Service Degradation and Compensation for Multiclass Traffic in Wireless Networks*

Dan Liao Lemin Li
School of Communication and Information Engineering
University of Electronic Science and Technology of China
E-mail: {liaodan,lml}@uestc.edu.cn

Bo Li
Dept. of Computer Science
Hong Kong University of Science and Technology
E-mail: bli@cs.ust.hk

Abstract**—The wireless networks need to support a wide range of applications with limited radio resources such as bandwidth. Some applications , such as multimedia applications, can be served with varied bandwidth. To increase the total carried traffic in an overloaded wireless system, some of the ongoing connections can operate under the degraded model with lower quality-of-service (QoS). To satisfy the user QoS, we should compensate the connections degraded. In this paper, we propose a new call admission control (CAC) scheme that has service degradation and service compensation in CDMA cellular networks. In CAC, the service degraded low priority connections release bandwidth fairly to accommodate new connections. To decrease the drop probabilities of handoff connections, the proposed scheme gives handoff connections higher priority. To minimize the bandwidth loss of the connections, we propose the compensation model in scheduling that operates when the system has residual bandwidth. Extensive simulation results show that our scheme can operate well in CDMA cellular networks.**

I. INTRODUCTION

Since the radio spectrum belongs to very scarce resources, the resource management is one of the most important engineering issues in wireless and mobile communication systems. The performance of a system with given physical resources (e.g., given bandwidth of radio spectrum) depends heavily on the resource management schemes including the multiple access techniques, the call admission control (CAC) policies, and the congestion control schemes. Among these, we in this paper study the service degradation and compensation in wireless networks supporting multiple traffic types, and give a new scheme combining the CAC and the scheduling with service degradation and compensation in CDMA cellular networks.

Several recent studies [1, 2, 5, 6, 7] have been conducted concerning the degrading of the QoS of ongoing traffic to improve the overall system performance. In [2], the authors propose an integrated framework for bandwidth degradation and CAC for multiclass real-time multimedia traffic. The proposed framework adequately models this tradeoff by introducing the negative revenue from bandwidth degradation, and finding the optimal degradation and admission policies that maximize the net revenue. In [1], the authors propose a rate-based, degrading scheme for QoS provisioning in high-speed cellular networks carrying multimedia traffic. In case of insufficient bandwidth, in order not to deny service to requesting connections, bandwidth of existing connections will be degraded, on a temporary basis. The amount of bandwidth degraded from a connection is proportional to its tolerance to bandwidth loss. And, the scheme ensures that the degraded connections promptly return to send at the desired rate.

The schemes in [1, 2] are not suitable for CDMA cellular networks, because they suppose that the cell has fixed capacity.

In [5], the authors propose a call admission control and bandwidth degradation scheme in CDMA cellular networks. They also propose a Markov model. From the results of the Markov model the threshold for maximal connection degradation is periodically adjusted according to the currently measured traffic in the radio access network. The scheme in [5] is not suitable for multiclass traffic. It doesn't study the problem that fairly degrades bandwidth of different traffic.

In this paper, we consider the fairness of different traffic. When the wireless system is overloaded, the proposed scheme degrades the ongoing connections with the priority not higher than the one of the requesting connection. These connections degrade bandwidth according to their weights. Their weights are decided by their request QoS. To decrease the drop probabilities of the handoff connections, we give the handoff connections the higher priority. All the degradation schemes mentioned above lead to bandwidth loss of the connections, and these schemes only send the traffic data at the desired rate when the cell isn't overloaded. To minimize the bandwidth loss, in this paper, we propose the compensation model in scheduling that operates when the cell has residual bandwidth.

The paper is organized as follows. Section II introduces the admission control and bandwidth degradation scheme. In section III, we introduce the compensation model. Section IV presents a comprehensive simulation study. Finally, concluding remarks are given.

