A SELECTIVE POINTER FORWARDING STRATEGY FOR LOCATION TRACKING IN PERSONAL COMMUNICATION SYSTEMS

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ABSTRACT

Location management is important to effectively keep track of mobile terminals with reduced signal flows and database queries. A system with single home location register and pointer forwarding is assumed. A mobile terminal is assumed to have memory to store the IDs of visitor location registers (VLRs) each of which has the forwarding pointer to identify its current location. To obtain the registration point which minimizes the database access and signaling cost from the current time to the time of power-off probabilistic dynamic programming formulation is presented. A Selective Pointer Forwarding scheme is proposed which is based on one-step dynamic programming. The proposed location update scheme determines the least cost temporary VLR which point forwards the latest location of the mobile. The computational results show that the proposed scheme outperforms IS-41, pure Pointer Forwarding, and One-step Pointer Forwarding at the expense of small storage and a few computations at the mobile terminals.

KEYWORDS

Location Management, IS-41, Pointer Forwarding, Dynamic Programming

1. Introduction

The personal communication service (PCS) is a system that aims to allow for communication anywhere in the world. In a PCS system, the location of a called mobile terminal (MT) must be determined before the connection can be established. Location tracking operation in a PCS network is expensive because many signal flows and database queries are needed to achieve the task. Therefore, a location management scheme is necessary to effectively keep track of the MTs and to locate a called MT when a call is initiated.

Many location management strategies use two classes of databases of user location information: the home location register (HLR), and the visitor location register (VLR). Under two commonly used standards of IS-41 and GSM, the HLR is required to store the location of an MT. In addition to the strategy in IS-41 and GSM, several methods have been proposed to improve the efficiency of location management strategy [4], [5]. They can be classified into two categories: Dynamic and static location management strategies. Three methods are prevalent as the dynamic location management; *time-based*, *movement-based*, and *distance-based* methods. It is generally demonstrated that the dynamic location management schemes produce better results than the static location management schemes. However, the dynamic location management schemes cannot be easily implemented in the near future because of the complexity of the procedures. Therefore, we consider the static location management schemes in this paper.

The static schemes include Pointer Forwarding (PF), hierarchical HLR, and distributed HLR schemes, in addition to the strategy in IS-41. PF strategy has been proposed to avoid the expensive HLR access each time an MT moves to a new RA. The PF schemes proposed in [6] and [7] are based on the observation that it is possible to avoid the registrations at the HLR by simply setting up a forwarding pointer from the previous VLR. A call to a user will first query the user’s HLR to determine the first VLR where the user was registered and then follow a chain of forwarding pointers to the user’s current VLR. However, the length of a forwarding pointer chain may be lengthened in the traditional pointer forwarding strategy. In [2], One-step Pointer Forwarding (OPF) with distributed HLRs was proposed to overcome this potential problem. The length of any forwarding pointer chain does not exceed one in the strategy. The idea of OPF can be easily applied to the single HLR case.

Here, by assuming single HLR for each subscriber we provide a more efficient strategy which reduces location management costs compared to the IS-41, PF, and OPF with single HLR. In the proposed scheme, an MT stores the IDs of VLRs which have information about its location. When an MT moves from one RA to another, the MT itself selectively determines how to make *registration* operation. While other schemes make *registration* operation independently of call-to-mobility ratio, proposed scheme takes the call-to-mobility ratio into account to make optimal decision. The proposed scheme decreases database access and signaling cost efficiently at the expense of a small storage and a few number of computations at MT.

2. A Selective Pointer Forwarding Scheme

In this section, we first propose that an optimal location update can be solved by dynamic programming, which minimizes the *registration* and *call delivery* cost starting from the current location update to the time of power-off. However, the computational burden to solve the dynamic programming is not appropriate to implement in the real situation. Thus, a prediction algorithm by one-step dynamic programming is proposed. The proposed Selective Pointer Forwarding (SPF) scheme selectively decides the *registration* point among VLRs the MT has registered. Clearly, SPF is an advanced strategy compared to other schemes which make *registration* to the point previously determined. For example, *registration* is always made to HLR in IS-41 and to the old VLR in PF.

