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
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


“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

Autonomic Computing

Self-management-capable computer systems

Service-Oriented Computing

Software as a Service

Client-Server Model

Service Provider—Service Requester

Distributed architecture without central coordination

Networked Cluster of High Performance Computers

Computation and storage as a metered service

Powerful computers for critical applications

Utility Computing

Grid Computing

Mainframe Computing

CLOUD COMPUTING

5/30

Kantarci B. and Mouftah H. T.

2011/08/09
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

GHG emission contribution of the telecom networks
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

Kantarci B. and Mouftah H. T.

2011/08/09
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

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

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

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

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 \( dt \)

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

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

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

Vectorize:
\[
T_{\text{in}}^{\text{in}}(t) = FT^{\text{sup}}(t) + DP(t)
\]
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

Cold-aisle heat map

Hot-aisle heat map

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

\[
\begin{align*}
\text{maximize} & \quad \sum_i \chi_i & \text{Maximize the number of sleeping nodes} \\
\text{min} & \quad \text{Energy} & \text{Minimize total energy consumption} \\
\text{min} & \quad \max\{\sum_w \lambda_{w}^{i,j}\}_{i,j} & \text{Minimize maximum resource (channel) consumption}
\end{align*}
\]
Solving a manycast-based ILP model may lead to significantly long runtimes.

Any faster solution?

Heuristics:

Evolutionary Algorithm for Green Light-tree Establishment (EAGLE)

Energy-Efficient Transport of Cloud Services in the Internet Backbone

- **Evolutionary Algorithm for Green Light-tree Establishment (EAGLE)**

  Sort the manycast demands in decreasing order
  
  Find an initial solution space $I$
  
  Solution Space $P = I$
  
  End condition reached?
  
  NO

  Compute a fitness function for each solution in $P$
  
  Select two candidate solutions in $P$ w.r.t *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?
  
  NO

  Age Solutions in $P$

  YES

  NO

  Add solutions to $P$
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

  \[ F_{\text{Min-Channel}} = \frac{1}{\max \{ \sum_w \lambda_{i,j}^w \}} \]  
  Minimize the maximum channel index

  \[ F_{\text{Min-Energy}} = \frac{1}{\text{Energy}} \]  
  Minimize the total consumed energy

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

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

- Energy consumption of EAGLE throughout the day
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