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A Cooperation-Based Fault Management Method for Satellite Networks

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Abstract: In order to efficiently diagnose the satellite network, a three level management architecture was proposed and a cooperated-based fault management method was put forward. In this method the traditional fault management method was used through network management technique when a satellite agent could respond to the network management instruction received from the management station. However, if the satellite agent could not respond to the network management demands, the intra-domain cooperation or inter-domain cooperation would be activated. The suspected fault satellite could be tested through cooperation among the satellite agents. The simulation results shows that in the circumstance of the low faulty frequency, the new method could be effectively used in satellite network with short cooperative time and low throughput.

Key words: Cooperation, fault management, network management, satellite networks

INTRODUCTION

The most important roles of satellite networks are to provide access by user terminals and to internetwork with terrestrial networks (Yong-jun *et al.*, 2004; ZHANG *et al.*, 2004; Yong-jun *et al.*, 2004) so that the applications and services provided by terrestrial networks such as telephony, television, broadband access and Internet connections can be extended to places where cable and terrestrial radio cannot economically be installed and maintained. In addition, satellite networks can also bring these services and applications to ships, aircraft, vehicles, space and places beyond the reach of terrestrial networks. Satellites also play important roles in military, meteorology, Global Positioning Systems (GPS), observation of environments, private data and communication services and future development of new services and applications for immediate global coverage such as broadband network and new generations of mobile networks and digital broadcast services worldwide.

The nature of satellite networks makes them fundamentally different from terrestrial networks in terms of distances (FAN and Jiang, 2003), shared bandwidth resources, transmission technologies, design, development and operation and costs and needs of users.

Functionally, satellite networks can provide direct connections between terrestrial networks. The user terminals provide services and applications to people, which are often independent from satellite networks, i.e., (LONG *et al.*, 2005). The same terminal can be used to access satellite networks as well as terrestrial networks. The satellite terminals, also called earth stations and are the earth segment of the satellite networks, providing access points to the satellite networks for user terminals via the User Earth Station (UES) (Giampiero *et al.*, 2002) and for terrestrial networks via the Gateway Earth Station (GES). The satellite is the core of satellite networks and also the centre of the networks in terms of both functions and physical connections (HOU *et al.*, 2006; Ming-qiao and Hai-rong, 2004).

Satellite network has become a hot topic. However the common satellite fault management models take the satellites as a single isolated entity (CHEN *et al.*, 2004), lacking of the satellite network fault management methods. Therefore according to the time-varying geometry characteristics and real-time fault detection requirements an efficient and effective satellite networks fault management method should be studied. The method based on the cooperation with the satellite agents can reduce the resources of satellite communication (Vladimir *et al.*, 2005).

In this study, the first section introduces the development of satellite networks and the necessary to research its management method. In the second section the satellite network architecture was described. The following section established a satellite networks management architecture and discussed the mechanism of how to establish management domains and their components. The fourth section detailed researched a

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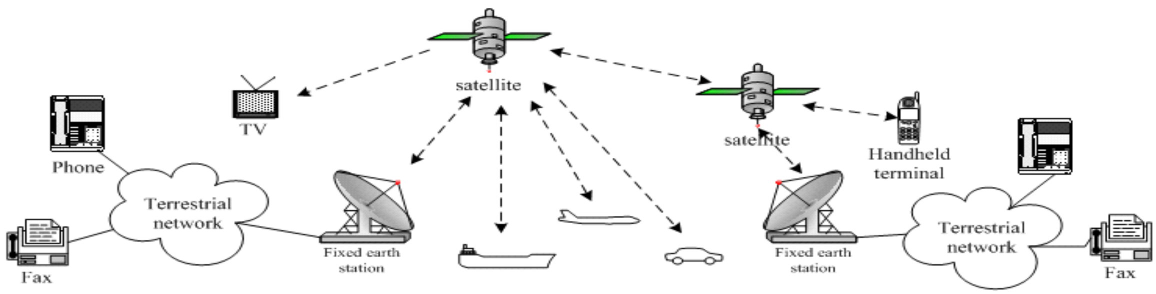

