A New MANET Route Protocols Fault Tolerance Ability Evaluation Method Based on Time-Spatial Network Model

Weiqiang Wu[1,2*]

[1]Postdoctoral Workstation, China Huarong Asset Management Co., Ltd. Beijing 100033, China

[2]School of Economics and Management, University of Chinese Academy of Sciences. Beijing 100190, China

*Corresponding Author Email: wuweiqiang@chamc.com.cn

Keywords: MANET, fault tolerance, route protocol evaluation, time-spatial network model

Abstract: Route protocols are designed to have fault tolerance ability which impact the reliability of MANET strongly, hence the evaluation of MANET protocol fault tolerance ability is helpful to measure and improve the network reliability and performability. The traditional evaluation methods prefer evaluating the fault tolerance ability through performance evaluation process and measurement metrics, without considering the fault tolerance mechanism of route algorithm. Based on these problems, a new network model and a corresponding evaluation method are proposed from route protocol fault tolerance mechanism perspective. At last, the validity of the model and approach are verified through a MANET simulation case study, through the contrast experiments with NS-3 simulation based on specific cases, the model and method proposed in this paper shows satisfactory performance on accuracy and efficiency. Then the correlation between fault tolerance ability and performance is further analyzed, and the result should be meaningful to network and protocol designing.

1. Introduction

MANET is formed by mobile nodes, which are independent and free to move, it is a kind of wireless network and have self-configuration feature. The data transfer between the wireless and movement nodes to perform the function of the network [1]. MANET are playing more and more important roles in disaster relief, environmental monitoring, intelligent transportation, military tactical system, etc.

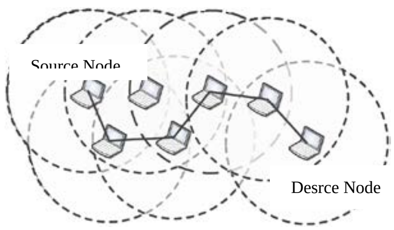

Fig. 1. MANET schematic diagram

So the reliability, especially the fault tolerance ability of MANET will lead the using efficiency and experience. As same as other kinds of wireless mobile network, the movement and wireless features assign MANET more usages in a lot of areas, but the features also limit the reliability and ability of fault tolerance enhancements, for example, the node failure may cause the data transfer path impediment, and the node failure of MANET may be caused by various of reasons: power failures, network attack, etc [2]. Meanwhile, to meet the demand on reliability and fault tolerance enhancements, the route algorithm research have to consider the fault tolerance ability of MANET [3]. To summary the route protocol algorithm for fault tolerance enhancement, we can category them by the number of paths as below:

1.1 Multiple path route

As we known, multipath routing algorithms are strong in their fault-tolerance ability, because they send multiple copies of packets through all possible (disjoint) routes between a pair of source-destination nodes. For example, as a kind of backup path methods, the double minimal path based backup path algorithm [4] can improve the multi-state network's reliability when the main paths fail.

1.2 Single Path Route

Single path route algorithms have the less ability of fault tolerance than multiple path route, but it also can detect the fault node and choose the good path by maintain the route map. For example, the AODV protocol can find the fault nodes and re-plan the path by analyzing the "RERR" packages [5, 6].

To sum up the fault tolerance concern in route protocol algorithm, all popular MANET route protocols use fault tolerance mechanism to handle the network component failures [2, 6-12]. Although there are a number of MANET protocols which have fault tolerance mechanism, how can indicate and verify the mechanism is effectiveness? The directly approach is to measure the performance metrics while the protocols are applied to network under nodes and links failure. From the network science's view, the network structure or topology define the function, if we consider the ability of fault tolerance as a part of the network's function, then we can consider the network's topology can affect the fault tolerance features [23].

The complex network theory, which is an important branch of network science consider the fault tolerance is a nature of the network [19, 24, 25]. For example, Cohen and Reuven[26] find the scale-free network have the fault tolerance ability under random attack; Yang, Xinsong[27] research the complex switching network have the ability of fault tolerance.

Summary the research of complex network theory, here we give some of metrics that can describe the network topology's nature ability of fault tolerance and performance, we will use these metrics for measure the network's ability of fault tolerance and performance, which was applied the route algorithm:

1.3 Clustering Coefficient

It is characterized by the nodes close degree. The network which has high clustering coefficient shows high efficiency, because the higher clustering coefficient nodes mean the connection relationship closer, so the data transmission should be more efficiency. The formula description is:

$$C_i = \frac{E_i}{(k_i(k_i-1))/2} = \frac{2E_i}{k_i(k_i-1)} \tag{1}$$

1.4 Number of Largest Component Nodes

It can characterize the fault tolerance ability of network in network science area, the metrics:

$$R = \frac{S(A)}{V} \tag{2}$$

S(A) denotes the number of Largest Component nodes of the network, V denotes the nodes number of the network.

