Research on the Repair Strategy of Aviation Network When Attacked

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Abstract —There isn't some effective way to repair the aviation network when it's being attacked, to repair the aviation network back to normal effectively, three repair strategies were compared to choose the optimal strategy. Three indicators were proposed to quantify the performance change of network, and the weight of each indicator was determined by using analytic hierarchy process. The experiment results show that concentrated strategy is the most effective one for Chinese aviation network; ratio strategy is the most effective one for the US aviation network.

Index Terms—Repair strategy; aviation network; attack; indicator

I. Introduction

With the progress of science and technology and economic development, the role of aviation network status is more and more important. It may seriously affect its political and economic functioning if a country's aviation network is destroyed by deliberate attacks. Therefore, how to repair the aviation network is a significant problem, but which remediation strategy should we choose to get the most effective results?

At present, there are two main kinds of methods for repairing the malfunctioning network: 1) node-based repair strategy. Rezaei *et al* [1] proposed a method that restoring the connectivity of network and repairing network by add random edges to the high degree nodes which were failed due to attacks. But the description of the attack in this method of is not specific, and it also lack of practical basis; Wang *et al* [2] used fuzzy clustering method in analyzing node connectivity, intersection flow, node betweenness and other indicators, and accessed the importance of intersections at different level, proposed an idea of dealing with congestion, however, this idea can be only applied to ground transportation, not suitable for aviation network; Feng [3] proposed a method which increase the connectivity between the hub nodes to improve network capacity based on the definition of node importance, but the route has capacity constraints, increased connectivity may lead to unsafe events. 2) Key route-based the repair strategy. Li *et al*. [4] constructed the optimal anti-congestion path selection model of the traffic network, and then designed the congested road network evacuation strategy of optimal anti-congestion route; He [5] proposed the optimal design of the key sections to reduce the negative effects and losses of congested road network. But these two repair strategies only consider congestion, without considering the attacking strategies, thus lack of comprehensiveness.

In order to overcome the shortcomings of the traditional methods which didn't consider attack mode, considering the difficulty of quickly recover after the failure of the aviation network node, which is the equivalent that the node is not put back after the attack, three repair strategies including key repair, average repair and ratio repair were compared; compared with the one-sided indicators of traditional methods, three aviation network repair indicators were proposed. Experiments show that the research method of this paper is more suitable for aviation network, and it is more effective in network repair.

II. Method

Based on complex network theory [6-8], the abstracted model of the aviation network needs to reflect the reality objectively. This paper takes the Chinese aviation network as example, deems the airport as node, the route as edge, the airport maintenance personnel and facilities as the repair factor.

The repair capacity of the maintenance personnel equipment is deemed as the repair probability of the repair factor, that is, each repair factor repairs the damaged airport node with a certain repair probability.

After abstraction, we can get the following repair model: the network always contains R repair units, repair probability of each repair unit to the node is p_r . The maximum probability of repair of a node will not exceeds p_{rc} , that is, each node can contain up to n_{vc} repair units at the same time,

$$n_{vc} = \frac{p_{rc}}{p_r} \tag{1}$$

For the sake of simplicity, it is assumed that the repair probability of the node is linearly related to the number of repair factors owned by the node, that is:

$$p_{vr} = 1 - (1 - p_r)^{n_v} \tag{2}$$

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The repair of aviation networks is a dynamic process. In the complex network repair model, this dynamic process needs to be abstracted as a repair mechanism:

Step 1: Adopt "no return" attack strategy to attack the network, assuming that attack only one node at a time;

Step 2: Repair the damaged nodes at the probability of p_{vr}, the nodes being repaired can be reconnected if restored successfully;

Step 3: Repeat steps 1 and 2.

A. "No return" Attacking Strategy

The attack strategy adopted in this paper is based on the "no return" node attack strategy. It works like this: after calculation of node importance, select the most important node, and attack it, then remove it, goes on the calculation of node importance and attacking of nodes. This method is more in line with the reality of network attacking, and has the highest attacking efficiency. The advantage of this "no return" attacking strategy is its ability to discover potentially optimal attack targets in the network. To give a simple example, as shown in Fig. 1, according to the traditional attack, the optimal attack target is node 2, nodes 2, 3, 4, 5 are of equal importance, it's difficult to distinguish them; When adopting "no return" attacking strategy, after removing node 2, node 4 becomes the optimal attack object. Compared with the traditional attacking strategy, "no return" strategy attacks the most critical nodes on the current network in each round of attacks.

