SDN Enterprise Network-based Integration Technology and Field Trial Deployment

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Abstract: Software-defined networking (SDN) is undoubtedly the trend in next-generation network technology development, but replacing all network devices with SDN-enabled devices in a short time is impractical for a full SDN environment construction. The smooth evolution of SDN networks is achieved by gradually replacing parts of the devices and making the traditional and SDN networks coordinated in operation. To address the issue of using SDN architecture in the enterprise network for migration, this article introduces a technique capable of ensuring edge switch migration without affecting the operation of the existing network. The developed technique provides the interface operating function of enterprise SDN, optimizes the mechanism of VLAN management and maintenance, and improves the maintenance performance of edge switch replacement. This article proposes the system architecture and key technologies developed through the enterprise SDN migration for the edge switch system. Then, the paper explains the intelligent control programs developed by the controller to construct the SDN migration technology. Furthermore, it introduces the system deployment architecture and service functions with the help of ITRI Information Technology Services Center for field trial actualization.

1. Introduction

The network environment provided by the enterprise not only allows workers to store service from the intranet and LAN on the internet but also includes the deployment of the special uses of the application network service, such as the wireless AP and IP camera monitoring. Amidst various network devices interfacing the enterprise network environment, different devices and network services may offer different managing policies, including storage limitation (such as storage permission, existence, and external online limitation) and controlling rules of network resources (such as bandwidth limitation, bandwidth guarantee, and low-delay route). In addition, satisfaction should be required when using network resources and differentiated management request of network safety to different user groups (such as staff, “bring your own device,” and guests). The VLAN mechanism is adopted to segment management in the traditional enterprise network such that management is complex, updating daily maintenance is difficult, information safety equipment management is expensive, abnormal detection solution is difficult, and other problems are caused. Therefore, the enterprise wishes to adopt the software-defined networking (SDN) controller management mechanism to deal with the problems. However, changing all network equipment into SDN-supported equipment and replacing a part of the equipment so that traditional and SDN networks operate together is impossible. In addition, the so-called mixed network forms and smoothens the SDN network evolution achieved without influencing network operation. Furthermore, simplifying network management, saving pay cost, and increasing network efficiency benefit improves the intention to conduct SDN migration and facilitates the deployment task, thereby contributing to the development of related industries. With the difference between the SDN central control management operation model and the traditional network-distributed operating mechanism, the discussion of SDN migration technology is an issue of concern because of its common operation and management, and the Open Networking Foundation (ONF) [1] has set up

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the Migration Project [2] to discuss the issue.

The target of the enterprise's SDN migration is divided into the data center aimed at the edge switch, core switch, and server farm to perform the evolution transfer; each of these parts has its request and object. The transfer of the edge switch is the main migration target, and the replacement or the edge switch increase is regarded as the transfer object. Various devices are connected to the edge switch, including the laptop and desktop used by general staff, wireless AP, IP camera supervision of the application network service, access control system, and u-Bike system supplied by ITRI. All types of devices connect with the same edge switch or different edge switches and should be segmented by different VLAN with different segments requests. For most of the port-based VLAN mechanism, connecting with the switch port set by the different VLAN by plugging in or extracting the equipment is impossible. When the edge switch is replaced or increased, it has to be reset according to the present VLAN. Thus, the maintenance becomes so complicated that the service is interrupted if the setting is left or an error is obtained if flow is obstructed or abnormal. The aforementioned disadvantage is easily improved with the use of technology and enterprise SDN migration system for edge switch developed by ITRI and features of the controller central management and programmable control in the SDN. The main features of the ESMES technology and system includes the following five aspects: (1) operation of SDN and traditional networks without affecting the present network operation; (2) flexible VLAN management mechanism that simultaneously mixes and adopts the port-, IP-, MAC-, user-based, and other methods to VLAN management; (3) convenience of plugging in and extracting terminal devices when connecting with the OpenFlow switch port in different VLANs because extra settings need not be conducted by network operation and maintenance staff; (4) function of quickly and easily replacing the OpenFlow switch, which largely reduces maintenance difficulty in changing the switch; and (5) availability and reliability of the network link, which improves the SDN segments. The second chapter introduces the basic operating mechanism of the SDN controller. The third chapter proposes the key technologies that should be addressed and offers a special service under the SDN system operation; the mixed network operation is intended for the ESMES system developed by the SDN smooth evolution technology of the edge switch migration, and the intelligent module function developed by the SDN migration technology in the controller is explained. The fourth chapter introduces the structure of the field trial deployment cooperated by the system and experiment center and service function. The fifth chapter concludes this paper.

