Energy Management in Real-time Multi-tier Servers

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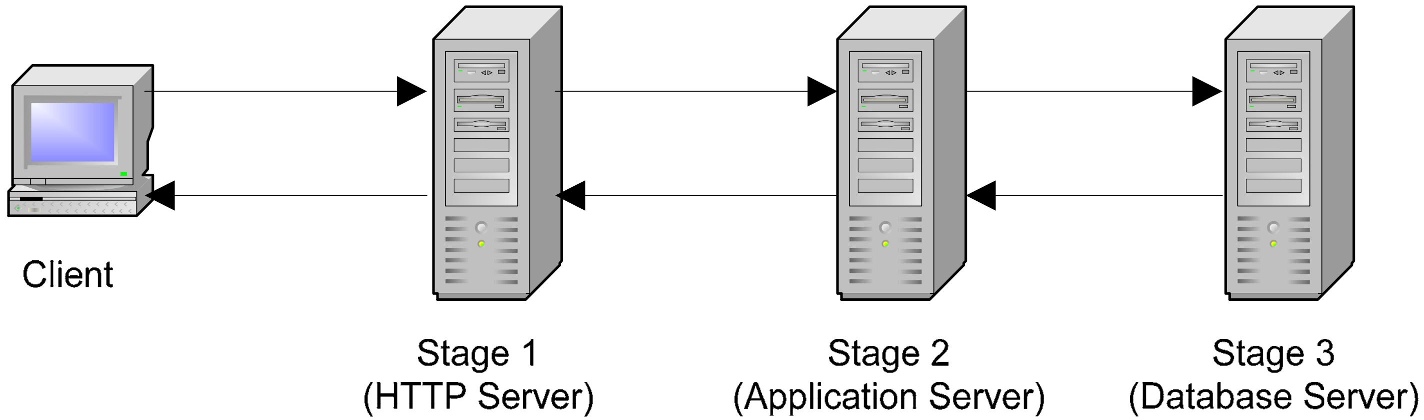
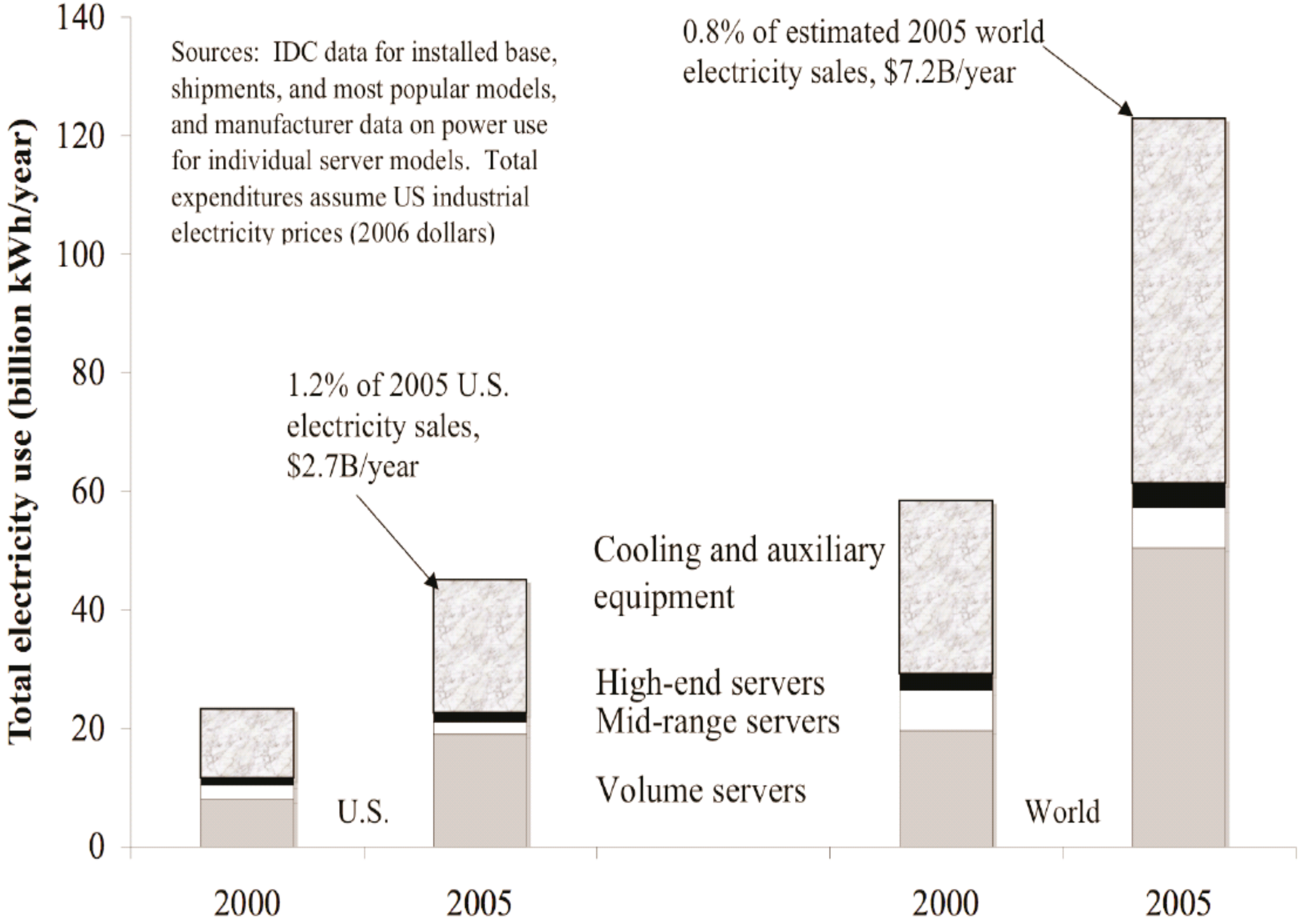
  - **Also partial funding from ARO re: graceful response to load spikes**
- **Now funded by AES track**

