P−SIGMA: Paging in End to End Mobility Management

Abu S. Reaz, **Mohammed Atiquzzaman**
Telecommunications and Networks Research Lab
School of Computer Science, University of Oklahoma,
Norman, OK 73019-6151, USA.
Email: {sayeem_reaz,atiq}@ou.edu

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Abstract— **Paging is a well established technique to reduce signalling cost in mobile devices. Different proposals in literature have shown the implementation and improvement of Mobile IP with paging. Here we propose P-SIGMA, an improved and signalling cost-effective version of SIGMA, an IP diversity based end-to-end mobility scheme. We show that with all the benefits of end-to-end mobility management scheme like SIGMA, P-SIGMA, as a mobility management scheme, is more efficient in terms of location management and is more cost effective in terms of signalling load.**

I. Introduction

Increasing demand for mobility in wireless data network has given rise to various mobility management schemes. Mobile IP (MIP) [1] is a network layer based scheme to handle mobility of Internet hosts for mobile data communication.

MIP has a number of problems, such as high handover latency, high packet loss rate, inefficient routing and conflict with security solutions . With the growing real time traffic over wireless networks, these problems become significant. A few improvements like Mobile IPv6 (MIPv6) [2], fast handovers for MIPv6 and Hierarchical MIPv6 have been suggested over Mobile IP to overcome these short-comings . But none of these improvements could reduce the high latency and resulting high packet loss. As most of the applications in the Internet are end-to-end, a transport layer solution should be more appropriate than network layer solution. A new transport layer scheme for mobility management, called Seamless IP diversity based Generalized Mobility Architecture (SIGMA) [3], has been proposed.

Fig. 1 illustrates handoff and location management of SIGMA. It is based on exploiting IP diversity [3] to support seamless handoff, and has the advantage of requiring no change in the network infrastructure. SIGMA requires a Location Manager (LM) to enable Correspondent Nodes (CN) to locate the Mobile Host (MH). Location management in SIGMA is done using DNS [4], [5] as use of almost every Internet application starts with a name lookup. Whenever an MH changes its address, the DNS entry is updated so that subsequent requests can be served with the new IP address.

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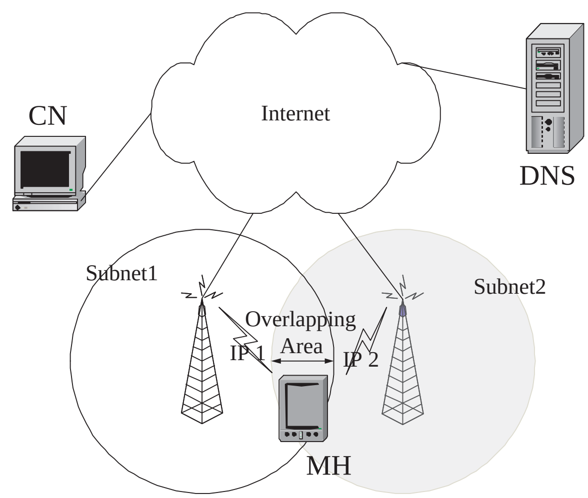

Fig. 1. DNS as a Location Manager.

SIGMA is fundamentally based on the concept that it would not require any change in the network infrastructure. However, introduction of some well established technique, like paging, with SIGMA, might increase the efficiency of this mobility management scheme at the cost of some changes in the network. The changes are not required at the backbone of the network, but would be at the very end of network, where the gateways need to communicate with MHs to establish last hop of the connection.

Paging is a widely deployed technique to locate and communicate with dormant devices in cellular networks. Paging can be integrated with IP network to reduce signalling load on the network [6]. A number of previous work have proposed different paging schemes for Mobile IP. Ramjee et al. [7] summarize different paging protocols, architecture and algorithms. All these work have Mobile IP as their primary focus. However, the authors are not aware of any work in the literature (including the above mentioned ones) that discusses paging-enabled transport layer end-to-end mobility scheme and the resulting improvement in the signalling cost. The *objective* of this paper is to introduce a paging extension for an end-to-end seamless mobility management scheme, SIGMA, and to analyze the improvement of signalling cost and location management. Our *contributions* in this paper are (i) introduction of a paging enabled transport layer end-to-end mobility management scheme, and (ii) analysis of efficiency of location manager and signalling cost improvement of the scheme.

