Proportional Backoff Scheme for Data Services in TDMA-based Wireless Networks

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***Abstract*—This paper proposes a backoff control scheme for guaranteeing fair packet transmissions in TDMA wireless networks. In order to maximize the system performance, the number of packets transmitted in a frame should be kept at a proper level. In the proposed scheme, the base station calculates the packet transmission probability according to the offered loads and then broadcasts to all the mobile stations. Mobile stations attempt to transmit a packet with the received probability. Simulation results show that the proposed scheme can offer better system throughput and delay performance than the conventional one regardless of the offered loads.**

***Index Terms*—MAC protocol, Backoff algorithm, TDMA system, Transmission probability**

I. INTRODUCTION

A major issue related to the realization of wireless packet networks is the design of a medium access control (MAC) protocol. The MAC protocol should efficiently and equitably allocate the scarce radio resources among the competing mobile stations. It also has to be designed to maximize the multiplexing gain over the radio interface [1][2].

The MAC protocols that have been proposed in the literature [3]-[6] are usually classified according to the scheme used to assign uplink data slots: contention, reservation, and polling. However, almost all the adapted methods for data services are based on a contention method [3]. Since the mobile stations change their state from active to idle and vise versa, the scheduler must exactly know the state of each terminal to avoid assigning vain uplink slots to idle stations.

In frame-based time division multiple access (TDMA) wireless networks, mobile stations transmit a packet with a given transmission probability. If the number of mobile stations that attempt to transmit their packets in a frame increases above a frame length, the packets received by the base station may collide. If the number of packets in a frame 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 attempting mobile stations needs to be limited with the use of backoff control scheme.

There are some researches for the backoff control aiming at improving the system throughput [7-10]. In these researches, the mobile station decreases its transmission probability when it fails in transmission. Continuously decreasing the transmission probability, a specific mobile station restricts excessively its transmission. As a result, the system throughput can be degraded, the transmission delay can be increased, and moreover, fairness between mobile stations cannot be guaranteed.

This paper is intended to improve the throughput and delay performance for data services in a frame-based TDMA wireless network. For these purposes, this paper proposes a backoff control scheme for TDMA packet radio networks. In the proposed scheme, the base station controls the transmission probability of mobile stations based on the traffic loads.

This paper is organized as follows. Section II describes the system model for the proposed scheme. The proposed backoff control scheme is explained in Section III, and simulation results are presented in Section IV. Concluding remarks are presented in Section V.

II. SYSTEM MODEL

Fig.1 shows the system model for the proposed scheme. The system consists of a base station and K mobile stations, each with an infinite buffer capacity. Each packet has a fixed length of L bits, which is equal to slot duration. Each mobile station synchronizes their transmissions so that they transmit their packets at the beginning of each slot. A TDMA frame consists of N time slots. Every mobile station generates a packet in each frame 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.

Fig.2 shows the operation mode of mobile station. As depicted in Fig.2, all the mobile stations may be in one of three different operation states: idle state, contention (CON) state, and retransmission (RETX) state.

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 attempts to transmit its packet at a slot of next frame with a given transmission probability P_n. A slot is selected randomly among N slots with equal probability. The mobile stations are informed as to whether or not the transmitted packets are received

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successfully by the base station in the form of acknowledgement. The mobile station that experiences a packet error or does not permitted in transmission enters into the retransmission state, and retransmits it at the next frame with a given retransmission probability P_r. After the packet is transmitted successfully, it 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.

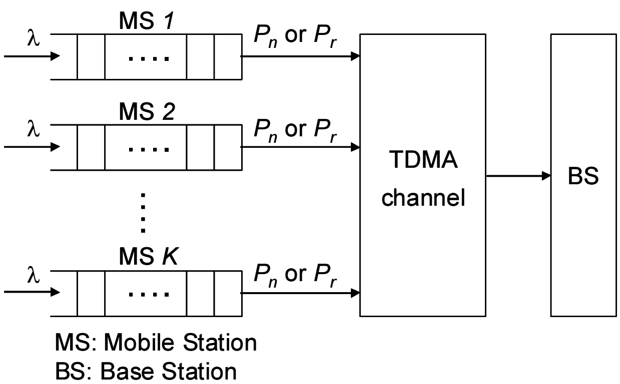

Fig.1. System model.

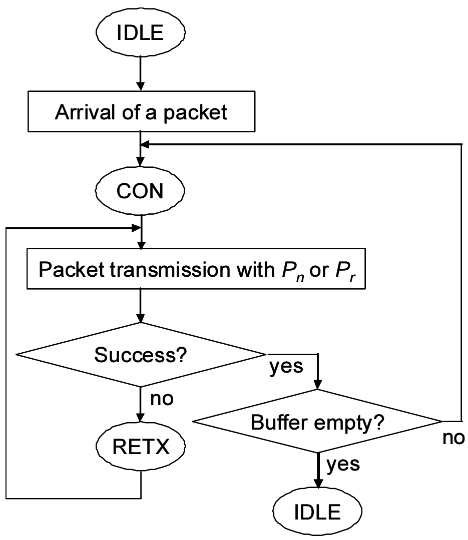

Fig.2. Operation mode of mobile station.

