PDQRAP - Prioritized Distributed Queueing Random Access Protocol

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Abstract[1]

A new MAC layer protocol, DQRAP (Distributed Queueing Random Access Protocol), provides performance with respect to throughput and delay that approaches that of an ideal protocol. This paper introduces PDQRAP, a prioritized version of DQRAP. Two formats, the Extra-bit and the Extra-slot, each a variation of the basic DQRAP are described. Simulation results are presented that show that under a total traffic load of 90%, a high priority segment of 20% - 30% in either format has delay characteristics ranging from one-third to one-half of the delay characteristics of the normal priority traffic. The relative advantages and disadvantages of each format are discussed. It is suggested that PDQRAP could be the mechanism that allowed a shared medium to economically transport traffic associated with multimedia services utilizing LANs, MANs, and WANs.

I Introduction

DQRAP, developed by Xu and Campbell at the Illinois Institute of Technology, is an extended model multiple access protocol that utilizes control minislots and two global queues to provide performance superior to other protocols with respect to throughput and delay. DQRAP provides immediate access at light offered loads but moves seamlessly to a reservation system at heavier traffic. DQRAP is effective in networks regardless of the value of "a", the ratio of propagation delay to frame transmission time.

All previous protocols based upon the extended channel model, i.e., use of control minislots, provided a throughput of one only by use of an infinite number of minislots [6]. DQRAP provides a throughput of one with use of three control minislots and thus can be considered a practical protocol. DQRAP is amenable to a variety of network topologies and is scaleable to any speed and distance. DQRAP is described in detail by Xu and Campbell [1] and the presentation of PDQRAP in this paper effectively provides details of how DQRAP operates. However we provide a short narrative of how and why DQRAP works.

DQRAP utilizes three control minislots and two global queues: a transmission queue (TQ), and a collision resolution queue (RQ). The states of these queues, which are actually counters maintained by each station, provide the basis for a four-state machine that governs the operation of DQRAP. There are three sets of rules governing the operation of DQRAP: DTR - data transmission rules, RTR - request transmission rules, and, QDR - queueing discipline rules. The equivalent rules in PDQRAP are presented later.

When a station has a frame ready for transmission it transmits what is effectively a reservation request in a minislot. The feedback from each minislot can represent (a) an empty minislot, (b) a success (a single transmission), or (c) a collision meaning more than one station transmitted in that minislot. The TQ at each station is incremented once for each minislot containing a success. The TQ is decremented each slot time since the station at the front of the queue transmits a frame. Thus the TQ at any instant in time represents the number of frames awaiting transmission.

The scenario described so far has, with minor variations, been in use for years. What makes DQRAP so special? It is the second queue, RQ. The feedback from each set of three minislots could indicate collisions in one or more of the minislots. All previous systems attempted to reduce the probability of collisions by increasing the number of minislots (see previous comment). When collisions did occur the stations simply tried again till successful. The RQ in DQRAP represents a queue, again actually a count, of the number of

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collisions that have occurred in the minislots. The group of stations representing the collision at the head of the queue are now given exclusive use of the minislots to resolve that collision, new arrivals are blocked till the RQ = 0. But meanwhile the stations already in the TQ continue to transmit when they reach the head of TQ. The second queue along with the three sets of rules ensure that with three minislots an arrival of multiplicity N is resolved in less than N data slots thus ensuring a throughput of one. One other feature - when the TQ and RQ are both empty then newly ready stations transmit in both a data slot and a minislot. If only one station was ready then the transmission is successful, if more than one station is ready then there is a collision in the data slot but the reservation process has already started in the minislots. This is the immediate access feature of DQRAP.

Now back to priorities. Many multiple access protocols support priority transmission mechanisms that provide high priority traffic with reduced delay and/or extra capacity. In the general class of multiple access protocols only the deterministic Token Ring and Token Bus protocols support practical priority mechanisms [7]. Those multiple access protocols based upon Aloha, CSMA, or the tree algorithm are not amenable to implementation of priority classes that will guarantee access to the channel in some finite time. In the non-deterministic world only p-persistent CSMA provides a semblance of a priority capability by dynamically providing a high priority station a greater probability of transmitting [7]. The performance of DQRAP is such that there is not the same degree of necessity for a priority class as with other protocols. However, a practical priority mechanism would be an asset even to DQRAP to support time-dependent traffic, situations where servers make extreme demands upon system capacity, and to support priority mechanisms of higher layers.

Xu first described the general mechanism for providing for priorities in DQRAP [8]. PDQRAP uses a scheme similar to operating systems, high and low priority queues wherein a packet in the high priority queue always transmit before a packet in the low priority queue. This implies pre-emption since in the situation where there are no packets in the high priority queue but one or more packets in the normal priority queue a newly arrived high priority packet will transmit in the next slot.

Section II describes a variation of priority DQRAP first simulated by Dixon [2] and presents simulation results. The Dixon format employs an extra minislot. Section III introduces the Extra-bit format as developed by Lin [3]. The Lin format employs an extra bit in each minislot to indicate the priority level. Section IV provides discussion and conclusions.

II Extra-slot (Dixon) Format PDQRAP

The Extra-slot format utilizes one or more extra minislots to provide exclusive access to the channel for the high priority packets. Our discussion is restricted to two classes of priority such that a single extra minislot suffices. The Extra-slot format is shown in Figure 1.