Fig. 1: Typical applications and services of satellite networking

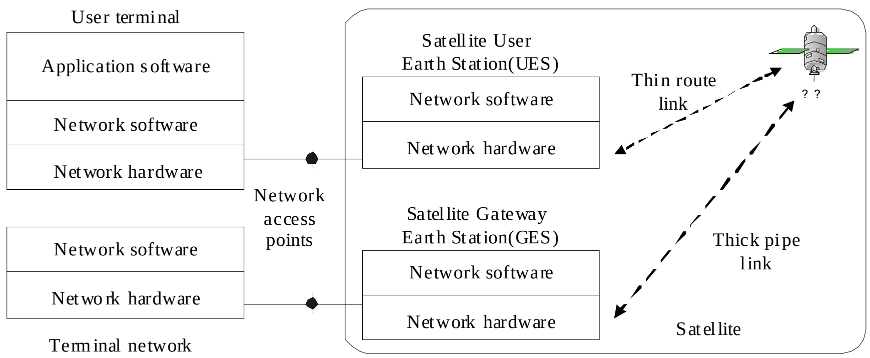

Fig. 2: Functional relationships of user terminal, terrestrial network and satellite network

satellite networks fault management method based on cooperation among the satellite networks management agents. The experiments results and the analysis base on them showed that the method proposed in this study is effective in the last.

METHODOLOGY

Satellite networks architecture: Satellite networking is an expanding field, which has developed significantly since the birth of first telecommunication satellite, from traditional telephony and TV broadcast services to modern broadband and Internet networks and digital satellite broadcasts. Many of the technological advances in networking areas are centred on satellite networking. With increasing bandwidth and mobility demands in the horizon, satellite is a logical option to provide greater bandwidth with global coverage beyond the reach of terrestrial networks and shows great promise for the future. With the development of networking technologies, satellite networks are becoming more and more integrated into the GNI. Therefore, internetworking with terrestrial networks and protocols is an important part of satellite networking.

Figure 1 illustrates a typical satellite network configuration consisting of terrestrial networks, satellites with an Inter-Satellite Link (ISL), fixed earth stations, transportable earth stations, portable and handheld terminals and user terminals connecting to satellite links directly or through terrestrial networks.

Like terrestrial networks, satellite networks are increasingly carrying more and more Internet traffic, which now exceeds telephony traffic (Fig. 2). Currently, Internet traffic is mainly due to classical Internet services and applications, such as WWW, FTP and emails. Satellite networks only need to support the classical Internet network applications in order to provide traditional best-effort services.

To support IP over satellites, the satellite networks need to provide a frame structure so that the IP datagram can be encapsulated into the frame and transported via satellite from one access point to other access points. In a satellite environment, the frame can be based on standard data link layer protocols. Encapsulation of IP is also defined in the existing networks, such as dial-up link, ATM, DVB-S and DVB-RCS, which support Internet protocols or internetwork with the Internet.

It is also possible to encapsulate an IP packet into another IP packet, i.e., to create a tunnel to transport the IP packets of one Internet across another Internet network.

Satellite networks management architecture: As an important establishment which is the access to space systems, ground systems seamless. Satellite network is

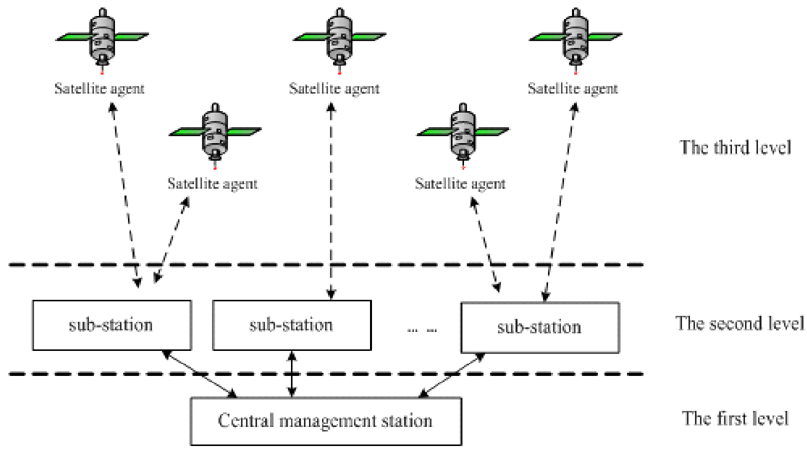

Fig. 3: Satellite network management architecture

playing an extremely important role in fields such as the defense and economic construction of the nation. But in order to make such a highly complex, dynamic heterogeneous network operate effectively and credibly, satellite networks must be effectively and efficiently managed to ensure that the network resources and information can be correctly regulated and configured (Alden *et al*., 2002). It should adapt to changes of the application tasks, oneself and the external condition and deal with complex emergency situations (Shajari and Ghorbani, 2004).

