PERFORMANCE OF MULTICHANNEL MULTIACCESS PROTOCOLS WITH RECEIVER COLLISIONS

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ABSTRACT

The throughput evaluation of multichannel slotted Aloha type protocols with receiver collisions is studied. The applied methods use Poisson approximations to evaluate the throughput and the probability of packet rejection at destination. Numerical results are presented showing the receiver collisions effect in the system performance for comparison with the case of without receiver collision scheme.

1. INTRODUCTION

There are two causes of packet loss in multichannel systems. First packets are destroyed if two or more stations transmit their packets in the same channel of the multichannel system and they are overlapped in time (channel collisions). Second additional packets are destroyed when a successfully transmitted packet cannot be received by the intended destination because its receiver buffer is 'full'(receiver collisions).

In much of the studies related to multichannel multiaccess protocols, the analysis has been done assuming infinite receiver buffer size. However the receiver buffer size used in practice have finite size and implies negative impact on the cost of the required network interfaces for the stations of the system. Thus the choice of the receiver buffer size of a multichannel protocol is widely depended on the strictly estimation of the receiver collisions phenomenon and its influence to performance measures. The effect of receiver collisions are rarely studied in the literature. The works reported in [1,2,3,4] are some of these very few studies. In [1] a M-CSMA-IC scheme assumes a simplified model in which the total offered traffic is Poisson and uses the Stirlings numbers of second kind to evaluate the effect of receiver collisions in the system performance for cases of receiver buffer size of one packet. In [2] the M-CSMA/CD protocol is examined for finite number of stations and receiver collisions assumption. In this study simulation techniques are used to estimate the effect of receiver collisions with various receiver buffer sizes. In [3] the M-CSMA/CD protocol with receiver collisions is examined for finite number of stations using discrete time Markov chains in which the probability of correctly received packets at destination is approximately evaluated for cases of receiver buffer size of one packet.

In [7,8] the concept of receiver collisions is different and it is not related with receiver buffer size. In these cases a receiver collision occurs when a collision-free packet transmission cannot be picked up by the intended destination since the destination's receiver may be tuned to some other channel for receiving data packet from some other source. However in these studies the effect of receiver collisions is ignored. In [4] and [5] Multichannel ALOHA-type protocols with asymmetric access and symmetric access rights to the channels correspondingly with destination conflicts are proposed. It is provided an exact evaluation of probability (without approximations) of the correctly received packets at destination assuming buffer size of one packet. It is analyzed a queueing model using discrete time Markov chains to evaluate the system performance for a finite number of stations. It is given a rigourous steady state analysis and delay-throughput characteristics has been presented for various number of stations and channels.

In this paper, we extent the analysis in [5] and examine an multichannel model using a) Poisson approximation methods for the total offered traffic to the system b) the number of correctly received packets at destination are also approximated as a Poisson random variable. The material of this paper is organized as follows: In section 2 the basic assumptions about the examined multichannel multiaccess protocols are given. In section 3 the analysis of the conventional Multichannel Aloha-type protocol without the effect of receiver collisions is presented assuming Poisson arrivals. Then the throughput performance with effect of receiver collisions is derived based on Poisson approximations statistics. In section 4 numerical results are presented for various number of channels and stations. Comments on numerical results and explanation of the behaviour are discussed. Also some concludings are made.

2. MODEL AND ASSUMPTIONS

A multichannel multiaccess communication system consisting of v parallel broadcast channels all of the same capacity is considered. A finite number, M, of stations each one connected by means of separate interfaces to every channel of the system is assumed. The time is slotted on all channels, and these slots are synchronized across all channels. Each station has access to all channels, i.e. it can transmit and/or receive constant length packets that fit to slot size. The round trip propagation delay is small enough (i.e. less than packet transmission time the slot duration) The set of rules that the proposed protocol implies for the stations in the multichannel system are as follows:

1) Every station is equipped with a receiver buffer and a transmitter buffer each one with capacity of one packet. If the transmitter buffer is empty, the station is said to be *free*, otherwise, it is *backlogged*. If a station is backlogged and generates a new packet, the packet is lost and never returns.

2) We assume that each packet has a source and a destination address information. A station ready to (re)transmit selects randomly one among the v ($2 \leq v \leq M$) channels at the beginning of the slot in order to attempt its (re)transmission. Each channel is chosen with equal and constant probability $P_i = 1/v$. If more than one station select the same channel during a time slot to (re)transmit a collision will occur.

3) The successfully (re)transmitted packets are uniformly distributed among the M stations. If the receiver buffer of the randomly selected station as destination is 'full' the packet is rejected. This phenomenon is called *receiver collision*.

4) If a backlogged station retransmits successfully during a time slot and the retransmission is not aborted due to a receiver collision, it becomes free at the next time slot. A free station becomes backlogged in case of a unsuccessful transmission or receiver collisions.

