# On Reducing Paging Cost in IP-based Wireless/Mobile Networks

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**Abstract.** For more scalable mobile services, it is important to reduce the signaling cost for location management. In this paper, we propose a cost effective IP paging scheme utilizing explicit multicast (xcast). Xcast is a new kind of multicast scheme for small sized groups which uses unicast with low maintenance overhead. In terms of the paging algorithm, we use a selective paging scheme to minimize the paging cost, by dividing a paging area into several sub-paging areas. For the performance analysis, we develop an analytical model based on the random walk model in the mesh and hexagonal cell configurations. Using this model, we compared the paging cost between IP paging scheme using xcast and that using unicast or multicast. The results indicate that the proposed paging scheme reduces the paging cost by 44-84% compared with traditional paging schemes using multicast.

## 1 Introduction

In wireless/mobile networks, since mobile users are free to move within the coverage area, the network can only keep track of the approximate location of each mobile user. When a request is made to establish a session with a particular user, the network needs to determine the user's exact location within the cell granularity. The operation of the mobile host (MH) informing the network about its current location is known as *location update*, and the operation of the network determining the exact location of the mobile user is called *terminal paging*.

Recently, with the advent of IP technologies, IP-based location management has become the focus of research in this area. In terms of location update, the Mobile IP Working Group in Internet Engineering Task Force (IETF) proposed various protocols based on Mobile IP. On the other hand, in terms of terminal paging, several protocols were proposed in [1], [2], and [3]. Unlike the paging protocols in cellular networks, these protocols are based on IP-layer messages so that they are called *IP paging protocols*. With time-constraint multimedia applications (e.g. VoIP and message applications) gaining in popularity, IP paging is being considered as one of the essential functions in next-generation mobile networks. However, previous studies didn't focus so much on the issue of cost optimization schemes, which provide system scalability, but only on the basic paging architecture, paging procedure, paging area design, and so on.

In this paper, we propose a cost-effective IP paging scheme. Among the various cost optimization factors we focus on rendering the delivery mechanism of paging request messages more efficient. Since paging in cellular networks is dependent on the specific link technologies, seeking a more efficient mechanism is somewhat redundant. However, a number of different delivery mechanisms (i.e. unicast, multicast, and so on) are available in IP networks. Therefore, it is necessary to determine which mechanism is the best to deliver the paging messages. In previous works, both simple unicast ([1]) and multicast ([2] [3]) were used. Unicast is easy to implement, but it is not an efficient method to page multiple access routers (AR) simultaneously. On the other hand, multicast is an efficient way to page a paging area (PA) consisting of a large number of ARs, however it requires a certain amount of overhead for multicast group management. Therefore, we utilized explicit multicast (xcast) [4] as delivery mechanism. Xcast is a variance of multicast, which is designed for small sized groups. Unlike multicast, xcast does not require group maintenance, and can therefore support simultaneous paging to multiple ARs with minimal overhead. Besides, xcast is an appropriate choice for the selective paging scheme [5], as it dynamically adjusts the size of the PA and thus can minimize the paging cost while meeting the paging delay bound.

The rest of this article is organized as follows. Section 2 proposes the selective IP paging scheme utilizing xcast. In Section 3, we develop an analytic model to evaluate the proposed scheme. Section 4 shows the numerical results and Section 5 concludes this paper.

## 2 Selective IP Paging Scheme using Explicit Multicast

### 2.1 Protocol overview

In this section, we present an overview of the selective IP paging scheme utilizing explicit multicast. When a paging request is destined for an MH, a paging agent receives the request and sends the paging request to the ARs in order to find the MH. In the selective paging scheme, the number of paging steps to be performed needs to be determined first, before sending a paging request to the ARs, by considering paging delay bound. Let $M$ be the number of paging steps. When determining the value of $M$, we should consider the paging delay bound and $N^*$, the feasible group size, which is the number of group members that will enable xcast perform to better than typical multicast in terms of the paging cost.

Once the above paging step has been performed, the PA is divided into $M$ sub-PAs and the paging agent sends the first paging request packet to the sub-group denoted by $A_0$. If the destination MH is in $A_0$, the paging procedure is terminated. Otherwise, a second paging procedure should be performed for the second sub-PA, denoted by $A_1$. These procedures are repeated until the destination MH is found out.

Fig. 1 provides an illustrated example of the selective paging scheme in a PA consisting of 19 ARs. It is assumed that the number of paging steps ($M$) is 4. In the selective paging scheme, the PA is divided into sub-PAs based on the location where the MH recently registered. The detailed method used to determine the size of the sub-PAs and the members of these sub-PAs will be presented in the next subsection.

