An SDN Controller Enabled Architecture for 5G Backhaul Networks

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***Abstract*—Because of the 5G diverse service needs, a centralized Software-Defined Networking (SDN) Controller in 5G backhaul networks is introduced for collecting network statuses and providing intelligent path computation and central service configuration. This paper will discuss the key technologies of the SDN controller for 5G backhaul networks. By using the centralized SDN controller, the end-to-end path can be specified or dynamically adjusted to meet the requirements of 5G multiple services.**

Keywords—5G backhaul, SDN, Controller, WAN SDN controller

I. INTRODUCTION

Mobile Internet has become part of our daily life since mobile communication systems have dramatically evolved from 1G to 5G. From the beginning, 1G networks only provide voice call services. 2G networks are upgraded to provide Short Message Service (SMS) and mobile Internet access at a relatively low link speed (several 10s of kbps). 3G networks become a mobile platform providing a link speed of few Mbps. Compared to 3G networks, the speed in 4G networks is further improved by 10 times.

In June 2018, 3GPP launched the first commercial 5G standard [1]. For the purpose of interconnection of everything, 5G networks aim at three major application scenarios, including Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC). Network performance also needs to take a huge leap in capacity and bandwidth. Therefore, 5G backhaul networks become even more critical [2][3].

5G networks will carry multi-service applications. Different types of users have diverse requirements in the Internet. Real-time interaction requirements of specific industries are also expected. Therefore, 5G backhaul networks should meet the following requirements: 1) Need to provide high bandwidth for supporting streaming media and virtual reality (VR) applications. 2) Should support end-to-end delays better than 1 millisecond to meet the stringent requirements of interactive experience and industrial control. 3) Should be able to satisfy full mesh data connections in a huge network with many nodes.

In this paper, we propose an SDN-enabled backhaul networks to flexibly perform automated dynamic resource provisioning, topology visualization, and capacity-aware path computation. The SDN architecture brings the possibilities of managing, extending, and dynamically reallocating resources in the backhaul networks.

The rest of the paper is organized as follows. Section II discusses the evolution of mobile backhaul networks and how the 5G backhaul networks benefit from SDN. Section III presents our proposed architecture and involved technologies. We show the experimental result in section IV. Finally, conclusions are presented in Section V.

II. RELATED WORK

A. Mobile Backhaul Network Evolution

The so-called backhaul networks refer to a network that transmits the data traffic generated by the local network back to the telecom core network. In terms of mobile networks, the backhaul networks are responsible for transmitting the mobile signal traffic that occurs between a cell site and the core network.

The mobile backhaul networks are constantly evolving [4] and upgrading, since the voice and data packets were sent from the Synchronous Digital Hierarchy (SDH) network to the mobile core network. For example, 3G mobile communication takes advantage of the lower cost of ethernet technology. The voice part of the base station is still sent to the mobile core network from the E1 interface of the SDH network, and the data part is sent to the mobile core from the Fast Ethernet (FE) interface of the SDH network. When 4G mobile communication evolves into all Internet Protocol (IP) networks, the voice and data parts of the base station are unified from the Packet Transport Network (PTN) network to the mobile core network, as shown in Fig. 1.

In 5G mobile communications, Multi-access Edge Computing (MEC) [5] with local switching and offloading of service traffic is introduced to meet the needs of 5G applications with low latency and mobility management. The 5G backhaul networks use IP technology to provide any to any transmission, which satisfies several aspects:

(1) Any media: provide access to any media, including optical fiber, cable, microwave, etc.

(2) Any topology: suitable for any topology configuration model

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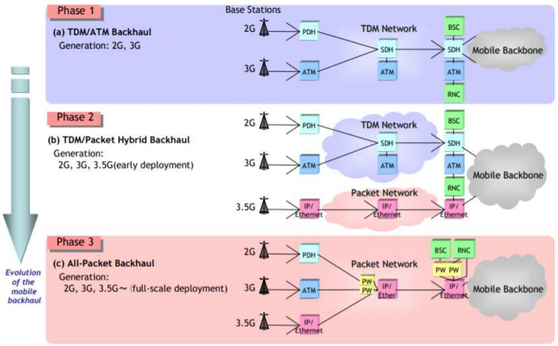

Fig. 1. Backhaul architecture migration.

(3) Any service: support Fixed-Mobile Convergence (FMC) [6] evolution requirements, provide 2G/3G/4G and third-party network service access

(4) Any location: provide service connection between users in any location

(5) Any scale: bear service of any network scale

B. *SDN architecture and advantages*

SDN is recognized as the evolution direction of the future network by the industry. Open Networking Foundation (ONF) has proposed three-layer SDN architecture [7]. From top to bottom, they are application layer, control layer, and infrastructure layer. The control layer is where the SDN controller locates. The infrastructure layer performs various actions under the control of the SDN controller. Then, the control layer also receives on-demand requests from the application layer for business purposes.