5) The channels are error free and there are no capture phenomena. Thus, packets may be corrupted only because of their concurrent transmission or receiver collisions. We approximate the total number of new transmissions and retransmissions with a Poisson process with mean rate G.

3. ANALYSIS

The throughput reduction induced by receiver collisions is related with the possibility of receiver buffers overflow and this is associated with buffer capacity and the system throughput without the effect of receiver collisions. The possibility of receiver buffer overflow gives rise to rejection probability at destination in steady state which substantiates the throughput loss in quantitative fashion. The analysis is composed from two parts. a) Throughput evaluation of conventional multichannel system protocol and b) Throughput analysis of finite receiver buffer size protocol. In the conventional multichannel protocol without receiver collisions, the traffic to i-th channel is given:

$$G_i = GP_i = G/v \qquad (1)$$

The throughput per channel in steady state, is $S_i = G_i \exp(-G_i) = G/v \exp(-G/v)$ and thus the total throughput is given by:

$$S = \sum_{i=1}^{v} S_i = G \exp(-G/v) \qquad (2)$$

Let S_{RC} be the multichannel system throughput, conditioning on the receiver collision effect. We still assume that the total offered traffic is Poisson. We define, S_{RC}, as the average number of the correctly received at destination in steady state during a time slot. Let S_v be a random variable representing the number of successful (re)transmissions during a time slot from multichannel system. Also $H_v(S)$ is a random variable representing the number of different stations selected as destination, given that the mean throughput rate is S packets/slot.

Let U_n be an indicator function denoting whether a station n(n=1,2...M) is selected as destination of packet,e.i

$$U_n = \begin{cases} 1 & \text{if station n is selected during } i_{th} \text{ slot} \\ 0 & \text{else} \end{cases} \tag{3}$$

Let $P_0 = \Pr\{ U_n = 0 \}$ in steady state. Consider that S_v=k packets are successfully (re)transmitted from multichannel system during the i_{th} slot. The random distribution of these packets in M stations gives M^k arrangements each with probability M^{-k}. In this case P_0 denotes that no one from k packets are destined to station n . Thus the k packets should be destined to the remaining (M-1) stations in $(M-1)^k$ different ways. The P_0 conditioning on the S_v=k can be expressed as follows

$$P_0(k) = (1 / M^k)(M-1)^k = [\, 1 - 1/M \,]^k \tag{4}$$

Using the approximation $(1 - x)^y \cong \exp(-xy)$ for small x [6] in (4), we take

$$P_0(k) \cong \exp(-k / M) \tag{5}$$

In steady state $E[\, S_v\text{=}k \,] = S$ and consequently

$$P_0 = E[\, P_0(k) \,] \cong \exp(-S / M) \tag{6}$$

Let P_f be the probability that at least one packet has been destined to station n during a time slot in steady state. Then

$$P_f = \Pr\{ U_n = 1 \} = 1 - P_0 = 1 - \exp(-S / M) \tag{7}$$

The probability $H_v(S) = k$, of finding k different stations that have been selected as destination during a time slot, obeys to binomial probability low.

$$\Pr[\, H_v(S) = k \,] = [\, M! / (M-k)!\, k! \,] (P_f)^k (P_0)^{(M-k)} \tag{8}$$

Thus

$$S_{RC} = E\{ \Pr[H_v(S) = k] \} = \sum_{k=1}^{M} k \Pr[H_v(S) = k] = M(1 - \exp(-S / M)) \tag{9}$$

AVERAGE REJECTION PROBABILITY AT DESTINATION

The average rejection probability at destination of a packet is evaluated as the ratio of the average number of packet rejection at destination per slot in steady state due to receiver buffer overflow, to the average number of successfully (re)transmitted packets per slot, then

$$P_{rej} = (S - S_{RC})/S \tag{10}$$

4. NUMERICAL RESULTS

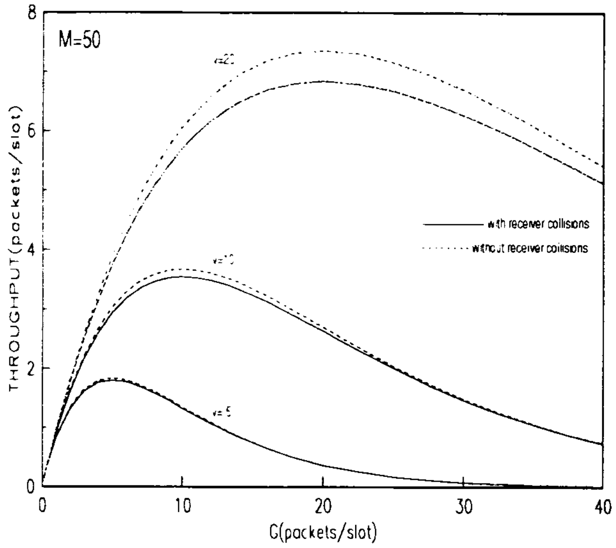

Figure 1: The throughput versus the offered traffic G characteristics for a v=5,10,20(channel)systems with M=50 stations. Analytical results with and without receiver collisions schemes.