2. Introduction of related technologies

Software-defined networking is a new-generation network concept which separates the control plane from the data plane functions. The traditional embedded control software is removed from the controller that is not in the switch; in other words, all network hardware in the data layer takes orders from the SDN controller of the central controller. Therefore, the solution of the related SDN application fields is achieved through the cooperation of the controller and the matching of intelligent applications.

The infrastructure, control, and application layers are aspects of SDN technology. The control layer is the SDN pivot for the controller that includes many control programs such as the core and intelligent technologies. In addition, this layer should master the network topology information formed by the infrastructure layer and define the packet transmission route of the network through the southbound interface. Network situation, resources, and service required by the application layer are offered through the northbound interface to support the optimization or creation of the service. The provision of the controller core technology supports the normal operation of the SDN-supported packet transmission and the information collection of the traffic statistics. To find the solution in adding SDN or creating an application service, the value-added function module should be developed in the controller platform; this approach enables provision of intelligent technology and establishment of SDN application service which is accorded with request and difference.

Compared with the traditional distributed network, SDN adopts the central control structure in full SDN; the determination of packet-transmitting procession should be judged in each ethernet

switch. When the SDN controller deals with the unicast packet (such as TCP and UDP), the suited route or transmitted method is found disposably so that the time of Packet-In3 is reduced. Aiming at a solution of the broadcast packet (such as ARP request and DHCP discovery), the establishment of the spanning tree causes the link-wasting problem to avoid broadcast storm compared with the traditional network. The SDN controller only transmits the broadcast packet of all ports except for the source and trunk ports (the link ports along the “off” switch) without establishing the spanning tree to solve the broadcast storm problem. Step 4 in Figure 1 directly transmits the port from the host through the packet-out rather than transmitting it among the trunk links. When the mechanism connects with the traditional switch, the problem of traditional switch learning errors occurs, which is explained in detail in the next chapter.

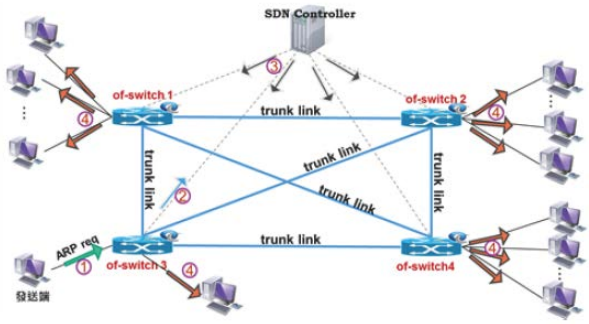

Fig. 1. Broadcast packet operation mechanism in full SDN

3. Introduction of ESMES system

Transmission technology connecting the ESMES system and the traditional network ensures that the network function operation is normal and obtains management advantage after it is converted into the SDN structure. The traditional enterprise network adopts the port-based VLAN mechanism set in advance by IEEE 802.1Q [4] to achieve the virtual network purpose. The virtual network aims to establish a logically independent shared entity network. Each virtual network performs service in a manner similar to the features of general LAN so that network resources achieve better availability and efficiency and helps the enterprise save investment cost of network devices and flexible network deployment. Therefore, the ESMES system offers the optimized virtual subnet clustering mechanism, simplifies the setting and maintenance VLAN work, and easily and quickly replaces the mechanism of the OpenFlow switch so that network management and maintenance are improved.

