Performance of Mobile Prepaid and Priority Call Services

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***Abstract*—In this letter, we conduct simulation experiments to study a mobile phone system that provides priority and prepaid call services using service nodes. An analytical model for the nonprepaid and prepaid services has been developed to verify the computer simulations. We observe that there exists a threshold point such that beyond this point, increasing the number of mobile switching center ports (service node ports or the radio channels) does not improve the system performance. Furthermore, our results show that priority assignment schemes may significantly affect the operator's revenue.**

***Index Terms*—Prepaid call, priority call, service node.**

I. Introduction

RECENTLY, the prepaid service has grown rapidly in mobile phone service business [7]. Four billing technologies have been used in mobile prepaid service: hot billing approach, service node approach, intelligent network approach, and handset-based approach. We have studied performance of the hot billing approach in [1] and the service node approach in [2]. Since the service node is widely deployed today, we use it as the platform for prepaid services. The architecture of the service node approach is depicted in Fig. 1. In this architecture, a service node (SN) is connected to a mobile switching center (MSC) using high-speed T1/E1 trunks and the MSC is connected to base stations (BSs). Each BS communicates with mobile stations through radio channels.

Two types of calls (i.e., nonprepaid calls and prepaid calls) exist in the network. For each originating prepaid call, the MSC routes the call to the service node for call processing. After the service node performs service control functions (e.g., checking the credit), the prepaid call is routed back to the MSC and then to the called party. Thus, to set up a prepaid call, it requires one radio channel, four MSC ports, and two SN ports. On the other hand, for a nonprepaid new call, the MSC directly routes the call to its destination. Hence, it requires one radio channel and two MSC ports to set up a nonprepaid call.

When a mobile initiates a call and the resources are insufficient, the call is blocked. Many priority solutions based on the queueing schemes have been proposed to reduce the call blocking and incompletion rates [3], [8]. We assume that the readers are familiar with the terms such as new call blocking, forced-termination and call incompletion probability. Details of these terms can be found in [6]. In the queueing schemes, when the resources are not enough, a priority call is placed in a queue until the resources are sufficient. On the other hand, a call request issued by a mobile without the priority service is blocked if the resources are insufficient. We have studied the priority call service in [8]. In this letter, a timer is also set when a priority call is placed in the queue. The buffered request must be served before the timer expires and before the mobile leaves the cell. Otherwise, the call is dropped. Based on the above model, we investigate the performance of an integrated service that combines prepaid call and priority call services.

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II. An Analytic Model

In this section we use the analytical technique developed in [5] to study the performance of prepaid and nonprepaid call services. This technique uses an iterative algorithm where the Kelly model [4] is utilized in each iteration to compute the blocking probabilities. Since the Kelly model does not consider the queueing effect of the priority calls, the results of numeric analysis were used only to verify the correctness of computer simulations that support both prepaid and priority services.

Assume that the MSC connects to k BS's. BS i is equipped with c_i radio channels for communication. Let the number of ports of the MSC and the SN be $2 \times C_{MSC}$ and $2 \times C_{\mathrm{SN}}$, respectively. The call arrivals to BS i are assumed to be Poisson with rate $\lambda_{o1,i}$ for nonprepaid new calls and with rate $\lambda_{o2,i}$ for prepaid new calls. The assumption is experimental fact for voice service in cellular networks. The call holding times of both nonprepaid and prepaid calls are assumed to be exponentially distributed with mean $1/\mu$. Assume that the cell residence time of a mobile station has a general distribution with mean $1/\eta$.

In the Kelly model, a route is a fixed path that accepts some calls in progress. Assume that $\Re$ denotes the set of all routes. Let $r_{1,i}$ and $r_{2,i}$ ($1 \le i \le k$) denote the route of nonprepaid and prepaid calls served by BS i, respectively. Let $\mathbf{n} = [n_{r_{1,1}}, n_{r_{1,2}}, \ldots, n_{r_{1,k}}, n_{r_{2,1}}, n_{r_{2,2}}, \ldots, n_{r_{2,k}}]$ be a $|\Re| \times 1$ matrix, where $n_{r_{1,i}}$ ($n_{r_{2,i}}$) is the number of nonprepaid (prepaid) calls in progress on the route $r_{1,i}$ ($r_{2,i}$), $\forall\, r_{1,i}$ ($r_{2,i}$) $\in \Re$. Therefore, vector $\mathbf{n}$ denotes the state of a stochastic process on the network. Since the total amount of resources used by the outstanding calls should be no more than the capacities of the routes, a legal state in the state space S must satisfy the following inequalities:

$$n_{r_{1,i}} + n_{r_{2,i}} \le c_i, \qquad \text{for } 1 \le i \le k$$

$$\sum_{i=1}^{k} n_{r_{1,i}} + 2\sum_{i=1}^{k} n_{r_{2,i}} \le C_{\mathrm{MSC}} \sum_{i=1}^{k} n_{r_{2,i}} \le C_{\mathrm{SN}}.$$

