Total Resource Requirements-Based Priority Queuing Scheme for DS/CDMA Cellular Networks

Shiquan Piao, Jaewon Park, and Yongwan Park

ABSTRACT—We propose and analyze a priority queuing scheme that gives priority in the same class of calls according to their total resource requirements (TRRs). The proposed scheme gives a higher priority to the calls that have a lower TRR over the calls that have a higher TRR. The numerical results show that the proposed priority queuing scheme provides better performance than the traditional queuing schemes in call blocking probability.

Keywords—CAC, DS/CDMA, total resource requirements, priority.

I. Introduction

Guaranteeing quality-of-service (QoS) and increasing resource utilization (or capacity) are the two key issues for CDMA systems. The call admission control scheme is essential to increase the system grade of service while guaranteeing that these calls meet their QoS requirements.

Priority queuing schemes for handoff calls are proposed in [1], where the handoff calls are not blocked immediately when no free channel is met, but are temporarily queued in the buffer until one channel is free for the queued call. This scheme significantly reduces the forced termination probability compared with the non priority scheme. The priority assignment for different classes of traffic is also proposed [2]. A priority mechanism is applied between different class calls as well as handoff calls and new calls. These priority schemes assign different priorities according to the requirements of the channels, QoS, grade of service, and so on. They can also be implemented on CDMA cellular networks. In addition, some important parameters were studied in previous works to precisely indicate the resource utilization, such as the signal-to-interference ratio (SIR) or interference [3], [4]. However, these existing priority mechanisms cannot provide priority in the same class of calls according to these existing parameters. In CDMA networks, although the resource requirements of one user in a home cell are the same if the class is the same, the total resource requirements (TRRs) in the networks is different. Thus, a TRR-based priority queuing scheme is proposed in this letter. The proposed scheme further classifies the same class of calls into low TRR calls and high TRR calls in order to provide the different priorities. For simplifying the analysis, we classified the same class of calls into low and high TRR calls, although they can be further classified into low TRR & new calls, low TRR & handoff calls, high TRR & new calls, and high TRR & handoff calls.

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Shiquan Piao (phone: +82 53 810 3942, email: psq0213@yahoo.co.kr), Jaewon Park (email: dolbird@yu.ac.kr), and Yongwan Park (email: ywpark@yu.ac.kr) are with the Department of Information & Communication, Yeungnam University, Gyeongsan, Gyeongbuk, Korea.

II. TRR-Based Priority Queuing Scheme

1. Total Resource Requirements

In FDMA/TDMA cellular networks, the same class of calls occupies the same amount of resources, that is, every voice call may occupy one channel in its home cell for communication, and every data call may occupy channels over one voice call in its home cell. However, the same class of calls in CDMA cellular networks not only requires the same amount of resources (received power in the home cell from the users) in the home cell, but also requires some different resources (interference in adjacent cells from the users) in the adjacent cells to decrease the efficient capacity of these cells [5]. We refer to the resources required by one user both in a home cell and adjacent cells in CDMA networks as total resource requirements.

The generally accepted radio propagation model is a path

loss with log-normal shadowing in direct sequence (DS)-CDMA cellular networks. Assuming the distance between a mobile and a base station (BS) is r, then the propagation between the mobile and the base station can be described as in [6] as

$$\Gamma(r) = 10^{\xi/10} r^{-a}, \quad (1)$$

where ξ is a normal or Gaussian random variable with zero mean and standard deviation σ, and the ranges are between 5 to 12 dB with a typical value of 8 dB. The typical value of α is 2.7 to 4.0 in cellular networks. Thus, BS k receiving power from user j, who is served by BS I, can be described as

$$P^r_{ij,k} = P^t_{ij} \cdot \left(10^{\xi_{ij,k}/10} \cdot r^{-a}_{ij,k}\right), \quad (2)$$

where $r_{ij,k}$ and $10^{\xi_{ij,k}}$ are the distance and shadowing between the BS of adjacent cell k and user j of home cell i, respectively. Thus, the required resource for user j in the home cell and all adjacent cells can be described as

