Evaluating Mission-Oriented Network Reliability via Simulation Test

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***Abstract*—This paper proposed a simulated test method for evaluating mission-oriented network reliability. We first defined the mission-network model and entity-capability model. Then, to test the mission-oriented network reliability, we employed a three-layer network, including mission-layer, sampling-layer and physical-layer. The nodes were sampled from physical-layer based on the entity capability model while link were mapped from mission-layer based on the mission network model. To investigate the effect of this testing method, we chose different entity-capability models to evaluate mission-oriented network reliability of a combat network. The simulation result showed that entity-capabilities played an important role in mission-oriented network reliability and the simulation test method could be used as an effective means for mission-oriented network reliability evaluating.**

Keywords*—*network system; simulation test; mission-oriented reliability;

I. INTRODUCTION

With the development of network technology, complex systems have been increasingly described as complex networks. Facing different kinds of missions, various functions could be achieved via correlating coupling of the system components. Thus, how to evaluate the mission-oriented network reliability has become an important subject in different areas.

Recently, some researchers have already started to discuss the performance reliability of some specialized networks which is a kind of mission-oriented network reliability. Chen et al. proposed that computer networks' performance reliability could be described from four profiles[1]. Dong et al. proposed a Markov model to evaluate mission reliability of a communication network[2]. Dai et al. defined the grid service reliability by the probability of the successful completion of a set of programs contained by the grid computing system[3]. In transportation networks, travel time reliability was defined as the probability that travel times remained below some acceptable threshold [4].

We proposed a simulation test method to evaluate mission-oriented network reliability in this paper which was applicable to various types of networks. For the convenience of illustration, a combat network has been used as a sample in our study.

II. NETWORK SYSTEM MODELING

A. *Model of Physical Network*

The network system was described as a simple non-directed graph $G(V^{type}, E)$, where $type$ denoted the type of entity in the system, v_i^{type} denoted the nodes and e_{ij} denoted the links. The physical network was constituted of $N = |V^{type}|$ notes and $M = |E|$ links. $A(G) = (a_{ij})_{N \times N}$ was the adjacency matrix of graph G, $a_{ij} = 1$ when there was a link between v_i^{type} and v_j^{type}, otherwise $a_{ij} = 0$. In combat network, based on combat circle theory[5], four types of nodes were defined, management agent, logistics agent, influence agent and target agent, and *M*, *L*, *I*, *T* for short. Therefore, $type \in \{M, L, I, T\}$.

We assumed that nodes in the network were absolutely reliable and the links were not. The reliability of link was $R(e_{ij}) = p_{ij}$ and the failure of each link was independent. Network topology was fixed as well. The mission-oriented network reliability was denoted by $R^M(G)$.

B. *Model of Mission Network*

Various patterns of coupling between heterogeneous nodes will bring about different functions when the system confronts different missions. Thus, we defined the mission-oriented coupling as a kind of logical association. According to the requirement of a mission, a logical network was established in which nodes denoted necessary types and quantity of entities while links between nodes denoted the logical association between them. We defined this logical network as mission network.

Taking combat network as an example, we established a mission network as shown in Fig. 1. Confronting a type of mission, influence agent and logistics agent are managed by management agent. They interwork with each other for influence or fight against target agent. And mission *k*, denoted by M_k, could also be denoted by a simple undirected graph $G^{M_k}(V^{M_k}, E^{M_k})$, in which V^{M_k} means the set of nodes in mission network and E^{M_k} means the set of logical links. We further defined $N^{M_k}=|V^{M_k}|$ as the amount of node and $M^{M_k}=|E^{M_k}|$ as the amount of logical links in G^{M_k} .