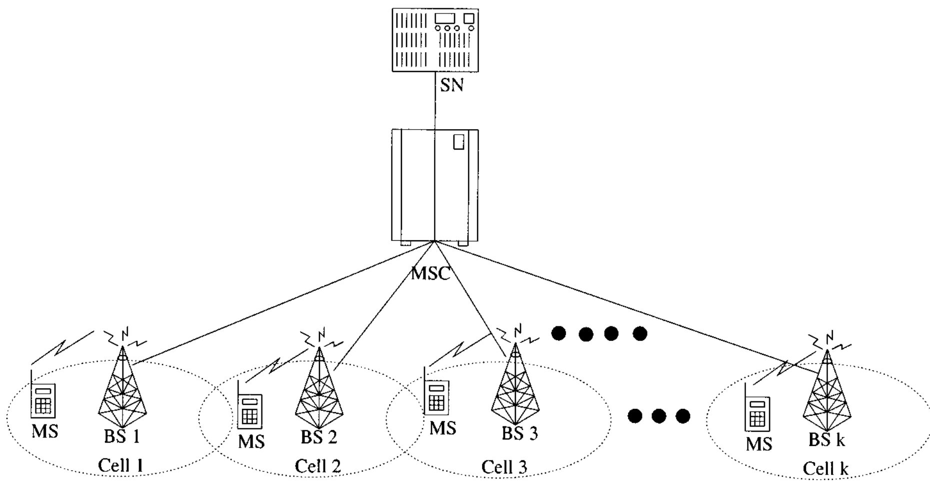

Fig. 1. The architecture of the service node approach.

Let $\rho_{1,i}$ and $\rho_{2,i}$ be the offered load on the route $r_{1,i}$ and $r_{2,i}$, respectively. Let $P_{o,1}(i)$ be the new call blocking probability of nonprepaid calls in BS i and $P_{o,2}(i)$ be that of prepaid calls in BS i. Let $P_{f,1}(i)$ and $P_{f,2}(i)$ denote the forced-termination probability of nonprepaid and prepaid calls in BS i, respectively. From the offered load equation in [6], $\rho_{1,i}$ and $\rho_{2,i}$ can be expressed as

$$\rho_{1,i} = \left(\frac{\lambda_{o1,i}}{\mu+\eta}\right)\left[1+\frac{\eta(1-P_{o,1}(i))}{\mu+\eta P_{f,1}(i)}\right], \quad \text{for } 1 \le i \le k$$
$$\rho_{2,i} = \left(\frac{\lambda_{o2,i}}{\mu+\eta}\right)\left[1+\frac{\eta(1-P_{o,2}(i))}{\mu+\eta P_{f,2}(i)}\right], \quad \text{for } 1 \le i \le k. \quad (1)$$

According to the Kelly model, the stationary probability of the state$\mathbf{n}$ can be computed as

$$p(\mathbf{n}) = G^{-1}\left[\prod_{i=1}^{k}\frac{\rho_{1,i}^{n_{r_{1,i}}}}{(n_{r_{1,i}})!}\right]\left[\prod_{i=1}^{k}\frac{\rho_{2,i}^{n_{r_{2,i}}}}{(n_{r_{2,i}})!}\right] \quad (2)$$

where G is a normalization factor to ensure that $\sum_{\mathbf{n}\in S} p(\mathbf{n}) = 1$. Let S_2^i denote the state space where a prepaid new call is blocked in BS i. A prepaid new call is blocked if either no radio channel is available or the capacity of the MSC/SN is insufficient. A state $\mathbf{n} \in S_2^i$ if $\mathbf{n}$ satisfies one of the following equations or inequality:

$$n_{r_{1,i}} + n_{r_{2,i}} = c_i$$
$$C_{\mathrm{MSC}} - 2 < \sum_{i=1}^{k} n_{r_{1,i}} + 2\sum_{i=1}^{k} n_{r_{2,i}} \le C_{\mathrm{MSC}}$$
$$\sum_{i=1}^{k} n_{r_{2,i}} = C_{\mathrm{SN}}. \quad (3)$$

From (3), we have

$$P_{o,2}(i) = \sum_{\forall \mathbf{n}\in S_2^i} p(\mathbf{n}). \quad (4)$$

$P_{o,1}(i)$, $P_{f,1}(i)$ and $P_{f,2}(i)$ can also be derived with similar equations and inequalities describing the resource constraints.

