



Satellite ground station site diversity by optimizing SDN-enabled handover

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Abstract

Using Software Defined Network (SDN) in space systems gains more focus nowadays. SDN can increase the reliability in satellite communication. Many researchers concluded that using SDN in satellite communication for both ground segment and space segment, improve space system reliability. The satellite ground station network has been always the backbone of the Space System. From this point of view, the reliability and performance guarantee of this network is mandatory. With the introduction of SDN in the field of satellite communications, greater capabilities have been expected to be achieved, in addition to the big reduction of operational and capital expenses in deploying and management of satellite ground network equipment. In this paper, the advantages of using SDN for handover between satellite ground stations (Site Diversity) to ensure higher reliability for the system and to increase its performance and throughput are discussed. Some scenarios have been implemented and shown in this paper to demonstrate the great potential of using SDN in ground stations handover and to help make decisions in case of link anomalies.

I. INTRODUCTION

Software-defined network (SDN) is a state of the art technology that has become the topic of researches and has got global attention in the last few years because of the enormous opportunities which are offered by this new technology. The massive increase of the internet bandwidth and traffic needed by the users all over the world due to many devices joining every day the global network has led to creating an agile solution to enduring such demands. Satellite ground networks have always been a key element in satellite communication due to the major responsibility in handling data from/to satellites. The high reliability of this network is a must to ensure an- uninterrupted stream of data communication between ground and satellites.

The traditional networks are built upon a tree hierarchy structure of network devices (switches and routers). This static structure is not suitable for today's dynamic demands for cloud computing, big data, and the high demands of storage and media contents. From this point, a need for a different and modern approach has arisen. SDN was the solution to this dilemma. SDN is an innovative network architecture in which the network control is decoupled from the data forwarding devices^[1]. This approach has provided abstraction of network services from network infrastructure and centralized control and management upon network architecture and devices from a single point.

The major function which SDN offers towards the computer networks generally and to satellite ground

network specifically is the ability of programming the network and to make the network more agile and manageable. This ability plays a great role in reducing the operational and capital expenditure of the whole system besides enhancing performance, reliability, and quality of service. With the introduction of SDN, the current satellite ground station networks will get great control and management flexibility in addition to a reduction of capital and operational expenses. The continuous reconfiguration needs in the satellite ground segment (for both hardware and software) are very challenging and complex. With SDN technology, this operation is facilitated compared to traditional networks.

Site diversity is one of the techniques used to enhance and maintain the communication link between the satellite and ground stations. In this technique, multiple ground stations are used as a backup in case of failure or fading in one of the operational links due to weather conditions.

This paper discusses the capability of using SDN for site diversity to enhance the satellite ground network system to achieve more reliable and controllable communications against problems that face satellite communications. The rest of the paper is organized as follows: Section 2 reviews the related work. Section 3 addresses Satellite network architecture. Section 4 gives an overview of satellite communication, and site diversity. Section 5 shows the experimental work to simulate the handover technique by means of SDN simulators. Finally, conclusions are stated in Section 6.

II Literature Review

Recently, SDN^[1] has emerged as a modern network architecture that provides direct network programmability and further levels of management, where the network centralized control is decoupled from data-forwarding. This architecture provides an abstraction of network services from the hardware of the network equipment. This allows the dynamic and flexible utilization of network resources in comparison with the static allocation which exists in traditional networks. Some papers have surveyed the topic of SDN, its design aspects, and its applications^[2] and some introduced a comprehensive survey^[3].

All the SDN capabilities are managed by a centralized machine which is the SDN controller. This controller monitors all network resources in high-level view and controls data flows within the network according to predefined policies and configurations. The controller is the brain and maestro of the whole network and the network switches only obey the controller commands and recommendations. This migration of network intelligence into a centralized entity provides this powerful level of

network control and saves a lot of time and cost beside simplification of network management. A lot of efforts have been devoted to such a critical part in the SDN network which is called the controller to achieve higher degrees of performance, reliability, modularity, and scalability.

The idea of programming the network has been introduced to cope with network evolution and extension. In SDN, the network intelligence is logically centered in the controller where the rest of network equipment like switches are abstracted for execution services only through the controller^[3] and these devices have turned out to be dumb forwarding devices. This mechanism leads to reduced complexity and cost of network equipment in addition to ease of reconfiguration and maintenance. SDN, in general, is a modern approach but it is growing so fast. The principle of separating the control plane from the data plane is represented in three layers^[2] as shown in Figure 1.

