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A SCPS-NP Routing Algorithm Based on Mobile IP Routing

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***Abstract*— Space communication protocol is a challenging problem in the future of space network. Now Mobile IP routing is very popular in the wireless communication network. The research shows the Mobile IP network has the much similar features to the space network. A Space Communications Protocol Specification Network Protocol (SCPS-NP) routing algorithm based on Mobile IP routing is proposed in the paper. Firstly, some basic knowledge about SCPS is introduced. The flooding routing algorithm in SCPS-NP protocol is studied. A new routing algorithm-optimized Mobile IP routing algorithm based on QoS is proposed. In order to verify the effects of the algorithm, A simulation model using NS2 network simulation tools is built and the comparisons between traditional Mobile IP routing and improved SCPS-NP routing are provided. The results show that optimized routing algorithm based on QoS could achieve better performance than traditional Mobile IP. Further, a working prototype based on SCPS-NP Gateway is implemented to test the algorithm's application. It shows that algorithm based on Mobile IP routing can be used in the future space network.**

***Index Terms*—Mobile IP, SCPS-NP, space network, routing algorithm, simulation**

I. INTRODUCTION

In 1982, the U.S. space agency and the other 7 co-sponsored the establishment of the Consultative Committee for Space Data Systems (CCSDS). The committee's mandate was to develop space data system architecture, standardize communication protocols and services, make data be exchanged or processed in a standardized way in the future space mission, speed up the development of space data systems, at the same time, promote international mutual support, cooperation and exchange. It is currently composed of 11 member agencies, 22 observer agencies, and over 100 industrial associates. Since its establishment, CCSDS has been actively developing Recommended Standards for data and information systems standards to reduce the cost to the various agencies of performing common data functions by eliminating unjustified project-unique design and development and promote interoperability and cross support among cooperating space agencies to reduce operations costs by sharing facilities. In the past 30 years, CCSDS had proposed a set of technical standards for space communications, which is shown in Fig. 1 [1].

In these standards, Advanced Orbit System (AOS) was a kind of data link protocol faced to air-to-air and air-to-ground measurement-control system and data management system. It could handle large capacity, high speed data transmission, and support simultaneous access from multiple users with different needs.

The Space Communications Protocol Specifications (SCPS) are a set of extensions to existing Internet protocols and some new protocols developed by the CCSDS to improve performance of Internet protocols in space environments. Now, SCPS has been adopted as an international standard by International Standard Organization (ISO). The SCPS protocol stack consists of four protocols: SCPS-File Protocol (SCPS-FP), SCPS-Transport Protocol (SCPS-TP), SCPS-NP, and SCPS-Security Protocol (SCPS-SP).

