Research on IP fast Recovery Based on Multi-topology Routing

Xinyuan Liu, Hui Wang, Limin Zhang

Abstract— **In order to reduce the need for rerouting of IP fast rerouting (rerouting the number of hops added by the packet). Based on the basic principle of multi-route backup configuration, this paper proposes a new backup topology generation method based on the ordering of important nodes in complex networks. The main idea is to sort the nodes in the network topology by using the K-Shell decomposition algorithm and introduce the contribution between the nodes, and then select the key nodes for the generation of the backup topology. The experimental results show that the proposed algorithm can effectively reduce the number of rerouting hops and verify the feasibility and effectiveness of the algorithm.**

Index Terms—**backup topology,IP fast recovery,key node,multi-topology routing**

I. INTRODUCTION

With the popularization of time-delay and packet-loss sensitive real-time services, users' requirements for network performance have become more and more strict [1]. For IP telephony streaming media online games and remote video conferencing and other real-time services packet loss or long delay will significantly reduce their performance and even cause business interruption. Therefore, how to avoid packet loss and reduce the delay has become a problem that network operators have to face. The rapid recovery technology of IP network failure has also become a research hotspot [2]. MRC (Multiple Routing Configurations) [3], LFA [4], Not-Via [5], FIFR [6] and RRL [7] are proposed successively. Rapid IP recovery is primarily achieved by reducing reconvergence time by using a backup topology calculated in advance. The main idea of MRC is to calculate multiple backup topologies in advance for the physical topology (or original topology) of the network and to calculate the backup routes corresponding to the backup topology in advance. When a packet encounters a malfunction, the malfunction ID is marked to the packet header, and the packet is forwarded to the next hop of the backup using a forwarding publication corresponding to the malfunction ID.

For the further research of MRC, reference [8] reduces the number of backup topologies by creating a spanning tree; According to the diversity of network topology, a topology analysis tool is proposed to reduce the number of virtual topology and improve the performance of MRC. In [10], an IMRC algorithm is proposed to reduce the total hops of recovery paths by increasing the number of available links during rerouting. However, the decrease of backup topology will lead to overload of some links in the network, and the number of available links in the backup topology will decrease, which will result in the increase of rerouting hops, and the increase of rerouting hops will result in the increase of packet delay. Reference [11] proposes a method of defining key node in the process of backup topology creation to reduce the number of rerouting hops. The key nodes are defined by using two simple parameters, the Betweenness and Closeness, of the nodes in the topology. In some networks with more nodes, the number of rerouting hops can be reduced to a certain extent. In some network topologies, the effect of MRC algorithm without adding key nodes is not satisfactory [12].

Aiming at the above problems, this paper proposes to select key nodes in the process of backup topology creation by using improved K-Shell decomposition algorithm to sort the importance of nodes in the network so as to select key nodes. In this paper, the concept of contribution degree is introduced to measure the importance contribution between nodes. [13]This paper improves the algorithm of evaluating the importance of nodes in complex networks to select the key nodes in the original topology. The algorithm aims to consider the global importance and local importance of nodes synthetically, and increase the available links of the key nodes selected in backup topology, which not only shortens the number of recovery path hops, but also separates the load of links. The simulation results show that the improved algorithm can reduce the number of hops and link load of rerouting obviously, and the number of hops of rerouting can be effectively reduced by considering the location of the key nodes in the large-scale network.

II. MULTIPLE ROUTING CONFIGURATIONS

In this section,we describe the characteristics of backup configurations used in the MRC[3] method and in literature and then discuss their problem.

A. *Backup Configuration Creation*

Multi-topology Routing (MTR) technology. The core idea is to create a set of logical topologies based on the original physical topology of the network, called backup topology or multi-topology, which is used to protect the link or node failure. Multiple Routing Configurations (MRC) is a multi-topology algorithm for fast rerouting under node/link failure. MRC is an active fast rerouting scheme.Because the algorithm protects all possible link faults or node faults in the network in advance, it has a high fault protection rate.

