A novel multi-factor simulation algorithm about tactical network connectivity reliability

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Abstract

Tactical network is a cooperative engagement of a collection of mobile nodes without the requirements of any centralized access points or existing infrastructures. Its connectivity is very crucial. Thus, the calculation of network's connectivity reliability has great significance to further research of tactical network. At present, the study of network is mainly through analytical methods. Those methods build abstract models alone without considering the transmission characteristics and terrain environment of a tactical network. Meanwhile, the existing simulation methods like Monte Carlo, is too abstract and simple. The OPNET simulation can solve the above problems better. In this paper, we analysed the related characteristics of tactical network and designed tactical network connectivity calculating algorithm based on the OPNET simulation. Through the algorithm, we take the transmission and environment features into consideration. As a result, we analysed the effects of wireless transmission characteristics, mobile models and terrain environment on network two-terminal reliability in specific cases.

Keywords: tactical network, OPNET simulation, two-terminal reliability, mobile networking, wireless networks

1 Introduction

As a future digitized battlefield support platform, tactical network completes both horizontal and vertical data transmission in tactical combat zone. It not only provides command and situational awareness information for all echelons, enhancing the commanders' and weapons platforms' ability of information resource sharing, but also meets the multi-level, multi-mode, and multi-cover communication needs of the future digital battlefield. Therefore, tactical network is under the spotlight in the military field.

Tactical network requires troops to ensure reliable connectivity among combat units, during a variety of complex tasks in the tactical environment. Thus, analyse connectivity reliability accurately is especially important for tactical network. In recent years, many scholars began to study the connectivity reliability of wireless and mobile network. Gabe Sierra and Lara Kauehak [1] defined several parameters characterizing the ad hoc networks, but there are no widely recognized definition and expression. Gabe Sierra [2] found that in the mobile wireless network there are still existing faults like large delay, high bit error rate and channel congestion, even when all the equipment are in good condition, so the reliability analysis method in the fixed topology network is difficult to be directly applied to the ad hoc network. Kharbash [3] took the mobility of nodes into consideration in his reliability assessment, but the evaluation model of wireless transmission characteristics was not given. [4, 5] used some mathematical models to evaluate the environment of wireless network, such as the Random Distribution Model and the Grey Relational Model. But they couldn't give a complete modelling of the environmental factors in ad hoc network. The complex terrain and weather could not be considered in detail in their models. All in all, current analyses of network merely complete reliability modelling, rarely take many features of a mobile network into account [6, 7], such as node transmission characteristics, topography, terrain and other environmental factors. On the other hand, the simulation methods existed, like Monte Carlo, is always too abstract and simple. For example, Wang Xuewang [8] used the distance between nodes to replace other terrains factors. The OPNET simulation can solve the above problems, but it is lack of specific reliability analysis module.

In this paper, we propose a tactical network two-terminal reliability analytical method based on the OPNET simulation. This method is based on the OPNET modeller and includes three parts, i.e., the network modelling, the simulation data collecting and the connectivity reliability calculating. OPNET network simulation belongs to the "network inside simulation" [9]. Namely, the network is simulated by dynamic behaviour, and we can analyse the network characteristic combining the accessed performance data. What's more, we can import the authentic terrain data into the simulation, which filling the gaps mentioned aforesaid. On this basis, the paper brought out a kind of network two-terminal reliability experimental method and comparatively analysed networks in different mobile models and environments.

The rest of this paper is organized as follows: Section 2 shows the design of simulation algorithm and experiment. Section 3 shows experiment with random

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mobile module and without terrain. Section 4 shows the influence of different mobile modules. Section 5 analyses the influences of terrain. Finally, Section 6 states our conclusions.

2 Design of algorithm and experiment

We define the two-terminal reliability *R(G)*, is as following: the probability that the destination node can maintain connectivity with the source node, receiving packets sent by the source node successfully. In a tactical network $G = (V, E)$, $V=\{v1,v2,\ldots vN\}$ is a set of *N* nodes in the network, and $E = \{e1, e2,\ldots,eM\}$ is a set of *M* links in the network. There are only two statuses of the link between the source node *vi*, and the destination node *vj*, connected or not, i.e. $\Psi(X)=1$ or $\Psi(X)=0$, $\Psi(X)$ is a Bernoulli random variable [10]. Assuming that *S* is the state space of *X*, and *X1,X2,…,XK* is the random *K* independent samples from *S*. Then the estimated value of the two-terminal reliability is as Equation (1).

$$R(G) = \frac{1}{K}\sum_{i=1}^{K}\psi(X)^{i} . \qquad (1)$$

Then we can get the value of *R(G)* through our multi-factor simulation algorithm, and use that value to analyse the reliability of the network. The process of the algorithm can be briefly described as follows:

Step 1. We build a project wireless-reliability-test in OPNET, and create several scenarios in it. Then, we put 30 wlan_wkstn_adv wireless mobiles nodes in one of the scenarios, and copy all of them to the other scenarios, ensuring that the nodes in all the scenarios have the same coordinates.