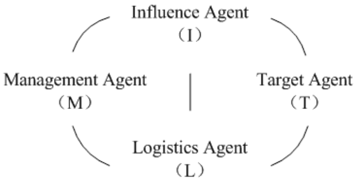

Figure 1. Mission network of Mk in combat network

C. Mission-Oriented Capability Model

Considering each entity always has different capabilities to accomplish different missions, we proposed a capability model in this paper. For instance, fighter aircraft, as an influence agent in combat system, has a high capability in an attack mission but a low capability in an investigation mission. We defined the capability as a matrix denoted by

$$B^{type}_{N^{type}\times K}=\begin{array}{c}\\ v_o^{type}\\ v_p^{type}\\ \vdots\\ v_q^{type}\end{array}\begin{array}{c}\begin{array}{cccc}M_1 & M_2 & \cdots & M_K\end{array}\\ \begin{bmatrix} w_{o1}^{type} & w_{o2}^{type} & \cdots & w_{oK}^{type}\\ w_{p1}^{type} & w_{p2}^{type} & \cdots & w_{pK}^{type}\\ \vdots & \vdots & \ddots & \vdots\\ w_{q1}^{type} & w_{q2}^{type} & \cdots & w_{qK}^{type}\end{bmatrix}\end{array}\quad , \tag{1}$$

where N^{type} is the amount of entities fitted into one type, $v_o^{type},v_p^{type}\cdots v_q^{type}$ are types of entities and $M_1\cdots M_K$ are types of missions that can be accomplished by the system. We also took combat system as a sample, in which $type\in\{M,I,L,T\}$. The elements of matrix denoted the mission-oriented capability of each entity. If we have history data of the network missions, the capability matrix can be learned from the data statistically. We further defined the normalized expression which was denoted by $\tilde{B}^{type}$.

$$\tilde{B}^{type}_{N^{type}\times K}=\begin{array}{c}\\ v_o^{type}\\ v_p^{type}\\ \vdots\\ v_q^{type}\end{array}\begin{array}{c}\begin{array}{cccc}M_1 & M_2 & \cdots & M_K\end{array}\\ \begin{bmatrix} \tilde{w}_{o1}^{type} & \tilde{w}_{o2}^{type} & \cdots & \tilde{w}_{oK}^{type}\\ \tilde{w}_{p1}^{type} & \tilde{w}_{p2}^{type} & \cdots & \tilde{w}_{pK}^{type}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{w}_{q1}^{type} & \tilde{w}_{q2}^{type} & \cdots & \tilde{w}_{qK}^{type}\end{bmatrix}\end{array}\quad , \tag{2}$$

where $\tilde{w}_{ij}^{type}=w_{ij}^{type}/\sum_{i=1}^{N_{type}}w_{ij}^{type}$.

III. SIMULATION TESTING OF MISSION-ORIENTED NETWORK RELIABILITY

A. Model of Hierarchical Network

Hierarchical network model has been well defined[6] and used for both communication network[7]and transportation network[8].There are always two layers where the upper-layer is a logical layer and lower-layer is a physical layer. Physical layer is composed of computers in computer network and cell phones in communication network. Logical layer is used to specify the missions running on the physical network.

Towards investigation of mission-oriented network reliability, we modeled a three-layer network as shown in Fig.2. The top-layer was called ***mission-layer*** in which the mission networks $G^{M_k}(V^{M_k},E^{M_k})$ were characterized. The physical network $G(V^{type},E)$ was the topology of system which was described in the bottom-layer called ***physical-layer***. The middle-layer was called ***sample-layer*** in which nodes were sampling from physical-layer while logical links were mapping form mission-layer.

