School of Arts and Sciences
La Salle University

Research Proposal — Summer 2014
Department of Mathematics and Computer Science

Optimal, Efficient, and Secure Network Virtualization: Towards an Agile Future Internet

Yang Wang, Assistant Professor of Computer Science
Phanvu Chau, Information Technology Major, History Minor
(Class of 2015)
Michael Mazzucca, Computer Science and Information Technology Dual Major
(Class of 2015)

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I. Faculty Name and Department

Yang Wang, Department of Mathematics and Computer Science

II. Student Name

Michael Mazzucca and Phanvu Chau

III. Research Project Description

The last decade witnessed a tremendous growth in Internet usage: millions of applications [1] are made available to billions of Internet subscribers. Simultaneously, it is observed that the fundamental infrastructure of the Internet (that supports Internet applications) is surprisingly **ossified**. For instance, on February *3rd*, 2012, **I**nternet **C**orporation for **As**signed **N**ames and **N**umbers announced the full depletion of *32*-bit IPv4 addresses [1] [2]. The successor, *128*-bit IPv6, although conceived over a decade ago, was reported to possess only 1% share of the Internet traffic until late November 2012 [2]. What stops the Internet from pro-actively (or at least actively) committing the migration?

There are two fundamental causes for the technological stagnation of the Internet infrastructure: *(i)* The stakeholders (i.e., ISPs who own the Internet infrastructure such as *Verizon*, *Sprint*) have no economic incentive for revolutionary technologies, given the considerable capital expenditure, risk, and potential service interruption; *(ii)* Due to the design of the current Internet, switching on new technologies calls for agreement and coordination among numerous "cooks" (e.g., technology innovators, hardware manufacturers, and ISPs, to name a few), which, unsurprisingly, is difficult to achieve in reality.

A promising resolution of this impasse is to strip the role of *technology decision maker* from the traditional ISP, and that entails a business model with two new roles: the *infrastructure provider* (InP), and the *service provider* (SP). The former solely deploys and manages the network infrastructure without providing end user services, while the latter offers end-to-end logical services to users (after purchasing and aggregating resources from the former). This decoupling of logical service from the physical infrastructure, known as **Network Virtualization** [3], provides the SPs a virtualized view of the underlying network and hence the architecture-oblivious freedom of adopting technical advancements agilely. Likewise, InPs can transparently upgrade the physical infrastructure with minimum impact on the logical service, motivated by revenue increase from securing and expanding their sales to SPs.

In this project, our team targets on a viable solution for an agile future Internet based on network virtualization. We will investigate key enabling technologies of network virtualization with a focus on three questions : *(i)* Given a logical service, how can we *optimally* allocate physical resources to instantiate the service? *(ii)* How can this allocation be done *efficiently* with a large volume of service requests (i.e., lesson from the *Health Care Website* Incident [4])? *(iii)* How can we guarantee that the allocation leads to a *secure* service? We briefly explain our major targets and methodologies on tackling those challenges below.

To understand the above questions, we first present a motivating example. A global SP needs to deploy three computing servers located in *Asia*, *Europe*, and *North America* to serve customers in respective continents. In Computer Networking, this service feature is modeled as a logical or virtual network as shown in Fig. 1, which contains three virtual nodes (representing the need for three computing servers), and three virtual links (indicating that servers should be logically connected to each other). After the SP submits the request, the InP explores the physical network in Fig. 2 where nine computing servers are connected via eleven physical links. As shown in Fig. 2, one possible offer from the InP is to map the three virtual nodes to (circled) physical servers located in *China*, *Sweden* and the *USA*, respectively, and connect each pair of servers

[1] In this proposal, application refers to the logical or software service deployed over the Internet infrastructure.

[2] IP address is a unique identifier assigned for any computer connecting to the Internet.

with a mapped path. Although it seems simple, this decision can be extremely hard since InP generally have a large server pool (e.g., nine above), hence leading to numerous combinations when picking up hosting servers (i.e., three for above example) as well as numerous choices of mapped paths. Among all of the combinations, the *best* or *optimal* offer from the InP should take the resource availability, location, and cost into consideration since all the resources are priced.

