Satellite Mobility Pattern Scheme for Centrical and Seamless Handover Management in LEO Satellite Networks

Ayşegül Tüysüz and Fatih Alagöz

Abstract: **Since low earth orbit (LEO) satellite constellations have important advantages over geosynchronous earth orbit (GEO) systems such as low propagation delay, low power requirements, and more efficient spectrum allocation due to frequency reuse between satellites and spotbeams, they are considered to be used to complement the existing terrestrial fixed and wireless networks in the evolving global mobile network. However, one of the major problems with LEO satellites is their higher speed relative to the terrestrial mobile terminals, which move at lower speeds but at more random directions. Therefore, handover management in LEO satellite networks becomes a very challenging task for supporting global mobile communication. Efficient and accurate methods are needed for LEO satellite handovers between the moving footprints. In this paper, we propose a new seamless handover management scheme for LEO satellites (SeaHO-LEO), which utilizes the handover management schemes aiming at decreasing latency, data loss, and handover blocking probability. We also present another interesting handover management model called satellite mobility pattern based handover management in LEO satellites (PatHO-LEO) which takes mobility pattern of both satellites and mobile terminals into account to minimize the handover messaging traffic. This is achieved by the newly introduced billboard manager which is used for location updates of mobile users and satellites. The billboard manager makes the proposed handover model much more flexible and easier than the current solutions, since it is a central server and supports the management of the whole system. To show the performance of the proposed algorithms, we run an extensive set of simulations both for the proposed algorithms and well known handover management methods as a baseline model. The simulation results show that the proposed algorithms are very promising for seamless handover in LEO satellites.**

Index Terms: **Footprint, handover management, mobility pattern, satellite networks.**

I. INTRODUCTION

Terrestrial wireless networks such as cellular networks provide mobile communication services with limited geographical coverage. In order to provide global coverage to a heterogeneously distributed user population, satellite communication networks are utilized to co-exist with terrestrial networks. Therefore, the role of satellites broadens from the traditional telephony and TV broadcast services to user oriented data services. This trend is expected to continue in the future. Due to this reason, next generation mobile networks will use smart satellites that will incorporate functions such as switching, buffering, and beam switching in addition to signal reproduction. In addition, satellite systems can play a significant role in broadband convergence networks (BcN). In BcN, the connection among heterogeneous networks both on horizontal and vertical structures, interaction among network-dependent elements of those networks should be carefully designed. Due to coverage superiority, a LEO satellite constellation may become a crucial element for supporting BcN. Therefore, this paper focuses on handover management problem for LEO satellite constellation.

A typical LEO satellite takes about 100 minutes to orbit the earth, which means that a single satellite is "in view" of ground equipment for only a few minutes [1]. As a consequence, if a transmission takes more than the short time period that any one satellite is in view, a LEO satellite system must hand over between satellites to complete the transmission. In general, this can be accomplished by constantly relaying signals between the satellite and various ground stations, or by communicating between the satellites themselves using "inter-satellite links" (ISLs) [1], [2]. LEO satellites are also designed to have more than one satellite in view from any spot on the earth at any given time, minimizing the possibility that the network will loose the transmission. Due to the fast-flying satellites, LEO systems must incorporate complicated tracking and switching equipment to maintain consistent service coverage. In this paper, we focus on the handover management of satellite networks, which is a crucial design problem for supporting mobile communication services in the co-existing terrestrial and LEO satellite networks.

The advantage of the LEO system is that the satellites' nearness to the ground enables them to transmit signals with a small amount of delay, unlike geosynchronous earth orbit (GEO) systems. Also, since the signals to and from the satellites need to travel a relatively short distance, LEO systems can operate with much smaller user equipment (e.g., antennae) than systems using a higher orbit. In addition, a system of LEO satellites is designed to maximize the ability of ground equipment to see a satellite at any time, which can overcome the difficulties caused by obstructions such as trees and buildings [1].

One of the proposed models for handover management in satellite networks is mobile IP (MIP) [3]. It enables a TCP connection to remain alive and to continue receiving packets when a mobile host moves from one point of attachment to another. Although MIP is a widely used approach applied to satellite networks, it has some important drawbacks including high handover latency and high packet loss.

Therefore, the following question naturally arises: How can we find an alternative approach for mobility support in handover management that will be applicable for integration of data

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The authors are with the Department of Computer Engineering, Boğaziçi University, Turkey, email:{aysegul.tuysuz, fatih.alagoz}@boun.edu.tr.

communications in both terrestrial and satellites networks using multiple interfaces? Since most of the applications in the Internet are end-to-end, we have proposed and developed seamless handover management scheme for LEO satellites (SeaHO-LEO), a seamless mobility solution as an alternative to MIP for handovers. To minimize the messaging traffic generated during the handover procedure, we have also developed satellite mobility pattern based handover management in LEO satellites (PatHO-LEO).

The *objective* of this paper is to describe our proposed schemes called a SeaHO-LEO for supporting mobility, its design issues, and PatHO-LEO and their suitability for satellite networks with and related design and performance issues. The basic idea of SeaHO-LEO is to use ISLs to prevent data loss while setting up a new path, thus achieving a seamless handoff between adjacent subnets. SeaHO-LEO can cooperate with normal IPv4 or IPv6 infrastructure without the support of MIP. SeaHO-LEO has also a number of advantages such as easier deployment because of no change required in the Internet infrastructure, co-operation with Internet's security protocols, efficient utilization of network bandwidth due to the absence of tunneling, etc. The aim of the PatHO-LEO is to eliminate the handover messages as much as possible. It offers satellites and mobile users to register with their mobility patterns to a central service provider database. Since all the handover information such as new subnet, new IP, etc., are known before the handover procedure in PatHO-LEO, lots of handover related messages are no more necessary to complete handover between satellites.

The main contributions of this paper can be listed as follows.

- Discussing different types of handover scenarios in LEO satellite networks.
- Proposing a central server called billboard manager for location updates of mobile users and satellites.
- Proposing and developing SeaHO-LEO and PatHO-LEO to solve the problems of MIP in satellite networks. The aim is to achieve seamless handover between satellites. Here by seamless, we mean low latency and low packet loss during handover process.
- Illustrating the handoff procedures, signaling procedures, and location management procedures in SeaHO-LEO and PatHO-LEO.
- Analyzing the performance measures of proposed handover management models and comparing them with MIP and other recent proposals.

