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The VLR Overflow Control Scheme considering Mobility of Mobile Users in Wireless Mobile Networks

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ABSTRACT

In wireless mobile networks, the service area is partitioned into several registration areas (RAs). Every RA is associated with a mobility database called Visitor Location Register (VLR). The VLR is used to achieve the location management of the mobile terminals. When a mobile terminal enters a new RA, the VLR stores the current location information of the mobile terminal before serving any mobile services. At that time, if the VLR is full, the registration procedure fails, and the system can not deliver services to the mobile user under the existing cellular technology. To resolve this problem, we propose a VLR overflow control scheme considering mobility of mobile users to accomodate incoming users during VLR overflow. The performance of the proposed scheme is evaluated by an analytic model in terms of costs for the location search and the location update, and compared with those of the overflow control scheme proposed by Lin[1].

Key words: Mobility management, VLR Overflow control, Mobility database, Visitor location register, Location management.

1. INTRODUCTION

The mobile communication services in wireless mobile networks are to facilitate the exchange of information (data, voice, image, audio, video, etc.) for mobile users at any time and in any place. One of the most important issues in mobile communications is *Mobility Management.* To support mobility management, an appropriate protocols such as *EIA/TIA Interim Standard 41* (IS-41) should be defined for wireless mobile communication service systems[2]. The mobility management strategies in IS-41 are two-level strategies in which they use a two-tier system with home and visitor system databases respectively. When a mobile user subscribes to the services of a wireless mobile communication service system, a record is created in the system database called *Home Location Register* (HLR). The HLR is the location register to which a permanent mobile terminal (MT) identity is assigned for recording purposes such as mobile user's directory number, profile information, current location, and validation period. So, the number of records in the HLR is the number of customers in the system. Every RA is associated with a mobility database called *Visitor Location Register* (VLR). The VLR is the location register other than the HLR used to retrieve information for handling of calls to or from a mobile user visiting the RA. When the mobile user visits a new RA, a temporary record for the mobile user is created in the corresponding VLR of the visited system, and then the HLR is updated with a new VLR address. Therefore, it enables the future calls for the MT to be delivered correctly to the new location. When the mobile user leaves the RA, the corresponding VLR record is deleted. In this scheme, however, considerable signaling traffics must be sustained to keep updating the HLR with the current location of the MT, so it may cause bottleneck on the databases and network signaling resources[3,4].

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The system operation referred to as a location management should be made to locate a mobile terminal whenever a call has to be delivered. The location management consists of a location update and a location search operation[3]. A location update operation is to modify its location whenever an MT changes its location. A location search operation is to locate a target MT whose location is unknown whenever a requesting MT wants to communicate with a target MT. In order to achieve these operations, the VLR should have the location information of the MTs. The VLR may overflow if too many mobile users move into the RA in a short period of time. If the VLR is full, the registration procedure for a mobile user fails in the database, thus the system can not deliver services to the user under the existing IS-41 scheme. It is called VLR overflow. In IS-41 scheme, the successful call delivery can be made when there is no failure in the HLR and the VLR of the current callee.[5].

In this paper, we propose a VLR overflow control scheme considering mobility of mobile users to accomodate incoming users during VLR overflow with optimal cost. The performance of the proposed scheme is evaluated by an analytic model in terms of costs for the location search and the location update, and compared with those of the *Overflow Control Scheme* proposed by Lin[1].

This paper is organized as follows; Section 2 presents an architecture of wireless mobile networks considered in this paper. Section 3 summarizes related works. The proposed VLR overflow control scheme is described in section 4. In section 5, the performance of the proposed scheme is investigated. Finally, section 6 offers concluding remarks.

2. THE ARCHITECTURE OF WIRELESS MOBILE NETWORKS

The architecture of wireless mobile networks is made up of a *Public Switched Telephone Network* (PSTN) and a signaling network. The PSTN is a traditional telephone system carrying voices, and the signaling network is used to locate the MT and provide information to the PSTN switches to establish the call. Fig. 1 shows a systematic overview of the wireless mobile network architecture. The service area is covered by a set of base stations, and it is referred to as a cell. The base stations are connected to the *Mobile Switching Centers* (MSCs) by land links. The MSC is a central office, which provides the call processing and channel setup function between the MT and the PSTN via base station. So, the MTs can access to the PSTN via base stations using wireless links. The base stations are grouped into *Registration Areas* (RAs). All MTs roaming in a RA have records in a VLR, which is responsible for recording the location information of the MTs in a group of RAs. Each MT is registered to a *Home Location Register* permanently. The HLR keeps the user profile and the information needed to locate the MT. Networks are interconnected as a transport mechanism for call control and database transactions, and network elements such as HLR and VLR are used for subscriber tracking and locating[6].

