Deadline-Driven Signaling Scheduling Scheme for Deterministic Service Restoration in F5G

Xin Li
State Key Laboratory of Info. Photonics and Optical Comm.
Beijing Univ. of Posts & Telecom
Beijing, China
lixin97212@bupt.edu.cn

Hongzhen Yang
Information and communication branch
State Grid Zhejiang Electric Power Co., Ltd
Hangzhou, China
yanghz@sina.com

Jiale He
Information and communication branch
State Grid Zhejiang Electric Power Co., Ltd
Hangzhou, China
nyhejiale@163.com

Mengxi Zhang
State Grid Economic and Technological Research Institute Co., Ltd
Beijing, China
zhang_mxi@163.com

Yongli Zhao*
State Key Laboratory of Info. Photonics and Optical Comm.
Beijing Univ. of Posts & Telecom
Beijing, China
yonglizhao@bupt.edu.cn

Jie Zhang
State Key Laboratory of Info. Photonics and Optical Comm.
Beijing Univ. of Posts & Telecom
Beijing, China
lgr24@bupt.edu.cn

***Abstract*—A deadline-driven signaling scheduling (*DDSS*) scheme is proposed for deterministic service restoration in F5G. Experiment results demonstrate the improved performance in terms of blocking probability, resource utilization rate, and average residual time compared with the benchmark scheme.**

Keywords*—*deterministic service restoration, deadline-driven, signaling scheduling, F5G

I. Introduction

The development of fixed networks is driven by service requirements and supported by technological development. According to the characteristics of different stages, the development of fixed networks can be divided into five eras. The fifth-generation fixed networks (F5G) era has become the main constituent of current fixed networks [1]. The guaranteed reliable experience (GRE) feature of F5G requires to support the service demand of deterministic latency, availability and reliability. As one of representative technologies of F5G, optical service unit (OSU) technology [2] enables a single fiber to carry thousands number of services. When a fault/failure occurs in such heavily used fiber connection, it is very critical to quickly restore the connection. Deterministic service restoration refers to ensuring that the restoration path is established within the maximum disconnection time that service can tolerate. Therefore, how to achieve deterministic service restoration when a fiber is disconnected is a key research problem.

In optical networks, fault recovery includes fault detection, fault notification, fault location/source identification, and fault restoration [3]. When a fault occurs, the devices on the precomputed restoration path are provisioned to complete service restoration. Traditional fault recovery mostly focuses on rapid recovery [4,5] and does not consider deterministic restoration of the service, resulting in a low failure recovery rate. In this paper, we propose a deadline-driven signaling scheduling (*DDSS*) scheme for deterministic service restoration in optical transport networks of F5G. Our experiments demonstrate improved performance compared to prior study [6] in terms of blocking probability (2.55%), resource utilization rate (0.26%), and average residual time (48ms).

II. Problem Statement and Delay Analysis

Fig. 1(a) demonstrates how OSU technology enables a single fiber to carry thousands number of services. Fig. 1(b) shows an example of the network infrastructure. Services are transmitted in optical transport network (OTN). Signaling transmitted in the data communication network (DCN) is used to establish the lightpath. The signaling process is shown in Fig. 2. "PATH" delay includes signaling propagation delay T_p, signaling transmission delay T_t, signaling processing delay T_{pro}, signaling queuing delay T_q, device configuration delay T_{con} and device cross-connection delay T_{cc}:

$$T_{path} = H \cdot T_t + \sum_{k=1}^{H} T_{pk} + (H+1) T_{pro} + (T_{con} + T_{cc}) + T_q \quad (1)$$

The number of hops of the restoration path is denoted as H. "ACK" delay is $T_{ack} = H \cdot T_t + \sum_{k=1}^{H} T_{pk} + T_q$. The total delay of the establishment of the restoration path includes "PATH" and "ACK" delay. Due to the device cross-connection delay and other delays can overlap, the total delay

