References

1 BUTTERWORTH, K.S., SOWERBY, K.W., and WILLIAMSON, A.G.: 'Base station placement for in-building mobile communication systems to yield high capacity and efficiency', *IEEE Trans. Commun.*, 2000, **48**, (4), pp. 658–669

2 PARAHIA, E., COX, D.C., and HO, S.: 'Shadow fading cross correlation between basestations'. Proc. IEEE VTC 2001 Spring, Rhodes, Greece, 2001, Vol. 1, pp. 313–317

3 DILWORTH, I.J., and STEVENS, R.D.: 'Mobile radio shadowing loss variability and co-channel signal correlations at 452 MHz', *Electron. Lett.*, 1996, **32**, (1), pp. 16–17

Overflow control in mobile communication using *N*-class replacement

Kuen-Liang Sue and Chi-Chun Lo

A strategy called *N*-class replacement (NR) policy is proposed to overcome visitor location register (VLR) overflow in a mobile communication system. The NR policy requires only few bits in the VLR record. It is feasible for separated VLR databases in real mobile networks. For the rate of excellent replacement, the simulation results show that the NR policy outperforms currently proposed policies.

Introduction: As a mobile user roams from home system to another cellular system, a temporary record for the user must be created in the visitor location register (VLR) of the visited system. The record includes information for handling calls to or from the user. More concepts relating to mobility management can be found in [1].

Owing to limited capacity, the VLR may be full if too many mobile users enter a VLR during a short period. While a VLR is full, the arriving mobile users cannot receive any service. The phenomenon is called *VLR overflow* and these users are *overflow users*. An attractive overflow control scheme is to select a record from the overflow VLR as a victim. The victim will be replaced with the record of the overflow user. *If a user whose record was replaced has no call activity before* he/she leaves the VLR area, the replacement is *excellent*. Otherwise, an additional replacement will be requested when a call for the victim user arrives.

An important criterion of replacement policies is the rate of excellent replacement. The random replacement (RR) policy is the simplest idea, but it has high replacement frequency [2]. The most-idle replacement (MR) policy was proposed to lessen the replacement frequency. During each call arrival or user arrival, the MR policy must reorganise the VLR (a double linked list) to keep the non-increasing order according to the idle time [3]. Hence, the MR policy has two serious limitations. First, it is inefficient in view of the considerable extra cost and time. Secondly, it is not feasible in a real mobile network, since the records of a huge VLR are physically stored in several separated databases.

A more efficient method called *N*-class replacement (NR) policy is presented in this Letter. The NR policy tends to select the inactive users for replacement. These inactive users have lower probability to request service after they have been replaced. Consequently, the NR policy is expected to gain a high rate of excellent replacement. Moreover, the NR policy overcomes limitations of the MR policy and makes the notion of VLR overflow control more feasible.

N-class replacement policy: In the NR policy, the inactive users are selected for replacement according to their active degrees. The active degree of a user is measured by the number of call arrivals to the user. The records in a VLR are divided into N classes (class 0 to class $N-1$). Each VLR record has a class indicator n. All VLR records are linked into a circular list (Fig. 1*a*). When a user issues/receives one call, the indicator n in his/her VLR record will increase by (e.g. record I in Fig. 1*b*) except that n has reached $N-1$. As record replacement is required, the victim is considered following the order of records in the circular list. If the indicator n of the record being considered is greater than zero, n will decrease by 1 and the record should be skipped; otherwise, the record will be replaced with that of the incoming user. Fig. 1*c* shows the process of victim selection, where record J and K are skipped. The record next to the replaced record is the new head of the circular list. The new record becomes the new tail of the circular list, and its indicator n is set to 1 (Fig. 1*d*). By such arrangement, the concept of the NR policy can be implemented with a pointer pointing at the dynamic head of the circular list. No database reorganisation is required.

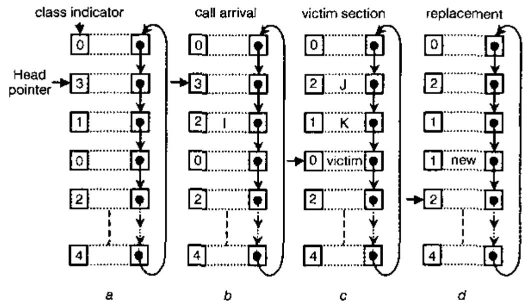

Fig. 1 *Illustration of NR policy*
a Class indicator
b Call arrival
c Victim selection
d Replacement

Performance analysis: For simplification, it is assumed that there are two categories of mobile users. One has a low call arrival rate $\lambda_{c,1}$, the other has a high call arrival rate $\lambda_{c,2}$. The user arrival rates of the two categories of users are $\lambda_{u,1}$ and $\lambda_{u,2}$, respectively. Both user arrivals and call arrivals are assumed to be Poisson process. In addition, the VLR residence time of all users is supposed to have a general distribution with mean $1/\lambda_m$ and variance V_m. Based on these assumptions, we are interested in the probability P_{nr} of excellent replacement using the NR policy.

