Software Defined Integrated Satellite-Terrestrial Network: A Survey

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Abstract. SDN paradigm has successfully manage to pave the way toward next-generation networking, but the research on SDN-based integrated satellite and terrestrial network has just started. SDN-enabled management and deployment architecture of integrated satellite-terrestrial network eases the complexity of management of infrastructures and networks, improves the maintaining and deployment costs, achieves efficient resource allocation and improves network performance of overall system. In this paper, we started introducing the SDN-based integrated satellite-terrestrial network architecture and discuss the unified and simple system functional architecture. Then we illustrate the two fundamental aspects of integrated network application functions. Following the demonstration of recent research works, we identify three challenges and discuss the emerging topics requiring further research.

Keywords: Software defined networking · Integrated satellite-terrestrial network · Network architecture

1 Introduction

The integration of satellite and terrestrial networks has been brought into research and discussed for years [1]. Back then, the satellite network has not been fully developed, the costly deployment and bandwidth resources limit it for valued uses, such as emergency response, military missions, world-wide operations and so on. With the rapid development of satellite technologies, satellite networks find the path for casual use, wide applications: communication, data transfer, remote sensing and Hi-Fi observation, and even Internet browsing. The satellite network can be integrated as one high-delay path, as complementary to terrestrial fixed and mobile access so that to increase QoS and QoE level delivered to end-users. In this context, satellite network shows that it is an essential part in the future heterogeneous networks (shown in Fig. 1): television broadcast, back-hauling of data in remote areas, instance mobile telephony, aircraft telecommunication services, and so on.

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Software defined and network virtualization technologies are also positioned as central technology enablers towards improving and more flexible integration of satellite and terrestrial systems [2]. SDN has been developed in terrestrial networks and achieved promising results. While the development of SDN-based satellite network has just started [3]. Essentially, SDN separates the data plane that only forwards packets and control plane, which is the centralized management of networks. In this case, it simplifies the connectivity of complex and heterogeneous infrastructures. It presents global network view and certain central control ability. This improves the collaboration between satellites and the compatibility of heterogeneous space systems. With all the benefits and advance SDN technology brings, how does the SDN technologies enhance the network performance and deliver high-level service quality in such integrated networks is worth investigating. Thus, in this paper, we summarize the technologies and research works have been done in each area, to discuss the research aspects, and hopefully to point out the research directions for the SDN based integrated system.

This paper investigates how SDN/NFV technologies can enhance the operation of satellite networks and the development and management of communication services across integrated satellite-terrestrial configuration variants. The advanced and newly brought-up techniques, schemes and the requirements are introduced. Besides, some challenges and possible directions are discussed in this area. The remainder of this paper is organized as follows. In Sect. 2, the network functional architecture is discussed. Section 3 illustrates the design aspects in network applications. Section 4 identifies some research challenges and points possible directions. Finally, Sect. 5 comes the conclusion.

2 Architecture of SDN-Based Integrated Satellite-Terrestrial Network

It is of utmost importance that next generation network architecture support multiple layers and heterogeneity of network technologies including satellite communications, WLANs, cellular networks and also kinds of terrestrial ad-hoc networks (shown in Fig. 1). In this integrated system, the communications happen in a wide range: communications between satellites and terrestrial, communications within terrestrial different networks, and also inter-satellite communications. SDN paradigm represents an opportunity to make it easier to deploy and manage different types of networks, including satellite networks, WLANs, and cellular networks. One of the most notably opportunities SDN technology provide is the simplification of management. The new SDN-enabled management and deployment architecture of hybrid satellite-terrestrial network eases the complexity of management of infrastructures and networks, improves the network performance of overall system, and decreases the maintaining and deployment cost. SDN-based implementation of hybrid architecture can bring the appropriate control level that current protocols and mechanisms cannot efficiently achieve.

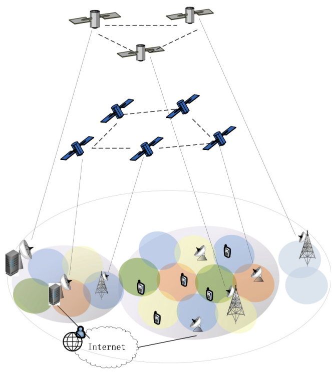

Fig. 1. Illustration of integrated satellite and terrestrial networks.

Based on the recent researched carried our, a unified functional architecture for SDN-based integrated satellite-terrestrial network is illustrated and shown in Fig. 2. Networks can be divided in three planes of functionality: the data, control, and management planes. Generally, the data plane consists of satellite and terrestrial switches and simply performing flow-based packet forwarding. Management plane includes networking applications, service interfaces, and network status management. Different network characters need to be monitored in this layer. The control plane consists of controllers located in the earth stations and terrestrial networks, which centralize all the network intelligence and perform network control for routing, handover, resource allocation and so on. Fallen within this range, research works has been focused on different aspects, and varies mainly on the design of controllers and switches.