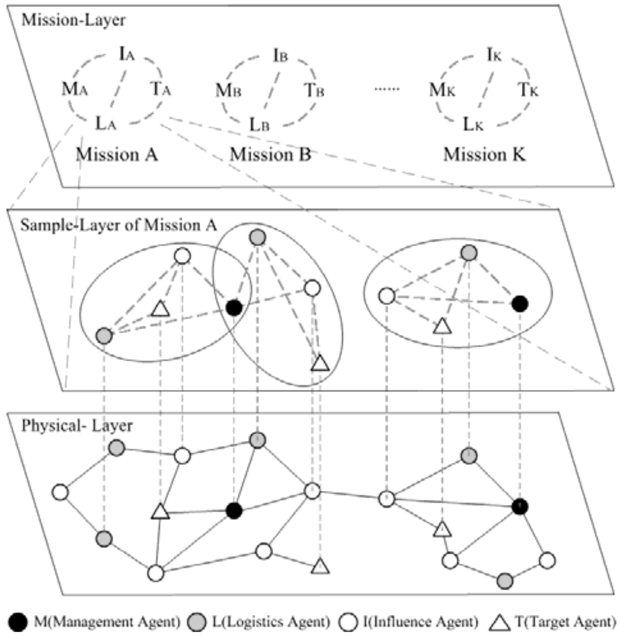

Figure 2. Hierarchical network model

B. Mission-Oriented Network Reliability

Based on the hierarchical network model, we sampled nodes from mission-layer and mapping logical links from physical-layer to sample-layer. $\tilde{w}_{ik}^{type}$ was the probability that node v_i^{type} was sampled. Nodes connected with each other in the pattern of mission network through mapping the logical links from mission-layer. Sample of M_k was denoted by $G_n^{M_k}(V_n^{M_k},E^{M_k})$.

The reliability of links in sample-layer were calculated by the ST reliability of the physical network for two end nodes of this link. In other words, a logical link in sample-layer stands for all the minimal paths between its two end nodes in physical-layer. Therefore, we denoted the ST reliability between v_i^{type} and v_j^{type} of the nth sample as $R_{ijn}^{M_k}$. ST reliability can be calculated by many algorithms, such as the binary decision diagram (BDD) algorithm[9]. In this paper, we took Sahinoglu’s overlap algorithm[10] to calculate mission-oriented network reliability. Consequently, we defined mission-oriented reliability of a sample as

$$R_n^{M_k}(G)=\frac{1}{M^{M_k}}\sum_{e_{ij}\in E^{M_k}}R_{nij}^{M_k}\ . \tag{3}$$

Towards M_k , the mission reliability could be denoted by

$$R^{M_k}(G)=\frac{1}{Num}\sum_{n=1}^{Num}R_n^{M_k}\ , \tag{4}$$

where Num is the amount of samples.

Assuming that K missions can be accomplished by the network system, we further defined the mission-oriented network reliability as

$$R^M(G) = \sum_{k=1}^{K} \omega_k R^{M_k} \ , \tag{5}$$

where ω_k stands for the weight of M_k .

C. Simulation Plan of Mission-Oriented Network Reliaibliy

Based on all definitions and assumptions above, the simulation plan of mission-oriented network reliability is given below:

- Step 1: Mission-network and capability model learning. In this step, mission-network G^{M_k} and capability model B^{type} can be learnt from the historic data statistically. Particularly, the elements in B^{type} are times each entity involving in each mission gaining via statistical data.
- Step 2: Sample-layer nodes sampling. Taking normalized matrix $\tilde{B}^{type}$ as the sampling probability, sample nodes from physical-layer to sample-layer.
- Step 3: Sample-layer links mapping. Map logic links between nodes in sample-layer from mission-layer.
- Step 4: Sample reliability calculating. Calculate the ST reliability between nodes with logical links $R_{ijn}^{M_k}$ in mission-layer. Afterwards, sample reliability $R_n^{M_k}$ can be calculate by (3). If $n < Num$,go to step 2, otherwise, go to step 5.
- Step 5: Mission reliability calculating. Calculate M_k 's reliability $R^{M_k}(G)$ by (4).
- Step 6: Mission-oriented network reliability calculating. Calculate network system's mission-oriented reliability $R^M(G)$ by (5).

IV. SIMULATION AND DISCUSSION

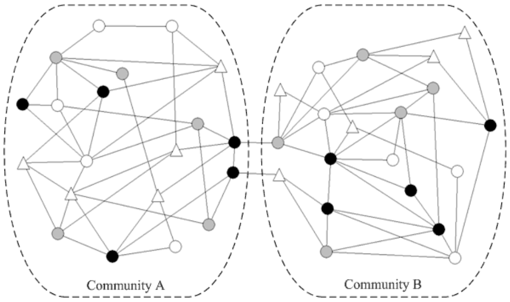

Figure 3. Topology of combat network.

