Application of Mobile IP in the Space-Ground Network Based on GEO Satellites

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Abstract. Current space-ground IP networks cannot achieve real-time signaling interaction between aircraft users and GEO freely in large service ranges, so there is packet drop rate when aircraft users hand off between different GEO satellites. This paper proposes a new scheme to provide seamless handover service for aircraft users. Since the control center can obtain the orbit and position of aircraft can be obtained timely and accurately, during the handover process, it initiates the control signaling in different aspects to fulfill a complete handover process based on standard mobile IP protocol. Compared with other schemes, the proposed scheme can reduce packet drop rate in the handover process. Moreover, the time delay for data transmission is reduced based on mobile IPv6 technique.

Keywords: Space-ground IP network · Mobile IP · Handover management

1 Introduction

With the development of space technology, the demand of real-time and reliable communication between space station and ground become more obvious. Currently, the communication between ground users and aircraft users is achieved with the help of GEO satellites through directional antennas [1]. Since the GEO satellites' directional antennas can only cover a relatively small area in their wide service ranges, it is difficult for aircraft users to initiate the communication with GEO satellites [1]. Besides, the real-time signaling interaction between aircraft users and GEO satellites cannot be achieved freely [3], as a result, standard mobile IP protocol [4] fails to work when aircraft flies through service ranges of different GEO satellites. Therefore, it is difficult to maintain reliable and continuous data transmission from ground users to aircraft users.

Nowadays, several solutions are proposed to solve the above problems. The Centralized Static Routing [5] establishes some possible routing sets for users to choose

Q. Chen et al. (Eds.): ChinaCom 2016, Part II, LNICST 210, pp. 421–430, 2018.
DOI: 10.1007/978-3-319-66628-0_40

when handover between aircraft users and GEO satellites happens. This scheme is applicable in small scale networks, but causes large calculation pressure in network management. Another solution is mobile router, a software resided in a network. It takes care of handover process in the network, and allows the whole network to roam [6]. However, during handover, the mobile router have to obtain care-of address and register with home agent (ground station1 in this paper) [7], which causes high delay and packets loss, especially in long distance space-ground network.

This paper proposes a new scheme based on mobile IP to present reliable and continuous data transmission in space-ground IP networks. The scheme ensures that aircraft can achieve seamless handover between different satellites. Under the premise that the orbit information and position of aircraft can be obtained timely and accurately by control center during the handover process, the control center can initiate the control signaling, including changing directions of antennas on GEO satellites, assigning new IP addresses for aircraft users and establishing IP address mapping table in ground station, sending multicast data to all of the ground stations. Thus the complete handover process of standard mobile IP protocol can be achieved without real-time signaling interaction between aircraft users and GEO satellites. Moreover, in order to reduce the time delay from ground users to aircraft users after handover, the scheme is improved with techniques in mobile IPv6 [9] to overcome the problem of "triangle routing" [8, 10].

In this paper, Sect. 2 introduces basic scenario of the space-ground IP network. Section 3 describes the operating modes of standard mobile IP and proposes solutions for mobile IP based on the space-ground network. Section 4 presents simulation analysis, including experimental simulation parameters, results and descriptions. Section 5 is the conclusion.

2 Description of Basic Scenario

The space-ground IP network mainly consists of two parts, the ground part and the space part [2].

As shown in Fig. 1, the ground part includes:

(1) Control center: manages the basic information about entire network.
(2) Ground stations: provide service for GEO satellites.
(3) Ground users: terminal users on earth, which are connected with space-ground network through internet.

The space part includes:

(1) GEO satellites: provide transparent forwarding between aircraft and ground stations. The radius of service range of GEO satellites is about 2.5×10^6 m. The radius of cover area of directional antennas is about 1×10^5 m, which is much less than the radius of service range.
(2) Aircraft users: terminal users in space.