1.5 Number of Hops

It denotes the data package from the source node to the destination node's distance.

Summary of the above, the network's structure and topology can define the basic features of the network. If we consider the paths which of the whole network at a time point profile as a new Abstract network, like Figure 2 shows, it also has the network nature features, include fault tolerance features, so we can analyze the network which is generated by the protocols, through the metrics of complex network analysis, we can evaluate the fault tolerance ability of protocols.

2. Time-spatial Network Model for Fault Tolerance Ability Evaluation

2.1 Network Time-Spatial Features

As the previous mentioned, the network which is formed by the path is a dynamic network. The dynamic features lie in these aspects:

Spatial is dynamic: due to the nodes' movement features, the path is not fixed, and meanwhile, the fault tolerance is another factor which can affect network spatial structure.

Time is progressing: the network spatial dynamic reflect in the time progressing, it means we will not observe the same path network topology at the different time point.

So, we consider the network which is Abstracted by path and controlled by route protocols have time-spatial features, then we name it "Time-Spatial" model, and the Abstracted network we call it Time-Spatial network in next content. We will use the Time-Spatial network model to describe time and spatial variation which is caused by route protocols and fault tolerance mechanism, and based on this model, to analyze the network topology features to measure and evaluate the route protocols fault tolerance ability, and further we will study the relationship between performance metrics and fault tolerance metrics, try to find out the balance between performance and fault tolerance ability from protocol generated network topology.

2.2 Time-Spatial Network Model Definition

Definition 1. MANET can be considered as a directed graph: $G=(V,E)$,V is the set of the whole network,the number of the nodes in the set is $|V|$,for $u \in V, v \in V$,$<u,v>$ denotes valid path from u to v, denoted by: $e<u,v>$,(u,v) express the link between u and v,denoted by: $e(u,v)$.$E=\{e<u,v>|u \in v, v \in v\}$ is defined as valid edge. The number of edges or links is defined as$|E|$.

Define the function W:$E \to R+$, $R+$ is a subset of the positive real number,$W(e<u,v>)$ express the weight of edge: $e<u,v>$,denoted by $w(u,v)$. If $w(u,v)$ is $+\infty$,then the link $e<u,v>$ is break.

Definition 2. The partially ordered set which is formed by V: $\{v_1, v_2, \dots v_{j-1}, v_j, v_{j+1}, \dots v_n\}$,is denoted a path which source node is v_1,destination node is v_n, and the node number of the path is n,$\forall k(2 \le k \le n)$, v_{k-1} is the upstream node in the path of v_k. $\forall m(1 \le m \le n-1)$. The node v_{m+1} is the downstream node in the path of node v_m.

Definition 3. For $v_i \in v, v_j \in v, Path(v_i, v_j)$ express the set of path that the source node is v_i, the destination node is v_j, in other words, it is the edges set of Time-Spatial Network. We assume: $path(v_i,v_j) \in Path(v_i,v_j)$, then define the function:$f: Path(v_i,v_j) \to \mathbb{R}+$, $f(path(v_i,v_j))$ denotes the evaluation function of $path(v_i,v_j)$.

The purpose of the routing that source node is v_i and destination node is v_j, is to find out an $path^*(v_i,v_j)$ which the evaluation function is optimal,satisfy the formula:

$$\exists path^*(v_i,v_j) \forall path(v_i,v_j)\ f(path^*(v_i,v_j)) \le f(path(v_i,v_j)) \tag{3}$$

subject to:

$$path^*(v_i,v_j) \in Path(v_i,v_j), path(v_i,v_j) \in Path(v_i,v_j) \tag{4}$$

3. Evaluation Method based on Network Model

Based on the model that we proposed, we also introduce an approach to evaluate the fault tolerance mechanism of the route protocols. Combined the metrics that introduced from complex network theory, the steps of the approach will listed as follows:

Step 1. Based on the Time-Spatial Network Model, build a spatial profile of the network: (express as a matrix), and the profile can describe the connection status of the nodes in Time-Spatial Network at one time point:

$$A[i,j]=\begin{cases} w_{ij}, & <v_i,v_j>\in E(G) \\ 0, & <v_i,v_j>\notin E(G) \end{cases} \tag{5}$$

Step2. Analyze the Clustering Coefficient (Metric C).