II. CAC BASED ON FAIR DEGRADATION OF MULTICLASS TRAFFIC

*National Natural Science Foundation of China(NSFC) and Research Grants Council(RGC) of Hong Kong Joint Research (NO. 60218002)

2.1. General description

In CDMA systems, blocking will be defined to occur when the interference level, due primarily to other user activity, reaches a predetermined level above the background noise level of mainly thermal origin. While this interference-to-noise ratio could, in principle, be made arbitrarily large, when the ratio exceeds a given level (about 10dB normally), the interference increase per additional user grows very rapidly, yielding diminishing returns and potentially leading to instability. Consequently, we shall establish blocking in CDMA as the event that the total interference-to-background noise level exceeds $1/\eta = 10$ (where $\eta = 0.1$ corresponding to 10dB)[4].

In this paper, it's assumed that perfect power control is applied so that all connections have the request signal-to-interference ratio (SIR) and there only is intra-cell interference. Assume that all connections in class k have the same request bit energy-to-interference density ratio $E_k^b / I_0 = \gamma_k^0$ and each user connection in class k is gated on with probability a_k and off with $1 - a_k$.

From [4], it can be derived that the admission controller accommodates a connection when the equation (1) is satisfied.

$$\sum_{k=1}^{N} \alpha_k \gamma_k^0 \sum_{j=1}^{M_k} R_{k,j} \le W(1-\eta) \quad (1)$$

Where $R_{k,j}$ is the transmission bit rate of connection j in class k, M_k is the number of ongoing connections in class k including the requesting connection and N is a total number of service classes in a CDMA cellular network. Let W denote the spread-spectrum bandwidth in the cell.

We consider a CDMA cellular network with a total number, N, of service classes. Each class represents a number of connections that are either from the same MS (mobile station)or distributed among different MSs. Connections that belong to the same service class are assumed to have the same QoS requirements. At setup time, each connection specifies to the cell in which it originates a maximum transmission bit rate $MAXR$ (called the desired bandwidth) and a minimum transmission bit rate $MINR$. The $MAXR$ is the desired bandwidth of the connection. If there is enough bandwidth, the connection should be sent at that rate. The $MINR$ is the minimum rate the connection can tolerance. Some traffic can't be degraded. They have the same $MAXR$ and $MINR$. We call them non-adaptive traffic. The traffic which can be degraded are called adaptive traffic.

2.2. CAC Based on Fair Degradation

This section describes the proposed admission control and bandwidth degradation scheme. Before a mobile user can start a new connection, an admission controller decides to accept or reject the user's request. When the cell is overloaded, we degrade the ongoing connections to accommodate more new connections. Because of more and more new applications in the CDMA cellular networks, the networks need to provide multiple service classes. Therefore, the proposed admission controller distinguishes multiclass traffic. The proposed scheme thinks about the fairness of the degradation of different traffic.

Assume that all connections in class k have the same maximum transmission bit rate $MAXR_k$, minimum transmission bit rate $MINR_k$. When a connection requests, the proposed scheme operates as follows:

1) When $R_{k,j} = MAXR_k$, if the equation (1) is satisfied, the connection is accommodated, and all the connections' transmission bit rate is $MAXR_k$, otherwise the scheme run step 2.

2) When $R_{k,j} = MINR_k$, if the equation (1) is satisfied, the scheme degrades the adaptive traffic class connections whose priority isn't higher than the priority of the requesting connection to accommodate the requesting connection. The transmission bit rate of connections, which aren't degraded, is $MAXR_k$, and the rate of degraded connections can be calculated according to equation (4). Otherwise it is rejected.