A. An Optimal Location Update by Dynamic Programming

For an optimal location update by dynamic programming, we introduce a temporary location register (TLR) of the MT. A TLR is a VLR which stores a forwarding pointer for a specific MT. Suppose that an MT has K TLRs. If $K = 0$, the HLR records the current VLR. Otherwise, The HLR records the first TLR. The kth TLR ($1 \leq k < K$) has a pointer which points to the (k+1)th TLR. The forwarding pointer of Kth TLR points the current VLR.

When an MT moves from one RA to another, the TLR is determined which is to be informed of the mobile's new location in the proposed scheme. It selects one of the following three cases to minimize the location management costs.

Case 1: Inform the HLR of the mobile's new location.

Case 2: Inform the old VLR of the mobile's new location.

Case 3: Inform the TLR_k of the mobile's new RA.

In Case 3, the pointer of kth TLR is set to point the current VLR. Including Case 1 and 2, K+2 cases need to be compared and the one which minimizes the expected *registration* and *call delivery* costs for the future N *interval*s is selected. Here we assume an MT makes N location updates until the power-off and an *interval* denotes time between two consecutive location updates. If Case 1 is selected as the minimum, then the *registration* strategy corresponds to the IS-41. If Case 2 is selected, it corresponds to the PF method. Whenever a *location update* occurs the best one among the K+2 cases is selected in the proposed scheme. To generalize the notation, let TLR_0 and TLR_{K+1} denote the HLR and the old VLR, respectively. Then the scheme is to determine the TLR to which the new VLR sends the location information of the MT.

For the optimization of the expected cost for the N consecutive *interval*s, we introduce the concept of probabilistic dynamic programming. Assume that $(\text{TLR}_1, ..., \text{TLR}_{K_n})$ is the set of TLRs recorded at the MT at the beginning of nth $(1 \leq n \leq N)$ location update. Then the set of candidate *registration* points r_n at that time becomes $(\text{TLR}_0, ..., \text{TLR}_{K_n}, \text{TLR}_{K_n+1})$, where TLR_0 and TLR_{K_n+1} denote the HLR and the old VLR, respectively. Now, the input variables at the time of nth location update are represented by (r_n, v_n), where r_n and v_n denote the set of candidate *registration* points and the new VLR at that time, respectively. Let the decision variables $k_n\,(1 \leq n \leq N)$ be the decision of *registration* point which is one of the set r_n. Let $f_n^*(\text{r}_n, v_n)$ be the minimum expected cost from nth location update to the time of power-off. Note in the $f_n^*(\text{r}_n, v_n)$ that r_n is determined by the previous decision and the new VLR v_n is probabilistically distributed which depends on the move direction. Thus, probabilistic dynamic programming needs to be solved to obtain the optimal decision.

Now, our goal is to obtain $f_1^*(\text{r}_1, v_1)$ which minimizes the expected cost for the N time *interval*s. The optimal *registration* points $k_1^*, k_2^*, \cdots, k_N^*$ can be obtained by solving a set of recursive equations given in (1) and (2). In the equations, two cost functions, $C_R(k_n, v_n)$ and $C_{CD}(k_n, v_n)$ are used. $C_R(k_n, v_n)$ denotes *registration* cost from the new VLR v_n to the *registration* point k_n. And $C_{CD}(k_n, v_n)$ denotes *call delivery* cost traversing $\text{TLR}_0, \text{TLR}_1, ..., \text{TLR}_{k_n}$, and the new VLR v_n when *registration* is made to TLR k_n. Especially, $C_{CD}(\text{HLR}, v_n)$ is the *call delivery* cost of the succeeding calls, where HLR already has the information about the current location of the MT from the delivery of the first call. In addition, two random variables, NC and V_{n+1}, are included in the equations. NC is the number of call arrivals for an *interval* and is assumed to be identically and independently distributed. V_{n+1} is the VLR of the RA into which the MT is to move at the end of *n*th *interval*, and is dependent on v_n and the mobility pattern of the MT. It is assumed that the system is composed of *M* RAs.