A traditional network is a closed and decentralized architecture. Network devices, such as routers, exchange messages through standard protocols to calculate the best route from source to destination. Administrators cannot accurately grasp the control of network packets. As a result, managing network becomes difficult and inflexible.

With the SDN concept, the control layer can grasp the overall topology and centrally manage equipment in the SDN controller. After mastering the overall topology, the load of the equipment can be measured, and real-time provision can be achieved. Once a service-oriented route is required, it is effective and flexible to adjust the settings from the SDN controller. There is no need to manually set each device one by one, making network maintenance easier.

III. Proposed Architecture

A. *SDN-based architecture for 5G backhaul networks*

We proposed an Internet Service Provider (ISP) 5G backhaul networks managed by an SDN controller, as shown in Fig. 2. The network nodes are classified into Provider Edge (PE) routers and Provider (P) routers, and both types are Segment Routing (SR) [9] Multi-Protocol Label Switching (MPLS) nodes. In a SR MPLS network, PE routers are used to originate and terminate label switched paths (LSP), while P routers are used to switch labels.

The actual network is adjusted in real time. In order to quickly meet the service change requirements in the service-driven network, the control layer will calculate and provision the path according to the needs of applications.

We propose an SDN controller-enabled architecture for the 5G backhaul networks using a variety of technologies including network topology visualization, path calculation, and SR. The key technologies are capable to fulfill end-to-end service assurance and meet the diversity of services.

B. *Topology Visualization*

Topology visualization helps network administrators easily view the entire network topology. For real-time topology collection, the SDN controller adopts standard southbound interface, Border Gateway Protocol Link-State (BGP-LS), which is responsible for the collection of interior gateway protocol (IGP) link-state and traffic engineering information from the 5G backhaul networks.

Traditional network topology collection is restricted within an IGP area, but BGP-LS can support multi-area topology collection. In each area, one of the network devices will be set as a router reflector, which is responsible for connecting to SDN controller and sending link-state information. It becomes flexible to realize end-to-end management for various application requirements.

C. *Path Computation*

In SDN-based 5G backhaul networks, the controller must calculate the optimal path for various applications based on global information, such as network topology, traffic conditions, and user-defined service level agreement (SLA). Once the real-time topology is collected, the SDN controller leverages Path Computation Element Communication Protocol (PCEP) [8] to provide an end-to-end path. In the definition of PCEP, the SDN controller is usually used as the path computation element (PCE), and the network device is the path computation client (PCC).

After the SDN controller calculates the path, it will convert the path into SR Label Switched Path (LSP). Then the SDN controller uses PCEP to push the SR label stack into the source network device. The network device will forward traffic according to the path specified by the label stack.

D. *Segment Routing*

The 5G backhaul networks are toward application-centric platforms. To fulfill more flexible, scalable, and simple network management, the SDN controller uses SR to steer packets through the network by pushing a list of stacking segments. A segment is an identifier for a specific instruction

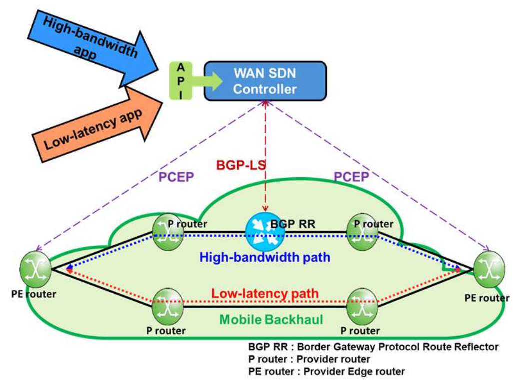

Fig. 2. The realized SDN-based architecture for 5G backhaul networks.

such as a given path or a service. SR is a source routing architecture protocol. Because the path that the packet has to traverse is indicated in the packet, intermediate routers do not have to maintain states for all steered paths. It becomes easy to provision an on-demand path via the SDN controller.

IV. Experiment

We conducted a set of experiments to validate the benefit of SDN in real-time network topology discovery. The evaluation includes the topology discovery function, link down, and node down scenarios.

A. Testbed

In the testbed, we used Open Network Operating System (ONOS) [10] as the SDN controller to manage three physical network devices as shown in Fig. 3. The three routers ran Integrated System to Integrated System (IS-IS) [11] as IGP protocol to exchange link-state routing information to form an IP network.

B. Topology Discovery

For topology discovery purposes, we chose Router 1 as the BGP Speaker which would set up BGP-LS [12] session with the SDN controller. Router 1 passed the IGP link-state database and traffic engineering database to the SDN controller through the BGP-LS protocol. Then, the SDN controller received the topology information including node, link, and prefix. We adopted an open-source application, pathman [13], to display network topology as shown in Fig. 4. The network topology was shown correctly.