When the ongoing connections are degraded to accommodate the requesting connection, fairness of the scheme must be thought about. Let PRI_k denote the priority of the connections of adaptive traffic class k, and PRI denote priority of the requesting connection.. Let A_1 be the set of the adaptive traffic classes whose $PRI_k <= PRI$, A_2 be the set of the adaptive traffic classes whose $PRI_k > PRI$ and B be the set of all the non-adaptive traffic classes. The rate of connections in set A_1 are $R_k = MINR_k + \Delta R_k$, where $\Delta R_k < MAXR_k - MINR_k$. To maximize R_k, from (1),

$$\sum_{j \in A_1} M_j \alpha_j \gamma_j^0 (MINR_j + \Delta R_j) + \sum_{i \in B \cup A_2} M_i \alpha_i \gamma_i^0 MAXR_i = W(1-\eta) \quad (2)$$

To guarantee the fairness of the scheme, let $\Delta R_i / \Delta R_j = W_i / W_j$, where W_k is the weight of the connections of adaptive traffic class k and is defined as $W_k = MAXR_k / \sum_{k \in A_1} M_k MAXR_k$. Let $\Delta R_k = W_k \Delta R$, from(2),

$$\Delta R = \frac{W(1-\eta) - \sum_{j \in A_1} M_j \alpha_j \gamma_j^0 MINR_j - \sum_{i \in B \cup A_2} M_i \alpha_i \gamma_i^0 MAXR_i}{\sum_{j \in A_1} M_j \alpha_j \gamma_j^0 W_j} \quad (3)$$

Thus, the rate of degraded connections of adaptive classes is

$$R_k = MINR_k + W_k * \Delta R \quad (4)$$

III. FAIR COMPENSATION MODEL IN SCHEDULING

In section II, we introduce the CAC based on fair degradation for multiclass traffic. The ongoing connections' degradation increases the total carried traffic in cell, but the increase is at the cost of the bandwidth loss. To minimize the loss, the scheme compensates the degraded connection in scheduling. [8] presents the design of an error compensation model for providing QoS support in a wireless network. The model fairly compensates the traffic which has the channel error. We propose a fairly compensation model according to the model in [8].

We use the scheduling scheme in [3]. The connection j in class k is served at a fixed rate $R_{k,j}$ in a scheduling interval, thus the key of the scheduling scheme is to decide the rate $R_{k,j}$. Let T denote scheduling interval, and $Lag_{k,j}$ denote the data that is less than the desired data that should be sent of connection j in class k. The $R_{k,j}$ have three cases as follows:

1) If $\sum_{j=1}^{N} M_j \alpha_j \gamma_j^0 MINR_j \le W(1-\eta) \le \sum_{j=1}^{N} M_j \alpha_j \gamma_j^0 MAXR_j$, the transmission bit rate of degraded connections can be calculated according to equation (4), and the rate of the other connections is $MAXR_k$.

2) If $\sum_{j=1}^{N} M_j \alpha_j \gamma_j^0 MAXR_j \le W(1-\eta)$ and $Lag_{k,j} = 0$ (for all k, j), $R_{k,j} = MAXR_k$.

3) If $\sum_{j=1}^{N} M_j \alpha_j \gamma_j^0 MAXR_j \le W(1-\eta)$ and $Lag_{k,j} > 0$ (for any k, j), the transmission bit rate of connections in non-adaptive traffic classes and the connections of adaptive traffic classes whose $Lag_{k,j} = 0$ are $MAXR_k$. The rate of connections in adaptive traffic classes whose $Lag_{k,j} > 0$ can be calculated according to equation (7).

Let A be the set of the connections in the adaptive traffic class and C_k be the set of the connections in adaptive traffic classes whose $Lag_{k,j} > 0$. The rate of connection in set C_k is $R_{k,j} = MAXR_k + \Delta R_{k,j}$. From (1),

$$W(1-\eta) = \sum_{k\in A}\sum_{j\notin C_k} \alpha_k \gamma_k^0 MAXR_k + \sum_{k\in A}\sum_{j\in C_k} \alpha_k \gamma_k^0 (MAXR_k + \Delta R_{k,j}) + \sum_{i\in B} M_i \alpha_i \gamma_i^0 MAXR_i$$

$$\sum_{k=1}^{N} M_k \alpha_k \gamma_k^0 MAXR_k + \sum_{k\in A}\sum_{j\in C_k} \alpha_k \gamma_k^0 \Delta R_{k,j} = W(1-\eta) \qquad (5)$$

To guarantee the fairness of the scheme, let $\Delta R_{p,i} / \Delta R_{q,j} = W_{p,i} / W_{q,j}$, where $W_{p,i}$ is the weight of the connection i in adaptive traffic class p and is defined as $W_{p,i} = (M_p MAXR_p / \sum_{k\in A} M_k MAXR_k) * (Lag_{p,i} / \sum_{i\in C_k} Lag_{p,i})$.

