Campinas, May-15, 2023

Faculty of Electronics and Information Technology
Nowowiejska 15/19
00-665 Warszawa
POLAND

Subject: Evaluation report of the Doctoral thesis by Tomasz Piotr Osiński

Being appointed as an external reviewer, this document serves as my assessment of the Ph.D. Thesis by Tomasz Piotr Osiński. The title of the thesis is "Data plane programmability for software datapaths in a virtualized network infrastructure", which is an accurate statement for the main topic and contributions of the thesis. In the following, the evaluation report covers the requested aspects.

Layout:

The thesis follows a well-defined structure that consists of six chapters. After the introduction Chapter 1 that provides an overview and setting the context for the research conducted, Chapter 2 that delves into the foundational knowledge required to understand the research, Chapter 3 examines the motivations and requirements behind the development of adequate programmable software switches for Software-Defined Networking (SDN). Various use cases are discussed and the necessary requirements for such SDN software switches are outlined along with a discussion on the limitations of existing solutions. In Chapters 4 and 5, the thesis presents the primary contributions, encompassing the design, implementation, and experimental evaluation of P4rt-OVS and NIKSS. Chapter 6, the final chapter, provides a summary of the entire thesis. It outlines the research outcomes achieved through the two proposed SDN software switches P4rt-OVS and NIKSS, highlighting their contributions to the field of programmable network data planes.

Overall, the thesis is structured in a logical and sequential manner, allowing readers to follow the progression of the research, from introductory concepts to detailed designs and evaluations, evolving from the initial contributions of P4rt-OVS to the improved design aspects brought by NIKSS, ultimately culminating in a comprehensive summary and future research prospects.

Literature:

The literature review is adequately covered in Chapter 3 and the position of the thesis contributions embodied in P4rt-OVS and NIKSS can be evidenced in Table 3.1 that provides a clear comparison of the most relevant state-of-the-art programmable software switches. The contributions of P4rt-OVS and NIKSS to advances in the state of the art are comprehensive and notable. In the initial part of Chapters 4 and 5 the literature and limitations of existing solutions are revisited.

Purpose:

The goal of this PhD dissertation is to explore the benefits of data plane programmability for software switches in virtualized networks. The purpose of the PhD is presented through the objectives to provide

answers to three relevant research questions around the design and implementation of SDN software switches.

The main objectives of the PhD can be synthesized around the following tasks regarding the two main software switches proposed (P4rt-OVS and NIKSS):

- To design and implement two systems that enable data plane programmability for software switches using P4 language: P4rt-OVS and NIKSS.
- To evaluate the performance, flexibility and operability of P4rt-OVS and NIKSS in different scenarios and compare them with existing software switches.
- To demonstrate the potential of P4rt-OVS and NIKSS for enabling novel network protocols and applications in end-to-end programmable networks.

P4rt-OVS extends Open vSwitch, the most popular SDN software switch, with protocol-independent and stateful packet processing capabilities of P4. NIKSS creates a new P4-programmable software datapath that leverages eBPF as a packet processing engine and P4 Portable Switch Architecture as a programming abstraction. Both systems enable novel network protocols and applications that can be easily prototyped and deployed in end-to-end programmable networks. The systems also achieve high performance and operability.

Methodology:

The proposed methodology is sensible and follows good practices of software engineering and networked systems. The thesis starts by identifying a set of requirements for a programmable SDN software switch that unfold into a set of objectives targeting gaps in state-of-the-art software datapaths. An initial approach is carried out through the design, implementation, and experimental evaluation of P4rt-OVS. Leveraging the experience and the identified limitations of P4rt-OVS, a second iteration to the main objectives of novel programmable SDN software switches is conducted through the design, implementation, and experimental evaluation of NIKSS. The validation of the proposed software switches is ratified through extensive functional and performance evaluation in relevant use cases and proper experiments, including microbenchmarks and in-depth performance analysis of test programs. In all of the chapters, the final conclusions section distills the relevant outcomes which contributes to an adequate line of thought. The concluding chapter provides convincing answers to the core research questions addressed by the PhD thesis.