Paper [4] introduces an SDN-enabled satellite/ADSL hybrid architecture. The SDN controller can be hosted at the service operator. In this case, the network application is running on top of the controller. Based on the data flow identifications and the designed dynamic forwarding rules, the data flow can be dispatched to the most appropriate link temporarily and dynamically to achieve its QoS requirements, with satisfying efficient utilization of different transmission links. In this case, the service provider allocates all its possessed resources including both satellite and terrestrial available bandwidth for different application requirements. However, instead of obtaining global vision, this kind of controller design achieves only partially/locally revision. Authors in [5] proposed a software-defined satellite network architecture-OpenSAN, which contains data plane, control plane and management plane. Data plane consists of multi-layered satellite infrastructures (e.g. GEO, MEO and LEO) and terminal routers distributed around the world. Control plane consists of the three GEO satellites which covers the whole data plane. The control plane GEOs communicate with terrestrial network by a centralized control center (NOCC) via a primary GEO, or by distributed NOCCs to increase the reliability. The NOCC is the management plane of the multi-layered satellite network. In this kind of architecture, the control plane-GEO group monitors the networks status (link status, network traffic, different flow status) information, and transmits the information to management plane-NOCC. Based on the various applications and schemes, NOCC runs different modules, such as routing policy calculation, virtualization, security, resource utilization and mobility management. After this, NOCC transmits the calculation results (e.g. new flow table) down to data plane. Data plane is responsible for translating the rules from management plane to data plane, and finally data plane (e.g. satellites and routes) run flow table match-action protocol and only focus on packets forwarding.

Authors in [6] proposed a new hybrid control structure with information forwarding through single layer inter-satellite links and GEO satellites broadcasting. Authors in [7] propose the integrated terrestrial-satellite software defined networking functional architecture. The paradigm shift towards virtualization of infrastructure components, pushes towards a cloud-based model for network resources and functionalities management. Control intelligence is centralized in the control layer which translates the upper layer instructions to configurations and date structures for infrastructure layer. Terrestrial and satellite network resources are federated in this layer, and the virtualized network slices are provided to the application layer users.

3 Network Functions

This section discusses the networks functions which implement control logic and dictate the behaviour of the forwarding devices. Despite the wide variety of use cases, the most essential and vital two SDN network functions are: resource management and routing mechanism.

3.1 Resource Management

The traditional resource-oriented resource management methods are no longer competitive for the largely increasing service requirements in the integrated networks. SDN-based flexible satellite resource management has been developed to advance the typical satellite broadband access service with the customer to be able to dynamically request and acquire bandwidth and QoS in a flexible and elastic manner [7]. This is to introduce more dynamicity in radio resource management of the satellite links. It optimizes the utilization of network resources, but also makes it possible to perform the network configuration, dimensioning and adjustment in real-time to fulfill the customer's expectation. Furthermore, the resource of satellite and terrestrial access networks can be federated, which means the pooling of different resources from two or more heterogeneous domains in a way to create one logical federation of network resources enabling easier control and allocation of these resources. That is to say, the network resources can be seen to transient among the networks, such as Wide Area Network (WAN), 5G networks, and satellite network for connectivity during a specific time period for service provision. This procedure can be generalized to provide the different QoS and service classes dynamically and on the fly [8]. Even in such resource federation case, the handover among different network domains and different network accesses is still necessary underlying. Authors in [9] propose a seamless handover in software defined satellite networking, but only in satellite networks.

Such SDN-based flexible federation of satellite and terrestrial networks requires efficient traffic control and traffic engineering. The main goal the traffic engineering is of minimizing power consumption, maximizing average network utilization, providing optimized load balancing and other generic traffic optimization techniques. Load balancing is one of the first to be envisioned. It distributes the traffic among the available paths/network links and among the available servers, taking into consideration of network load, link conditions, and server capacities. In this case, load balancing service alleviates the network congestions, avoids bottleneck situations, and simplifies the placement of network services in the network to provide more flexibility to network overall utilization and network servers. Thus, traffic optimization is especially important for large- scale service provider in a large integrated system, where dynamic scale-out is required. Recent work has shown that the optimizing rules placement can increase network efficiency. Traffic engineering is a crucial issue in all kinds of networks, thus, upcoming methods, techniques, and innovations can be expected in the context of SDN-based integrated satellite-terrestrial networks [10].

