



 POLITECNICO DI MILANO



Model Identification for Energy-Aware Management of Web Service Systems

Mara Tanelli¹, Danilo Ardagna¹, Marco Lovera¹, Li Zhang²

¹Politecnico di Milano, Dipartimento di Elettronica e Informazione, Italy

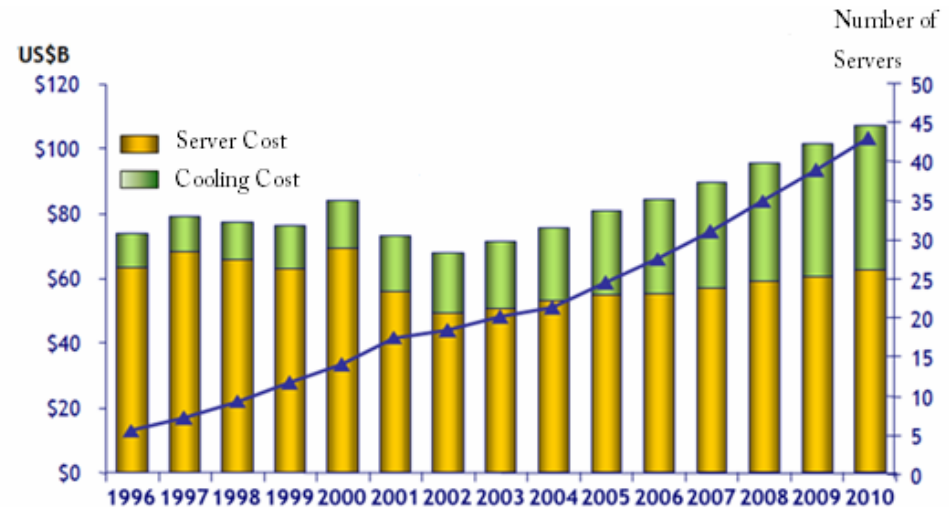
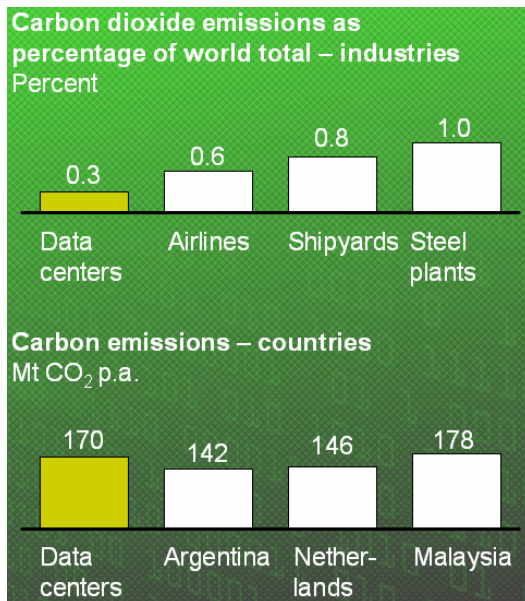
²IBM Research, T.J. Watson Research Center, NY

