An Adaptive Multi-Queue Service Room Protocol for Wireless Networks with Multipacket Reception

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Abstract

An adaptive medium access control (MAC) protocol for heterogeneous networks with finite population is proposed. Referred to as the Multi-Queue Service Room (MQSR) protocol, this scheme is capable of handling users with different Quality-of-Service (QoS) constraints. By exploiting the multipacket reception (MPR) capability, the MQSR protocol adaptively grants access to the MPR channel to a number of users such that the expected number of successfully received packets is maximized in each slot. The optimal access protocol avoids unnecessary empty slots for light traffic and excessive collisions for heavy traffic. It has superior throughput and delay performance as compared to, for example, the slotted Aloha with the optimal retransmission probability. This protocol can be applied to random access networks with multimedia traffic.

1 Introduction

In multiaccess wireless networks where a common channel is shared by a population of users, a key issue, referred to as medium access control (MAC), is to coordinate the transmissions of all users so that the common channel is efficiently utilized and the Quality-of-Service (QoS) requirement of each user is satisfied. The schemes for coordinating transmissions are called MAC protocols.

Based on the assumption of homogeneous QoS constraints and a collision channel model where concurrent transmission of two or more packets results in the destruction of all the transmitted information, numerous MAC protocols, such as Aloha [1, 13], tree algorithm [4], first come first serve algorithm [6], and a class of adaptive schemes [12, 3, 10, 9], have been proposed. However, with the development of spread spectrum, space-time coding, and new signal processing techniques, this collision channel model does not hold in many important practical communication systems where one or more packets can be successfully received in the presence of other simultaneous transmissions. For instance, the capture phenomenon is

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common in local area radio networks. Other examples include networks using CDMA and/or antenna array along with multiuser detection techniques.

This new channel model which offers the capability of multipacket reception (MPR) presents a new challenge for the design of MAC protocols. Some researchers have considered the issue of extending existing MAC protocols to channels with MPR capability. In [5, 11], the contention free scheme TDMA is extended to a fully connected half-duplex ad hoc network with total P conventional collision channels. In [7, 8], the performance of slotted Aloha for MPR channels with infinite population is analyzed. In [14], the authors propose a dynamic queue protocol designed explicitly for channels with MPR capability. However, these protocols still assume homogeneous QoS constraints among all users, which may not hold in multimedia networks.

In this paper, we propose a MAC protocol for networks with MPR capability and heterogeneous QoS requirements. In particular, we consider a finite population of users whose QoS requirement is characterized by the packet delay at the heaviest traffic load. Since, in general, packet delay increases with the traffic load, this delay constraint specifies the worst case performance of the network. Our goal is to design a MAC protocol that maximizes the expected number of successfully received packets in each slot while ensuring each user's QoS requirement. To satisfy the heterogeneous delay constraints, users are assigned with different priorities for accessing the channel. According to their priorities, an appropriate subset of users who gain access to the channel are chosen at the beginning of each slot so that the expected number of successfully received packets is maximized in each slot. As a consequence, significant improvement in throughput and delay performance over existing MAC schemes such as slotted Aloha with optimal retransmission probability is achieved by the proposed protocol.

2 The Problem Statements

2.1 The Model

We consider a communication network with M users who transmit data to a central controller through a common channel. Each user generates data in the form of equal-sized packets. Transmission time is slotted and each packet requires one time slot to transmit. Each user has a single buffer. At the beginning of each slot, a user independently generates a packet with probability p, but only accepts this packet if its buffer is currently empty. A packet generated at the beginning of a slot may be transmitted in this slot, and a successfully transmitted packet leaves its buffer. Packets generated by a user with a full buffer are assumed lost.

Users are partitioned into L groups according to their QoS constraints. The M_l ($l = 1, \cdots, L, \sum_{l=1}^{L} M_l = M$) users in the lth group require their packet delay at $p = 1$ no greater than d_l, where we define packet delay as the expected number of slots from the time a packet enters a buffer until the end of its successful transmission.

