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Computer Communications 23 (2000) 476–482

computer communications

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Channel assignment for GSM half-rate and full-rate traffic

P. Lin, Y.-B. Lin*

Department of Computer Science and Information Engineering, National Chaio Tung University Hsinchu, Taiwan, ROC

Abstract

Global System for Mobile Communications (GSM) supports full-rate and half-rate calls. In this paper, we propose analytical and simulation models to study the performance of four channel assignment schemes for GSM half-rate and full-rate traffic. Our study indicates that among the four schemes, the repacking scheme has the best performance for mixing half-rate and full-rate traffic. We also observe that good performance is expected if the standard derivation of the cell residence time for a mobile station is large.

Keywords: Global system for mobile communications; Full-rate; Half-rate

1. Introduction

Global System for Mobile Communications (GSM) [1] is a standard adopted by cellular systems widely developed in Europe and Asia. In a GSM network, a mobile station (MS) initiates a communication session by making an access request to a base station (BS), if the MS is in the cell (the radio coverage area) of the BS. If no channel is available at that cell, the call is *blocked*. If the MS moves to another cell during the conversation, then the radio link to the old BS is disconnected and a radio link to the new BS is required to continue the conversation. This process is called *handoff* [2,3]. If the new BS does not have any idle channel, the handoff call is *dropped* or *forced* to *terminate*. Handoff requests and new call requests compete for radio channels in a cell. Several channel assignment schemes [4] have been proposed to reduce call blocking and call dropping.

GSM combines *time division multiple access* (TDMA) and *frequency division multiple access* (FDMA) for radio channel allocation. In this approach, a frequency carrier is divided into eight time slots per frame, which are used to support speech and data transmission. GSM supports full-rate calls and half-rate calls. A full-rate call uses one time slot in every frame, while a half-rate call uses one time slot in every two frames. Once an MS initiates a full-rate (half-rate) call request, the MS will operate in full-rate (half-rate) mode until the call is terminated. A call may alternate between full-rate and half-rate channels [5]. Such an approach is not considered here. In this paper, mixing full- and half-rate calls in a frequency carrier result in eight full-rate calls, 16 half-rate calls, or any feasible combinations. To simplify the description, we view a GSM time slot as a "full" time slot that can be divided into two half time slots. Fig. 1 shows a feasible combination. In this figure, time slots 4 and 7 are idle. Time slots 1, 2 and 5 are occupied by full-rate calls F1, F2 and F3, respectively. Time slot 3 is occupied by two half-rate calls H2 and H3. Time slots 0 and 6 are occupied by half-rate calls H1 and H4, respectively. These two time slots are referred to as "partially occupied" time slots. The channel allocation strategies for incoming calls may significantly affect the performance. For example, if eight half-rate calls occupy eight different full time slots in a frequency carrier; that is, the eight time slots are partially occupied, then the next incoming full-rate call will be blocked. On the other hand, if these half-rate calls are packed into four full time slots, then the frequency carrier can accommodate four extra full-rate calls. In this paper, we evaluate four GSM channel assignment schemes described in Ref. [6]: random, repacking, fair-repacking and best-fit. These schemes are elaborated as follows.

Random: all full-rate and half-rate calls are assigned to any free time slots without any control.

Best-Fit: each incoming full-rate call is allocated an empty full time slot. A half-rate call is always assigned a partially occupied time slot that has already contained a half-rate call. If no such time slot exists, then an empty full time slot is assigned to the half-rate call. Note that when a half-rate call departs, it is possible that more than one partially occupied time slots exist.

* Corresponding author. Tel.: +886-35-731842; fax: +886-35-724176.

PII: S0140-3664(99)00202-9

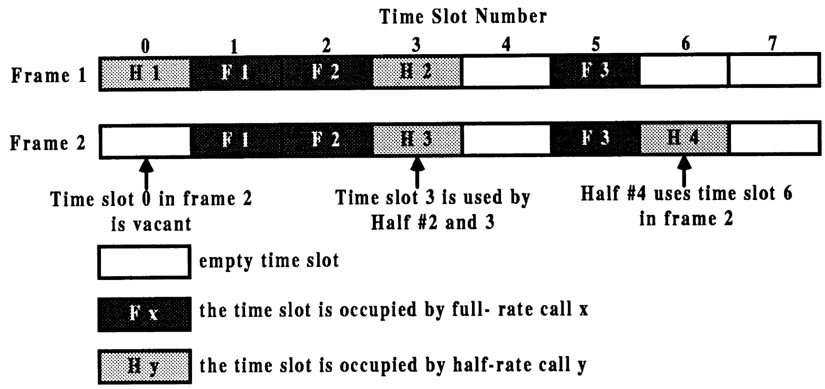

Fig. 1. An example for full- and half-rate traffic.

