An Enhanced Selective Aperiodic Checkpointing Strategy for VLR Failure Recovery in Wireless Mobile Networks

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Abstract – **An enhanced version of a selective aperiodic checkpointing strategy is proposed here for the restoration of VLR failure in wireless mobile networks. VLR data are backed up in the non-volatile storage whenever its location update counter exceeds its threshold value and restores the backed up VLR data immediately after its failure. Unlike the previous approach it sends location confirmation request message only to the selected BTSs, other than all BTSs of the RAs, whose information is updated within the period of backed up and failure of the VLR. As a result, number of channel collision is decreased significantly which eventually minimizes the total location management cost. The benchmark results from the analytical modeling also show that the proposed method outperforms other previous approaches.**

Keywords – **Periodic checkpointing, aperiodic checkpointing, location update, VLR, RA, BTS, failure restoration.**

I. INTRODUCTION

Location management in wireless mobile networks is a process of tracking Mobile Terminals (MTs) in the network coverage area. There are two types of standards which are used for this purpose such as basic IS-41 [1] and GSM [2]. Both of these are based on a two-level hierarchy of location databases called Home Location Register (HLR) and Visitor Location Register (VLR) for storing and maintaining MTs' updated location information. In these standards, the whole network coverage area is partitioned into cells of same size and shape. Each cell has a Base Transceiver Station (BTS) in its center through which MTs of this cell communicate through a wireless link. Group of these cells are used to form a larger group called Registration Area (RA). While all the BTSs within the RA are in wire-connected to a VLR, MTs are wireless-connected to the BTSs. These VLRs are wire-connected to one or more centralized database called HLR through Mobile Switching Center (MSC). One such network is shows in Figure 1.

Two important operations in wireless mobile networks are location registration and call delivery. The first one happens when an MT moves from one RA to another and the second one occurs when a call should be delivered to another MT. If the VLR mobility database fails, it is not possible to deliver the call to subscribers and even not possible to perform location registration. As a result, VLR mobility database recovery is an essential task for assuring continuous service availability to subscribers. A lot of research work has
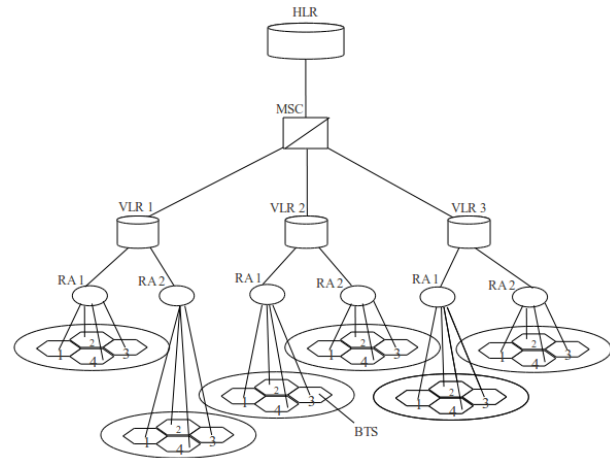

Figure 1. Wireless mobile network architecture.

been done on mobility database failure recovery and most of them are studied in [1], [2], [3], [4], [5], [6], [8].

In this paper, we propose an enhanced version of selective aperiodic checkpointing strategy for the failure recovery of VLR databases. This approach aperiodically stores VLR database information when location update counter exceeds its threshold. These information are restored when the databases are failed. But the information which are updated between checkpointing and failure time are obsolete. This approach sends location confirmation request messages only to the selected BTSs instead of all BTSs of the RAs whose location information are obsolete. In this way it reduces the number of unnecessary request messages in the network and eventually minimizes the total location management cost.

The rest of the paper is organized as follows. An overview of the related work is given in Section 2. Section 3 describes proposed method. Section 4 provides analytical modeling and benchmark of different approaches. Finally, a concluding remark is given in Section 5.