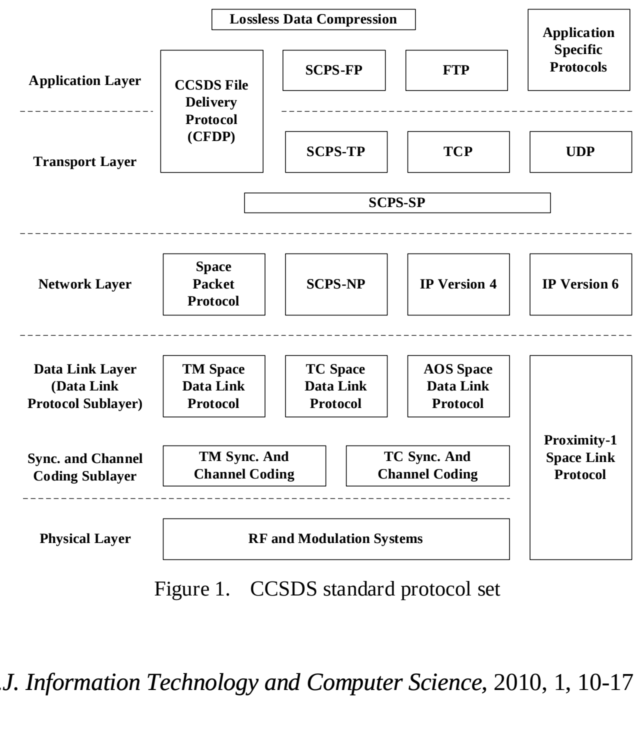

Figure 1. CCSDS standard protocol set

Corresponding to the ISO network model, SCPS-FP is a set of extensions to FTP to make it more bit-efficient and to add advanced features such as record update within a file and integrity checking on file transfers. SCPS-TP is a set of TCP options and has some modifications to improve TCP performance in stressed environments including long delays, high bit error rates, and significant asymmetries. It has implemented three capabilities to address the problem of data loss due to high bit error rate: explicit corruption response, Selective Negative Acknowledgment (SNACK), and a loss-tolerant compression mechanism. Different from Van Jacobson congestion control, the traditional congestion control approaches used in TCP, SCPS-TP [2, 3] is configured to run TCP Vegas congestion control. SCPS-NP [4] is a bit-efficient network protocol analogous to but not interoperable with IP. SCPS-SP is a security protocol comparable to IPSec which works between transport layer and network layer [5].

Among the above SCPS protocols, the position of SCPS-NP protocol is corresponded to the IP protocol in TCP/IP protocol family. As is well-known, one of the functions of the IP protocol is to take charge of the inter-network routing of data packet delivery, and SCPS-NP has the similar function. So far, IP protocols have been developed quite sophisticated, and derived in the different uses of routing algorithm. Since the IP protocols are originally designed for the terrestrial environment which is totally different from the harsh space environment, an issue that whether they can be applied to the space network directly is emerging. To give an answer to this question, we must make an analysis to the existing IP routing algorithms.

The rest of the paper is organized as follows. In Section II, some existing routing algorithms that have been widely used in the Internet are reviewed. The SCPS-NP routing is analyzed in detail and a new SCPS-NP routing based on Mobile IP is proposed in Section III. Section IV is focused on the design of our simulation modeling which is modeled by NS2 simulation tool. In Section V, the simulation results are presented and a reference implementation of SCPS gateway is shown. At the last part of the paper, there comes a conclusion in Section VI.

II. Analysis of Common Routing Protocols

A. TCP/IP Routing

Among all the common routing protocols, TCP/IP routing has the longest history and has been used most widely. Traditional TCP/IP routing protocols can be divided into two subsections: the first part is interior routing protocols, which are used between routers in an autonomous system and the second is exterior routing protocols, used among autonomous systems.

The routing protocols used to exchange routing information between routers within an Autonomous Systems (AS) are called interior routing protocols. If you were the administrator of an AS, you are free to determine whatever interior routing protocol that best suits your network. The result of this is that there is no agreement on the use of a single TCP/IP interior routing protocol. Nowadays, there are several common protocols in use. As is generally the same case, some of them are more popular than others. Among them, Routing Information Protocol (RIP) and Open Shortest Path First (OSPF) are the most widely used protocols. RIP uses the distance-vector routing algorithm that has a long history and works well in a small-scale of routers. However, with the scale of autonomous systems becoming larger, some serious limitations in both scalability and performance come up. To solve this problem, a new routing protocol was developed in the late 1980s that uses a more capable and complex algorithm called link state or shortest path first routing. It figures out many of the issues with RIP and allows routes to be selected dynamically based on the current state of the network, not just a static state of how routers are connected.

Obviously, if interior routing protocols are used within autonomous systems, we need another set of routing protocols to send that information between autonomous systems. This requires a kind of exterior routing protocol that all autonomous systems can agree upon, and in today's TCP/IP that protocol is the Border Gateway Protocol (BGP). If you want some more details on BGP, please refer to RFC 1771, which is available online at http://www.apps.ietf.org/rfc/rfc1771.html.