The slotted channel is such that the probability of having k successes in a slot where there are n transmissions depends only on the number of transmitted packets

$$C_{n,k} = \mathsf{P}[k \text{ packets are correctly received} \mid n \text{ are transmitted}] \; (1 \le n \le M, 0 \le k \le n).$$

The multipacket reception matrix of the channel is then defined as

$$\mathbf{C} = \begin{pmatrix} C_{1,0} & C_{1,1} & & & \\ C_{2,0} & C_{2,1} & C_{2,2} & & \\ \vdots & \vdots & \vdots & & \\ C_{M,0} & C_{M,1} & C_{M,2} & \cdots & C_{M,M} \end{pmatrix}. \tag{1}$$

For such an MPR channel, we define the channel capacity as

$$\eta \triangleq \max_{n=1,\cdots,M} \mathcal{C}_n, \tag{2}$$

where

$$\mathcal{C}_n \triangleq \sum_{k=1}^{n} k C_{n,k} \tag{3}$$

is the expected number of packets correctly received when n packets are transmitted. Let

$$n_0 \triangleq \min\{\arg \max_{n=1,\cdots,M} \mathcal{C}_n\}. \tag{4}$$

We can see that at heavy traffic load, n_0 packets should be transmitted simultaneously to achieve the channel capacity η. Noticing that the number of simultaneously transmitted packets for achieving η may not be unique, we define n_0 as the minimum to save transmission power. For MPR channels with n_0 greater than 1, contention should be preferred at any traffic load in order to fully exploit the channel MPR capability.

This general model for MPR channels, also considered in [7, 8, 2], applies to the conventional collision channel and channels with capture as special examples. The reception matrix of the conventional collision channel and channels with capture are given by

$$\begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ 1 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & 0 & 0 & \cdots & 0 \end{pmatrix}, \quad \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ 1-p_2 & p_2 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 1-p_M & p_M & 0 & \cdots & 0 \end{pmatrix}, \tag{5}$$

where p_i is the probability of capture given i simultaneous transmissions.

We assume that the central controller can distinguish without error between empty and nonempty slots. Furthermore, if some packets are successfully demodulated at the end of a slot, the central controller can identify the source of these packets and inform their sources so that their buffers can be released. However, if at least one packet is successfully demodulated at the end of a slot, the central controller does not assume the knowledge whether there are other packets transmitted in this slot but not successfully received. We illustrate this point in Figure 1 where we consider possible outcomes of a slot: empty, nonempty with success, and nonempty without success (successfully received packets are illustrated by shaded rectangles). To the central controller, the two events happened in the third and forth slots are indistinguishable.

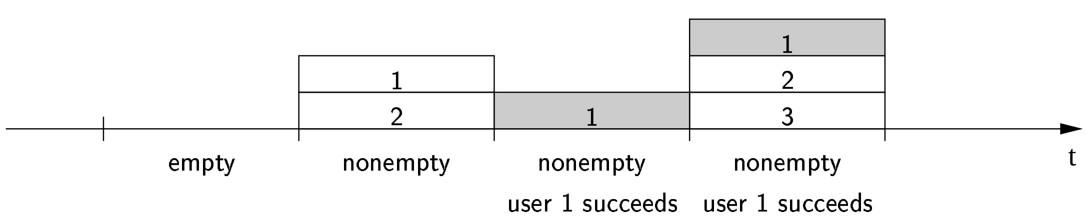


Figure 1: Possible Outcomes of A Slot

2.2 The Problem

Our goal here is to design a MAC protocol for an MPR channel so that the expected number of successfully received packets in each slot is maximized under the constraint that the packet delay D_l of the lth group at $p = 1$ is no larger than d_l for $l = 1, \cdots, L$. Before pursuing the protocol design, we give the necessary and sufficient condition for the existence of a MAC protocol with such delay constraints.