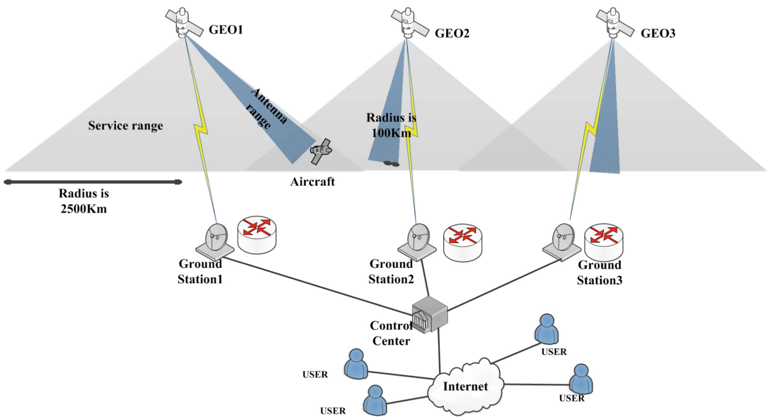

Fig. 1. Basic scenario of the space-ground IP network. It includes space part (GEO satellites and aircraft) and ground part (ground stations, control center and users). The radius of service range of GEO is 2.5×10^6 m, the radius of antenna range is 1×10^5 m. Control center can management the entire network.

2.1 Process of Handover Management

This scenario describes the process that aircraft users cross the network segments made by GEO satellites, using handover management to maintain normal communication with ground users. The specific process is given below:

When the aircraft is in the service range of the GEO1, the business data from ground user is encapsulated into IP packets to be routed to the control center, after processing, packets are forwarded to the ground station 1, and then the ground station1 transmits them to GEO1. Finally packets are delivered to aircraft user. When the aircraft user flies into service range of the GEO2, the connection between aircraft and ground becomes ground station 2. In the ground network, packets are routed according to IP address, ground user does not know the IP address of the aircraft has changed, so the packets are still routed to ground station 1 in accordance with the previous address, which causes communication error. Thus mobile IP is needed to solve the problem.

2.2 Overview of Mobile IP

Mobile IP has three basic elements: mobile node, home agent, foreign agent [4].

Protocol overview is as following:

(1) When mobile node is in the home network, it will be assigned an address, which is called home address. For user, this address is mobile node's permanent address [4].
(2) When mobile node moves to a foreign network, it obtains a care-of address [4] from foreign agent, then mobile node registers its new care-of address with home agent.

(3) Host sends packets to mobile node, via standard IP routing mechanism transmitting the packet to the home agent.
(4) Home agent tunnels the packets to the care-of address [4] (usually address of foreign agent).
(5) The foreign agent decapsulates packets and transmits them to the mobile node.

The above is the working mechanism of mobile IP in ground network, but it cannot be applied in the space-ground IP network. Because mobile node, home agent, and foreign agent are demanded to periodically broadcast their status, so that they can have frequent signaling interaction. Thus it has a very high demand for real-time performance and reliability to the network. However, the characteristics of the space network are long distance, high time delay, complex link status, and the present conditions of GEO satellites can only communicate with directional antenna, the aircraft is unable to detect and connect to GEO actively. So ground-based mobile IP network obviously can not meet the requirements of space-ground IP network, which need to improve existing schemes (Fig. 2).

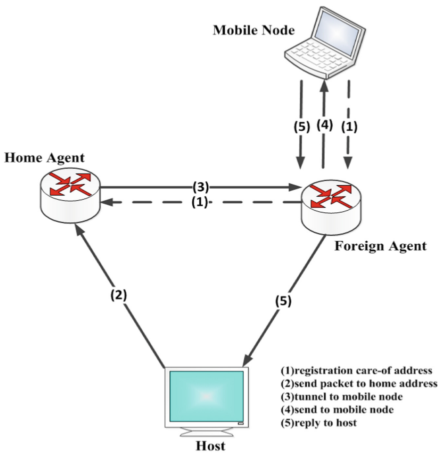

Fig. 2. Overview of mobile IP. The mobile node, home agent and foreign agent periodically broadcast their status, and have frequent signaling interaction.

3 Solution Scheme

This paper proposes revised schemes based on standard mobile IP to solve the problem that the signaling interaction between GEO satellites and aircraft users is not real-time, and the handover process exists packet loss and high time delay. Particularly, the ground station 1 is equivalent to the home agent, the ground station 2 is equivalent to the foreign agent, the aircraft is a mobile node, the control center schedules the entire network.

