Analytical Model for Location Management for 3G Cellular Networks

S.D.Markande and S.K. Bodhe

Abstract-- **Location management is very important issue in personal communication service networks to ensure the mobile terminals to continuously receive services when moving from one place to other. In this paper, study of Dynamic movement- based location management scheme (DYNAMIC-3G) for 3G cellular networks has been presented. The analytical model is proposed and the cost functions are formulated analytically. The simulated results show that as the call interarrival time increases, the total cost of location updates and paging also increases. Also, as the distance between the current cell and the last cell where the VLR location update is performed increases, the cost function reduces.**

Index Terms-- **Location management, 3G cellular network, personal communication service**

I. INTRODUCTION

THE new Third Generation (3G) cellular services known as Universal Mobile Telecommunications System (UMTS) or IMT-2000 will sustain higher data rates and open the door to many internet related applications.

Mobility management is one of the most important issues in Personal Communications Service (PCS) networks. In the ANSI-41 [3] and Global System for Mobile communication (GSM) Mobile Application Part (MAP) [4], which are the 2G cellular networks, the two-tier mobility databases, Home Location Register (HLR), and Visitor Location Register (VLR), are utilized to support mobility management for Mobile Terminals (MTs). The service area is partitioned into Location Areas (LAs). Within each LA, there are a number of cells. In each cell, there is a Base Station (BS) and many MTs. All the BSs within one LA are connected to a Mobile Switching Center (MSC). All the MSCs are finally connected to the Public Switching Telephone Networks (PSTN). Each LA is associated to a VLR, which is used to store the temporary records of MTs profiles and location information. An HLR is used to record mobile user's permanent subscription information. With increase in roaming users, the signaling traffic increases. In order to reduce the roaming signaling traffic, the Gateway Location Register (GLR) within the (UMTS) Core Network is proposed in specification 3GPP 23.119 [5]. The GLR is a node between the VLR and / or SGSN (Serving GPRS Support Node) and the HLR. It handles location management of roaming subscribers in visited network without involving the HLR in every change of LAs. Therefore, the signaling traffic between the visited mobile system and the home mobile system will be reduced and the location updating and the handling of user profile data across network boundaries are optimized. The GLR is located in the visited network. It stores the roamer's information, and handles location management within the network.

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The basic operations in location management are location update and paging. Location update is a process through which a system keeps track of the location of mobile terminals that are not in conversations. Paging is a search process conducted in a Paging Area (PA). A PA may include one or more cells. When an incoming call arrives, the system searches for the mobile terminal by sending polling signals to cells in the PA. Many location management schemes have been proposed for PCS cellular networks with two-tier mobility databases [6], [7], [8]. Basically, these are: static schemes and dynamic schemes. In a static location update scheme with two-tier mobility databases (STATIC-2G), the HLR location update and VLR location update are performed when an MT enters an LA and the PA is the same as the LA. Therefore, the PA size is fixed. There are three kinds of dynamic location update schemes in which the PA size is variable: movement-based location update, distance-based location update, and time-based location update. Similar to the static location update scheme, the HLR location update is performed when an MT enters an LA in a dynamic location update scheme. In the distance based location update scheme, the VLR location update is performed when the distance between the current cell and the last cell where the VLR location update is performed reaches a threshold d in terms of number of cells. In the time-based location update scheme, the VLR location update is performed in each d units of time. The movement- based location update scheme is the most practical one among the three kinds of dynamic location update schemes [7].

In a movement-based scheme (DYNAMIC-2G), a VLR location update is performed either when an MT crosses an

LA boundary or when the MT completes d movements between cells, where d is the movement threshold. The PA is the area within the LA, where the last VLR location update is performed, and a circular area with the diameter *d-1* and with the center where the last VLR location update is performed. Therefore, a PA size is a variable. Most existing movement-based schemes [7], [8] only consider that a VLR location update occurs when the MT completes d movements between cells, and fail to consider the case that a VLR location update also occurs when the MT crosses an LA boundary. It is reasonable that a VLR location update also occurs when the MT crosses an LA boundary since an HLR location update occurs anyway. The problem becomes much more complex when both of the above cases are considered. The difficulty exists since it is very hard, if not impossible, to derive the number of cell boundary crossings between two LA boundary crossings when the residence time in an LA follows a general distribution.

