Fault Recovery of Classified Services based on Hybrid Protection and Restoration in F5G

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***Abstract*—This study proposes a fault recovery scheme based on hybrid protection and restoration in F5G, which makes the average advanced services recovery success probability of the scheme 15.5% and 25.1% higher than benchmarks.**

Keywords—F5G, Fault recovery, Protection, Restoration

I. Introduction

We are facing various applications from supporting classic telecommunication scenarios to fiber-to-the-x (FTTX). The network scale and the number of access users are expected to be increased to support more services. These network changes drive the technical development of the Fifth-Generation Fixed Network (F5G) [1]. There are multiple different classes and granularities of services in F5G. Different services have different performance requirements. Some services such as cloud VR and video conference are sensitive to latency and bandwidth. If the transmission is not performed in time, it will result in poor customer experience. While some services such as data backup and browsing have lower requirements of latency. Therefore, the services can be divided into two types: the advanced services with high latency requirements for the network and the basic services with low latency requirements for the network.

Optical transport networks (OTN) have the benefit of providing high-quality bandwidth, which will be fundamental infrastructures for F5G. Fault management is an important study in optical networks, and it is typically achieved through protection or restoration [2]. OTN can provide multiple protection mechanisms for the Optical Data Unit (ODU) in the electrical domain, also known as Subnetwork Connection Protection (SNCP). However, the traditional protection schemes in optical networks result in too much idle bandwidth, whether they are dedicated protection or shared protection. To reduce the number of reconfigured forwarding rules in the restoration process, a study proposes the use of local fast rerouting [3-4]. This method involves redistributing each affected service to a local restoration path and aggregating all services assigned to the same local reroute path into a new flow. However, it cannot achieve globally optimum fault management. A centralized network view enables the analysis of network behavior and workload to calculate the optimal path or locate the location of the fault [5-6]. Most of the proposed recovery algorithms are based on the current network state, if the basic services occupy too many network resources, it will reduce the recovery success probability of advanced services.

OTN is gradually evolving to directly carry end-user services, and Optical Service Unit (OSU) is a new transport technology that can provide bandwidth ranging from 2Mbps to 100Gbps for services. As a result, OTN is transforming from a connection-oriented network to a service-oriented network. In addition, the hitless bandwidth adjustment of OSU has a smaller latency [7], which eliminates the limitation of requiring integral multiples of 1.25G as needed for traditional Optical Data Unit (ODUk). This provides a good solution for service protection. In F5G, a single fiber can carry even thousands of random services, so when a network link fault occurs, it leads to the high concurrency of multiple types of services. Efficiently recovering a large number of different types of multi-granularity services is a new challenge for traditional recovery algorithms. Therefore, as for fault recovery, how to restore as many advanced services as possible under limited resources becomes the focus of the research.

This paper focus on the electrical domain and proposes a new fault recovery scheme for classified services based on hybrid protection and restoration (HPR) over OTN. The scheme is capable of recognizing different types of services and specifying different recovery strategies for each type of service. It can break through the limitations of current resources, and it improves the recovery success probability of advanced services by minimizing the interruptions of basic services on the protection path through the OSU bandwidth adjustments.

The following sections of the paper are organized as follows: the research problem is described in Section II, then the principle of the scheme is designed in Section III, and then the experimental results are analyzed in Section IV. Finally, we summarize the research and conclude the paper in Section V.

II. Problem Statement

The optical transport networks can be logically divided into the transport layer, the control layer and the application plane. The transport layer consists of network devices and optical fiber, while the control layer is managed by the SDN controller for global topology and resource usage information. The available resources of different links are different, and the proportions of the two types services carried on each link are also different, as shown in Fig. 1. The mathematical symbols are represented as follows:

Notations:

- $G=(\mathbf{V},\mathbf{E})$: network topology, where $\mathbf{V}$ denotes the set of nodes and $\mathbf{E}$ denotes the set of links
- C : the capacity of each link in the network
- bo : the OSU protection connections bandwidth for advanced services
- $\mathbf{E}_f$: the failed link set in the network, $e_f \in \mathbf{E}_f$
- $\mathbf{P}_c$: the calculated path set, $p_c \in \mathbf{P}_c$
- $\mathbf{P}_o$: the protected path set, $p_o \in \mathbf{P}_o$
- $\mathbf{R}$: the set of network service requests
- $r(t_r, s_r, d_r, b_r)$: each network service request, t_r is the type of service, s_r and d_r are the source node and the destination node generated randomly, and b_r is the bandwidth of the service request, $r \in \mathbf{R}$
- $\mathbf{R}^{'}$: the set of fault-affected service requests in the network, $r^{'} \in \mathbf{R}^{'}$
- $\mathbf{R}^{'}_a$: the set of fault-affected advanced requests
- $\mathbf{R}^{'}_b$: the set of fault-affected basic requests
- $\mathbf{R}^{'}_{af}$: the set of advanced service requests failed to be recovered
- $\mathbf{R}^{'}_{bf}$: the set of basic requests failed to be recovered
- $\mathbf{R}^{'}_{ob}$: the set of basic requests whose transmission is suspended due to the bandwidth adjustment of OSU protection connections
- k : the number of reroute paths
- $c^{p_{ok}}_{s\min}$: the second smallest remaining capacity of the link of the OSU protection path p_{ok}
- $c^{p_r}_{\min}$: the smallest remaining capacity of the link of the request path p_r
- $b^{p_{ok}}_m$: the biggest bandwidth of the basic requests of the link of the OSU protection path p_{ok}

After detecting a link failure, the controller should employ a recovery method to restore services. In Fig. 1, a failure occurs on the link between node c and d of the network. The traditional restoration strategies calculate k shortest paths based on the link distance from s_r to d_r, then allocate resources for requests according to the priority of $\mathbf{R}$. However, these strategies based on the current network state, if the new path of p_c transmits lots of basic services such as the link between node b and node d in Fig. 1, the advanced services may fail to be recovered due to insufficient resources. Besides, the traditional dedicated protection strategies reserve enough backup resources in advance for each service, if no failure occurs, these resources are idle, and these strategies cannot utilize network resources efficiently.

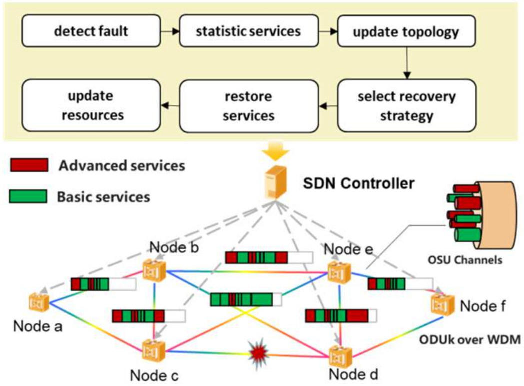

Fig. 1. An example of link fault in network

Therefore, under the limited resources, how to maximize the recovery success probability of advanced services is a problem. The objective is presented as Eq. (1), the advanced services recovery success probability is equal to the advanced services recovered successfully divided by all the advanced services in the faulty link :

Objective:

$$\max\left(\frac{\left|\mathbf{R}^{'}_a\right|-\left|\mathbf{R}^{'}_{af}\right|}{\left|\mathbf{R}^{'}_a\right|}=\sum_{r^{'}_a\in\mathbf{R}^{'}_a,\, r^{'}_{af}\in\mathbf{R}^{'}_{af}}\left|\frac{r^{'}_a-r^{'}_{af}}{r^{'}_a}\right|\right) \qquad (1)$$

III. Hybrid Protection And Restoration Scheme

The HPR scheme takes advantage of OSU hitless bandwidth adjustment and designs different strategies for advanced service requests and basic service requests. Before a failure occurs, the HPR scheme reserves k OSU end-to-end connections with bo for advanced services, and the protection connections do not coincide with the working path. Fig.2 shows an example of HPR scheme, which shows only one recovery connection. The specific scheme steps are as follows:

