Energy Efficient Cloud Computing: Challenges and Solutions

Burak Kantarci and Hussein T. Mouftah
School of Electrical Engineering and Computer Science
University of Ottawa
Ottawa, ON, Canada
08 September 2011
Outline

• PART-I: CLOUD COMPUTING
  • Cloud computing
  • Energy Consumption of Cloud Computing

• PART-II: ENERGY-EFFICIENCY IN CLOUD COMPUTING: PROCESSING AND STORAGE
  • Energy Savings in High Performance Data Centers (HPDCs)
  • Wireless Sensor Network (WSN)-based Thermal Activity Monitoring in HPDCs

• PART-III: ENERGY-EFFICIENCY IN CLOUD COMPUTING: TRANSPORT
  • Energy-efficient manycast provisioning

• PART-IV: CONCLUSION
  • Research Challenges and Open Issues
PART I:
CLOUD COMPUTING
What is cloud computing?

- Many definitions of cloud computing exist


  20 definitions of cloud computing are studied

  “Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

Cloud Computing

- Self-management-capable computer systems
- Service-Oriented Computing
- Software as a Service
- Distributed architecture without central coordination
- Client-Server Model
- Service Provider-Service Requester
- Peer-to-Peer
- Grid Computing
- Networked Cluster of High Performance Computers
- Utility Computing
- Mainframe Computing
- Power for critical applications
- Computation and storage as a metered service
- Autonomic Computing
Towards “Green” ICT

- Why is energy efficiency important?
  - ICT consumes 4% of the electricity and expected to be doubled (8%)
  - Telecommunication networks contribute a big portion of the CO$_2$ emissions of ICTs
    - L. Kumar and L. Mieritz, “Conceptualizing Green IT and Data Center Power and Cooling Issues”, 2007
Cloud Computing and Energy Efficiency

- Cloud Computing infrastructure is housed in **Data Centers**
  - US Data Centers consume 1.7%~2.2% of the total electricity consumed in the country (61 billion kWh in 2006, doubled in 2007)
  - Worldwide data centers consume 1.1%~1.5% of all electricity consumed in the world
  - Proper Power Management in the data centers can lead to significant energy savings
    - Virtualization of computing resources
    - Sleep scheduling

- Shared Servers and Storage Units
  - Energy savings possible if users migrate IT services towards remote resources
  - Increase in the network traffic and the associated network energy
  - Will be addressed in PART III

PART II:
ENERGY EFFICIENCY IN CLOUD COMPUTING
Energy-Efficiency of Data Centers

• **Heat Generation**
  - Non uniform workload distribution
  - Heterogeneity of computing hardware

• **Heat Extraction**
  - Layout of server racks
  - Placement of Computer Room Air-Conditioner (CRAC) unit fans and air vents

• **Autonomic Data Center Management**
  • Solutions:
    • Thermal and Energy-Aware Resource Provisioning
    • Cooling system Optimization
    • Anomaly Detection
  • Requirements:
    • Continuous processing and analysis of real-time feedback
Energy-Efficiency of Data Centers

- A key metric to evaluate how “green” is a data center
- Power Usage Efficiency (PUE)
  \[ PUE = \frac{P_{\text{process}} + P_{\text{cool}}}{P_{\text{process}}} \]

- Data Center Efficiency (DCE)
  \[ DCE = \frac{P_{\text{IT Equipment}}}{P_{\text{Data Center}}} \]

- A good DCE is 0.625
- A reasonable DCE target is 0.5

C. Belady, Hewlett Packard

Source: Google
Energy-Efficiency of Data Centers

- Job Management in Data Centers

No cooling and thermal-awareness

Cooling and thermal-aware job management
Energy-Efficiency of Data Centers

Coordinated job and cooling management in Data Centers
Energy-Efficiency of Data Centers

- Temporal Job Scheduling
  - First Come First Serve (FCFS)
  - Earliest Deadline First (EDF)

- Spatial Job Scheduling
  - Thermal-Aware Job Scheduling
    - Minimum Re-circulated Heat (MRH)
  - Cooling-aware Job Scheduling
  - Highest Thermostat Setting (HTS)

A. Banerjee et al., Integrating cooling awareness with thermal aware workload placement for HPC data centers, *Sustainable Computing: Informatics and Systems*, vol 1., Issue 2, pp.134-150, 2011
Energy-Efficiency of Data Centers

- Highest Thermostat Setting (HTS): A Cooling and Thermal-Aware Workload Placement scheme
  - Temporally schedule the jobs
    - EDF / FCFS
  - Server Ranking
    - According to the requirement of thermostat set temperature to meet the redline for 100% utilization
  - Spatial scheduling
    - Place jobs to the available servers with the lowest rank
    - Obtain power distribution vector $P_h$
    - Set thermostat setting to the highest possible value ($T_{th}^{high}$)
Energy-Efficiency of Data Centers

- Determining the highest thermostat value

\[
(T_{th}^{\text{high}})^{\text{max}} = F^{-1}T_{\text{red}} - \left[ \frac{P_{h}^{\text{comp}} - P_{\text{ex}}^{\text{low}}}{r_{\text{room}}} - \frac{P_{\text{ex}}^{\text{low}}}{r_{\text{ac}}} \right] - F^{-1}.D.P_{h}
\]

- \(r_{ac}\): Thermal capacity of air flowing out of the CRAC
- \(r_{room}\): Thermal capacity of air flowing in the data center room

Heat input to chassis \(i\) in time \(dt\) = the input from CRAC at chassis \(i\) in time \(dt\) + re-circulated heat to chassis \(i\) from all other chassis in time \(dt\)

\[
\left( l_{i}.r_{ac} + \sum_{j=1}^{n} a_{ji}.r \right)T_{i}^{\text{in}}(t).dt = l_{i}.r_{ac}T^{\text{sup}}(t).dt + \sum_{j=1}^{n} a_{ji}.r.T_{j}^{\text{out}}(t).dt
\]