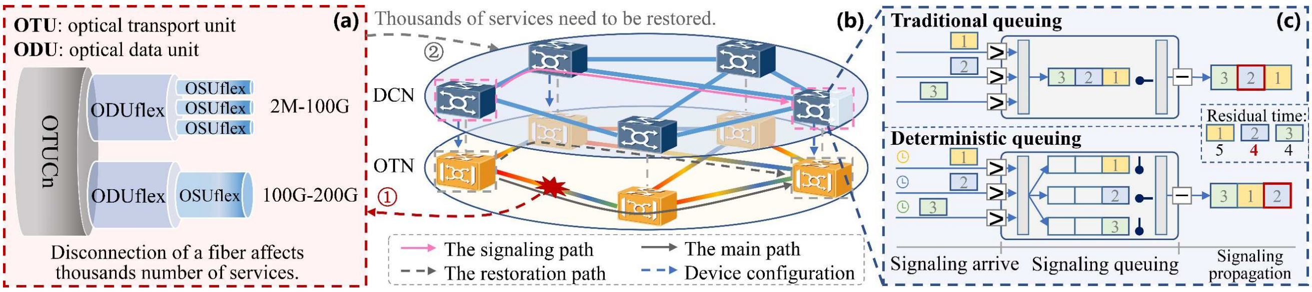

Fig. 1. (a) OSU technology; (b) network infrastructure; (c) node internal structure.

$$T_{total}=\begin{cases} T_{path}+T_{con}+T_{cc}, T_{con}+T_{cc}>T_{ack} \\ T_{path}+T_{ack}, T_{con}+T_{cc}<T_{ack} \end{cases}. \quad (2)$$

When multiple lightpaths need to be established simultaneously, the signaling packets are queued at the nodes in DCN. As in Fig. 1(c), traditional queuing method is based on the first-in, first-out principle. Deterministic queuing is to sort the packets according to the delay requirement. Here, the signaling packets are sorted based on the residual time, and the signaling packets can be scheduled according to different service requirements, leading to the deterministic restoration of the services.

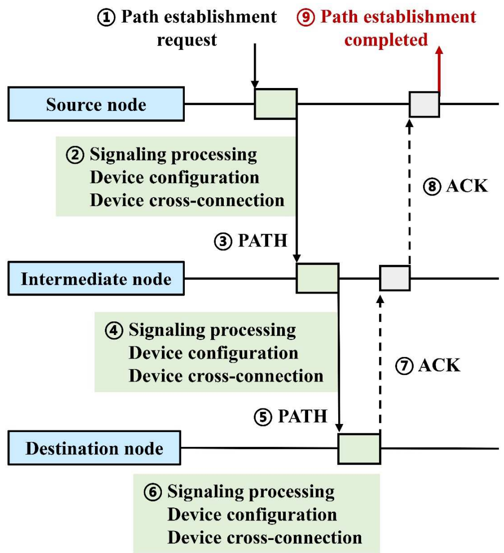

Fig. 2. The service restoration process.

The OTN topology is denoted by $G_o=(\mathbf{V}_o,\mathbf{E}_o)$, where $\mathbf{V}_o$ is the set of optical nodes, $\mathbf{E}_o$ is the set of optical links, $e_{oi}(v_{osi},v_{odi},w_{oi},b_{oi})\in\mathbf{E}_o$, where v_{osi} and v_{odi} are the two vertices, w_{oi} is the weight of the link and b_{oi} is the bandwidth used by each optical link. The DCN topology is denoted by $G_d=(\mathbf{V}_d,\mathbf{E}_d)$, where $\mathbf{V}_d$ is the set of DCN nodes, $\mathbf{E}_d$ is the set of DCN links, $e_{di}(v_{dsi},v_{ddi},de_{di})\in\mathbf{E}_d$, where v_{dsi} and v_{ddi} are the two vertices and de_{di} is the delay of the link. A service s_k in service set $\mathbf{S}$ is denoted by $s_k(b_k,p_k^{pri},p_k^{res},t_k)$, where b_k is the required bandwidths, p_k^{pri} is the primary path, p_k^{res} is the restoration path and t_k is the maximum disconnection delay that the service can tolerate. It should be noted that p_k^{pri} and p_k^{res} are two disjoint paths. The *KSP* algorithm is used to calculate p_k^{pri} and p_k^{res}. p_k^{pri} and p_k^{res} are an ordered sequence of links. For example, $p_k^{pri}=\{e_{o0}^k,e_{o1}^k,...,e_{on}^k\}=\{[v_{os0}^k,v_{od0}^k],[v_{os1}^k,v_{od1}^k],...,[v_{osn}^k,v_{odn}^k]\}$, where $v_{odj}^k=v_{os(j+1)}^k$.

