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An IP mobility management scheme with dual location areas for IP/LEO satellite network*

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Abstract: One of the issues of mobility management in a low Earth orbit (LEO) satellite network is the high-frequency location binding update initiated by mobile nodes (MNs). To solve this problem, we propose a location management scheme based on dual location area (LA) in an IP/LEO satellite network. The proposed scheme uses two kinds of LA, the fixed Earth station LA and satellite LA, to manage the location of the MNs together. MNs operate the binding update procedures only when they are moving out of both of the two LAs last registered. Geographical location information of MN is used in the binding update procedures, so that the network can page the idle MNs near their last registered location first, to enhance the probability of paging success. A detailed description of the implementation of the scheme is provided. Mathematical analysis shows that the proposed scheme reduces the location management cost and minimizes the influences of the distance between MN and its home agent. Paging cost is also reduced by introducing geographical location information in the binding update procedures.

Key words: Location management, IP/LEO satellite network, Mobile IP (MIP), GPS
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1 Introduction

Low Earth orbit (LEO) satellite networks are well known for providing ubiquitous connectivity in the world and also in the space while guaranteeing short propagation delays. With the expansion of Internet business and the increase in users' demand, there is a huge demand for research and development of Internet Protocol (IP) based satellite networks (Fan *et al.*, 2000), which can be integrated into terrestrial IP networks (Akyildiz *et al.*, 2004). With IP technologies, aircrafts can also communicate with the ground through LEO satellite networks (Rash *et al.*, 2002). To provide continuous connection, one of the main issues in IP/LEO satellite networks is the mobility management scheme, which is more complex than in terrestrial networks because of the movements of the satellites (Passas *et al.*, 2008). An adaptable location management strategy is also needed in IP/LEO satellite networks due to the diversity of users (Conforto *et al.*, 2004; Wang *et al.*, 2008).

Location management aims to locate mobile nodes and guarantee data delivery (Akyildiz *et al.*, 1998). The two procedures for location management are binding update and data delivery. The Mobile IP (MIP) protocol has already been designed to solve the mobility problem in Internet networks by binding the users' own unique names to their corresponding new addresses as the users' locations change. The binding update initiated by the users is executed only when a handover has occurred (Sarikaya and Tasaki, 2001). While implementing MIP in LEO satellite networks, the high mobility of both satellites and end systems will generate a large number of binding update requests, which require a massive amount of network bandwidth resources and computational load (Fan *et al.*, 2007). The core problem in location management of IP/LEO satellite networks is how to efficiently

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handle these binding updates.

Conventional MIPv6 (Johnson *et al.*, 2004) is a precise management strategy which results in an invocation of binding update upon each handover occurrence. This ensures every node is ready to communicate all the time. The paging method is used in IP networks to enhance mobility management performance (Hu *et al.*, 2004). Zhang *et al.* (2002) proposed a loose location management for idle nodes by the paging expansion. Hierarchical methods such as Hierarchical MIPv6 (HMIPv6) have been used to decrease the signaling overhead (Castelluccia, 2000). Wan *et al.* (2006) proposed a three-level hierarchical architecture for mobility management in HMIPv6 networks. In satellite networks, however, the location areas formed from the coverage areas of a certain number of satellites continue changing. This may result in burst binding updates to occur as well when mobile nodes cross the boundary of the location area irrespective of its size (Joe and Kim, 2009).

Fixed Earth station (FES) can also be used to determine location areas (Nie and Qing, 2009). Since the FES connects at least three satellites, the location area is relatively large and static. The frequency of binding update of the terrestrial nodes can thus be decreased. However, the paging procedures operating under three or more satellites will occupy much network bandwidth (McNair, 2000). For aircrafts and other high speed nodes, the frequency of binding update hardly decreases.

A handover-independent mobility management scheme has been proposed by Tsunoda *et al.* (2004), to exploit geographical location information to make the mobility management independent of satellite handovers. In this method, the Earth surface is divided into a number of cells which act as location areas, to reduce the number of update requests. The implementation, however, is complex and requires much storage space and processing capacity of the satellites.

In this paper, a dual-LA design is proposed based on the mobility characteristics of different nodes. The geographical location information is added in the binding update procedure to ensure a precise paging area. With this method the impact of handover occurrences on the binding update cost can be mitigated together with the paging bandwidth.

2 Architecture of the dual-LA scheme

To formulate a proper location management strategy for IP/LEO satellite networks, the location management issues should be discussed first. Then the basic idea of the proposed method is presented.