3.1 Solution of MAC Confusion Learning Problem

The ESMES system adopts the OpenFlow switch to gradually replace the traditional edge switch or increase the OpenFlow switch as the object of the edge switch so that many independent OpenFlow edge switches mix with interfacing traditional L2 or L3 switches and are controlled by the same SDN controller. This condition causes the so-called discontinuous SDN switch control blocks; three SDN blocks are presented in Figure 2.

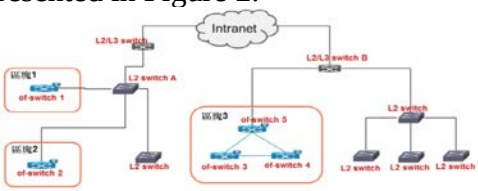

Fig. 2. Many SDN blocks caused by mixed network environment

The broadcast packet operating mechanism is described in Figure 2; the SDN controller transmits the broadcast packets to all ports except the source and trunk ports for the SDN controller to reduce the times of packet-in and avoid the broadcast storm problem caused by the loop. When a traditional ethernet switch network is connected, MAC learning confusion caused by the ethernet

switch and the host learning confusion caused by the SDN controller affects the correctness of the subsequent unicast transmission. Step 2 in Figure 3 enables the L2 switch A to receive the packet from blocks 1, 2, and 3, respectively. In this way, L2 switch A may wrongly think that the position of the transmitting terminal host are blocks 1, 2, or 3.

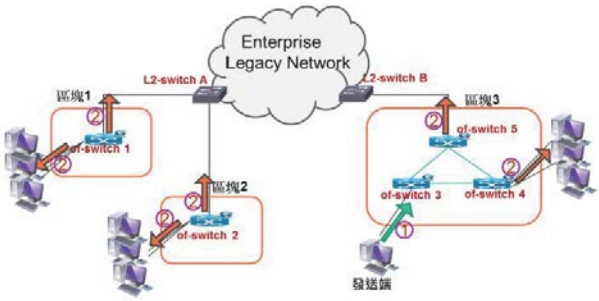

Fig.3. Packet broadcast operating situation of unmodified SDN block mechanism

Therefore, the packet-handling mechanism adopts the SDN switch control block as the designed unit; its operating logic is shown in Figure 4. When the SDN controller receives the packet-in of the broadcast packet from block 3 of step 1, handling of the packet is limited in block 3. Step 2 transmits the host port from “off” switches 3, 4, and 5 from block 3 and the trunk port without belonging to the “off” switch. The packet should enter blocks 1 and 2 after passing the legacy switch. After the SDN controller receives the packet-in from block 2 of step 3, the packet transmits from the host port of “off” switch 2 in block 2 as shown in step 4. The handling logic of block 1 is the same. When each block only has the structure of an OpenFlow switch, the design logic cannot save the times of the packet-in. If many OpenFlow switches exist in a block, the time of the packet-in is effectively reduced and the availability of the link is improved.