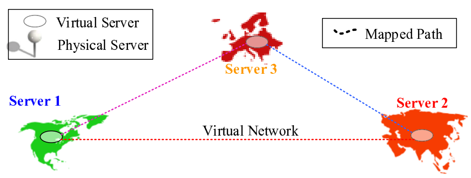

Fig. 1. An Example of A Virtual Network

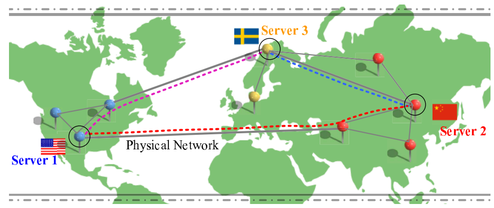

Fig. 2. Mapping The Virtual Network to The Physical Network

The general process that allocates physical resources to a given service request is called *Virtual Network Embedding* (VNE) problem, which contains two decision processes: *(i)* Decide the hosting physical server for each virtual node; *(ii)* Decide the physical (mapped) path for connecting virtual nodes according to the virtual link. Unfortunately, the VNE problem can be shown to be NP-Hard [5], which is a type of problem that is extremely hard to solve for large instances. To answer the first question of our project, we will present an *optimal* solution based on the Integer Linear Programming (ILP) transformation of the VNE problem. Logically, the ILP model is equivalent to the VNE problem. However, a state-of-the-art ILP solver software - *IBM CPLEX* Optimization Studio, is available for obtaining an optimal solution to an ILP-based VNE model.

The answer to the second question deals with the *response time* to customer requests, and that is critical since InPs may receive a large volume of requests simultaneously. In Computer Science, this time metric is referred to as the *time efficiency* of an algorithmic approach. Given the extensive time in acquiring an *optimal* solution [3], our strategy is to improve *time efficiency* with limited tradeoff in the *optimality*. This approach, namely the *approximation* or relaxation method, can lead to a reasonable sub-optimal solution in a timely manner. In addition, traditionally, multiple requests are accommodated one by one in a *First-Come-First-Serve* (FCFS) manner. We instead will develop a novel *batch* approach. The logic behind **Batch VNE** is that more knowledge (i.e., considering a group of requests rather than one) leads to a better holistic decision. A daily analogy of Batch VNE is that a *Mini-Cooper* could occupy one large parking slot and blocks a following *van*. In contrast, a smarter schedule could accommodate both vehicles by parking the *Mini-Cooper* at a smaller slot.

The answer to the third question aims to address security breaches. In network virtualization, virtual nodes from different SPs may be hosted by the same physical node (e.g., websites of *Coca Cola* and *Pepsi* at the same server). Those virtual nodes share the server hardware such as CPU, memory, and network interfaces. When one virtual node (say, the *Coca Cola* one) is aggressively consuming shared resources, the other (i.e., the *Pepsi* one) will experience a noticeable performance degradation (e.g., longer website loading time). There are two resulting security issues: *(i)* this performance difference perceived by one virtual node can leak the usage pattern (e.g., the peak hour) of the other virtual node, in the form of a *side channel* attack; *(ii)* If shared resources are abused by one vicious virtual node, other nodes may suffer an intolerable user experience, i.e. a form of the notorious *Denial of Service* (DOS) attack. We plan to extensively investigate a wide spectrum of potential attacks, ranging from small to large scale ones. Based upon the categorization of those attacks, we will develop an effective isolation policy to ensure the security of a customer according to per-customer Service Level Agreement

[3]Even with IBM CPLEX, it takes a few days to weeks to solve a large scale NP-hard problem.

(SLA). An interesting outcome is that each user will be able to customize his or her security level based on the business feature and budget. For instance, by paying more, a hosted banking website will be promised a high security level guarantee. Finally, those policies are physically deployed by our security-aware VNE process.

It is worth noting that the above three questions are not isolated. An ***optimal*** ILP-based VNE model is the foundation to develop an ***efficient*** solution for accommodating a batch of requests. The ***security-awareness*** adds extra complexity while sharing a common problem structure on the resource allocation, thus can be inspired by the solutions of the other two. The proposed solutions, when combined together, will serve as a basis to enable an agile future Internet that pro-actively or actively endorses technological advancements.

REFERENCES

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[2] Y. Poppe, "Ipv6: A 2012 report card," *CircleID*, 28 November 2012.
[3] M. Chowdhury, M. R. Rahman, and R. Boutaba, "ViNEYard: Virtual network embedding algorithms with coordinated node and link mapping," *IEEE/ACM Transcations on Networking*, vol. 20, no. 1, pp. 206–219, February 2012.
[4] "Obama: Health care website problems inexcusable," Oct. 21st 2013, http://www.usatoday.com.com.
[5] D. G. Andersen, "Theoretical approaches to node assignment," 2002, unpublished Manuscript, http://repository.cmu.edu/.