Step 2. Set the costumer business and routing protocol. We make the setting that source node sends destination node a 360 bytes data packet every 360 seconds, and choose the AODV routing protocol [9].

Step 3. Import the terrain data to the scenario if necessary. Import 100 random seeds into the project, and run the scenarios at the same time to get a set of reliability result from each scenario. Put the mobile module in all scenarios and set the required mobile model for all the nodes in two scenarios.

Step 4. Repeat the simulation for 50 different sets of random seeds. Average the results and draw the two-terminal curves for all the scenarios.

In this paper, we conducted three experiments. In all the three simulation experiments, we first establish a network scenario according to the parameters in Table 1. After that, we get random seeds form a C++ program, and obtain the K independent samples by importing the seeds into the network scenario in OPNET. At last, we can get the estimated value of the two-terminal reliability through Equation (1). The specific parameters of the simulation are shown in Table 1.

TABLE 1 Simulation experiment parameters

Parameters	Value
Network size	Scenario1000m^2, nodes 30
Simulation times	5000times (50*100)
Simulation length	100h
Transmission range	100m
Source node	Node 1
Destination node	Node 30
Mobile model	Random movement
Packet size	360byte
Packet sending interval	360s

3 Experiment with random mobile module and without terrain

We create a 1000 m*1000 m network in OPNET, and put 30 "wlan_wkstn_adv" wireless mobile nodes into the scenario randomly. Then we add task module, application module and profile module to the network scenario in order. The finished network scenario is shown in Figure 1.

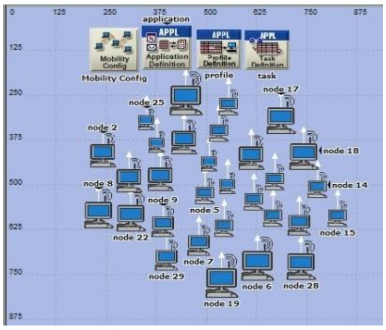

FIGURE 1 The first simulation experiment scenario

After building the network scenario, we begin to set the node parameters. Firstly, set node transmission power and reception sensitivity to 0.005W and - 81 respectively, so the maximum transmission distance will be 100 m according to the Equation (2).

$$Los = 32.44 + 20\lg d(km) + 20\lg f(MHz) . \qquad (2)$$

Then, we set Demand Distance Vector Routing (AODV) for all nodes, and add OPNET Default Random Waypoint Model to all the nodes in "Topology-Random mobility" [11]. We complete the custom business setting in the task, application and profile modules. Let Node 1 send a 360 bytes packet to Node 30 every 360 seconds. Under the circumstance that these two nodes are always connected, it can be seen that the destination node receives 1 byte data every second on average. Figure 2 shows the specific business setting.

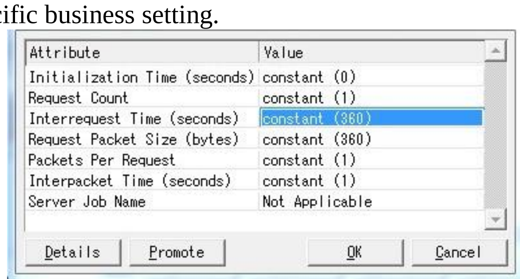

FIGURE 2 Custom business settings

After finishing the setting process of node and business, right click on the scene and select Traffic Received (bytes/sec) as the statistics we need in Chose Individual DES Statistics. Set the simulation length to 100h and import the 100 random seeds generated in C++ program into the OPNET, and click run to start the simulation.

After running the process, we can get the results of byte data, which the source nodes received every second in 100 h, corresponding to the 100 random seeds. Based on the Equation (1), we can obtain a connectivity reliability estimation curve from the above 100 samples. Repeat this process 50 times and average the 50 results, then we get the final two-terminal reliability curve without terrain and random mobile model (Figure 3).

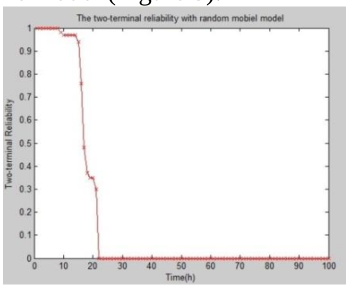

FIGURE 3 Final two-terminal reliability

In the 50 times of experiments, the most volatile point is at 17th hour. As showed in Figure 4. Through the calculation, we obtain the variance of the 50 reliability at 17th is 0.03, within acceptable limits. Therefore, the result of the simulation is quite stable.

