Service Profile Replication Scheme with Local Anchor for Next Generation Personal Communication Networks

Jinkyung Hwang, Eun-Shil Bae, and Myong-Soon Park

Abstract: **It is expected that per-user customized services are widely used in next generation Personal Communication Network. To provide personalized services for each call, per-user service profiles are frequently referenced and signaling traffic is considerably large. Since the service calls are requested from the places where user stays, we can expect that the traffic is localized. In this paper, we propose a new service profile replication scheme, named *Follow-Me Replication with local Anchor* (FMRA). By replicating user's service profile in a user-specific location area, *local anchor* of each region, the signaling traffic for call and mobility can be distributed to local network. We compared the performance of the FMRA with two typical schemes: Intelligent Network-based Central scheme and IMT-2000 based full replication scheme, as we refer it to *Follow-Me Replication Unconditional* (FMRU). Performance results indicate that FMRA lies between Central and FMRU schemes according to call to mobility ratio, and we identified the efficient ranges of CMR for FMRA depending on the various network parameters.**

Index Terms: **Intelligent Network, service profile, replication scheme, local anchor.**

I. INTRODUCTION

As the network evolves to the next generation Personal Communication Network, it is expected that users' needs for personalized services will grow. For even a basic call connection, the originating or terminating party's customized service are requested based on the user's predefined service configuration. The service information such as abbreviated dial numbers, incoming call dispositions, or black/white screen lists are defined as the service profile (SP) [1], and it is different per-user. In this environment, the size of the SP is considerably large, and the number of SP references should be frequent. Also to provide the same subscribed services to users who roam in different network domains, the SP should be referenced from the current location of the user. This network capability is known as *Virtual Home Environment* (VHE). Regarding these, the efficient service profile management is required as an essential process.

In order to provide such per-user customized service on network basis, Intelligent Network (IN) architecture is one solution [2]. IN service systems include Service Data Point (SDP) storing subscriber's service profile (SP) database, and Service Control Point (SCP) executing service logic based on the profiles. Since these service systems are basically centralized, they will be overloaded and can cause a bottleneck due to the frequent service transactions. The other scheme is the full replication of SP wherever the user moves to. This is the modified SP management scheme of the IMT-2000 named *Follow-Me-Replication-Unconditional* (FMRU) [3], but it also makes high traffics since the large SPs are downloaded and uploaded from/to central Home Location Register (HLR).

In this paper, we propose a new SP replication scheme, *Follow-Me Replication with local Anchor* (FMRA). This scheme is simply a *region-basis* FMRU. We consider SP replication in a two level hierarchical architecture distributing the SPs to a local service system, named local anchor (LA) in each region. The central SCP/HLR is only accessed when a user crosses region-boundaries. A region is defined as a group of Registration Areas (RAs), and a designated per-user Visited Location Register (VLR) serves as an LA. The LA replicates a user's SP by downloading from HLR when the user enters the region. At the time the user leaves the region, the SP is uploaded from the LA to the HLR. Inside the region, the user can use service calls by Central scheme with the service execution from the LA, or by replicating SPs from the LA. Therefore, since the service traffics are localized, the load of the central SCP/HLR is reduced and the network signaling traffic can be distributed in the regions.

Note that proposed scheme is only applicable for service profile management and orthogonal to the mobility management: So both service and mobility management schemes can be used together for efficient service network design. Smart card approach is one of the alternative service profile management mechanisms [4]: Since the subscriber always carries his SP in the Subscriber Identification Module (SIM) card, it is an SP replication to the extreme at the nearest point of the subscriber. But we do not consider this terminal based scheme in this paper because it is not able to utilize network information such as user's location [4].

The rest of this paper is organized as follows. In Section II, we introduce service network architecture. In Section III, replication scheme with local anchor is described. Numerical analysis and examples are shown in Section IV and Section V, respectively. We summarize the paper in Section VI.

A. Related Works

In mobility management, there have been efforts to distribute traffic loads of HLR to the local VLR by replicating or caching the location data of mobile users for fast lookup [4]–[7]. But the service profile management does not draw much attention. Although the current mobile systems of Personal Communication

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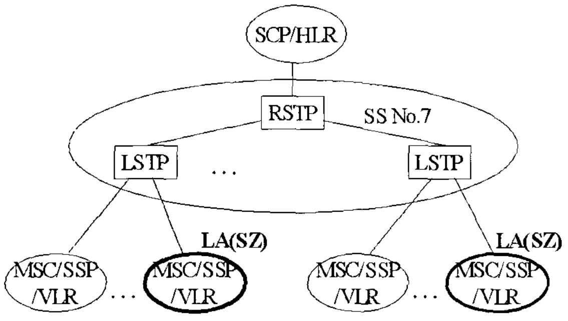


Fig. 1. Reference architecture for SP replication with LA.