Our results illustrate that P-SIGMA substantially reduces the signalling cost of SIGMA. Moreover, Fu et al. [8] showed that SIGMA has lower signalling cost than MIPv6. So we can conclude that P-SIGMA is a more cost effective mobility solution and less-burdensome on network than both SIGMA and MIPv6; and incorporating paging with SIGMA is a feasible tradeoff between change in infrastructure and cost improvement.

The rest of the paper is organized as follows. Sec. II gives an overview of SIGMA. Sec. III develops protocol, architecture and algorithm of P-SIGMA. Secs. IV and V show signalling cost model and the results demonstrating the improvements, respectively, followed by conclusions in Sec. VI.

II. Overview of SIGMA

There has been a few mobility solutions based on end-to-end mobility [9]. SIGMA is a complete end-to-end mobility management scheme that supports soft handoff, location management and reduced loss and latency [3], [8], [9].

A. SIGMA Handoff

SIGMA exploits IP diversity offered by multiple interfaces in mobile devices for handoff [3]. When a MH moves into the coverage of a new subnet, it obtains a new IP address while retaining the old one in the overlapping area of the two subnets. The MH communicates through the old IP address while setting up a new connection through the newly acquired IP address. When the signal strength of the old Access Point (AP) drops below a certain threshold, the connection is handed over to the new subnet and the new IP address is set to be the primary one. When the MH leaves the overlapping area, it releases the old IP address and only communicates over the new IP address [3]. Each time the MH handsoff to a new subnet, it updates the DNS with its new IP address [5].

B. SIGMA Location Management

SIGMA deploys Domain Name System (DNS) server as location manager [5]. Whenever a MH changes its point of attachment, it registers the new IP address with the Authoritative Name Server (ANS) via dynamic secure update [10]. As DNS is invariant and almost ubiquitous connection originator, all subsequent queries to the DNS for the MH will be served with the new IP address reflecting the new location of the MH.

Fig. 2 shows the sequence of updates to the DNS by the MH. At times t_1, t_2 and t_3, MH obtains new IP address, hands off to new subnet and leaves the old subnet releasing the old IP address, respectively. At each of this point, ANS is updated to ensure CN always gets the updated IP address [5].

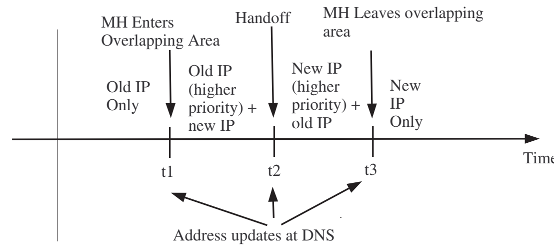

Fig. 2. MH's IP addresses in different stages of Handoff and their respective DNS updates.

III. Overview of P-SIGMA

Kirby [11] shows that 69% of the mobility is local. Many of MH movements are in an *idle* mode, which basically indicates the MH is not receiving any data for a certain period of time. These idle MHs really need not update its location whenever they are moving locally. Paging schemes allows an idle MH roam without updating its location information [6]. Paging is signalling by the network through APs to locate an MH to establish a last hop connection. In this section, we incorporate paging with SIGMA and discuss the architecture, protocol and algorithm of that paging scheme. We call this paging extension of SIGMA as P-SIGMA.

A. P-SIGMA Architecture

The first and most fundamental concept for paging is the Paging Area (PA). It is a set subnets whose APs are controlled by a single gateway. Thus, a PA is controlled by a gateway, called Paging Gateway (PGW). An idle MH can change subnets within a PA without updating its location information. But when an MH crosses a PA, it has to update the DNS with its new IP address.

The formation of paging area is another important aspect. The PGW needs to know the APs it is controlling. There are two ways of forming a PA. The first one is assigning a predetermined PA ID to the APs that are under a single PA. The other one is advertising the set of domain addresses of each of the subnets instead of an ID.

The benefit of the first one is ease of implementation and less load. But the later one enables to implement over-lapping PA and adaptive paging. This is our initial work on paging with SIGMA, and we would not use overlapping PA. Thus, for P-SIGMA, ID based PA detection is more appropriate. Fig. 3 illustrates the architecture of P-SIGMA.

B. P-SIGMA Protocol

A fundamental decision of any paging scheme is identifying an idle MH. Almost all the paging scheme follows a similar approach and we are going to do so for P-SIGMA. If an MH does not receive any packet for a certain period of time, T, it goes to the idle mode. Whenever it receives a packet, it goes to active mode and restarts T.

