Institution: University of Derby

Unit of Assessment: 11

Title of case study: Sustainable Cloud Computing

1. Summary of the impact

This impact case study delivers a sustainable approach to the provision of large-scale Cloud Computing resources, through an international research collaboration. Such a platform enables the widening of participation in Higher Education (HE) across nations, by transforming the provision of IT system resources. The transformation is achieved through the effective sharing and utilisation of flexibly reconfigurable computing resources, whilst reducing the impact upon global carbon emissions. Significantly, the international nature of this research has been recognised by considerable funding from both Chinese and UK agencies. Additionally, the creation of closer research links between international partners has resulted in industrial commercialisation.

2. Underpinning research

In December 2012, Liu (Reader in Distributed Computing) and Antonopoulos (Professor of Distributed Systems) established an international research partnership (Sino-UK) between University of Derby (UoD) and the following Chinese Universities: Tongji University, Beihang University and Jiangsu University. The Sino-UK Higher Education Research Partnership for PhD Studies is funded by the UK Department of Business, Innovation and Skills (BIS), Welsh and Scottish Governments, and China Ministry of Education (MoE).

The focus of the research is the international development and application of secure, sustainable approaches to the provision of Cloud Computing for large scale IT systems, and the quality of this research is evidenced by 38 peer-reviewed publications (13 journal papers, 3 book chapters, 22 conference papers), which are co-authored by Liu and Chinese partners since September 2010, when Liu joined UoD.

This research explores the design and application of innovative methods to achieve increased energy efficiency in data centres, by utilising small, environmental sensors to gather and analyse data, enabling greater optimisation to take place. Novel virtualisation technologies developed by this work permit power consumption and therefore carbon emissions to be reduced [3.1]. By widening international access to technology-enhanced online learning, and fundamentally, creating a need to increase the sustainability of IT facilities, specific attributes of Cloud Computing are realised such as faster systems deployment, reduced maintenance costs, and flexible and scalable infrastructures.

A Cloud-based virtual desktop [3.2, 3.3] is identified as one way of widening international access to UK HE. However, existing virtual desktop protocols cannot securely support dynamic collaboration amongst multiple users at the application level. This research developed CyberLiveApp, a secure sharing and migration approach for live virtual desktop applications in Cloud environments [3.3].

Using CyberLiveApp enables desktop device screens to be shared, whilst controlling interventions from connected users. In a teaching situation, students can collaborate and utilise Cloud-specific capabilities such as dynamic application migration.

In contrast to content-centric VLEs (e.g. Blackboard), Cloud-based environments provide a broad range of software applications and virtualised hardware appliances, and users can receive technical guidance and hands-on support from their tutors in online practical sessions.

Security and privacy [3.4] remain a concern for Cloud computing, and therefore a virtualisation security assurance architecture for Green Cloud computing (CyberGuarder) was also developed [3.5], which enables the trusted loading of network software applications, isolation between them, and adaptable deployment of virtual security appliances in a virtualised network. Moreover, a resource-efficient Infrastructure as a Service (IaaS) Cloud monitoring system, known as CloudMon [3.6], has been developed to optimise resource utilisation in Cloud environments.

Liu's work has made significant contributions towards two key challenges of research into Cloud Computing infrastructure. First, by addressing the general concern of secure access to large-scale distributed computing platforms, particularly when personal data is likely to be stored and exchanged (such as in Virtual Learning Environments). Second, by achieving a reduction in energy consumption of Clouds through advanced architectures that continuously monitor and optimise the utilisation of virtualised resources.

3. References to the research

3.1. L. Liu, O. Masfary, N. Antonopoulos, Energy Performance Assessment of Virtualization Technologies Using Small Environmental Monitoring Sensors, Sensors, Vol. 12(5), pp 6610-6628, 2012. DOI: 10.3390/s120506610

3.2. L. Liu, D. DaSilva, N. Antonopoulos, Z. Ding, Y. Zhan, Achieving Green IT Using VDI in Cyber Physical Society, Journal of Internet Technology, Vol. 14(3), pp.413-424, 2013. DOI: 10.6138/JIT.2013.14.3.06

3.3. J. Li, Y. Jia, L. Liu, T. Wo, CyberLiveApp: A Secure Sharing and Migration Approach for Live Virtual Desktop Applications in a Cloud Environment, Future Generation Computer Systems, Elsevier Science, Vol 29(1), pp. 330-340, 2013. DOI: 10.1016/j.future.2011.08.001

3.4. J. Xu, D. Zhang, L. Liu, X. Li, Dynamic Authentication for Cross-Realm SOA-Based Business Processes, IEEE Transactions on Service Computing, Vol. 5(1), pp. 20-32, 2012, DOI:10.1109/TSC.2010.33

3.5. J. Li, B. Li, T Wo, C. Hu, J. Huai, L. Liu, KP Lam, CyberGuarder: A Virtualization Security Assurance Architecture for Green Cloud Computing, Future Generation Computer Systems, Elsevier Science, Vol 28(2), pp 379–390, 2012. DOI: 10.1016/j.future.2011.04.012

3.6. B. Li, J. Li, L. Liu, CloudMon: A Resource-Efficient IaaS Cloud Monitoring System Based on NIDS Virtual Appliances, Concurrency and Computation: Practice and Experience, Wiley, 2013. DOI: 10.1002/cpe.3166

Funding Secured

- HECloud: A Green Cloud Platform for Higher Education, Sino-UK Higher Education Research Partnership for PhD Studies, British Council and Chinese Scholarship Council, December 2012 – December 2014. (£58,000 with £36,000 from British Council)

4. Details of the impact

Impact 1: Economic Development

The success of this international collaborative research led by Liu, has resulted in two economic impacts:

1. From 2010 to 2011, Liu's team systematically assessed and evaluated the performance, dependability and power consumption of iVCS (Internet-based Virtual Computing System) which was developed originally by Beihang University [5.8]. This consultancy directly contributed to the successful commercialisation of the system in 2012, by Beijing Teamsun Technology Co., Ltd [5.5], a leading IT service provider in China.
2. During 2013, UoD's research partners in Beihang University have successfully secured a project on Big-Data Computing, with a value of 25m RMB, ~£2.5m, funded by the National Basic Research Program of China. [5.5].

