Real-Time Workshop

October 6th, Bell Labs, Stuttgart

Scuola Superiore Sant'Anna
di Studi Universitari e di Perfezionamento

Virtualized Soft Real-time Cloud Computing Infrastructures on Linux

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Workshop Outline

Modules of the workshop

- Motivations and Background
- Real-Time Scheduling on GPOSes and Linux
- Improving Linux for Real-Time Applications
- Optimum Deployment of Virtual Machines
- Probabilistic Real-Time Guarantees
- Adaptive Real-Time Scheduling
- New Research Themes

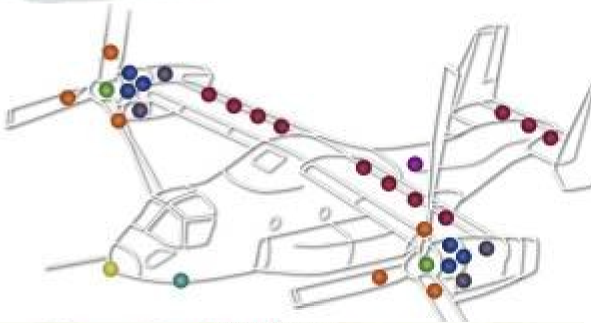
Motivations and background

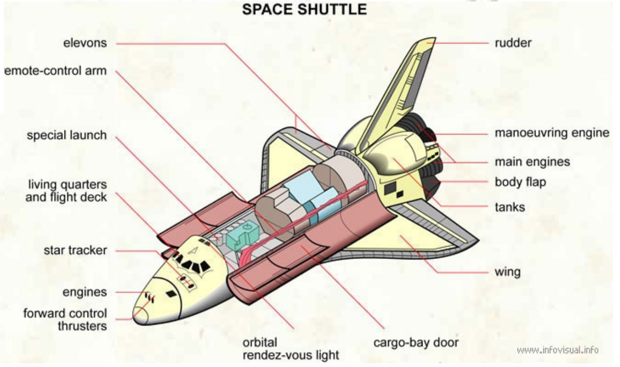
What is Real-Time

Drive assistance

- Engine control, brakes, stability, speed, parking
- Trajectory and set-up control

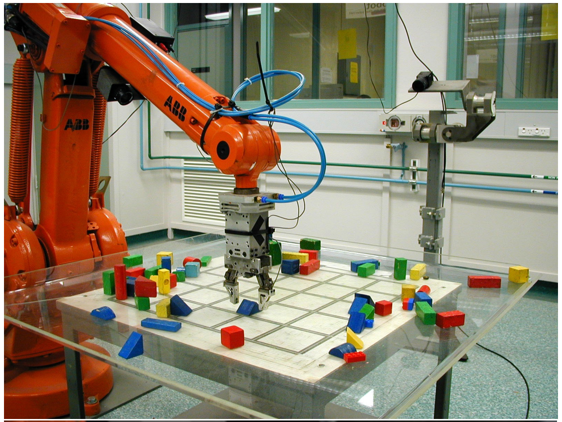
Defence, army, space

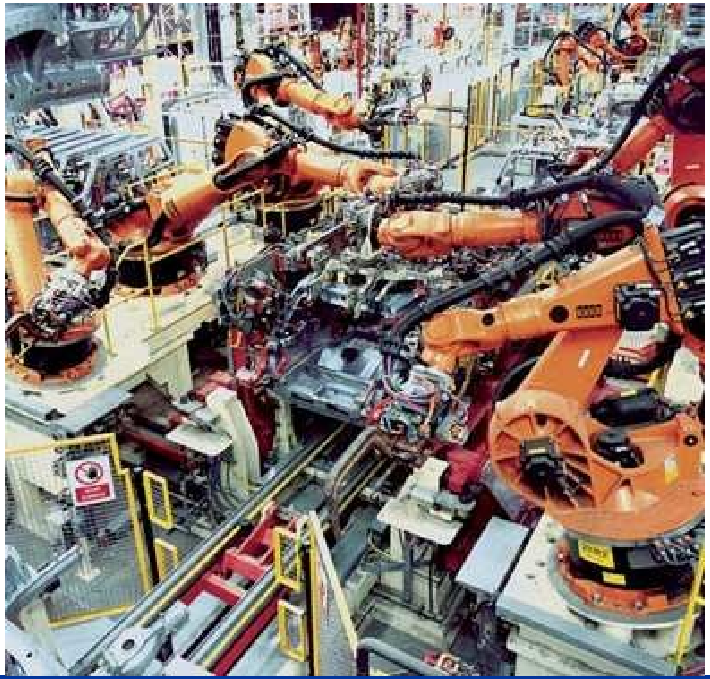




What is Real-Time

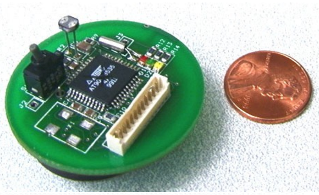
- Control of chemical and nuclear plants
- Control of productive processes and industrial automation
- Traffic control

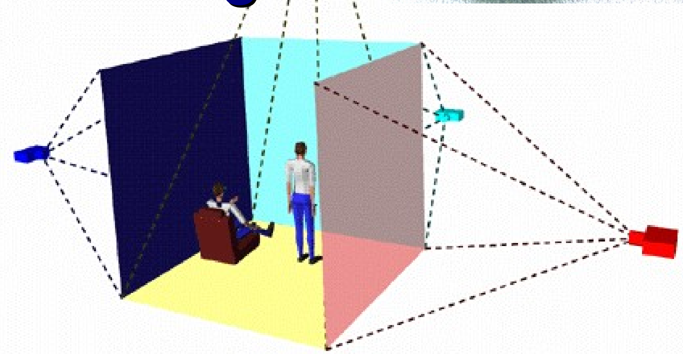




What is Real-Time

- **Multimedia, videosurveillance**
- **Augmented virtual reality**
- **Telecommunications**
- **Environment monitoring**





Criticality of time requirements

Systems with critical timing requirements

- e.g., defence, army, space

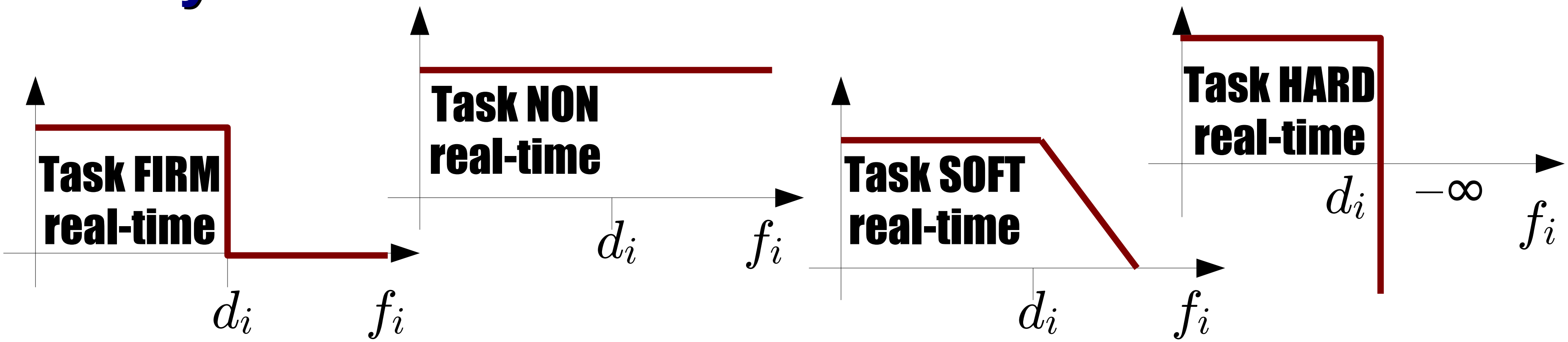
Systems with lower criticality timing requirements

- e.g., industrial automation

Systems with non-critical timing requirements

- e.g., multimedia, virtual reality, telecommunications

Utility function



Our Focus

We focus on systems

- With **non-critical soft real-time** requirements
- Where the use of a **GPOS is desirable and feasible**
  - As opposed to a **traditional RTOS**

Motivations

General-Purpose Operating Systems

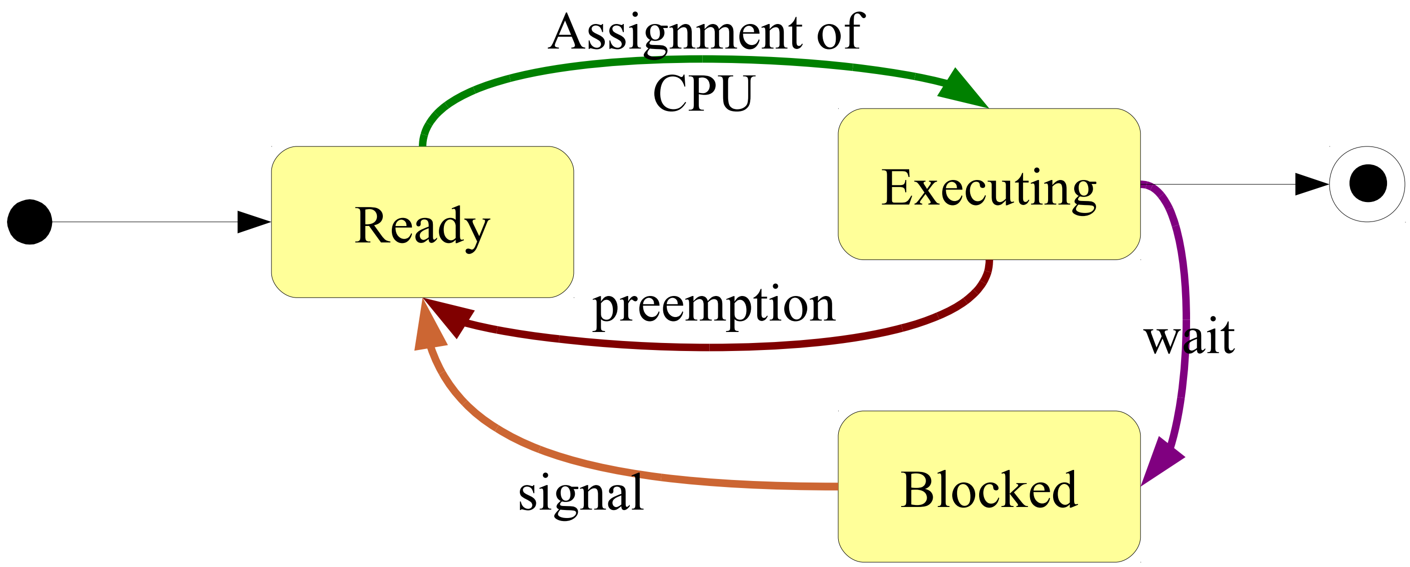
- Very effective for storing & managing multimedia contents
- Designed for
  - **average-case** performance
  - serving applications on a **best-effort** basis
- They are not the best candidate for serving *real-time applications* with **tight timing constraints**
  - nor for **real-time multimedia**

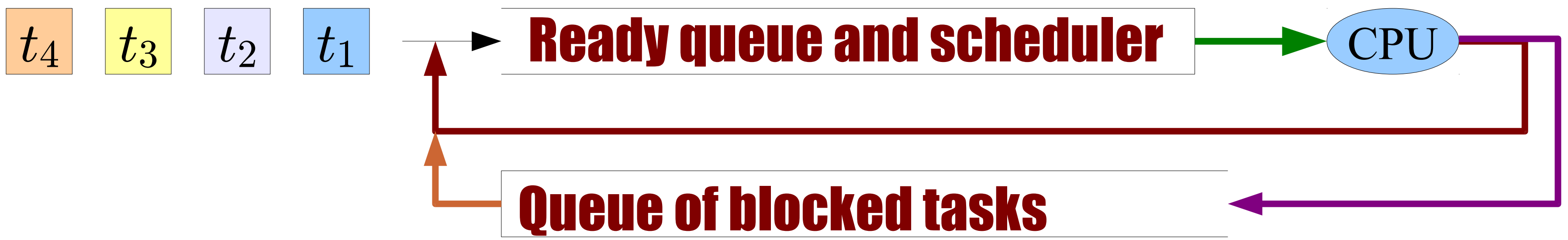
Motivations

Overcoming limitations of a GPOS for multimedia

- **Large buffers** used to compensate *unpredictability*
  - ==> poor real-time interactivity and no low-latency multimedia
- **One-application one-system** paradigm
  - For example, for low-latency real-time audio processing (jack), gaming, CD/DVD burning, plant control, etc...
- **POSIX real-time extensions**
  - Priority-based, **no temporal isolation**
  - Not appropriate for deploying the multitude of (soft) real-time applications populating the systems of tomorrow

States of a process/thread/task



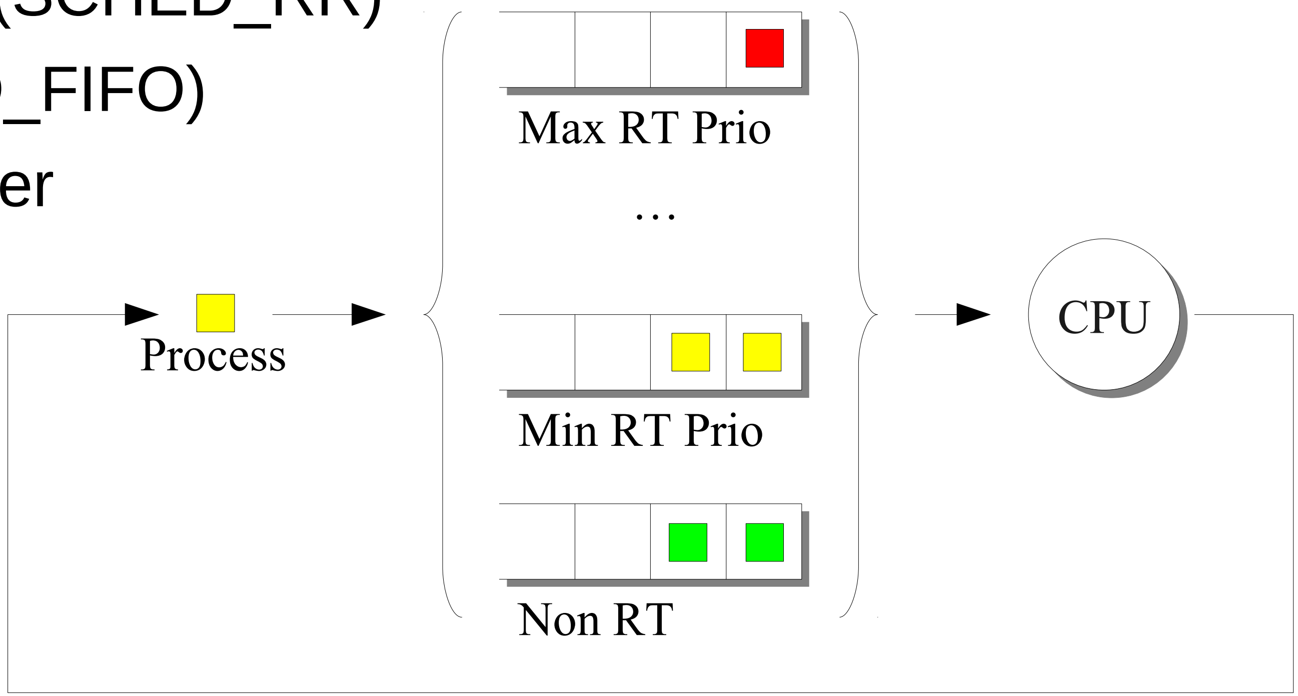


POSIX
Real-Time Scheduling

Multi-queue priority-based scheduler

Processes at same priority

- Round-Robin (SCHED_RR)
- FIFO (SCHED_FIFO)
- Sporadic Server
  (see later)



Traditional RT Systems (and Priority Scheduling)

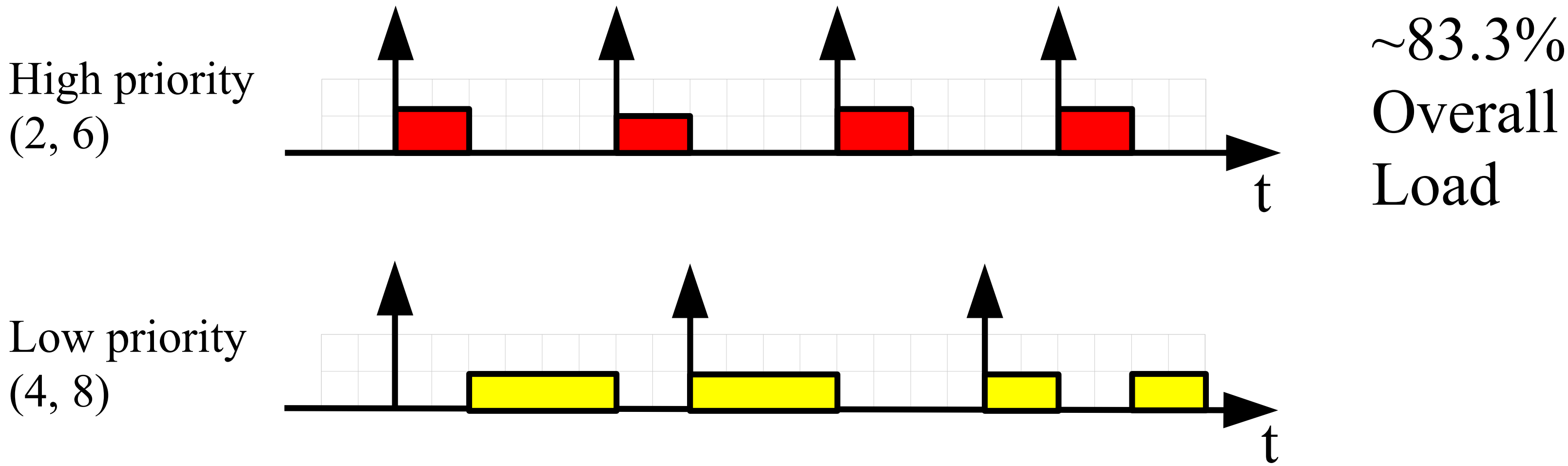
All deadlines respected as far as system behaves as foreseen at design time

- Traditional (C, T) task model
  - C: Worst-Case Execution Time (WCET)
  - T: Minimum inter-arrival period

