on system CPUs
- Cpusets can be effectively used to define a partitioning of system CPUs. This is often the first step of several multiprocessor real-time scheduling policies
- If used together with IRQ affinity we can enforce real-time tasks isolation w.r.t. other non-real-time tasks in the system

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- *Assign priority* to IRQ handlers

The Real-Time Patch

The Real-Time Preemption Patch allows to cope with these problems:

- The patch is the continuation of the *Montavista*[1] real-time preemptive patch, mainly due to Ingo Molnar

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  - Substitution of almost all spinlocks with semaphore locking mechanisms (preemptable mutexes)

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The Real-Time Patch (Cont.)

Further modification of RT scheduler load-balancing:

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Further modification of RT scheduler load-balancing:

- Load-accounting and load-balancing are optimized for real-time tasks
- Balancing decisions are taken *only* before or after a context switch ("inside" `schedule()`)

The Real-Time Patch (Cont.)

Further modification of RT scheduler load-balancing:

- Load-accounting and load-balancing are optimized for real-time tasks
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- When a high priority task wakes up (and it would preempt the currently executing one), check if it can run on a less loaded CPU

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  - Used in `pthread_mutex` with prio inheritance implementation

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  - Hook the scheduling class functions in the scheduler core through the `struct sched_class` structure

Some results (HRT)

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- Task periodicity is obtained by reprogramming the RTC (so that it ticks every $\approx 64Hz$)

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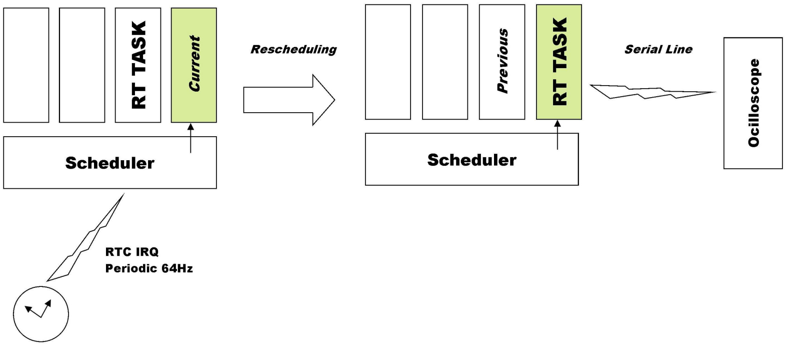


System was configured using cpusets and giving higher priority to RTC IRQ handler

Some results (HRT)

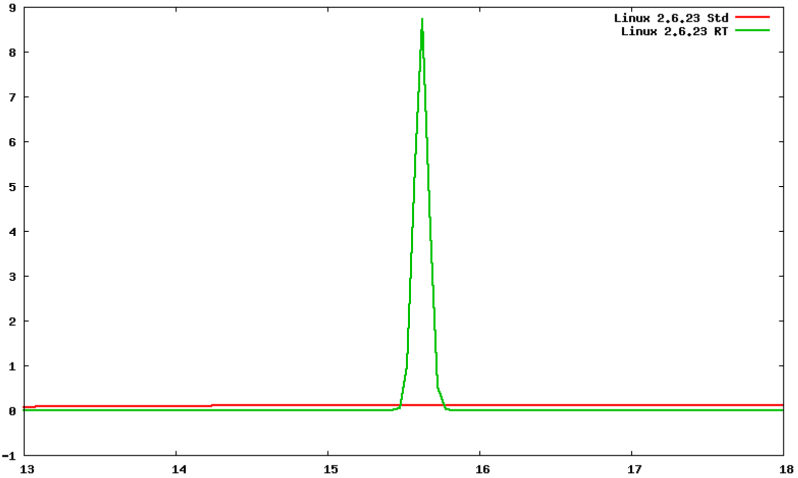
- A comparison between performances obtained using standard Linux kernel and kernel with RT patch, cpusets and IRQ prioritarization.
- “Load” is composed by a mixture of different loads (CPU, memory and disk)

	NO LOAD			
	min(*ms*)	max(*ms*)	mean(*ms*)	StdDev(μs)
Linux 2.6.23 Std	15.59	15.71	15.63	46.30
Linux 2.6.23 RT	15.59	15.71	15.63	46.18

	LOAD			
	min(*ms*)	max(*ms*)	mean(*ms*)	StdDev(μs)
Linux 2.6.23 Std	1.04	33.16	16.11	**3310**
Linux 2.6.23 RT	15.59	15.71	15.62	45.21

Some results (HRT)

Linux 2.6.23 Standard vs Linux 2.6.23 RT (Load - NoLoad)



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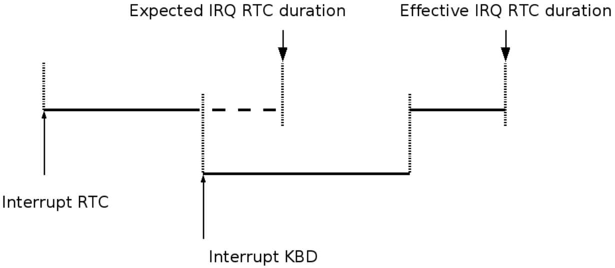


Some results (HRT)