3.1 Scheme 1

This scheme is proposed on the condition that control center have real-time status information about aircraft (flight obit, position, flight time), and can send signaling to each node and schedule them. It can achieve seamless handover.

(1) Initial condition

When the aircraft is in the service range of GEO1, the transmission path of user data is ground user → control center → station 1 → GEO1 → aircraft.

(2) Set the trigger condition

The trigger condition can be flight time or the position of the aircraft. When the aircraft enters into the overlapping coverage of the two satellites, control center sends signaling to GEO2, which is to let the antenna of GEO2 begin to swing in the direction of GEO1.

(3) Send multicast data to ground stations

When the aircraft enters into the overlapping coverage, the control center sends the data, which is from users, to all of the ground stations. This progress is multicast, which continues to the end of the handover. Using multicast mechanism can guarantee data from users send to all of the ground stations at the same time, including the home agent ground station1 and the foreign agent ground station2. Ground stations store the received data till the aircraft connected with the GEO2, then the data is sent to the aircraft via the GEO2. This progress can result in some data packets are repeatedly received, but can ensure seamless handover.

(4) Establish home agent mapping table

Control center sends the IP address of the ground station 2 to the ground station 1, then the ground station 1 establishes an address mapping table. That is to say, when the aircraft left the service range of GEO1, the data packets via the mapping table are routed from the ground station 1 to the ground station 2.

(5) Assign a new address to aircraft

After establishing the mapping table, control center assign a new IP address to aircraft, which is in the same network segment with the IP address of the GEO2.

(6) Connect GEO2 and aircraft

The antenna of GEO2 is aligned with the aircraft and builds connection, the connection is generally assumed that is instantaneous. Since the ground stations are not connected with each other, they all connect to the control center, the transmission path of the packets is user → control center → ground station 1 → control center → ground station 2 → GEO2 → aircraft.

Since the number of nodes in this scene is small, the connection between aircraft and the next satellite is obvious. Therefore, after the aircraft entered in the overlapping range of the two satellites, the control center can adjust network by sending signaling. It sends the GEO2 instructions, so that the GEO2 has enough time to adjust the antenna, which can improve the probability of successful connection. Besides, it assigns care-of address to aircraft so that aircraft can connect with GEO2. This scheme can achieve seamless handover, on the condition that the connection is instantaneous.

3.2 Scheme 2

The above scheme is proposed based on Mobile IPv4, which can achieve seamless handover between two satellites. However, it still is not good enough because of “triangular routing”. Inspired by banding update mechanism of Mobile IPv6 [9], we proposed an optimization routing scheme, called Mobile IPv4-E.

In Mobile IPv4-E, steps of (1), (2), (3), (4), (5) and (6) are the same as the first scheme, additional step is that:

When the handover is completed, the user establishes an address mapping table. Packets should be sent to the ground station 1 are mapped to the ground station 2. Thus, the transmission path of the packets in this scheme is user → control center → ground station 2 → GEO2 → aircraft.

Compared with the first scheme, the transmission path of each packet can decrease by two hops, which can reduce the transmission delay in the ground network. Figure 3 is the Schematic diagram of scheme 1 and scheme 2.

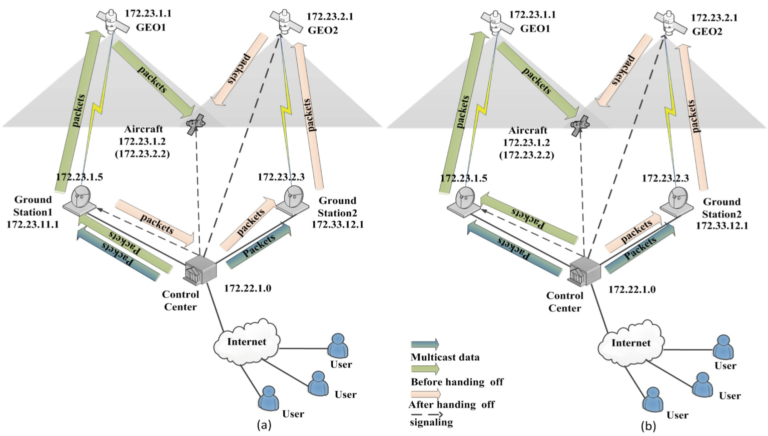

Fig. 3. Schematic diagram of (a) scheme 1 and (b) scheme 2. The green strips are the packet transmission path before the handover, the yellow strips are the transmission path after the handover, the dotted line is signaling, the blue strips are the multicast data sent from control center to all of the ground stations. The difference between scheme 1 and scheme 2 is in the ground network, after the handover, scheme 2 can decrease the transmission path by two hops. (Color figure online)

