Path Location Register for Next-Generation Heterogeneous Mobile Networks

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Abstract. Deployment of a global all IP wireless/mobile network is not a straightforward decision. Heterogeneous mobile networks combined with wireless "hot-spot" locations seams to be one of the most realistic early deployments. Commercial public wireless LAN solutions however offer proprietary location management capabilities compared to the traditional cellular networks. The increasing demands for heterogeneous services necessitate fast and efficient location management mechanisms that allow the future personal communication service network to locate mobile users roaming across different systems. This paper introduces and analyzes a Path Location Register (PLR) mechanism for Location Management that reduces significantly the cost of mobile terminal location update and paging. The performance evaluation of the PLR scheme demonstrates its effectiveness in next generation heterogeneous mobile networks.

1. Introduction

Forth generation (4G) all-IP networks are expected to provide a substantially wider and enhanced range of interactive multimedia services. Terminal and personal mobility will enable users to access their personal profile, independently of the terminal type or the point of attachment to the network. However, deployment of a global all-IP wireless/mobile network is not a straightforward decision, due to technical and economical issues. A phased approach, integrating heterogeneous 2G+/3G and wireless LAN technologies on "hot-spot" locations, appears to be one of the most realistic early deployment approaches. In order to facilitate global connectivity with maximum bandwidth and minimum cost a variety of mature wireless/ mobile technologies can be considered. In the local area, the Wireless LAN (WLAN) is a well-established and expanding market, with superior bandwidth compared to any cellular technology and supported by international standards (i.e. IEEE 802.11 a, b, g, e, ETSI HiperLAN I & II, Bluetooth). Regarding the wide area network, mature cellular standards are already deployed (i.e. GPRS, EDGE, IS-95, CDMA). In case of absence of cellular network, satellite links can fulfill the requirement for worldwide coverage [1].

Connectivity at the physical layer is mandatory, but this is only a part of the problem. The increasing demand for heterogeneous services necessitates fast and efficient location management mechanisms that allow the future personal

Zahariadis T. and Voliotis S. (2004).
Path Location Register for Next-Generation Heterogeneous Mobile Networks.
In *Proceedings of the 3rd International Workshop on Wireless Information Systems*, pages 142-151
DOI: 10.5220/0002670301420151

communication service (PCS) network to locate mobile users roaming across different systems. Generally a location management scheme contains two processes: location update and paging. In case of uniform systems, many location management schemes have been proposed and evaluated for both cellular systems [2][3] and computer oriented networks [4][5]. In case of heterogeneous PCS systems, the registration, call delivery and handset identity are discussed in [8], while methods for enhancing the network's location management in multitier (GSM, IS-95, IS-54) systems have been proposed in [6][7]. Roaming across systems imposes a significant increase in signaling traffic. However, 3G+ and 4G Mobile Networks will not be voice-centric, but QoS aware data centric; thus specific location management algorithms that take into account parameters like QoS, call and packets loss, paging delay should be considered. In this paper, a Location Management scheme for heterogeneous networks is analyzed and evaluated. The scheme is based on the introduction of a layer of Path Location Register (PLR) servers along with roaming and paging algorithms that handle mobile terminals mobility on local or regional base. The performance evaluation of the proposed scheme demonstrates its effectiveness in heterogeneous next generation mobile networks.

2. All-IP heterogeneous network architecture

In a multitier system consisting of heterogeneous wireless technologies, different networks are combined in order to cover a specific geographical area. Each network may comply with different specifications and standards, and encompass different number of cells, while cell overlapping is expected. Cells' physical or logical diameters and transmission characteristics (e.g. bandwidth, maximum number of terminals, connection set-up time, call tear-down probability) may vary. Even in the same tier, parameters like the signaling messages sequence and format, the authorization rights etc. may differ.

For example in Fig. 1, three different networks are shown. A mobile terminal (MT) may roam between cells of the same tier or between cells of different networks. In case MT enters an area where cells overlap, it may select to handoff to the newly entered network or remain attached to the previous one. The handover selection may be based on the networks'/ cells' characteristics or on the network handoff/location management overheads. As shown, an extended Home Location Register (HLR+) may control a number of different networks either of the same or of different types. When a terminal roams between cells of the same type, it may or may not change servicing area (and Visiting Location Register, VLR). For example, when the MT roams from cell A to cell B, it does not change servicing area or network. When it roams from cell B to C, it changes cell, servicing area and network; thus it changes from VLR2 to VLR3. Moreover, when the terminal roams from cell D to E, it changes VRL and HLR+, though it does not roam to a new wireless network technology.

