低轨卫星通信网络中动态位置更新管理方案*

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A Dynamic Location Updating Management Scheme in Low Earth Orbit Networks

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Abstract: Mobility management is an important aspect in LEO (low earth orbit) systems. In terrestrial wireless networks, the movement of the user triggers location updating and determines the paging scheme, while in LEO satellite systems, the location updating and paging is mainly based on the movement of satellite. Terrestrial location management techniques must be altered to fit the LEO systems. This paper introduces a modified movement-based location updating and paging scheme in LEO networks. In this scheme the meta-cell concept is proposed which includes two spot-beams of one satellite. First the location management scheme based on the architecture with meta-cell location area is presented. Then an analytical model is applied to formulate the cost of location updating and paging for the movement meta-cell based dynamic location updating scheme. The comparison of performance between the meta-cell architecture method and the conventional signal-spot-cell architecture method is provided to demonstrate the cost-effectiveness and robustness of the proposed scheme under various parameters. To reduce the impact of meta-cell architecture on the location paging cost, a forced location updating strategy is presented which is used in the cases that the meta-cell includes the two spot-beams from different satellites.

Key words: location management; movement-based; terminal paging; meta-cell; location updating

摘 要: 移动性管理是LEO(低轨卫星(low earth orbit))卫星网络通信系统中的一个重要问题.提出了LEO网络中一种改进的基于移动的位置更新和寻呼方案.在这种方法中我们引入了“元小区”概念,它由两个相邻波束组成.首先阐述了基于“元小区”模型的位置管理策略,然后推导了基于移动的动态位置管理的数学模型,并利用该模型分别计算了 LEO 网络中单位呼叫的位置更新和寻呼代价.通过元小区方案和普通小区的在各种网络参数

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环境下的性能比较证明了“元小区”方法的有效性和健壮性.最后为了进一步减小“元小区”方法中的寻呼代价,提出了强制更新策略,它强制移动终端在穿越两颗卫星覆盖区的边界时进行位置更新操作.

关键词: 位置管理;基于移动;终端寻呼;元小区;位置更新

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Mobile satellite systems in the future mobile communication services will be integrated with terrestrial cellular systems to provide global coverage to a more diverse user population. Various satellite systems are envisaged, e.g., low earth orbit (LEO) satellite systems[1]. The term LEO is used to classify satellites with orbiting altitudes between 500 and 2000 km above the Earth's surface. The speed of a LEO satellite is ~26000km/hr, and the coverage period of the satellite is very short, around ten minutes. Due to the attached multi-spot-beam antennas, one satellite covers several cells and the maximum visibility time of a cell is around 1~2 minutes. The desire of providing worldwide roam and the growth of the signaling load corresponding to the increased size of LEO networks have critically increased the importance of an efficient paging and location updating method. Terrestrial location management techniques must be altered to fit LEO systems, including the methods that perform location updating and paging with respect to the moving cell of satellites, because mobile satellite systems present relevant differences when compared with terrestrial mobile networks. In terrestrial wireless networks, the movement of the user triggers location updating and determines the paging scheme, while in LEO satellite systems, the location updating and paging is mainly based on the movement of satellite.

In this paper, we concern the dynamic movement-based scheme in LEO networks. To reduce the updating cost, our scheme uses a meta-cell-based location area architecture for location management in LEO networks. The location update decision is determined when the mobile user crosses every twice the bound of spot-beam of a satellite. In addition to a simple terminal paging operation, we present a forced location update when the meta-cell includes two spot-beams form different satellites. This paper is organized as follows. In Section 1, the prevoius work on the location management in wireless networks is presented. In Section 2, we describe the meta-cell model for the location management in LEO networks. In Section 3, we formulate the average total cost per call in the movement-based scheme and propose the forced updating strategy. A performance comparison between our scheme and the normal cell is given in Section 4. Section 5 concludes the paper.

1 Prevoius Work

Location management consists of two main activities: location updating and terminal paging. In a terrestrial wireless network architecture, the network is divided into some LAs (location areas). One LA may include one or more cells. Location update occurs when a mobile terminal enters a new LA, and the mobile terminal updates its location in the database. The paging occurs when ever it is required to locate a user. When a call is coming, the network pages all cells to find the exact location of a mobile user. Performing location updating or paging will incur a significant amount of cost (e.g., wireless bandwidth and processing power of mobile user and base-station). It is well known that a large location area will result in a decrease in the cost of location update and an increase in the cost of paging, and vice versa. An efficient location management scheme must tradeoff between the cost of location updating and the cost of terminal paging. Optimal size of a LA is critical for minimizing the total cost of the location update and terminal paging.