$$
\begin{aligned}
f_n^*(\mathrm{r}_n, v_n) \;=\; & \min_{k_n \in \mathrm{r}_n} \Big[\, C_R(k_n, v_n) \;+\; P(NC=0) \sum_{v=1}^{M} P(V_{n+1}=v)\; f_{n+1}^*(\mathrm{r}_{n+1}, v) \\
& + \sum_{i=1}^{\infty} P(NC=i) \,\Big\{\, C_{CD}(k_n, v_n) + (i-1)\; C_{CD}(\mathrm{HLR}, v_n) + \sum_{v=1}^{M} P(V_{n+1}=v)\; f_{n+1}^*(\mathrm{r}_{n+1}, v) \,\Big\}\Big], \qquad (1)
\end{aligned}
$$

for $n = 1, \cdots, N-1$,

and

$$
f_N^*(\mathrm{r}_N, v_N) \;=\; \min_{k_N \in \mathrm{r}_N} \Big[\, C_R(k_N, v_N) \;+\; \sum_{i=1}^{\infty} P(NC=i) \,\big\{\, C_{CD}(k_N, v_N) + (i-1)\; C_{CD}(\mathrm{HLR}, v_N) \,\big\}\Big]. \qquad (2)
$$

The total cost at the time of *n*th location update is the sum of *registration* and *call delivery* cost for the *interval* and expected costs $f_{n+1}^*(\mathrm{r}_{n+1}, v)$ for the next $N-n$ consecutive *interval*s to follow. Obviously, when $NC = 0$, *call delivery* cost for the *interval* is zero. In general, $C_R(k_n, v_n)$ is the highest when *registration* is made to TLR_0 or HLR, and the lowest when *registration* is made to TLR_{K_n+1} or old VLR. When $NC = 0$, since the set of TLRs recorded at the MT at the end of the *interval* is $(\mathrm{TLR}_1, ..., \mathrm{TLR}_{k_n})$, r_{n+1} becomes $(\mathrm{TLR}_0, ..., \mathrm{TLR}_{k_n}, v)$ if V_{n+1} is v. When $NC > 0$, note that the *call delivery* costs for the first call in the *interval* and the following calls are different. This is because when a call arrival occurs, the current VLR returns a TLDN to HLR and the following calls are delivered directly from HLR to the current VLR. Moreover, if a call arrival occurs, the set of TLRs recorded at the MT is updated to (TLR_0) to keep valid information about the modified situation. Therefore, when $NC > 0$, r_{n+1} becomes (TLR_0, v) if V_{n+1} is v.

From the above formulation it is clear that the optimal strategy at a particular location depends on the probability distribution of the future trajectory of an MT. However, the probability distribution of the mobility pattern of an MT may not be well predicted. In addition, the computational burden to solve the dynamic programming grows explosively with the number of location updates. In the following subsection, we propose a selective pointer forwarding scheme that is based on the dynamic programming discussed in this subsection.

B. Selective Pointer Forwarding

At the time of initial location update we have K_1+2 candidate TLRs for location *registration* point. Among them, optimal *registration* point k_1^* is determined based on the expected cost. The cost function is given by the following equation.

$$
\begin{aligned}
f_1^*(\mathrm{r}_1, v_1) \;=\; & \min_{k_1 \in \mathrm{r}_1} \Big[\, C_R(k_1, v_1) \;+\; P(NC=0) \sum_{v=1}^{M} P(V_2=v)\; f_2^*(\mathrm{r}_2, v) \\
& + \sum_{i=1}^{\infty} P(NC=i) \,\Big\{\, C_{CD}(k_1, v_1) + (i-1)\; C_{CD}(\mathrm{HLR}, v_1) + \sum_{v=1}^{M} P(V_2=v)\; f_2^*(\mathrm{r}_2, v) \,\Big\}\Big]. \qquad (3)
\end{aligned}
$$

In the above equation when *NC* > 0, since the record of HLR and the set of TLRs recorded at the MT are updated after the first *call delivery*, the succeeding *call delivery* cost and candidate *registration* point for the very next *interval* are independent of the decision of the current *interval*. Also, to approximate the above objective function let us assume that the set of candidate *registration* points r_2 is identical under any decision k_1. Then, the three items $P(NC=0)\ \sum_{v=1}^{M} P(V_2=v)\ \ f_2^*(\mathrm{r}_2, v)$, $(i-1)\ \ C_{CD}(\mathrm{HLR}, v_1)$, and $P(NC>0)\ \sum_{v=1}^{M} P(V_2=v)\ \ f_2^*(\mathrm{r}_2, v)$ are identical under any initial decision. Thus, the following approximation results. In the equation, the subscript denoting the *interval* is omitted.

