A Receding Horizon Approach for the Runtime Management of IaaS Cloud Systems

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Agenda

* Introduction
* Problem
  * Problem statement and design assumption
  * Receding Horizon algorithm
* Experimental Analysis
* Conclusions

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Introduction

The advent of Cloud Computing changed dramatically the ICT industry

- Google, Amazon, Microsoft, Salesforce, Oracle, SAP, SoftLayer, Rackspace etc…
- Cost-effective solutions
- Computational power
- Reliability
- Auto-scaling

New business paradigms appeared on the market

- IaaS, PaaS, SaaS
- But also DaaS, BDaaS, HDaaS, etc…

Introduction: challenges

The growing popularity of Cloud Computing opens new challenges

- Vendor lock-in
- Design for Quality of Service (QoS) guarantees
- Managing the lifecycle of a Cloud application
- Managing Elasticity
  - Resource Provisioning
  - Self-adaptation

Introduction: resource provisioning

Resource Provisioning: mechanism for leasing and releasing virtual cloud resources to guarantee adequate QoS

… it requires management solutions that support

* Performance prediction,
* Monitoring of Service Level Agreements (SLA),
* Adaptive re-configuration actions.

Tools currently supplied by IaaS providers, are often too basic and inadequate for

* Highly variable workload,
* Applications with a dynamic behavior characterized by uncertainty.

Introduction: our approach

Proposal: a fast and effective Capacity Allocation technique

* based on the Receding Horizon control strategy
* integrated within MODAClouds runtime platform
* that minimizes the execution costs of a Cloud application,
* guaranteeing QoS constraints expressed in terms of average response time

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Problem: design assumptions

Perspective of a **Software-as-a-Service (SaaS)** provider hosting his/her applications on an **Infrastructure-as-a-Service (IaaS)** provider

Applications are single **tier** hosted in virtual machines (VMs) that are dynamically instantiated by the IaaS provider

Each VM hosts a single **WS application**

Multiple **homogeneous** VMs implementing the same WS application can run in parallel

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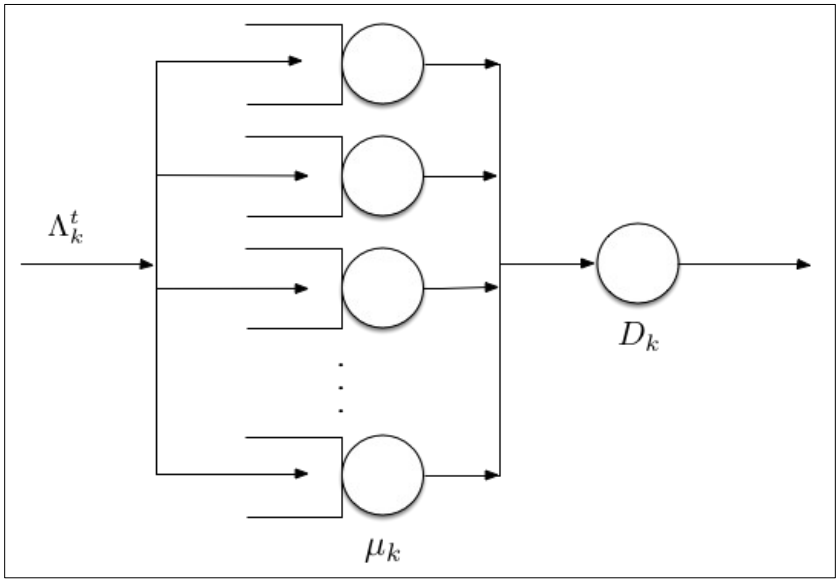
Problem: design assumptions

Each **WS class** hosted in a VM is modeled as an **M/G/1 queue** in tandem with a delay center

SLA based on the average response time R_k: every WS class has to provide a response time lower than a threshold $\overline{R_k}$



