Designing Dependable Control Platforms for Software Defined Networks

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Abstract—Controllers of software defined networks are critical elements to ensure a correct and reliable network operation. However, the main focus of current controllers is on scaling issues of the control plane. To add and ensure dependability properties on control platforms, we introduce requirements and elements that can be leveraged to improve availability and reliability of software defined networks in a by design approach.

I. Introduction

Software defined networks (SDNs) are a new opportunity to solve old networking problems such as security policy enforcement and middleboxes management. The decoupling of control and data planes allows an SDN architecture to easily provide a logically centralized view of the network through network operating systems [1] (a.k.a. controllers), making it easier for developers to reason about and program the network behavior.

Flexibility is one of the most important added values of software defined networking, leading to a new pace of innovation in networking infrastructures. It is achieved by using standard open interfaces (e.g., OpenFlow [2]) that make it possible to program forwarding devices (e.g., switches) through external applications running on top of controllers.

Howbeit, the key characteristics of software defined networking, logical centralization and programmability, come with a price. While SDNs are allowing a flexible and progressive evolution of networking architectures, they also introduce elements and features that potentially augment the impact of failures and the threat surface [3]. This scenario undoubtedly pinpoints for the need of considering security and dependability properties as first class priorities of future SDNs.

Furthermore, while the dependability of the data plane is the common target of networking research, it has been shown that the reliability of networking infrastructures can be increased with more dependable control planes [4]. Hence, a natural way to improve the security and dependability of SDNs is through highly available and fault tolerant control platforms.

Existing controllers can be classified in centralized (e.g., NOX [1]) and distributed (e.g., Onix [5]). The main weakness of the former is to be a single point of failure, whereas the second group addresses mostly control plane scaling issues. Consequently, dependability is still an open issue in SDNs.

Based on our previous work [3] and findings about the impact of dependable control planes on network infrastructures [4], we argue that dependability should be considered as a first class priority of SDNs. Elements and mechanisms to

build more dependable networks should be introduced in the design of control platforms, as discussed in following sections.

II. RELATED WORK

Most of the existing controllers, like NOX [1], are centralized and single points of failure. A single controller failure can compromise the overall network operation. To circumvent this problem, replicated components and distributed controllers can be used to improve the system availability.

Onix [5] and Kandoo [6] are examples of distributed controllers. Despite the differences in architecture and design of the system, they essentially address scaling issues of the control plane. Onix provides a network information base, where critical data can be kept and distributed among the controlling instances in a WAN, ensuring a consistent global view of the network state, but paying the price of a low performance distributed relational database [5].

A replicated NOX component [7] can be used to support crash faults on the control plane. The solution is based on a simplified ad-hoc primary-backup approach with significant performance drawbacks and static configuration of networking devices. For instance, crash failures are only tolerated on the primary replica and forwarding devices are not capable of dynamically re-associate to new replicas. Furthermore, it cannot ensure availability nor liveness of the system since there are no proactive and reactive replica recovery methods.

Another recent work proposes an elastic distributed controller [8]. The idea is that the number of controllers can dynamically grow to support more networking devices. Its main weaknesses are the limitations of the OpenFlow's master-slave approach and static association of networking elements. The solution does not address master-slave handover problems (e.g., a slave starts by flushing the flow rules of devices) nor failures of multiple masters, which can lead to inconsistent network state and leave devices without control.

In summary, existing controllers yet do not effectively handle high availability and fault tolerance on the control plane. Thus, there are different challenges and opportunities on building dependable SDN control platforms.

III. PROPOSED APPROACH

The design of SDN control platforms should consider availability and reliability properties from the first hour. Figure 1 gives an overview of how a dependable control platform would looks like. Some of the key elements are an east/westbound

API, a common northbound API, and diversity of controllers. Furthermore, it is crucial that data plane devices provide support for dynamic association with controllers.

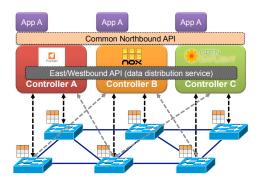


Fig. 1. Resilient control platforms: a by design approach

East/westbound API. A distributed fault tolerant control platform requires an east/westbound API to provide data consistency among controllers, ensuring reliable handovers of controllers in case of failures. For instance, if controller B fails, controllers A and C can assume B's devices. However, to avoid network state inconsistencies (e.g., flow path setup, security policy enforcement), controllers A and C need to known the last operations executed, or not, by B.

