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Slotted Random Access Protocol with Dynamic Transmission Probability Control in CDMA System

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Abstract—In packet radio networks, simultaneously transmitted packets act as multiple access interference. In order to maximize the system performance, the number of simultaneously transmitted packets should be kept at a proper level. This paper proposes a slotted random access protocol with dynamic transmission probability control scheme in the spread spectrum system. In the proposed scheme, the base station calculates the packet transmission probability in the next slot according to the offered loads and then broadcasts it to all the mobile stations. Mobile stations, which have a packet to transmit, transmit packet with the received probability. Simulation results show that the proposed scheme can offer better system throughput and average delay performance than the conventional one.

Keywords—Transmission probability control, S-Aloha protocol, CDMA system

I. INTRODUCTION

Spread spectrum code division multiple access (CDMA) technique has been widely used in military communication systems. CDMA technique provides the following advantages: a multiple access capability, a potential for high spectrum efficiency, external interference rejection capability, and inherent frequency diversity [1][2]. Slotted ALOHA (S-ALOHA) access protocol has been widely recognized for packet radio applications because of its simplicity in managing packet transmissions. In S-ALOHA protocol, it is assumed that whenever more than one packet is transmitted at the same time slot, the information in the transmitted packets will be lost. Moreover, if a high traffic load is offered to the system, then the system will become unstable [3]. This would not be the case if S-ALOHA was used with CDMA technique. Application of the conventional S-ALOHA protocol to CDMA technique, namely CDMA S-ALOHA system, offers relatively high system capacity [4][5].

In CDMA S-ALOHA system with a transmitter-based code method, mobile stations that have a packet transmit the packet with a given transmission probability[6]. Mobile stations that fail to transmit a packet retransmit it with a given retransmission probability. If the number of simultaneously transmitting mobile stations, i.e. the level of multiple access interferences, increases above a certain threshold, almost all the packets received by the base station can be erroneous. Hence, unsuccessful packet transmissions are caused entirely by the number of simultaneously transmitting mobile stations. If the level of multiple access interferences can be remained close to the level that the system can support, it is expected to achieve the best system performance. Therefore, the number of simultaneously transmitting mobile stations needs to be limited with the use of transmission probability control scheme.

Most previous researches have been based on a fixed transmission probability without the transmission probability control algorithms, and have been done without distinguishing between new packet and retransmission packet. In the case of a high transmission probability, packet errors will frequently occur due to the increased level of multiple access interferences as becoming the offered load high. On the other hand, if the transmission probability is low, the system throughput will decrease because of the excessive restriction of packet transmissions. There are some researches to control the transmission probability aiming at improving the system throughput [7][8]. In these researches, mobile stations that fail to transmit a packet retransmit it with a decreased transmission probability. Continuously decreasing the transmission probability of mobile stations that fail to transmit, the transmission probability of a specific mobile station becomes excessively decreased. As a result, the system throughput performance can be decreased, the transmission delay of failed mobile station can be increased, and moreover, fairness between mobile stations cannot be guaranteed.

This paper is intended to improve the throughput and delay performance and guarantee the fairness between mobile stations. For these purposes, this paper proposes a transmission probability control scheme for CDMA S-ALOHA system with a transmitter-based code method. In the proposed scheme, the base station dynamically controls the transmission probability of new and unsuccessful packets based on the traffic loads.

This paper is organized as follows. Section II describes the system model of CDMA S-ALOHA. The proposed transmission probability control scheme is explained in Section III, and simulation results are presented in Section IV. Concluding remarks are presented in Section V.

II. SYSYEM MODEL

In this paper, the bit error probability $P_e(m)$ of CDMA system is assumed as follows [6]:

$$P_e(m) = Q\left(\left[\frac{m-1}{3N} + \frac{N_0}{E_b}\right]^{-\frac{1}{2}}\right) \tag{1}$$

Here, N is the processing gain, m is the number of simultaneously transmitted packets, E_b/N_0 is the ratio of energy-per-bit to noise power spectral density, and $Q(x)$ is given by

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-u^2/2} du \tag{2}$$

From (1), the number of simultaneously transmitted packets as well as the processing gain has a strong influence on the bit error probability of CDMA system. Accordingly, the system throughput, which is defined as the number of successful packets, can be affected by the bit error probability. It is assumed that a packet is successfully received at the base station when all the bits of a packet are error-free. When m packets are transmitted simultaneously, the probability $P_s(m)$ that a packet is successfully received and the number of successful packets $S(m)$ can be expressed as follows, respectively:

$$P_s(m) = \{1 - P_e(m)\}^L \tag{3}$$

$$S(m) = m \cdot \{1 - P_e(m)\}^L \tag{4}$$

where L is the length of a packet in bits.