Heat input to chassis \(i\) in time \(dt\) + Heat generated from chassis \(i\) in time \(dt\) = Heat output of chassis \(i\) at time \(dt\)

\[
\left( l_{i}.r_{ac} + \sum_{j=1}^{n} a_{ji}.r \right)T_{i}^{\text{in}}(t).dt + P_{i}(t).dt = r.T_{j}^{\text{out}}(t).dt
\]

\(p_{h}^{\text{comp}}\): Total computing power at the period \(h\)
\(p_{\text{ex}}^{\text{low}}\): Power extracted by CRAC

Vectorize:

\[T^{\text{in}}(t) = FT^{\text{(sup)}}(t) + DP(t)\]
Energy-Efficiency of Data Centers

- **RACNet: Wireless Sensor Networks (WSNs) in Data Centers**
  - Wireless sensor network developed for Microsoft Research Data Center Genome project
  - Provides fine-grained and real-time visibility to data center cooling behaviour
  - ~700 sensors deployed in a MMW data center
  - Hierarchical topology
    - Master and slave sensor nodes
  - Large-scale sensor network
    - Multiple slave sensors for collecting temperature, humidity
    - Several master sensors providing connectivity
  - Uses IEEE 802.15.4 radios

Energy-Efficiency of Data Centers

An instance of the heat map generated from 24 sensors in the front and back of a row in the Genome Data Center.

Cold-aisle heat map

Hot-aisle heat map
PART III:
ENERGY EFFICIENCY IN CLOUD COMPUTING
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- Conventional network services
  - Unicast
    - \( (s, d) \)
  - Multicast
    - \( (s, D) \)

- Cloud computing services
  - Anycast
    - \( (s, d_i \subseteq D) \)
  - Manycast
    - \( (s, D_k \subseteq D) \)
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- **Transport medium:**
  - Wavelength Routed (WR) Network
  - During off-peak hours, WR nodes can enter the *sleep* mode
    - Can add traffic
    - Can drop traffic
    - No pass-through traffic

- **Demand Provisioning**
  - Lightpath
  - Light-tree

**Problem:**
Energy-Efficient Light-Tree (EELT) selection
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- Optimization Model for EELT

**Objective**

\[\text{maximize} \sum_i \chi_i \longrightarrow \text{Maximize the number of sleeping nodes}\]

\[\text{min} \ Energy \longrightarrow \text{Minimize total energy consumption}\]

\[\text{minimize} \ max \{\sum_w \lambda_{ij} \}_{i,j} \longrightarrow \text{Minimize maximum resource (channel) consumption}\]
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- Solving a manycast-based ILP model may lead to significantly long runtimes.
- Any faster solution?
  - Heuristics:
    - Evolutionary Algorithm for Green Light-tree Establishment (EAGLE)
Evolutionary Algorithm for Green Light-tree Establishment (EAGLE)

- Sort the multicast demands in decreasing order.
- Find an initial solution space \( I \).
- Solution Space \( P = I \).
- Compute a fitness function for each solution in \( P \).
- Select two candidate solutions in \( P \) with respect to fitness proportionate.
- Crossover on two solutions. Obtain new two individuals.
- Channel assignment on the new individuals.
- Mutate new individuals with probability of \( \gamma \).
- New solutions valid?
  - YES: End condition reached?
  - NO: Age Solutions in \( P \).
- Add solutions to \( P \) if valid.

End condition reached?
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- **Fitness Functions in EAGLE**

\[ F_{\text{Max-Sleep}} = \sum_i \chi_i \]

Maximize the number of sleeping nodes

\[ F_{\text{Min-Channel}} = \frac{1}{\max \{ \sum_w \lambda_{i,j} \}} \]

Minimize the maximum channel index

\[ F_{\text{Min-Energy}} = \frac{1}{\text{Energy}} \]

Minimize the total consumed energy

\[ \text{Energy} = \sum_i \sum_j (\left[ \frac{\text{dist}(i,j)}{\Delta_{\text{span}}} \right] - 1) \cdot E_{\text{EDFA}} + \sum_i \sum_j \sum_w \lambda_{i,j} \cdot E_{\text{EMEMS}} + \sum_i \beta_i \cdot E_{\text{ON}} \]

\( \beta \) of the idle power is consumed in the sleep mode
Energy-Efficient Transport of Cloud Services in the Internet Backbone

- Cloud service demands arrive in four time zones
  - EST, CST, MST, PST

- Size of the destination set: \{3,4\}
- Crossover prob. 0.20
- Mutation ratio: 0.01
- Solution space: 100 solutions
Energy consumption of EAGLE throughout the day

*Figure showing energy consumption across different hours.*
PART IV: RESEARCH CHALLENGES AND OPEN ISSUES
Conclusion and Future Directions

• Energy Efficient cloud computing
  • Balance between process, storage and transport
• Processing and Storage
  • Workload placement
    • Thermal-aware
    • Cooling-aware
    • Thermal-and-cooling-aware highest thermostat setting
  • Thermal activity monitoring of data centers by WSNs
• Transport
  • Energy-efficient anycasting/manycasting of cloud service demands
Further reading

- B. Kantarci, H. T. Mouftah, "Energy-Efficient Cloud Services over Wavelength-Routed Optical Transport Networks", in Proc. of IEEE GLOBECOM- Selected Areas in Communications Symp.- Green Communication Systems and Network Track, Dec. 2011, Houston, TX, USA (accepted).

Thank you for your attendance

For further info:

kantarc@site.uottawa.ca, mouftah@site.uottawa.ca