A Smooth Aggressive Location Restoration Proposal

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***Abstract* — A proposal on smooth aggressive location restoration by forwarding pointer is given in this paper. In this proposal, radio resources would be saved based on the cost of wire signal and operation of location databases. A mobile communication system's robustness in case of a location-database failure is improved without the need for periodic location update operations. Meanwhile, a chain of forwarding location pointers has been used during the period of HLR failure. So mobile stations are unconscious of the failure of HLR, and mobile subscribers can always make outgoing call.**

***Index Terms* — Mobility Management; Location Restore; Forwarding Pointer**

I. Introduction

In PCS network, the network stores the location of Mobile Station (MS) in location information databases (LID) and the information would be retrieved during call delivery. Current mobile system uses a two level hierarchy of LIDs for location management, which includes Home Location Register (HLR) and Visitor Location Register (VLR). When a LID fails, calls might be lost as the location information of MS in the LID is unavailable. Because HLR is a global database in which all MS information is stored, the failure of HLR will drop the performance of PCS seriously.

The procedure, which is used to reestablish the record of location information about MS in HLR or VLR, is called Location Restoration. After the failure of LID, location information can be reestablished by the radio contact, and that MS makes an outgoing call or enter a new Location Area. If MS stays in the same LA for a long time and no outgoing call is made, the location information in LID will be unavailable for a long time and incoming calls to this MS will be lost. In current system, MS makes Location Update (LU) regularly no matter weather in the same LA. So the time interval of LR can be limited to an accepted range. During the normal working period of LID, limited radio resource would be consumed by the frequent periodic LU. According to the retaining time and calling traits of MS, [3][4] gives a method to optimize the frequency of periodic LU and make a tradeoff between calls loss and radio resource cost.

In [5][6], HLR can directly retrieve location information from VLRs after failure. This method will shorten the interval of LU in HLR. Before failure happens, HLR would records the location information to disk regularly. After restarting, HLR will request related VLRs to transfer changed location information after checkpoint. By choosing appropriate checkpoint period, radio resources can be saved based on the cost of wired signal and location database processing. [6] uses Mobile Switch Center (MSC) as the agent of MS during HLR failure period, thus could report the changed LA of MS to HLR frequently until the restarting of HLR. So the location information can be restored in time for the frequently moving MS.

In above related articles, only the loss of incoming calls is considered when HLR fails. The outgoing call loss is neglected during the period of HLR failure. In [6] some MS can have much shortened interval of periodic LU because of the MS movement. But this method can't solve the outgoing calls problem. Along with the rapid increasing of subscribers, records in HLR become huge accordingly, thus the restarting time of HLR will be longer, and at the same time the MS movement will be more frequent because cells become smaller. So if we are intending to handle HLR failure problem, we must take unsuccessful LUs and outgoing call loss into account. In this article we provide a smooth aggressive LR proposal, at the same time suggest using a forwarding pointer to support LU and outgoing calls of MS during HLR failure. So the HLR failure would have a limited influence to the performance of system, and radio resources would be saved along with the cost of wire signal and location database processing.

In current mobile systems, it is difficult to apply aggressive LR proposal described in [4][5]. There are three important problems should be handled: First, when HLR recovers from failure, VLRs send location information of related users to HLR at the same time. This will challenge the loading ability of HLR that manage huge mount of MSs. Second, time synchronization among LDs is needed in the proposal, which is almost impossible for modern large mobile communication system. Last, if MS moves to a new LA belonged to another VLR during

HLR failure period, the MS cannot complete LU correctly. And the location information of the MS cannot be aggressively restored when HLR reloads successfully.

However, the three problems mentioned above can be solved by smooth aggressive location restoration proposal based on forwarding pointer.

II. PROPOSAL DESCRIPTION

A Smooth aggressive location restoration

In HLR user records are stored to disk regularly with time interval that is called checkpoint interval T_{CH}. T_{CH} can be adjusted according to the user capacity of HLR and the latest frequency of LU. In order to support smooth aggressive location restoration, LD must store some essential information as follows.

Table 1 Information Stored in Location Databases

Parameters	Description	LD
T_{ch}	The occur time of latest checkpoint	HLR
VLR_lists	The all VLRs which serve the MS of HLR currently	HLR
RECs	MS's records which include subscribe and location information	HLR, VLR
T_u	The occur time of location update	VLR

When MS A is moving from the LA of VLR1 to VLR2, the procedure of LA is as follows.