According to the time-varying geometry of satellite network, a dynamic hierarchical network management system has been put forward in Wen *et al*. (2004). Based on this system architecture, the satellite network management system is divided into three levels. The first level is the central management station deployed on the ground, which is responsible for the management of sub-station and in charge of creating the satellite network topology, etc. The second level is consisted of the sub-stations deployed on the ground. These sub-stations are responsible for managing the satellite agents in the management domain and creating the local network topology. The upper level is consisted of satellite agents which are managed by the sub-stations and the central station. The satellite network management level is shown in Fig. 3.

In the satellite network management architecture (Vivero and Serrat, 2002), the sub-station and the satellites agents composed a management domain. Satellite agents could dynamically registered in and logged out the management domain according to the communication delay between the sub-station and the satellite agents (Liu *et al*., 2009). For the whole satellite network there are multiple management domain exist. A management domain is the aggregate of satellite agents which have registered in the management sub-station on the ground. The aggregate update dynamically. When a new satellite agent wants to join the management domain, it first registered to the management sub-station. Then the management sub-station justifies the satellite agent. If the satellite agent is accepted, it could be management by the sub-station. This network management mechanism is suitable to satellite network of the time-varying geometry (Wen and Wang, 2003).

As for the network management, a clear division of management domains contributes to enhance the scalability of the system and avoid the duplication operations. In the traditional network management, the division of management domains is usually by the geographical or structure due to most of the network device nodes is fixed. That is to say, firstly determine the location of the station manager and then do topology configuration according to the geographical location of the network nodes and designate a management domain corresponding to the station manager. Once the management domain is identified, the nodes inside the domain cannot casually move to another management domain. This management mechanism is able to ensure that the network management applications won be overlapped and because of the relatively fixation of network nodes, network topology management is also relatively easy to be implemented. However, this management domain partition method cannot be applied in satellite networks.

Referring to the satellite network, the mobility of the satellite (or constellation) and frequently dynamic changes of the network topology due to provisional of the links, so the network management domain must have a clear division of ownership in order to avoid overlapped management operations. At present, researchers have proposed the management domain splitting strategy based on the delay tests and management domain splitting strategy based on delay and hop counts. The basic idea of these strategies is to make the proposed algorithm can reduce the negative impact that link delay brought about to the satellite network management. In order to achieve a dynamic division of management domains, the satellite nodes must be able to dynamically register to the management domain and logout from the management domain, this study proposed the alteration mechanism of satellite network management domains based on login and logout and designed the communication primitives. It is noted that this study assumes that the satellite network will use SNMPv3 as its management protocol in the future (Choi *et al*., 2009).

In the initial state, all satellite network sub-station managers located on the ground periodically broadcast the login packets to satellites within its ken. Such a broadcast packet provides a chance of validation when the satellite joins the management domain. The role of the broadcast packet is similar to the public access channel of mobile communication systems. The login and logout mechanism provide a good flexibility and scalability for the satellite network nodes to access.

The satellite registers to internal initialization sub-station manager after entering the orbit. When the satellite goes through another sub-station manager and receives the registered packets, it records the information of the sub-station manager and sends the delay test information. Then it compares the communication delays to different station managers according to the delay test results and determines whether to move to another management domain. The delay test process can reduce the impact of the communication delay on network management. The login and logout mechanism can improve the effectiveness and accuracy of the network management.

The management domains of the sub-station manager are a collection of all the registered satellite nodes, which is dynamically updated and can be flexible to accept new satellites. When a new satellite node joins the network, it does not need to know the distribution of the station managers in the network. With its own orbit operation and doing a certain degree of security authentication, it can register to the sub-station manager flexibility. This login and logout mechanism of the satellite network ensures that the satellite nodes do not depend on a specific management of the sub-station manager. Especially when a few of the sub-station manager are paralyzed due to the failure, it is still able to effectively manage the satellite nodes. But the temporary satellite launched for the specific tasks do not have to notice all of the station managers before the launch.