Repacking: this scheme is similar to the best-fit scheme except that when a full-rate call arrives to a cell, the scheme repacks the half-rate calls if two partially occupied time slots exist. Repacking is achieved by intracell handoff technology.

Fair-Repacking: this scheme is a variation of the repacking scheme. The only difference between repacking and fair-repacking is that in fair-repacking, if only one half time slot is left in a cell, the next incoming half-rate calls will be blocked. In Ref. [6], the authors claimed that with fair-repacking, the blocking/force-termination probabilities of full- and half-rate calls are likely to be equal for mix traffic. Our study will indicate that when the number of channel in a cell is small, fair-repacking significantly degrades the performance of the full-rate calls without improving the half-rate call performance. On the other hand, the performance of fair-repacking is similar to repacking for a GSM cell with a large channel number. Since the implementation complexity for fair-repacking is higher than that for repacking, fair-repacking may not be appropriate for a practical GSM network.

The above four algorithms have been evaluated in Ref. [6] without considering the MS mobility. By accommodating the MS mobility, this paper proposes an analytical model for repacking and simulation models for the four schemes.

2. Input parameters and output measures

This section lists the input parameters and output measures used in this paper. The input parameters include

- λ_f (λ_h): the new full-rate (half-rate) call arrival rate to a cell
- $1/\mu_f$ ($1/\mu_h$): the expected full-rate (half-rate) call holding time
- η_f (η_h): the full-rate (half-rate) MS mobility rate
- c: total number of time slots in a cell

The output measures include

- $\lambda_{h,f}$ ($\lambda_{h,h}$): the handoff full-rate (half-rate) call arrival rate to a cell
- $p_{f,f}$ ($p_{f,h}$): the force-termination probability for the full-rate (half-rate) call
- $p_{b,f}$ ($p_{b,h}$): the new call blocking probability for a full-rate (half-rate) call
- $p_{nc,f}$ ($p_{nc,h}$): the probability that a full-rate (half-rate) call is not completed (either blocked or forced to terminate)
- $p_{nc} = (\lambda_f p_{nc,f} + \lambda_h p_{nc,h})/(\lambda_f + \lambda_h)$: the probability that a full-rate or half-rate call is not completed

3. An analytical model for repacking

This section proposes an analytical model for the repacking scheme, which accommodates MS mobility. We assume that the full-rate (half-rate) call arrivals to a GSM cell form a Poisson process. Consider the timing diagram in Fig. 2. Let t_{c_i} be the call holding time for type i call where $i = $ f (full-rate) or h (half-rate), which is assumed to be exponentially distributed with the density function

$$f_{c_i}(t_{c_i}) = \mu_i \, e^{-\mu_i t_{c_i}} \qquad \text{for } i = \text{f or h} \tag{1}$$

and the mean call holding time is $E[t_{c_i}] = 1/\mu_i$. The cell residence time of an MS (for type i call service) at a cell j

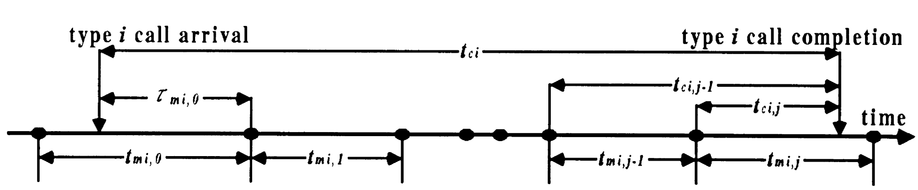

Fig. 2. The timing diagram.

is $t_{m_i,j}$. In this figure, $t_{m_i,0}$ is the time that the MS resides at cell 0, and $t_{m_i,j}$ (where $j \geq 1$) is the residence time at cell j. We assume that $t_{m_i,0}, t_{m_i,1}, t_{m_i,2}, t_{m_i,3}, t_{m_i,4}, \ldots, t_{m_i,k}$ are independent and identically distributed random variables with a general density function $f_{m_i}(t_{m_i,j})$ with mean $(1/\eta_i)$. Let $f^*_{m_i}(s)$ be the Laplace transform of the cell residence time distribution. Then

$$f^*_{m_i}(s) = \int_{t_{m_i,j}=0}^{\infty} f_{m_i}(t_{m_i,j})\, e^{-st_{m_i,j}}\, dt_{m_i,j} \qquad \text{for } i = \text{f or h.} \quad (2)$$