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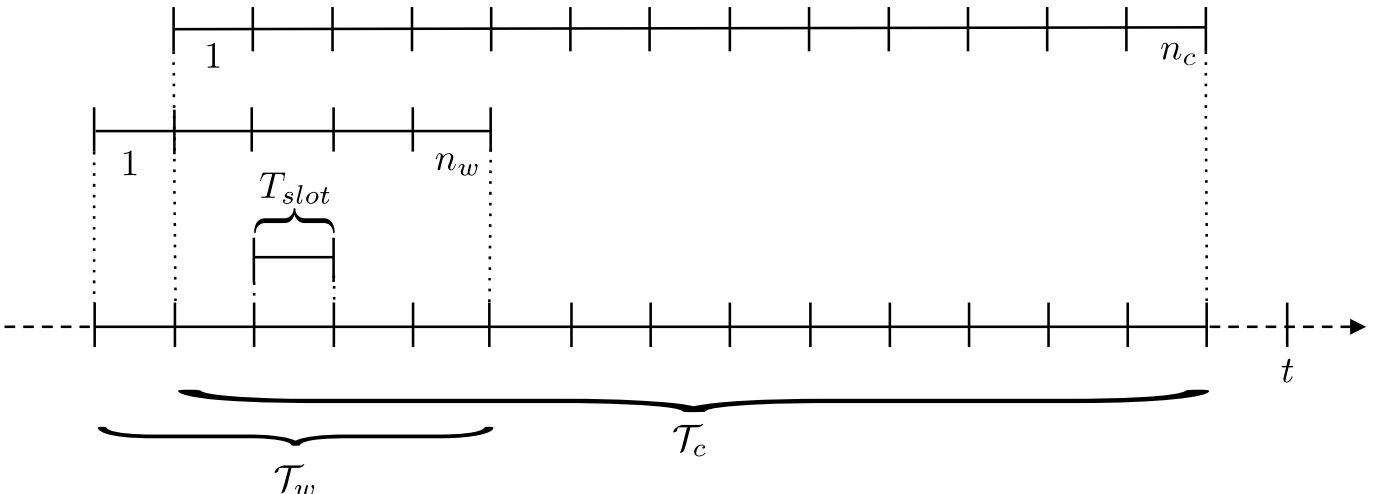
Problem: design assumptions

IaaS providers **charge** software providers on an **hourly basis**

* *reserved* VMs (ρ time-unit cost)
* *on demand* VMs (δ time-unit cost $\rho < \delta$)

Time management:

* Time slots: T_{slot} (5, 10 min)
* Time window: T_w (1-5 T_{slot})
* Charging interval: T_c (60 min)



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Problem: formulation

Time unit costs

Time management

Freely available VMs

Workload prediction

CA plan

System parameters

$\mathcal{K}$	Set of WS applications
δ	Time unit cost (measured in dollars) for *on-demand* VMs
ρ	Time unit cost (measured in dollars) for *reserved* VMs
$\mathcal{T}_w$	Set of time slots within the sliding time window
$\mathcal{T}_c$	Set of time slots within a charging interval
T_{slot}	Short-term CA time slot, measured in minutes
n_c	Number of time slots within the charging interval $\mathcal{T}_c$
n_w	Number of time slots within the time window $\mathcal{T}_w$
$\overline{r}_k^t$	Number of *reserved* VMs freely available at time slot t in the interval under analysis, for request class k
$\overline{d}_k^t$	Number of *on-demand* VMs available for free at time slot t in the interval under analysis, for request class k
Λ_k^t	Real local arrival rate (measured in requests/sec) for request class k, at time slot t
$\widehat{\Lambda}_k^t$	Local arrival rate prediction (measured in requests/sec) for request class k, at time slot t
$\overline{R}_k$	Average response time threshold for request class k
W	Maximum number of *reserved* instances available

Decision Variables

d_k^t	Number of *on-demand* VMs to be allocated for request class k at time slot t
r_k^t	Number of *reserved* VMs to be allocated for request class k at time slot t

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Problem: formulation

The CA problem can be formulated as:

$$(\mathrm{P}) \qquad \min_{r_k^t, d_k^t} \sum_{k \in \mathcal{K}} \left(\rho \sum_{t=1}^{n_w} r_k^t + \delta \sum_{t=1}^{n_w} d_k^t \right)$$