Multi-tier Servers



- Requests are processed by a server pipeline
  - E.g. HTTP Front-end, Application Server, Database Server
- Functionally distributed
- Can be significantly imbalanced
  - Each request has different resource needs on each stage

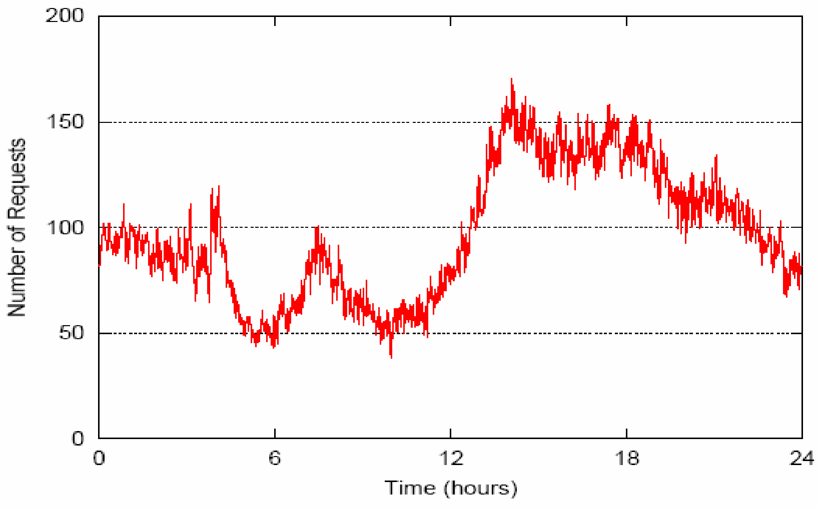
Motivation

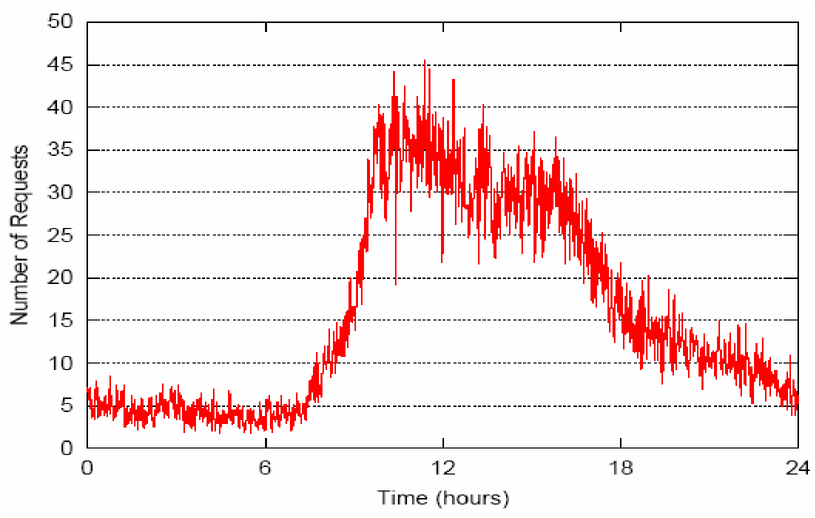


Source: Jonathan G. Koomey, *Estimating Total Power Consumption By Servers In The U.S. And The World*, 2007

Does not include many servers, e.g. Google data centers!

Typical Workloads





- **Peak load much higher than average**
  - **Capacity is planned to satisfy worst-case load**
- **Light load during long periods of time**
  - **The server sits idle**
  - **Idle operation wastes energy**
- **Great potential for energy savings**
- **First focus: DVS**

Source: Bohrer et al., ***The Case For Power Management In Web Servers*** **(IBM Research)**

Constraints

- **Soft real-time performance**
  - **Power management must not impair user experience significantly**
  - **User experience → only *end-to-end* delay guarantees are relevant**
  - **DVS settings across the pipeline must be coordinated to meet deadlines *while* minimizing power consumption**
- **Commodity server software**
  - **Linux, Apache, JBoss, MySQL**
- **Dynamic workload with target latencies**
  - **TPC-W benchmark**

