# Impact of SDN Controllers Deployment on Network Availability

*(Technical Report)*

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*Abstract*—**Software-defined networking (SDN) promises to improve the programmability and flexibility of networks, but it may bring also new challenges that need to be explored. The purpose of this technical report is to assess how the deployment of the SDN controllers affects the overall availability of SDN. For this, we have varied the number, homing and location of SDN controllers. A two-level modelling approach that is used to evaluate the availability of the studied scenarios. Our results show how network operators can use the approach to find the optimal cost implied by the connectivity of the SDN control platform by keeping high levels of availability.**

## I. INTRODUCTION

During the recent years, the SDN has emerged as a new network paradigm, which mainly consists of a programmable network approach where the forwarding plane is decoupled from the control plane [1], [2]. Despite programmable networks having been studied for decades, SDN is experiencing a growing success because it is expected that the ease of changing protocols and provide support for adding new services and applications will foster future network innovation, which is limited and expensive in todays legacy systems.
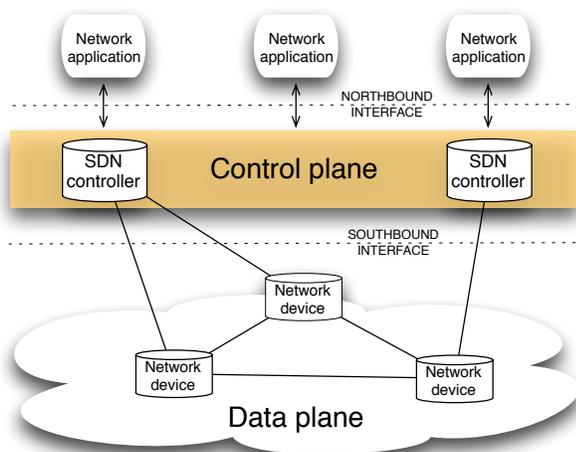


Fig. 1. SDN architecture (exclusive the management plane)

A simplified sketch of the SDN architecture from IRFT RFC 7426 [1] without the management plane is depicted in Figure 1. The control plane and data plane are separated. Here the control plane is logically centralised in a software-based controller ("network brain"), while the data plane is composed of the network devices ("network arms") that conduct the packet forwarding.

The control plane has a northbound and a southbound interface. The northbound interface provides an network abstraction to the network applications (e.g. routing protocol, firewall, load balancer, anomaly detection, etc...), while the southbound interface (e.g. OpenFlow) standardises the information exchange between control and data planes.

In [3], the following set of potential advantages of SDN were pointed out:

- centralised control;
- simplified algorithms;
- commoditising network hardware;
- eliminating middle-boxes;
- enabling the design and deployment of third-party applications.

However, from a dependability perspective, the SDN poses a set of new vulnerabilities and challenges compared with traditional networking, as discussed in [4]:

- consistency of network information (user plane state information) and controller decisions;
- consistency between the distributed SDN controllers in the control plane;
- increased failure intensities of (commodity) network elements;
- compatibility and interoperability between general purpose, non-standard network elements
- interdependency between path setup in network elements and monitoring of the data plane in the control plane;
- load sharing (to avoid performance bottleneck) and fault tolerance in the control plane have conflicting requirements;

The objective of this technical report are to compare the overall availability of SDN when the number, homing and

location of SDN controllers are varied. Note that this work needs to be intent as a preliminary study of [5].

that may be achieved with SDN to that of a traditional IP routed network and to investigate under which parametric condition one is better than the other. In order to do this, we introduce a two level modelling approach, where the top-level catches the structural properties of the networks, and the lower layer the dependability characteristics of the different network elements/subsystems under hardware, software and operational model. The models of network elements/subsystems in the two kinds of networks are developed in order to maintain similarities and establish a parametric relation.

In Section II, we introduce the two-level hierarchical model that has been used in this study. The evaluation of the deployment of the SDN controllers has reported in Section III. Finally, the conclusions are summarized in Section IV.