Admission Control, e.g., for RM:

$$\sum_{i=1}^{n} \frac{C_i}{T_i} \leq n\left(\sqrt[n]{2} - 1\right)$$

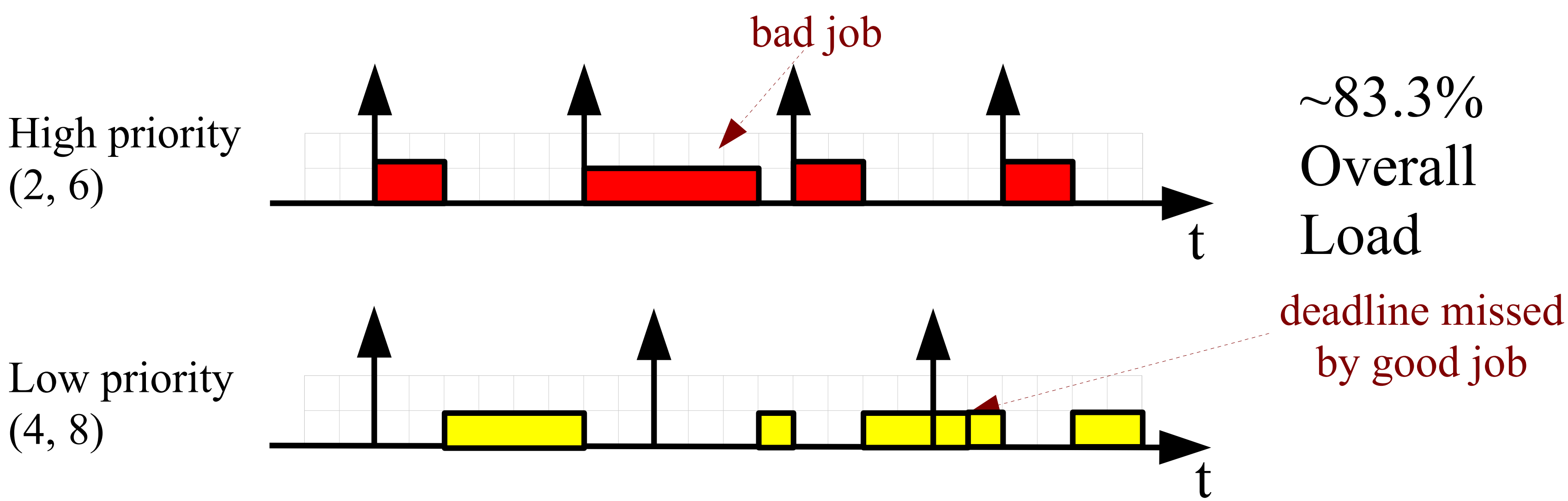
$$\prod_{i=1}^{n} \left(\frac{C_i}{T_i} + 1\right) \leq 2$$



Problems of Priority Scheduling

High-priority processes may indefinitely delay low-priority ones

- Coherent with the typical real-time/embedded scenario
  - Higher-priority processes are **more important** (e.g., safety critical)
- What if processes have same importance/criticality ?



Deadline-based Scheduling

Optimum for single-processor systems

- Necessary and sufficient admission control test for simple task model:

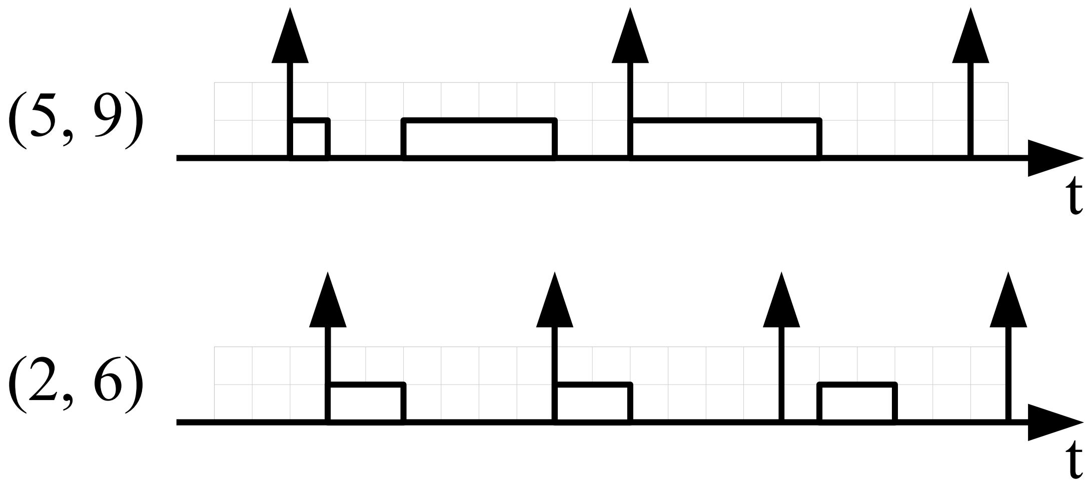
$$\sum_{i=1}^{n} \frac{C_i}{T_i} \leq 1$$

Same problems of PS

- Deadlines respected as far as the WCETs are respected
- Things may go bad when
  - One or more tasks exhibit higher computation times than foreseen
  - One or more tasks behaves differently than foreseen
    - e.g., it blocks on a critical section for more than foreseen
- The task that suffers may not be the misbehaving one

Reservation-based scheduling: (Q_i, P_i)

- “Q_i time units **guaranteed** on a CPU every P_i time units”



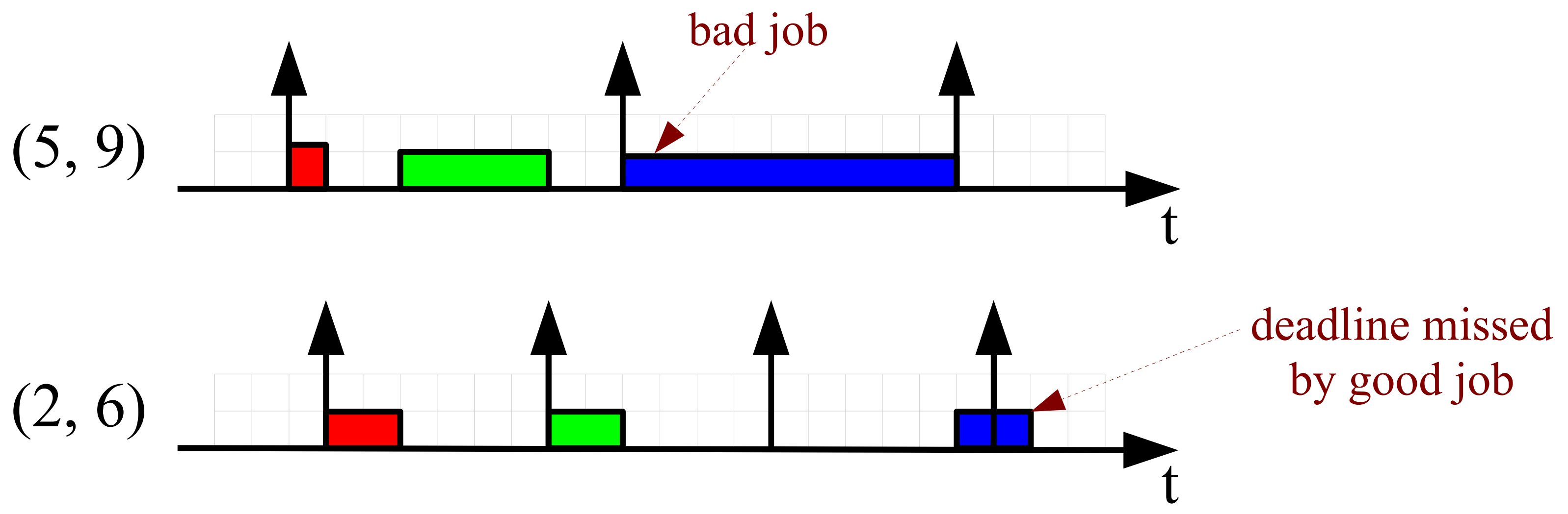
~88.9% Overall Load

- Independently of how others behave (**temporal isolation**)

Temporal Isolation

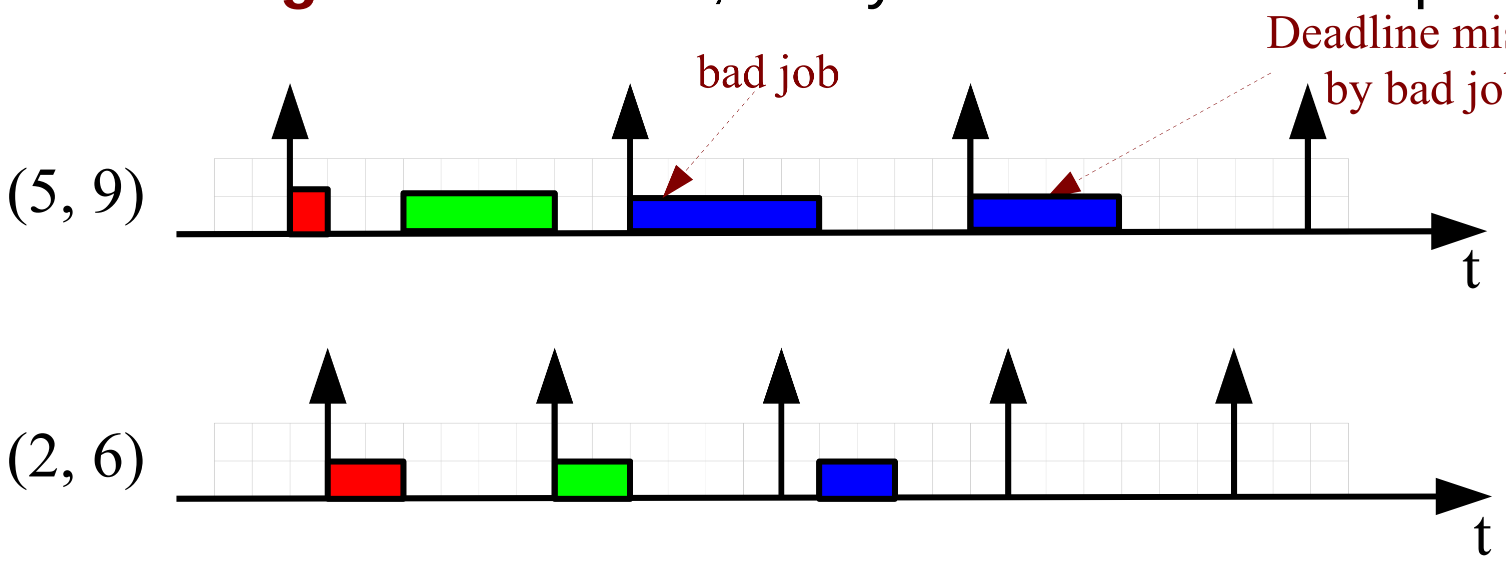
Enforcement of temporal isolation

- Not only EDF scheduling



Enforcement of temporal isolation

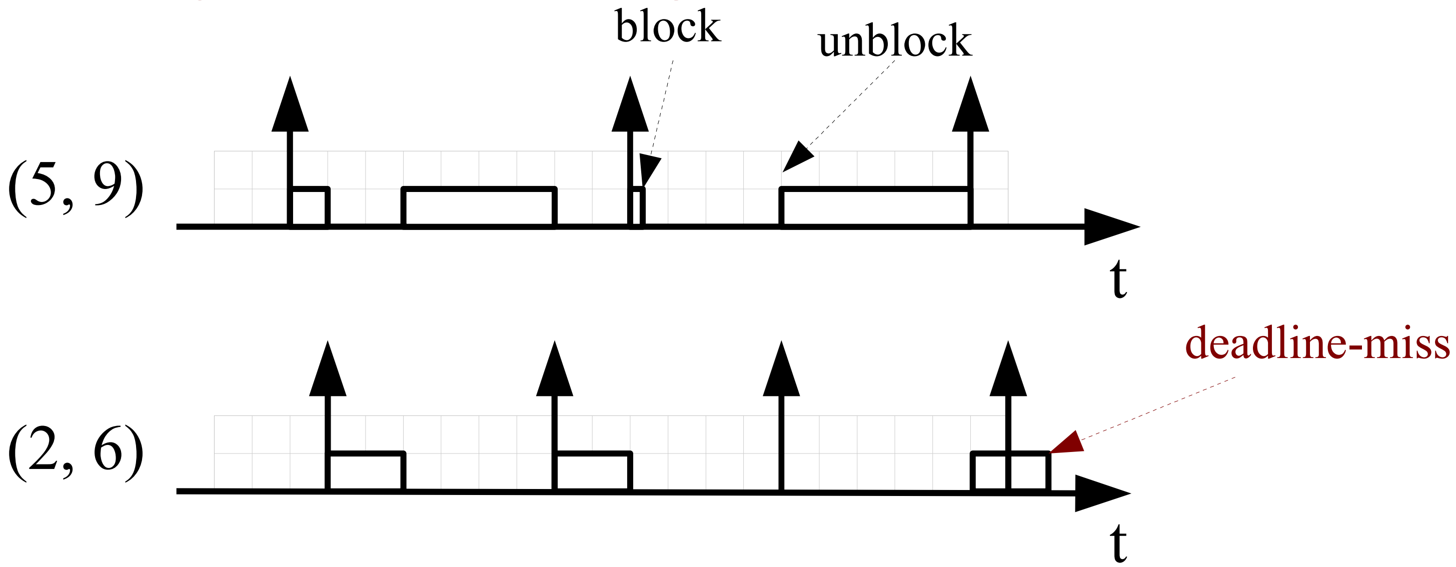
- Once **budget exhausted**, delay to next activation period



Temporal Isolation

Is needed despite blocks/unblocks

- Not only EDF scheduling



Temporal Isolation

Is needed despite blocks/unblocks

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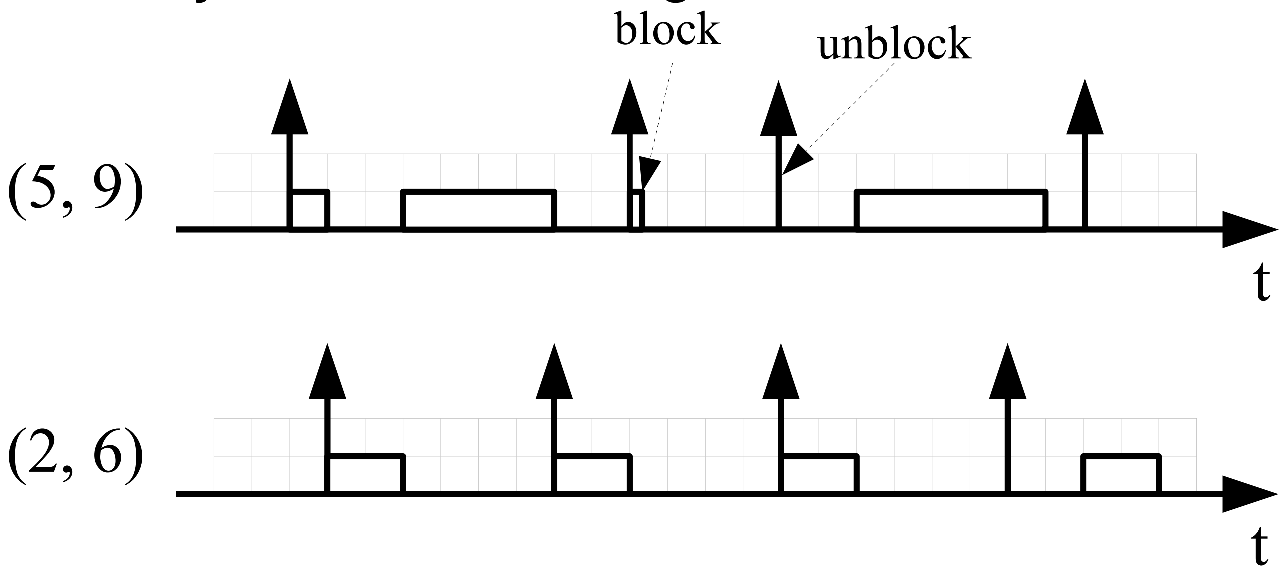
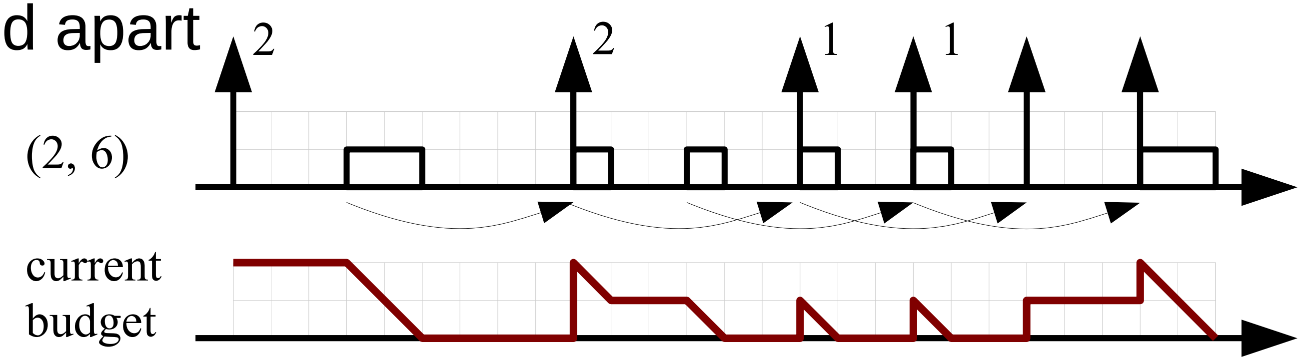


See CBS "unblock rule"

POSIX Sporadic Server

SCHED_SS

- Provides a form of temporal isolation
- Parameters: (Q, P, RT Priority, Low RT Priority)
- Budget exhausted => lower the priority till next recharge
- For every time interval in which the task executes, post a recharge of budget equal to the consumed CPU time one period apart



SCHED_SS may be analysed using FP techniques

- Patching the standard for getting rid of the “bug”

Process Scheduling in Linux

Linux

- Not a Hard Real-Time OS
- Monolithic structure
  - Device drivers may adversely affect responsiveness

Advances in Linux temporal behavior (responsiv.)

