A Dissertation submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

Autonomic Management of Software Defined Networks

DAIM can provide the environment for building autonomy in distributed electronic environments - using OpenFlow networks as the case study

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Spring 2016

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Certificate of Original Authorship

I certify that the work in this dissertation has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the dissertation has been written by me. Any help that I have received in my research work and the preparation of the thesis it self has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the dissertation.

Signature of Candidate

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_____ day of _____, 2016

Acknowledgments

I would like to express my sincere gratitude to my supervisor Professor Robin Braun, who guided me through this research, was a great source of encouragement, and always made me go that extra mile to resolve the various dilemmas that lead to this dissertation. I learned a lot from his mature view on topics from a high level and excellent computer and networking skills. I am gratefully thanking him for his guidance to me throughout the years. Also, his patience with me is always acknowledged and appreciated. I would also thank my Co-supervisor, Dr Bruce Moulton, for supporting me throughout this research work.

I am grateful to Dr Zenon Chaczko from the School of Computing and Communications for assistance in the publication of Springer book chapters, Chairing AP-CASE'14 in Bali and being a member of my CA panel. Also, for the very helpful technical chats and continuous support in the past years.

I am pleased to work in close collaboration with Pakawat Pupatwibul, my research collaborator and best friend, and I am gratefully thanking him for his invaluable contributions and innovative ideas towards this research project. I am so proud of what we have achieved together, thank you Pakawat.

During the period of this research, I also benefited greatly from interactions and discussions with my colleagues, namely Dr Abdallah AL Sabbagh and to whom I'm deeply indebted. A special mention also goes to Md Imam Hossain from the School of Electrical and Mechanical Engineering of ongoing solutions to the problems in C/C++ programming and extensive help in setting up the testbed used for this research. My big thanks also go to the anonymous reviewers for their work in improving the quality regarding my publications which have been published and being under review now.

The interactions, technical discussions and conversations with my friends and members of the Centre for Real-time Information Networks helped me during the period of this research, not only regarding resolving quick technical challenges but also with regards to "lightening up". I have enjoyed many useful and happy chats with them. I have been very fortunate to have them around during my Ph.D. research study.

I am honoured to have got government's scholarship from saudi arabia. Thank for their generosity, which has allowed me to be able to pursue the degree. Without this, I would not have been able to do it. I would also like to acknowledge the School of Computing and Communications at UTS for ongoing travel and infrastructure support.

Last, but by no means the least, I would like to thank my family for their endless support and all of the sacrifices that they have made on my behalf. Thank you to my mother, Jamilah Banjar, also to my daughter, Miar. You have provided me with plenty of love, patience, support, and encouragement over the years and for that I am incredibly grateful.

Some contents in chapter 1 and chapter 2 have been submitted to UTS subjects (32144: IT Research Preparation and 32931: Technology Research Methods). These subjects aim to guide research students to prepare literature reviews also experience in the design of research studies, in the analysis and interpretation of data, and in report presentation. As these contents have not been published; they can not be referenced but they can be searched by some software such as Turnitin.

Abstract

Next generation networks need to support a broad range of services and functionalities with capabilities such as autonomy, scalability, and adaptability for managing networks complexity. In present days, network infrastructures are becoming increasingly complex and challenging to administer due to scale and heterogeneous nature of the infrastructures. Furthermore, among various vendors, services, and platforms, managing networks require expert operators who have expertise in all different fields.

This research relied on distributed active information model (DAIM) to establish a foundation which will meet future network management requirements. The DAIM is an information model for network solutions which considers challenges of autonomic functionalities, where the network devices can make local and overall network decisions by collected information. The DAIM model can facilitate networks management by introducing autonomic behaviours. The autonomic behaviours for communication networks lead networks to be self-managed and emerge as promising solutions to manage networks complexity.

Autonomic networks management aims at reducing the workload on network operators from low-level tasks. Over the years, researchers have proposed a number of models for developing self-managed network solutions. One such example is the common information model (CIM), which is described as the managed environment that attempts to merge and extend the existing conventional management and also uses object-oriented constructs for overall network representation. However, the CIM has limitations coping in complex distributed electronic environments with multiple disciplines.

