Location Management Framework for Next Generation Wireless Systems

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***Abstract*— Overlapping coverage areas of the systems in next generation networks cause high signaling overhead if the users are tracked in multiple systems independently. Selecting the system over which paging will be done is yet another problem. In this paper, we present a general next generation wireless network architecture and propose a location registration scheme that updates the location information only in the relevant subsystems. We also propose an efficient paging scheme that exploits the location information in multiple subsystems. User preferences, network availability, and connection history are considered while determining the subsystems to be used for location registration and paging.**[1]

I. INTRODUCTION

Next Generation Wireless Systems (NGWS) will provide high bandwidth access anytime, anywhere for services including multimedia with QoS requirements. Existing systems fail to satisfy all NGWS objectives *simultaneously* due to constraints like global coverage, indoor/outdoor communications, and frequent handoffs. Therefore, NGWS will combine the existing technologies and the new technologies to come to provide high bandwidth access everywhere. PCS, WLAN, satellite, and new wireless systems like 4G Mobile will serve as *subsystems* in NGWS. The basic properties of NGWS can be summarized as follows:

- Completely packet-based, including the air interface.
- Support for voice, multimedia, and data traffic with QoS provisioning.
- The backbone traffic carried over the Internet.

Different NGWS architectures are described in [1] and [2] with a focus on the possible driving forces for the deployment of these networks. NTT DoCoMo proposes an architecture that is an extension of the 3G architecture [3]. Telefonica proposes a layered architecture composed of WLANs, cellular networks, personal area networks, and distribution networks [4]. In the Wine Glass Project, [5], WLAN and UMTS are merged. Siemens [6] adopts 3GPP's IP Based Multimedia System (IMS) specifications [7] and defines its own architecture. Although certain characteristics of these proposals are common, they are independent of each other in terms of architecture and operation.

Integrating multiple subsystems brings many challenges ranging from interworking among inherently different wireless subsystems to QoS provisioning [5], [8]. In the literature, many location registration and paging schemes are proposed for homogeneous wireless systems [8], [9], [10]. If each subsystem retains its own schemes, location information is updated in all subsystems independently causing high power consumption in the mobile terminals and high signaling overhead in the access network. Furthermore, paging over all possible wireless subsystems incurs high paging cost that can become prohibitively large. To the best of our knowledge, the only work addressing this problem in NGWS is [11]. However, this proposal is designed for heterogeneous systems with partially overlapping coverage at the boundaries, and therefore it is not applicable for systems where multiple subsystems fully overlap.

In this paper, we introduce a location management framework that consists of *Next Generation Location Registration (NGLR)* and *Next Generation Paging (NGP)* methods. NGLR and NGP can function in NGWS that consist of a variety of wireless subsystems including, but not limited to, WLANs, UMTS, 4G Mobile, and satellite networks. We propose to classify the subsystems in NGWS as *relevant* or *non-relevant* with respect to the mobile terminals depending on the connection arrival and connection request history as well as instantaneous subsystem availability. Based on this idea, NGLR method performs location registration only in relevant wireless subsystems. This approach reduces the power consumption in the mobile terminal as well as the registration signaling traffic in the access network. NGP method pages the mobile terminals only over one of the relevant subsystems that has up-to-date location information. Furthermore, we make use of the location information from multiple subsystems to reduce the number of cells in which paging messages are broadcast, reducing the signaling cost. We also incorporate the paging delay constraint in the construction of the paging area.

II. NETWORK ARCHITECTURE

A. Subsystem Interconnectivity

The Next Generation Wireless System NG is composed of a set of wireless subsystems SS^i:

$$\begin{aligned} NG = \left\{SS^i\right\}, \qquad & i = 1, \cdots, \mathcal{N} \\ SS^i \in SS, \qquad & SS = \{wl, um, sa, 4g, \cdots\} \end{aligned} \tag{1}$$

where $\mathcal{N}$ is the number of subsystems in NGWS, and SS is the set of different types of subsystems. In Equation 1, *wl, um,*

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sa, and *4g* correspond to WLAN, UMTS, Satellite, and 4G, respectively. Note that the set SS can be expanded as needed to include other types of wireless subsystems.

