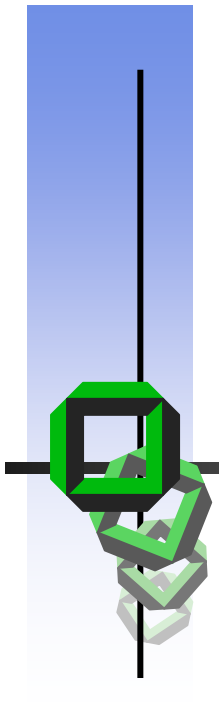

Distributed Energy Management for Virtual Machines

Gesellschaft für Informatik, Fachgruppe Betriebssysteme

Fujitsu Siemens Computers GmbH München

October 2006

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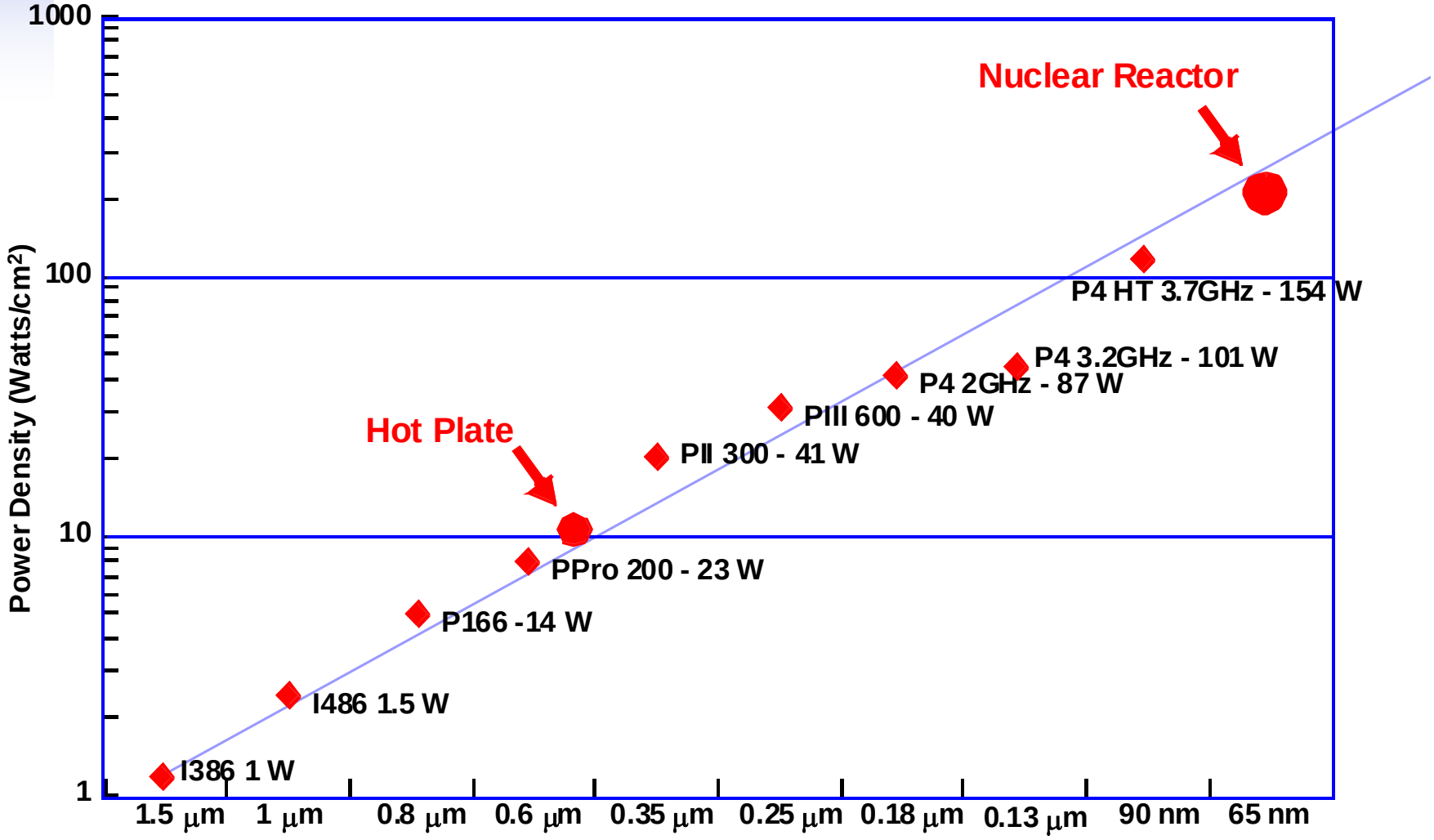
System Architecture Group