II. RELATED WORK

There are significant amount of work has been done in location management. A very basic approach called basic IS-41 scheme is proposed in [1] where there is no checkpointing for HLR and VLRs. In this scheme, VLRs reconstruct their
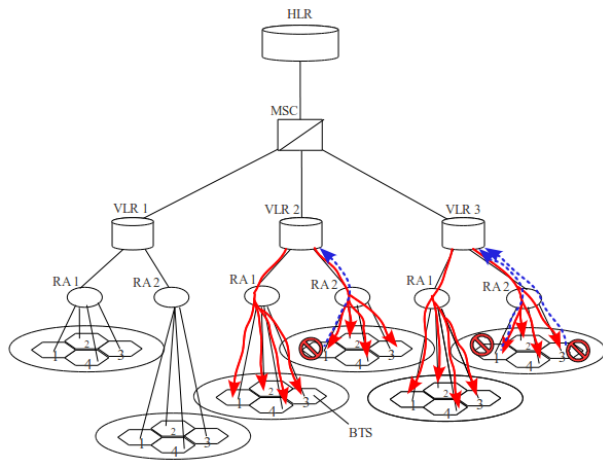
Figure 2. Updating obsolete VLR information in aperiodic checkpointing approach.
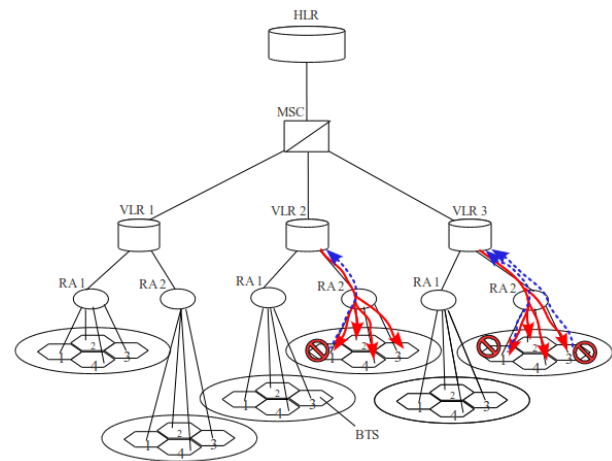

Figure 3. Updating obsolete VLR information in selective aperiodic checkpointing approach.

databases during the exchange of registration messages between the MTs and the HLR after the occurrence of a failure. A GSM approach is proposed in [2] where there is periodic checkpointing for both HLR and VLRs. Although HLR may aggressively restore its databases by sending location request messages to the known VLRs, but VLRs cannot do this aggressively to the RAs to restore their databases.

Periodic HLR and VLR checkpointing as well as location update is proposed in [3]. This restores VLR databases from the non-volatile storage just after the failure and recovers the obsolete information by periodic location update from the MTs. Although this approach reduces VLR restoration cost; but location update increases paging cost.

Periodic checkpointing of HLR and VLR databases with location update on demand is proposed in [4]. This approach periodically backed up VLR databases similar to [3], but recovers the obsolete information from the restored VLR databases by location update message on demand when the failure occurs. This approach is a little bit better than [3] as it sends location update messages from MTs to the VLR only at the time of failure instead of sending periodically.

An aperiodic checkpointing of HLR and VLRs with location update on demand is proposed in [5]. This approach aperiodically checkpointing VLR databases in the non-volatile storages when location update counter of that VLR exceeds to a threshold value. These databases are restored immediately to the corresponding VLRs after the failure. However, the information which are updated between the checkpointing time and failure time become obsolete. In order to update this obsolete information, a location confirmation request message is broadcasted to all the RAs under corresponding VLR to confirm the MTs' current location information to that VLR. As an illustration suppose MTs in BTS1 under RA2 of VLR2 and in BTS1 and BTS3 under RA2 of VLR3 in Figure 2 are obsolete. This approach

broadcasts the solid line messages as location confirmation request message and the dotted line messages are send by the MTs as location confirmation. This approach reduces the unnecessary VLR checkpointing when the MTs not performing location update to the VLRs. But it broadcasts the location update message to all the RAs although the location information for all these RAs are not obsolete.