Sydney, December 4 2008



Data Center issues

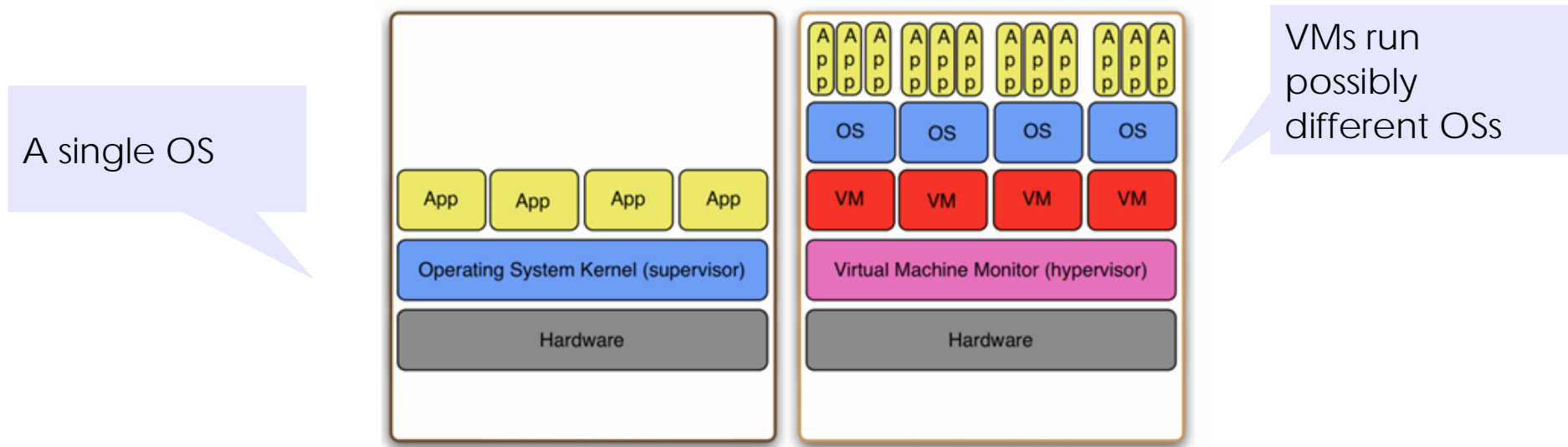
- § Energy consumption
 - 2% of CO2 emission
 - By 2012 energy costs will be 40% of TCO
 - Related costs: cooling, UPS, ...
- § QoS guarantees and workload variability
- § Dynamic resource management

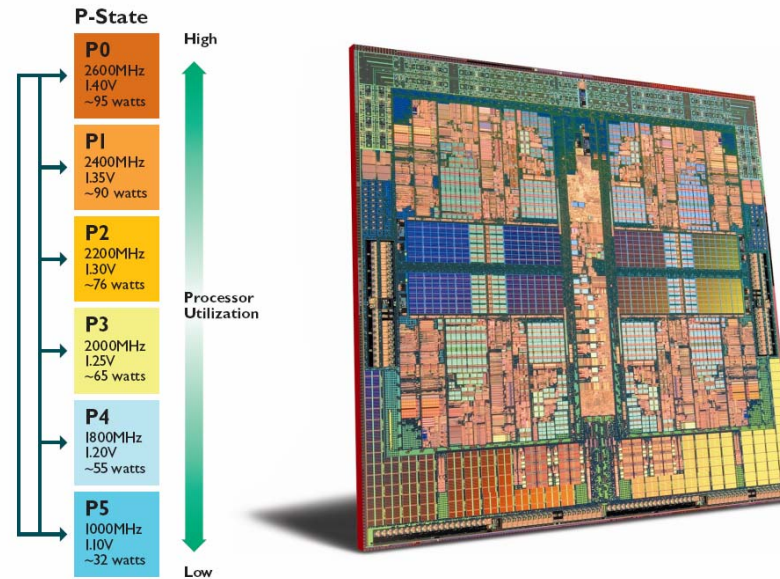




Virtualization

- Hardware resources (CPU, RAM, ecc...) are partitioned and shared among multiple **virtual machines** (VMs)
- The virtual machine monitor (VMM) governs the access to the physical resources among running VMs
- Performance isolation and security





Dynamic Frequency Scaling (DFS)

- Modern CPUs can work in multiple **p-states** (performance-state) characterized by a given value of voltage and clock frequency
- A p-state transition implies a CPU clock update and, hence, different cost and performance
- Reduced overheads



- Utility Based Approach: Queueing Network model + Optimization framework (e.g., IBM's Tivoli)
 - § Multiple decision variables
 - § Long term time horizon (several minutes)
 - § Steady state assumption
- Control Theory Approach
 - § Short time frame (minutes, seconds)
 - § System identification used to develop models for:
 - Capturing system transients
 - Taking into account workload variability
 - § Advanced control design techniques used to:
 - Ensure closed-loop stability
 - Guarantee performance (QoS) levels *a priori*



- Use experimental data to construct dynamical models for performance control of Web services
- Single class Web server with FIFO scheduling
 - § λ_k : requests arrival rate
 - § s_k : service time, CPU time required to serve a single request
 - § R_k : response time, overall time a request stays in the system
 - § X_k : system throughput, requests service rate
- Dynamic frequency scaling modeling:
 $s_{u,k} = s_k / u_k$ effective service time