## II. MODELLING

A two-levels model (initially introduced in [6] and then extended [5]) is used to evaluate the dependability of SDN in a global network. In particular, the dependability is measured in terms of steady state availability, in the following referred to as availability. The two-level hierarchical availability modelling approach consists of:

- *Structural* model of the network topology;
- *Dynamic* model of network elements.

The approach seeks to avoid the potential uncontrolled growth in model size by compromising the need for modelling details and at the same time modelling a (very) large scale network. The detailed modelling is necessary to capture the dependencies that exists between network elements, and to described multiple failure modes that might be found in some of the network elements and in the controllers. The structural model disregards this and assumes independence between the components considered, where a component can be either a single network element with one failure mode, or a set of elements that are interdependent and/or experience several failure modes with an advanced recovery strategy. For the dynamic models we can use a Markov model or Stochastic Petrinet (e.g., Stochastic Reward Network [7]). For the structural model we can use reliability block diagram, fault trees, or structure functions based on minimal cut or path sets.

The objective of the modelling approach is to compare the availability of SDN with a traditional IP network with the same topology of network elements (SDN forwarding switched and IP routers).

## III. NUMERICAL EVALUATION

In this evaluation we consider the national backbone network depicted in Figure 2 and consists of 10 nodes across 4 cities, and two dual-homed SDN controllers. The nodes are located in the four major cities in Norway, Bergen (BRG), Trondheim (TRD), Stavanger (STV), and Oslo (OSL). Each town has duplicated nodes, except Oslo which has four nodes (OSL1 and OSL2). The duplicated nodes are labelled, $X_1$ and $X_2$, where $X$=OSL1, OSL2, BRG, STV, and TRD. In

addition to the forwarding nodes, there are two dual-homed SDN controllers ($SC_1$ and $SC_2$), which are connected to TRD and OSL1.
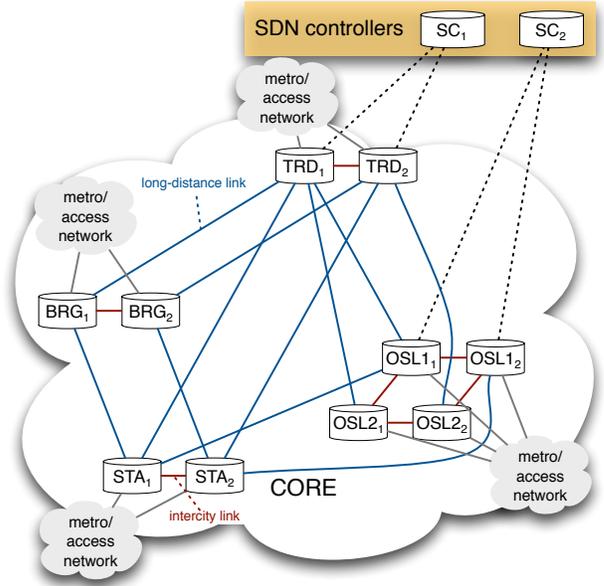


Fig. 2. Topology of the nation-wide backbone network

We assume that nodes, links, and controllers in the system may fail. The peering traffic in a city is routed through an access and metro network with a connection to both (all four) nodes in the city. The system is working (up), when all the access and metro networks are connected. Note that for SDN, at least one controller must be reachable from all nodes along a working path.

To evaluate the availability of traditional networks and SDN, we consider the same typical parameters used in [5], which are inspired by and taken from several studies [8], [9], [10].