In order to eliminate unnecessary broadcast messages of the aperiodic checkpointing approach [5], a selective aperiodic checkpointing approach is proposed in [8]. Checkpointing and restoration after the failure of this approach is similar to that of [5], except location confirmation process of the MTs whole location are still obsolete after the restoration of the checkpointed database. Unlike [5], it broadcasts a location confirmation request message only to the selected RAs under the corresponding VLR to confirm the MTs' current location information to that VLR. As an illustration suppose MTs in BTS1 under RA2 of VLR2 and in BTS1 and BTS3 under RA2 of VLR3 in Figure 3 are obsolete like Figure 2. This approach broadcasts the solid line messages as location confirmation request message and the dotted line messages are send by the MTs as location confirmation. Observe that it does not broadcast location confirmation request messages to RA1 of VLR2 and RA1 of VLR3, but aperiodic approach [5] does this. As a result, it reduces the unnecessary channel collision which eventually minimizes location management cost. But broadcast of location confirmation request messages are sent to all the BTSs under an RA although the location information for all these BTSs are not obsolete.

A broadcast approach for Universal Mobile Telecommunications System (UMTS) is proposed in [6] where a broadcast message is issued in the network to recover the mobility databases after the failure.
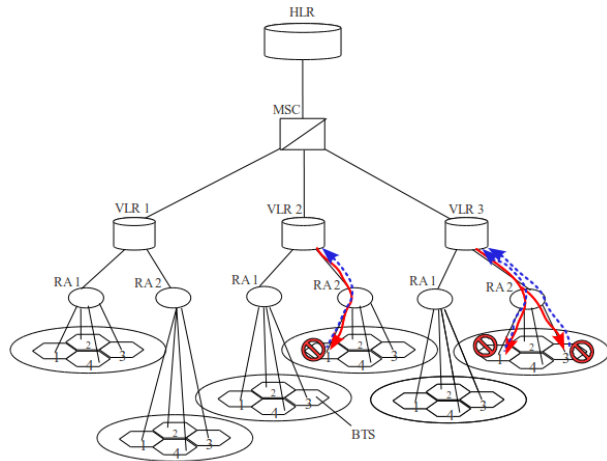
Figure 4. Updating obsolete VLR information in enhanced selective aperiodic checkpointing approach.

TABLE 1. TERMS OR SYMBOLS USED IN PROPOSED ALGORITHMS.

Term or Symbol	Meaning
VLR	The VLR in which the MT is currently located (the MT entered this VLR at time ts)
pid	The permanent identity of the MT
TMSI	The current temporary Identification (ID) of the MT assigned by the VLR
RA	The current registration area (RA) the MT is visiting (the MT entered this RA at time ts)
Ts	The time stamp of the MT's latest registration
TS	The last database backup (checkpointing) time of the VLR
Counter	A 2-D array of location update counters in the RAs
Dirty_flag*	A 2-D array of flags that identify whether or not the VLR backups for the RAs are obsolete or not saved in the non-volatile sorage
N_v	A threshold value for VLR checkpointing process
VLR*	The backup of the VLR in the non-volatile storage
TS*	The backup of the last database backup (checkpointing) time of the VLR in the non-volatile storage

III. PROPOSED APPROACH

We proposed an enhanced selective aperiodic checkpointing approach for VLR failure recovery in wireless mobile networks. A data structure named *Counter* (a 2-D array of counters) counts the number of MTs location update from each RA to the VLR. VLR database is checkpointed in the non-volatile storage when its count exceeds a predefined threshold. This storage is then used to restore the database when it fails. But location information which are updated between checkpointing and restoration time are obsolete. A data structures named *Dirty*_flag* (a 2-D array of flags) and a variable named *TS** (the last checkpointing time) are used to keep track of the BTSs to check whether their backup location information is obsolete or not and the last VLR checkpointing time, respectively. The VLR sends location confirmation request message to the selected BTSs (instead of all BTSs of the selected RAs) whose backup information is obsolete (*Dirty*_flag* is set). MTs within this selected BTSs then send location confirmation message to the VLR through BTS as well as RA if they update their location later than *TS** as an acknowledge of this request message. As an illustration suppose MTs in BTS1 under RA2 of VLR2 and in BTS1 and BTS3 under RA2 of VLR3 in Figure 4 are obsolete like Figure 2 and 3. This approach broadcasts the solid line messages as location confirmation request message and the dotted line messages are send by the MTs as location confirmation just similar to that of Figure 2 and 3. Observe that it does not broadcast location confirmation request messages to BTS2, BTS3, BTS4 of RA2 under VLR2 and BTS2 and BTS4 of RA2 under VLR3, but selective aperiodic approach [8] does this (See Figure 3). In this process, VLR database is restored on it after the failure and the probability of channel collision is reduced since the number of MTs and BTSs involved in location confirmation is significantly smaller than the previous approaches. Figure 5 shows the data structures and

Table 1 shows the terms and symbols used to describe the algorithm of the proposed method. The proposed enhanced selective aperiodic VLR restoration algorithms are Algorithm 1, 2, 3, and 4.