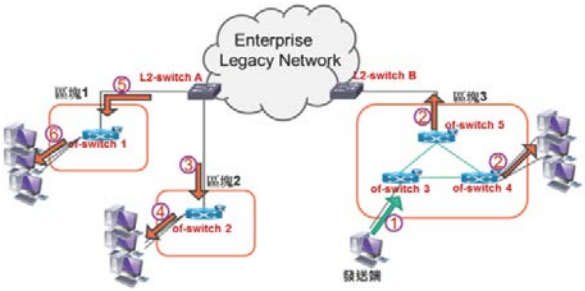

Fig.4. Packet broadcast operating situation of modified SDN block mechanism

3.2 Flexible VLAN Provision Management Mechanism

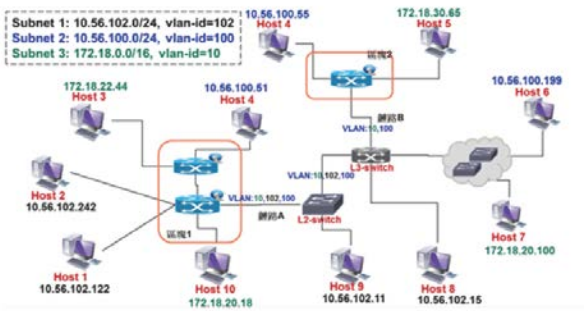

Fig.5. Operating figure of flexible clustering in ESMES system

To improve the complicated process problem of setting and maintaining the traditional network VLAN, the system designs a flexible virtual subnet clustering mechanism to perform the virtual subnet management in terms of port-, IP-, MAC-, and user-based mechanisms. The four mechanisms can be adopted in combination. For example, when a certain MAC address uses a specific port, it belongs to subnet 1. If other ports are adopted, it belongs to subnet 2. In this way,

users flexibly determine the rules and orders by adjusting the priority method. Host 1 is through the MAC-based mechanism, host 2 is through the port-based mechanism, and host 3 is through the IP-based mechanism shown in Figure 5.

To interface the virtual subnet mechanism in the enterprise traditional network during the migration process, the packets transmitted by the trunk link between the OpenFlow and legacy switches must carry the VLAN tag. Therefore, the highly automatic detection mechanism is offered by matching the virtual subnet mechanism of the ESMES system to simplify network deployment and maintenance. In this way, the ESMES system automatically detects the trunk link interfacing with the traditional network and VLAN values without being set manually by the network staff.

The SDN controller transmits the link layer discovery protocol (LLDP) packets to detect network topology through the periodic packet-out. These LLDP packets should be remarked to identify that the LLDP packets are transmitted by the SDN controller. Therefore, when the SDN controller receives the LLDP packets through the packet-in, it quickly remarks and identifies the LLDP packets from the internal or external networks of the SDN. In this way, these ports in the OpenFlow switch and the trunk port interfaced with the legacy switch is obtained (as shown in links A and B of Figure 5). When the system detects that the trunk port appears, the subnet belonging to the host connected to the OpenFlow switch with the trunk port in the SDN block should be checked. The trunk port should bind the VLAN tag in these subnets. Link A partly interfaced the legacy switch with block 1 in Figure 5; block 1 includes the host of subnets 1, 2, and 3. Therefore, link A should be bound with VLAN tags 102, 100, and 10. Block 2 includes the host of subnets 2 and 3, and link B should be bound to VLAN tags 100 and 10.

3.3 Fast and Easy Switch Maintenance

When the OpenFlow switch is changed as a result of fault or age, the manager can easily use the spare OpenFlow switch with a fast and easy function. The original connecting lines should be connected into any port in the spare switch, and then the substitutional OpenFlow switch is selected through the replacement function key provided by the imaging management interface. In addition, the system automatically finishes the related port-based settings and rules so that all present service is normally operated without being set in terms of the present VLAN. In this manner, the maintenance work of the managers is simplified and maintenance cost is reduced.

3.4 Structure of ESMES System

The ESMES system adopts the open-source controller OpenDaylight [5] as the SDN controller platform of the system and the design and development basis of the module. The Open Service Gateway initiative structure is adopted as the service platform for all modules according to the platform framework of OpenDaylight. The module structure of the ESMES system is shown in Figure 6. The component functions of the intelligent control programs in SDN migration include subnet management, detection and maintenance of mixed network topology, handling of ARP and DHCP packets, and routed handling of the unicast packets in a situation with many SDN control blocks. The application service management components related to the SDN is developed, the network management server is independently offered to the control platform, and service is deployed through the graphical interface.

