

Best of Two Worlds: Reinforcing NaaS Capability with Software-defined Networking

Feng Liu

Leibniz Supercomputing Centre (LRZ)
Garching b. München, Germany

Abstract—In this paper we argue that adding SDN-capability to NaaS can greatly enhance its management flexibilities and offer new service opportunities both for administrators and users of on-demand network services enabled by NaaS. We describe our approach to integrate Network-as-a-Service (NaaS) with Software-defined networking (SDN). Specific envisioned enhancements through SDN are explained in details and an integration methodology and architecture are presented.

I. INTRODUCTION

Flexible network infrastructures are crucial part for today's IT landscape. Advance in hardware technologies constantly improves performance of networking devices to suite the needs of applications and accommodate simultaneous traffic flows. On the other hand, usage scenarios of today's network infrastructures are very dynamic, ranging from networking for cloud computing and Network Functions Virtualization (NFV) to deal with short-lived network traffic spikes such as flash-crowd effect, providers should react agilely to frequently changing user requirement on networks. This requires more flexibilities in configuration as well as provisioning of resources in a very short time due to limited reaction time.

Considering those two aspects, an ultimate challenge currently faced by network service providers today is thus how to deliver dynamic network infrastructures at relatively low costs and in a timely manner. Furthermore network element should be application-aware as well, which means requirements from high level applications should be considered and reflected in the underlying network infrastructure. Obviously traditional network paradigm which purely based on dedicated networking hardware is not efficient to address this challenge due to its lacking of flexibility and reconfigurability. Recently a paradigm called Network-as-a-Service (NaaS) [1] which based on network virtualization technology, sheds lights on this problem. With a layer of software entity, NaaS paradigm allows creation of virtualized switches, routers and optical devices ect. using physical devices, thus enables multiple tenants to use a slice of shared resources according to their specific needs. NaaS can be seamlessly integrated into other virtual services such as cloud computing and NFV. NaaS allows more control of network elements from users' perspective of view. Despite its conceptual advantages, it is still an unsolved question that how to efficiently control physical network resources in a fine-granulate and precise way.

A recent effort towards programmable networks with Software-defined networking (SDN) has attract vast research interests. The idea of separation of data forwarding and control

plane of networking devices can improve controllability and manageability of networks drastically. If properly integrated, we believe such flexibility can extent the management and usage of NaaS thus provides as a plausible solution for sustain the network controls of physical network devices. In this paper, we analyze the advantages of integration of SDN into NaaS paradigm and how such integration can be properly designed and implemented. The main contribution of this work are:

- Proposing an architecture which integrates SDN into NaaS;
- Sustaining and enhancing functionalities of NaaS with refined network controls;
- Convergence of network infrastructures with cloud computing and NFV.

This paper is organised as followings: Section II provides briefly background information regarding NaaS and its use cases; in Section III we discuss in-depth on enhancements of OpenNaaS with support of SDN technology and in the meanwhile provides detailed design of integration; Section IV and Section V both detailed discussion on architecture and a prototypical simulation result is presented; this paper is concluded by discussion on future works.

II. BACKGROUND: NAAS

A. NaaS

B. Use Cases

III. ENHANCING NAAS SERVICE WITH SDN

Having the concept and architecture of OpenNaaS presented, in this section we focus on enhancements that highlight OpenNaaS service with SDN technology and corresponding functional requirements are derived from those enhancements.

A. Enhancements

1) Programmable Virtual/Physical Network Appliances:

The separation of control and data-forwarding mechanisms allows more flexible control of packet-forwarding devices. Comparing to classical way of managing network devices, behaviour of SDN-compatible devices can be programmed through their north-bound interfaces on centralised management station. A SDN switch, for example, can be easily programmed to behaviour not only packet forwarding device,

but also as a firewall or a load-balancer. The instructions can be realized in just few lines of code.

For OpenNaaS framework, a set of SDN-compatible devices can be programmed into different network appliances *according to usage scenarios*. In this way, programmable network can not only be reused but also aggregated or split in an on-the-fly manner which provide flexibility from both user and administrator perspective of views. Additionally middle-boxes could be replaced by unified, programmable and multi-purposed devices, which simplifies management and maintenance as well.