Let $\Delta R_{k,j} = W_{k,j} \Delta R$, from(2),

$$\Delta R = (W(1-\eta) - \sum_{k=1}^{N} M_k \alpha_k \gamma_k^0 MAXR_k) / \sum_{k\in A}\sum_{j\in C_k} \alpha_k \gamma_k^0 W_{k,j} \qquad (6)$$

Thus, the rate of connections in adaptive traffic classes whose $Lag_{k,j} > 0$ is

$$R_{k,j} = MAXR_k + W_{k,j} * \frac{W(1-\eta) - \sum_{k=1}^{N} M_k \alpha_k \gamma_k^0 MAXR_k}{\sum_{k\in A}\sum_{j\in C_k} \alpha_k \gamma_k^0 W_{k,j}} \qquad (7)$$

After scheduling interval, we must refresh the $Lag_{k,j}$. Let $New\_Lag_{k,j}$ denote the $Lag_{k,j}$ which have been refreshed.

1) If $R_{k,j} = MAXR_k$, $New\_Lag_{k,j} = Lag_{k,j}$.

2) If $R_{k,j} < MAXR_k$,

$New\_Lag_{k,j} = Lag_{k,j} + (MAXR_k - R_{k,j}) * T$.

3) If $R_{k,j} > MAXR_k$,

$New\_Lag_{k,j} = \max(0, Lag_{k,j} - (R_{k,j} - MAXR_k) * T)$

IV. NUMERICAL RESULTS

This section illustrates the benefit of the proposed scheme. The simulation shows that the proposed scheme have good performance in CBP(call blocking probabilities), throughput and the fairness.

The system parameters used in the simulation are as follows. We assume spread-spectrum bandwidth of $W = 3.84MHz$ as defined for WCDMA, which will be applied in UMTS networks [9]. It is suggested in [3] that $\eta = 0.1$. And we assume scheduling interval T is 10ms.

TABLE I
Traffic Characteristics for Our Simulation Model

Symbol	Class I	Class II	Class III
γ^0	5.6dB	5.6dB	3.2dB
α	0.5	1	1
$MAXR$	12.2Kbps	64 Kbps	144Kbps
$MINR$	12.2 Kbps	32 Kbps	72 Kbps
$1/\mu$	120s	180s	300s

We present herein the numerical examples with three classes of traffic. The nominal parameter values used in this section are listed in Table I. Table 1 lists bit energy-to-interference density ratio γ^0, on probability a, maximum transmission bit rate $MAXR$,minimum transmission bit rate $MINR$ and average serviced rate μ. In a cell, connections are Poisson distributed with average arrival rate of class k is λ_k and average service rate of class k is μ_k listed in Table 1. Let $\rho_i = \lambda_i / \mu_i$ denote class i call intensity. We assume $\rho_1 = \rho_2 = \rho_3 = \rho$. In the simulation, call intensity ρ is varied from 5 to 10. Assume that the priorities of the Class II and Class III all are 1. Because the handoff connections are just dealt with like the connections which have higher priority in our scheme, we just give the simulation of the new connections.

Fig.1 illustrates the call blocking probabilities for Class I alone and for Class I, II, III combined, respectively. It demonstrates how degradation scheme allows a significant improvement in the call blocking probabilities (CBP).

However, all this success does not come without a price. Bandwidth degradation subjects connections to possibly frequent fluctuations in the amount of bandwidth they are provided. It also decreases the probability that calls will always be provided with their desired amount of bandwidth. Fig.2 shows the average rate of class II and class III. It demonstrates how compensation scheme allows an improvement in the average rate. Fig.3 shows that the scheme using degradation has higher throughput than scheme without using degradation and scheme using degradation and compensation has higher throughput than scheme using degradation and without using compensation. It demonstrates that the compensation decrease the bandwidth cost of degradation connections.

