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A Location Management Strategy Based on Dual Location Areas in LEO Satellite Network

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Abstract: In order to reduce the location management cost of users moving to and fro between two location areas, a location management strategy based on Dual Location Areas in LEO satellite network is proposed. A combined two location area with satellite location area and Fix Earth Station (FES) location area is designed to divide network coverage area. Users initiate location update procedure when both boundaries of the two location areas are crossed. Based on the Dual Location Areas a corresponding two-step paging strategy is implemented without complicated calculation in order to detect users' location. Compared with the location management strategy used in Iridium system, simulation results indicate that the strategy decreases location update cost of to-and-fro users and the system paging bandwidth is also saved.

Key words: Location management, location area design, LEO satellite network

INTRODUCTION

In mobile networks, the location of a Mobile Terminal (MT) has to be known by the network for the routing of incoming calls (Akyildiz *et al*., 2004). In GSM, for example, the system coverage area is divided into Location Areas (LAs), which are clusters of cells where a code unique to this LA is broadcast. The network keeps track of the LA of every switched on mobile terminal. When a MT crosses the boundary between two LAs, it performs a location update, to inform the network of its change of LA. When the terminal has to be contacted for an incoming call, a paging message is transmitted over all the cells of the LA (Awan *et al*., 2008). The size of the LA is a trade-off between the location updating signaling (high for small LA) and the paging signaling (high for large LA) (Zhang *et al*., 2009).

Mobile satellite network is an important part of global telecommunication infrastructures. Location Management of both users and satellites is an important aspect of future LEO satellite networks. In LEO satellite networks, location update scheme is mostly triggered by movement of satellites. Location management including location update and paging in terrestrial mobile networks need to be adapted to moving coverage area of satellite networks (Jinglin and Zhigang, 2010).

Location management of LEO satellite networks is based on definition of appropriate location area (Dinis *et al*., 1996). Each LA is composed of multiple cells, in which movement of user causes no location update. Since LEO network management access the location databases via FES, the LA design in LEO satellite networks must investigate relation of Satellite and FES. The signaling cost of location update and paging is determined by efficiency of the LA design. So LA design is an important issue for location management in LEO satellite networks. Three satellite LA designs including the FES-LA (Akyildiz *et al*., 1998), the Satellite-LA (McNair, 2000; Naor *et al*., 2002) and the Satellite-FES Pair (Passas *et al*., 2008) have been proposed. In the FES-LA design, each LA is defined by the coverage of satellites, which are connected to the same FES. Because of large scale coverage of FES-LA, the location update frequency is low and the paging cost is extremely high. The SAT-LA design is defined by the coverage area of each satellite. Because of movement of satellites, the location update cost is high, even for fixed users without movement. The Satellite-FES Pair design has the smallest coverage of LA with the highest location update cost and low paging cost (Senzaki and Chakraborty, 2008).

In the existing LA designs, mobility characteristics of users has not been considered, which influences performances of location management strategy. For users crossing LA boundaries up and down between two LAs frequently, location update cost is high.

In this study, based on mobility characteristics of users, a Dual-LA design is proposed for location management in LEO satellite networks. According to the Dual-LA design, location update and paging strategy are investigated to decrease location management cost of LEO satellite networks.

DUAL-LA DESIGNS

Both the SAT-LA and the FES-LA are introduced in the Dual-LA location management. Different from the