The service area of each subsystem SS^i is split into cells. The size, shape, and location of the cells is different for each subsystem. Thus, each subsystem has its own cellular layout. We define the set of cells that belong to a subsystem SS^i as C^i. We denote the k^{th} cell in the set C^i as C^i_k, where $C^i = \left\{C^i_k\right\}$, $k = 1, \cdots, \mathcal{C}^i$, and $\mathcal{C}^i$ is the total number of cells in SS^i. Let us also denote m^{th} mobile terminal in NGWS as MT^m.

The cells in a subsystem SS^i are grouped into *registration areas* RA^i_j, $j = 1, \cdots, \left|\mathcal{R}^i\right|$ for efficient location management where $\mathcal{R}^i$ is the set of registration areas in SS^i. We denote the current registration area of MT^m in subsystem SS^i as $\mathcal{RA}\left(MT^m, SS^i\right)$. Each registration area RA^i_j is assigned to a *local register* LR^i_j. Without loss of generality, we assume that there is a one-to-one mapping between the local registers and registration areas. We do not envision the local registers as new components in the subsystems. Instead, we propose utilizing the existing local registers, i.e., the gateway mobility agent (GMA) in Mobile IPv6, and the visitor location register (VLR) in PCS networks, etc. Thus, each subsystem employs its own location management procedure internally, but the local registers communicate with the global home register. Since HR provides appropriate interfaces to all LRs, no alterations are required in LRs.

In NGWS, there is a *home register* HR that serves all subsystems in mobility and connection management. The home register resides outside the subsystems, as a node in the Internet (Figure 1). The function of the home register HR is to store static and dynamic information about all registered users. HR has a different interface for each type of subsystem and acts as the home agent for WLAN networks, as the HLR for the PCS networks, etc. We do not adopt the idea of adding a super HLR [12] over the location register structures of the subsystems because this would impose an extra layer on the location management system, and increase the latency in location update, paging, and connection admission procedures. To provide redundancy and avoid creating a bottleneck in the system, HR should be implemented as a database system with replicas.

An example configuration of NGWS consisting of satellite, PCS, and WLAN subsystems is depicted in Figure 1. The service area is covered with overlapping cells of different subsystems. The coverage area of the subsystems may be discontinuous, as in the case of WLAN. Thus, the set of subsystems to which a mobile terminal can access at a given moment varies. Each subsystem has its own LR, and the backbone traffic between the subsystems is carried over the Internet. A global HR serves all subsystems.

In wireless systems, the administrative domain keeps information about each user. This information is stored in the home register and it typically includes the user identity, location, and billing information. In this paper, we define our extensions, *user profile (UP)*, to the user information in home register.

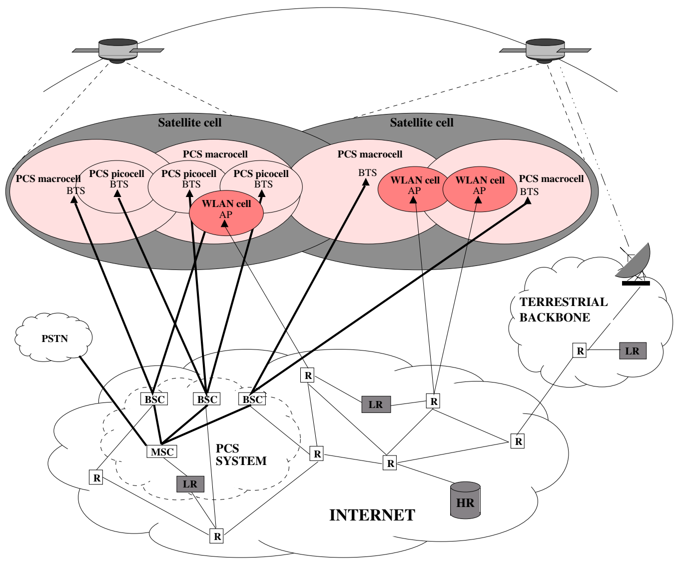

Fig. 1. An example configuration for NGWS

The UP structure is composed of a *static* and a *dynamic* part. The static part contains long-term information about the user and the mobile terminal. Some part of this information, such as the user preferences and terminal capabilities, may be updated as needed. The dynamic part contains a short-term history of the location information updates of the user. The static and dynamic parts of UP are stored in the home register node for paging, and in the mobile terminal for calculating the relevance of subsystems. Since the static part is fixed and the dynamic part contains only connection information, the mobile terminal can maintain the UP without the help of the network. Therefore, replicating the UP at the mobile terminal does not increase signaling overhead in the core and access networks.