Let's assume that a correspondent host (CH) would like to initiate a session with an MH, which registered at $AR_0$ last but has moved to $AR_{11}$ without any location registration because the MH remained in the idle state. First, the paging agent receiving the paging request forwards the request to all of the ARs in the first sub-PA ($A_0$) using xcast. If there is no response, the paging agent performs the second paging procedure to the sub-PA ($A_1$). Since the MH is currently located in $AR_{11}$, the MH responds to the third paging request sent to the third sub-PA ($A_2$), and at this point the paging procedure is finished.

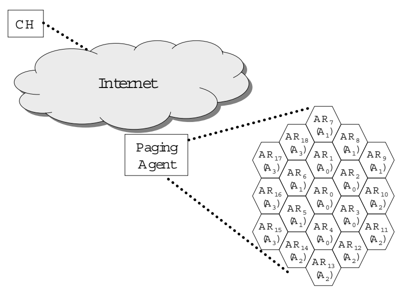



**Fig. 1.** Protocol overview: Selective IP paging scheme using xcast

### 2.2 Determination of Paging Group Size and Paging Step

Before partitioning a PA into multiple sub-PAs for the selective paging scheme, we have to determine the value of $M$, the number of paging steps. To determine $M$, the paging delay bound and the maximum feasible xcast group size ($N^*$) need to be taken into consideration. As mentioned above, xcast is a more light-weight delivery scheme than multicast, because there is no management cost involved. However, if the group size exceeds a certain value, the packet size becomes too large and this affects the packet processing cost traffic load in wireless access networks. Hence, the maximum feasible group size in xcast should be set to a reasonable value by the network administrator. Once $N^*$ has been determined, we can decide the value of $M$ using the following relationship where $D$ is the paging delay bound and $M$ is an integer value.

$$N_{AR}/N^* \leq M \leq D$$

For example, if there are 61 ARs in a paging area, $N^*$ is 20 and paging delay bound is 5, then $M$ can be either 4 or 5. If the paging delay is more sensitive factor, we choose the value of 4 for $M$. On the other hand, if the paging cost is more important factor, $M$ is set to 5. In addition, there are two types of grouping algorithms. One ($G1$) is an algorithm in which the group size is set to $\lfloor N_{AR}/M \rfloor$ and the other ($G2$) is an algorithm in which the group size is set to $N^*$. For example, if $M$ is 4, the 61 ARs in the example paging area are divided into sub-PAs consisting of 15 ARs, 15 ARs, 15 ARs, and 16 ARs in the case where $G1$ used. In contrast, in $G2$, the 61 ARs are divided into sub-PAs consisting of 20 ARs, 20 ARs, 20 ARs, and 1 AR. $G1$ is more beneficial if the goal is to reduce the paging cost, whereas $G2$ is more advantageous if the objective is to reduce the paging delay. Therefore, in this paper, we utilized both $G1$ and $G2$ as grouping algorithms and compared their performance.

### 2.3 Paging Group Construction by Partitioning Paging Area

In the previous section, we discussed how to decide the size of the sub-PA groups scheme. Once this has been done, we need to construct the sub-PA groups In this section, we propose a PA partitioning algorithm, which allows the division of a PA into various sub-PAs, which are numbered from $A_0$ to $A_{M-1}$.

In the selective paging scheme, A PA is divided into sub-PA groups based on the geographical cell topology [7]. The innermost cell (In this paper, the term *"cell"* refers to the coverage of an AR.) is labeled "0". Cells labeled "1" form the first ring around cell "0" and so forth. In general, $r_k$ ($k \geq 0$) refers to the $k$th ring away from the cell "0". Let $n(r_i)$ be the total number of cells from ring $r_0$ to ring $r_i$.

In [6], the shortest-distance-first (SDF) was proposed for selective paging in dynamic location management. In SDF, since there is no such concept as the feasible group size, sub-PAs are divided into based on the number of rings. In contrast, in the selective paging scheme using xcast, the sub-PAs are constructed by considering the maximum feasible number of sub-PA group members, which can be calculated as explained before.

Algorithm 1 shows how to partition a PA into M sub-PAs. When $n(A_0)$ is greater than $n(r_0)$, all of the cells in $r_0$ and several of the cells in $r_1$ become the members of $A_0$. In such a case, various criteria can be used to select the cells in $r_1$ which are become members of $A_0$. For example, one of the choices might be to select those ARs with smaller paging delay. In this paper, the ARs are selected in a random manner for the simplicity of analysis. This grouping procedure is repeated until all of sub-PAs have been constructed.