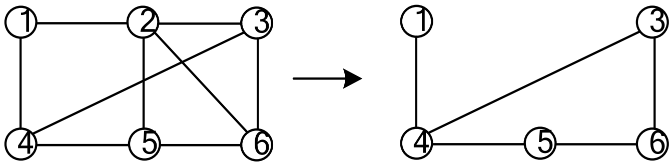


Fig. 1. Network example

Based on this attack strategy, we compare the three repair strategies in repairing the aviation network, show the advantages and disadvantages of the three repair strategies.

B. Repair Strategy

In regard to the "no return" strategy of the aviation network attack, three kinds of repair strategies were proposed. The difference between the three repair strategies is the distribution of the repair factor. Here are some explanations of three repair strategies.

Concentrated repairing strategy: distribute the repairing units according to the comprehensive importance of the nodes, select the first 10% important nodes of the network and distribute the repairing units to them averagely, this is to ensure that these nodes repair probability is the largest. The sequence number of node v_i is r_i, n_v is the number of repair factors, n_f is the number of failed nodes, the repair probability of node v_i:

$$p_{vr_i} = \begin{cases} 1-(1-p_r)^{\frac{n_v}{0.1n_f}}, r_i \le 0.1n_f \\ 0, r_i > 0.1n_f \end{cases} \tag{3}$$

Ratio repairing strategy: according to the comprehensive importance of each node, calculate the importance proportion of them, and distribute the repair units in proportion. In this way, each node can be assigned of some repair units, but there is a big difference of quantity. s_i is the comprehensive importance of the node v_i, and the repair probability p_{vr_i} is:

$$p_{vr_i} = 1-(1-p_r)^{l_i} \tag{4}$$

$$l_i = n_v \cdot \frac{s_i}{\sum_{i=1}^{n_f} s_i} \tag{5}$$

l_i is the quantity of repair units assigned to node v_i.

Average repairing strategy: Regardless of the importance of the node, the repair units is assigned to each network node averagely, the probability of repair for each node are p_{vr_i}:

$$p_{vr} = n_v p_r = 1-(1-p_r)^{\frac{n_v}{n_f}} \tag{6}$$

C. Aviation Network Repair Effect Indicators

How to measure the effect of aviation network repair is an important problem, therefore, the evaluation index must consider network static characteristics and dynamic function. For example, some traditional methods take the shortest path, average between-ness and centrality as the network performance indicators [9-11]. Here we take network efficiency, link-density, network flow as the three overall performance indexes.

Network efficiency E refers to the mean value of all node pairs' distance reciprocal sum, used to reflect the extent of difficulty in transmitting information in the network, the larger the value of E, the easier it is for the information to transmit in the network, and the better overall performance is. E can be expressed as:

$$E = \frac{1}{N(N-1)} \sum_{i \neq j} 1/d_{ij} \tag{7}$$

where N being the total number of nodes included in the network, d_{ij} being the distance between node v_i and node v_j.

Network link-density was defined as the ratio of actual number of existing edges to possible number of edges in the network. For a weighted network, the larger the link-density is, the more heterogeneous the network is, the more connected the network is, and the better overall performance is. For undirected weighted network, link-density is defined as (2):

$$\rho_L = \frac{\bar{s}}{\bar{w}(N-1)} \tag{8}$$

where $\bar{s}$ is the average point strength of weighted network, $\bar{w}$ is the average link weight value, therefore, link density $\rho_L \in [0,1]$.

The flow of network ϕ is defined as the total flow the network is capable of transmitting, for the network, transmitting information is an important function, and the amount of information is an important index of overall performance.

$$\phi = \sum_{i=1}^{N} s_i \tag{9}$$

where s_i is the weight value of node i, the ratio of network flow before and after removing the node is defined as TR:

$$TR = \frac{\phi(G - v_i)}{\phi(G)} \tag{10}$$

$\phi(G - v_i)$ is the network flow after removing node v_i, $\phi(G)$ refers to the initial network flow.

By adopting AHP (Analytic Hierarchy Process) [12], we determined the weight of each indicator, $w_E = 0.1047$, $w_{TR} = 0.63701$, $w_R = 0.25828$.

