Application Scenarios based on SDN: An Overview

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Abstract—As a new network concept, SDN subverts the vertical structure of traditional network integration, decoupling the control plane and data plane of the network, replacing distributed control with centralized control, and transforming the closed network into an open one. Programming platform to promote the innovation of network applications, in order to deeply study the application of SDN, we put forward the concept of "SDN+", which combines SDN with different network scenarios to provide a new paradigm for network applications. The article analyzes the architecture of SDN and investigates the application of SDN in different scenarios.

1. INTRODUCTION

The digital society established by the Internet connects almost everything and can be accessed anytime, anywhere. The hierarchical structure of the traditional network promotes the rapid development of the Internet. The traditional network adopts distributed control, and the control plane and the data plane are closely coupled. However, for the complexity and scalability of the current network requirements, the traditional network gradually exposes architectural defects, including three aspects: 1) closed network deployment management is difficult; 2) flow control requires high network operation and maintenance costs; 3) distributed architecture limits network configuration and network innovation.

In 2006, SDN (Software-Defined Networking) was born in the Stanford University Clean Slate project funded by the GENI project in the United States. The purpose of this project is to reinvent the Internet and change the existing network infrastructure. The concept of SDN came into being.

SDN is essentially a new type of network architecture or a network design concept, which uses IT technology to soften the network. Moreover, SDN is application-centric and software-based. The comparison between SDN and traditional network architecture is shown in Figure 1. The SDN network architecture has three layers, which are the application layer, the control layer and the data layer, from top to bottom, as shown in Figure 2. The core of SDN technology is to separate the control plane and data plane of the network, and make the network open and programmable through centralized control. By separating the control plane in the traditional network equipment from the hardware, using the gradual generalization and standardization of the underlying hardware, the entire virtualized network layer is loaded on the physical network, laying the foundation for the introduction of virtualization technologies such as NFV. The application layer is composed of some applications, which are connected to the control layer through the northbound interface, thereby programming the underlying device and developing various business applications according to the needs of the user. The control layer is responsible for formulating the flow table to issue commands to the data layer, maintaining...
topology state information of the entire network, and dynamically allocating network resources; the data layer is mainly responsible for forwarding data packets, and is connected to the control layer through the southbound interface.

![Comparison of traditional network architecture and SDN network architecture.](image)

**Fig. 1.** Comparison of traditional network architecture and SDN network architecture.

**Fig. 2.** SDN network architecture.

### 2. THE OVERVIEW OF SDN APPLICATION SCENARIO

SDN originally originated from the experimental innovation of the campus network. The research team led by Professor Nick McKeown of Stanford University proposed the concept of Openflow [15], which promoted the birth of SDN. SDN succeeded in Google's B4 [6] network, in the early stage of development of SDN, the application scenarios are mainly focused on: data center network, interconnection between data centers, government and enterprise networks, telecom carrier networks, and Internet company business deployment. The article will outline the initial application of SDN and some innovative application scenarios in the later stage.

#### 2.1. SDN+WAN

Paper [6] proposes a software-defined WAN architecture B4, as shown in Figure 3, which is one of the first and largest SDN/OpenFlow deployments. This is the first publicly available commercial case for SDN-based data center interconnection and the first publicly available SDN-based distributed controller application case. This network uses a three-tier architecture consisting of switch hardware layer, site controllers layer, and global layer. The hardware layer of the switch uses switches made by Google. The switches run the OpenFlow protocol and support new services such as centralized TE, which is mainly responsible for forwarding traffic. The site controller layer is composed of OpenFlow Controller...
(OFC) and Network Control Server (NCS). The OFC cluster runs on the NCS, and the OFC maintains the network status according to the instructions of the network control application and switch events. The global layer consists of an SDN gateway and a central traffic engineering server, responsible for centralized and unified control of the entire network. The SDN gateway collects link information from the OFC and abstracts it to the TE Server to learn the global path information. The forwarding entry information generated by the TE server is translated by the SDN Gateway and sent to the underlying switch through the OFC. The centralized traffic engineering of the architecture allocates bandwidth according to the level of demand and priority. The bandwidth utilization of the link is improved by more than 3 times and the long-term is close to 100%, therefore the link cost is greatly reduced. This proves that SDN can be successfully applied to large-scale networks interconnected by data centers.