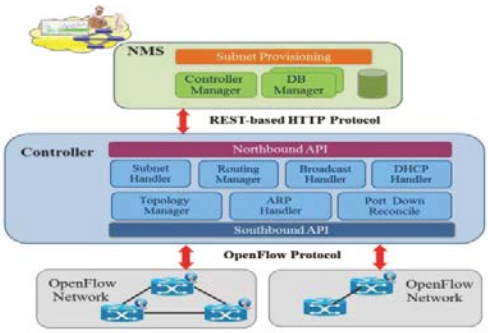

Fig.6. Structure of ESMES system

1) Subnet manager is responsible for managing the subnet; adopting the virtual subnet clustering mechanism operation to perform logical processing, learning, and recording of all host information; and automatically detecting the VLAN value of the trunk link interfaced with the traditional network.

2) Topology manager is responsible for detecting and maintaining the mixed network topology, automatically detecting the trunk link and the information of the SDN blocks interfaced with the legacy switch, and offering the link information so that the subnet manager automatically detects it.

3) Routing manager is responsible for establishing the route and routing the unicast packets in a situation with many SDN control blocks.

4) ARP handler is responsible for processing the ARP packets and reducing the frequencies of the ARP broadcast. In the meantime, other modules should be offered to detect whether the specific host is online by initiative transmission of the ARP broadcast.

5) DHCP handler is responsible for the transmission process of the DHCP relay or DHCP packets and collecting information in the DHCP packets to record and control the subnet manager.

6) Broadcast handler is responsible for the processing of broadcast packets.

7) Port down reconcile is responsible for transmitting the packets through the original fault link and automatically converting them into other link failovers.

8) NMS offers the management interface in the graphical system, including the management of the subnet deployment, the statistical information of the network flow, and the information of real-time network topology.

3.5 Efficiency of ESMES System

The system offers a flexible VLAN management mechanism. Compared with the legacy switch that only adopts the signal rule, the ESMES system adopts the port-, IP-, MAC-, and user-based mechanisms in the meantime. It has the advantage of variable and flexible application. The convenience of the random plugs in the terminal devices is offered though its interface with the OpenFlow switch in the different network segments. In this way, service takes effect without the extra settings.

The designed replacement function of the OpenFlow switch enables the network personnel to easily replace the OpenFlow switch. The entire system automatically finishes setting and applying the rules so that it can operate although the original setting parameters are not obtained with the original switch damage. Thus, the system largely reduces maintenance difficulty and saves maintenance cost.

In addition, each link is adopted without establishing the spanning tree in the SDN blocks; each link is used as a backup path or traffic load sharing to improve the availability and reliability of the network link.

4. Field Trial Deployment

The ESMES system is used in field trial verification by combining two SDN controlling blocks deployed in the experiment center, namely, the SDN Testbed laboratory on the third floor of the 51 pavilions and the LAN in the network communication technical department office on the fifth floor. In fact, the system interfaces the laptop and desktop devices used by the staff to offer a general LAN service as well as to connect the wireless AP and IP camera supervising devices to offer the application network service; the LAN and the applied networks belong to different subnets and each has a VLAN value. In addition, the system cooperates with traditional networks to achieve the purpose of trial in transmitting the SDN network without influencing the present network operations. Field deployment in the ESMES is shown in Figure 7, and the SDN Testbed lab deployment on the third floor of the 51 pavilions is shown in circle 1.

An SDN controller controls the information switch and control plane through the independent network and interface of the OpenFlow switch between the third and fifth floors, which is responsible for the related processing behaviors of many SDN controlling blocks.

An OpenFlow switch is regarded as the edge switch, and the control plane is directly connected

to the controller. The data plane is interfaced with the traditional switch through the trunk link so that the trunk link should carry different VLAN tag values, and the connected terminal devices include the following three types: many laptops and desktops used by LAN service in the network communication technical department belongs to the LAN network segments in the network communication technical department. In this way, the staff can conduct network tasks, such as intranet and internet services, without being influenced.

An NMS is offered to enable the supervision of mixed network topology, detection of online host information, viewing and analysis of network flow, management and maintenance of the subnet, setting and management of the OpenFlow switch, and management function of replacing the switch.