In the existing PCS networks, the size of a location area is fixed. Every cell in a location area pages once when a call arrives for any mobile user currently registered in the location area. This is a static location updating and paging scheme in the sense that the location area is determined a priori. Under the static schemes, however, a mobile user close to the boundary of a location area may perform excessive location updates as he moves back and forth between two location areas. Dynamic location updating schemes are proposed for dealing with the problems of the static schemes. In the dynamic schemes, the location area size is determined dynamically according to the changes of mobility and calling patterns of the mobile users. Three kinds of dynamic location updating schemes: distance-based, movement-based and time-based, have been proposed[3-5]. The movement-based is the most practical and effective scheme in PCS networks[6]. The performance of movement-based location management in LEO networks is not analyzed in the literatures.

2 Meta-Cell Model

In this section, we present the meta-cell model for LEO networks and formulate the analytical mobility model of a mobile terminal. In this paper, we use the same mobility models as those[2] in LEO networks, but our work distinguishes with the prevoius work in the following aspects. Our location area of LEO networks is based on the meta-cell which consists of two spot-beams of the satellites. As shown in Fig.1, when the call is initiated, the MT is in point O. At the position of point A, the MT first crosses the footprint boundary of the beam-spot (a conventionally normal cell which relates to our meta-cell). In the normal cell architecture, the MT then crosses the boundary of the normal cell at point M and finally crosses the boundary of the normal cell at point B, but in the meta-cell architecture, it crosses the boundary of the meta-cell at point B. The boundary cross at point M will not be considered a boundary cross, because the MT movements in the same meta-cell 1 which consists of normal cell 1 and normal cell 2 respectively, are the second and third cells that the MT crosses in its movement direction. Let $t_{m,1}$ be the interval between the call initiation and the first meta-cell boundary cross, $t_{m,j}$ be the period between the call initiation and the ith meta-cell boundary cross, V_{orb} be the projection of orbit speed of the satellite onto the earth surface, R be the side length of the normal cells (In this paper the cell is supposed to be hexagonal). With the above parameters we can calculate the probability density function of t_m and $t_{m,j}$, as expressed in (1) and (2), and their Laplace-Stieltjes Transforms, as expressed in (3) and (4). The expectation value of $t_{m,1}$ is given by (5).

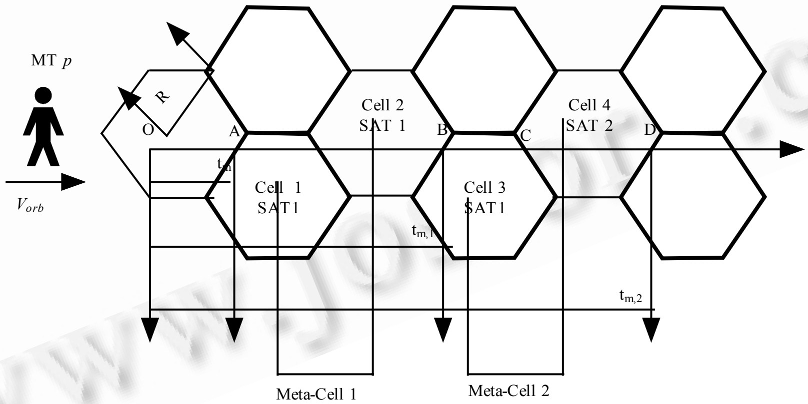

Fig.1 Meta-Cell architecture in LEO networks

$$f_{t_{m,1}}(t)=\frac{V_{orb}}{2R}\ln\left(\frac{2R}{V_{orb}t}\right) \tag{1}$$

$$f_{t_{m,i}}(t)=\frac{V_{orb}}{2R}\ln\left(\frac{2R}{V_{orb}t-\frac{i-1}{2}3R}\right),\frac{R}{V_{orb}}\left(\frac{i-1}{2}\right)\le t\le\frac{R}{V_{orb}}\left(\frac{i+1}{2}\right),i=1,2,... \tag{2}$$