Ramjee et al. [7] defines paging protocol as determination of the node that initiates paging and classifies the protocols of paging schemes as Home Agent (HA), Foreign Agent (FA) and domain based paging protocol.

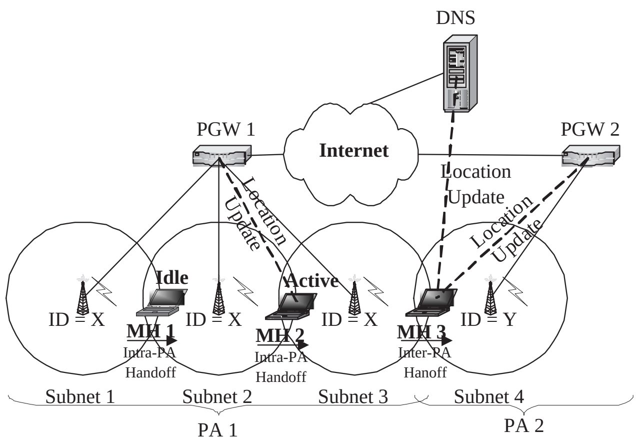

Fig. 3. P-SIGMA architecture and protocol.

Fig. 3 describes the paging protocol of P−SIGMA. As routing in SIGMA is done based on domains, so natural choice of paging protocol for P−SIGMA would be a variant of domain paging. Just like domain paging, P−SIGMA paging is initiated by MH's last attached router or gateway. But as it is an end-to-end solution, and location management is done using DNS, all the routers in the middle does not require to know the state of the connection. Whenever a MH moves out of its subnet but is still within the PA in an active state, it performs SIGMA handoff (Sec. II-A) and continues its communication with the CN with the new IP address of the new subnet, and MH updates the PGW with the new IP address. But when the MH crosses PA, it performs SIGMA handoff and updates both the LM and PGW with the new address (Sec. II-B). But in idle state, when MH crosses a subnet, it does not obtain any new IP address as long as it stays within the PA. When MH moves into a new PA in idle state, it obtains an IP address from the corresponding subnet and registers it with the LM as described in Sec. II-B. The difference in DNS updating strategy for SIGMA and P−SIGMA is, for P−SIGMA(Fig. 2), the IP 2 would be the IP address obtained from the new PA instead of a new IP address obtained from any neighboring subnet as in SIGMA.

C. P-SIGMA Algorithm

Ramjee [7] refers to the paging algorithm as technique and location of paging and classifies paging algorithms into three classes: fixed, hierarchical and last location paging.

As paging is implemented at the last attached gateway for P−SIGMA, a combination of fixed and last-location paging is more suitable. If prior knowledge of the mobility pattern of MHs in a particular subnet is available, then if the mobility is low in that subnet, last location paging would be more appropriate. For other cases, fixed paging would be implemented. For example, if a subnet is in a cafe, the mobility would be low but if it is in a highway, mobility would be very high. In a particular PA, depending on the subnet, both of these techniques might be implemented together. In that case, the PGW needs to decide which technique to follow based on the last attached subnet. The paging would be done using the MAC address of the MH as it remains unchanged for a particular interface. Fig. 4 depicts the paging algorithm for P−SIGMA. In the figure, the connection request to MH 1 is done using last-location paging and to MH 2 is done using fixed paging.

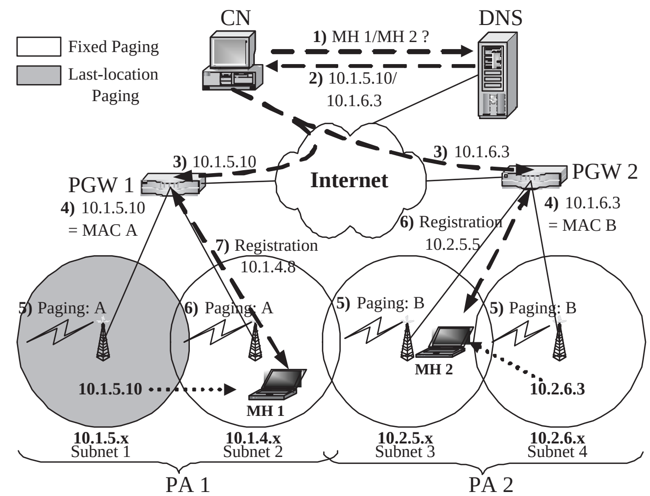

Fig. 4. P-SIGMA algorithm and location management.