III. Deadline-Driven Online Signaling Scheduling Scheme

Table 1 shows the detailed procedures of the *DDSS* scheme. When signaling reach the nodes in DCN, services with the same next link are sorted in ascending order according to the residual time r_k^j (*Lines 1-4*). If the next link of the service has sufficient bandwidth resources and the residual time of the service is greater than 0 at time T, the residual time of signaling will be updated according to the service order. Then, signaling are transmitted to the next node. Otherwise, the service is blocked and is deleted in $\mathbf{S}$ (*Lines 5-14*). If the entire path is successfully reserved, "ACK" message is returned (*Line 15-17*). The residual time r_k^j of signaling s_k at node v_{osj} is

$$r_k^j=t_k-\left[2H\cdot T_t+2\sum_{i=1}^{H}T_{pi}+(H+1)T_{pro}\right]. \quad (3)$$

TABLE I. Detailed Procedures of *DDSS* Scheme

Algorithm: Deadline-driven signaling scheduling (*DDSS*) algorithm	
Input: $G_o(\mathbf{V}_o,\mathbf{E}_o)$, $G_d(\mathbf{V}_d,\mathbf{E}_d)$, $\mathbf{S}$	
Output: Number of services that fail to schedule *fail*	
1	**For** the i th hop of services in $\mathbf{S}$ **then**
2	**For** $e_{om}\in\mathbf{E}_o$ **then**
3	**If** $e_{oi}^k==e_{om}$:
4	Sort services according to r_k^i ;
5	**For** v_{osi}^k on p_k^{res} of s_k at T **then**
6	**If** $b_{oi}-b_k\geq 0$ and $r_{ik}\geq 0$, **then**
7	Update r_k^i ;
8	Transmit service to $v_{os(i+1)}^k$;
9	Occupy resource of e_{oi} ;
10	**Else** delete s_k in $\mathbf{S}$;
11	$fail\leftarrow fail+1$;
12	**End if**
13	Update $G_o(\mathbf{V}_o,\mathbf{E}_o)$;
14	**End for**
15	**If** e_{om} is the last hop:
16	Return "ACK" message;
17	**End if**
18	**End if**
19	**End for**
20	**End for**

The time complexity of the proposed *DDSS* algorithm is $O(|\mathbf{S}|\times|\mathbf{E}_o|\times|p_{\max}|)$, where $|\mathbf{S}|$ denotes the number of service in $\mathbf{S}$, $|\mathbf{E}_o|$ denotes the number of links in $\mathbf{E}_o$, and $|p_{\max}|$ denotes the maximum number of nodes on p_k^{res}.

IV. Experiment Results

Our experimental results are based of *NSFNET* topology. The bandwidth of each link in OTN and DCN is set to 400Gbps and 5Mbps [7], respectively. The device configuration delay is 1 millisecond (ms) [8] and device cross-connection delay is 7ms [9]. The signaling packet size is 1000Byte [10]. During the scheduling process, the minimum unit is 1.6ms. The evaluation benchmark is the traditional restoration path establishment method [6], i.e., each node forwards the signaling in the order of arrival.

Fig. 3 shows the resource utilization rate R_{ru} and the number of services to be restored after a fiber breaks. As the number of services carried by the network increases, the number of services affected by fiber break will increase. When the total number of services is 7000, the number of services to be restored is 1389, and the resource utilization rate difference before and after a link failure is 10.48%.