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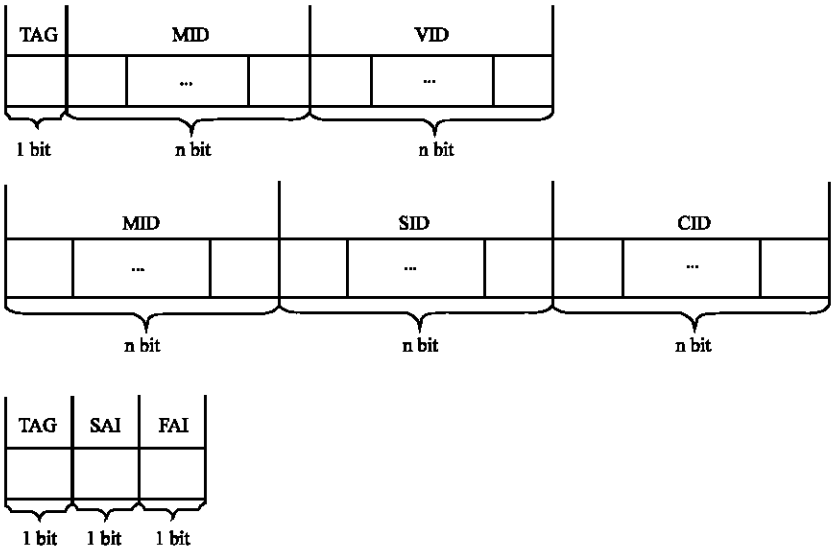

Fig. 1: Data structure; (a) Data structure of HLR, (b) Data structure of VLR and (c) Structure of registration code

Satellite-FES Pair LA design, the two kinds of LAs are independent. LA is chosen by Mobile Terminal (MT) according to mobility characteristics.

A two-level hierarchical mechanism is used to maintain two classes of location databases. One is Home Location Register (HLR) and the other is Visitor Location Register (VLR). HLR contains the location information of all the MTs in LEO satellite network and VLR contains the location information of the MTs in the FES-LA.

The location information stored in the HLR consists of MT ID (MID), VLR ID (VID) and a flag (TAG), as shown in Fig. 1a. The VID indicates the last VLR in which the MT registers. The TAG denotes register status of the MT.

The location information stored in the VLR consists of MID, Satellite ID (SID) and Cell ID (CID) as shown in Fig. 1b. SID represents the last satellite that MT registers. CID indicates the last cell that the MT registers. The size of MID, VID, SID and CID is designed according to the scale of the LEO satellite network.

Based on the Dual-LA design, system can locates all users in LEO satellite networks according to the location information in the HLR and VLR.

LOCATION UPDATE STRATEGY OF DUAL-LA

In LEO satellite network, both the satellite and the FES broadcast coverage area identities which are received by the MT in LEO satellite network. The MT executes a location update procedure when both of the current satellite coverage area identities and FES coverage area identities are changed. A registration controller installed in the MTs controls location update initiation by registration codes, which contains three bits as shown in Fig. 1c.

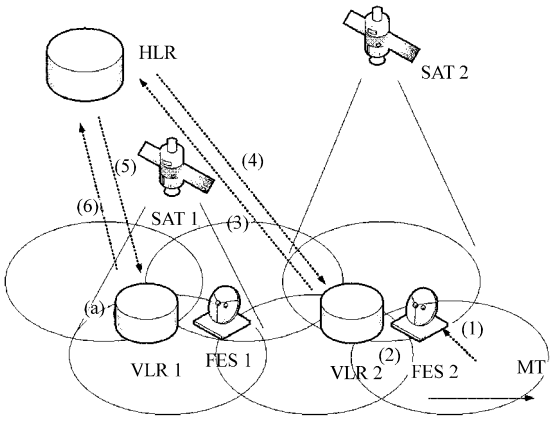

Fig. 2: Location update procedure

TAG denotes whether the MT has received the location area identity. When both the FES and satellite location area identities are received, TAG is set as 1. Otherwise, TAG is always 0. Satellite Area Identity (SAI) denotes change of the received satellite coverage identity. When the satellite coverage identity is changed, SAI is set as 1. Otherwise, SAI is always 0. FES Area Identity (FAI) denotes change of the received FES coverage identity. When the FES coverage identity is changed, FAI is set as 1. Otherwise, FAI is always 0.

Only when the three bits of the registration controller are all 1, the registration controller initiates a location update procedure. After location update accomplishment, both the SAI and FAI are set as 0.