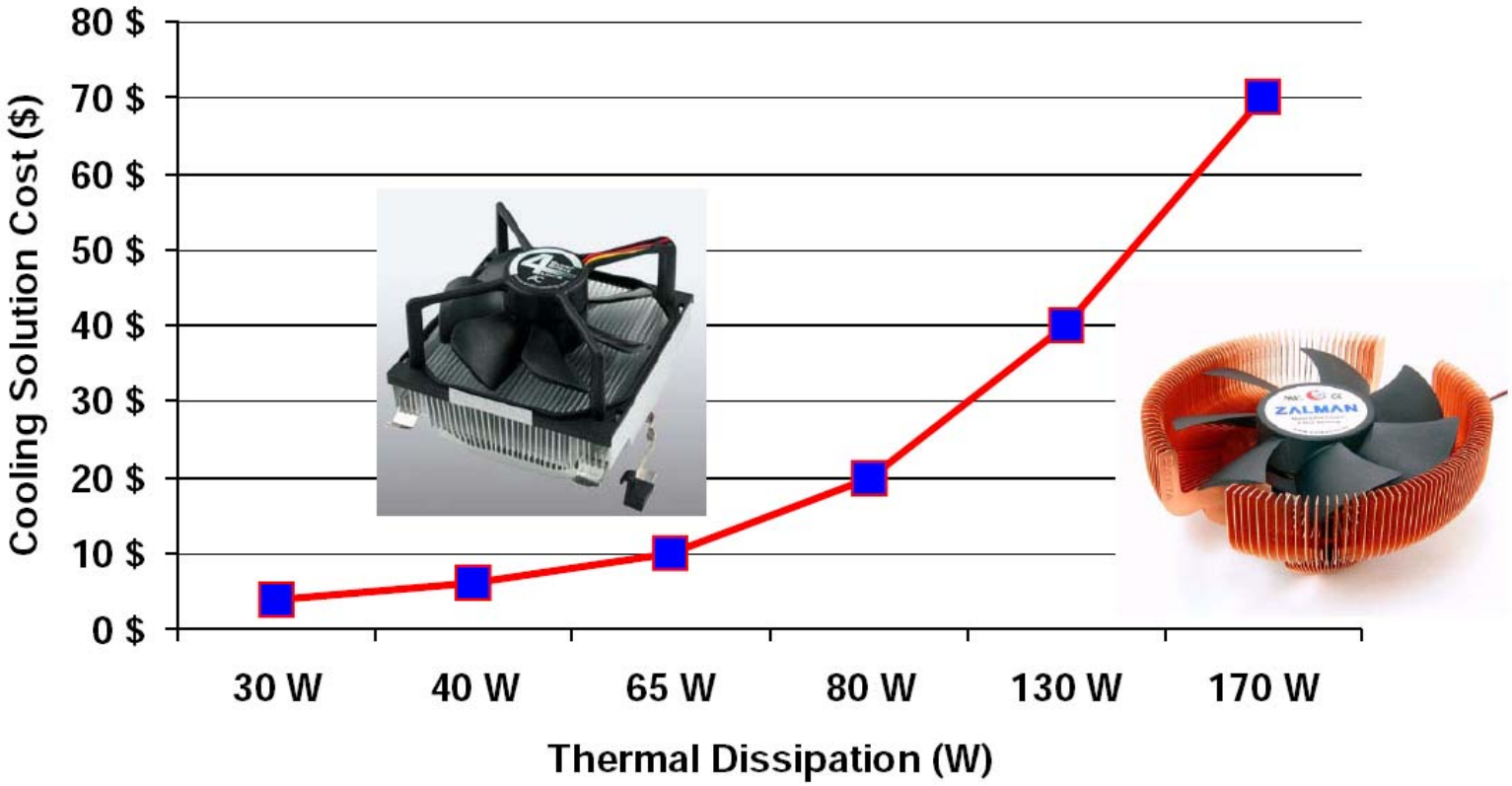
University of Karlsruhe

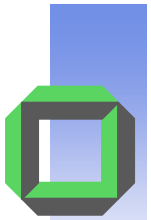
Moore's Law for Power



State of the Art in Thermal Design

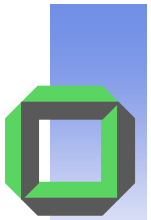
- Increasing energy dissipation in computer systems
- Increasing cooling costs





Goals of OS-Directed Energy Management

- Power management
  - Limits of battery/backup-generator
  - Peak power contracted with electric company
- Thermal management
  - Ensure safe operation in case of cooling failure
  - Design for the average case, no overprovisioning
  - Reduce energy and cooling cost
- User management
  - Control power/temperature per user
  - Ensure QoS and energy constraints at the same time
  - Pay-per-use model

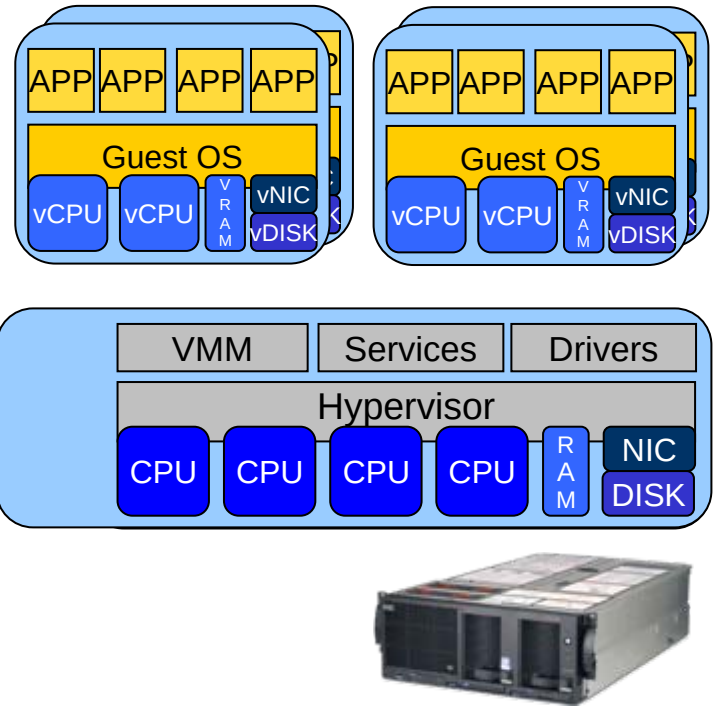


State-of-the-Art in Energy Management

- Hardware mechanisms for reduction of active power
  - Basic idea: multiple device power states
  - Processor halt cycles
  - Processor frequency/voltage scaling
  - Multi-speed disks
- Energy-management in current OSes
  - Widely used: system-wide throttling
    - Low power state during inactivity
    - Low power state on thermal/power emergencies
  - More recently: user-centric energy management
    - Throttling of energy-intensive low-priority tasks
    - Balancing hot and cold tasks among devices

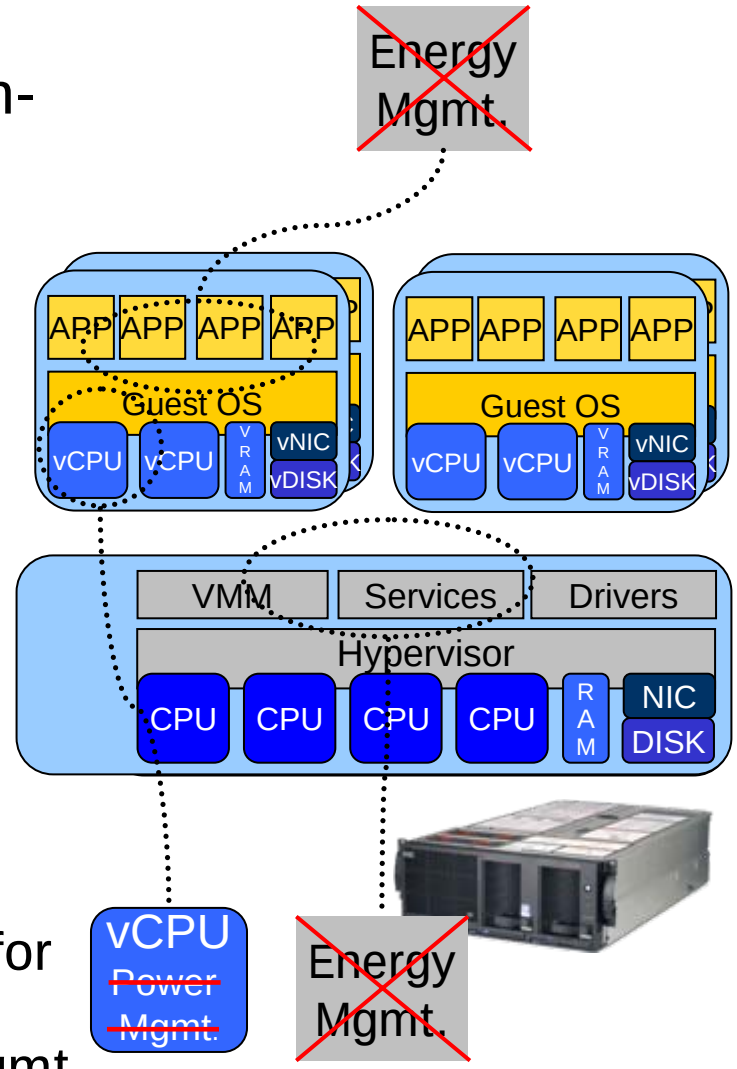
The Trend to OS Virtualization

- Virtual infrastructure
  - Multiple guest OSes
  - Hypervisor
  - Drivers and service containers
- Improve/innovate OS functionality
  - Server consolidation
  - Live migration
  - Improved reliability
- Retain legacy compatibility
  - Convenient migration path
  - Simultaneously use multiple OS personalities