The UP structure is given in Figure 2. The static part of UP contains information about the user and does not change frequently. Most of the fields are self-explanatory. *Next generation user address* uniquely identifies the user in all subsystems. *Preference* shows how much the user is willing to receive this type of service over the corresponding subsystem. A default configuration is provided for the static part, but the advanced user may also specify his own preferences.

The dynamic part of UP is a short-term history of the updates to the location information of the user. The location update information is gathered with both the location registration messages and the incoming/outgoing connections. Every subsystem SS^i is classified as *relevant* and *non-relevant*. The subsystems that are frequently used and currently accessible are considered as relevant. On the other hand, the subsystems that are rarely used or currently not accessible are considered as non-relevant. For each subsystem, only the most recent entry is stored in the history.

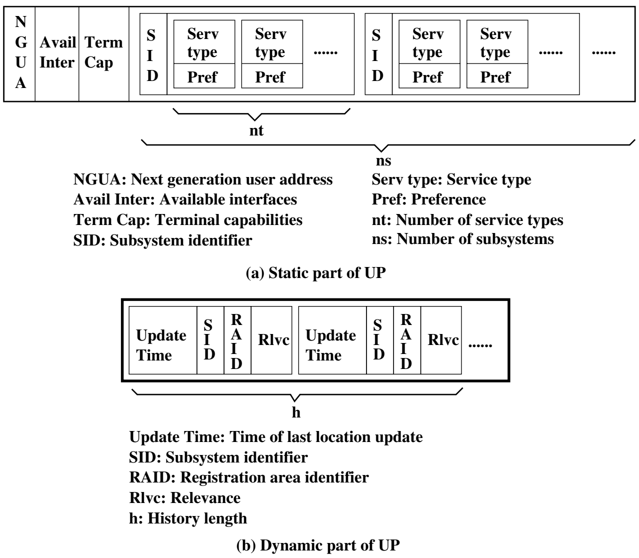

Fig. 2. UP structure

B. Determining the Relevant and Non-Relevant Subsystems

A mobile terminal MT^m considers a subsystem SS^i to be relevant if it prefers SS^i over other subsystems for location registration. The interface preferences specified in the static part of the UP, network availability, and the connection history are considered in this decision.

Let A_i be 1 if SS^i is accessible, 0 otherwise. Also, let us denote with p_i how much the user prefers subsystem SS^i. The preference field in the UP is specified for all types of services, for all subsystems. Each preference value denotes how much the user is willing to receive that type of service over the specified subsystem. We obtain the total preference p_i for a subsystem SS^i as $p_i = \sum_{j=1}^{nt} p_{ij}$, where p_{ij} is the interface preference value in the static part of the UP for connection type j in SS^i. The dynamic part of the UP contains information about the last connection established over each subsystem. Let us sort the dynamic part with respect to update time specified in the dynamic part of UP, starting with the earliest. We denote the rank of subsystem SS^i as r_i.

For each subsystem SS^i, we define the weight w_i as $w_i = A_i \cdot (\mathcal{N} - r_i + 1) \cdot p_i$. The weights of all subsystems are normalized as $\widehat{w}_i = \frac{w_i}{\sum_{k=1}^{\mathcal{N}} w_k}$.

Let $\mathcal{SS}(MT^m)$ be defined as the set of all accessible subsystems for mobile terminal MT^m. Then, the set of relevant subsystems for MT^m is defined as $\mathcal{SS}_r(MT^m) = \{SS^x \mid SS^x \in \mathcal{SS}(MT^m), \widehat{w}_x \geq \tau\}$ where τ is the *relevance threshold* value for the normalized weights. Let also the set of non-relevant subsystems with respect to MT^m be denoted as $\mathcal{SS}_n(MT^m)$. Since the sets $\mathcal{SS}_r(MT^m)$ and $\mathcal{SS}_n(MT^m)$ partition the set of accessible subsystems $\mathcal{SS}(MT^m)$, the set of non-relevant subsystems is formally defined as

$$\begin{aligned}\mathcal{SS}_n(MT^m) &= \mathcal{SS}(MT^m) - \mathcal{SS}_r(MT^m)\\ &= \{SS^x \mid SS^x \in \mathcal{SS}(MT^m), \widehat{w}_x < \tau\} .\end{aligned}$$

The sets $\mathcal{SS}_r(MT^m)$ and $\mathcal{SS}_n(MT^m)$ are recalculated in the following three cases:

- The accessibility of a subsystem changes.
- Location information in a subsystem is updated.
- A connection is setup over a relevant or non-relevant subsystem.