### 2.4 Paging operation

The last step is to perform terminal paging to the sub-PAs constructed using the Algorithm 1. In order to find an MH in idle state, the paging agent sends a paging request to the ARs of each sub-PA. The paging agent keeps on sending paging requests until it receives the paging response from the MH being sought

**Algorithm 1** Paging Group Construction

```
i ← 0; j ← 0;
initiate n(A_j);
while j < M do
    if n(r_i) ≥ n(A_j) then
        j++;
        transfer n(A_j) of the cells in r_i to A_j;
        n(r_i) = n(r_i) − n(A_j);
    else
        i++;
        transfer all of the cells in r_i to A_j ;
        n(A_j) = n(A_j) − n(r_i);
    end if
end while
```

as shown Algorithm 2. When an MH receives a paging request from the paging agent, the MH checks whether or not it is still located in the same AR in which it registered last. If the MH is still located in the same AR, the MH sends a paging response back to the paging agent without any registration. Also, the MH sets its state to the active state and restarts its active timer. Otherwise, the MH starts the registration procedure. Following registration, the MH responds to the paging request by sending a paging response message.

**Algorithm 2** Paging Operation

```
i ← 0;
while i < M do
    Paging agent sends requests to all ARs in A_i;
    if MH in A_i then
        MH sends response; break;
    end if
    i++;
end while
```

## 3 Performance Evaluation

### 3.1 Mobility Model

To evaluate the performance of the selective IP paging scheme using xcast, we developed an analytic model. In terms of the user mobility model, we used the random walk mobility model on the mesh and hexagonal cell configurations [7]. Let $p^K_{(x,y),(x'y')}$ be the transition probability that an MH in cell $(x, y)$ moves to cell $(x', y')$ after $K$ movements. $p^K_{(x,y),(x'y')}$ can be obtained from $\alpha((x, y), (x', y'))$, which denotes the probability that an MH moves from cell $(x, y)$ to cell $(x', y')$.

We use two cell classification schemes proposed in [7] (mesh) and [8] (hexagonal). Based on these classifications, it is possible to draw a state diagram and to find the state transition probability. From the transition probability matrix, the probability that an MH resides in the cell $(x, y)$ after $K$ movements can be calculated. Detailed equations and derivations can be found in [11].

### 3.2 Unit Paging Cost

To determine the different paging costs when the various delivery schemes are utilized, the unit paging cost for each scheme should be determined in advance. To do this, we formulate the unit paging cost $(C_T(N))$ when the paging group size is $N$ using the comparative results listed in Table 1 [11]. Also all terms can be defined in Table 2.

**Table 1.** Cost comparison

| Cost | Unicast | Multicast | Xcast |
|---|---|---|---|
| $C_L$ | $N \cdot L_u \cdot S_u \cdot \alpha$ | $L_m \cdot S_m \cdot \alpha$ | $L_x \cdot S_x \cdot \alpha$ |
| $C_N$ | $(L_u + 1) \cdot \beta$ | $(L_m + 1) \cdot \beta$ | $N \times \beta + \sum G \times \beta$ |
| $C_M$ | 0 | $P_V \cdot \left(\frac{1}{\lambda_s} \cdot r_m \cdot \alpha\right) + (1 - P_V) \cdot (\theta_{Tree} + T \cdot r_m \cdot \alpha)$ | 0 |

**Table 2.** Definition of Terms

| | |
|---|---|
| $\alpha$ | unit cost when a unicast packet is transmitted over a wired link |
| $\beta$ | unit processing cost incurred at an intermediate node |
| $L_u$ | the average length of a unicast routing path |
| $L_m(L_x)$ | the total length of a multicast(xcast) distribution tree |
| $S_u(S_m,S_x)$ | the relative paging request packet sizes in relation to the size of a unicast packet in case of unicast(multicast,xcast) |
| $P_v$ | probability that a valid distribution tree exists when a paging request arrives |
| $r_m$ | the message delivery rate required to maintain the group membership |
| $\theta_{Tree}$ | tree construction cost |
| $\lambda_s$ | parameter of Poisson process |
| $T$ | valid time of a distribution tree is alive |

Since the transmission cost is generally much larger than the processing cost [9], $\alpha$ and $\beta$ are set to 10 and 1, respectively. $L_m$ and $L_x$ can be calculated from the relationship, $L_m(or\ L_x) = N^{\kappa} \cdot L_u$ [9]. The message delivery rate for group management $(r_m)$, is dependent on the type of multicast protocol. We assumed that PIM-SM is used in order to reduce the management overhead. Since there is no periodical message exchange in PIM-SM, $r_m$ is set to 0. $\theta_{Tree}$ can be approximated to $N \cdot L_m$ because all of the ARs belonging to the paging group send a join message to the paging agent, which serves as a core node in the multicast tree. In addition, $\lambda_s$ and $T$ are set to 0.01 and 120, respectively. Table 3 shows the parameter values for the unit paging cost.