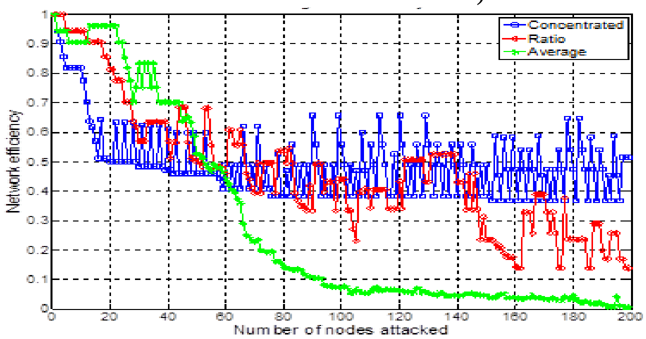
III. Experiments and Results

In the experiment, the Chinese and American aviation networks were taken as the experimental objects, and "no return" strategy was adopted to attack the network. Each attack on the network is equivalent to removing an airport node at a certain probability. Repair the network using the three attack strategies while under attack.

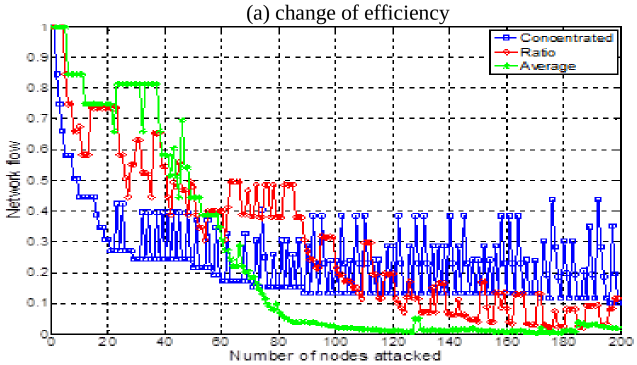
A. *Chinese Aviation Network*

First test bed is Chinese aviation network, it has a total of 199 airport nodes, the data was obtained from http://www.qunar.com.

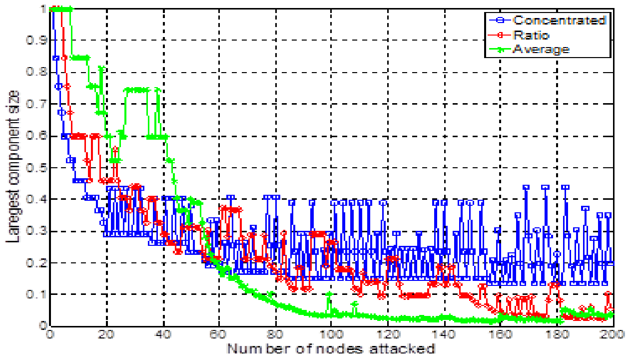
Suppose that there are $n = 199$ repair units, the repair probability of each repair unit on the node is $p_r = 0.002$. The maximum probability of repair of the node will not exceed $p_{vc} = 0.25$. Using the attack and repair strategy proposed in this paper, the change of each indicator were drawn below (each indicator has been normalized).



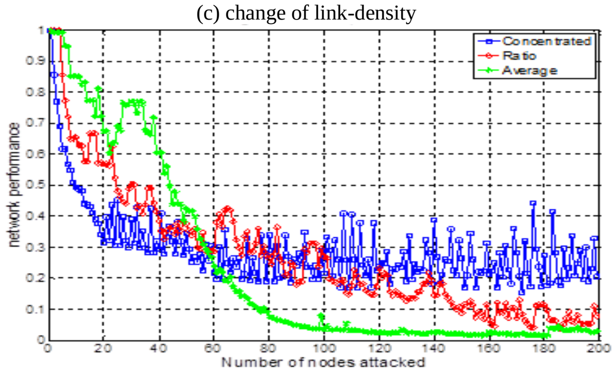
(a) change of efficiency



(b) change of flow



(c) change of link-density



(d) change of comprehensive performance

Fig. 2. Change of each indicator

It can be seen from Fig. 2 that with the increase of attacked nodes number, the value of three indicators of Chinese aviation network has decreased, but the descending speed is gradually reduced, indicating that the repair strategy is effective. Among the three strategies, concentrated repair strategy is the most unstable one and average repair strategy is the most stable one.

From the network efficiency changes in (a), we can see that when the attacked nodes number is less than 40, average repair strategy is better than concentrated strategy and ratio strategy, when it's more than 60, average repair strategy is significantly inferior to the other two; when it's less than 70, ratio strategy is better than concentrated strategy, but later concentrated strategy is better than ratio strategy.