When using the MRC algorithm, the main process of creating a standby topology: the original physical network

Xinyuan Liu, College of Information Engineering, Henan University of Science and Technology, Luoyang 471023, China
Hui Wang,Network Information Center, Henan University of Science and Technology, Luoyang 471023, China
Limin Zhang, College of Information Engineering, Henan University of Science and Technology, Luoyang 471023, China

topology is shown in Figure 1. Because of the design idea of MRC fast rerouting scheme, This technique ensures that all nodes and links in the network can be protected in at least one of the corresponding backup topologies.

Figure 1 shows an original network topology consisting of six nodes and eight links and three corresponding backup topologies using the MRC algorithm. All backup topologies are composed of two nodes (normal node and isolated node) and link is divided into three types: normal link, isolated link and restricted link.

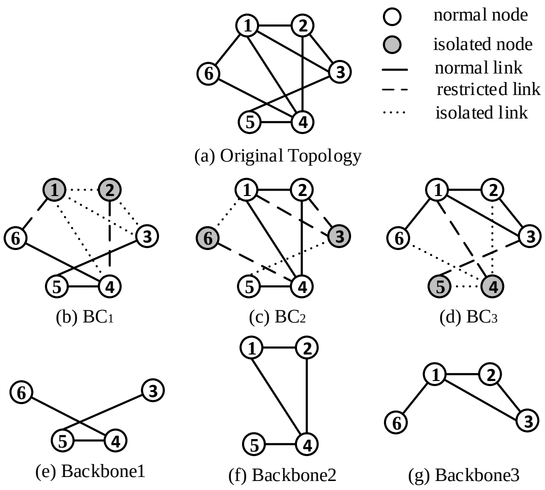

Figure 1. Original topology and backup topology

To achieve rapid recovery using the corresponding backup topology when a link or node failure occurs, the backup topology must meet the following conditions:

1. Each backup substructure is the same as the original network structure, and each needs to contain a single backbone, that is, each isolated node in the standby topology can still be connected after the link is removed. All isolated nodes in the backup topology can be connected to the backbone via one or more restricted links.

2. The isolated nodes in the backup topology can only be connected to the isolated link and the restricted link, and both ends of the restricted link in the same backup configuration cannot be isolated at the same time.

All links and nodes in the network structure diagram must be isolated at least once within a single standby configuration.

B.*Problems*

In the original MRC algorithm, the backup topology is generated by setting all the components in the network as isolated nodes or links in turn and generating a series of backup topologies accordingly, which is used to realize the rapid recovery of network faults. From this process, we can see that in the process of backup topology generation, all nodes of the network are protected in turn, there is no priority in the order, is treated uniformly.

However, in the actual network structure, different nodes have different importance for the network itself because of their degree of access, degree of centrality, median value and the actual traffic size and so on. The main idea of the improved algorithm proposed in this chapter is to add the key nodes in the process of generating the backup topology and shorten the hops of the shortest path by increasing the available links of the key nodes. For the selection of the key nodes, we should not only consider the position of each node in the network or the influence of the median value to give the importance of the node ranking, thus ignoring the impact of some other complex factors on the importance of the node.

III. PROPOSED BACKUP TOPOLOGY DESIGN METHOD

Aiming at the social interpersonal network, the research of complex network arises. The discovery algorithm of many important nodes is also accompanied by the rapid development of network technology, and has also been developed and applied in the fields of Internet and so on. More and more attention has been paid to the research of important nodes in complex networks. Many important node discovery algorithms have been proposed by researchers, such as the methods based on dielectric value, degree centrality, etc. These methods are relatively simple, in the more complex network structure with this kind of simple algorithm can not properly select the key nodes in the network topology. In this part, we propose an improved K-shell decomposition algorithm which introduces the contribution degree between nodes.