Having the synchronization data between the sub-station managers and the central manager, network managers can be kept informed of launching a new

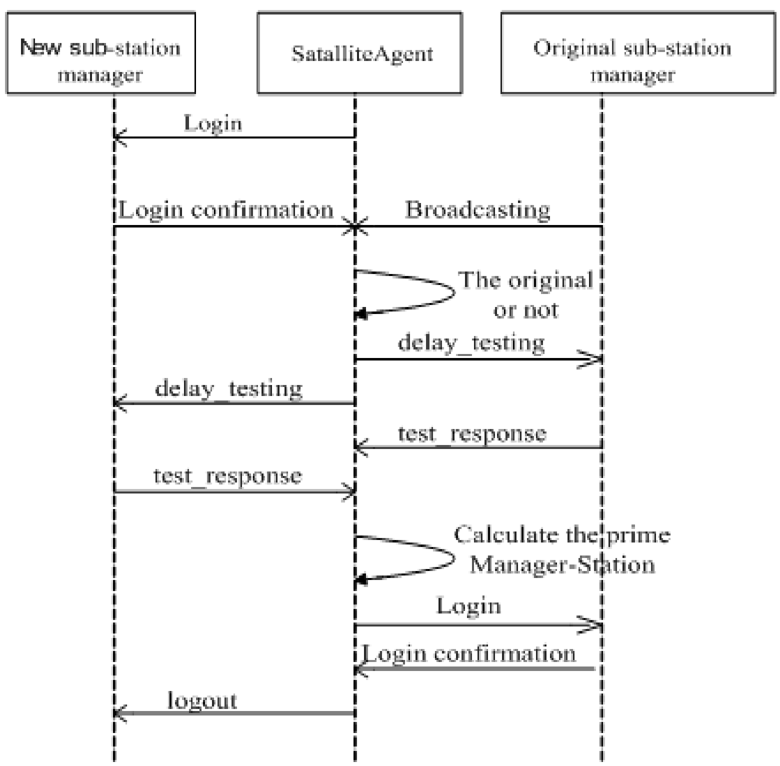

Fig. 4: Timing sequence diagram of the login and logout mechanism

satellite into orbit because of an emergency situation. At the same time, this login mechanism can be easily expanded. Because it is a long course to establish and operate the satellite network, the size of the initial network construction will be limited. The dynamic division of the management domains and the way the network elements (including satellite and the station manager) join the network will not impact the whole network management systems and can maintain stability of the system to some extent. The timing diagram of the login and logout mechanism is shown in Fig. 4.

Cooperation-based fault management: An efficient fault detection method could efficiently and effectively support the satellite network. So the satellite network fault detection is a hot topic. In order to establish the satellite network fault detection mothod and give prominence to the main problems for the fault detection, we supposed with simplicity. Firstly in this satellite network the network management protocol was SNMP, the central management station and the sub-station run the satellite network management system. Each satellite runs the SNMP agent (called Satellite Agent, SA). Secondly the fault of communication link was not considered in this paper. So the communication link could provide satisfactory service. Thirdly, the management domain which satellite agents belong to remains the same during the management sub-station polling all the satellites agents in this domain. In order to define the fault of satellite network, this study defined the fault as three types: node fault, agent fault, interface fault. In satellite networks, if satellite node can not be managed normally in network, namely, the satellite have no response to the network management instructions (SNMP instructions) and each satellite interface can not be connected, we define this kind of fault as node fault. In satellite network, if the satellite network node could be managed normally, but at least one interface cannot be used to communicate, we define this type of fault as agent fault. In satellite network, if the state of one port in nodes-switcher of satellite is failure, or the port cannot communicate with others, we define the satellite which is corresponding to the port as agent interface fault.

Fault management based on typical method: By polling the MIB information in the network node, the management sub-station can judge whether the work condition of each interface in the satellite is proper. The decision can be made according to the value of the ifOperStatus. If the value of the ifOperStatus is zero, it shows the interface is faulty, otherwise the interface work properly. On the other hand, the congestion and link failure of each interface in the satellite can also be detected by analyzing the data of the interfaces. Each management sub-station manage the satellite within management domain and report the state information data of all the interfaces in each satellite on management center after a polling is finished. The management center could establish the whole network topology according to the MIB information.