The rest of the paper is organized as follows. Section II summarizes handover architectures in LEO satellite constellations. Section III gives a brief discussion of mobility management in terrestrial mobile networks and LEO satellite networks. Section IV describes in detail the signal flow and the simulation results of the SeaHO-LEO. In Section V, we mention about the PatHO-LEO and its mobility management cost analysis. Finally, Section VI concludes the paper.

II. HANDOVER TYPES IN LEO SATELLITE CONSTELLATIONS

The mobility management in LEO is much more challenging than in GEO or medium earth orbit (MEO) systems, because LEO satellites have the non-geostationary characteristics and high speed movement. Thus, handovers are of significant importance in mobility management. There are two general handover types in LEO satellite networks which are link layer and network layer handover. In what follows, we briefly discuss these handover types.

A. *Link Layer Handover*

The link layer handover procedures in LEO satellites can be classified as follows [4].

A.1 Inter-Satellite Handover

This type of handover occurs when the end user's communication point is changed from one satellite to another. The change of satellite will affect the routing of the ongoing session and the resource allocation of the satellites [5].

A.2 Spotbeam Handover

The spotbeam handover occurs when the mobile user switches between the spotbeams of a satellite. Since spotbeam handovers occur very frequently, admission control algorithms and schemes for reducing the blocking rate for handover connection is the main concern of the researches done in this area [6].

A.3 Link Handover

This type of handover happens when a LEO satellite passes over the polar area. Because the ISLs to the neighbor satellite are switched off temporarily on the polar areas, the ongoing connections utilizing these links must be transferred to other links which causes link handovers.

These types of handovers are called as link layer handover, because these handovers cause the change of one or more links between the two communicating endpoints. These types of handovers sometimes result in change of the IP address of the endpoints so that it is possible that a network layer handover is also required after a link layer handover.

B. *Network Layer Handover*

If either satellite or user node changes its IP address due to the movement of satellite or mobile user, a network layer handover is required to transfer the connection of higher level protocol (e.g., TCP, UDP) to the new IP address. Below, two events causing network layer handover in a satellite environment are defined.

B.1 Satellite as a Router

When a satellite is used only for routing, and does not generate or consume data, the satellite acts as a router in the Internet. Mobile nodes (MN) are handed over from one satellite's footprint to another as they come under the footprint of different satellites going around the earth. A MN needs to establish a continuous connection with the correspondent node (CN) while their attachment point changes from Satellite A to Satellite B. Different satellites can be assigned with different IP network addresses [1]. Therefore, IP address change occurs during an inter-satellite handover requiring a network layer handover.

B.2 Satellite as a Mobile Host

When a satellite has on board equipment to generate data that are transmitted to workstations on the earth or it receives control signal from the control center, the satellite acts as the endpoint of the communication. Although the satellite's footprint moves from ground station A to B, the satellite should maintain continuous connection with its CN. If the IP address of the satellite has to be changed when it is handed over to ground station B, a network layer handover has to be performed.

III. MOBILITY MANAGEMENT IN TERRESTRIAL MOBILE NETWORKS AND LEO SATELLITE NETWORKS

A. *Outline of General Mobility Management*

The main concern of mobility management is to locate MNs in the network and to guarantee a seamless data transmission upon change in nodes position. Mobility management basically contains two operations, namely binding update and data delivery.

The binding update operation aims to associate reachability identity (Reach.ID) and routing identity (Route.ID) of each node [7]. The Reach.ID indicates a unique name of the node and is not subject to change, whereas the Route.ID specifies the position of the node in the network and changes in response to node movement. When a mobile node changes its position, the Route.ID changes as well and the old binding is no longer valid. To update the binding, mobile nodes are requested to send their new Route.ID to the location directory (LD) [8].

The main problem of this procedure arises when LD is geographically too far from mobile nodes. In this case, the cost of binding update becomes very expensive, especially in a high mobility environment such as satellite networks [9]. Although a handover is a local process that concerns only the MN, the old AR, and the new AR, a binding update is a global process that may affect other network elements in addition to the three adjacent entities.

Route.ID can be used to indicate the position of the MN; therefore, no further operation is needed to do data transmission seamlessly. However, using Route.ID as the precise location of the MN requires frequent update of MNs registration even upon a slight movement of the nodes. Thus, the required update cost can be very huge [10].

On the other hand, when Route.ID is used to indicate location of the MN roughly, an additional operation called paging is needed to find precise position of the MN. However, the paging cost can be very high in case of wide paging areas.

As a result, Route.ID has a significant importance on the mobility management cost. The role of the Route.ID should be chosen carefully according to mobility management issues of underlying network.

B. *Mobility Management in Terrestrial Mobile Networks*

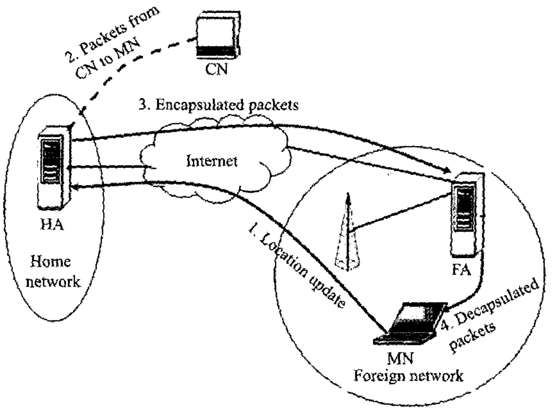

Fig. 1. Handover flow of mobile IP.

In terrestrial IP networks, IP addresses are designed for Route.IDs and are also used as Reach.IDs in higher layers. This causes an important problem for mobility management since a MN can not be identified in the higher layers when its IP address changes after handover.

The most dominant protocol among existing mobility management protocols is MIP that was proposed to solve this problem by using two different IP addresses for the two locations of MNs. First location is called as home network and identified by home address which serves as a Reach.ID. Second location is visiting network and identified by care of address (CoA) which functions as a Route.ID. In this protocol, locations of MNs are precisely managed by binding update for every handover occurrence. The details of MIP and its drawbacks will be discussed in the remainder of this section.