- The message *UPDATE_Req*(Ms_{id}, $VLR2_{id}$) is sent by VLR2 to HLR.
- After successful Authentication, the subscribe information of MS is sent to VLR2 by HLR.
- HLR get current time T_c and rewrite location information of MS A with $VLR2_{id}$. Then HLR sends *UPDATE_Rsp(Msid,* T_c*)* to VLR2 and requests VLR1 to delete the record of MS A.
- VLR2 creates record of MS A and stores the update time T_u equal to T_c.

According to T_{CH}, HLR saves the records of MSs to disk regularly and updates T_{ch} and VLR_lists at the same time. When finding the occurrence of failure, HLR begins to reload and rebuilds the records of MS based on the latest checkpoint information stored in disk. After reloading, HLR would start the procedure of location restoration. The procedure is described as follows.

- HLR computes the interval of failure by comparing T_c and T_{ch}. According to the capability and the mobile characteristics, HLR speculates the possible amount of records restoration needed and ascertains the optimal amount of smooth restoration time T_r. then it informs all related VLRs in *VLR_lists* to enter location restoration procedure via *RESTORE_Ind (*HLR_{id}, T_{ch},, T_r*)*.
- According to the HLR_{id}, VLR searches out all users belonged to the HLR and checks the T_u of user record. If $T_u > T_{ch}$, it indicates user has changed his location after latest checkpoint. And then VLR will create a list of related users, considering user mobility characteristics and calling feature, VLR sends *UPDATE_Req* message to HLR in uniformity during the interval of T_r.
- HLR updates the location information of user record. The longest time of location restoration is T_r.

B Replacing failed HLR with link of location pointers

The failure process of HLR can be divided into two phases: from failure happening to successful reloading, it is called off-period; the other is location restoration procedure which is called recovery-period. With periodic location update proposal, all incoming calls, location update and outgoing calls after LU will be lost during off-period. Some incoming calls will be lost during recovery-period. As the recovery period is relatively longer than off-period, the loss happened in off-period is usually neglected. But in aggressive location restoration proposal, recovery-period is much shorter, so how to reduce the loss happened in off-period is a key problem.

As described in this article, VLR will substitute the failed HLR with forwarding location pointer. When a MS enter a new LA during off-period, VLR will get a location update request from MS. If the VLR cannot get response from HLR, it sends the request to old VLR which provides service to MS previously. The new VLR can get the MS's subscribing information from old VLR and a location pointer between two VLRs will be established at the same time. Depending on the link of location pointers, MS can complete location update normally and the outgoing calls could be always made successful during off-period.

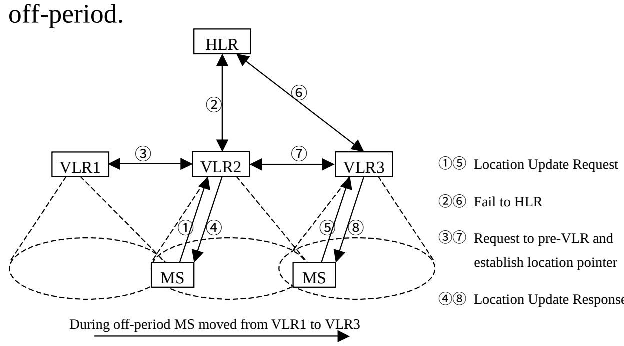

Fig.1. Replacing failure HLR with link of location pointers

As the failed HLR enters recovery-period from off-period, HLR resetting information will start to be sent from the head VLR of link to the tail VLR, which complete location updating to HLR for the MS immediately. For the MS that changed its LA during off-period, we can provide normal location update and outgoing call via the link of location pointers, thus providing quick location recovery. The procedure of establishing the pointer link is described in figure 1.

III. PERFORMANCE ANALYSIS

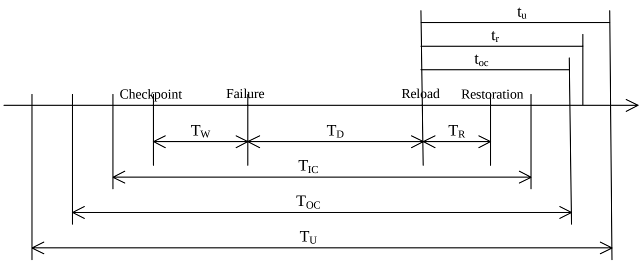

Fig. 2 The time diagram of HLR failure restoration

The time diagram for HLR failure restoration is described in figure 2. Let T_{IC}, T_{OC} and T_U denote, respectively, the inter-arrival time of incoming calls, the inter-arrival time of outgoing calls and the LA residence time. Let T_W, T_D and T_R denote, respectively, the interval time between latest checkpoint and failure happening, the interval time of off-period and the interval of location restoration. Different with [4], we define t_r as a factor which is used to smooth the restoration requests from VLR after HLR reloading. According to t_r, VLRs can use some strategies to send restoration requests to HLR, so HLR avoids the congestion outburst when it starts the location restoration.