Cooperation-based fault management method: When the node is fault, the management sub-station cannot differentiate the satellite node fault or the interface fault, for the fault node could not respond to the polling from the management sub-station. Namely there is no response after the management sub-station sending the network management instructions. Only when all satellite interfaces are justified by fault, the satellite node fault could be deduced. But how to deduce all satellite interfaces fault is difficult. In this paper a lightweight and efficient fault detection method is put forward. This method is based on the cooperation among the satellite agents. The cooperation algorithm is described as below.

- When the SNMP command from the ground management sub-station could be responded by the satellite agent, the satellite node then check up the node as suspected fault node and initialize a new cooperation.
- The management sub-station decompose and synchronize the tasks and separate the task to a series of MetaActions.

$$T=\{\ MetaAction_1,\ MetaAction_2,\ldots,\ MetaAction_n\ \}$$

- Moreover, the sub-station manager synchronizes tasks and determines the execution sequence of each MetaAction.
- After the above steps, the sub-station manager can establishes the theoretical topology and actual topology of management domain in which the suspected fault node is belonged to. Based on these topologies, a best satellite was chosen to correspond to the interface of the suspected fault satellite node. If there is no satellite node could be cooperated with in management domain, turn to (5).
- Under this situation the sub-station manager sends cooperation tasks to each cooperation agents. Each agent excutes the cooperation task and try to communication to the suspected fault satellite node and reported the cooperation result to sub-station manager, turn to step (8).
- If the satellite node corresponding with the specific interface of suspected fault satellite in the management domain could be found, the sub-station manager sends a cooperation requests to network central manager and sends the task decomposition and synchronization information to central manager.
- Network central manager generates theoritical topology of global satellite network and actual global topology and selects an optimal coordination satellite

corresponding with one interface of suspected fault satellite. If the choice is successful, turn to step (8).

- If the choice is lost, wait for a random time (<200 ms), turn to step (6).
- Network central manager sends coordination tasks to the best cooperation node. Collaboration nodes report the result to the central manager after finishing coordination, the network central manager will transmit the results to sub-station manager after receiving and confirming the fault type.
- Cooperation ended.

This cooperation method is efficient and lightweight for it had no more resources request for each satellite agents. Furthermore it can run efficiently. By analyzing this method, we can find that the algorithm choose satellites as cooperation node in management domain preferentially in the process of cooperation, it can greatly reduce the communication cost which the real-time fault detection and cooperation bringing in. It will trigger the cooperation between the management domain when there is no cooperation node in management domain, the network central manager selects the cooperation node according to specific algorithm. This also can reduce the overhead of communication cooperation and improve the real-time fault detection effectively.

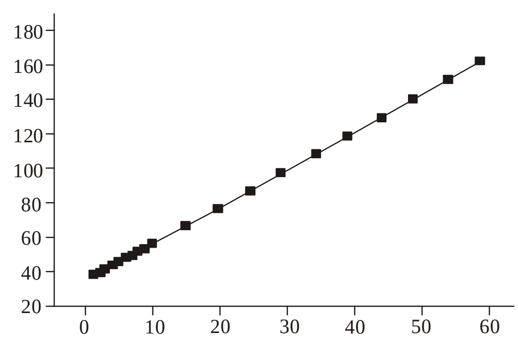

Fig. 5: Relationship between attributes number and response time

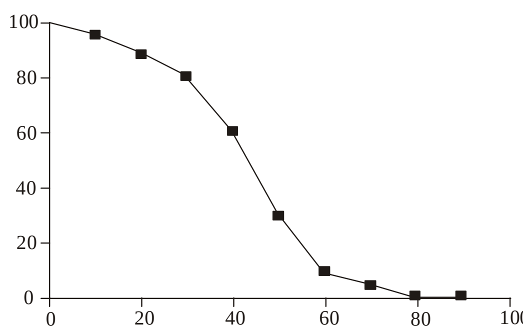

Fig. 6: Relationship between the percentage of fault and the fully diagnosis

CASE STUDY

In order to reduce the complexity of the simulation system, using the command of ping to test the communication between satellite agencies. System sets five ports for each space-borne agent to simulate the satellite interface.

To reduce the complexity of simulation system, in the simulation system, we use ping command for testing among the satellite agencies. To simulate interface of satellite, the simulation system sets five ports for each star-carried agent.