II. MOBILITY DATABASE STRUCTURE

The DYNAMIC-3G location management scheme for 3G wireless cellular systems (particularly UMTS) is described here. Fig. 1 shows network architecture for UMTS system with the GLR. A GLR contains roamer's subscriber profile and location information. At the first location update procedure under the GLR, the subscriber profile information is downloaded from the HLR to the GLR. The GLR handles Update Location messages from the VLRs as if it were the HLR of the subscribers at the subsequent location updates. It enables the location update procedure to be handled locally for the movement within the visited network so that the costly intervisited-network signaling for location management can be minimized. It keeps the profile information until a Cancel Location message is received from the HLR. The relationship between the GLR and the HLR in 3G wireless systems is the same as that between the VLR and the HLR in the 2G wireless cellular systems (such as in GSM) in terms of the signaling traffic for location management. From the viewpoint of the VLR at the visited network, the GLR can be treated as the roaming user's HLR located at the visited network. From the viewpoint of the HLR at the home network, the GLR can be treated as the VLR. A GLR can interact with multiple VLRs. Here the Ring concept for the movement-based location update schemes is used: Ring-*r* has 6r cells except that Ring-0 has only one cell, where $r = 0; 1; 2; \ldots$. The types of location updates in 3G cellular networks are HLR location updates, GLR location updates, and VLR location updates. Location updates and paging procedures will cause a significant amount of cost such as wireless bandwidth and processing power at the mobile terminals, the BSs and mobility databases. In DYNAMIC-3G scheme, unlike the 2G networks, the service area is partitioned into Gateway Location Areas (G-LAs).A G-LA is further partitioned into Location Areas (LAs). An LA consists of a group of cells. An HLR update is performed when an MT crosses a location boundary of a G-LA; a GLR location update is performed when an MT crosses a boundary of an LA. For the DYNAMIC-3G scheme, a Paging Area (PA) includes a number of cells within an LA (which is also within a G-LA), while the PA's size is variable. A VLR location update is performed when an MT completes *d* movements between cells, where *d* is the movement threshold. An HLR location update involves both a GLR location update and a VLR location update, and a GLR location update involves a VLR location update. A PA is the area within the LA, where the last VLR location update is performed, and the circle area with the diameter being *d-1* and the center where the last VLR location update happens.

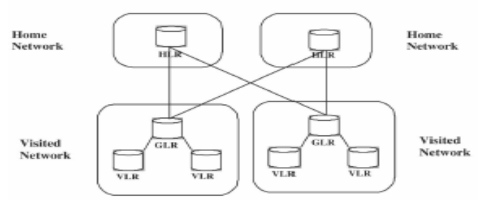


Fig. 1. Mobility database architecture.

III. MATHEMATICAL BACKGROUND

Lemma 1. Let $\{N_1(t), t \geq 0\}$ and $\{N_2(t) \geq 0\}$ be two independent Poisson processes with rate λ_1 and λ_2, respectively. Let t1 and t_2 denote the times of the first event of the first process and the second process, respectively. The probability of one event occurs in the first process before one event occurs is given as follows:

$$P(t < t_2) = \delta(\lambda_1, \lambda_2) \equiv \frac{\lambda_1}{\lambda_1 + \lambda_2} \quad \text{--(1)}$$

Lemma 2. Let $\{N_1, (t), t \geq 0\}$ and $\{N_1, (t), t \geq 0\}$ be two independent Poisson processes with rate $\lambda_1 \, and \, \lambda_2$ respectively. Let $\alpha(\lambda_1, \lambda_2, \pi)$ denote the probability that exactly n events occur in the first process between two events, which occur in the second process. We have,

$$\alpha(\lambda_1, \lambda_2, n) = \delta(\lambda_2, \lambda_1)\,[\delta(\lambda_1, \lambda_2)]_n \quad \text{--(2)}$$