The first (lower) layer comprises the data switches forwarding devices (switches), the second layer includes the controllers, and the third (upper) layer includes the applications and management. The interfaces between the layers is through well-defined API.

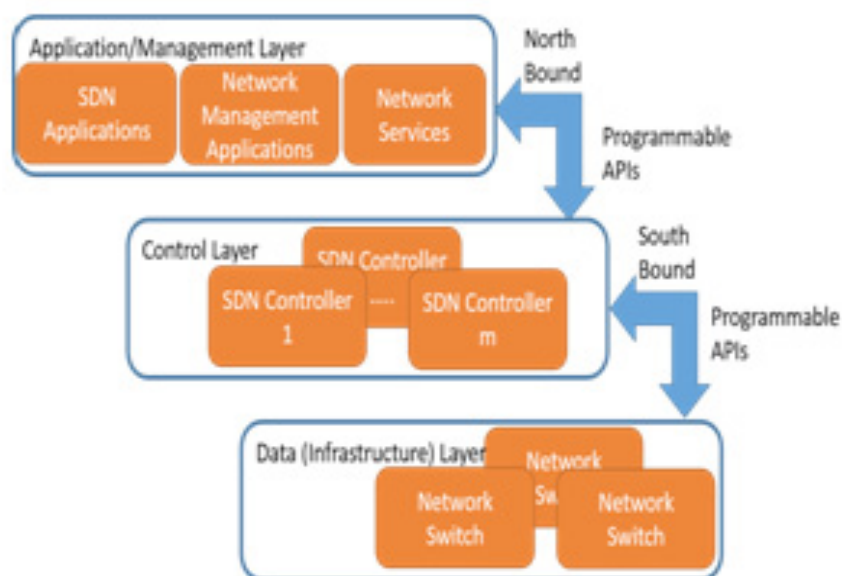


Fig. 1: SDN three layers

OpenFlow^[4] is the first standard protocol for the communication between the SDN controller and SDN forwarding switches^[1]. Open flow is an SDN control plane protocol which acts between the controller and network switches. It is implemented on both control and forwarding planes. Open flow works on the base of traffic per flow, it identifies network traffic according to predefined flow rules which is updated by the SDN controller. SDN controller monitors the network traffic and available resources then respond to the real-time changes according to pre-

programmed rules. OpenFlow is the only standardized SDN protocol that allows the possibility of reconfiguration of forwarding plane devices like switches^[1]. OpenFlow gives network administrators and managers the agility to program, configure, optimize, and balance the network resources dynamically from a centralized control location. Due to its programmability and flexibility, it provides the capability of controlling the behavior of the whole network. With the SDN technology application in many areas and new technologies like Network Function Virtualization

(NFV), new possibilities have emerged and more fields are covered especially satellite network framework. NFV introduces flexible provisioning and deployment in addition to the centralized management of network functions and services.

Network virtualization, in general, tends to create multiple independent networks over a shared resource. A virtual node which is an abstraction of a real network device hosted on a physical node carries out network functions like routing, forwarding, load balancing, etc. by taking a part of the available resources of the hosting node and some researchers have investigated the network services virtualization in a ground station^[5]. In NFV, the goal is to abstract network functions (NFs) away from dedicated hardware^[6]. After that, the software function is implemented on other hardware like a computer, a server, or even a virtual machine in the cloud as a service. This approach unleashes the power of using network functions regardless of the hardware or the physical equipment dedicated to this function which means a great decrease in Capital Expenditure (CAPEX) and Operational

Expenditure (OPEX)^[7] and improving the network performance in addition to the efficient sharing of network resources.

The integration of NFV with the SDN network leads to traffic routing agility^[8] and dynamic optimization of network resources and functions in addition to the benefits of centralized management. To not confuse SDN with NFV, SDN is for centralization of management and control whereas NFV is the act of virtualization of network functions. We can say Software-defined NFV impacts centralized management and network services virtualization to minimize the cost of service providing and maximize the utilization of the network resources. NFV framework is shown in Figure (2) NFV infrastructure relies on the abstraction of hardware components to be available as virtual resources. Virtual Network Functions (VNFs) are initiated and run upon these virtual resources with the help of management software known as orchestration. Orchestration manages, monitors and coordinates the required resources for providing the services of NFV.