Proposition 1 *Let M_l $(l = 1, \cdots, L)$ be the number of users who require their packet delay at $p = 1$ no larger than d_l. Then there exists a MAC protocol that guarantees each user's delay requirement if and only if*

$$\sum_{l=1}^{L} \frac{M_l}{d_l} \leq \eta, \tag{6}$$

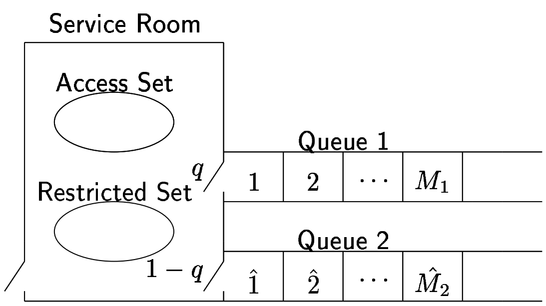
where η is the channel capacity.

3 The Multi-Queue Service Room Protocol

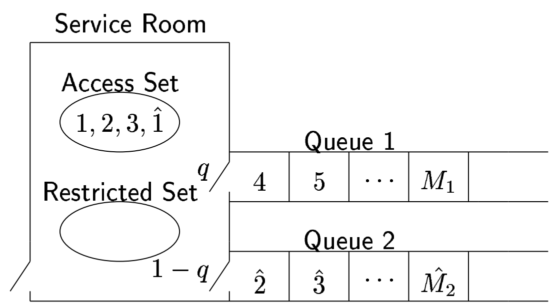
3.1 The Basic Structure

We develop the multi-queue service room (MQSR) protocol for the case of $L = 2$, where users in the first group require $D_1 \leq d_1$. Its extension to cases with $L > 2$ is straightforward.

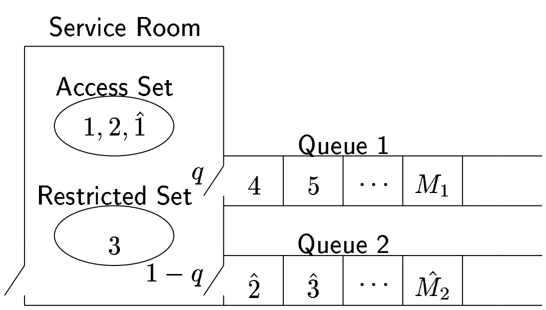
We illustrate the basic procedure of the MQSR protocol in Figure 2, where users from the second group are indicated by $\hat{i}$ $(i = 1, \cdots, M_2)$. As shown in Figure 2-A, users of the two



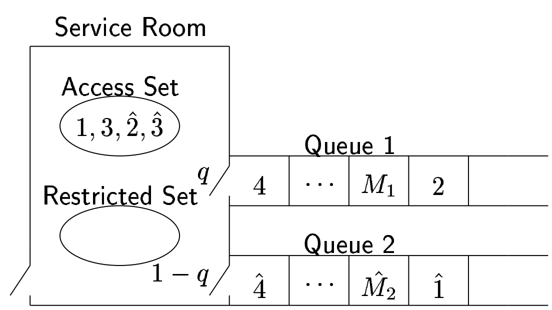
A.



B. $K(1) = 4$
$K_1(1) \sim B(q, K) = 3,\ K_2(1) = K(1) - K_1(1) = 1$
Outcome: nonempty, no one succeeds; $\mathcal{P}(1) = \phi$



C. $K(2) = 3$
$K_1(2) \sim B(q, K) = 2,\ K_2(2) = K(2) - K_1(2) = 1$
Outcome: user 2, $\hat{1}$ succeed; $\mathcal{P}(2) = \{2, \hat{1}\}$



D. $K(3) = 4$
$K_1(3) \sim B(q, K) = 2, K_2(3) = K(3) - K_1(3) = 2$
Outcome: empty; $\mathcal{P}(3) = \{1, 3, \hat{2}, \hat{3}\}$

Figure 2: The Basic Procedure of the Multi-Queue Service Room Protocol.

groups are waiting, respectively, in two queues to enter the service room. Users in the service room may transmit packets generated before they enter the service room. Packets generated by a user inside the service room are held in the user's buffer (if the buffer is empty) and can not be transmitted until the next time this user enters the service room. After entering the service room, a user stays there until the central controller detects that this user has been processed, *i.e.,* it has no packet to transmit. At this time, this user leaves the service room and goes to the end of its queue.