C. Link Down and Node Down Scenarios

We also evaluated how fast the SDN controller received topology updates once a topology node or a link was changed. First, we emulated a link-down situation. We disconnected the link between Router 1 and Router 2. Then, Router 1 sent the topology update to the SDN controller via the BGP-LS protocol. As a result, the pathman application immediately showed the correct topology as shown in Fig. 5.

Second, we wanted to emulate a node-down situation. We followed the previous test and disconnected the link between Router 2 and Router 3. The link update was sent to the SDN controller as we expected. However, Router 2 remained in the topology with no link between Router 1 and Router 3. This result is related to the IS-IS LSP survival time. The default value is 1200 seconds (20 minutes). After 1200 seconds, Router 1 sent node update information to the SDN controller, and the final network topology was shown in Fig. 6.

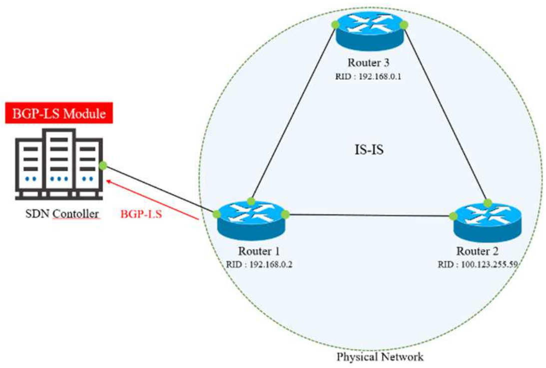

Fig. 3. The overall architecture of the experimental network.

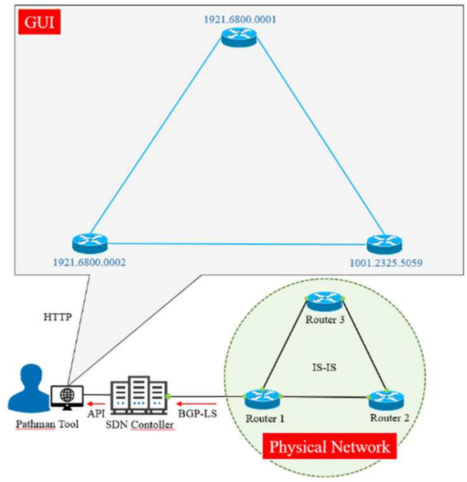

Fig. 4. The topology is graphically presented on the physical network.

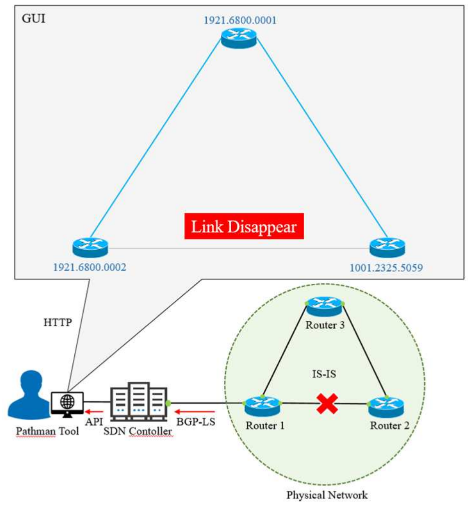

Fig. 5. The link disconnection scenario in the physical network.

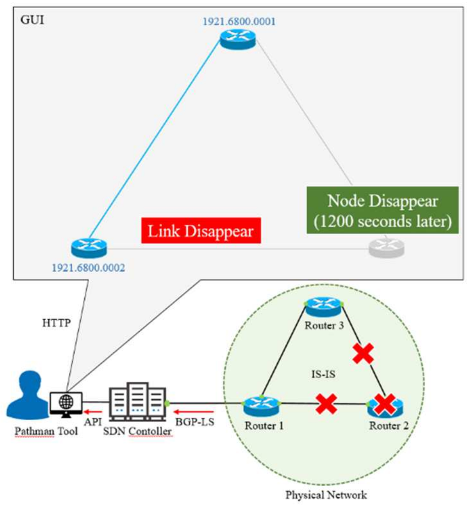

Fig. 6. The node disconnection scenario in the physical network.

V. CONCLUSION

Applying the SDN controller technology to the 5G backhaul networks is to grasp the status of the entire network efficiently. With real-time network topology, the SDN controller has intelligent path calculation capabilities to meet the needs of 5G diversified and novel services. In addition to provides 5G mobile services. The 5G backhaul networks can also carry Internet and television services at the same time. It is moving towards the goal of FMC.

This paper proposes an experimental method for SDN applied to 5G Backhaul networks. This method uses the BGP-LS protocol as the control signaling in the control plane, and also uses the SR protocol as the data signaling in the data plane. In the experiments, we demonstrated that the SDN controller can efficiently collect link and topology information. Once the network topology changed, the centralized SDN controller got updated. In future experiments, we will use realistic network topology to evaluate performance. Then, we will collect LSP information through the PCEP protocol, use path calculation to select the best path, achieve intelligent switching to meet the needs of 5G diversified and novel services, and solve the data transmission questions of big data.

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