Consider type i calls. Let $\lambda_{h,i}$ be the handoff call arrival rate to a cell, $p_{b,i}$ be the new call blocking probability, $p_{f,i}$ be the force-termination probability, and $p_{nc,i}$ be the probability that a type i call is not completed. From Ref. [7], $\lambda_{h,i}$ can be expressed as:

$$\lambda_{h,i} = \frac{(1-p_{b,i})\eta_i[1-f^*_{m_i}(\mu_i)]\lambda_i}{\mu_i[1-(1-p_{f,i})f^*_{m_i}(\mu_i)]} \qquad \text{for } i = \text{f or h.} \quad (3)$$

For the moment, we assume that $p_{b,i}$ and $p_{f,i}$ are known. Both probabilities are derived by using an iterative algorithm to be described later. From Ref. [7], type i call traffic ρ_i to a cell is:

$$\rho_i = \frac{\lambda_i}{\mu_i}\left\{1 - \frac{\eta_i p_{b,i}[1-f^*_{m_i}(\mu_i)]}{\mu_i[1-(1-p_{f,i})f^*_{m_i}(\mu_i)]}\right\} \qquad \text{for } i = \text{f or h} \quad (4)$$

and $p_{nc,i}$ is

$$p_{nc,i} = p_{b,i} + \left\{\frac{(1-p_{b,i})\eta_i[1-f^*_{m_i}(\mu_i)]}{\mu_i[1-(1-p_{f,i})f^*_{m_i}(\mu_i)]}\right\} p_{f,i} \quad (5)$$

for i = f or h

Finally, the average probability p_{nc} that a call (either full-rate or half-rate) is not complete can be computed as follows:

$$p_{nc} = \frac{\lambda_f p_{nc,f} + \lambda_h p_{nc,h}}{\lambda_f + \lambda_h} \quad (6)$$

We will use $p_{nc,i}$ and p_{nc} as the major output measures in our performance study.

To derive the new call blocking probability $p_{b,i}$, we consider a stochastic process with state $\mathbf{n} = (n_h, n_f)$ where n_h and n_f represent the numbers of the outstanding half-rate and full-rate calls in a cell, respectively. Suppose that there are c full time slots in a cell where a full time slot can be used by one full-rate call or two half-rate calls, then in the repacking scheme, the following constraints must be satisfied:

$$n_h + 2n_f \leq 2c,\ 0 \leq n_h \leq 2c,\ \text{and } 0 \leq n_f \leq c$$

The state space S of the stochastic process is

$$S = \{(n_h, n_f) | n_h + 2n_f \leq 2c,\ \ 0 \leq n_h \leq 2c,\ \ \text{and } 0 \leq n_f \leq c\} \quad (7)$$

According to Zachary [8] and Kelly [9], the stationary probability of the state $\mathbf{n} = (n_h, n_f)$ can be computed as

$$p(\mathbf{n}) = G^{-1}\left(\frac{\rho_f^{n_f}}{n_f!}\right)\left(\frac{\rho_h^{n_h}}{n_h!}\right) \quad (8)$$

where

$$G = \sum_{\mathbf{n}\in S}\left[\left(\frac{\rho_f^{n_f}}{n_f!}\right)\left(\frac{\rho_h^{n_h}}{n_h!}\right)\right] \quad (9)$$

The second and third terms of the right hand side of Eq. (8) are the weights contributed by the full-rate call traffic and the half-rate call traffic, respectively. G in Eq. (9) is a normalized factor to ensure that $\sum_{\mathbf{n}\in S} p(\mathbf{n}) = 1$.

With the above stochastic process model, $p_{b,f}$ is computed as follows. When a full-rate call arrives at a cell, it is blocked if no more than one half time slot is left in that cell. That is, $n_h + n_f = 2c$ or $n_h + n_f = 2c - 1$ when the full-rate call arrives. Define E_1 as

$$E_1 = \{(n_h, n_f) | n_h + 2n_f = 2c \text{ or } n_h + 2n_f = 2c - 1,\ \ 0 \leq n_h \leq 2c,\ \ 0 \leq n_f \leq c\} \quad (10)$$

Then we have

$$p_{b,f} = \sum_{\mathbf{n}\in E_1} p(\mathbf{n}) \quad (11)$$

Similarly, when a half-rate call arrives at a cell, it is blocked if all time slots are busy. That is, $n_h + 2n_f = 2c$ when the half-rate call arrives. Let

$$E_2 = \{(n_h, n_f) | n_h + 2n_f = 2c,\ \ 0 \leq n_h \leq 2c,\ \ 0 \leq n_f \leq c\} \quad (12)$$

then

$$p_{b,h} = \sum_{\mathbf{n}\in E_2} p(\mathbf{n}) \quad (13)$$

With Eqs. (3)–(6), (11) and (13), we use an iterative algorithm [7] to compute $\lambda_{h,f}$, $\lambda_{h,h}$, $p_{nc,f}$ and $p_{nc,h}$.