To illustrate the effect of entities' capability on the mission-oriented network reliability, we compared the reliability for different capability model. We also took a combat network as example in which there were 40 nodes and two communities. Nodes in communities were randomly connected with the average degree of 4 and the number of entities of each type was 10. To simplify the calculation, we further assumed that all links in physical-layer had same reliability $R(e_{ij}) = p_{ij} = 0.9$. The topology of the combat network is shown in Fig.3. The mission network in Fig.1 was used as well.

First, we assumed that each entity of same type had equal capacity confronting to M_k . In other words, each nodes would be sampled equiprobably. The capability model was

$$(B^M)^T = (B^T)^T = (B^I)^T = (B^L)^T = [1 \ \ 1 \ \ 1 \ \ 1 \ \ 1 \ \ 1 \ \ 1 \ \ 1 \ \ 1 \ \ 1] \ .$$

We sampled node from physical-layer by (2) and calculated sample reliability by (3). Refer to overlap algorithm[10], themaximum $R_n^{M_k}$ of Fig.3 was 0.8100 and minimum $R_n^{M_k}$ was 0.7617. Obviously, as a result of equal capability assumption, the nodes sampling was actually a random sampling. The simulation was carried out 1000 times and the result was shown in Fig. 4. The sample mean was 0.7924, sample median was 0.7911 and sample mode was 0.7877.

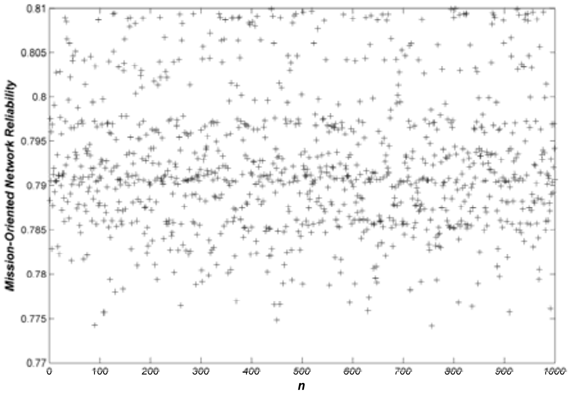

Figure 4. Scatter plot of sample number against the sample reliability $R_n^{M_k}$ based on equal capability model.

To further illustrate the effect of capability model on mission-oriented network reliability, we made another assumption. Assuming that the capability model of management agent and target agent are

$$(B^M)^T = (B^T)^T = [5 \ \ 5 \ \ 5 \ \ 5 \ \ 5 \ \ 0 \ \ 0 \ \ 0 \ \ 0 \ \ 0] \ ,$$

we gained a network that nodes *M* and *T* only in community A could accomplish M_k . The capability model of influence agent and logistics agent were

$$(B^I)^T = (B^L)^T = Step \cdot n + [0 \ \ 0 \ \ 0 \ \ 0 \ \ 0 \ \ 5 \ \ 5 \ \ 5 \ \ 5 \ \ 5] \ ,$$

where $Step = [10^{-3} \cdots 10^{-3} - 10^{-3} \cdots - 10^{-3}]$ is the step size of variation, $n \in [1, 5000]$ is the number of sample. In other words, the capability model of influence agent and logistics agent were changing during the simulation. As shown in Fig. 5(a), when *M* and *T* entities in community B had no capabilities to accomplish M_k while *I* and *L* entities in community A had very limited capabilities to accomplish M_k , network system shown a very poor mission reliability. When n belong to interval $[1, 1000]$, the sample mean was 0.7824, sample median was 0.7818 and sample mode was 0.7741. However, along with the increasing capability of *I* and *L* entities in community A, samples with high reliability increased gradually.