3.2 Routing and Networking

Routing is always the basic and important function in any network, where the priority job is to guarantee the end-to-end delivery of data packets. To achieve this goal, routing schemes are to define the path through which packets will flow from one point to another, based on network feature input. And efficient and intelligent routing protocol should be able to provide flexible adjustments for various network conditions. Diversity of network participators, the complexity and dynamic network topology raises the challenge for adaptive routing mechanism in SDN based integrated satellite-terrestrial network to achieve the internetworking within the same domain and across different network domains. In traditional integrated satellite-terrestrial networks, the interoperability of different protocols is one of the main issues, while with the SDN paradigm, the rules and regulations are the same for the overall system, components of system follow the same instruction, which erase this problem already.

The most effective aspects of routing in such system include deal with frequently changing of network topologies, and guarantee of QoS requirements of various services [11]. Firstly, the largely and highly dynamic topology changing leads to dynamic network nodes and control nodes (e.g. relatively high velocity of satellites and terrestrial terminals), which brings in much more difficulties

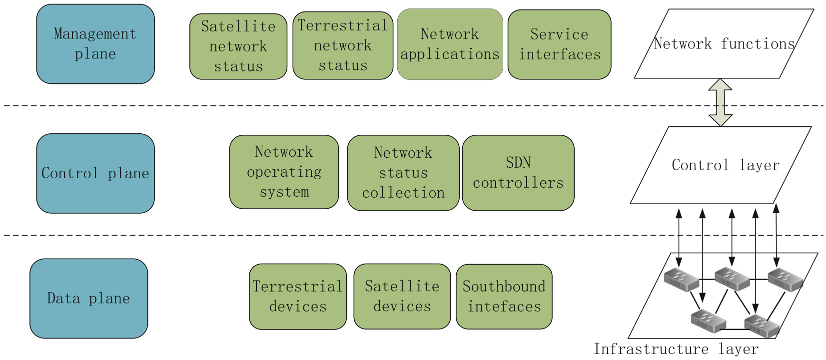

Fig. 2. Software defined integrated satellite-terrestrial networking functional architecture.

for the routing mechanisms. As the topology of both satellite and terrestrial network changes, it is difficult to maintain the stability. The static routing is clearly not suitable for such large delay network, and the dynamic routing, on the other hand, is quite resource consuming. Beside, the accusation of network status is important in such networks. The control messages, which demonstrate the network conditions, need to be delivered across different planes in SDN-based system architecture, which increases the control overhead. Hence, a scheme with trade-off between flexibility and control cost is essential for the SDN-based integrated network [6]. Secondly, one of the cases can be envisaged when taking into account Quality of Service (QoS) is that QoS oriented routing protocol. The routing mechanisms are developed to choose the best route depends on the QoS parameters and link quality. Different metrics (e.g. delay, loss rate, jitter and throughput) can be used in path selection algorithms to achieve high level of service satisfaction under specific objectives. For example, different service applications (e.g. voice call, data transfer, and video streaming) require various aspects and levels of service quality (e.g. short delay, high bandwidth and high secure). While in integrated satellite-terrestrial network, (such as GEO satellites provide long delay and world-wide transmission, LEO satellites can deliver low delay to internet browsing but costly, and the terrestrial links guarantee the low delay and probably high bandwidth). How to develop such comprehensive application-aware routing mechanisms to achieve the best use of the integrated network is of vital importance [9].

4 Ongoing Research Efforts and Challenges

This section highlights research efforts we consider of particular importance for unleashing the full potential of SDN, mainly in three aspects: flexibility and scalability, security, and performance evaluation.

4.1 Flexibility and Scalability

Network virtualization technology is to reduce the satellite network operator costs, this leads to a fast and easy upgrade and replacement of these functionalities but also flexibility to deployment of new innovative functions. Virtualization principles are applied to physical network infrastructure, abstracting network services to create a flexible pool of transport capacity that can be allocated, utilized and repurposed on demand. Essentially, network virtualization in integrated satellite-terrestrial network includes infrastructure virtualization and resource virtualization. The virtualization of radio resources is to abstract and share a number of network resources. Virtualization of network functions enables the centralized upgrade and maintenance of SDN-based architecture instead of operated on infrastructures [12]. For example, with the network virtualization paradigm, PEP (performance-enhancing proxy) will no longer be implemented as a dedicated middelbox but rather in software that can be run on different devices. In this way, the PEP function can be dedicated to a communication context (e.g. dedicated to an ST (satellite terminal)) and can be tuned according to the application requirements (security, mobility, performance, etc.). In this way, if an ST makes a handover from one satellite hub to anther, its dedicated virtual PEP will migrate to the new hub and will continue to performance the appropriate TCP optimization [3]. However, the virtualization of network functions should be developed in a unified and consistent way.