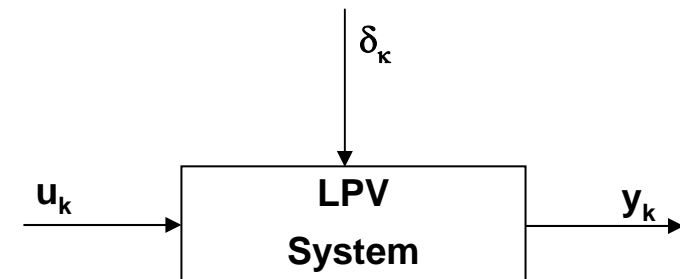


- Linear Parameter Varying systems are a class of time-varying systems

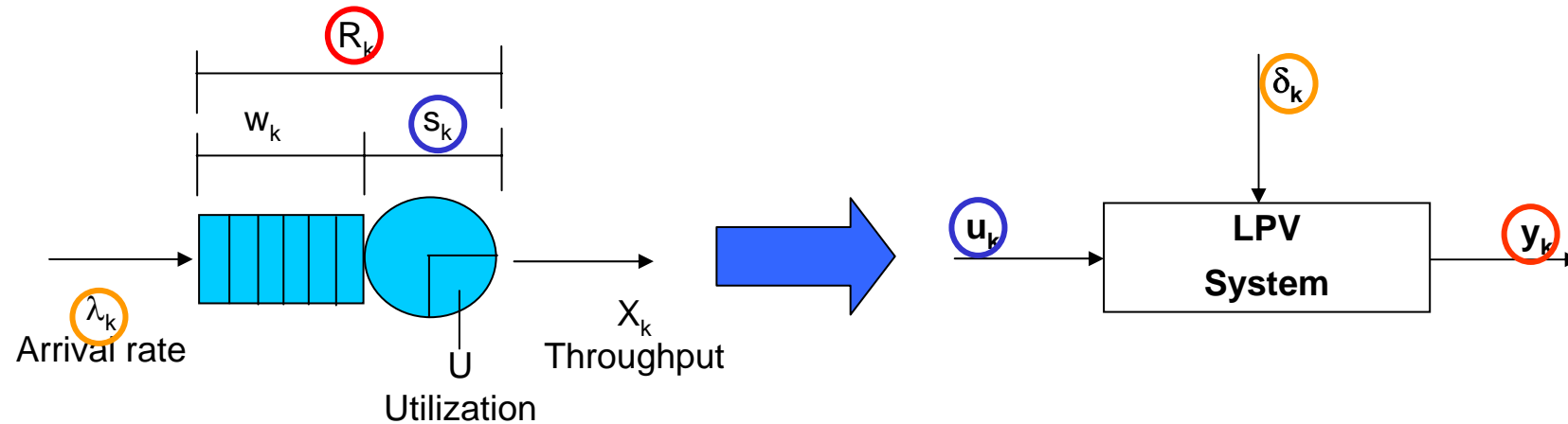
- In discrete-time state space form:

$$x_{k+1} = A(\delta_k)x_k + B(\delta_k)u_k$$

$$y_k = C(\delta_k)x_k + D(\delta_k)u_k$$



- “Time varying systems, the dynamics of which are functions of a measurable, time varying parameter vector δ .”
- Models for LTV systems or linearizations of non linear systems along the trajectory of δ , gain scheduling control problems



We use models with:

- Affine parameter dependence (LPV-A), that is

$$A(\delta_k) = A_0 + A_1\delta_{1,k} + \dots + A_s\delta_{s,k}$$

and similarly for the B, C and D matrices

- Input-Affine (LPV-IA) parameter dependence, i.e., only the B and D matrices are parametrically varying



- The problem is set up as in the classical output error minimization framework
- The system is described by a set of parameters θ , identification is performed minimising the cost function