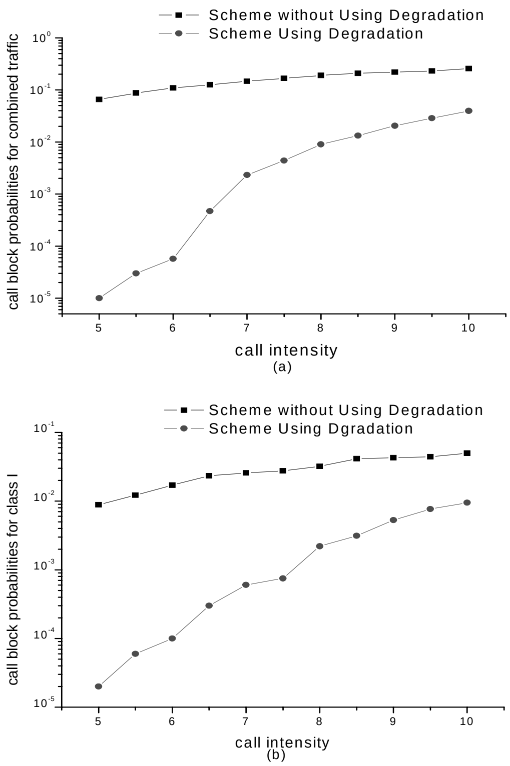

Figure 1 (a) Illustrating call block probabilities for Class I , II, III combined.
(b) Illustrating call block probabilities for Class I.

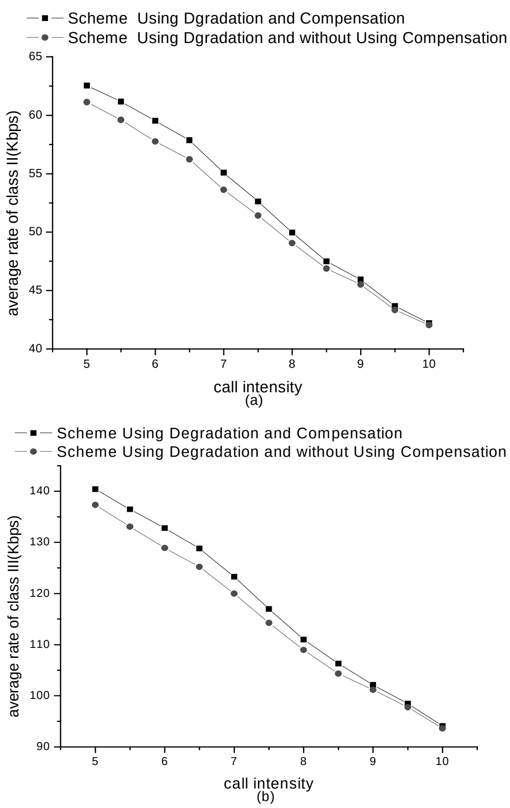

Figure 2 (a) average rate of Class II (b) average rate of Class III

The proposed scheme is fair for multiclass traffic. Let unitary

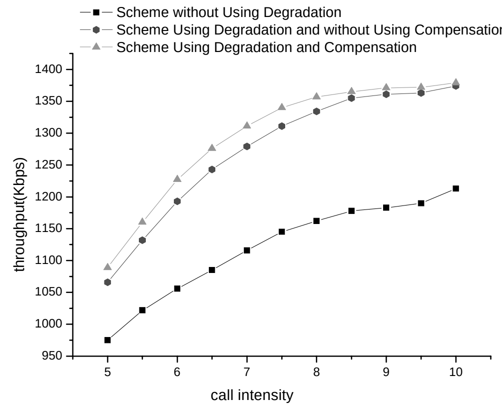

Figure 3 throughput of a cell

rate ratio of class II and class III be r :

$$r = (average\_rate2 / average\_rate3) / (MAXR_1 / MAXR_2)$$

Where $average\_rate2$ is the average rate of the class II, and $average\_rate3$ is the average rate of the class III. If the bandwidth is absolutely allocated among the different class connections, the r should be 1. Fig.4 shows the r in the proposed scheme is very close to 1. It demonstrates that the proposed scheme is good at fairness.