III. Next Generation Location Registration

With NGLR, we propose sending location registration messages selectively only in the subsystems that are *relevant* for the user. The location registration messages for the non-relevant subsystems are suppressed. Thus, both the signaling cost and the power consumption are reduced at the cost of reduced precision of the location information in the subsystems that are non-relevant.

The location registration procedure is triggered in three cases:

- When mobile terminal is turned on.
- When mobile terminal crosses a registration area boundary in a relevant subsystem.
- When the relevance of one or more subsystems changes.

We also propose an extension to the location registration message in order to improve the precision of location information in the non-relevant subsystems. When a mobile terminal moves from one registration to another in a non-relevant subsystem, the registration message is buffered. The buffered message is piggy-backed on the registration message that is sent for a relevant subsystem. The piggy-back mechanism has the advantage that the loss in the precision of the location information in non-relevant subsystems is reduced by increasing the size of the location registration message slightly. Note that buffering the registration message from non-relevant subsystems also provides a solution to the ping-pong effect in non-relevant subsystems.

NGLR Algorithm:

1) Mobile terminal MT^m is turned on. For all subsystems SS^x such that $SS^x \in \mathcal{SS}(MT^m)$:
   a) MT^m finds its registration area RA_a^x in which MT^m resides using the function $\mathcal{RA}(MT^m, SS^i)$.
   b) MT^m issues a location registration message to the local register LR_a^x.
   c) MT^m updates the dynamic part of its copy of UP structure to reflect this information.
   d) LR_a^x transmits the location registration information of MT^m to home register HR.
   e) HR updates the dynamic part of its copy of UP structure to reflect this information.
2) Mobile terminal MT^m moves from RA_a^x to RA_b^x of SS^x. MT^m checks if it considers SS^x as a relevant subsystem.

a) If SS^x **is not** relevant, i.e., $SS^x \in \mathcal{SS}_n(MT^m)$:
   i) MT^m replaces any buffered message for SS^x by rm_b^x.
   ii) MT^m defers the registration message rm_b^x. The entry in the dynamic part of the UP that corresponds to SS^x is not changed yet.

b) If SS^x **is** relevant, i.e., $SS^x \in \mathcal{SS}_r(MT^m)$:
   i) MT^m checks if there is any non-relevant subsystem SS^y in the dynamic part of the UP structure for which a registration message rm_c^y has been buffered. For all such non-relevant SS^y:
      - MT^m piggy-backs the buffered entry on the registration message.
      - MT^m updates the dynamic part of its copy of UP structure to reflect this information about SS^y.
      - MT^m deletes registration message rm_c^y.
   ii) MT^m sends rm_c^y (with possible piggy-backs) to the local register LR_b^x and updates the dynamic part of its copy of UP structure.
   iii) LR_b^x transmits rm_c^y to the home register HR.
   iv) HR updates the dynamic part of its copy of UP structure to reflect the information about SS^x and for all piggy-backed subsystems.

IV. Next Generation Paging

In NGWS, paging over all subsystems is not feasible since it implies that all mobile terminals are paged over all subsystems. Paging signaling cost can be reduced by a factor of $\mathcal{N}$ by choosing only one subsystem to broadcast paging messages, where $\mathcal{N}$ is the number of subsystems in NGWS. However, this cost can be further reduced by leveraging the existence of multiple subsystems in the same service area. With NGP, we propose to broadcast paging messages in a smaller number of cells subject to paging delay constraints.

The set of cells in which the paging message is broadcast over the air interface is called the *paging set*. In blanket paging, the paging set and the registration area are equivalent, i.e., the paging process is executed in cells $\forall cl \mid cl \in \mathcal{RA}(MT^m, SS^i)$ where $SS^i \in \mathcal{SS}_r(MT^m)$. We propose exploiting the location information from subsystems to make the paging set narrower. The paging set is constructed by the HR. Although the subsystems are working autonomously, HR is capable of merging the location information from subsequent subsystems to construct the paging set $\mathcal{PS}(MT^m)$ by taking the intersection of a subset of registration areas for MT^m. $\mathcal{PS}(MT^m)$ is formally defined as follows:

$$\left\{ cl \in \bigcap_{SS^x \in \mathcal{SS}_{PS}(MT^m)} \mathcal{RA}(MT^m, SS^x) \right\}, \qquad (2)$$

where $\mathcal{SS}_{PS}(MT^m)$ is the set of subsystems for which the location information is considered in the construction of the paging set $\mathcal{PS}(MT^m)$. Given a paging delay constraint of c cycles, $c \in \mathbb{Z}$, $\mathcal{SS}_{PS}(MT^m)$ can be constructed by including all relevant subsystems and $c-1$ non-relevant subsystems with highest weights w. $\mathcal{SS}_{PS}(MT^m)$ is formally defined as $\mathcal{SS}_r(MT^m) \cup [\mathcal{SS}_n(MT^m)]_{q-1}$ where $[X]_a$ is the first a elements of a sorted set X, and q is number of remaining paging cycles. Note that q is initially set equal to c and decremented as long as paging attempts are not successful and $q > 1$.

In NGP, instead of paging the user in all cells in the registration area as in blanket paging, only the cells in the paging set are paged. Since the cellular layouts are fixed, the intersection areas, i.e., the paging sets are also fixed. Thus, the process of finding the paging set becomes a table lookup in an $\mathcal{N}$-dimensional array, where $\mathcal{N}$ is the number of subsystems. Since the paging set is narrower than the registration area, i.e., $\mathcal{PS}(MT^m) \subset \mathcal{RA}(MT^m, SS^x)$, the signaling cost both in the wireline core network and the air interface is reduced.

The NGP paging scheme has the following advantages:

- The mobile user is paged over only one subsystem.
- Paging message is broadcast only in a narrow paging set rather than the registration area.
- Paging set is further narrowed for connections that do not require fast paging.

NGP Algorithm:

1) HR receives an incoming connection request rq for mobile terminal MT^m.
2) $q \leftarrow c$, where c is the paging delay constraint in terms of paging cycles specified in rq.
3) HR selects subsystem $SS^i \in \mathcal{SS}_r(MT^m)$ such that SS^i has the most recent location information.
4) HR constructs the paging set $\mathcal{PS}_q(MT^m)$ for MT^m as follows:
   a) If the paging delay constraint in rq is the *minimum paging delay*, i.e., $c = 1$, then $\mathcal{SS}_{\mathcal{PS}}(MT^m) = \mathcal{SS}_r(MT^m)$.
   b) Otherwise, if the paging delay constraint in rq is **not** the minimum paging delay:
      - Sort $\mathcal{SS}_r(MT^m)$ with respect to weights w of the subsystems.
      - $\mathcal{SS}_{\mathcal{PS}}(MT^m) = \mathcal{SS}_r(MT^m) \cup [\mathcal{SS}_n(MT^m)]_{q-1}$, where $[X]_a$ is the first a elements of a sorted set X.
   c) The paging set $\mathcal{PS}_q(MT^m)$ is calculated as in Equation 2:
   $\mathcal{PS}_q(MT^m) \leftarrow \{cl \in \bigcap_{SS^x \in \mathcal{SS}_{PS}(MT^m)} \mathcal{RA}(MT^m, SS^x)\}$
5) HR sends a paging request message to LR_k^i, which serves $\mathcal{RA}(MT^m, SS^j)$ specifying the paging set $\mathcal{PS}_q(MT^m)$.
6) LR_k^i sends a paging request message to each cell $C_p^i \in \mathcal{PS}_q(MT^m)$.
7) If MT^m replies to the paging request:
   a) The paging reply is passed to HR.
   b) HR utilizes the paging reply also as a location registration message.

c) Paging is successful. Connection admission control mechanism is started.

8) Otherwise, if a paging reply message is not received:

a) $q \leftarrow q - 1$.

b) $\mathcal{SS}_{\mathcal{PS}}(MT^m) \leftarrow \mathcal{SS}_r(MT^m) \cup [\mathcal{SS}_n(MT^m)]_{q-1}$

c) Another paging attempt is made:

- Construct $\mathcal{PS}_q(MT^m)$ using $\mathcal{SS}_{\mathcal{PS}}(MT^m)$ (as in Step 3.c).
- $\mathcal{PS}_q(MT^m) \leftarrow \mathcal{PS}_q(MT^m) - \mathcal{PS}_{q+1}(MT^m)$.
- Go to Step 5.