$$G_{t_{m,1}}(s)=\int_{t=0}^{\infty}\mathrm{e}^{-st}f_{t_{m,1}}(t)\mathrm{d}t \tag{3}$$

$$G_{t_{m,i}}(s)=\mathrm{e}^{-\frac{i-1}{2}3R}G_{t_{m,1}}(s) \tag{4}$$

$$E(t_{m,1})=1/\lambda_m \tag{5}$$

3 Movement-Based Location Update

In this section, we formulate the cost of the location update and paging in the meta-cell movement-based location scheme. An analytical model to envaluate the performance of the movement –based location updating scheme is proposed in Ref.[6]. In this paper we apply this model in LEO networks with the meta-cell architecture to obtain the optimal threshold D_{opt}, which minimizes the total cost of the location updating and terminal paging. According to the movement scheme under the meta-cell architecture, the location update is performed after the dth meta-cell boundary crossing since the last location registration. Assume the following parameters:

U is the cost for performing a location updating operation,

P is the cost for a terminal paging operation,

d is the movement threshold for location update scheme,

t_c is the interval between calls to MT p, without loss of generality, we assume that the incoming call is a Poisson process and its probability density function is given in (6).

$\alpha(t)$ denotes the probability that there is 1 meta-cell boundary crossing between two call arrivals to MT p.

θ is the *CMR* (Call to Mobility), as given in (7) , the smaller the *CMR*, the higher the mobility of an MT.

The expected location updating cost per call arrival C_u is described in (8).

$$f_{t_c}(t)=\lambda_c e^{-\lambda_c t}, E(t_c)=1/\lambda_c, \tag{6}$$

$$\theta=\lambda_c/\lambda_m, \tag{7}$$

$$C_u=U\sum_{i=1}^{\infty}i\sum_{j=id}^{(i+1)d-1}\alpha(j), \tag{8}$$

$$C_u=U\frac{\left(1-\mathrm{e}^{-\frac{d-1}{2}3R}G_{t_{m,1}}(\lambda_c)\right)}{\theta}\times\left(\prod_{i=1}^{d-1}\mathrm{e}^{-\frac{i-1}{2}3R}\right)\frac{G_{t_{m,1}}(\lambda_c)^{d-1}}{1-G_{t_{m,1}}(\lambda_c)^{d}}. \tag{9}$$

The total expected location management cost per call arrival C_t is the sum of C_u and C_p[6]:

$$C_t=C_u+C_p=C_u+P*(3+d). \tag{10}$$

In the meta-cell scheme, when the meta-cell includes two cells from different satellites, the cost for terminal paging is very high. As shown in Fig.1, meta-cell 2 consists of cell 3 from sat 1 and cell 4 from sat 2. Paging with two satellites demands more power from them and the delay for paging is very high. To resolve this problem for meta-cell, we propose the forced location updating strategy. When the MT p crosses the boundary of the two satellites, the location update is triggered forcedly.