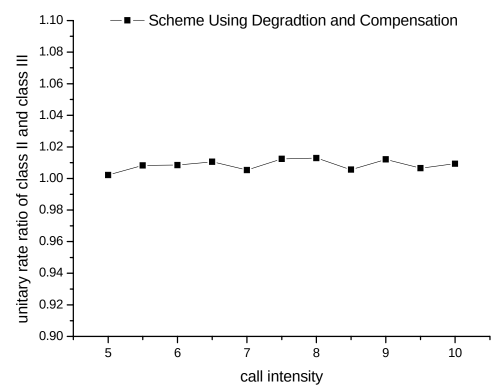

Figure 4 unitary rate ratio of class II and class III

V. CONCLUSION

In this paper, we study the service degradation and compensation in wireless networks supporting multiple traffic types, and present a novel call admission control with bandwidth degradation and compensation scheme for multiclass traffic in CDMA cellular networks. The proposed scheme degrades the ongoing connections to crease the carried connections number when the cell is overloaded, and compensates the degraded connection when the cell has the residual bandwidth. The degradation and the compensation are fair among different class traffic.

The numerical results show that the proposed scheme has good performance. In summary, the proposed CAC scheme can be a good solution for the CDMA cellular networks supporting multiclass traffic.

throughput(Kbps)

REFERENCES

[1] M. Ei-Kadi, S. Olariu, H. Abdel-Wahab, “Rate-based borrowing scheme for QoS provisioning in multimedia wireless networks,” Parallel and Distributed Systems, IEEE Transactions on , Volume: 13 , Issue: 2 , pp.156 – 166, Feb. 2002.

[2] S. K. Das, S. K. Sen, K. Basu, Haitao Lin, “A framework for bandwidth degradation and call admission control schemes for multiclass traffic in next-generation wireless networks,” Selected Areas in Communications, IEEE Journal on , Volume: 21, Issue: 10, pp. 1790 – 1802, Dec. 2003

[3] H. Fattah, C. Leung, “A transmission rate scheduling scheme for multimedia services in wireless CDMA networks,” GLOBECOM '03. IEEE , Volume: 6 , pp.3427 – 3431 1-5 Dec. 2003

[4] A. M. Viterbi and A. J. Viterbi, “Erlang capacity of a power controlled CDMA system,” IEEE Journal on Selected Areas in Communications, vol. 11, no. 6, pp. 892–900, August 1993.

[5] Lindemann,Christoph; Lohmann,Marco; Thümmler,Axel, “Adaptive Call Admission Control for QoS/Revenue Optimization in CDMA Cellular Networks,” Wireless Networks, vol. 10, no.4 pp. 457-472, July 2004.

[6] C. Chou and K. G. Shin, “Analysis of combined adaptive bandwidth allocation and admission control in wireless networks,” in Proc. IEEE INFOCOM, vol. 2, June 2002, pp. 676–684.

[7] S. K. Sen, S. K. Das, K. Basu, and J. Jawanda, “Quality of service degradation strategies in multimedia wireless networks,” in Proc. IEEE Vehicular Technology Conf., May 1998, pp. 1884–1888.

[8] S. Bucheli, J. R. Moorman, J. W. Lockwood, S. M. Kang, “Compensation modeling for QoS support on a wireless network,” Global Telecommunications Conference, 2000. Vol. 1, pp. 198 – 202, 27 Nov.-1 Dec. 2000.

[9] H. Kaaranen, A. Ahtiainen, L. Laitinen, S. Naghian and V. Niemi, “UMTS Networks, Architecture, Mobility and Services,” Wiley, New York, 2001.