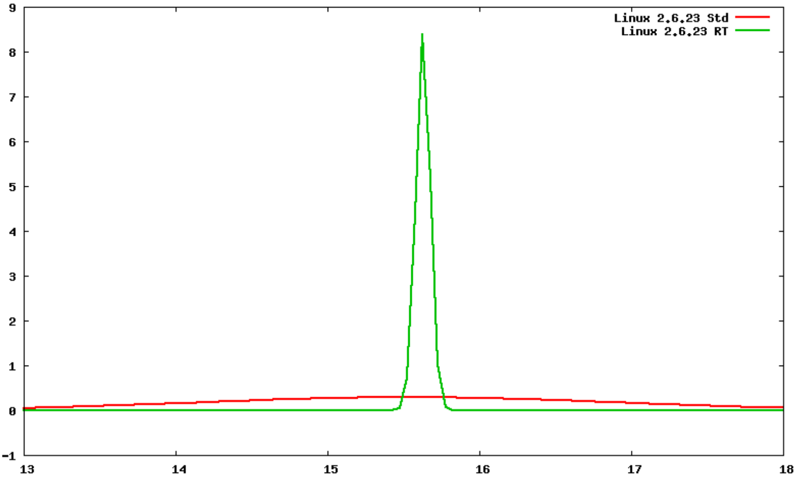
- Quantitative performances:

	NO Interrupts			
	min(ms)	max(ms)	mean(ms)	StdDev(μs)
Linux 2.6.23 Std	15.59	15.71	15.63	48.69
Linux 2.6.23 RT	15.59	15.71	15.62	45.44

	KBD interrupts			
	min(ms)	max(ms)	mean(ms)	StdDev(μs)
Linux 2.6.23 Std	7.280	19.86	15.43	**1368**
Linux 2.6.23 RT	15.59	15.71	15.63	47.44

Some results (HRT)

Linux 2.6.23 Standard vs Linux 2.6.23 RT (KBD test)



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- Server offers 70 Audio Streams which are asked by clients using Real-Time Streaming Protocol (RTSP)
  - Stream transfer is done via RTP

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Soft Real-Time

- *Idea*: Test soft real-time kernel features in the typical application context of *Audio Streaming*
- We selected *VideoLan VLC* for both streaming server and clients
- Server offers 70 Audio Streams which are asked by clients using Real-Time Streaming Protocol (RTSP)
  - Stream transfer is done via RTP
- We measure the interarrival frame jitter (RFC 3550) relatively to frames in the same stream
- We remove head and tail jitter data and we focus on the central part of each audio stream transfer

Some Results (SRT)

- Server: AMD Athlon 64 X2 Dual-Core 4000+ (2.1GHz), 1 GB RAM, Sata HDD, Slamd64, Linux 2.6.24.3
- Clients: Dual-Core AMD Opteron 8212 (4 Dual-Core processors, 2GHz each), 16 GB Ram, Sata HDD, Slamd64, Linux 2.6.24.3
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- Gigabit Ethernet connection link
- One client CPU (two cores) is reserved to network traffic sniffing, while all the other CPUs are dedicated to VLC clients

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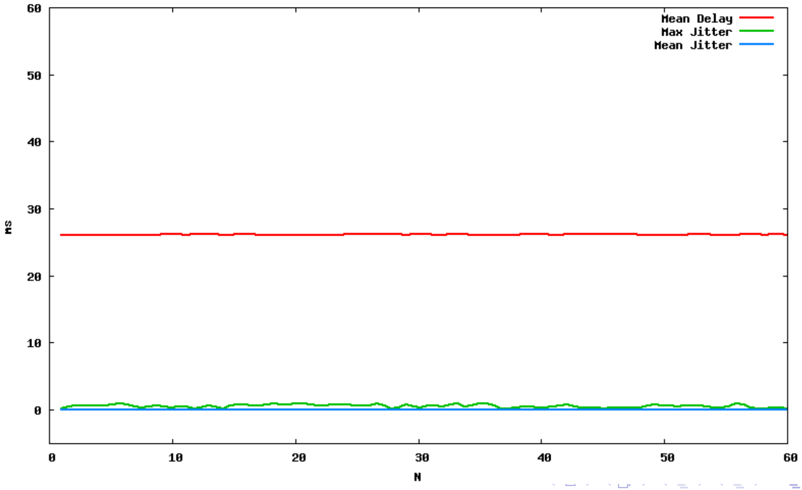
  - Light load (“only” the streaming server)
  - Heavy load (CPU an disk load plus streaming server load)

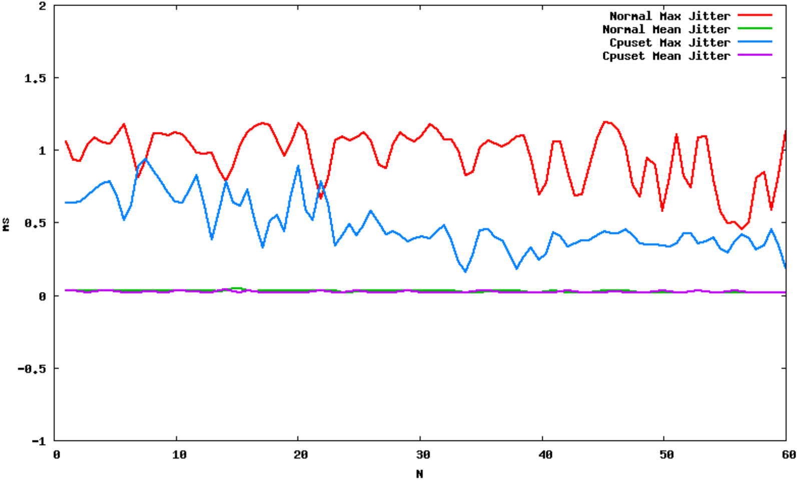
Some Results (SRT)

Light load, Normal configuration



Some Results (SRT)

Heavy load, Normal configuration vs. Cpuset configuration



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- Linux is already a very good *soft real-time* system. . .
- Linux in its real-time variants (Mono / Dual Kernel) is able to provide predictable and reliable hard real-time performances
- In its rapid evolution, Linux is moving towards a good yet flexible *hard real-time* support
- Of course, the road to strong hard real-time performances or to certification is long and winding. . .