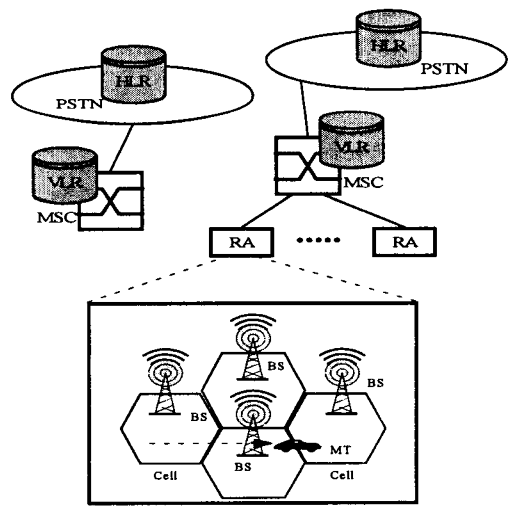

Fig. 1. The Architecture of Wireless Mobile Networks.

3. RELATED WORKS

The mobility management strategies in IS-41 are two-level strategies in which they use a two-tier system with home and visitor system databases. When the mobile user enters a new RA, a temporary record for the mobile user is created in the corresponding VLR, and then the system can deliver services to the user. If the VLR is full, the registration procedure for a mobile user fails in the database, thus the system can not deliver services to the user under the existing cellular technology [1]. It is called VLR overflow. In IS-41 scheme, the successful call delivery can only be made when there are no failures in the HLR and the VLR of the current callee.[5].

Lin[1] proposed the *Overflow Control Scheme* that can resolve the overflow problem of the mobility database in a cellular phone system. In this scheme, the replacement policy is used to select a record to be deleted when the VLR is full. The replacement policy may be based on various heuristics. For example, it may select a record randomly, select the oldest record, or select an inactive record. The storage for a deleted record is used to store new incoming user's information. The VLR forwards the registration request to the HLR with the indication that the user's record is deleted due to database overflow. Then, the HLR updates the location of new user, and sets the overflow flag in deleted user's record.

The Fig. 2 shows the registration operation for Lin's overflow control scheme. It claims only extra one bit of flag to control overflow in a HLR record. The replacement policy, however, can cause considerable overhead to register new mobile users, and to de-register the mobile users during overflow period of a VLR because it has to select and restore overflow users continuously. It also has drawbacks that the call establishment for deleted users and location query procedure may be complicated.

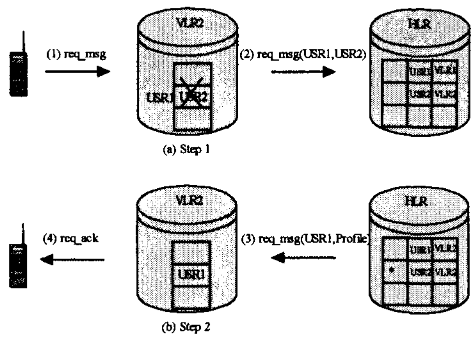

Fig. 2. The Registration Operation(Overflow)

4. THE VLR OVERFLOW CONTROL SCHEME

The mobility of the mobile users may have some special behavior patterns according to the place and the time. The mobile pattern of the MTs may be different in the morning, afternoon, and evening. It may also different in weekdays and weekend. The behaviors of mobile users may be affected by the place. The mobility pattern in commercial area is obviously different from that in residence area. If the mobile communication service system applies this mobility pattern of the MTs to the overflow control scheme, it can predict the best neighbor VLR to borrow when the current VLR is full. So, It may reduce overhead for updating location information of the mobile users in registration procedure and call delivery service procedure. In this section, we present a VLR Overflow Control Scheme (VLR-OCS) considering the Mobility Information of mobile users such as current mobile direction in mobile networks. If the VLR is full, the registration procedure fails, and the system can not deliver services to the mobile user. A new VLR-OCS scheme can resolve this problem. We assume that the total storage capacities of the VLRs are the same, and each VLR manages the arrival rates λ and the service rates μ of mobile users during recent Δt times in its RA.