2) *Refined NaaS Control of Network Resources*: Management rules and policies can be explicitly stated and enforced using proper programming or configuration languages, e.g. [2], [3]. Rules can be inserted into device's flow table where forwarding mechanism behaves accordingly, for example if data packets with certain origins have to traverse through a pre-determined switches can be expressed as flow rules.

In terms of OpenNaaS, a refined control of network resources can dramatically reduce the overhead for administrator to configure networks with complex user requirement. Policies can be singly used or even be negotiated with user to adapt to their needs.

3) *Incorporating Advanced Analytics of Networks Behaviors*: SDN technology inherently facilitates in-network information gathering and analysis in order to gain deeper insights of network behaviours and event in real-time. Current OpenFlow specification [4] for example, allows asynchronous and symmetric messages to be sends from devices to controller which contain network events such as `Packet-in/out`, `Port-status`, `Flow-Removed` etc. Given availability of such types of messages provided by the resource layer devices, complex analytics can be done in order to assist either human operators or automated mechanisms to understand network behaviours and reacts to network event if necessary. Analytics can be done either at controller layers at integral part of network OS or controller can simply make those data available through its northbound interface for the above layer to conduct analysis. Note that depending on the scenario, deluge of data may be required to be processed in a real-time in order to achieve the goal, thus analytics in network is also an across research area with big data.

4) *Incorporating QoS into on-demand Network*: With support of configuration or programming languages, QoS requirements of network services created by NaaS can be expressed explicitly as rules in flow tables so that QoS policies are reflected and realized, for example the control of bandwidth for NaaS virtual networks with different quality and load-balancing requirements could be enforced using SDN rules expressed in the form of functions [5] as in conventional programming languages.

5) *Enabling Multi-domain SDN/OpenNaaS Service*: Networking capabilities represented by both virtual and physical devices or resource slices can be orchestrated to form complex networking services. Since state-of-the-art SDN specification does not support inter-domain networking, using other inter-domain capable resources allows SDN networks in a single domain to forward their data packet to other domains, for instance, if particular kind of traffic must be routed outside

of its own domain, an underlying SDN switches can be programmed with inter-domain routing capabilities such as EGP or BGP, for example a SDN-based inter-domain data exchange component at the edges of an organization can be a potential solution to allow multi-domain NaaS service.

6) *Allowing Continuum in the Network Management*: Continuum in the network management refers to implementation and refinement of management policies or rules from high-level perspective to low-level executable management actions. Due to lack of an unified method, providing a consistent network management continuum is currently difficult, if at all possible. For services such as NaaS, a flexible control has to be in place in order to allow administrators to re-configure the network resources to adapt to ever changing management policies. A set of executable actions down to network interfaces level must be resulted to reflect the change of policy changes. With SDN policy languages such as Pyretic [5], a solid foundation could be built to express network management intentions in terms of a unified programming scripts in a generic way, programming language concepts such as functions and classes can be used to express the management rules and policies.

7) *Intelligent Network Management with SDN*: As underlying technology for NaaS platform, SDN works as a flexible intermediate layer between high-level services offered by NaaS and low-level infrastructures, e.g. switching/routing hardwares. In a highly utilized NaaS environment, SDN devices may generate a large number of events and messages from OpenFlow channels, for example, asynchronous and symmetric messages sent back and forth between controller and data layers. Those message carries important management information that reflects the current behavior, such as changes, faults such as mis-configurations and even security informations. Thus aggregation, correlation and in-depth comprehension of such messages is of vital importance for understanding the performance of network in a real-time manner. It is also a great assistant for activities such as debugging of network failures or finding bottle neck of networks. Obviously this is not a trivial task, sheer mount of data and complex inter-correlation of data require the processing algorithms to be capable of dealing with such data deluge in a highly efficient manner. Methods available to data-mining and machine learning researches can be explored for this purpose.

8) *Coherent Resilience and High Availability*:

B. Requirements

IV. SOLUTION ARCHITECTURE

In this section, we present the architecture of adapting SDN-capability to OpenNaaS framework, in which we try to answer following technical questions:

- How to model and architect SDN-based OpenNaaS framework?
- How to properly map SDN components to OpenNaaS framework?
- How could SDN-compatible networking devices expose their control primitives to OpenNaaS framework and in what granularity?