Service (PCS) and International Mobile Telecommunication-2000 (IMT-2000) [8] do have the basic SP management scheme that downloads the basic SP to VLR at location registration time, it only includes mobile terminal related information rather than the user's service information. A recent study [9] proposed the SP replication for IMT-2000 IN subscribers with the integrated systems of SCP and HLR. In these schemes, a user's SP is downloaded to VLR at location registration time, and deleted from the zone when the user departs. If the local replica needs to be modified, the master profile of SCP/HLR should be updated by the centralized service control of IN, or by uploading of the modified profile to SCP/HLR to keep the consistency.

To provide efficient SP management with replication, several SP replication schemes following user (replicating in subscriber's current location) were introduced in our previous work [3], [10]: *Follow-Me-Replication Unconditional* (FMRU) is an extension of IMT-2000 replication scheme by uploading SP when updated. *Follow-Me Replication Unconditional on Demand* (FMRUD) is on demand downloading when the first call is requested in the zone. *Follow-Me-Replication Conditional* (FMRC) is a hybrid scheme of Central and FMRU with the user's frequent zone concept that replicates SP in the zones where services are frequently used or otherwise it uses Central scheme. *Follow-Me-Replication Conditional on Demand* (FMRCD) is on demand version of FMRC. Though these schemes are also considered traffic distribution by replication, they are designed for one level network.

In [11], the local anchor scheme was proposed that localizes the message traffic between HLR and VLR by reporting location update message to a nearby VLR, called local anchor. A fixed local anchor scheme applying local anchor concept to wired network for UPT user was presented in [12]. Since these schemes are only concerned about the mobility management, we extend this anchor scheme to SP management in this paper.

II. SERVICE NETWORK ARCHITECTURE

We model the service network with the integrated Personal Communication Service (PCS) and Intelligent Network (IN) systems. The systems of the next generation PCS mobile network include HLR, VLR and Mobile Switching Center (MSC). Also IN service systems are SCP, Service Switching Point (SSP) and Intelligent Peripheral (IP). Our integrated service network model has the following systems:

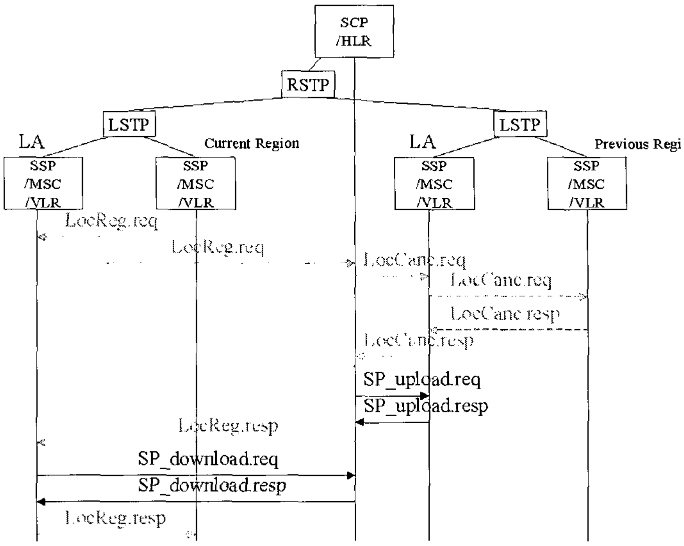


Fig. 2. Location registration procedure between regions.

- SCP/HLR: It includes master profile of location and service data and service logic information for users. We consider that all mobile users are served by SCP/HLR profiles and service systems. It has the functions of Service Control Function (SCF), Service Data Function (SDF) and Location Management Function (LMF).
- VLR: It may replicate profiles and the service logics of the users who register in current RA and reside in its associated SSP/MSC, depending on her SZ or LA. It has the SDF and LMF.
- SSP/MSC/IP: It processes the service execution and call control as well as announcement and prompting user information. It is assumed that these are co-located with the VLR. Because services are to be executed inside the region, we assume that it has the function of SCF as well as Service Switching Function (SSF). It is also assumed that the local systems are equipped with Service Logic Execution Environment (SLEE).