The mobile direction of an MT is estimated by the history of recent entry to new RA in registration procedure. The history represents the entry from any RA among neighboring RAs to the current RA (see Fig. 3).

The forecasted mobile angle of the MT is computed by *adaptive-response-rate single exponential smoothing method* (ARRSES)[7]. The basic equation for forecasting with the method of ARRSES is as follows;

$$F_{t+1} = \alpha_t Y_t + (1-\alpha_t) F_t$$

where, $\alpha_t = \left| \frac{A_t}{M_t} \right|$

$$A_t = \beta E_t + (1-\beta) A_{t-1}$$

$$M_t = \beta |E_t| + (1-\beta) M_{t-1}$$

$$E_t = Y_t - F_t$$

In the equation above, Y_t represents the average angle that the MT enters from the last RA to the existing RA, F_t represents the forecasted mobility angle of the MT at the last MSC, and β is a parameter that has the value between 0 and 1. With these mobility information of mobile users who are entering current RA, the system can predict the best neighbor VLR to borrow in case of the VLR overflow. If the VLR is full, the system borrow this VLR based on these mobility information of mobile users. After all, it may reduce not only the cost for location update in registration procedure but also the overhead for call delivery.

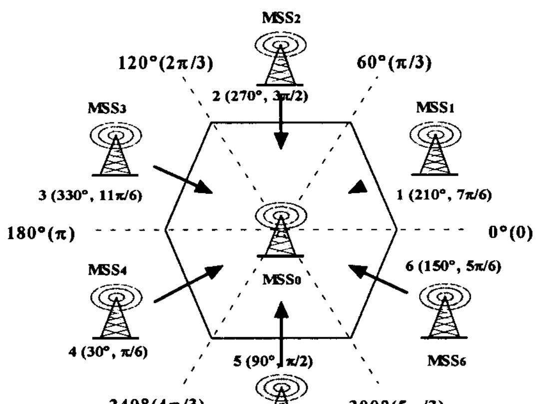

Fig. 3. The Average Angle that the MT enters RA according to Mobile Direction.

To simplify our discussion, we assume that every MSC covers a RA, and every VLR controls exactly one MSC. Our results can easily be generalized to the cases where a VLR controls several MSCs, and a MSC controls several RAs. The algorithm to resolve the VLR overflow in VLR-OCS is as follows;

(1) If the utilization of a storage for some VLRs is $\frac{S_{u_i}}{S_{t_i}} \geq \Theta_{ov}$, and if $\gamma_i = \frac{\lambda_i}{\mu_i} > 1$ for Δt, then it starts to gather the information of current mobile directions of the MTs registered in this VLR recently, and finds the overflow storage space from neighbor VLRs based on these mobility information, where, S_{u_i} is the amount of storage space used in a VLR_i, S_{t_i} is the total storage capacity in a VLR_i, and Θ_{ov} $(0 < \Theta_{ov} < 1)$ represents the threshold value of overflow warning.

(2) When the VLR is full, the system determines the VLR as an overflow storage space according to the mobility information of the MTs collected in step (1). The overflow VLR_i sends overflow_request message to the neighbor VLR to which the majority of the MTs proceed ahead recently.

(3) The VLR_j that received overflow_request message sends back (a_j, γ_j) to the overflow VLR_i, where, a_j represents the amount of available location databases in the VLR_j.

(4) If a_j is greater than the space of $S_j = C\Theta_{ov} + c_k$, and $\gamma_j \leq 1$, then borrow overflow space of b_j from the neighbor VLR_j which has enough overflow storage space, where, C represents the total amount of location databases in VLR_j, and c_k represents a stable amount of available location databases for the operations in the VLR.

(5) If a_j is less than the space of S_j, find another VLR to which the next majority of the MTs proceed in order, and send overflow_request

message to this VLR. Then, go back to step (3).

(6) Set the overflow flag on the last entry of the VLR_i, and adjust the location pointer to the VLR_j.

(7) When the amount of available databases of the VLR_i is $a_i \geq c_k$, send the overflow_return message and start to restore the overflow space.

Let's assume that the mobile user U_1 moves from the location RA_1 to RA_2, and the VLR_2 in RA_2 borrows the overflow storage space from VLR_3 in RA_3 since the VLR_2 is full. Then, the registration procedure is performed between the HLR and VLR_2 for RA_2, and cancellation procedure is performed between HLR and VLR_1 for RA_1.

