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ZASTOSOWANIE TECHNOLOGII SYMULACJI DO OCENY NIEZAWODNOŚCI SIECI TYPU AD HOC

APPLICATION OF SIMULATION TECHNOLOGY IN RELIABILITY EVALUATION OF AD HOC NETWORKS

Ocena niezawodności sieci Ad Hoc przy użyciu technik analitycznych zazwyczaj wymaga wielu założeń. Dlatego też techniki analityczne nie są w stanie uwzględnić wielu czynników stochastycznych charakteryzujących sieci tego typu. Ostatnio symulacja stała się popularnym podejściem do oceny niezawodności sieci Ad Hoc. W niniejszym artykule przedstawiono scenariusze symulacji i omówiono proces projektowania modeli symulacji do oceny niezawodności sieci Ad Hoc. Omówiono również kierunki przyszłych badań.

Słowa kluczowe: *Sieć Ad Hoc, symulacja niezawodności, ocena niezawodności.*

Reliability evaluation of Ad Hoc networks using analytical techniques usually requires many assumptions. Thus, analytical techniques are unable to consider many stochastic factors of the networks. Simulation has become a popular approach for evaluating the reliability of Ad Hoc networks. This paper introduces simulation scenarios and discusses simulation model design for reliability evaluation of Ad Hoc network. Future research directions are also discussed.

Keywords: *Ad Hoc network, reliability simulation, reliability evaluation.*

Abbreviations

UDP	User Datagram Protocol
S/R	Segmentation/Reassembly
IP	Internet Protocol
QoS	Quality of Service
AODV	Ad Hoc On-Demand Distance Vector Algorithm
DSR	Dynamic Source Routing
DSDV	Destination-Sequenced Distance-Vector Routing
CSMA	Carrier Sense Multiple Access
E-TDMA	Evolutionary-Time Division Multiple Access
FDM	Frequency Division Multiplexing
TDM	Time Division Multiplexing
MTTRF	Mission Time to Restore Function
MR	Mission Reliability

1. Introduction

An Ad Hoc network is a kind of mobile network. It does not have a fixed infrastructure. The nodes in the network can form the network topology randomly through wireless links. Each node has equal status and is able to perform both the host and the router functions. The stochastic factors that affect the reliability of Ad Hoc networks can be divided into external factors and internal factors. External factors include network traffic, node mobility, terrain, weather, etc. Internal factors include the reliability of network equipment, network topology, network protocol, QoS assurance mechanism, etc. Many of these stochastic factors are difficult to incorporate when evaluating the reliability of the network. Evaluating the reliability of Ad Hoc networks with the approach of mathematic modeling usually needs many assumptions [2, 3, 5, 6]. These assumptions are unable to address many of the stochastic factors and the mathematical treatment may be intractable. Simulation has become a popular approach for reliability evaluation of such networks. In this paper, we introduce simulation scenarios and investigate simulation model design for reliability analysis of Ad Hoc networks. We will also discuss future research directions.

2. Reliability simulation scenario design

The reliability simulation problem to be addressed in this paper comes from army digital mechanical musketeer brigade. The simulation network covers an area of 100 km x 100 km. The used simulation tool is OMNEST. The simulation network has a three level topological structure and a five level architecture. The topological structure and architecture are shown in Fig. 1 and Tab. 1.

Tab.1. Simulation Network Architecture

Application layer: five level voice operation, five level data operation
Transport layer: UDP protocol, S/R protocol
Network layer: IP protocol, QOS AODV protocol, DSR protocol, DSDV protocol
MAC layer: CSMA protocol, E-TDMA protocol
Physics layer: FDM, TDM

The reliability simulation is based on army digital mechanical musketeer brigade Ad Hoc typical mission profile in aggression combat. The Ad Hoc typical mission profile is shown in Fig. 2.

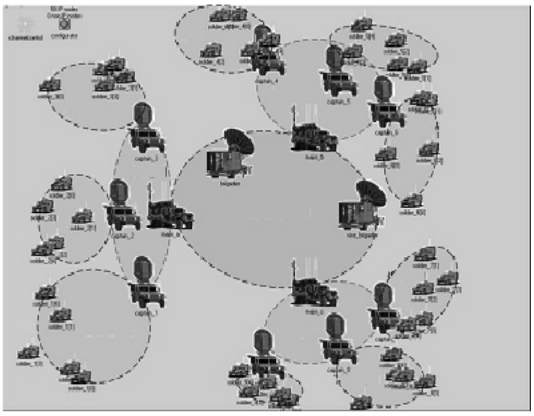

Fig. 1. Simulation network topological structure

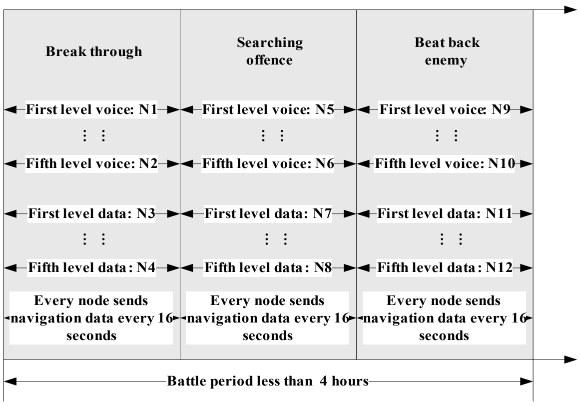

Fig. 2. Ad Hoc typical mission profile in aggression combat

3. Riliability simulation model design

Ad Hoc reliability simulation covers many models. In this paper, we introduce only the network traffic model, the node mobility model, and the node failure model.