Fig. 1 shows the reference architecture of the service network with *local anchor* (LA). It consists of *one* SCP/HLR, n VLRs and n SSP/MSC/IPs. They are connected to the signaling network (Signaling System 7), to exchange signaling messages or transfer SPs between a SCP/HLR and MSC/SSP/VLR through Regional Signaling Transfer Point (RSTP). We call a Registration Area (RA) as a zone and it corresponds to one MSC/SSP/VLR. A *region* is a group of RAs. In each Local Signal Transfer Point (LSTP) region, a specific VLR is designated as a LA for each service user. The *Service Zone* (SZ) is also defined as the zone where service user requests SP. Consequently, it forms a two level hierarchical architecture.

III. FOLLOW-ME REPLICATION WITH LOCAL ANCHOR

A. Location Registration

Fig. 2 presents the location registration procedures that incur SP uploading and downloading when a user enters a new region. At the first location registration in a zone of a new region, the

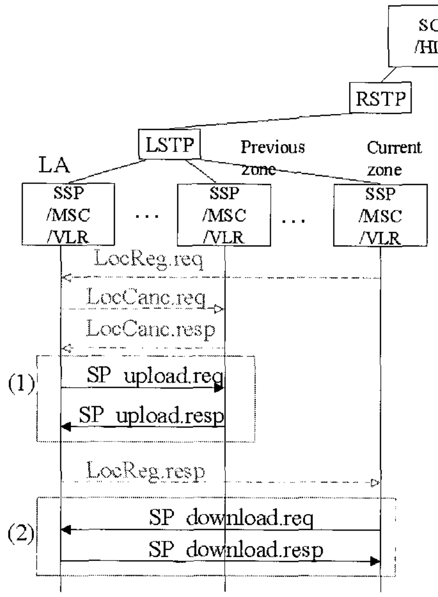


Fig. 3. Location registration procedure in a region.

SP stored in a LA's VLR of the previous region is uploaded to SCP/HLR, and then downloaded to the LA's VLR in the new region. Since we only consider the SP management, the location procedure (dashed lines in Fig. 2) refers the local anchor scheme [11] and is not counted in the performance analysis in this paper.

For movements in a region, a user can request SP in current zone where she/he expects many service calls. When the user stays in a zone other than LA, the user downloads the SP from the LA to the current VLR. Then we call the zone as Service Zone (SZ) of the user, where the SP is downloaded. In [3], [10], the SZ is defined per-user, based on her/his frequent residence and service usages. The examples of the SZs are the school, office, and home areas of the user. The SZs can be defined by network operator (based on the zone resident/service usage probabilities), or the user himself can decide current zone as a SZ, by explicitly requesting SP in the zone. This paper only considers the latter approach: We do not investigate the residence probability effect, in this paper.

We assume that the users can request SP downloading/uploading in any zone and any time. In the figures, it is shown that the SP downloading/uploading is a subsequent procedure of location registration, but it is a separate procedure whenever the subscriber requests the SP in the current zone for example, by pushing a special button in the Mobile Terminal (MT). Fig. 3 shows movement scenario inside a region. If the previous zone was the SZ, the SP is uploaded from VLR to the LA (1). In a new zone, user can download SP from the LA to current VLR (2), where the zone becomes a SZ. When the user does not request to download, he can use service by the central service execution of LA with the IN service control.

B. Service Call

Fig. 4 shows service call procedures when a user stays in a zone other than her/his LA or SZ. The originating subscriber's service call is executed by his LA's VLR/SSP/MSC, and likewise the terminating party's call is served by terminating user's LA with IN scheme, exchanging the Intelligent Network Application Part (INAP) messages [2]. In this case, the LA has the SCF, and the current VLR/SSP/MSC has the SSF. If the user is in his LA or SZ, the service can be executed locally, so the network traffic cost does not occur. Again, we only consider the solid lines of service control messages, not regarding dashed lines for the bearer connection.

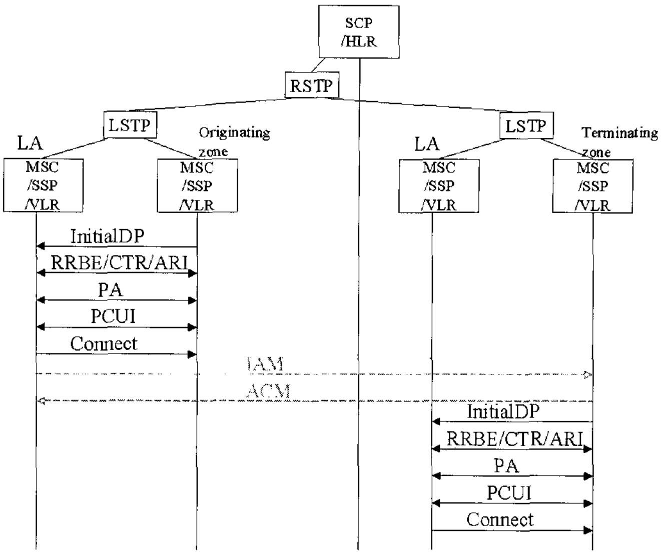


Fig. 4. Service call procedures.