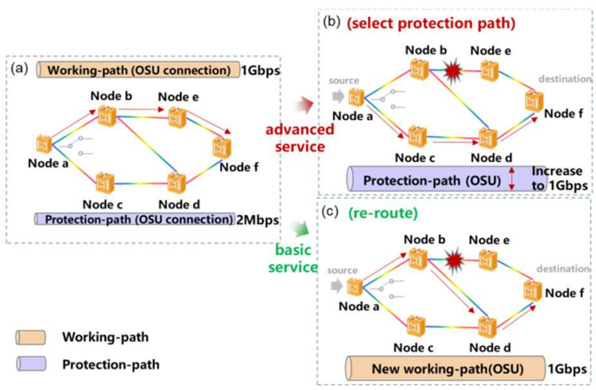

Fig. 2. (a)the initial network state before failure occurs, (b)an example of advanced service recovery, (c)an example of basic service recovery

First, the HPR calculates a working path for r based on the shortest path algorithm, represented as p_r, and then allocates resources for the request, and updates C. The constraint condition (2) ensures enough resource allocating for each connection, the smallest remaining capacity of the link of the request path should be more than the bandwidth of the service request. If the constraint condition (2) is not satisfied, the HPR will record the blocked initial services number n_b.

$$b_r \le c_{\min}^{p_r} (b_r \in r, c_{\min}^{p_r} \in C) \tag{2}$$

When a network failure occurs on e_f, as shown in Fig. 2, the HPR gets the affected services set $\mathbf{R}'$, and sorts all the services in $\mathbf{R}'$ according to the service type.

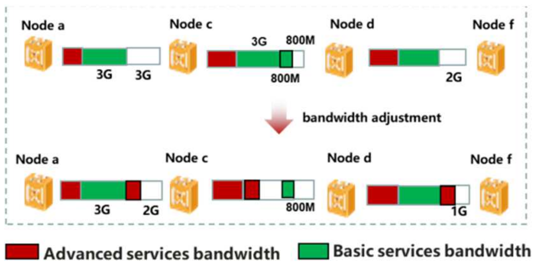

Fig. 3. An example of bandwidth adjustment of advanced service

If the service class is advanced, the HPR scheme sorts the link remaining capacity of the OSU protection path in increasing order, if the constraint condition (2) or the constraint condition (3) is met, the HPR will adjust the pipeline connection bandwidth from the OSU protection connections bandwidth to the service request bandwidth. The constraint condition (3) ensures more advanced services can be recovered successfully by minimizing the interruptions of basic services in the protection connection. If the bandwidth of the advanced service is more than the smallest remaining capacity of the link of the path, the sum of the smallest remaining capacity and the biggest basic requests bandwidth of the link should be less than the second smallest remaining capacity. As shown in Fig. 3, the available capacity between node c and node d is less than service bandwidth, so the HPR suspends the basic service with biggest bandwidth and release resource to ensure the advanced service recovery. If the current advanced service does not meet the above two conditions after traversing k paths, it is failed to restore and can be considered blocked, and the HPR updates the number n_{ab} of $\mathbf{R}_{af}'$.

$$\begin{cases} b_r' \ge c_{\min}^{p_{ok}} \\ b_m^{p_{ok}} + c_{\min}^{p_{ok}} \le c_{s\min}^{p_{ok}} \end{cases}, (b_r' \in r', b_m^{p_{ok}} \in r, c_{\min}^{p_{ok}}, c_{s\min}^{p_{ok}} \in C) \tag{3}$$

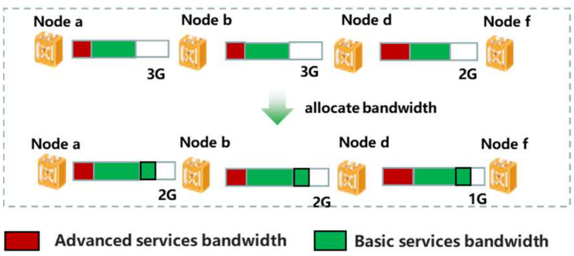

Fig. 4. An example of allocating bandwidth of basic service

If the service type is basic, the HPR scheme reroutes k paths for r' from s_r to d_r, if the constraint condition (1) is met, the recovery is successful, otherwise the service is considered blocked, and then HPR updates the number n_{bb} of $\mathbf{R}_{bf}'$. The recovery success probability of basic services is the fault-affected basic service divided by the successful basic service recovery.