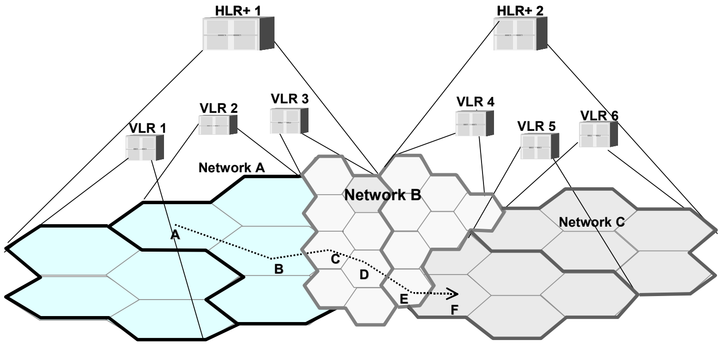


Fig. 1. Network Hierarchy Architecture

The problem in the above architecture is that the respective VLRs and HLR+ have to be updated every time the MT roams to a new cell. This heavily increases the signaling overhead especially in case the MT moves back and forth in the surroundings of a servicing area, the so-called "ping-pong" effect. Apart from the extensive signaling, the ping-pong roaming effect causes additional overheads, due to the locality of the IPv4 addresses. Mobile IP and various alternatives and extensions [8] aim to face the problem of mobility in both wireless and mobile environment, but none has yet managed to take into account the mobility management, the QoS requirements and the heterogeneity of the network, while other (i.e. HAWAII [9], Cellular IP, UniWA [10]) use layer-3 signaling, increasing the handover latency and originating significant packet losses.

3. Path Location Register

Aiming to solve efficiently the mobility problem in heterogeneous all-IP wireless/mobile networks, we introduce a Path Location Register (PLR) management scheme. The scheme includes an intersystem roaming and a paging algorithm.

In the proposed schema, a PLR servers' layer is introduced in lower hierarchy from the VLR that trail the MT when roaming, primarily on the boundaries between IP networks. Terminals are assumed to be multi-band/multi-standard devices able to gain connectivity either in macrocell or microcell environment. Each MT is permanent associated with an extended HLR+. When the MT moves to a visiting network, it is temporary assigned to a VLR, which updates the HLR+ for the terminal position. In parallel, a PLR is also informed in order to keep track of the MT movements in local basis. When the MT roams to a neighboring cell, the PLR may continue to route traffic to the terminal either directly or via a PLR that is "closer". The distance between the terminal and the PLR may be defined as a function of the cell characteristics (diameter, load, current number of terminals, QoS capabilities), the terminal motion (speed, direction) or the call requirements (bandwidth, handoff sensitivity, error correction). As the traffic is routed via the PLR, it can easily track the MT and inform the neighboring PLR when the MT is approaching the servicing area boundaries. When the MT roams to a cell or network of different type, the PLR may handle additional issues, such as air interface compatibility, user/terminal authentication, billing etc.

