A generic IP Paging architecture and protocol

Marco Liebsch, Bernd Lamparter

NEC Network Laboratories Europe
Kurfürsten-Anlage 36, 69115 Heidelberg, Germany

Abstract - **Mobile communication systems are increasingly adopting Internet Protocol solutions for mobility management. Considering an increasing number of mobile devices that communicate actively for only a fraction of the time, compelling all devices to maintain detailed location information in the network, causes unnecessary signaling overhead and battery drainage. Contemporary cellular mobile communication systems deploy technology-specific paging, which supports the maintenance of a mobile terminal's coarse location information and to request its exact location when a call comes in. IP paging goes beyond that by targeting heterogeneous access in IP based mobile communication networks, and by contributing towards meeting IP mobility management requirements on the scalability of future systems. This paper describes a generic IP paging architecture and protocol for heterogeneous mobile communication systems that integrates modularly into various IP based mobility protocols. The concept facilitates flexible paging area design and the deployment of enhanced paging strategies aimed at optimizing overall signaling costs. While striking a balance between flexibility and complexity, the concept meets requirements on IP paging protocol solutions. The concept is analyzed with regard to its characteristics to save signaling costs and compared with a different paging concept (P-MIP). Design and associated performance characteristics are evaluated based on the topological structure of a domain's access network.**

1. Introduction

Following the trend of mobile communication systems towards the integration of IP based mobility management protocols implies taking additional enhancements into account to meet associated requirements. Support for reachability in IP based mobility management systems requires a roaming mobile terminal to send location update signaling messages to the network each time it enters a new IP subnet area. Maintaining a high degree of accuracy of a mobile terminal's location is appropriate when data packets are being delivered to the mobile terminal and tracking its exact location keeps associated routing states in the network updated and allows continuous forwarding of data packets. However, when no packets are being delivered to and from a moving mobile terminal for some time, frequent location update signaling is unnecessary, wastes scarce radio bandwidth and drains the mobile terminal's battery. Since a mobile terminal actively communicates for only a fraction of the time, the need and the potential to optimize overall signaling costs and battery energy consumption becomes obvious. If a mobile terminal is allowed to enter a *dormant* mode when no packets are being delivered, it is relieved from sending location updates while roaming in a specific enlarged area, which is the *paging area*. When a user-data packet is sent to a dormant mobile terminal, at some point on its path no exact routing information is available. Rather, the location of the mobile terminal is then known with the accuracy of the paging area, which comprises multiple locations that would have to be updated by the mobile terminal if it were active. When user-data packets are to be delivered to a dormant mobile terminal, some control protocol has to be deployed to locate and re-activate the addressed mobile terminal and to initiate re-establishment of its routing information in the network to allow routing the user-data packets to their final destination. The procedure of searching for a dormant mobile terminal and of initiating active mode transition is called *paging*. This paper proposes a generic architecture and protocol for IP paging in heterogeneous networks that support IP mobility management protocols, while taking functional and non-functional requirements into account. This IP paging proposal supports the deployment of enhanced paging strategies, aiming at the optimization of associated signaling and processing costs. This paper focuses on the paging architecture and the protocol operation for an integration of the paging concept with a Mobile IPv6 based network infrastructure. It covers an analytical evaluation of the concept's signaling costs characteristics compared to a system without paging support as well as to a system integrating P-MIP [4] for paging support. Requirements on security have been taken into account for the design of the paging concept, but are not focused on within this paper.

2. Design Goals and Requirements

Taking heterogeneous access within IP mobility managed networks into consideration, a generic and flexible solution for an IP paging protocol should be independent of the actual access technologies. On the other hand, to take advantage of individual technologies' support for dormant mode and paging, mapping of the generic paging protocol to access technology specific dormant mode and paging control functions should be allowed. Important design goal was support for modular integration into various IP mobility management schemes and meeting associated requirements, while striking a balance between flexibility and protocol complexity. Further functional and non-functional requirements, which have been taken into account for the design of the paging protocol, can be found in [1].

3. Related Work

Aiming at a generic architecture and protocol for IP paging, the solution should be capable of arranging with the different classes of mobility management solutions with regard to routing and re-addressing based approaches. Paging support for individual per-host routing based protocols, such as Cellular IP [2] as well as HAWAII [3], has been proposed. Cellular IP routers within a domain are designed to provide efficient handover performance for fast moving mobile terminals and may have a paging cache entry in addition to routing cache entries. The protocol proprietary paging extensions for Cellular IP supports to take load of routing caches and to offer cheap passive connectivity. A paging extension for HAWAII deploys a special multicast tree routing for distribution of paging control messages. A paging area is uniquely identified by a multicast group address. To associate a static paging area with a multicast group address makes it difficult to allow for individual and dynamic paging area construction as well as for deployment of enhanced paging strategies.