Total cost

Subject to the conditions:

$$R_k(r_k^1, \overline{r}_k^1, \ldots, r_k^t, \overline{r}_k^t, d_k^1, \overline{d}_k^1, \ldots, d_k^t, \overline{d}_k^t, \widehat{\Lambda}_k^1, \ldots, \widehat{\Lambda}_k^t) \leq \overline{R}_k$$

$$\forall k \in \mathcal{K}, \ \forall t \in \mathcal{T}_w$$

Response time

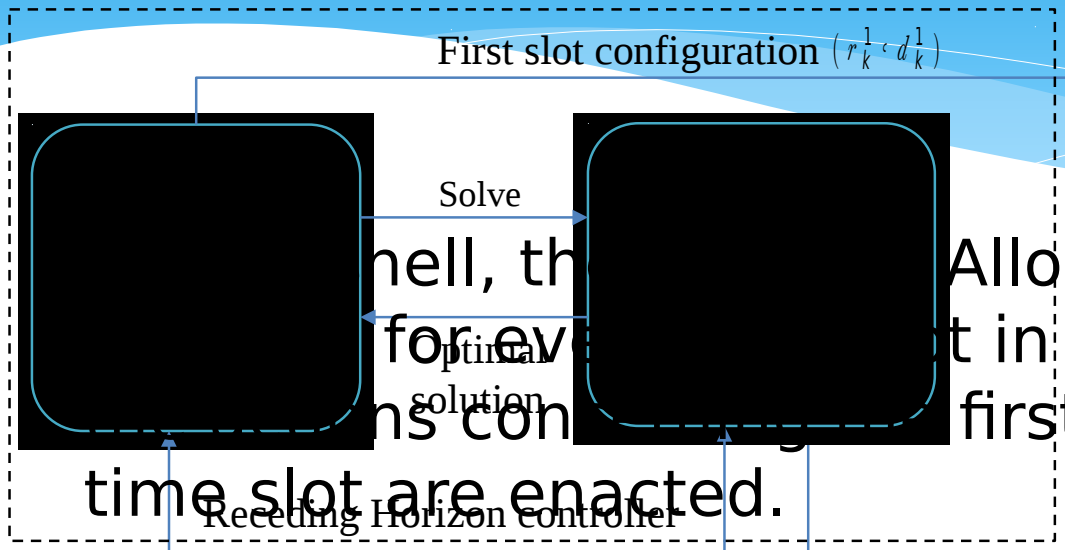
$$\sum_{k \in \mathcal{K}} (r_k^t + \overline{r}_k^t) \leq W, \ \forall t \in \mathcal{T}_w$$

limited number of reserved VMs

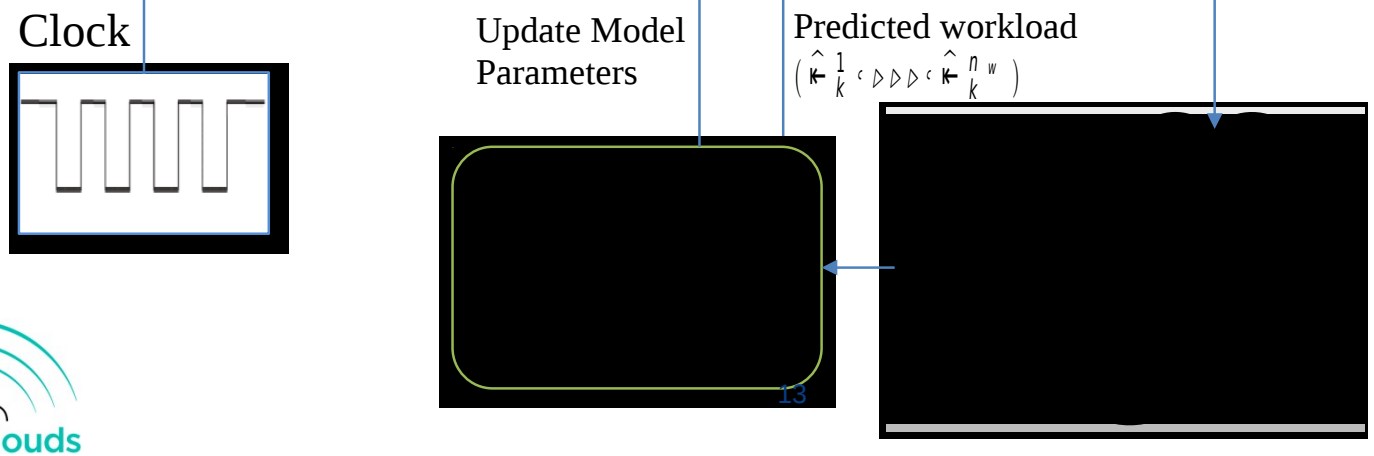
$$r_k^t \geq 0, \ r_k^t \in \mathbb{N} \quad \forall k \in \mathcal{K}, \ \forall t \in \mathcal{T}_w$$

$$d_k^t \geq 0, \ d_k^t \in \mathbb{N} \quad \forall k \in \mathcal{K}, \ \forall t \in \mathcal{T}_w$$

Receding Horizon Algorithm



hell, th Allocation problem
for ev t in but only
ns con first forthcoming
time slot are enacted.