$$P^r_{ij,i} = P^t_{ij} \cdot \left(10^{\xi_{ij,i}/10} \cdot r^{-a}_{ij,i}\right) \text{ and} \quad (3)$$

$$P^r_{ij,\Lambda} = \sum_{k\in\Lambda} P^t_{ij} \cdot \left(10^{\xi_{ij,k}/10} \cdot r^{-a}_{ij,k}\right), \quad (4)$$

where Λ is the set of adjacent cells and $P^r_{ij,\Lambda}$ is the sum of every adjacent cell receiving power from user j of cell i. The transmission power P^t_{ij} of a different user is different, but the received power in the home cell from any user $P^r_{ij,i}$ is the same due to the power control mechanism used; thus, $P^r_{ij,i}$ can be normalized as 1. Therefore, Φ_{ij}, the TRR of the j-th user of cell I, can be rewritten as

$$\Phi_{ij} = \left(1 + \sum_{k\in\Lambda} \frac{10^{\xi_{ij,k}/10} r^{-a}_{ij,k}}{10^{\xi_{ij,i}/10} r^{-a}_{ij,i}}\right). \quad (5)$$

It is clear that the TRR Φ_{ij} is defined by the position of the call in its home cell and shadowing effect. Thus, we rewrite the TRR as a function of (r, α, σ) and remove the lower notation ij to simplify it as $\Phi(r, \alpha, \sigma)$, where r is the distance between a call and home cell. Its expectation can be described as in [7] as

$$E(\Phi(r,a,\sigma)) = 1 + \sum_{k\in\Lambda} \left(\frac{r_k(r)}{r}\right)^{-a} e^{\beta^2\sigma^2}. \quad (6)$$

The expectation of the TRR for different (r, α, σ) is depicted in Fig 1, where R is a cell radius. It shows that the TRR of a call is very different for different distance and shadowing deviations, even if these calls are in the same class and require the same amount of resources in the home cells. The results shown in Fig.1 give us the motivation to design a priority

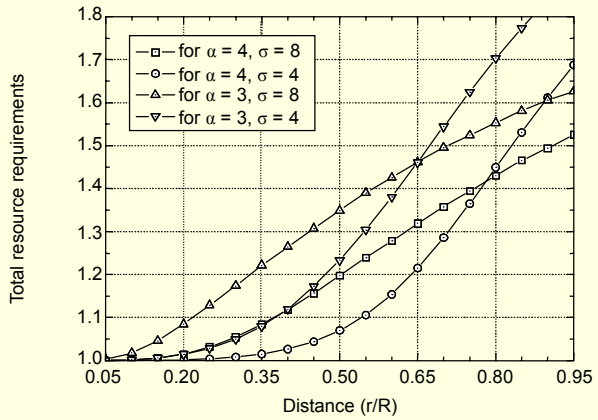


Fig. 1. Total resource requirements for different parameter sets.

queuing scheme: in CDMA networks, for the same class of calls, disregarding whether they are new calls or handoff calls, the calls can be further classified into different groups to assign different priorities according to the TRR, for example, they could be classified as high TRR calls and low TRR calls.

The mobile required resource in neighboring cell i can be obtained by the BS transmitted pilot signal and the mobile received pilot signal both in neighboring cell i and the home cell as in [8] as

$$\Phi_i = \frac{10^{\xi_i/10} r_i^{-a}}{10^{\xi_h/10} r_h^{-a}} = \frac{p_m(i)/P(i)}{p_m(h)/P(h)}, \quad (7)$$

where $p_m(i)$ and $p_m(h)$ are the mobile received pilot signals from the BS of cell i and the home BS, respectively, and $P(i)$ and $P(h)$ are the transmitted pilot signals of the BS of cell i and the home BS, respectively.

2. System Model and TRR-Based Priority Scheme

In this section, we provide a brief description of the assumed system model. A new call arrives according to the Poison probability, and its channel holding time is exponentially distributed. User mobility is not considered and handoff calls are not modeled. A newly arrived call must find the service channel in the networks first. If the current signal-to-noise ratio can't satisfy the requirements, or if there isn't any available spreading code, the new call is temporarily queued in the buffer. If the buffer is also full, the new call will be blocked.