**Table 3.** System parameter values

| $\alpha$ | $\beta$ | $L_u$ | $r_m$ | $\kappa$ | $\lambda_s$ | $T$ | $S_u(S_m)$ |
|---|---|---|---|---|---|---|---|
| 10 | 1 | 5 | 0 | 0.8 | 0.01 | 120 | 1.0 |

### 3.3 Paging Cost

In this paper, we focus on the design of an efficient delivery scheme to reduce the paging cost. Therefore, we didn't consider the location update cost and we assume that this cost is identical in the three different delivery schemes (i.e. unicast, multicast and xcast). On the other hand, the paging cost is proportional to the unit paging cost and the number of ARs to be paged. The unit paging cost in each delivery scheme is a function of the number of ARs to be paged as mentioned in the previous section. Let $C_P((x,y))$ be the paging cost when the AR where the MH most recently updated its location is $(x,y)$. The paging cost for the first sub-PA, $A_0$, is as follows:

$$C_T(n(A_0)) \cdot \sum_{(x',y') \in A_0} \alpha((x,y),(x',y'))$$

On the other hand, the paging cost for the second sub-PA, $A_1$, is the sum of the paging costs of the first and second sub-PAs. This is because the second paging step is performed only after the first paging step is finished and when the destination MH was not found in the first paging step. Based on this relationship, the total average paging cost ($C_P(x,y)$) when the last registered AR is $(x,y)$ can be expressed as Eq. 1.

$$C_P((x,y)) = \sum_{i=0}^{M-1} \sum_{j=0}^{i} C_T(n(A_j)) \cdot \sum_{(x',y') \in A_j} \alpha((x,y),(x',y')) \tag{1}$$

where $M$ is the number of paging steps and $A_i$ is the $i$-th sub-PA. $(n(A_i))$ denotes the number of ARs belonging to the $i$-th sub-PA. $C_T(n(A_i))$ is a delivery cost function when the group size is $(n(A_i))$.

Let's assume that the probability that an MH updated its location in cell $(x,y)$ follows a uniform distribution in $[1, N(n)]$. $N(n)$ denotes the total number of ARs within the areas by $n$-th ring. In addition, let $N(x,y)$ be the number of ARs of cell type $(x,y)$. Hence, the mean paging cost can be calculated as Eq. 2.

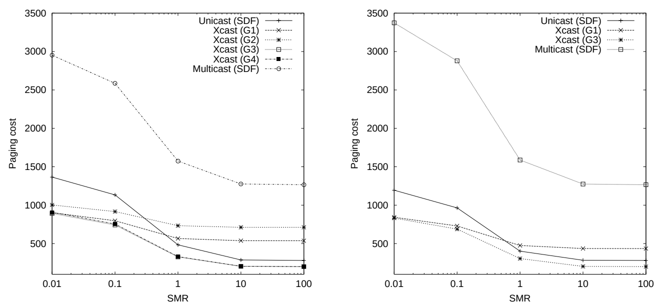
$$C_P = \sum_{all \quad (x,y)} C_P((x,y)) \cdot \frac{N(x,y)}{N(n)} \tag{2}$$

## 4 Numerical Result

The proposed IP paging scheme can be used not only with the static location management scheme but also with the dynamic location management scheme

[10]. However, in this analysis, it is assumed that the dynamic location management scheme (e.g., movement-based, distance-based, or timer-based) is used. Therefore, $(x, y)$, which is the last location updated cell, is simply $(0, 0)$. Also we assume that the cell residence time has a Gamma distribution.

To evaluate the performance of the proposed paging scheme, we compare the paging costs when xcast, unicast and multicast are used. The paging schemes using unicast and multicast use SDF for the paging group construction. In contrast, xcast is incorporated with G1 and G2 as mentioned above.




(a) $N^* = 20$ and $M = 4$ (b) $N^* = 20$ and $M = 5$

**Fig. 2.** Paging cost - Mesh configuration and $N^* = 20$

Fig. 2 shows the paging cost as the the session-to-mobility ratio (SMR) is changed under the mesh cell configuration. As the SMR increases, the paging cost decreases. This is because a large SMR implies that an MH's mobility is low (i.e., static MH). The static MH is likely to be connected to an AR in the vicinity of the one to which it was last registered when a paging procedure is invoked. Therefore, the paging cost decreases as SMR increases.