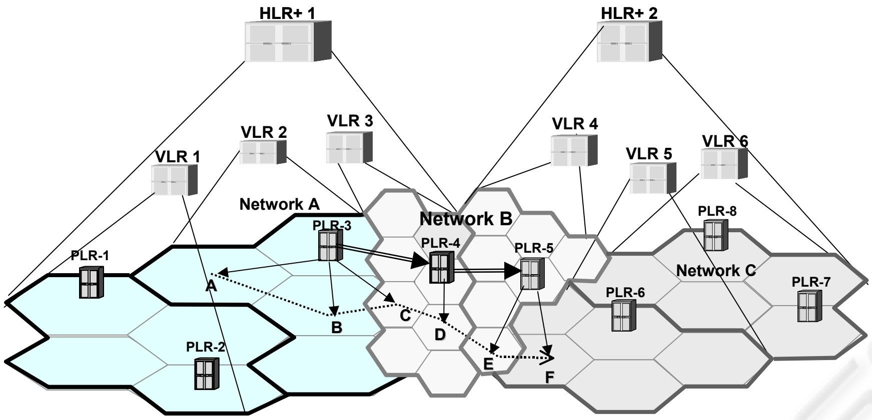
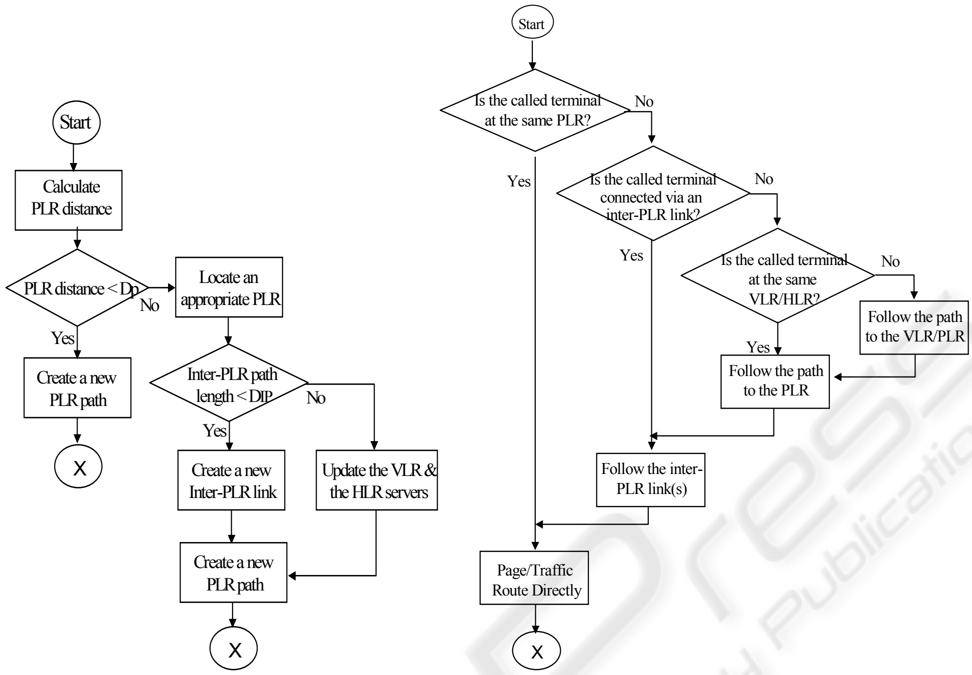


Fig. 2. Path Location Register Network Architecture

For example in Fig. 2, when the MT is located in cell A, it is also assigned to HLR+ 1, VLR1 and PLR3. The same PLR keeps tracking the MT and routes traffic until it reaches position C. As the networks A and B overlap, the MT may decide to avoid roaming to Network B, but continue to communicate via PLR3. Nevertheless the PLR4 is informed that the terminal has entered its servicing area, so according to MT move, call requirements and network load, the PLR4 performs a preliminary resource allocation in the neighboring cells. For instance if Network B is a public Wireless LAN, the MT may select to keep the cellular interface active, while in parallel the MT's 802.11 interface and the network access node are prepared for a potential handoff. In this way, if the MT returns to cell B no actual roaming is performed, while if the MT roams to cell D, traffic is routed via PLR4. As PLR3 and PLR4 belong to the same HLR+, they are considered "close by"; thus the VLR layer is not informed at all, while the roaming is handled in PLR layer. According to network ownership, these PLRs may be considered "close by" or "remote". For example, if the MT roams to cell E, traffic may be routed via direct links between PLR3, PLR4 and PLR5, or the VLR and HLR+ hierarchy may be informed. The drawback is that inter-PLR links increase the paging delay; thus thresholds in PLR links paths are introduced.