2.1 Location management issues in IP/LEO satellite networks

In IP/LEO satellite networks, mobile nodes' constant handover between the satellites acting as access routers (AR) leads to the frequent binding update requests. To decrease the location management cost, fixed LAs should be chosen for location management in IP/LEO satellite networks (Taleb *et al.*, 2005).

Geographical location areas fulfill this requirement. When delivering data to a mobile node, huge and complex operations should be done by the network to determine the satellites' access to the node at that moment. A more convenient strategy is needed to solve this problem.

Using FES to define the location areas will decrease the frequency of binding update, especially for the low speed or static nodes. When FES is used to define the LA, two methods can be used for data delivery. First, FES can be used as a mobility anchor point (MAP), which means, upon each handover between the satellites, mobile nodes update addresses to the FES instead of their home agent (HA). This, however, does not solve the fundamental problems caused by the frequent binding update. Another method introduces paging into the location management strategy. In this protocol, the coverage area of a certain number of satellites connected to the same FES is considered as a single paging area. When packet data destined for an idle node arrives at one of the satellites in a paging area, the satellite broadcasts a paging request to all the other satellites that sequentially send paging messages within their own coverage areas until the response is received. This results in a huge paging bandwidth cost at the same time, and also the emergency of the flip-flop issue.

In addition, IP/LEO satellite networks support various mobile nodes. The location management for high speed nodes such as airplanes should also be taken into consideration.

2.2 Description of the proposed method

In the dual-LA strategy, both the FES and satellites are introduced in the binding update procedure. FES LAs are used to decrease the update frequency of static and low speed nodes, while satellite LAs are defined for the high speed nodes with the purpose of keeping their binding update at a low level. Since the network cannot recognize the mobility characteristics of the nodes, the two kinds of LAs are both available to the nodes, and binding update strategies are used for the terminal nodes to take the benefit of the two kinds of LAs.

In the proposed method, when doing binding update, mobile nodes (MNs) report both the satellite and FES LA information to its home agent (HA). As the MN moves, a binding update would not be initiated until the MN moves out of the two LAs that were reported to the HA through the last binding update procedure. The benefits of this update strategy are presented below.

Fig. 1 shows two MNs with different mobility characteristics in the satellite network at time t_0 and t_1.

Since a loose location management has been introduced, paging messages must be broadcasted when delivering data to an idle node in the network. To further decrease the paging cost, geographical location information obtained from the Global Positioning System (GPS) devices of the MNs is added in the binding update procedure. With this information the network can page the MNs near the last updated location first instead of the whole paging area, so the paging bandwidth can be decreased.

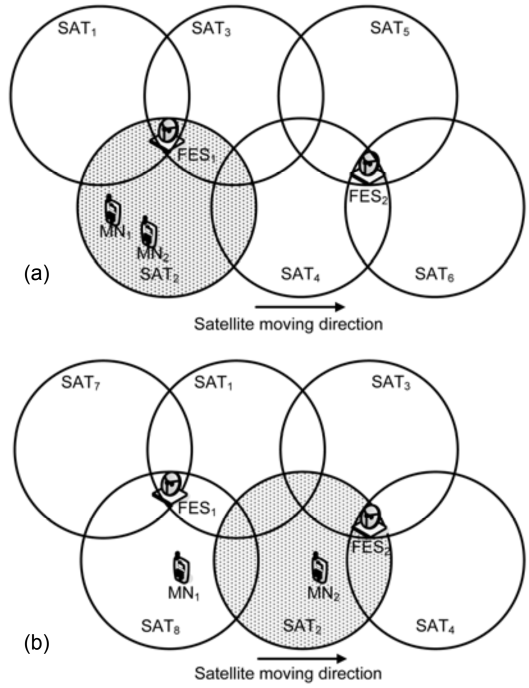

Fig. 1 Two kinds of mobile node (MN) moving in the satellite network at time t_0 (a) and t_1 (b)

MN_1 is a low speed node and MN_2 is a high speed node. The fixed Earth station (FES) location area (LA) is defined as the coverage area of the satellites to which the FES is connected at the same time. At time t_0 the LA of FES_1 is the coverage area of SAT_1, SAT_2, and SAT_3. Since the MNs are both in the footprints of SAT_2, at time t_0 the MNs' binding update messages including SAT_2 and FES_1 LAs are sent to their home agents (HAs). As time goes on, both the satellites and MNs are moving in the network. At time t_1, MN_1 is under the coverage of SAT_8, and MN_2 as a high speed node has moved into the LA of FES_2. In addition, as the satellites move, the FES_1 LA has changed to the footprints of SAT_7, SAT_8, and SAT_1. SAT_2 and SAT_3 have both moved into the FES_2 LA. Though both of the two MNs have changed the access point to the network, according to the proposed strategy, neither of the two MNs will initiate a binding update process, as MN_1 is still in the FES_1 LA and MN_2 is still in the SAT_2 LA. This essentially decreases the binding update frequency of the two kinds of MNs