$$f^*(\mathrm{r}, v) \ = \ \min_{k \in \mathrm{r}} \left[C_R(k, v) \ + \ P(NC>0) \times C_{CD}(k, v) \right]. \tag{4}$$

3. Performance Analysis

This section examines the performance of SPF and compares it with IS-41, PF, and OPF. Let call-to-mobility ratio (CMR) be λ / μ, where λ is the call-arrival rate, and μ is the location update rate from current RA. We assume that call-arrivals follow poisson distribution and the residence times of an MT have exponential distribution. We also assume that the two distributions are independent of each other. In addition, estimates of network cost are made as follows to simplify the comparison.

1) The database access cost of the HLR is normalized to 1.
2) The database access cost of the VLR is α. Since HLR is a signaling bottleneck, $\alpha \le 1$ is expected.
3) The signaling cost is $\beta \times$ distance. The assumption that signaling cost is proportional to the distance is reasonable. And β represents signaling cost of a unit distance (Euclidean distance between centers of two adjacent RAs) given that the database access cost of the HLR is normalized to 1.

A. The Analytical Model

Since the *call delivery* cost from the call originator to the HLR and radio link cost between the current VLR and the MT are the same in three schemes to compare they can be excluded in this analytical model. We thus consider the *call delivery* cost from the HLR to the current VLR and the *registration* cost from the current VLR. Let d (A - B) denote the Euclidean distance from A to B and *nc* denote the number of call-arrivals during the *interval*.

a. IS-41

During the *registration* operation, one access to HLR occurs. *Registration* and *call delivery* costs in IS-41 are respectively

$$\begin{aligned} C_R^{IS-41} &= 1 + \beta \times d\,(\mathrm{VLR}_{\mathrm{new}} - \mathrm{HLR}), \\ \text{and} \ \ C_{CD}^{IS-41} &= \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_{\mathrm{new}}), \end{aligned} \tag{5}$$

where, $\mathrm{VLR}_{\mathrm{new}}$ denotes the new VLR. Therefore, the total cost between two consecutive *registration*s becomes

$$C^{IS-41} = C_R^{IS-41} + nc \times C_{CD}^{IS-41}. \tag{6}$$

b. Pointer Forwarding

Assume that the length of forwarding pointer chain is *P* and the chain consists of VLR$_1$, VLR$_2$, …, VLR$_P$ after *registration* operation. VLR$_P$ denotes the VLR of the old RA from which the MT departs. Then the *registration* cost is

$$C_R^{PF} = \alpha + \beta \times d\,(\mathrm{VLR}_{\mathrm{new}} - \mathrm{VLR}_P). \tag{7}$$

The first *call delivery* cost in PF is

$$\begin{aligned} C_{FCD}^{PF} = {} & \alpha P + \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_1) + \beta \times d\,(\mathrm{VLR}_1 - \mathrm{VLR}_2) + \ldots + \\ & + \beta \times d\,(\mathrm{VLR}_P - \mathrm{VLR}_{\mathrm{new}}). \end{aligned} \tag{8}$$

After the first call arrives, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{PF} = \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_{\mathrm{new}}). \tag{9}$$

Therefore, the total cost between two consecutive *registration*s becomes

$$\begin{aligned} C^{PF} & = C_R^{PF}, \quad \text{if } nc = 0 \\ & = C_R^{PF} + C_{FCD}^{PF} + (nc - 1) \times C_{SCD}^{PF}, \quad \text{if } nc \geq 1. \end{aligned} \tag{10}$$

c. One-step Pointer Forwarding

The length of forwarding pointer chain is always one in the OPF. Let VLR$_{\mathrm{pre}}$ denote the “Previous VLR”. Then the *registration* cost is

$$C_R^{OPF} = \alpha + \beta \times d\,(\mathrm{VLR}_{\mathrm{new}} - \mathrm{VLR}_{\mathrm{pre}}). \tag{11}$$