III. PROPORTIONAL BACKOFF SCHEME

The system model of backoff control scheme, named as the Proportional Backoff (PB) scheme, is presented in Fig.3. 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 load and broadcasts over an error-free downlink control channel.

The mobile station that fails in transmission of its packet at frame t will retransmit with $P_r(t+1)$ at the next frame $(t+1)$, while the mobile station that enters into the contention state at frame t will transmit with $P_n(t+1)$ at subsequent frame. The $P_n(t+1)$ and $P_r(t+1)$ are calculated as follows:

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

$$P_r(t+1) = \begin{cases} 1, & \text{if } N_r(t+1) \le N \\ \dfrac{N}{N_r(t+1)}, & \text{otherwise} \end{cases} \quad (2)$$

where N is the number of slots in a frame, and $N_r(t+1)$ is the number of mobile stations in the retransmission state at frame $(t+1)$. Let $N_f(t)$ be the number of unsuccessful mobile stations at frame t, and $N_b(t)$ the number of mobile stations not permitted at frame t. Then $N_r(t+1)$ can be derived as follows:

$$N_r(t+1) = N_f(t) + N_b(t) \quad (3)$$

In the above equation, $N_b(t)$ is given by

$$N_b(t) = N_n(t-1)\{1 - P_n(t)\} + N_r(t)\{1 - P_r(t)\} \quad (4)$$

In Eq.(4), $N_n(t)$ is the number of mobile stations that enter into the contention state at frame t, and can be derived by

$$N_n(t) = \{K - N_r(t) - N_n(t-1)\} \cdot \lambda \quad (5)$$

In (5), K is the number of registered mobile stations in the system, and λ is the probability that a mobile station generates a packet in each frame. The base station cannot exactly know how many packets are generated in one frame. Therefore, λ is computed using a moving time average number of new packets that are successfully received.

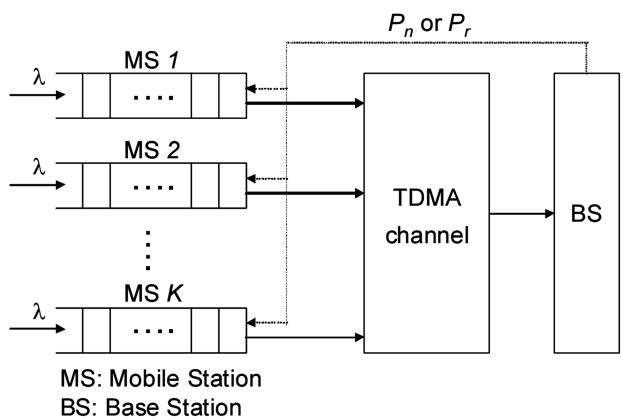

Fig.3. System model of backoff control scheme.

In the proposed scheme, if the number of mobile stations in the retransmission state is less than the number of slots in s frame, all 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 the number of slots in a frame, 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 packets that are retransmitted becomes N, in order to minimize the transmission delay.

IV. SIMULATION RESULTS

In this section, we compare the proposed scheme with other algorithm by evaluating them through the computer simulations. The simulation program was developed with the SMPL libraries [11] and Microsoft Visual C++ 6.0. For simulation, it is assumed that the total number of mobile stations is 1,000, and each mobile station generates packets according to the Poisson process. It is assumed that a frame consists of 10 slots. Also, we assume that the length of window used for computing the moving time average of packet arrival rate is set to 1,000 frames.

The performance measures of interest are the system throughput, average delay, and throughput fairness index. The system throughput is defined as the number of successfully transmitted packets during one frame. The average delay is defined as the average time between the arrival of packet and its successful reception at the base station. And the throughput fairness index is defined as follows [12]:

$$Fairness = \frac{\left(\sum_{i=1}^{K} Y_i / Z_i\right)^2}{K \sum_{i=1}^{K} \left(Y_i / Z_i\right)^2} \tag{6}$$

where Y_i and Z_i are the measured throughput and the fair share throughput of mobile station i, respectively, and K is the total number of mobile stations in the system.

In this paper, the performance of proposed PB scheme is compared with the existing Harmonic Backoff (HB) scheme [7][8]. In HB scheme, the mobile station that fails in transmission 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

$$P_{i+1} = \frac{1}{P_i + 1}, i \geq 1 \tag{7}$$
$$P_1 = 1$$

The average delay and throughput according to the offered load are shown in Fig.4, and Fig.5, respectively. In HB scheme, mobile stations that are generated a new packet transmit their packet unconditionally. Therefore, the mobile station in the retransmission state continuously decreases the transmission probability due to the packet collision, and moreover, the transmission probability of specific mobile station becomes excessively decreased.

From Fig.4 and Fig.5, PB scheme gives better performance than HB scheme. The reasons are as follows: i) PB scheme can control the number of transmitted packets more precisely than HB scheme; ii) in the PB scheme, the base station does not permit the transmission of new packets in case of the heavy traffic load.