D. P-SIGMA Location Management

Paging actually introduces a hierarchy of location management. DNS has the most updated address of the MH that represent the current PA. On the other hand, PGW has the exact address of the MH. It should be mentioned that, PGW is a light weight LM because it does not not keep a large set of records like DNS, rather it just keeps a mapping of MAC to IP address for each MH under it. So update cost of PGW is significantly less than DNS. Moreover, PGW is just one-hop away from the corresponding AP. So, the possibility of a query failure [5] is close to zero as the PGW would be updated before the MH leaves the overlapping area. Thus, the PGW can forward the packet to the MH without failure because in the overlapping area, the MH can be reached with multiple address (Sec. II-A).

Fig. 3 describes the location management in P−SIGMA. Any connection request from a CN would initiate from a DNS lookup which is served with the IP address of the MH that corresponds to a particular PA. As all packets destined to the domain addresses of the subnets under a particular PA is sent to the PGW of the PA, the connection initiation request first reaches the PGW. If the MH is in active state, PGW knows the current address of the MH and forwards the initiation packet to MH. On the other hand, if MH is in idle state, PGW pages the subnets under its control (Sec. III-C). When MH receives a paging message, it registers itself with the subnet it is in, updates the PGW, and moves to active state from idle. Then the PGW sends the packet to the new address of MH. Then the MH updates the CN with its news address and the subsequent communication is done using end-to-end transport layer communication.

IV. Performance Analysis

Introduction of paging to SIGMA has a two-fold improvement. First, for movement within a PA, the location update is done to PGW, which is light weight and very close to the AP. Thus the update and communication cost would be less, and the location management can be done with higher success. Secondly, as the idle hosts are not updating them with the PA, signalling cost will be significantly reduced.

A. Performance improvement of LM

PGW is just one hop away from all the APs under its control. Thus the time taken to update PGW is very low. So, we can assume that the PGW would always be able to reach the MH without any failure (Sec. III-D).

Now, for SIGMA, let for an MH in a particular subnet,

T_{cr} = critical time or the fraction of time during which DNS would serve incorrect IP address during handoff process

T_{sub}^{res} = the residence time of an MH in a particular subnet

Then, we can find the number of failures during a single handoff as E$[\chi(T_{cr})]$ and total number of queries as $E[\chi(T_{sub}^{res})]$ where $\chi(t)$ represents number of queries within time t. If λ is the arrival rate of name lookup query to the LM, we have $E[\chi(T_{cr})] = \lambda T_{cr}$ and $E[\chi(T_{sub}^{res})] = \lambda T_{sub}^{res}$.

The success of DNS as a LM, depends on the fraction of time it can successfully serve the right IP address out of all the queries. So, Success Rate, ρ, can be defined as

$$\rho = \frac{E[\chi(T_{sub}^{res})] - E[\chi(T_{cr})]}{E[\chi(T_{sub}^{res})]} \quad (1)$$

But for P-SIGMA, DNS is updated only when the MH crosses a PA. We assume that PGW would not serve any incorrect IP address. So, T_{cr} = 0 for PGW. Thus, if there are k subnets in a particular PA, the success rate of location manager in P-SIGMA, ρ_P can be defined as

$$\rho_P = \frac{kE[\chi(T_{sub}^{res})] - E[\chi(T_{cr})]}{kE[\chi(T_{sub}^{res})]} \quad (2)$$

So, the performance improvement, ϕ, would be defined as $\frac{\rho_P}{\rho}$ which would be

$$\phi = \frac{kE[\chi(T_{sub}^{res})] - E[\chi(T_{cr})]}{E[\chi(T_{sub}^{res})] - E[\chi(T_{cr})]} \quad (3)$$

B. Signalling Cost

The signalling cost analysis of SIGMA is done in [8]. This section introduces the signalling cost for P-SIGMA and compares with the cost of SIGMA.

