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A New Rate Control Technique for cdma2000 1xEV

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Abstract—**In cdma2000 1xEV, each mobile station determines its data rate based on a reverse activity bit (RAB) broadcasted by the base station and a set of up/down probabilities. In this paper, we propose a new rate control scheme that allows mobile stations to choose between two optimal rates determined by the rise over thermal (RoT) constraints. The base station determines the RAB signal based on the current RoT and estimated parameters of the next frame transmission. The proposed scheme is modelled using a Markov process. Both our simulation and analytical results confirm that the proposed scheme achieves better performance than previously proposed rate assignment schemes.**

I. INTRODUCTION

In the last few years, the third generation partnership project two (3GPP2) approved the single carrier evolution data-optimization (1xEV-DO) packet mode standards [1] to satisfy the demands for high data rate wireless networks. In 1xEV-DO, each mobile station (MS) transmits on the reverse traffic channel which consists of a data channel, reverse rate indicator (RRI), pilot channel, data rate control channel (DRC), and an acknowledgement channel (ACK). A slot is a basic transmission unit, and a group of 16 slots is referred to as a frame. The data channel supports five data rates with 26.66 ms time frame packets (see Table I). The RRI channel indicates the data rate of the associated data channel. The pilot channel is used for channel estimation and coherent detection. The DRC channel informs the access network of the best serving cell and the supportable data rate on the forward traffic channel. The ACK channel informs the access network whether a packet transmitted on the forward traffic channel has been received successfully.

The rate assignment mechanisms supported by the 1xEV reverse data channel can be categorized as autonomous, differential, or absolute rate schemes [2]. In autonomous rate assignment schemes, the BS grants each MS a rate from the set of allowable rates. The MS is then free to transmit using this rate or any other rate below it. Differential rate assignment allows the MS to change its rate by one step up or down. The BS can send one of three commands (Up, Down, or Hold). In absolute rate assignment schemes, the BS authorizes the MS to send on a certain rate. The grant message is initiated when the BS receives a change rate request from the MS.

The cdma2000 1xEV-DO standard has a distributed rate control on the reverse link in which the MS determines the data rate of the next frame in response to a reverse activity bit (RAB) broadcasted by the base station (BS) and a pre-specified set of up/down probabilities. All active MSs start with the lowest rate, R_1, and determine the data rate of the next frame according to a RAB broadcasted from the BS to all MSs. The RAB indicates whether or not the reverse traffic load exceeds a certain threshold. If the traffic load exceeds the threshold, the RAB is set down command. Otherwise, it is set to up command. Whenever an up RAB is received, each MS transmitting with a rate R_i, $i = 1, 2, 3, 4$, increases its transmission rate to R_{i+1} with probability p_i. Similarly, whenever a down RAB is received, each MS transmitting with a rate R_i, $i = 2, 3, 4, 5$, decreases its transmission rate to R_{i-1} with probability q_i. Different sets of p_i and q_i are defined in [3] and [12]. Furthermore, to ensure quality of service (QoS), 3GPP2 [3] specifies that the rise over thermal (RoT) per slot should not exceed 7 dB more than 1% of the time. It should be noted that QoS is also maintained through other mechanisms such as call admission control [4]- [7], scheduling [13]- [18], and power/rate control [8]- [12].

	Data Rates in Kbps	$TPRD$ in dB
R_1	9.6	3.75
R_2	19.2	6.75
R_3	38.4	9.75
R_4	76.8	13.25
R_5	153.6	18.5

TABLE I
ALLOWABLE RATES AND CORRESPONDING TRAFFIC TO PILOT RATIOS

In what follows we briefly review some of the pervious rate control techniques. Ci and Guizani [11] proposed an optimal rate assignment technique for the 1xEV-DV forward link. The scheme was proposed to support delay bounded multimedia services. In their analysis, they consider one user with mixed traffic per time slot. The scheme's objective is to maximize the one slot capacity subject to some constrains such as the number of available Walsh codes, service type, packet length, and maximum allowable data rate. Yeo, and Cho [12] used Markov models to model a data rate control scheme in which the next frame data rates are determined based on the traffic load of the current frame. Price and Javidi [8] showed that, by using an optimization framework, it is possible to construct a distributed rate assignment algorithm which addresses issues like interference and congestion control. They formulated this as a maximization problem subject to interference and congestion constraints, and developed distributed algorithms to solve this maximization problem. Rodriguez and Goodman [10] addressed power and data rate allocations for each of N terminals, such that the network weighted throughput is max-