V. SIMULATION RESULTS

We have developed a simulator that considers 2500 subscribers served by five subsystems over an area of $100\,km^2$. Each subsystem has 12 *nonidentical* registration areas and each subsystem is accessible with 90% probability. A random walk model with mobile speeds ranging from 6 to $120\,km/h$ is used to represent mobile users from pedestrians to vehicles. The connection arrival rate ranges from $55\,calls/min$ to $500\,calls/min$, system-wide.

A. Performance Evaluation of NGLR

In order to demonstrate the performance of NGLR, we compared NGLR with two alternative location registration methods. In the first alternative method, the location registration messages are sent in all subsystems that make up the NGWS. With the second alternative method, one of the subsystems (say SS^0) is selected statically and location registration is performed only over that subsystem. The experiments conducted to evaluate the performance of NGLR address the location registration signaling cost, the distribution of the signaling cost to individual subsystems, and the effect of location method on paging error rate.

In Figure 3, the registration signaling costs of three location registration methods are plotted for varying average mobile terminal speeds. For all three location registration methods, the signaling cost of location registration grows linearly with increasing mobile speed since more location registration messages are issued as mobiles move faster. However, the remarkable point is that the signaling cost for performing location registration in all subsystems is approximately four times higher than NGLR and location registration over SS^0. Hence, NGLR and location registration over SS^0 both reduce the signaling cost by 75%.

Although NGLR and location registration over SS^0 have the same performance in terms of the total number of messages in all subsystems, only our new proposed NGP achieves signaling load sharing among subsystems. In Figure 4, the signaling load in individual subsystems under NGLR and location registration over SS^0 is shown. The simulation results show that the location registration cost is shared equally by all subsystems when NGLR is used. Under the same simulation scenario, if registration is done over a fixed subsystem SS^0, 95% of the signaling is carried by SS^0, and the rest is shared among the

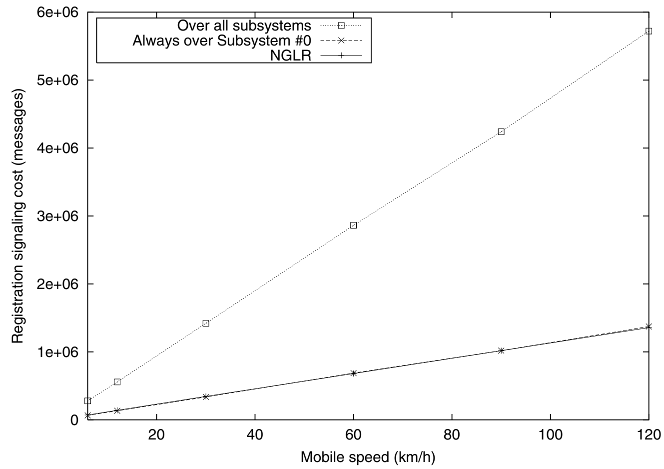

Fig. 3. Effect of mobile speed on location registration signaling cost

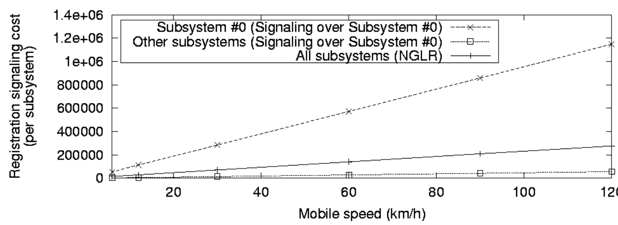

Fig. 4. Location registration signaling cost per subsystem

remaining subsystems. The remaining 5% is overflown to other subsystems due to probabilistic unavailability of SS^0. From these results, it can be concluded that the our new NGLR method achieves low location registration cost and distributes the registration load equally among all subsystems.

We also performed simulations to analyze the effect of the three location registration schemes on the accuracy of paging. In this set of simulations, NGP is used as the paging method when NGLR is used and when location registration is performed over all subsystems. When location registration is performed over as single subsystem SS^0, it is not possible to use NGP since location information is not received from multiple subsystems. Therefore, location registration over SS^0 is used in combination with blanket paging. The paging errors occur in two cases:

- When the subsystem over which the registration message is sent is not available, i.e., the mobile terminal changes location, but the system is not notified.
- When the mobile terminal loses connection to the subsystem over which the paging is performed, i.e., when the system knows where the mobile is, but the mobile is not reachable over that subsystem.