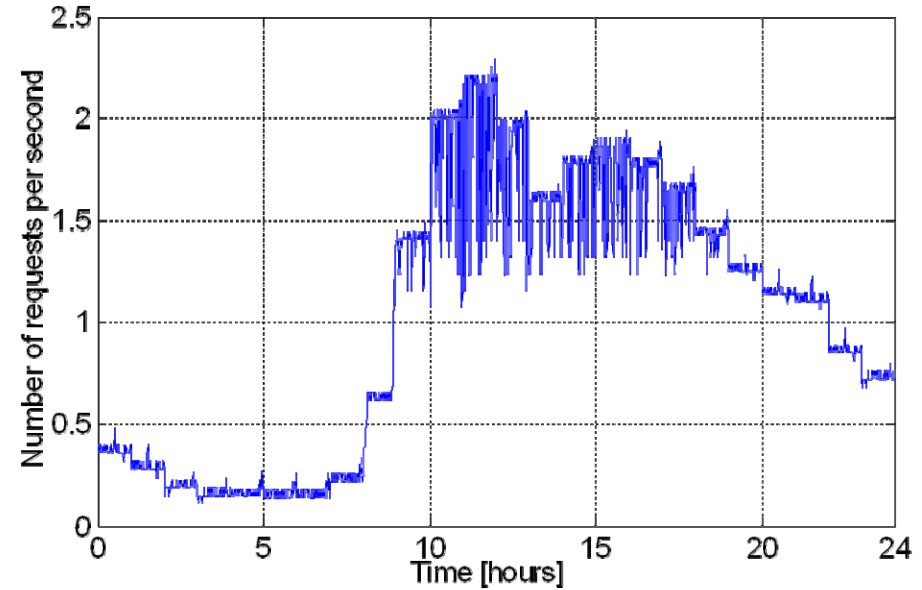
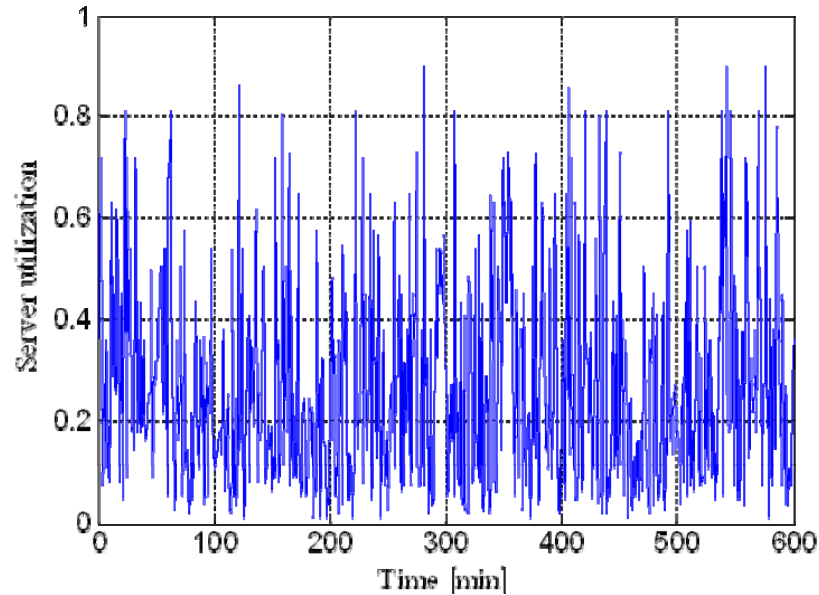
$$V_N(\theta) := \sum_{k=1}^N \|y_k - \hat{y}_k(\theta)\|_2^2$$

with respect to θ

- Minimization carried out via a gradient search method (Levenberg-Marquardt algorithm)



- A workload generator:
 - § Apache JMeter custom extension
- Micro benchmarking web application
 - § CPU service time generated according to deterministic (identification), exponential, lognormal, Pareto (validation) distributions
- Application instrumentation (otherwise, ARM API or kernel-based measurement)
- Validation: synthetic workload inspired by a real-world usage (Politecnico di Milano Web site, 24 hours)

