Location Registration and Paging in Mobile Satellite Systems

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Abstract

Mobile satellite systems are a crucial component of the future global telecommunications infrastructure. An important aspect of the future system is to manage the location of both users and satellites. This paper presents a strategy for location registration (update) and paging in Low Earth Orbit (LEO) mobile satellite systems. First, we discuss the tradeoff that exists between four proposed satellite location area designations. Then we introduce a scheme that selects a simple location area design and uses a hierarchical database architecture to reduce the location management signaling delay. The performance of the scheme is analyzed in terms of the paging bandwidth and the location update signaling delay. Finally, we present the numerical results for several planned systems, such as GlobalStar, ICO, and IRIDIUM.

I. INTRODUCTION

Mobile satellite systems are a crucial component of the future global telecommunications infrastructure. Planned Low Earth Orbit (LEO) systems (GlobalStar, IRIDIUM), and Medium Earth Orbit (MEO) systems (ICO), not only function as stand-alone wireless systems, but also provide integrated use with terrestrial systems such as the Global System for Mobile Communications (GSM) and the Electronic and Telephone Industry Association Interim Standard 95 (IS-95) [1]. In terrestrial systems, the movement of the user triggers location update and determines the paging scheme. In satellite systems, the need for location update is determined by the movement of the satellites in orbit. Terrestrial-based location management techniques must be altered to fit satellite systems, including methods that allow location updates and paging with respect to the moving satellite coverage area.

Figure 1 shows the basic satellite network, which consists of the *air interface segment*, the *space segment*, and the *ground segment* [1]. The air interface segment consists of the physical, media and link layer access. The space segment is the fleet of satellites that provide wireless connections to user terminals. (For networks such as the IRIDIUM system, this includes inter-satellite links.) The ground segment is made up of four components: (1) fixed earth stations (FESs) connected by a global terrestrial Wide Area Network (WAN), (2) fixed (FT) and mobile (MT) user terminals, (3) the network coordination and/or operations center, and (4) Telemetry, Tracking and Command stations. The user communicates with the satellite network directly or through the FES by using a mobile terminal (MT) [1]. Direct satellite communication is achieved via the satellite footprint. Each footprint is divided into smaller sections, called spot beams, that create smaller cells and implement frequency reuse within the footprint coverage area. The FES performs network management functions, such as measuring link quality to handle handoffs, transmitting paging messages over the satellite spotbeams, and controlling the databases for location management [2].

In order to implement a location management strategy for satellite networks, an appropriate location area (LA) must be determined. The LA is an area consisting of multiple cells, within which the user can roam freely without performing a location update, i.e., without recording its new position in a location database. Once the LA boundary is crossed, the user must perform an update. Since the satellite system uses the FES to access the location databases, proposals for the LA design in satellite networks are in terms of the Satellite/FES relationship. The important issue for location registration and paging in LEO mobile satellite networks is determining the effect of the LA design on the location registration and paging signaling loads.

In this paper, we present a strategy for location

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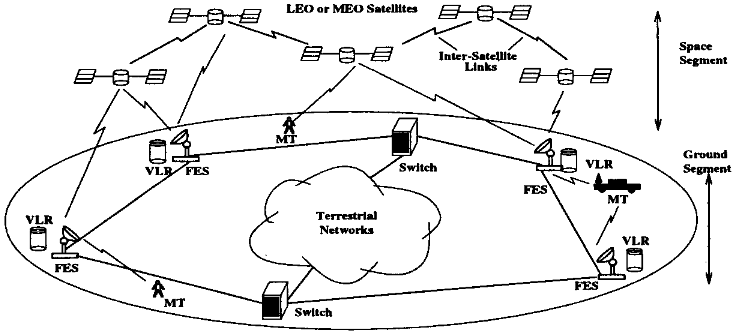

Fig. 1. The Mobile Satellite System Architecture

registration and paging in LEO mobile satellite systems. In Section II, we discuss the tradeoff between four proposed satellite LA designations. Next in Section III, we introduce a scheme that selects a simple location area designation and uses a hierarchical database architecture to reduce the signaling load due to location management operations. Then in Section III-C, we discuss the location database placement within the LEO system. In Section IV, the performance of the scheme is analyzed in terms of the signaling bandwidth consumed by paging, and the location update signaling delay. Finally, numerical results for selected planned satellite systems are presented in Section V.