$p(q)$ is the long term percentage that a class 1 (class 2) user is chosen for replacement when a replacement request arrives. We have $p+q=1$. In the NR policy, the more call arrival rate you get, the less probability of being replaced you have. Hence,

$$p = \frac{\lambda_{c,2}}{\lambda_{c,1}+\lambda_{c,2}} \tag{1}$$

After a class i user u_i is replaced, $p_{1,i}$ is the probability that u_i will have no call activity before he/she departs from the VLR area. Let $t_{m,i}$ ($t_{c,i}$) be the time of u_i's departure (first call arrival) since he/she was replaced. Then,

$$\begin{aligned} p_{1,i} &= Pr[t_{m,i} < t_{c,i}] \\ &= \int_{t_{m,i}=0}^{\infty}\int_{t_{c,i}=t_{m,i}}^{\infty} \lambda_{c,i}e^{-\lambda_{c,i}t_{c,i}}\lambda_m[1-F_m(t_{m,i})]dt_{c,i}dt_{m,i} \\ &= \left(\frac{\lambda_m}{\lambda_{c,i}}\right)[1-f_m(\lambda_{c,i})] \end{aligned} \tag{2}$$

where $F_m(\cdot)$ is the distribution function of VLR residence time and $f_m(\cdot)$ is the Laplace transform of the VLR residence time distribution.

P_{nr} can be computed substituting (1) and (2) into the following formula:

$$P_{nr} = pp_{1,1} + qp_{1,2} \tag{3}$$

Simulation results: The output of the discrete-event simulation are P_{nr}, P_{mr}, and P_{rr} which are the excellent replacement rate of the NR, MR, and RR policies, respectively. For the same ratio of VLR size to user arrival rate, we found that P_{nr} has the same value. Identical property is observed in computing P_{mr} and P_{rr}. Hence, it is assumed that $\lambda_{u,1}=\lambda_{u,2}=1000\lambda_m$ and smaller VLR size is considered in this Section. The same result can be inherited for larger VLR size with the same ratio of VLR size to user arrival rate. The residence time distribution for all users in the experiment has the Gamma distribution with mean $1/\lambda_m$ and variance $V_m = 1/\lambda_m^2$.

The effects of N values in the NR policy are shown in Fig. 2, which plots P_{nr} against VLR size where $\theta = \lambda_{u,1}/(\lambda_{u,1}+\lambda_{u,2})$. The case $N=1$ is trivial since the NR policy degenerates to a FIFO policy. For $2 \le N \le 5$, the larger N, the better P_{nr} curve. P_{nr} value will converge to an upper bound for $N > 5$.

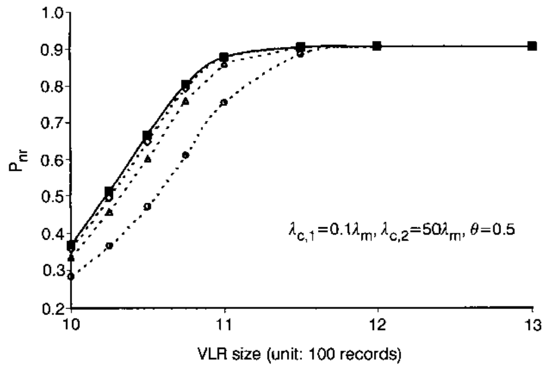

Fig. 2 *Performance of NR policy*
- -○- - P_{nr} (N-class replacement, N = 2)
- -△- - P_{nr} (N-class replacement, N = 3)
- -◇- - P_{nr} (N-class replacement, N = 4)
- -■- - P_{nr} (N-class replacement, N = 5)

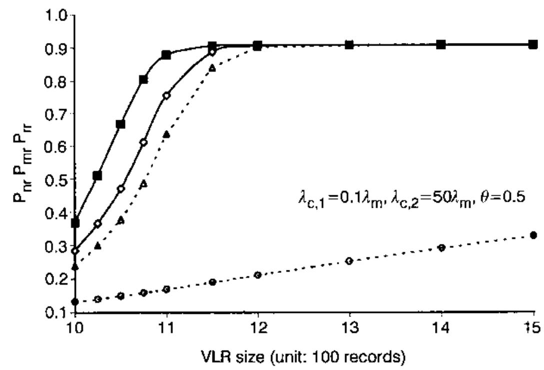

Fig. 3 *Effects of VLR size on P_{nr}, P_{mr} and P_{rr}*
- -○- - P_{rr} (random replacement)
- -△- - P_{mr} (most-idle replacement)
- -◇- - P_{nr} (N-class replacement, N = 2)
- -■- - P_{nr} (N-class replacement, N = 5)

Fig. 3 compares P_{nr}, P_{mr}, and P_{rr} based on various VLR size. P_{rr} increases linearly and slowly as the VLR size increases, so we omit it from further discussion. It is observed that the threshold of VLR size in this experiment is 1200. If VLR size is less than the threshold, the overflow situation will be very serious. Because inactive users are insufficient for replacement, some active users will also be selected as victims. Consequently, increasing VLR size decreases the number of active victims and lifts P_{nr} and P_{mr} significantly. While VLR size is larger than the threshold, the number of inactive users is sufficient for replacement. P_{nr} and P_{mr} become stable. Fig. 3 also shows that even if $N = 2$, P_{nr} is better than P_{mr}. As N increases to 5, the NR policy can outperform the MR policy up to 76.63% for VLR size = 1050.