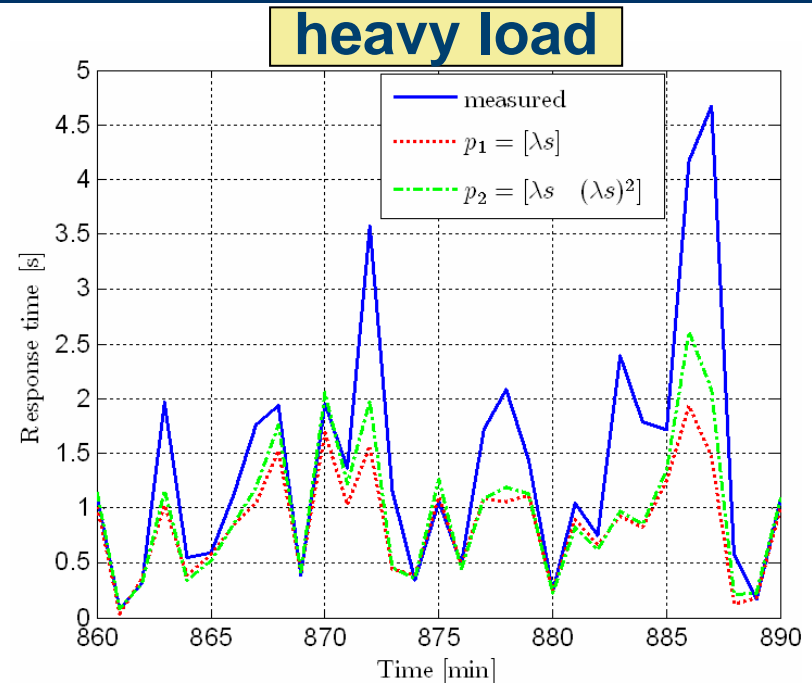
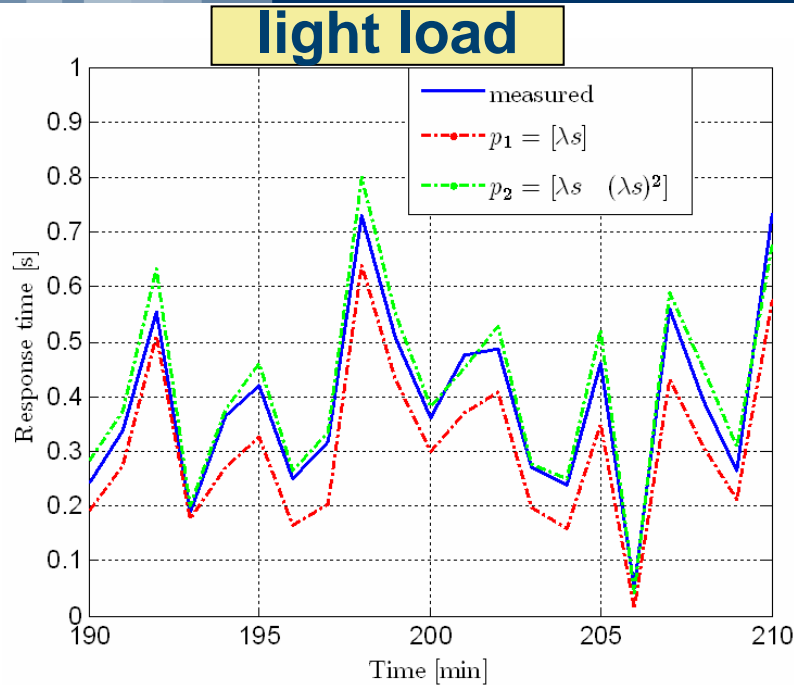


Performance metrics:

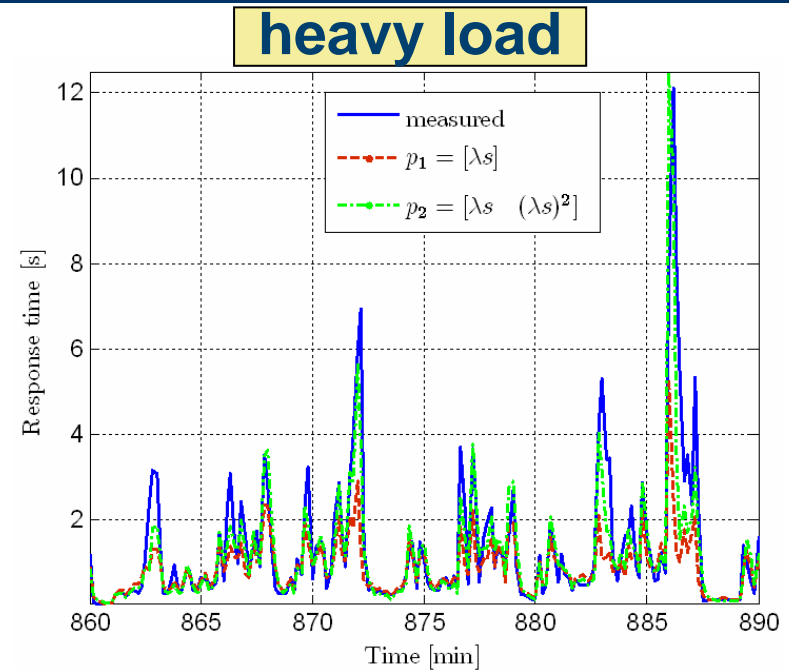
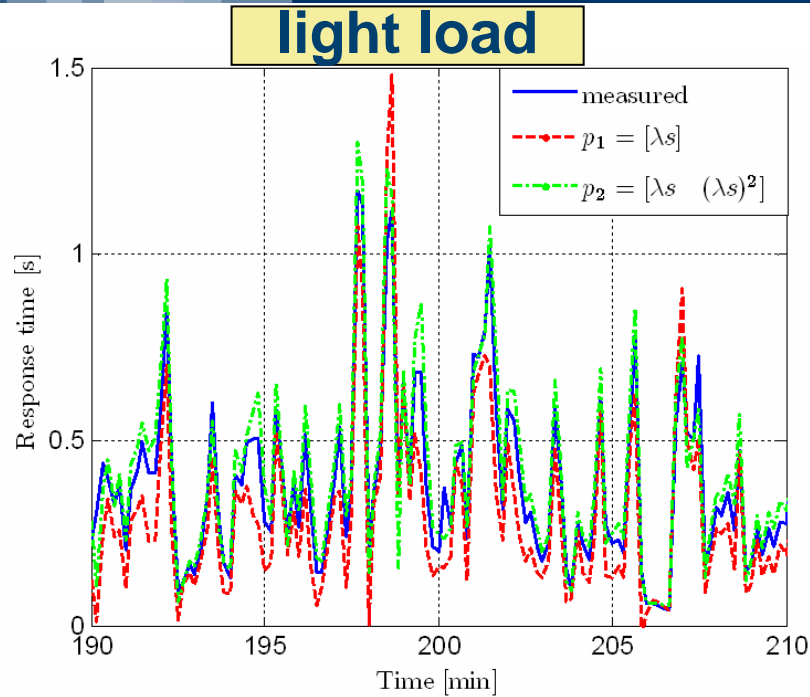
- Variance accounted for (VAF)
- Average simulation error (e_{avg})

$$VAF = 100 \left(1 - \frac{Var[y_k - y_{sim,k}]}{Var[y(k)]} \right)$$

$$e_{avg} = 100 \left(\frac{E[|y_k - y_{sim,k}|]}{E[|y_k|]} \right)$$



Valid. Performance $\Delta t = 1$ min	LPV-IA(p_1)	LPV-IA(p_2)
VAF on 24h	58.14%	65.18%
VAF light load (1-8)h	91.7%	89.8%
VAF heavy load (9-20)h	52.4%	60.1%
e_{avg} on 24h	25.7%	19.37%
e_{avg} light load (1-8)h	20.9%	10.5%
e_{avg} heavy load (9-20)h	29.2%	24.17%



Valid. Performance $\Delta t = 10s$	LPV-IA(p_1)	LPV-IA(p_2)
VAF on 24h	54.01%	71.5%
VAF light load (1-8)h	78.6%	80.2%
VAF heavy load (9-20)h	48.5%	67.1%
e_{avg} on 24h	20.3%	7.4%
e_{avg} light load (1-8)h	20.02%	2.5%
e_{avg} heavy load (9-20)h	22.5%	9.25%



- Framework for modelling Web Services application performance at very fine grained time scales and in transient conditions
- Validation with application benchmarks
- Control design for single-class systems
- Extension to multi-class virtualized environments (MIMO systems)