A paging extension to the Mobile IPv4 protocol is P-MIP [4]. The protocol introduces a simple set of paging extensions for paging in Mobile IP, which is not dependent on an underlying micro-mobility infrastructure. The proposal handles paging from Mobile IPv4 Foreign Agents (FA). It is quite a flexible approach with regard to the design of paging areas, the consideration of overlapping paging areas as well as the strategy of polling a paging area, but this approach assumes the existence of Foreign Agents. A more distributed architecture and protocol is proposed in [5], which compares the protocol's signaling costs characteristics with P-MIP. The protocol is independent of a specific IP mobility management scheme, but appears quite complex with regard to signaling between associated functional components. Three different approaches for a paging architecture are studied in [6], maintaining paging relevant states either at a mobile terminal's Home Agent, at its Foreign Agent or within a domain in a distributed manner. The different schemes are analyzed, taking reliability, scalability and confidentiality aspects into account, as well as evaluated using three different paging algorithms. Following the analysis performed in [6], the paging architecture and protocol proposed in our paper aims at integrating relevant beneficial aspects of the studied protocols, like meeting requirements on confidentiality, scalability, efficiency and flexibility, while keeping the design extensible and allowing the use of enhanced paging algorithms.

In addition to the different paging protocol proposals, valuable work has been done on paging costs reduction by deployment of enhanced paging strategies. We argue that it is important that a paging system can handle various paging strategies, as evaluated in [7] and [8]. The architecture and protocol as described in this paper takes this into consideration and allows for sequential addressing of a paging area's individual locations, as required for the deployment of enhanced paging strategies. [9] proposes a functional component, the Paging Area Configuration Agent (PACA), to allow sampling and aggregation of mobile terminal's movement pattern for optimized configuration of paging areas. This facilitates the use of adaptive and per-host paging areas, rather to rely on static and administratively configured paging areas. The proposed PACA represents an additional function for IP based paging architectures and protocols, which can be efficiently integrated with the paging architecture and protocol described in this paper.

4. IP Paging - Architecture and Protocol

In this chapter, we describe the architecture of the proposed paging concept and refer to the requirements on associated paging functional entities, as addressed in [1], respectively. The protocol operation is described, followed by a discussion of the concept's characteristics.

4.1. The IP Paging Architecture

[1] depicts three functional entities to distribute tasks for the handling of dormant mobile terminals. Required protocol control functions as referred to in [1] cover a *Tracking Agent functional entity* (TA-FE), which is responsible for tracking a dormant host's location. The *Paging Agent functional entity* (PA-FE) coordinates protocol signaling to page the mobile terminal. Functions to handle user-data packets, which address a dormant mobile terminal, should be assigned to a *Dormant Monitoring Agent functional entity* (DMA-FE). According to [1], the paging architecture and protocol should be able to benefit from using available registration mechanisms of the mobility management protocols. Following these requirements, this paper describes the modular integration of the proposed IP paging solution with a Mobile IPv6 [10] environment, as we performed within the framework of the European IST Project Moby Dick [12] for proof of concept, and illustrates the proposed protocol's mode of operation. In the Mobile IPv6 architecture, paging areas are organized as a set of Access Routers, which allows for sequential addressing of individual Access Routers within a paging area during a paging process, hence provides support for using enhanced paging strategies, as recommended in [7] and [8]. The mapping to Layer 2 paging areas is coordinated from paging attendants, which can be implemented with individual Access Routers, but is out of the scope of this paper.

The IP paging architecture introduces a separate agent, the *Paging Agent node* (PA), which is added to a domain's infrastructure servers. To allow mapping the paging functional entities, as identified in [1] to be part of a paging architecture, to the components of the paging concept proposed in this paper, the following description refers to these functions. These associated functional components have been co-located, distributed or even split into sub-functions to meet the design goals of the proposed paging concept. The Paging Agent node integrates the TA-FE and the *IP protocol* *functional part* of the PA-FE. The DMA-FE can be co-located with the Paging Agent node if the mobility management protocol allows for explicit registration of the PA. Explicit DMA registration with the mobile terminal's mobility agent enables reception of initial user-data packets, which are destined for dormant mobile terminals, at the PA and follows [1] with regard to the efficient use of available registration mechanisms provided by the mobility protocol. In addition to the PA node, the domain's Access Routers or associated IP-addressable Access Points implement *paging attendant* functions, allowing the generic IP paging protocol to be kept access technology independent up to the Access Routers supporting heterogeneous access networks. The mapping to access technology specific control of dormant mode and paging related functions as well as the handling of sub-IP layer paging areas is supported by the paging attendant, but is not focussed on within this paper. The integration of the paging architecture into a Mobile IPv6 environment is illustrated in Fig.1.

