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ON ADAPTIVE CONTROL OF MOBILE SLOTTED ALOHA NETWORKS

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An adaptive control scheme for mobile slotted ALOHA is presented and the effect of capture on the adaptive control scheme is investigated. It is shown that with the proper choice of adaptation parameters the adaptive control scheme can be made independent of the effect of capture.

KEYWORDS: Mobile slotted ALOHA, adaptive control, effect of capture

1. INTRODUCTION

Mobile radio networks are employing a multiple access protocol based on slotted ALOHA [1]–[2]. Though the maximum achievable throughput of the slotted ALOHA is e^{-1}, its performance is degraded by the saturation phenomenon caused by the inherent bistable behavior [3]–[4]. Adaptive control schemes utilizing feedback information [5]–[6] are proposed to maximize the steady state throughput. However, in mobile slotted ALOHA, there is the effect of capture, that is, a packet with the strongest signal may be successfully transmitted in the presence of colliding packets due to fading, shadowing, and spatial distribution of mobile users [1]–[2], [7]–[8]. This effect can substantially improve the throughput of adaptive mobile slotted ALOHA.

In this paper, we apply the framework of [9] to mobile radio networks and investigate the effect of capture on adaptive mobile slotted ALOHA networks with a finite number of buffered users. To avoid duplications, the results of [9]–[10], utilized in this paper, are referred to rather than repeated anew. The reader might want to consult [9]–[10] while reading this paper.

2. ADAPTIVE MOBILE SLOTTED ALOHA

Consider the slotted ALOHA network defined by the following assumptions:

(a) the channel propagation delay is zero,
(b) transmission of a packet across a channel requires a unit interval of time,

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(c) the network consists of $1 << M < \infty$ users communicating through the collision channel; every user has a buffer capable of storing $1 \le N < \infty$ packets, and generates a packet with probability p_a during each time slot $[n,n+1)$,

(d) if a packet is generated by a user having its buffer full, the newly generated packet is rejected; otherwise, it is stored in the first empty cell of the buffer,

(e) if a positive acknowledgement is received by an active user at time $n+1$, the packet transmitted during $[n,n+1)$ is eliminated from the first cell of its buffer and a packet stored in its mth cell, $m = 2, ..., N$, instantaneously moves down to be stored in cell $m-1$.

The main specificity of adaptive mobile slotted ALOHA is that i) the retransmission probability, p, is adjusted according to the feedback information, ii) the signal power difference among packets transmitted simultaneously allows a packet with the strongest signal to be successfully transmitted.

To account for this situation, introduce the following additional assumptions:

(f) every user that has at least one packet attempts a transmission at the beginning of time slot $[n,n+1)$ with probability $p(n)$ where

$$p(n+1) = \begin{cases} \max\{ p(n) - \frac{1}{M}\alpha_1, 0\} & \text{if there was a collision} \\ & \text{during } [n,n+1) \\ \min\{ p(n) + \frac{1}{M}\alpha_2, 1\} & \text{otherwise} \end{cases} \quad (1)$$

and α_i, = 1,2 is a positive constant to be chosen,

(g) if two or more packets are transmitted simultaneously during $[n,n+1)$, one packet can be successfully transmitted during $[n,n+1)$ with probability r due to the effect of capture; without losing much generality, it is assumed that $0 \le r \le 0.7$.

3. ASYMPTOTIC ANALYSIS

The network defined by (a)–(g) represents a process of slow-in-the-average Markov walks [10]. Applying the asymptotic theory for analysis of such processes [9]–[10], we obtain the following: Let y_{is}, $i = 1, ..., N$, denote the steady state value of the averaged normalized occupancy of the ith layer of buffers, and q_s denote the steady state value of the averaged retransmission probability. Then

$$y_{is} = y_{1s}\frac{y_{(i-1)s} - y_{N_s}}{1 - y_{N_s}}$$

$$(1 - y_{n_s})Mp_a = F(y_{1s}, q_s) \quad (2)$$

where $F(y_{1s}, q_s) = F_1(y_{1s}, q_s) + r(1 - F_0(y_{1s}, q_s) - F_1(y_{1s}, q_s))$, $F_0(y_{1s}, q_s) = (1-q_s)^{My_{1s}}$, $F_1(y_{1s}, q_s) = My_{1s}q_s(1-q_s)My_{1s}-1$. Eq. (2) coincides with eq. (20) in [9] with the only difference that $F_1(y_{1s})$ is substituted by $F(y_{1s}, q_s)$. Thus the intersections of that load line $(1 - y_{Ns})Mp_a$ and the transmission line $F(y_{1s}, q_s)$ define the steady state and their stability [9].