In addition, the regional environment deployment office in the network communication technical department on the fifth floor is shown in circle 2 of Figure 7. Its deployment devices include the following types. An OpenFlow switch built on the fifth floor is used as the edge switch, and the control plane is directly connected to the SDN controller on the third floor; the data plane is interfaced with the traditional L2 switch through the trunk link. The connected terminal devices include the following types.

The laptops and desktops used by LAN service in the network communication technical department belongs to the LAN network segments. In this way, the staff can conduct network service without being influenced. The LAN deployed on the third floor belongs to the same segment as the different SDN blocks; the network transmitting service between the two blocks can normally perform tasks such as file sharing without being influenced.

The wireless AP belongs to the application network service segment and offers the wireless internet service with the online AP controller.

The IP camera belongs to another application network service segment and is supervised.

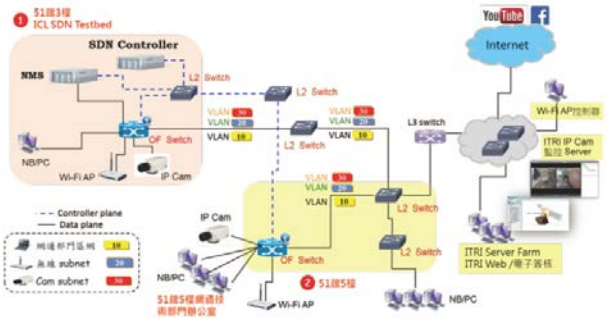

Fig.7. Field trial deployment structure of ESMES system

The offered key verification service behavior in the trial field deployment of many SDN blocks is shown in Figure 8.

The mixed network topology interface formed by the present migration is shown through the NMS interface, including the OpenFlow switch, interfaced first-layer legacy switch, and online host information.

The network manager increases, sets, and maintains the subnet through dynamic NMS without setting the specific VLAN to the subnet in each OpenFlow switch and simplifying VLAN maintenance.

The laptops and desktops in each block store intranet and internet services through the wired LAN or wireless AP application network under the network structure of many SDN blocks, and both normally operate without being affected. The supervision service of the IP camera is the same.

The network wiring in the interfaced terminal devices (such as the IP camera) is plugged by network managers into other random switches in the OpenFlow switch without the extra settings so that the service is normally operated. Although the original switch belonging to different segments (such as laptops) is replaced, the extra switch setting of the network managers is not required. The service conducted by the devices, such as the IP camera supervising service, is immediately effective. Thus, the VLAN setting is based on the port-based mechanism in the traditional network,

and the complicated and wrong disadvantages are maintained.

When the OpenFlow switch is changed to solve problems related to errors or old age, the managers can easily replace the standby OpenFlow switch through the easy replacement function offered by NMS. In this way, the system automatically finishes the process of setting and using the rules of the new and old OpenFlow switches. All the current services can be operated immediately and maintenance work is simplified.

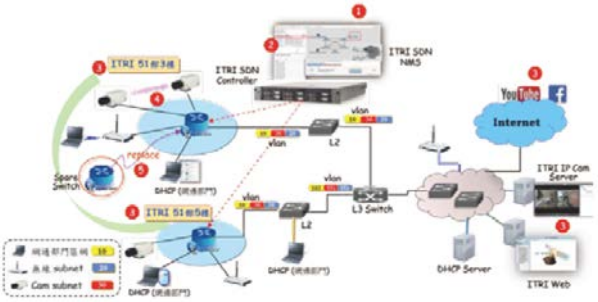

Fig.8. Deployment service configuration of ESMES system

5. Conclusion

Undoubtedly, SDN is a developing trend in network technology in the next century. Building a full SDN situation by changing entire network devices into devices with SDN ability is impractical under a real enterprise network situation. Therefore, part of the devices is generally replaced by improving maintenance efficiency of network management and increasing network transmission and utilization efficiency of resources. Thus, the traditional network and SDN can cooperate to achieve the smoothing evolution of SDN in the mixed network structure without influencing the present network operation. This condition is the primary goal of migration technology development.

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