Figure 1 shows the achievable throughput of CDMA system versus the number of simultaneously transmitted packets, where the packet length is 432 bits, the processing gain is 64, and E_b/N_0 is 15dB. As shown in Figure 1, when the number of simultaneously transmitted packets is over 12, the throughput decreases as a result of packet errors due to the excessive multiple access interferences. Therefore, in order to achieve the maximum throughput in CDMA system, the number of simultaneously transmitted packets should be controlled at a proper level.

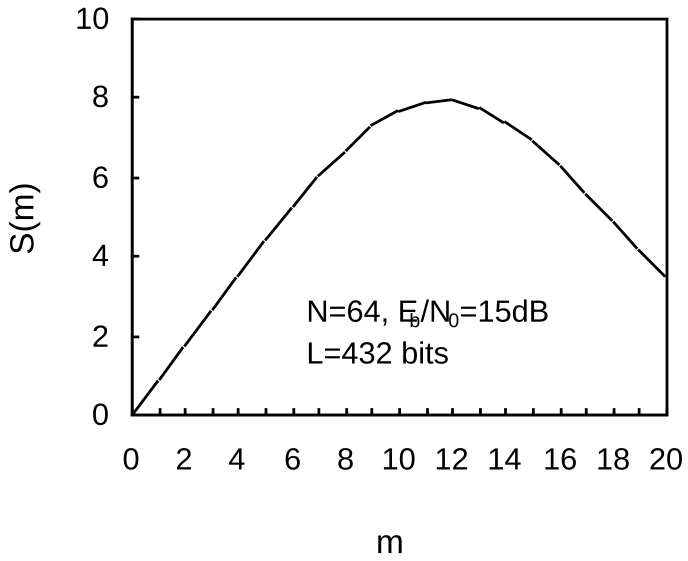

Figure 1. The achievable throughput of CDMA system versus number of simultaneously transmitted packets.

III. TRANSMISSION PROBABILITY CONTROL SCHEME

The system model of transmission probability control scheme, which is named as the proportional backoff (PB) scheme, is presented in Figure 2. In the proposed scheme, the base station controls the transmission probability of mobile stations in the centralized manner. The mobile stations in the contention state and retransmission state attempt to transmit packets with the transmission probability P_n and retransmission probability P_r, respectively. The base station calculates these probabilities based on the estimated traffic loads and broadcasts over an error-free downlink control channel.

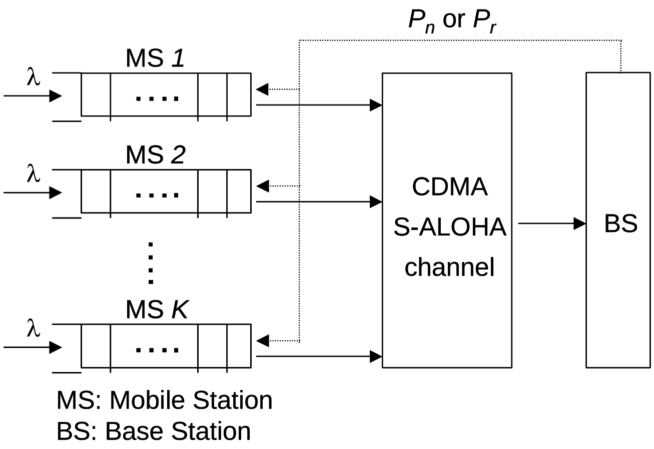

Figure 2. System model of transmission probability control scheme.

Every mobile station generates a packet in each slot with arrival rate λ. When the mobile station generates a packet, it is stored at the buffer. Stored packets are served on a first-in-first-out discipline. Figure 3 shows the operation mode of each mobile station. As depicted in Figure 3, all of the mobile stations may be in one of three different operation states: idle state, contention (CON) state, and retransmission (RETX) state.