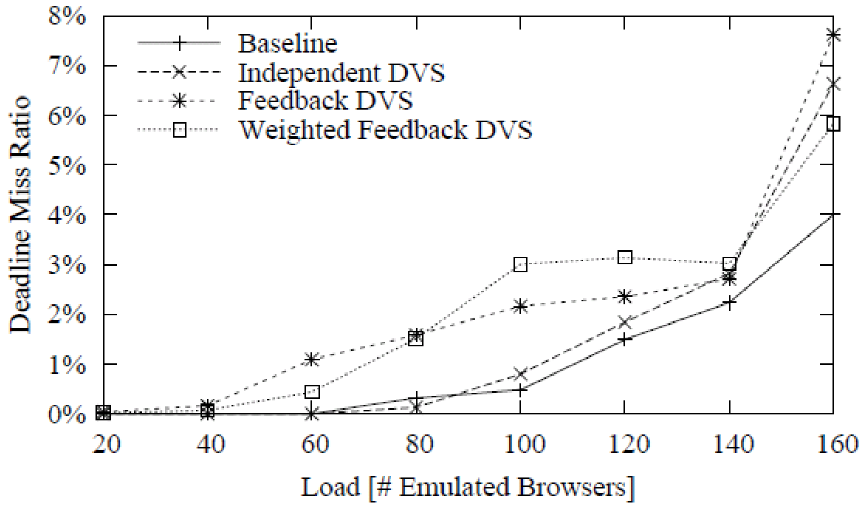
Algorithms

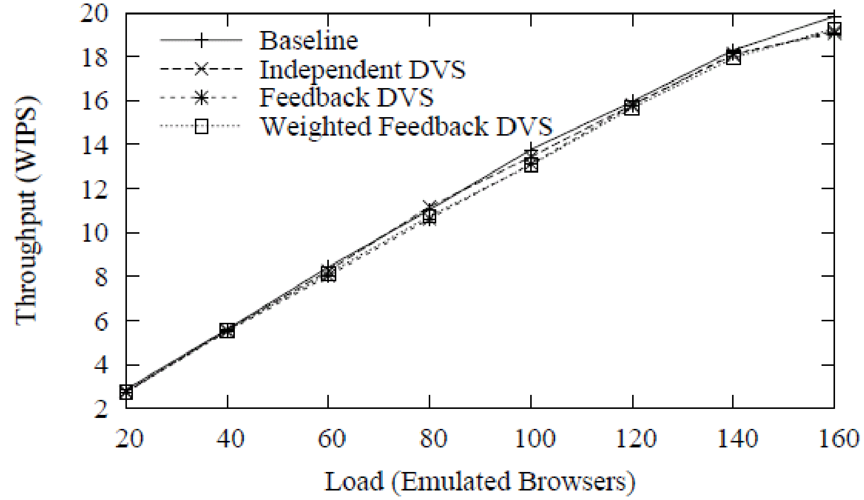
- **Simple DVS**
  - Good approximation for homogeneous systems
  - Feedback controller with simple rules:
    - If total latency > target → speed up stage with maximal CPU utilization
    - If total latency < target → slow down stage with minimal CPU utilization
- **Weighted DVS**
  - Based on analytical optimality condition
    - With knowledge of workload and machine power characteristics
  - Feedback controller adjusts CPU speeds to stay close to the optimality condition
    - Dead zone feedback control
    - Thresholds determined by max tolerable deadline miss ratio (eg, 5%), conditional probability analysis

