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Abstract

Software-Defined Networks (SDNs) have been used in the last decade as a solution to provide greater flexibility in controlling traffic being distributed over a network, promoting the reuse and optimization of network resources. SDN´s architecture decouples routing intelligence (Control Plane) from routing functions (Data Plan/Forwarding Plane), through a component called SDN controller which centralizes the Control Plane. Therefore, it is required that the controller´s performance and functions provide an optimal integration with both Forwarding Devices (Network Elements) and with the support to new applications to be proposed within the context of software-defined network paradigm. Nevertheless, the rapid development of this paradigm and the increasing availability of different controllers within the market makes it difficult to choose a suitable one. This paper compares briefly the top six SDN controllers according to the market preference, looking not only to unveil some theoretical aspects but also to have an insight about their market acceptance.

1 Introduction

According to Kreutz et al [1], SDN is an emerging network paradigm that allows to overcome the limitations of current network infrastructures, being defined as a four pillars network architecture: Data and Control Planes are decoupled, the routing decisions are flow-based instead of destination based, the control logics is executed by an external entity called SDN Controller and, the network is programmable through software applications running on the top of the SDN Controller. According to the literature review some efforts were carried out to compare the available SDN Controllers. In [1], Kreutz et al conducted a generalized systematic review of the SDN paradigm and its technological aspects. Nevertheless, this review was not oriented to a comparative study of controllers according to the market perspective. In [4], a systematic review of the SDN controllers and a comparative approach was based on some criteria such as learning curve, supported APIs, documentation availability, Openflow version, among others. Unfortunately, this work does not carry out a comparative classification among the presented controllers and this approach does not focus on the market view perspective, which is important for the acceptance of any technology. At last, Salman et al [3] present a comparison among SDN controllers considering criteria such as programming language, documentation, modularity and performance, also not performing a market-oriented comparison. The main contribution of this paper is the comparative review of the available SDN controllers and their main features, beyond technical and functional perspectives, but also with a market acceptance perspective, documentation availability and OpenFlow support. Therefore, we present a comparative qualitative and quantitative review with a hybrid academic and market perspectives of the top 6 SDN controllers currently available.

2 SDN Controllers

According to Zhu et al [2], an SDN Controller is the core component of any SDN infrastructure, it has the overall network perspective that includes all devices in the data plane. The controller connects these resources with management applications and executes flow control actions dictated by the application policies throughout the devices of the data plane. Figure 1 illustrates the overview of the architecture of an SDN controller and its main components. Other important components in this architecture are the East-West bound interfaces. East-West bound interfaces are also used to communicate with third party APPs and others SDN Controller.

Some important functions in an SDN network operating system are providing abstractions, essential services and providing application programming interfaces to support network programmability. Therefore, being at the top of the control plane, the generic functionalities in an SDN controller can be offered as services such as: network state, network topology information, device discovery and configuration distribution and network actuation/reconfiguration. Some of the main characteristics of SDN Controllers are: (1) *Architecture and Design Axes*, determining a centralized or distributed design providing a higher flexibility and performance to the traffic; (2) *East/Westbound APIs*, which are essential components including functions such as importing and exporting data between controllers, algorithms for data consistency models, monitoring and notification capability, etc.; (3) *Programming languages*, providing interoperability, multithreading, low learning curve, fast access to memory and good memory management are taken into account; (4) *Support to Openflow and other protocols* in the Southbound interface and network programmability.

3 Top 6 SDN Controllers

Classify SDN controllers is a challenge, since there are several criteria that can be applied and some of them are mutually exclusive. Thus, the results of this study aim to support market and academia acceptance of these SDN controllers. Each controller design has a different use case, since their utilization depends not only on their capabilities, but also on the cultural adjustment of the organization and project. In market big picture, according to Bort [5], Cisco incorporated Insieme Networks for $863 million in 2013, with an earlier investment of over $1 billion in the startup, at the time Cisco dominated about 70% of the switch and router market. Cisco, in 2012, had already acquired Cariden Tech for $141 million according to Whittaker [6], thus positioning itself in the SDN market and the new trends in network programmability. Juniper Networks bought Contrail Systems for $176 million in 2012, according to Meyer [7]. An overview could not be made without reporting forecasts on the SDN market. To fill this gap, Dean [8] and Framingham [9], based on the report produced by the International Data Corporation (IDC) about the global SDN market indicates a compound annual growth rate (Compound Annual Growth Rate - CAGR) of 53.9% between 2014 and

2020, which will worth about US$ 12.5 billion in 2020. The following classification was based on the parameters and criteria identified in this study, which consider both technical/academic criteria regarding market criteria indicating the adoption by manufacturers. In addition, based on the SDN Controllers research and classification carried out by Froehlich [10] and IT Central Station [11], the list of 6 top most SDN controllers in evidence in the market is as follows:

6°) HUAWEI AGILE CONTROLLER - Huawey SDN controller, component of its Cloudfabric Solution solutions, Based on ONOS. Strong point is its ability to interoperate with third-party platforms like Vmware vCenter and the broad support for the integration with Openstack platforms, another strength is its support to several protocols for SBI besides Openflow (up to 1.4), such as Restful, Restconf, Webservice, Snmp, OVSDB, JSON-RPC, and sFlow. Due to strict hardware specifications, it requires a large server sizing hardware: CPU 32 cores@2.4 Ghz, 32G memory, 4*1200GB SAS HDD. As a week point, is your large hardware specification.