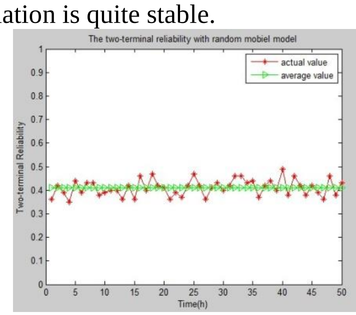

FIGURE 4 The stability test of the result

4 Experiment with different mobile modules

In the tactical network, the moving pattern of wireless nodes will directly affect the network topology, and affect the reliability of the network. In this chapter, we will study the different moving patterns' influence on two-terminal reliability according to the above simulation method [8]. In this paper, we use two-dimensional normal cloud model to create node mobile model. Two-dimensional normal cloud model can effectively describe the fuzziness and randomness of typical tactical moving pattern. See in Equation (3).

$$\mu_i(t) = \exp(-(\frac{(x_i(t)-E_x(t))^2}{2E_{nx_i}(t)} + \frac{(y_i(t)-E_y(t))^2}{2E_{ny_i}(t)})) . \qquad (3)$$

In Equation (3), (*Ex (t), Ey (t))* is a two-dimensional normal random variable, whose expectation is (*Ex (T), Ey (T))* and entropy is (*Hex2 (t), Hey2 (t)).* (*xi(t), yi(t)*) is also a two-dimensional normal random variable, whose expectation is *(Ex (t), Ey (t))* and entropy is *(Enxi2 (t), Enyi2 (t)). μi(t)* is a measured of *(xi(t), yi(t))* belonging to some degree domain. The two-dimensional normal cloud model could create five different mobile models depending on the different parameters selection of *(Ex, Ey, Enx, Eny, Hgx, Hgy, n)* [8]. Through some programming work, we develop the five normal cloud mobile modules in OPNET.

According to the algorithm method in Section 2, we add the five mobile models to the network scenario and run the simulation in proper order. After collecting the simulation data and calculating the two-terminal reliability, we can get the reliability comparison result curves of the five mobile models in Figure 5.

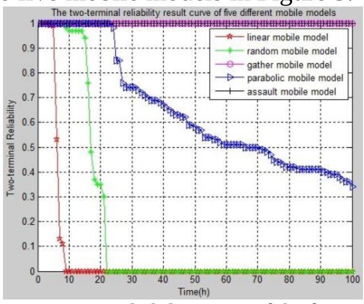

FIGURE 5 Connectivity reliability curve of the five mobile model

It can be seen from Figure 5 that, different from the traditional products fault, the two-terminal reliability between assigned source node and destination node in tactical network is not so significantly affected by time. But with different influencing factors, variation trends have large differences. Like the different tactical mobile model in this section, it has great influence on two-terminal reliability.

The reason is that two-terminal reliability mostly depends on the relative location of the assigned two-terminal nodes in the scenario and other nodes distribution situation between them, while the latter is greatly influenced by the mobile model. So the assigned moving pattern of nodes is significantly important to the two-terminal reliability of the network.

5 Experiment with terrain data

Terrain environment has an effect on the connection reliability of tactical network in several aspects. In this section, we study the impact on reliability caused by the terrain environment. Figure 6 shows the scenarios with terrain environment.

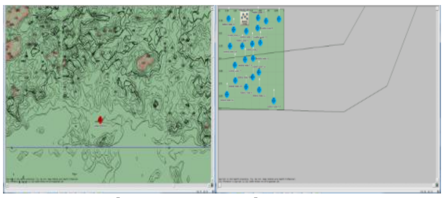

FIGURE 6 The scenarios with terrain environment

We set the parabolic mobile module to nodes in the above network, and through our algorithm, we get the curves both in scenarios with and without terrain environment. Figure 7 shows the details.

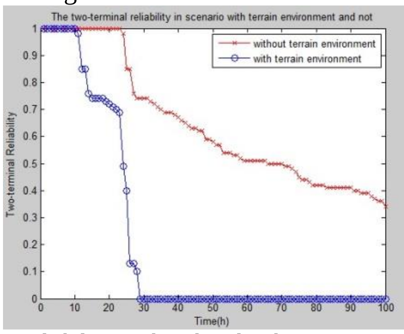

FIGURE 7 Reliability graph with and without terrain environment

It can be seen from Figure 7 that the terrain environment not only causes the value of two-terminal reliability decreases earlier, but also accelerates the decline rate. It is clear that the terrain environment dose have a significant effect on two-terminal reliability. The terrain environment can influence the connectivity reliability of the tactical network in several aspects. The two main reasons are given below:

1) With terrain environment under consideration, the max transmission distance decreases. Because signal attenuation between nodes is greater than that in a vacuum environment, which is caused by terrain shelter, and then the connection reliability reduces at both ends.

2) Terrain factor has much effect on the moving speed and location of mobile nodes, which affect the topological structure of networks, and finally impact the two-terminal reliability.

6 Conclusions

This paper provides a detailed simulation analysis and computing method of the two-terminal reliability of tactical network based on OPNET, upon which we could finish experiments and analyse the effect that complex terrain environment and mobile models in tactical network have on connectivity reliability. The innovative point of this paper is that it finished the analysis of the effect terrain environment and mobile models have on connectivity reliability, which is very difficult to be analysed comprehensively by traditional analytical methods.

In the future, we will apply our analysis method to the study of other network connectivity reliability aside from the two-terminal reliability. What's more, we want to expand use of this method to the research of network performance reliability. For these purposes, we will perform some other practical cases for the utilization of the proposed analytical method further.

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