As shown in Fig. 2, when a MT moves from location (SAT1, FES1) to location (SAT2, FES2), a location update procedure is described as follows:

1: The MT initiates a location update procedure to FES2 via the serving satellite (SAT2) after the registration code has been set as 1
2: FES2 submits a registration query to VLR2
3: VLR2 updates the record of the MT location and sends a location registration message to HLR
4: The HLR authenticate the MT and records the ID of VLR2. Then an acknowledgement message is sent to VLR2
5: The HLR sends a registration cancellation message to the former VLR (VLR1)
6: The VLR1 removes the record of the MT and returns a cancellation acknowledgement message to the HLR

TWO-STEP PAGING STRATEGY OF DUAL-LA

In Dual-LA strategy, when MT crosses the coverage boundary without location information update in the databases, a two-step paging strategy is proposed to guarantee connection of calls (Zhou *et al*., 2004).

In Fig. 3, the two-step paging strategy for Dual-LA location management strategy is shown.

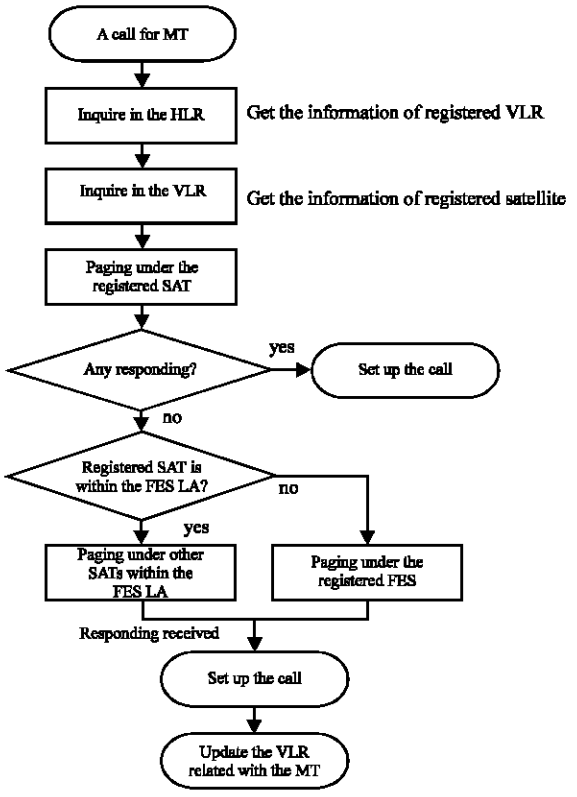

Fig. 3: Flow chart of the paging strategy

The satellite ID of the registered MT is stored in the VLR. When the HLR set up a call, the SID is inquired in the VLR firstly, then paging messages are broadcasted by the last satellite that the MT registered. If the satellite paging failed, the FES estimated the coverage of the satellite to determine the paging area and then HLR pages the MT around the FES coverage area. After the paging operation completed, the HLR updates the location information of the MT in VLR.

SIMULATION AND ANALYSIS

The location update and paging performances of the proposed Dual-LA designs in LEO satellite network are simulated based on the Iridium constellation and the parameters shown in Table 1.

In the simulations, the Dual-LA location management strategy is analyzed according to two kinds of mobility of MTs. The normal Mts are at speed of 100 km h^{-1} and the up-and-down MTs are at speed of 100 km h^{-1} with 4 times h^{-1} across the coverage boundary.

Performance of location update rate: The performance of location update rates between the proposed Dual-LA design and the existing LA designs are compared in Fig. 4a and b.

The update rate of the Satellite-FES Pair scheme is highest because of frequent location update caused by either change of FES coverage or SAT coverage. Due to high mobility of LEO satellites, the update rate of SAT-LA scheme is higher than the proposed Dual-LA.

