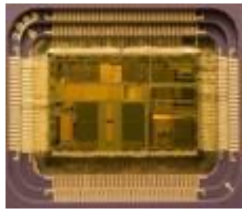


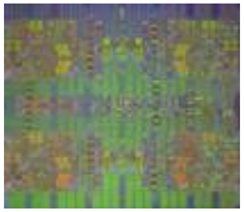
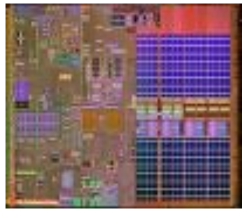

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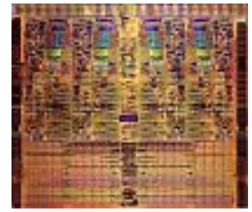


WASP: Workload Adaptive Energy-Latency Optimization in Server Farms using Server Low-Power States

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The Era of Data Explosion

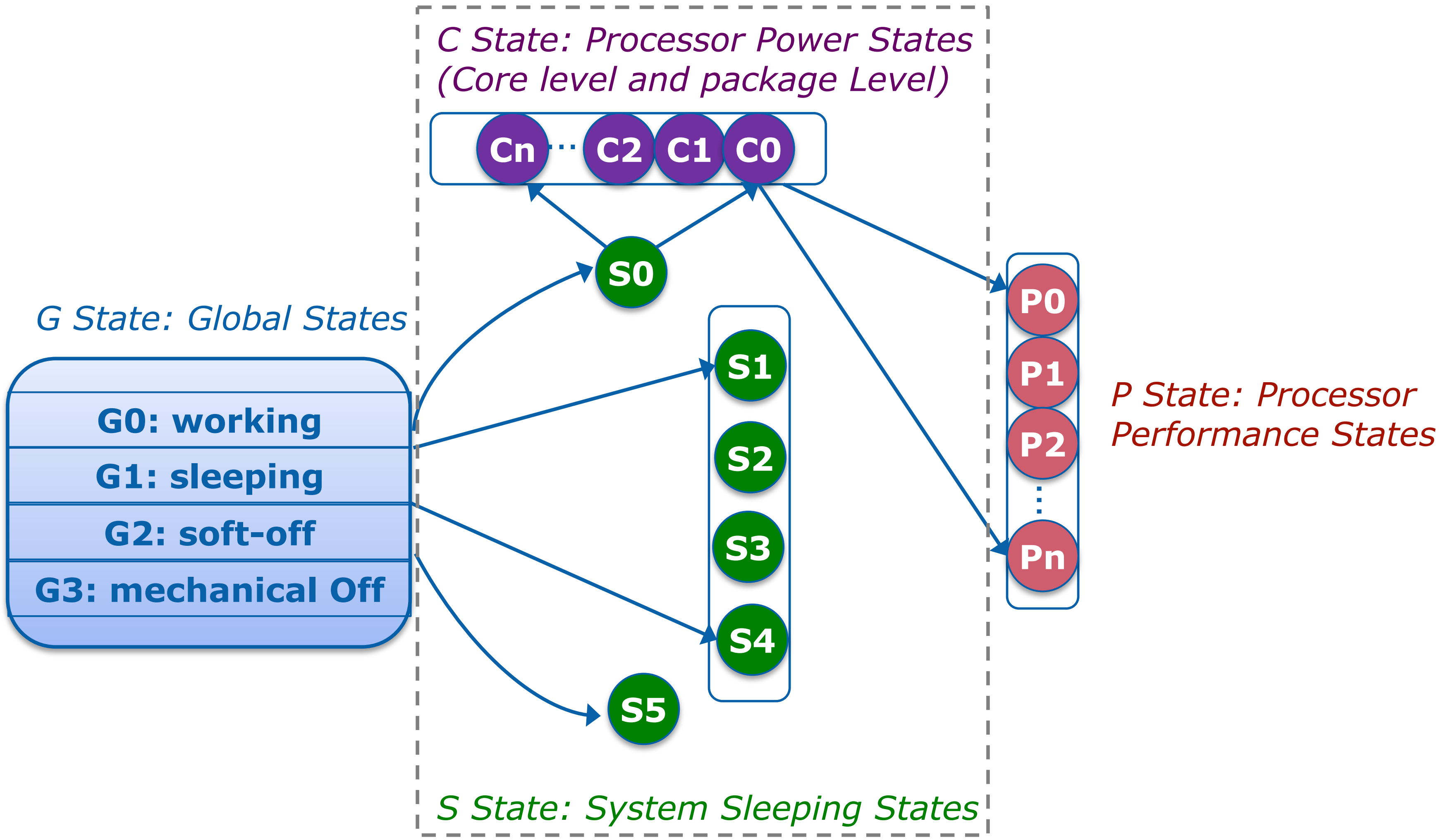
- **Tremendous advances in cloud computing**
  - Size of computing infrastructure grows rapidly
- **Modern data centers are increasingly power-hungry**
  - Power/cooling cost of data center increased over 400% last decade
  - IT equipment dominates the power consumption
- ***Limiting server farm energy envelope is critical***