The Iterative Algorithm.

Step 1: Select initial values for $\lambda_{h,h}$ and $\lambda_{h,f}$.
*Step 2:*Compute $p_{b,f}$ and $p_{b,h}$ by using Eqs. (4), (11) and (13).
Step 3: $\lambda_{h,f,old} \leftarrow \lambda_{h,f}$ and $\lambda_{h,h,old} \leftarrow \lambda_{h,h}$.
Step 4: Compute $\lambda_{h,f}$ and $\lambda_{h,h}$ by using Eq. (3).
Step 5: If $|\lambda_{h,f} - \lambda_{h,f,old}| > \delta\lambda_{h,f}$ and $|\lambda_{h,h} - \lambda_{h,h,old}| > \delta\lambda_{h,h}$ then go to Step 2. Otherwise, go to Step 6. Note that δ is a pre-defined threshold. In our study, δ is set to 0.00001.
Step 6: The values for $\lambda_{h,f}$, $\lambda_{h,h}$, $p_{b,f}$, and $p_{b,h}$, converge. Compute $p_{nc,f}$, $p_{nc,h}$ and p_{nc} by using Eqs. (5) and (6).

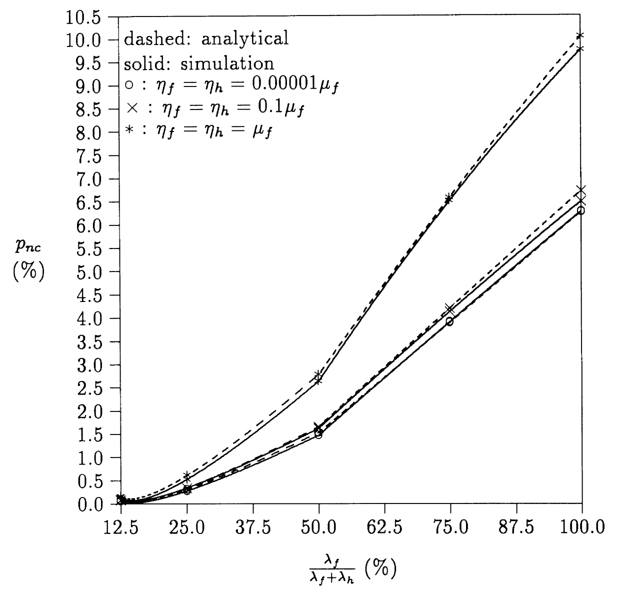

Fig. 3. Comparison of the analytical and the simulation results ($\lambda_f + \lambda_h = 4\mu_f$, $\mu_h = \mu_f$, $c = 7$).

4. Discrete event simulation models

This section describes a discrete event simulation model for repacking, best-fit, fair-repacking and random. In our simulation experiments, the GSM network is configured with k^2 BSs connected as a $k \times k$ wrapped mesh [10], where $k = 6$ is found adequate to simulate a large-scale GSM network. We assume that an MS resides at a cell for a period, and then moves to one of the four neighboring cells with the same routing probability (i.e. 0.25). The full-rate (half-rate) call arrivals to each cell form a Possion process with arrival rate λ_f (λ_h).

We develop a discrete event simulation model for these schemes. Three types of events are defined to represent a new call arrival, a call completion, or a handoff call moving from the old cell to the new cell. An event is either for a full-rate call or a half-rate call. The events are inserted into an event list, and are deleted/processed from the event list in non-decreasing timestamp order. A simulation clock t_s is maintained to indicate the progress of the simulation. In each experiment, more than 100,000 incoming calls are simulated to ensure that the results are stable. Several counters are maintained in the simulation including the number N_f (N_h) of full-rate (half-rate) call arrivals, the number $N_{b,f}$ ($N_{b,h}$) of blocked new full-rate (half-rate) calls and the number $N_{f,f}$ ($N_{f,h}$) of force-terminated handoff full-rate (half-rate) calls. These counters are used to compute $p_{nc,f}$ and $p_{nc,h}$:

$$p_{nc,f} = \frac{N_{b,f} + N_{f,f}}{N_f} \qquad \text{and } p_{nc,h} = \frac{N_{b,h} + N_{f,h}}{N_h}$$

In the simulation model, a cell j is modeled as an object *Cell(j)*. Every cell object contains c time_slot sub-objects and a member function *Channel_allocation* used to allocate channels based on the four different schemes described in Section 1. The data structure of time_slot consists of a state variable and an array of channel allocation times. The state indicates whether the time slot is empty, occupied by one half-rate call, two half-rate calls, or a full-rate call. The channel allocation times indicate when the time slots are occupied by the corresponding calls. The simulation flow is similar to that in Ref. [11] with the following exceptions:

Before channel allocation, the repacking and the fair-repacking simulations repack the time slots of the time_slot object. When Channel_allocation function is invoked, the simulation manipulates the time_slot objects according to the channel assignment schemes described in the previous section.