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imized. The weights admit various interpretations, including levels of importance, utility, and price. They utilized a model which can accommodate many physical layer configurations of practical interest. Shu and Niu [9] proposed a dynamic rate assignment based on computing the optimum number of simultaneous transmissions on one time slot with respect to multiple access interference. In this scheme, the authors assume that all the users have the same packet size, each user is allowed to send more than one packet per slot, and the number of packets are computed as a function of the optimum number of transmissions and the buffer length of each user.

In this paper we propose a new rate control scheme in which two optimal rates, R_{low} and R_{high}, are determined based on the RoT constraints. MSs are allowed to choose between R_{low} and R_{high} based on the RAB signal. In our proposed scheme, the BS determines the RAB signal based on the current RoT figure and some estimated figures of the next frame. The proposed scheme is modelled using a Markov process and validated through simulations. The obtained results show that our scheme outperforms previously proposed schemes [3], [12].

II. THE PROPOSED RATE ASSIGNMENT TECHNIQUE

The rise over thermal (RoT) [12] is defined as the ratio between the total power received to the thermal noise power at the base station. To ensure quality of service (QoS), 3GPP2 [3] specifies that the RoT per slot should not exceed 7 dB more than 1% of the time.

In what follows we explain the model for the RoT to be used in our work. Let P_T, and P_N be the total power and the thermal power received at the BS respectively. Then the RoT is given by $RoT = P_T/P_N$. Assume M active mobiles in the sector under consideration. Therefore, $P_T = \sum_{i=1}^{M} P_i + P_N$, where P_i is the received power of the i^{th} mobile at the BS. Thus $RoT = P_T/(P_T - \sum_{i=1}^{M} P_i)$, which can be expressed as

$$RoT = (1 - \sum_{i=1}^{M} \frac{P_i}{P_T})^{-1}. \tag{1}$$

Let $\overline{P_i}$ be the pilot channel power for the i^{th} mobile. Define the total traffic to pilot ratio for the i^{th} mobile as $TPR_i = P_i/\overline{P_i}$. Denote the targeted signal to noise and interference ratio for the pilot channel as $\tau_i = \overline{P_i}/(P_T - P_i)$, where $P_T - P_i$ is the total interference and the thermal power for the i^{th} mobile. By substituting into equation 1, we get

$$RoT = (1 - \sum_{i=1}^{M} \frac{TPR_i}{TPR_i + 1/\tau_i})^{-1}, \tag{2}$$

where M is the number of active MSs, $\tau_i = \tau = 10^{0.1SINR}$, and $SINR$ denotes the target signal-to-noise plus interference ratio for the pilot channel which is assumed to be constant for all MSs. The total traffic to pilot ratio corresponding to the i^{th} user is determined by

$$TPR_i = 1 + 10^{0.1TPRD_i} + 10^{0.1TPDRC}, \tag{3}$$

where $TPRD_i$ denotes the traffic to pilot ratio in dB on the reverse data channel associated with the i^{th} user data rate, $TPDRC$ denotes the traffic to pilot ratio in dB associated with the DRC channel [3]. Table I shows the five allowed rates and their associated $TPRD$ [1] for the 1xEV-DO standard.

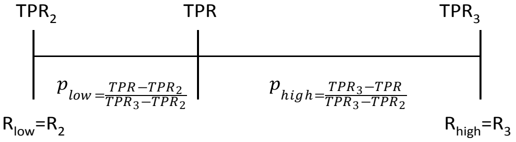

Fig. 1. p_{low} and p_{high} when $TPR_2 \leq TPR \leq TPR_3$.