A.K-Shell decomposition algorithm

Researchers such as Kitask believe that if node I is at the core of the network, Even if the value of this node's penetration is small, Its influence on network topology is also enormous. Similarly, if a node j is located at the edge of the network structure and has a high degree of access, its importance to the network is far less than that of node i. Based on the above theory, Kitask and other researchers propose a coarse-grained node importance ranking scheme, i.e. K-Shell decomposition algorithm.

The decomposition steps of the K-Shell decomposition algorithm are as follows: First, assume that all nodes in a network have degrees greater than or equal to 1, That is, the degree of all nodes is k1, The first step is to strip all nodes in this network with a degree value of 1, After spalling the new network structure, the nodes with degree 1 will still appear. Then the previous steps will be repeated. Then the nodes with degree 1 in the network will be spun off until the degree value of all the nodes in the new network is k2. At this time, the previously spilled nodes will be defined as 1-shell (1-Shell) in the network. The degree value of the nodes in the network structure obtained at this time is k2. The steps are similar to the previous step. All the nodes whose degree value is 2 are sputtered repeatedly until the degree value of all the nodes in the network is k3. The node whose second step is sputtered is called 2-shell of the network. And so on until all the nodes in the subnetwork are stripped.

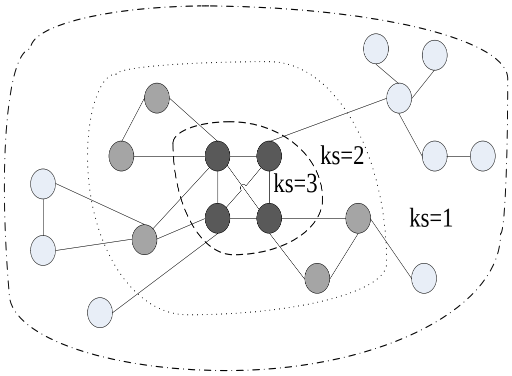

Figure 2.A simple network with three shells

According to the above steps, K-Shell decomposition algorithm can concisely and effectively obtain the core nodes of different levels in the network, but the results can not further distinguish the difference of node importance.

After using K-Shell decomposition results for a network, all the nodes of ks k are referred to as K-Core (K-kernel) of the network. For Figure 2, 1-Core (1-kernel) is the union of all nodes in the network, namely 1-Shell, 2-Shell and 3-Shell, 2-Core is the union of 2-Shell and 3-Shell in the network, and 3-Core is equivalent to 3-Shell.

B.*Improved Algorithm*

After the initial K-Shell decomposition algorithm is used to peel the network layer by layer, the core node set is not considered the influence of the local environment of the important node. Therefore, the contribution degree between nodes is introduced, and the environment around nodes is fully considered, that is, the influence of the neighbor nodes of nodes. In the evaluation of the importance of nodes in network topology, it is too one-sided to simply consider the degree, the median, the center approaching degree, the eigenvector index, and so on, and the node importance ranking is not reasonable. Therefore, on the basis of K-Shell decomposition algorithm, the influence of all adjacent nodes of each node on its importance is further considered. The contribution of the neighbor node is different, and if the node does not have a contiguity with the node, the contribution is 0 (in this case only for unauthorized networks), otherwise the contribution is defined as follows:

$$N_{ij}=\frac{|l_i\cap l_j|}{|l_i\cup l_j|-1} \qquad (1)$$

The *li* and *lj* in formula 1 represent the degree of node *i* and node *j* respectively. *Nij* is the proportion of the number of common neighbors of node *i* and node *j* to their total number of neighbors.

For Formula 1, when there is no public neighbor node between the two nodes, the contribution of the node is 0, which is obviously unreasonable, because as long as there are concatenated edges between the nodes, they will affect each other, that is, there is a contribution that is not zero. At the same time, the contribution of node i to node j and the contribution of node *j* to node *i* should be different. Set a threshold to two times the network average.