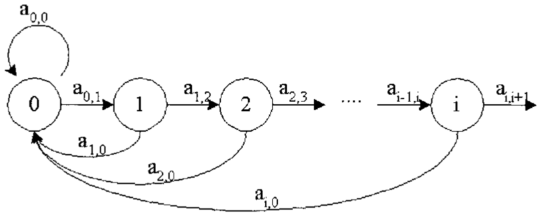


Fig. 5. Imbedded Markov chain model.

IV. NUMERICAL ANALYSIS

A. Movement Cost

Let t_c, t_s and t_m be independent and identically distributed (*iid*) random variables representing the service call inter-arrival time, SP request inter-arrival time, and zone residence time, respectively. We assume that t_c, t_s and t_m to be exponentially distributed with rates λ_c, λ_s and λ_m. We also assume the probability density function of t_m to be $f_m(t)$ with Laplace transform $f_m^*(t)$ and mean $1/\lambda_m$. Fig. 5 presents an imbedded Markov chain model which shows mobility and SP request patterns of a service user. The state i is defined as the number of zone movements since a SP is requested. State transition occurs immediately before the user's departure from a zone, the number of movements since the SP requested is $i+1$. According to FMRA scheme described in Section III, the SZ is determined only after a SP request arrival. As a result, the state transition probability $a_{i,i+1}$ from state i to $i+1$ is the probability that there is no SP request arrival between $(i+1)$th and $(i+2)$th zone movements,

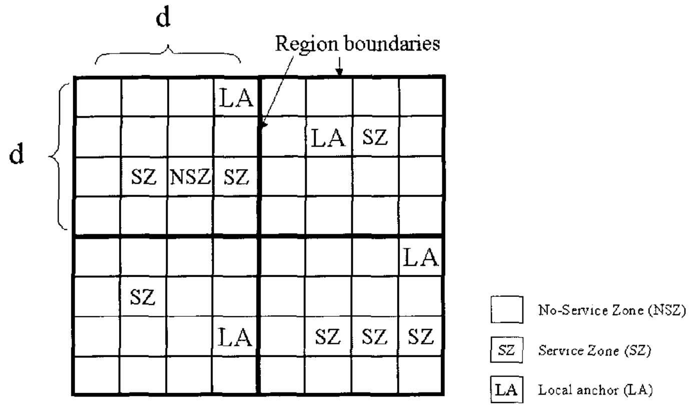


Fig. 6. Registration area (zone) and region examples with LA, SZ and NSZ distribution.

Table 1. The probability and the cost for six possible movement cases.

Move cases	Probability	Cost
SZ → SZ	$P_{SS}(n) = \frac{1}{k}\sum_{i\in SZ}\sum_{j\in SZ}\alpha_{i,j}(n)$	$C_{SS} = 2T_{lm}$
SZ → NSZ	$P_{SN}(n) = \frac{1}{k}\sum_{i\in SZ}\sum_{j\in NSZ}\alpha_{i,j}(n)$	$C_{SN} = T_{lm}$
SZ → RR	$P_{SR}(n) = 1 - P_{SS}(n) - P_{SN}(n)$	$C_{SR} = T_{rm}$
NSZ → SZ	$P_{NS}(n) = \frac{1}{d^2-k}\sum_{i\in NSZ}\sum_{j\in SZ}\alpha_{i,j}(n)$	$C_{NS} = T_{lm}$
NSZ → NSZ	$P_{NN}(n) = \frac{1}{d^2-k}\sum_{i\in NSZ}\sum_{j\in NSZ}\alpha_{i,j}(n)$	$C_{NN} = 0$
NSZ → RR	$P_{NR}(n) = 1 - P_{NS}(n) - P_{NN}(n)$	$C_{NR} = T_{rm}$

and $a_{i,0}$ from state i to 0 is the probability that there is more than one SP request arrivals from $(i+1)$th to $(i+2)$th movement.