And it also describes some lessons in the research and future research directions.

Fig. 3. B4 architecture overview[6].

2.2. SDN+ Cellular Networks
For the limitation of the current cellular network, as shown in Figure 4, the authors in [7] designed an SDN-based architecture of the programmable control plane in cellular network, and analyzed how the introduction of the SDN architecture can better solve the problems of the cellular network, such as reducing the extra equipment in the network. Cellular providers can effectively monitor traffic at different levels of granularity; SDN will provide common control protocols across different cellular technologies, making mobility management easier and reducing latency; SDN can make distributed implementation of QoS and firewall policies based on network-wide views, and manage traffic scheduling through multi-hop QoS classes in the network; SDN can support network virtualization. The mobile virtual operator can subscribe to the corresponding service according to its own needs; the SDN has a global view of the base station, and supports centralized control of the base station. And the SDN controller can allocate radio resources more efficiently to handle new users. The scalability of controllers, switches and base stations is proposed from four aspects: 1) The architecture will automatically convert policies based on user packet processing rules of IP addresses and network locations. 2) Under the direction of the controller, a software agent capable of performing simple local operations should be run on the switch. 3) The cellular network will support deep packet inspection, header compression and message-based control protocols. 4) The architecture virtualizes base station resources, allowing each "slice" of controllers to control radio resource management, admission control, and mobility control.
2.3. SDN+Mobile Cloud

Paper [8] proposes several mobile cloud architecture designs based on SDN and Ad hoc networks. As shown in Figure 5, different wireless technologies are used in the control plane and data plane respectively: the remote wireless connection is used for LTE in the control plane, and the high bandwidth wireless connection is used for Wi-Fi in the data plane. The global SDN controller is the core intelligent component of the architecture and is responsible for populating the flow table of the SDN wireless node to control the way the traffic moves in the network. The SDN wireless node is equivalent to the switch in the SDN network. Each SDN wireless node has an alternate local SDN controller to ensure normal communication of the network when there is a problem with the global controller. The global SDN controller and the SDN wireless node have two connection examples, which are a continuously connected global SDN controller and an intermittently connected global SDN controller. In the MANET system, each SDN wireless node constructs a node connection graph by exchanging beacon messages, and the SDN controller can make intelligent routing decisions based on general algorithms or flow-based routing information according to the path information provided by the node connection graph. The article also describes the mobile cloud instance based on SDN frequency selection. According to the interface frequency configuration, the wireless node can be divided into: wireless nodes with wireless interfaces configured to specific frequencies and wireless nodes with reconfigurable wireless interfaces. In addition, there are three potential application cases: wireless network virtualization, reserved traffic, and frequency hopping. The article proves the feasibility of SDN-based mobile cloud architecture by emulating on NS-3. Based on SDN routing, it is better than traditional Adhoc routing protocol, which can achieve good packet transmission rate. Finally, the author proposes three future exploration directions: 1) recovery mechanism when SDN controller is lost; 2) standby SDN wireless architecture; 3) frequency selection use case.

Fig. 4. Cellular SDN architecture[7].