4 Simulation and Analysis

The simulation was carried out on an discrete-event system simulation platform. The simulation scenario includes two GEO satellites, an aircraft, two ground stations, a control center and several ground users. Basic parameters about network nodes are shown in Table 1. The height is the distance to the center of the earth. The care-of address is 172.23.2.2.

Table 1. Basic parameters of the each node.

Node name	Height\m	Latitude	Longitude	IP address
GEO1	4.2×10^7	0°	16° E	172.23.1.1
GEO2	4.2×10^7	0°	108° E	172.23.2.1
Ground station 1	6.4×10^6	39° N	101° E	172.23.1.5
Ground station 2	6.4×10^6	34° N	116° E	172.23.2.3
Control center	6.4×10^6	34° N	108° E	172.22.1.0
User	6.4×10^6	20° N	105° E	172.23.3.1
Aircraft	6.7×10^6	——	——	172.23.1.2

4.1 Parameters of the Simulation

Besides, the bandwidth of the forward link (ground station → GEO) is 10 M, the backward link (GEO → ground station) is 25 M, the ground link is 100 M, the buffer size of link is 10 M, the sending rate of packets randomly changes between 5 M to 15 M bps, transmission delay in the ground network is 10 ms.

4.2 Result of Simulation

Compared among the mobile router scheme [6], scheme 1 and scheme 2 proposed in this paper, we can get the result:

The mobile router scheme is proposed in [6], which adds a software, called mobile router, into the space-ground network, so device connected with mobile node is unaware of mobility [7]. The mobile router asks for care-of address and then registers it with ground station, this process has delay, which causes packet losing.

Figure 4 shows that the received packet percent of scheme 1 and scheme 2 can achieve 100%, that is to say control center sends signaling to manage GEO and aircraft, cooperated with the multicast data sent from control center to ground stations, can effectively achieve seamless handover.

Another question we concerned is end to end transmission delay. According to the relationship of the distance, time, and the speed of light, the transmission delay

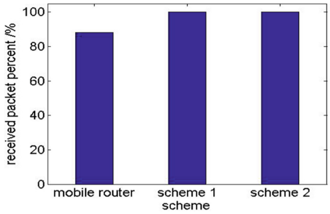

Fig. 4. Received packet percent in different schemes. The received packet percent is defined as the number of received packets divided by the number of sending packets. The received packet percent is statisticsed from the time that the aircraft entries the overlapping service range, to the time that the handover is completed.

between ground station and GEO is about 0.12 s, assume that transmission delay in the ground network is 0.01 s. The simulation result of end to end packet delay in each position can be seen in Table 2.

Table 2. End to end packet delay of the handover process.

Position of the aircraft	Transmission path	End to end delay/s
Before handover	user → control center → ground station 1 → GEO1 → aircraft	0.25
During handover multicast	user → control center → ground station ground station 2 (store the multicast data) → GEO2 → aircraft	0.73
After handover Scheme 1	user → control center → ground station 1 → control center → ground station 2 → GEO2 → aircraft	0.75
After handover Scheme 2	user → control center → ground station 2 → GEO2 → aircraft	0.73

During the handover process, control center sends multicast packet data to all of the ground stations, packets sent to the ground station1 are transmitted directly to the GEO1, but the packets sent to the ground station2 are stored and not transmitted until the aircraft connects with the GEO2. Since the aircraft breaks the connection with the GEO1, and then connects with the GEO2, which needs about 0.48 s. The packets stored in the ground station2 are transmitted to the next hop, which also needs 0.48 s. Since the control center sends multicast packets to all of the ground stations, these packets have been sent by the ground station1. That is to say repeatedly sending packets can ensure a seamless handover process.