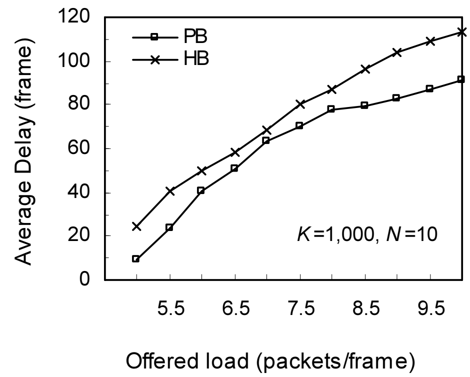

Fig.4. Average delay according to offered load.

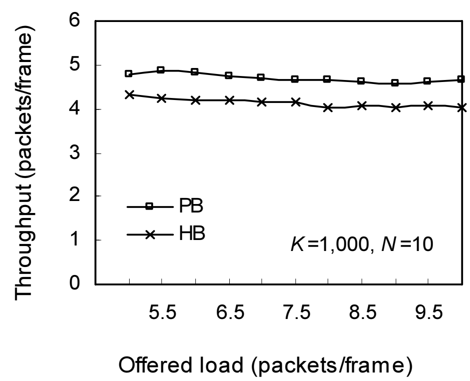

Fig.5. Throughput according to offered load.

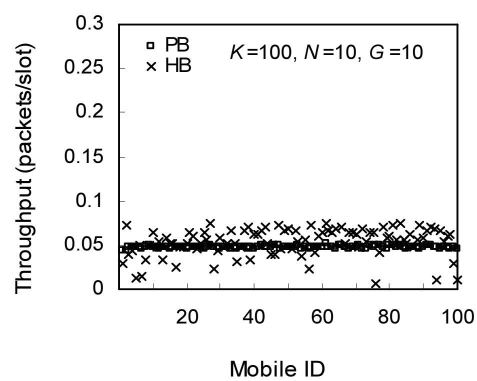

Fig.6. Throughput of each mobile station (G=10).

Fig.6 and Fig.7 demonstrate the throughput of each mobile station when the offered load (G) is 10 and 50, respectively. With the light traffic load i.e. G=10, there is no significant difference in the throughput of each mobile station. As shown in Fig.6, both schemes provide a good fairness when the offered load is low. In HB scheme, the mobile stations in the retransmission state continuously decrease the transmission probability, while the mobile stations in the contention state transmit their packet with the probability P_1. Therefore, the mobile stations in the contention state are permitted to transmit their packet prior to the mobile stations in the retransmission state. On the other hand, in PB scheme, when the number of mobile stations in the retransmission state is more than the number of slots in a frame, the mobile stations in the contention state are not permitted to transmit a packet. Therefore, as shown in Fig.6, the proposed PB scheme provides fairer throughput for each mobile station than HB scheme when the offered load is high.

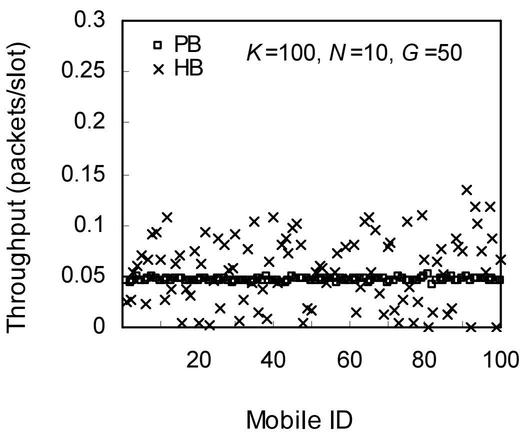

Fig.7. Throughput of each mobile station (G=50).

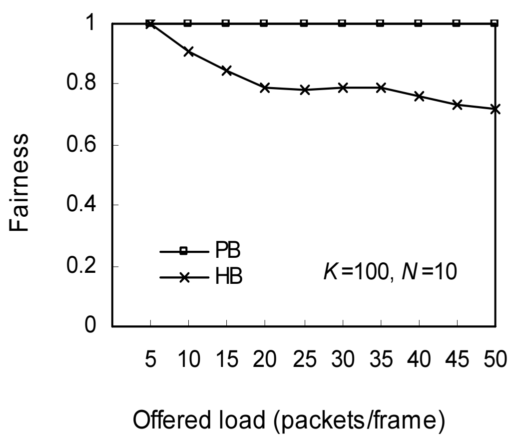

Fig.8. Fairness index according to offered load.

Fig.8 compares the fairness index according to the offered load. The fairness index of HB scheme decreases sharply when the offered load increases. However, the proposed PB scheme maintains the fairness index into almost 1 regardless of the offered load. Therefore, PB scheme can guarantee fair packet transmissions to all the mobile stations even though the offered load increases.

V. CONCLUSIONS

This paper has proposed a backoff control scheme for frame-based TDMA packet radio networks. The design objective of proposed scheme is to improve the system throughput and delay performance, and to guarantee the fairness among all the mobile stations. In the proposed scheme, the base station determines the packet transmission probability of mobile stations according to the offered load and then broadcasts to all the mobile stations.

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