If the active MSs can be assigned any rate between R_1 and R_5, i.e., not just the five rates specified in Table I, then the optimal rate that grantees the fairness among all MSs can be determined by setting $TPR_i = TPR$ for all MSs where TPR is the maximum possible value that satisfies the RoT constraint. From (2), this TPR value can be determined by setting

$$\left(1 - \sum_{i=1}^{M} \frac{TPR}{TPR + 1/\tau}\right)^{-1} = 10^{0.1\times\zeta} \tag{4}$$

and hence we get

$$TPR = \frac{1-10^{-0.1\times\zeta}}{(M-(1-10^{-0.1\times\zeta}))\tau}. \tag{5}$$

Since the rate corresponding to the above TPR value is unlikely to be one of the five allowable rates, using (3), we determine two rates from Table I, R_{low} and R_{high}, as follows

$$\begin{cases} R_{low} = R_{high} = R_1, & TPR \leq TPR_1, \\ R_{low} = R_{high} = R_5, & TPR \geq TPR_5, \\ R_{low} = R_k, R_{high} = R_{k+1}, & TPR_k < TPR < TPR_{k+1}, \end{cases} \tag{6}$$

where $1 \leq k \leq 4$. For the two cases where $R_{low} = R_{high}$, all MSs will be assigned the same rate and the system stabilizes at this distribution where all MSs are assigned either R_1 or R_5 as determined by the above equation. On the other hand, when $R_{low} = R_k$ and $R_{high} = R_{k+1}$, then the optimal target rate distribution can be achieved by distributing the MSs among these two rates such that the expected value of the traffic to pilot ratio is very close to the un-quantized case given by (5). This can be achieved by allowing the MSs to choose between R_{low} and R_{high} with probabilities

$$p_{low} = \frac{TPR - TPR_k}{TPR_{k+1} - TPR_k}, 1 \leq k \leq 4$$

and $p_{high} = 1 - p_{low}$, respectively. Fig. 1 depicts a scenario for determining p_{low} and p_{high} when $TPR_2 \leq TPR \leq TPR_3$.

Let $\mathbf{x} = (x_1, x_2)$ be the number of MSs transmitting with data rates $R_{low} = R_k$ and $R_{high} = R_{k+1}$, respectively. Let $RAB(\mathbf{x})$ denote the outgoing RAB signal based on the current MSs distribution. At the beginning, the MSs are distributed between R_{low} and R_{high} with probabilities p_{low} and p_{high} respectively. The BS calculates the RoT with the current distribution. If the RoT is above the prespecified threshold, ζ, then a down ($RAB(\mathbf{x}) = -1$) signal is sent to all users. MSs transmitting at R_{high} lower their rate to R_{low} with probability p_{down}. To avoid toggling the RoT around ζ, when the RoT is below ζ, the BS estimates the RoT if one MS, currently transmitting at R_{low} is allowed to increase its transmission rate to R_{high}. If the estimated RoT exceeds the threshold ζ, a hold signal ($RAB(\mathbf{x}) = 0$) is sent to all MSs to keep their current rates. The BS keeps on sending this hold signal unless the number of users changes. On the other hand, if this estimated RoT is still below the threshold ζ, an up signal ($RAB(\mathbf{x}) = 1$) is sent and users at R_{low} move to R_{high} with probability p_{up}. Let $c_i = \frac{TPR_i}{TPR_i+1/\tau}$, then (2) can be rewritten as $RoT(\mathbf{x}) = (1 - x_1 c_k - x_2 c_{k+1})^{-1}$. Thus the $RAB(\mathbf{x})$ is calculated as $RAB(\mathbf{x}) =$

$$\begin{cases} 1, & (1 - c_k(x_1 - 1) - c_{k+1}(x_2 + 1))^{-1} < 10^{0.1\times\zeta}, \\ 0, & (1 - c_k(x_1 - 1) - c_{k+1}(x_2 + 1))^{-1} \geq 10^{0.1\times\zeta}, \\ -1, & (1 - c_k x_1 - c_{k+1} x_2)^{-1} > 10^{0.1\times\zeta}. \end{cases} \quad (7)$$

Let $\mathbf{xt} = (xt_1, xt_2)$ denote the target distribution of MSs among the data rates R_{low} and R_{high}, respectively, where $xt_1 = M \times p_{low}$ and $xt_2 = M \times p_{high}$. To accelerate the system convergence to steady state, the up and down probabilities p_{up} and p_{down} are computed based on the current users distribution $\mathbf{x} = (x_1, x_2)$ and the target distribution $\mathbf{x}t = (xt_1, xt_2)$ as follows

$$p_{up} = \begin{cases} \frac{x_1 - xt_1}{x_1}, & x_1 \geq xt_1 \\ 0, & x_1 < xt_1 \end{cases} \quad (8)$$

$$p_{down} = \begin{cases} \frac{x_2 - xt_2}{x_2}, & x_2 \geq xt_2 \\ 0, & x_2 < xt_2. \end{cases} \quad (9)$$