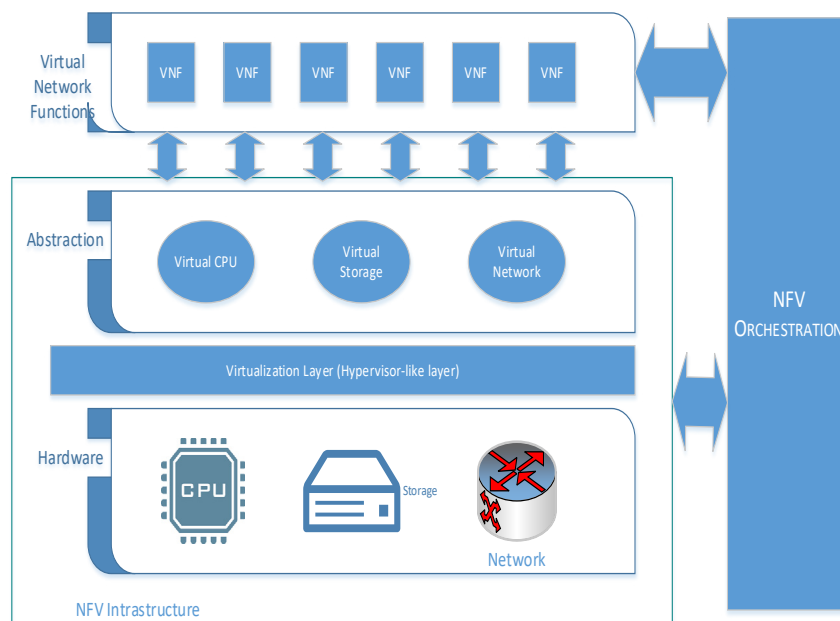


Fig. 2: NFV Framework^[7].

Many researchers investigated using SDN/NFV related to gateway diversity^[9,10] and these papers have done a great job in this area. Some other researches focused on using the SDN technology in the field of satellite communication^[11-15]. The authors in^[16] researched the enhancement that SDN and NFV can provide in case of site diversity scenario.

Some researches offer unified architecture for the integration between satellite network and terrestrial network using SDN and divided them into three SDN planes. In general, satellite and ground switches are located in the data plane for packet forwarding based on each

flow characteristic. Ground satellite station controllers are located in the control plane which accommodates all the SDN network intelligence and control and deals with handover and resource allocation^[17, 18]. Applications for interface management and networking are located in the application (management) plane^[19].

III. Satellite Network Architecture

Any space satellite system consists of two main parts, a space segment that is represented by one or more satellite (or a spacecraft) and a ground segment.

The ground segment is meant to be all equipment to maintain the satellite mission by sending commands and receiving telemetry information from the satellite in addition to user terminals which make use

of satellite link services. The satellite network architecture is shown in Figure 3, where 3 satellites are shown communicating with both user and control/management segments.

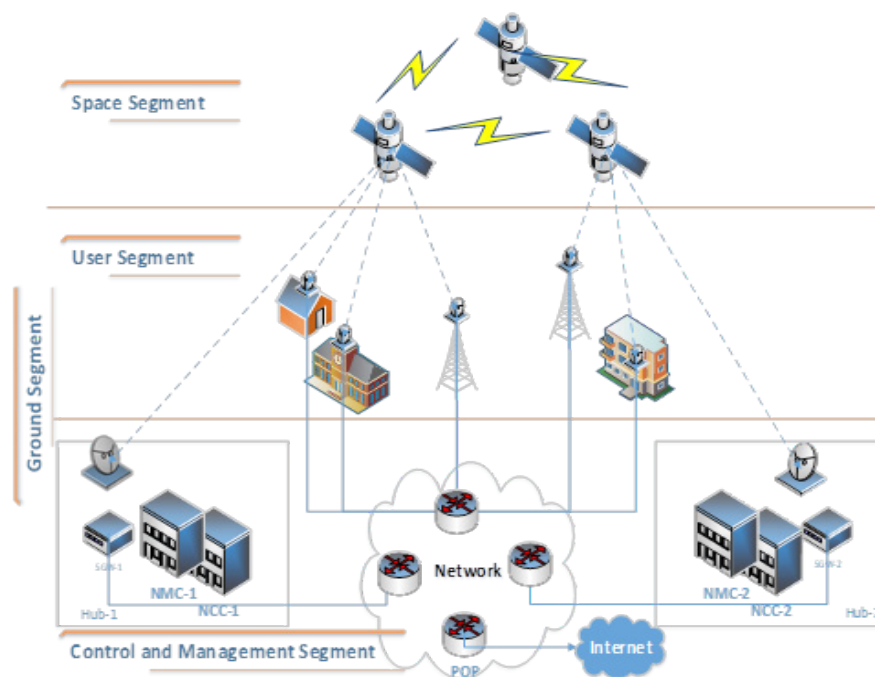


Fig. 3: Satellite Network Architecture

A typical communication satellite ground network, is shown in Figure 4. The user segment mainly consists of Gateways (GW), Satellite terminals (ST) and the ground segment backbone network is responsible for connecting all ground equipment, gateways, and user terminal together. A gateway provides internetworking functions between the satellite network and terrestrial network and it is a part of the hub's functionality.