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Receding Horizon Algorithm

Algorithm 1 Receding Horizon Algorithm

1: **procedure** SOLUTION ALGORITHM
2: **for all** $k \in \mathcal{K}$ **do**
3: **for** $w \leftarrow 1, n_w$ **do**
4: $\widehat{\Lambda}_k^w \leftarrow$ ***GetPrediction*** (w, k)
5: $\overline{r}_k^w \leftarrow N_{res,k}^{t+w}$
6: $\overline{d}_k^w \leftarrow N_{ond,k}^{t+w}$
7: **end for**
8: **end for**
9: ***Solve*** $(P, \overline{r}, \overline{d}, \widehat{\Lambda}) \leftarrow$
10: **for all** $k \in \mathcal{K}$ **do**
11: ***Scale*** $(k, r_k^1, d_k^1) \leftarrow$
12: **for** $j \leftarrow 1, n_c$ **do**
13: $N_{res,k}^{t+j} \leftarrow N_{res,k}^{t+j} + r_k^1$
14: $N_{ond,k}^{t+j} \leftarrow N_{ond,k}^{t+j} + d_k^1$
15: **end for**
16: **end for**
17: **end procedure**

Initialization

Solving the current model

Applying the changes according to the first time slot decisions

State update

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Experimental Analysis

Scalability:

* Large set of randomly generated instances
* Daily distribution of requests from real log traces

Comparison with state of the art approaches:

* Heuristic
* Oracle with perfect knowledge of the future

Time scale analysis:

* SLA violations

Experiment Design

Workload prediction

- Incoming workload has been obtained for traces of a very large dynamic web-based system
- Different workload for each WS class
- Prediction obtained by adding white noise to each sample
- Noise proportional to the arrival rate
- Inaccuracy increases with the time slot