3 Implementation issues of the proposed method

To realize the proposed method in practice, the following issues should be taken into account: (1) network addressing and location area definition, (2) the binding update procedure, and (3) the paging scheme.

3.1 Addressing and location area definition

To support a large number of MNs that have different characteristics, IPv6 seems to be quite appropriate for IP/LEO satellite networks. In MIPv6 the binding update operation aims to associate reachability identity (Reach ID) and routing identity (Route ID) of each node. Reach ID indicates the unique name of the node and is not subject to change, and Route ID specifies the position of the node in the network and changes in response to the node movement. When an MN changes its position and the Route ID changes, the new Route ID should be notified to the HA for binding maintenance. In the proposed method the basic Route ID structure is considered as

Route ID=FES ID+SAT ID+MN ID.

As the data is routed to FES, the SAT ID connected to the MN can be obtained and the destination address is changed to

Destination address=SAT ID+MN ID.

Here the FES acts similar to the HA of the MN. While different from the ordinary HA, the FES records only the first SAT ID when the MN moves into the FES LA and the geographical location information obtained from the GPS devices of the MN. The paging strategy is needed to figure out the satellite coverage area where MN locates, when there is need to set up a connection. Then the destination address is used by the corresponding node to deliver packets to MN.

In this IP/LEO satellite network, the satellites broadcast their own LA identities together with the connected FES identity. When receiving the satellite advertisement, the MN is aware of both the SAT and FES LA where it locates.

In the proposed method the MN executes a binding update procedure when moving out of both the FES and SAT LA, i.e., when the current receiving identities from both of the satellite and FES are changed. This can be realized easily by a binding controller on the MN. One tag is set for each of the identity of SAT or FES. Upon the change of each identity received, the corresponding tag is changed by the MN. When both the two tags are changed, a binding update procedure is initiated after the tags are reset.

3.2 Binding update procedure

To manage and deliver data to MNs, the IP/LEO satellite network must record and store the location information of the MNs. The network keeps the location information effective by the binding update procedures initiated by MNs. In the proposed method, the MNs operate a binding update procedure when moving out of both the FES and SAT LAs last updated.

Fig. 2 shows the binding update process of the MN. Through this process, the location information of MNs stored in the network remains correct and can be used for data delivery, which will be presented in the following.

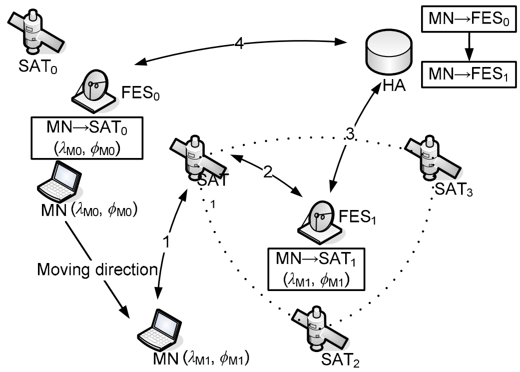

Fig. 2 Binding update procedure of the mobile node (MN)
The last binding update operated when MN was at latitude λ_{M0}, longitude ϕ_{M0} and in the FES$_0$ SAT$_0$ LA. As MN moves into the FES$_1$ SAT$_1$ LA, the binding controller shows that both the two registered LAs are changed. Then a binding update procedure is initiated. The binding update process is as follows: 1. The MN records the latitude and longitude information as (λ_{M1}, ϕ_{M1}) using the GPS and then sends it together with a binding update request to SAT$_1$. 2. SAT$_1$ forwards the message to its connecting FES, FES$_1$. Receiving the request messages, FES$_1$ makes a binding between MN and its location information. The location information includes the geographical location and the MN's satellite LA at the moment. 3. After the binding, FES$_1$ sends a binding update message to HA through the satellite network. The HA authenticates the MN and changes the binding for MN to FES$_1$. 4. A cancellation message is sent to the last binding FES, FES$_0$, from HA, and the binding information of MN stored in FES$_0$ is deleted

3.3 Paging scheme

The proposed scheme introduces a loose location management and applies paging to locate nodes to decrease the binding update frequency.