Conclusion: We propose the N-Class replacement (NR) policy to achieve the overflow control on a mobility database. For the rate of excellent replacement, the performance of the NR policy gets better as N increases. Even though $N = 2$, it outperforms currently proposed replacement policies. Higher N gains lower replacement frequency due to better rate of excellent replacement, but may take more time to select victims. We suggest that system parameter N can be determined manually or automatically according to the degree of VLR overflow to provide flexibility. Moreover, the NR policy needs only few additional bits (e.g. 3 bits for $N \leq 7$) in the VLR record. The database reorganisation is not necessary during call arrival or user arrival. Most importantly, it is feasible for the separated databases in the real mobile network. Since the NR policy does not require global information about the idle time, it can be executed in individual databases. To sum up, the NR policy is both efficient and feasible for resolving mobility database overflow.

15 November 2002
Electronics Letters Online No: 20030171
DOI: 10.1049/el:20030171

Kuen-Liang Sue and Chi-Chun Lo (*Institute of Information Management, National Chiao Tung University, 1001, Ta Hsueh Road, 30050 Hsinchu, Taiwan, Republic of China*)

E-mail: klsue@csie.nctu.edu.tw

References

1 SUE, K.-L., and TSENG, C.-C.: 'One-step pointer forwarding strategy for location tracking in distributed HLR environment', *IEEE J. Sel. Areas Commun.*, 1997, **15**, (8), pp. 1455–1466
2 LIN, Y.-B.: 'Overflow control for cellular mobility database', *IEEE Trans. Veh. Technol.*, 2000, **49**, (2), pp. 520–530
3 HUNG, H.-N., LIN, Y.-B., PENG, N.-F., and YANG, S.-R.: 'Resolving mobile database overflow with most-idle replacement', *IEEE J. Sel. Areas Commun.*, 2001, **19**, (10), pp. 1953–1961

Performance of multicode DS-CDMA using frequency domain equalisation in frequency selective fading channel

F. Adachi, T. Sao and T. Itagaki

For the reception of multicode direct sequence (DS)-CDMA signals, the MMSE frequency domain equalisation is applied instead of RAKE combining. The achievable BER performance in a frequency selective Rayleigh fading channel is evaluated by computer simulation. It is shown by computer simulation that the DS-CDMA with MMSE frequency domain equalisation outperforms the DS-CDMA with RAKE combining and shows only slight performance degradation compared to the MC-CDMA with minimum mean square error combining (MMSEC).

Introduction: In direct sequence code division multiple access (DS-CDMA), one way to achieve high-speed data transmission is to use orthogonal multicode multiplexing [1]. However, frequency selective multipath fading encountered in a broadband wireless communication system severely degrades the bit error rate (BER) performance of multicode DS-CDMA. An effective technique to improve the BER performance is a RAKE receiver. However, as the spreading chip rate becomes higher, the frequency selectivity of the multipath channel becomes more severe due to the increasing number of resolvable propagation paths. This causes a number of problems. The intercode interference (ICI) becomes stronger and the accurate channel estimation necessary for RAKE combining becomes more difficult. The RAKE receiver complexity increases due to the increasing number of RAKE fingers required.

Recently, much attention has been paid to multicarrier CDMA (MC-CDMA) [2], in which the frequency domain spreading is used. The frequency selective fading distorts the MC-CDMA signals and destroys the orthogonality property of the spreading codes. Before despreading of the received MC-CDMA signal, frequency domain equalisation is applied for partial restoration of code orthogonality. The most effective frequency equalisation and despreading is the minimum mean square error combining (MMSEC) [3]. The frequency domain equalisation has also been attracting much attention recently for the single carrier wireless transmission systems [4].

In this Letter, we apply the concept of frequency domain equalisation to multicode DS-CDMA signal reception. First, a signal transmission system model of DS-CDMA with frequency domain equalisation based on minimum mean square error (MMSE) is presented and then, the achievable BER performance in a frequency selective Rayleigh fading channel is evaluated by computer simulation. The performance comparison is presented for the DS-CDMA with MMSE frequency domain equalisation and with RAKE combining (i.e. time domain equalisation) and the MC-CDMA with MMSEC.