OpenSAN: A Software-defined Satellite Network Architecture

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ABSTRACT
In recent years, with the rapid development of satellite technology including On Board Processing (OBP) and Inter Satellite Link (ISL), satellite network devices such as space IP routers have been experimentally carried in space. However, there are many difficulties to build a future satellite network with current terrestrial Internet technologies due to the distinguished space features, such as the severely limited resources, remote hardware/software upgrade in space. In this paper, we propose OpenSAN, a novel architecture of software-defined satellite network. By decoupling the data plane and control plane, OpenSAN provides satellite network with high efficiency, fine-grained control, as well as flexibility to support future advanced network technology. Furthermore, we also discuss some practical challenges in the deployment of OpenSAN.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Centralized networks, Network communications

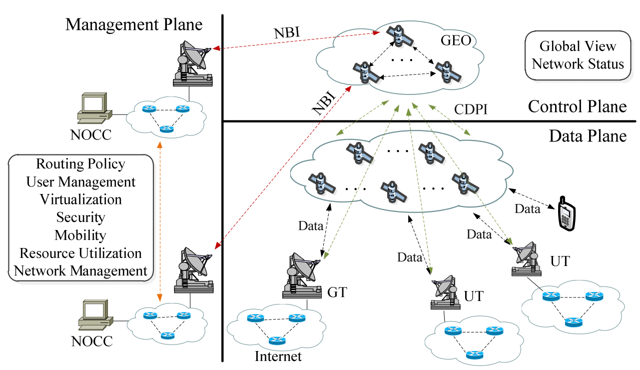
Keywords
Satellite Network, Software-Defined Network

1. INTRODUCTION
In recent years, the development of satellite technologies such as OBP and ISL has greatly promoted the development of satellite network [1]. The traditional approach of satellite network is bent pipe, which means that all the packets are transmitted from transmission terminal to an intermediate station, and then relayed to the reception terminal. This approach simplifies the architecture of satellite payload, but leads to a long latency because of two-hop communication. The OBP indicates that the satellite payload has the capabilities to support signal regeneration, packet switching and so on. Compared with Bent Pipe, OBP enhances the utilization of resources and decreases the communication time. There are two types of OBP according to its orbits. One is GEO, such as IRIS. The IRIS JCTD placed an IP router payload on a Geostationary Earth Orbit (GEO) satellite to accelerate network-centric capabilities in space [2]. It has a great improvement in the delay compared with bent pipe technology. The other one is Low Earth Orbit (LEO)/ Medium Earth Orbit (MEO), such as Teledesic. Teledesic is a constellation of Low Earth Orbit (LEO) communication satellites connected by ISL. The advantage of LEO with OBP is small delay and full connectivity, but it makes the management and routing more complex [3]. Since the OBP supports on-board switching and the satellites connect with each other by ISL, applying the mature and future advanced technologies of terrestrial Internet to satellite network become possible.

However, there are many difficulties to build a future satellite network with current terrestrial Internet technologies. (1) The resources of satellite nodes are severely limited. (2) The satellite network is closed and scheduled, so the maintenance, upgrade and expansion of satellite network are difficult. (3) As the topology changes frequently, it is difficult to maintain the stability of satellite network. The static routing algorithm used in satellite network which is called snapshot is inflexible and lacks the ability of fault tolerance. However, the dynamic routing algorithm is resource-consuming. Therefore, it requires a mechanism to balance the flexibility and cost. (4) The number of new services and applications increases fast, but the satellite payload cannot identify various kinds of new services.

To address the above issues, we propose OpenSAN, a novel architecture of software-defined satellite network. By decoupling the data plane and control plane of each satellite [4], OpenSAN provides satellite network with efficiency, fine-grained control, as well as flexibility to support future advanced network technology.

2. AN OVERVIEW OF OPENSAN
The overview of our software-defined satellite network architecture is shown in Fig. 1. It contains three parts: Data Plane (Satellite infrastructure, terminal router), Control Plane (GEO Group) and Management Plane (Network Operations and Control Center).



