Energy Adaptive Computing

Krishna Kant
George Mason University
National Science Foundation

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How do you make data centers environmentally smart?

Smart energy mgmt is necessary but not sufficient
Computing Power is Growing

• 2020 projections
  – Clients: 8x in number, 3X in power
  – Data Centers: > 2X increase
  – Network: 3X increase
Smart Energy Mgmt is Essential

• Hardware Level
  – Aggressive power mgmt at each level
  – Coordination within & across levels

• Server Level
  – Fans, power supplies, OS, & app level power mgmt

• Data Center Level
  – Cooling & airflow management, placement, scheduling, …
Is Energy Efficiency Enough?

• Energy efficiency less important, its carbon footprint really matters
• Energy efficiency may not reduce energy usage.

• Additional sustainability considerations
  – Use locally generated renewable energy
  – Reduce infrastructure & resource use (metals, water, …)
Cooling Infrastructure

- Cooling is very resource intensive
  - Lot of materials
  - Water, much of which evaporates
Power Distribution Infrastructure

- 9-10% distribution loss at power source
- Lots of earth’s resources used (metals, rare earths, …)
Overdesign

• Overdesign is the norm
  – Huge UPS, Generators, dist. frames, power supplies, fans, …

• Engineered for worst case
  – Huge waste of power, materials, …

• Example: Power Supply
  – Low utilizations, especially for duplex config ➔ Low efficiency
  – Voltage regulators: Similar issues
Sustainability Considerations

• Use of renewable energy
  – Must deal with variability & inadequacy of available energy

• Thrifty use of energy & materials
  – Free Cooling instead of CRAC
  – Reduce size of UPS, generators, power supplies, heat sinks, fans, …

• Smart adaptation to deal with under-capacity
Data Center Energy Opportunities

Power Conversion & Distribution
- High voltage distribution
- High efficiency UPS systems
- Efficient redundancy strategies
- Use of DC power

Server Load/Computing Operations
- Server innovation
- Virtualization
- High efficiency power supplies
- Load management

Cooling Equipment
- Better air management
- Move to liquid cooling
- Optimized chilled-water plants
- Use of free cooling
- Heat recovery

Low Carbon Infrastructure & Demand Adaptation
- On-site generation
  Including fuel cells and renewable sources
- CHP applications
  (Waste heat for cooling)

Source: US DOE: Data Center Energy Efficiency Program
6/4/2012
Renewable Energy Powered IT?

- Limit grid energy draw
  - Less infrastructure & losses, but variable supply
  - Impact on performance, QoS, SLA, …

- Variability Issues
- Reliability issues (small installations)

Need better power adaptability
High Temperature Operation

• Chiller-less data centers
  – Less energy/materials, but space inefficient

• High temperature operation of comm./computing equipment
  – Smaller $T_{\text{outlet}} - T_{\text{inlet}}$
  – Deal with occasionally hitting temp. limits.

Need smarter thermal adaptability
Energy Adaptive Computing

• Dynamic end to end adjustment to
  – Workload adaptation: What & how to run?
  – Infrastructure adaptation: Where & when to run?

• What’s new?
  – Mandatory, rather than opportunistic power and thermal mgmt.
  – Coordination across compute, network & storage.
  – Integration of workload/infra adaptation
Adaptation Methods

• Workload Adaptation
  – Shut down low priority tasks
  – Lower resolution, precision, partial service, …
  – Pre-compute or pre-communicate

• Infrastructure Adaptation
  – Load consolidation & migration
  – QoS degradation
    • Higher delay (Batched service, mandatory sleep)
    • Lower tput (lower freq/voltage, “width” control, …)
Adaptation Challenges

- **Client-server adaptation**
  - Transparently adapt to client energy states
  - Coordinated adaptation of client, network & servers
- **Server side adaptation**
  - Multi-level coordination: Server, rack & DC levels
- **Adaptation among peers**
  - Group adaptation to maximize overall utility
Data Center Adaptation

• Need a multilevel scheme –
  – Individual “assets” up to entire data center
• Need both supply & demand side adaptations
Hard vs. Soft Power Limits

• Hard limits
  – Energy availability, circuit limits, thermal limits, …

• Soft limits
  – Rationing at each level
Adaptation

- Supply side: set soft limits as needed
- Demand side
  - Dynamic migration
  - Load consolidation

- Combined supply & demand side adaptation
  - Hierarchically organized scheme that
    - Minimizes imbalance and ping-pong
    - Minimizes error accumulation down the hierarchy.
A Proposed Algorithm

- Systematic control
  - Power budgets changes move downwards
  - Load migration moves up the hierarchy, from local to global.
  - Details available (IPDPS 2011 paper)
Sample Results
Adaptation to Thermal Profile

• Scenario
  – 3 levels, 18 servers
  – 3 apps (25 app instances)

• Adaptation to handle hot-spots
  – Servers 1-14: $T_a=25^\circ C$
  – Servers 15-18: $T_a=40^\circ C$
  – Temperature limit: $65^\circ C$
Recent Results (with QoS)

- 3 types of queries w/ different QoS needs
- Willow: Our adaptation mechanism
- Performs better than just QoS aware scheduling

Results in ACM JETC
Adaptation in Multi-Tier Systems

• Typical 3-tier system
  – Heterogeneous servers
  – Some fraction of power is renewable

• Reallocate power budget to
  – Balance delays across tiers
  – Consolidation in each tier
  – Minimize pwr state changes for servers & switches

• Results in ITJ paper
Sample Results

- Careful planning of power state changes
  - Minimizes state changes & control delays
- Maximization of green energy use
  - Requires specially designed power infra.
- At low utilization only green energy is used.

![Average Delay (ms) over Time (mins)]

![% of total power over Number of concurrent sessions]
Energy Adaptation in P2P Systems

- Multiple energy groups
  - Joined based on remaining battery of mobiles
- Break the normal tit-for-tat
  - Download rate $\alpha$ upload rate only within a group

- Exploit transmit energy $>>$ receive energy
  - Low battery: Low upload rate, but high download
  - Extra downloads from higher energy groups
P2P Adaptation Results

- P2P Adaptation
  - High download rate at low energy!
  - Need a credit mechanism used to avoid abuse
Mandatory Sleep

• **Blink architecture [ASPLOS’11]**
  – Define a duty cycle for each server
  – Adjust sleep durations based on current power availability.
  – Proactive workload mgmt to deal with sleep
    • Migrate tasks away before the sleep begins.
    • Migrate tasks in just in time for wakeup

• **Characteristics**
  – Another form of energy adaptive computing
  – Mandatory sleep for all servers, instead of keeping some servers down ➔ More overhead
Future Challenges
Power Estimation Challenges

• Notion of effective power?
  – Additive relationship: Workload \(\Rightarrow\) power
  – Why is this hard? Interference

• Available power
  – Determined by power, thermal & perhaps other issues (noise).
  – Required at multiple levels: facility, enclosure, machine, …
Network Role in EAC

• Energy Adaptation
  – Aggressive control of switch/router ports
    • Speed, state & width controls
  – Traffic consolidation across paths

• Adaptation induced congestion
  – Propagation (e.g., ECN, EBCN) & response
    • Computation – communication tradeoff ?
    • Redirection ?

• Network protocol support for adaptation?
Other Issues

• Storage adaptation
  – Storage devices, controllers & network.

• Preprocessing
  – More work during energy plenty times in anticipation of deficit

• EAC Security
  – Attacks on power sources
  – Energy Attacks on IT, e.g.,
    • Demanding too much, cyclic demands, …

• Coordinated end to end control is hard!
  – Formal models to understand impact of energy adaptation.
Thank You!

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