Based on the definition of Clustering Coefficient, the Clustering Coefficient of one node in the network is:

$$C_i=\frac{E_i}{(k_i(k_i-1))/2}=\frac{2E_i}{k_i(k_i-1)} \tag{6}$$

Here we use this method to express the Clustering Coefficient:

In step 1, we got: $A[i,j]=(a_{ij})_{M\times N}$,we assume i,j,k is the three vectors of the triangle, which is include node i and included in the network. Then $a_{jk}a_{ki}a_{ki}=1$,or these 3 nodes cannot form triangle, and $a_{jk}a_{ki}a_{ki}=0$. Hence ,the number of triangles are included in A is:

$$E_i=\frac{1}{2}\sum_{j,k}a_{ij}\,a_{jk}a_{ki}=\sum_{k>j}a_{ij}a_{jk}a_{ki} \tag{7}$$

Based on Clustering Coefficient formula, the Clustering Coefficient of node i is:

$$C_i=\frac{2E_i}{k_i(k_i-1)}=\frac{1}{k_i(k_i-1)}\sum_{j,k=1}^{N}a_{jk}a_{ki}a_{ki}=\frac{\sum_{j\neq i,k\neq j,k\neq i}a_{jk}a_{ki}a_{ki}}{\sum_{j\neq i,k\neq j,k\neq i}a_{ij}a_{ik}} \tag{8}$$

So the Clustering Coefficient of whole network is:

$$C=\frac{1}{V}\sum_{i=1}^{N}C_i=\frac{\sum_{i=1,j\neq i}^{N}\sum_{k\neq i,j\neq k}a_{ij}a_{ik}a_{jk}}{\sum_{i=1,j\neq i,}^{N}\sum_{k\neq i,j\neq k}a_{ij}a_{ik}} \tag{9}$$

Step3. The Largest Component (Metric R) analysis

Based on the model which is built in step 1, we can obtain the size of largest component, and the value of R, with the purpose of analyzing the fault tolerance ability:

$$R=\frac{S(A)}{V} \tag{10}$$

Step4. Metrics Correlation Analysis.

In order to reveal the relationship between fault tolerance and performance, here we introduced metrics correlation analysis method to analyze the relationship between metric C and metric R.

In this approach, we are focus on Largest Component size and Clustering Coefficient, so the correlation analysis result can reflect the correlation between fault tolerance and performance. Here we use linear correlation coefficient to analyze and quantify:

We assume the correlation coefficient is r:

Then:

$$r=\frac{\sum_{t=1}^{L}\left(C_i-\bar{C}\right)\left(R_i-\bar{R}\right)}{\sqrt{\sum_{t=1}^{L}\left(C_i-\bar{C}\right)^2}\cdot\sqrt{\sum_{t=1}^{L}\left(R_i-\bar{R}\right)^2}} \tag{11}$$

$$=\frac{L\sum_{t=1}^{L}C_iR_i-\sum_{t=1}^{L}C_i\cdot\sum_{t=1}^{L}R_i}{\sqrt{L\sum_{t=1}^{L}C_t^2-(\sum_{t=1}^{L}C_t)^2}\cdot\sqrt{L\sum_{t=1}^{L}R_t^2-(\sum_{t=1}^{L}R_t)^2}}$$

L is the total time steps length, t is the time point t in L.

4. Case Study

Here we build a case to verify the validity of the model and approach and analyze the metrics that mentioned in the evaluation approach.

4.1 Case Introduction and Fault Tolerance Ability Assessment

The case framework is based on a MANET network which is applied AODV protocol. In real using scenario and environment, MANET nodes have movement nature, and meanwhile, the probability of communication between nodes is related with the application profile. Since our model and approach currently are not considering the features of application which is deployed on the MANET, and the node inner failure mechanism, so with the purpose of trying to closer with the real network usage profile, inspired by the simulation designing of R. Jain, et.al. [15], in this case, we setup the simulation as Table 1 shown:

Table 1. Simulation Setup

ATTRIBUTE	VALUE
MAP SIZE	120m*120m
NODE SCALE	100
NODE COMMUNICATION RADIUS	50m
TIME STEPS	1000
MOVEMENT MODE	Random
NODE FAILURE MODE	Random
PROTOCOL	AODV

AODV use three kind of messages to investigate the route :RouteRequest(RREQ), RouteReply(RREP) and RouteError(RERR). When a node need to deliver data packages to the destination node, first it have to broadcast RREQ, and RREQ record the address of source node and destination node, the neighbor nodes will receive the RREQ and validate whether it is target node, if it is the target node, it will send RREP to source node, or broadcast forward RREQ to its neighbor nodes which are include its communication radius.