II. THE SATELLITE LOCATION AREA TRADEOFF

In the terrestrial networks, there exists a location update/paging tradeoff for the LA. As the LA gets larger, the required the paging area increases, along with the corresponding signaling operations. However, the number of location updates is reduced. The opposite is true for smaller LAs—much less paging is required, but many more location updates are needed. In the satellite networks, the location update/paging tradeoff also depends on the LA designations as a result of the Satellite/FES relationship to the LA. Proposed LA designations are as follows:

1. The geographical position of the user [3], [4],
2. The Satellite Cell [5], [6],
3. The FES coverage area [3], [5], [6], and
4. The (Satellite,FES) pair [5].

A. Geographical Position Location Area

To determine the geographical position of the MT, a *terminal positioning* technique is invoked, e.g., the global positioning system (GPS). The MT obtains a measurement and then notifies the network of its current geographical position. When the MT's traveling distance exceeds a pre-determined radius, a location update must be performed. This technique has a variable location update load, depending on the calculated radius and the behavior of the user. However, this technique requires a large paging area consisting of all of the FESs and satellites that have access to the MT's geographical position.

B. Satellite Cell Location Area

For the *Satellite Cell LA*, the MT must perform a location update whenever it loses the current satellite broadcast. The MT sends an update message to the FES with the identity of the new serving satellite. Due to the fast movement of the LEO satellites, this LA designation inherently creates a large number of location updates, even for stationary MTs. For fast-moving MTs (e.g., trains, airplanes), the vehicle may travel for longer distances before requiring an update, and thus may be on the order of thousands of kilometers from the FES/VLR by the time the next update is triggered. Finally, when a call arrives for the MT, each FES that has access to the current satellite location must perform separate paging operations over the spotbeams of the same satellite to find the MT.

C. FES Location Area

The third option is the *FES coverage area LA*. In this technique, the MT updates its location profile each time it loses the broadcast of the current FES. Since each FES accesses several satellites and has a large coverage area (thousands of kilometers), the number of updates are expected to be low. However, upon call delivery to the MT, the FES must page the MT over the spotbeams of each satellite within its range—resulting in a large increase in paging operations. For a large number of MTs traveling near the same FES, signaling traffic due to paging messages can introduce heavy loads. In addition, as shown in [6], MTs positioned in the overlap areas of the satellite spot beams experience a great increase in the required number of location updates.

D. Satellite, FES Location Area

The final LA designation is the *(Satellite,FES) pair LA*, which is the compromise between the previous two techniques. Here the MT receives both the satellite and the FES identity broadcasts, and performs a location update when either the current satellite broadcast or the current FES broadcast is lost. This method eliminates the long-distance updates for fast-moving MTs, and the paging is reduced since the network knows both the FES and the satellite. Two problems for the (Satellite,FES) pair LA are an increase in location updates with satellite movement, and the tendency to have *flip-flop* updates between adjacent FESs near the same satellite orbit [5].

Our location management technique uses the (Satellite,FES) LA. We have chosen this designation in order to take advantage of the small paging loads. We then introduce a hierarchical database scheme to reduce the location update load associated with the chosen LA design. In the next section, we present the new satellite network hierarchical database strategy.

III. SATELLITE NETWORK HIERARCHICAL DATABASE STRATEGY

The satellite network hierarchical database strategy will reduce the number of location updates for satellite systems with (Satellite,FES) LA designations. We first illustrate the location update procedure for planned satellite networks [7], [4] and use the (Satellite,FES) LA technique. Then demonstrate the procedure of the techniques using the new hierarchical scheme.

A. AMPS-based Location Update Procedure

As shown in Figure 2, the procedure begins with the MT in the LA (SAT_0, FES_0). The MT performs a location update at FES_0 to VLR_0 (Figure 2(a)) as follows:

1. The MT transmits a location update message to FES_0 via SAT_0.
2. FES_0 launches a registration query to VLR_0.
3. VLR_0 updates its record of the location of the MT. Then VLR_0 sends a location registration message to the HLR.
4. The HLR performs the required procedures to authenticate the MT and records the ID of VLR_0. The HLR then sends a registration acknowledgement message to VLR_0.
5. The HLR sends a registration cancellation message to the former VLR.
6. The former VLR removes the record of the MT and returns a cancellation acknowledgement message to the HLR.