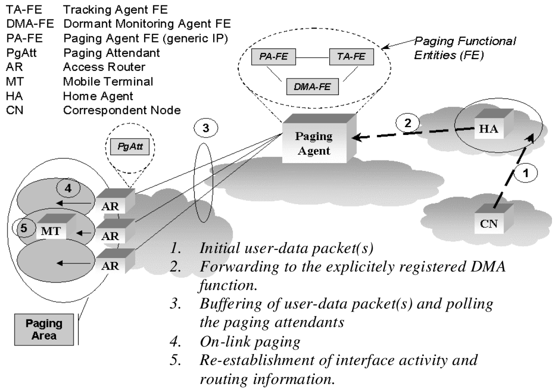
TA-FE Tracking Agent FE
DMA-FE Dormant Monitoring Agent FE
PA-FE Paging Agent FE (generic IP)
PgAtt Paging Attendant
AR Access Router
MT Mobile Terminal
HA Home Agent
CN Correspondent Node
Paging Functional Entities (FE)
PA-FE
TA-FE
DMA-FE
Paging Agent
PgAtt
HA
CN
AR
AR
AR
MT
Paging Area
1
2
3
4
5
1. Initial user-data packet(s)
2. Forwarding to the explicitely registered DMA function.
3. Buffering of user-data packet(s) and polling the paging attendants
4. On-link paging
5. Re-establishment of interface activity and routing information.

Figure 1: Illustration of the IP paging architecture integrated with a Mobile IPv6 environment.

4.2. Protocol Operation

When a mobile terminal decides to enter the dormant mode, its responsible Paging Agent is to be discovered. This agent is a long-term PA, responsible for tracking the mobile terminal's location beyond the scope of the currently visited paging area. Once it holds a registration for an individual dormant mobile terminal, the discovered PA node must be updated when the dormant mode registration lifetime expires or when the mobile terminal enters a different paging area. Initially, the mobile terminal sends a *DormantRequest* to its current Access Router to discover the responsible PA and to request a dormant registration from the paging attendant. Since the mobile terminal has a previously established security association (SA) with the AR it is currently attached to, the AR can authenticate the incoming request's originator. The AR sends the *DormantRequest* message, which carries the mobile terminal's information, to the responsible PA for dormant mode registration. The concept supports the dynamic establishment of a SA between a registering mobile terminal and the PA. For this, the PA generates a key on reception of the registration request either locally or with the help of the local AAA-server, using it as key-distribution-center. The lifetime of that key is associated with the respective registration. The PA originated *DormantReply* message conveys the granted registration lifetime back to the MN through the respective AR's paging attendant. To allow the DMA function in the Paging Agent to receive initial user-data packets on behalf of the dormant mobile terminal, the PA is registered with the HA by means of binding the PA's address as the alternate care-of address (*altCoA*, [10]) to the dormant mobile terminal's home address. The signaling flow for the combined PA discovery and dormant registration is illustrated in Fig. 2.

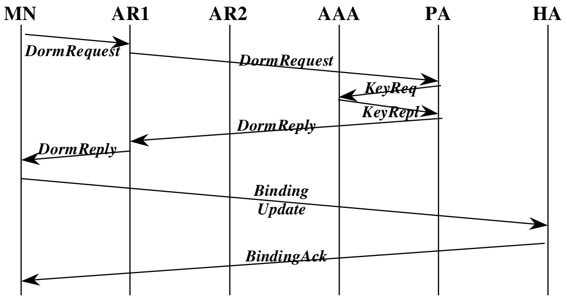
MN
AR1
AR2
AAA
PA
HA
DormRequest
DormRequest
KeyReq
KeyRepl
DormReply
DormReply
Binding Update
BindingAck

Figure 2: Service Discovery and Dormant Registration

The roaming dormant mobile terminal has to scan paging area identification information, which is broadcast from the system through IP broadcast mechanisms or appropriate Layer 2 mechanisms of individual access technologies. When the mobile terminal has realized that it has entered a new paging area on receiving different paging area identification information, the new paging area has to be registered with the mobile terminal's PA. If no appropriate support from access technologies is available, the mobile terminal activates IP layer functionality to send an updating *DormantRequest* message to its PA, which conveys the new paging area's identifier. The mobile terminal could refrain from activating full IP functions if access technologies allow for appropriate support of Layer 2 interactions between a mobile terminal and its current Access Router. The paging attendant could generate the updating *DormantRequest* on behalf of the mobile node and take care of appropriate mapping of further paging related control messages, as illustrated in Fig. 3.