To evaluate the impact of the connectivity and the redundancy of the SDN controllers in the national backbone network we consider the following case studies:

1) There is only one controller and it is connected to $OSL1_2$;
2) There are two single-homed controllers ($SC1$ connected to $TRD_2$ and $SC2$ connected to $OSL1_2$);
3) Reference scenario depicted in Figure 2;
4) The controllers are triple-homed (added connections from $SC1$ to $BRG_1$ and from $SC2$ to $BRG_2$ to the reference scenario);
5) The controllers are quadruple-homed (added connections from $SC1$ to $STV_1$ and from $SC2$ to $STV_2$ to the previous scenario);
6) There are three controllers (added controller connected to $BRG_1$ and to $BRG_2$ to the reference scenario);
7) There are four controllers (added controller connected to $STV_1$ and to $STV_2$ to the previous scenario);
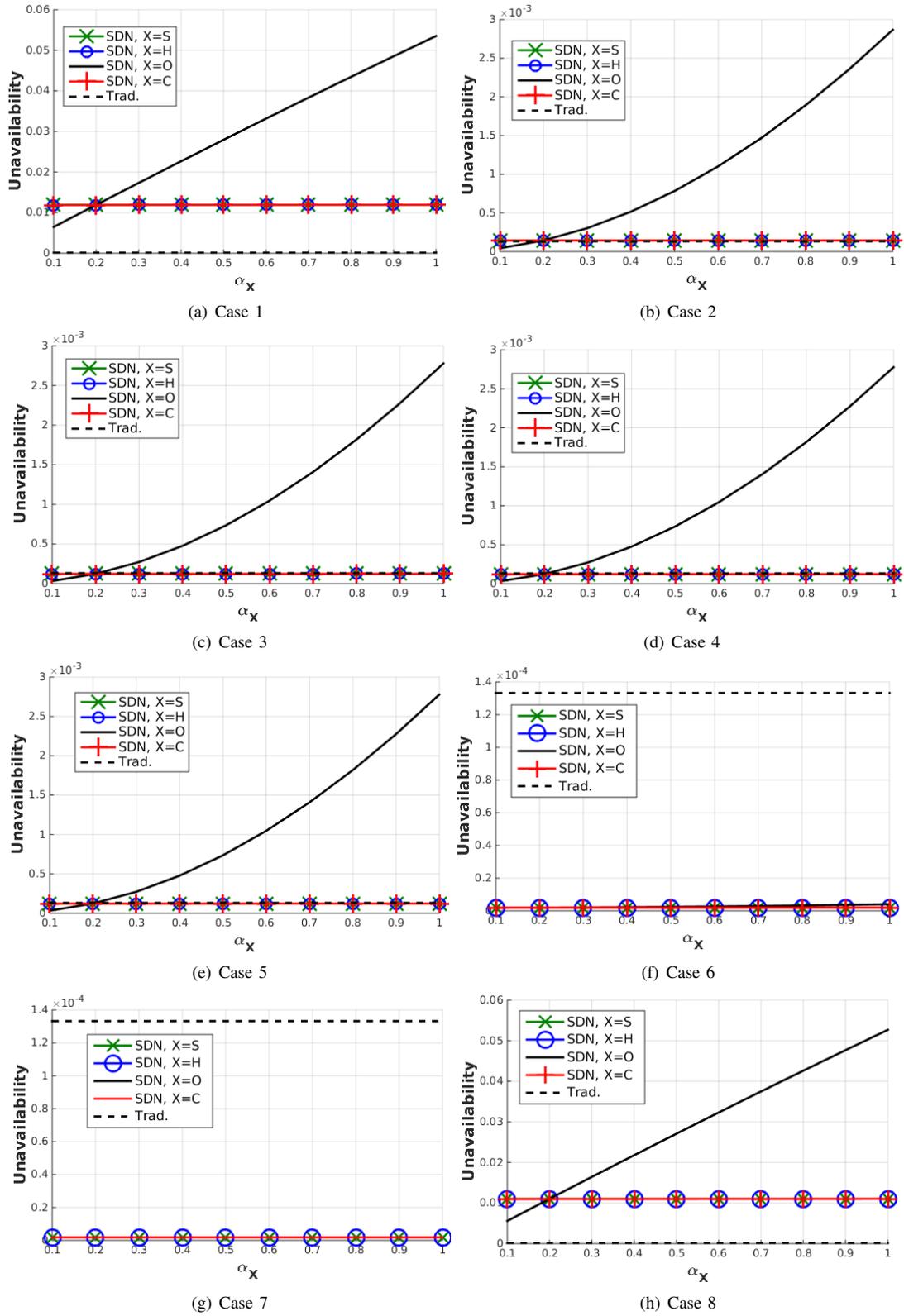
(a) Case 1