Variables for SIGMA and P-SIGMA

l_{ml} = avg. no. of hops between MH and LM

l_{mc} = avg. no. of hops between MH and CN

N_{mh} = total number of MH

N_{cn} = avg. number of CN communicating with a MH

T_{sub}^{res} = Subnet residence time of MH

S = no. of sessions per transport layer association where MH is a server

λ_s = per sessions arrival rate

λ_p = avg. paging request arrival rate

LU_{ml} = Transmission cost of one location update from MH to LM

BU_{mc} = Transmission cost of one binding update from MH to CN

γ_l = Processing cost at LM

δ_{UL} = per hop location update message transmission cost from MH to LM

δ_{UB} = per hop binding update message transmission cost

ψ = linear coefficient of no. of MH to lookup cost

v_l = LM look up cost per sec for each association

ω = ratio of MHs that are servers to total MH

σ = session-mobility ratio defined as $\lambda_s \times T_{sub}^{res}$.

Variables for SIGMA

Ψ_{LM}^{LU} = Location manager update cost per sec

Ψ_{MC}^{BU} = binding update cost per sec between MHs and CNs

Ψ_{LM}^{LUP} = look up cost per sec for CNs and MHs

Ψ_{SIG}^{TOT} = total signaling cost per sec

Variables for P-SIGMA

$p\Psi_{LM}^{LU}$ = Location manager update cost per sec

$p\Psi_{APGW}^{LU}$ = PGW update cost per sec for active hosts

$p\Psi_{IPGW}^{LU}$ = PGW update cost per sec for idle hosts

$p\Psi_{A}^{BU}$ = Binding update cost per second for active hosts

$p\Psi_{I}^{BU}$ = Binding update cost per second for idle hosts

$p\Psi_{PC}^{LUP}$ = Lookup cost per second for paging

$p\Psi_{LM}^{LUP}$ = Lookup cost per second in LM

$p\Psi_{SIG}^{TOT}$ = total signaling cost per sec

LU_{mp} = Transmission cost of one location update from MH to PGW

PC_{sub} = paging cost in a subnet

γ_p = Processing cost at PGW, necessarily $\gamma_p \leq \gamma_l$

k = number of subnets in PA

θ = wireless proportionality constant

δ_{UG} = per hop location update message transmission cost from MH to PGW, $\delta_{UG} \leq \delta_{UL}$

δ_P = per hop paging message transmission cost

α = ratio of active to total MH, $\alpha \leq 1$

$\overline{\alpha}$ = ratio of idle MH becomes active to total MH, $\overline{\alpha} \leq (1-\alpha)$

Location update cost

1) LM update cost:
In SIGMA, whenever an MH crosses a subnet in every T_{sub}^{res} seconds, it updates its location at DNS. A location update cost includes the transmission cost and processing cost at DNS for all the MHs. From Sec. II-B, we know there would be 3 such updates for each handoff for each MH. Bur for P-SIGMA, this update occurs in every kT_{sub}^{res} seconds as this update takes place only when MH crosses the PA.
Thus,

$$p\Psi_{LM}^{LU} = \frac{\Psi_{LM}^{LU}}{k} = 3N_{mh}\frac{LU_{ml} + \gamma_l}{kT_{sub}^{res}} \quad (4)$$

where $LU_{ml} = 2(l_{ml} - 1 + \theta)\delta_{UL}$ and $(l_{ml} - 1)$ = the number of wired hops.

2) PGW update cost for active hosts :
PGW would be updated only when an active host crosses a subnet. So, the update cost for PGW would be computed for active hosts only:

$$p\Psi_{APGW}^{LU} = \alpha N_{mh} \frac{LU_{mp} + \gamma_g}{T_{sub}^{res}} \tag{5}$$

To update a PGW, the update message travels only one hop via wireless link. So, $LU_{mp} = \theta\delta_{UL}$.

3) PGW update cost for idle hosts :
When an idle host becomes active, it obtains an IP address and updates the PGW. So, if $\overline{\alpha}$ is the fraction of idle MH becoming active, we get

$$p\Psi_{IPGW}^{LU} = \overline{\alpha} N_{mh} \frac{LU_{mp} + \gamma_p}{kT_{sub}^{res}} \tag{6}$$

Binding update cost

To calculate the binding update cost, we do not consider the update cost at the hosts as it is not part of signalling cost.

1) For SIGMA :
Binding update takes place at MHs and CNs. For handoff, every MH would update their respective CNs. So we get

$$\Psi_{MC}^{BU} = N_{mh} N_{cn} \frac{BU_{mc}}{T_{sub}^{res}} \tag{7}$$

where $BU_{mc} = 2(l_{mc} - 1 + \theta)\delta_B$.

