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Survivable and fault-tolerant topology control algorithm in ad hoc networks

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ABSTRACT

In order to improve survivability and fault tolerance in Ad Hoc networks, a topology control algorithm was proposed. In the stage of initial topology construction, the algorithm based on the shortest path is adopted to select K disjoint paths for unicast services, and the fault-tolerant algorithm based on K-connectivity is adopted to select K disjoint paths for multicast services. In the stage of topology optimization, the algorithm deletes the links with the highest link efficiency indicator one by one to optimize the topology. In the stage of topology recovery, the algorithm collects local information around critical points, and uses the shortest path algorithm to recover connectivity of link groups, and ultimately recovers connectivity of local network by adding least cost links. Simulation results shown that the algorithm can improve the quality of services, enhance the ability of survivability and fault tolerance.

KEYWORDS

Ad Hoc networks; Services; Survivable; Fault-tolerant; Topology control.

INTRODUCTION

Ad Hoc networks[1] are widely used in military and emergency communication field. The characteristics including the existence of critical points, dynamic nodes, poor safety, and harsh living environments cause topology to change frequently over time, which raises a very high demand for survivability and fault tolerance. Topology control[2] allows networks to tolerate passively frequent topology changes by preserving redundant links and responds proactively to frequent topology changes by reconstructing topology, and thus improves network performance[3].

RELATED WORKS

Survivable and fault-tolerant topology control technique is a main component to ensure network reliability whose purpose is to improve network fault tolerance and communication reliability. At present, in Ad Hoc networks, most research has been focused on survivable and fault-tolerant routing reconfiguration on the network layer, but the survivability of the network topology is the basis of service survivability[4]. At the same time, the topology connectivity is the prerequisite for the routing effectiveness. When the nodes and links fail, even though the network may still be connected, there are problems such as larger delay, lower efficiency and smaller network throughput with using the remaining routings to transmit data. Therefore, a survivable and fault-tolerant topology control scheme is used to break and set up links to create a new topology, so that when the links or nodes fail, fault-tolerant operation and rapid service reconfiguration can be achieved. The survivable and fault-tolerant scheme brings the network performance back to a good level and improves the survivability, invulnerability of Ad Hoc networks as well[5].

So far, the research on survivable and fault-tolerant topology control is carried out from two aspects of the passive and active control. As an active method, topology control is defined as the autonomous network capability to dynamically reconfigure its physical topology. The passive method is defined as the self-healing and recovery capability to reconstruct topology when suffering from failures.

The passive topology control[6,7] aims to construct K-connectivity topology to tolerate K-1 node or link failures, thus improve network performance. Saha I put forward a distributed algorithm[8] which achieves K-connectivity by adjusting node transmitting power. Chen C W selected K redundant nodes for each backbone node[9,10] to ensure the ability of survivability and fault tolerance. The active topology control[11] aims to reconstruct the network topology timely to restore network performance on detecting topology changes. Coleri restored network topology based on re-routing[12]. Le T used redundant nodes to replace the failed nodes[13], enhancing network connectivity. Although the research on survivable and fault-tolerant topology control makes great achievements, few algorithms consider network performance. As a result, there is broad research space.

TOPOLOGY CONTROL ALGORITHM

The algorithm adopts periodic operation, Operation cycle is determined by the dynamic degree of networks， topological invariant in a cycle.

Initial topology construction

Considering the differences among different services, the services are divided into unicast services and multicast services, different topology control algorithms are used for different services to build K-connectivity topology (k is fault tolerant coefficien, the value determined by the topology of the network redundancy and fault tolerance requirements, $k \geq 1$), meeting the QoS requirements while improving the ability of survivability and fault tolerance.

(a) The algorithm based on the shortest path

Let K=2, the algorithm based on shortest path is as follows:

(1) The shortest path algorithm is used to search the shortest path *a-b-c-d* (in Figure 1(G)), the sum of whose weights is 1+3+3 = 7;

(2) The remaining network topology $\boldsymbol{G}_{\mathbf{R}}$ ($\boldsymbol{V}$, $\boldsymbol{E}_{\mathbf{R}}$) shown in Figure 1($G_R$), the shortest path algorithm is used to search the shortest path, obtaining a new shortest path *a-e-d*. Finally, the K-connectivity topology $\boldsymbol{G}_{\mathbf{U}}$ ($\boldsymbol{V}$, $\boldsymbol{E}_{\mathbf{U}}$) is constructed.

(b) The fault-tolerant algorithm based on K-connectivity

In a multicast service as an example, as shown in Figure 2(G)， K=2， s is source node， d1、d2、d3 is destination node， other nodes are intermediate node.