The other segment which is the control and management segment mainly consists of Network Control Centre (NCC) which provides real-time control functions such as connections and resource allocation and Network

Management Centre (NMC) which provides non-real-time management functions like performance and security management. The combination of (GW/NCC/NMC) is denoted by a satellite hub. A Hub is a large ground station that supports two-directional communications with the satellite. It consists of an outdoor unit (ODU), a Forward Link Transmission Unit, a Return Link Reception Unit, a GW for connecting to external networks, NCC and NMC. Also, it includes some network devices to enhance communication with the satellite like Performance Enhancing Proxy (PEP) for optimizing the use of TCP protocol performance over satellite links.

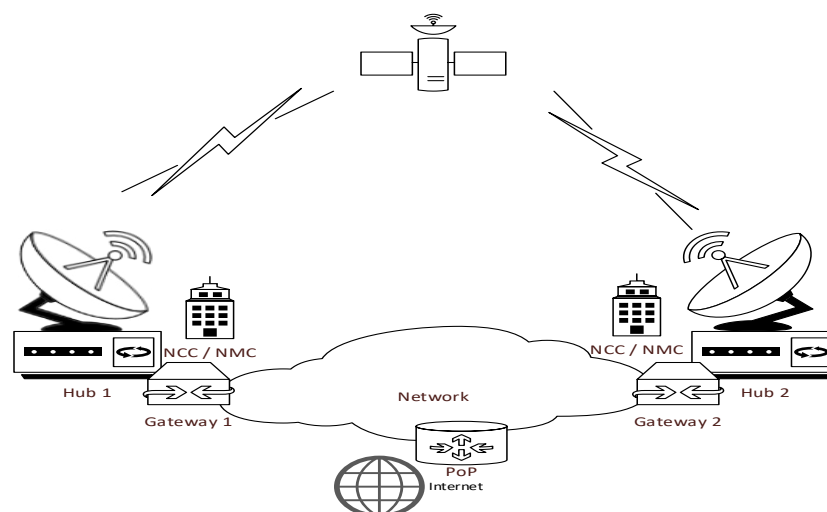


Fig. 4: Communication Satellite Ground Segment System Architecture^[20].

IV. Site Diversity in Satellite Communication

IV.1. Site Diversity Description and Current Practices

Site diversity^[5] is a technique from several techniques used for enhancing the reliability of the satellite communication system. It is used as a method to overcome the atmospheric effects especially rain attenuation at high-frequency bands such as KA or V bands). These bands and higher are more vulnerable to attenuation which leads to lower throughput and QoS (especially in real-time communications like media streaming and VoIP).

The site diversity technique is based on linking more than one ground station receiving the same signal from the same satellite together. This technique can improve the maneuverability between ground stations. If there are some communication link efficiency degradations due to weather disturbances over one ground station, the other remote station can take over the communication link. This concept is called site diversity.

IV.2. SDN in Site Diversity

SDN can help in the operation of gateway/hub handover for site diversity and facilitate a successful and efficient handover operation. It is required to make some minor modifications and additions to the ground station network to be able to make use of the SDN concept., as stated in the following points:

- An SDN controller t responsible for running the network application for gateway/hub handover management.
- OpenFlow switches in hubs
- NCC/NMC Interfaces for the link management and