The probability that a SP request arrives between two zone movements, denoted by ρ can be obtained as

$$\rho = \int_{t=0}^{\infty} (1 - e^{-\lambda_s t}) f_m(t) dt = 1 - f_m^*(\lambda_s). \tag{1}$$

The state transition probability from state i to state j is denoted by $a_{i,j}$ is

$$a_{i,j} = \begin{cases} 1-\rho, & \text{for j = i + 1} \\ \rho, & \text{for j = 0} \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

Let p_i be the equilibrium state probability of state i. Then it can be obtained as

$$p_i = (1-\rho)^i p_0, \tag{3}$$

where $p_0 = \rho$.

Since we assume that the t_m follows the exponential distribution $f_m^*(\lambda_s) = \frac{\lambda_m}{\lambda_s + \lambda_m}$, therefore

$$\rho = 1 - f_m^*(\lambda_s) = \frac{\lambda_s}{\lambda_s + \lambda_m}. \tag{4}$$

We assume the cost parameters of each network element.

- C_h: Cost for a query/update/execution of SCP/HLR.
- C_v: Cost for a query/update/execution of VLR/SSP/MSC.
- C_l: Cost for sending a message between local VLR/SSP/MSC and LA through the LSTP.
- C_r: Cost for sending a message between LA and remote SCP/HLR through the LSTP and RSTP.
- s: The average number of messages to execute a service call.
- m: Size of the SP for uploading or downloading, represented as times of a unit message.
- T_{ls}: Cost of the local service execution = $(C_v + C_l) \cdot s$.
- T_{rs}: Cost of the remote service execution = $(C_h + C_r) \cdot s$.
- T_{lm}: Cost of the SP uploading or downloading from/to the local system = $(C_v + C_l) \cdot m$.
- T_{rm}: Cost of the SP uploading or downloading from/to the remote system = $(C_h + C_r) \cdot m$.

It is assumed that the zones are square shaped and each LSTP region consists of $d \times d$ zones. Service users are assumed to equally reside in any zone, and have same probability of movements to four neighboring zones with $1/4$. The average number of SZs is assumed to be k $(k \leq d^2)$. Fig. 6 depicts an example of distribution of three types of zones LA, SZ, and NSZ in regions with regard to a location of a service user.

Let $\alpha_{i,j}(n)$ be the probability that a service user originating at zone i moves to zone j after n zone movements. Then $\alpha_{i,j}(n)$ is obtained as

$$\alpha_{i,j}(n) = \frac{f(n,x,y)}{4^n}, \tag{5}$$

where $f(n,x,y)$ is the number of possible paths from zone i to zone j in exactly n movements, and the x and y are distances of each coordinates between two zones respectively. Also, 4^n is the number of possible paths that a user can travel n movements when the destination is not specified [11]. Then we can drive a probability that a user originating from zone i in a group of zones X to zone j in another group of zones Y after n movements as

$$\frac{1}{x}\sum_{i\in X}\sum_{j\in Y}\alpha_{i,j}(n), \tag{6}$$

where the x is the number of zones of group X.

Table 1 summarizes the probabilities and costs for each movements between SZ and NSZ, including Remote Region (RR). The subscript S, N, R denotes SZ, NSZ, and RR, respectively.

Let the expected movement costs during the service user stay in state i of the imbedded Markov chain be $c_m(i)$. The expression for $c_m(i)$ is

$$\begin{aligned} c_m(i) = P_{SS}(i) \cdot C_{SS} + P_{SN}(i) \cdot C_{SN} + P_{SR}(i) \cdot C_{SR} \\ + P_{NS}(i) \cdot C_{NS} + P_{NN}(i) \cdot C_{NN} + P_{NR}(i) \cdot C_{NR}. \end{aligned} \tag{7}$$

The average movement cost per state transition is

$$C_M' = \sum_{k=0}^{\infty} p_k \cdot c_m(k). \tag{8}$$

The average movement cost per unit time is

$$C_M^{FMRA} = \lambda_m \cdot C_M'. \tag{9}$$

Table 2. The probability and the cost for two possible service call cases.

Call cases	Probability	Cost
SZ	$P_S(n) = \frac{1}{d^2} \sum_{i \in \Re} \sum_{j \in SZ} \alpha_{i,j}(n)$	$C_S = 0$
NSZ	$P_N(n) = 1 - P_S(n)$	$C_N = T_{ls}$

Table 3. Cost paramters.