IV. ANALYTICAL MODELING AND EXPERIMENTAL RESULTS

A. Analytical Modeling

In this section we will discuss the model of VLR failure restorations of the periodic checkpointing, aperiodic checkpointing, selective aperiodic checkpointing, and the proposed enhanced selective aperiodic checkpointing approaches. We will derive the cost of delivering a call to a MT and compare the performance of our proposed enhanced selective aperiodic checkpointing scheme with that of the existing periodic and aperiodic checkpointing schemes. The terms and symbols used for analysis are available in [8].

If the normalized cost of paging in an RA is 1, then the normalized cost of the periodic checkpointing approach under the normal operation is as follows [8].

$$C_p = 1 + \frac{\gamma}{\lambda_d T_v} \qquad (1)$$

On the other hand, the normalized cost of the aperiodic checkpointing approach, selective aperiodic checkpointing approach, and enhanced selective aperiodic checkpointing approach under the normal operation is as follows [8].
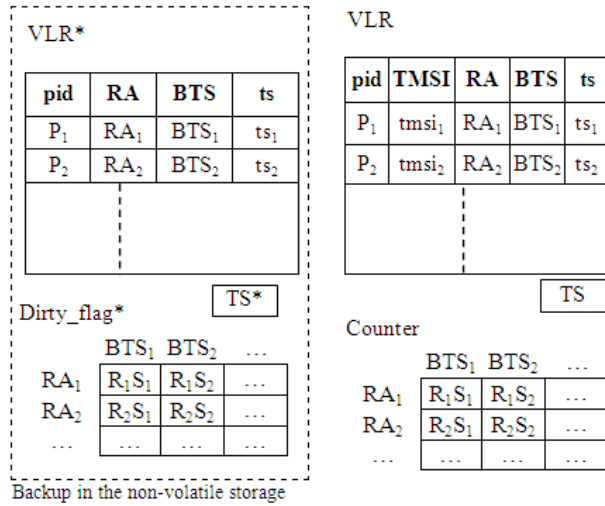
Figure 5. The data structures used to recover the VLR.

$$C_a = 1 + \frac{M\gamma}{RN_v}$$

$$= 1 + \frac{M\lambda_m\gamma}{\lambda_d N_v} \qquad (2)$$

Where, $R = \dfrac{\lambda_d}{\lambda_m}$ [7].

Alternatively, the VLR restoration after the failure depends on whether the first event is a call delivery or call origination or location confirmation. So, the normalized cost for the periodic checkpointing approach after the failure under this dependency is as follows [8].

$$C_p = P[X \text{ is call delivery}] \times C_1 +$$

$$P[X \text{ is call origination}] \times C_2 +$$

$$P[X \text{ is location confirmation or registration}] \times C_3 \qquad (3)$$

Where, C_1, C_2, C_3, P_M, $P[X$ is call delivery], $P[X$ is call origination], and $P[X$ is location confirmation or registration] terms are calculated in [8].

On the other hand, the normalized cost of the aperiodic checkpointing approach after the failure under the first event dependency is as follows [8].

$$C_a = (1 - P_f) + P_f \times C_f \qquad (4)$$

Where, C_f and P_f are calculated in [8].

Similarly, the normalized cost of the selective aperiodic checkpointing approach after the failure can be represented as follows.

$$C_{ap} = (1 - P_f) + P_f \times C_{fp} \qquad (5)$$

Where, P_f and C_{fp} terms are defined in [8].