Server Farm Energy Inefficiency

- **Servers are typically provisioned to match peak load**
  - Server farms are often under-utilized (30% utilization is common)
  - Wasteful energy is spent in keeping extra servers active

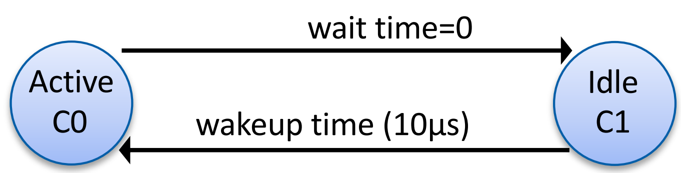
- **Today's server lacks energy-proportionality**
  - When active, server at 30% utilization consumes 60% of peak power
  - When idle, server consumes 20% ~ 55% of peak power

Server Low-power States

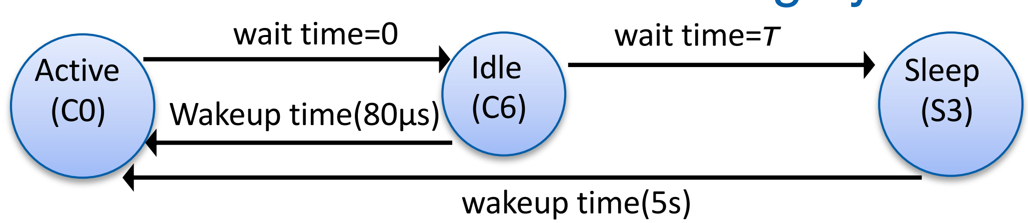


Exploration of Low Power States

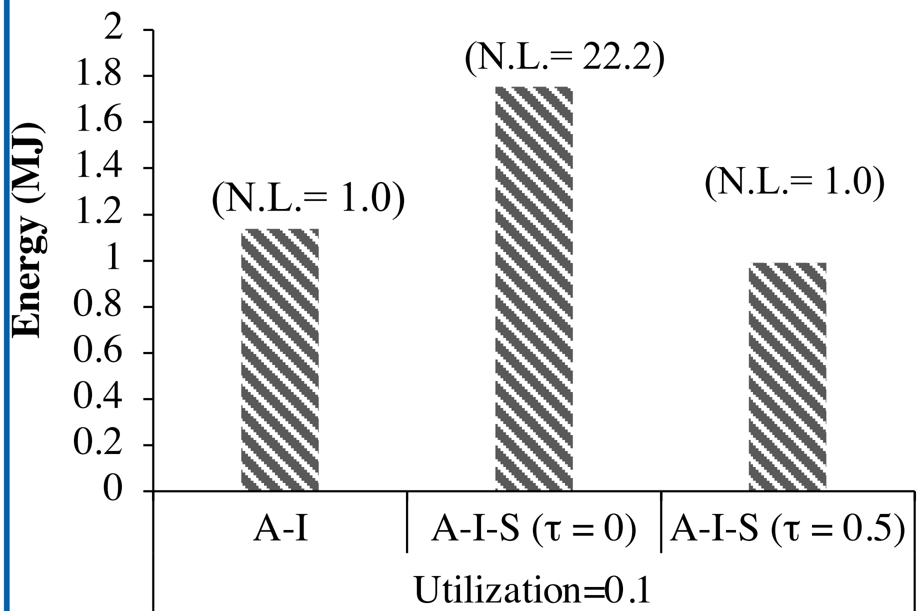
- **Two illustrative policies**
  - The *Active-Idle* configuration
    - Server alternates between active (*C0*) and idle state (*C1*)

