Multi-node Cooperative Recovery against IP node failure Enabled by Flexible Optical Network

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Abstract: We propose a multi-node cooperative recovery method against IP node failure through joint selection and flow table splitting. The recovery time saves by 89.5%, and the success rate improves by 25.6% in heavily loaded network. © 2022 The Author(s)

1. Introduction

With the development of the Internet, more and more vertical industry services are transmitted in the network, which enhances the importance of the IP network's reliability [1]. The optical network is usually considered as a static network for the IP layer, and IP failure recovery is mainly performed at the pure IP layer [2]. The development of equipment technology and virtualization technology in the optical network has enhanced the optical network's flexibility [3], suggest the underlying optical network be considered during IP layer recovery. Based on this idea, some of previous researches proposed IP node failure recovery method enabled by the flexible optical network [4], which provide one "sleep" IP node to replace the failed IP node and re-connect the optical connection. However, due to the limitation of IP node forwarding capability and transmission distance between IP nodes, it's may be difficult to find one node for replacement, which is not solved by the previous research.

In this paper, we proposed a multi-node cooperative recovery methodology combined with the GA algorithm, achieving efficient and reliable IP node failure recovery. A joint selection method based on GA is adopted to realize the concurrent selection of multiple IP nodes and optical connections. The method of flow table splitting is adopted to realize the transmission of services between multi-nodes. The method achieves efficient and reliable node-level failure recovery. Experiments show that, compared with the traditional rerouting method, the multi-node cooperative recovery method saves 89.5% time when the faulty IP node is fully loaded and improves the success rate by 25.6% compared with the present research.

2. Methodology

2.1. Multi-node Cooperative Failure Recovery Method Introduction

The method is carried out in three key stages.

Stage 1. Multi-node selection: Since the IP node is a full-mesh structure, services can be transmitted between any two ports. Multi-node needs to exhibit the same forwarding capability as an IP node which means that multiple failure services with different source and destination ports need to be transmitted simultaneously in multi-nodes.

Stage 2. Inner node and outer node connection: The transmission of the services between IP nodes needs the support of the optical network. Both inside the multi-node and outside the multi-node require optical connections to realize the transmission of services between the nodes affected by the fault.

Stage 3. Flow table splitting: In order to forward and transmit services in the network, the original flow table needs to be split. For the node affected by the fault, the outgoing port of the service flow table needs to be adjusted. For nodes within the multi-node, the flow table needs to be created according to the forwarding mode between multi-nodes and original flow table.

2.2. Joint Selection Algorithm Based on Genetic Algorithm

In order to realize multi-node selection and inner node and outer node connection, we designed a joint selection based on genetic algorithm, implementing the concurrent selection of multiple IP nodes and optical connections. We define an optical link connection (OLC) as the connection between an IP node to the adjacent IP node through the IP layer and the optical layer. Affected node pair (A, B) consisting of node A and node B is defined as a pair of neighbor nodes with service transmission affected by the fault.

The algorithm aims at minimizing the resource cost. The resource cost consists of the sum of OLCs' resource cost between multi-nodes used for recovery and the resource cost generated by connecting the multi-nodes between the affected nodes. Constraint (2) indicates that the multi-node should have the same ability as the original faulty