Algorithm 1: VLR_REGISTRATION

(Registration message handling)
1: **if** $VLR = VLR_{old}$ **then** // Intra-VLR
2: Find the portable p that satisfies $VLR[p].TMSI = tmsi$;
3: **else** // Inter-VLR
4: Send a request for the portable's identity to the old VLR;
5: Get the portables identity p;
6: Create a new record for the portable;
7: Inform the HLR of the registration;

(TMSI assignment)
8: Generate a new $TMSI$, $tmsi_{new}$, for the portable;

(Location update)
9: Set $VLR[p].ts = t$;
10: Set $VLR[p].TMSI = tmsi_{new}$;
11: Set $VLR[p].RA = RA_{new}$;
12: Set $VLR[p].BTS = BTS_{new}$;

(Counter update)
13: Set $Counter[RA_{new}][BTS_{new}] = Counter[RA_{new}][BTS_{new}] + 1$;
14: **if** $Counter[RA_{new}][BTS_{new}] = 1$ **then**
15: Set $Dirty\_flag * [RA_{new}][BTS_{new}] = 1$;

(Checkpointing)
16: **if** $Counter[RA_{new}][BTS_{new}] > N_v$ **then**
17: Trigger a VLR checkpointing process;

Algorithm 2: VLR_DEREGISTRATION

1: Find the portable's identity p where $VLR[p].TMSI = TMSI$;
2: Send the identity p to VLR_{new};
3: Set $t = VLR[p].ts$;
4: **if** $t > TS$ **then**
5: Set $Counter[RA_{old}][BTS_{old}] = Counter[RA_{old}][BTS_{old}] - 1$;

6: **if** $Counter[RA_{old}][BTS_{old}] = 0$ **then**
7: Set $Dirty\_flag * [RA_{old}][BTS_{old}] = 0$;

Algorithm 3: VLR_CHECKPOINTING

1: Set $VLR* \leftarrow VLR$;
2: Set $TS* \leftarrow TS$;

3: **for** all RA_i and BTS_i **do**
4: Set $Counter[RA_i][[BTS_i]] = 0$;

5: **for** all RA_i and BTS_i **do**
6: Set $Dirty\_flag[RA_i][[BTS_i]] = 0$;

Now calculate the normalized cost, C_{eap}, of the proposed enhanced selective aperiodic checkpointing approach which can be represented as follows.

$$C_{eap} = (1 - P_f) + P_f \times C_{efp} \qquad (6)$$

Where, P_f is calculated in the similar way as that of [8]. On the other hand, C_{efp} is calculated in the similar way of calculating C_f in [8], but α (penalty factor for retransmission due to channel collisions) should be replaced by a fraction of

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Algorithm 4: VLR_RESTORATION

(Restore the backup VLR which are checkpointed previously)

1: Set $VLR \leftarrow VLR*$;
2: **for** all RA_i and BTS_i **do**
3:     **if** $Dirty\_flag * [RA_i][BTS_i] = 1$ **then**
       (execute a confirmation algorithm)
4:        VLR sends location confirmation request message to BTS_i of RA_i;
5:        MTs confirm their location information to the VLR through BTS_i of RA_i which perform handoff or location update after $TS*$;
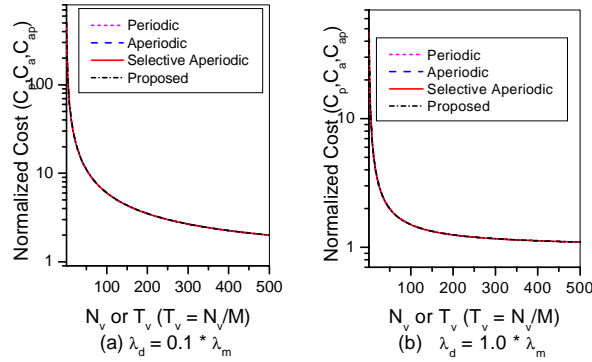

Figure 6. The normalized cost of delivering a call in normal operation.

Figure 7. The cost of delivering a call after a VLR failure (when $\gamma = 0.5$).