The goal of this research is defined as development of a network architecture or a solution based on the DAIM model, which is effectively distribute and automate network's functions to various network devices. The research first looks into the possibilities of local decision-making and programmability of network elements for distributed electronic environments with an intention to simplify network management by providing abstracted network infrastructures. After investigating and implementing different elements of the DAIM model in network forwarding devices by utilising virtual network switches, it discovers that a common high-level interface and framework for network devices are essential for the development of network solutions which will meet future network requirements.

The outcome of this research is the development of (DAIM OS) specification. The DAIM OS is a network forwarding device operating system which is compliant with

the DAIM model when it comes to network infrastructure management and provides a high-level abstracted application programming interface (DAIM OS API) for creating network service applications. Through the DAIM OS, network elements will be able to adapt to ever changing environments to meet the goals of service providers, vendors, and end users. Furthermore, the DAIM OS API aims to reduce complexity and time of network service applications development.

If the developed DAIM OS specification is implemented and if it functions as predicted in the design analyses; that will result in a significant milestone in the development of distributed network management.

This dissertation has an introduction in chapter 1 followed by five parts in order to draw a blueprint for information model as a distributed independent computing environment for autonomic network management. The five parts include lending weight to the proposition, gaining confidence in the proposition, drawing conclusions, supporting work and lastly is appendices.

The introduction in chapter 1 includes motivations for the research, main challenges of the research, overall objectives, and review of research contributions. After that, to lend weight to the proposition as the first part of the dissertation, there is chapter 2 which presents the background and literature review, and chapter 3 which has a theoretical foundation for the proposed model. The foundation consists of a generic architecture for complex network management and agents to aggregate distributed network information. Moreover, chapter 3 is probably more about a state of the art in software engineering than about real implementation to engineer autonomic network management.

The second part of the dissertation is to gain confidence in the proposition which includes attempting to implement the DAIM model in chapter 4 with some tests to report good performance regarding convergence and robustness for the service configuration process of network management. Also, the second part has a specification of true abstraction layers in chapter 5. The specification of true abstraction layers proposes a high-level abstraction for forwarding networking devices and provides an application program interface for network service applications developed by network operators and service providers. The implementation in chapter 4 is supported by the fourth part of the dissertation in chapter 10 which supports the theoretical foundation, designing, modelling, and developing the distributed active information model via simulation, emulation and real environments.

The third part of this dissertation provides the way to draw conclusions as shown in chapter 7 which has the overall research summary, validation of the propositions, contributions and discussion, limitations and finally recommendations for future works.

Finally are the appendices in Appendix A, Appendix B, Appendix C and Appendix D which provide a developing code of the core DAIM model and show different setting up for testbed environments.

My Related Publications

Most of the technical discussions, contributions, and theories in this dissertation are based on the following publications written by the author, and the other three are co-authored:

A. International Journal Publications:

[J1] Pakawat Pupatwibul, Ameen Banjar, Abdallah AL Sabbagh, and Robin Braun. A comparative review: Accurate OpenFlow simulation tools for prototyping. Journal of Networks, 10(5):322–327, 2015.

[J2] Pakawat Pupatwibul, Ameen Banjar, and Robin Braun. Performance evaluation of tcp/ip vs. OpenFlow in INET framework using OMNeT++, and implementation of intelligent computational model to provide autonomous behaviour. In Osaka acbpp actis 2014, number 2189-1028, pages 43–56, Osaka, Japan, 2014. The International Academic Forum (IAFOR), The Asian Conference on Technology, Information & Society 2014.

[J3] BANJAR, A., PUPATWIBUL, P., BRAUN, R. 2014, DAIM: a Mechanism to Distribute Control Functions within OpenFlow Switches. Journal of Networks, North America, 9, jan. 2014. Available by: goole shearsh < jnw090119>. Date accessed: 08 Oct. 2014.

[J4] Banjar, A., Pupatwibul, P., Sabbagh, A.A. & Braun, R. 2014, 'Using an ICN Approach to Support Multiple Controllers in OpenFlow', International Journal of Electrical & Computer Sciences, vol. 14, no. 2.