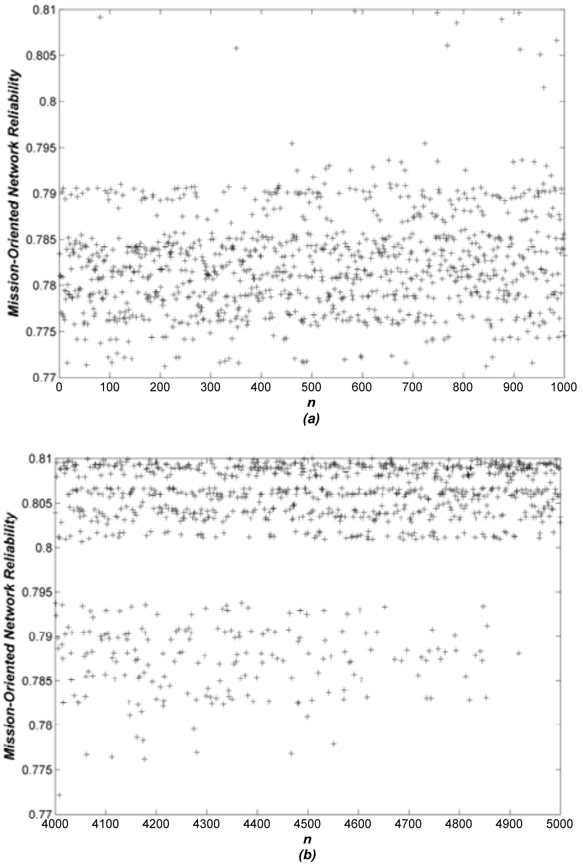

Figure 5. Scatter plot of sample number against the sample reliability $R_n^{M_k}$ based on variant capability model where $n \in [1,1000]$ in (a) and $n \in [4001,5000]$ in (b).

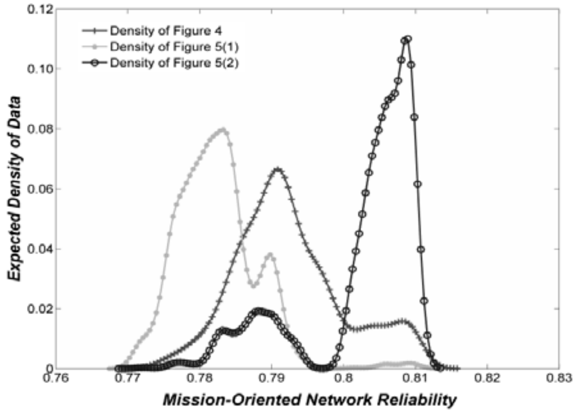

Figure 6. Density plot of mission-oriented network reliability against the samples' probability density.

Differ from Fig. 5(a), samples in Fig. 5(b) showed relatively high mission reliability. When n belong to interval $[4001,5000]$,the sample mean was 0.8026, sample median was 0.8060 and sample mode was 0.8038. As a result of improving capability of I and L entities in community A, nodes sampling tended to within the community other than between communities which led to a high mission-oriented network reliability.

Fig. 6 showed the samples' probability density of Fig. 4, Fig. 5(a) and Fig. 5(b). Under different capability assumption, the same network topology showed a statistical disparity of mission-oriented reliability. In summary, topological connectivity is only one aspect of the network reliability. Mission-oriented network reliability can be improved by adequate consideration of entities' capability.

V. CONCLUSION

Along with the increasing of scale and complexity, the integrated network systems are becoming more and more universal. Evaluating multi-function system's reliability quickly and accurately has become an important project. In this paper, we proposed a simulation testing method to evaluate mission-oriented network reliability via a three-layer network model which composed by physical-layer, sample-layer and mission-layer. We defined a capacity model serving for mission-oriented nodes sampling. We further defined a mission model serving for mission-oriented links mapping. Based on the hierarchical model we calculated the mission-oriented network using ST reliability. The statistic result of simulation testing indicated that this method can distinctly reflect mission-oriented system reliability. Corresponding to the expected result, centralized sampling lead to a high reliability while decentralized sampling lead to a low reliability according to various capacity model. The method we proposed is applicable to various networks, for instance, communication networks, computer networks. It is also a valid instrument in both network reliability designing and improving.

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