Power Management vs. OS Virtualization

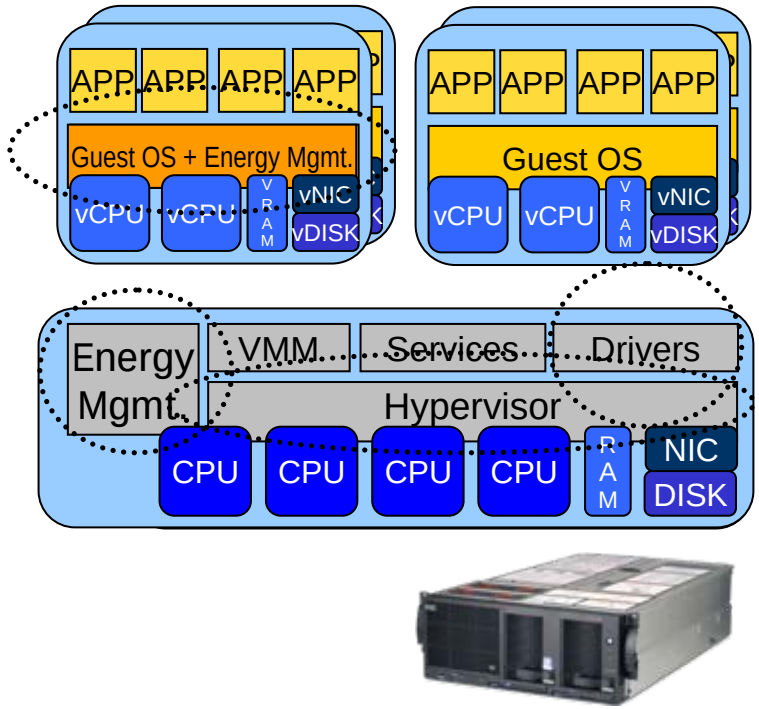
- Energy-management virtualization-unaware
  - Assumes full control over devices
  - Assumes full control over apps
  - Guest OSes have none
- Virtual infrastructure energy-unaware
  - Distributed control over devices
  - Distributed control flow and applications
  - Physical effects hard to virtualize
- Required
  - Distributed energy management for VM environments
  - Virtual energy for user-centric mgmt.



Distributed Energy Management

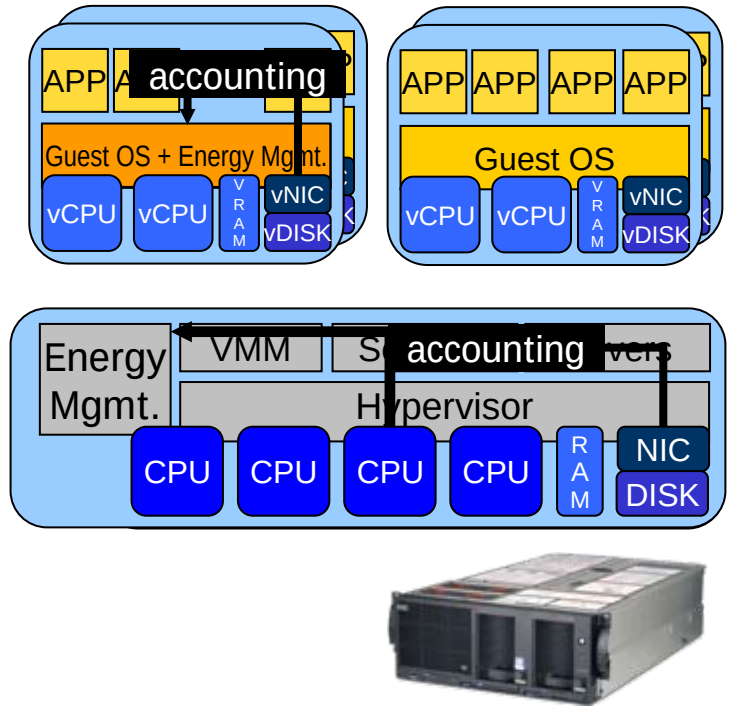
- Novel framework for distributed, multi-layered OS environments
- Use energy as basic notion
  - Unified, partitionable, distributable
  - Express thermal constraints via thermal model
- Assume parties to be distributed
  - Energy management substeps

1. Energy accounting
2. Analysis and allocation decision
3. Power control and allocation



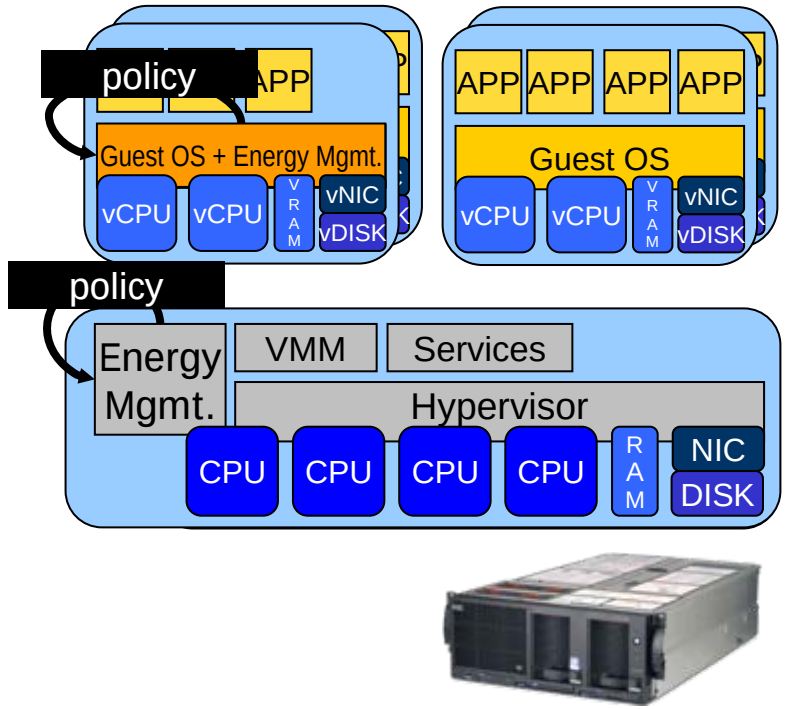
Distributed Energy Management

1. Distributed energy accounting
   - Measure/estimate energy per activity and resource
   - Incorporate layers and dependencies