- **Preemptability** of kernel-space code
- **High-resolution timers**
- Increasing use of **RCU** primitives
- Nearly complete support for **POSIX real-time** extensions
  - **Sporadic Server is missing (!)**
- **IRQ handlers as kernel threads** (preempt-rt branch)

Linux Scheduling Policies

POSIX compliant OS

- Implements priority-based scheduling
- Implements almost all real-time extensions
- Does not implement Sporadic Server
  - SSSA has an implementation available (still) as a separate patch
- pthreads compliant multi-threading support
  - The kernel deals with "**tasks**"

Goes beyond POSIX

- Support for multi-processor and multi-core systems (affinity)
- Support for NUMA machines
  - Scheduling domains with control over cpu sets and memory banks
- …

Linux Default Scheduler

Default Scheduler

- Design principles
  - **Round-Robin** policy as a starting base, for **fairness** among tasks
  - **Heuristic** to dynamically identify and **boost interactive (real-time)** tasks as compared to **batch** processing ones
  - Allow user-space to distinguish more/less important tasks
    - By setting their "**nice level**"
- Actual implementation changes from time to time
  - Completely priority-based, inefficient O(n) scheduler, 2.4 kernels
    - priority = nice level + dynamic priority offset (+/- 5)
  - Very Efficient O(1) scheduler, from 2.6.x
  - Efficient O(log n) Completely Fair Scheduler (CFS), from 2.6.y
    - Nice level corresponds to a weight in a (kind of) weighted RR

Linux and T.I.

Need for T.I. evident in mainline Linux

- A (buggy) real-time task can **starve** the entire OS
- **Real-time throttling** prevents this to happen

Real-Time Throttling

- Different design principles
  - Priority-based scheduling
  - Constraints to "no more than Q_i every system-wide P"
  - Behaves like "Deferrable Servers"

Thanks for your attention

Questions ?

Making Linux a better place

(for multimedia and soft real-time applications)

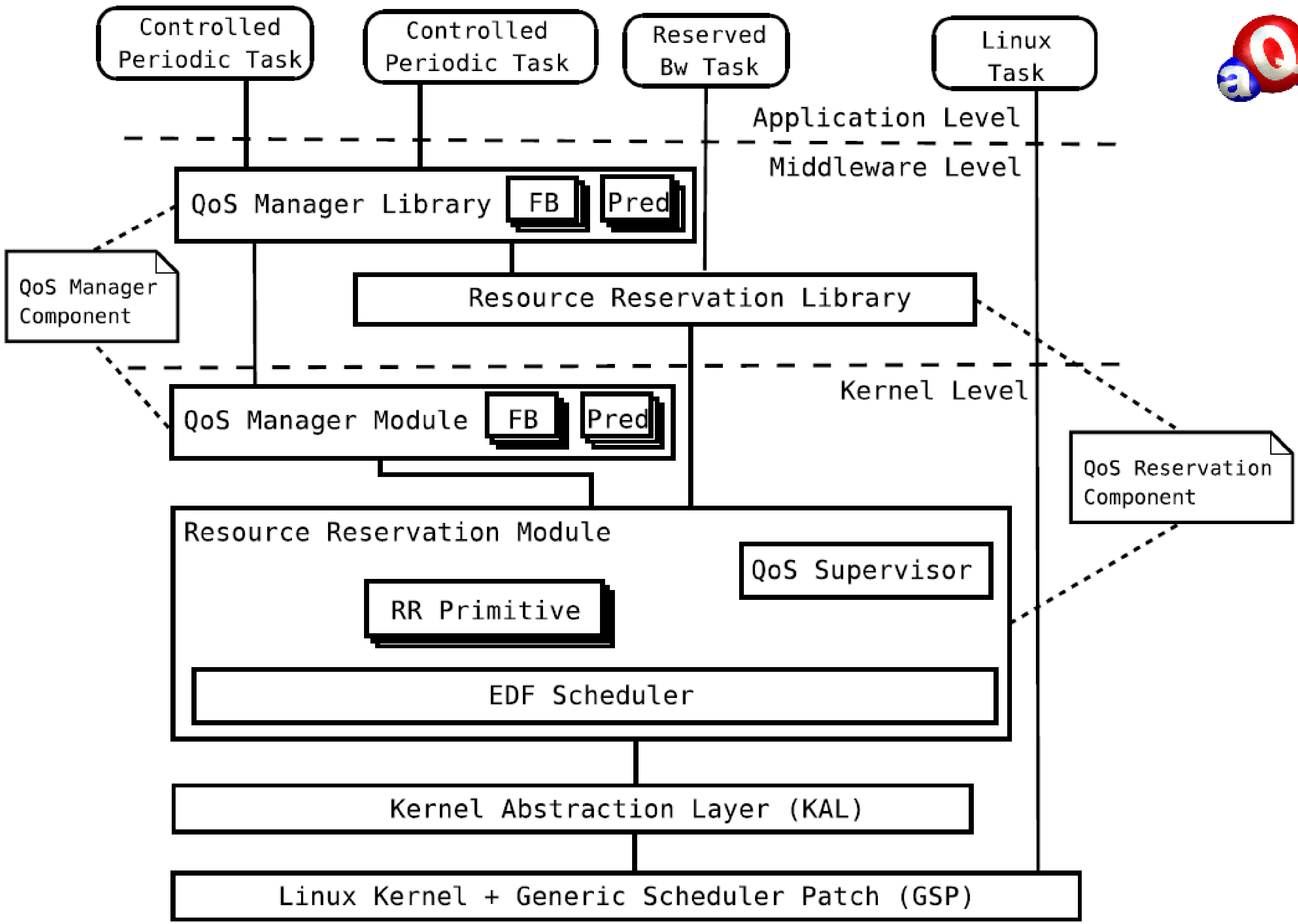
Research on Linux for Real-Time Systems at RETIS

- Applying techniques from Real-Time Systems to a GPOS
- **Improving responsiveness** and stability of performance for time-sensitive applications
- Investigating effectiveness of **Adaptive Reservations**
- **Synchronization** protocols for real-time multimedia
- Stabilising performance of **virtualized applications**
- **Isolating** computing and **I/O traffic** for Virtual Machines
- Effective exploitation of **multi-cores** in real-time systems
- **Programmability** of multi-threaded, distributed, real-time applications (API)

Resource reservation scheduling in Linux

- Adaptive Quality of Service Architecture
  - Single-processor embedded systems
  - **Multi-threaded** applications
- Hybrid Deadline/Priority Scheduler
  - **Multi-processor** systems
  - **Multi-threaded virtualized** applications
- Partitioned/Global EDF Scheduler SCHED_DEADLINE
  - **Multi-processor** systems
  - **Single-threaded control** applications

Adaptive Quality of Service Architecture for Linux



Framework for Real-time Embedded Systems based on COntRacts

Soft and hard real-time

Support for CPU, disk, network

Distributed real-time systems

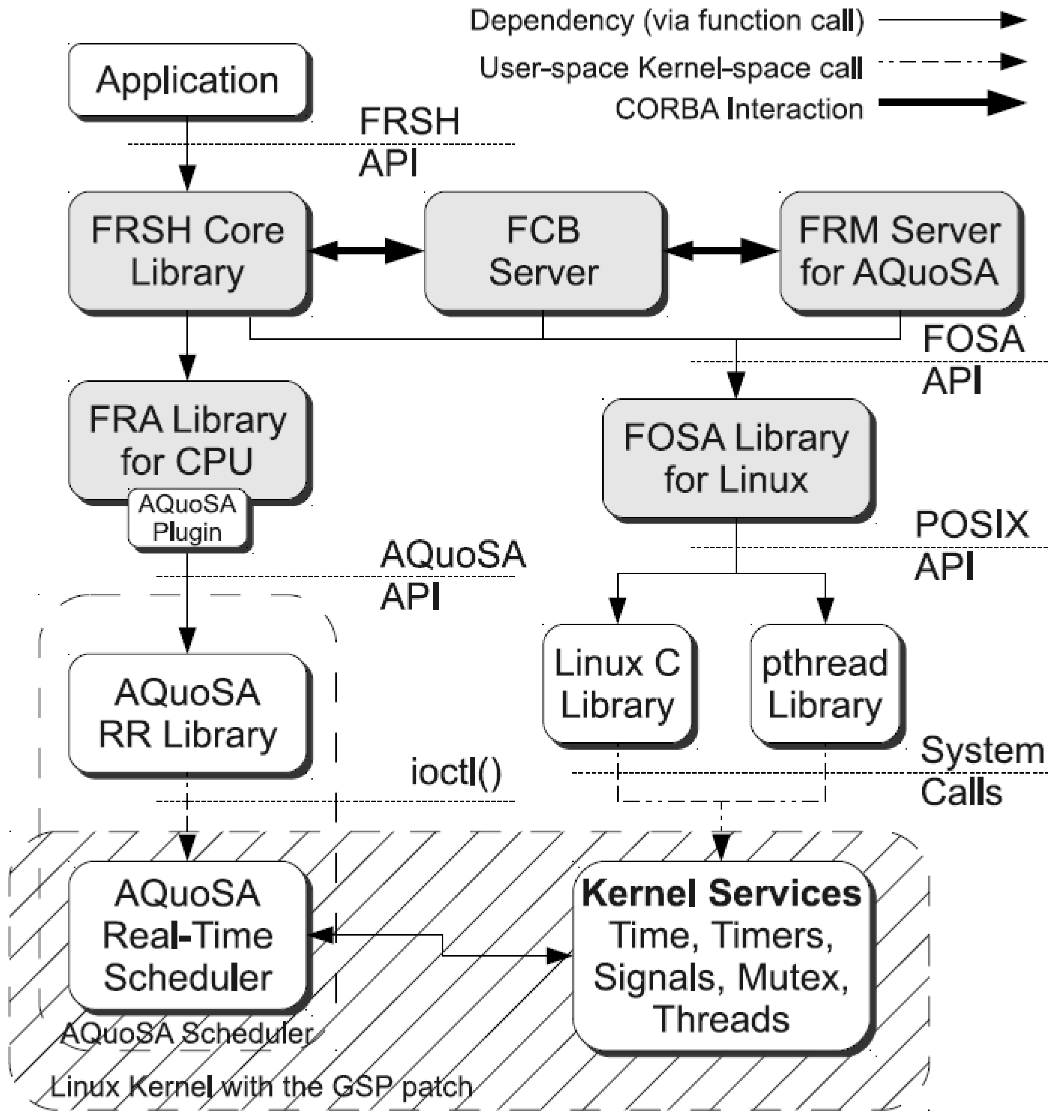
Portability across RTOSs

Adaptive real-time systems

Application-level QoS control

QoS power-aware optimization

Atomic negotiations



http://www.frescor.org

The IRMOS Scheduler

IRMOS

Interactive Realtime Multimedia Applications
on Service Oriented Infrastructures

IRMOS Scheduler

Features at a glance

- Resource Reservations
  - EDF-based scheduling (hard CBS)
- **Hierarchical scheduling**
  - Multiple tasks attached to same reservation
  - POSIX Fixed Priority scheduling inside each reservation
- **Multi-processor** reservations
  - Partitioned scheduling for improved efficiency
  - Migration of tasks among CPUs
- Simple **admission control**

IRMOS Real-Time Scheduler Design Goals

Replace real-time throttling

Tight integration in Linux kernel

- Modification to the Linux RT scheduler

Reuse as many Linux features as possible

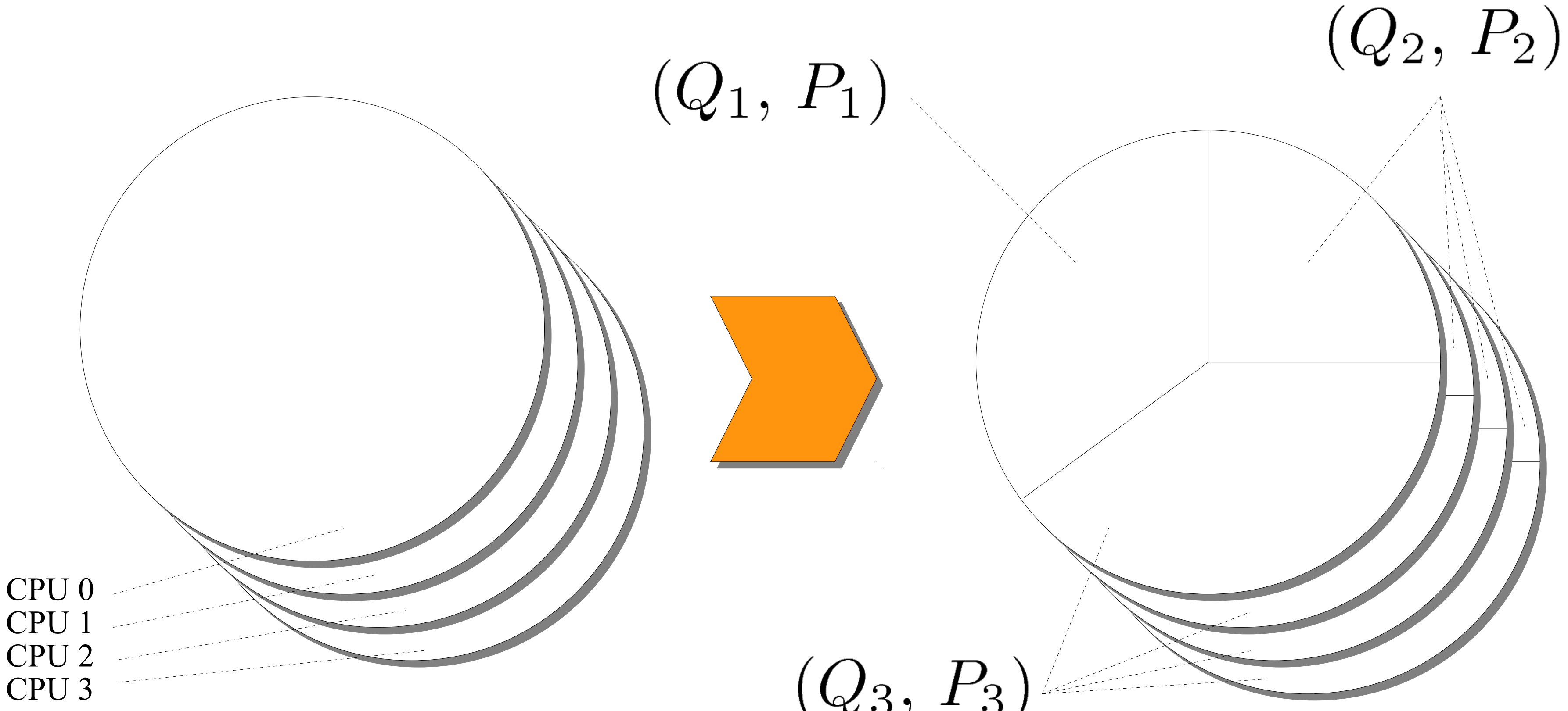
- Management of task hierarchies and scheduling parameters via **cgroups**
- POSIX compatibility and API