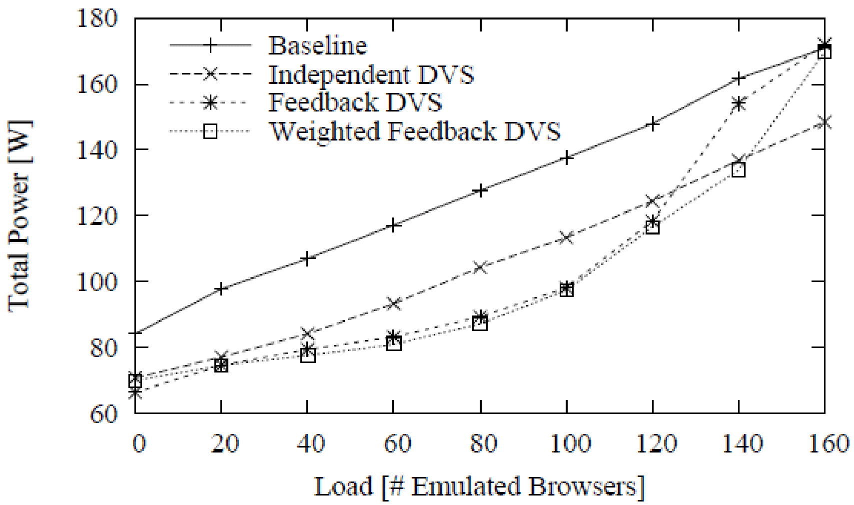
Optimality Condition

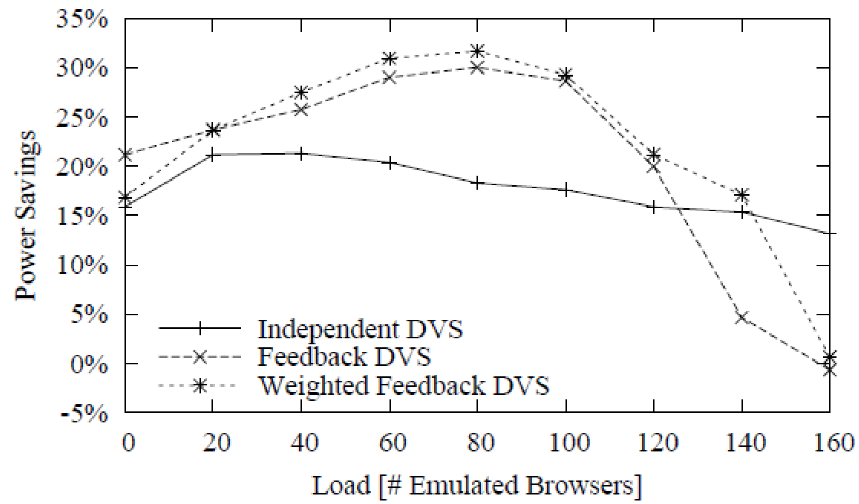
- **Workload-dependent delay function:**
  - $D_i^{CPU} = T_i / (1 – U_i)$
- **Hardware-dependent power function:**
  - $P_i = A_i f_i^n + B_i$
- **End-to-end latency constraint:**
  - $\sum_{i=1}^{N} D_i^{CPU} + D_i^{block} \leq L$
- **Solution:**
  - $W_1 H(U_1) = W_2 H(U_2) = \ldots = W_N H(U_N)$
  - W_i : weight calculated from workload and power fns
  - $H(U_i) = (1 - U_i)^2 / U_i^{n+1}$
- **Basic idea: weighted utilizations should be equalized across tiers**

Results









Testbed of 3 AthlonXP laptops with multiple DVS levels

Results

- **Target performance achieved**
  - **End-to-end deadline miss rate within 3% of baseline (max tolerable set at 5%)**
  - **Throughput was almost unaffected**