a) PLR Roaming Algorithm b) PLR Paging Algorithm

Fig. 3. PLR Roaming Algorithm & PLR Paging Algorithm

In Fig. 3a the PLR roaming algorithm flow diagram is shown. For simplicity we assume that there are no ownership, deployment or other issues, but the decision for handoff is based only on performance criteria. As shown two thresholds are measured: the D_P, which is the maximum allowed distance between the MT and the PLR and the $D_{IP,}$ which is the maximum length of the inter-PLR link. In classical roaming algorithms, the VLR and the HLR+ should know the path to the terminal in order to be able to route incoming calls and packets. This would result in many routing entries updates, and many VLR and HLR+ signaling messages. In order to minimize this overhead in the PLR scheme, we postpone the HLR+ update and treat the roaming in local or regional layer. When a terminal roams to a new servicing area the distance between the servicing PLR is checked. If it is less than the maximum distance D_P a new PLR route is created and no further actions take place. If the maximum distance is exceeded, an “appropriate” new PLR server is located and an inter-PLR link is created. Many criteria can be involved in the selection of the new PLR: the distance from the terminal, the location, the terminal’s call and connection requirements, the PLR load, or even statistical measurements and profiles may be involved. For simplicity reasons each PLR has a list of neighboring PLR’s, so searching is efficient. When creating the inter-PLR link, an optimal routing algorithm may be invoked to check if the path has some cycles, or if a path between the PLR servers already exists. If no “appropriate” PLR can be found, the VLR and HLR+ are informed and the complete path to the terminal is refreshed.

Due to PLR roaming algorithm, the paging algorithm is also modified. Additionally to direct indexing from HLR+ to MT, we have to trace the PLR and the inter-PLR links if exist. As shown in Fig. 3b, the paging/traffic routing algorithm starts from the PLR that the MT is located, and follows a bottom up approach. If the intermediate layers fail to locate the MT in the servicing area, the HLR+/VLR layer is reached and normal routing is followed. The paging delay is the overhead, the PLR has to pay for benefit of less signaling at the roaming phase. However, if the paging is not a critical factor, the longer the inter-PLR link chain, the largest saving could be obtained. In some cases due to the heterogeneity of the network, the PLR paging/traffic routing algorithm may be even more efficient than normal paging, as it assumes larger servicing areas and omits searching in adjacent network systems.

The main benefit of the PLR scheme is that it significantly reduces the signaling cost and the set-up overhead caused by the intersystem roaming. Traffic routing is not modified, but the network traces the MT as it moves from cell-to-cell and from network-to-network and adds or drops links and paths accordingly. Moreover, roaming is handled locally in each servicing area, so the ping-pong effect is omitted. Another advantage of the PLR scheme is that the additional layer of PLR servers does not affect the original database architecture. The additional hardware and communication links between PLRs can be safely balanced by reducing the number of VLR servers in an area.

4. Performance Analysis

In this section we adapt the analytical model of [12] in order to evaluate the performance of the proposed PLR scheme. Lets assume that the calls towards a terminal have mean rate λ and the mean time a terminal is located in the servicing area of a PLR is $1/\mu$. Then the terminal call-mobility ratio *(CMR)* in this area would be $CMR=p=\lambda/\mu$. If the PLR algorithm is not applied, the HLR+ and the VLR servers will be informed every time the terminal roams to a new cell. Otherwise it will be informed each time the path to the terminal exceeds a maximum distance of $D_{PLR} = D_{IP} + D_P$, where D_{IP} is the length of inter-PLR links and D_P is the distance between the last PLR and the terminal. If we assume that by average the terminal changes PLR every T_P moves and the D_{IP} has a length of T_{IP} links, the D_{PLR} distance will by average result after $T_P T_{IP}$ moves assuming that no circles are measured.

If the user roams to n different PLR servers between two calls the HLR+ will be updated $N_{HLR}=\left\lfloor \frac{n}{T_{IP}T_P} \right\rfloor$ times. The number of PLR routing table updates will be $N_{PLR}=\left\lfloor \frac{n}{T_{IP}} \right\rfloor - \left\lfloor \frac{n}{T_{IP}T_P} \right\rfloor$, while the number of inter-PLR routing table updates will be $N_{IPLR}= n - \left\lfloor \frac{n}{T_{IP}} \right\rfloor$. The expected cost for the PLR roaming algorithm will be:

$$\overline{C_{ROAM}} = \sum_{n=0}^{\infty} \{N_{HLR} \cdot C_{HLR} + N_{IPLR} \cdot C_{IPLR} + N_{PLR} \cdot C_{PLR}\} pr(n) \quad \textbf{(1)}$$

where C_{HLR} is the cost of an HLR+ update, C_{IPLR} the cost for inserting/updating an inter-PLR link, C_{PLR} is the cost for updating a routing entry, and $p_r(n)$ is the probability that n different PLR servers are crossed within two calls. After the HLR+ is updated, the length of the path to the terminal consists of

$$L_{PLR} = \left\lfloor \frac{n - \left\lfloor \frac{n}{T_{IP}T_P} \right\rfloor T_{IP}T_P}{T_{IP}} \right\rfloor \tag{2}$$