The call registration operation when the VLR is full in the VLR-OCS is illustrated in Fig. 4. In the call registration operation of the VLR-OCS, the MT of user U_1 sends a registration message to a VLR_2. If database is full, then this message is sent to the neighbor VLR_3 that is connected as an overflow storage space. After setting up the record for U_1 on the VLR_3, the location information of the U_1 in the HLR is updated. Then, the HLR sends the U_1's profile to a VLR_3 via a VLR_2.

In the call termination operation of the VLR-OCS, the calling party dials the phone number of U_1 and the location information of U_1 is queried to the HLR. Then, the HLR identifies the VLR address of U_1, and sends the request message to the VLR_2 to get the routing information. If database is full, this message is forwarded to the neighbor VLR_3 which is connected by a forwarding pointer. The routable address of U_1 is returned from the VLR_3 to the HLR via a VLR_2 and the call path is established.

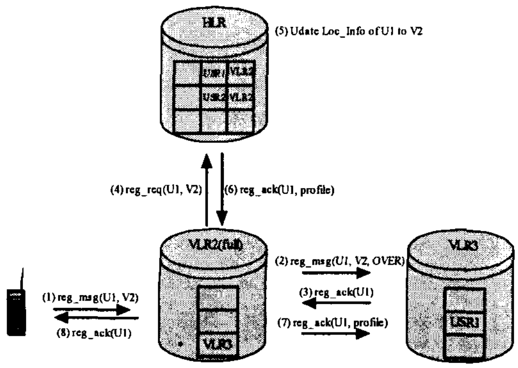

Fig. 4. The Call Registration Operation(Overflow)

Fig. 5 shows the call termination operation of the proposed VLR-OCS scheme. The algorithm of the proposed VLR overflow control scheme is shown in Fig. 6.

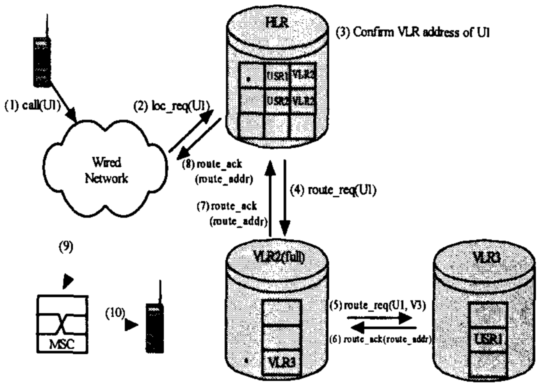

Fig. 5. The Call Termination Operation(Overflow)

5. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed VLR overflow control scheme by an analytic model in terms of costs for location management in wireless mobile networks, and compared with the *Overflow Control Scheme* proposed by Lin. We analyzes the performance of the VLR-OCS for calls arrived from outside the RA of the MT and the mobility that the MT traverses the RA. The cost of the message transmission is defined as a usage of a network due to the message transfer.

The following terminologies are used in the performance evaluation;

- p_{OL} : the probability of the overflow occurred in VLR.
- N : the expected number of users in a RA.
- M : the size of a VLR.

Algorithm I. Registration (see Fig. 4) :
If the VLR_2 is not full, then the existing algorithm of IS-41 is executed. If the VLR_2 is full, then the following steps are executed.

Step 1. (Registration Request)
(1) The MT of user U_1 sends a registration message to a VLR_2.
(2) If the database is full, then this message is sent to the neighbor VLR_3 that is connected as an overflow storage space.
(3) The record for U_1 is set on the VLR_3. After receiving reg_ack message from VLR_3, the VLR_2 sends the registration request to the HLR.

Step 2. (Registration Response)
(1) The HLR updates the location of U_1.
(2) The HLR acknowledges the registration operation and sends U_1's profile to the VLR_2.
(3) The VLR_2 forwards the U_1's profile to the VLR_3.
(4) The VLR_2 sends an acknowledgement to the MT.

Algorithm II. (Call Termination) (see Fig. 5) :

Step 1. (Location Query)
(1) The calling party dials the phone number of U_1. The request is sent to the originating switch in PSTN.
(2) The location information of U_1 is queried to the HLR.
(3) The HLR identifies the VLR address of U_1, and sends a query message to the VLR_2 to get the routing information.
(4) If the database is full, this message is forwarded to the neighbor VLR_3 which is connected as an overflow storage space.