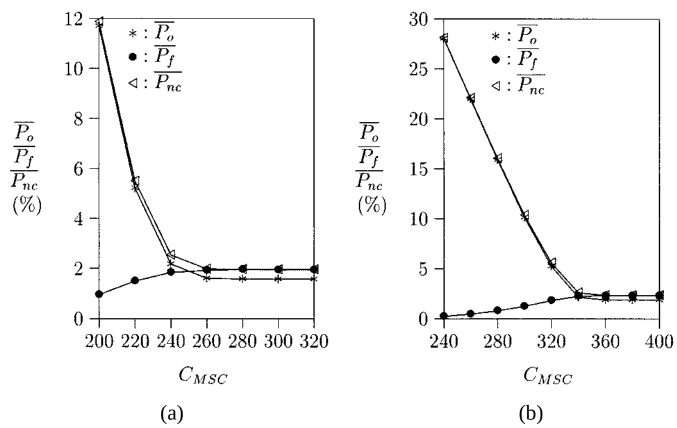

Fig. 2. Effects of C_{MSC} for various d ($k = 36$, $c = 10$, $\lambda_o = 5\mu$, $\mu = 1\ \mathrm{min}^{-1}$, $\eta = \mu/5$, $C_{\mathrm{SN}} = 150$ and $T_\theta = 30$ s). (a) $d = 20\%$. (b) $d = 80\%$.

Let $P_{nc,1}(i)$ and $P_{nc,2}(i)$ be the call incompletion probability of nonprepaid and prepaid calls, respectively. From [6, eq. (14)],$P_{nc,1}(i)$ and $P_{nc,2}(i)$ can be expressed as

$$P_{nc,1}(i) = P_{o,1}(i) + \frac{\eta(1-P_{o,1}(i))[1-f_1^*(\mu)]P_{f,1}(i)}{\mu[1-f_1^*(\mu)+P_{f,1}(i)f_1^*(\mu)]}$$
$$P_{nc,2}(i) = P_{o,2}(i) + \frac{\eta(1-P_{o,2}(i))[1-f_1^*(\mu)]P_{f,2}(i)}{\mu[1-f_1^*(\mu)+P_{f,2}(i)f_1^*(\mu)]} \quad (5)$$

where $f_1^*(\mu)$ is the Laplace transform of the density function of the residence time.

The values of c_i and k determine the scale and the configuration of a PCS network. We consider a homogeneous network where $c_i = c$, $\lambda_{o1,i} = \lambda_{o1}$, $\lambda_{o2,i} = \lambda_{o2}$, $\rho_{1,i} = \rho_1$ and $\rho_{2,i} = \rho_2$, for $1 \le i \le k$. The homogeneous network model is a good approximation for a large-scale network. In this case, the blocking probabilities, forced-termination probabilities and call incompletion probabilities for all BS's are the same. We use the notations $P_{o1} = P_{o,1}(i)$, $P_{o2} = P_{o,2}(i)$, $P_{f1} = P_{f,1}(i)$, $P_{f2} = P_{f,2}(i)$, $P_{nc1} = P_{nc,1}(i)$ and $P_{nc2} = P_{nc,2}(i)$, for $1 \le i \le k$. The values of P_{o1}, P_{o2}, P_{f1}, P_{f2}, P_{nc1} and P_{nc2}, can be computed by using the iterative algorithm in [6] with (4) and (5) until all values of blocking probabilities converge.

III. Numeric Results

Based on the analytical model described in Section II, we have validated our simulation model. Each simulation experiment was repeated 4 000 000 times to ensure stable results. In this section, we present the simulation results on the performance of prepaid and priority call services. We assume that a priority call can wait in the queue for T_θ seconds. The queued call can be served if the resources are sufficient before the waiting timer expires and before the mobile leaves the cell.

