(Revised 07/09)

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NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Toward Trustworthy Cloud Computing with Component-based Design, Online Evaluation, and Runtime Optimization Techniques

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Professor LYU Rung-Tsong Michael	Professor WANG Huaimin
Post	Professor	Professor
Unit / Department / Institution	Computer Science & Engineering / The Chinese University	Faculty of Computing, National University of Defense Technology
Co-investigator(s) *(with title)*		Prof. WANG Ji National University of Defense Technology

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1/1/2012		
Project Completion date	12/31/2014		
Duration *(in month)*	36		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Component-based design for trustworthy cloud computing

The objective of this task is to identify general and reusable techniques for building trustworthy cloud applications at design and deployment phases. In particular, we will investigate how to identify vulnerable cloud components in the complex distributed cloud applications, and how to predict cloud node quality for cloud application designers in making optimal cloud application deployment.

2. Online evaluation for trustworthy cloud computing

Software faults, either accidental or malicious, are inevitable in computer systems, especially the complex distributed cloud applications, resulting in security holes and unreliable system functionalities. Online evaluation is a critical approach to detecting and eliminating software faults so as to build trustworthy cloud applications. Our objective here is to design cloud-tailored online evaluation methodologies for detecting robustness, Quality of Service (QoS), and functional problems of cloud applications at runtime.

3. Runtime optimization for trustworthy cloud computing

Runtime system adaptation and optimization techniques are necessary for building trustworthy cloud applications which are running in the highly dynamic Internet. In this task, based on the information of system problems detected by Task 2, we will focus on how to conduct system reconfiguration, how to design runtime reputation mechanism, and how to establish new access control to build trustworthy cloud applications.

4. Implementation and experiments

To facilitate the development of trustworthy cloud applications, we will develop an open-source toolkit, incorporating the paradigms, techniques, and methods of this project. Moreover, we will provide online versions of our proposed approaches as services in the cloud for other users. For example, cloud component quality prediction as a service, cloud monitoring as a service, etc. In order to verify our approaches, we also plan to deploy an experimental framework in a real-world cloud platform developed in the Internet-based Virtual Computing Environment (iVCE) project, a funded National 973 project. Finally, we will release real-world datasets for future research on cloud computing.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Totally 3 journal papers and 13 conference papers have been published, all acknowledging the support of this grant. These publications cover the proposal's research objectives in various aspects. We describe the resulting research outcomes as follows. (We use [J1] label to refer to journal publication [1], and [C1] label to refer to conference publication [1], etc.).

In component-based design for trustworthy cloud computing, we developed a fast algorithm for analyzing the reachability with applications to alias analysis [C4]. With our approach, designers of cloud applications can efficiently analyze the reachability of their applications. Moreover, we also design granger causality-aware diagnosis of software degradation [C2] for component-based design for trustworthy cloud computing.

Regarding online evaluation for trustworthy cloud computing, we conducted comprehensive investigations and proposed a serial of cloud-tailored online approaches to detect and eliminate software faults so as to build trustworthy cloud applications. The approaches include unsupervised and scalable performance diagnosis approach [J1], performance anomaly root cause identification [J3], and P-Tracer (a path-based performance profiling approach) [C8]. Moreover, beside cloud computing applications, we also investigated online evaluation on wireless sensor networks, including mobility-assisted diagnosis [J2] and non-intrusive behavior profiling based online protocol verification approach [C7].

In runtime optimization for trustworthy cloud computing, we investigated runtime system adaptation and optimization techniques. Since the cloud applications are running in the highly dynamic Internet, runtime reconfiguration and adaption becomes important. To enable runtime adaption, we proposed several runtime quality prediction approaches, including scalable QoS prediction [C1], network-coordinate based Web service positioning framework for response time prediction [C10], real-time performance

prediction [C11], and location-based Web service recommendation [C13]. Based on the prediction results, we further designed a latency-aware co-deployment mechanism for cloud applications [C9]. We also investigate the theory of model-based collaborative filtering models, which can be employed for runtime prediction of cloud applications. Beside cloud computing, we also extended our investigation to space predictive diagnostics [C3], epileptic seizure prediction [C5], and Telerobot Operation in Space [C12] .

Potential for further development of the research and the proposed course of action *(maximum half a page)*

In this project we have investigated various techniques for building trustworthy cloud computing applications, including component-based design, online evaluation, and runtime optimization techniques. Further research can be conducted for incorporating the proposed approaches into open source cloud platforms. This would allow our formulated trustworthy cloud computing techniques to be disseminated for wide adoption among researcher's and practitioner's communities.