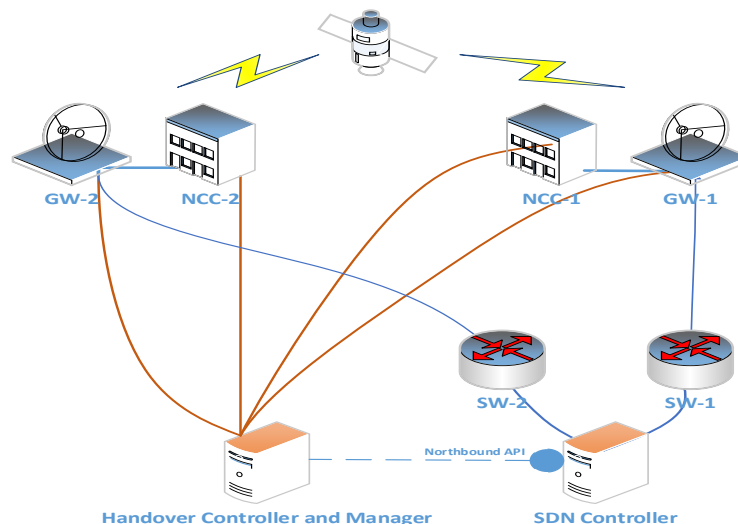


Fig. 5: Gateway Diversity using SDN General Layout

Due to SDN controller direct programmability and provision of simple network device management instead of complex means used nowadays in active networks, a predefined scripting language can be used

handover control application that monitors links traffic information and has the capability to change some satellite terminals configurations like routing tables.

Decision upon initiation the handover is according to the following variants:

- User QoS requirements / on-demand.
- Estimation of performance and available resources for satellite link and terrestrial backbone network.
- Emergency situations.

IV.3. Handover control/management application functions:

The related handover control/management application functions include the followings:

- Automatic detection of satellite link efficiency
- Monitoring of all system resources and status (communication links and terrestrial network)
- ST configuration change if required
- Mapping new routes in routing tables for satellite terminal (ST)
- Change SDN controller configuration to reroute traffic according to updated parameters from Handover management application
- Inform about frequency change if required.

SDN controller will redirect the traffic from the failed hub or gateways to the newly assigned one. SDN controller will update all routing tables for all SDN-enabled switches by OpenFlow protocol. The handover control/management application is installed in this site for seamless handover between gateways. Figure 5 shows the concept and general layout of system components.

to offer a message protocol between SDN controller, link management, and handover control application. Figure 6 shows interfaces of the three layers of SDN in case of using the handover control application. SDN

controller can provide real-time centralized management and control of all network traffic. With the ability to obtain real-time network status and predefined policies, this will lead to network configuration

optimization and overall network performance improvement^[13] in addition to customized on-demand networking with optimal utilization of network resources.

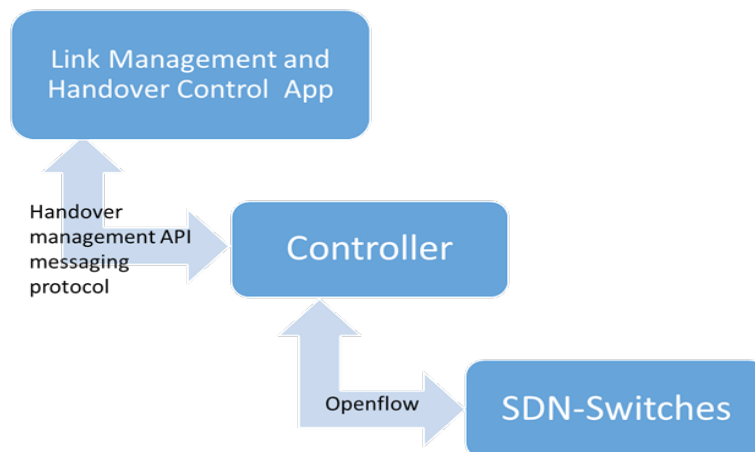


Fig. 6: Application of SDN layers and protocols

V. Experimental Work

The objective of the executed experiment is to compare between the effect of bandwidth throttling and throughput decreasing (due to link anomaly) on the data loss from one hand. On the other hand, the effect of switching delay between links on data loss during transition. Then a comparison will be held between the two scenarios to find the point at which to choose to switch to another link once the controller detects a decrease in link throughput taking into consideration the amount of data that will be lost in both cases according to the assumed scenarios.

The experimental framework has been implemented using Mininet simulator 2.2.2^[21] as the main SDN virtualization platform for our work. This gives the capability to emulate the SDN network and topologies at no cost. Floodlight controller is used for comparing different results and implementing different nodes on separate machines to simulate satellite nodes and different nodes simulating different hubs (sites) as shown in Figure 7.