Let K=2, the fault-tolerant algorithm based on K-connectivity is as follows:

Step 1: In Figure 4, the shortest path algorithm is used to search the shortest path for source node to each intermediate node in the original topology graph $\boldsymbol{G}$, getting the network topology $\boldsymbol{G}_{\mathbf{S}}$ ($\boldsymbol{V}$, $\boldsymbol{E}_{\mathbf{S}}$). As shown in Figure 2, the shortest paths from the source node to intermediate nodes are sm_1, sm_2, sm_3, sm_2m_4, sm_5, the input links to the destination nodes are m_1d_1, m_3d_1, m_4d_1, m_3d_2, m_4d_2, m_5d_2, m_4d_3, m_5d_3;

Step 2: Calculate the number of the shortest paths from the source node s to each destination node d_i ($d_i \in$ D, i = 1,2 • • • | D |) in topology $\boldsymbol{G}_{\mathbf{S}}$ and their minimum is m;

Step 3: If $K \leq$ m, go to step 4; Otherwise, go to step 5;

Step 4: In topology G_S, search K shortest disjoint paths from the source node s to each destination node d_i, building topology $\boldsymbol{G}_{\mathbf{M}}$ ($\boldsymbol{V}$, $\boldsymbol{E}_{\mathbf{M}}$), and the algorithm terminates.

Step 5: In topology $\boldsymbol{G}_{\mathbf{S}}$, search m shortest disjoint paths from the source node s to each destination node d_i;

Step 6: For each destination node d_i, delete m disjoint shortest paths in the original topology and reuse the above algorithm in the remaining topology $\boldsymbol{G}_{\mathbf{R}}$ ($\boldsymbol{V}$, $\boldsymbol{E}_{\mathbf{R}}$). Search K-m shortest disjoint paths from the source node s to each destination node d_i and the algorithm terminates.

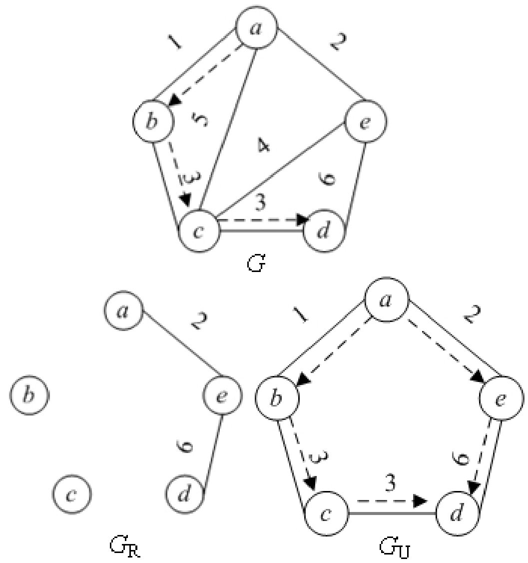

Figure 1 : Topology gragh

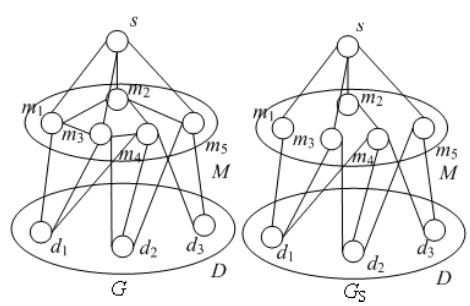

Figure 2 : Topology gragh G and G_S

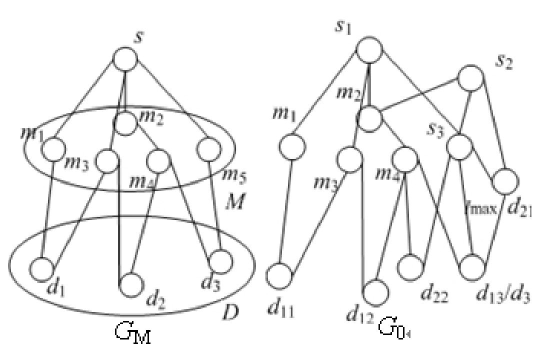

Figure 3 : Topology gragh G_M and G_0

Topology optimization

(a) Constructing a temporary topology

As Figure 3 shown, K=2, the initial topology $\boldsymbol{G_0}$ includes multicast service Q_1 (disjoint path cluster $s_1m_1d_{11}$, $s_1m_3d_{11}$, $s_1m_3d_{12}$, $s_1m_2m_4d_{12}$, $s_1m_2m_4d_{13}$, $s_1s_3d_{21}d_{13}$), Q_2 (disjoint path cluster s_2d_{21}, $s_2s_3d_{21}$, $s_2m_2m_4d_{22}$, $s_2s_3d_{22}$) and unicast service Q_3 (disjoint path cluster s_3d_3, $s_3d_{21}d_3$).

