Energy Efficient Systems

White Paper

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Introduction

With the rapid technological advancements in ICT there is an increasing concern about the rising cost of energy and the impact of the ICT industry as a contributor to global CO_2 emissions. It is estimated that ICT consumes 7.8% of all energy produced in EU, which is expected to grow to 10.5% by 2020[1]. This is a financial, political, regulatory and ethical issue, which also raises significant questions about the overall environmental sustainability of ICT as its uptake increases. In this respect, there is an ever increasing need for innovative solutions to address the issues concerning energy consumption and resulting CO_2 emissions at different levels of ICT e.g. from application design and execution to the modelling and management of underlying ICT infrastructure.

Among recent developments in ICT, cloud computing offers a new and different approach from Software-as-a-Service and other utility based models when it comes to managing workloads in cost effective and highly scalable manner. Nonetheless, with compound annual growth rate of 28.8% projected up to 2015[2], cloud computing is not only raising its stakes in global ICT infrastructure but also attracting concerns about its long term environmental or ecological consequence.

With its focus on cloud computing the Special Session on *Energy Efficient Systems* at IEEE SMC 2013 conference (Manchester, October 2013) provided a timely opportunity to present and discuss current initiatives targeting energy efficiency in the cloud as well as in the wider ICT domain. The special session also served as a showcase for the European Commission (EC) funded ECO_2Clouds[3]: *Experimental Awareness of CO_2 in Federated Cloud Sourcing* project. ECO_2Clouds aims to develop a CO_2 aware solution for the deployment and management of workloads on cloud infrastructure that can ensure best energy-performance ratios. The project particularly focuses on federated cloud infrastructure where applications may span over different cloud sites making it relatively difficult to track their energy consumption and CO_2 footprint as compared to when they are deployed at one cloud site.

This white paper presents the overview of 6 research papers presented in the special session on *Energy Efficient Systems* along with the summary of discussions that took place during the session.

Overview of Papers

The papers presented in the Special Session on *Energy Efficient Systems* addressed energy efficiency and CO_2 issues in different areas of ICT with particular focus on cloud computing.

The paper *Energy Efficient and CO_2 Aware Cloud Computing: Requirements and Case Study* presented a set of requirements for energy efficient and CO_2 aware cloud computing that can provide basis for the development of new approaches and techniques in this area. Although the requirements were drawn for cloud computing they can be considered equally relevant in wider ICT domain. The requirements were mainly organized under the following categories:

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[1] Communication from the Commission: http://ec.europa.eu/information_society/activities/sustainable_growth/docs/com_2009_111/com2009-111-en.pdf

[2] Cloud Computing Energy Efficiency: http://www.navigantresearch.com/research/cloud-computing-energy-efficiency

[3] ECO_2Clouds (Oct. 2012 – Sept. 2014) is funded by European Commission under 7th Framework Programme

- *Quantification of energy consumption and CO_2 footprint* to identify where most energy is used and where efficiencies can be made. A measurement or quantification framework is vital to access the energy efficiency and environmental impact of cloud computing.
- *Energy efficient scheduling* to consider among other factors (e.g. matching application resource requirements and QoS constraints with cloud offerings) the overall mix of energy sources and CO_2 footprint of cloud facilities at different level e.g. site, host and VM level
- *Application level support* to complement the infrastructure level scheduling with application specific decision making about optimal resource utilization.
- *Monitoring* to provide measured values of energy consumption, energy composition and CO_2 footprint of applications as well as underlying infrastructure.
- *Cloud API support* to expose energy consumption information, allow energy aware scheduling and runtime adaptation actions.

In the second half, the paper presents the case study of EC funded ECO_2Clouds project that takes into account the above requirements to deliver an innovative approach to energy efficient and CO_2 aware cloud sourcing. The ECO_2Clouds approach is primarily based on designing implementing and testing energy efficient optimization and application deployment and execution strategies that, among other factors, consider the environmental impact of running applications on the cloud.