III. MARKOV MODEL

Markov models are among the most powerful tools available for analyzing communication systems. If the Markov model is irreducible, aperiodic and positive recurrent, the state probabilities reach steady state values that are independent of the initial state probabilities. The steady state probabilities $\pi(\mathbf{x})$ for a state $\mathbf{x}$ can be obtained by solving the linear equations $\pi(\mathbf{y}) = \sum_{\forall \mathbf{x}} p_{\mathbf{xy}} \pi(\mathbf{x})$ and $\sum_{\forall \mathbf{x}} \pi(\mathbf{x}) = 1$ [19].

Let $S_1(t)$ and $S_2(t)$ denote the number of MSs assigned data rates R_{low}, R_{high} at the t^{th} time slot. We define a state vector $\mathbf{S}(t) = (S_1(t), S_2(t))$. We assume that the system is always loaded with M MSs which implies that $S_1(t) + S_2(t) = M$ and hence the number of valid states is given by $\binom{M+2}{2}$ [19].

Let $\mathbf{L}(t+1) = (L_1(t+1), L_2(t+1))$, where $L_1(t+1)$ and $L_2(t+1)$ denote the number of MSs leaving data rate R_{low} and R_{high} respectively (after receiving certain $RAB(\mathbf{x})$ signal) at the end of the t^{th} time slot, i.e., at the beginning of slot $t+1$. Similarly, let $\mathbf{J}(t+1) = (J_1(t+1), J_2(t+1))$, where $J_1(t+1)$ and $J_2(t+1)$ denote the number of MSs joining data rate R_{low} and R_{high} respectively at the end of the t^{th} time slot. Let $\mathbf{x} = (x_1, x_2)$, and $\mathbf{y} = (y_1, y_2)$ be the sample of $\mathbf{S}(t)$ and $\mathbf{S}(t+1)$ respectively. Similarly let $\mathbf{l} = (l_1, l_2)$, and $\mathbf{j} = (j_1, j_2)$ be the sample of $\mathbf{L}(t+1)$ and $\mathbf{J}(t+1)$ respectively. Then the state transition probability $p_{\mathbf{xy}} = p(\mathbf{S}(t+1) = \mathbf{y}|\mathbf{S}(t) = \mathbf{x})$ is given by $p_{\mathbf{xy}} =$

$$\sum_{\mathbf{l},\mathbf{j}} p(\mathbf{S}(t+1) = \mathbf{y}|\mathbf{l}, \mathbf{j}, \mathbf{x}) \times p(\mathbf{J} = \mathbf{j}|\mathbf{l}, \mathbf{x}) \times p(\mathbf{L} = \mathbf{l}|\mathbf{x}). \quad (10)$$

The conditional probability $p(\mathbf{S}(t+1) = \mathbf{y}|\mathbf{l}, \mathbf{j}, \mathbf{x})$ is given by

$$p(\mathbf{S}(t+1) = \mathbf{y}|\mathbf{l}, \mathbf{j}, \mathbf{x}) = \prod_{k=1}^{2} p(y_k = x_k - l_k + j_k) \quad (11)$$

where

$$p(y_k = x_k - l_k + j_k) = \begin{cases} 1, & y_k = x_k - l_k + j_k, \\ 0, & y_k \neq x_k - l_k + j_k. \end{cases} \quad (12)$$

The assumption that the system is always loaded with M MSs implies that $j_1 = l_2$ and $j_2 = l_1$. Thus

$$p(\mathbf{J} = \mathbf{j}|\mathbf{l}, \mathbf{x}) = p(j_1 = l_2) p(j_2 = l_1) \quad (13)$$

where

$$p(j_1 = l_2) = \begin{cases} 1, & j_1 = l_2 \\ 0, & \text{otherwise.} \end{cases}, p(j_2 = l_1) = \begin{cases} 1, & j_2 = l_1 \\ 0, & \text{otherwise.} \end{cases} \quad (14)$$