To study the cost of lost calls, we make some hypothesis as follows:

- The periodic interval time of checkpoint T_{CH} is invariable, T_W is evenly distributed.
- According to the amount of subscribers in HLR, the reloading time of HLR is a constant.
- The process of the calls and LA changes contributes to a Poisson process, i.e., T_{IC}, T_{OC} and T_U are exponentially distributed with parameters λ_{IC}, λ_{OC} and λ_U respectively. Let t_{oc} and t_u denote, respectively, the residual life times of T_{OC} and T_U.
- HLR defines the smooth restoration t_r time which is evenly distributed according to the T_W.

A The cost of incoming calls loss

In off-period and recovery-period, the incoming calls will be lost because HLR can not give correct location information. Let P_{LI} denote the cost of incoming calls loss. Because the incoming calls form Poisson process, we can obtain a form

$$P_{LI} = \lambda_{IC} \cdot E[T_R + T_D] = \lambda_{IC} T_D + \lambda_{IC} E[T_R] \qquad (1)$$

Let $f_R(t)$ be the density functions of T_R. The HLR failure recovery time is given by

$$T_R = \min(t_r, t_{OC}, t_u) = \min(t_r, \min(t_{OC}, t_u)) = \min(t_r, t_\phi)$$

Because t_r is direct proportion with T_w, it is also evenly distributed. Let α denote the smooth restoration factor which is related to the capability of HLR.

$$f_r(t) = 1/\alpha T_W \qquad 0 < t < \alpha T_W$$

Because t_r is direct proportion with T_w, it is also evenly distributed. Let α denote the smooth restoration factor which is related to the capability of HLR.

t_{oc} and t_u are exponential distributed. So we can deduce the density function of T_R..

$$f_\phi(t) = (\lambda_{OC} + \lambda_U) e^{-(\lambda_{OC}+\lambda_U)t} = \lambda_a e^{-\lambda_a t} \qquad (\lambda_a = \lambda_{OC} + \lambda_U)$$

$$f_R(t) = f_\phi(t)\int_t^\infty f_r(\tau)d\tau + f_r(t)\int_t^\infty f_\phi(\tau)d\tau$$

$$= \lambda_a e^{-\lambda_a t}\int_t^{\alpha T_W} \frac{1}{\alpha T_W} d\tau + \frac{1}{\alpha T_W}\int_t^{\alpha T_W} \lambda_a e^{-\lambda_a \tau} d\tau$$

$$= (\lambda_a + \frac{1}{\alpha T_W}) e^{-\lambda_a t} - \frac{\lambda_a t}{\alpha T_W} e^{-\lambda_a t} - \frac{1}{\alpha T_W} e^{-\beta\lambda_a} \qquad (0 < t < \alpha T_W)$$

$$E[T_R] = \int_0^\infty t f_R(t) dt$$

$$= (\lambda_a + \frac{1}{\alpha T_W})\int_0^{\alpha T_W} t e^{-\lambda_a t} dt - \frac{\lambda_a}{\alpha T_W}\int_0^{\alpha T_W} t^2 e^{-\lambda_a t} dt - \frac{1}{\beta} e^{-\beta\lambda_a}\int_0^{\alpha T_W} t dt$$

$$= \frac{\beta\lambda_a - 1}{\beta\lambda_a^2} - \frac{\beta^2\lambda_a^2 - 2}{2\beta\lambda_a^2} e^{-\beta\lambda_a} \qquad (\beta = \alpha T_W)$$

Put E[T_R] into (1). We can get the cost of incoming calls loss as follows:

$$P_{LI} = \lambda_{IC} T_D + \frac{\lambda_{IC}(\beta\lambda_a - 1)}{\beta\lambda_a^2} - \frac{\lambda_{IC}(\beta^2\lambda_a^2 - 2)}{2\beta\lambda_a^2} e^{-\beta\lambda_a} \qquad (2)$$

B The cost of location updating and outgoing call loss

According to the common proposal of location restoration, during the off-period T_D all the inter-VLR LU of MS will be lost. As if there is no subscriber information in new VLR, related MS cannot make correct outgoing call. With the forwarding location pointers, we can save the cost of related radio resources and outgoing calls by unsuccessful LUs. So the mobile subscribers will be unconscious of the failure of HLR.