In the initial topology G_0, links with the highest link efficiency indicator l_{max} are deleted. Thus a temporary topology $\boldsymbol{G_T}$ is generated, as shown in Fig.4.

(b) Temporary topology detection

(1) Whether $\boldsymbol{G_T}$ meets K-connectivity for a certain service or not is determined. If $\boldsymbol{G_T}$ meets K-connectivity for a certain service, step b will be excuted; Otherwise, the link l_{max} can not be deleted and a temporary topology will be constructed again with links in the remaining link set E_0-l_{max}.

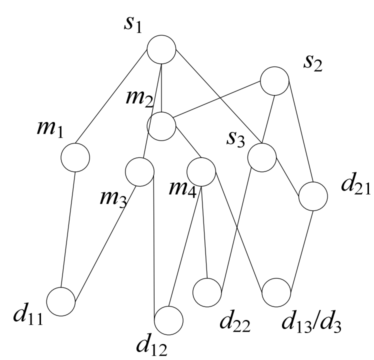

Figure 4 : Temporary topology gragh $\boldsymbol{G_T}$

(2) Whether the total energy consumption of the network decreases also need to be judged. If so, the temporary topology $\boldsymbol{G_T}$ is treated as a new initial topology $\boldsymbol{G_0}$ and the above optimization process should be repeated; otherwise, the link l_{max} can not be deleted and repeat the above detection process in the remaining link set E_0-l_{max}.

Topology recovery

First, the wireless interference, node mobility, limited energy result in node and link failure seriously. Second, threats and attacks are increase critical. Third, small K value results in tolerating a small number of node or link failures. Therefore, the topology recovery algorithm based on critical point failures is proposed to ensure the network reliable and safe operation.Figure 5(a-d) illustrate the process of topology recovery algorithms based on critical point failure.

(a) Collecting local topology information

In this step, two-hop topology information around critical points is collected and the links belonging to the same path cluster as a group are designated. As Figure 5(a) shown, three different link groups L_1, L_2, L_3 are generated.

(b) Restoring the connectivity of the link group

The connectivity of path b_1ab_6 in link group L_1 will be destructed, if the critical point a fails. Then the link cost in link group L_1 is set ∞. The shortest path algorithm is used to search for a new path $b_1b_4b_3b_6$ from node b_1 to node b_6 which is showed in Figure 5(b). At this time, the connectivity in link group L_2 is recovered and a new path $b_4b_1b_2b_5$ can be found in Figure 5(b); otherwise, the shortest path algorithm need to be adopted again to restore connectivity. Repeat the above process for the remaining link groups. Note that the connectivity of the link group L_3 can not be restored temporarily.

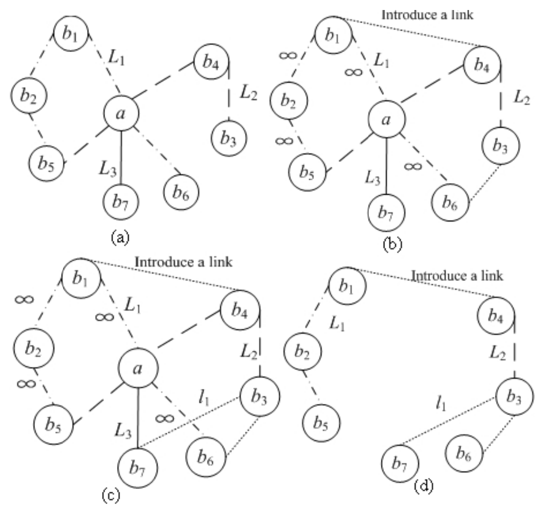

Figure 5 : Local network topology gragh

(c) Restoring the local network connectivity

The number of clusters N when the critical point fails is calculated. If N is not 1, the least cost link l_i (i= 1,2,3 ...) which deceases the number of clusters N should be added until N=1, like l_1 shown in Figure 5(c); otherwise, the algorithm terminates. Figure 5(d) shows the topology after recovered.

The proposed algorithm is operated in a short time slot, in which the topology of the network is assumed relatively stable. Thus our algorithm is not suitable for highly dynamic Ad Hoc networks.

PERFORMANCE ANALYSIS

Efficiency

Compared with the algorithm CBTC not for services, the algorithm TCSP for unicast services and the algorithm FTCK for multicast services, we use NS2 to measure the efficiency of our algorithm TCTO for unicast and multicast services. We simulate a system of 16 nodes in accordance with random distribution of the non-uniform probability density on a 1000×1000m^2 area. A source node sends CBR traffic through UDP. Each packet carries 512 bytes of data payload.