Fig. 3 plots the p_{nc} curves obtained from the analytical model (the dashed curves) and the simulation model (the solid curves) of the repacking scheme. The figure indicates that the analytical and simulation results are consistent.

5. Performance evaluation

This section investigates the performance of the four GSM channel assignment schemes based on the performance models developed in Sections 3 and 4. In our study, the considered input parameters λ_f, λ_h, η_f, η_h and μ_h are normalized by μ_f. For example, if the expected full-rate call holding time is $(1/\mu_f) = 2$ min, then $\lambda_f = 2\mu_f$ means that the expected full-rate inter call arrival time is 1 min.

5.1. Effect of the proportion of λ_f

Fig. 4(a) plots p_{nc} as a function of the ratio $(\lambda_f/(\lambda_f + \lambda_h))$, where $\eta_f = \eta_h = 2\mu_f$, $\mu_h = \mu_f$ and $c = 7$. In this figure, the net call arrival rate is a fixed value $\lambda_f + \lambda_h = 4\mu_f$.

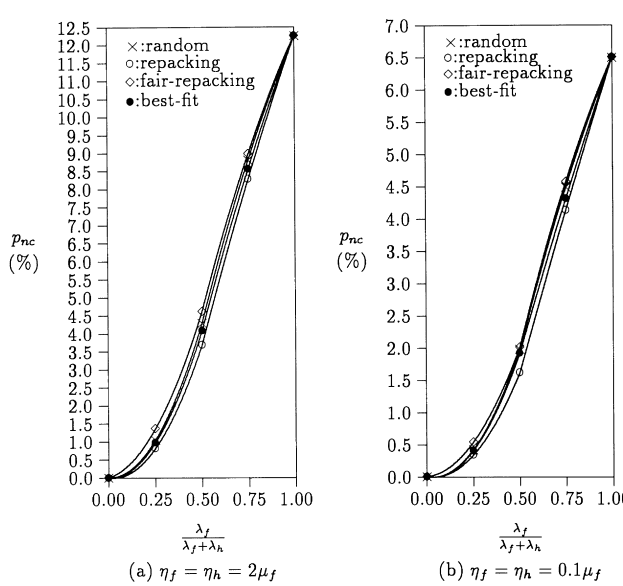

Fig. 4. Effect of proportion of λ_f($c = 7$, $\lambda_f + \lambda_h = 4\mu_f$, $\mu_h = \mu_f$).

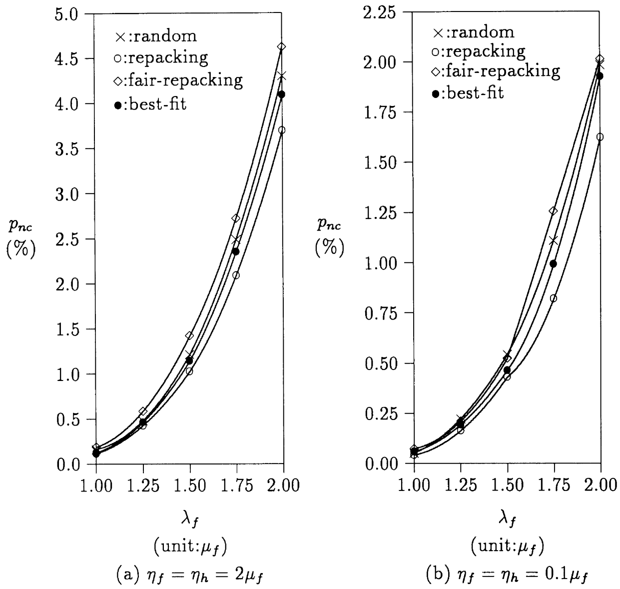

Fig. 5. Effect of incoming call traffic ($c = 7,\ \mu_h = \mu_f,\ \lambda_h = \lambda_f$).

The figure indicates that the order, from the best to the worst, of the p_{nc} performance for the four schemes is: repacking, best-fit, random and fair-repacking. Note that the performance differences are most significant when $(\lambda_f/(\lambda_f + \lambda_h)) = 0.5$, where the repacking scheme results in 20% improvement over fair-repacking, 14.2% improvement over random and 9.68% improvement over best-fit. It is clear that if the GSM network only has single type traffic, i.e. when $\lambda_f = 0$ or $\lambda_h = 0$, the performance of the four schemes is the same.