We also have $p(\mathbf{L} = \mathbf{l}|\mathbf{x}) = p(\mathbf{l}|RAB(\mathbf{x})) =$

$$\begin{cases} 1, & RAB(\mathbf{x}) = 0, \text{ and } l_1 + l_2 = 0 \\ 0, & RAB(\mathbf{x}) = 0, \text{ and } l_1 + l_2 \neq 0 \\ \prod_{k=1}^{2} p(l_k), & \text{otherwise} \end{cases} \quad (15)$$

and

$$p(l_k) = \binom{x_k}{l_k} (p_k)^{l_k} (1 - p_k)^{(x_k - l_k)}, \quad (16)$$

where $p_1 = p_{up}$ and $p_2 = p_{down}$ are given by (8), (9), respectively. By noting that the above Markov model is irreducible, aperiodic, and positive recurrent [20], there will be a unique steady-state probability $\pi(\mathbf{x})$ for a state $\mathbf{x}$. The steady state system throughput is then given by $\sum_{\forall \mathbf{x}} (x_1 R_{low} + x_2 R_{high}) \pi(\mathbf{x})$, where $\pi(\mathbf{x})$ denotes the steady state probability distribution of $\mathbf{S}$. Also, the average RoT is given by $\sum_{\forall \mathbf{x}} RoT(\mathbf{x}) \pi(\mathbf{x})$ and the percentage of time during which the RoT is above the threshold ζ is given by $\sum_{\forall \mathbf{x} \in \mathbf{x}_{out}} \pi(\mathbf{x})$, where $\mathbf{x}_{out}$ are the sets of $\mathbf{x}$ for which the $RoT(\mathbf{x})$ is above ζ.

Fig. 2 shows the variation of the set of available rates with the number of users and Fig. 3 shows the corresponding distribution of users between R_{min} and $Rate_{max}$.

In what follows, we consider a distributed system in which each sector performs scheduling for its active set of MSs without prior coordination with other sectors. The values of $TPDRC$, and $SINR$ are set to $-1.5\ dB$, $-22\ dB$ respectively [3]. The proposed scheme is compared to both the standard rate control scheme [3] and the rate control scheme proposed in [12]. Fig. 4 shows that the average RoT for the

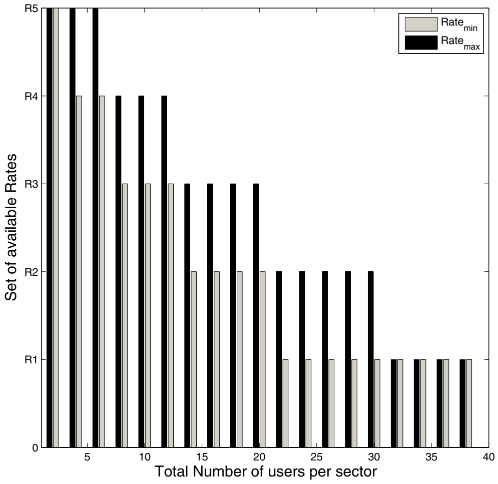

Fig. 2. Set of available rates $\{R_{min},R_{max}\}$ for different numbers of users

proposed scheme outperforms the other techniques where it is always below the $\zeta = 7$ dB threshold. From Fig. 5, it is clear that our proposed technique satisfies the restriction, imposed by the standard, that the RoT should not exceed $\zeta = 7$ dB more than 1% of the time, while the other techniques barely satisfy this condition.

Fig. 6 shows that all three techniques approximately achieve the same throughput when we assume that all packets are accepted from the first transmission. However in real wireless networks, if the RoT exceeds the prespecified threshold $\zeta = 7$ dB, the QoS is degraded and some packets might be lost or errored. Thus, the real throughput achieved by our proposed scheme is greater than the throughput achieved by the other two schemes since, as depicted in Fig. 5, the percentage of time in which the RoT exceeds ζ in our proposed scheme is negligible compared to the schemes in [3], [12].

IV. CONCLUSION

A rate control technique for the reverse data channel of the 1xEV-DO was proposed. The distribution of the MSs among the chosen data rates is modelled as a Markov process. The results show that the proposed scheme improves the stability of the reverse link by maintaining the reverse link load close to the target RoT. Furthermore, it outperforms previously proposed schemes in terms of the achieved throughput.