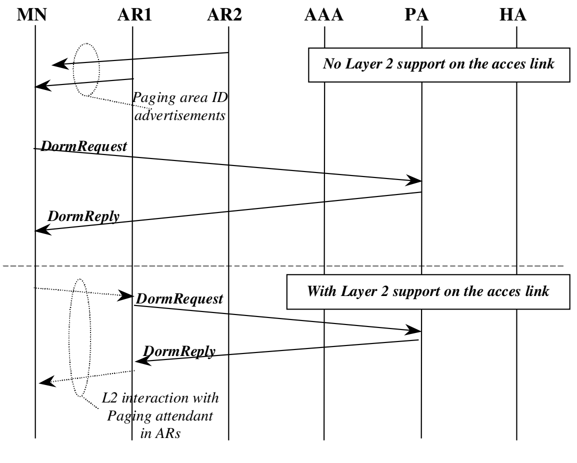
MN
AR1
AR2
AAA
PA
HA
No Layer 2 support on the acces link
Paging area ID advertisements
DormRequest
DormReply
With Layer 2 support on the acces link
DormRequest
DormReply
L2 interaction with Paging attendant in ARs

Figure 3: Paging area registration updating

On arrival of a validated user-data packet at the Paging Agent, the packet is buffered by the DMA function. Information on the addressed dormant mobile terminal's current paging area is retrieved from the TA-FE before the PA-FE is triggered to initiate the paging procedure. According to the paging strategy, the Paging Agent sends *PagingRequest* messages to all paging attendant functions in the ARs assigned to the mobile terminal's current paging area. On reception of the *PagingRequest* message, individual paging attendants map the request either to access technology-specific paging control functions, or deliver the IP *PagingRequest* to the mobile terminal by means of IP transport mechanisms. After receiving the paging message, the mobile terminal performs the system's standard network attach procedure and acquires a new care-of address. The binding with its Home Agent is updated and its current location is notified to the Paging Agent by carrying the new CoA in the dormant de-registration message (*ActiveRequest*). On reception of the CoA information, the DMA-FE of the Paging Agent can forward buffered user-data packets to the reactivated mobile terminal. The paging process is illustrated in Fig. 4.

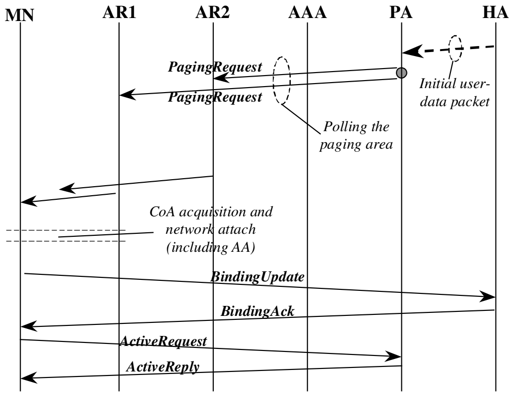

Figure 4: Paging process and dormant de-registration

4.3. Discussion of Characteristics

Compared to a more distributed architecture, the co-location of the generic paging functional entities in a Paging Agent node allows introduction of redundant Paging Agents and restricts the effort for fail-over handling to a minimum set of nodes. To integrate the described paging protocol into IP mobility schemes without support for DMA registration, the DMA functional entity is distributed appropriately on domain Routers. The function should then capture user-data packets and check whether or not individual packets address a dormant mobile terminal. The distributed DMA approach requires an appropriate protocol to be deployed between the Paging Agent and the distributed DMA functions, which is out of the scope of this paper. With both approaches, the PA node co-located DMA as well as the distributed DMA function, it should be possible to provide a highly flexible IP paging architecture and to support collaboration with various IP mobility protocols. The paging attendant functions on Access Routers are responsible for mapping the generic IP paging protocol to access technology specifics. Since an IP subnet, supported by an individual Access Router, could comprise multiple Layer 2 paging areas, the paging attendant function should handle this mapping by interacting with the IP subnet's Access Points. Also paging area identifiers should allow for distinct identification of IP paging areas and Layer 2 paging areas.