When the satellite orbit moves the footprint of SAT_0 out of range, the footprint of SAT_1 begins to cover the MT. However, it does not cover FES_0, as shown in Figure 2(b). Thus, the MT "enters" a new LA: (SAT_1, FES_1). The MT must perform another location update (as described in steps 1-6 above and labeled in Figure 2(b)) at FES_1, even though the MT has not moved . Then, continuing in the orbit, the footprint of SAT_1 will begin to cover FES_0, but will no longer include FES_1. The MT will enter a new LA: (SAT_1, FES_0). The MT must perform a second location update at FES_0 and VLR_0, executing steps 1-6 again, even though the MT has remained relatively stationary. The next satellite in the orbit, SAT_2, will start the process again, with the MT entering the new LA: (SAT_2, FES_1), and requiring location update procedures executed at FES_1 for the second time.

The flip flop between FES_0 and FES_1 creates an excessive amount of location update signaling. To prevent this condition, we propose a three-level hierarchy of databases, as shown in Figure 3, and use a limited pointer forwarding policy to reduce the flip-flop effect.

B. Hierarchical Databases Procedure

Using our new technique, the MT begins in LA (SAT_0, FES_0), and performs an initial location update at FES_0 to VLR_0 with the following changes in procedure (see Figure 3(a)):

1. The MT transmits a location update message to FES_0.
2. FES_0 launches a registration query to VLR_0.
3. VLR_0 updates its record on the location of the MT. Then VLR_0 sends a location registration message to initialize a new *intermediate location register (ILR)*.
4. The new ILR records the ID of VLR_0, and then forwards the location registration message to the HLR.
5. The HLR performs the required procedures to authenticate the MT and records the ID of the new ILR. The HLR then sends a registration acknowledgement message to the new ILR.
6. The HLR sends a registration cancellation message to former ILR (not shown in Figure 3).
7. The former ILR removes the record of the MT and returns a cancellation acknowledgement message to the HLR (not shown in Figure 3).

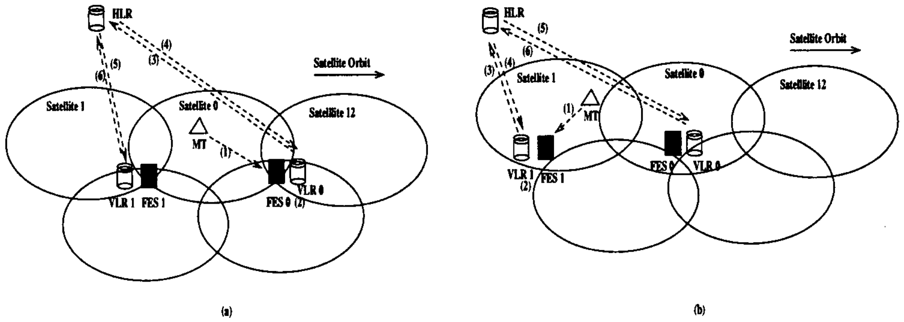

Fig. 2. Flip Flop Effect:(a) LA (SAT_0, FES_0) (b) LA (SAT_1, FES_1)

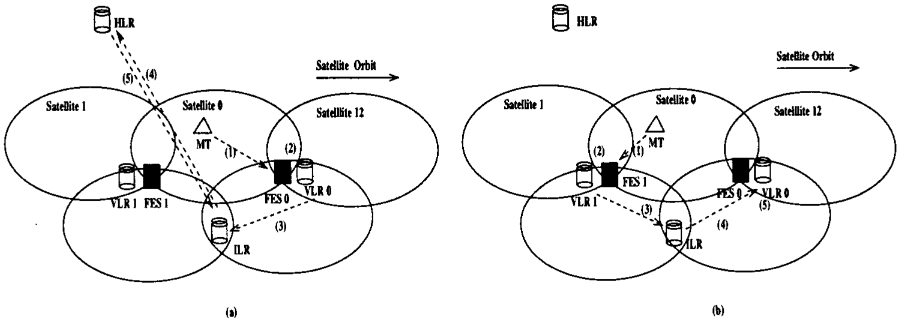

Fig. 3. Three-level Database Hierarchy(a) LA (SAT_0, FES_0) (b) LA (SAT_1, FES_1)