Efficient for SMP

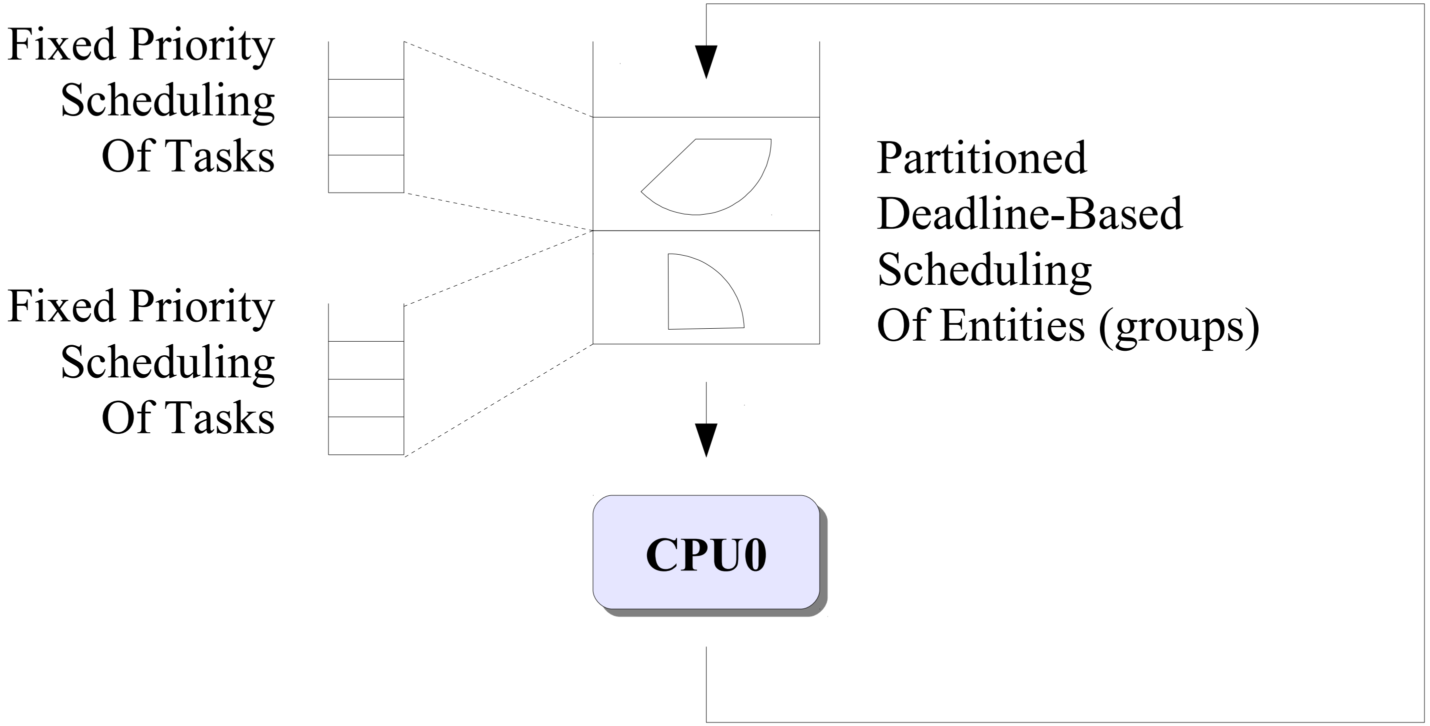
- Independent runqueues

IRMOS Scheduler

Slice the available computing power into reservations

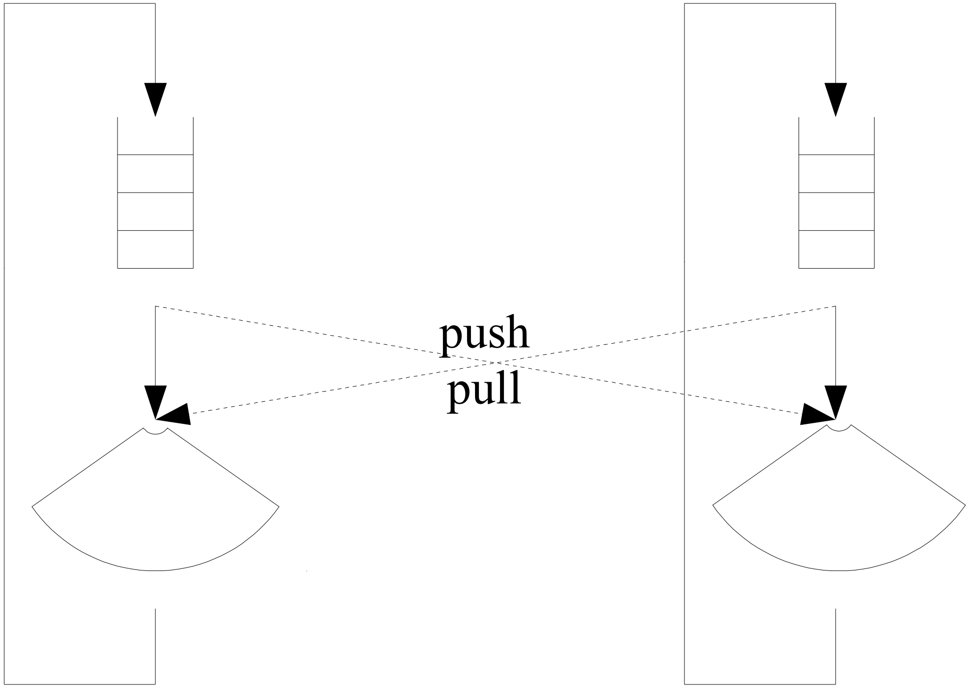


Partitioned CBS



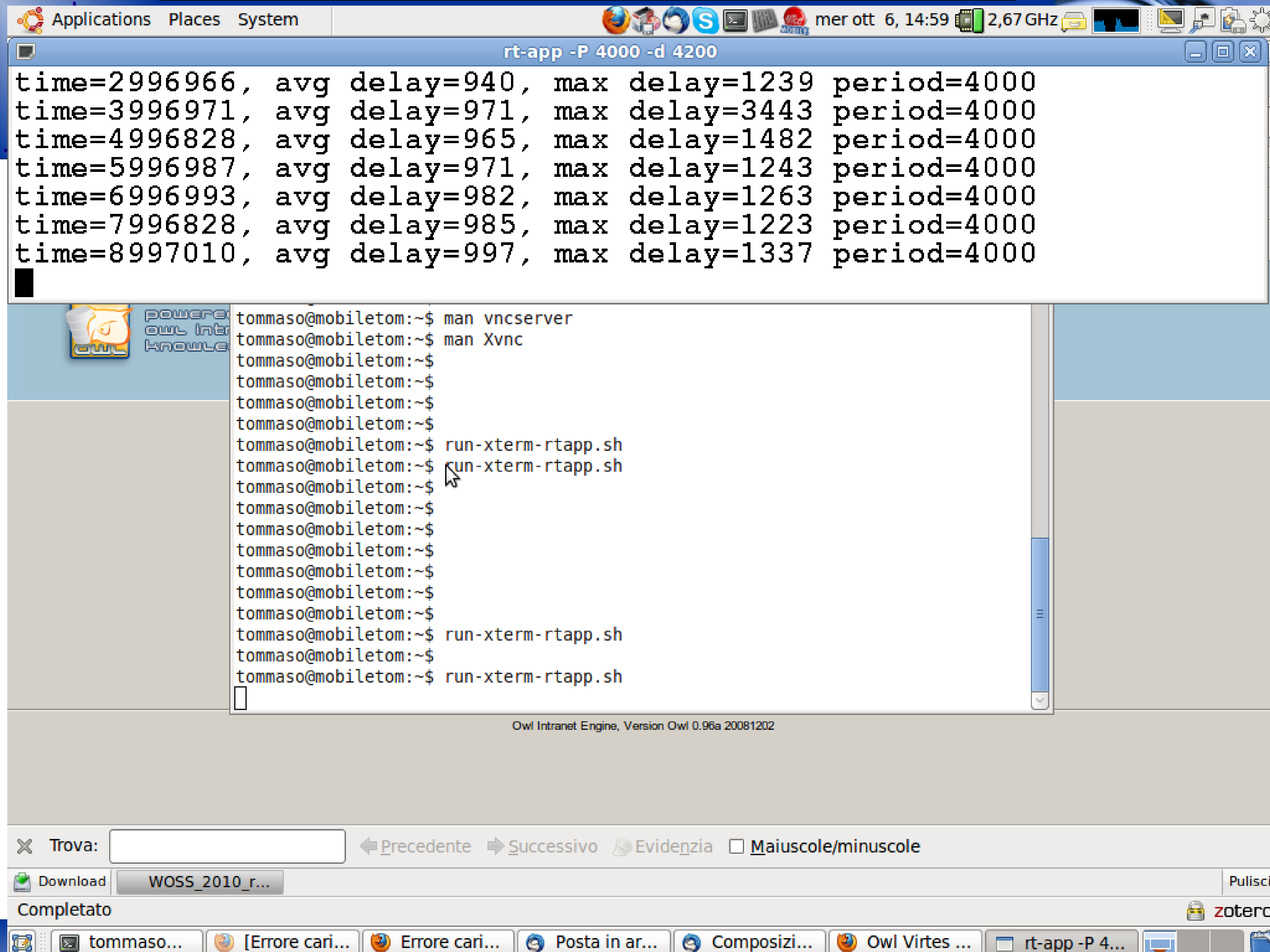
Group-wide POSIX Fixed-Priority

- SCHED_RR, SCHED_FIFO both possible
- With M CPUs, if N ≤ M partitioned reservations are scheduled, then the N highest priority tasks in the group concurrently run



IRMOS Real-Time Scheduler

Short Demo


Applications Places System
mer ott 6, 14:59
2,67 GHz
rt-app -P 4000 -d 4200
time=2996966, avg delay=940, max delay=1239 period=4000
time=3996971, avg delay=971, max delay=3443 period=4000
time=4996828, avg delay=965, max delay=1482 period=4000
time=5996987, avg delay=971, max delay=1243 period=4000
time=6996993, avg delay=982, max delay=1263 period=4000
time=7996828, avg delay=985, max delay=1223 period=4000
time=8997010, avg delay=997, max delay=1337 period=4000
tommaso@mobiletom:~$ man vncserver
tommaso@mobiletom:~$ man Xvnc
tommaso@mobiletom:~$
tommaso@mobiletom:~$
tommaso@mobiletom:~$
tommaso@mobiletom:~$
tommaso@mobiletom:~$ run-xterm-rtapp.sh
tommaso@mobiletom:~$ run-xterm-rtapp.sh
tommaso@mobiletom:~$
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tommaso@mobiletom:~$ run-xterm-rtapp.sh
tommaso@mobiletom:~$
tommaso@mobiletom:~$ run-xterm-rtapp.sh
Owl Intranet Engine, Version Owl 0.96a 20081202
Trova:
Precedente
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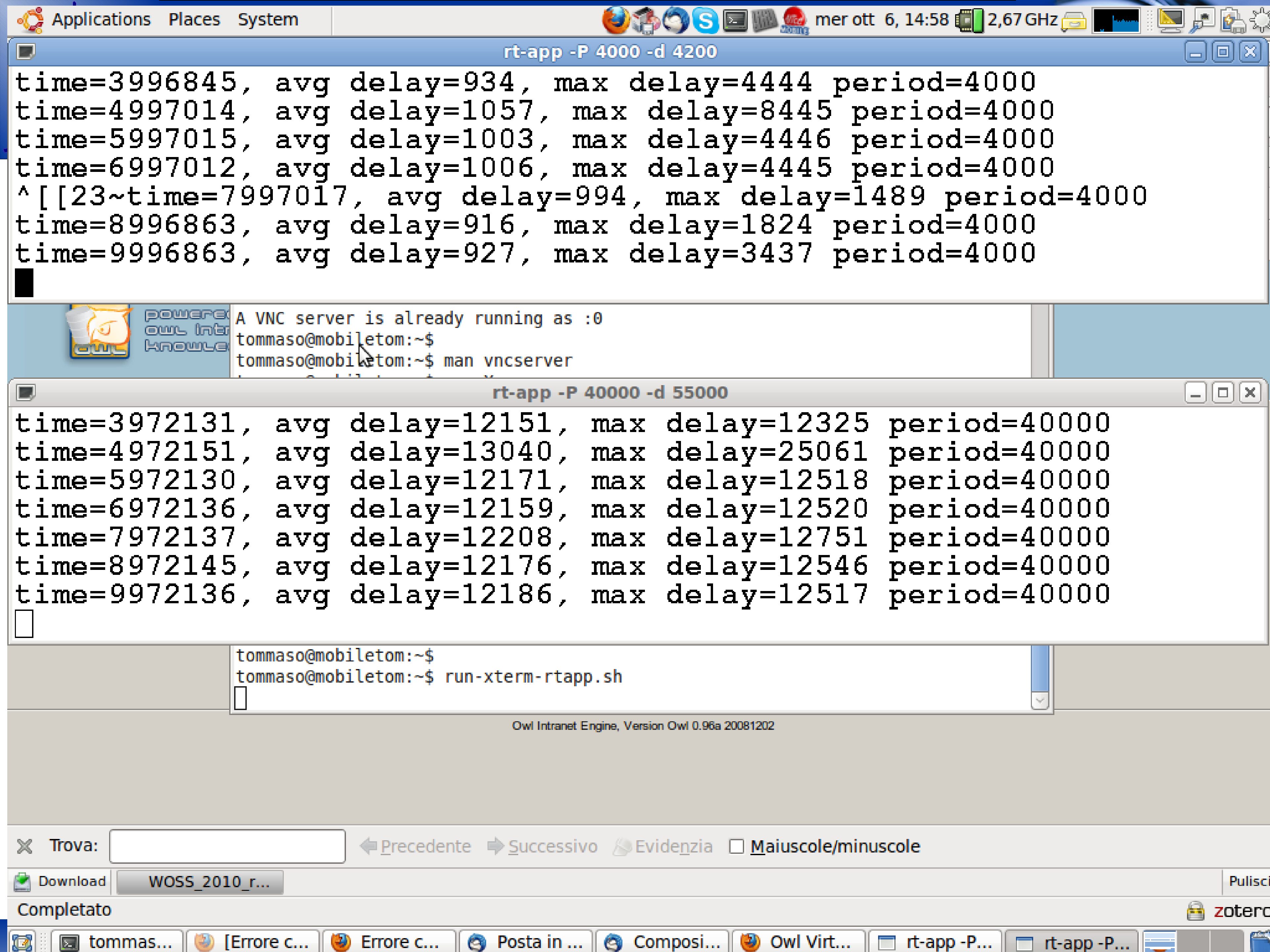
rt-app -P 4...


Applications Places System
mer ott 6, 14:58 2,67 GHz
rt-app -P 4000 -d 4200
time=3996845, avg delay=934, max delay=4444 period=4000
time=4997014, avg delay=1057, max delay=8445 period=4000
time=5997015, avg delay=1003, max delay=4446 period=4000
time=6997012, avg delay=1006, max delay=4445 period=4000
^[[23~time=7997017, avg delay=994, max delay=1489 period=4000
time=8996863, avg delay=916, max delay=1824 period=4000
time=9996863, avg delay=927, max delay=3437 period=4000
A VNC server is already running as :0
tommaso@mobiletom:~$
tommaso@mobiletom:~$ man vncserver
rt-app -P 40000 -d 55000
time=3972131, avg delay=12151, max delay=12325 period=40000
time=4972151, avg delay=13040, max delay=25061 period=40000
time=5972130, avg delay=12171, max delay=12518 period=40000
time=6972136, avg delay=12159, max delay=12520 period=40000
time=7972137, avg delay=12208, max delay=12751 period=40000
time=8972145, avg delay=12176, max delay=12546 period=40000
time=9972136, avg delay=12186, max delay=12517 period=40000
tommaso@mobiletom:~$
tommaso@mobiletom:~$ run-xterm-rtapp.sh
Owl Intranet Engine, Version Owl 0.96a 20081202
Trova:
Precedente
Successivo
Evidenzia
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rt-app -P...
rt-app -P...

rt-app -P 4000 -d 4200

```
time=1996772, avg delay=777, max delay=799 period=4000
time=2996772, avg delay=777, max delay=803 period=4000
time=3996772, avg delay=778, max delay=1172 period=4000
time=4996788, avg delay=817, max delay=929 period=4000
time=5996854, avg delay=788, max delay=941 period=4000
time=6996855, avg delay=872, max delay=1243 period=4000
time=7996790, avg delay=846, max delay=959 period=4000
```

```
[    10][qres_set_params_imp     ]<DBG>  Using Q=1200, P=4000, BW= 0.300000/0.75
0000
[    11][qres_set_params_imp     ]<DBG>  Creating new sever
```

rt-app -P 40000 -d 55000

```
time=1972095, avg delay=12097, max delay=12118 period=40000
time=2972095, avg delay=12102, max delay=12145 period=40000
time=3972096, avg delay=12099, max delay=12133 period=40000
time=4972269, avg delay=12224, max delay=12300 period=40000
time=5972269, avg delay=12271, max delay=12313 period=40000
time=6972268, avg delay=12260, max delay=12303 period=40000
time=7972267, avg delay=12259, max delay=12289 period=40000
```

```
irmos/bin/rt-app -P 4000 -d 4200
[    15][qres_cleanup            ]<DBG>  Cleaning up
```

Owl Intranet Engine, Version Owl 0.96a 20081202

Trova: Precedente Successivo Evidenzia Maiuscole/minuscole

Download WOSS_2010_r... Pulisci

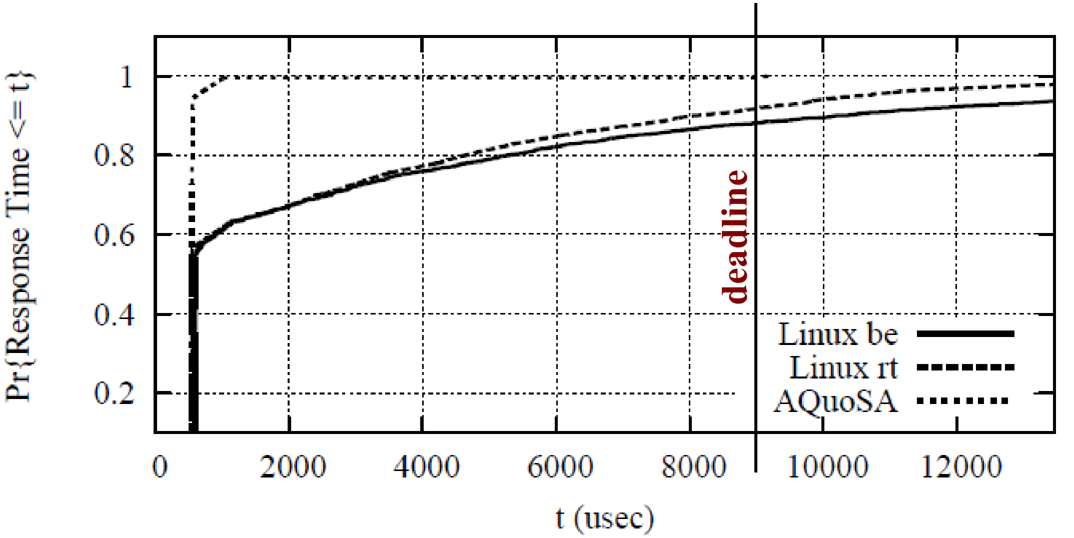
Completato zotero

Let's Give Some Numbers

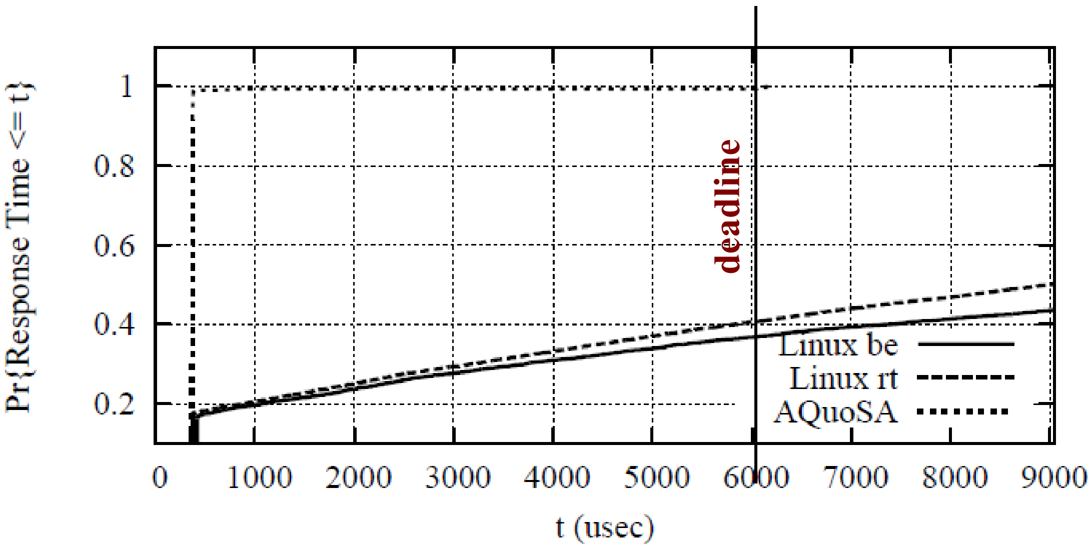
Experimental results

(Pentium 4 @ 2GHz, Linux 2.6.29.1 + AQuoSA)

Response-time CDF for the real-time task with the shortest period under light load (48%)