5. Signaling Cost Analysis

To evaluate an important measure about how the proposed concept performs with regard to reducing signaling costs for IP based mobility management schemes, the following analysis first compares a Mobile IPv6 based platform, having the proposed concept integrated as illustrated in Fig. 1, with a Mobile IPv6 platform without 'dormant mode' and paging support. Furthermore, the proposed paging concept is compared with P-MIP [4], while taking various topological characteristics of the associated local access network into consideration. The latter modification of local access network characteristics is quite important, since recent evaluations of paging concept proposals assumed a single and specific characteristic for local access networks, which makes a fair comparison of different paging concepts difficult. With the latter analysis, we want to evaluate the signaling costs characteristics of the paging concept proposed in this paper, which introduces the Paging Agent and distributed paging attendant functions, compared to the P-MIP concept, which assigns all paging related protocol functions to the edge network's Foreign Agents. Since from signaling flow point of view, *location-updating* costs are the same for basic Mobile IPv4 and Mobile IPv6, and Foreign Agents are implemented with Access Routers, signaling costs of the two paging concepts can be directly compared. Since no assumptions can be made about how the topology of access networks will look like in future systems, signaling cost characteristics of both concepts are evaluated and compared while parameterizing the associated access network's characteristics. It is analyzed, how the value in saving mobility management related signaling costs depends on the routing characteristics of the local access network. Here, the evaluation of signaling costs has been performed while modifying the number of cells assigned to a paging area. Based on the same analysis framework, signaling costs characteristics can be studied while modifying other parameters, i.e. a mobile node's moving velocity or mobile node density, which has not been incorporated into this paper. The following evaluation is based on the same analytical approach as used for the P-MIP evaluation in [4] and takes over the analytical model, parameters and mobility characteristics for comparison of the two concepts. The network model is based on a *core network* part and on a *local network* part. The local network represents the cellular access network, where cells are assumed square shaped for the analysis, having a cell perimeter of length l. A paging area comprises n cells, each having a perimeter of length L, where $L = l \cdot \sqrt{n}$.

$$
\begin{aligned}
&C_{P-MIP} = \\
&D_{HAFA} \cdot \left(r_p + \left(r_c \cdot n - r_p \right) \cdot \alpha + \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot r_r + \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \cdot (\lambda_a + \lambda_d) \right) + \\
&D_{FAFA} \cdot (n-1) \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \cdot \lambda_a \\
&= D_{HAFA} \cdot \left(\frac{\rho \cdot v \cdot L}{\pi} + \frac{\rho \cdot v \cdot l}{\pi} \cdot \left(n - \sqrt{n} \right) \cdot \alpha + \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot r_r + \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \cdot (\lambda_a + \lambda_d) \right) + \\
&D_{FAFA} \cdot (n-1) \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \cdot \lambda_a
\end{aligned}
\tag{1}
$$

As in [4], the occurrence rate of events due to cell crossing rate (r_c) or paging area crossing rate (r_p) follows the fluid flow model and is $r_c=(\rho \cdot v \cdot l)/\pi$, or $r_p=(\rho \cdot v \cdot L)/\pi$ respectively, where v is the average velocity of mobile nodes and ρ represents the average density of mobile nodes (*mobiles/m*^{2}). A Mobile IP Home Agent is connected to the model's core network, whereas the Paging Agent is located in the administrative domain's local network adjacent to the link connecting the core network. The signaling costs (C) are evaluated and given as a *'weighted distance (hops) a number of signaling packets (pks) travel per second (sec)' (hops·pks/sec)*. The distance between two arbitrary nodes A and B is indicated as d_{AB} (*hops*) and is given as the number of hops in between these two nodes. The distance D_{AB} represents the *weighted* distance between two nodes A and B, where the weighting factor ω is different for the core network (ω_{core}) and the local access network (ω_{local}). Furthermore, occurrence rates of a data session's initial data packets are important for the evaluation, since they trigger either a mobile initiated *active* registration with the network due an outgoing data session with rate λ_d (1/sec), or a paging process initiated *active* registration due to incoming traffic with rate λ_a (1/sec). α denotes the ratio of active mobile terminals to the total number of mobile terminals. The evaluation refrains from specifying a static number of nodes in the local access network (distance between core network and Access Routers), but allows modifying this value as a parameter N_{var} (hops). The same is done for the parameter representing the average number of hops between ARs, which has been assumed to be $\sqrt{n}$ in [4], but is a variable parameter M_{var} in this analysis. Evaluating now C for both concepts over n, while modifying N_{var} and M_{var}, allows analyzing significant characteristics of the studied paging concepts. The parameters listed in Table 1 have been taken for the analysis.