Also, there are other mobility management protocols such as paging mobile IP (P-MIP) [11] and cellular IP [12] which are based on the principle of loose location management of idle nodes. In loose location management, location management is done for only idle nodes. When idle node becomes active, paging is usually used for locating the node in the network. Loose location management protocols will not be covered in this paper.

C. *Mobility Management in LEO Satellite Networks*

The most widely used protocol for mobility management over satellite networks is again mobile IP. MIP is the standard proposed by the Internet engineering task force (IETF) to handle mobility of Internet hosts for mobile data communications [13]. The MIP enables IP host mobility without breaking the high level connection. It enables a TCP connection to remain alive and to continue receiving packets when an MN moves from one point of attachment to another. MIP is based on the concept of home agent (HA) and foreign agent (FA) for routing of packets from one point of attachment to the next. During handover from the HA to the FA, a MN registers with the FA, waits for the allocation of channels, and updates its location in the HA database. The traffic flow of MIP is depicted in Fig. 1. When MN moves to a new domain, a location update is sent to HA.Therefore, the HA is informed by the CoA of the MN. The packets from the CN to MN are encapsulated and forwarded to MN's current CoA. Then, these packets are decapsulated and delivered to upper layer protocols.

In this procedure, the operation in which HA is informed by

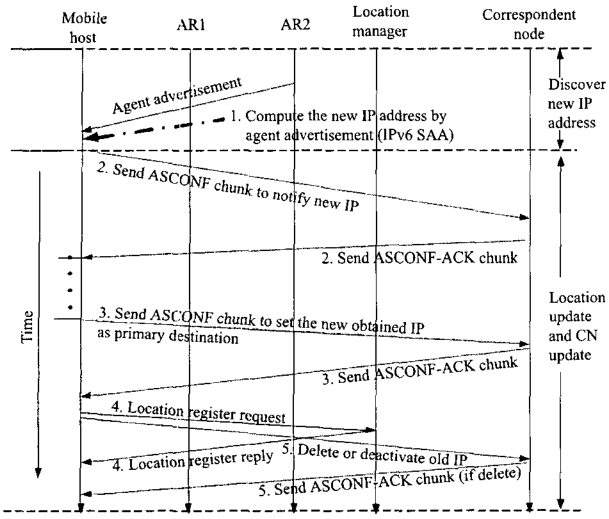

Fig. 2. Signaling flow of TraSH-SN.

the CoA of the MN is called *binding update*. The binding update operation aims to associate Reach.ID (home network address) and Route.ID (CoA) of each node. The home network address indicates a unique name of the node and is not subject to change, whereas the CoA specifies the position of the node in the network and changes in response to node movement. When a mobile node changes its position, the CoA changes as well and the old binding is no longer valid [10].

Although MIP is a widely accepted concept in both industry and research [14], it has a number of important drawbacks. First problem is *high handover latency*. A MN needs to wait for completion of the steps, which are discovering the new CoA, registering the new CoA with the HA (*binding update*), and forwarding packets from the HA to the current CoA, before it can receive forwarded data from the previous point of attachment. Since the frequency of handover occurrences in LEO satellite networks is very high, a large number of binding update requests is likely to be generated in a single burst. Secondly, *high packet lost rate* is another drawback of MIP. During the HA registration period, some or all of the packets directed to the MN's old CoA will be lost because the old point of attachment does not know the new point of attachment of the MN so that it cannot communicate with the MN during this period. Thirdly, it has an *inefficient routing path* since large amount of data is routed to the HA, and then tunneled to the MN. This may decrease the scalability issues as the number of MNs managed by a HA increases. Finally, the MIP *conflicts with network security solutions* such as ingress filtering and firewalls. It is hard to duplicate HA to various locations to increase survivability and manageability since HA must reside in MN's home network. Therefore, this model needs some modifications to be applicable to internet infrastructure.

Atiquzzaman *et al.* proposes another mobility management protocol for satellites called transport layer seamless handoff scheme for space networks (TraSH-SN) which is based on the association of two IP addresses (one obtained from the current subnet and the other obtained from the next subnet) [15]. This model uses a new transport protocol for Internet namely stream control transmission protocol (SCTP) to associate two IP addresses. According to the model, after MN enters to a new footprint, it obtains a new IP in this new domain. Then, MN notifies CN about the new IP. When the new satellite becomes more efficient, MN lets CN set primary address to new IP address. MN also updates a central server called location manager. Finally, it deletes and deactivates old IP. Fig. 2 depicts the signal flow of TraSN-SN. Although this model provides an increased throughput during handover, the handover blocking probability increases very rapidly since it allocates two IP addresses in association during handover process. Besides, no information on analysis of mobility management cost of the model is given in this work.

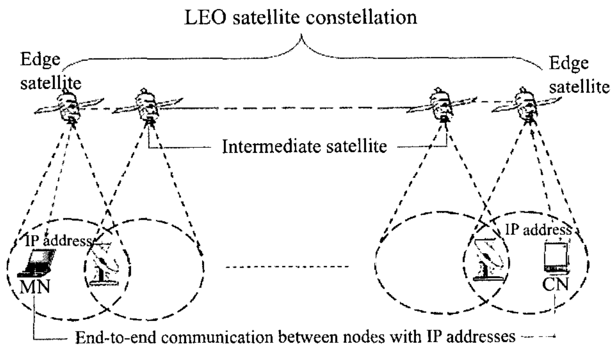

Fig. 3. IP/LEO satellite network.

Since it is not possible to decrease frequent occurrence of handovers in LEO satellite networks, new mobility management protocols are needed to develop to minimize binding update and related mobility management costs.

IV. A NEW SEAHO-LEO

In the proposed models, we assume that the direction of the traffic flow is from CN to MN which illustrates the applications like file downloading or web browsing by the mobile users. The CN does not move, so its location is fixed. The Fig. 3 illustrates the integration of terrestrial IP network and LEO satellite networks.