3.1. Network traffic model design

Our earlier studies indicate that the operation traffic of a packet switch network shows self-similarity and abruptness. We will introduce a heavy tailed distribution and a self-similar process first before explaining the traffic model.

X is a stochastic variable, its cumulative distribution function (cdf) is $F(x) = P[X \leq x]$, and its reliability function is $\overline{F}(x) = 1 - F(x) = P[X > x]$. Define $F(x)$ as a heavy tailed distribution [1], if

$$\overline{F}(x) \sim cx^{-\alpha}, 0 < \alpha < 2 \tag{1}$$

where c is a positive constant and $a(x) \sim b(x)$ means $\lim_{x\to\infty} a(x)/b(x) = 1$. If $F(x)$ is a heavy tailed distribution, the variance of X is infinity when $\alpha \leq 1$ and the mean of X is infinity too. Pareto distribution is a typical heavy tailed distribution, whose probability density function (pdf) is

$$p(x) = \alpha k^{\alpha} x^{-\alpha-1}, \qquad 0 < k \leq x; \alpha > 0 \tag{2}$$

and its cdf is

$$F(x) = 1 - (\frac{k}{x})^{\alpha} \tag{3}$$

where the positive constant k means the smallest value of the stochastic variable.

If a stochastic process has an autocorrelation function of $r(k) \sim k^{-\beta}$, $k \to \infty$, $0 < \beta < 1$, then the process is called self-similar [8]. We use Hurst parameter ($H = 1-\beta/2$) to describe the autocorrelation degree of self-similar processes. For a self-similar process, which can be used to represent network operation traffic, if $1/2 < H < 1$, the network operation traffic is positive correlated. As $H \to 1$, the traffic self-similarity degree increases.

Heavy tailed distributions and ON/OFF traffic models can be used to explain the cause of self-similar operation traffic [9]. The ON/OFF model assumes that the data source alternates between sending data and halt. The sending data period and the halt period are called the ON period and the OFF period, respectively. When the data source is sending data with a constant speed, we say that it is in the ON period. Aggregating data sent from N independent sources following the same ON/OFF model often causes the operation traffic to be self-similar. The length of the ON period and the length of the OFF period each follows a heavy tailed distribution.

3.2. Node mobility model design

A group mobility model is needed for network simulation. Its parameters include node excursion angle θ, node moving speed v, node moving time t_1, node halt time t_2, and network communication range R_n ($n = 1$, 2, and 3 representing network grade). All nodes are initially halted when the simulation starts, and halt time decreases from superior nodes to junior nodes [7].

As shown in Fig. 3, when a superior node moves along direction $\overrightarrow{GM}$, all junior nodes follow it with their relative positions unchanged. Adding a stochastic displacement $\overrightarrow{RM}$, a junior node's position after n moves can be expressed as follows:

$$\overrightarrow{P_n} = \overrightarrow{P_{n-1}} + \overrightarrow{GM} + \overrightarrow{RM} \tag{4}$$

If some node moves out of its communication range after a move, then accept this event with probability of 0.1. If such an event is not accepted, change the node excursion angle θ, and the node continues to move. As shown in Fig. 3, if nodes move out of their communication range at C and E, then readjust the nodes to D and F.

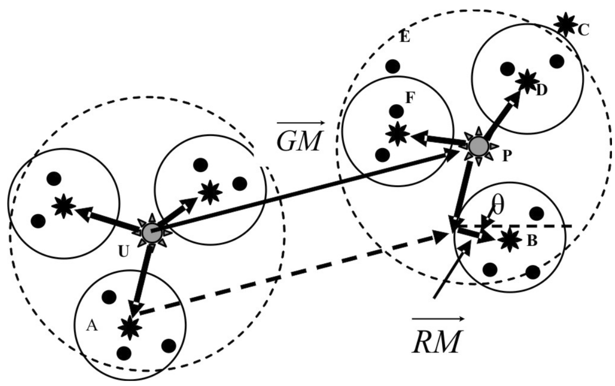

Fig. 3. Group mobility model

3.3. Node failure model design

A node failure model is needed in order to simulate the stochastic failures of node (except failures caused by human factors). A flow chart of the node stochastic failure simulation is shown in Fig. 4.

a) When simulation starts, all nodes are registered following the global failure management module, confirming node failure status based on the node mission reliability set by the user.
b) Computing the mean number of operations between failures based on the total number of operations and pre-specified time points of failure.
c) When the simulation progresses to a pre-specified time point of failure, choose a node randomly from the failure nodes confirmed in step (1) and change the status of this node to failure.
d) If a node can be repaired, confirm node repair time based on the ratio between mission time and repair function set by the user.