Moreover, we plan to apply the proposed paradigm to a number of research projects in cloud computing area, collecting real world data for publication and sharing. Researchers can further investigate with our published datasets for further exploration of trustworthy cloud computing.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

We formalized a systematic and efficient paradigm for trustworthy cloud computing, including component-based design, online evaluation, and runtime optimization techniques. The effectiveness of this paradigm in advancing the current state-of-the-art trustworthy cloud computing has been demonstrated through the implementation of experimentation of the proposed techniques therein. This project enables cloud application designers and developers to efficiently build trustworthy cloud applications, which are reliable and trustable. The resulting paradigm is both comprehensive and systematic. The proposed techniques in this project promote the development of trustworthy cloud computing research in general, and facilitate the ongoing research in the Internet era, where more and more large-scale Internet-based applications are appearing. The proposed approaches in this project will promote the research of trustworthy cloud computing in both industry and academic.

(Revised 07/09)

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project
(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.))

The Latest Status of Publications				Author(s) *(bold the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*					
2013				**Haibo Mi*, Huaimin Wang, Yangfan Zhou, M.R. Lyu**, and Hua Cai	"Towards Fine-Grained, Unsupervised, Scalable Performance Diagnosis for Production Cloud Computing Systems," IEEE Transactions on Parallel and Distributed Systems (TPDS), vol.24, no.6, 2013, pp.1245-1255		Yes	Yes
2013				**Junjie Xiong*, Yangfan Zhou,** Evan F.Y. Young, and **M.R. Lyu**	"MDiag: Mobility-assisted Diagnosis for Wireless Sensor Networks," Journal of Network and Computer Applications (JNCA), vol. 36, no. 1, 2013, pp. 167-177.		Yes	Yes

2012				**Haibo Mi*, Huaimin Wang, Yangfan Zhou, M.R. Lyu**, and Hua Cai	"Localizing Root Causes of Performance Anomalies in Cloud Computing Systems by Analyzing Request Trace Logs,"Science China Information Sciences, vol. 55, no. 12, 2012, pp. 2757-2773.		Yes	Yes

9. Recognized International conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
June/2014/ Madrid	Towards Online, Accurate, and Scalable QoS Prediction for Runtime Service Adaptation	34th International Conference on Distributed Computing Systems (ICDCS 2014)		Yes	Yes
6/2014/Alaska	Granger Causality-aware Prediction and Diagnosis of Software Degradation	11th IEEE International Conference on Services Computing (SCC 2014)		Yes	Yes
3/2013/ Montana	A Machine Learning Framework for Space Medicine Predictive Diagnostics with Physiological Signals	34th IEEE Aerospace Conference (Aerospace 2013)		Yes	Yes
6/2013/Seattle	Fast Algorithms for Dyck-CFL-Reachability with Applications to Alias Analysis	34th annual ACM SIGPLAN conference on Programming Language Design and Implementation (PLDI 2013)		Yes	Yes
11/2012/Larnaca	Exploration Of Instantaneous Amplitude And Frequency Features For Epileptic Seizure Prediction	12th IEEE International Conference on Bioinformatics & Bioengineering (BIBE 2012)		Yes	Yes

8/2012/Catalina Island	Response Aware Model-Based Collaborative Filtering	28th Conference on Uncertainty in Artificial Intelligence (UAI 2012)		Yes	Yes
8/2012/Huangshan	Online Protocol Verification in Wireless Sensor Networks via Non-intrusive Behavior Profiling	International Conference on Wireless Algorithms, Systems, and Applications (WASA 2012)		Yes	Yes
7/2012/Izmir	P-Tracer: Path-Based Performance Profiling in Cloud Computing Systems	36th IEEE International Conference on Computers, Software, and Applications (COMPSAC 2012)		Yes	Yes
6/2012/Hawaii	A Latency-aware Co-deployment Mechanism for Cloud-based Services	5th IEEE International Conference on Cloud Computing (CLOUD 2012)		Yes	Yes
6/2012/Hawaii	WSP: A Network Coordinate based Web Service Positioning Framework for Response Time Prediction	19th IEEE International Conference on Web Services (ICWS 2012)		Yes	Yes
4/2012/Shenzhen	Real-Time Performance Prediction for Cloud Components	15th IEEE International Symposium on Object/Component/ Service-Oriented Real-Time Distributed Computing Workshop		Yes	Yes
3/2014/ Montana	An EMG Enhanced Impedance and Force Control Framework for Telerobot Operation in Space	35th IEEE Aerospace Conference (Aerospace 2014)		Yes	Yes
6/2014/Alaska	Location-based Hierarchical Matrix Factorization for Web Service Recommendation	21st IEEE Conference on Web Services (ICWS 2014)		Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Junjie Xiong	Ph.D.	August 2009	June 2012
Yilei Zhang	Ph.D.	August 2010	Sept. 2013

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

Collaboration with National University of Defense Technology (NUDT) on a national level key project (973 project) to increase the impact of the research results of this project.

Collaboration with Beijing University of Posts and Telecommunications (BUPT) to build a joint lab of Internet technology, which increase the impact of our research output in mainland China.