A. Handover in SeaHO-LEO

Here, we discuss the details of SeaHO-LEO. We develop an efficient and seamless handover scheme which would be applicable to satellite environment. First, we will describe the steps of the proposed scheme. Compared to MIP system, where each subnet has to locate a location management component (HA) causing a really difficult task of dealing with a large number of location management entities, our model reduces the system complexity and maintenance cost.

The research results in [16] show that the mean number of available satellites for a given MN is at least two for latitudes less than 60 degrees. This means that MN is within the footprint of two satellites most of the time, which makes our model effective for handover management of satellites to reduce packet loss and handover latency. The whole handover procedure depicted in Fig. 4 is divided into three parts which are described as

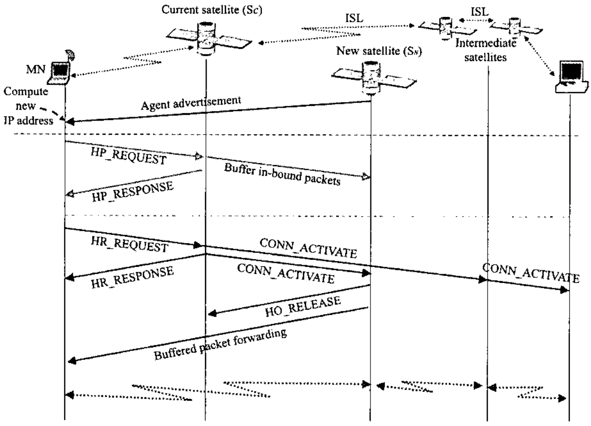

Fig. 4. Signaling flow of SeaHO-LEO.

follows.

1) *Calculate a new IP:* The handover preparation procedure generally begins when the MN moves into the overlapping coverage area of two adjacent satellites' footprints. As illustrated in Fig. 4, when the MN receives the agent advertisement (AA) from the new satellite (i.e., S_N), it will initiate the steps of obtaining a new IP address. The MN measures the received signal strength, and determines the need for handover when the signal strength of the current radio link deteriorates below a certain threshold while still allowing communications. If there are more than one candidate satellites for handover, MN should choose the most favorable one according to the connections QoS parameters. After it determines the leading candidate satellite, it starts to obtain a new IP for new satellite. Obtaining new IP address can be performed with a dynamic host configuration protocol (DHCP) [17], dynamic host configuration protocol for IPv6 (DHCPv6) [18], or IPv6 stateless address autoconfiguration (SAA) [19]. The main difference of these methods is the generation of IP address either by a server (DHCP/DHCPv6) or by the MN itself (IPv6 SAA). Since the IPv6 SAA significantly reduces the required signaling time, it is recommended for the proposed handover protocol. In new IP generation step, MN only requires the address to be unique and routable.
2) *Send handover preparation request to current satellite:* After MN computes a new IP address, it sends a handover preparation request (i.e., HP_REQUEST) to the current satellite (S_C). This message includes new IP of MN, and the IP of S_N. After S_C receives HP_REQUEST, it replies to MN by sending a handover preparation response (i.e., HP_RESPONSE) message to indicate the success of receiving the new IP. At that time, S_C also starts buffering all inbound packets on S_N during the handover. Thus, all the inbound packets coming to the S_C for MN will also be sent directly to the next satellite S_N by using ISL between S_C and S_N. The buffering mechanism creates a virtual path between CN and the new satellite S_N. This buffering procedure is an intelligent one in which the current satellite does not send the packets whose acknowledgements from MN delivered by S_C. Therefore, S_N receives only packets that are not received by MN.
3) *Start to use new IP to send data packets:* When MN moves further into the footprint of the new satellite S_N, data path between MN and S_N becomes increasingly more reliable than data path between MN and current satellite S_C. At that time, MN may want to start to redirect data traffic to the new IP to increase the possibility of successful delivery of data packets to the MN. Therefore, MN sends a handover ready request (i.e., HR_REQUEST) to current satellite S_C to say that new IP is available for data transmission. When S_C receives HR_REQUEST message, new IP is sent to CN by the message CONN_ACTIVATE. When CN receives the new IP, it replies to current satellite with an acknowledgement indicating the success of obtaining the new IP. After S_C receives HR_REQUEST message, it also stops buffering the in-bound packets on next satellite S_N since the new IP is ready to receive new packets. At that point, S_C sends a CONN_ACTIVATE message to S_N to make connection establishment complete. When S_N receives this message, it understands that MN will communicate with CN via S_N. In other words, new IP is ready for the communication. Therefore, the final message causes the next satellite S_N to forward all the buffered packets to the MN. As soon as the new IP becomes ready to receive packets, S_N sends all the buffered packets to MN and starts communication with MN. Moreover, S_N sends a HO_RELEASE message to S_C to complete disassociation and release of radio resources at the old satellite.
4) *CN starts to use new satellite:* After CN receives the new IP of the MN, it sends the next data packets to MN via new satellite S_N.

The SeaHO-LEO provides efficient utilization of network bandwidth because of the absence of tunneling, and also does not need any change in the existing internet infrastructure. SeaHO-LEO uses the efficiency of ISL. Therefore, our model is very effective to provide continuous communication between a CN and a MN whose mobility is random.

On the other hand, some researches on mobility of terrestrial nodes show that MNs have a pattern during a specific period of time. Also, as we mentioned in the introduction, a typical LEO satellite passes over the same geographical area of the earth in repeating periods of time generating a mobility pattern. A novel handover management algorithm based on mobility patterns of satellites and MNs will be discussed in Section V. Since HP_REQUEST and HR_REQUEST messages are eliminated by using this approach, handover management cost of the proposed model will be minimized.

B. Simulation Results of SeaHO-LEO

In order to evaluate the performance of the SeaHO-LEO, we compared it to the MIP scheme and the TraSH-SN scheme proposed in [15]. Each algorithm is evaluated by analyzing both the MNs' average throughput and handover call blocking probability. In addition, we compared the handover latency behaviors of all models. The performance of the decision schemes are evaluated by using OPNET [20] as illustrated in Fig. 5.