Distributed Energy Management

1. Distributed energy accounting
   - Measure/estimate energy per activity and resource
   - Incorporate layers and dependencies
2. Separate policy management
   - Multiple subsystems
   - Each responsible for distinct devices and activities

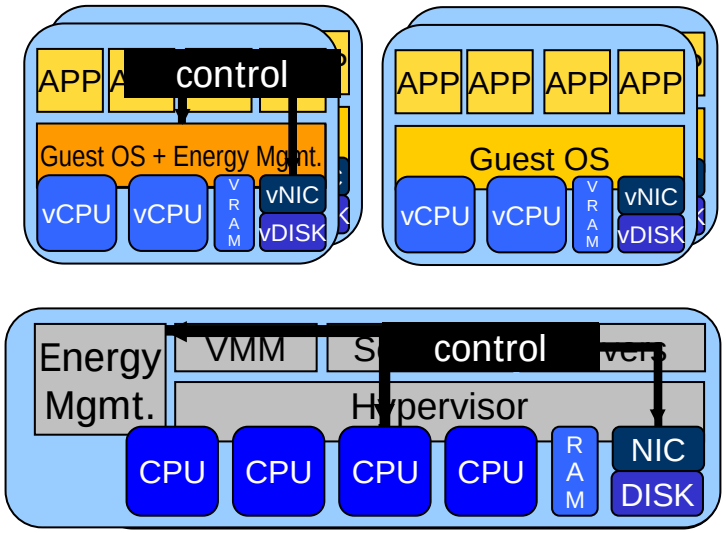


Distributed Energy Management

1. Distributed energy accounting
   - Measure/estimate energy per activity and resource
   - Incorporate layers and dependencies

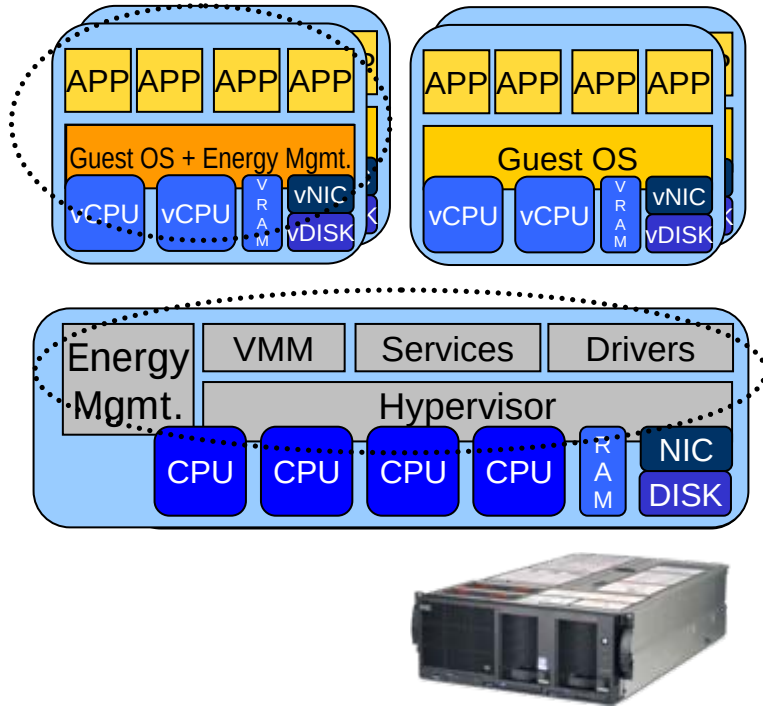
2. Separate policy management
   - Multiple subsystems
   - Each responsible for distinct devices and activities

3. Exposed control of active power
   - HW: halt cycles, DVFS
   - SW: Activity throttling, migration



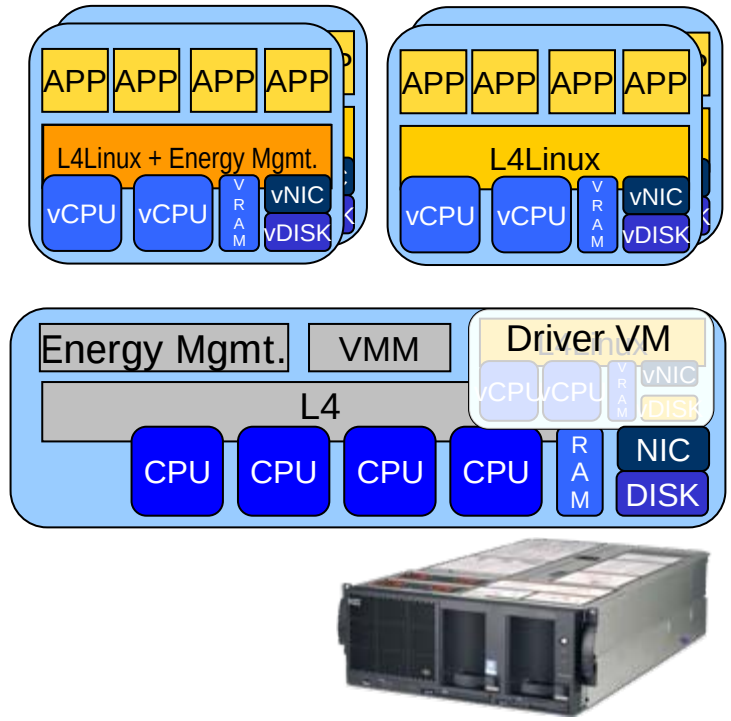
A Prototype for Hypervisor-Based Systems

- Two-level system, based on the previous design principles
- Host-level energy management
  - Constrains energy across VMs
  - Enforces constraints for energy-unaware or malicious VMs
  - “Virtualizes” energy
- Optional guest-level energy management
  - Fine-grain, application-level energy management
  - Linux-compatible