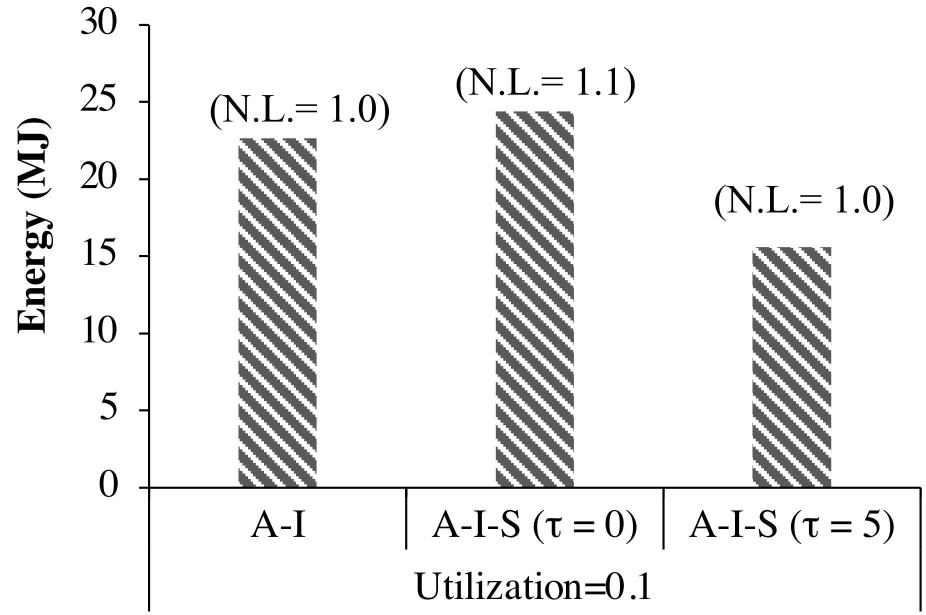


  - The *Delay-Doze (τ=c)* configuration
    - Transitions among active (*C0*), shallow sleep (*C6*) and deep sleep (system sleep *S3*)
    - Processor enters C6 when idle
    - Wait for τ seconds in C6 before entering system sleep.



Motivational Example





N.L. represents latency normalized to average service time.300K jobs are run for each workload