When there is need to set up a connection to an MN, the packet data destined for the node is first routed to the MN's HA. Then the data is routed to the FES which is described as FES ID=HA ID+MN ID in the network. And the MN has been registered to the FES. With the SAT ID of the MN restored in the FES, the paging request is first sent to the satellite to which the MN has been registered. If the MN is still under the coverage area of the satellite, a connection can be set up and data can be delivered successfully. There is this kind of situation in which the registered SAT is no longer the AR of the MN. Then paging is still needed to obtain the destination address of the MN.

Considering the fact that there are more MNs with low speed in the network, the paging messages are broadcasted around the registered location of the

MN. The geographical location of MN is known to the above mentioned FES. The FES is able to calculate which satellite is covering the exact position at the paging time. If the position is in the overlap area of two or more satellites, the satellite with the largest elevation angle to the position is chosen. Since the number of satellites connected to an FES is limited, the operation of the process is not complicated and will not take much resource of the FES. Then the paging request is sent to the chosen satellite and the paging can be executed. Most of the low speed MNs can be found through the first time paging. Considering the MNs with other mobile characteristics, a continuous paging procedure is required.

Before the last paging, the network knows that the MN is neither in the SAT LA nor in the nearby area of the registered position. The only possible position of the MN is the other SAT LAs connected to the FES. Then paging messages are broadcasted and the exact SAT LA of the MN at the moment is acquired. After updating the SAT LA of the MN, the FES forwards data packets toward the MN through the exact satellite.

Fig. 3 shows the process of packet delivery. Note that when a handover between two satellites occurs, the path between two communicating nodes changes, resulting in a possible disconnection of the nodes. The FES acting as MAP can be used to avoid this kind of situation. Upon handover, the active MN notifies the FES of its new access satellite, and the FES forwards the packets that are destined for the node to the new satellite. Unlike the binding update process, this mechanism generates only some control messages between MN and FES, whose cost is much smaller than the cost of the binding update.

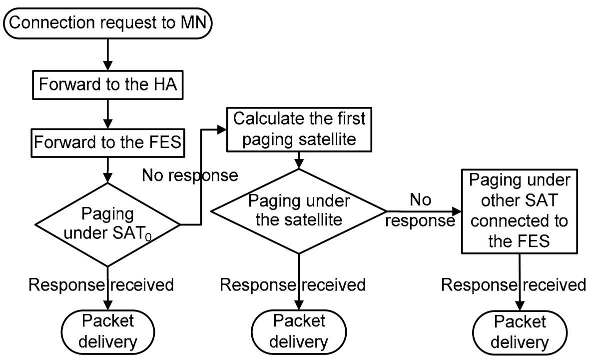

Fig. 3 Flow chart of packet delivery

4 Performance evaluation

The location management costs of the proposed method, Mobile IP, Paging Mobile IP, and Handover-Independent Mobile IP are evaluated in this section.

4.1 Analysis of location management cost

The location management cost includes three parts: binding update cost, connection maintenance cost, and paging cost (Makaya and Pierre, 2008).

1. Binding update cost: M denotes the control message size and it is assumed that the control messages generated for mobility management are of the same size, $d_{\mathrm{MN,HA}}$ is defined as the number of hops between MN and HA, and $R(t)$ is defined as the rate of handover occurrence. The binding update cost C_{b} can be described as (Tsunoda *et al.*, 2004)

$$C_{\mathrm{b}} = Md_{\mathrm{MN,\,HA}}R(t). \tag{1}$$

2. Connection maintenance cost: This kind of cost is generated only when using protocols with a paging process. When handover between satellites occurs, control messages should be produced to ensure the connections of the active MNs. The connection maintenance cost C_{m} is as follows:

$$C_{\mathrm{m}} = Md_{\mathrm{MN,\,LD}}R(t), \tag{2}$$

where $d_{\mathrm{MN,LD}}$ is the number of hops between MN and location directory, which varies in different methods.

3. Paging cost: Paging cost contains the paging request cost and the paging messages broadcasting cost. The paging request cost C_{pr} is (Zhang *et al.*, 2002)

$$C_{\mathrm{pr}} = Md_{\mathrm{FES,\,SAT}}S, \tag{3}$$

where $d_{\mathrm{FES,SAT}}$ is the number of hops between FES and SAT used for paging, and S denotes the number of satellites in one paging area.