The relationship between interior routing protocol and exterior is shown in Fig. 2. However, they cannot meet the requirement of space network, because these protocols only fit static topology, while the topology of space network will be variable.

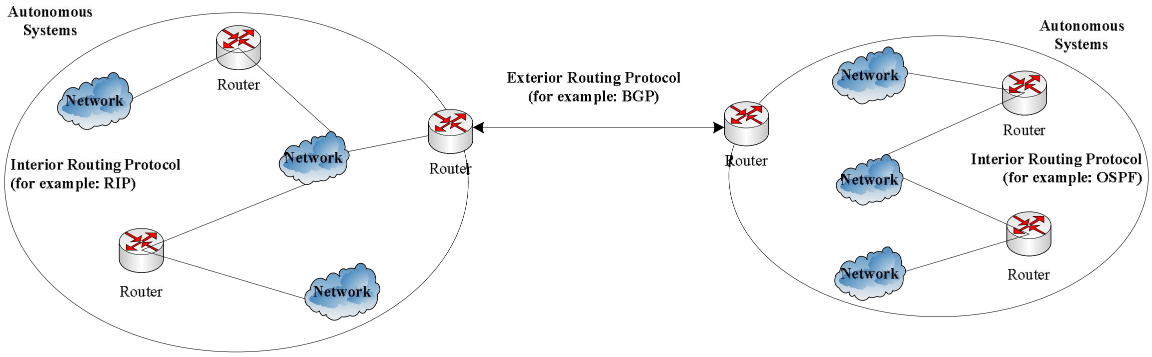

Figure 2. Autonomous system, interior routing protocol and exterior routing protocol

B. P2P Routing

Peer-to-Peer (P2P) is a distributed network, where each node is reciprocal. P2P always works over the application layer, so it is an overlay network. The main purpose of P2P network is to facilitate the exchange of resources and services in the network nodes [6].

P2P systems can take many forms. Email, Internet Relay Chat and Napster are all examples of P2P systems. P2P has three patterns, including centralized pattern, distributed pattern and mixed pattern. In the three patterns, distributed pattern is an absolute P2P network, which can be further divided into unstructured and structured P2P networks. In structure network, the most well-known routing algorithm is Chord proposed by MIT, which main idea is base on Dynamic Hash Table (DHT).

Another kind of P2P network is the overlay network. Overlay network builds a virtual topology on top of the physical links of the network. Nodes leave and join this network dynamically and the average uptime of individual nodes is relatively low. The topology of an overlay network may change all the time. Once a route is established, there is no guarantee of its lifetime that can remain valid and run correctly.

From above analyses, we can infer that P2P routing is an application algorithm based on overlay network, so it cannot resolve the problem of space network at the network layer.

C. Ad-hoc Routing

An ad-hoc network is a self-configuring network of wireless links connecting mobile nodes. These nodes may be routers or hosts. Each node or mobile device is equipped with a transmitter and receiver [7, 8]. They are said to be purpose-specific, autonomous and dynamic. This is very different from wireless networks, as there is no master-slave relationship that exists in a mobile ad-hoc network. Nodes rely on each other to established communication, thus each node acts as a router. Therefore, in an ad-hoc network, a packet can be transferred from a source to a destination directly. The mobile nodes communicate without the aid of access points, and therefore have no fixed infrastructure. They form an arbitrary topology, where the routers are free to move randomly and arrange themselves as required [7].

Routing protocols between any pair of nodes within an ad-hoc network will be difficult because nodes can move randomly and can also join or leave the network at any time. This means that an optimal route at a certain time may get a poor performance some time later. For this reason, ad-hoc has its own routing algorithm, including table-driven protocols, on-demand-driven protocols and hybrid protocols. In table-driven protocols, DSDV is the most popular protocol. Among on-demand-driven protocols, DSR and AODV are both well-known protocols [8].