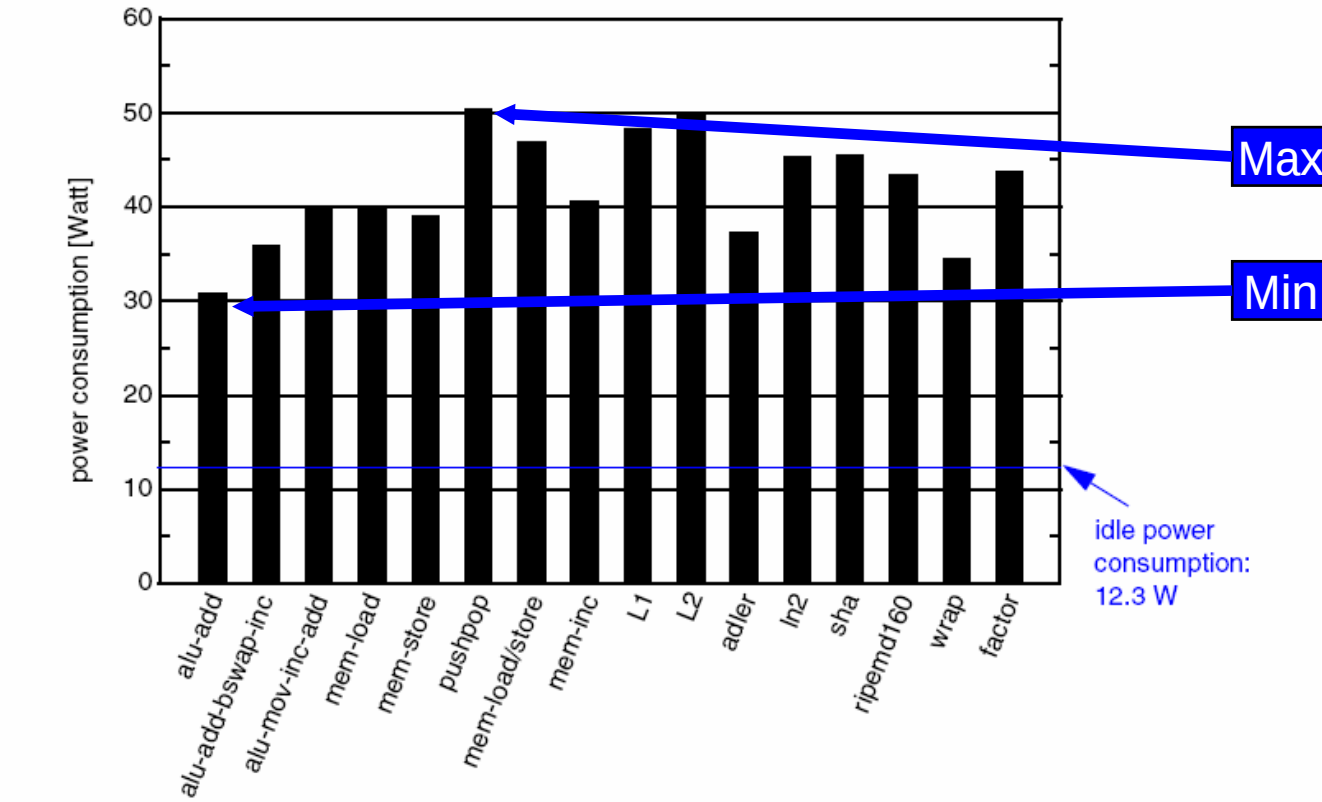
A Prototype for Hypervisor-Based Systems

- Based on L4 hypervisor/microkernel
- Virtualization technology
  - Para-virtualized L4Linux instances
  - Legacy application workload
  - Energy-aware/unaware guests
  - User-level device drivers
- Microkernel paradigms
  - Host-level energy manager app.
  - Lightweight abstractions
- Currently supported devices
  - CPU
  - Hard disk



CPU Energy Accounting

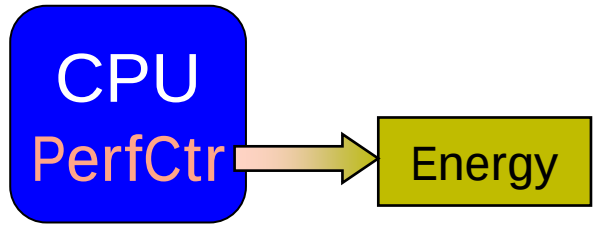
- P4 2GHz with compute intensive tasks (100% CPU load)



- Required: high resolution energy accounting

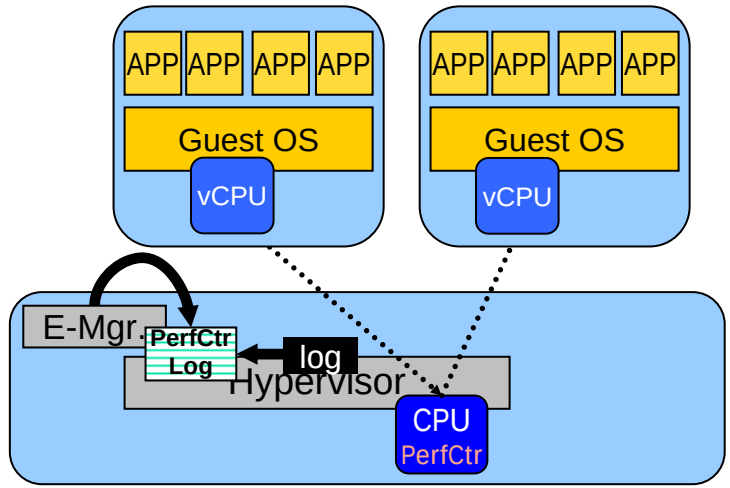
CPU Energy Accounting

- Event-driven energy estimation
  - Leverage performance monitoring counters
  - Energy = Σ_i #event$_i$ x weight$_i$



- Report to energy manager
  - Hypervisor traces PerfCtrs on vCPU context switches
  - Stores them in user-accessible PerfCtr logs
  - Energy manager derives active and idle energy from logs

vCPU1	*vCPU2*	*...*
8_i+12_a	8_i+20_a	

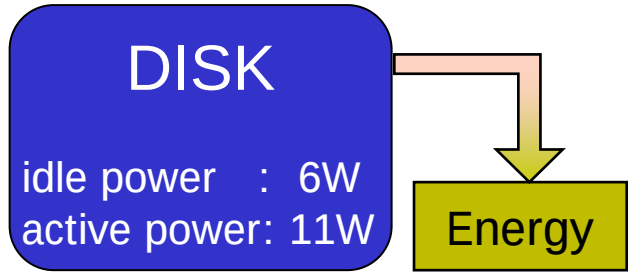


$$idle_{VCPU} : \frac{1}{\#vCPU} \Sigma_{vCPU} \#event_{tsc,vCPU} \times weight_{tsc}$$

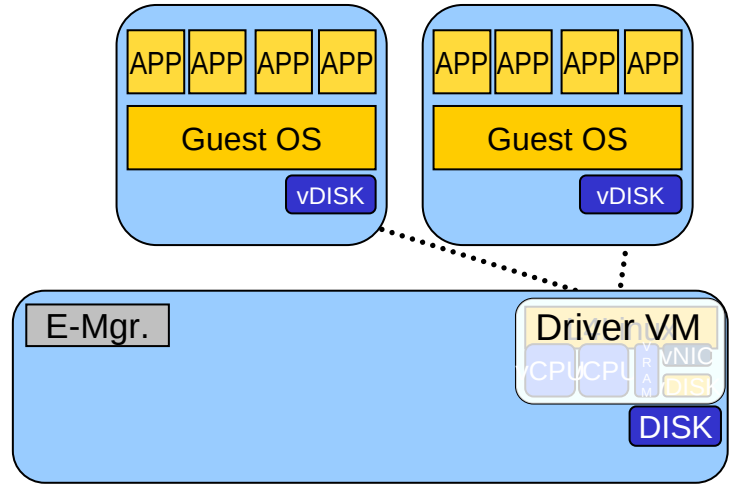
$$active_{vCPU}: \Sigma_{i \setminus tsc} \#event_{i,vCPU} \times weight_i$$