The improvement to formula 1 is as follows: if *li-lj* > threshold, compensate the contribution of node i to node j, that is:

$$N_{ij}=\frac{|l_i\cap l_j|}{|l_i\cup l_j|-1}+a*(l_i-l_j) \qquad (2)$$

If *ki-kj* does not exceed the threshold, the contribution is:

$$N_{ij}=\frac{|l_i\cap l_j|+1}{|l_i\cup l_j|-1} \qquad (3)$$

But according to different network structure, the selection of threshold and the selection of parameters are different, in order to better adapt, further simplify the formula: Formula 2, 3 is simplified as:

$$N_{ij}=\frac{|l_i\cap l_j|+1}{l_i+1} \qquad (4)$$

K-Shell decomposition algorithm can be used to divide the core nodes of the network concisely, but the results are coarse-grained. The importance of the node is not only associated with its own attributes, but also needs to pay attention to the impact of the local surrounding nodes. In this paper, an improved K-shell decomposition algorithm is proposed. The contribution degree is introduced into the classical K-shell decomposition algorithm, which reflects the contribution of nodes to the neighbor nodes. It can be more reasonable to sort the importance of all nodes in the network topology scientifically and reasonably. The improved K-Shell decomposition algorithm in this section considers the location of nodes in the network and the contribution of neighbor nodes to its importance. Construct node importance contribution matrix:

$$M=\begin{bmatrix} k_s(1) & \delta_{12}n_{12}k_s(1) & \dots & \delta_{1n}n_{1n}k_s(1) \\ \delta_{21}n_{21}k_s(2) & k_s(2) & \dots & \delta_{2n}n_{2n}k_s(2) \\ \dots & \dots & \dots & \dots \\ \delta_{n1}n_{n1}k_s(n) & \delta_{n2}n_{n2}k_s(n) & \dots & k_s(n) \end{bmatrix}$$

(5)

In formula 5, *ij* represents two nodes that are adjacent to each other in the current network structure, and when there is a connection between the two nodes *i* and *j*, it is = 1, otherwise = 0. *M* (*i*, *j*) = *ijnijks* (*i*) is used to represent the importance contribution value of node *i* to node j. Combined with the matrix *M* of importance in Formula 5, and considering the influence of node itself and adjacent nodes, the importance *K* of node is defined:

$$K_i = ks(i) * \sum_{j=1, j\neq i}^{n} \delta_{ji} n_{ji} k_s(j) \qquad (6)$$

Considering the local and global importance of nodes, the above method can calculate the importance of nodes scientifically and reasonably. The importance K of each node calculated by Formula 6 is sorted according to the order of magnitude. Then the appropriate number of nodes is selected as the key node and put into the improved MRC algorithm to generate the backup topology.

C.*New Backup Topology Generation*

The input variable of the algorithm is the number K of the key nodes and the output variable is the number N of the backup topology. Initially,N is defined as 1,the algorithm is then executed consecutively from step 1 to step 5.

Step 1: According to the key point selection method of Formula 6, the importance of all nodes is sorted, and then the key nodes are selected.

Step 2: According to the importance of the order of the order of K key nodes, there are mainly several selection methods: Step 1 of the method and the use of degree centerline, median centrality and other methods to select K key nodes.

Step 3: Protect the link adjacent to the key node. Ensure that all backup topologies have a minimum number of protected links to ensure that all key nodes have multiple links available in each topology. The number of protected links connected to the key node in the total backup topology is set to M and the maximum degree of access of the key node is defined as D, then the maximum integer value of M is less than or equal to ceil (D/N) + 1. (N is the total number of nodes in the network topology)

Step 4: The link to be adjacent to the normal node is carried out. The original MRC algorithm is used to protect the link.

Step 5: According to the result of the calculation, the rules of the original MRC backup topology generation are qualitatively determined whether the improved backup topology generated at this time can satisfy the original MRC backup topology generation. If satisfied, the algorithm runs to this end. Otherwise, add the value of N to 1 and continue to execute from step 1.

The optimization goal of the improved algorithm is to increase the available links of the key nodes while minimizing the hops of the shortest paths when rerouting. For the selection of the key nodes, the improved K-Shell algorithm, median centrality, degree centrality and other methods are used to generate the backup topology.