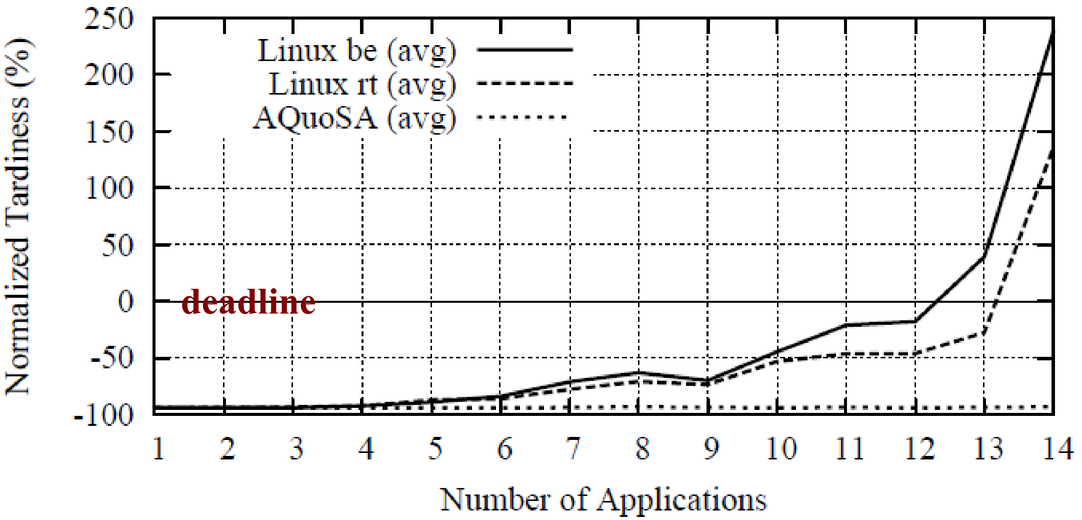
Response-time CDF for the real-time task with the shortest period under heavy load (84%)



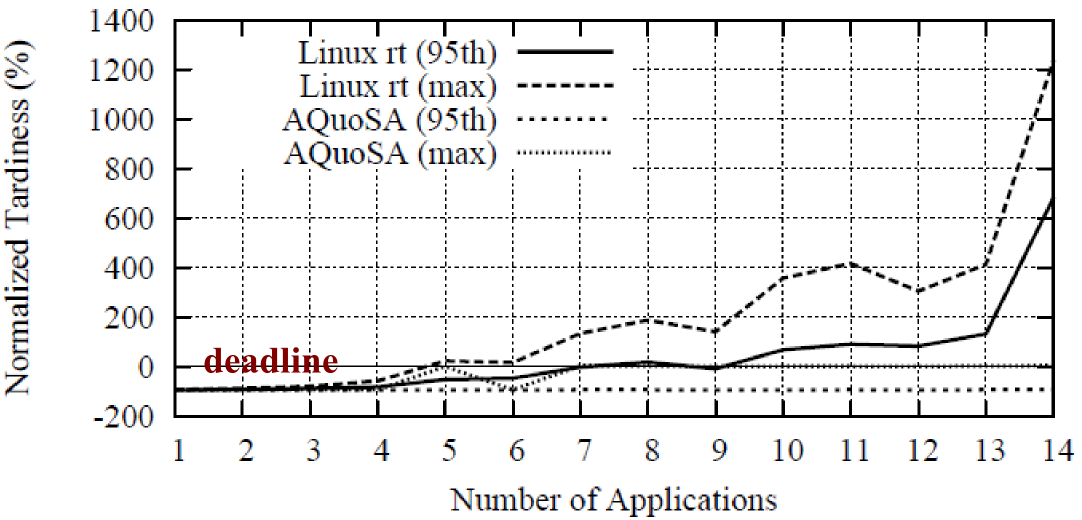
Experimental results

(Pentium 4 @ 2GHz, Linux 2.6.29.1 + AQuoSA)

Average normalized tardiness for the real-time task with the shortest period, varying the number of real-time tasks in the system.



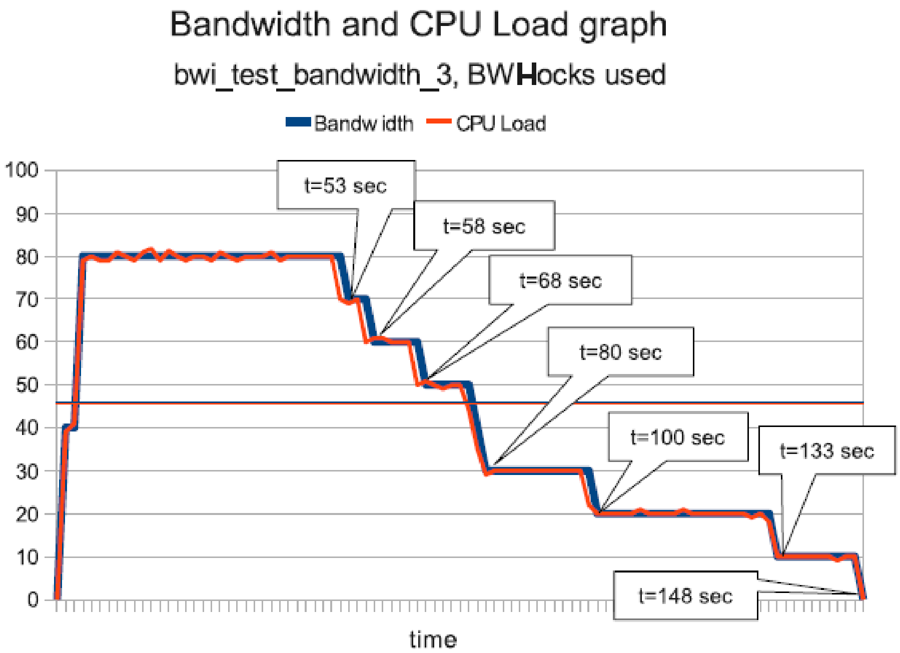
Maximum and 95th percentile of the normalized tardiness for the real-time task with the shortest period, varying the number of real-time tasks in the system.

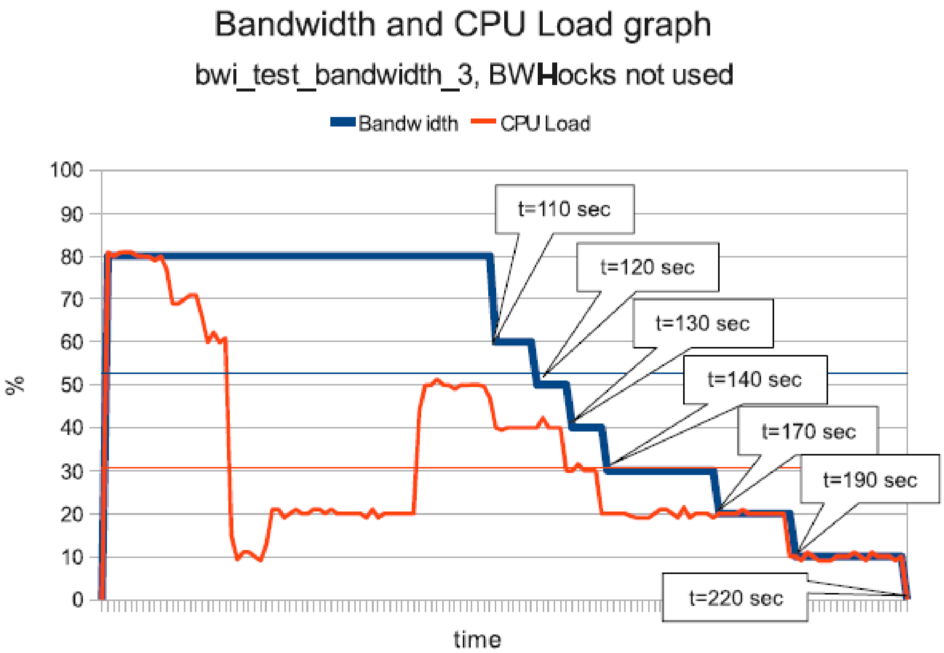


Synchronization

Bandwidth Inheritance (BWI / M-BWI)

- Deals with **Priority Inversion** in EDF scheduling
- **Deadline inherited** from lock owner





Thanks for your attention

Questions ?

Virtualized Real-Time Applications

(Real-Time IaaS)

Virtualization & real-time increasingly interesting

- Wide availability of broadband connections ==> shift in computing paradigms towards distributed computing (**cloud computing**)
  - Not only *remote storage* and *batch processing*
  - But also *remote processing* for *interactive applications*
- Examples
  - **Virtual Reality** with heavyweight physics simulations
  - Distributed editing of HD video (**film post-production**)

Introduction

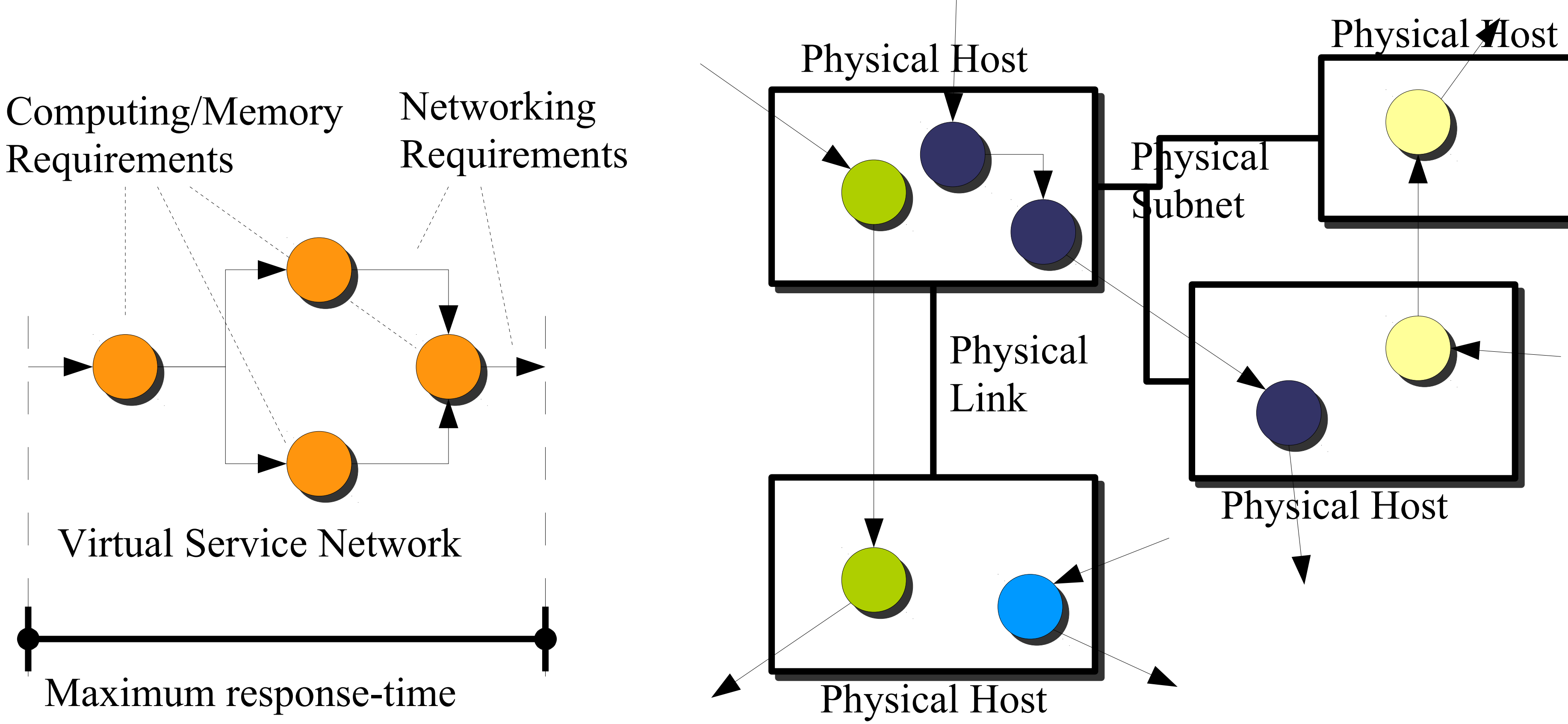
Service-Oriented Architectures

- Promising approach to distributed computing
- Taking advantage of virtualization techniques:
  - Location independence
  - Security
  - Fault-Tolerance
- Distributed Interactive/Real-Time Applications may benefit from SOA design

Problem presentation

Optimum/reasonable deployment of VSNs on PNs

- Given computing/network/memory requirements
- Respecting end-to-end timing constraints



Problem presentation

Issues in deploying RT SW Components in VMs

- Scheduling and timing
  - **VM scheduling impacts on the vision of time by guest OSes**
    - Time granularity (for measuring time and setting timers)
    - Non-uniform progress-rate of applications
  - SMP-enabled guests
    - Spin-lock primitives assume release of locks within very short time-frames
      - What happens if the **lock-owner VM is descheduled** ?
- **Benchmarking**
  - A VM may be deployed on different HW (SOA scenario)
    - How to achieve predictable performance ?
  - VMs may be deployed on **General-Purpose HW** (with cache)
    - How to account for **HW-level interferences** ?

Problem presentation

Issues in deploying RT SW Components in VMs

- **Temporal isolation** across VMs
  - Compute-bound and I/O-bound VMs
  - Shared host resources (e.g., network interrupt drivers)
  - Intensive I/O on virtualised peripherals
- Proper management of shared resources:
  what MP resource-sharing protocol is appropriate ?
  - Proper management of **priority inversion**
  - Reduced overheads (limited number of preemptions)
  - Run-time schedulability analysis and **admission control**

Approach

Traditional (hard) real-time techniques are not appropriate

- lead to poor resource utilization
- imply high/unsustainable development costs

Soft real-time techniques are more appropriate

- **Stochastic models** for system/QoS evolution
- **Probabilistic guarantees** (as opposed to deterministic ones)

Pragmatic approach

- Theory is always applied
  - on **real GPOS** (Linux)
  - with a **real Virtual Machine Monitor** (KVM)
  - on **real multimedia applications**

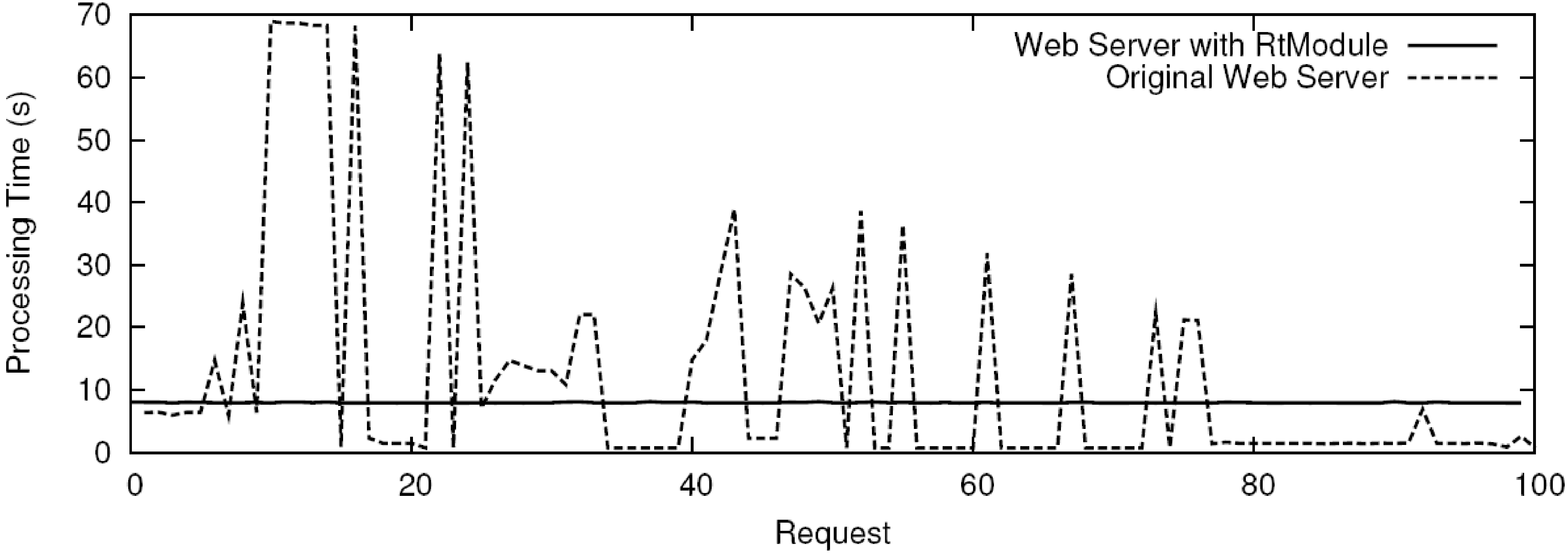
Approach

Basic Building blocks

- Linux Kernel as host OS enriched with our RT Scheduler(s)
- Each VMU is attached RT scheduling parameters (defining its temporal capsule)
- Improvements on the real-time virtualization performance
  - Modifications at the hypervisor level
  - Modifications at the kernel level
- Analysis of Virtualized Real-Time applications by Hierarchical Real-Time Schedulability Analysis

Temporal isolation of compute-intensive VMUs

- Response-times of Apache2 Web Server
  - → From **unpredictable and highly variable**
  - → To **predictable and very stable** (low fluctuations)
    - – At the cost of an *increased minimum response-time*



Experimental results (VHPC 2010)

Temporal isolation of networking traffic among concurrent VMUs

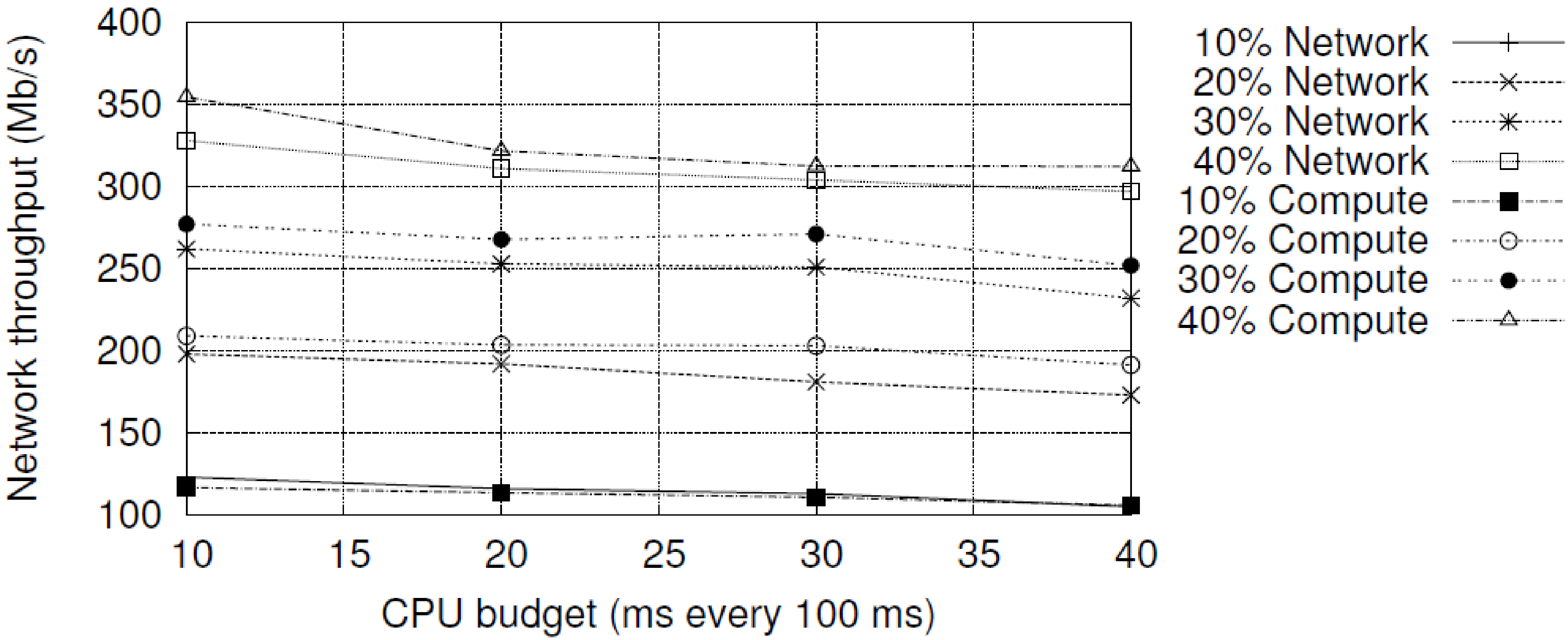


Fig. 3: Network throughput (Y axis) for a VM as a function of the CPU share of the other VM (X axis), at varying CPU shares for itself (different curves), in case of CPU- and I/O-intensive loads.