On condition that network management of satellite network nodes is normal, take the response that satellite nodes give to Getrequest message for example, the relationship between response time and the attribution number of nodes acquired is shown in Fig. 5. On condition that network management of satellite network nodes is viable, the response time increases as the number of network attributes rises, response time of network management instructions is in millisecond grade, that meets the time demand of satellite network management.

The relationship between the collaboration flow and the failure rate is shown in Fig. 6. In this study, collaboration flow refers to the network traffic generated through collaboration during the fault detection of suspected fault stars in the satellite nodes and it is calculated by the number of packets interacted among the management sub-station, network management center and satellite nodes in the collaboration period. Provided that the percentage of the suspected faulty satellites (cannot be managed by SNMP) is p, the percentage of the fully diagnosis is D.

From the Fig. 6, it is easy to know that with the increasing of the percentage p, the percentage of the successful fault diagnosis is lower. When the percentage of fault is more than 35%, the percentage of the successful fault diagnosis lowed obviously. That is because with the increasing of the percentage of the fault, the sub-station and the central station in the satellite networks cannot find the proper satellite node to cooperate. The percentage of the fully diagnosis declined for no cooperation can be applied to diagnose.

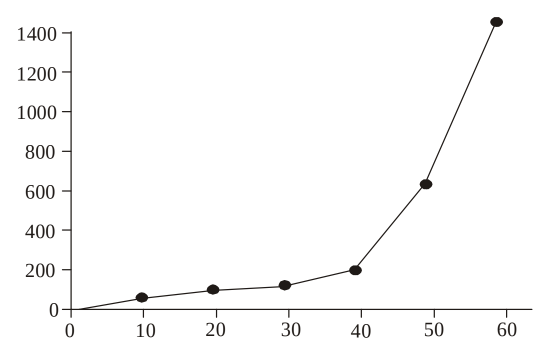

Fig. 7: Relationship between the percentage of fault diagnosis and the cooperation time

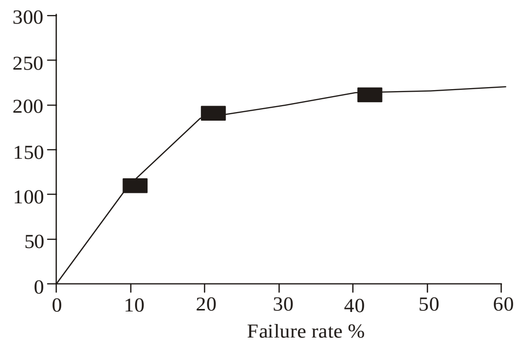

Fig. 8: Relationship between failure rate and collaboration flow

From the Fig. 7 it can be known that with the increasing of the percentage of satellite fault, the cooperation time grows exponentially. Under the circumstance the percentage of satellite fault is lower, the cooperation time is short. This is because that the sub-stations and the central station can control the certain satellite nodes to apply cooperation. The time costs in task decomposition, cooperation nodes search, task assignment and executing the tasks and returning the cooperation results. On the other hand, when the percentage of satellite fault is high, it is difficult for the sub-stations and the central station to find the proper cooperation nodes, the cooperation time becomes longer.

Through the analysis of Fig. 8, we can see that collaboration flow rises as the failure rate increases, once the failure rate is more than 40%, the increase of network traffic that collaboration generated is not distinct, this is because the algorithm chooses collaboration nodes by comparing the theoretical and practical topology in the management sub-station or network management center and it will cause the waste of network traffic instead of the frequent interaction between management sub-station and network management center interact with the satellite nodes .

Comprehensive simulation results show that, on condition that network management of satellite network nodes is viable, we can do nearly real-time detection of the interface faults of the nodes. Otherwise, the fault detection can be completed by the collaboration among nodes. In the case of low node failure rate, the completeness rate of the fault diagnosis is high, cooperate time is short and flow is low. However, in the case of high failure rate, the completeness rate of the diagnosis decreased significantly, collaboration time is significantly longer and is unable to meet the needs of fault detection. It can be seen that this model is applicable to satellite network of low failure rate and it meets the demands of satellite networks for the fault detection.

CONCLUSION

Satellite network is characterized by its time-varying topology and long communication delay. But this network is very important and its resources are very scare and costly, the fault detection for the network is a important topic. In this study an efficient and lightweight fault detection was put forward and simulated. The simulation results show that the faulty frequency is lower, the cooperative time is shorter. Furthermore the lower the throughput, the higher the efficiency.

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