ω_{core}	8
ω_{local}	1
$d_{HA,PA}$	8 (hops)
$d_{HA,FA}$	$d_{HA,PA} + N_{var}$ (hops)
$d_{HA,AR}$	$d_{HA,FA}$
$d_{FA,FA}$	M_{var} (hops)
v	28.9 (m/sec)
ρ	0.0002 (nodes/m^2), i.e. 200 (nodes/km^2)
α	5%
λ_a	3 (1/hr) i.e. 0.0008 (1/sec)
λ_d	3 (1/hr) i.e. 0.0008 (1/sec)
λ_c	0.0304 (1/sec)
r_r	0.001 (1/sec)
l	4000m

Table 1: *Parameters used for the evaluation.*

Based on the described static and variable parameters, the calculation of signaling costs for P-MIP has been taken from [4] and adapted to the variable parameter for the number of hops in the local access network (N_{var}) and the average amount of hops between ARs (M_{var}). As a result, the costs for the P-MIP architecture can be calculated as given in equation (1), where $D_{HAFA} = d_{HAPA} \cdot \omega_{core} + N_{var} \cdot \omega_{local}$ and $D_{FAFA} = d_{FAFA} \cdot \omega_{local} = M_{var} \cdot \omega_{local}$ and represents the weighted distance (number of hops) between two Foreign Agents in the P-MIP-enhanced Mobile IP architecture. For the computation of Mobile IP signaling costs, the equation derived in [4] has been used and adapted to the parameterized values for the local networks characteristics (N_{var}, M_{var}). Since the paging concept proposed in this paper specifies an explicit dormant registration with the Paging Agent, which is located between the core network and the local network, the equation (3) to calculate the signaling costs must have the dormant transition rate incorporated, which can be calculated from the parameters λ_a and λ_d when taking steady states into consideration. The dormant transition rate has been referred to and used for the same purpose in [5] and allows ascertaining the dormant transition rate (λ_c).

$$
\lambda_c = \frac{(1-\alpha) \cdot (\lambda_a + \lambda_d)}{\alpha} \tag{2}
$$

Furthermore, since the Paging Agent will be registered with a mobile terminal's Home Agent using the alternate-CoA registration support, a longer registration lifetime could be allowed for this explicit dormant mode registration and is assumed to be 10 times longer

$$
\begin{aligned}
&C_{PA} = \\
&D_{HAAR} \cdot \left(\lambda_c \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot \alpha + r_r \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot \alpha + \tfrac{1}{10} \cdot r_r \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) + (\lambda_a + \lambda_b) \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) + \frac{\rho \cdot v \cdot l}{\pi} \cdot n \cdot \alpha \right) + \\
&D_{PAAR} \cdot \left(\lambda_c \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot \alpha + \frac{\rho \cdot v \cdot L}{\pi} \cdot (1-\alpha) + (\lambda_a + \lambda_b) \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \right) + \\
&\tfrac{1}{2} \cdot D_{PAAR} \cdot \left(n \cdot \lambda_a \cdot \rho \cdot \left(\frac{l}{4} \right)^2 \cdot n \cdot (1-\alpha) \right)
\end{aligned}
\tag{3}
$$

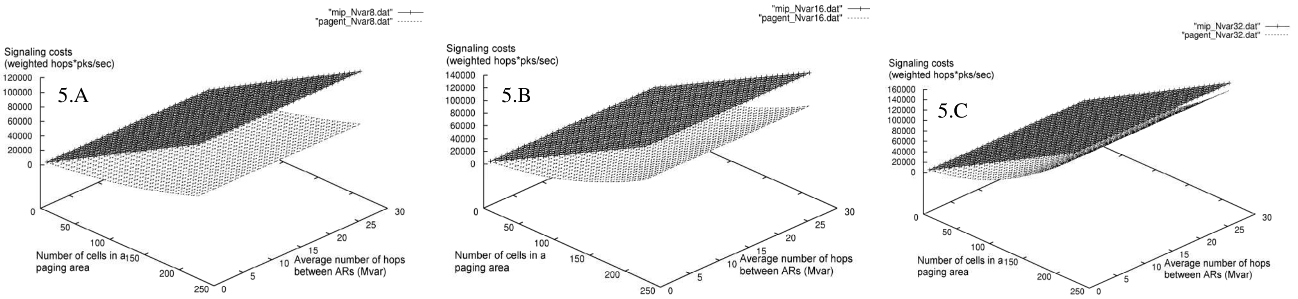

Figure 5: Evaluation of signaling costs for the Paging Agent based concept and Mobile IPv6 over the paging area size (n) and mean inter-AR distance (M_{var}) for different local network sizes, connecting the core with ARs through 8 (5.A), 16 (5.B) and 32 (5.C) hops.