Since the latter case applies to both blanket paging and NGP, any difference in paging error rate is due to the different location registration success rates.

In Figure 5, paging error rate is plotted against varying average mobile speeds for the three location registration

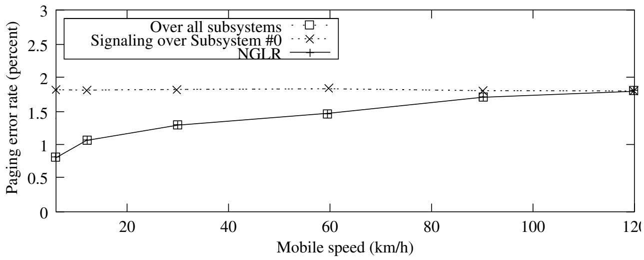

Fig. 5. Effect of mobile speed on paging error rate

methods. NGLR and registration over all subsystems show the same paging error performance because both methods can find alternative subsystems to send the location registration messages. They fail to send registration messages only when all subsystems are unavailable. The probability of this event increases with the increasing average mobile speed. On the other hand, location registration over SS^0 fails to update its location whenever SS^0 is not available. Location registration over SS^0 achieves a constant paging error rate of 1.8%, which is always greater than or equal to the error rates of the other two methods. Note that, although the effect of NGLR and registration over all subsystems on the paging error is the same, the signaling cost of registration in the latter method is four times larger than NGLR. Therefore, these simulation results show that NGLR is overall an efficient location registration method for NGWS.

B. *Performance Evaluation of NGP*

In order to demonstrate the performance of NGP, we compared NGP with blanket paging method. In blanket paging, all cells in mobile terminal's current registration area are paged. In NGP, only the cells in a narrower paging set (Section IV) are paged. The experiments conducted to evaluate the performance of NGP address the paging signaling cost with respect to connection arrival rate. The paging signaling cost is defined as the number of cells in which paging message is broadcast.

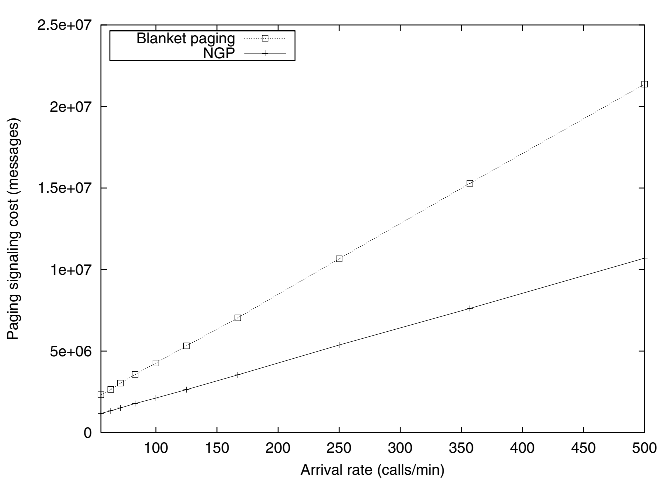

Fig. 6. Effect of connection arrival rate on paging signaling cost

The effects of call arrival rate on paging signaling cost are shown in Figure 6. Paging signaling cost grows linearly with increasing call arrival rate for both paging schemes since a higher call arrival rate triggers a proportionally higher number of paging attempts. Signaling cost of NGP remains half of the cost of blanket paging for all values of call arrival rate. Also note that NGP pages the mobile terminals in a paging set which can grow as large as the intersection of all relevant subsystems, for which the location information is up-to-date. Therefore, blanket paging and NGP provides the same paging error rate when NGLR is used as location registration method. These results show that NGP is capable of reducing the paging signaling cost without compromising the paging accuracy.

VI. Conclusions

In this paper, we introduced a location management scheme for Next Generation Wireless Systems. The proposed scheme consists of Next Generation Location Registration (NGLR) and Next Generation Paging (NGP) methods. These methods can operate on a variety of next generation wireless system configurations. With the NGLR method, we update the location information only in the selected subsystems to reduce signaling overhead and battery consumption. The NGP method benefits from the location information in the relevant and non-relevant subsystems to page the user in a smaller paging area. NGP reduces signaling cost while guaranteeing to meet the paging delay constraints of the connections.

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