We simulated 1 orbit with 6 satellites. In the simulation environment, the number of available satellites for a given MN is

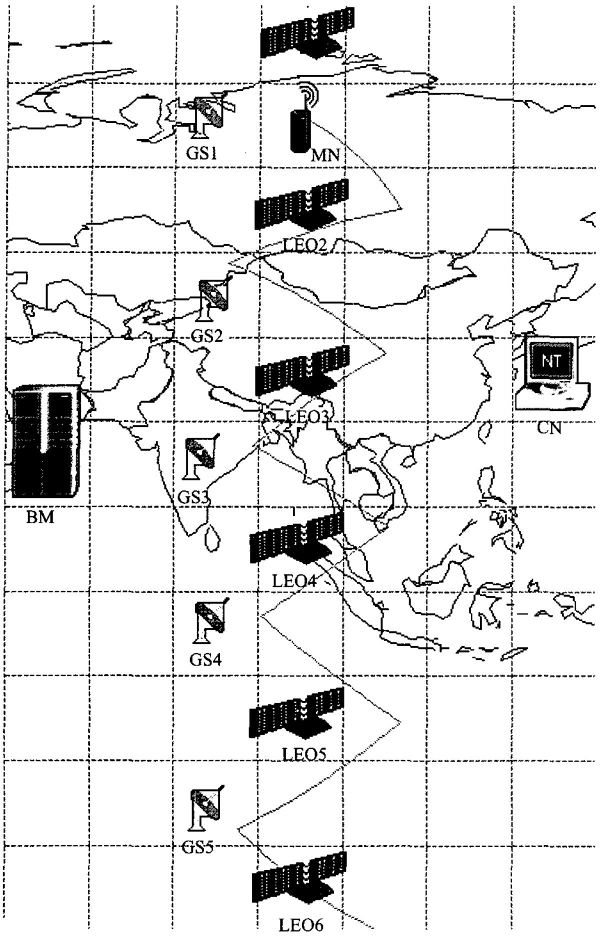

Fig. 5. LEO satellite network model in OPNET.

Table 1. Parameters used in the simulations.

Parameter	Value
Footprint length	1650 km
t_F (time in a footprint)	5.10 min
V_{sat} (footprint's velocity)	5.3922 km/sec

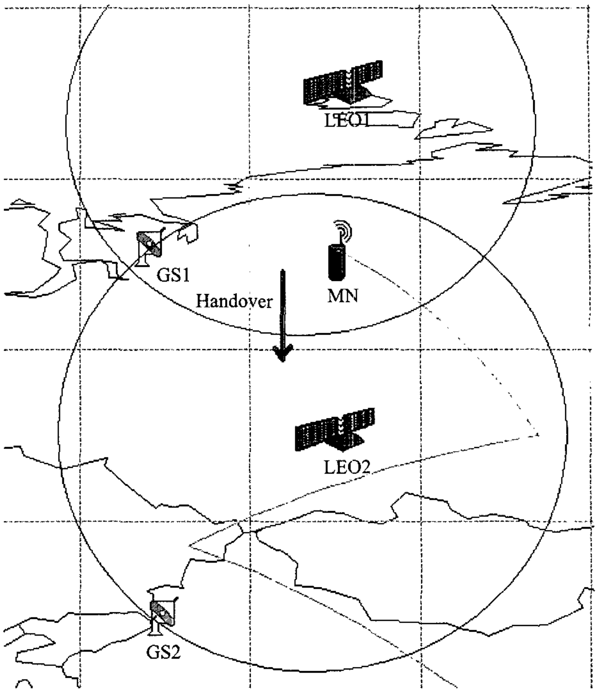

Fig. 6. Handover management in simulation.

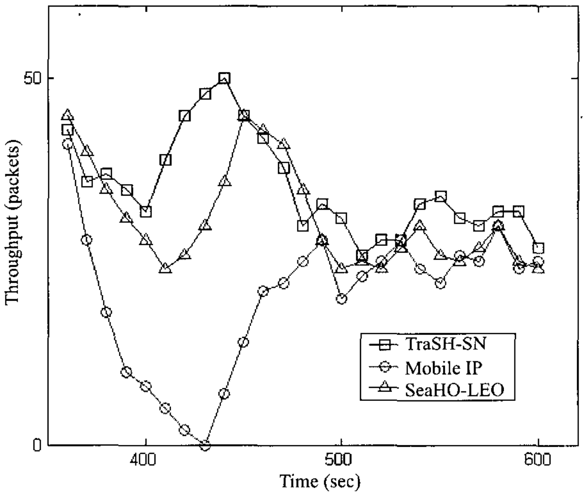

Fig. 7. Simulation results of a MN's handover throughput.

two as shown in Fig. 6. The network consists of 6 LEO satellites (altitude 1000 km, inclination 98°) and a number of fixed ground stations and mobile terminals. Furthermore, we applied the parameters shown in Table 1. t_F defines the maximum time that a MN can stay in a satellite footprint. A CN generates traffic according to a Poisson distribution function.

Fig. 7 compares the MN's average throughput during a handover process. Since TraSH-SN lets a MN to use two IP addresses at the same time, the resulting throughput is relatively higher. In mobile IP, due to the tunneling between HA and FA, the throughput of the channel between MN and CN converges to zero during the handover. When the handover process is completed, the throughput reaches a reasonable value. Our model SeaHO-LEO throughput is better than MIP and very close to TraSH-SN's throughput.

Fig. 8 depicts the handover call blocking probabilities of TraSH-SN, MIP, and SeaHO-LEO. Among these three handover management models, TraSH-SN has the highest blocking probability since it establishes an association between current IP address and new IP address by allocating one channel for each subnet (i.e., one channel for current satellite's subnet and one channel for new satellite's subnet). In other words, TraSH-SN is based on the principle of decoupling registration causing high handover blocking probability for crowded networks. On the other hand, MIP and SeaHO-LEO have almost same level of blocking probability. As illustrated in Fig. 8, SeaHO-LEO has very low blocking probability comparing to TraSH-SN.