Theoretically Optimum Deployment

of

Distributed Real-Time Workflows

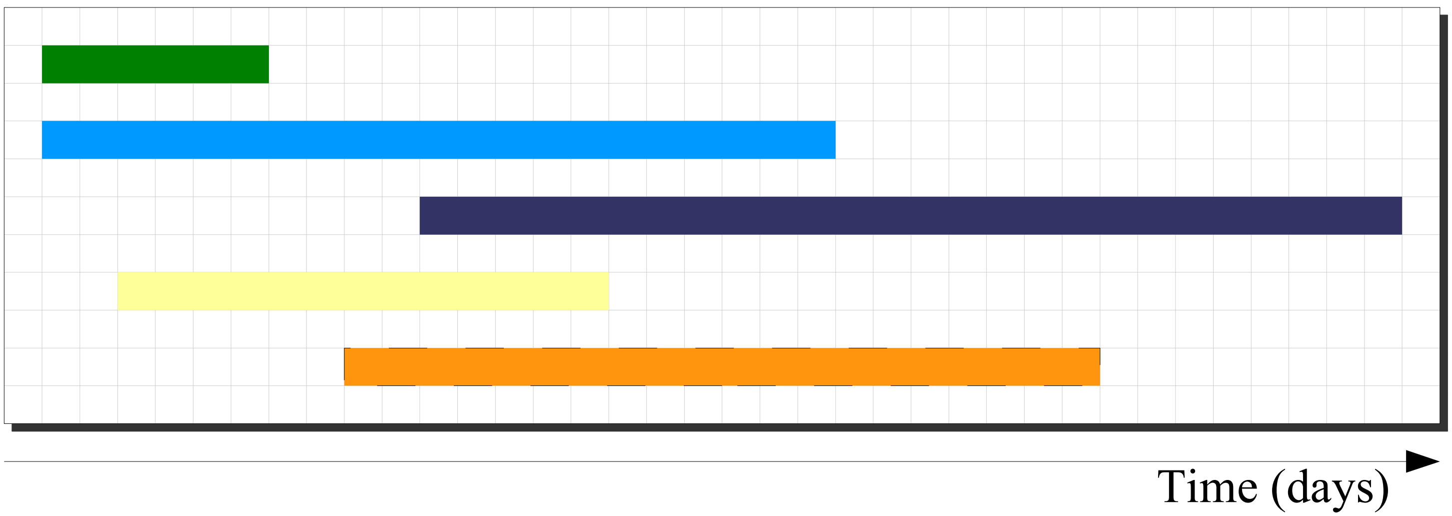
with

End-to-end Response Requirements

Problem presentation

Optimum deployment of VSNs on PNs

- Considering expected usage time-horizon (**advance reservations**)
- Periods of overlapping reservations



Proposed approach

Temporal isolation among independent application workflows

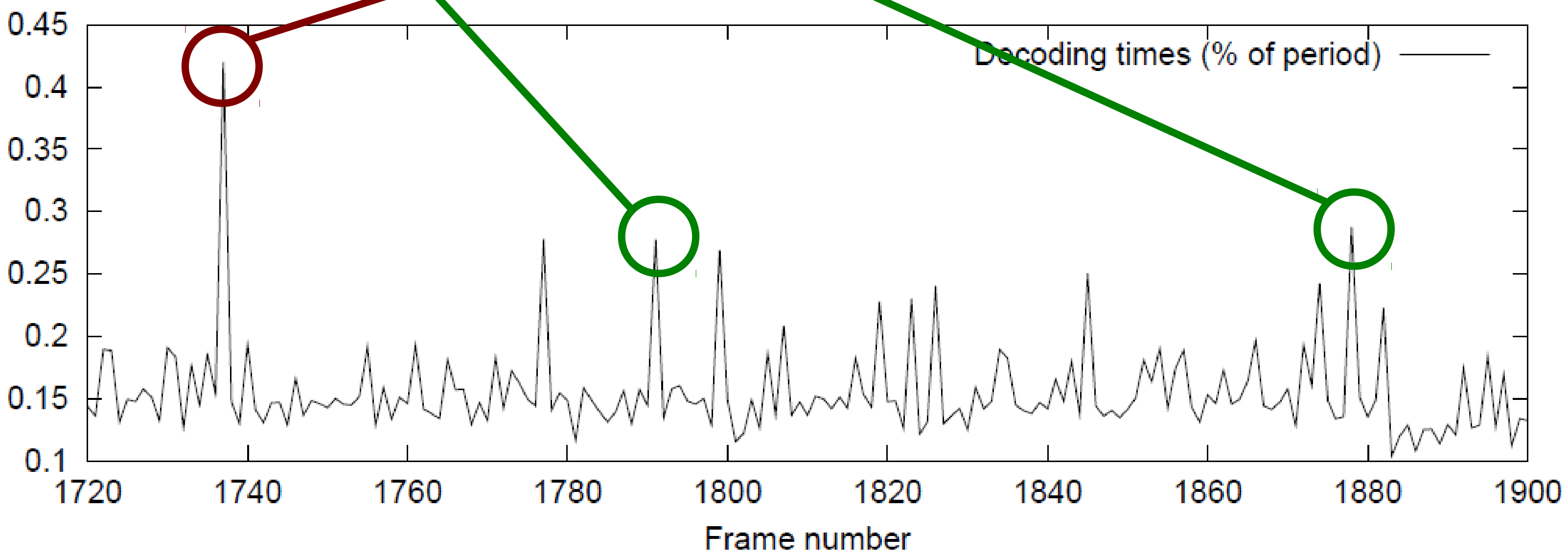
- Time-sharing of **heterogeneous** computing nodes
  - Through **real-time scheduling** at the OS/kernel level
- Time-sharing of network links
  - Through **QoS-aware scheduling** of the medium (e.g., Wf^2Q+)

How to tune resource allocation ?

- i.e., real-time scheduling parameters

Probabilistic availability guarantees

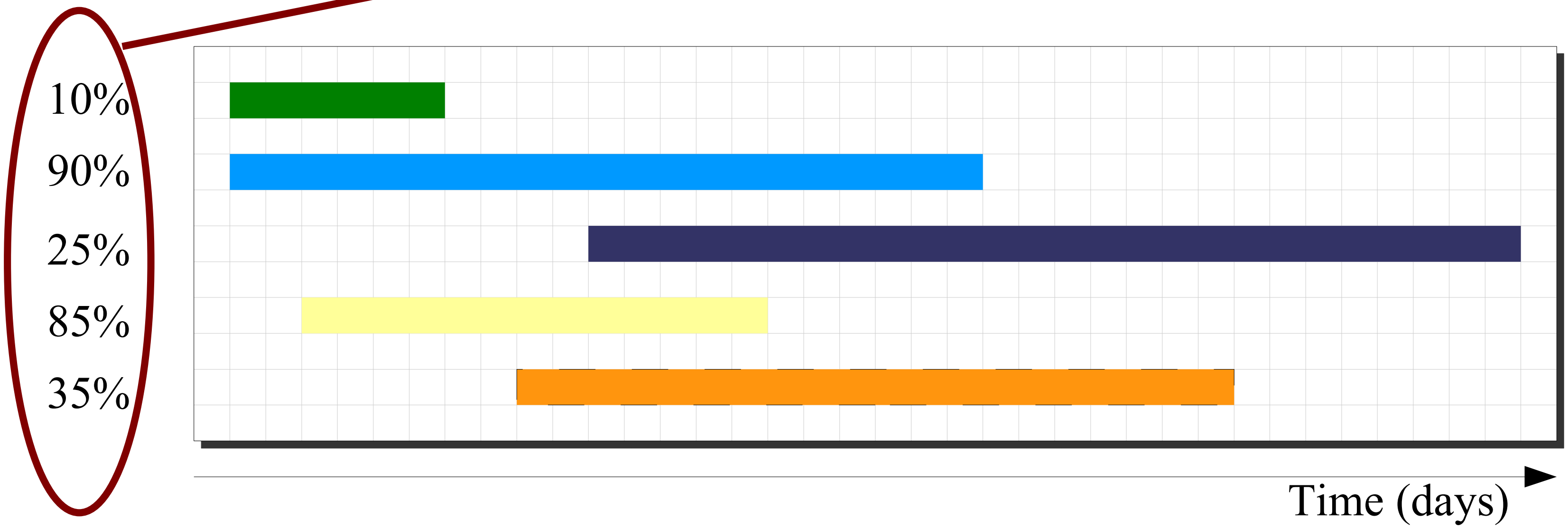
Tune allocation on computation-time percentile (instead of WCET)



Probabilistic availability guarantees

Applications sharing the same PH may be independently activated

Provider relies on actual probabilities of activation for admitted & new services



Modelling

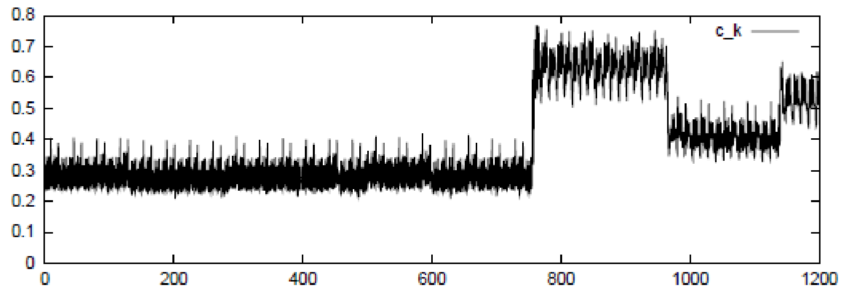
Finally, we obtain a Mixed-Integer Non-Linear Programming (MINLP) optimization problem

- Constraints
  - Physical resources topology
  - Application (VSN) topology
  - Deterministic formulation
    - Maximum end-to-end latency for deployed workflows
    - Maximum saturation level for each physical host and link
  - Probabilistic formulation
    - Minimum probability of having enough resources when the application is actually activated by the user
    - Minimum probability of respecting the end-to-end latency
- Objective function
  - e.g., minimize number of used hosts, maximize provider's revenue

Adaptive Reservations

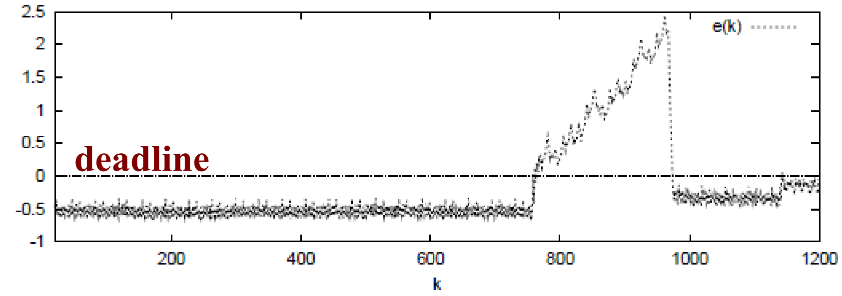
Need for adaptivity

Computation times for decoding MPEG frames



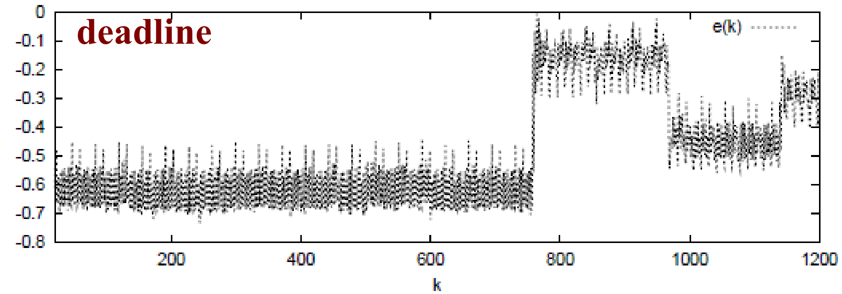
(a)

Scheduling error with an over-allocation of 30% over the average



(b)

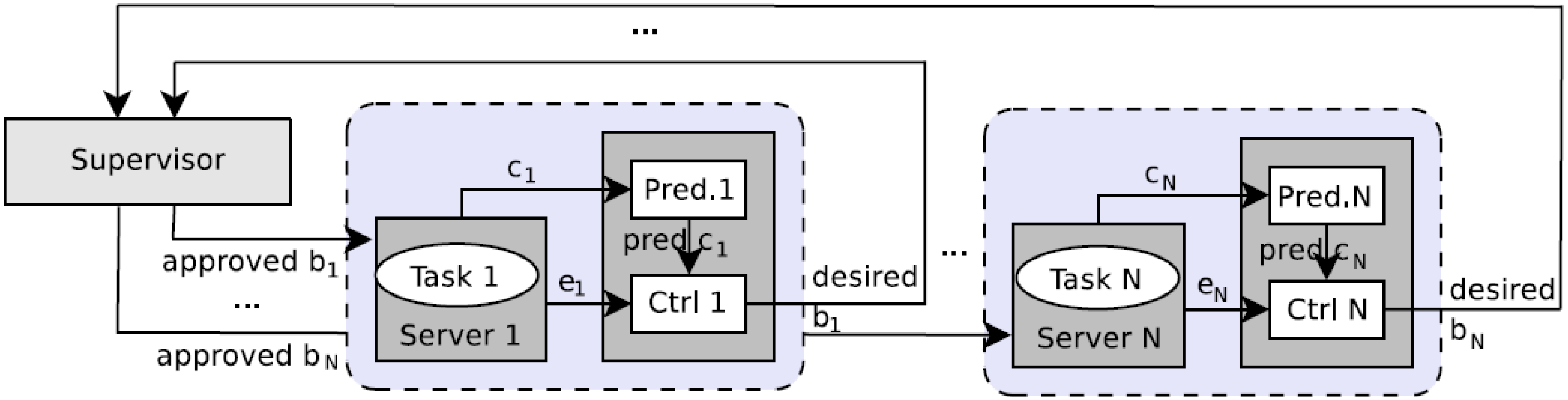
Scheduling error with allocation tuned on maximum



(c)

Feedback-based scheduling

- **Sense**: tracking of workload fluctuations
- **Compute**:
  - Prediction/estimation of workload for next period(s)
  - Compensation for possible current delays
- **Actuate**: adapt the scheduling parameters (Q_i, P_i)



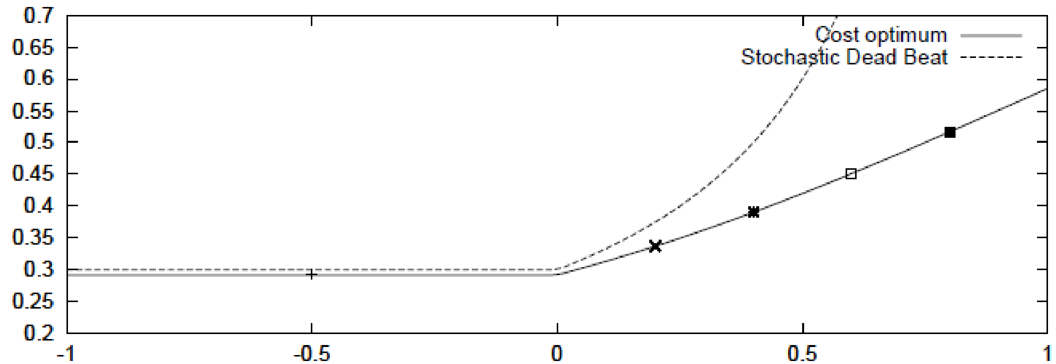
Adaptive Reservations

Workload prediction

- Moving average
- Percentile estimation over moving window
- FIR decorrelation + error estimation

Budget controller

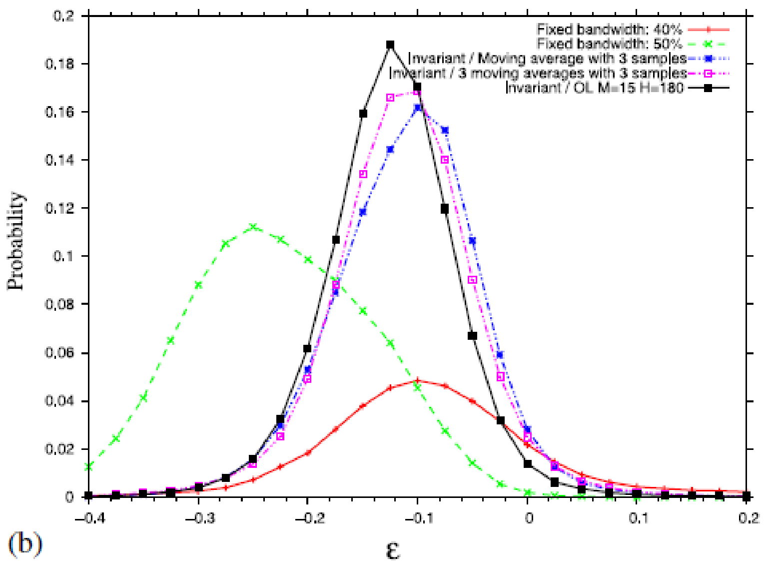
- Target region around deadline
- Stochastic approaches
  - Probability of deadline-miss
  - Optimum error/bandwidth trade-offs