Then, when the satellite orbit moves the footprint of SAT_0 out of range as shown in Figure 3(b), the footprint of SAT_1 begins to cover the MT, but not FES_0. The MT is now located in LA (SAT_1, FES_1 and must perform a location update at FES_1, as shown in Figure 3(b) and listed below:

1. The MT transmits a location update message to FES_1.
2. FES_1 launches a registration query to its associated VLR_1.
3. VLR_1 updates its record on the location of the MT. Then VLR_1 sends a location registration message to the *ILR*.
4. The ILR performs the required procedures to authenticate the MT and sends an establisher pointer message to VLR_0.
5. Then VLR_0 establishes a pointer to VLR_1.

Continuing in the satellite orbit, the footprint of SAT_1 begins to cover FES_0, but no longer includes FES_1. the MT (now in LA (SAT_1, FES_0)) performs another location update using pointers as follows:

1. The MT transmits a location update message to FES_0.
2. FES_0 launches a registration query to its associated VLR_0.
3. VLR_0 checks to see if it has a record of the MT and an established pointer. If it does, the pointer is deleted and the update is complete.

Again, the next satellite in the orbit, SAT_2, continues the process, with the MT entering the new LA: (SAT_2, FES_1). The location update is performed at FES_1 for the second time, using steps 1-5 listed above for LA (SAT_1, FES_1).

The intermediate location register reduces the amount of long distance signaling that is transmitted to/from the VLRs to the HLR, while the one-hop pointer between adjacent VLRs reduces the amount of signaling between the VLRs and the ILR. As the location updates begin to flip-flop between VLR_0 and VLR_1, only a pointer-add or pointer-delete operation is necessary, and no long distance signaling is required. For call delivery, the location queries follow the chain from HLR to ILR to VLR through a pointer to the next VLR, if necessary. When the MT moves to a VLR that does not have a direct connection to the ILR, then a new ILR must be initialized as in steps 1-7 listed above for LA (SAT_0, FES_0).

Next, we explore the performance of the new hierarchical strategy for (Satellite,FES) LAs.

C. Database Placement

The placement of the ILR within the satellite system depends on the geographical location of the gateways, as well as the local availability of public land mobile network (PLMN) / public switched telephone network (PSTN) location databases within the satellite footprint. For example, the planned GlobalStar system allows for a high level of interoperability between the satellite and terrestrial cellular networks by using the PLMN Mobile Switching Centers (MSCs) and location databases, where available. In rural areas, the GlobalStar gateways will be equipped with MSC capabilities [2]. The geographical positioning of the GlobalStar gateway is determined by the service providers, the regional customer presence and demand. Since the GlobalStar system will be interoperable with the PLMN/PSTN, the ILR can be selected from existing PLMN/PSTN location databases that fall at some intermediate distance between GlobalStar gateways.

IV. ANALYSIS

We now calculate the bandwidth consumption and signaling delay due to the location management operations. Since we are concerned with the comparison between schemes, we assume that for each of the techniques the messages are delivered successfully, without retransmission.

A. Bandwidth, BW

Now we calculate the bandwidth that is consumed by the paging process. The paging bandwidth is determined by summing the required bandwidth for each of the signaling operations at the FES, the HLR, and/or the satellite spotbeams:

$$BW_{PG} = \sum BW_i, i = signalingstep \tag{1}$$

For steps that depend on the number of satellites, satellite spot beams, or FESs within the service area of the MT, we calculate

$$BW_{PG} = \sum_{i}^{N_F} \sum_{i}^{N_S} \sum_{i}^{N_C} BW_i, \tag{2}$$

where N_S is the number of satellites that are paged, N_C is the number channels at each satellite where the MT is paged, and N_F is the number of FESs that are involved in the paging process.

B. Signaling Delay, T_d

The location update signaling delay is obtained from the transmission of the messages outlined for each technique in the steps of Section III. For example, for the technique presented in Section III-A, the delay is the time to transmit all of the messages for Steps 1-6. Therefore, the signaling delay, T_d, is calculated:

$$T_d = \sum T_i, \tag{3}$$

where T_i is the time spent in performing Step (i) in Figures 2 and 3. We can determine:

$$T_i = \alpha_i + \beta_i + \gamma_i, \qquad i = number of steps \tag{4}$$

where α_i is the transmission time, β_i is the propagation time for the control message in Step i, and γ_i is the processing time for the control message in Step i. The transmission time, α_i, for the control message in Step i is computed by:

$$\alpha_i = \frac{b_i}{B}, \tag{5}$$

where b_i is the size of the control message and B is the bit rate of the link on which the message is sent.