than a normal location-update registration. This is a reasonable value, which has been realized in an implementation of the proposed concept in [12], and reduces the registration refresh rate with a Home Agent while a mobile terminal is in *dormant* mode (r_r [active]= 1/10 · r_r [dormant]). This saves additional battery energy on the mobile terminal and scarce radio bandwidth. The signaling costs of the proposed concept implies, in addition to location update and registration refresh rate, the dormant registration, the paging area update, the paging costs and the active registration:

$$C_{PA} = C_{update} + C_{dormreg} + C_{pareaupdate} + C_{activereg} + C_{paging}$$

The costs for the Paging Agent based concept can be calculated as given in equation (3), where $D_{HAAR} = d_{HAPA}\cdot \omega_{\text{core}} + N_{var}\cdot\omega_{\text{local}}$ and $D_{PAAR} = d_{PAAR}\cdot\omega_{\text{local}} = N_{var}\cdot\omega_{\text{local}}$ represents the *weighted* distance (number of hops) between the Home Agent and Access Routers in the Mobile IPv6 architecture. The last term calculates paging costs and takes into account, that *Paging Request* messages travel only one way without being acknowledged (factor 1/2) directly, but indirectly through the initiated de-registration process.

For the core network components, the distance between the Home Agent and the Paging Agent, which is located here at the same level as the node (Router), connecting the core network and the local network, is assumed to be constant (8 hops). Computing the signaling costs (*C*) modifies the number of cells, which are assigned to a paging area (*n*), and the mean number of hops between Access Routers or Foreign Agents respectively (M_{var}). Different values representing the number of hops in the local network (N_{var}) are incorporated in different computations. Results of computing the signaling costs of Mobile IPv6 (*mip_Nvar_8/16/32*) with a platform having the Paging Agent based concept integrated (*pagent_Nvar_8/16/32*) is illustrated in Figure 5.

Analyzing the diagrams in Figure 5 shows that the Paging Agent concept is independent of the forwarding characteristics between ARs (M_{var}), but costs increase in a non-linear way with increasing paging area size (*n*) and when increasing the distance (hops) between core network and ARs (N_{var}). Increasing N_{var} more and more would result in higher costs with paging compared to Mobile IP, but this is only for very large paging areas and local network characteristic much larger than 32 hops.

Computing and comparing signaling costs of Mobile IP with a platform having the P-MIP concept integrated (*pmip_Nvar_8*) generates costs diagrams as illustrated in Figure 6, which are based on equation (1) for P-MIP, while taking the adapted models into consideration. It can be seen, that the P-MIP concept is optimal for meshed ARs in the local access network and gets worse

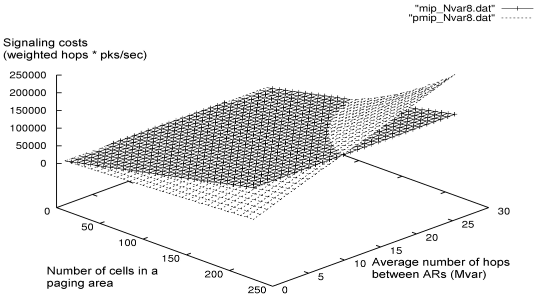

Figure 6: Evaluation of signaling costs for Mobile IP and the P-MIP paging concept, assuming a weighted core network-to-AR distance of 8 hops (N_{var})

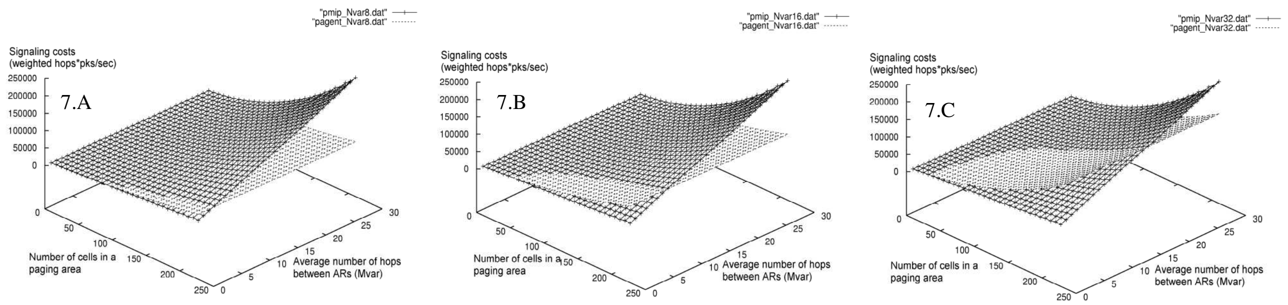

Figure 7: Evaluation of signaling costs for the Paging Agent based concept and P-MIP over the paging area size (n) and mean inter-AR distance (M_{var}) for different local network sizes, connecting the core with ARs through 8 (7.A), 16 (7.B) and 32 (7.C) hops.

for increased inter-AR distances (hops). Diagram characteristics shown in [4] can be found here as well when evaluating the cost values of the P-MIP concept over n and following the value for the mean inter-AR distance (N_{var}) according to $\sqrt{n}$, as assumed in [4]. Computing and comparing now the costs of the P-MIP concept with the Paging Agent based concept according to equation (1) and (3) gives the diagrams illustrated in Figure 7.