From the network flow changes in (b), we can see that when the attacked nodes number reach 70, average repair strategy is significantly inferior to concentrated and ratio strategy; when adopting concentrated strategy, the initial decline of network flow is very fast, but when the attacked nodes number reach 120, concentrated strategy is obviously superior to the other two; ratio repair strategy is slightly better than the average strategy.

From the network link-density changes in (c), we can see that the repair effect of average and ratio repair strategy is similar, when the attacked nodes number is less than 60, concentrated strategy is inferior to the other two, but later otherwise.

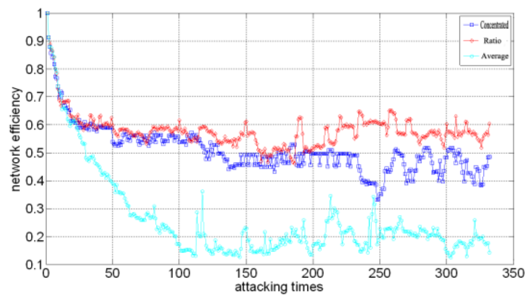
From the network comprehensive performance change in (d), we can see that concentrated strategy is better than ratio strategy, and ratio strategy is better than average strategy.

B. American Aviation Network

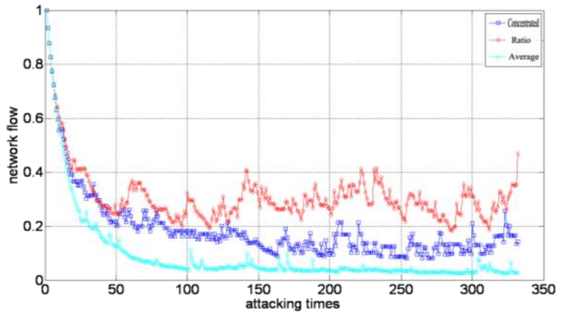
The next one is American aviation network, the Data is acquired from the http://vlado.fmf.uni-lj.si/pub/networks/data/mix/USAir97.net, which contains 332 airport nodes, 2126 edges (flight).

Suppose that there are $n = 332$ repair units, the repair probability of each repair unit on the node is $p_r = 0.002$. The maximum repair probability of the node can't exceed $p_{vc} = 0.25$.

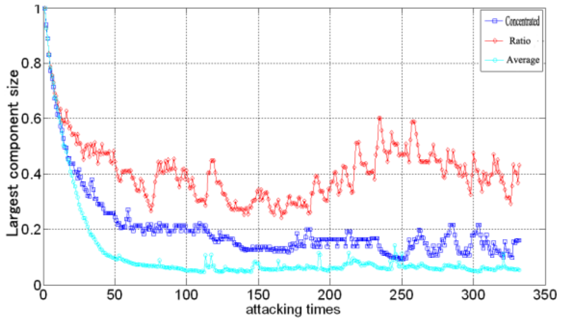
As we can see from the changing curves of the 3 indicators and overall performance in Fig. 3, compared with Chinese aviation network, in the US aviation network attack, the repair effect of three repair strategy is more distinct. When attacked nodes number is less than 25, the effect of the three repair strategies is close, there is no significant difference. But after 25, the difference among the three has gradually appeared, ratio strategy is better than concentrated strategy, concentrated strategy is better than average strategy. Ratio strategy is the most unstable one, average is the most stable one.



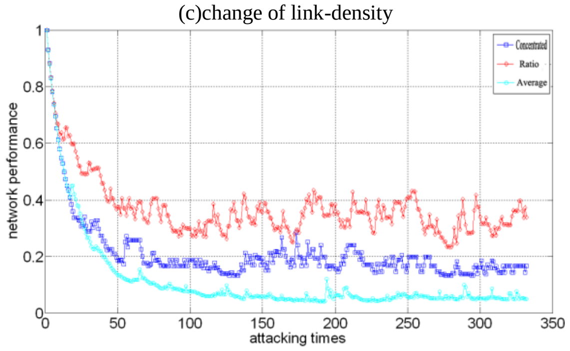
(a)change of efficiency



(b)change of flow



(c)change of link-density



(d)change of comprehensive performance

Fig. 3. Change of each indicator

IV. Conclusions

In this paper, three aviation network repair indicators were selected and the weight of them was determined. The experimental results show that concentrated strategy is the most effective one for Chinese aviation network; ratio strategy is the most effective one for the US aviation network. In the next step, we hope to do some research on repairing the network through backup airport and air-route.

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