At the end of slot t, the central controller first determines the set, denoted by $\mathcal{P}(t)$, of processed users of slot t. After removing the processed users from the service room, the central controller decides the size $K(t+1)$ of the access set which consists of users who gain access to the channel in slot $t+1$. With probability q, a user who joins the access set is from the first group, and with probability $1-q$, it is from the second group. Let $K_l(t+1)$ $(l=1,2)$ be the number of users from the lth group who will access the channel in slot $t+1$. Then $K_1(t+1)$ obeys a binomial distribution with $K(t+1)$ trials and a success probability q (denoted by $K_1(t+1) \sim B(q, K(t+1))$), and $K_2(t+1) = K(t+1) - K_1(t+1)$. Let $\alpha_l(t)$ $(l=1,2)$ be the number of users from the lth group who remain in the service room after processed users have been removed from the service room at the end of slot t. Then, if $K_l(t+1) > \alpha_l(t)$, the first $K_l(t+1) - \alpha_l(t)$ users in Queue l enter the service room and join the access set at the beginning of slot $t+1$ (see Figure 2-B and D). On the other hand, if $K_l(t+1) < \alpha_l(t)$, the last (according to their time of entering the service room) $\alpha_l(t) - K_l(t+1)$ users from the lth group join the restricted set at the beginning of slot $t+1$ (see Figure 2-C). Users in the restricted set remain in the service room, but they can not access the channel in current slot.

After specifying the basic structure of the MQSR protocol, we now consider parameters that remain to be designed. The first parameter to be determined is q, an indicator of the priority of users in the first group over users in the second group. Since q is constant for each slot, it can be designed off line. The two parameters to be determined on line are $K(t)$, the size of the access set for slot t, and $\mathcal{P}(t)$, the processed set of slot t. The problem of choosing q and determining $K(t)$ for each t is formulated in Section 3.2 and the determination of $\mathcal{P}(t)$ is detailed in Section 3.4.

We point out that the optimal window protocol proposed in [10] has a similar structure as the MQSR protocol proposed here. Relying on exhaustive search, however, the window protocol is only computationally feasible for networks with 2 or 3 users and no MPR. Furthermore, homogeneous QoS constraints are assumed by this protocol.

3.2 Problem Formulation

Let $X_i^{(l)}(t)$ $(l=1,2,\ i=1,\cdots,M_l)$ be the number of packets held by user i in the lth group that may be transmitted in slot t. To the central controller, $X_i^{(l)}(t)$ is a random variable with possible values of 0 and 1. Let $\mathcal{A}(t)$ denote the access set for slot t. We have

$$\mathcal{A}(t) = \{1, \cdots, K_1(t)\} \bigcup \{\hat{1}, \cdots, \hat{K}_2(t)\}, \tag{7}$$

where $\hat{i}$ indicates the ith user of the second group and we assume users of the lth group are relabeled at the beginning of each slot, starting from the service room to the end of the lth queue. Let $F(t)$ be the outcome of slot t, which contains information on whether slot t is empty and whose packets are successfully received in slot t (see Figure 1). Denoted by $I_{[1,t-1]}$, the information available for determining $K(t)$ at the beginning of slot t is the initial condition of the network in the form of the distribution of $X_i^{(l)}(1)$ $(l=1,2,\ i=1,\cdots,M_l)$, the access sets $\mathcal{A}(1), \cdots, \mathcal{A}(t-1)$ for previous slots, and the outcomes $F(1), \cdots, F(t-1)$ of previous slots.

Finally, let $S(t)$ denote the number of successfully transmitted packets in slot t. It is a random variable whose distribution conditioned on $I_{[1,t-1]}$ depends on $\mathcal{A}(t)$ and the channel MPR matrix $\mathbf{C}$.