In the simulation, the end to end transmission delay of scheme 1 and scheme 2 is different, which is shown in Fig. 5. After the handover, the end to end transmission delay of scheme 1 is about 0.75 s, but the transmission delay of scheme 2 is about 0.73 s.

The end to end transmission delay of two schemes in Fig. 5 both have several segments. In the scheme 1, the first segment is about 0.25 s, which is equal to the transmission time from the control center to the ground station1 via the GEO1 and then to the aircraft. The second segment is about 0.73 s, which is the sum of 0.25 s and

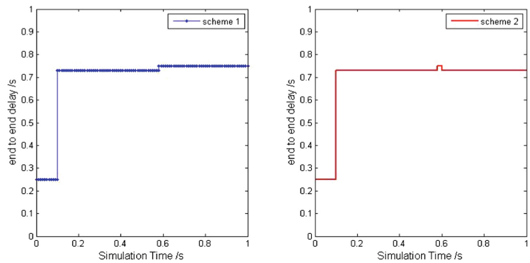

Fig. 5. End to end transmission delay. The delay of scheme 1 and scheme 2 is different.

0.48 s. The meaning of 0.48 s is that multicast packets stored in the ground station2 need about 0.48 s to send to the next hop. The 0.25 s is the same with the first second. The first and the second segments of the scheme 2 is the same with the scheme 1. The comparison of the third segment and the forth segment can be obviously seen in Fig. 6.

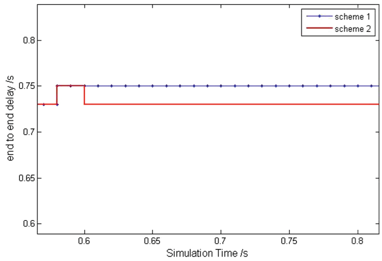

Fig. 6. Comparison of end to end delay of scheme 1 and scheme 2. Note that it is the partial enlarged picture of Fig. 5. Due to the routing optimization, the transmission delay of scheme 2 is less than scheme 1.

Figure 6 partially enlarges the picture, which contains scheme 1 and scheme 2, since scheme 2 has routing optimization in the ground network, the transmission delay is less than scheme 1 after the handover. In the scheme 1, packets sent to the ground station2 (foreign agent) must be via the ground station1 (home agent), that is to say there is a "triangle transmission", which is about 0.02 s in the ground network. So after handover, the end to end delay is about 0.75 s. However, in the scheme 2, there is routing optimization in the ground network, the transmission delay is less than scheme 1 after the handover.

5 Conclusion

In the current space-ground IP network that bases on GEO satellites, when aircraft users with high speed fly through the service range of different GEO satellites, the most important thing is mobility management, i.e., to route packets to the correct destination. However, the standard mobile IP can not be applied, since there is no real-time signaling interaction between aircraft and GEO satellites, they can only communication through directional antenna. A scheme proposed in this paper is that control center uses the flight time and position of the aircraft as a trigger, then sends signaling to GEO satellites, and assigns new IP address, called care-of address, to aircraft users, and sends multicast data to all of the ground stations. This scheme can achieve seamless handover in current condition, which has been verified by simulation. Nevertheless, there is "Triangle Routing" in the scheme, a optimization routing scheme based on the first scheme is further proposed. According to the simulation result, we draw the conclusion that the scheme can reduce transmission delay in the ground network.

The above proposed schemes are based on the current equipment condition. With the development of space technology, high-orbit satellite antenna in the future may be able to support sending signaling and data transmission at the same time. In this case, there will be no need unified scheduling by control center when the aircraft in the overlapping region. The only thing that aircraft in the overlapping region should do will be to send a request to GEO. Then GEO will assign new IP to it and connect with it. It will be similar with mobile IP in the ground network that achieves automatic handover management.

Acknowledgments. This work is supported in part by National Natural Science Foundation of China (Grant Nos. 61231013, 91438206, 91538202 and 61521091) and Fundamental Research Funds for the Central Universities (Grant No. YMF-14-DZXY-027).

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