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DPAC: Dynamic Paging Area Configuration

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Status of This Memo

Abstract

This document defines dynamic paging area configuration extensions to IP paging. The motivation is three fold: First, paging areas are auto-configured, hence human effort is minimized. Second, paging area shapes adapt to host mobility characteristics, hence more efficient. Third, paging area sizes are variable, allowing future optimization.

Dynamic paging area configuration can be regarded as the major advantage of having L3 paging areas.

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1.0 Introduction

The DMHA (Dormant Mode Host Alerting) protocol offers IP paging services to dormant mode capable Internet hosts in order to reduce power and bandwidth consumption [PROB][REQ].

The flexibility of IP paging allows dynamic paging area configuration. Manual paging area configuration is difficult, prone to human error and not necessarily well adapted to user movement. This document defines extensions for Dynamic Paging Area Configuration (DPAC) for flexibility of administration and better paging performance.

DPAC aims to be scalable, low-cost and adaptive: Paging areas should be available to millions of hosts regardless of their points of attachment in a cellular system comprising millions of cells (scalable). Furthermore, the cost of paging area configuration on mobile host operation and bandwith consumption should be negligible (low-cost). Finally, paging area shapes should adapt to hosts' mobility characteristics in order to efficiently reduce the rate of registrations. In addition, paging area shapes should adapt to the changes in the cellular topology, e.g., the addition of a new cell (adaptive).

2.0 Paging area model

A dynamically configured paging area is a list of network prefixes (i.e. cells). The size of a paging area is the size of that list, hence the number of cells. These paging areas have the following properties:

+ Per-cell: There is a paging area corresponding (relative) to each cell. Naturally, paging areas overlap.

+ Loadable: A host requests the network a pre-configured paging area relative to its current cell.

+ Host-centered: A mobile host which obtains a new paging area is initially at the center of that paging area.

3.0 Dynamic paging area configuration

3.1 Sampling

A Cellular Sampling Agent (CSA) is a new function responsable for collecting samples sent by mobile hosts moving in its domain.

A sample is an ordered pair of adjacent cells. Samples are generated randomly by mobile hosts. Upon location registration, a mobile host sends a sample to its current CSA with a very small probability (e.g. 1%, 2%) so that sampling has no impact on power consumption on mobile hosts nor bandwith consumption.

The identity of the host which sends a given sample has no importance. This way DPAC captures the aggregated movement characteristics which are more or less common to each individual host. This sampling policy is at the heart of DPAC scalability.

Then, the collected samples give the "aggregated host direction probabilities" in each cell of a CSA domain. In a given cell A, the probability of a given direction is the probability of moving to a corresponding cell in the neighborhood. For example, the samples [A|B], [A|C], [A|D], [A|B], ... will help extract the direction probabilities in cell A. This is illustrated in Figure 1.

```
      +     +
     / \   / \
    /   \ /   \
   +     +     +
   |  G  |  B  |
   +     +     +
  / \   / \   / \
 /   \ /   \ /   \
+     +     +     +
|  F  |  A  |  C  |
+     +     +     +
 \   / \   / \   /
  \ /   \ /   \ /
   +     +     +
   |  E  |  D  |
   +     +     +
    \   / \   /
     \ /   \ /
      +     +
```

Figure 1. Six possible directions that hosts may take in cell A (where P(B) + P(C) + P(D) + P(E) + P(F) + P(G) = 1)

For example, on a two-way highway the direction probabilities will be approximately 0.5 and 0.5 in each cell along that highway.

3.2 Paging area composition

A paging area PA relative to a given cell A and of a given size S, can be composed as follows:

```
PA={A};                 \\initially the paging area contains
                        \\only one cell.
i=1;

while (i<S){
        add to PA, the cell which       \\this cell is computed
        would be most probably visited  \\using the movement
        upon leaving PA;                \\direction
                                        \\probabilities.
        i++;
}
```

This way, the shape of PA adapts to the aggregated host mobility pattern around the cell A.

Using the algorithm described above, the CSA can configure a paging area relative to each cell in its domain. The paging area size can be fixed by the operator. However, by configuring large paging areas, it is possible to choose smaller paging areas later.

For example, let

```
PA={A,B,C,D,E,F,G,H,I,J,K}      (S=11)
```

a paging area relative to cell A, configured as above. Then, by preserving the same order, one can pick smaller paging areas such as:

```
PA' ={A,B,C,D,E,F}              (S=6)
PA" ={A,B,C}                    (S=3)
```

where PA, PA' and PA" are concentric paging areas relative to a same cell A and they have all an optimal shape.

See Section 7 for the motivations behind paging area size flexibility.