PLR links (entries at the PLR routing tables), and

$$L_{IPLR} = n - \left\lfloor \frac{n}{T_{IP}T_P} \right\rfloor T_{IP}T_P - N_{IPLR}T_{IP} \tag{3}$$

Inter-PLR links. If C_P is the cost for a direct terminal paging, O_{PLR} is the overhead to follow an entry in the PLR routing table and O_{IPLR} the relevant overhead for the inter-PLR roaming, the overall cost for the PLR paging algorithm will be

$$\overline{C_{PAGE}} = \sum_{n=0}^{\infty} \left\{ L_{PLR} \cdot O_{PLR} + L_{IPLR} \cdot O_{IPLR} \right\} p_r(n) + C_p \tag{4}$$

In order to evaluate the $p_r(n)$, we assume that the mean rate λ of the call arrivals is a Poison distribution and the interval between two PLR roaming instances is a random variable, which for simplicity has a general density function described by a Gamma distribution with mean $1/\mu$. The Laplace transform of the Gamma distribution is

$$f_{C_r}(\lambda) = \left(\frac{\gamma\mu}{\lambda + \gamma\mu} \right)^{\gamma} \xrightarrow{\gamma = 1} f_{C_r}(\lambda) = \frac{1}{1+p}$$

where $p=\lambda/\mu$. For simplicity we have assumed an exponential distribution, thus $\gamma=1$. It can be shown that (1) and (4) are equal to

$$\overline{C_{ROAM}} = \frac{C_{IPLR}}{p} + \frac{C_{PLR} - C_{IPLR}}{(1+p)^{T_{IP}} - 1} + \frac{C_r - C_{IPLR}}{(1+p)^{T_{IP}T_P} - 1} \tag{5}$$

$$\overline{C_{PAGE}} = C_p + \frac{O_{IPLR}}{p} - \frac{O_{IPLR}T_{IP}T_P}{(1+p)^{T_{IP}T_P} - 1} + \frac{(O_{PLR} - T_{IP}O_{PLR})[(1+p)^{T_{IP}T_P} - T_P(1+p)^{T_{IP}} + T_P - 1]}{[(1+p)^{T_{IP}T_P} - 1][(1+p)^{T_{IP}} - 1]} \tag{6}$$

Without the PLR algorithm the overall cost for maintaining the location information and page the terminal is:

$$C = \frac{C_r}{P} + C_P \tag{7}$$

While the overall cost for the PLR architecture is

$$C_{PLR} = \overline{C_{ROAM}} + \overline{C_{PAGE}} \tag{8}$$

The roam (G_{ROAM}), page (G_{PAGE}) and overall (G_{Total}) gains are

$$G_{ROAM} = \frac{\overline{C_{ROAM}}}{C_r}\ , \ G_{PAGE} = \frac{\overline{C_{PAGE}}}{C_p}\ , \ G_{TOTAL} = \frac{C_{PLR}}{C} \tag{9}$$

From (1)-(9), the $\overline{G_{TOTAL}}$ can be evaluated. If we assume that $C_{IPLR} = 2O_{IPLR}$ and $C_{PLR} = 2O_{PLR}$, from (8)-(9), we can depict the PLR roam, page and total gains as a function of terminal Call-Mobility Ratio (*p*).