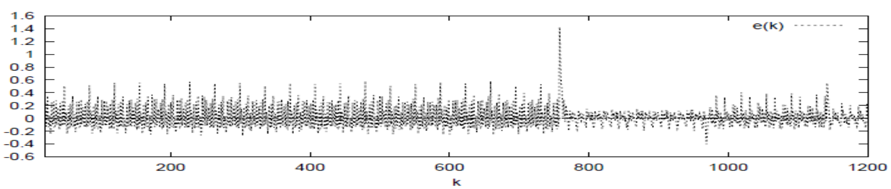
$$
\begin{aligned}
B_k(\varepsilon_k) &= \sqrt[3]{\rho + \delta(\varepsilon_k)} + \sqrt[3]{\rho - \delta(\varepsilon_k)} \\
\rho &= \frac{\gamma(\sigma^2 + \mu^2)}{(1-\gamma)} \\
\delta(\varepsilon) &= \sqrt{\left(\frac{\gamma}{1-\gamma}\right)^2 (\sigma^2+\mu^2)^2 + \left(\frac{2}{3}\frac{\mu\gamma[1-S(\varepsilon_k)]}{1-\gamma}\right)^3}
\end{aligned}
$$

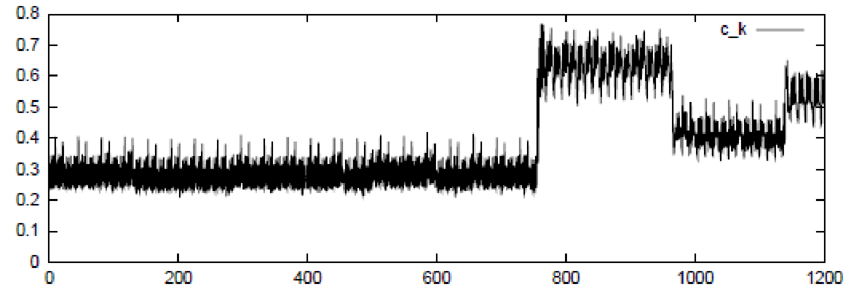
Experimental results

PMF of scheduling error with various budget control strategies

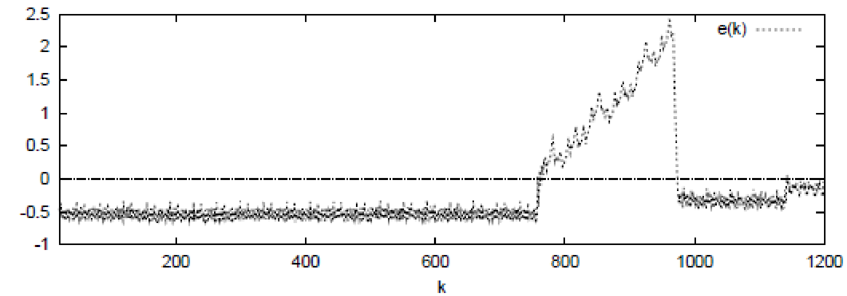


(b)

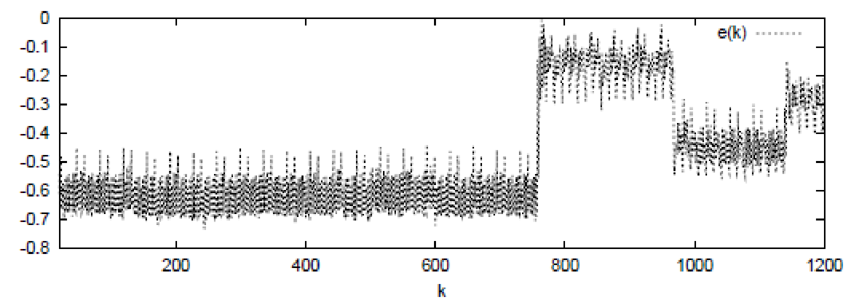




(a)



(b)



(c)

Automatic Identification of Scheduling Parameters

Recent developments in GPOS CPU scheduling

- Various APIs for accessing the enhanced functionality
  - For example, the FRSH API
  - For example, the AquoSA API
- They require **modifications** of the applications
  - at the **source-code level**
- Can we provide real-time guarantees to **unmodified** applications ?
  - For example, for **legacy multimedia** applications ?
  - Or, simply because of no time to modify the applications

Objectives

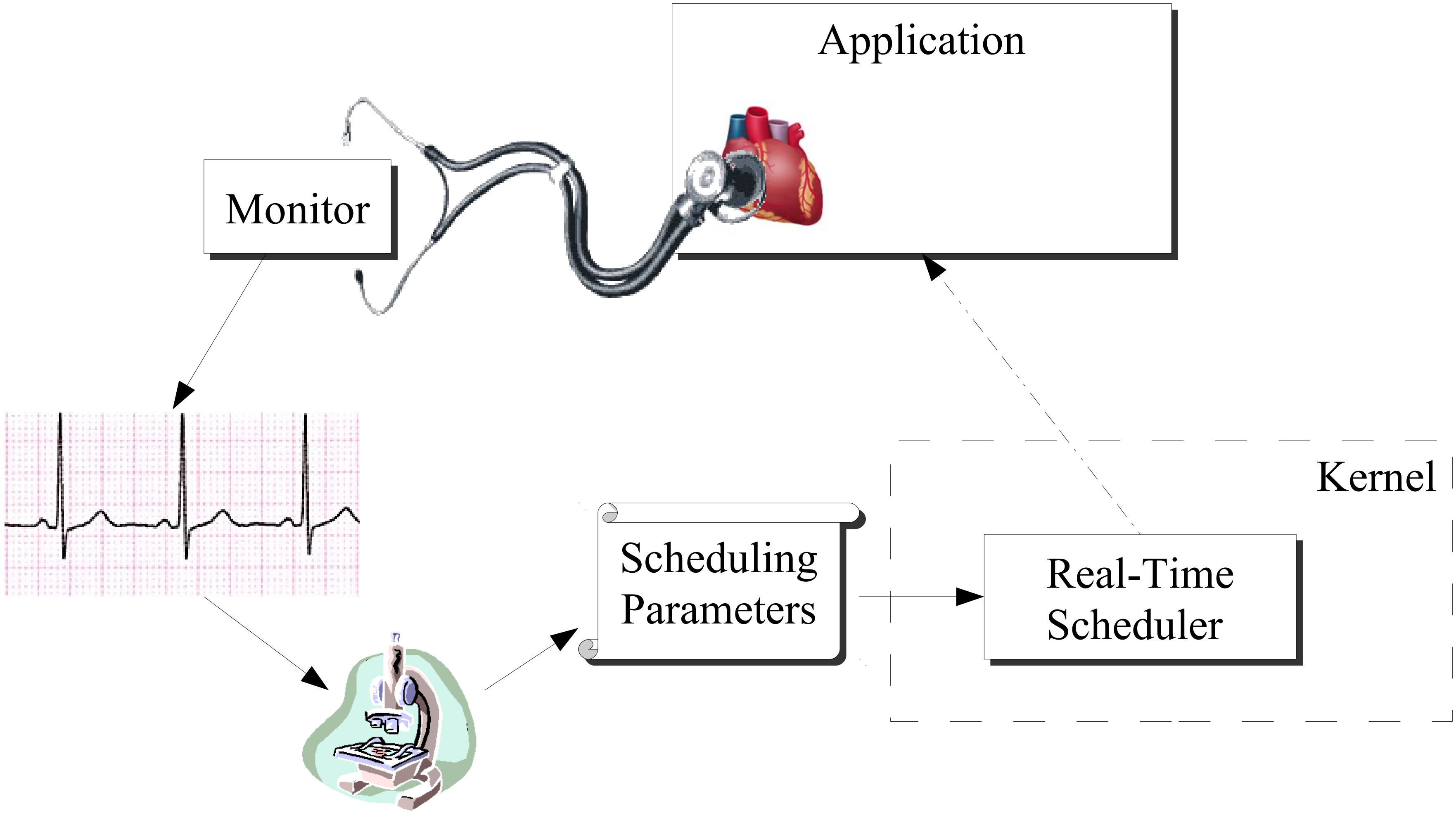
We actually can

- allow (legacy) real-time periodic applications
  - benefit of real-time scheduling facilities increasingly available on a GPOS

Objectives

We actually can

- allow (legacy) real-time periodic applications
- to benefit of real-time scheduling facilities increasingly available on a GPOS
- **without any change** in the application source-code


Application
Monitor
Kernel
Scheduling Parameters
Real-Time Scheduler

Proposed approach

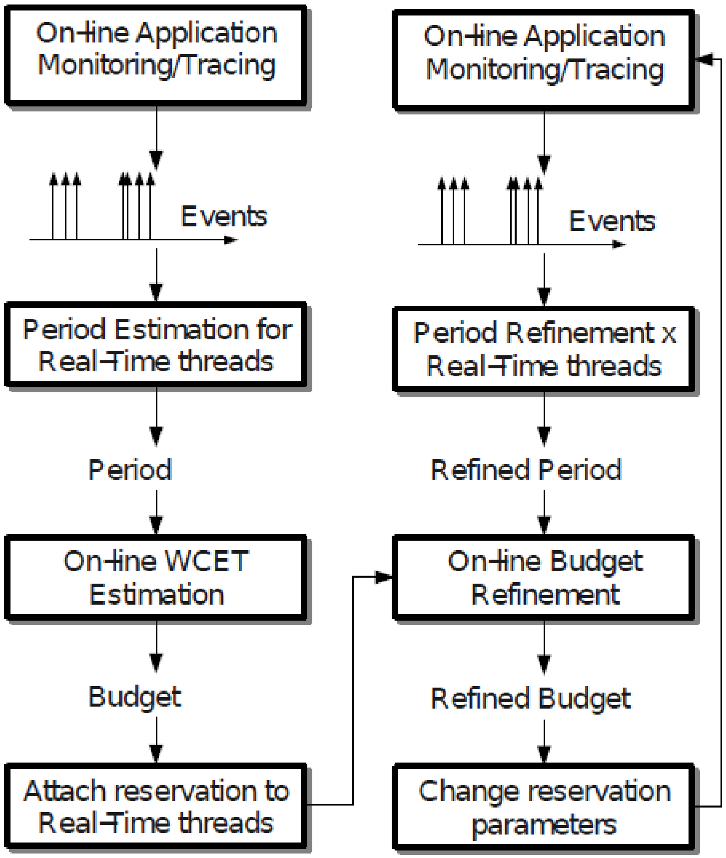
Legacy Feedback Scheduling (LFS++)

- An appropriate **tracing mechanism** observes the application, *inferring main parameters* affecting a (periodic) multimedia application temporal behaviour:
  - *job execution time*
  - **period**
- Scheduling guarantees are **automatically** provisioned by the OS, according to proper **scheduling parameters**
  - Based on sound arguments from real-time theory

Proposed approach

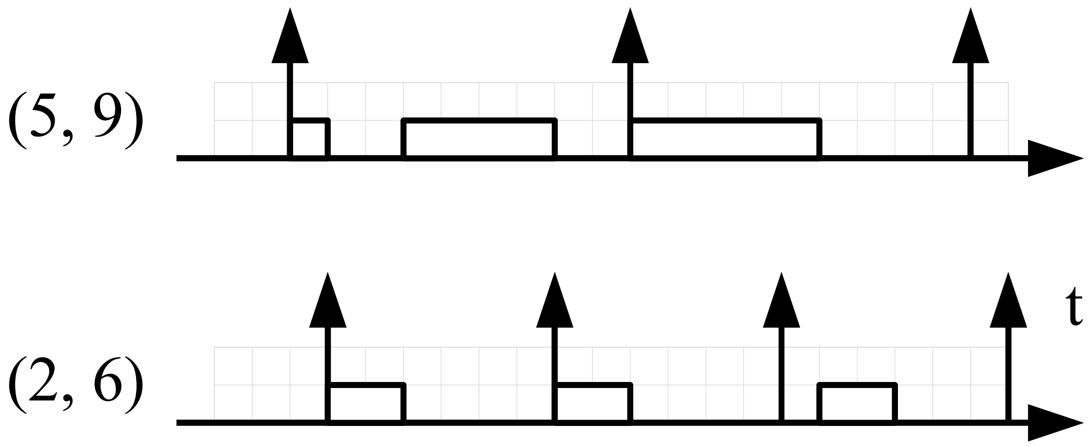
Comprehensive view

- Application tracing
- Period estimation (events analysis)
- On-line WCET estimation
- Automagic provisioning of scheduling guarantees



Reservation-based scheduling: (Q_i, P_i)

- "Q_i time units **guaranteed** on CPU every P_i time units"



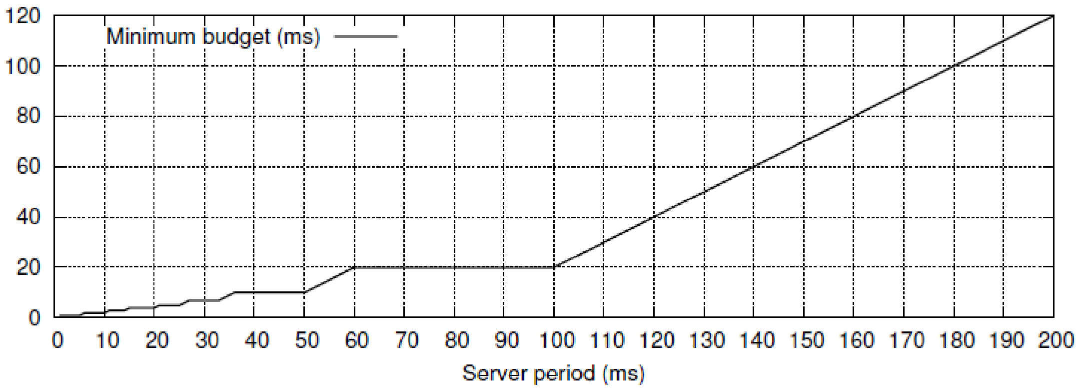
Real-time throttling on Linux is different

- Only constraint to "no more than Q_i every system-wide P"

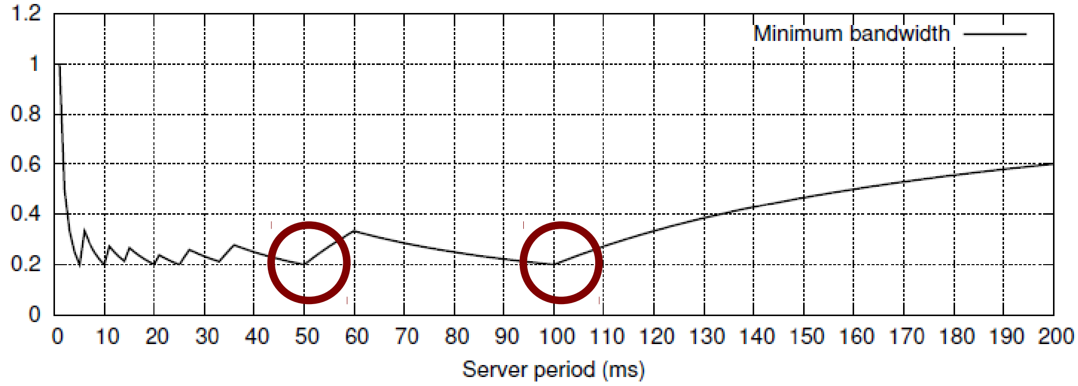
What are the reservation parameters needed for correctly scheduling a real-time periodic task with assigned WCET and period ?

The <u>minimum</u> reservation utilization is achieved

- when the **reservation period equals the task period**
  - or any integer sub-multiple



(a)



(b)

Core problem

How to detect the application period ?

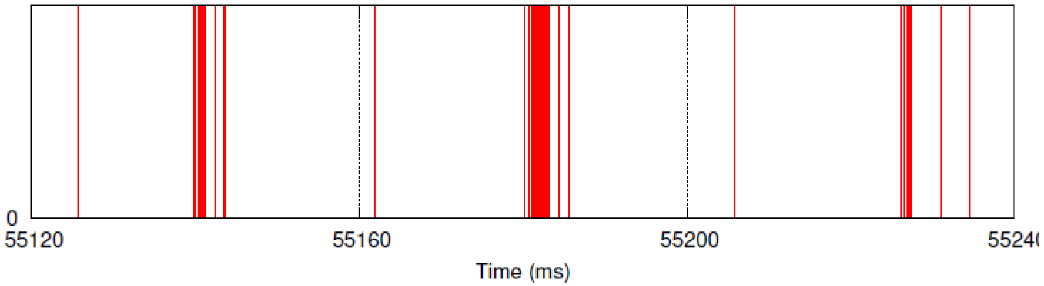
- Of a legacy real-time application (no source-code availability, no modifications)

Proposed approach

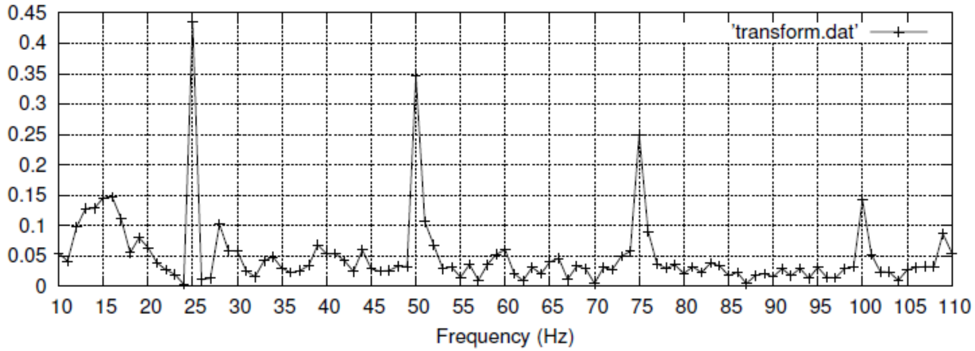
- Tracing the application behaviour *at run-time*
- For the purpose of identifying "**periodicity patterns**"