We are now ready to formulate the problem of determining q and $K(t)$ for each t.

Given $\mathbf{C}$ and p, determine q and $K(t)$ for each t based on $I_{[1,t-1]}$ by solving the following constrained optimization problem:

$$\{q, K(t)\} = \arg \max_{\substack{K(t)=1,\cdots,M, \\ K_1(t) \sim B(q,K(t)), \\ K_2(t)=K(t)-K_1(t)}} E[S(t) \mid (K_1(t), K_2(t)),\ I_{[1,t-1]}] \text{ subject to } D_1 \leq d_1, \quad (8)$$

where $K_1(t)$ is a realization of the binomial distribution with parameters q and $K(t)$, and $E[S(t) \mid (K_1(t), K_2(t)),\ I_{[1,t-1]}]$ is the expected number of successfully transmitted packets given $I_{[1,t-1]}$ and $\mathcal{A}(t)$ which consists of the first $K_l(t)$ $(l = 1, 2)$ users of the lth group.

This constrained optimization problem can be decoupled into two steps. We first choose q so that the delay constraint $D_1 \leq d_1$ is satisfied. Then with q determined, choose $K(t)$ for each t so that $E[S(t) \mid I_{[1,t-1]}]$ is maximized. These two steps are detailed in, respectively, Section 3.3 and Section 3.5.

3.3 The Determination of q

At $p = 1$, every user has a packet to transmit at the beginning of each slot. To maximize $E[S(t) \mid I_{[1,t-1]}]$, we should choose $K(t) = n_0$ for each t. In this case, the throughput T, defined as the expected number of successfully transmitted packets in one slot, achieves the channel capacity η. Let T_1 denote the throughput for users in the first group, *i.e.*, the expected number of packets from the first group that are successfully received in one slot. We can show that q is the ratio of T_1 to the overall throughput η, *i.e.*,

$$q = \frac{T_1}{\eta}. \quad (9)$$

Furthermore, for a network where users have homogeneous and independent traffic load, we have the following relation between throughput and delay under equilibrium condition [10]:

$$D_1 = 1 + \frac{M_1}{T_1} - \frac{1}{p}. \quad (10)$$

Since $p = 1$ in our definition of D_1 and T_1, we have

$$D_1 = \frac{M_1}{T_1}. \quad (11)$$

Thus, $D_1 \leq d_1$ implies $T_1 \geq M_1/d_1$. From (9) we then have

$$q \geq \frac{M_1}{d_1 \eta}. \quad (12)$$

To avoid the second group making unnecessary sacrifice, we choose

$$q = \frac{M_1}{d_1 \eta}. \quad (13)$$

3.4 The Determination of the Processed Set

At the end of slot t, the central controller needs to determine the processed set $\mathcal{P}(t)$. By definition, $\mathcal{P}(t)$ is a subset of $\mathcal{A}(t)$. It consists of users whose packets are successfully transmitted in slot t and users who the central controller can assert have an empty buffer upon entering the service room. Let $X_i^{(l)}(t^+)$ $(l=1,2,i=1,\cdots,K_l(t))$ denote the number of packets held by the ith user of the lth group at the end of slot t after successfully transmitted packets have been removed from their buffer. We then have

$$\begin{aligned}\mathcal{P}(t) = \quad & \{i:\ 1\leq i\leq K_1(t),\ E[X_i^{(1)}(t^+)\mid I_{[1,t]}]=0\}\\ & \bigcup\{\hat{i}:\ 1\leq i\leq K_2(t),\ E[X_i^{(2)}(t^+)\mid I_{[1,t]}]=0\}.\end{aligned} \tag{14}$$