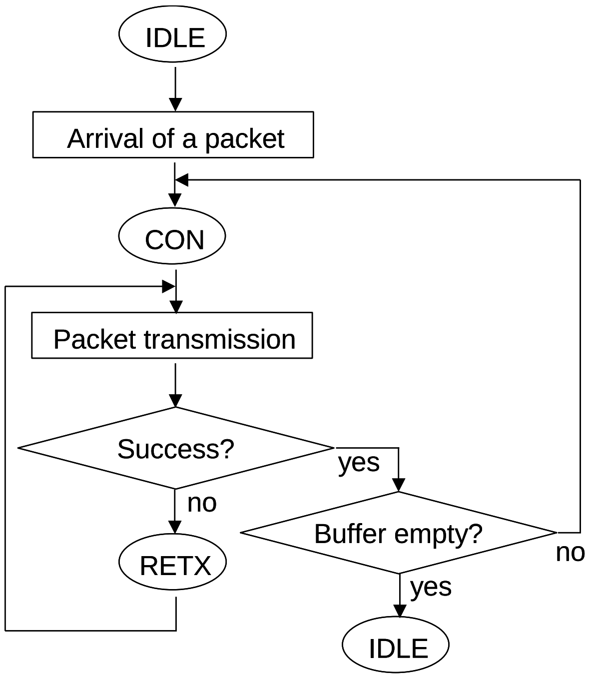

Figure 3. Operation mode of mobile station.

The mobile station, which does not have any packet in the buffer, is said to be in the idle state. When the mobile station in the idle state generates a packet, it enters into the contention state and transmits a packet at the next slot with a given transmission probability P_n. The mobile stations are informed as to whether or not the transmitted packets are successfully received by the base station in the form of acknowledgement through an error-free downlink channel. The mobile station that fails to transmit a packet or does not permitted to transmit enters into the retransmission state, and retransmits the packet at the next slot with a given retransmission probability P_r. After successful transmission, the packet is removed from the buffer and the mobile station serves the next packet if exists. The retransmission process is repeated until the packet is successfully received.
The mobile station that fails to transmit its packet at slot t will retransmit with $P_r(t+1)$ at slot $(t+1)$, while the mobile station that enters into the contention state at slot t will transmit with $P_n(t+1)$ at subsequent slot. The $P_n(t+1)$ and $P_r(t+1)$ are calculated as follows:

$$P_n(t+1) = \begin{cases} 1, & \text{if } N_r(t+1) \le TH_m \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

$$P_r(t+1) = \begin{cases} 1, & \text{if } N_r(t+1) \le TH_m \\ \dfrac{TH_m}{N_r(t+1)}, & \text{otherwise} \end{cases} \tag{6}$$

where TH_m is the number of simultaneously transmitted packets at which the system throughput can be maximized, and $N_r(t+1)$ is the total number of mobile stations in the retransmission state at slot $(t+1)$. Let $N_f(t)$ be the number of failed mobile stations at slot t, and $N_b(t)$ the number of mobile stations not being permitted to transmit at slot t. Then $N_r(t+1)$ can be derived as follows:

$$N_r(t+1) = N_f(t) + N_b(t) \tag{7}$$

The threshold value TH_m can be determined by (4), and $N_b(t)$ is given by

$$N_b(t) = N_n(t-1)\{1 - P_n(t)\} + N_r(t)\{1 - P_r(t)\} \tag{8}$$

$N_n(t)$ in (8) is the number of mobile stations that enter into the contention state at slot t, and can be derived by

$$N_n(t) = \{K - N_r(t) - N_n(t-1)\} \cdot \lambda \tag{9}$$

In (9), K is the total number of mobile stations in the system, and λ is the probability that each mobile station generates a packet in each slot. The base station cannot exactly know how many packets are generated in one slot. Therefore, λ is computed using a moving time average of the number of new packets that are successfully received.

In the proposed scheme, if the number of mobile stations in the retransmission state is less than TH_m, all of the mobile stations in both the contention state and the retransmission state should be allowed to transmit a packet. If the number of mobile stations in the retransmission state becomes more than TH_m, the base station sets P_n into 0 to suppress the transmission of new packets. Also, in this case, the base station sets P_r as the values at which the total number of simultaneously retransmitted packets becomes TH_m, in order to minimize the transmission delay.

IV. SIMULATION RESULTS

This section presents simulation results for the proposed transmission probability control scheme. In this paper, it is assumed that the packet length is 432 bits equal to slot duration, the processing gain is 64, E_b/N_0 is 15 dB, the total number of mobile stations is 100, and each mobile station generates packets according to the Poisson process. With these assumptions, it can be seen that TH_m is equal to 12 from Figure 1. Also, it is assumed that the total length of window used for computing the moving time average of packet arrival rate is set to 1,000 slots.

The performance measures of interest are the system throughput, average delay. The system throughput is defined as the number of successfully transmitted packets during one slot time. The average delay is defined as the average time between the arrival of packet and its reception at the base station.