Finally, Fig. 9 shows the average handover latency. Handover latency is dependent on the time taken to establish the new path segment between MN and new satellite. In other words, *handover latency* is the time interval between last data segment re-

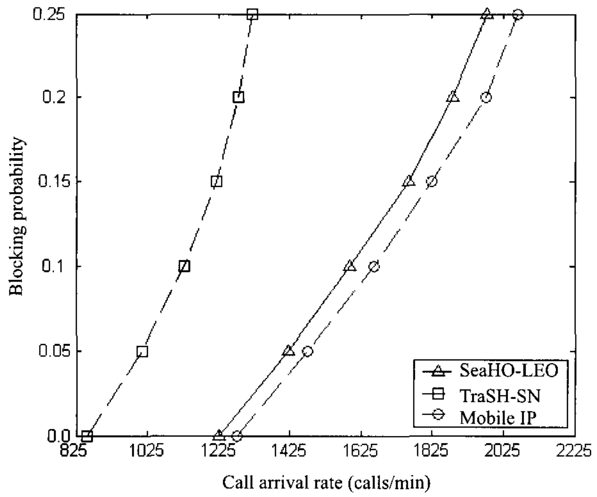

Fig. 8. Blocking probability of a handover call.

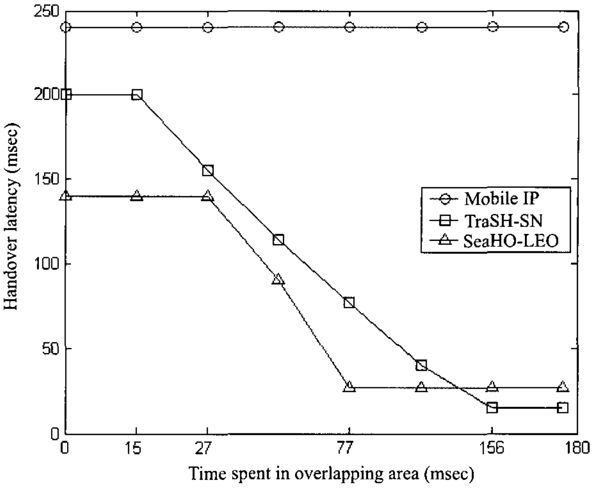

Fig. 9. Handover latency.

ceived through the old path and the first data segment received through the new path from CN to MN.

In small overlapping areas, handover latency of SeaHO-LEO is better than TraSH-SN, since TraSH-SN does not have enough time to finish all the signaling. Some packets sent to the outdated AR (satellite) are lost and CN is forced to back off by SCTP's congestion control algorithms. Therefore this process results in higher handover latency for small overlapping areas. On the other hand, in SeaHO-LEO, as soon as old satellite receives a HP_REQUEST message, it establishes a virtual communication path between the new satellite and MN by the help of ISL between it and new satellite. This process needs very short time (i.e., approximately 20 ms). Therefore, the handover latency of SeaHO-LEO is smaller than that of TraSH-SN for small overlapping areas. However, after a specific threshold, signaling of TraSH-SN requires a slightly less time than SeaHO-LEO does. In MIP, handover latency is immense because MN has to send location update message to its HA to associate its home address and CoA. This binding update process is a time consuming operation. MIP is incapable of receiving packets in flight during this registration process. In the case of MIP, the MN always uses its home address to send and receive packets, and it cannot contact the old FA (satellite) while registering with new FA (satellite). We can see that there is a transmission stall of about 240 ms, which represents the handover latency when using MIP. This handover latency is independent from the time spent in overlapping area of new and old satellites.

V. PATHO-LEO

A. Handover in PatHO-LEO

Here, we discuss the details of PatHO-LEO handover management model. As we mentioned in Section III, applying MIP to LEO satellite networks will result in a precise management of mobile nodes location, and consequently, binding update will be invoked upon each handover occurrence. Given the high frequency of handover occurrences in LEO satellite networks, a large number of binding update requests is likely to be generated, all in a single burst. To process such bursts of binding update requests, a massive amount of network bandwidth and computational load are required. This is intuitively a critical issue for scalability of mobility management in LEO satellite networks. In PatHO-LEO, we try to decrease this excessive number of binding updates during handover processes.

A typical LEO satellite takes less than two hours to orbit the earth, which means that a single satellite passes over the same geographical area of the earth in repeating periods of time. This characteristic provides a satellite mobility pattern (SMP) scheme which includes when and where a satellite passes over a location. On the other hand, some researches such as in [21] show that MNs also have a pattern during a specific period of time. Mobile subscribers usually follow a limited number of mobility patterns in their daily lives. For example, people generally take almost the same path and same time to go to work every day. In the user mobility pattern (UMP) scheme, an MN collects the data (location, time, etc.) related to these patterns, and predicts the UMP based on the collected data.

By combining these two concepts, we come up with a novel idea to manage handovers between satellites as illustrated in Fig. 10. The PatHO-LEO [22] is introduced for location updates of MNs during the handover between LEO satellites. In this approach, MNs and satellites learn their patterns and store their history data in a database located in a central server that is called billboard manager (BM). The database in BM contains the time and the place where a MN is in and the corresponding satellite which passes over the same place at the same time with the MN. In our model, all binding update operations, which are caused by handovers occurred during a single communication between CN and MN, are reduced to a single query operation from BM database, since all the routing identities, which will be used during the communication, are stored in BM. Therefore, HA of the MN does not need to be informed by MN after each handover, instead it obtains all CoAs from BM at the beginning of the communication. As a result, this operation eliminates huge amount of binding update operations done in MIP.

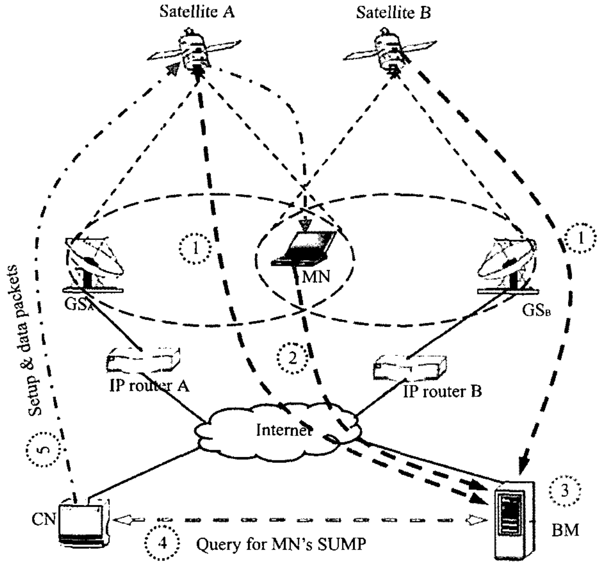

Fig. 10. Handover scenario in PatHO-LEO.