Step 2. (Location Response)
(1) The routable address of U_1 is returned from the VLR_3 to the HLR via a VLR_2.
(2) The HLR returns the routable address to the originating switch.
(3) The originating switch sets up the trunk to the MSC based on the routable address.
(4) The MSC pages the MT and the call path is established.

Fig. 6. The Algorithm of the VLR-OCS Scheme.

- λ : the call arrival rate for a mobile user.
- μ : the service rate in a RA.
- C_{total} : the total cost of the location management algorithm.
- C_{search} : the location search cost.
- C_{update} : the location update cost per RA traverse.
- C_{PN} : the average message transmission cost between a Base Station and a VLR in RA.
- C_{LR} : the average message transmission cost between a VLR and a HLR.
- C_R : the overhead for the replacement policy in Lin's overflow control scheme.
- C_a : the overhead for computing the direction of the MT when overflow warning.

When the number of users in the RA is larger than the size of the VLR database, the overflow is occurred in a VLR database. Let p_n be the probability that there are n users in the RA. In the steady state, the rates that MTs move into a RA equals to the rates that they move out from the RA. So, the net input stream to a RA can be approximated as a Poisson process with the arrival rate $\lambda^* = N\mu$. So, the distribution for the MT populations can be modeled by an M/G/∞ queue with the arrival rate of λ^* and the service rate of μ. From a queuing theory [8], the steady state probability p_n is derived as follows;

$$p_n = \left(\frac{\lambda^*}{\mu}\right)\frac{e^{\frac{-\lambda^*}{\mu}}}{n!} = N^n \frac{e^{-N}}{n!}$$

Since VLR overflows when there are more than M mobile users in the RA, we have

$$p_{ov} = \sum_{n=M+1}^{\infty} p_n$$

Table 1 shows the cost of a location update and a location search for each scheme respectively, We assume that the average cost of message transmission among VLRs equals to those cost between a BS and a VLR in the RA.

The performance of the location management algorithm can be evaluated by the following performance measure[3].

$$C_{total} = \frac{1}{\gamma} C_{update} + \gamma C_{search}$$

Therefore, the total cost of location management

Table 1. The Cost of the Location Management for each Scheme.

scheme \ cost	Search Cost (C_{search})	Update Cost (C_{update})
Lin's	$8C_{LR}+8C_{PN}+C_R$	$4C_{LR}+2C_{PN}+C_R$
VLR-OCS	$4C_{LR}+4C_{PN}+C_a$	$4C_{LR}+5C_{PN}+C_a$

algorithm, C_{total}, that considers the VLR overflow, can be computed as follows;

$$C_{total} = \frac{1}{\gamma}\{(1-p_{ov})C_{update} + p_{ov}C_{update}^{ov}\} + \gamma\{(1-p_{ov})C_{search} + p_{ov}C_{search}^{ov}\}$$

where, C_{update}^{ov} and C_{search}^{ov} are the location update and the location search cost when the VLR overflows respectively. According to Lin[1], the probability of the VLR overflow is less than 0.2% when $M > 1.3N$. So, if we normalize the message transmission cost C_{LR} to 1 then $C_{PN} \ll C_{LR}$.

Fig. 7 shows the location update cost of the overflow control schemes over call-mobility ratio in case of the probability of overflow in a VLR is $p_{ov}=0.2$. In the figure, we know that the location update costs of the both schemes are drastically decreased with increase of the call-mobility ratio since the chances of the update of the MTs are relatively decreased in higher call-mobility ratio. We also know that the location update costs for the proposed VLR-OCS scheme is almost the same as those of the Lin's overflow control scheme.

Fig. 8 shows the location search cost of the overflow control schemes over call-mobility ratio in case of the probability of overflow in a VLR is $p_{ov}=0.2$. As depicted in the figure, the location search costs of our scheme is much lower than that of Lin's overflow control scheme. Specially, the performance of our scheme is getting much better in higher call-mobility ratio.

Fig. 9 shows the total cost of the overflow control schemes over call-mobility ratio in case of the probability of overflow in a VLR is $p_{ov}=0.2$. As shown in the figure, the total cost of the VLR-OCS scheme is much lower than that of Lin's overflow control scheme. Specially, the performance of our scheme is getting much better in higher call-mobility ratio.