Liu is now working with the ACT institute in Beihang University to further develop the iVCS, using sustainable Cloud computing technologies and inter-cloud scheduling technologies developed by the School of Computing and Mathematics at UoD. Further to this, an additional 5M RMB (~£0.5M) has been solicited from Phase II of the China National Cloud Computing Programme.

Impact 2: International Participation in Higher Education

Both UK and Chinese universities are direct beneficiaries of this research. Two academic collaboration agreements, supporting the exchange of staff and research students, have been signed by UoD with Tongji University and Jiangsu University, respectively [5.3, 5.4].

A PhD Agreement on higher education research partnerships was signed in London on 16th April 2012 between the UK and Chinese governments. One of three objectives set by Sino-UK Higher Education Research Partnership for PhD Studies is to "develop joint PhD training mechanisms through exchange of PhD students." [5.1] As one of 28 Sino-UK Higher Education Research Partnerships funded by UK BIS, Welsh and Scottish Governments and China MoE, UoD, Tongji University and Jiangsu University have extended the current research collaboration between Liu and his research partners to develop collaborative PhD programmes offering dual degrees.

Two Chinese students have been selected by Tongji University and Jiangsu University, respectively, to be accepted into collaborative PhD programmes. The successful development of the collaborative PhD programmes has been highly praised by the British Council [5.2]. A Visiting Scholar from China at UoD and Liu, secured funds from Jiangsu Provincial Department of Education in May 2013 with a value of $21,600, which is used to support the Visiting Scholar's research at UoD [5.6]. Innovations for technology-enhanced teaching and learning, developed as a result of this research, have also been promulgated in the Chinese universities.

Impact 3: Effective Knowledge Dissemination

Liu served as program chair and successfully organised seven international conferences and workshops for the dissemination of knowledge and research results generated by the collaborative research during 2010-2013, including three International Workshops on Dependable Service-Oriented and Cloud computing (DSOC), ADIM 2011 on Recent Advances in Cloud Storage, EIDWT 2012 Track on Data Centres and Cloud Computing, MWNS 2012 and IEEE CPSCom 2013 conferences. In addition to international conference organisation, Liu co-edited the book entitled "Principles, Methodologies, and Service-Oriented Approaches for Cloud Computing" which was published by IGI Global in January 2013.

Green Cloud Computing for Higher Education has now become a standalone workshop organised by Liu and Antonopoulos from UoD, as part of the 8th International Symposium on Service-Oriented Systems Engineering 2014.

Impact 4: UK Digital Economy

This research demonstrates significant potential to positively impact upon the UK Digital Economy, as evidenced by knowledge transfer from this research into industry that has already occurred.

Four undergraduate and two postgraduate students previously involved in this project are now working for UK ICT industries. A BSc graduate from the School of Computing and Mathematics, joined Lockheed Martin UK in July 2013 as a Cyber Systems Integrator, working on an energy-efficient Cloud Computing project [5.7] utilising knowledge and expertise that was developed as a direct result of this research.

As a result, the graduate is now responsible for a project that captures and analyses the power consumption of anti-virus products in data centres, in order to reduce energy consumption in secure environments. This engagement has played a principal role in the project on energy efficient Cloud Computing, resulting in a successful series of experiments, and production of an overall report [5.7].

5. Sources to corroborate the impact

5.1. Guidance Notes for Sino-UK Higher Education Research Partnerships for PhD Studies, British Council, on behalf of the Department for Business, Innovation and Skills of the British Government (BIS), Welsh and Scottish Governments and Ministry of Education of P.R. China (MOE). available at: http://www.britishcouncil.org/china-education-highereducation5-phd.htm

5.2. Feedback to the first progress report, sent by Yvonne Yang, Project Coordinator from British Council, 07 May 2013.

5.3. Academic Collaboration Agreement between Tongji University and the University of Derby, signed in June 2012.

5.4. Academic Collaboration Agreement between the University of Derby and Jiangsu University, signed in January 2013.

5.5. Letter of support from Beihang University China.

5.6. Scholarship Confirmation Letter from Jiangsu Provisional Department of Education, May 2013.

5.7. C. Howden, T. Wright, Anti-Virus Power Consumption Trial, Issue 1,0, Technical Report, Lockheed Martin UK Integrated Systems & Solutions Limited. (Under the approval from Lockheed Martin UK to be shared with the University of Derby).

5.8. J. Hardy, L. Liu, N. Antonopoulos, W. Liu, L. Cui, J. Li, Assessment and Evaluation of Internet-based Virtual Computing Infrastructure, Proceedings of 15th IEEE International Symposium on Object/component/service-oriented Real-time distributed Computing (ISORC 2012), Shenzhen, China, April 11-13, 2012. pp. 39-46, IEEE Computer Society Press. DOI: 10.1109/ISORC.2012.14.

5.9. Introduction to iVCS operating system (in Chinese), available: http://www.teamsun.com.cn/dev/