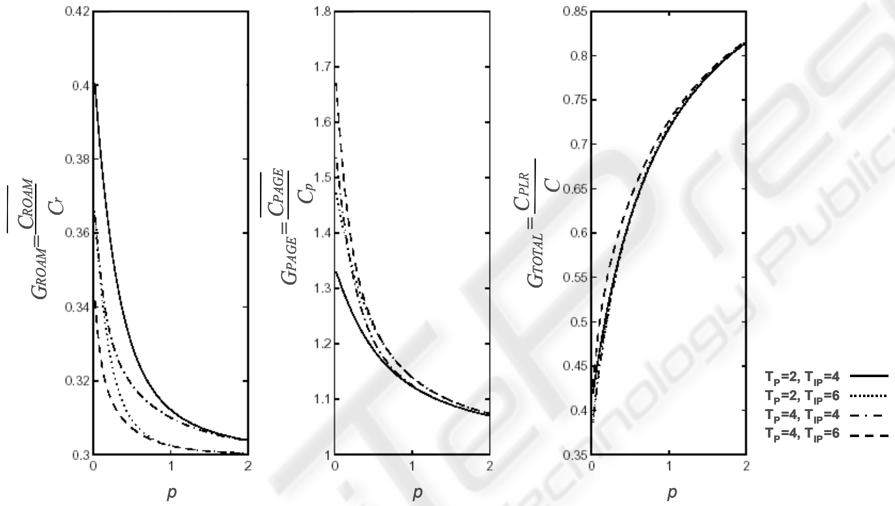


Fig. 4. PLR Algorithms Gain ($C_{PLR} = 0.45$, $C_{IPLR} = 0.3$)

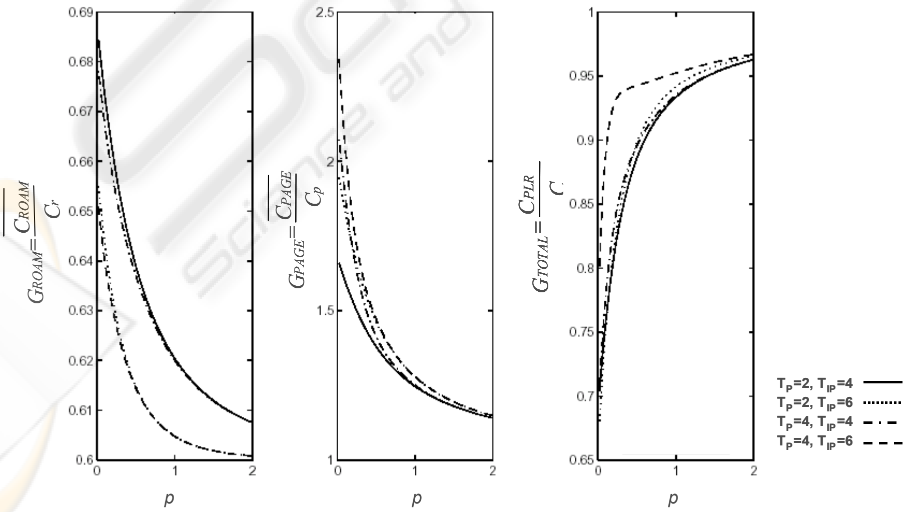


Fig. 5. PLR Algorithms Gain ($C_{PLR} = 0.9$, $C_{IPLR} = 0.6$)

As shown in Fig. 4, the gain G_{ROAM} of the PLR scheme can be up to 70%, while the G_{PAGE} leads to higher paging time. However, the overall gain G_{Total} can be up to 60%. It should be underlined however that in this evaluation we do not measure the actual G_{PAGE}, in case the system had to locate a terminal in heterogeneous adjacent network location management systems. The graphs also show that as the terminal Call-Mobility Ratio (p) increases, the G_{ROAM} and the G_{PAGE} gain degrease. When the p is small, the user roams more often. This leads to more frequent updates and larger paging paths, so smaller G_{PAGE}

The G_{Total} increases as more updates are local, and the HLR+ is not informed so often. If we increase the C_{IPLR} and C_{PLR} values, the gain of the overall PLR algorithm degrades faster with large $T_{IP}.T_P$ value, compared with small $T_{IP}.T_P$ value (Fig. 5). This is due to the fact that larger thresholds T_{IP}, T_P lead to longer paths towards the terminals, thus the system is more sensitive to the costs of inserting/updating a routing entry in a PLR server.

5. Conclusions

Since a variety of mature wireless technologies are already available, a phased approach may be deployed as evolving steps towards 4G. Future mobile terminals will require to uninterruptedly roam from different in-building wireless networks, into heterogeneous public picocellular/microcellular or even wide area macrocellular or satellite networks.

Commercial public wireless LAN solutions however offer limited location management capabilities compared to the traditional cellular networks. In order to overcome these limitations, we introduced a Path Location Register (PLR) scheme for Mobile Terminals Location Management. As has been shown in the performance evaluation section, the proposed scheme reduces significantly the cost of mobile terminal location update and paging, without dramatically increasing the system complexity.

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