Lemma 3. Let x be real number so that $0 < x < 1$. We have the following equations:

$$\sum_{i=0}^{\infty} x^i = \frac{1}{1-x}, \quad \text{--(3)}$$

$$\sum_{i=0}^{\infty} i x^i = \frac{x}{(1-x)^2}, \quad \text{--(4)}$$

$$\beta(\lambda_1, \lambda_2, d) \equiv \sum_{m=0}^{\infty} m \sum_{k=md}^{(m+1)d-1} \alpha(\lambda_1, \lambda_2, k) = \frac{\delta(\lambda_1,\lambda_2)^d}{1-\delta(\lambda_1,\lambda_2)^d} \quad \text{--(5)}$$

$$\sum_{j=0}^{\infty} \alpha(\lambda_1, \lambda_2, j) = 1, \quad \text{--(6)}$$

$$\sum_{j=0}^{\infty} j\alpha(\lambda_1, \lambda_2, j) = \frac{\lambda_1}{\lambda_2}, \quad \text{--(7)}$$

$$\Upsilon(\lambda_1, \lambda_2, d) \equiv \partial\beta(\lambda_1,\lambda_2)^d = \frac{\delta(\lambda_1,\lambda_2)^d \log \delta(\lambda_1,\lambda_2)}{[1-\delta(\lambda_1,\lambda_2)^d]^2} < 0$$

$$\phi(\lambda_1, \lambda_2, d) \equiv \frac{\partial^2 \beta(\lambda_1,\lambda_2,d)}{\partial^2 d} > 0 \quad \text{--(8)}$$

$$= \frac{[1+\delta(\lambda_1,\lambda_2)^d]\delta(\lambda_1,\lambda_2)^d \log^2 \delta(\lambda_1}{[1-\delta(\lambda_1,\lambda_2)^d]^3} > 0 \quad \text{--(9)}$$

$$\lim_{d\to 0^+} \Upsilon(\lambda_1, \lambda_2, d) = -\infty \quad \text{--(10)}$$

Lemma 4. Let $\{N_1(t), \geq 0\}$ and $\{N_2(t), \geq 0\}$ be two independent Poisson processes with rate λ_1 and λ_2, respectively. Let N denote the mean number of events occurring in the first process between two events in the second process. We have $N = \lambda_1, \lambda_2$.

The mean number of area boundary crossings between two call arrivals is $N = \eta / \lambda$.

IV. ANALYTICAL MODEL

The total cost function for DYNAMIC-3G scheme is derived here. It is assumed that mobile terminal's residence times follow exponential processes with mean $1/\eta_{GLA}$, $1/\eta_{LA}$, and $1/\eta_{cell}$ in a G-LA, an LA, and a cell, respectively and call arrivals to each mobile terminal follow a Poisson process with rate λ. Let C_{TOTAL} =Total cost, C_{HLR}= HLR location update cost, C_{GLR} =GLR location update cost, C_{VLR} = VLR location update cost, and C_{Paging} = Paging cost, R_{HLR}= HLR location update cost, R_{GLR}= GLR location update cost, R_{VLR}= VLR location update cost, R_{poll} = the cost for polling a cell.

$$C_{DYNAMIC\_3G} = C_{HLR} + C_{GLR} + C_{VLR} + C_{Paging} \quad \text{--- (11)}$$

$$C_{HLR} = R_{HLR} \frac{\eta_{GLA}}{\lambda} \quad \text{--- (12)}$$

$$C_{GLR} = R_{GLR} \frac{\eta_{LA}}{\lambda} \quad \text{--- (13)}$$

To derive C_{VLR}, the movement of MTs among PAs, LAs, and G-LAs is considered. By Lemma 2, the probabilities that there are i G-LAs, j LAs, and k cells' boundary crossings between two call arrivals are $\alpha(\eta_{GLA}, \lambda, i)$, $\alpha(\eta_{LA}, \lambda, j)$, $\alpha(\eta_{cell}, \lambda, k)$, respectively.

Assume that when the previous phone call arrives, the MT resides in the G-LA,GLA_0, and the LA, $LA_{0,0}$, where $LA_{0,0}$ is one LA in GLA_0. Let N_{VLR}= the average number of VLR location updates between two call arrivals, N_{VLR_i} = the average number of location updates in VLRs with our movement-based location update scheme when the MT receives the next phone call in the ith GLA, GLAi , (i = 0, 1, 2, . . .) and $N_{VLR\,i,j}$ = the average number of location updates in VLRs with our movement based location update scheme when the MT receives the next phone call in the jth LA, $LA_{i,j}$, (j = 0, 1, 2, . . .)in the ith G-LA, GLAi , (i = 0, 1, 2, . . .). The above G-LAs and LAs are indexed by the time-sequence of the MTs entering . In other words, the ith G-LA, GLAi , (i = 0, 1, 2, . . .) is the ith GLA which the MT enters when beginning at the 0th G-LA,GLA0. Similarly, the jth LA, $LA_{i,j}$, (j = 0, 1, 2, . . .), is the jth LA which the MT enters within the ith G-LA, GLAi , (i = 0, 1, 2, . . .). Between two call arrivals, if the number of GLA boundary crossings is i, the number of VLR location updates is N_{VLR_i} , and the probability that there are i G-LA boundary crossings is $\alpha(\eta_{GLA}, \lambda, i)$. $N_{VLR_i}\,\alpha(\eta_{GLA}, \lambda, i)$, is the average number of VLR location updates if the number of GLA boundary crossings is i. Therefore, we obtain (14).