The diagrams illustrated in Figure 7 allow a qualitative comparison of the dependency of a Paging Agent based and a P-MIP concept based paging architecture and protocol. For optimized inter-AR routing distances (meshed Access Routers), a P-MIP concept based paging architecture and protocol is very efficient, whereas a Paging Agent and paging attendant based paging concept performs better when optimizing the links connecting the core network with the Access Routers by means of keeping the amount of intermediate hops between the Paging Agent and ARs low. From the evaluation it appears that the Paging Agent based concept is less dependent on an increasing distance between the Paging Agent and Access Routers than the P-MIP concept on increasing the mean distance between Access Routers. Some gain in performance characteristics for the proposed paging concept are supported by the fact, that only the Paging Agent is to be updated when the mobile terminal enters a new paging area. Associating an extended lifetime with the Home Agent registration when the mobile is in dormant mode supports keeping a large amount of signaling from the core network.

6. Conclusion

In this paper we described a generic IP paging architecture and protocol, flexible enough to be integrated with various IP based mobility management protocols, while minimizing complexity with regard to paging-function related protocol interactions. The proposed paging architecture and protocol keeps the IP paging protocol independent of access technologies and allows for mapping of the IP paging protocol to technology specific functions to optimize the control and management of dormant modes and the paging process. The signaling costs characteristics of the Paging Agent and paging attendant based concept has been analyzed and compared with a standard Mobile IPv6 platform without support for paging, as well as with the P-MIP concept, which assigns all paging functions to the access network's edge routers. The analytical evaluation has parameterized topology characteristics of the model's local network in order to see how the two concepts' signaling costs depend on the local network structure and associated weighted distances. From the evaluation results it can be seen, that the Paging Agent and attendant based concept performs well when the amount of hops between a Paging Agent and the paging attendant functions can be kept low. Since P-MIP co-locates all paging functions in Foreign Agents, which are assumed to be implemented with Access Routers, associated signaling costs heavily depend on the amount of hops required for inter-Access Router signaling.

ACKNOWLEDGEMENTS

This work is supported by the European Union IST project Moby Dick [12].

REFERENCES

[1] J. Kempf et al., *Requirements and Functional Architecture for an IP Host Alerting Protocol*, RFC 3154, August 2001.

[2] A. G. Valko et al., *Design, Implementation, and Evaluation of Cellular IP*, IEEE Personal Communications, Special Issue on IP-based Mobile Telecommunications Networks, August 2000.

[3] R. Ramjee et al., *Paging support for IP mobility*, draft-ietf-mobileip-paging-hawaii-01.txt, a work in progress, July 2000.

[4] X. Zhang, J. Castellanos, A. Campbell, *P-MIP: Paging in Mobile IP*, The Fourth International Workshop on Wireless Mobile Multimedia, July 2001.

[5] T. Zhang, S. Li, Y. Ohba, N. Nakajima, *A Flexible and Scalable IP Paging Protocol*, IEEE Globecom 2002,November 2002.

[6] R. Ramjee et al., *IP Paging Service for Mobile Hosts*, In Proceedings of MobiCom 2001, July 2001.

[7] C. Rose and R. Yates, *Ensemble Polling Strategies for Increased Paging Capacity in Mobile Communication Networks*, ACM Journal of Wireless Networks, vol. 3, no. 2, pp.159--167, 1997.

[8] W.-S. Wong and V.M. Leung, *Location Management for Next-Generation Personal Communication Networks*, IEEE Network, Sept 2000.

[9] C. Castellucia, P. Mutaf, *An Adaptive Per-Host IP Paging Architecture*, Computer Communication Review, a publication of ACM SIGCOMM 2001, October 2001.

[10] D. B. Johnson et al., *Mobility Support in IPv6*, draft-ietf-mobileip-ipv6-24.txt, a work in progress, June 2003.

[11] M. Liebsch et al., *Solutions for IPv6-based mobility in the EU project Moby Dick*, paper presented at WTC 2002.

[12] The EU IST project Moby Dick, *Mobility and Differentiated Services in a Future IP Network*, IST-2000-25394, 2000, http://www.ist-mobydick.org