Figure 1 illustrates the throughput versus the offered traffic G for a v=5,10,20(channel)systems with M=50 stations. It can be observed that throughput measures are on decrease as they compared with the protocol case without destination conflicts for all values of traffic rates. It is interesting to observe that for fixed number of stations, the differences S-S_{RC} are increasing functions of v. The reason is that for a fixed value of G, as v increases, the throughput S increases and consequently the possibility of a packet to be rejected at destination due to receiver collisions is large. For example let G=4, we have for v=5 (S=1.797, S_{RC}=1.765 and P_{rej}=1.776%), for v=10 (S=2.681, S_{RC}=2.610 and P_{rej}=2.634%) and for v=20 (S=3.275, S_{RC}=3.170 and P_{rej}=3.204%).

Figure 2 presents the histogram of the maximum average percent rejection probabilities for v=2,5,10,20(channel)systems with M=50,100 stations. It is obvious that the maximum rejection probability $P_{rej}(max)$ in a multichannel system corresponds to maximum achievable throughput S_{max}. If we set the first derivative of the equation (2) with respect to G equal to zero, we find the optimal G that maximize the throughput of the system.

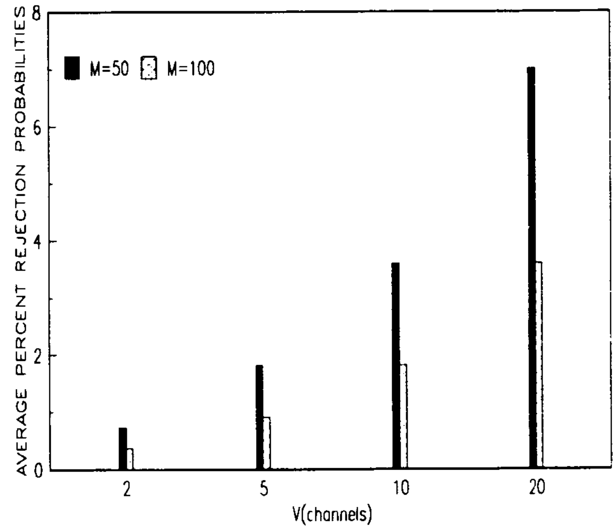

Figure 2: The histogram of maximum average percent rejection probabilities for v=2,5,10,20(channel)systems with M=50,100 stations

Thus we take G_{opt}=v. From the Figure 2 is evident that as M increases the $P_{rej}(max)$ decreases. Also as v increases $P_{rej}(max)$ increases too. In case of M=50 we have for v=5, $P_{rej}(max)$=1.817% and for v=20, P_{rej}=7%. We can say that three parameters characterize the performance behaviour of the multichannel system {v,M,$P_{rej}(max)$}. Figure 3 illustrates the average rejection probabilities versus Traffic G(packets/slot) for v=5,10,20(channel)systems with M=50 stations. For low value of the traffic G, the average rejection probability increases linearly with G (low values of the throughput S). As the G increases approaching G_{opt} and the throughput approaching S_{max}, P_{rej} begins to saturate increasing slowly towards $P_{rej}(max)$. For higher values of G ($G>G_{opt}$) the S is reduced due to collisions at multichannel system so P_{rej} decreases because the possibility of collision at destination is low.

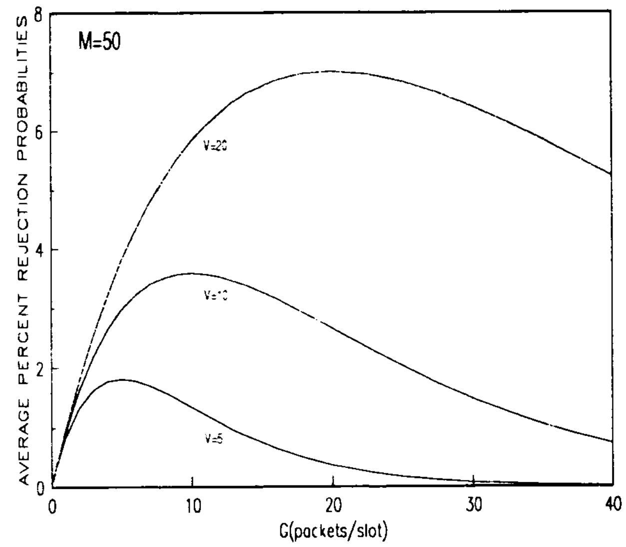

Figure 3: Average rejection probabilities versus Traffic G(packets/slot) for v=5,10,20(channel)systems with M=50 stations

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