In this paper, we analyze the performance of the proposed PB scheme in comparison to the conventional harmonic backoff (HB) scheme [7]. In the HB scheme, the mobile station that fails in the transmission of packet decreases its transmission probability independently with the traffic load. For the first attempt of packet transmission, the transmission probability P_1 is set to 1. If the transmission becomes unsuccessful, then P_{i+1} for $(i+1)$th attempt is decreased according to

$$P_{i+1} = \frac{P_i}{P_i + 1}, i \geq 1 \qquad P_1 = 1 \tag{10}$$

The number of simultaneously transmitted packets, throughput, and average delay versus the offered load are shown in Figure 4, 5, and 6, respectively. As shown in Eq. (10), in the HB scheme, the mobile station that fails to transmit a packet decreases its transmission probability independently with the number of mobile station in the retransmission state. As the traffic load increases, so the bit error rate of each packet increases because of the unconditional transmission of new packets. Because the mobile station in the retransmission state continuously decreases the transmission probability due to the packet error, the transmission probability of a specific mobile station becomes excessively decreased. As a result, as shown in Figure 4, the number of simultaneously transmitted packets in the HB scheme is far less than TH_m. On the other hand, in the proposed PB scheme, the base station controls the transmission probability of mobile stations based on the traffic load and the threshold TH_m. Therefore, the PB scheme maintains the number of simultaneously transmitted packets the threshold TH_m in spite of the increased offered load. From Figure 5 and 6, the PB scheme gives better performance than the HB scheme. The reasons are as follows: i) the PB scheme can control the number of simultaneously transmitted packets more precisely that the HB scheme; ii) in the PB scheme, the base station does not permit the transmission of new packets in the heavy traffic load.

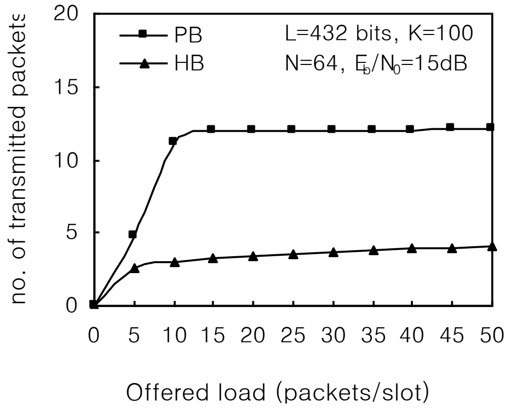

Figure 4. Number of transmitted packets versus offered load.

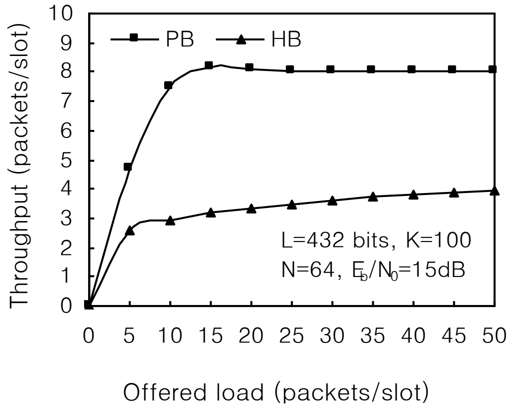

Figure 5. Throughput versus offered load.

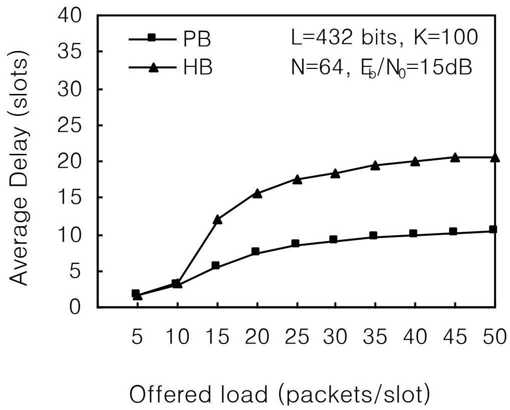

Figure 6. Average delay versus offered load.

V. CONCLUSIONS

This paper has proposed a slotted random access protocol with a dynamic transmission probability control scheme. The design objective of the proposed scheme is to improve the system throughput and delay performance. In the proposed scheme, the base station dynamically determines the packet transmission probability of mobile stations according to the offered load and then broadcasts it to all the mobile stations.

Simulation results have showed that the proposed scheme maintains the number of simultaneously transmitted packets at the optimum threshold, which can achieve the maximum throughput of spread spectrum system. The throughput and delay performance of the proposed scheme have outperformed by far those obtained with the conventional scheme.

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