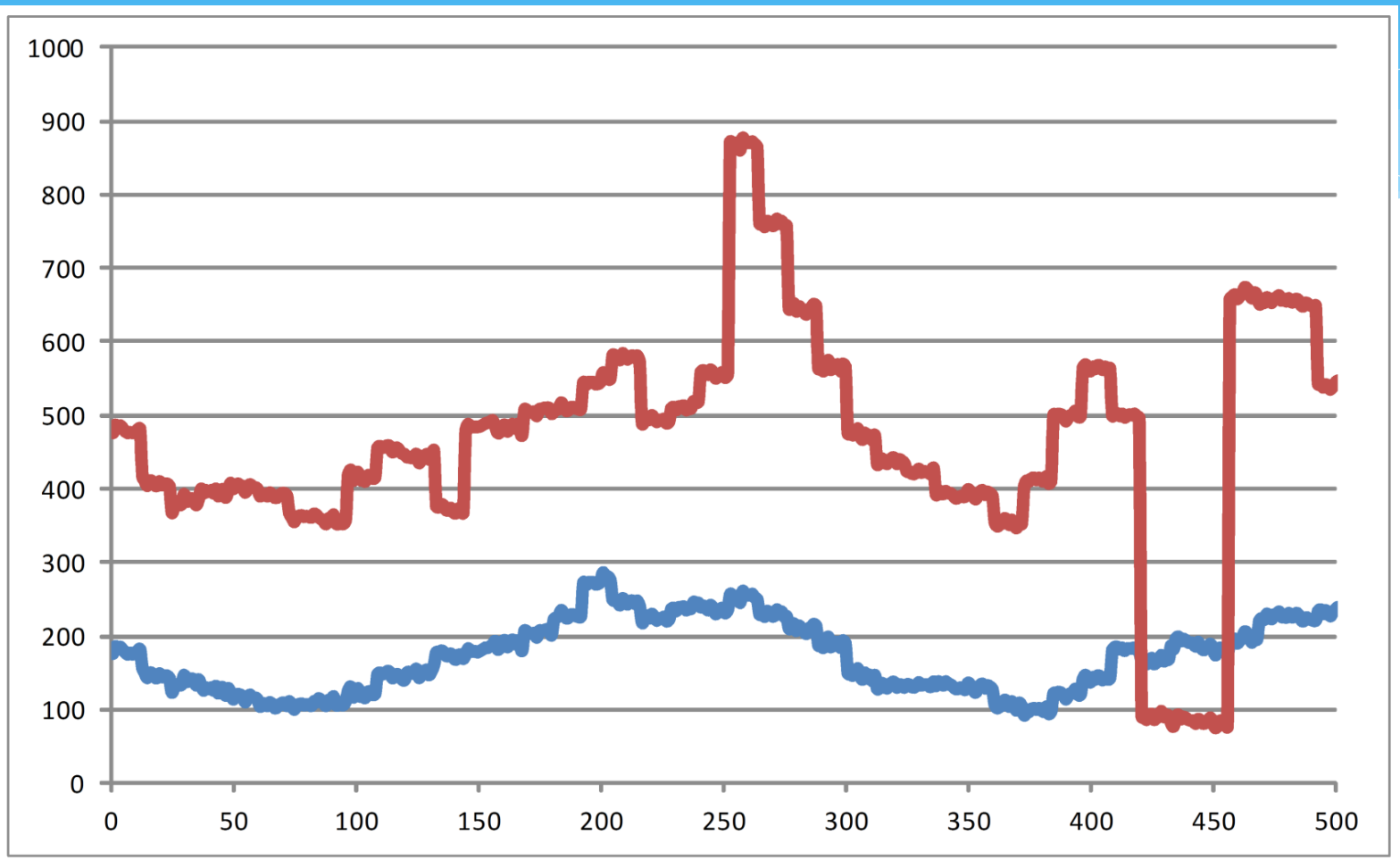
Performance parameters

- Service rate $\mu_k \in [200, 400] \quad req/sec$
- Queueing delay $D_k \in [0.001, 0.05] s$
- Reserved instances $W = 10$

Instance cost

- Randomly generated considering prices currently charged by common IaaS providers

Experiment Design



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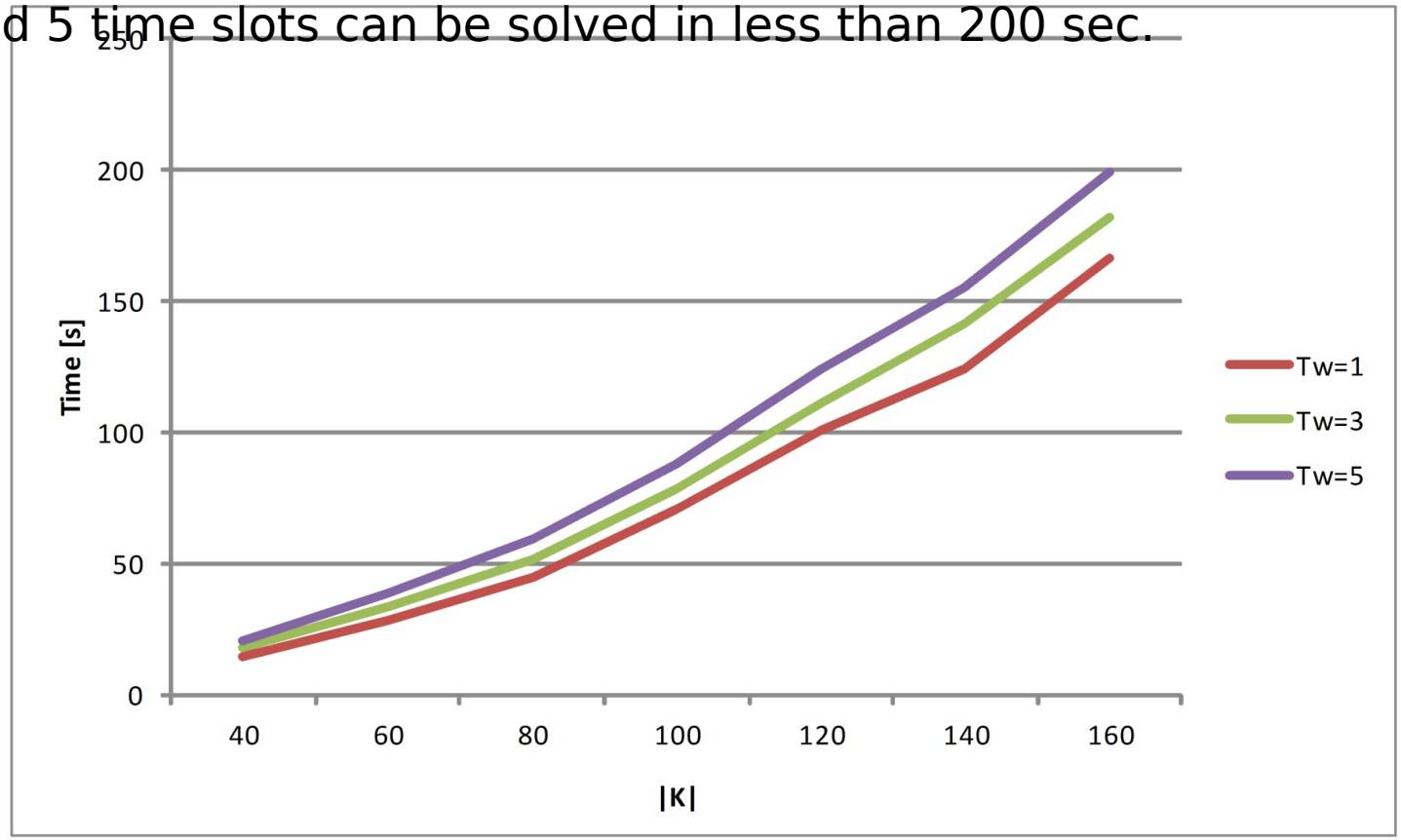
Scalability