The first *call delivery* cost in OPF is

$$C_{FCD}^{OPF} = \alpha + \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_{\mathrm{OPF}}) + \beta \times d\,(\mathrm{VLR}_{\mathrm{pre}} - \mathrm{VLR}_{\mathrm{new}}). \tag{12}$$

After the first call arrival, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{OPF} = \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_{\mathrm{new}}). \tag{13}$$

Therefore, the total cost between two consecutive *registration*s becomes

$$\begin{aligned} C^{OPF} & = C_R^{OPF}, \quad \text{if } nc = 0 \\ & = C_R^{OPF} + C_{FCD}^{OPF} + (nc - 1) \times C_{SCD}^{OPF}, \quad \text{if } nc \geq 1. \end{aligned} \tag{14}$$

d. Selective Pointer Forwarding

This section consists of two parts. The first part is to determine the TLR$_{k*}$ satisfying Equation (4), which is informed of the latest location update. The second part is to obtain the *registration* and *call delivery* cost in the *interval* when *registration* is made to the TLR$_{k*}$ in the proposed scheme.

First to determine the *registration* point Equation (4) is solved. To compute $P[NC > 0]$ in Equation (4), let *X* and *Y* respectively denote the first occurrence time of call-arrival and location update from the beginning of each *interval*. Then, *X* and *Y* are both exponentially distributed random variables with respective means $1/\lambda$ and $1/\mu$. Thus, we have

$$\begin{aligned} P[NC>0] = P[X<Y] & = \int_0^\infty P[X < Y \mid Y = y]\,\mu\, \mathrm{e}^{-\mu y} dy \\ & = \int_0^\infty \int_0^y \lambda\, \mathrm{e}^{-\lambda x} dx\, \mu\, \mathrm{e}^{-\mu y} dy = \frac{\lambda}{\lambda + \mu} = \frac{\mathrm{CMR}}{\mathrm{CMR} + 1}. \end{aligned} \tag{15}$$

Assume that the length of forwarding pointer chain is *K* and the chain consists of TLR$_1$, TLR$_2$,…, TLR$_K$ before *registration* operation. If TLR$_k$ is informed of the new VLR, then the *registration* cost in

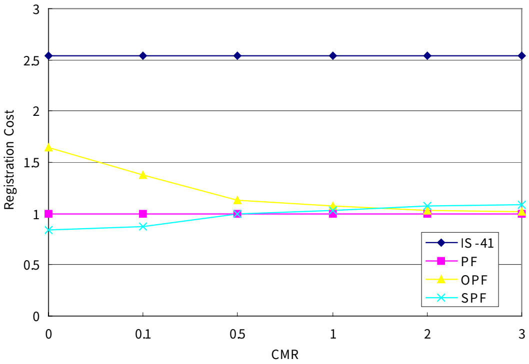

Fig. 1. Registration cost per location update when (α, β) = (0.5, 0.5).

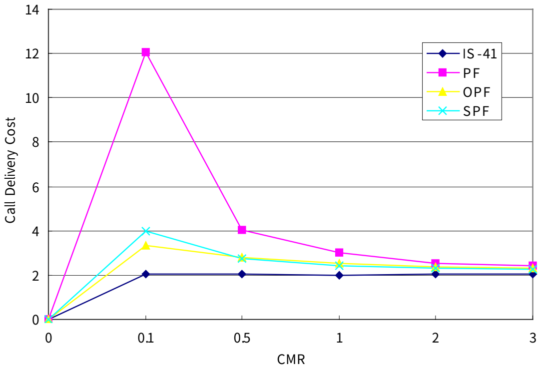

Fig. 2. Call delivery cost per call arrival when (α, β) = (0.5, 0.5).