Ad-hoc routing has some advantages as follows: routing process requires fewer network resources, routing information updates very fast, routing-discovery can quickly adapt itself to the changes of network topology. However, ad-hoc routing has a serious problem that the routing-discovery process will cost plenty of time to meet the growing network. So ad-hoc routing is also not appropriate for the space network.

D. Mobile IP Routing

In TCP/IP networks, routing is based on stationary IP addresses. A device on a network is reachable through normal IP routing by the IP address that is assigned for the device [9]. The problem occurs when a device roams away from its home network and is no longer reachable using normal IP routing. Therefore, the Mobile IP protocol is proposed to fix this problem [10, 11, 12]. The Mobile IP protocol allows location-independent routing of IP datagram transmitted on the Internet. Each mobile node is identified by its home address. While away from its home network, a mobile node is associated with a Care-of address (CoA) which indicates its current location and it is connected with home address through a tunnel. Mobile IP specifies how a mobile node registers with its home agent and how the home agent routes datagram to the mobile node through the tunnel.

Mobile IP provides an efficient, scalable mechanism for roaming within the Internet. Using Mobile IP, nodes may change their access points to the Internet without changing their home IP address. This allows them to maintain transport and higher-layer connections while roaming. With the development of wireless communication and the population of cell phone these years, Mobile IP technique becomes more and more important. Its advantages make up for the deficiencies of the traditional TCP/IP protocols. Moreover, it owns higher network security. However, the Mobile IP routing needs the data forward by the home agent of a mobile node. Without algorithm optimization, the Mobile IP routing will have the problem of transmission efficiency. In the next section, the principle of Mobile IP and optimized Mobile IP would be specified.

III. SCPS-NP Routing Algorithm

According to the analysis of the common routing protocols in the Section II, here comes a table that lists the features of five different kinds of routing protocols. As shown in Tab. 1, obviously, space network and the Mobile IP network have the same characters of variable topology, large scale and long node distance. Therefore, Mobile IP routing can be modified a little to employ in the space network as a point-to-point routing algorithm. Firstly, the traditional SCPS-NP routing algorithm would be analyzed.

TABLE 1. Comparision of Different Networks

Network Type	**Contents**		
	Topology	***Scale***	***Node Distance***
Normal IP Network	Fixable	Large	Long
Mobile IP Network	Variable	Large	Long
P2P Network	Stable	Medium	Medium
Ad-hoc Network	Variable	Small	Near
Space Network	Variable	Large	Long

A. Related Work on SCPS-NP Routing Algorithm

SCPS-NP protocol can support either static routing or dynamic routing. To meet the requirement of space network, it has designed two dynamic routing algorithms in SCPS-NP. One is flooding routing, the other is point-to-point routing.

First of all, flooding routing is introduced. The routing process of the flooding routing is shown as follows:

- Using the source address and source timestamp of a SCPS-NP data packet to build an *ID* number.
- The source node sends the data packet by broadcast, and stores the *ID* number to its routing table.
- A node *k* who has received the data packet will scan its routing table to determine whether the *ID* number of the data packet has been existed.
- If the *ID* number is existed, then the data packet will be discarded, else node *k* will store this *ID* number into its routing table and forward this data packet.
- A router will check its routing table to delete table items out of date.
- This process will not stop until the data packet reaches its target node.

The flooding routing can avoid delivering repeatedly through the mechanism of *ID* number. However, when the scale of the network is large enough, the number of derived data packets caused by flooding would be enormous.

So far, there is no a recommended point-to-point routing algorithm for SCPS-NP. The reason for that is the scale of space network in the past is relatively small and the number of spacecraft is not too large, the ability of flooding routing is enough to deal with space network at that time. As more and more countries around the world involved in the exploration of space, the number of spacecraft is rapidly increased, the limitation of the flooding routing to such large scale network has come up. So it is necessary to design a kind of point-to-point routing algorithm for future space network which is suitable for space communication.