The analysis demonstrated that our approach scales almost linearly with
respect to the number of request classes. Systems up to 160 classes and 5 time slots can be solved in less than 200 sec.



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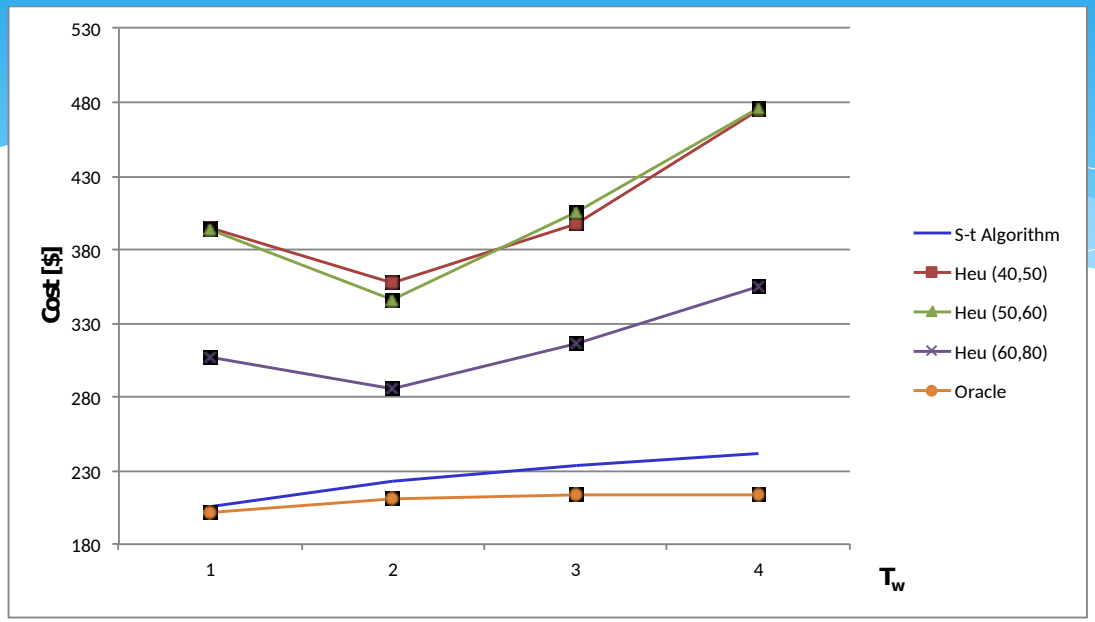
Cost – Normal traffic