To make the calculation simple, the satellites used for paging are considered to be single-beam satellites and the paging messages broadcasting cost C_{pb} can be calculated as

$$C_{\mathrm{pb}} = M\cdot 1\cdot S. \tag{4}$$

4.2 Management cost of different methods

For further comparison, the location management cost of four different methods is calculated.

4.2.1 Management cost of Mobile IP

Since there is no paging in MIP, the location management cost at time t, $C_{\mathrm{MIP}}(t)$, can be expressed as

$$C_{\mathrm{MIP}}(t)=Md_{\mathrm{MN,\,HA}}R_{\mathrm{SAT}}(t),\tag{5}$$

where $R_{\mathrm{SAT}}(t)$ is defined as the rate of handover occurrence in the coverage area of one satellite, calculated as

$$R_{\mathrm{SAT}}(t)=V_{\mathrm{SAT}}L_{\mathrm{SAT}}\int_{V_{\mathrm{SAT}}(t-\Delta t)}^{V_{\mathrm{SAT}}t}D(V_{\mathrm{SAT}}t)\mathrm{d}t,\tag{6}$$

where V_{SAT} and L_{SAT} are the speed of the satellites and the length of the satellite coverage area boundary, respectively, and $D(V_{\mathrm{SAT}}t)$ is the area density of nodes on the coverage boundary at time t.

4.2.2 Management cost of Paging Mobile IP

The rate of nodes crossing the paging area boundary at time t, $R_{\mathrm{P}}(t)$, is calculated as

$$R_{\mathrm{P}}(t)=\frac{1}{S}V_{\mathrm{SAT}}L_{\mathrm{P}}\int_{V_{\mathrm{SAT}}(t-\Delta t)}^{V_{\mathrm{SAT}}t}D(V_{\mathrm{SAT}}t)\mathrm{d}t,\tag{7}$$

where L_{P} denotes the length of the paging area boundary.

The binding update cost can be expressed as

$$C_{\mathrm{Pb}}(t)=Md_{\mathrm{MN,\,HA}}R_{\mathrm{P}}(t).\tag{8}$$

The connection maintenance cost can be expressed as

$$C_{\mathrm{Pm}}(t)=Md_{\mathrm{MN,\,HA}}[R_{\mathrm{SAT}}(t)-R_{\mathrm{P}}(t)]a,\tag{9}$$

where a denotes the ratio of the number of active nodes to the total number of nodes in the coverage area of the satellites.

Define N as the total number of nodes in the coverage area of one satellite and λ as the rate of coming connections to an idle MN. $d_{\mathrm{HA,SAT}}$ is the number of hops between HA and SAT used for paging. The paging cost of Paging MIP is

$$C_{\mathrm{Pp}}=C_{\mathrm{Ppr}}+C_{\mathrm{Ppb}}=(Md_{\mathrm{HA,\,SAT}}S+MS)N(1-a)\lambda.\tag{10}$$

The total location management cost of Paging MIP is

$$C_{\mathrm{P}}=C_{\mathrm{Pb}}+C_{\mathrm{Pm}}+C_{\mathrm{Pp}}.\tag{11}$$

4.2.3 Management cost of Handover-Independent Mobile IP

Similar to Paging Mobile IP, the location management cost of Handover-Independent MIP is

$$\begin{aligned}C_{\mathrm{H}}&=C_{\mathrm{Hb}}+C_{\mathrm{Hm}}+C_{\mathrm{PHp}}\\&=Md_{\mathrm{MN,\,HA}}R_{\mathrm{H}}(t)+Md_{\mathrm{SAT,\,SAT}}R_{\mathrm{SAT}}(t)a\\&\quad+(Md_{\mathrm{HA,\,SAT}}S+MS)N(1-a)\lambda,\end{aligned}\tag{12}$$

where C_{H} is the total location management cost of Handover-Independent MIP, C_{Hb} and C_{Hm} are the binding update cost and connection maintenance cost of Handover-Independent MIP, respectively, C_{PHp} is the paging cost, and $d_{\mathrm{SAT,SAT}}$ denotes the number of hops between two adjacent satellites.