5º) HP VAN SDN CONTROLLER - HP SDN Controller, also presentes a strict hardware requirements (minimum specifications proposed by HP is 2.2ghz server (intel Xeon or intel Core2 8-core or equivalent)) with 16gb ram and 64gb minimum Storage. Strong points is a very rich API with excellent RSDoc documentation available and a marketplace with several utilities to expand functions via NBI. As a weak point, it only supports Openflow in SBI which greatly limits its applicability.

4º) JUNIPER CONTRAIL - Juniper SDN controller, with end-to-end dynamic configuration and optimization application and control for any cloud infrastructure. Stront points are its extensive documentation, broad support in both SBI and NBI, integration with most cloud services such as the Contrail Cloud service, as well as Kubernets, Openshift and Mesos. It also supports Network Functions Virtualization, A hardware specification with x86 2.2ghz quad-core processor, 12gb RAM, 2 tb HDD meets minimum specifications. As a week point is your high cost.

3º) CISCO ACI (APPLICATION CENTRIC INFRASTRUCTURE) - Cisco SDN Controller, which makes up a set of SDN-applied IP solutions with full native Layer 2-7 integration that supports Vxlan as an extensible overlay/network logic protocol and NFV using GRE (NV-GRE). Strong points are, the extensive case documentation (except for the little NBI documentation) available and a huge marketplace to provide extensions to the controller's native functions via NBI.As a server specification, cloud deployment support (AWS Cloud Support (M5.2x large with Storage Standard S3 Storage and minimum hardware specifications for Baremetal server, 8vCPUs 2.1 Ghz Xeon, 32gb memory, 100gb SSD/300gb . As a weak point is your high cost.

2º) OPENDAYLIGHT SDN CONTROLLER – Linux Foundation's widely used opensource controller, is the basis for several proprietary controllers such as the Ericsson SDN Controller, Fujistu Virtuora, and others. Some of its strengths are its extensive protocol support in SBI as a service abstraction layer with support to a wide range of protocols such as Openflow, OVSDB, NETCONF, BGP, P4, LISP, SNMP, PCEP among others. Some of its weaknesses are the small and outdated documentation of the project on its original website. As for its server specification, 8-cores 64-bit CPU (Intel 64/AMD64) 20gb memory (recommended 3gb memory for each CPU core), 40gb disk.

1º) ONOS SDN CONTROLLER – The Open Network Operating System, is a Linux Foundation project and a leading open source SDN controller for building next generation SDN/NFV solutions and is the basis for several proprietary controllers like Huawei and good market acceptance. As a strength, is the very good documentation and adopt in market. Due to a very rich SBI support to Openflow, P4, NETCONF, TL1, SNMP, BGP, RESTCONF and PCEP protocols, ONOS places itself as one of the controllers with a wider range of SBI coverage. Another great strength is its low hardware requirement: 2x1.8 ghz CPU, 2 GB RAM, 10 GB hdd. For this comparative study, is #1.

4 Conclusions

The comparative study of SDN controllers reveals that there are many options available, between free and proprietary software. The acceptability of SDN controllers was analyzed according to their support to multiple protocols in the SBI, support to different applications at NBI and wide documentation availability. Nonetheless, it is also important to understand the motivations behind the available platforms. Therefore, each designer has different use cases since their utilization depend not only on their functional capabilities, but also on the cultural adequacy of the organization and the project to be applied on. Among the compared SDN controllers ONOS, ODL and CISCO ACI were considered the 3 top-most controllers accepted by the market according to the adopted criteria. Nevertheless, the differences in these criteria from one controller to other criteria can be very subtle, in particular, concerning their technical requirements. For this reason, the adopted criteria were useful to come to a decision. As future work, the context of this article indicates a constant update of the table I due to the dynamic evolution of the related technologies and also of the market oscillations. Opensource projects can oscillate in criteria, requirements and functionalities as well as proprietary designs may also be simply for market reasons, discontinued by their respective owners thus making a classification of SDN controllers beyond a complex task due to the number of possible criteria and the dynamic aspect of these, we can also add the dynamic aspect of the market, which brings this relationship into line with the time of publication and needs to be updated periodically. Also as future work we can include the criterion of adoption of SDN controllers in 5G projects (In Core, Edge, Access/RAN) that size also has the same issues of temporality and technological paradigms mentioned above, as well as the fact that, would lead to a greatly increased ratio of controllers, changing the comparative context from TOP 6 to TOP 10.

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