The experiments were carried out on a Fujitsu Desktop PC Esprimo –P900 with the following specifications:

- CPU: Intel Core i7-2600, 3.4GHz
- RAM: 8 GB DDR3
- HDD: 500GB WD SATA
- OS: Linux Ubuntu-16.04.1
- Network emulator: Mininet simulator 2.2.2
- Virtual switch: OVS ver. 2.1
- SDN controller: Floodlight ver. 1.2

Design of the scenario components is as follows:

- OpenVirtual switch: consists of one or more flow tables and a group table, which perform packet lookups and forwarding, and an OpenFlow channel to an external controller. Once the switch receives a new packet, it searches for a rule which complies with this packet and forwards it upon this rule. If the switch did not find this corresponding rule, it sends the packet to the controller. Consequently, the controller updates the forwarding table in the switch with a new forwarding rule using the OpenFlow protocol for this received packet or any subsequent packets with the same forwarding rule. Forwarding tables contain some fields for identification of received packets such as IP address, MAC address, ports, and some forwarding matching rules assigned by the controller. The used version of the OpenFlow protocol is v1.4.

- SDN Controller: The used controller is Floodlight^[22]. Floodlight is a more advanced controller than other primitive controllers like POX. Floodlight controller has some advanced capabilities like the support of OpenFlow 1.4. Also, it has a web interface for monitoring system performance and showing the contents of the flow table in each of the connected switches.

- The used topology is a “partially mesh” topology as shown in Figure 7. Each node is represented by a host. In the topology, a satellite is represented by a node and another two nodes to represent the main hub (hub-1) and the backup one (hub-2) in addition to another node to represent a user satellite terminal(ST) All nodes are connected to OpenFlow switches and all switches are connected to the main controller.

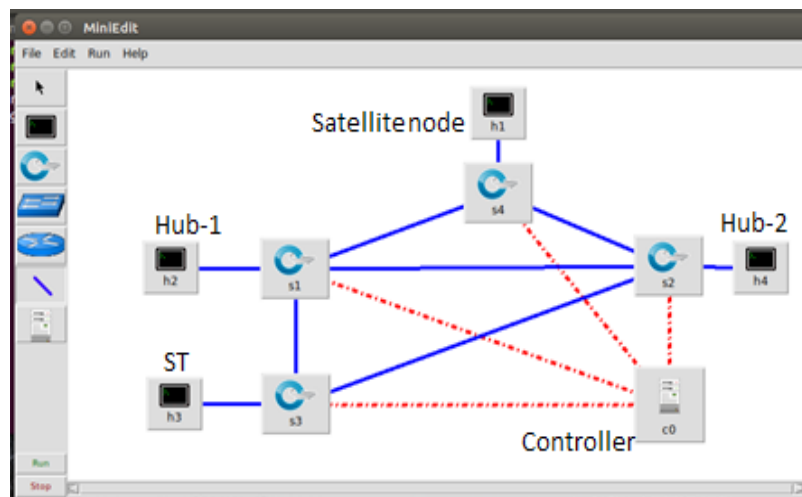


Fig. 7: Basic topology used in the experiment

All test instructions are stored in a testing script which is composed of Linux Bash commands. Fortunately, Mininet uses a queuing hierarchy which is managed by TC (Traffic Control). The testing script uses TC commands to manipulate links in Mininet in real-time. The

TC command allows attaching any queuing discipline to any network interface. These commands are used by Mininet to control and manage links. Figure 8 shows the general steps for performing the scenario test.

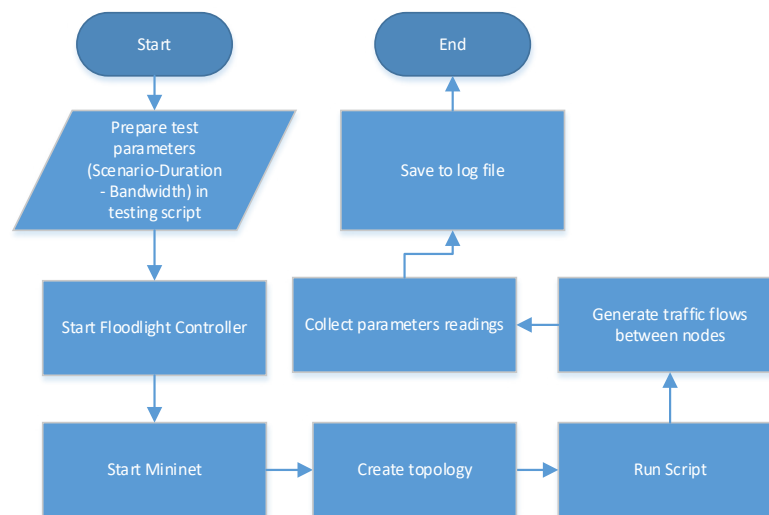


Fig. 8: Flowchart describing how to perform a test

The generation of traffic is carried out with the iperf tool. Iperf is a network testing tool that is commonly used to measure the throughput of the network through TCP and UDP streams by generating random traffic. It can also measure the bandwidth (bit rate) between two nodes to test the link quality. It has a server-side and client-side. One node is defined as a server and the other one as a client. It runs on the Linux platform and can be accessed through Mininet to achieve scenario tests.