Disk Energy Accounting

- Time-based energy estimation
  - Assume constant disk power
  - Idle energy accounted to client VMs
  - Active energy accounted to requests
    - based on their transfer time
    - $time_{req} = size_{req} / transfer\ rate$



- Report to energy manager
  - Driver VM periodically obtains active and idle energy per vDISK



vDISK1	*vDISK2*	*...*
3_i+2_a	3_i+3_a	

$idle_{VDISK} : \frac{1}{\#VDISKS}$ idle power x period

$active_{vDISK} = \Sigma_{req(vDISK)}$ active $power_{req}$ x $time_{req(vDISK)}$

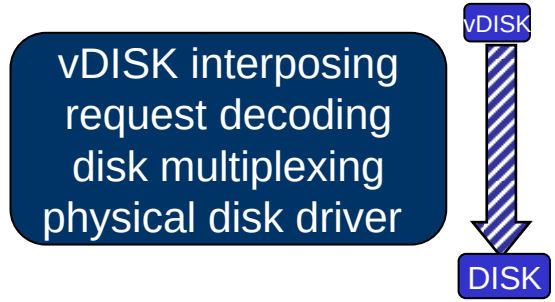
Recursive Energy Accounting

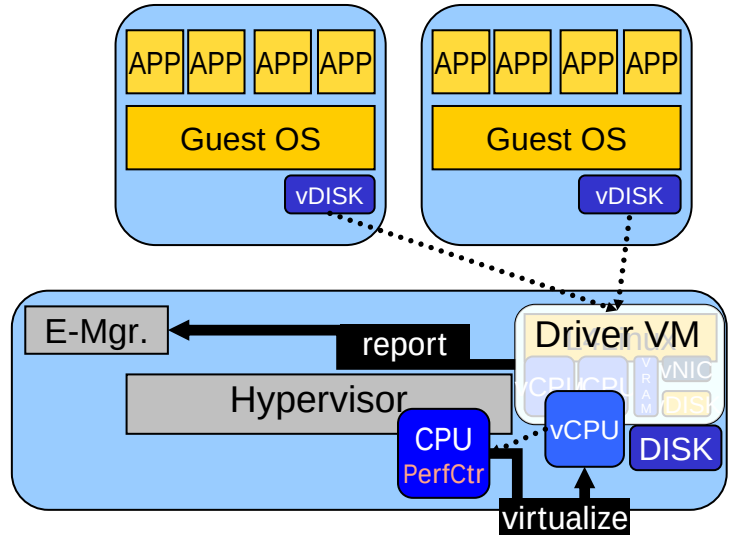
- Disk virtualization requires CPU processing
- Recursively account CPU energy
  - Disk driver VM
    - Accounts per-VM disk utilization
    - Accounts its own vCPU utilization

	vDISK1	*vDISK2*	...
DISK	3_i+2_a	3_i+3_a	
vCPU	4_i+4_a	4_i+6_a	

  - Hypervisor
    - Accounts and virtualizes driver CPU energy consumption

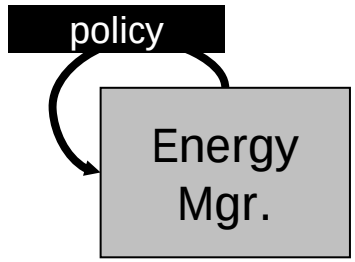
	vCPU
CPU	6_i+12_a



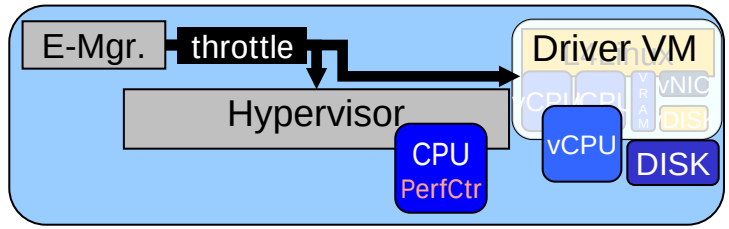


Exposed Power Control

- Energy manager
  - Obtains current CPU & disk energy
  - Limits it via per-VM energy reallocation



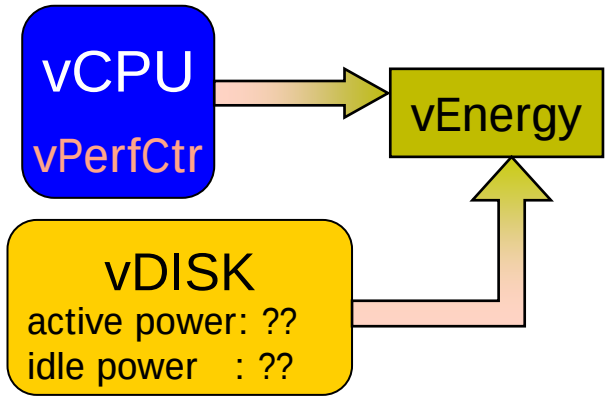
- CPU allocation
  - Hypervisor uses stride scheduler
  - Strides exported to energy manager
  - Unalloted cycles translated into halt cycles

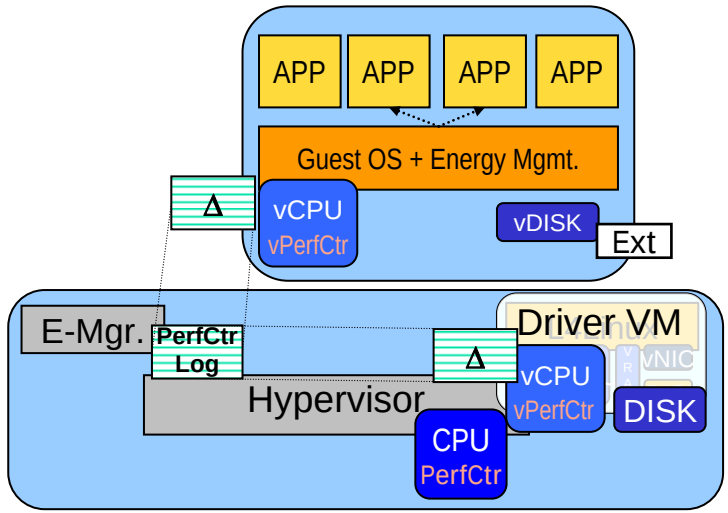


- Disk (and driver vCPU) allocation
  - Driver VM uses a throttle factor
  - Delays the throttled requests until the next timer tick

