Flexible Optical Network Enabled Hybrid Recovery for Edge Network with Reinforcement Learning

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Abstract: The proposed hybrid recovery utilizes flexible optical network with reinforcement learning to recover IP fault for edge network. The testbed experiments indicate, the recovery time is 20% of rerouting-based strategy for a heavy-loaded network.
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1. Introduction

Flexible transponders and SDN based centralized control provide flexibility of optical networks on connection management, resource allocation and online optimization. It makes optical networking a suitable technology to support the flexible communications among edge datacenters [1]; thus, the edge network is more likely to become an "IP/Optical" hybrid infrastructure. In order to meet the essential requirement of low-latency and high-reliability in edge networks, a fast fault recovery method is needed for this hybrid edge network. A leverage flexible flow aggregation in fast reroute is proposed in [2], and Proactive Failure Recovery was proposed in [3]. But with the development of edge computing, the number of services carried by the nodes in the edge network has increased dramatically [4]. Then, the recovery time of conventional flow-based recovery method will increase almost linearly with the failed service flows, so it is valuable to investigate a novel recovery method to reduce the dependency between recovery time and the failed services.

In this paper, the main idea is to recover the faulty IP node instead of the affected services individually, to achieve a quick network capability recovery in seconds level. Utilizing the flexible optical network, a hybrid network node fault recovery method is proposed for the recovery of faulty node carried enormous service flow in the edge network. Through dual-migration in IP +optical hybrid network and reinforcement learning recovery algorithm, the fault recovery time is almost independent of the number of fault services. The testbed experiments show the recovery time of flexible optical network enabled hybrid recovery saves about 80% recovery time compared to rerouting recovery for a faulty IP node which carried 12000 flows.

2. Methodology

2.1 Architecture and process of flexible optical network enabled fault recovery

As shown in Fig. 1(a), we provide a controller structure for network fault recovery by dual-mitigation in IP network and optical network. The super controller (SC) is responsible for integrating network resources, calculating recovery result, and collaborating the IP controller (IPC) and optical controller (OC). IPC is the SDN controller, which is responsible for monitoring network information in real time, and the generation and migration of stand-by node configuration. OC is the SDON controller, which is responsible for the migration of optical connection.

Hybrid network resource collection： SC integrates the hybrid network resources periodically. IP Network recourse Collection (IPNC) and Optical Network recourse Collection (ONC) do resource collection for IP and optical network, and send the recourse information to Resource Pool (RP) in SC.

Recovery step 1, flexible optical network enabled recovery calculation: By making full use of optical network flexibility, the IP node can be used as a recovery resource if it is connected in the optical network. Therefore, under the permission that the optical network is variable, more IP resources can be used for fault recovery. In Fig. 1(b) (1), Recovery Calculation (RC) in SC runs the recovery algorithm (Details in 2.2) to calculate the stand-by nodes for recovery, based on the fault information and the resource information in the whole resource pool. Then, RC sends the recovery result of IP nodes and optical connection to IP controller and optical controller.

Recovery step 2, dual-migration of IP configuration and optical connection: (1) In Fig. 2(b) (2), based on the recovery result from step 1, Port Mapping (PM) and Flow Table Modify (FTM) generate stand-by node configuration file, so that the stand-by node can implement all switch functions of the faulty node. If the faulty node configuration file has a backup in the DB, it can be used directly. Config-msg Generate & Delivery (CG&D),

responsible for migration configuring, issues the configuration file to the stand-by node. (2) ONC updates the optical resources recording in Connection Database (CDB) according to optical connection migration result. OpenFlow Agent (OFA) sends the optical connection migration result to Optical Equipment Agent (OEA) via the OpenFlow protocol. Optical controller can control the optical connection device by OpenFlow through OEA. Finally, Wavelength Migration (WM) and Optical Port Migration (OPM) in the OEA issue wavelength migration command, and port migration command to the optical transmission device to implement optical connection migration.