We now consider evaluating $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]$. If slot t is empty, we readily have $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]=0$ for $l=1,2$ and $i=1,\cdots,K_l(t)$, and

$$\mathcal{P}(t)=\mathcal{A}(t). \tag{15}$$

If, on the other hand, slot t is nonempty and $s_i^{(l)}$ packets from the ith user of the lth group are successfully received at the end of slot t, we have $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]=0$ for $(i,l)\in\{(i,l):s_i^{(l)}=1\}$. However, it is also possible that $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]=0$ for some (i,l) with $s_i^{(l)}=0$ (consider, as an extreme example, the conventional channel; one successful transmission implies that other users in the access set do not have packets). In order to evaluate $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]$ for $\{(i,l):\ s_i^{(l)}=0\}$, we compute the conditional joint distribution of $\{X_i^{(l)}(t^+),\ l=1,2,\ i=1,\cdots,N_l(t)\}$, where $N_l(t)$ is the number of users from the lth group that are inside the service room in slot t. For $0\leq x_i^{(l)}\leq 1-s_i^{(l)}$ $(l=1,2,\ i=1,\cdots,N_l(t))$, we have,

$$\begin{aligned}& P[\{X_i^{(l)}(t^+)=x_i^{(l)},\ l=1,2,\ i=1,\cdots,N_l(t)\}\mid I_{[1,t]}]\\ &= \frac{P[\{X_i^{(l)}(t^+)=x_i^{(l)},\ l=1,2,\ i=1,\cdots,N_l(t)\},\ F(t)\mid \mathcal{A}(t),\ I_{[1,t-1]}]}{P[F(t)\mid\mathcal{A}(t),\ I_{[1,t-1]}]}\\ &= \frac{C_{z,S}P[\{X_i^{(l)}(t)=x_i^{(l)}+s_i^{(l)},\ l=1,2,\ i=1,\cdots,N_l(t)\}\mid I_{[1,t-1]}]}{\sum_{\{0\leq x_i^{(l)}\leq 1-s_i^{(l)},l=1,2,\ i=1,\cdots,N_l(t)\}}C_{z,S}P[\{X_i^{(l)}(t)=x_i^{(l)}+s_i^{(l)},\ l=1,2,\ i=1,\cdots,N_l(t)\}\mid I_{[1,t-1]}]}\end{aligned} \tag{16}$$

where $z=\sum_{l=1}^{2}\sum_{i=1}^{K_l(t)}(x_i^{(l)}+s_i^{(l)})$, and $S=\sum_{l=1}^{2}\sum_{i=1}^{K_l(t)}s_i^{(l)}$ is the total number of successfully transmitted packets in slot t.

With the conditional joint distribution of $\{X_i^{(l)}(t^+),\ l=1,2,\ i=1,\cdots,N_l(t)\}$, we can evaluate $E[X_i^{(l)}(t^+)\mid I_{[1,t]}]$ and obtain $\mathcal{P}(t)$. Recall that $\alpha_l(t)$ denotes the number of unprocessed users from the lth group in slot t, and without loss of generality, we assume they are the first $\alpha_l(t)$ users of the lth group. Since unprocessed users remain in the service room in slot $t+1$, packets generated by them at the beginning of slot $t+1$ can not be transmitted until the next time they enter the service room. We thus have $X_i^{(l)}(t+1)=X_i^{(l)}(t^+)$ for $l=1,2,\ i=1,\cdots,\alpha_l(t)$. Hence, the conditional joint distribution of $\{X_i^{(l)}(t+1),\ l=1,2,\ i=1,\cdots,\alpha_l(t)\}$ can be easily obtained from the conditional joint distribution of $\{X_i^{(l)}(t^+),\ l=1,2,\ i=1,\cdots,N_l(t)\}$ (given by (16)) by summing out the processed users, *i.e.*,

$$\begin{aligned}& P[\{X_i^{(l)}(t+1)=x_i^{(l)},\ l=1,2,i=1,\cdots,\alpha_l(t)\}\mid I_{[1,t]}]\\ &= \sum_{\{x_i^{(1)},\ x_j^{(2)},\ i,\hat{j}\in\mathcal{P}(t)\}}P[\{X_i^{(l)}(t^+)=x_i^{(l)},\ l=1,2,i=1,\cdots,N_l(t)\}\mid I_{[1,t]}].\end{aligned} \tag{17}$$

The joint distribution of $\{X_i^{(l)}(t+1),\ l=1,2,\ i=1,\cdots,\alpha_l(t)\}$ conditioned on $I_{[1,t]}$ serves as the basis for determining $\mathcal{A}(t+1)$ and $\mathcal{P}(t+1)$.