- 10 minutes time scale
- Low noise level

Costs comparison

Solution	$\mathcal{T}_w$ 1	2	3	4
Oracle	0.00%	0.00%	0.00%	0.00%
S-t Algorithm	2.00%	5.78%	9.31%	13.05%
Heu (40%, 50%)	95.81%	68.97%	85.51%	122.15%
Heu (50%, 60%)	95.09%	63.72%	85.59%	122.88%
Heu (60%, 80%)	52.39%	34.88%	47.54%	65.81%

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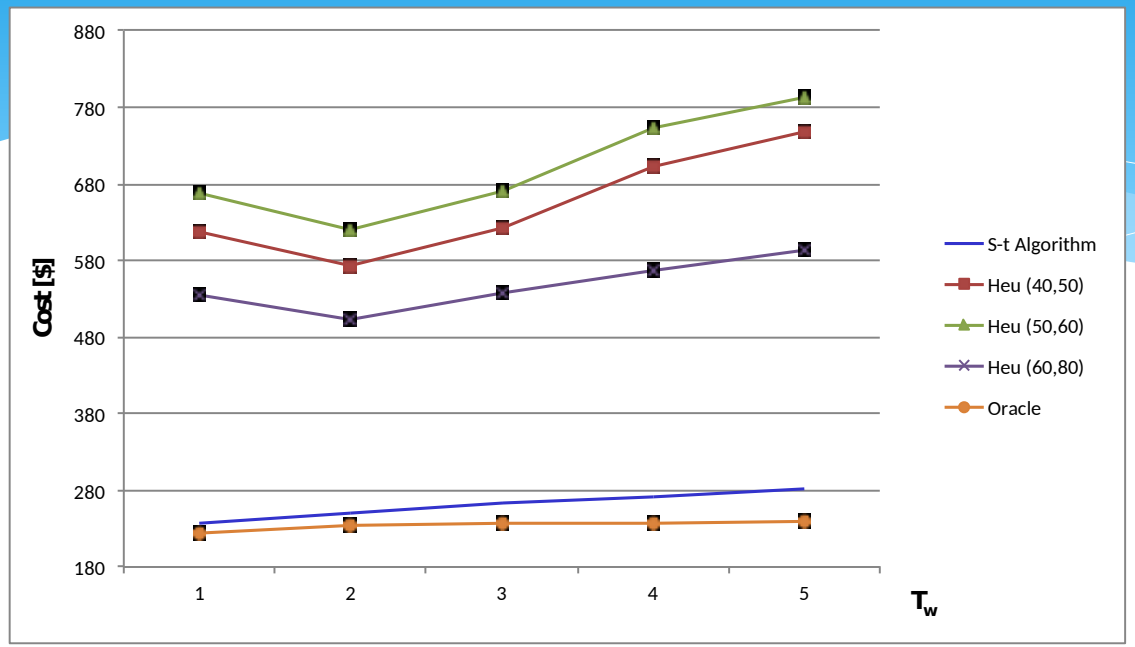
Cost – Spiky traffic



5 minutes time scale

Low noise level

Costs comparison

Solution	$\mathcal{T}_w$ 1	2	3	4	5
Oracle	0.00%	0.00%	0.00%	0 .00%	0.00%
S-t Algorithm	5.10%	7.75%	11.02%	13.73%	16.86%
Heu (40%, 50%)	175.37%	145.68%	162.70%	195.95%	210.97%
Heu (50%, 60%)	197.36%	165.89%	183.58%	216.52%	229.00%
Heu (60%, 80%)	138.10%	115.46%	126.85%	138.88%	146.38%