The whole handover management scenario is divided into four parts as shown in Fig. 10 which can be described as follows.

1) *Satellites register to BM*: Satellites register to BM with their mobility patterns (SMP). If any updates are needed for a specific satellite, it informs BM about the changes.
2) *MN registers to BM*: Once the MN accomplishes to set its path, it registers to BM with its mobility pattern (UMP). An MN can register with more than one UMP for different time intervals.
3) *BM establishes the satellite and user mobility pattern (SUMP) table*: After BM receives both SMP and UMP, it establishes a new table called SUMP table which contains the time and the place where an MN is in and the corresponding satellite which passes over the same place at the same time with the MN. Table 2 shows an example of the content of a SUMP table. The SUMP table is composed of the following fields.
   - UMP identity ($\mathrm{ID}_{\mathrm{UMP}}$),
   - satellite identity ($\mathrm{IP}_{\mathrm{SAT}}$),
   - expected entry time (EET),
   - the duration of MN on the satellite's footprint (t_F),
   - the IP of MN for the corresponding satellite ($\mathrm{IP}_{\mathrm{MN}}$).

   In Table 2, $\mathrm{ID}_{\mathrm{UMP}}$ have two different values, 0 and 1, and each of these $\mathrm{ID}_{\mathrm{UMP}}$ values identifies different patterns. For example, $\mathrm{ID}_{\mathrm{UMP}} = 0$ shows the pattern of the user in the weekdays, whereas $\mathrm{ID}_{\mathrm{UMP}} = 1$ shows the pattern of the user in the weekends. Therefore, a user can specify more than one pattern.
4) *CN and BM establish connection*: When a new connection is established between MN and CN, the BM informs CN about MN's pattern including its corresponding IP addresses for corresponding satellites which are on the way of MN. Therefore, CN learns the time and IP pairs of MN in order to communicate via specified satellite. During a location update in the handover process, the SUMP is examined by the CN and its relevant entry with the new IP address in the new satellite's footprint is extracted and started to be used by both CN and MN. BM manages this process precisely to avoid failures. The most significant benefits of BM are as follows.
   - Storing user location information into a central secure database, namely in billboard manager database, is much more secure than scattering it in various HAs located at different sub-networks like in the case of MIP.
   - Centralized billboard management provides a way for an organization/service provider to control user accesses from a single server
5) *CN sends data packets to MN*: CN makes connection setup and then starts to send data packets to MN via corresponding satellite.

Table 2. Content of SUMP table.

ID	$\mathrm{IP}_{\mathrm{SAT}}$	EET	$t_F(s)$	$\mathrm{IP}_{\mathrm{MN}}$
0	192.122.1.37	08:43:54	0842	157.158.10.12
0	192.122.1.38	08:57:42	1030	157.121.10.17
0	192.122.1.39	09:13:58	0304	157.125.11.19
0	192.122.1.40	09:17:49	1959	157.135.12.21
0	...	...	...	...
1	192.122.1.157	20:26:46	0892	81.215.21.139
1	192.122.1.158	20:40:01	0407	81.213.10.141
1	...	...	...	...

On the other hand, BM can become a single-point of failure although a central server model is useful for management. To overcome this problem, a satellite system administrator can allocate more than one billboard manager servers to store its register satellites and mobile users. In the case of more than one billboard manager servers are allocated, the communication between these servers should also be well maintained. Another approach to solve this problem is holding a copy of billboard manager database in a GEO satellite. The copy database stored in the GEO satellite can be updated when any change occurs in original database. However, this operation increases the complexity of the model. Instead of making updates for each change in BM, periodic updates (i.e., making updates in 1800 second-periods) can be applied to reduce traffic load and complexity.

As a result, in the PatHO-LEO handover model, all handover messaging steps are eliminated and handover latency is approximated to the time of sending only one acknowledgement sent by BM to MN and CN which is needed to handshake for handing over to new subnet on the right time. Unless the MN detects that its pattern deviates significantly from the registered SUMP, it performs the pattern based handover model. If MN breaks the pattern, then it can start to proceed with the steps of SeaHO-LEO or MIP. This approach is capable of handling handovers between satellites accurately in a short time. However, the software is needed in both satellite and MN to generate and store SMP and UMP. Also, an efficient algorithm should be implemented for MN to learn its pattern precisely. Moreover, BM should be well designed to manage SMP and UMP of each MN efficiently and adapt gracefully to the growth in the number of mobile users.

B. Analysis of Mobility Management Cost of PatHO-LEO

We analyze the handover management cost of PatHO-LEO protocol and compare it to that of mobile IP. Also, a more detailed simulation results of PatHO-LEO can be found in our previous work [22]. The handover management cost consists mainly of the cost of binding update and data delivery. In [11], the management cost is computed as the product of the generated control message size, M, and the number of hops, H, required to deliver the message. (1) indicates the definition of the cost in this evaluation.

$$\text{Cost} = M \cdot H. \tag{1}$$

Three different costs are required for each handover management event; binding update, local forwarding, and paging. In mobile IP, the binding cost is the product of (1) and the rate of handover occurrence, whereas the paging cost is 0. The mobile IP handover management cost, $C_{\mathrm{MIP}}(t)$, can be expresses as

$$C_{\mathrm{MIP}}(t) = M \cdot H_{\mathrm{MN,LD}} R_{\mathrm{HO}}(t) \tag{2}$$

where, $H_{\mathrm{MN,LD}}$ denotes the number of hops between a MN and location directory. The rate of handover occurrence [10], $R_{\mathrm{HO}}(t)$, is

$$R_{\mathrm{HO}}(t) = V_{\mathrm{sat}} L_{\mathrm{sat}} \int_{V_{\mathrm{sat}}(t-\Delta t)}^{V_{\mathrm{sat}} t} D_L(V_{\mathrm{sat}} t) dt \tag{3}$$