B. Design of SCPS-NP Point-to-Point Routing Algorithm

The Mobile IP process has three main phases, agent discovery, registration and tunneling. During the agent discovery phase, the home agent and foreign agent advertise their services on the network. The mobile node listens to those advertisements to determine whether it is connected to its home network or foreign network. When the mobile node determines that it is in the foreign network, it receives a care-of address in the foreign agent. After that, all packages sent to the mobile node are routed to its home network, where home agent intercepts and tunnels them to the care-of address toward the mobile node. In the reverse direction, the mobile node sends packages to the foreign node, which routes them to their final destination, the correspondent node. How Mobile IP works is shown in Fig. 3.

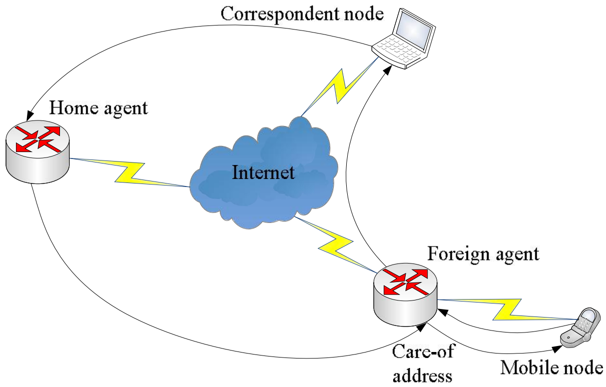

Figure 3. The mechanism of traditional Mobile IP

But Mobile IP routing algorithm has a fatal deficiency called "triangle routing" problem: the data from the correspondent node have to travel through the home agent. If the current location of the mobile node is close to the sender's but the correspondent node is far away, packets have to take a long detour.

In order to resolve this issue, optimized Mobile IP routing has been proposed. Any node is willing to maintain a binding cache. When the home agent intercepts a packet for a mobile node that is away, it may send a binding update message to the source of the packet, informing the source of the mobile node's current care-of address. The source then updates its binding cache, and in the next time tunnels packets for the mobile node directly to its care-of address [13, 14].

Although optimized Mobile IP routing improves the network efficiency, it will cause additional system overhead if the most data packets are short in length in the Mobile IP network. The specific analysis process is shown as follows:

- The minimum IP data length is set to *1L*, and the maximum IP data length is set to *nL (n > 1).*
- The occurrences of data packet length from *1L* to *nL* are equally likely events.
- The transmission overhead of every data packet, which adopts optimized Mobile IP routing is set to *T*.
- The extra-overhead of setting up binding and releasing binding is set to *S*.
- The transmission overhead of every data packet, which adopts traditional Mobile IP routing is set to *U*. Setting the IP data packet transmission interval time is *0*. When data length is *1L*, the transmission overhead will be

$$C1 = (U + S) \tag{1}$$

When data length is *2L*, the transmission overhead will be

$$C2 = (U + S + T) \tag{2}$$

When data length is *3L*, the transmission overhead will be

$$C3 = (U + S + 2T) \tag{3}$$

Therefore, we can get the mathematical expectation of the transmission overhead in the network, which is shown as follows:

$$R = \frac{S}{E(C)} = \frac{S}{\sum_{i=1}^{n} P_i * C_i} = \frac{S}{\frac{1}{n}\{nU + nS + [0T + 1T + ... + (n-1)T]\}} = \frac{S}{U + S + \frac{n-1}{2}T} \quad (4)$$

According to (4), if n value is very small, R value will be very large, and the extra-overhead will increase fast leading to the system performance dropping seriously, so the optimized Mobile IP routing algorithm has severe drawback in dealing with the short data packet. Besides, when the IP address of target node is changing quickly, the optimized routing algorithm will process the binding request from different home networks frequently and lead to the tunnel switching repeatedly. This procedure will decrease the performance of the network severely. To resolve the problem, the tunnel switching action should be controlled by some measures.