For the purpose of comparison, we defined the paging cost gain ($G_{pc}$) of scheme A as follows:

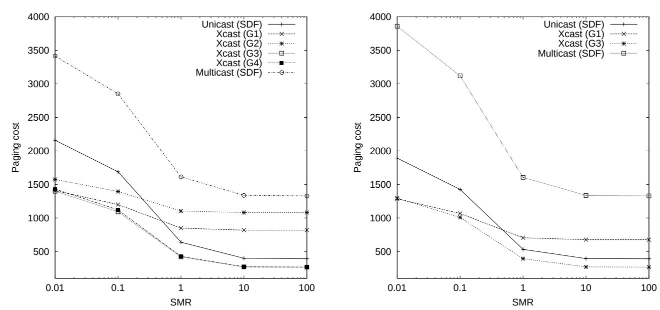
$$G_{pc} = \frac{Paging\ \ cost\ \ of\ \ scheme\ \ A}{Paging\ \ cost\ \ of\ \ multicast}$$

The $G_{pc}$ of G1 and G2 are 0.30 and 0.34, respectively, when the SMR is 0.01. However, the gain decreases to 0.42 and 0.56 when the SMR is 100. On the other hand, the $G_{pc}$ values of unicast based on SDF are 0.46 and 0.22 when the SMR is 0.01 and 100, respectively. In other words, the paging cost of unicast can be lower than that of xcast using G1 and G2 when SMR is high.(Of course, this result doee not mean that the paging cost of unicast is necessarily less than that of xcast because, in our calculation, we assumed that the transmission cost is 10 times the processing cost. However, the transmission cost may be much higher than the processing cost due to advances in processing technology [9].) This is because xcast using G1 and G2 creates a sub PA with a fixed size of ($N^*$ or $\lfloor N_{AR}/M \rfloor$).

However, SDF makes a sub-PA based on the ring area. These values are much smaller than $N^*$ or $\lfloor N_{AR}/M \rfloor$, which are typically set to a value between 10 and 30. As mentioned above, the probability that an MH remains connected to an AR in near to the most recently registered AR, increases as the SMR increases. Hence, it is wasteful to make a sub PA with a larger fixed group size, in the case of xcast using G1 or G2. As a result, the paging costs of G1 and G2 can be higher than that of unicast based on SDF.

To overcome these drawbacks, we propose two enhanced grouping algorithms called G3 and G4. Unlike G1 and G2, the first sub-PA in G3 and G4 consist of ARs located in ring 0 and 1. However, subsequent sub-PAs are constructed using the same grouping algorithms, G1 and G2. Fig. 2 shows the paging cost in the case of G3 and G4. The $G_{pc}$ values of G3 and G4 are 0.30 and 0.30, respectively, when the SMR is 0.01. Besides, the $G_{pc}$, when SMR is 100, is 0.16 for both G3 and G4. Namely, the performance gain of xcast using G3 and G4 is higher than that of unicast using SDF.

The cost variation in other cases (e.g. $N^* = 20$ and $M = 5$) is almost the same as the result of the case where $N^* = 20$ and $M = 4$. In the case of where $N^* = 20$ and $M = 5$, there are no sub-PAs satisfying the grouping algorithm, G2. Therefore, only G1 and its enhancement, G3, are compared.




(a) $N^* = 30$ and $M = 4$ (b) $N^* = 30$ and $M = 5$

**Fig. 3.** Paging cost - Hexagonal configuration and $N^* = 30$

In terms of the hexagonal cell configuration, $N^*$ is set to 30 because a 6-area location area is composed of 91 cells. In the case of $N^* = 30$ and $M = 3$, unicast exhibits a smaller paging cost than G1 and G2, when the SMR is larger than 1 and 0.1, respectively. However, G3 and G4 exhibit more smaller paging costs than unicast.

When comparing G1 (G3) with G2 (G4), G1 (G3) exhibits a lower paging cost than G2 (G4). Hence, G1 (G3) is a more suitable choice to minimize the paging cost .

## 5 Conclusion

In this paper, we introduced the selective IP paging scheme utilizing explicit multicast (xcast). The proposed paging scheme is more cost effective than the existing schemes based on unicast and multicast in terms of the paging cost. In order to support IP paging in IP-based wireless/mobile networks using xcast, we proposed two types of grouping algorithms and their enhancements. The numerical results indicated that selective IP paging scheme based on xcast incurs only 16-56% of the paging cost, in the case of the IP paging scheme using multicast or unicast based on SDF

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