where, V_{sat} and L_{sat} denote the ground speed of satellite and the coverage boundary length, respectively. $D_L(V_{\mathrm{sat}} t)$ is the linear density of nodes on the coverage of satellite at time t. In our evaluation, we calculated nodes density as the ratio of the total number of nodes to the coverage surface area. In the PatHO-LEO model, the local forwarding and paging scheme create some additional cost. The total cost of PatHO-LEO model, $C_{\text{PatHO-LEO}}(t)$, is

$$\begin{aligned} C_{\text{PatHO-LEO}}(t) = &M \cdot H_{\mathrm{MN,LD}} + \\ &M \cdot H_{AR,AR} R_{\mathrm{HO}}(t)\alpha + \\ &\{M \cdot H_{AR,AR}(S-1) + M \cdot S\} \\ &\times n(t)(1-\alpha)\lambda \end{aligned} \tag{4}$$

where, $H_{AR,AR}$ and S denote the number of hops between two adjacent satellites and the number of single-beam satellites that cover a single paging area, respectively. $n(t)$ and α denote the total number of MNs per a coverage area at time t and the ratio of active MNs to the total number of MNs, respectively. The rate of new connections to a MN is denoted as λ. The first term in (4) indicates the handshaking cost of PatHO-LEO. Since all binding update operations are done at the beginning of the communication, there is no binding cost during handover in the PatHO-LEO. The second and third terms represent the local forwarding and paging costs, respectively. In the third term, the expression $n(t)(1-\alpha)\lambda$ indicates the occurrence rate of paging. Since a satellite is required to send a paging request to its $S-1$ neighboring satellites, the cost of sending these requests is $M \cdot H_{AR,AR}(S-1)$. Then, each satellite broadcasts the paging messages to the MNs within its coverage area, so the cost of this operation is $M \cdot 1 \cdot S$. In the following results, the performance evaluation of MIP and PatHO-LEO model is based on the mobility management cost derived from (2) and (4).

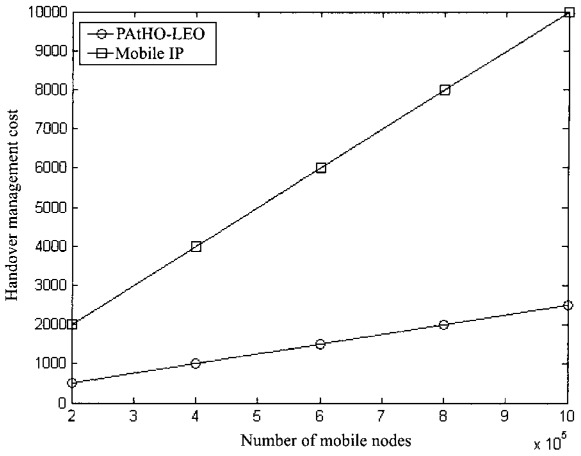

Fig. 11. Performance evaluation in terms of handover management cost.

Fig. 11 presents the evaluation results. The figure demonstrates that the PatHO-LEO significantly outperforms the MIP. Also, due to this low handover management latency in the PatHO-LEO, the throughput degradation period is also reduced. Since MN quickly starts to take service from the new satellite with a new efficient path, the low throughput becomes higher in a shorter time.

VI. CONCLUSION

In this paper, we have proposed two new handover management mechanisms namely SeaHO-LEO and PatHO-LEO which decrease the handover latency and data loss.

We first described a simple mobility management protocol called SeaHO-LEO for LEO satellites. We also described different handover scenarios such as MIP and TraSH-SN used for satellite networks to establish a reference model for performance comparisons. We underlined their major drawbacks. Relying on the simulation results, we showed that the SeaHO-LEO mechanism decreases latency significantly while increasing throughput in a short time. Furthermore, SeaHO-LEO model is suitable especially for dense networks in which the number of MNs is high due to low handover call blocking probability.

Moreover, to eliminate some handover messaging traffic, we proposed our second model PatHO-LEO. The PatHO-LEO mechanism employs a BM which is responsible for location updates of mobile users as well as comes with additional benefits such as security, scalability and manageability. Also, BM reduces the system complexity since the satellite service provider only deals with a central location update manager. Comparison of PatHO-LEO model performance to that of MIP was made through a mathematical analysis. Performance evaluation results showed that management cost of PatHO-LEO is much smaller than that of MIP. In the considered models one end point of communication (i.e., CN) is not mobile. We are currently devising to improve the proposed model to account for mobility in both ends.

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Ayşegül Tüysüz was born in Istanbul, Turkey, on June 17, 1980. She received the B.Sc. degree in Computer Engineering from Yeditepe University, Turkey, in 2004 and the M.Sc. degree in Computer Engineering from Bogazici University, Turkey, in 2006. From January 2003 to June 2004, she was a student assistant in the Yeditepe University. Since October 2005, she is affiliated researcher at the Satellite Networks Research Lab., Bogazici University. She is a project manager in Naryaz Software, Turkey, since February 2005. Her major interests are wireless and mobile networks, network management, and satellite networks.

Fatih Alagöz is an associate professor in the Dept. of Computer Eng., Bogazici University, Turkey. He is also affiliated with the Dept. of Electrical Eng., Harran University, Sanliurfa, Turkey. From 2001 to 2003, he was with the Dept. of Electrical Eng., United Arab Emirates University, AlAin, UAE. In 1993, he was a research engineer in a missile manufacturing company, Muhimmatsan AS, Turkey. He received the B.Sc. degree in electrical engineering from METU, Turkey, in 1992, and M.Sc. and D.Sc. degrees in electrical engineering from George Washington University, USA, in 1995 and 2000, respectively. His current research interests are in the areas of satellite networks and wireless/mobile networks, UWB communications. He has contributed/managed to seven research projects for various agencies/organizations including US Army of Intelligence Center, Naval Research Laboratory, TUBITAK, BAP, etc. He has edited five books and published more than 60 scholarly papers in selected journals and conferences. Dr. Alagöz is the satellite systems advisor to the Kandilli Earthquake Research Institute, Istanbul, Turkey. He has served on several major conferences technical committees, and organized and chaired many technical sessions in many international conferences. He is a member of the IEEE Satellite and Space Communications Technical Committee. He has numerous professional awards.