3.5 The Determination of the Access Set

At the end of slot t, after determining the processed users and removing them from the service room, we choose $\mathcal{A}(t+1)$ by specifying $K_1(t+1)$ and $K_2(t+1)$.

For a q given by (13) and all possible sizes of the access set $K(t+1)$ ($K(t+1)=1,\cdots,M$), we choose $(k_1(t+1),k_2(t+1))$, where $k_1(t+1)\sim B(q,K(t+1))$, is a realization of the binomial distribution with parameters q and $K(t+1)$, and $k_2(t+1)=K(t+1)-k_1(t+1)$. Among these M pairs of $(k_1(t+1),k_2(t+1))$, we choose $(K_1(t+1),K_2(t+1))$ so that $E[S(t+1)\mid I_{[1,t]}]$ is maximized, *i.e.*,

$$(K_1(t+1),K_2(t+1))=\arg\max_{(k_1(t+1),k_2(t+1))} E[S(t+1)\mid (k_1(t+1),k_2(t+1)),\ I_{[1,t]}], \quad (18)$$

where $E[S(t+1)\mid (k_1(t+1),k_2(t+1)),\ I_{[1,t]}]$ denotes the number of successfully transmitted packets in slot $t+1$ if the first $k_l(t+1)$ $(l=1,2)$ users from the lth group access the channel. It can be computed as

$$\begin{aligned}&E[S(t+1)\mid (k_1(t+1),k_2(t+1)),\ I_{[1,t]}]\\&=\textstyle\sum_{n=1}^{k_1(t+1)+k_2(t+1)}\mathcal{C}_n P[\sum_{i=1}^{k_1(t+1)}X_i^{(1)}(t+1)+\sum_{i=1}^{k_2(t+1)}X_i^{(2)}(t+1)=n\mid I_{[1,t]}].\end{aligned} \quad (19)$$

To obtain $P[\sum_{i=1}^{k_1(t+1)}X_i^{(1)}(t+1)+\sum_{i=1}^{k_2(t+1)}X_i^{(2)}(t+1)=n\mid I_{[1,t]}]$ for all possible $(k_1(t+1),k_2(t+1))$, we need the joint distribution of $\{X_i^{(l)}(t+1),\ l=1,2,\ i=1,\cdots,M_l\}$ conditioned on $I_{[1,t]}$. Since users generate packets independently, this conditional joint distribution can be obtained from the conditional joint distribution of $\{X_i^{(l)}(t+1)\ (l=1,2,\ i=1,\cdots,\alpha_l(t))\}$ given by (17) and the marginal distribution of $X_i^{(l)}(t+1)$ $(l=1,2,\ i=\alpha_l(t)+1,\cdots,M_l)$. The latter can be computed as

$$P[X_i^{(l)}(t+1)=x]=\begin{cases}(1-p)^{W_i^{(l)}} & \text{if } x=0\\ 1-(1-p)^{W_i^{(l)}} & \text{if } x=1\\ 0 & \text{otherwise}\end{cases}, \quad (20)$$

where $W_i^{(l)}=t+1-\tau_i^{(l)}$ with $\tau_i^{(l)}$ defined as the index of the slot in which the ith user in the lth group last time entered the service room or the index of the slot in which this user last time successfully transmitted a packet, whichever is larger.

3.6 Stability

The following theorem gives a sufficient condition under which the proposed protocol is stable.

Theorem 1 *For an MPR channel with $C_{n,k}>0$ $(n=1,\cdots,M,\ k=0,\cdots,n)$, the proposed protocol is stable in the sense that for any $p\in[0,1]$, the packet delay of each user is finite.*

It can be shown that the stability of the proposed protocol is equivalent to the finiteness of the expected number of slots a user stays in the service room during one visit, which can be proved with the help of Borel-Cantelli Lemma.