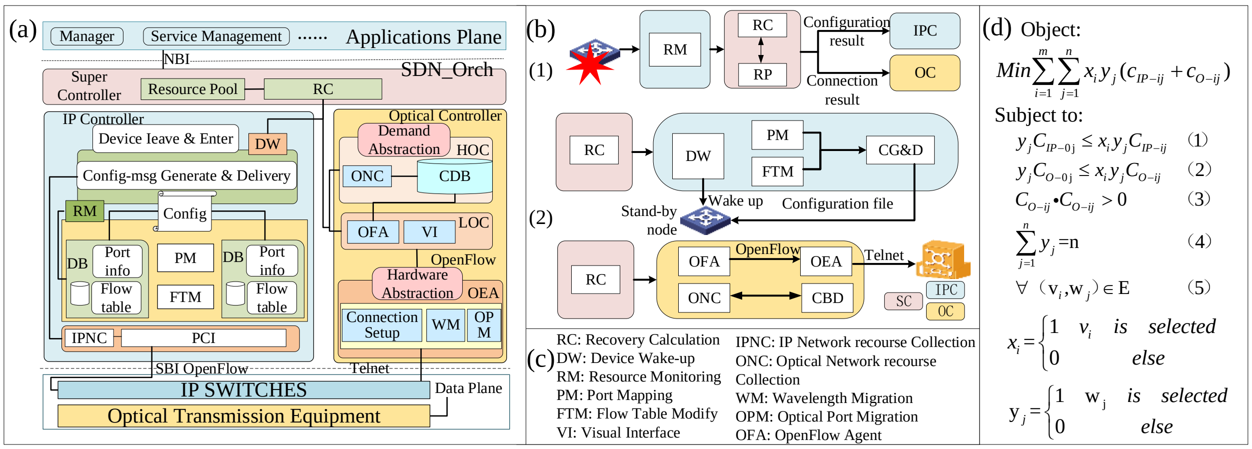

Fig. 1. (a) Controller architecture of network fault recovery Q-learning algorithm, (b) Dual-migration recovery process, (c) Abbreviation table, (d) Recovery algorithm.

2.2 *Flexible optical network enabled recovery algorithm based on Q-learning*

In order to make full use of the optical network flexibility, the topology and flow distribution of the network are changed after each fault recovery, so the flexible optical network enabled recovery algorithm needs to be able to adapt to the dynamic network. Q-learning has the advantage of fast convergence in a dynamic network environment. Therefore, Q-learning is used to calculate the dual-migration recovery result.

Because of the flexibility of optical connections, IP nodes in the network can be interconnected through optical networks, and IP resources are fully utilized. Therefore, in the algorithm, we mainly consider the resource cost, and the capacity of IP ports and optical connections. IP nodes in the network are divided into two parts: service transmission nodes, and resource nodes in the resource pool (the resource pool also contains optical connection resources). In Fig. 2(d), V_i represents the possible stand-by nodes, where $0 \le i \le n$, and $i = 0$ indicates the fault node. W_j represents the connected to a faulty node and carrying faulty services, where $1 \le j \le n$. The recovery node V must be able to connect all W and can carry faulty services on W. C_{IP-ij} , C_{O-ij} are the capacity of IP port and optical connection between node V_i and W_j . c_{IP-ij} , c_{O-ij} represents IP resource cost/optical resource cost of the connection between V_i and W_j . The object is to minimize the cost of recovery. Constraint (1) and (2) represent that the recovery links capacity of IP ports, and optical connections are not less than the original links. Constraint (3) ensures that V_i and W_j are interconnected by optical network. Constraint (4) represents that all services in the failed node are recovered.

Starting from a service transmission node connected to the faulty node, the IP stand-by node is randomly selected nearby this node for next hop. After ensuring the capacity of this IP port and optical connection meet the requirements, the next state with one hop is entered, until service transmission nodes connected to the faulty node are all reached hop by hop. Taking the remaining resources of the network as the Q value, the Q transfer equation is:

$$Q(s,a) = Q(s,a)+\alpha[r + \gamma \max_{a'}(Q(s',a') - Q(s,a)] \text{ where } r = All\_Resource - c_{IP} - c_O \quad (1)$$

3. Verification by Experimental Testbed

In the experiment, flow table is the node configuration file for migration and OXC connection is optical connection for migration. The experimental testbed is shown in Fig. 3(a). We use SDN switch (PICA8 P3297) as the IP switching device, and use Optical Cross-Connect (OXC, POLATIS) to simulate optical connection network.