IV. SIMULATION EXPERIMENT VALIDATION

A. *Experimental Environment*

According to the previous analysis, the original MRC algorithm backup the isolated links in the topology can not be used to forward the packets in the backup topology, so that the packets can avoid the failure of the network components, so that the packets can be smoothly forwarded to the destination node.

Aiming at the problems mentioned above, this chapter uses an improved backup topology generation algorithm for fast rerouting when IP network failures. The key problem solved by the improved algorithm in this part is how to select the key nodes scientifically and reasonably. At the same time, we must select the appropriate number of key nodes to generate the backup topology under the hard premise that the network connectivity cannot be destroyed. Considering the influence of node location on the experimental results, and comparing with the proposed improved algorithm, the feasibility of the proposed algorithm is further verified.

This section uses NS2 software to carry on the experiment simulation. Firstly, a stochastic network topology generator, Brite, is used to generate six original network topologies based on a typical stochastic Wax model and a Ba model. The average degree of nodes is set to 2, and the number of nodes is set to 20, 40 and 60, respectively, and integer 1 is chosen as the weight of each link. Then, in each network topology, the traditional MRC algorithm and several improved MRC algorithms are used to simulate and compare the length of the rerouting path under single fault. Finally, the results are analyzed to verify that the key nodes selected by the improved K-Shell algorithm have good performance for backup topology generation.

The selection method of key nodes and the number of key nodes in the simulation experiment will have a direct impact on the results of the experiment, and also affect the successful creation of a series of reasonable backup topologies, so it is necessary to select the appropriate number of key nodes on the premise of not destroying the network connectivity.

B. *Analysis of Rerouting in Link Failure*

According to the randomly generated six sets of network topologies, assuming that one of the links or nodes has faults, MRC algorithm and several improved algorithms are used to calculate the rerouting length of backup paths, and then compare and analyze them.

Table 1 shows the rerouting hops of six groups of topologies using different algorithms for fast rerouting under fault-free and single-link faults. The results show that it is effective to determine the key node in the backup topology and maximize the number of available links for the key node.

Table 1. Fast reroute total hop count with single link failure.

Topology	MRC	Degree centrality	Clossness degree	Dielectric degree	improved K-shell
Ba20	31482	31456	31393	31371	31318
Ba40	316150	315111	314525	314796	314325
Ba60	1265018	1261312	1249890	1260405	124382
Wax20	33840	33758	33604	33746	33693
Wax40	341596	340177	339285	339776	339146
Wax60	1395660	1393742	1385131	1391478	1377639

From the table above, it can be seen that the total hops of fast rerouting by improved K-Shell decomposition algorithm are less than the original MRC algorithm and several other improved algorithms when single link failure occurs in the network simulation experiments using six network topologies generated by the network topology generator.

The above experiment is to use the improved K-shell decomposition algorithm and other algorithms to describe the importance of nodes. In order to scientifically compare the performance of the improved algorithm, several methods such as point tightness and dielectric value are used to select the key nodes in each topology, and then the horizontal comparison is made. By comparing the results we can see that the improved K-Shell decomposition can reduce the total number of rerouting hops to a greater extent.

In the generated six network topologies, when a single point (link/node) failure occurs, the average paths length after the routing reconvergence is completed are shown in Figures 3 and 4, respectively, after the backup paths of several algorithms are used for fast rerouting.