V. NUMERICAL RESULTS

We now compare the performance of the various LA designations for satellite systems.

A. Bandwidth Consumption

We assume that each MT is within the coverage area of two FESs. The bandwidth for the MT, FES, and Satellite signaling channels are chosen to be 10, 15, and 64 Kbps, respectively. Figure 4 shows the bandwidth consumed by each of the LA schemes for different satellite diversities. Mobile satellite systems have planned for a satellite visibility of one to four satellites visible to the user at any point in time. The geographical position LA performed the worst, since the adjacent FES and satellite cells must be paged. The FES LA performed better than the Satellite Cell LA, due to the overlap of FESs that must be paged within the same satellite. Finally, as expected, the (Satellite,FES) pair performed best.

We now compare the performance of our scheme for three satellite networks: IRIDIUM, GlobalStar, and ICO. First, we show the difference in signaling delay when the new hierarchical databases scheme is used for the three systems. There are two major differences in the three systems that must be considered. First, the IRIDIUM and GlobalStar systems both use LEO satellites in order to achieve a minimum satellite propagation delay. The ICO system uses medium earth orbit (MEO) satellites. A greater propagation

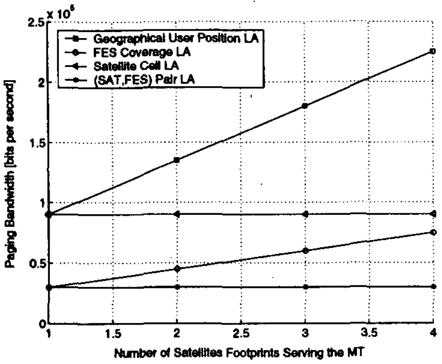

Fig. 4. Comparison of Paging Bandwidth for Different Satellite Diversities

delay will affect the overall signaling delay. The second major difference is the use of the ground segment. Both GlobalStar and ICO use the ground segment for signaling and routing, while the IRIDIUM system uses intersatellite links for signaling and routing throughout the satellite network. In our calculations, we have obtained three sets of results corresponding to each system and its propagation delay and ground segment routing characteristics.

B. Signaling Delay

Figure 5 shows the location registration signaling delay for several registration operations. The three different cases are denoted by a square, a circle, and a triangle shape, and the results of our new scheme are highlighted by dashed lines. Our new scheme performed better than each of the particular systems, and improved in signaling delay as the number of repeated registrations increased.

We found that the new technique performs better for signaling delay, since the new technique's location registration does not require a intersatellite path to send signaling messages each time the mobile terminal must update its location. The repeated long distance signaling causes the IRIDIUM delay to increase, while the addition of the pointer scheme causes the delay to decrease while the MT is located near the same ILR.

VI. CONCLUSION

In this paper, we presented a strategy for location registration (update) and paging in Low Earth Orbit (LEO) mobile satellite systems. After examining the location area tradeoff that exists between four proposed satellite location area designations, we selected the (Satellite,FES) location area. Then we introduced a new hierarchical scheme that uses a hierarchical database architecture to reduce the location management signaling load. The performance of the location area selection was demonstrated in terms of paging bandwidth consumption, and the performance of the hierarchical database scheme was demonstrated to reduce location update delay for several planned systems, i.e., GlobalStar, ICO and IRIDIUM.

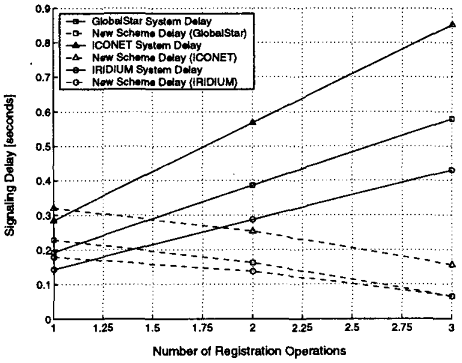

Fig. 5. Comparison of Signaling Delay for Several Registration Operations

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