Figure 8. The cost of delivering a call after a VLR failure (when $\gamma = 1.0$).

it. Because, channel collision is reduced significantly in the proposed method than that of [8]. Please compare the number of location confirmation request messages shown in Figure 3 and 4. Suppose *frac* denotes that fraction. So, C_{efp} will be calculated as follows.
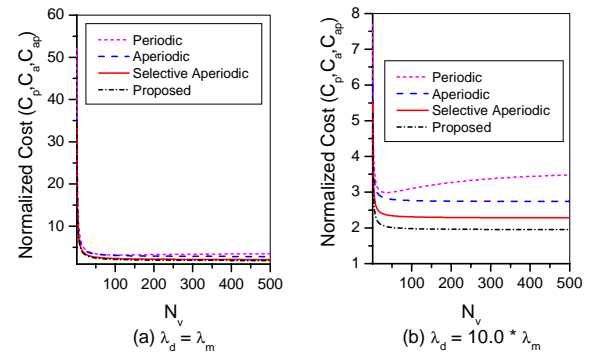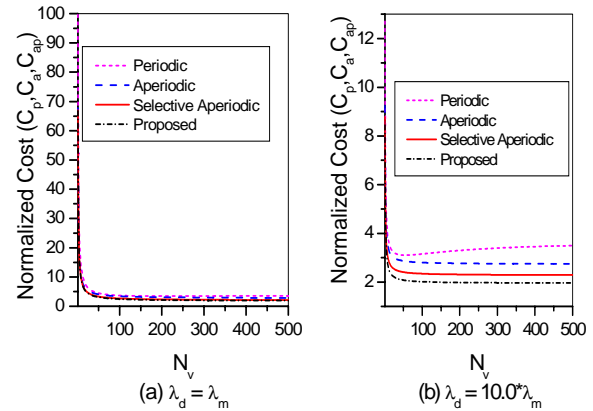
$$C_{efp} = P[X \text{ is call delivery}] \times \delta \times (E[N_{RA}]) +$$
$$P[X \text{ is location confirmation or registration}] \times (1 + frac \times \alpha) +$$
$$P[X \text{ is call origination}] + \frac{M\lambda_m\gamma}{\lambda_d N_v} \qquad (7)$$

Where, the rest of the terms of Equation 7 are calculated in the similar way as that of [8].

B. Experimental Results

In order to obtain benchmark results of the proposed and previous approaches, we used Little's Result ($N = \lambda \times T$) to transform the coordinates of the periodic checkpointing approach to the aperiodic checkpointing approaches. Here, transformation parameters are $N = N_v$, $\lambda = M\lambda_m$, and $T = T_v$. We assume that the penalty factor due to channel collision of the proposed method reduced by 30% and so $frac = 0.7$. Moreover, we assume $M = 100$, $N_{RA} = 4$, $\delta = \alpha = 2$, and $\gamma = 0.5$ and 1.0.

The normalized call delivery cost of the previous and

proposed approaches under the normal operation is shown in Figure 6. It shows that the cost of these four approaches for any given CMR are same and going downwards with the increase of N_v or T_v. The reason of this result is that there is no change in algorithms under this condition.

On the other hand, the normalized call delivery cost of the previous and proposed approaches after the VLR failure is shown in Figure 7 and 8. It is observed from these figures that the proposed method outperforms other three methods irrespective of the values of N_v, CMR, and γ and decreases the cost with the increase of N_v. These trends are expected as the VLR broadcasts the location confirmation request message to the selected BTSs for the proposed approach instead of broadcasting this message to all the BTSs under the corresponding RA for the selective aperiodic checkpointing approach. In contrast, for the periodic checkpointing approach, VLRs are periodically checkpointed irrespective of the number of location updates in that VLR. As a result, the call delivery cost increases for this approach. Moreover, the number of VLR checkpointing decreases with the increase of

N_v and therefore the call delivery cost decreases for these approaches.

V. CONCLUSION

We have proposed a new enhanced selective aperiodic checkpointing approach for VLR failure recovery in wireless mobile networks. In this approach, the VLR databases are checkpointed in the non-volatile storage when the location update counter exceeds its predefined threshold. After the failure, databases are restored from the non-volatile storage, but some of its location information which are updated between the checkpointing and failure period may become obsolete. In order to update these obsolete information, 2-D data structures are used to list the BTSs whose location information is updated during this time period. The VLR then broadcasts the location confirmation request message to these selected BTSs instead of broadcasting to all BTSs under an RA. As a result, total normalized call delivery cost of the proposed method after the failure is significantly reduced than the other approaches. The analytical modeling and numerical results also shows that the proposed method after the failure outperforms previous methods.

We are currently working on measuring the exact value of penalty factor for retransmission due to channel collisions.

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