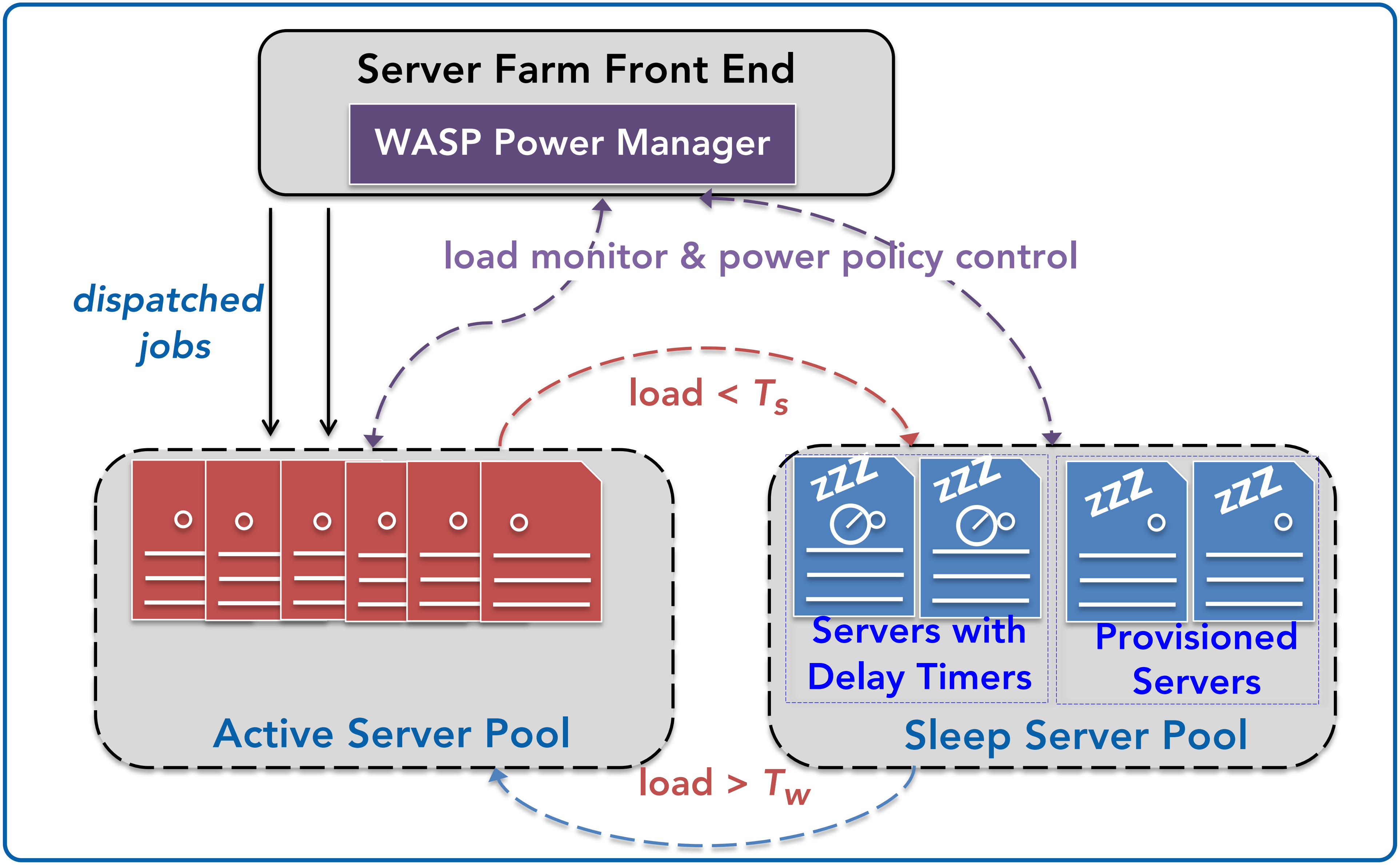
Energy consumption: **small workload**

Energy consumption: **large workload**

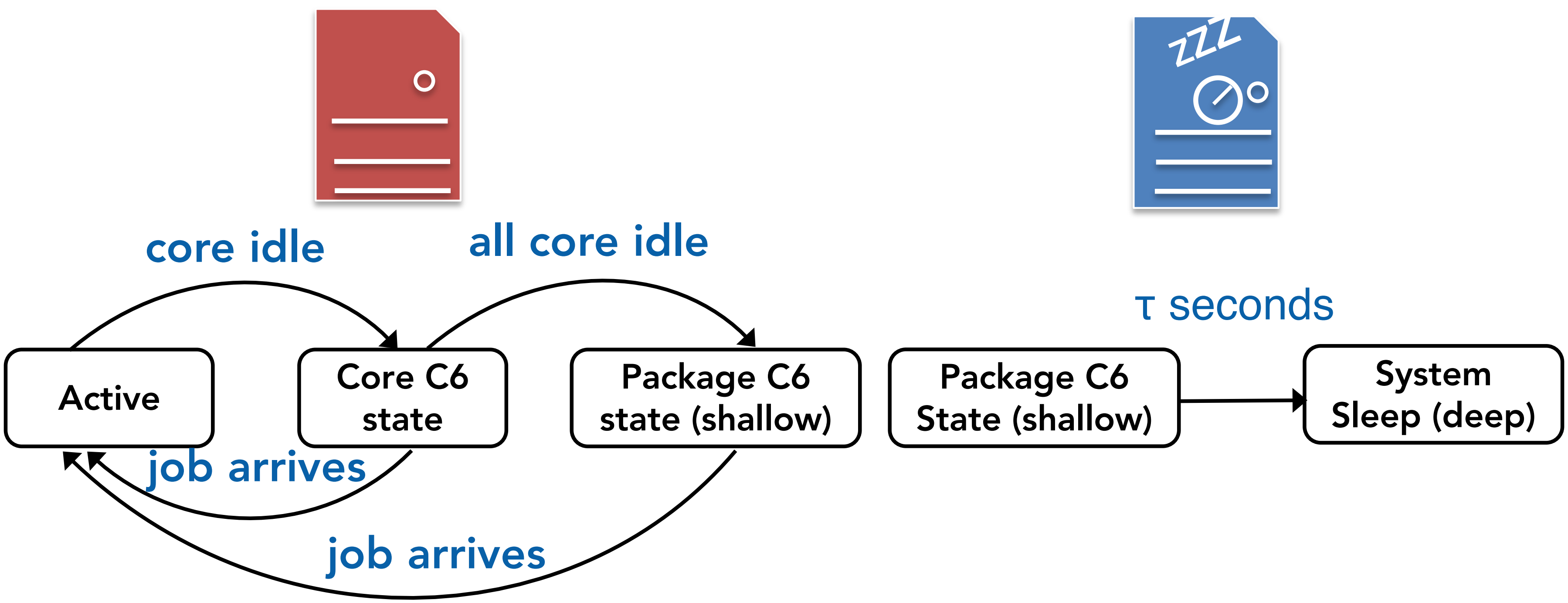
Workload Adaptive Energy-Latency Optimization