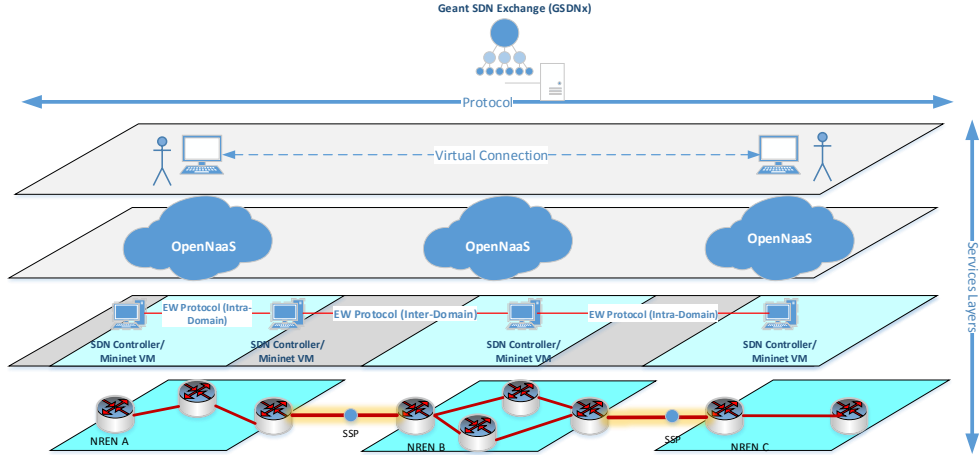


Fig. 1. Architecture of Inter-domain NaaS Service over SDN Facilities

- How to represent SDN abstractions to users and administrators of OpenNaaS framework?

A. An Architecture for Building NaaS over SDN Facility

Figure 1 illustrates our proposal of integrating NaaS service over SDN facilities over multiple domains. We structure the proposed architecture into functional/service layers, where each layer provides services to its above layers. Within layers, protocols are used to facilitate information exchanges between different participants. Explanation regarding each layer is given as following:

1) *Resource Layer*: At bottom level of the proposed architecture, basic data packets forwarding capability allows simple data forwarding either within or between domains. Note that at this layer, no routing decision is made regarding the destinations of packets, it simply forwards data packets according rules that are determined by the controller, thus we say the resource layer provides data-forwarding serviced by implements rules made by the control layer, e.g. using OpenFlow protocols.

2) *Control Layer*: The behavior of data forwarding devices at resource layer is defined by the control layer, where standard protocol can be used to define and communicate forwarding rules to devices forwarding table. It is important to notice that current specifications and standards of OpenFlow for example, do not consider East-West(EW) communications, thus collaboration between controller is difficult, if not impossible. We argue that integration of controller-to-controller protocols will be vital sheer from scalability point of view. We extend OpenFlow (OF) protocols to include east-west inter-controller communications. Since we are dealing with inter-domain networking scenario, we need to distinguish the difference between intra- and inter-domain controller-to-controller protocols. To the above layer, the control layer exposes its fine granular network control interfaces in terms of, for example, application programming interfaces (API). In term of SDN, the controller exposes its northbound interfaces to the layer above and let it controls the behaviour of the network more precisely and in an unified manners.

3) *NaaS Service Layer*: This layer performs actual service provisioning process and interacts with end users of on-demand network services. This layer determines for example network topologies, routes and, together with other parameters such as QoS related, NaaS service sets link properties as end-users require and performs provisioning using services provided by the underlying control layer. This the layer where configuration knowledge and intelligence are located. Network parameters need to be translated and transported on to SDN routing devices for implementation. To this end, it is imperative that NaaS service maintain a set of well-defined interfaces to the underlying control layer. From SDN perspective of view, northbound interfaces in terms of loosely-coupled technologies such as RESTful API, RPC or WebServices. Note that currently NaaS platforms such as OpenNaaS do not support inter-domain network services, its relies on underlying layers to provide inter-domain routing/switching capabilities by establishing virtual networks across multiple domains.