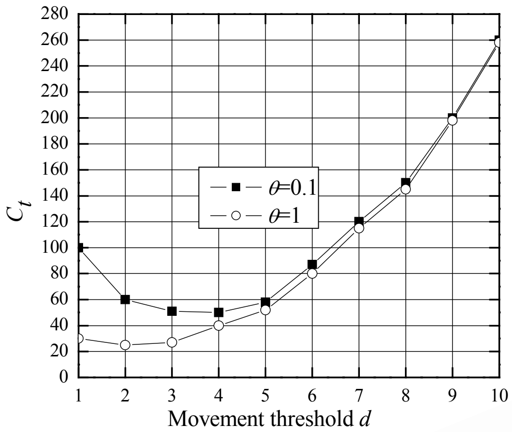

Fig.2 Total cost per call with threshold d

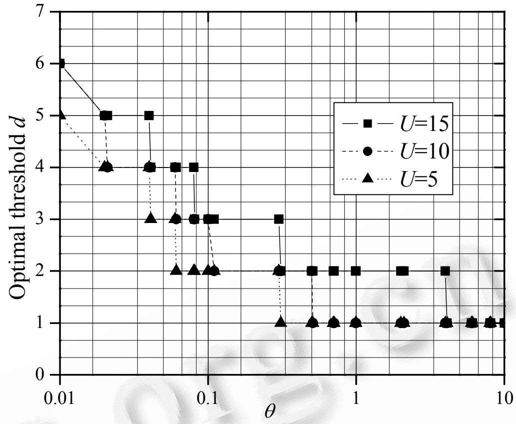

Fig.3 Optimal threshold with P=1

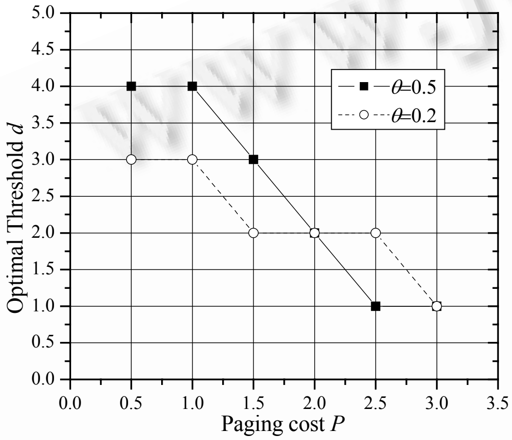

Fig.4 Optimal threshold d with U=1

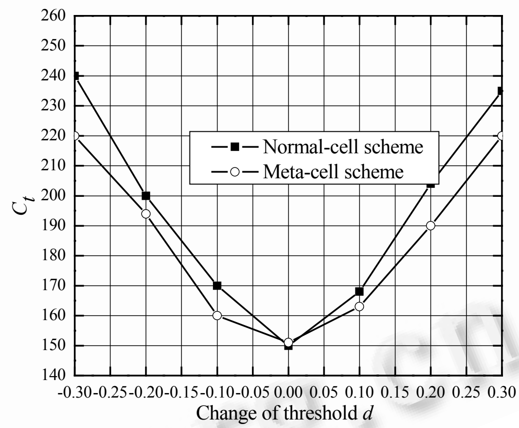

Fig.5 C_t and threshold d in two schemes

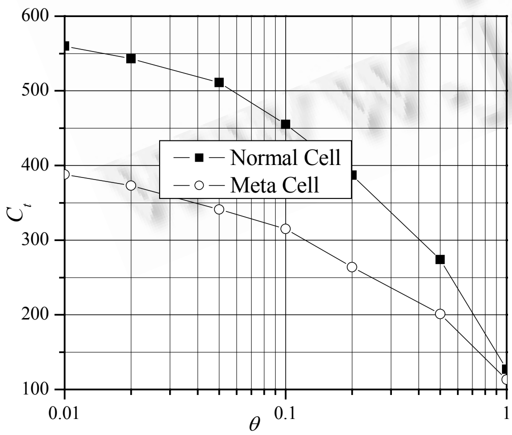

Fig.6 C_t and P in two schemes

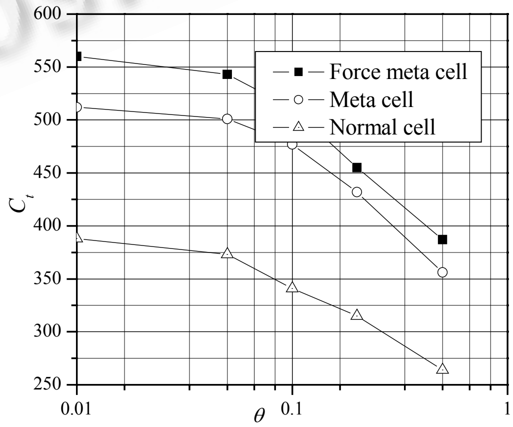

Fig.7 Performance comparison of three schemes

4 Simulation and Numerical Analysis

In this section we quantitatively compare the meta-cell scheme and normal cell scheme described in Section 3. The comparison includes the average location management cost per call C_t. This analysis provides insight into the effect of the key parameters of the meta-cell scheme, such as CMR, P,d,U. The simulation results are collected on SUN UltraOne workstation with software SATLAB and BONes.

4.1 Total cost per call arrival C_t

In this subsection, variation of C_t in the meta-cell scheme with some parameters is given. Figure 2 demonstrates that C_t varies, depending on parameters CMR and d. For the movement-based location management scheme in wireless terrastrial networks and the meta-cell scheme in LEO networks, the C_t varies widely as d changes. Under a given CMR, C_t can be reduced to a minimum value by selecting the appropriate value of d. We define the optimal total cost per call, C^*_t, to be the minimum of C_t that can be achieved by adjusting the movement threshold d. In addition, we define the optimal movement threshold d^* to be the movement threshold that results in the optimal total cost per call. The value of C^*_t and d^* depend on the system parameters. For different CMR, the value of d^* is different. When CMR=1, d^* is small, because the mobility of the user is low. When CMR=0.1, d^* increases, because the mobility of the mobile user increases. In order to minimize C_t, the movement threshold should be selected dynamically based on other parameters.