- **Optimize energy saving**
  - Leverage system/processor low power states
- **Maintain QoS constraints**
  - Satisfy tail latency requirements (e.g.,90th percentile response time)
- **Adaptive to distinct workload**
  - Adjust energy saving strategies according to various workloads

WASP Framework: Global Level



WASP Framework: Local Level



WASP Algorithm

- **Job scheduler dispatches jobs to schedulable servers**
  - Servers in active state but with free cores
  - Server in idle state with delay timer not expired
  - Job scheduler has a priority to select shallow sleep servers
  - When no such sever available, select deep sleep servers
- **Parameters to set:**
  - T_s: threshold (pending jobs per core) to put a server to sleep
  - T_w: threshold (pending jobs per core) to wake up a server
  - τ: waiting time threshold to enter system sleep state

Simulation Setup

- **Developed an event-driven simulator**
  - Model job queuing in multi-core, multi-server system
  - Models server processor and platform power
  - Reports job response time and energy consumption statistics
- **The simulated server farm configuration**
  - 50 servers
  - Each core is able to serve one job at a time
- **Simulation settings**
  - Small workload (average service time 1~10 ms, e.g., web services)
  - Large (average service time 100~200 ms, e.g., DNS services)
  - First 10,000 jobs are ignored for simulation warm-up

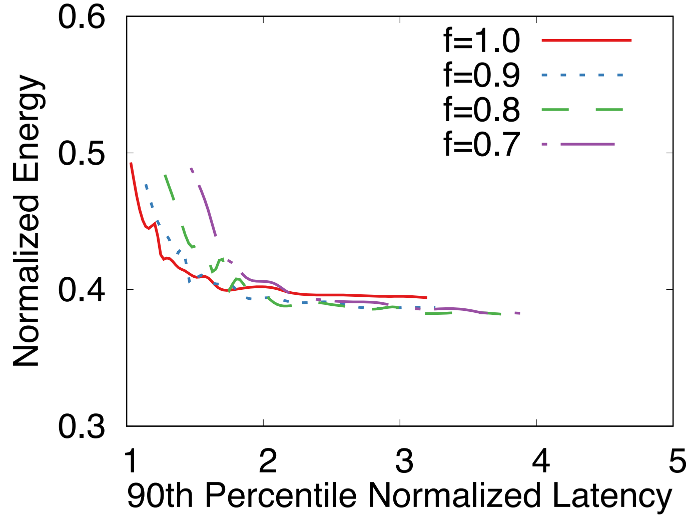
Server Power Model

Component	Core sleep C1*	Core sleep C6 †	Pkg. sleep C6	System sleep
CPU	$33.0+3.1\times(n_a-1)$	$23.0+3.8\times(n_a-1)$	8.3	8.3
RAM	10.8	10.8	4.9	1.4
Platform	45.5	45.5	23.6	4.8
Total Power	$89.3+3.1\times(n_a-1)$	$79.3+3.8\times(n_a-1)$	36.8	14.5

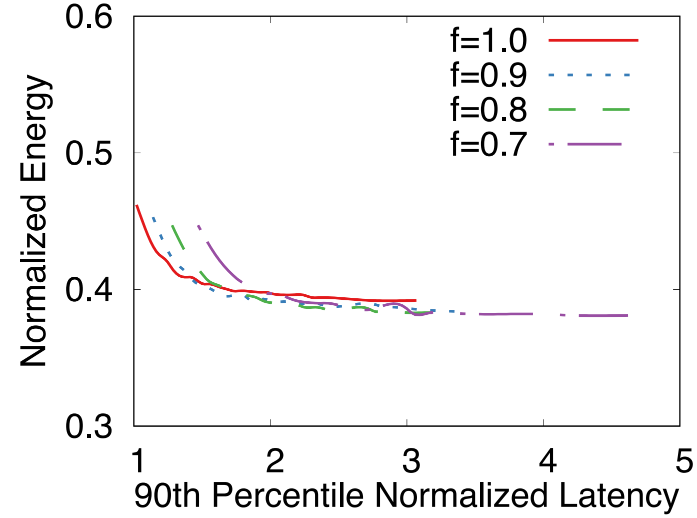
n_a : the number of cores in active state
Core sleep C1 : processor is active, idle cores are in c1 state
Core sleep C6 : processor is active, idle cores are in c6 state
Pkg. sleep C6 : entire processor in C6 state

CPU power is based on linear regression model using power profiles for the Intel Xeon E5-2680 processor