The HPR scheme uses M to represent the longest path hops, and uses p_o to represent the path set of the current disrupted advanced service, and uses p_c to represent the path set of the current disrupted basic service, the complexity of the HPR scheme is $O[M\times(|\mathbf{R}_a'|\times|p_o|+|\mathbf{R}_b'|\times|p_c|)]$.

According to the above rules, the pseudo code of HPR scheme is shown in Table 1:

TABLE I. PSEUDO CODE OF HPR

Input: $G=(\mathbf{V},\mathbf{E})$, $\mathbf{R}$, $\mathbf{P}_c$, $\mathbf{P}_o$, C, bo, $\mathbf{E}_f$, k

Output: n_{ab}, n_{bb}

Initialization: $\mathbf{R}$, $\mathbf{P}_c$, $\mathbf{P}_o$, C, bo, e_f

Get initial service set $\mathbf{R}$, get k shortest paths and allocate resources, record blocked service number n_b

Get faulty link e_f and fault-affected service set $\mathbf{R}'$

For each affected service r' of $\mathbf{R}'$:
- **if** service type == advanced **then**:
  - traverse p_{ok} in p_o, get $c_{s\min}^{p_{ok}}$, $c_{\min}^{p_r}$, $b_m^{p_{ok}}$;
    - **if** constrain (1) is satisfied:
      - recovery succeeded and update C
    - **else if** constrain (2) is satisfied:
      - release resource $b_m^{p_{ok}}$ of r
      - adjust the bo to b_r' and update C
    - **else:**
      - $n_{ab} \leftarrow n_{ab}+1$
    - **end**
- **if** service type == basic **then**:
  - traverse p_{ck} in p_c, get $c_{s\min}^{p_{ok}}$:
    - **if** constrain (1) is satisfied:
      - recovery succeeded and update C
    - **else:**
      - $n_{bb} \leftarrow n_{bb}+1$
    - **end**
- **end**

end

IV. SIMULATION RESULTS

As shown in Fig.5, the network model has 14 nodes and 22 bidirectional links, the number on each communication link represents the length of the link, and initial capacity of each link is 100Gbps. The source and destination nodes of each service in the network are randomly generated, and the services bandwidth are evenly distributed between 1Gbps and 3Gbps. We simulated 200 to 800 services with a step size of 50. For each experiment we randomly select a link from the failed link e_f, bo equals to minimum bandwidth 2Mbps, the maximum value of k is set as 5. Based on the above assumptions, this study makes the simulation analysis of the resource utilization, the service blocking probability and the recovery succeeded probability of different schemes. The end-to-end restoration scheme (ETER) represents after the failure occurs, the SDN controller reroutes k paths from the service source node to the destination node, and the local restoration scheme (LR) represents the SDN controller reroutes k paths between fault nodes after the failure occurs.

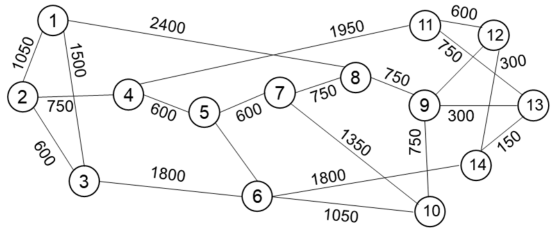

Fig. 5. NSFNET topology

Fig. 6 shows the changes in the success probability of advanced service recovery of the three schemes. As the number of network services increases, the average recovery success probability of HRP scheme is 15.3% and 24.9% higher than that of ETER and LR, respectively. This is because the protection connection bandwidth between each pair of nodes is just 2Mbps, which is much smaller than the link capacity, and the interrupted basic service can release many resources for advanced service recovery. Furthermore, since the protection path does not coincide with the working path, it can fully occupy the resources of the entire network and avoid congested links, unlike ETER.

Fig. 7 shows the changes in the recovery success probability of basic service of three schemes. As the number of services increases, the recovery success probability of the HPR and ETER is much higher than the LR scheme. So the HPR scheme does not reduce the recovery success probability of basic services while improving the recovery success probability of advanced services.