The paper *Monitoring and Assessing Energy Consumption and CO_2 Emissions in Cloud-based Systems* defines a set of metrics to measure the greenness of a cloud infrastructure at different levels such as application, virtualization and infrastructure levels. The metrics and associated monitoring mechanism provides a detailed view of the behaviour of the system, which in turn allows identification of the causes of the energy waste in the system.

The paper *Optimizing Energy Efficiency in the Cloud Using Service Composition and Runtime Adaptation Techniques* describes an approach for energy efficient utilization of cloud resources. The experimental results of the approach demonstrate its ability to determine a set of cloud services that not only satisfy the resource requirements of a modular application but also represent the most optimal choice in terms of energy efficiency. In the end the paper presents a runtime adaptation model that can be developed to minimize the energy consumption of cloud resources (used by an application) at runtime.

The paper *Modelling Service Execution on Data Centres for Energy Efficiency and Quality of Service Monitoring* presents a modelling approach for virtualized data centre environment. The approach allows the collection of simulation data at different workload rates that can be used to reason about quality of service and energy efficiency issues in the data centre. The simulation results presented in the paper highlight the direct relation between the CPU and energy consumption of VMs and servers (hosting those VMs). The paper also presents what-if analysis as a way to evaluate workload deployment configuration in terms of energy efficiency and quality of service aspects.

The paper *Algorithm to Optimize Electrical Flows* proposes a Power Load Distribution Algorithm (PLDA) to optimize the electrical flows of power infrastructure. The proposed PLDA adopts the energy flow model to compute sustainability impacts and cost issues while considering the energy related restrictions of different components in the infrastructure. The paper presents a case study

analysis of six private cloud providers that illustrates the ability of proposed PLDA to reduce energy consumption by 10.7% and an improved environmental impact of over 140%.

Finally, the paper *Power Profiling and Inherent Lag Prediction of a Wind Power Generating System for its Integration to an Energy Storage System* address the issue of intermittency arising from the use of renewable energy, which can cause unavailability of energy at all times and reducing the efficiency of power infrastructure. The model proposed in the paper predicts the power output of renewable energy sources using artificial neural network techniques. The predictive information can improve the performance of energy storage systems and address intermittency.

Summary

Energy efficiency is a profoundly debated and researched topic in ICT domain. The growing financial pressure to reduce energy related costs combined with the policy and regulatory measures about CO_2 emissions are influencing the provision and consumption of ICT services faster than ever. Where on one hand ICT service (software or infrastructure) providers are trying to cut their energy costs to be more competitive, environmental awareness and pressure by regulatory authorities (such as EC) is influencing consumers' selection criteria for ICT services.

As for cloud computing, evidently it is emerging as a big stakeholder in global ICT offerings; it must be at the forefront of developing and adopting environmentally aware services. In this respect, it is no longer sufficient to optimize cloud sourcing models based solely on functional features, quality of services and low costs without considering the energy mix and overall CO_2 impact of the cloud-based solutions

The discussions that took place during the special session on *Energy Efficient Systems* appreciated the ECO_2Clouds work programme as both timely and innovative. The participants (from various sects of ICT but mostly with cloud and datacentre backgrounds) analysed the relevance and significance of different approaches presented in the session. Discussions mostly centred around the need for finding synergy across different efforts and techniques with the aim to address environmental implication of cloud computing and in general ICT.

Furthermore, it was noticed that a lot of research was carried out in the area of energy efficiency with limited outreach, thus resulting in weak adaption by readily available industrial solutions. The contributing factors to this issue were narrowed down to financial constraints of continual investment in green energy sources and relevant technical solutions as well as vagueness of existing regulatory measures that do not ensure transparency across different levels of the market.

About the author: *Dr Usman Wajid is a researcher at University of Manchester (UK) where he conducts research and development in the areas of service systems and future Internet. His research addresses problems in enabling automated interactions and multi-criteria optimization. Usman is currently the science and technology leader of EC funded ECO_2Clouds project (2012-2014) that aims to raise CO_2 awareness in cloud sourcing using energy aware application deployment and adaptation techniques.*

(The papers presented in the Special Session on Energy Efficient Systems will be published in the proceedings of IEEE SMC 2013 conference)