If the simulation includes N nodes and X operations, every node has the same mission reliability the mean number of operations between failures (Δ) is:

$$\Delta = \frac{X}{N*(1-MR)} \tag{5}$$

4. Network reliability evaluation approach

Network reliability is the capability that the network will satisfy user's normal requirements under stated operation conditions for a stated operation period of time. The stated operation conditions include not only network traffic, node mobility, terrain, and weather, but also equipment stochastic failures in the process of network operation (except failures caused by human factors).

Although the factors that affect the reliability of Ad Hoc networks are sophisticated, their effect must be incorporated through network operation results in the end [4]. Thus, we measure the reliability of Ad Hoc networks with the probability of performance parameters meeting thresholds in the process of network operation. Through reliability simulation, we can compute these probabilities. Take the mean delay of the network as an example. Using the same simulation configuration (stated operation conditions), in the same simulation duration (stated operation period of time), we carried out 80 simulations with different stochastic seeds, obtained a mean delay sample, and then drew the mean delay frequency histogram based on the sample, which is shown in Fig. 5.

In Fig. 5, r_i is frequencies falling into every group and $f_i = \frac{r_i}{k}$ is percentage falling into every group. The mean delay cumulative frequency histogram is shown in Fig. 6.
F_i is the cumulative frequency in group i,

$$F_i = \sum_{j=1}^{i} f_j = \sum_{j=1}^{i} \frac{r_j}{k} = \frac{R_i}{k} \tag{6}$$

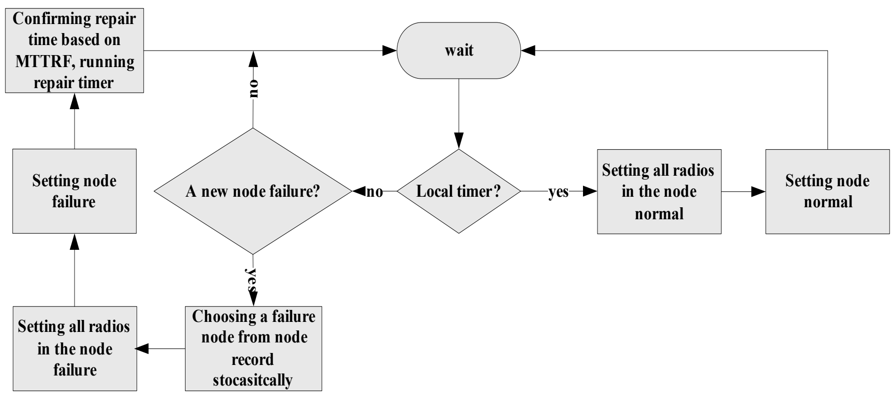

Fig. 4. Node failure simulation flow chart

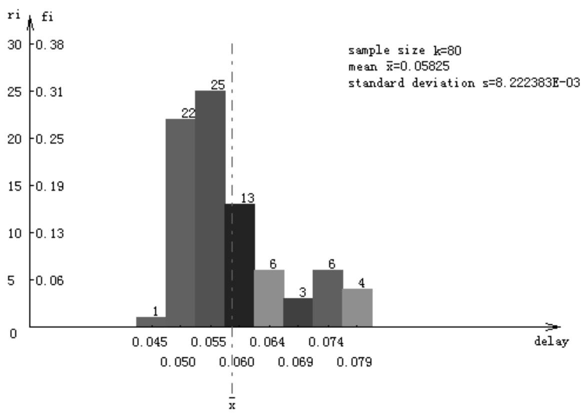

Fig. 5. Mean delay frequency histogram

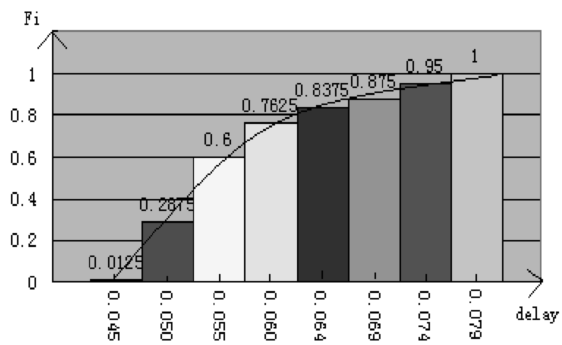

Fig. 6. Mean delay cumulative frequency histogram

R_i is cumulative frequencies when group *i* end. If *k*->∞, the interval between groups Δ*t*->0, then the line connecting the midpoints of every rectangle will tend towards a smooth curve, which is the probability distribution curve of the Ad hoc network's mean delay. According to the above histogram we can work out approximately that P (mean delay < 65 ms) = 0.8391.

The simulation approach outlined here takes care of the various stochastic factors affecting the reliability of the Ad Hoc more comprehensively than the mathematic modeling approach. It is simpler and more practical.

5. Conclusion

The simulation approach outlined in this paper can be used for not only Ad Hoc networks but also other communication networks. However, the probability of a parameter meeting its threshold covers only one aspect of communication network reliability. How to obtain integrated measures from several "aspects" deserve further studies in the future.

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6. References

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