Fig. 8 shows the changes in the blocking probability of the three schemes. The blocking probability is the blocked service (includes initial assignment failed services and recovery failed services) divided by the total services. In Fig. 8, as the number of service numbers increases, the BP-HPR is lower than that of the BP-ETER and BP-LR. This is because the BP-LR is limited to the network resources between the failed link nodes, when the number of services is large, the HPR scheme can restore more services than the other two schemes.

Fig. 9 shows the changes in resource utilization after recovery of three schemes. It can be seen as the number of services increases, the resource utilization of HPR is higher than that of the other schemes. This is because the HPR scheme reserves protection bandwidth resources for each pair of nodes, and it can restore more services than others. LR restores fewer services than the other schemes, so its resource utilization is lower.

V. Conclusions

In the Fifth-generation Fixed Network failure scenarios, the high concurrency of multiple types of services poses a significant challenge to the traditional recovery scheme. This paper proposes a hybrid protection and restoration fault recovery scheme to address the issue of poor service awareness ability of traditional schemes and low recovery success probability of advanced services. This scheme specifies different recovery strategies for different types of services. As the number of services gradually increases, the average recovery success probability of advanced services is 15.5% and 25.1% higher than that of the compared two recovery schemes. In addition, the HPR scheme maintains the basic services recovery success probability without reduction and exhibits lower blocking probability compared to the other two recovery schemes.

Acknowledgment

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References

[1] Li Z, Zhao Y, Li Y, et al. Deterministic Full-Fiber Service Network for the Fifth-Generation Fixed Network (F5G)[J]. IEEE Network, 2023.

[2] Saini H, Garg A K. Protection and restoration schemes in optical networks: a comprehensive survey[J]. International Journal of Microwaves Applications, 2013, 2(1).

[3] Cheng Z, Zhang X, Li Y, et al. Congestion-aware local reroute for fast failure recovery in software-defined networks[J]. Journal of Optical Communications and Networking, 2017, 9(11): 934-944.

[4] Mohan P M, Truong-Huu T, Gurusamy M. TCAM-aware local rerouting for fast and efficient failure recovery in software defined networks[C]//2015 IEEE Global Communications Conference (GLOBECOM). IEEE, 2015: 1-6.

[5] Fonseca P C, Mota E S. A survey on fault management in software-defined networks[J]. IEEE Communications Surveys & Tutorials, 2017, 19(4): 2284-2321.

[6] Petale S, Thangaraj J. Link failure recovery mechanism in software defined networks[J]. IEEE Journal on Selected Areas in Communications, 2020, 38(7): 1285-1292.

[7] Jing R, Zhang C, Zhou H, et al. Innovation and demonstration of optical service unit-based metro-optimized OTN technologies[J]. Journal of Optical Communications and Networking, 2022, 14(4): 236-247.

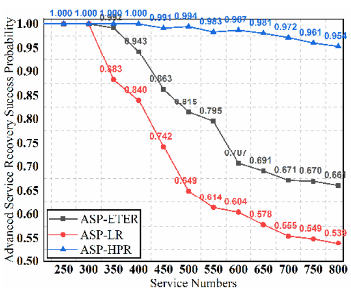

Fig. 6. Advanced services recovery success probability

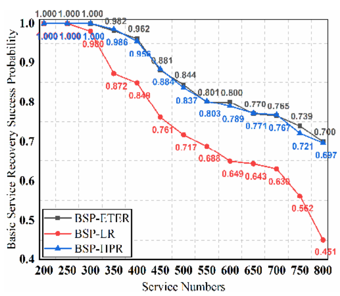

Fig. 7. Basic services recovery success probability

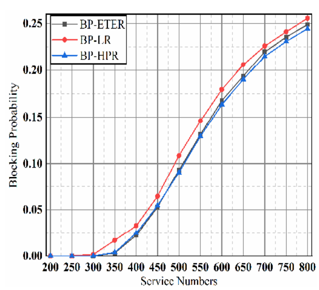

Fig. 8. Network blocking probability

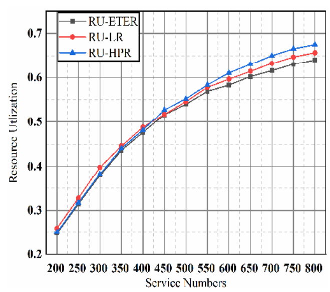

Fig. 9. Network resource utilization