The modularity and flexibility of composition of controllers are still ongoing research. With the virtualization technique, SDN has the potential to facilitate the deployment and management of network applications and services with greater efficiency. However, SDN techniques to-date, largely target infrastructure-based networks. They promote a centralized control mechanism that is ill suited to the level of decentralization, disruption and delay present in infrastructure-less environment. In integrated satellite-terrestrial networks, the traditional centralized control mechanisms cannot be adapted and suitable for the large-scale and largely-increasing service requirements. As the essential design of SDN technology, the architecture of control plane are critical for the flexibility and scalability of integrated system.

4.2 Security

Security is the essential problem in all kinds of networks. There is a crucial need to assure the privacy and security of residents in such heterogeneous networks. Being highly programmable makes the potential impact of threads far more serious in SDN, compared to traditional networks. The research in SDN-based security is still on the early stage. Thus, security is one the top priorities in such network and more effort should be put in future researches. Possible challenges and future directions for security in SDN-based integrated satellite-terrestrial network could be classified in several groups. Firstly, some thread vectors should be identified and followed: faked or forges traffic flows in data plane, which can be used to attack forwarding devices and controllers; faulty or malicious controllers or applications in controller plane, which can be used to reprogram the entire network and grant an attacker the control of the network; lack of trusted resources for forensics and remediation, which can compromise investigations and preclude network recovery to safe condition. Secondly, orchestrating security policies across heterogeneous networks is crucial. Mechanisms, which translate security privileges across domain boundaries, are needed to enforce a uniform federated security policy in a seamless and efficient manner. Last but not least, customizing overlay networks could be used to provide secure environments [13].

4.3 Performance Evaluation

With the benefits SDN paradigm represents, a growing number of researches and experiments about SDN-based integrated satellite-terrestrial networks are expected in the near future. This will naturally create new challenges, as questions regarding SDN performance have not yet been properly investigated. Some OpenFlow based implementations have been developed for simulation studies and experimentations for the SDN-based network architecture. Except for the widely used time-consuming simulation and expensive experimental techniques for performance evaluation, analytical modeling could, in another way, draw the description of a networking architecture which paves the way for network designer to have a quick and approximate estimate of the performance of their design. Despite of the evaluation of network architecture, there are also other designed mechanisms to be evaluated. When it comes to routing mechanisms, resource allocation algorithms, and networking schemes, analytic models can quickly provide performance indicators. They can be used to capture the closed form of certain network performance, such as packet delivery rate, packet delay, buffer length, network throughput, network blocking probability and so on. Although a wide range of research works proposes SDN-based networks, there are very few performance evaluation and analytical modeling studies about these works, even for terrestrial networks, let alone for the integrated satellite - terrestrial network.

4.4 Migration and Integrated Deployment

With the benefits SDN paradigm represents, the large amount of research results, and the achievements of software-defined radio technologies, the SDN-based integrated network is reaching the migration challenge regarding with the incremental deployability. Some efforts have already devoted to the migration and hybrid SDN engineered with the current network infrastructures. The fundamental step will be allowing the coexistence of traditional environments of routers and switches with the new OpenFlow-enabled devices. Next step is to ensure the interconnection of control plane and data plane of legacy and new network elements. The initial SDN operational deployments are mainly based on virtual switch overlay models or OpenFlow based network controls. The controllers are designed to introduce SDN-like programming capabilities in traditional network infrastructures, making the integration of legacy and SDN-enabled networks a reality without side effects in terms of programmability and global network control. Future works are required to devise techniques and interaction mechanisms that maximize its inherited benefits while limiting the added complexity of the paradigm coexistence.

5 Conclusion

Traditional networks are complex and hard to manage since the control and data planes are vertically integrated. SDN creates an opportunity for solving this problem - decoupling of the control and data plane. The global view of network is logically centralized in control plane and packets delivery is highly efficient in data plane. SDN brings flexibility, automation and customization to the network, SDN paradigm represents an opportunity to make it easier to deploy and manage different types of networks, including satellite networks, WLANs, and cellular networks. SDN has successfully manage to pave the way toward next-generation networking, but the research on SDN based integrated satellite and terrestrial network has just started. In this paper, we started introducing the SDN-based integrated satellite-terrestrial network architecture and discuss the unified and simple system functional architecture. We illustrate the two fundamental aspects of integrated network applications. Following the demonstration of recent research works, we identify four challenges and discuss the emerging topics requiring further research.

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