After complete step 1, we can obtain the Time-Spatial network topology graph. From the generated topology graph at different time points, we can obtain that the topology is varying with the time increasing, and the network metrics changes obviously (Fig.2):

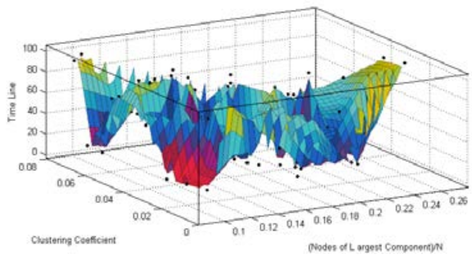

Fig.2. Network metrics R and C values varying in time and spatial dimensions

We collect the data of metric R and C during the simulation process, due to these two metrics are represented by the network structure which is based on time-spatial network model, and the we didn’t consider the power factors for case designing, so the fault tolerance ability curve is not monotonic with the node battery power decreasing. Actually it is not effect the assessment result because if we use the traditional method which is based on performance evaluation to evaluate the fault tolerance (i.e the method which is mentioned in reference[15]), the curve is not monotonic as well. The details of evaluation comparison we will disscuss in next sections.

The results are shown as Fig. 3. From the result we can obtain that either performance or fault tolerance tolerance ability are dynamic and changing with time increasing. From the curves under different time ranges, there should be some correlation between network performance and network fault tolerance ability, in Sec. 4.4 we would like to discuss the correlation analysis according to Equation (19) which is mentioned in step 4 of our evaluation method.

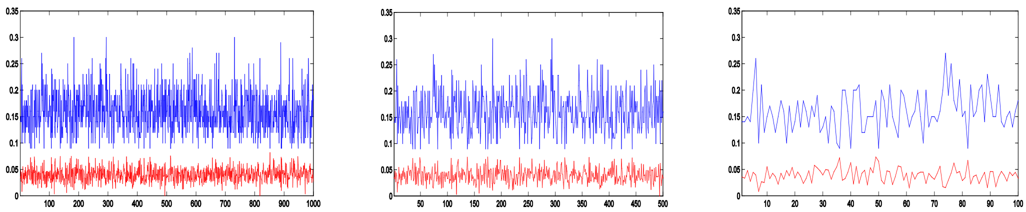

Fig. 3. Curves of metric C and R within different time ranges

4.2 Validity Verification

With the purpose of verifying the accuracy of proposed approach and model, we compare the simulation result with traditional approaches by performing on NS-3 platform under the same scenario setup. First, we perform the base setup following Table 1, then set radom number of source nodes and destination nodes, once all source nodes send the packets completed, we track and count the delivered packets' conditions from destination nodes, and this process is considered as one "time step". At last, we set 100 time steps as simulation time both on NS-3 platform and Time-Spatial model based simulation platform. Here we choose packets loss ratio (PLR) which is under random movement and random node failure mode as the traditional fault tolerance ability metric. The lower PLR, the stronger fault tolerance ability. So we also adopt Metric R which directly denote fault tolerance ability in time-spatial model for comparing with PLR. From Fig.4, we can observe that 2 metrics present the same fault tolerance ability under the scenario. The X-axis denote the time step increasing and Y-axis denote the value of PLR and Metric R.

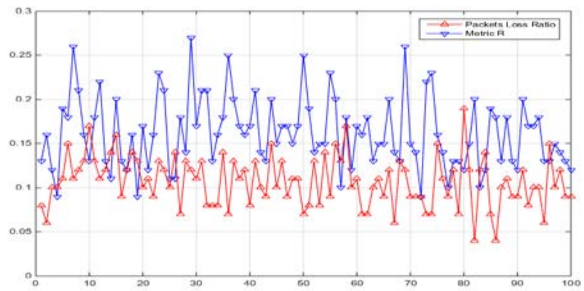

Fig. 4. Comparing the fault tolerance ability result by using NS-3 and Time-Spatial model under the same scenario

5. Conclusion

In this paper, we proposed a time-spatial model and corresponding approach for MANET route protocol fault tolerance ability evaluation. Because of ignorance of factors of route algorithm fault tolerance mechanism, the traditional evaluation methods for protocol fault tolerance are inefficiency while performing evaluation process, and due to the measurement metrics and process are as same as performance assessment, it is hard to recognize the relationship between fault tolerance ability and performance, so that the traditional evaluation result is unilateral and cannot effectively support the route protocol improvement and network designing. By constructing the model to describing the route protocol algorithm fault tolerance mechanism, firstly, we solve the problem of low execution efficiency through analyzing the fault tolerance mechanism features which reflected by proposed time-spatial network model; secondly, based on the time-spatial network model, thanks to the specify fault tolerance ability metrics introduction, we solve the problem of recognition relationship between fault tolerance ability and performance. At last, through a case study, the contrast test verify the accuracy and efficiency for the proposed model and approach, Simulation result further analysis is benefit to the Abstracted time-spatial model and independent fault tolerance ability metrics, linear correlation which is existing during fault tolerance ability, network performance and network cost could be found and analyzed.

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