- **Up to 30% power savings are achieved**
  - **Weighted DVS was superior**
  - **Simple DVS was a good approximation**

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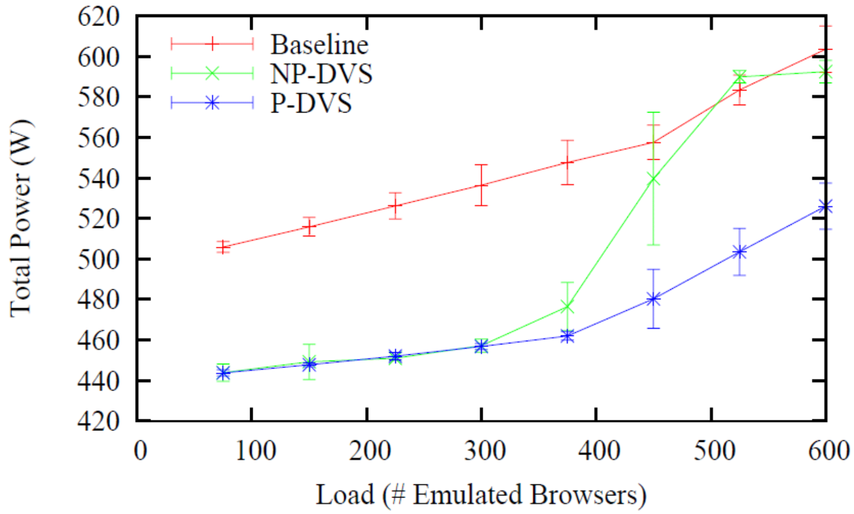
Service Prioritization

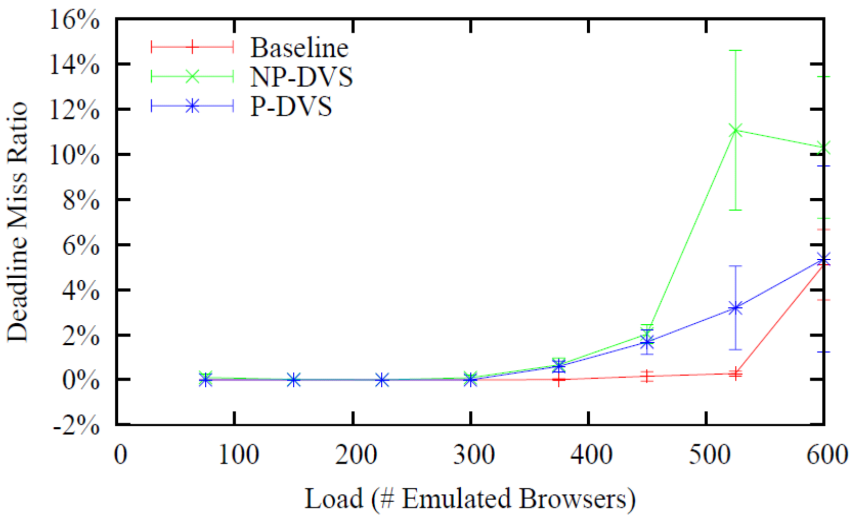
- **Different clients – different performance requirements**
  - **For example, interactive vs. background tasks; paying vs. free customers**
- **Deadlines of lower-priority requests can be relaxed**
- **Additional energy savings can be realized**
  - **Servers need priority request scheduling**
  - **DVS algorithm needs to recognize the different classes**
- **Questions:**
  - **How to implement this with the least effort?**
  - **How much energy can be saved?**
  - **How much is the performance penalty?**