GT -- Gateway Terminal; UT -- User Terminal ;NOCC -- Network Control Center
CDPI -- SDN Control to Data-Plane Interface; NBI -- SDN Northbound Interfaces

Figure 1. The Architecture of OpenSAN

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2.1 Data Plane: Satellite infrastructure

The data plane consists of the terminal router distributed around the world and the multi-layered satellite infrastructure (such as GEO, MEO, LEO). The satellites and routers run flow table "match-action" protocol and focus on packets forwarding. The protocol matches the header of each packet such as IP address, port and user-defined segment to support forwarding, multicast, virtual network, access management, IPv6 and so on. The multi-layered satellite network has distinguished features. For example, the GEO satellite has a long delay but its link is reliable. On the contrary, the delay of LEO satellite is short. Therefore by choosing different routes, the multi-layered satellite network can guarantee the QoS of various services.

Since OpenSAN decouples the satellite and router from the control plane, the data plane is more flexible and controllable based on fine-grained flow table. And it also makes the device tend to be standard and decreases the cost.

2.2 Control Plane: GEO Group

Due to the ability of reliable link, wide coverage, broadcasting and stationary to the ground, the GEO satellite is suitable to control the data plane. As three GEO satellites can cover the earth, the GEO Group consists of at least three GEO satellites to cover the whole data plane. GEO Group is a logically centralized entity which focuses on 1) translating the rules from management plane to the data plane, 2) monitoring the satellite network's status (link status, network traffic, different flow status) information through CDPI interface, and then sending to the management plane for an abstract view of the satellite network. Compared with the traditional satellite monitoring and control system, OpenSAN reduces the number of ground stations and simplifies the process of control flow.

As shown in Fig. 2, there are three topologies of GEO Group distinguished by reliability and complexity. In Fig. 2(a), the GEO controllers communicate with NOCC via a primary GEO, this topology is suited to a small scale of data plane. In Fig. 2(b), the topology chooses a primary Ground Station to centralized relay the packets, which reduces the burden of primary GEO. And in Fig. 2(c), the topology increases the reliability by distributed NOCCs, but it requires a protocol to keep the consistency of satellite network.

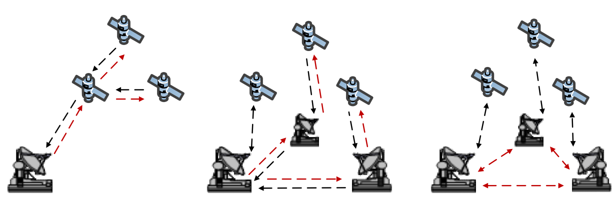

Figure 2. The topology of GEO controller

2.3 Management Plane: NOCC

NOCC is the management plane of the multi-layered satellite network. It runs different modules for various kinds of applications, such as routing policy calculation, virtualization, security, resources utilization and mobility management. The applications depend on the satellite network's status provided by GEO Group. For example, when a mobile terminal joins the network, NOCC has to recalculate routing policy and translate the new flow table down to data plane.

3. PRELIMINARY ANALYSIS

The centralized topology of OpenSAN has a significant progress in decreasing the link bandwidth compared with the traditional dynamic routing protocols. For example, OSPF routing protocol sends $O(n^2)$ packets, n is the number of routers. All link states are broadcasted to every router and each of them calculates the route based on the Dijkstra algorithm. In OpenSAN, the GEO Group needs to collect the status of data plane, and the NOCC performs routing calculation. Then it broadcasts the route updates to the data plane leading to a $O(n)$ cost.

4. DYNAMIC SDN CONTROL STRATEGY

Different from traditional fixed or mobile networks, the satellites (mainly LEO) in the Data Plane run quickly around the earth, which makes the topology of the whole network change frequently. And another problem is that the user traffic changes with the time and location. All these characteristics of satellite network pose challenges to the present SDN control strategy.

Fortunately, the satellite is regular and predictable. So the applications and controller can predict the status of the whole network. In OpenSAN, we can use prediction-based algorithm such as neural network to aware the change of the whole network. Combining with back-up flow table, it can avoid the disruption of service. And we will further explore the design of NBI and CDPI to achieve a reliable and efficient control path.

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