4.2 Optimal movement threshold *d*

In this subsection, we study quantitatively the effcts of various parameters on the optimal threshold d^*. These parameters include the update cost U, the paging cost P and the CMR. Other parameters used here are typical from the previous study[4].

Figure 3 captures the effect of U and CMR on the optimal movement threshold d* at the given value P=1. From Fig.3, we observe that the optimal threshold decreases as the CMR increases. As the CMR increases to 3, the optimal movement threshold is 1 for all U values. This result is easily understood. The higher value of CMR means lower mobility of mobile user, so the ideal value for the threshold is reduced to 1.

Figure 4 captures the effect of P and CMR on the optimal movement threshold d* at the given value U=1. From Fig.4, we find that the optimal threshold decreases as the P increases. As the P increases to 3, the optimal movement threshold is 1 for all CMR values. The higher value of P means that the paging cost is the main part of total cost per call of the mobile user, therefore the network should record the exact position of the mobile user to reduce the paging cost, and the ideal value for the threshold is reduced to 1.

4.3 Performance comparison between meta-cell and normal cell schemes

In this subsection, we compare the performence of our meta-cell scheme with the normal cell scheme. The evaluated metrics is the average per call total cost C_t. First, we evaluate the relation between C_t and d, which demonstrates the effectiveness of our meta-cell scheme. Second, we focus on the relation between C_t and P, which demonstrates the robustness of our meta-cell scheme.

Figure 5 shows the performance comparison result of the meta-cell and normal cell architecture schemes. The results demonstrate that the meta-cell scheme is more efficient than the normal cell scheme in term of total cost of location management when the optimal movement threshold changes. We vary the change from 0% to 30%. 0% means that the optimal movement threshold d is a constant and 30% means that the maximum change of the threshold d is 0.3 of its maximum. When the d dynamically changes, the number of the unnecessary location update increases in the normal cell scheme, and the meta-cell scheme decreases the probability of this location updating operation, so the total cost per call is reduced. The change of the threshold d is mainly caused by the estimation error λ_c of the average interval between two continuous call arrivals, and the complexity for the exact estimation of λ_c is high in LEO networks because of the limited power, memory and high speed of satellites. An efficient location management in LEO networks must deal with the impact of the unexact estimation of λ_c on the total cost per call. In this respect, the meta-cell scheme outgoes the normal cell scheme.

Figure 6 shows that the total location management cost varies with CMR under different unit location paging costs. From Fig.6, we observe that at the given value of CMR, the impact of P on the total location management cost C_t is small. When P increses form 0.3 to 0.5 at CMR=0.4, C_t only increases 10% in our meta-cell scheme. On the other hand, the increase is 20% in the normal cell scheme. Form above results, we can conclude that our meta-cell scheme is more robust than the normal cell scheme.

4.4 Performance of forced location update

Though our scheme reduces the cost of the location update, the paging cost of this scheme may increase when the meta-cell includes two cells from different satellites, as shown by the meta-cell 2 in Fig.1. To demonstrate the efficiency of the forced meta-cell scheme, we compare the performance of three schemes under several cell configurations. Let a denote the number of cell in one satellite footprint. The satellite constellation affects a. With the increasing complexity of constellation, a increases. Figure 7 shows the performance of the forced meta-cell scheme under different values of a. Form the results, we can see that the forced meta-cell scheme is the best of the three schemes.

5 Conclusions

In this paper, we introduce a meta-cell movement-based location management scheme in LEO networks. Our scheme combines the meta-cell architecture and movement-based location management to reduce the total cost for location update and terminal paging per call arrival. We also present the forced location update when the meta-cell includes two spot-beams from different satellites. Using an analytical model, we compare the performance of the meta-cell, the forced meta-cell and the normal cell schemes under various parameters. The simulation and numerical result indicates that our proposed scheme can efficienctly reduce the cost for location management in LEO Networks.

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