Research Results:

As already stated, the main research results are the two software switch systems, P4rt-OVS and NIKSS, that enable advanced data plane programmability for software switches in virtualized networks using P4 language. P4rt-OVS is an extension of Open vSwitch that supports protocol-independent and stateful packet processing through the incorporation of a P4 pipeline. The NIKSS software datapath uses eBPF as a packet processing engine and P4 Portable Switch Architecture as the programming abstraction. Both systems allow the implementation of novel network protocols and applications with high performance and flexibility. The systems are open-source and can be used for research and development.

As eloquently elaborated in the concluding Section 6, the research results of the PhD thesis can be understood through the answers provided to three research questions: (1) Can programmable data plane and P4 be successfully used for software datapaths without sacrificing performance? Yes; (2) Given the hardware

focus, is P4 flexible enough to express all software capabilities needed to implement most common features of a hypervisor switch or Virtual Network Function? Generally yes, but there are limitations; (3) Is the P4 Portable Switch Architecture (PSA) the right architecture for software datapaths? Partially.

Although not explicitly presented as result contributions, the author has contributed to seven publications (references [127] to [133]), all of them regarded as high quality venues in the networking community. P4rt-OVS [132] was published in IFI 2020 and NIKSS [130] in ACM CoNEXT 2022, a tier 1 conference in the field of networking and distributed systems.

Noteworthy are the reproducibility results of NIKSS [130] that we recognized through the award of three ACM reproducibility badges, namely Artifacts Evaluated – Functional v1.1, Artifacts Available v1.1, and Results Reproduced v1.1

Applicability:

Beyond the common scientific applicability of the research publications resulting from the PhD, highly remarkable is the open-source nature of both P4rt-OVS (https://github.com/Orange-OpenSource/p4rt-ovs) and NIKSS (https://github.com/NIKSSvSwitch/nikss). As already highlighted, the main publication outcome (CoNEXT [130]) received a valuable recognition regarding the applicability of the results through three ACM artifact review and badging distinctions: Artifacts Evaluated – Functional, Artifacts Available, and Results Reproduced.

Correctness:

No flaws have been identified and overall the language used is correct regarding English grammar and adequate use of technical terms as expected in a scientific production. There are only few minor improvements that could be done, for instance a very large single paragraph on page 68 (Section 3.3) when discussing existing solutions in the state of the art.

Originality:

The thesis features novel contributions to the field of SDN software switches as noted in the state-of-the-art comparison in Table 3.1. The originality of the PhD can be also evidenced through the high-quality publication achievements.
In essence, P4rt-OVS enables runtime data plane programmability for OVS using P4 and leverages userspace BPF for extensibility while maintaining performance. NIKSS's P4-programmable packet processing model has two designs: a general-purpose design and a specialized design for better performance. A ternary packet classification algorithm for eBPF was designed and implemented.The PSA to eBPF compiler is an extension to the P4 compiler that implements the PSA model for NIKSS, with compiler optimizations for eBPF code performance. All of them have been contributed as open-source.

Knowledge & Independence:

There is sufficient evidence to assess that the PhD thesis demonstrates the candidate's overall theoretical and practical knowledge to carry out impact and quality research work in the field of networking, more

specifically in the subfield of programmable software switches. There are also convincing signs (e.g. first author role of the candidate in multiple scientific publications) of independence in the scientific work, a feature of the candidate that can be also recognized through the logical organization of the PhD manuscript.

Conclusions:

The conclusion of this review report is very positive, as argued throughout the key aspects assessed so far. As per the concluding remarks in the PhD manuscript itself, Section 6.1 provides a convincing wrap up discussion on the research outcomes of the PhD work. Furthermore, each Chapter includes a conclusions section that contributes to a comprehensive analysis of the work in scope obtained.

After taking into consideration all the evaluated elements, my judgment is that the thesis features the expected quality and contributions of a PhD degree, and, therefore, the candidate is ready for defense.

Despite all the positive highlights regarding the quality of the PhD pointed out by this reviewer, due to lack of familiarity with the common institutional practices to indicate a distinguishment, this reviewer does not oppose to such a justification but prefers not to individually pursue this aspect of the PhD work.

PROF. DR. CHRISTIAN ESTEVE ROTHENBERG
UNICAMP/FEEC/DCA
Matr. 304513