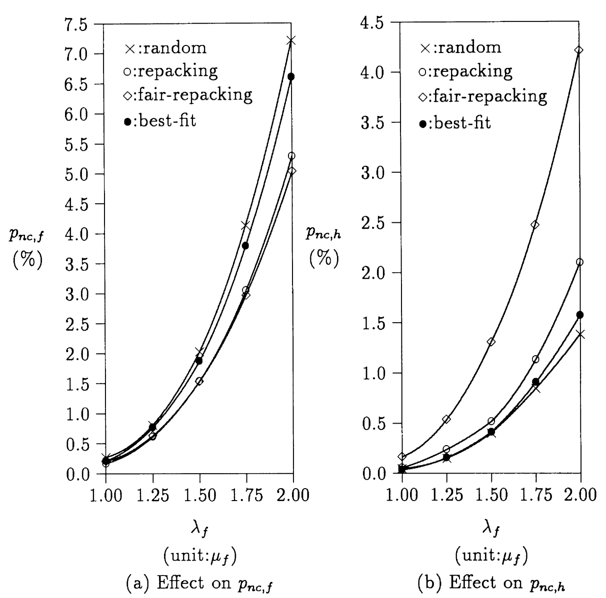

Fig. 6. Effect of incoming call traffic (Cont.; $c = 7,\ \eta_f = \eta_h = 2\mu_f,\ \mu_h = \mu_f,\ \lambda_h = \lambda_f$).

5.2. Effect of incoming call traffic

Fig. 5(a) plots p_{nc} as a function of λ_f, where $\lambda_f = \lambda_h,\ \mu_h = \mu_f,\ \eta_f = \eta_h = 2\mu_f$ and $c = 7$. The performance superiority among these four schemes is the same as what we observe in Fig. 4. The performance differences among these schemes become more significant as λ_f (λ_h) increases. Fig. 6(a) and (b) plots $p_{nc,f}$ and $p_{nc,h}$ as functions of λ_f, where $\lambda_f = \lambda_h,\ \mu_h = \mu_f,\ \eta_f = \eta_h = 2\mu_f$ and $c = 7$. Fig. 6(a) indicates that the $p_{nc,f}$ performance from the best to the worst is in the following order: fair-repacking, repacking, best-fit and random. The performance differences among the four schemes become more significant as λ_f (λ_h) increases.

Fig. 6(b) indicates that the $p_{nc,h}$ performance from the best to the worst is in the following order: random, best-fit, repacking and fair-repacking. The performance differences among the four schemes also become more significant as λ_f (λ_h) increases. Fig. 6(a) and (b) indicates that, when $p_{nc,f}$ for a scheme is large, the scheme will have a small $p_{nc,h}$ value compared with the other schemes. The reason is that when more time slots are occupied by full-rate (half-rate) calls, the half-rate (full-rate) calls are more likely to be blocked. Note that $p_{nc,h}$ for repacking is much lower than that for fair-repacking. On the other hand, $p_{nc,f}$ for both repacking and fair-repacking are about the same. In other word, "fairness" of fair-repacking is achieved by significantly degrading the half-rate call performance without improving the full-rate call performance. Thus, it is clear that repacking is better than fair-repacking.

5.3. Effect of MS mobilities η_f and η_h

Fig. 4(a) shows the p_{nc} performance for high MS mobility ($\eta_f = \eta_h = 2\mu_f$), and Fig. 4(b) shows the p_{nc} performance for low MS mobility ($\eta_f = \eta_h = 0.1\mu_f$). For each of the four schemes, p_{nc} decreases as the MS mobility decreases. When the MS mobility is high, the performance differences among the four algorithms are not consistent with that for low MS mobility. For example, consider the case when $(\lambda_f/(\lambda_f + \lambda_h)) = 0.5$. For $\eta_f = \eta_h = 2\mu_f$, the repacking scheme results in 9.68% improvement over best-fit, 14.2% improvement over random and 20% improvement over fair-repacking. On the other hand, for $\eta_f = \eta_h = 0.1\mu_f$, repacking results in 15.8% improvement over best-fit, 18.34% improvement over random and 19.43% improvement over fair-repacking. Fig. 5(a) and (b) indicates similar results.