2) For P-SIGMA :
But for P-SIGMA, this binding update would only take place for active hosts because idle hosts do not participate in data communication. So we would get

$$p\Psi_{A}^{BU} = \alpha N_{mh} N_{cn} \frac{BU_{mc}}{T_{sub}^{res}} \tag{8}$$

Lookup cost

1) DNS lookup cost:
If the MH is a server, the CN is the connection initiator and requires to perform a DNS lookup. This lookup would take place S/λ_s seconds when each session duration time is independent from each other. We assume the number of MHs is linearly related to location database search cost. So we would get $v_l = \frac{\psi N_{mh} \lambda_s}{S}$. So the total database lookup cost would be

$$\Psi_{LM}^{LUP} = \omega N_{mh} N_{cn} v_l = \omega N_{mh}^2 N_{cn} \frac{\psi \lambda_s}{S} \tag{9}$$

As this cost is there for P-SIGMA as well, necessarily $p\Psi_{LM}^{LUP} = \Psi_{LM}^{LUP}$.

2) Paging cost:
Though our paging algorithm includes a combination of fixed paging and last-location paging, we would consider every paging is done as last-location paging as it would give the worst case scenario when we always consider that the MH would not be found in the last known location. Paging would take place when an idle host is to become active. So we have

$$p\Psi_{PC}^{LUP} = \frac{\overline{\alpha} N_{mh} k(\theta\delta_P + PC_{sub})}{1/\lambda_p} \tag{10}$$

So, by summing up all the costs from Eqns. (4), (7) and (9), we would get for SIGMA,

$$\Psi_{SIG}^{TOT} = \Psi_{LM}^{LU} + \Psi_{MC}^{BU} + \Psi_{LM}^{LUP} \tag{11}$$

and from Eqns. (4), (5), (6), (8), (9) and (10), for P-SIGMA,

$$\begin{aligned} p\Psi_{SIG}^{TOT} = p\Psi_{LM}^{LU} + p\Psi_{APGW}^{LU} + p\Psi_{IPGW}^{LU} + \\ p\Psi_{A}^{BU} + p\Psi_{I}^{BU} + p\Psi_{PC}^{LUP} + p\Psi_{LM}^{LUP} \end{aligned} \tag{12}$$

V. RESULTS

When combined with paging, location management of SIGMA improves. Eq. (3) defines the improvement of success rate for DNS as LM. When we have higher number of subnets in a PA, the probability of query failure is reduced. Fig. 5 clearly shows that higher number of subnets in a PA increases the improvement ratio.

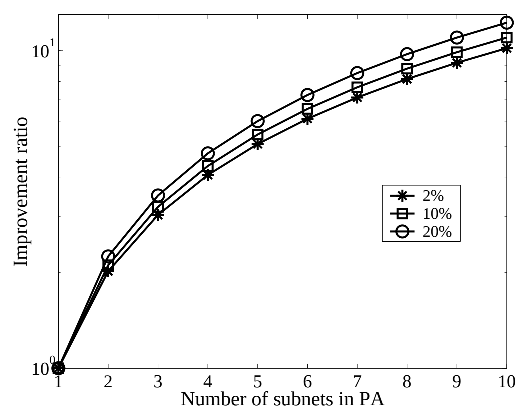

Fig. 5. Improvement ratio over PA size for different critical time

Now we analyze the signalling cost. For numerical calculations, we use the following parameter values used in previous work [8]: γ_l = 30, $\gamma_p = 0.75 \times \gamma_l$, ψ = 0.3, S = 10, θ = 10, l_{lm} = 35, l_{mc} = 35, λ_s = 0.01, λ_p = 0.01, δ_{UL} = 0.2, δ_{UB} = 0.2, δ_P = 0.2, α = 0.7, $\overline{\alpha}$ = 0.1, ω = 0.5, PC_{sub} = 7. Here, we assumed that the per hop cost for every kind of signalling message is same, 70% of MHs are active and one-third of the rest 30% idle MHs become active, 50% of the MHs are servers and PGW processes updates in three-fourth of the time taken by DNS to do the same.

First, we examine the impact of number of MHs for different subnet residence times on total signalling cost of SIGMA and P-SIGMA (Eqns. (11) and (12)) as depicted in Fig. 6. Values used here are N_{cn} = 1, N_{mh} from 20 to 100 and T_{sub}^{res} = 60, 120 and 180 sec. When the residence time is lower, it increases the rate of handoff, leading to the increment of per second signalling cost. We can see that the signalling cost of P-SIGMA is lower than SIGMA due to the fact that there are

k = 3 subnets for which there is only one DNS update and a reduced number of update and binding cost for the 30% idle mobile hosts.