Similarly, between two call arrivals, if the number of LA boundary crossings is j within i G-LA boundary crossings, the number of VLR location updates is $N_{VLR_{i,j}}$ and the probability that there are j LA boundary crossings is $\alpha(\eta_{LA}, \lambda, j)$. $N_{VLR_{i,j}}\,\alpha(\eta_{LA}, \lambda, j)$ is the average number of VLR location updates if the number of LA boundary crossings is j within i G-LA boundary crossings. Therefore, we obtain (15).

$$N_{VLR} = \sum_{i=0}^{\infty} N_{VLR,i}\,\alpha(\eta_{GLA}, \lambda, i) \quad \text{--- (14)}$$

$$N_{VLR,i} = \sum_{j=0}^{\infty} N_{VLR,i,j}\,\alpha(\eta_{LA}, \lambda, j) \quad \text{--- (15)}$$

$$N_{VLR,i,j} = i\frac{\eta_{GLA}}{\eta_{LA}}\beta(\eta_{cell}, \eta_{LA}, d) + j\beta(\eta_{cell}, \eta_{LA}, d) + \beta(\eta_{cell}, \eta_{LA}, \lambda, d) \quad \text{--- (16)}$$

$$N_{VLR} = \beta(\eta_{cell}, \eta_{LA}, d)\frac{(\eta_{GLA})^2}{\lambda\eta_{LA}} + \beta(\eta_{cell}, \eta_{LA}, d)\frac{\lambda_{LA}}{\lambda} + \beta(\eta_{cell}, \lambda, d) \quad \text{--- (17)}$$

Let N_{cell} be the number of cells in a paging area. Assume that the PCS networks have hexagonal configurations. Then,

$$N_{cell} \approx 1 + \sum_{m=0}^{d-1} 6m = 3d^2 - 3d + 1$$

$$N_{paging} = R_{poll}(3d^2 - 3d + 1) \quad \text{--- (18)}$$

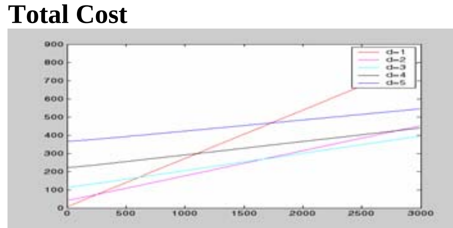
Hence, the total cost per call arrival for movement based location update scheme is,

$$C_{DYNAMIC-3G} = R_{HLR}\frac{\eta_{GLA}}{\lambda} + R_{GLR}\frac{\eta_{LA}}{\lambda} + R_{poll}(3d^2 - 3d + 1) + R_{VLR}\beta(\eta cell, \eta_{LA}, d)\frac{(\eta_{GLA})^2}{\lambda\eta_{LA}} + R_{VLR}\beta(\eta cell, \eta_{LA}, d)\frac{\eta_{LA}}{\lambda} + R_{VLR}\beta(\eta cell, \lambda, d) \quad \text{--- (19)}$$

V. SIMULATED RESULTS

Fig.2 shows the obtained results which shows the total cost of the DYNAMIC-3G scheme over the call interarrival time for different thresholds.

Total Cost



Call Interarrival Time

Fig. 1. Call Interarrival Time vs. Total Cost for different thresholds

VI. CONCLUSIONS

The study shows that-

1. As the call interarrival time increases, the total cost of location updates and paging also increases. In other words, as the CMR decreases (the mobility increases), the total cost increases.
2. Also as the distance between the current cell and the last cell where the VLR location update is performed increases, the cost function reduces.

VII. REFERENCES

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VIII. BIOGRAPHIES

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