The testing scenario assumed the use of a 300Mbit/sec bandwidth links between switches, controller, and for every link in the emulated topology. The testing scenario depends on decreasing bandwidth every 10 seconds from 300Mbit/sec until reaching bandwidth of 20 Mbit/sec using a testing script. Figure 9 shows the relationship between bandwidth and throughput during the scenario period with time as the third axis in the fully utilized link.

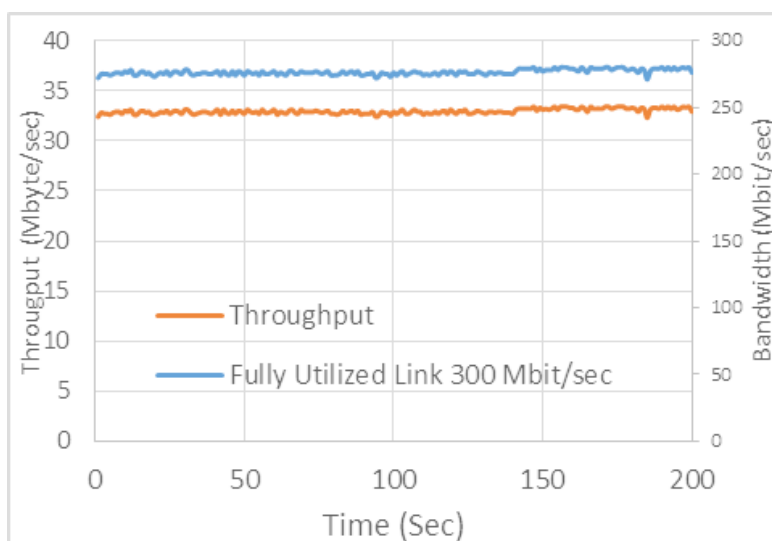


Fig. 9: Fully Utilized Link Throughput-Bandwidth Relationship

The fully utilized link does not encounter any throttling. This case was considered to be a reference for other tests. A comparison will be made with other scenarios to show the percentage of loss in each scenario compared to this reference. Scenarios are repeated on the same basis until

reaching 20 Mbit/sec in the last scenario. In each scenario, the bandwidth is decreased for more than 20 Mbit/sec (according to the script and flowchart in the previous section). The plot for bandwidth throttling to 20 Mbit/sec scenario is shown in Figure 10.

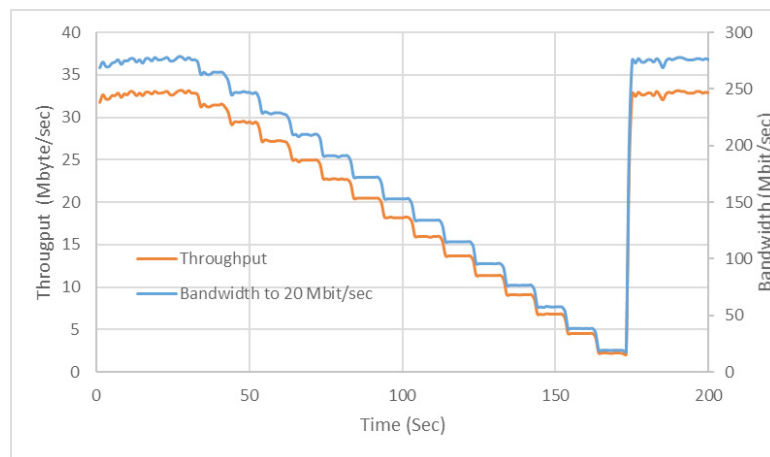


Fig. 10: Decreasing link bandwidth to 20 Mbit/sec

The other testing scenarios depend on results from the performed tests corresponding to switching delay between data exchange links in different testing scenarios. Switching delay means the period of time needed for the controller to detect a link failure and then reroute the traffic to an alternative link. The testing scenario assumed the use of a 300Mbit/sec bandwidth links between switches,

controller, and for every link in the emulated topology. The testing scenario depends on changing the switching delay in the controller after detecting a faulty or downlink. The switching delay is affected by the configuration of the controller and the topology of the network (number of nodes, length of links). The results include monitoring of switching delay and its effect on throughput.