Period detection

The tracer produces a sequence of time-stamps



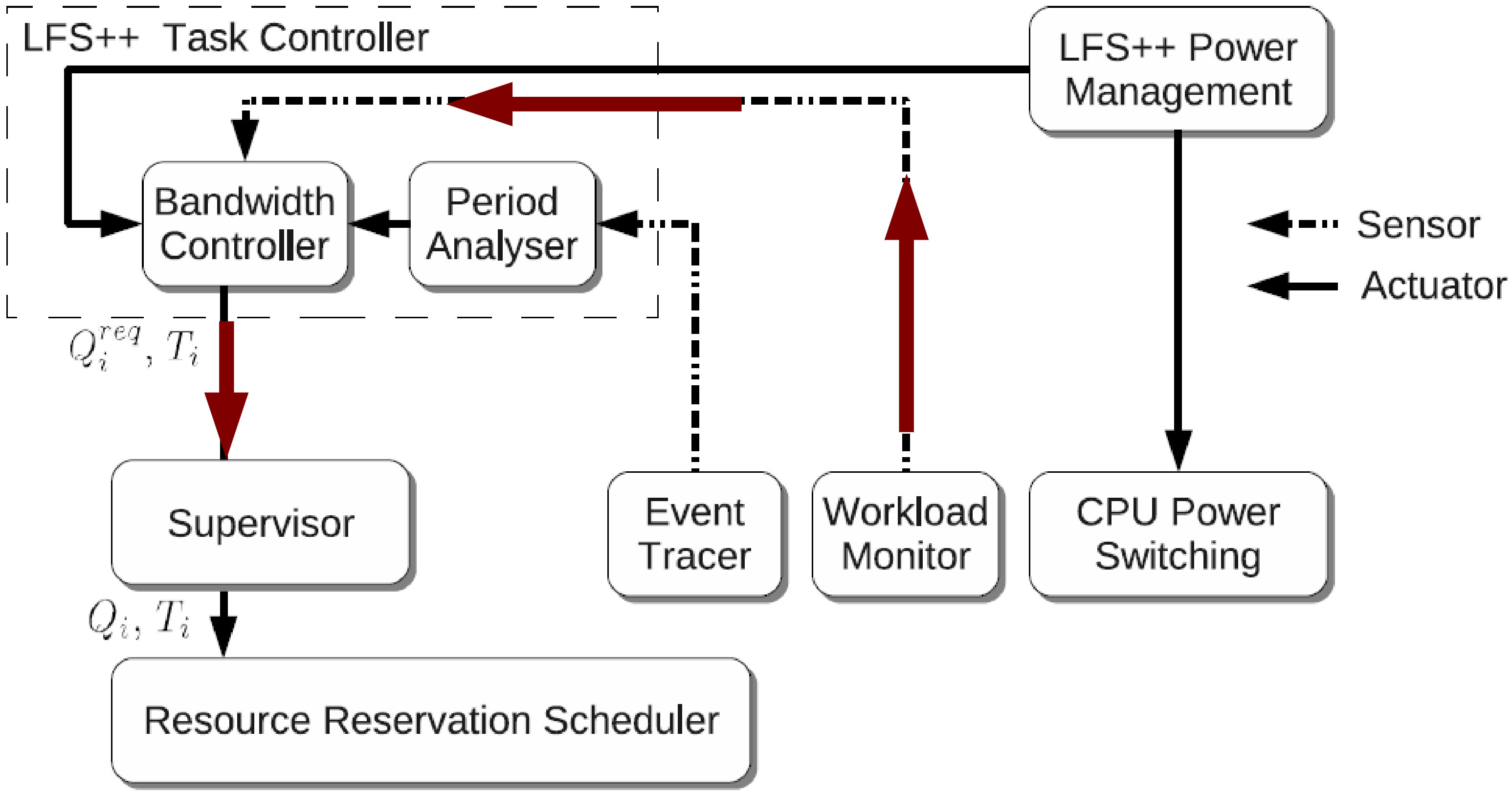
Time-stamps used to compute a Fourier-transform



A heuristic catches the first harmonic

Budget identification

"Feedback-based scheduling" budget control loop



Experimental results

Set-up

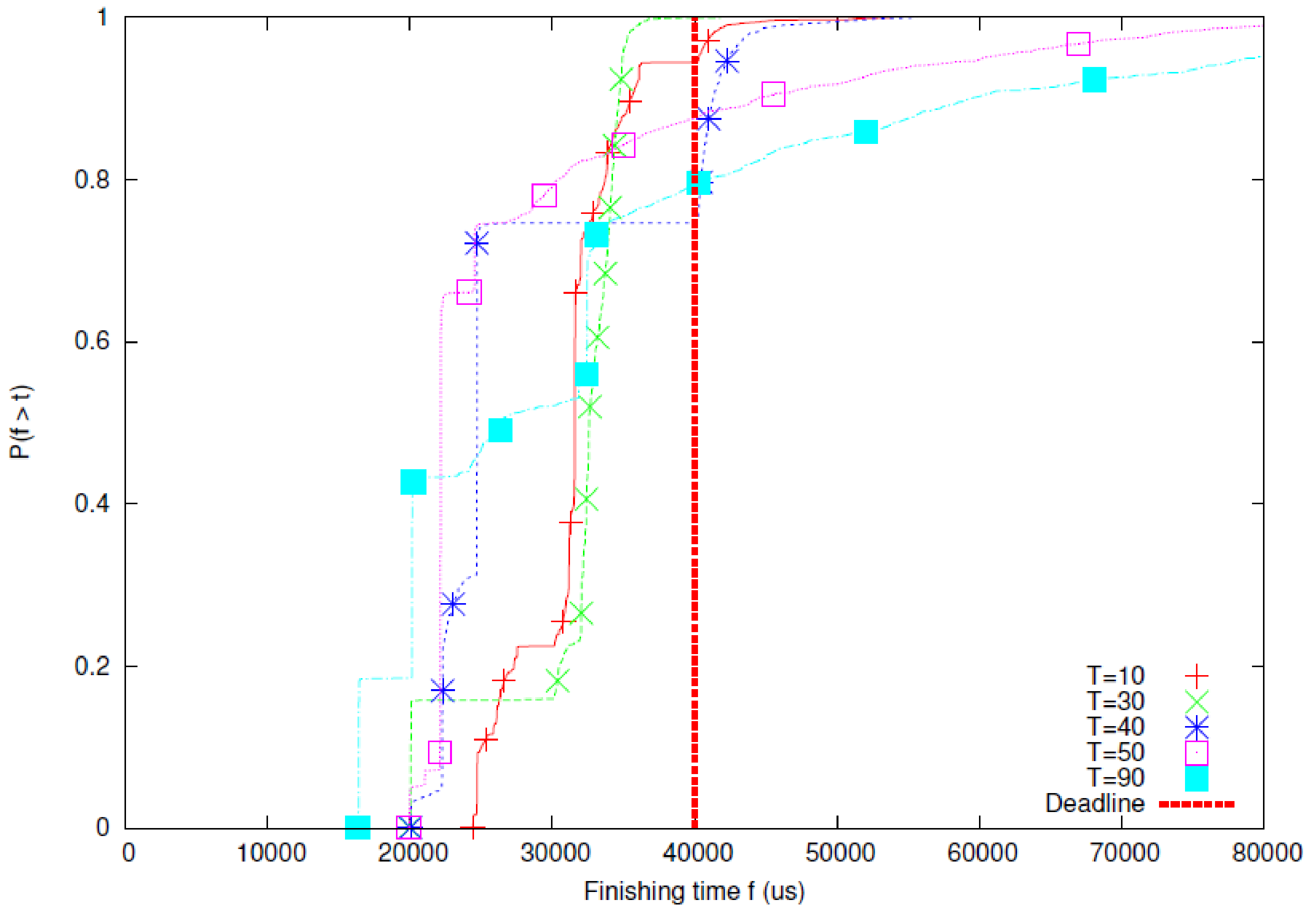
- Linux 2.6.29, with an implementation of the CBS scheduler
- Feedback-scheduling by means of AQuoSA
- **mplayer**
  - modified to monitor the **Inter-Frame Time (IFT)** and
- Application tracing by using **qtrace** (kernel-level)

Validation metrics

- **Inter-Frame Time** (for mplayer)
- **A/V desynchronisation** (for mplayer)
- **Response-time** (for synthetic application)
- **Allocated bandwidth** on the Real-Time scheduler

Experimental results

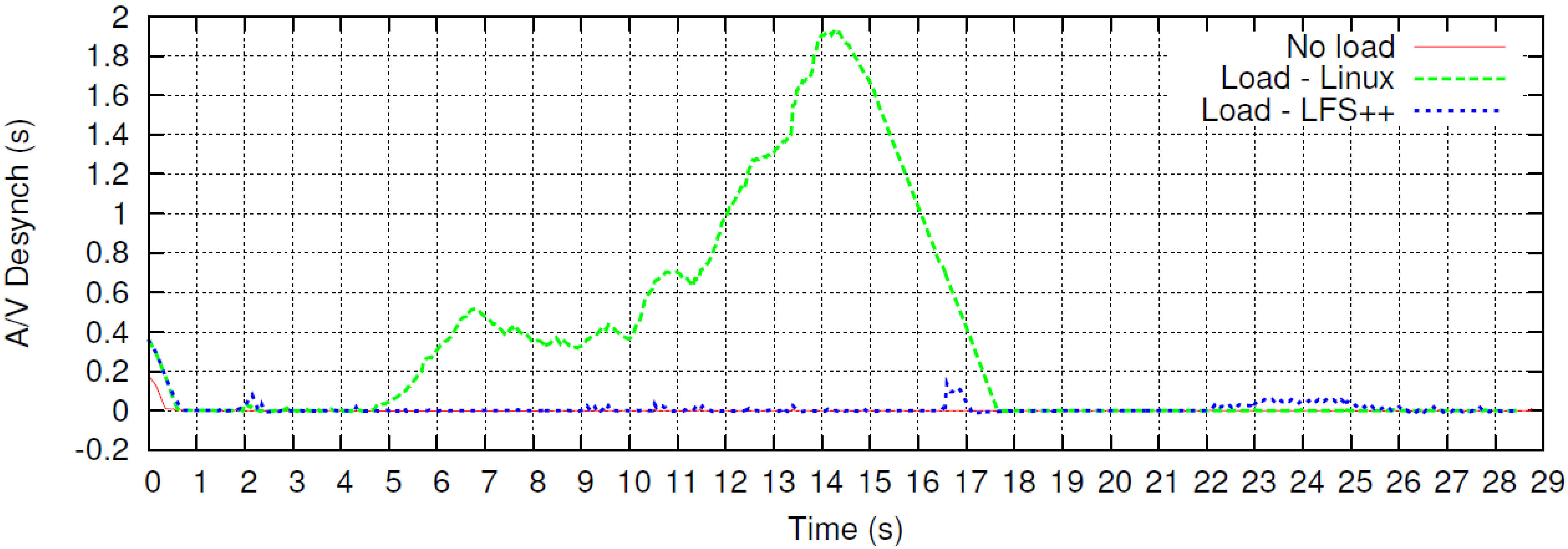
Using the correct reservation period is better



Benefits for the application
(LFS++ improves over Linux)

A/V desynchronisation in mplayer while starting the Eclipse IDE

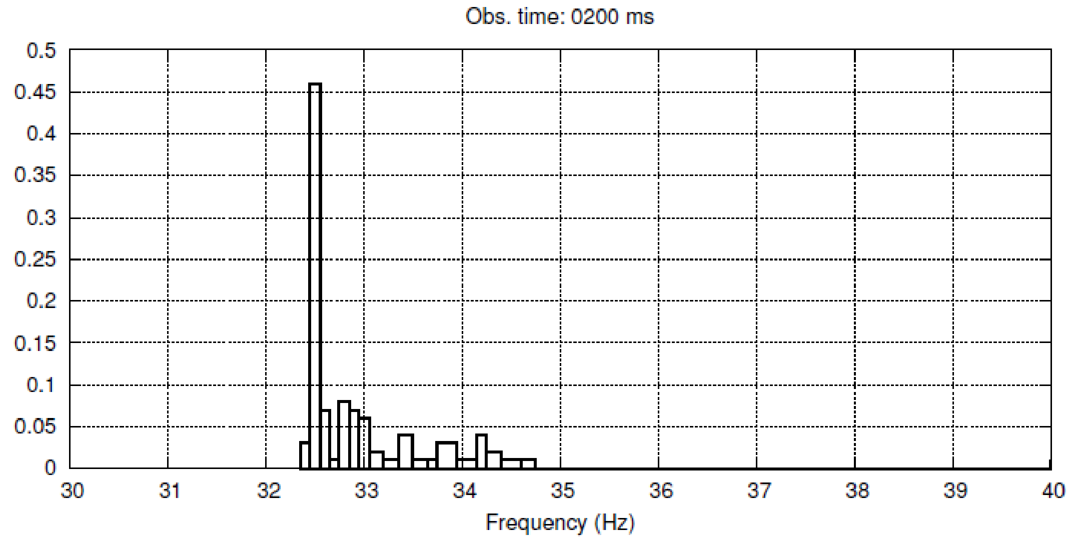
- **90% reduction** of the peak A/V desynchronisation



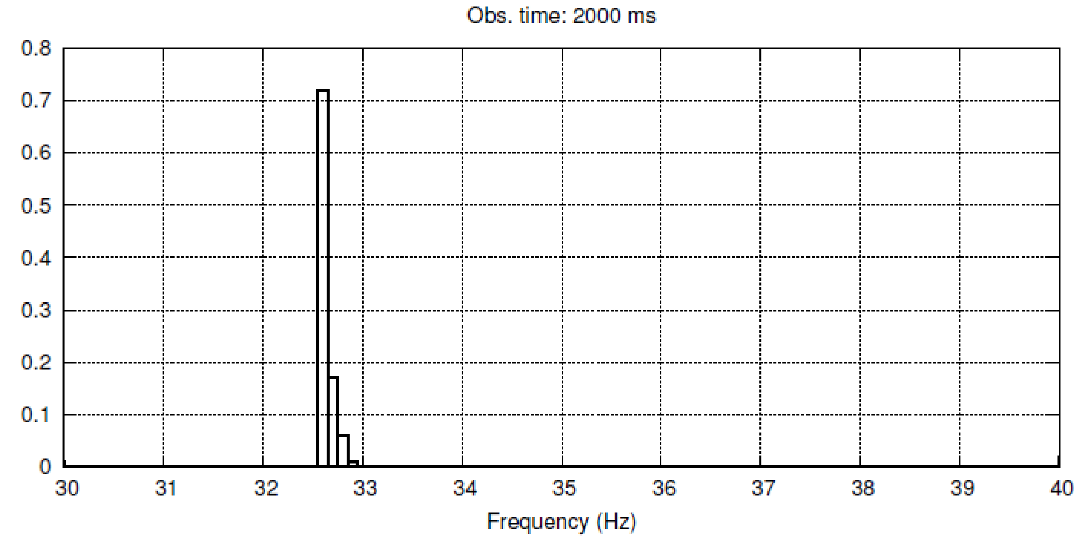
Precision of frequency detector

PMF of detected frequency when observation-time goes

- From 0.2 ms



- To 2 s



Cost of tracing

Tracing overhead

- When using strace: +5,51%
- When using qostrace: +2,69% (previous paper)
- When usinig qtrace: +0.63% (kernel-level tracer)

88.57% overhead reduction with the custom tracer

Tracer	Average (sec)	Relative average	Standard deviation (sec)
NOTRACE	21.0916	-	0.094951
QTRACE	21.2253	0.63%	0.143581
QOSTRACE	21.658	2.69%	0.221327
STRACE	22.2536	5.51%	0.140593

Table 1. Overhead introduced by various tracers, compared to when no tracer is used (first row).

Thanks for your attention

Questions ?

New Research Themes

at RETIS

Tera-scale devices

Future and Emerging computing platforms

- **Massively parallel** processors
  - → Hundreds/thousands cores per-processor
  - → Hundreds/thousands processors per-system
- **Heterogeneity** in
  - → **Computing power** and capabilities
  - → Communication **latencies**
- Nowadays **Operating Systems inadequate** for
  - → **Massively parallel applications**
  - → With **temporal constraints** (e.g., performance / interactivity)
  - → Running on **massively parallel systems** (**no scalability**)

S(o)OS
Service-oriented Operating Systems

Problem presentation

Issues to be investigated

- Partitioning of cores among functionality
  - → For reducing contention and enhancing cache efficiency
  - → e.g., **kernel cores**, **application cores**, **interrupt cores**, …
- Kernel based on **message-passing**, not **shared memory**
  - → For reducing contention in accessing shared kernel-level data
  - → A kernel instance per core
- Application-level control of (and API for):
  - → sharing level for kernel data (e.g., file descriptors)
  - → page table entries
- **Scalable synchronisation** primitives
- **Distributed** protocols for **in-chip resources allocation**
  - → e.g., spatial **scheduling**

Recent Publications (2009/2010)

Journals

- *A robust mechanism for adaptive scheduling of multimedia applications*, T. Cucinotta, L. Abeni, L. Palopoli, G. Lipari, to appear on ACM Transactions on Embedded Computing Systems
- *QoS Control for Pipelines of Tasks using Multiple Resources*, T. Cucinotta, L. Palopoli, IEEE Transactions on Computers, Vol. 53, No. 3, pp. 416--430, March 2010
- *A Real-time Service-Oriented Architecture for Industrial Automation*, T. Cucinotta, A. Mancina, G. F. Anastasi, G. Lipari, L. Mangeruca, R. Checcozzo, F. Rusinà, IEEE Transactions on Industrial Informatics, Vol. 5, n. 3, August 2009

Conferences/Workshops

- *Providing Performance Guarantees to Virtual Machines using Real-Time Scheduling,* T. Cucinotta, D. Giani, F. Checconi, D. Faggioli, VHPC 2010, August 2010
- *An Exception Based Approach to Timing Constraints Violations in RT and Multimedia Applications,* T. Cucinotta, D. Faggioli, IEEE SIES 2010
- *The Multiprocessor BandWidth Inheritance Protocol*, D. Faggioli, G. Lipari, T. Cucinotta, ECRTS 2010, July 2010
- *Advance Reservations for Distributed Real-TimeWorkflows with Probabilistic Service Guarantees*, T. Cucinotta, K. Konstanteli, T. Varvarigou, in SOCA 2009, December 2009, Taipei, Taiwan
- *Self-tuning Schedulers for Legacy Real-Time Applications*, T. Cucinotta, F. Checconi, L. Abeni, L. Palopoli, EuroSys 2010, Paris, April 2010
- *Hierarchical Multiprocessor CPU Reservations for the Linux Kernel*, F. Checconi, T. Cucinotta, D. Faggioli, G. Lipari, OSPERT 2009, Dublin, Ireland, June 2009
- *Respecting temporal constraints in virtualised services*, T. Cucinotta, G. Anastasi, L. Abeni, RTSOAA 2009, Seattle, Washington, July 2009

Thanks for your attention

Final questions ?

http://retis.sssup.it/people/tommaso