4.0 Convergence of paging areas

How much time will take the convergence of paging areas? Assume the following parameters:

```
#users/cell = 25 (uniformly distributed)
#registrations / host / hour = 1 (on the average)
```

Sampling rate = 2% (i.e. 1 sample / 50 registrations)

Then assuming that one needs on the average 50 samples/cell, then the CSA will have enough information for composing the paging areas relative to each cell in its domain, in:

$$\frac{50}{25 \times 1 \times 0.02 / \text{hour}} = 100 \text{ hours } (\sim 5 \text{ days})$$

In the same manner, if the sampling rate is 1%, the convergence of paging areas will take ~9 days (which is still in the acceptable region). This is a promising prediction although we make weak assumptions. In practice both number of users and registration rates are higher. On the other hand, the number of samples that is needed for convergence, depends on hosts' mobility characteristics. For example, along a one-way highway where all mobiles move in the same direction, 1 sample/cell will be enough. However, when host mobility pattern is less predictable (in urban areas for example), more samples will be needed.

The convergence speed is self-tuning. As mentioned above, samples are sent upon location registrations. Therefore, initially (when there is no configured paging areas), hosts will send location registrations frequently (hence, sampling frequency will be high). Then, as the paging areas converge, the rate of registrations hence, sampling frequency will gradually decrease.

5.0 Model of operation with relevance to the DMHA protocol

Dynamically configured paging areas have to be communicated to mobile hosts. Then, the DMHA protocol should operate as follows:

1. Whenever a host crosses the boundaries of a paging area, it requests its current paging agent a paging area relative to its current cell along with its registration message,

2. The paging agent sends this information to the requesting host along with an acknowledgement message,

3. The host remains dormant while moving in the paging area,

4. When a packet destined for the dormant host arrives, the paging agent pages the host in its most recent paging area.

Secondly, paging has to be carried out in a SMG (Small Group Multicast) style [SGM]. In this scheme, all destination cell addresses forming a paging area are initially carried in a page packet header. Then, the addresses are split by intervening routers forwarding the packet to two or more interfaces. This is illustrated in Figure 2.

```
                                      B
                                 +----------->
                       A,B,C,D  /              A
        paging agent ----------+             +---->
                              R1\   A,C,D   /           C
                                 +---------+          +--->
                                          R2\  C,D   /
                                             +------+
                                                   R3\  D
                                                      +--->
```

Figure 2. Illustration of paging a DMH
on a paging area comprising the nets A,B,C,D.

6.0 How to support DPAC in current DMHA protocol proposals?

In MIPv6HP [HP] dormant mode state is hold by a MAP [HMIP]. MAPs can be augmented with CSA functionality for sampling and paging area composition. The MAP will be responsable for sampling and composing the paging areas relative to the cells in its domain. Samples can be sent along with dormant mode registrations (in a Binding Update sub-option). Paging area request and reply messages can be also defined as Binding Update sub-options.

In LH-DMHA [LH], the last contacted access router holds the dormant mode state. The CSA function can be implemented on a MAP or a dedicated machine. Then, LH-DMHA can be augmented with a message exchange between the CSA and each access router in its domain. In this case, the CSA will configure paging areas as described above and send each access router in its domain the paging area relative to the cell served by that access router. The access router will cache this information, and periodically (once per week for example) update it by requesting the CSA a new one in order to adapt to some changes in paging area shape. Paging area request and reply messages can be defined in TLV formatted LH-DMHA messages.

7.0 Picking the paging area size

Manual configuration of paging area sizes is considered difficult. A cellular operator faces an impossible decision:

1. If I choose large paging areas, then I'll increase the cost of paging,

2. If I choose small paging areas, then I'll increase the rate of registrations and battery consumption.

What do to? In current systems, cellular operators choose fixed paging area sizes. This is by no means optimal.

DPAC will support adaptive schemes with per-host and time-varying paging area sizes (picked by each individual host) [ADAPT]. This scheme minimizes the costs of location tracking and provides better power savings. The idea is quite simple: If a host moves slowly, then the paging area for that host can be small since the cost of registrations will be small. On the other hand, if a host rarely receives incoming sessions, the paging area for that host can be large since the cost of paging will be small.

If the DMHA protocol is DPAC compatible (as described in Section 5), a host can request its paging agent a paging area of a personally defined size which adapts well to its mobility and incoming session rate characteristics. This way paging area sizes can be also auto-configured.

8.0 Security considerations

Security issues with relevance to paging area auto-configuration, are not discussed in this document.

9.0 Conclusion

The flexibility of IP paging allows dynamic paging area configuration. With auto-configured, adaptive paging area shapes and flexible paging area sizes, this can be regarded as the major advantage of having L3 paging areas. In this document we proposed dynamic paging area configuration extensions to IP paging.

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