Fig. 5. SDN-based mobile cloud overview[8].
2.4. **SDN+VANET**

Authors in paper [9] proposed the SDN-based VANET architecture and its operation mode as shown in Figure 6. According to the degree of control of the SDN controller, the architecture is divided into three modes: centralized control mode, distributed control mode and hybrid control mode. The three advantages of the architecture are analyzed: 1) Path selection: When the SDN controller senses that data traffic may become unbalanced, it can initiate a rerouting process to improve network utility and reduce congestion. 2) Frequency/Channel Selection: SDN-based VANET can dynamically coordinate the channel/frequency used by SDN wireless nodes with multiple available wireless interfaces. 3) Power selection: Due to the awareness, SDN-based VANET can dynamically change the wireless interface power and its transmission range according to the perception. Finally, the SDN-based routing and traditional MANET/VANET routing protocols are compared by simulation, which proves the feasibility of software-defined VANET.

![Software-Defined VANET Communications](image)

2.5. **SDN+Air-Space-Ground Integration Network**

An SDN-based air-ground integration network described in paper [10], consists of a three-layer structure of an air-based network layer, a space-based network layer and a ground-based network layer. Each layer works independently and is interconnected. The space-based network layer is mainly composed of satellites. The air-based network layer is composed of UAV Ad-hoc network. The ground-based network layer is mainly composed of some cellular networks and digital cluster systems. In addition to the space-based system, the other two layers are equipped with SDN controllers to implement unified centralized control for each layer of the network. In the UAV Ad-hoc network, each cluster head is equipped with a micro SDN controller, and has real-time global information of the cluster network, and other UAVs do not need to carry any processing and decision-making equipment, greatly improving the endurance capability of the UAV Ad-hoc network. The ground station controller can be used as the master controller to command the entire UAV Ad-hoc network. If the link between the UAVs and the ground station fails, the ground-based satellite relay can be used to contact the ground station. The cooperation of the three layers of the network ensures the normal operation of the entire network. In this paper, the delay is used as an indicator to simulate the performance of AODV routing protocol and OLSR and DSR routing protocols. At the same time, the traditional air-space-ground integrated network and the SDN-based air-space-ground integrated network are compared by simulation. The results show that the transmission of SDN-based air-space-ground integrated network is better, the end-to-end delay is shorter, and the overall performance is superior.

Integrated space and terrestrial network architecture envisioned in paper [11] is based on the SDN architecture. The application layer consists of a number of spatial tasks. The control plane consists of the controller nodes of the space base and the ground, and is represented by the network operating system in the logical architecture. The control plane is the core of the network and has an overall global view of the network to implement routing decisions and management and control of the entire spatial information network. The data plane consists of satellite nodes and is mainly responsible for data...
processing and forwarding. The physical architecture consists of a space-based backbone network, a data forwarding layer, and a ground information port. The space-based backbone network consists of three GEO satellites, the data forwarding layer consists of MEO and LEO satellites in the middle and low orbit, and some ground station controllers are set up in the ground information port. The controller node of the ground information port and the GEO satellite node in the space-based backbone network together form a control plane in which multiple controllers cooperate. In a multi-controller deployment scenario, each controller is responsible for its own control area, with network status information of the local area, manages and maintains the normal operation of the network in the area, and communicates between the controllers through the east-west interface to generate the global topology view of entire network. Since there are still large technical difficulties in placing the controller on the satellite, the SDN controller is placed on the ground in the early stage. The global view of the SDN architecture provides a more reasonable routing strategy for the satellite network. The centralized resource allocation and management guarantees higher service transmission quality. The open and programmable features make the configuration of the satellite network more flexible and convenient. The unified standards and interfaces well solve the problem of heterogeneity of the spatial network. The separation of the data plane and the control plane simplifies the architecture of the satellite function and the design cost, effectively reducing the complexity of satellite management.