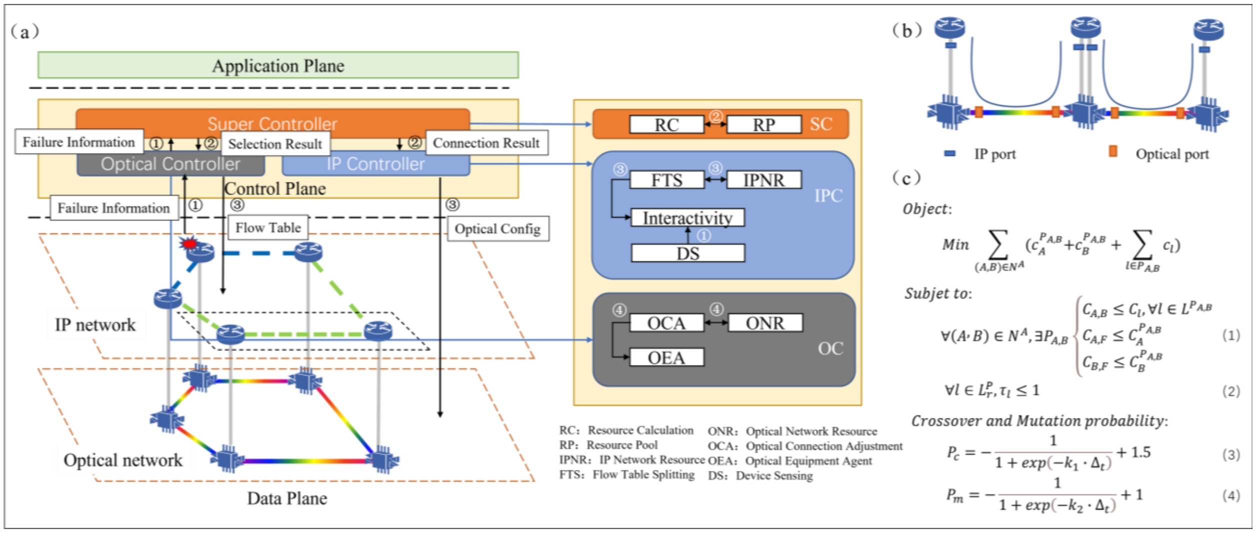

Fig.1. (a) Recovery process in IP over flexible optical network; (b) Optical connection link; and (c) Recovery algorithm.

node. Constraint (3) represents the multiplexing of an optical link that is not considered in fault recovery due to its complexity. So, the number of failed service groups/sub-groups transmitted in any OLC is less than or equal to 1.

The algorithm is mainly divided into two steps. (1). Select a suitable search network. The calculation time of the genetic algorithm is closely related to the size of the search network. This algorithm constructs a suitable sub-network as the search network. (2). Obtained the optimal solution by genetic algorithm. The resource cost and capacity constraints are used as the basis for the design of the fitness function. In order to avoid falling into the optimal local solution, formula (3) and (4) show the algorithm adaptively adjusts the probability of crossover and mutation according to the dispersion degree of the solution space Δ_t .

2.3. Multi-node Cooperative Failure Recovery Process

The architecture of IP over flexible optical network is shown in Fig.1. (a)The application plane interacts with the control plane through the controller's northbound interface. The control plane is a two-layer architecture. The super controller (SC) exchanges information with the IP controller (IPC) and the optical controller (OC) through the southbound interface. The SC stores the IP and the optical resources in the resource pool. The data plane includes the IP layer and the optical layer, wherein the IP layer link is logical, and the optical layer link is physical. The link and devices can be adjusted under the config command received from the control plane.

Recovery process is as followed. ①*Failure aware*: When an IP device leaves, the Device Sensing in IPC receives a failure information and reports it to SC. ②*Recovery calculation*: Recovery Calculation runs the joint selection algorithm in SC according to the network resource in Resource Pool. Then, the SC sends the selection and connection result to IPC and OC. ③*Flow table splitting*: According to the multi-node selection result receiving from SC and resource in IP Network Resource, Flow Table Splitting in IPC processes the flow table and delivers them to corresponding IP devices through Interactivity. ④*Connection establishing*(concurrent with ③): According to the Inner node and outer node connection result receiving from SC and resource in Optical Network Resource, Optical Connection Adjustment derives the adjustment method of connection. Optical Equipment Agent delivers the config to corresponding optical devices.

3. Experiments results

The experimental platform is shown in Fig.2. (a). We use SDN switches as IP switching devices, programming OXC as optical network devices. We use the method of combining virtual with actual to conduct simulation experiments. The experimental network topology showed in Fig.2. (b) consists of four practical nodes (node 10,13,14 and17) and other virtual nodes.

$$T_{R\_multi} = T_{FR} + T_{C\_multi} + s * switch\_num\_multi * T_{FP} + T_E \quad (5)$$

$$T_{R\_reroute} = T_{FR} + \sum_{i=1}^{s} (T_{C\_reroute} + switch\_num\_i * T_{FP}) + T_E \quad (6)$$