$R_{\mathrm{H}}(t)$ is the rate of binding update occurrence in the coverage area of one satellite when dividing a satellite coverage area into C cells. V_{MN} is the speed of the MN, L_{C} is defined as the length of the cell boundary, and $R_{\mathrm{H}}(t)$ is expressed as

$$R_{\mathrm{H}}(t)=CV_{\mathrm{MN}}L_{\mathrm{C}}\int_{V_{\mathrm{MN}}(t-\Delta t)}^{V_{\mathrm{MN}}t}D(V_{\mathrm{MN}}t)\mathrm{d}t.\tag{13}$$

4.2.4 Management cost of our proposed method

$R_{\mathrm{FES}}(t)$ is defined as the rate of crossing the FES LA boundary in the coverage area of one satellite, and the FES LA is n times the SAT LA. $R_{\mathrm{FES}}(t)$ can be calculated as

$$R_{\mathrm{FES}}(t)=\frac{1}{n}V_{\mathrm{MN}}L_{\mathrm{FES}}\int_{V_{\mathrm{MN}}(t-\Delta t)}^{V_{\mathrm{MN}}t}D(V_{\mathrm{MN}}t)\mathrm{d}t,\tag{14}$$

where L_{FES} denotes the length of the FES coverage area boundary.

The probability of MNs moving out of the FES LA in the coverage area of one satellite is $P_{\mathrm{F}}=R_{\mathrm{FES}}(t)/N$. The probability of MNs moving out of the SAT LA in the coverage area of one satellite is $P_{\mathrm{S}}=R_{\mathrm{SAT}}(t)/N$. In the proposed method, MNs perform the binding update when moving out of both the two LAs, so the rate of binding update occurrence in the proposed method is $R_{PR}(t)=NP_FP_S=R_{FES}(t)R_{SAT}(t)/N$. Thus, the binding update cost is

$$C_{PRb}(t)=Md_{MN,HA}R_{PR}(t)=\frac{1}{N}Md_{MN,HA}R_{FES}(t)R_{SAT}(t). \quad (15)$$

The connection maintenance cost of the proposed method is

$$C_{PRm}(t)=Md_{MN,FES}R_{SAT}(t)a. \quad (16)$$

Since the paging request is first sent to the satellite (SAT_0) to which the MN was registered last time, the first time paging cost can be described as

$$C_{PRp1}(t)=Md_{FES,SAT_0}+M. \quad (17)$$

And the second time paging cost is calculated as

$$C_{PRp2}(t)=Md_{FES,SAT_1}+M. \quad (18)$$

d_{FES,SAT_0} is the number of hops between FES and SAT_0, and d_{FES,SAT_1} is the number of hops between FES and the chosen satellite (SAT_1) as mentioned in Section 3.2.

The cost of the last time paging is

$$C_{PRp3}(t)=Md_{FES,SAT}(S_{PR}-1)+M(S_{PR}-1), \quad (19)$$

where S_{PR} denotes the number of satellites in one paging area in the proposed method.

The probability of success in first time paging is defined as α, and the probability of success in second time paging as β. The total paging cost of the proposed method is

$$C_{PRp}=[C_{PRp1}\alpha+(C_{PRp1}+C_{PRp2})\beta+(C_{PRp1}+C_{PRp2}+C_{PRp3})(1-\alpha-\beta)]N(1-a)\lambda. \quad (20)$$

The total location management cost of the proposed method is

$$C_{PR}=C_{PRb}+C_{PRm}+C_{PRp}. \quad (21)$$

4.3 Analysis results

The management cost of the proposed method is compared with those of MIP (Johnson *et al.*, 2004), Paging MIP (Zhang *et al.*, 2002), and Handover-Independent MIP (Tsunoda *et al.*, 2004). Then, the impacts of the paging success rate and the size of FES LA on the performance of our proposed method are discussed.

The radius of the satellites coverage area is set as 700 km, and the satellites' ground speed is 7 km/s. Five percent of all MNs are assumed to be active and the idle nodes become active three times per hour on average. Thus, α and λ are 5% and 0.0008, respectively. 1 000 000 MNs are set to reside in the coverage area of one satellite.

In the evaluation, the link between satellites and the link between satellites and the ground are assumed to be the same in the network, and $d_{SAT,SAT}$, $d_{FES,SAT}$, and d_{FES,SAT_1} are all set as 1. Thus, $d_{MN,FES}$, which is the sum of $d_{MN,SAT}$ and $d_{FES,SAT}$, is set as 2. $d_{MN,HA}=d_{HA,SAT}+d_{MN,SAT}$, so $d_{HA,SAT}=d_{MN,HA}-1$. All the MNs in the network are moving with a speed of 17 m/s.