The problem of adaptive mobile slotted ALOHA is how to choose the adaptation parameters, α_i, $i = 1,2$, so that the steady state throughput is maximized. From (1), α_i's should be chosen to satisfy

$$0 < \alpha_2 = \frac{\alpha_1(1 - F_0(y_{1s}, q_s) - F_1(y_{1s}, q_s))(1 - r)}{1 - (1 - F_0(y_{1s}, q_s) - F_1(y_{1s}, q_s))(1 - r)} \tag{3}$$

Since $M >> 1$, $F_0(y_{1s}, q_s) \simeq e^{-My_{1s}q_s}$, $F_1(y_{1s}, q_s) \simeq My_{1s}q_s e^{-My_{1s}q_s}$. Thus

$$F(y_{1s}, q_s) \simeq Ge^{-G} + r(1 - e^{-G} - Ge^{-G}) \tag{4}$$

where $G = My_{1s}q_s$. From (4), it is noted that $F(y_{1s}, q_s)$ reaches its maximum with respect to q_s, if

$$q_s = \frac{1}{My_{1s}(1 - r)} \tag{5}$$

As it follows from (3), (4), and (5), the required α_i's become

$$0 < \alpha_2 = k\alpha_1, \quad k = \frac{(1 - e^{-\frac{1}{1-r}} - \frac{1}{1-r}e^{-\frac{1}{1-r}})(1 - r)}{1 - (1 - e^{-\frac{1}{1-r}} - \frac{1}{1-r}e^{-\frac{1}{1-r}})(1 - r)} \tag{6}$$

The choice of α_i's depends on the value of r which may be unknown. In order to eliminate this dependency, investigate the coefficient of α_i in (6) with respect to r. Taking into account that $0 \leq r \leq 0.7$, from (6), we obtain that $0.33 < k < 0.43$ $\forall r \in [0, 0.7]$. Let

$$0 < \alpha_2 = 0.38\alpha_1, \qquad \forall r \in [0, 0.7] \tag{7}$$

Then, from (1) and (7),

$$q_s = \frac{1}{My_{1s}(1 - \hat{r})} \tag{8}$$

where $\hat{r}$ is calculated from the following condition obtained from (3), (4), (7), and (8):

$$(1 + \frac{1}{1 - \hat{r}})e^{-\frac{1}{1-\hat{r}}} = \frac{1 - 1.38r}{1.38 - 1.38r} \tag{9}$$

Fig. 1 shows the relationship between r and $\hat{r}$. The steady state throughput of adaptive mobile slotted ALOHA with αi's according to (6) is

$$F(y_{1s}, q_s) \simeq \frac{1}{1 - r}e^{-\frac{1}{1-r}} + r(1 - e^{-\frac{1}{1-r}} - \frac{1}{1 - r}e^{-\frac{1}{1-r}}) \tag{10}$$

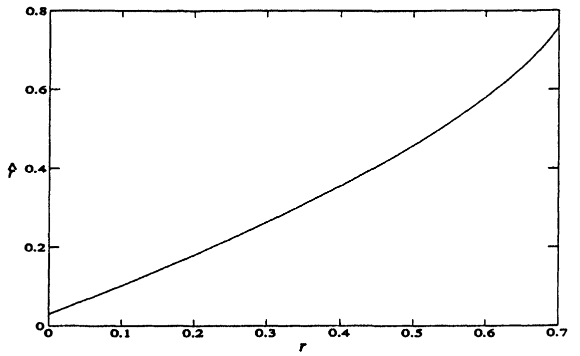

Figure 1. Relationship between r and $\hat{r}$.

whereas the steady state throughput of adaptive mobile slotted ALOHA with α_i's according to (7) is

$$F(y_{1s}, q_s) \simeq \frac{1}{1-\hat{r}} e^{-\frac{1}{1-\hat{r}}} + r\left(1 - e^{-\frac{1}{1-\hat{r}}} - \frac{1}{1-\hat{r}} e^{-\frac{1}{1-\hat{r}}}\right) \tag{11}$$

Fig. 2 shows the steady state throughputs of adaptive mobile ALOHA with α_i's according to (6) and (7). As it follows from Fig. 2, the degradation of the steady state throughput due to the unknown r is negligible. In most cases, r is unknown. Therefore, in such cases, it seems reasonable to choose α_i's according to (7).

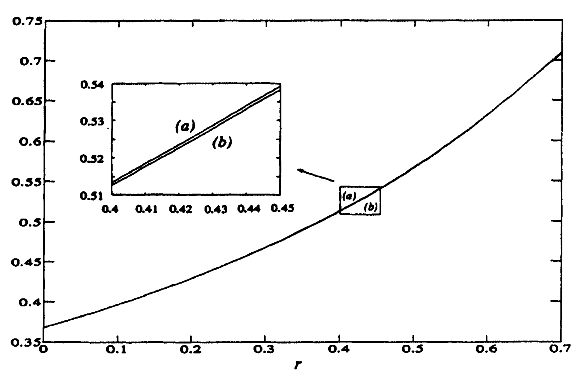

Figure 2. Steady state throughput of adaptive mobile slotted ALOHA. (a) Adaptation parameters according to (6); (b) Adaptation parameters according to (7).

4. CONCLUSIONS

In this paper, the effect of capture on adaptive mobile slotted ALOHA is investigated. It is shown that the steady-state throughput can be maximized by choosing the adaptation parameters according to (6) that depends on the capture probability. It is also shown that this dependency can be eliminated with the negligible throughput degradation by choosing the adaptation parameters according to (7).

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