An east/westbound API should provide data distribution mechanisms such as distributed hash tables for weak consistency and/or state machine replication for strong consistency. One possible solution is a backend distributed consistent data store [9]. Such data store can be leveraged by controllers and applications to store critical information required to safeguard the correct network state in case of controllers' handovers or failures. Nevertheless, one challenge of this approach is to select which data should be kept consistent without impairing the required performance of the control plane.

Common northbound API. A common northbound API (e.g., network programming language, system interface) would enable application portability among controllers. Currently, each SDN controller has its own northbound API, making it harder to run the same software module on different controllers, because it would have to be adapted to each controller.

The solution goes through the definition of a common northbound API. Notwithstanding, alternative solutions could be a starting point since we are yet only on the early stages of SDNs. One example could be a more high level abstraction for application development, such as proposed in the Open-Daylight control platform architecture [10]. While enabling application portability, it still requires a specific implementation for each controller. A more long term solution would be a POSIX-like standard for network operating systems.

Diversity of controllers. Diversity of controllers can be leveraged to increase the system robustness by reducing the probability of shared vulnerabilities. For example, an attack targeting a specific vulnerability may compromise only a subpart of the system, without compromising its overall operation.

In order to allow diversity of controllers in dependable SDNs, common northbound and east/westbound APIs are two essential requirements. The former provides portability of

applications, while the latter is required to ensure correctness and reliability in case of device control handovers or failures.

Dynamic device association. A replicated or distributed control platform will not be effective with static or manual device association, like it happens in current OpenFlow enabled networks. As replicas can be added or replaced at any time in a highly dependable system, forwarding devices need to be able to dynamically associate to controllers. To this purpose, lookup and trustworthy association mechanisms have to be put in place to allow devices to find controllers and establish a trusted relationship. For instance, devices should be able to detect and avoid compromised controllers in the network.

IV. CLOSING REMARKS

We are working towards the identification and definition of common system abstractions and elements required to build secure and dependable control platforms for SDNs. Some of the crucial requirements and challenges (e.g., dynamic device association without impairing security and east/westbound APIs without compromising performance) have already been characterized, as shown in the previous sections. Future work include the refinement of these elements and practical evaluations, observing how effective they can be, or which are the additional requirements in building resilient control platforms.

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REFERENCES

- N. Gude, T. Koponen, J. Pettit, B. Pfaff, M. Casado, N. McKeown, and S. Shenker, "NOX: towards an operating system for networks," SIGCOMM Comput. Commun. Rev., vol. 38, no. 3, Jul. 2008.
- [2] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "OpenFlow: enabling innovation in campus networks," SIGCOMM Comput. Commun. Rev., vol. 38, no. 2, Mar. 2008.
- [3] D. Kreutz, F. M. Ramos, and P. Verissimo, "Towards secure and dependable software-defined networks," in *Proceedings of the second* ACM SIGCOMM HotSDN '13. ACM, 2013.
- [4] J. Korniak, "The GMPLS controlled optical networks as industry communication platform," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, nov. 2011.
- [5] T. Koponen, M. Casado, N. Gude, J. Stribling, L. Poutievski, M. Zhu, R. Ramanathan, Y. Iwata, H. Inoue, T. Hama, and S. Shenker, "Onix: a distributed control platform for large-scale production networks," in Proceedings of the 9th USENIX OSDI. USENIX Association, 2010.
- [6] S. Hassas Yeganeh and Y. Ganjali, "Kandoo: a framework for efficient and scalable offloading of control applications," in *Proceedings of the* first ACM SIGCOMM HotSDN '12. ACM, 2012.
- [7] P. Fonseca, R. Bennesby, E. Mota, and A. Passito, "A replication component for resilient openflow-based networking," in *IEEE Network Operations and Management Symposium (NOMS)*, april 2012.
- [8] A. Dixit, F. Hao, S. Mukherjee, T. Lakshman, and R. Kompella, "Towards an elastic distributed SDN controller," in *Proceedings of the second ACM SIGCOMM HotSDN' 13*. ACM, 2013.
- [9] F. Botelho, F. M. V. Ramos, D. Kreutz, and A. Bessani, "On the feasibility of a consistent and fault-tolerant data store for SDNs," in Second European Workshop on Software Defined Networking, 2013, to appear.
- [10] OpenDaylight Community, "Opendaylight controller architectural framework," 2013, http://goo.gl/QaAKnI.