Compare with the existing LA designs, the Dual-LA design has better performance of location update rate, especially for up-and-down MTs, because the MT only updates location information when both the current FES coverage and satellite coverage are changed. The scale of the LA coverage adapt to mobility of MTs so as to decrease the location update rate.

Performance of location update cost: To analyze the location update cost, the LEO satellite network costs must be defined. According to the message cost between HLR and VLR, the network costs are normalized as follows.

The C_{HV} and C_V are defined respectively as the message cost between HLR and VLR and the query or update cost of VLR database .which are both set as 1. The C_{MV} is defined as the message cost between MT and VLR which is set and normalized as 2. And the C_H is defined as the query or update cost of HLR database which is set and normalized as 0.4.

In Fig. 5a and b, the performances of location update cost are compared. For the normal MTs, location update cost of the Dual-LA design is the same with the FES-LA design, which is lower than the cost of the other two

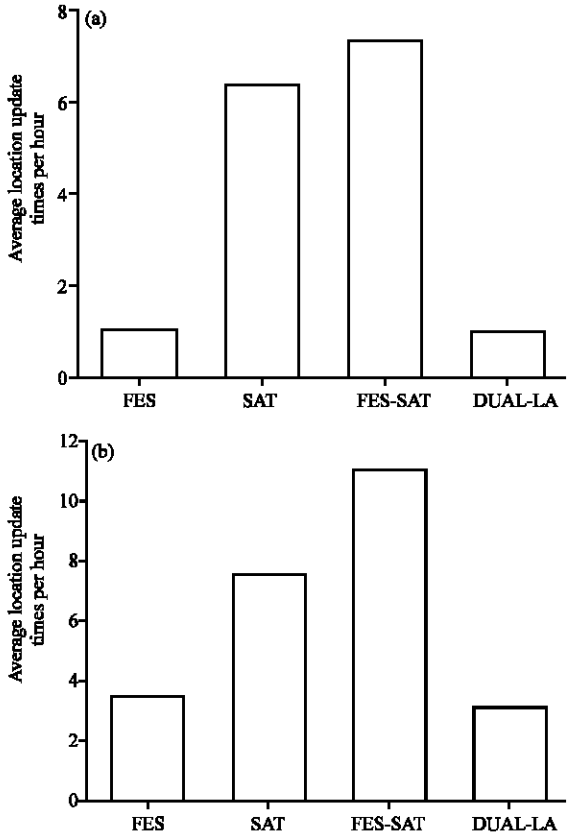

Fig. 4: Comparison of location updates rates; (a) normal MTs and (b) up-and-down MTs

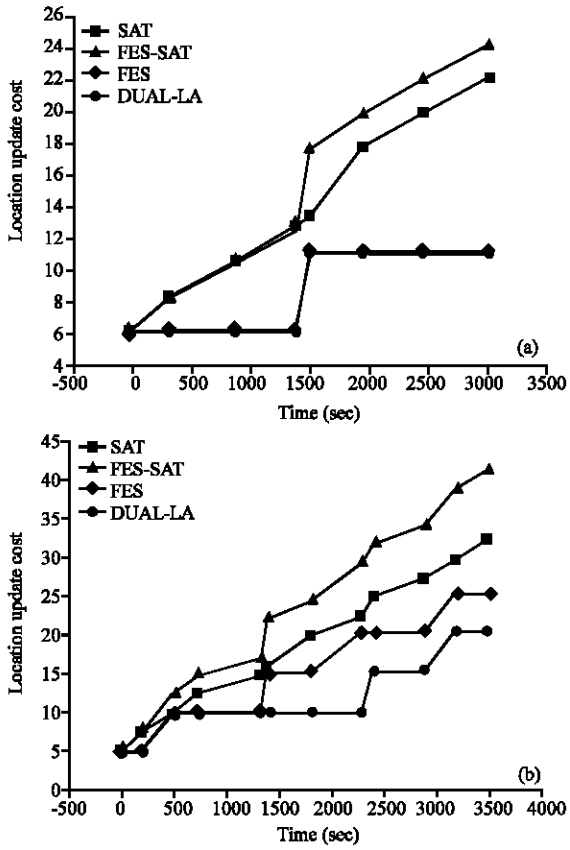

Fig. 5: Comparison of location update cost; (a) normal MTs and (b) up-and-down MTs