Set	C_v	C_h	C_l	C_r
1	1	2	1	2
2	1	3	2	5
3	1	4	3	9
4	1	5	4	16

B. Service Call Cost

Service call requests are from two cases of SZ (including LA) and NSZ in a region. We can express the service call cost as the summation of the unit cost and the probabilities of the two cases as shown in Table 2. The subscript $\Re$ denotes the set of all zones in a region.

Likewise, the expected service call costs $c_s(i)$ of the service user in state i of the imbedded Markov chain is expressed as

$$c_s(i) = P_S(i) \cdot C_S + P_N(i) \cdot C_N. \tag{10}$$

The average service call cost per state transition is

$$C_S^{\prime} = \sum_{k=0}^{\infty} p_k \cdot c_s(k). \tag{11}$$

The average service call cost per unit time is

$$C_S^{FMRA} = \lambda_c \cdot C_S^{\prime}. \tag{12}$$

C. Total Cost

C.1 FMRA Scheme

The total cost is per unit time is represented as the summation of (9) and (12).

$$C_T^{FMRA} = C_M^{FMRA} + C_S^{FMRA}. \tag{13}$$

C.2 Central Scheme

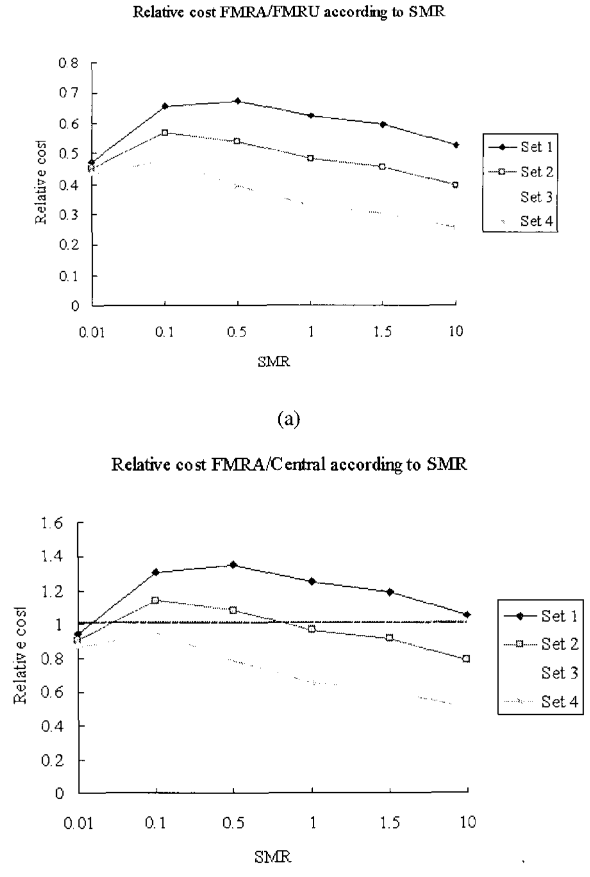
Since the cost of the Central scheme is only from the call request through the remote SCP/HLR, the service call cost equals to T_{rs} and the movement cost is 0. As a result, the total cost of Central scheme is

$$C_T^{CENTRAL} = C_S^{CENTRAL} = T_{rs} \cdot \lambda_c. \tag{14}$$

C.3 FMRU Scheme

FMRU scheme generates network cost only by movement, the remote SP transaction between local VLR and remote SCP/HLR. As we assume that the users always upload SP upon departing the zone, the movement costs is $2T_{rm}$. Therefore the total cost of FMRU is equals to

$$C_T^{FMRU} = C_M^{FMRU} = 2 \cdot T_{rm} \cdot \lambda_m. \tag{15}$$



(a)

(b)

Fig. 7. Relative cost according to CMR (SMR $(\lambda_s/\lambda_m) = 0.01$, SZ ratio=1/64): (a) Relative cost of FMRA and FMRU, (b) relative cost of FMRA and Central.

C.4 Total Cost Comparison

To compare the three schemes, we get the differences between them and check the signs. Let $y_1 = C_T^{FMRU} - C_T^{FMRA}$ and $y_2 = C_T^{CENTRAL} - C_T^{FMRA}$. The condition for FMRA's advantage over FMRU and Central, $y1$ and $y2$ should be positive. Since the total cost of FMRA is the function of both λ_m and λ_c, but total costs of FMRU and Central are functions of λ_m and λ_c, respectively, the advantageous range of CMR (λ_c/λ_m) of FMRA over FMRU and Central schemes are bounded like

$$\frac{a_1}{c_1 - a_2} < \frac{\lambda_c}{\lambda_m} < \frac{u_1 - a_1}{a_2}, \tag{16}$$

$$\text{where} \begin{cases} C_T^{FMRA} = a_1\lambda_m + a_2\lambda_c, \\ C_T^{FMRU} = u_1\lambda_m, \\ C_T^{CENTRAL} = c_1\lambda_c, \\ y_1 = (u_1 - a_1)\lambda_m - a_2\lambda_c > 0, \quad and \\ y_2 = (c_1 - a_2)\lambda_c - a_1\lambda_m > 0. \end{cases}$$