(b) Case 2

(c) Case 3

(d) Case 4

(e) Case 5

(f) Case 6

(g) Case 7

(h) Case 8

Fig. 3. Unavailability by varying $\alpha$s in the different connectivity and redundancy configurations

8) There is one dual-homed controller (deleted $SC2$ from the reference scenario).

Figure 3 shows the unavailability of SDN in the case studies. In the figure the $\alpha_X$ factors where $X = S, H, O, C$, which affect the intensity of the related failure sources (software, $\alpha_S$, hardware, $\alpha_H$, O&M, $\alpha_O$, and coverage, $\alpha_C$) and are defined as follows:

- $\alpha_H = \dfrac{\lambda_H}{N/K\ \lambda_{dC}}$;
- $\alpha_S = \dfrac{\lambda_S}{N\ \lambda_{dS}}$;
- $\alpha_O = \dfrac{\lambda_O}{N\ \lambda_{dO}}$.

### A. Evaluating SDN controller connectivity

To evaluate the impact of the SDN controllers connectivity in the national backbone network we consider the case studies 2, 3, 4, and 5.

Figures 3(c), 3(d), and 3(e) highlight that the unavailability in the cases 3, 4, and 5 is almost the same, so having a triple- or quadruple-homed controller would not enhance the availability performance but would increase the deployment cost especially if inter-city connections are needed. The most critical case is of course the case 1 when there is just one single-homed controller, in this case the unavailability in increased by one order of magnitude. The difference between cases 2 and 3 (better depicted in Figure 4) is really small, this is likely due to the high availability of the links.

### B. Evaluating SDN controller redundancy

To evaluate the impact of the SDN controllers redundancy in the national backbone network we consider the case studies 3, 6, 7, and 8.

Figures 3(c) and 3(h) show the network availability in the case with two dual-homed controllers and the case with one dual-homed controller. the comparison highlights that the unavailability with one controller is from one to two orders of magnitude higher than the unavailability with two controller and two orders magnitude higher that the unavailability of the traditional network.

Figures 3(f) and 3(g) show that the unavailability in the cases of three and four dual-homed controllers is lower than the unavailability of the traditional network. Figure 5 highlights that the unavailability with three and four controllers is on the same order of magnitude and two orders of magnitude lower than both traditional network and the SDN with two controllers.