Guest-Level Support – Virtual Energy

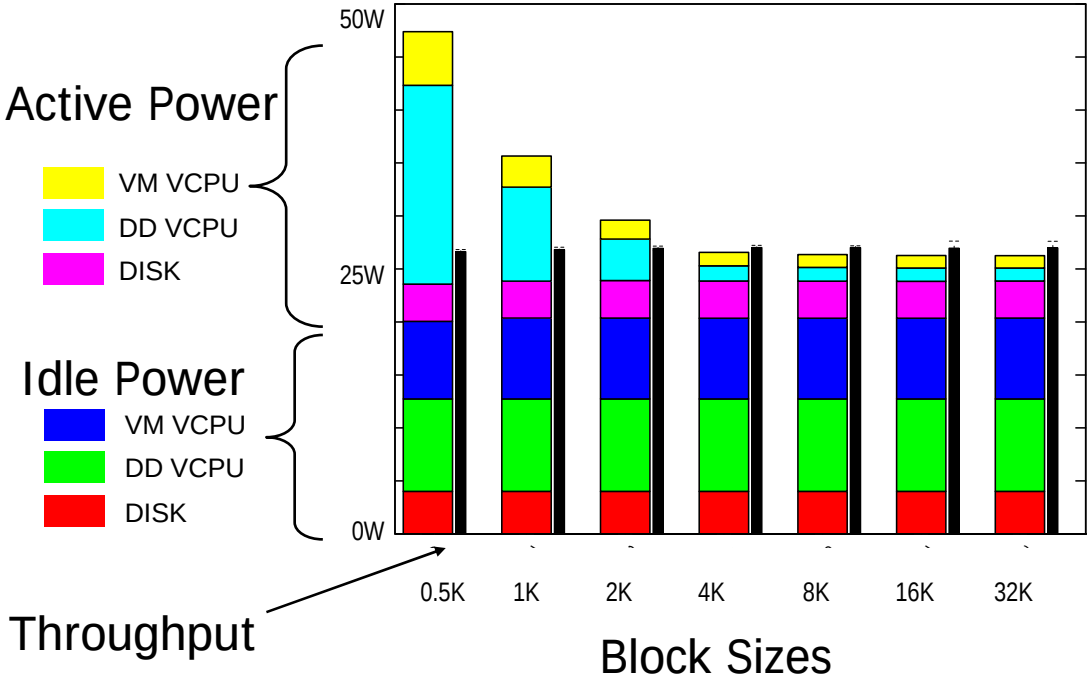
- Virtual CPU energy
  - Virtualize performance counters
- Virtual disk energy
  - Power depends on level of sharing
  - Use para-virtual disk extension
- Virtualizing Performance Counters
  - $PerfCtr_{virt} = PerfCtr_{phys} - \Delta PerfCtr_{OtherVMs}$
  - Get $\Delta PerfCtr_{OtherVMs}$ from logs
- Virtual disk extension
  - Idle energy exported as meter
  - Active energy exported with normal request data

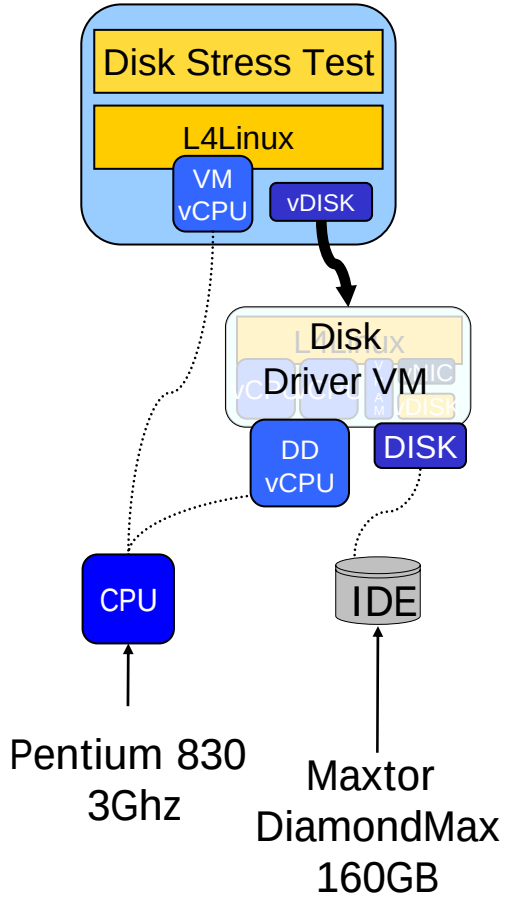




Experiments and Results

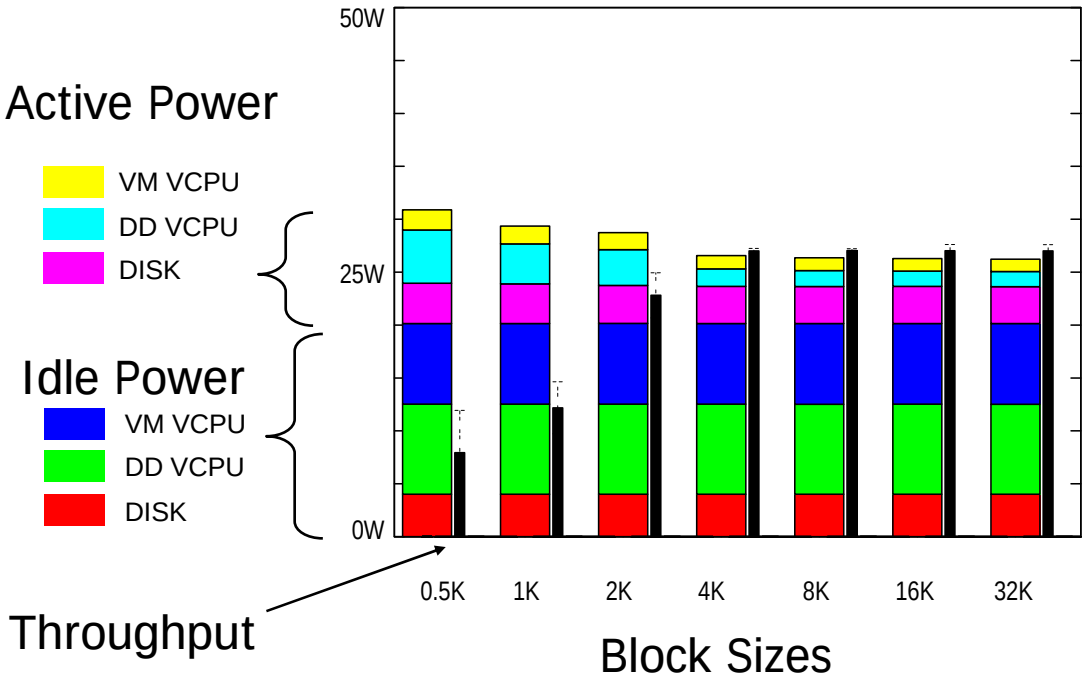
- Energy distribution of disk processing