This paper will take an algorithm based on QoS to control the tunnel switching. The algorithm is described as follows:

- The default algorithm is optimized Mobile IP routing.
- When the packet is a long data sequence composed by many data frames, the QoS option can be set to optimized Mobile IP routing algorithm.
- When the packet is a short data sequence, the QoS option can be set to Mobile IP routing by users.

The mechanism of optimized Mobile IP routing based on QoS is illustrated in Fig. 4.

The optimized Mobile IP routing based on QoS can switch from optimized routing to traditional routing by users' commands. By this means, the network system will get an optimal performance, so it can be used as improved SCPS-NP routing algorithm.

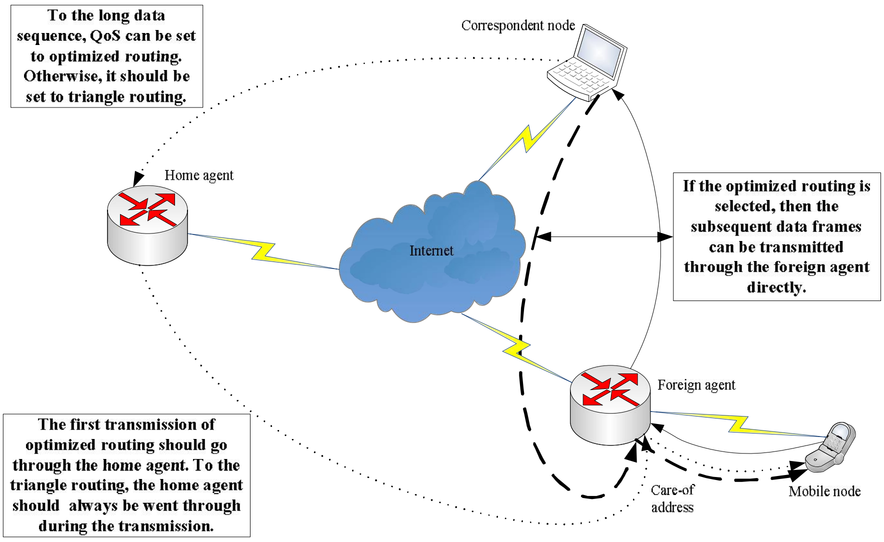

Figure 4. The mechanism of optimized Mobile IP routing algorithm based on QoS

IV. The Model of Simulation

In order to verify the effect of the algorithm, a simulation model was built using NS2 network simulation tool.

A. Introduction to NS2

NS2 is a set of open source software developed by the University of California, Berkeley [15]. It can simulate the protocols of TCP, routing and multicast broadcast on the wired, wireless and satellite networks. Because the NS2 software has the feature of open source, so its source code can be modified by the researchers easily. NS2 uses the development mechanism of split-object model, by which the C++ language is selected on the data path, the OTCL language is used on the non-data path and using the TCLCL language as the connection bridge between C++ and OTCL. NS2 is a discrete-time simulator, which has a virtual clock. All the network simulations are driven by the discrete events. NS2 is the result of a project featuring the participation of both industry and academia, which is freely available for research purposes.

B. The Satellite Network in NS2

Polar orbiting satellite systems, such as Iridium, can be simulated with NS2 [15, 16]. The simulator models constellation of satellites that follow purely circular trajectories. In a constellation, the satellites that belong to the same orbital plane are spaced equally along the orbit, and multiple orbital planes with relative fixed phase between them are arranged.

In order to define the satellite constellation that the user is requested to specify the satellite altitude, the number of orbital planes, the number of satellites per plane and the inclination of plane with respect to the Earth axis. By means of the inclination parameter, the user can also set up retrograde orbits.

For polar orbiting constellations, interplane, intraplane and crossseam intersatellite links (ISL) can be established. The intraplane ISLs are connections between satellites which belong to the same orbit plane and are never deactivated or handed off. The interplane ISLs are established between satellites of neighboring co-rotating planes. These links are deactivated near the Earth poles because the antenna pointing mechanism cannot track these links in the Polar Regions. Finally, the crossseam ISLs are intersatellite links subjected to hand-off, which for instance happens when orbit planes are counter-rotating.