IV. STUDENT RESEARCH COMPONENT

A. Role of Student in Project

Through this project, both students are expected to train and sharpen the following abilities: *(i)* How to efficiently review the literature study associated with the research topic; *(ii)* For networking research, how to combine the major methodologies with creative ideas of their own; *(iii)* How to evaluate networking protocols/algorithms via simulations, experiments, and analyses; *(iv)* How to professionally present research findings; *(v)* How to effectively work as a team.

Motivated by the above goals, students will be assigned guided tasks in different phases of the project. In the initial literature review phase[4], they are assigned a few important recent publications, and both of them are crawling over references and further references therein. Due to the high load of their current course work (i.e., six classes for Michael, and five classes for Phanvu), this phase may last until the early weeks of summer.

When approaching the end of the literature review stage, we will have a few group meetings to discuss major networking research methodologies, and evaluation approaches. Following that, in the problem solving stage, guided tasks will be given for them to apply the methodologies to a specific aspect of our challenges, and further to a more general setting with gradually increased complexity. Given their interest difference, in this stage Michael and Phanvu will spend a major focus on the *efficiency* aspect and *security* aspect of our study, respectively, while I will provide them guidance on how to address the *optimality* aspect. Both of them are expected to independently apply available approaches to their own focus, but collaboration and cooperation will be stimulated via brainstorming discussion on addressing specific challenges.

As a preparation for the evaluation phase, I have recently enrolled in the IBM Academic Initiative Program, and tested the cutting-edge *IBM CPLEX* Optimization studio. This experience is documented and will be shared among the team. To facilitate sharing and collaboration, we will install one FTP server for document sharing, and one Version Control Server for programming source sharing and management. Both students are expected to setup their own evaluation environment, and implement their creative ideas under my guidance.

During the final stage, students will prepare to present their work in both written and spoken form. They will use professional editing tools such as *LaTex*, and plotting tools such as *GnuPlot*,

[4]which has already been launched as both Michael and Phanvu have been voluntarily working with me since Fall 2013.

to prepare an *IEEE* format technical report/paper. This report/paper is expected to summarize the surveyed literature, major contributions, detailed solutions, evaluation approaches and results, as well as major conclusions in a professional manner. Likewise, I will provide guidance to help them prepare a version of the project report in spoken form with supporting *PowerPoint* slides.

Michael and Phanvu are two of the most brilliant students in the department with strong self-learning skills, enthusiasm, and dedication for networking research. Instead of being solely driven by me, we are all confident that this project will be an exciting joint collaboration and cooperation.

B. Student Authored Statement of Interest

"I struggled for a long time trying to choose a career field. I wanted to find something that was not only going to be lucrative but also something that seemed to promise growth in importance in the future. My attention eventually came to the field of Computer Science and Information Technology. This field is not only shaping the way the world works but also the ways in which we can perceive the world. As I found, I was already familiar with many of the theoretical and mathematical concepts that allowed technology to operate the way that it does, and so while I have always enjoyed the hands-on aspects of the field, I have also enjoyed learning about the theory behind algorithms and electronics. When I learned about this project opportunity from Dr. Wang, I was immediately attracted: on one hand, it provides me with a hands-on experience on state-of-the-art networking research; on the other hand, designing my own solution links to the theory of algorithms. I sincerely hope that I will be able to gain some experience in practicing creative ideas that could have a direct impact on the work of others rather than just for the purposes of self-education. " – *Michael Mazzucca*

"I have always been fascinated by how fast and how extreme the Internet changes. My first Information Technology class I took as part of my major was one on network communication. At that time, cloud computing and the entire endeavor of network virtualization were on everyones lips. They were gaining popularity as prominent solutions to effectively accommodate and allocate the existing Internet resources. Shortly afterwards, it became a reality and everyone was implementing and utilizing this paradigm. I was excited to be part of this new technology and to witness something new happen. However, security vulnerabilities soon arose, and theoretically and practically they have been exploited to attack cloud-based frameworks. Through a class on network administration I took with Dr. Yang Wang last semester, I have broadened my knowledge in this field. Dr. Wang and I began discussing security aspects of cloud computing, and agreed that some solutions could be devised. Although it is a relatively new practice in the fields of Information Technology and Computer Science, network virtualization remains promising for years to come. Since the pace is rapid, I think any research effort devoted to this endeavor to enhance and secure it will be beneficial, not only to me as a student in the field, but also to corporations. The research will be a rewarding opportunity for me as I will be able to analyze problems from a practical standpoint and gain valuable insights. I consider it a wonderful and privileged learning opportunity. I hope to learn a lot from it. It will help me secure a place in my graduate studies, and will also provide me extensive experience for my career. I will strive to dedicate my passion and commitment to conducting and completing the research. I will perform to the best of my ability to be an active and helpful research partner with Dr. Wang in contributing to the area of network virtualization and its continuous development."
– *Phanvu Chau*