4) *Virtual Connection Layer*: This layer is responsible for actual user perception of networking services. In Fig.1 an virtual end-to-end (E2E) connection is illustrated, where actual packet-forwarding and control mechanism locate in the underlying layers. Users of network service could connect customer premises (CP) device to one of provider edge (PE) network devices.

B. Mapping between Layers

One of the cornerstones of the aforementioned architecture is to design a set of well-defined interfaces for each presented layer as service primitives to interact with their neighbouring layers. In analogie to ISO/OSI model the functionalities of a layer are exposed by service primitives to interact with other layers. Individual layer utilizes functions provisioned by its neighbour abover and provides service to its under layer.

Given the fact that frameworks reside at each individual layer may have its own interfaces makes the definitions of inter-layer interaction and mapping of functionalities a more prominent issue to be tackled. Further more employing interfaces and service primitives decouples concept from its implemenetation thus renders our design technology-agnostic.

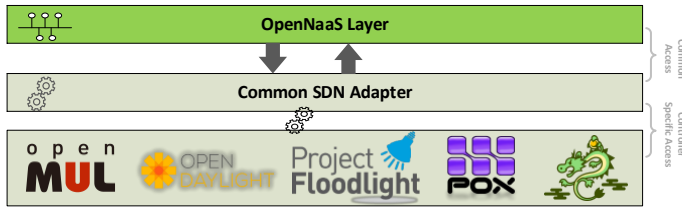


Fig. 2. Interactions between NaaS layer and SDN controller layer through a generic adapter

In this section, we provide detailed analysis and present our proposals for service primitives and communication protocols between and across layers.

1) *Resource Layer Primitives & Protocols*: Service primitives of this layer towards upper layer are defined by the OF specification from the Open Networking Foundation (ONF). The main task for the SDN device is forwarding data packets in terms of flow according to flow tables and registers network events such as incoming of data packets that do not match any pre-defined flow rules. Contrast to conventional ones, flow tables of SDN-capable devices can be modified at any time point by a controller. In terms of SDN, a southbound interfaces implements OF specifications and dictates device-to-controller communications. Note that according to specific technologies used for the resource layer, reconfigurable protocols other than OF can be applied as resource layer primitives [6].

2) *Control Layer Primitives & Protocols*: A SDN controller exposes its service primitives through its northbound interfaces. Unlike southbound interfaces, definition of northbound interfaces is not standardized, it's depends solely on the different concrete controller implementations what services primitives in terms of API are considered. In order to make our solution generic for all controllers, we identify a set of interfaces with functionalities that are critical for the network management that cover complete life-cycle of services. Provided with such information, we design an overarching framework by applying software design patterns [7]. Some of potential candidates are for example adapter, proxy and abstract factory patterns. Fig. IV-B illustrates interactions between NaaS layer and diverse controllers through a common SDN adapter.

A further issue concerning control layer protocols is the inter-domain capability of controllers. Current specification unfortunately does not support establishing SDN segments across multiple domains thus does not scale [8]. Even within a domain, orchestration of multiple controller instances are not yet well-defined. This is due the inherent characteristics that OF based SDN is proposed and created for campus networks [9]. In order to sustain this inter-domain capability, the current protocols have to be extended in Fig. 1 we illustrated this extension as East-West (EW) protocol. To tackle this problem, we envision two potential approaches:

- *Flow Exchanges Protocols*. To improve scalability and robustness of SDN based infrastructures, multiple controllers which are capable of exchanging informations with each others can be used to allow inter-controller communications and maintain a global state of the composed networks. To serve this goal, a EW protocol

must be in place. Due to the differences between inter- and intra-domain connections, we distinguishing two types of EW protocols, respectively.

- *Global SDN Exchange* In order to allow peering of domains in the global level, we propose a SDN exchange instance that allows exchanges of flow tables between registered SDN domains.

3) NaaS Service Layer Primitives & Protocols:

4) Virtual Connection Layer Primitives & Protocols:

V. IMPLEMENTATION/VERIFICATION

VI. FURTHER CHALLENGES AND FUTURE WORK

VII. CONCLUSION

ACKNOWLEDGMENT

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