Meanwhile, controller and SDN-Orch are implemented by python script on Ryu. In addition, the recovery time is measured using data quality analyzer (ANRITSU MD1230B).

The experimental topology is shown in Fig. 3(b), and the result of recovery algorithm is shown in Fig. 3(c). In Fig. 3(d), The recovery time consists of four parts: the fault reporting time T_F , the recovery calculation time T_C , the flow table release time T_{FR} , and the flow table effect time T_E . T_{FR} includes the flow table processing time and releasing time. In Fig. 3(e), the experiment testbed verifies that the recovery time by dual-migration for a fault node carried 4 service flows is 669ms, where T_C is 47ms, shown in Fig. 3(c). The optical connection migration does not involve flow table, so the connection migration time is less than flow table migration. Because two migration are performed simultaneously, only the flow table migration time needs to be calculated. Due to the limit of experimental device, we were unable to test the rerouting of such large number of services. The rerouting recovery time can also be calculated. Form Fig. 3(d), we can see that except T_C , the rest of the recovery time is only related to devices. T_{FR} can be tested, and it is 1ms / flow table. The recovery time of rerouting is:

$$T_C\_reroute + T_E + T_{FR}\_reroute = T_C\_reroute + (dual\_migration\_time - T_C\_dual\_migration - T_{FI}) + T_{FR}\_reroute \quad (2)$$

The rerouting time is 2ms/flow, calculating on the same controller, and the maximum routes for P3297 is 12000. Therefore, when the switch is near full load, reroute recovery time is 60684ms, and dual-migration recovery time is 12665ms. Our recovery saves 80% recovery time compared to rerouting recovery and it is almost independence with service flow number.

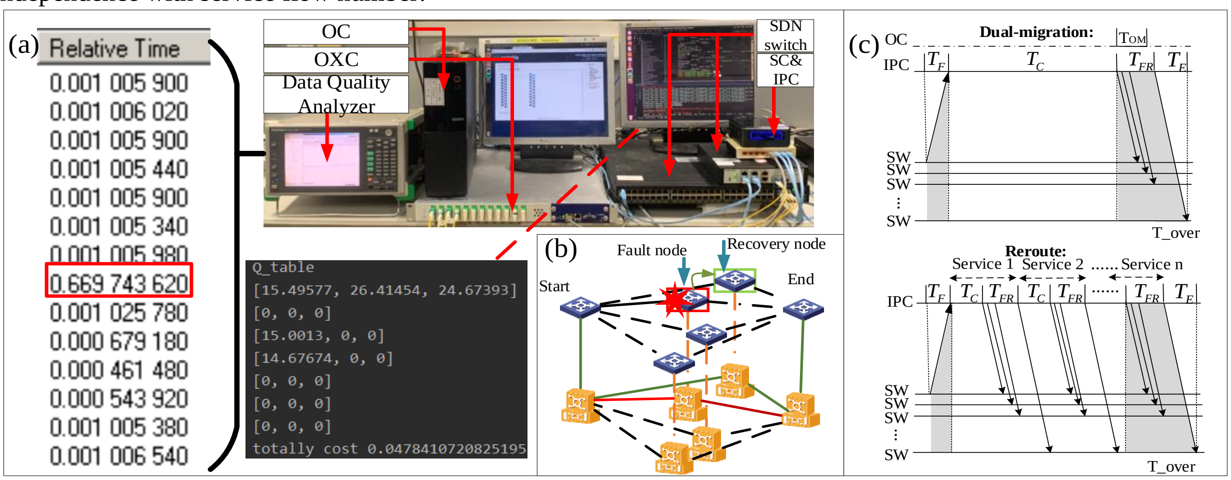

Fig. 3. (a) Experimental testbed of dual-migration recovery, (b) Experimental topology, (c) Recovery time analysis.

4. Conclusion

This paper proposes a hybrid network fault recovery for edge network based on reinforcement learning, enabling flexible optical network. By making full use of optical network flexibility, dual-migration of IP configuration and optical connection is used in hybrid edge network for fault recovery. In the experiment on real SDN-orchestrated testbed, for a 12000-flow fault node recovery, the flexible optical network enabled recovery time is 20% of rerouting recovery, showing the characteristic of service number independence.

5. Acknowledgments

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5. References

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