In the non-queuing system, the SIR or interference-based call admission scheme is suitable to CDMA networks [3]. In the queuing system, only a first-in-first-out (FIFO) queuing scheme can be applied for same class calls in previous works [1]. However, as mentioned in section II, the same class calls also could be further classified as high TRR users and low

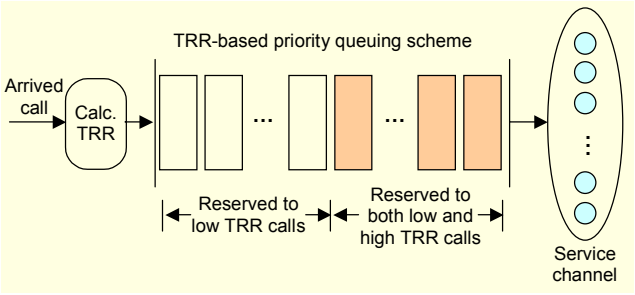


Fig. 2. TRR-based queuing scheme.

TRR users in CDMA networks. Thus, this letter proposes a priority queuing scheme in the same class calls based on the TRR. The proposed TRR-based priority queuing scheme is described in Fig 2, where the total C_Q queuing buffer is assumed. The proposed priority assignment scheme can be described as follows: The buffer is partitioned into two parts to provide a priority between high TRR users and low TRR users. If the occupied buffer is smaller than the predefined number of buffer C_k, both high TRR users and low TRR users could be queued in the buffer. Otherwise, only low TRR users are queued in the buffer. Although high TRR users may suffer more blocking probability than low TRR users in such treatment, it still is a desirable priority scheme if it can efficiently increase the system capacity.

3. Performance Analysis

In this letter, a modified queuing model taking into account the CDMA soft capacity is used to analyze the queuing scheme for CDMA cellular networks. We use (i, j) to denote the system state, where i denotes the number of service calls and j denotes the number of queued calls in the buffer. A system state transition from (i, j) to $(i+1, j)$ or $(i-1, j)$ is not considered. We assume that if a call is ended, total interference in the home cell of the ended call is immediately reduced. Thus, if there are buffered users, one of the buffered users can be immediately accepted by the system, that is, if a call is ended, only the system state is changed from (i, j) to $(i, j-1)$. Meanwhile, since our priority scheme is proposed for the same class calls, just one class of calls is considered to simplify the analysis. If there are two or more service classes, the proposed scheme can also be implemented within each class.

The call blocking probability, where there are i active service calls, can be obtained as in [7] as

$$p_{blo}(i) = Q\left[\frac{A(\eta_{blo} - E(Z',i))}{\sqrt{Var(Z',i)}}\right], \tag{8}$$

where

$$A(\eta_{blo}) = \frac{(W/R)(1-\eta_{blo})}{\exp(\beta m)},$$

$$E(Z',i) = i\rho(1+f)\exp\left[(\beta\sigma)^2/2\right],$$

$$Var(Z',i) = i\rho(1+f)\left\{\exp\left[(\beta\sigma)^2/2\right] - \exp\left[(\beta\sigma)^2\right]\right\},$$

where ρ is the voice activity, σ is the standard deviation of Eb/No, f is the other cell interference fraction, and η_{blo} is a threshold of the background noise power to interference power. If the arrival rate of low TRR and high TRR users are λ_L and λ_H, respectively, and the blocking probability of low TRR and high TRR users are p_{bL} and p_{bH}, respectively, then the average ratio of the other cell interference can be described as

$$f = \frac{(\Phi_L - 1)\lambda_L(1-p_{bL}) + (\Phi_H - 1)\lambda_H(1-p_{bH})}{\lambda_L(1-p_{bL}) + \lambda_H(1-p_{bH})}, \tag{9}$$