Table 1: Parameters of Iridium constellation in simulation

Parameters	Values
Altitude (km)	780.0
Planes	6.0
Satellites per plane	11.0
Inclination (deg)	86.4
Inter-plane separation (deg)	31.6
Elevation (deg)	8.2
ISLs per satellite	4.0
ISLs bandwidth (Mb sec^{-1})	25.0
Up/downlink bandwidth (Mb sec^{-1})	1.5
Diameter of satellite coverage area (km)	4204.4

designs. For the up-and-down MTs, the location update cost of the Dual-LA design is better than the others.

In the Dual-LA design, only when both the boundaries of FES coverage and satellites coverage are crossed, location information is updated, which decreases the location update cost.

Performance of paging bandwidth: To evaluate efficiency of the proposed Dual-LA design, the performances of paging bandwidth are compared between the Dual-LA design and FES-LA design (Lee *et al*., 2004).

r is defined as the probability that the registered FES is in the coverage of the registered satellite before the second paging. The average paging bandwidth of the two-step paging strategy is calculated as:

$$W_{\text{two-step}} = p_1\bar{W} + (1-p_1)\left[r(N-1)\bar{W}+(1-r)N\bar{W}\right] \quad (1)$$

where, $\bar{W}$ is the paging bandwidth under a satellite, N is the number of satellites connected to the FES and p_1 is the probability of successful paging at the first time.

In FES-LA design, all the satellites connected to the FES are required to page at the same time. So the average paging bandwidth is calculated as:

$$W_{FES} = N\bar{W} \quad (2)$$

The difference of average paging bandwidth between the Dual-LA and FES-LA is compared as:

$$W_{\text{two-step}} - W_{FES} = \left(p_1 - Np_1 - r + rp_1\right)\bar{W} \quad (3)$$

Under condition of, the normalized difference of average paging bandwidth is shown in Fig. 6.

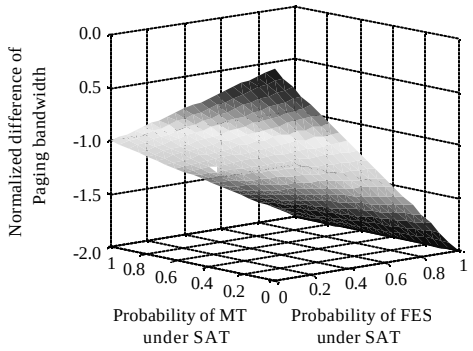

Fig. 6: Comparison of paging bandwidth

In Fig. 6, the normalized difference of average paging bandwidth is less than 0, which means the average paging bandwidth of the proposed two-step paging strategy in the Dual-LA is less than that of the paging procedure in FES-LA.

According to movement of MTs, the difference of the average paging bandwidth varies. When the MT is paged under coverage of the registered satellite, the two-step paging strategy cost the least average paging bandwidth. When the MT is paged outside coverage of the registered satellite and the registered FES is outside coverage of the registered satellite, the two-step paging strategy cost the highest paging bandwidth as same as that of the paging procedure in FES-LA.

CONCLUSION

In this study, a Dual-LA design is proposed with location update strategy and two-step paging strategy for location management in LEO satellite networks. With a registration controller in MTs, MTs only update location information at the time that both the registered FES and the registered satellite are lost. Performances show that the proposed Dual-LA strategy generates low location update signaling for normal MTs and decrease the location update cost for up-and-down MTs. The two-step paging strategy in Dual-LA decreases the average paging bandwidth, but long paging delay is introduced. Future research will be involved to improve the performance of paging delay.

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