A ground to satellite link (GSL) is a connection established between the terminal and satellite. While geostationary satellite links are static, GSLs for low earth orbit (LEO) constellations are periodically handed off. Periodically, the satellite terminal checks the elevation angle of satellite. If the elevation angle drops below a threshold (the elevation mask), the terminal searches for a new satellite above the elevation mask.

C. Simulation Model in NS2

According to the optimized Mobile IP routing algorithm based on QoS, the NS2 topology model of the improved SCPS-NP routing is proposed, which is shown in Fig. 5 [17, 18].

For the general satellite height of the LEO, the propagation delay time from the satellite to the foreign agent can be set to 240ms.

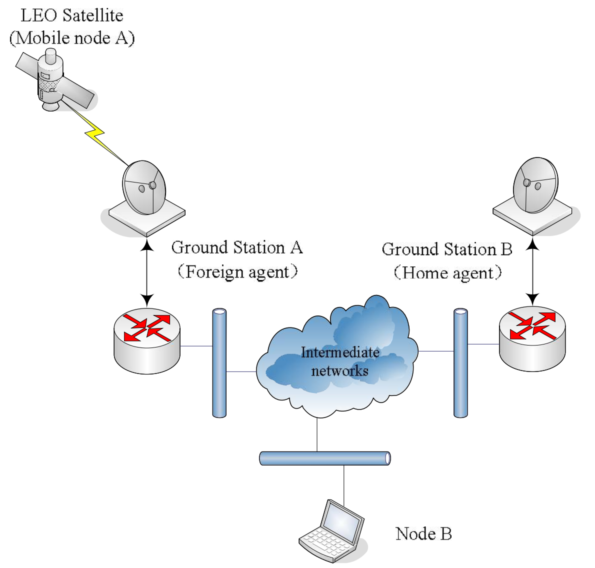

Figure 5. The topology of improved SCPS-NP routing

```
global opt
set opt(chan)          Channel/Sat
set opt(bw_down)       20Mb; # Downlink bandwidth (satellite to ground)
set opt(bw_up)         3Mb; # Uplink bandwidth
set opt(phy)           Phy/Sat
set opt(mac)           Mac/Sat
set opt(ifq)           Queue/DropTail
set opt(qlim)          50
set opt(ll)            LL/Sat
set opt(wiredRouting)  OFF
set opt(alt)           780; # Polar satellite altitude (Iridium)
set opt(inc)           86.4; # Orbit inclination w.r.t. equator


# Create the satellite nodes
$ns node-config -satNodeType polar \
                -llType $opt(ll) \
                -ifqType $opt(ifq) \
                -ifqLen $opt(qlim) \
                -macType $opt(mac) \
                -phyType $opt(phy) \
                -channelType $opt(chan) \
                -downlinkBW $opt(bw_down) \
                -wiredRouting $opt(wiredRouting)
```

Figure 6. The configuration parameters of the satellites nodes

The propagation delay from the foreign agent to the home agent is set to 100ms. The propagation delay from the (LEO Satellite) mobile node A to the foreign agent is set to 60ms. The propagation delay form the node B to the foreign agent is set to 60ms, the communication bandwidth from the satellite to the foreign agent is set to 20Mbps, and other bandwidth is set to 3Mbps. Parts of the Otcl files are shown in Fig. 6 [19, 20]. These commands could configure a normal node into a LEO Satellite node.

V. Performance Evaluation

A. The Results of Simulation

We modified the NS2 simulation source code of mobile IP section in accordance with the simulation model above mentioned. After that, we use the Gawk and Xgraph tools to extract the graph data which is shown as follows.