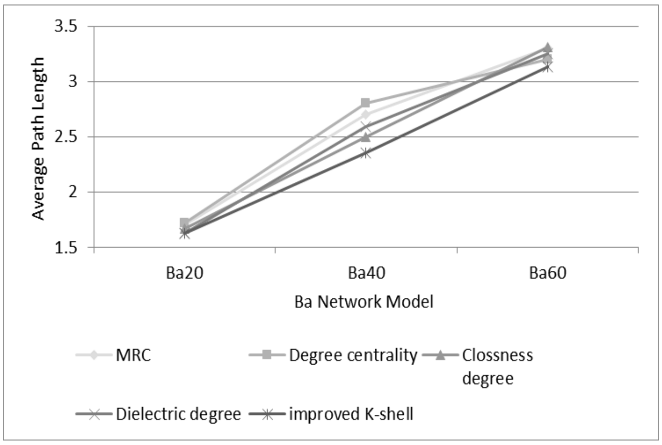

Figure 3.The path length of Ba network single link failure

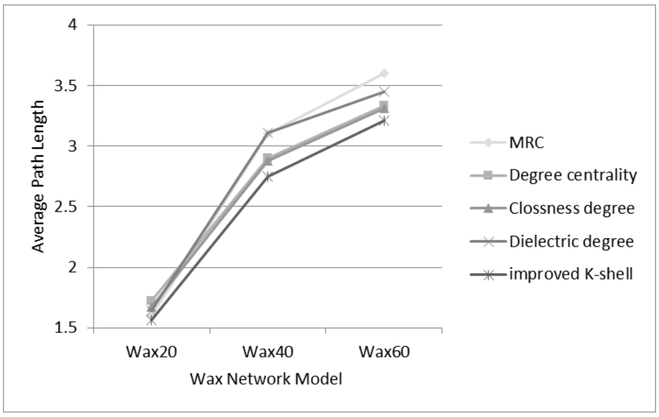

Figure 4.The path length of Wax network single link failure

In the improved MRC algorithm, the number of key nodes K that can successfully create the backup topology to complete the fast rerouting is not unique, and the value of K will directly affect the experimental results. Table 5 is the experimental comparison of the optimal number of key nodes in each topology and its proportion to all nodes in the topology.

Table 1. Fast reroute total hop count with single link failure.

Topology	Optimal Number of Key Nodes	Key Nodes Proportion
Ba20	3	15%
Ba40	7	17.5%
Ba60	8	13.3%
Wax20	3	15%
Wax40	6	15%
Wax60	11	18.3%

The results show that, When single-link failure occurs in several groups of network topologies used in this experiment, Compared with the other four algorithms, the improved K-Shell decomposition algorithm reduces the total number of hops in fast rerouting to varying degrees: Compared with the other four algorithms, the improved K-Shell decomposition algorithm in the network with fewer nodes (Ba20, Wax20) reduces the total number of rerouting hops by 4%-11%, and the improved K-Shell decomposition algorithm in the network with more nodes (Ba60, Wax60) reduces the total number of rerouting hops by 9%-25%. Therefore, we can see that the improved K-Shell decomposition algorithm can achieve better results in the network topology with more complex structure and more nodes. At the same time, when using improved K-Shell decomposition algorithm to generate backup topology, when the number of key nodes in the whole topology is between 10% and 20%, the backup topology set can be successfully created, and the optimal result is obtained, that is to say, the minimum total number of rerouting hops.

V. CONCLUSION

In this paper, a new backup topology design algorithm is proposed to reduce the increase of routing hops in IP fast rerouting. Compared with the traditional MRC algorithm, this algorithm reduces the impact of network faults on service data transmission, and the convergence of the algorithm can be guaranteed. When single link failure occurs, the location of the key node is considered and the improved K-shell algorithm is used to select the key node to minimize the number of rerouting hops.

The main idea of this method is to introduce the concept of key node in the process of creating backup topology and compare the total hops of rerouting paths after single fault in different number of key nodes. Experimental results show that the proposed algorithm can achieve good results in large-scale networks.

In the future, we hope to use the new backup topology creation algorithm to recover multiple faults quickly and realize the minimum routing cost. On the other hand, we put the new algorithm into the real network environment for further verification.

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Xinyuan Liu received the Mechanical Design and Manufacturing and Automation degree in Henan University of Science and Technology ,Luoyang , China.Currently, he's a graduate student at the College of Information Engineering, Henan University of Science and Technology.His research areas include network performance improvement and data mining.