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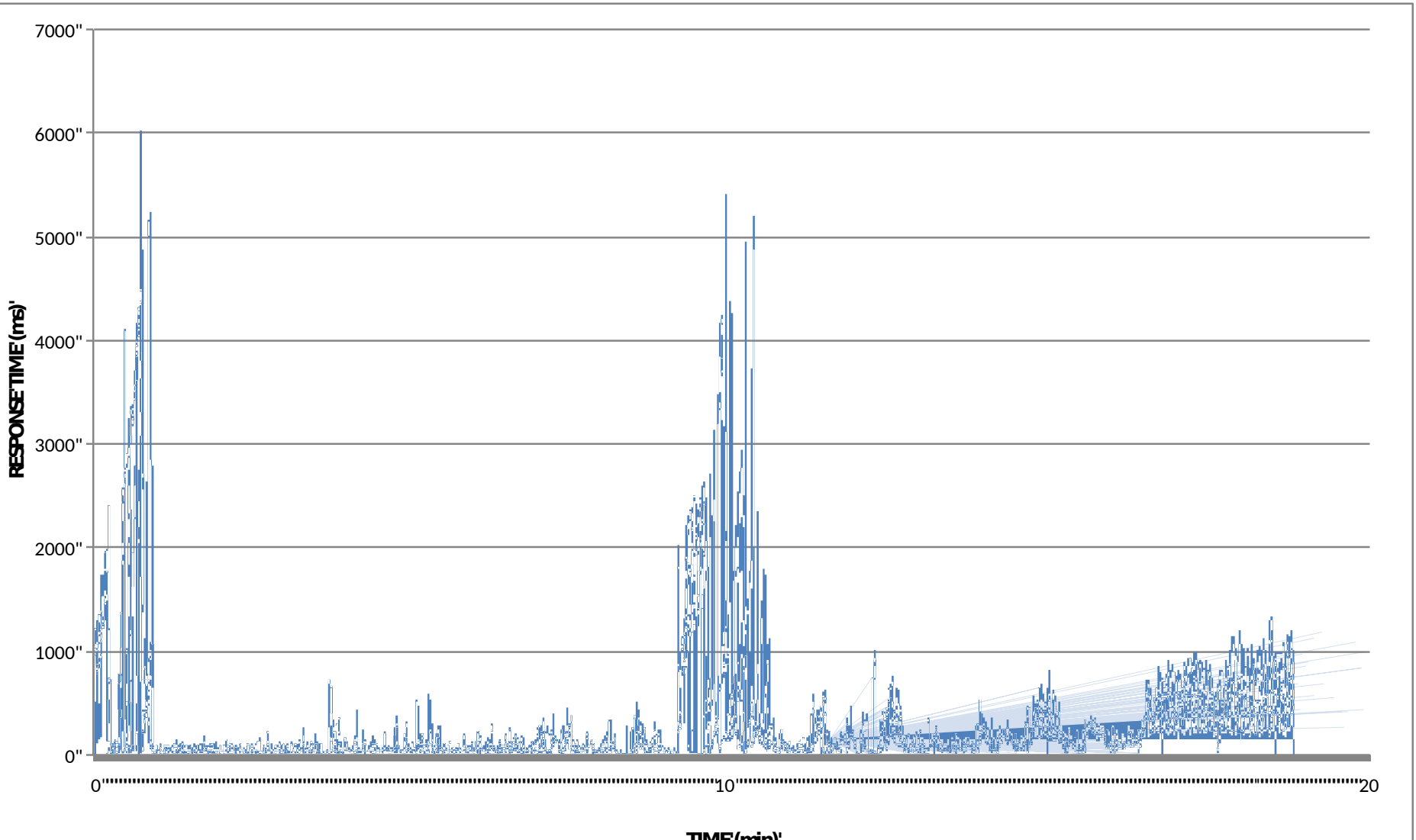
Time scale analysis



Time scale analysis

$\mathcal{T}_w$	SLA Violations [%]		Dropped Requests [%]	
	5 min	10 min	5 min	10 min
1	0.49	1.74	5.56	6.71
2	1.08	0.56	5.91	6.34
3	0.90	1.81	5.99	6.26
4	1.15	1.88	5.61	5.95

The values are related to a 24 hours analysis with low noise and averaged over 10 executions.

A control time granularity of 5 minutes tends to provide better performance if compared to granularity of 10 minutes both in terms of SLA violations and in terms of dropped requests.

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Conclusions and Future Works

We proposed optimization approach to achieve fast, scalable and effective capacity allocation based on a fine grained time scale

Our technique is able to minimize costs in a more efficient way than the current state of the art

The QoS defined into the SLA is almost always respected (less than 2% and 7 min)

Future works:

* development of an adaptive approach able to switch between different time scales according to the workload conditions
* Test on a real prototype environment

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Thank You!

Questions ?