As a result, for extremely high CMR user, the FMRU performs better than FMRA, and for very low CMR user, the Central scheme outperforms FMRA. But in the middle range of CMR that we expect the almost users are included, the FMRA scheme is the most effective. In [3], [10], similar results are investigated for hybrid schemes of FMRU and Central.

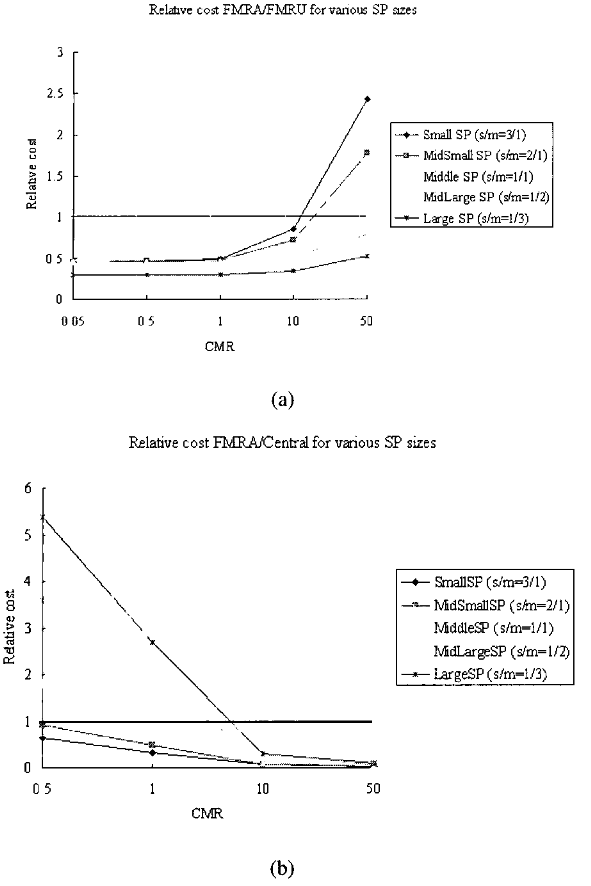


Fig. 8. Relative cost for various SP sizes (SMR=0.01, SZ ratio = 1/64, Set 2): (a) Relative cost of FMRA and FMRU, (b) relative cost of FMRA and Central.

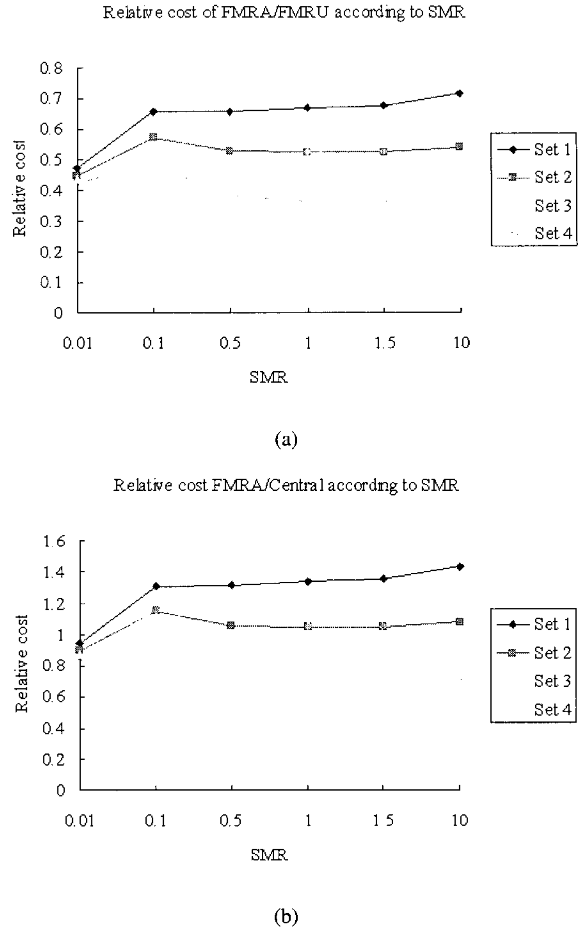


Fig. 9. Cost according to SMR (CMR = 1, MiddleSP): (a) Relative cost of FMRA and FMRU, (b) relative cost of FMRA and Central.