The process of LU form a Poisson process, so during the off-period of HLR the lost of LU will be:

$$P_{LU} = \lambda_U T_D$$

When the first LU fails, all the following outgoing calls of MS will be lost. We define T_Y as the interval between the happening of the first LU and the end of HLR

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reloading, and let t_V denote the remainder interval of LU after HLR failure happened. The process of subscriber's outgoing calls reaching form a Poisson process, so the lost outgoing calls during the off-period will be:

$$P_{LO}=\lambda_{OC}E[T_Y]=\lambda_{OC}T_D-\lambda_{OC}E[t_V] \qquad (t_V<T_D)$$

Because t_V is exponentially distributed, we can get the cost of outgoing call as following:

$$P_{LO}=\lambda_{OC}T_D-\lambda_{OC}\int_0^{T_D} t\lambda_U e^{-\lambda_U t}dt=\lambda_{OC}T_D-\frac{\lambda_{OC}}{\lambda_U}[1-(\lambda_U T_D+1)e^{-\lambda_U T_D}] \qquad (3)$$

C The cost Analysis

In order to study the outgoing call loss due to the HLR failure, we define the MS's calling and mobility parameters as follows: 1) the incoming call parameter, λ_{IC}, equal to twice per hour; 2) the frequency of LU and outgoing call, λ_a, is defined four different value which respectively denote the different mobility characteristics; 3) the off-period interval equal to 0.1 hour and T_W equal to 1 hour. Figure 3 is the result of the incoming call loss based on different smooth restoration factor α. The smaller λ_a is , the more P_{LI} is . Because the MS seldom takes radio touch such as LU or outgoing call, the location information can't be quickly restored by such radio touch. In this situation we can adopt the small α to accelerate the restoration process. Selecting too small α needs the higher process ability of HLR. Based on the statistics of MS's mobility and calling characteristics, HLR can compute the optimized α according to different VLR.

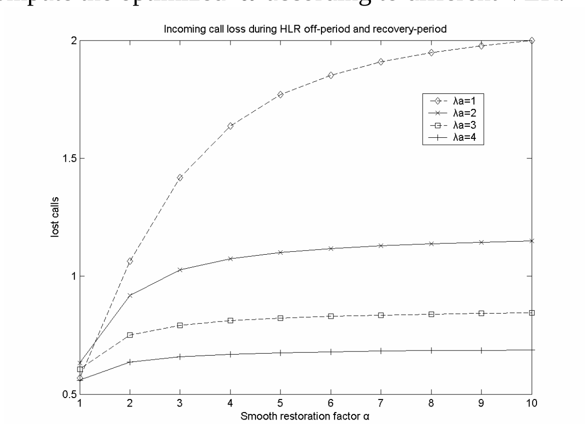

Fig. 3 Incoming call loss during off-period and recovery period

According to (3), let *M* ($M=\lambda_U T_D$) denote the mobility frequency of MS during HLR failure and *C* ($C=\lambda_{OC}/\lambda_U$) denote the CMR of MS. Figure 4 is the result of outgoing call loss with different M and C. The more the mobility frequency is, the more the outgoing call will be lost especially for the MS with high CMR. Too much outgoing call loss will depress the QoS of system, and much radio resource will be wasted by unsuccessful LU during the period of HLR failure.

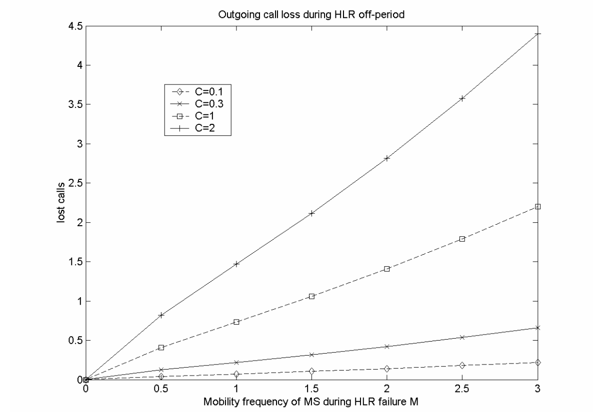

Fig. 4 Outgoing call loss during off-period

IV. Simulation

With OPNET network simulation tool, we have constructed a simulation platform to compare three different location restoration proposals: smooth aggressive location restoration proposal based on forwarding pointer (SARP), location restoration based on periodic location update (PLRP), and random location restoration (RLRP). The periodic LU proposal is being used in current PCS network. The random location restoration is the reference proposal, which means no special operation is used, and location information is restored by MS's radio touch such as outgoing call or LU of inter-LA.