REFERENCES

[1] 3GPP2, *cdma2000 High Rate Data Packet Data Air Interface Specification,* Version 4.0, Oct. 2002.

[2] D. Comstok, R. Vannithamby, S. Balasubramanian, L. Hsu, and M. Cheng, *Reverse Link High-Speed Packet Data Support in cdma2000 1xEV-DV Upper Layer Protocols,* IEEE Communications Magazine, vol. 43, no. 4, pp. 48-56, April 2005.

[3] 3GPP2, *cdma2000 Evaluation Methodology,* Dec. 2004.

[4] Y. Guo and B. Aazhong, *Call Admission Control in Multiclass Traffic CDMA Cellular System Using Multiuser Antenna Array Receiver,* Proceedings of IEEE Vehicular Technology Conference (VTC 2000), vol. 1, pp. 365-69, May 2000.

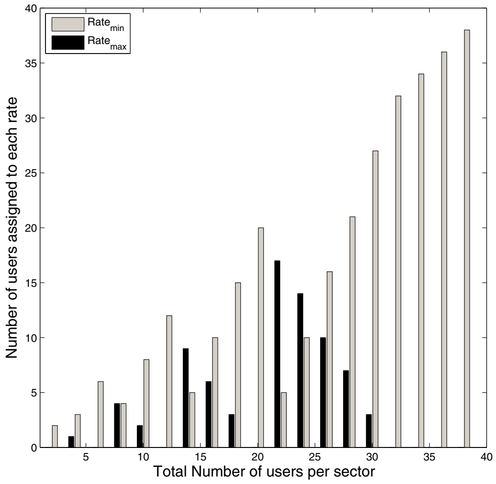

Fig. 3. The distribution of users between R_{min} and $Rate_{max}$ for different numbers of users

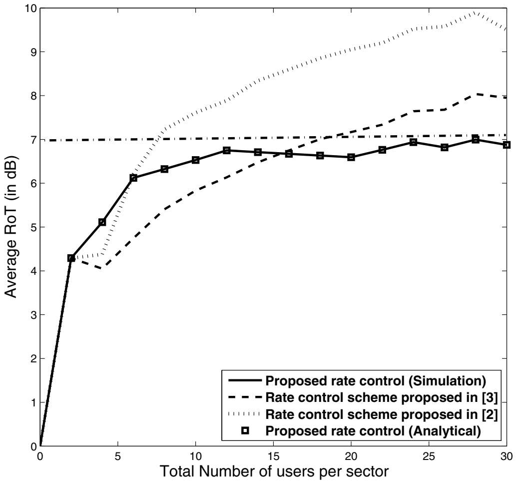

Fig. 4. Average RoT.

[5] J. Evans and D. Everitt, *Effective Bandwidth-based Admission Control for Multiservice CDMA Cellular Networks,* Proceedings of IEEE Vehicular Technology Conference (VTC 1999), vol. 48, pp. 36-46, Jan. 1999.

[6] J. Kuri and P. Mermelstein, *Call Admission on the Uplink of a CDMA System Based on Total Received Power Communications,* Proceedings of IEEE International Conference on Communications (ICC 1999), vol. 3, pp. 1431-36.

[7] Lei Wang, and Weihua Zhuang, *A Call Admission Control Scheme for Packet Data in CDMA Cellular Communications,* IEEE Transactions on Wireless Comunications, vol. 5, no. 2, pp. 406-416 ,Feb. 2006.

[8] J. Price, and T. Javidi, *Cross-Layer (Mac and Transport) Optimal Rate Assignment in CDMA-Based Wireless Broadband Networks,* Proceedings of IEEE Conference of Signals, Systems and Computers, vol.1, pp.1044-1048, Nov. 2004.

[9] T. Shu, and Z. Niu, *A dynamic rate assignment scheme for data traffic in cellular multi-code CDMA networks,* Proceedings of IEEE Vehicular Technology Conference (VTC 2002), vol.2, pp.811 - 815, May 2002.