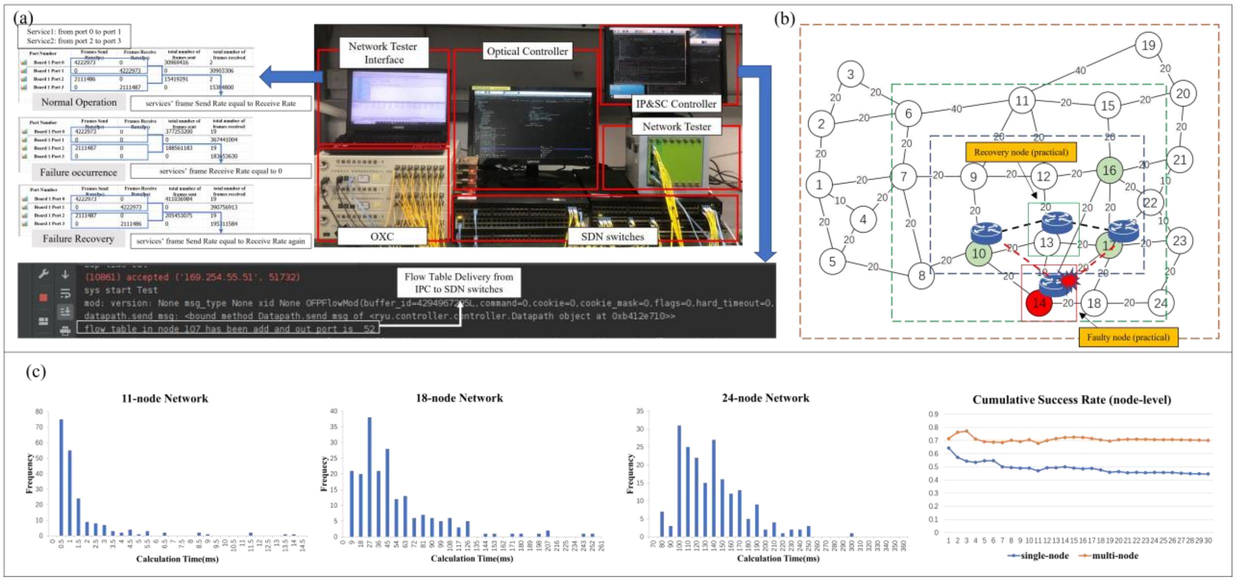

Fig.2. (a) Experimental testbed for multi-node recovery method; (b) Experimental network topology; and (c) Calculation time and Cumulative recovery success rate.

As for the recovery time. The fault recovery time T_R consists of fault reporting T_{FR} , failure recovery calculation time T_C , flow table processing T_{FP} and flow table effective time T_{FE} . Formula (5) and (6) shows the composition of the failure recovery time of the multi-node cooperative failure recovery method and the rerouting method when there are s services in the faulty IP node.

When the experimental network topology size is 11,18 and 24 nodes, the average calculation time is 14ms, 48ms, and 133ms under the multi-node cooperative failure recovery method showed in Fig.2. (c). The recovery time of the multi-node cooperative failure recovery method is 1104ms in a 11-node network. The calculation time of the traditional rerouting method is 0.78ms/flow on the same SC. An SDN switch in the experiment carries at most 12000 flows. When the flow table is sent to the switches with the same total number and the faulty switch is fully loaded, the traditional rerouting method is at least 10450ms. The recovery time of the multiple node method is 10.6% of the rerouting method. In fact, the number of switches that need to deliver the flow table for rerouting should be larger than the multi-node method, which means that there should be a more significant improvement in recovery time.

As for the recovery success rate, compared with the single-node recovery method we studied before, the success rate of the multi-node recovery method is improved by 25.6% showed in Fig.2. (c).

4. Conclusion

In order to solve the problem of IP failure, multiple IP nodes implement the forwarding of all faulty services cooperatively, and flexible optical devices adjust to implement the transmission between IP nodes, achieving node-level fault recovery. In experiments utilizing the testbed, the recovery time is 10.5% of the rerouting method, and the success rate improves by 25.6% of the single node recovery method.

Acknowledgments

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