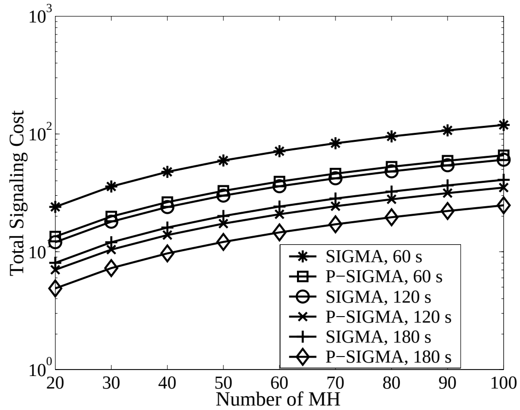

Fig. 6. Signalling cost for SIGMA and P-SIGMA over number of MH for different residence time.

We examine the impact of average number of communicating CN and per hop transmission costs for different signalling messages. For T_{sub}^{res} = 60 and N_{mh} = 80. We observe from Fig. 7 that as the number of CN increases, the signalling cost increases (Eqns. (7), (8), (9)). As the transmission costs increase, naturally the overall signalling cost gets increased. Fig. 7 shows that even with variation in update costs and number of CN, `P-SIGMA` still has less signalling cost than `SIGMA`.

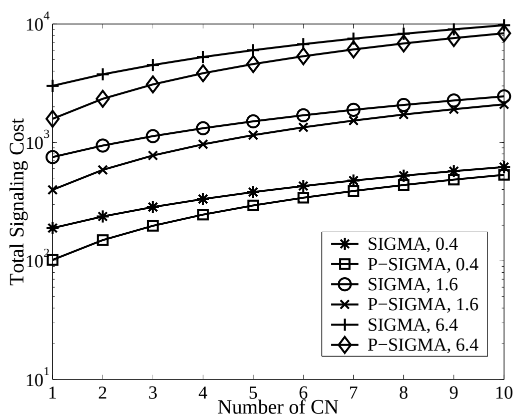

Fig. 7. Signalling cost for SIGMA and P-SIGMA over number of CN for different transmission cost.

Session to Mobility Ratio (SMR) is a mobile packet networks counterpart of Call to Mobility Ratio (CMR) in PCS networks. We vary T_{sub}^{res} from 75 to 375 seconds with λ_s fixed at 0.01, which yields a SMR (σ) of 0.75 to 3.75. Fig. 8 shows the impact of SMR on total signaling cost for different n_{mh}. Higher value for σ indicates low mobility, thus less number of updates and less signalling cost. So, we can see that the signalling cost decreases with increment of σ.

We can see from Fig. 5 that `P-SIGMA` improves the performance of the location manager. Figs. 6, 7 and 8 depict the fact that `P-SIGMA` has reduced signalling cost for different residence time, mobility rates, update costs and number of MH and CN. Fu et al. [8] showed `SIGMA` has lower signalling cost than HMIPv6. So, can say that `P-SIGMA` is a very cost effective, end-to-end mobility management scheme.

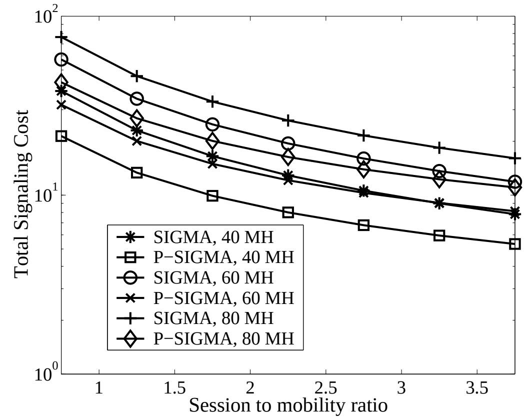

Fig. 8. Signalling cost for SIGMA and P-SIGMA over SMR for different number of MH.

VI. Conclusions

`SIGMA` is a very stable, low-loss and low-latency end-to-end mobility management scheme. We introduced protocol, architecture and algorithm of `P-SIGMA`, an extension of `SIGMA` for reduction of signalling cost. We compared the performance of location manager and the signalling cost for `SIGMA` and `P-SIGMA`. Our results clearly show that `P-SIGMA` improves the success rate of LM and reduces the overall signalling cost by a factor of ******.

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