### C. Evaluating SDN controller location

Figure 6 shows that the unavailability of SDN does not change by varying the location of the SDN controller. We note only a minor increase when one of the controller is connected to OSL1, we suppose that is because OSL1 belongs to Oslo that is the only city with 4 nodes. Anyway, the problem of SDN controller placement should be more deeply analysed in a larger and more complex network.
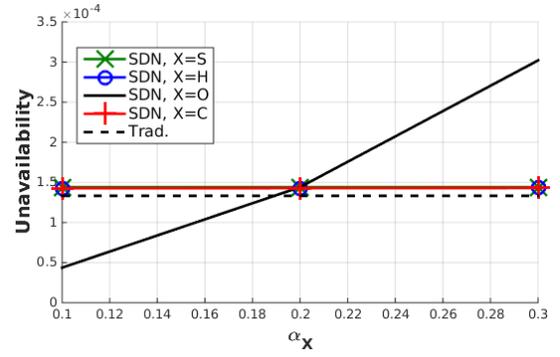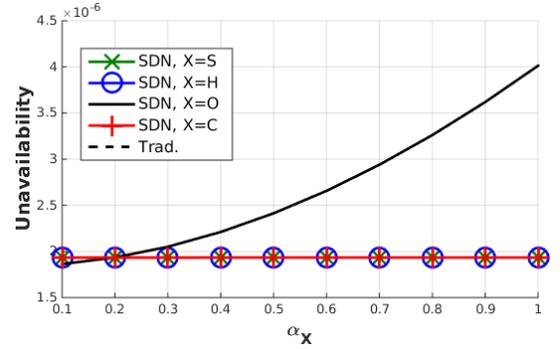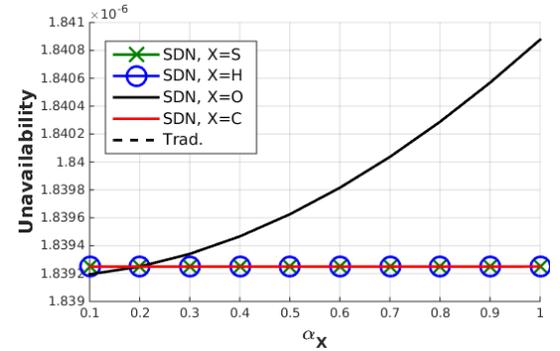


(a) Case 2
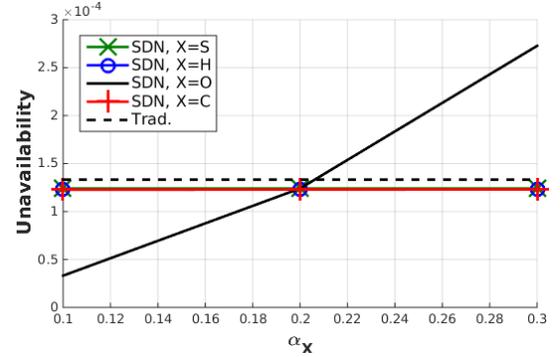


(b) Case 3

Fig. 4. Unavailability by varying $\alpha$s in the different connectivity configurations (zoomed version)



(a) Case 6



(b) Case 7

Fig. 5. Unavailability by varying $\alpha$s in the different redundancy configurations (zoomed version)
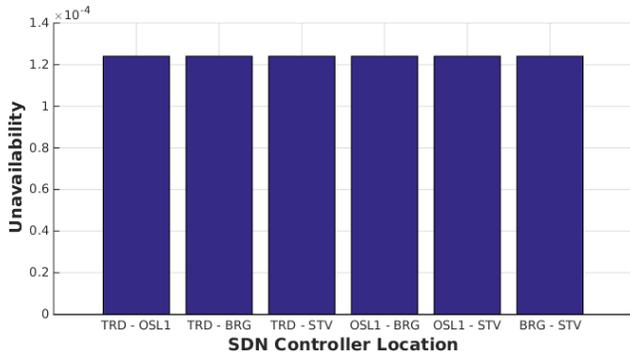
Fig. 6. Unavailability by varying the location of the SDN controllers ($\alpha_S = 1$, $\alpha_H = 1$, $\alpha_O = 0.2$, and $\alpha_C = 1$)

## IV. CONCLUSIONS

In this technical report, we have evaluated how the overall availability of SDN is influenced by the number, homing and location of SDN controllers. The results show that having a triple- or quadruple-homed controller would not enhance the availability performance, but would unnecessary increase the deployment cost to be made by operators. Single-homing has reduced the availability as wall but the impact is limited. Comparing the number of SDN controllers, one SDN controller is not enough to guarantee an acceptable availability. Two controllers allows the SDN to have an availability comparable to the traditional network. Instead, three and four controller permit to obtain a really low unavailability but the deployment cost may be excessive to a network operator, which target is to provide an availability similar to the current traditional network. In the addressed study, the location of the SDN controllers has not influence on the overall availability.

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