4.3.1 Comparison of mobility management cost

In the proposed method, it is assumed that the FES is connecting to three satellites at a time, so n is 3. To make evaluations at the same level, for Paging MIP, the paging area is assumed to be the coverage areas of three satellites, and S is set as 3. Assume that at the first paging time, the MN's registered satellite has moved out of the FES coverage area, and d_{FES,SAT_0} is set as 3. α and β are set as 0.2 and 0.4, respectively.

Fig. 4 shows the change of location management cost with the increase in the number of hops between MN and HA. MIP has the highest location management cost, while the proposed dual-LA method has the lowest location management cost. This is because MNs in MIP update their location information frequently. By using paging, Paging MIP increases the LA and decreases the location update frequency. The paging process adds extra cost to the total location management cost. Handover-Independent MIP uses geographical location information for location update and further decreases the location update frequency. However, the LA in Tsunoda *et al.* (2004)'s method is only part of the SAT LA, so the frequency of location update is still high. In the proposed dual-LA method, the use of both FES LA and SAT LA makes the MNs' location update frequency much lower than those of the other methods. GPS information is also used in the paging process to decrease the paging cost. Thus, the total location management cost of the dual-LA method is the lowest among the four methods.

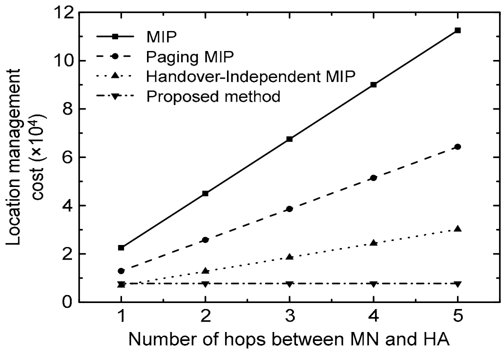

Fig. 4 Management cost as a function of the number of hops between the mobile node (MN) and home agent (HA)

For the other three methods, as the number of hops between MN and HA increases, the location management cost increases rapidly. This is because the cost of one location update procedure increases as the number of hops increases. In the proposed method, the frequency of binding update is very low, so the location update cost does not increase significantly as the number of hops between MN and HA increases. The paging cost is independent of the distance between MN and HA, so the total location management cost does not increase significantly.

4.3.2 Impacts of the paging success probability

In mobility management methods, location management cost comprises location update cost and paging cost. Usually location update cost is much higher than paging cost, so the discussion of paging cost is often omitted. In the proposed dual-LA method, since the frequency of location update is low, the location update cost and the paging cost are nearly at the same level, so the discussion of paging cost is required. In this discussion, S_{PR}=3, $d_{FES, SAT_0}=3$, and $d_{MN,HA}$=2.

In the proposed method, GPS information is used for the network to page MNs in the smaller area first, and a two-step paging procedure is used. Fig. 5 shows the management cost influenced by the probability of success in the first and the second time paging. As α and β increase, the total management cost decreases. This is because when paging is successful, the network does not need to perform other processes, which will obviously save the resource used for location management. This means that the earlier the network succeeds in paging the MNs, the less system resource will be used.

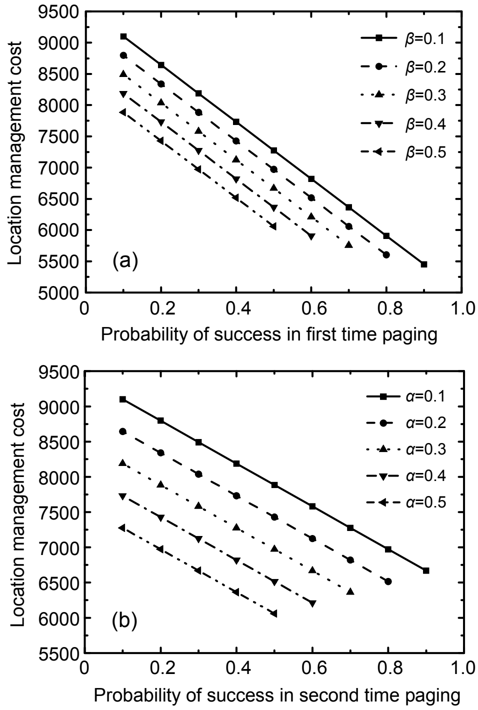

Fig. 5 Location management cost as a function of α (a) or β (b) in the proposed dual-LA method

According to the movement characteristic of the MNs, the paging steps in the proposed method can be reordered. For low speed MNs, GPS information is useful and the network can begin paging the MNs under the satellite covering the MNs' registered location first. For high speed MNs, the network can page the MNs under the registered satellites first. Through regulating the paging steps, the probability of success in first and second time paging may increase and the paging cost will be optimized.