Fig. 7 plots $p_{nc,f}$ and $p_{nc,h}$ of repacking for the case when $\eta_f \neq \eta_h$. In this figure, $\lambda_f = \lambda_h,\ \mu_h = \mu_f$ and $c = 7$. Fig. 7(a) and (b) plots $p_{nc,f}$ and $p_{nc,h}$ as functions of η_h and λ_f by fixing $\eta_f = 2\mu_f$. This figure indicates that changing η_h does not affect $p_{nc,f}$ significantly. On the other hand, $p_{nc,h}$ increases as η_h increases. In Fig. 7(c) and (d), we fix $\eta_h = 2\mu_f$. The figure indicates that changing η_f has significant effect on $p_{nc,f}$, and only has insignificant effect on $p_{nc,h}$. We conclude that the full-rate (half-rate) MS mobility has

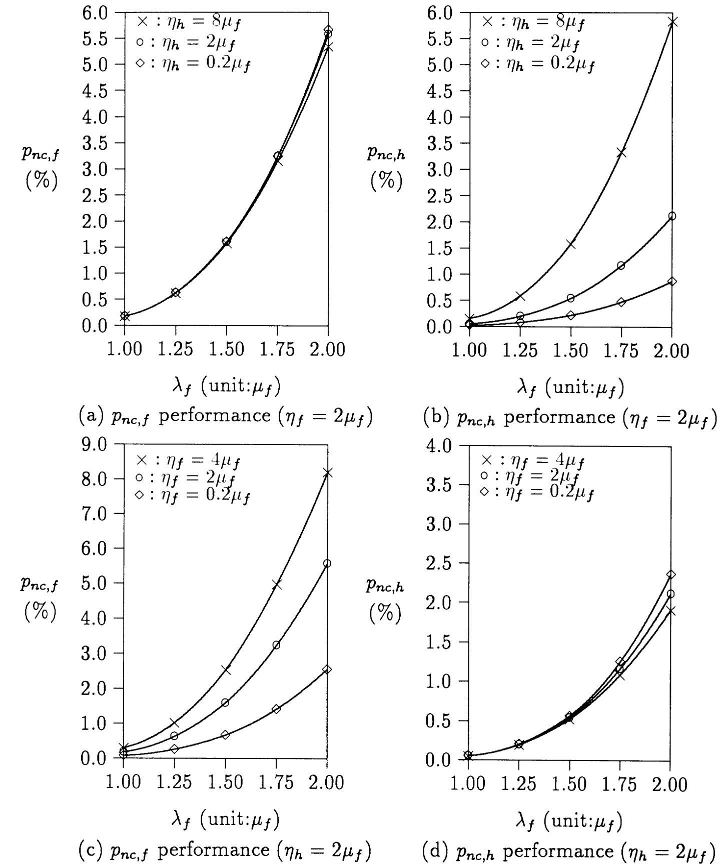

Fig. 7. Effect of MS mobilities η_f and η_h ($c = 7,\ \mu_h = \mu_f,\ \lambda_h = \lambda_f$).

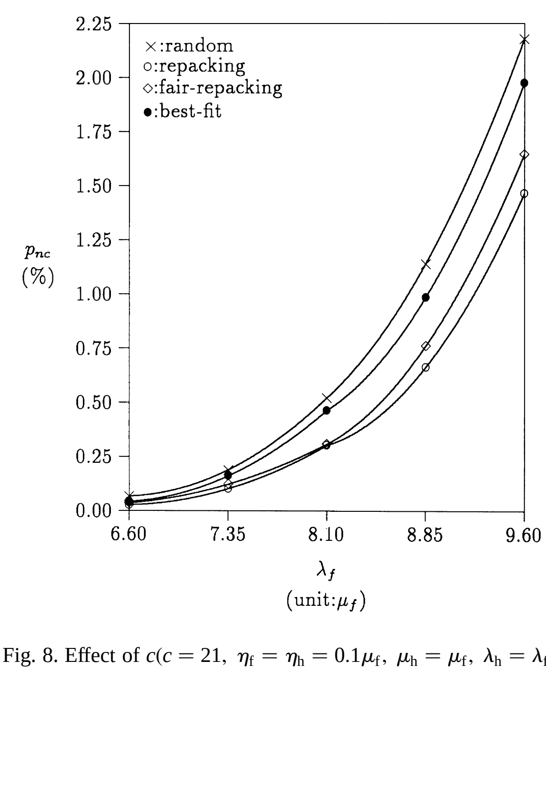

Fig. 8. Effect of c($c = 21,\ \eta_f = \eta_h = 0.1\mu_f,\ \mu_h = \mu_f,\ \lambda_h = \lambda_f$).