where Φ_L and Φ_H are the average TRR of low TRR users and high TRR users, respectively. The high TRR users suffer more blocking probability than low TRR users in the TRR-based priority queuing scheme. Expression (9) shows that the interference fraction is, therefore, decreased in the proposed scheme. It will decrease the blocking probability and increase the system capacity. The state transition probability from state $(i-1, j)$ to (i, j) can be described as

$$\begin{aligned} p_{state}(i,j) &= \frac{(1-p_{blo}(i-1,j))\lambda}{i\mu} p_{state}(i-1,j) \\ &= \frac{\left[1 - Q\left(\frac{A(\eta_{blo}) - E(Z',i)}{\sqrt{Var(Z',i)}}\right)\right]\lambda}{i\mu} p_{state}(i-1,j). \end{aligned} \tag{10}$$

The total summation of the system state probability must be equal to 1:

$$\sum_{i=0}^{M}\sum_{j=0}^{C_Q} p_{state}(i,j) = 1, \tag{11}$$

where M is the number of spreading codes. Total system state $p_{state}(i, j)$ can be derived from (10) and (11).

The performances of the low TRR and high TRR call blocking probabilities and the overall call blocking probability can be obtained according to the system state as follows:

$$p_{bL} = \sum_{i=0}^{M}\sum_{j=C_Q}^{C_Q} p_{state}(i,j), \tag{12}$$

$$p_{bH} = \sum_{i=0}^{M} \sum_{j=C_k}^{C_Q} p_{state}(i,j), \quad (13)$$

$$p_{bT} = \frac{\lambda_L p_{bL} + \lambda_H p_{bH}}{\lambda_L + \lambda_H}. \quad (14)$$

III. Numerical Results

Parameters Φ_L=1.2, Φ_H=1.9, and $\lambda_L = \lambda_H$ are assumed for the numerical evaluation. The proposed TRR-based queuing scheme is compared with the FIFO queuing scheme and the non queuing interference-based call admission control scheme. It shows that queuing schemes are better than a nonqueuing scheme in the performance of the call blocking probability. If the offered load is low, the proposed TRR-based queuing scheme cannot achieve performance gain over the FIFO queuing scheme. But, when the offered load is increased, the performance gain of the proposed TRR-based scheme over the FIFO queuing scheme is increased. For example, the performance gain of the TRR-based queuing scheme over the FIFO scheme in the offered load of 10 Erlang is 28.4%, but in the offered load of 15 Erlang, the performance gain is increased to 41.1%. The uses of $\lambda_L = 3\lambda_H$ are also provided to evaluate the performance of the proposed algorithm versus the ratio of the arrival rate of the low TRR and high TRR users.

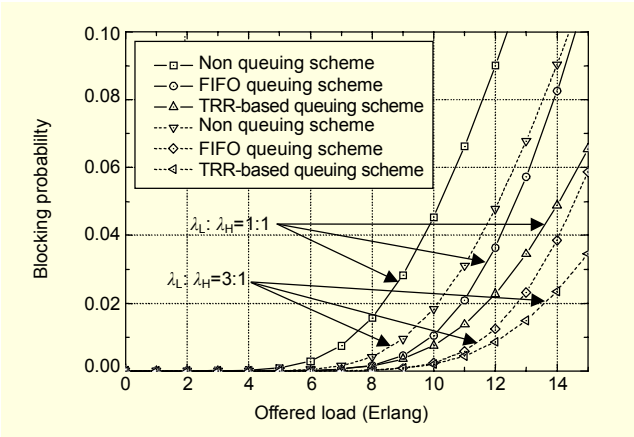


Fig. 3. Performance of the blocking probability as the offered load.

IV. Conclusion

In this letter, we have proposed and analyzed a TRR-based priority queuing scheme. The priority is made by measuring the TRR of the calls; the TRR of calls is decided by the propagation environment of each call and can be detected by a pilot signal in the CDMA system. If there are enough free buffers, the systems will queue all calls. Otherwise, the system will queue only low TRR calls. Thus, the scheme gives priority to the calls that have a better propagation environment. The performance is evaluated by the call blocking rate. An analytical model is provided for the performance evaluation. The numerical results show that the proposed scheme outperforms the FIFO queuing scheme and nonqueuing scheme.

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