2.6. SDN+ Satellite network
OpenSAN [12], software-defined satellite network, is composed of three planes: management plane, control plane and data plane, as shown in figure 7. The management plane consists of network operations and control centers; the control plane consists of three GEO satellites that cover the globe; the data plane consists primarily of satellite infrastructure and terminal routers. The management plane and the control plane are connected through the SDN Northbound Interface (NBI), and the data plane and the control plane are connected through the SDN Southbound Interface (CDPI). The control plane has a global topology view, which is responsible for monitoring the network status and sending dynamic information of the network to the management plane. The management plane (NPCC) can provide functional modules such as routing policy, user management, virtualization, security, resource utilization and network management. The management plane calculates a new flow table through the global network information and sends it to the data plane through the control plane. The data plane only needs to complete the forwarding of the data packet according to the flow table. Since the motion of the satellite is periodic, we can predict the changes in the entire network using the corresponding prediction-based algorithms (such as neural networks). By decoupling the data plane and control plane, OpenSAN saves the resources of satellite nodes, overcomes the difficulty of satellite network closure and expands, provides efficient and fine control, and supports the flexibility of future advanced network technologies and services.

Fig. 7. The Architecture of OpenSAN[12].
Paper [13] proposes a Software Defined Satellite Network Architecture (SDSN), which has three layers: the application layer, the control layer, and the infrastructure layer, as shown in figure 8. The application layer is the Network Operations Control Center (NOCC), which has functions such as routing policy calculation and application generation. The control layer is a ground station that translates instructions from the upper NOCC into simple data structures and sends them to the infrastructure layer. The infrastructure layer is made up of satellites, and the satellites only need to implement the simplest forwarding and hardware configuration functions, which reduces the development and design cost of the satellite. The SDSN distributes routing tables and configuration commands through a single-layer inter-satellite link (ISL) and GEO satellites to implement a satellite control model with a global network view. When the network update is small, single-layer ISL forwarding is adopted; when the network update is large, GEO satellite broadcasting is adopted. This new hybrid control structure enables real-time and fast network configuration, reducing the number of ground stations and greatly improving the update speed of traditional satellite systems. The software-defined network technology decouples the data plane and the control plane, and obtains a global network view through centralized control, and deploys a more granular management strategy to optimize the calculation of the global routing path.

![Fig. 8. The SDSN architecture](image)

2.7. SDN+ UAV network
In paper [14], an SDN-based UAV backbone network framework was designed. Figure 9 shows the illustration of the SDN-based UAV network in this paper and figure 10 shows the functional architecture of a UAV network. The control core includes a UAV controller and an SDN controller. The UAV controller is responsible for managing information such as flight control, location, battery storage, etc. The SDN controller is responsible for network information management. The UAV controller and the SDN controller can interact to work together and share information to make optimal decisions. Based on the two core issues of information management and resource management of UAVs, an SDN controller monitoring platform is proposed, which includes four modules, namely monitoring display, traffic management, link management and strategy. According to the analysis results of the monitoring platform, a load balancing algorithm is further proposed in the policy module to fully utilize the UAV network resources and maintain the desired network traffic balance.
3. CONCLUSIONS

Traditional networks have given the Internet a vibrant life but have also hindered the longer-term development of the Internet. The new dynamic network architecture of SDN has successfully transformed traditional networks into diverse application-oriented platforms. By decoupling the control plane and data plane in the network architecture, the hardware cost of the network equipment can be effectively reduced, so that the network can be flexibly large-scale programming and simplified management like the computer infrastructure; the centralized control logic can make the network have a global view information can be globally optimized and resource-adapted. The deployment and maintenance of network nodes will be more agile; open and programmable network can promote more business network service innovation. However, the current SDN technology is not fully mature, including the standardization and unification of various interfaces, the compatibility of heterogeneous networks, multi-controller coordination and some security issues. The expansion of SDN applications is also facing more challenges. In this paper, we surveyed 7 different areas to analyze SDN-based application scenarios. The "SDN+" architecture provides a new way of thinking for networks with different applications, expanding the intelligence of the network and achieving maximum optimization.

The application of SDN is no longer limited to the campus network, the WAN network between data centers, but has a broader space, not just the ground network, and even some good application ideas have been made in space-based networks. In the future, we will focus on exploring more application scenarios of "SDN+" and optimized routing algorithms that are more suitable for SDN architecture.
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