B. Chapter of Book Publications:

[B1] Banjar, A., Pupatwibul, P., Sabbagh, A. & Braun, R. 2015, 'Comparison of TCP/IP routing versus OpenFlow table and implementation of intelligent computational model to provide autonomous behavior', In Computational Intelligence and Efficiency in Engineering Systems, pages 121–142. Springer, 2015.

[B2] Pupatwibul, P., Banjar, A., Sabbagh, A. & Braun, R. 2014, 'An Intelligent Model for Distributed Systems in Next Generation Networks', in R. Klempous,

J. Nikodem, W. Jacak & Z. Chaczko (eds), Advanced Methods and Applications in Computational Intelligence, vol. 6, Springer International Publishing, pp. 315-34.

C. International Conference Publications:

[C1] Banjar, A.; Pupatwibul, P.; Braun, R.; Moulton, B., "Analysing the performance of the OpenFlow standard for software-defined networking using the OMNeT++ network simulator," Computer Aided System Engineering (APCASE), 2014 Asia-Pacific Conference on , vol., no., pp.31,37, 10-12 Feb. 2014

[C2] Pupatwibul, P., Banjar, A., Al Sabbagh, A. & Braun, R. 2013, 'Developing an application based on OpenFlow to enhance mobile IP networks', Local Computer Networks Workshops (LCN Workshops), 2013 IEEE 38th Conference on, IEEE, pp. 936-40.

[C3] Al Sabbagh, A., Pupatwibul, P., Banjar, A. & Braun, R. 2013, 'Optimization of the OpenFlow controller in wireless environments for enhancing mobility', Local Computer Networks Workshops (LCN Workshops), 2013 IEEE 38th Conference on, IEEE, pp. 930-5.

[C4] Pupatwibul, P., Banjar, A. & Braun, R. 2013, 'Using DAIM as a reactive interpreter for OpenFlow networks to enable autonomic functionality', Proceedings of the ACM SIGCOMM 2013 conference on SIGCOMM, ACM, pp. 523-4.

[C5] Pupatwibul, P., Sabbagh, A.A., Banjar, A. & Braun, R. 2012, 'Distributed Systems in Next Generation Networks', 1st Australian Conference on the Applications of Systems Engineering ACASE'12, p. 32.

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Nomenclature

AC	Autonomic Computing
ACS	Autonomic Computing System
AI	Artificial Intelligence
ANM	Autonomic Network Management
ANS	Autonomic Nervous System
API	Application Programming Interface
AS	Autonomous System
CIM	Common Information Model
CLI	Command Line Interface
CMIP	Common Management Information Protocol
CMIS	Common Management Information Service
CPU	Central Processing Unit
DAIM	Distributed Active Information Model
DAIM OS	DAIM Operating System
DMTF	Distributed Management Task Force
DTR	Data Transmission Rate
GPU	Graphics Processing Unit
HD	Hard Drive
iBGP	interior Border Gateway Protocol
ICN	Information-Centric Networking
IOS	International Organisation for Standardisation

IP	Internet Protocol
LLDP	Link Layer Discovery Protocol
MAC	Media Access Control
MIB	Management Information Base
MTU	Maximum Transmission Unit
NE	Network Elements
NETCONF	Network Configuration Protocol
NGN	Next Generation Network
NIB	Network Information Base
NM	Network Management
NMS	Network Management System
NOS	Network Operating System
NSOS	Network Switch Operating Systems
OS	Operating System
OSS	Operating Support System
P2P	Peer-to-Peer
POSIX	Portable Operating System Interface
POX	Python based controller
QoS	Quality of Service
RAM	Random-access memory
RCP	Routing Control Platform
SDN	Software-Defined Networking
SID	Shared Information and Data Model
SNMP	Simple Network Management Protocol
SRD	System Requirement Database

TCP	Transmission Control Protocol
TLS	Transport Layer Security
TMF	TeleManagement Forum
UML	Unified Modelling Language
XML	Extensible Markup Language
XML-RPC	XML-encode Remote Procedure Call

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