Equation (4) becomes

$$C_R\ (k, \mathrm{VLR}_{\mathrm{new}}) = \alpha + \beta \times d\,(\mathrm{VLR}_{\mathrm{new}} - \mathrm{TLR}_k). \tag{16}$$

The cost of first *call delivery* at the new RA is

$$\begin{aligned} C_{CD}(k, \mathrm{VLR}_{\mathrm{new}}) &= \alpha\ k + \beta \times d\,(\mathrm{HLR} - \mathrm{TLR}_1) \\ &+ \beta \times d\,(\mathrm{TLR}_1 - \mathrm{TLR}_2) + \ldots + \beta \times d\,(\mathrm{TLR}_{k-1} - \mathrm{TLR}_k) + \beta \times d\,(\mathrm{TLR}_k - \mathrm{VLR}_{\mathrm{new}}). \end{aligned} \tag{17}$$

From Equations (15), (16), and (17) the expected cost of (4) is computed. Let TLR_{k*} denote the TLR determined in Equation (4).

Given that the *registration* point is determined, we calculate the cost of SPF for the *interval* to compare it with IS-41, PF, and OPF. When *registration* is made to the TLR_{k*}, the cost of *registration* and first *call delivery* is calculated in the same way as above. That is,

$$C_R^{SPF} = C_R\ (k^*, \mathrm{VLR}_{\mathrm{new}}) \ \text{ and } \ C_{FCD}^{SPF} = C_{CD}(k^*, \mathrm{VLR}_{\mathrm{new}})\,. \tag{18}$$

After the first call arrives, the HLR updates its pointer to the current VLR. Thus the *call delivery* cost of the succeeding calls is

$$C_{SCD}^{SPF} = \beta \times d\,(\mathrm{HLR} - \mathrm{VLR}_{\mathrm{new}}). \tag{19}$$

Therefore, the total cost between two consecutive *registrations* becomes

$$\begin{aligned} C^{SPF} &= C_R^{SPF}\,, \quad \text{if } nc = 0 \\ &= C_R^{SPF} + C_{FCD}^{SPF} + (nc - 1) \times C_{SCD}^{SPF}\,, \quad \text{if } nc \geq 1. \end{aligned} \tag{20}$$

In the next section, we compare the SPF with IS-41, PF, and OPF strategy.

B. Simulation Results

In the experiment ten thousand consecutive location updates are performed for each value of different CMR ranging from zero to three. The area is divided into 25 RAs. The average *registration* cost per location update and *call delivery* cost per call arrival of IS-41, PF, OPF, and SPF are compared as in Fig. 1 - 2. As was expected, the highest *registration* and lowest *call delivery* costs are obtained by the IS-41. The PF scheme shows the opposite result. Note that IS-41 and PF show constant *registration* cost under any CMR because the number of call arrivals is not considered in the two methods. Since the *registration* point in the OPF is dependent on the number of call arrivals during the previous interval, *registration* cost varies with the CMR even though OPF does not take into account the CMR. The registration cost of OPF is much higher than that of the PF under relatively low CMR. This is because when CMR is low, the OPF behaves like the IS-41. A tradeoff between *registration* and *call delivery* is achieved by the proposed SPF. The total cost during an

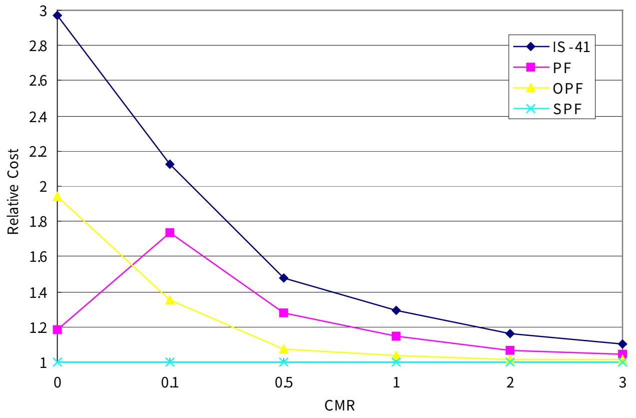

Fig. 3. Relative registration and call delivery cost when (α, β) = (0.5, 0.5).

interval is obtained by summing the total *call delivery* cost and the *registration* cost. We define the relative cost as the ratio of the total cost during ten thousand *interval* of each scheme to that of the proposed scheme. Fig. 3 compares the relative costs of IS-41, PF, OPF, and SPF. The proposed SPF outperforms three other schemes. The HLR access cost is normalized to one. Another tendency worth noting in the figures is that the cost differences by the four strategies become smaller as the CMR increases. This is mainly due to the fact that *call delivery* costs are identical in the four schemes after the first call arrival.

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