A. Effect of the Number of MSC Ports

In this subsection, we consider the case where only the prepaid new calls are given priority services. Let λ_o be the total new call arrival rate of prepaid and nonprepaid calls. Let d be the ratio of the new call arrival rate of prepaid calls over that of total new calls (i.e., $d = \lambda_{o2}/\lambda_o$). Let $\overline{P_o} = (1-d)P_{o1} + dP_{o2}$, $\overline{P_f} = (1-d)P_{f1} + dP_{f2}$ and $\overline{P_{nc}} = (1-d)P_{nc1} + dP_{nc2}$. Probabilities $\overline{P_o}$, $\overline{P_f}$ and $\overline{P_{nc}}$ provide the net effect of the output measures for both nonprepaid and prepaid calls.

Fig. 2 plots $\overline{P_o}$, $\overline{P_f}$ and $\overline{P_{nc}}$ as functions of C_{MSC}, where $k = 36$ and $c = 10$. The values of c and k are chosen to capture the behavior of a system without incurring high overheads associated with large simulations. Intuition suggests that as C_{MSC} increases, the probability that a new call is blocked decreases and $\overline{P_o}$ decreases. In addition, since the number of accepted new calls increases, the number of available channels decreases and $\overline{P_f}$ increases. Fig. 2 also shows that there exists a threshold point C^*_{MSC} such that beyond this point, increasing C_{MSC} does not improve the system performance. The value of C^*_{MSC} shifts from 260 to 340 for $d = 20\%$ (i.e., less prepaid calls) to 80% (i.e., prepaid calls dominate).

Our results indicate that an improper expansion of the MSC capacity may not improve the system performance. Similar phenomenon can also be observed in the effect of increasing the number of SN ports and the radio channels.

B. A Revenue Function C

In this subsection, we propose an output measurement C that computes the total charge of the nonprepaid and prepaid calls. Two priority assignment schemes are compared: scheme PP where the prepaid new calls have priority, because they are charged at a higher rate than the nonprepaid new calls; scheme NP where the nonprepaid new calls have priority, since they consume less resources than the prepaid new calls.

Let $C = (1-d)[(1-P_{nc1})T_{c1} + \sigma P_{i1}T_{i1}] + \alpha d[(1-P_{nc2})T_{c2} + \sigma P_{i2}T_{i2}]$, where T_{c1} (T_{c2}) is the expected holding time of a complete nonprepaid (prepaid) call, σ ($0 \le \sigma \le 1$) is the discount factor for an incomplete call, P_{i1} (P_{i2}) is the probability that a nonprepaid (prepaid) call is connected but is eventually forced to terminate, T_{i1} (T_{i2}) is the expected holding time of an incomplete nonprepaid (prepaid) call and α is the normalized charge of a prepaid call. According to a report of FarEastone (a mobile company in Taiwan, R.O.C.) in 1999, $d \approx 40\%$ and $\alpha \approx 2$. Fig. 3 plots C as a function of α under the two priority assignment schemes. It is clear that if the charge of a prepaid call is much higher than that of a nonprepaid call (e.g., $\alpha \ge 2$), scheme PP provides higher revenue than scheme NP. On the other hand, the scheme should be selected to favor the calls that have higher traffic ratio. From Fig. 3, we observe that scheme NP is better than scheme PP for $d = 0.1$, and for $d = 0.2$ when $\alpha < 2$. We conclude that both d and α have significant effect on the choice of priority assignment schemes.

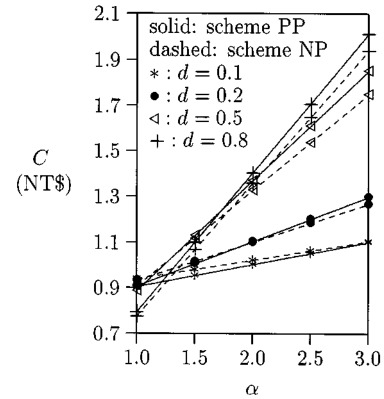

Fig. 3. Effect of α ($k = 36$, $c = 10$, $\lambda_o = 7\mu$, $\mu = 1\ \text{min}^{-1}$, $\eta = \mu/5$, $C_{\text{MSC}} = 360$, $C_{\text{SN}} = 150$, $T_\theta = 30$ secs and $\sigma = 0.5$).

IV. Conclusions

In this letter, we studied a mobile phone system that provides priority and prepaid call services based on the service node approach. We observed that there exists a threshold point such that beyond this point, increasing the number of mobile switching center ports does not improve system performance. Similar phenomenon can also be observed in the effect of increasing the number of service node ports and the radio channels. Finally, we propose a revenue function that can be used as a guideline to select the priority assignment scheme.

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