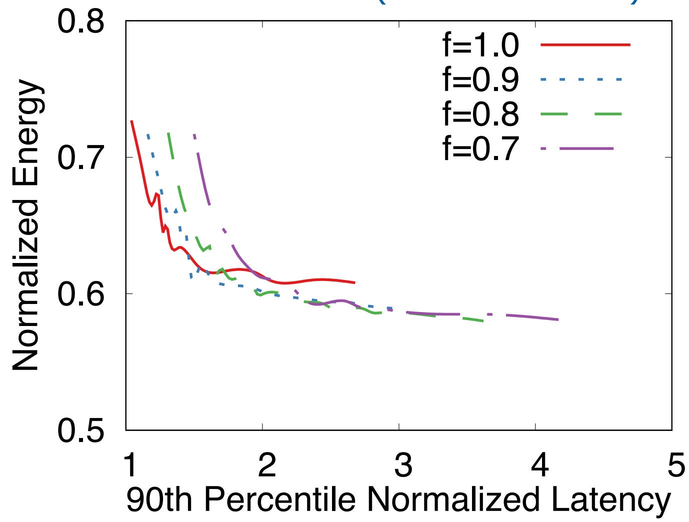
Pareto-optimal Space Exploration



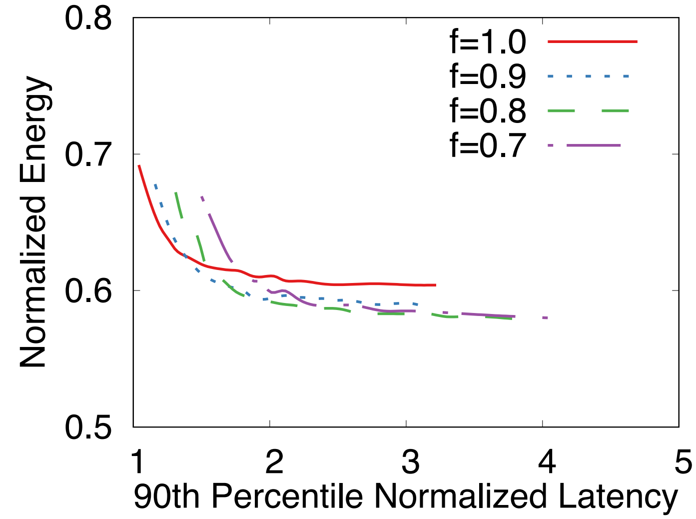
Web Service (Utilization 10%)



DNS Service(Utilization 10%)



Web Service (Utilization 30%)



DNS Service(Utilization 30%)

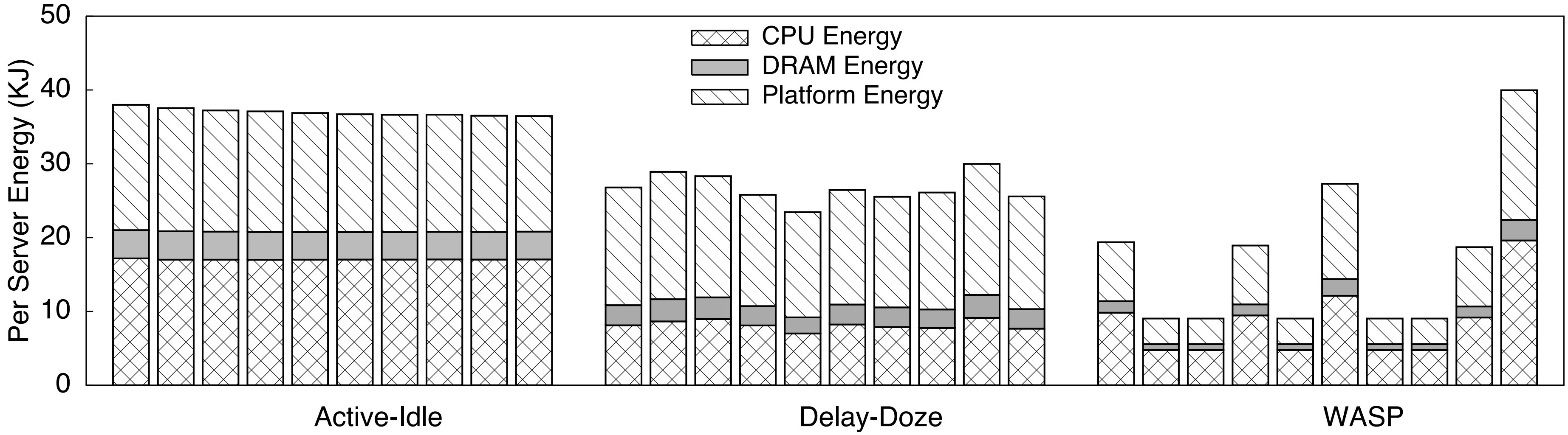
Exploration Observations

- τ is independent of utilization levels, but is job-size dependent.
- T_w is independent of utilization levels.
- T_s values are independent of job execution latencies and utilization levels.