Multi-tier Server Prioritization

- **Ideal design is expensive to implement:**
  - **Server applications do not typically support priority scheduling; many are closed source**
  - **Widely used server OSs do not support priorities for all resources**
  - **Communication protocols between tiers do not propagate priority information**
- **Simple, inexpensive design:**
  - **Run multiple server application instances, prioritized at the process level; no application or OS modification**
  - **Requires real-time process priorities in OS**
  - **Effectively creates separate queues and communication channels for each class of service**
  - **Has limitations: e.g. databases, I/O-bound workloads**
    - **Solution: minimize queuing in such tiers**

Prioritized System Results





- **Load is evenly divided into 3 priority classes**
- **Comparison**
  - **Baseline: no DVS**
  - **NP-DVS: Non-priority aware DVS**
  - **P-DVS: Priority-aware DVS**
- **Additional energy savings of up to 15%**
- **Less than 3% increase in average deadline miss rate**

Testbed of 8 Athlon64 desktops:
1 front end, 2 Apache, 4 JBoss, 1 MySQL

Current Work

- **Power management for large datacenters**
  - **Sleep modes can be used (in addition to DVS)**
    - **Comprehensive power management policy**
    - **Find the optimal balance of the different power states available**
  - **Dynamic assignment of machines to tiers**
    - **Helpful if the bottleneck tier shifts over time**
  - **New optimization problem**
    - **New optimality conditions for:**
      - **number of machines in each tier**
      - **CPU frequencies for each tier**
    - **More complex feedback controller needed**
  - **Sensor-actuator based control framework**

Future Work

- **AES project:**
  - **Implications of multicore processors**
  - **Supporting virtualized environments**
    - **How will multi-tier apps be consolidated?**
    - **How to ensure end-to-end delays?**
    - **Dealing with sessions**
  - **Accounting for thermal load**

Future Work

- **NGS-related work (NSF SEI/IIS, Intel, NVIDIA)**
  - **Hardware support to simplify parallel programming**
    - **Key problem: legacy codes and legacy brains**
  - **Can already support dozens of threads/core, hundreds of PEs/chip**
    - **Let programmer use these for performance *or* simplified programming model**
  - **Must all be subject to power and thermal constraints**
  - **Major complicating factor: heterogeneous architecture**
    - **Accelerators**
    - **Parameter variations and hard faults**

Bullet for Later Discussion

- **How to make decentralized but globally optimal decisions while preserving real-time characteristics**

Backup

Power Management Methods

- **Sleep Modes**
  - Turn off unnecessary machines in a cluster
    - Wakeup solution required
  - Consolidate remaining work on alive machines
    - Not possible with some workloads (e.g. large state)
  - Saves most power
  - High impact on:
    - software design (must work in a dynamic cluster)
    - performance (sleeping nodes perform no work)
- **Dynamic Voltage Scaling (DVS)**
  - Slow down the CPUs of machines
  - Saves significant power
  - Low impact (all cluster nodes still work)
  - Can take advantage of I/O bottlenecks
    - CPU slowdown has very little effect on I/O delay