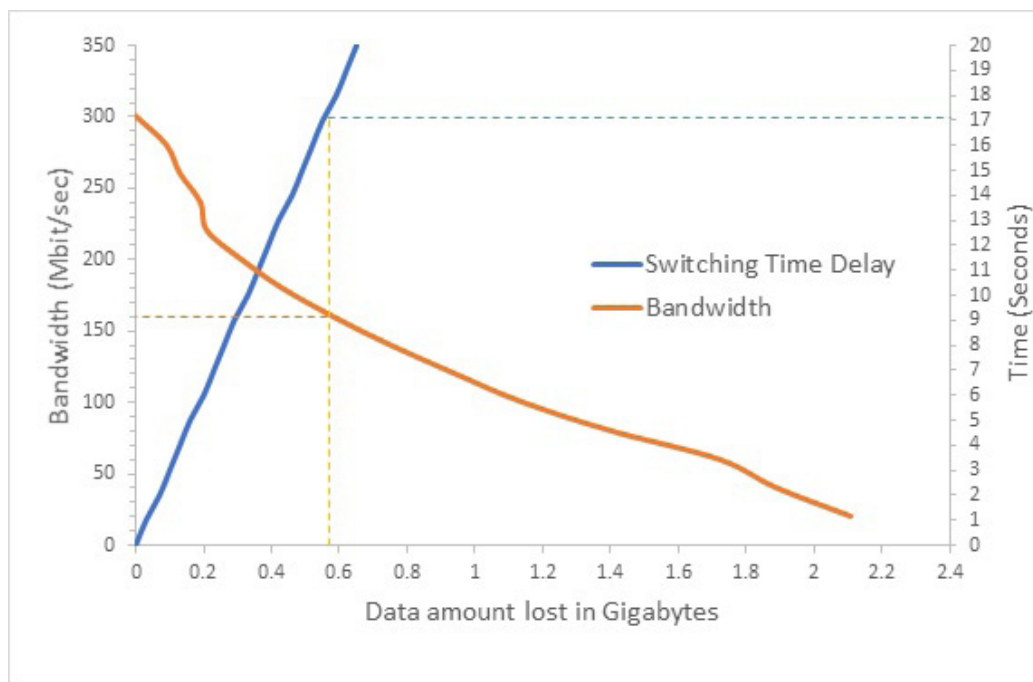


Fig. 11: Relationship Between Decreasing Bandwidth and Throughput w.r.t Switching Time Delay

Figure 11 combines bandwidth and switching delay with lost data to find a relation between them. The graph has one horizontal axis for showing the amount of data lost in Gigabytes and two vertical axes. The primary vertical axis to show bandwidth and the other secondary axis for the time in seconds. The two curves have been plotted to find the exact point at which the choice to switch the working link after losing about 10% of data in case of link fading or attenuation. This 10% of data was calculated and estimated before, upon the executed scenarios with about 0.6 GBytes of traffic data (which is estimated from the reference scenario of the fully utilized link). As shown in the graph, the least allowed bandwidth which will not exceed these losses according to the executed scenarios is about 160 Mbit/sec. Beyond this bandwidth value, losses will exceed 10%. The same amount of losses (10%) will be reached in seventeen seconds of link switching delay using the reference scenario of a fully utilized link. So from testing scenarios analysis of results obtained, to not lose more than 10% of throughput, link must be switched if bandwidth falls to 160Mbit/sec or the link is down for about 17 seconds.

VI. CONCLUSION

The presented work has shown the effect of bandwidth reduction and controller switching delay on throughput. By applying so many scenarios for these two approaches, an analysis was introduced to help take the decision of changing the operating link after bandwidth loss to a certain value. The approach guarantees no more than 10% of data to be lost to achieve a higher degree of QoS. The scenarios carried out and the results of handover

methodology have shown great potential in combining SDN with satellite ground networks.

SDN offers simplicity, centralized network management, better performance. Applying SDN satellite ground station system architecture shall enhance the overall network reliability and how far this network will sustain in the face of anomalies such as a drop of links throughput which heavily impacts the performance. In case of a link failure, the introduced technique shall maintain a higher system throughput and performance during handover relative to traditional methods.

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