System Evaluation

- **A cluster of 10 servers**
  - Dell M1000e cluster
- **Each server is equipped with 12 cores**
  - Dual-socket Intel X5650 processor
  - 12GB DRAM
  - 256GB Disk
- **Deployed with apache web service**
  - Wikipedia and NLANR workload
- **QoS Goal: 90th percentile latency as 2x service time**

Energy Savings for Wikipedia Workload

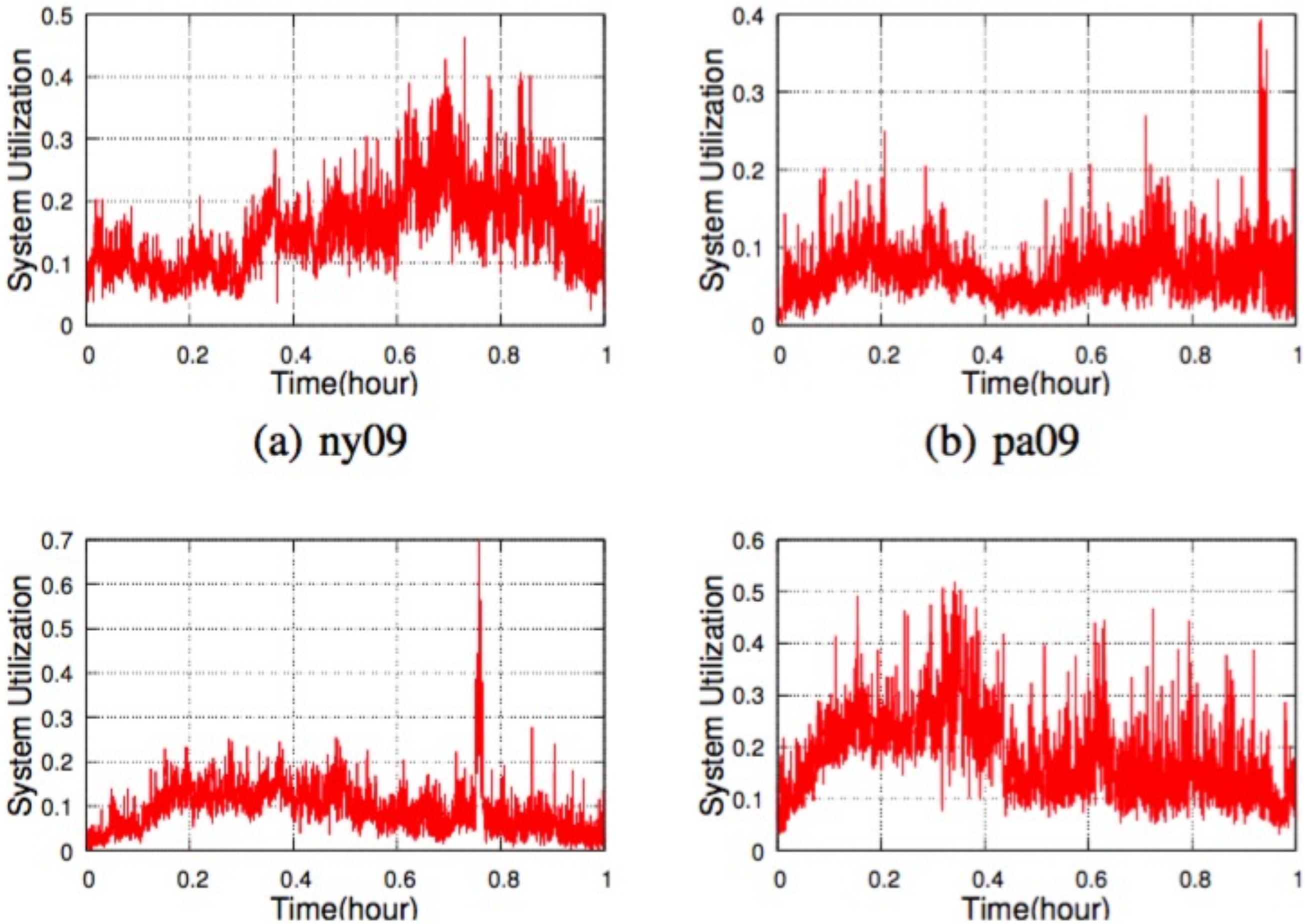


**For each configuration, the 10 bars represent the energy consumption for the 10 servers*

WASP achieves 57% energy saving active-idle
WASP achieves 39% energy saving over delay-doze