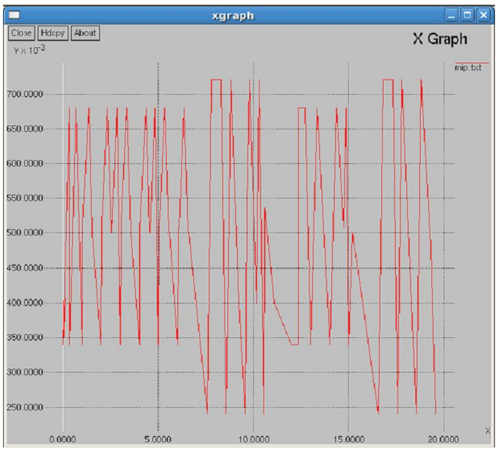

Figure 7. The end-to-end propagation delay by “triangle routing”

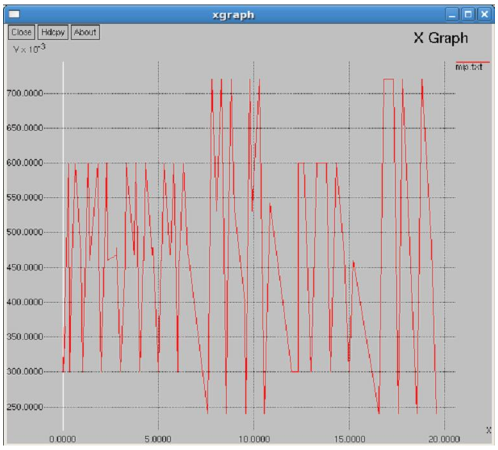

Figure 8. The end-to-end propagation delay by improved SCPS-NP routing

By the comparison between Fig. 7 and Fig. 8, in Fig. 8, the propagation delay is mainly under 600,000, which gets much better performance than being showed in Fig. 7. We notice that although the two routing algorithms have the almost equal maximum propagation delay and minimum propagation delay, the improved SCPS-NP routing (this paper proposed) has the minimal average delay. So, the SCPS-NP routing algorithm can achieve a better network performance.

B. The Reference Implementation of SCPS-NP

A working prototype based on SCPS Gateway was implemented to support the application.

SCPS gateway ships with the SCPS reference implementation. The function of SCPS gateway is transforming the format of data between TCP/IP and SCPS, as is shown in Fig. 9. After a data packet is generated in the Network A, it is sent to the gateway 1, where the data is transformed into the form of SCPS. The gateway 2 does the reverse work to convert SCPS into TCP/IP.

SCPS gateway implements SCPS protocol and it can truly reveal the performance of the new algorithm. The SCPS gateway is just configured, and it can run regularly now. The running experiments show that algorithm is going very well. The future work is to test the algorithm in the larger scale network based on the working prototype of SCPS gateway.

VI. Conclusion

The space environment has its unique features, including long delays, high bit error rates and significant asymmetries. The common routing algorithms cannot be applied to the space network directly. According to the analysis of common networks, the space network and Mobile IP network has the similar characters. However, Mobile IP routing algorithm has performance problem.

To deal with this problem, a new kind of SCPS-NP routing algorithm based on the Mobile IP routing and QoS option is proposed in this paper.

Through the network simulation, we get a simulation result that the improved SCPS-NP routing algorithm can get better performance than traditional Mobile IP routing and optimized Mobile IP routing. Therefore, there comes a conclusion that the improved SCPS-NP routing algorithm would be suitable for the hash space environment.

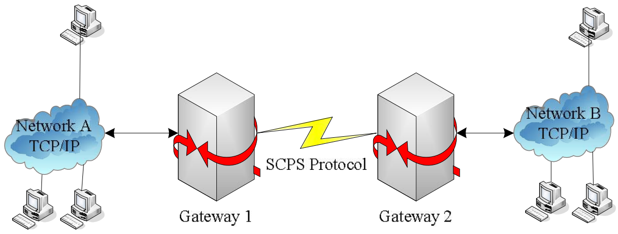

Figure 9. The architecture of SCPS gateway

Acknowledgments

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