Under the VLR overflow situation in a Lin's overflow control scheme, the overhead for the replacement policy grows in higher call-mobility

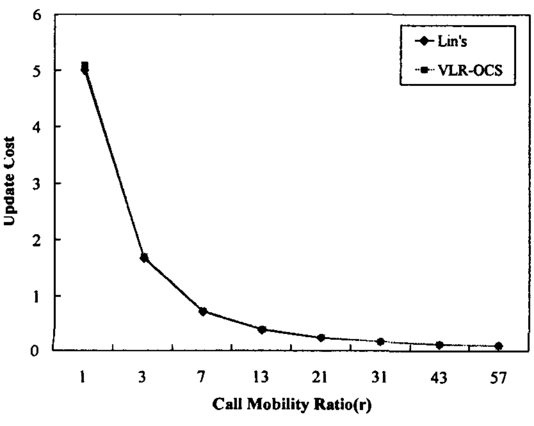

Fig. 7. The Location Update Cost over Call-Mobility Ratio with $P_{ov}=0.2$, $C_{LR}=0.5$.

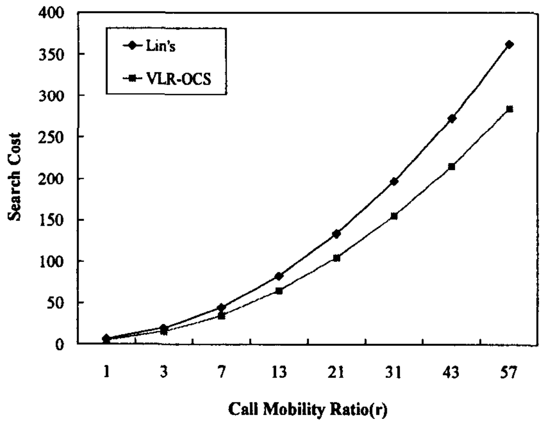

Fig. 8. The Location Search Cost over Call-Mobility Ratio with $P_{ov}=0.2$, $C_{LR}=0.5$.

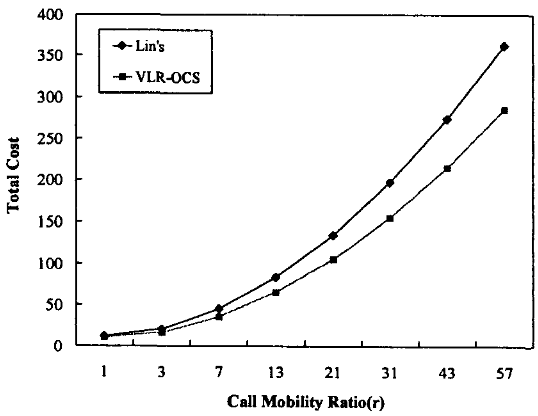

Fig. 9. The Total Cost of the Overflow Control Scheme over Call-Mobility Ratio with $P_{ov}=0.2$, $C_{LR}=0.5$.

ratio, and the number of deleted records for the overflow users are also multiplied. Accordingly, the number of messages exchanged among databases to serve those overflow users are increased, and the total cost of this scheme rapidly grows in higher call-mobility ratio. So, we know that our scheme can efficiently tolerate the overflow situation of a VLR and the performance of our scheme is much better than that of the Lin's overflow control scheme.

6. CONCLUSION

The mobility of the MTs may have some special behavior pattern according to the place and the time. If the mobile communication service system applies this mobility pattern of the MTs to the overflow control scheme, it can predict the best neighbor VLR to borrow when the current VLR is full. So, It may reduce overhead for updating location information of the mobile users in registration procedure and call delivery service procedure. If the VLR is full, the registration procedure fails, and the system can not deliver services to the mobile user under the existing IS-41 scheme.

In this paper, we present a VLR overflow control scheme considering mobility information of mobile users such as current mobile directions in wireless mobile networks to accomodate the incoming mobile users during VLR overflow with optimal cost. The performance of the proposed scheme is evaluated by an analytic model in terms of the location search cost and the location update cost, and compared with those of the Overflow Control Scheme proposed by Lin. According to the results of the performance evaluation, we know that the proposed VLR-OCS scheme can efficiently tolerate the overflow of a VLR and the performance of our scheme is much better than that of the Lin's overflow control scheme especially in higher call-mobility ratio.

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