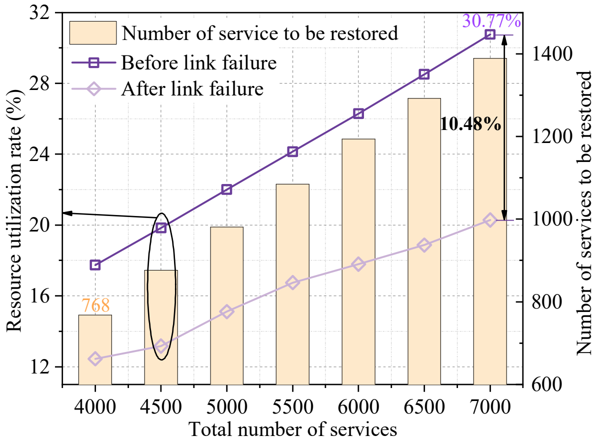

Fig. 3. R_{ru} and the number of services to be restored.

Figs. 4-5 compares the performances of different schemes in terms of blocking probability BP, R_{ru} and average residual time RT_a. "-T" represents the total BP. "-P" represents the BP of the "PATH" process, which is defined as the number of failed services in the "PATH" process divided by the number of services to be restored. The RT_a is defined as the sum of the residual time of successfully scheduled services divided by the number of successfully scheduled services.

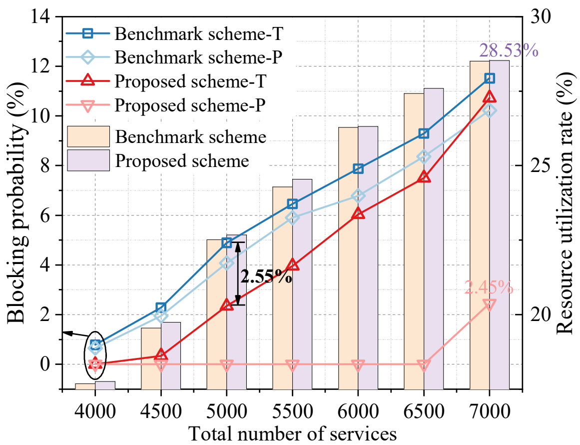

Fig. 4. BP and R_{ru} under different schemes.

Figs. 4-5 are the BP, R_{ru} and RT_a under different schemes. The BP and RT_a of the proposed scheme is always lower than that of the benchmark scheme. The R_{ru} of the proposed scheme is always higher than that of the benchmark scheme. As the total number of services increases, the BP and RT_a increase, and the RT_a decreases. The BP of the benchmark scheme is 2.55% higher than that of the proposed scheme, and the RT_a of the benchmark scheme is 48ms higher than that of the proposed scheme. The reason is that the proposed scheme prioritizes the scheduling of service with fless residual time. The number of failed services due to missing the deadline decreases, the BP decreases and the RT_a decreases.

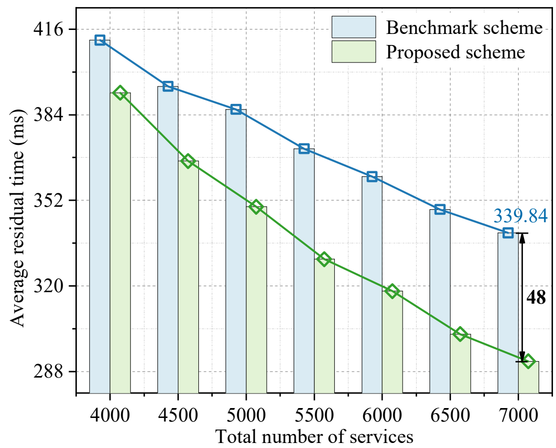

Fig. 5. RT_a under different schemes.

V. Conclusions

This paper studies the deterministic service restoration problem in F5G and proposes a deadline-driven signaling scheduling (*DDSS*) scheme to tackle the impact of signaling queuing at the nodes in DCN. Results show that the proposed scheme can reduce blocking probability and average residual time up to 2.55% and 48ms, respectively.

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