V. Summer Work Commitments

A. Faculty

I will not teach classes in Summer 2014, although I will be preparing for the *Network Security* class of Fall 2014. In fact, the results uncovered in the study of the security aspect of the proposed project can considerably contribute to this class. This preparation, however, will not conflict in any way with the research project agenda.

B. Student

Michael and Phanvu are not taking summer classes, and are willing to devote all of their summer study efforts to this project. Their detailed time commitments are shown in the section below.

VI. Existing Summer Research Support

None.

VII. Faculty and Student Time Commitments

Michael and Phanvu have voluntarily worked with me since Fall 2013 through the CSIT 320 LANs and Network Administration class. Both of them have been prepared with basic background on the state-of-the-art research on network virtualization, and demonstrated tremendous interests on proceeding with their studies. Consequently, there will be no lead time to start a comprehensive research with dedicated focus during the summer.

I will spend a minimum of 180 hours on the project for the 10 weeks of summer beginning June 3, with an average of 18 hours per week. Michael and Phanvu will both spend a minimum of 120 hours on the project, with an average of 12 hours per week on the project during each of the ten weeks.

We note that these numbers are given as a minimum commitment; more time and efforts may be needed in the early, and final stage of this project for experiments and report/paper writing. We will adjust our meeting frequency accordingly, with two personal meetings per week on average, and also actively exchange ideas via phone, e-mail, and *Google* hangouts whenever new challenges prompt.

VIII. Peer Reviewed Work Expected

As I have done in the past, the project will disseminate the results through workshop/conference presentation/proceedings, and journal publications. We expect this project will lead to the submission of at least one joint peer-reviewed conference paper, as well as the possible submission of a peer-reviewed journal paper based on the feedback and enhancement of the former. Subject to the date/deadline of the conference, we may spend extra time (not included in the commitment above) for the manuscript preparation. It is expected that Michael and/or Phanvu will present their findings in a talk for the ACM or Math Club. In addition, we will also seek external/internal supports for Michael and/or Phanvu to attend networking conferences and present their work.

The following networking conferences are under our consideration for publication, where all the technical papers go through a rigorous peer-review process by at least three domain experts: IEEE Global Communication Conference, IEEE International Communication Conference, IEEE International Computer Communication and Networking Conferences, and IEEE Sarnoff Symposium. Equally, we will seek for publication in the following journals: IEEE/OSA Journal of Optical Communication and Networking, IEEE Communication Letters, IEEE Journal of Lightwave Technology, Computer Networks, Optical Switching and Networking. Feedbacks/interactions from above leading networking conferences/journals will surely increase both the La Salle's reputation and the quality of our work.

It is worth noting that although this is my first time (as I joined in Fall 2013) applying for the dean's undergraduate research grant, I have experience in guiding undergraduate student research via the NSF REU (Research for Undergraduate) program for two undergraduate students: Wa'el Belkasim('09) and Dirk Carey('11) on pedagogy study at Georgia State University (GSU). The former student has played an important role in helping GSU establish the first networking lab, while the latter has successfully helped my research group compile a new undergraduate course curriculum: *Introduction to Internet*. Likewise, I have guided four master projects and co-authored a paper with one of the four students. Those details can also be found in my attached resume. Given my past experience and the high competence of Michael and Phanvu, we are very confident with the outcome of this summer research. I sincerely believe that not only do Michael and Phanvu deserve this precious opportunity for booting up their promising careers, but also that the other La Salle undergraduates will benefit from the impact of our study, both from a research (e.g., to proceed along their findings) and teaching viewpoint (e.g., to enhance the teaching of networking topics).

IX. Attachments

A. Faculty Resume

Please see attached document.

B. Student Resume

Please see attached document.

C. Department Chair Endorsement

Please see letter sent electronically by Dr. Jonathan Knappenberger.