It is shown in Figure 6 and Figure 7 the network performance under the control of TCTO algorithm is better than the others. Firstly, TCTO algorithm takes the needs of the application layer into account and ensures the QoS requirements, improving quality of service. Secondly, TCTO algorithm constructs K-connectivity topology, which lays a good foundation for load balancing and routing. Therefore, the network performance under the control of TCTO algorithm has been maintained at a high level.

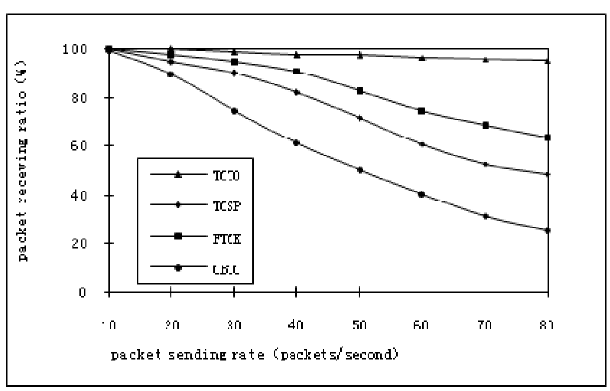

Figure 6 : Compare of packet delivery ratio vs. sending rate

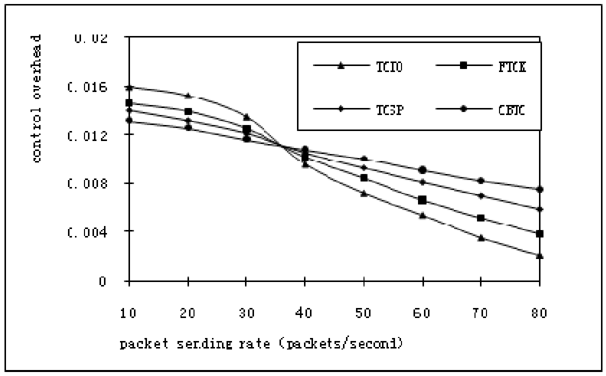

Figure 7 : Compare of control overhead vs. sending rate

Invulnerability

Compared with the 1-connectivity algorithm GG and the *K*-connectivity algorithm TCTO for services, we use network simulator NS2 to measure the invulnerability of our algorithm SFTC under node random failures and deliberate attacks. Simulation parameters are as same as that of efficiency.

Figure 8-9 reflect that network performance changes with random failures. With the number of random failures increasing, the probability of critical point failure increases gradually, network performance under the control of SFTC algorithm is almost unaffected. It is because that SFTC algorithm not only constructs *K*-connectivity topology for services, but also conducts failure recovery on detecting critical node failure effectively. As a result, network performance is almost unchanged.

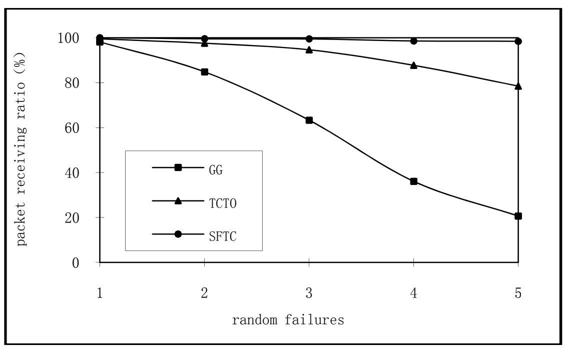

Figure 8 : Compare of packet delivery ratio vs. random failures

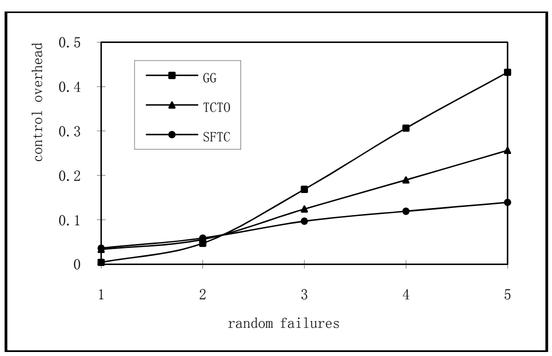

Figure 9 : Compare of control overhead vs. random failures

SUMMARY

A survivable and fault-tolerant topology control algorithm was proposed in Ad Hoc networks. The algorithm is mainly composed of initial topology construction, topology optimization, topology recovery. Simulation results show that the proposed algorithm can improve the quality of services, enhance the ability of survivability, fault tolerance and failure recovery, and thus optimize integral network performance.

ACKNOWLEDGEMENT

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