4.3.3 Impacts of the number of hops between FES and SAT_0

In the proposed method, MNs operate the binding update procedures only when they are moving out of both the last registered FES and SAT LAs. Therefore, the paging scheme is needed when there is a need to set up a connection. At first the paging message is broadcasted under the satellite to which MN was registered last time. As the satellites move, the number of hops between the registered FES and SAT should be more than two in some cases.

The impact of the number of hops between FES and SAT_0 is discussed here. S is set as 3. Assume α and β are set as 0.2 and 0.4, respectively. All the MNs in the network are moving with a speed of 17 m/s. Fig. 6 shows the management cost influenced by the number of hops between FES and SAT_0. Results show that the location management of the proposed scheme increases as SAT_0 moves further away from FES. This is because paging control signaling should be forwarded from FES to SAT_0, and as SAT_0 moves, the number of hops between FES and SAT_0 should be increased. Even in the worst case, however, the total mobility management cost is much lower than those of the other three methods.

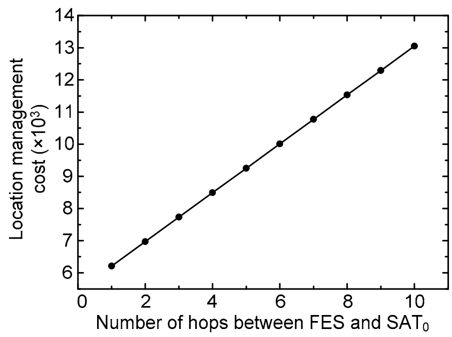

Fig. 6 Relationship between cost and the number of hops between FES and SAT_0 (d_{FES, SAT_0}) in the dual-LA method

4.3.4 Impacts of the FES LA size

In an IP/LEO satellite network, the LAs can be set larger by introducing the paging process. As the LA size increases, the location update cost decreases, but the paging cost increases. In the former analysis, it is assumed that the FES is connected to three satellites at a time. While the number of satellites connecting to an FES changes, the size of the FES LA changes too. This will impact the performance of the proposed dual-LA method. In this discussion, α=0.2, β=0.4, $d_{FES, SAT_0}=3$, and $d_{MN,HA}$=2.

Fig. 7 shows the relationship between the location management cost and the number of satellites connecting to one FES at different MN speeds. Results show that, as the size of FES LA increases, the management cost first decreases and then increases. This is because at the beginning when the size of FES LA increases, the frequency of MNs' location update decreases and the location update cost also decreases. Since the paging cost does not increase rapidly at the beginning, the total management cost will also decrease. When the size of FES LA becomes large enough, the location update rate does not decrease obviously, while the paging cost is still increasing. This will result in the increase of the total management cost. Through the analysis, the best size of FES LA with the lowest location management cost can be chosen. When the speed of the MNs increases, more system resource is needed for the network to manage their mobility. The best size of FES LA also increases as the MNs speed up.

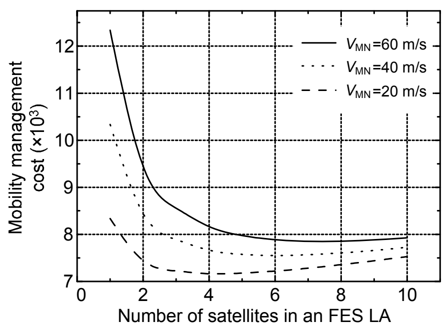

Fig. 7 Relationship between cost and FES LA size in the dual-LA method

5 Conclusions

In this paper, the issue of location management in IP/LEO satellite networks is analyzed and a dual-LA design is proposed for IP/LEO satellite networks. The MNs perform only the binding update process when moving out of both the SAT and FES LAs. This will obviously decrease the frequency of binding update. During the binding update, GPS information is introduced for use in the paging procedures to locate the MNs. The performance of the proposed method is compared to those of MIP, Paging MIP, and Handover-Independent MIP through a mathematical analysis. Results show that the proposed method decreases the location management cost and minimizes the influences of the distance between MN and HA. The paging scheme is also analyzed and the GPS information used in the paging strategy increases the probability of success in the first and second paging, and the paging cost is decreased. The impact of the size of FES LA is also discussed. The best size of FES LA can thus be chosen according to different speeds of the MNs to minimize the total location management cost.

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