The topology of platform and the related parameters are described as follows:

- Network nodes: 1 HLR, 7 VLR, 1 PSTN switch, 36 mobile phones and 72 fixed phones. To accelerate the process of simulation, the functions of base station and MSC are integrated to the VLAN. The PSTN has the function of GMSC.
- Radio coverage: hexagon cell is used and the radius of cell is 2.5km. There are 7 cells all together and each is corresponding with one service area of VLR.
- Mobility model: the movement of MS is simulated by two-dimensional random walk model.

According to different moving speed and proposal, we make a 10-hour simulation. There are 27 simulations have been completed. During the 10-hour simulation, HLR will go through 4 working period, that is to say 4 HLR failures will be processed. The simulation result of MS is the mean value drawn form of 36 MS and the result of network node is the average of all corresponding type nodes.

Figure 5 is the result MS's incoming call loss during HLR recovery-period. Because HLR can get location information from disk and aggressively acquire location information from VLR, SARP has the shortest recovery time and the least incoming call loss. The higher the MS's moving speed is, the more frequent the LU is and the shorter the recovery time can be. On the situation of high speed moving, three proposals can all achieve small incoming call loss.

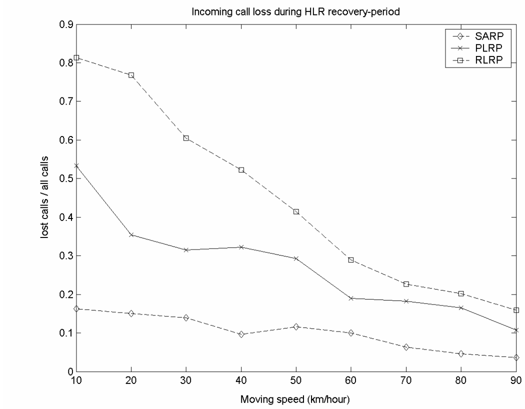

Fig. 5 Incoming call loss during recovery-period

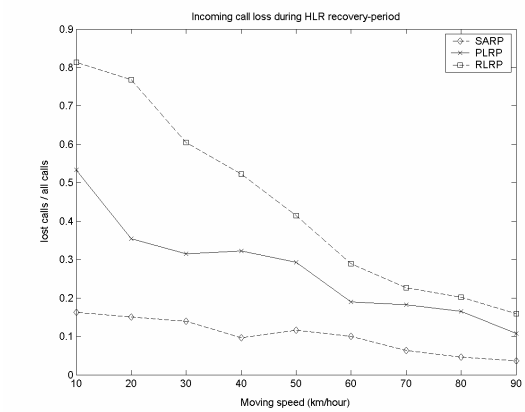

Fig. 6 Outgoing call loss during recovery-period

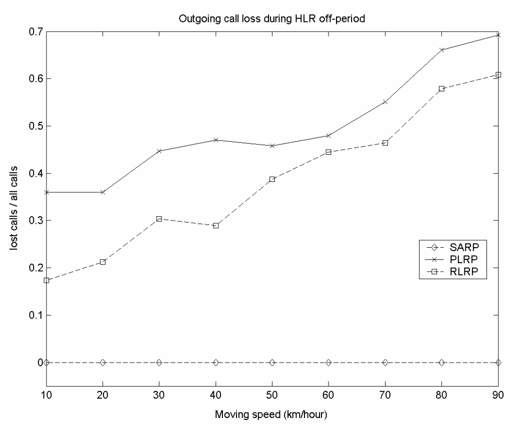

Fig. 7 Outgoing call loss during off-period

The results of MS's outgoing call loss during HLR recovery-period and off-period are given in figure 6 and figure 7. To make successful outgoing call, the service information of MS must be stored in current VLR. If a MS can't complete LU in current VLR, the VLR can't get valid subscribing information from HLR and the outgoing calls from this MS will be lost. When we adopt SARP, during off-period, MS can correctly complete LU from old VLR to current VLR with the assistance of the forwarding pointer. So in SARP the outgoing call loss is zero.

VI. Conclusions

Compared with periodic location update proposal, the aggressive location restoration can be used to save some expensive radio resources with the process ability of location database. Because the instantaneous process bottleneck is not considered and the location changes during HLR failure can't be restored, the former aggressive location restoration proposal has the practicability problem. The problem has been handled in our smooth aggressive location restoration base on forwarding pointer. According to the mobility and calling characteristics of MS and the process ability of HLR, HLR can smoothly get the changed location information from VLR. The proposal can handle the LU problem during HLR failure, so the subscribers have no consciousness of the HLR failure. Except the latest LU time and recovery factor parameters on the old signal, no new signal is needed. Depending the processing of new parameters and forwarding pointer in location database, the frequent periodic LU operations can be given up and the QOS of system is improved.

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