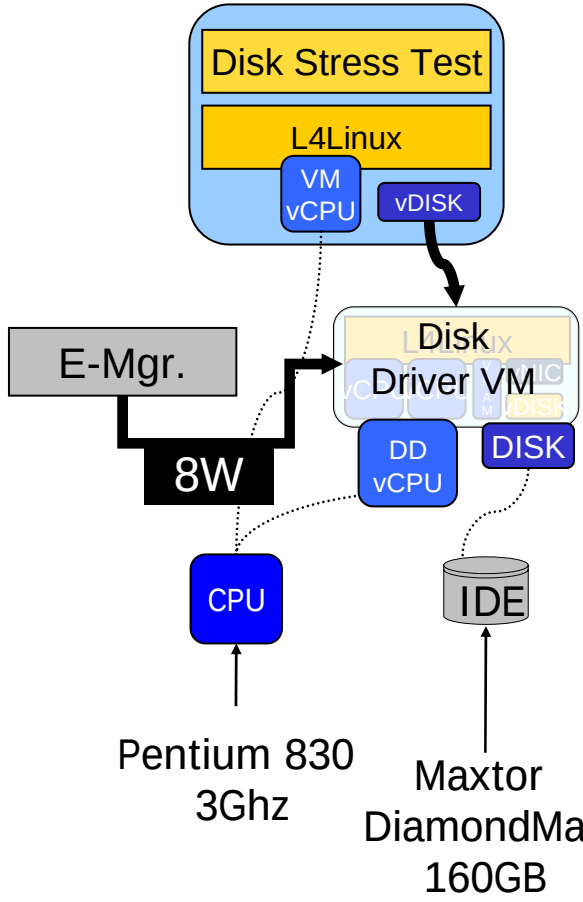




Experiments and Results

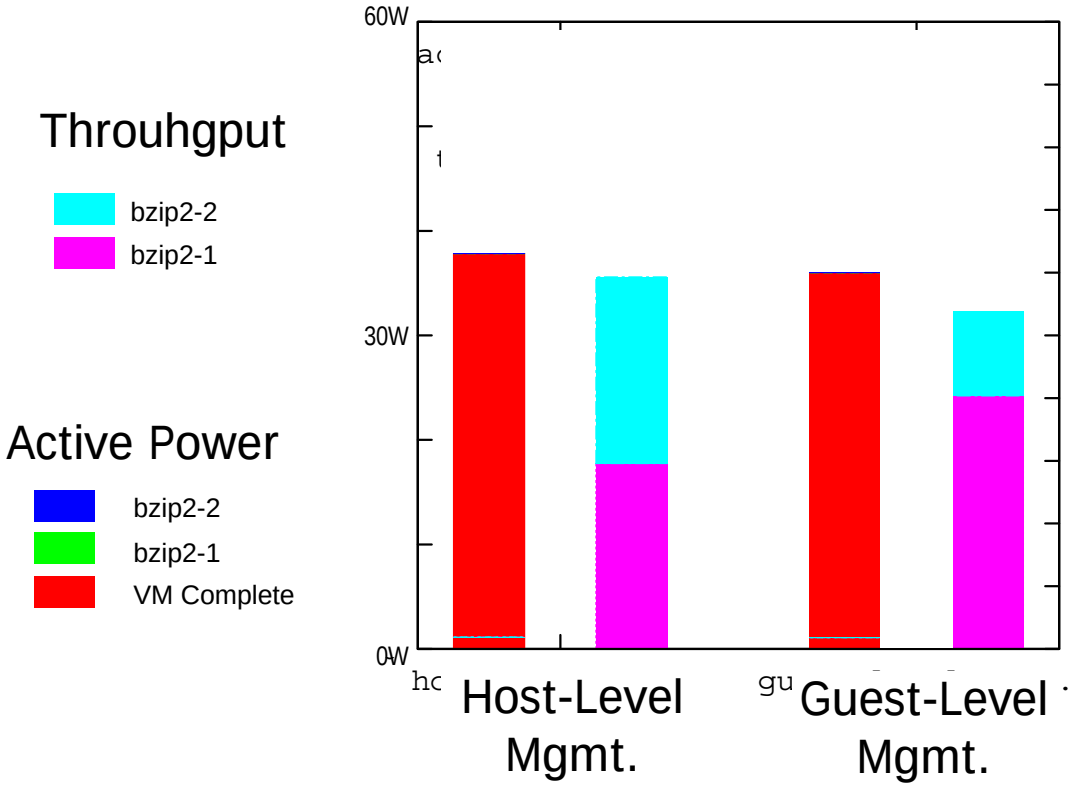
- Energy distribution of disk processing

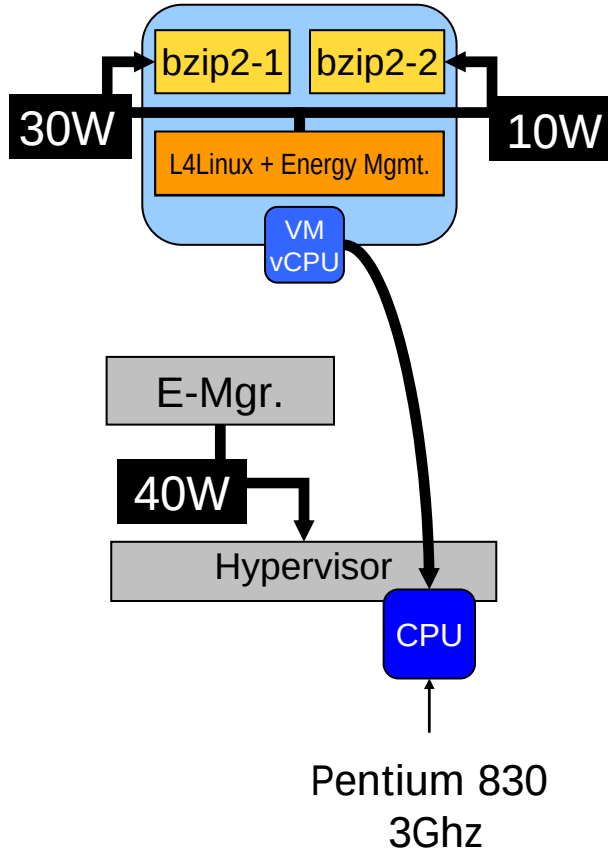


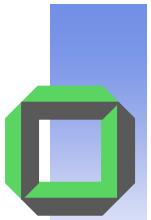


Experiments and Results

- Two-layer CPU energy management







Conclusion & Future Work

- The Problem
  - Current energy-management virtualization-unaware
  - Virtualization solutions disregard energy aspects
- Approach: Distributed energy management
  - Distributed, recursive energy accounting
  - Exposed control over active device power
  - Prototype supports control of CPUs and disks
  - Fine-grain, enforceable management at two layers
- Future Work
  - Other device types and management policies
  - Full virtualization, many-core architectures