Bursty NLANR workloads

- **Workload Patterns**



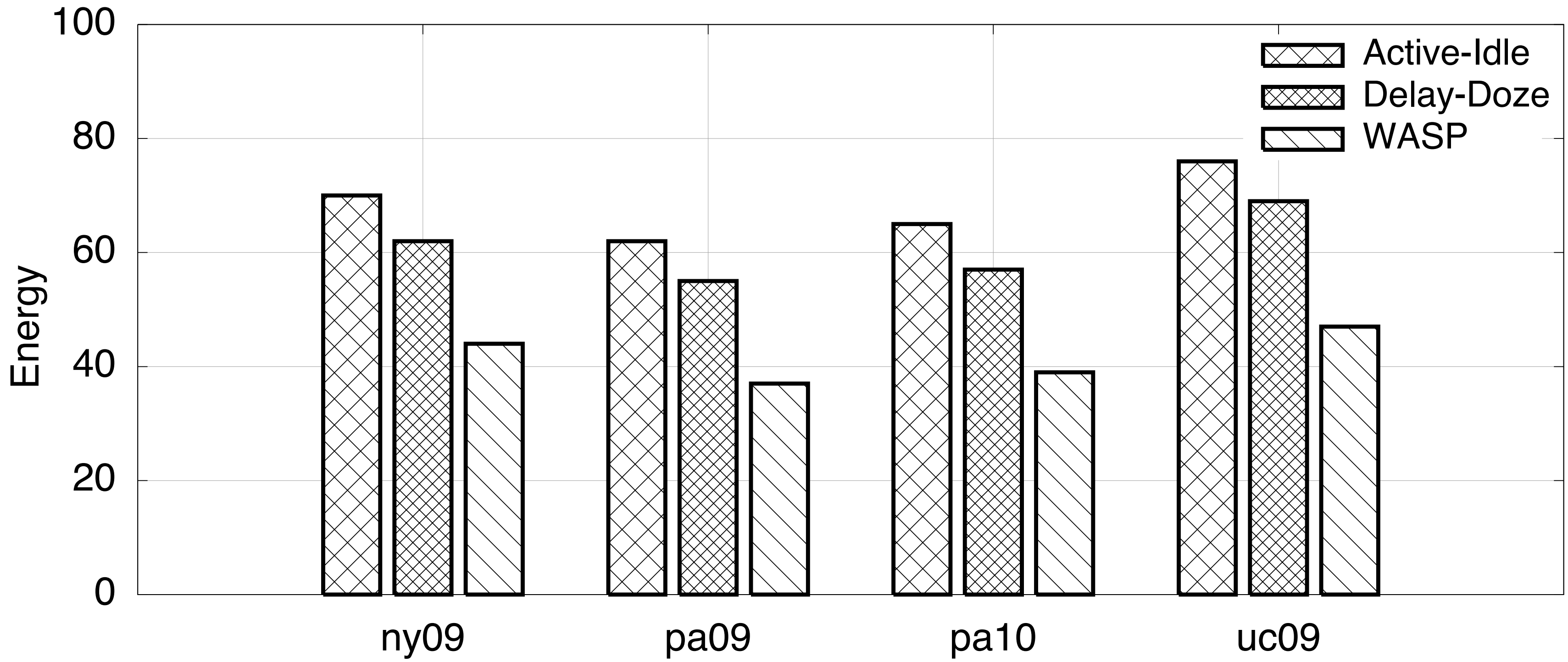
(a) ny09

(b) pa09

(c) pa10

(d) uc09

Energy Savings on Cluster



Energy is normalized to the peak energy the system consumes when all server are running at peak power

Delay-Doze only achieves 9%~12% energy saving
WASP achieve 34%~40% energy saving compared to Active-Idle

Conclusions

- We proposed techniques that makes smart use of processor/system low-power

- We performed an exploration of Pareto-optimal Energy-Latency tradeoffs

- We implement a prototype on real system and showed upto 57% energy saving with QoS guarantees.

- **Acknowledgements**