[10] F. Rodriguez, D. Goodman, *Power and Data Rate Assignment for Maximal Weighted Throughput in 3G CDMA,* Proceedings of IEEE

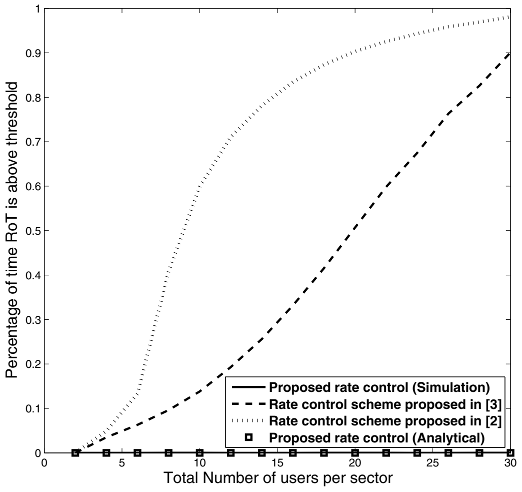

Fig. 5. Percentage of time during which $RoT > 7$ dB.

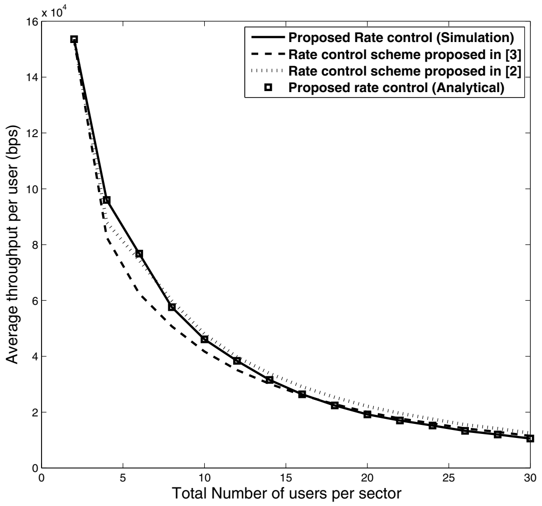

Fig. 6. Average throughput.

Wireless Communications and Networking (WCNC 2003), vol.1, pp.525-531, March 2003.

[11] S. Ci, M. Guizani, and G. Brahim, *A Dynamic Resource Allocation Scheme for Delay-Constrained Multimedia Services in CDMA 1xEV-DV Forward Link,* IEEE Journal on Selected Areas in Communications, vol. 24, pp. 46-53, Jan. 2006.

[12] W. Yeo, and D. Cho, *An Analytical Model for Reverse Link Rate Control in cdma2000 1xEV-DO Systems,* IEEE Communications Letters, vol.9, No.3, pp.270-272, March 2005.

[13] H. Fattah, and C. Leung, *An Overview of Scheduling Algorithms in Wireless Multimedia Networks,*" IEEE Wireless Communications, pp.76-83, October 2002.

[14] L. Almajano, and J. Prez-Romero, *Packet Scheduling Algorithms for Interactive and Streaming Services under QoS Guarantee in a CDMA System,* Proceedings of IEEE Vehicular Technology Conference (VTC 2002), vol. 3, pp.1657 - 1661, Sept. 2002.

[15] A. Jalali, R Padovani, and R. Pankaj, *Data Throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless systems*, Proceedings of IEEE Vehicular Technology Conference (VTC 2000), pp.1854-1858, May 2000.

[16] I. Lopez, P. J. Ameigeiras, J. Wigard, and P. Mogensen, *Downlink Radio Resource Management for IP Packet Services in UMTS,* Proceedings of IEEE Vehicular Technology Conference (VTC 2001), vol. 4, pp.2387-2391, May 2001.

[17] B. Al-Manthari, N. Naser, and H. Hassanein, *Fair and Efficient Channel Dependent Scheduling Algorithm for HSDPA System,* 2^{nd} International Symposium on Wireless Communication Systems (ISWCS2005), Siena, Italy, September 2005.

[18] Li Wang, Yu-Kwong Kwok, Wing-Cheong Lau, and V. K. N. Lau, *Channel Adaptive Fair Queuing for Scheduling integrated Voice and Data services in Multicode CDMA Systems,* ELSEVIER Computer Communications, vol. 27, pp. 809-820, 2004.

[19] Alberto Leon-Garcia, *Probability and Random Processes for Electrical Engineering,* Addison-Wesley, 2nd edition July 1993.

[20] Pierre Bremaud, *Markov Chains: Gibbs Fields, Monte Carlo Simulation, and Queues,* Springer Verlag, 1999.