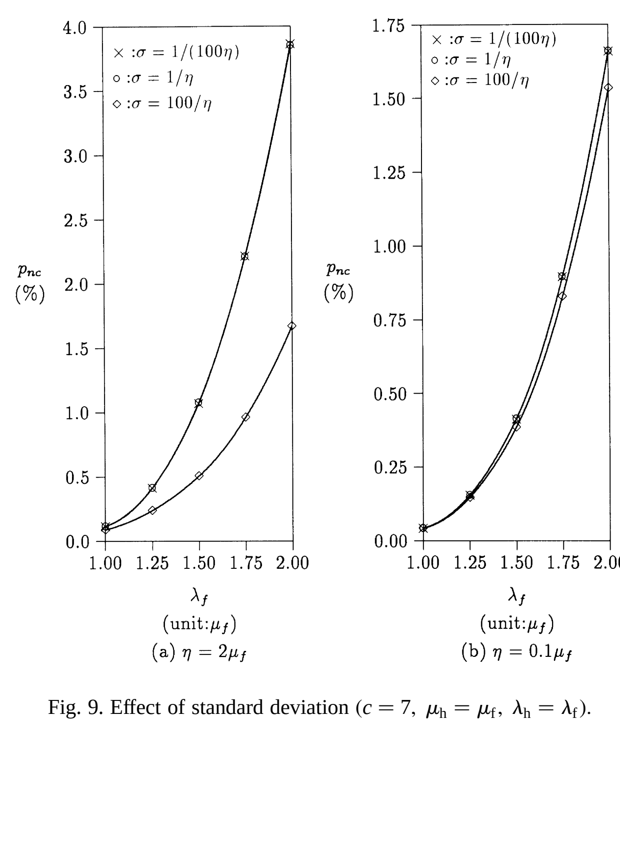

Fig. 9. Effect of standard deviation ($c = 7,\ \mu_h = \mu_f,\ \lambda_h = \lambda_f$).

significant effects on $p_{nc,f}$ ($p_{nc,h}$), but only has insignificant effects on $p_{nc,h}$ ($p_{nc,f}$) for the half-rate (full-rate) calls.

5.4. Effect of c

Fig. 8 plots p_{nc} as a function of λ_f, where $\lambda_f = \lambda_h$, $\mu_h = \mu_f$, $\eta_f = \eta_h = 0.1\mu_f$ and $c = 21$. In both Figs. 5(b) and 8, the offered loads to a GSM cell are selected such that p_{nc} is bounded by 2.25%. From Fig. 8, we observe that with large c, p_{nc} performance from the best to the worst is in the following order: repacking, fair-repacking, best-fit and random. This order is different from that with small c as shown in Fig. 5(b).

When $c = 21$, the repacking scheme results in larger improvement over the best-fit and random schemes. For example, when $\lambda_f = \lambda_h = 9.6\mu_f$, the repacking scheme results in 25.8% improvement over the best-fit scheme and 32.7% improvement over the random scheme. As c increases, fair-repacking behaves more like the repacking scheme. That is, it becomes "less fair" and has much better p_{nc} performance.

5.5. Effect of standard deviation of the cell residence time

In Fig. 9, we use the same Gamma cell residence time distributions [12,13] for both full-rate and half-rate MSs. We assume that the Gamma distribution has the mean value $1/\eta$, the standard deviation $\sigma = (1/(\eta\sqrt{\alpha}))$, where α is the shape parameter for MS cell residence times. Fig. 9 shows the effect of σ on the p_{nc} performance for repacking, where $\lambda_f = \lambda_h$, $\mu_h = \mu_f$, and $c = 7$. Fig. 9(a) plots p_{nc} as a function of with high MS mobility ($\eta = 2\mu_f$). This figure indicates that if it is sufficiently small (i.e. $\sigma \le 1/\eta$), then p_{nc} is not sensitive to the change of σ. On the other hand, for $\sigma > 1/\eta$, p_{nc} decreases as σ increases. Fig. 9(b) plots p_{nc} with low MS mobility ($\eta = 0.1\mu_f$). This figure indicates results similar to that in Fig. 9(a) except that the effect is not as significant. We conclude that high MS mobility with large variation (standard deviation) has significant effect on p_{nc} compared with low MS mobility with large variation.

6. Conclusion

We proposed analytical and simulation models to investigate GSM channel assignment performance for half-rate and full-rate traffic. The channel assignment schemes under evaluation are random, best-fit, repacking and fair-repacking. Our study indicated that the repacking scheme can significantly improve the p_{nc} performance over the other three schemes (about 20% improvements are observed). The probability p_{nc} increases when the proportion of full-rate call traffic increases. We also observed that changing η_f (η_h) has significant effect on $p_{nc,f}$ ($p_{nc,h}$), and only has insignificant effect on $p_{nc,h}$ ($p_{nc,f}$) in the repacking scheme. Furthermore, good p_{nc} performance is expected when the variation (standard deviation) of the MS residence time is large.

Acknowledgements

P.L.'s work was supported in part by National Science Council, Contract No. NSC88-2213-E009-079.

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