4 Simulation Examples

Presented in this section are simulation studies on the throughput and delay performance of the proposed MQSR protocol in a CDMA network with $M = 10$ users. The MPR capability of this network is provided by 3 orthogonal codes. A packet is transmitted with a code randomly picked from these 3 codes. A packet is successfully received if and only if no other packet transmitted in this slot uses the same code. It can be shown the capacity of this MPR channel is $4/3$.

We first consider the scenario of homogeneous QoS requirement $(L = 1)$ and compare the throughput of the proposed MQSR protocol with that of slotted Aloha with optimal retransmission probability. As shown in Figure 3, significant improvement in throughput was achieved by the MQSR protocol. Figure 3 also shows that the MQSR protocol achieved the channel capacity at heavy traffic load.

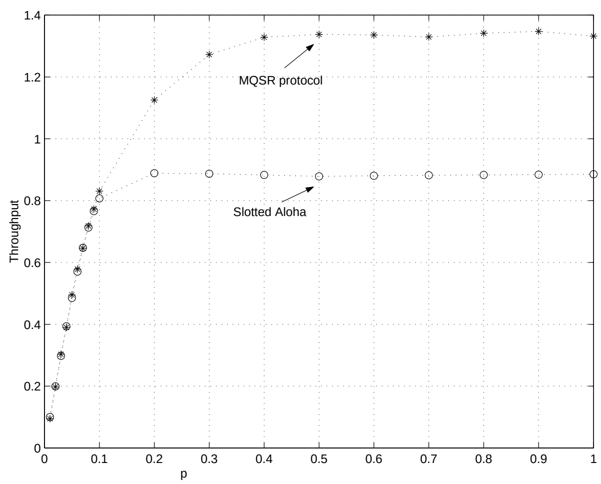


Figure 3: Throughput Comparison between MQSR Protocol and Slotted Aloha with Optimal Retransmission Probability

We now consider the case of $L = 2,\ M_1 = M_2 = 5$, and users of the first group require their packet delay D_1 at $p = 1$ no larger than d_1. We considered different delay requirement of the first group, as illustrated by asterisks in Figure 4. The corresponding q was obtained by (13). The simulated delay of the first group was indicated by the solid line in Figure 4. The circles and dashed line indicate, respectively, the calculated delay and simulated delay of the second group for a given q. Figure 4 shows that the delay requirement of the first group was satisfied for the choice of q given in (13).

5 Conclusion

In this paper, we propose a multi-queue service room MAC protocol designed explicitly for multiaccess networks with MPR capability. The proposed protocol dynamically controls the size of the access set according to the traffic load and the channel MPR capability so that the expected number of successfully transmitted packets is maximized under a set of heterogeneous delay constraints. This protocol achieves the channel capacity at heavy traffic load and is stable in the sense that the packet delay of each user is finite for any traffic load.

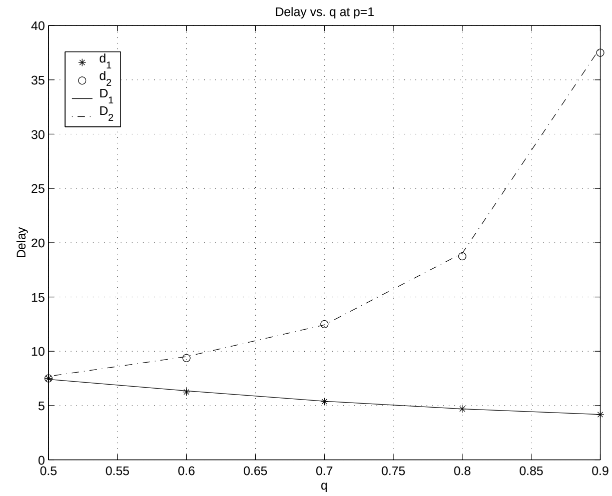


Figure 4: Delay Performance of MQSR Protocol at $p = 1$

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