V. NUMERICAL EXAMPLES

We define *SP request to mobility ratio* (SMR) as the ratio of the SP request arrival rate to the mobility rate such that SMR = λ_s/λ_m. A high SMR indicates that large number of SP request arrives between two consecutive movements, and also the number of SZ is proportionally large. The call to mobility ratio (CMR)[1] is also defined as the ratio of the call rate to the mobility rate as CMR = λ_c/λ_m.

In order to show the cost reduction of FMRA, we compare relative cost with the FMRU and Central schemes by introducing C_T^{FMRA}/C_T^{FMRU} and $C_T^{FMRA}/C_T^{CENTRAL}$, respectively. The size of an LSTP region[2], $d \times d$ is set to 64. The SMR is varied from 0.01 to 10, and CMR is considered from 0.05 to 50. We also define s/m, the ratio of service transaction size (s) over SP size (m), to see the performance trends according to SP sizes. Four sets of the values for cost parameters C_v, C_h, C_l, and C_r are given in Table 3. As a set number increases, we consider that it is more expensive to send a message to HLR (through RSTP) compared to sending a message to VLR (LA) (through LSTP). C_v is normalized to one compared to other parameters.

Fig. 7 shows the relative total cost for varying the value CMR when the SMR is 0.01 and SZ ratio is 1/64. In Fig.7(a), the comparison of FMRA and FMRU presents that the relative cost increases according to CMR because FMRA has additional calling cost that FMRU does not have. When CMR values are lower than 32 for Set 1 and 71 for Set 4, the FMRA performs better than FMRU, but in the opposite case, the FMRU is more efficient than FMRA. Fig. 7(b) shows for low CMR under 0.22 for Set 1 and 0.18 for Set 4, Central scheme has good performance rather than FMRA. We can see that the advantageous range of FMRA lies between FMRU and Central, (0.22 $\sim$ 32 for Set 1, and 0.18 $\sim$ 71 for Set 4) as we explained in Section IV.

Fig. 8 shows relative cost for various sizes of SP, according to CMR. Comparing FMRA and FMRU, since the FMRA has the service call cost, FMRA's cost increases more sharply for smaller SP (big s/m) according to CMR increase. For CMR lower than 14 for Set 1 and lower than 85 for Set 4, the FMRA is more efficient than FMRU (Fig. 8(a)). Fig. 8(b) shows the opposite case. For smaller SP size, FMRA performs better than Central.

In Fig. 9, we show the effect SMR or the number of SZ for fixed CMR (= 1) and middle sized SP. As the SMR increases, service call cost gets smaller, so both the relative cost of FMRA decrease.

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[1] Note that the Call to Mobility Ratio (CMR) for service management is different with that for mobility management in that for the former, the source of the service calls and the registration request comes from the same zone, by the same person, but for the latter, the source of the call request is different from the registration request.

[2] The value d between 7 and 8 is shown to be suitable for one LSTP serving a LATA, and each zone corresponds to an SSP in [11].

VI. CONCLUSIONS

In this paper, we proposed a service profile replication scheme with local anchor, FMRA. The proposed scheme is a region-basis replication mechanism in that the central SCP/HLR is only accessed when users move between region boundaries. In a region, service call processing and SP up/downloading is performed inside the region. Since it utilizes service user's locality, FMRA reduces the network signaling cost compared to Central and FMRU for different ranges of CMR.

We identified the CMR ranges for various network parameters, profile sizes, and ratio of SZs. In conclusion, its performance lies between Central and FMRU according to CMR, but in the middle range of CMR where we expect the most users are included, the FMRA scheme is the most effective. According to the service user's CMR and network parameters, we can choose the service profile management schemes. The FMRA can be further extended to have SZ defined based on residence and service call probabilities. With this frequent zone concept of users, we expect performance gain of FMRA to be higher because more service calls are made within the SZ, proportionally reducing the service call cost in NSZ.

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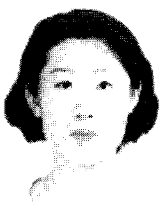

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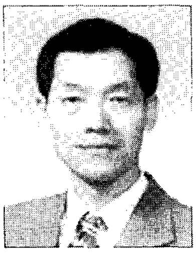

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