High priority packets have exclusive use of minislot 1. Minislots 2 to 4 are utilized by high and/or normal priority packets following the rules of the protocol. For example, when H_RQ > 0 the high priority packets at the head of the queue H_RQ use minislots 2-4 to

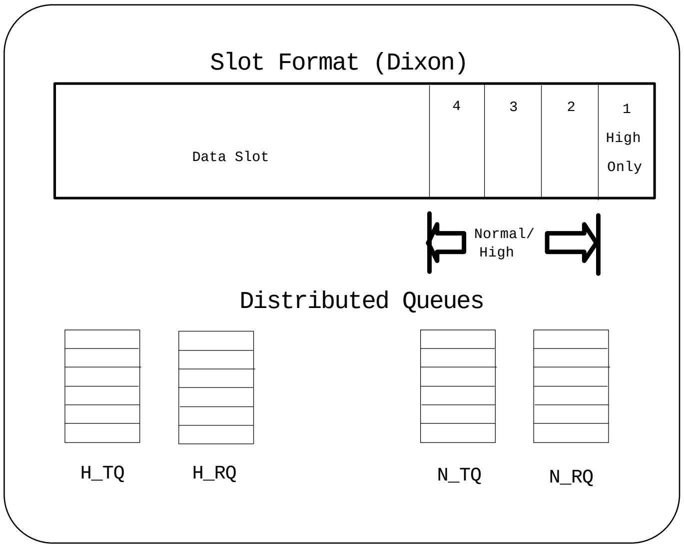

Figure 1. PDQRAP Extra-slot (Dixon) Format

resolve a collision. In such a case normal packets are blocked from accessing minislots 2-4. When H_RQ = 0, i.e., there are no high priority packet collisions to resolve, and N_RQ > 0, the normal priority packets at the head of N_RQ use minislots 2-4 to resolve a collision. These are just two of the cases using the Extra-slot format. Following the spirit of the original DQRAP rules there are four queues maintained thus Extra-slot PDQRAP has $2^4 = 16$ states. Fortunately there are several "don't care" states that reduce the 16 states to 9 unique states. For example, when the case H_TQ > 0, H_RQ > 0 occurs there is no difference in action regardless of the state of N_TQ. This is because the high priority queues control all access to both the minislots and the data-slot. Thus N_TQ becomes a DC (don't care) condition. Six more states are eliminated in the same manner. The Extra-slot PDQRAP rules are listed below.

Case 1: |H_TQ| > 0, |H_RQ| > 0, |N_TQ| & |N_RQ| - DC

DTR: Station that has the first entry in H_TQ, the high priority data transmission queue, transmits a high priority packet.

RTR: Stations that have the first entry in H_RQ, the high priority contention resolution queue, try to resolve a collision using minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases H_TQ by one.
Each station increases H_TQ by n which is the number of successes in minislots 1-4.
Each station decreases H_RQ by one.
Each station increases H_RQ by n where n is the number of collisions in minislots 1-4.

Case 2: |H_TQ| > 0, |H_RQ| = 0, |N_RQ| > 0, |N_TQ| - DC.

DTR: Station that has the first entry in H_TQ transmits high priority packet.

RTR: Stations that have the first entry in N_RQ resolve their collision using minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases H_TQ by one.
Each station increases H_TQ by 1 if minislot 1 is successful.
Each station increases N_TQ by n
which is the number of successes in minislots 2-4.
Each station decreases N_RQ by one.
Each station increases H_RQ by 1 if minislot 1 is collided.
Each station increases N_RQ by n
where n is the number of collisions in minislots 2-4.

Case 3: |H_TQ| > 0, |H_RQ| = 0, |N_RQ| = 0, |N_TQ|- DC

DTR: Station that has the first entry in H_TQ transmits high priority packet.

RTR: New normal priority arrivals make requests in minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases H_TQ by one.
Each station increases H_TQ by 1 if minislot 1 is successful.
Each station increases N_TQ by n
which is the number of successes in minislots 2-4.
Each station increases H_RQ by 1 if minislot 1 is collided.
Each station increases N_RQ by n where n is the number of collisions in minislots 2-4.

Case 4: |H_TQ| = 0, |N_TQ| > 0, |H_RQ| > 0, |N_RQ|- DC

DTR: Station that has the first entry in N_TQ transmits normal priority packet.

RTR: Stations that have the first entry in H_RQ resolve the collision using mini-slots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases N_TQ by one.
Each station increases H_TQ by n
which is the number of successes in minislots 1-4.
Each station decreases H_RQ by one.
Each station increases H_RQ by n which is the number of collisions in minislots 1-4.

Case 5: |H_TQ| = 0, |N_TQ| > 0, |H_RQ| = 0, |N_RQ|> 0

DTR: Station that has the first entry in N_TQ transmits normal priority packet.

RTR: Stations that have the first entry in N_RQ resolve the collision using mini-slots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases N_TQ by one.
Each station increases H_TQ by 1 if minislot 1 is successful.
Each station increases N_TQ by n which is the number of successes in minislots 2-4.
Each station decreases N_RQ by one.

Each station increases H_RQ by 1 if minislot 1 is collided.
Each station increases N_RQ by n where n is the number of collisions in minislots 2-4.

Case 6: |H_TQ| = 0, |N_TQ| > 0, |H_RQ| = 0, |N_RQ| = 0

DTR: Station that has the first entry in N_TQ transmits normal priority packet.

RTR: New normal priority arrivals make requests in minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station decreases N_TQ by one.
Each station increases H_TQ by 1 if minislot 1 is successful.
Each station increases N_TQ by n which is the number of successes in minislots 2-4.
Each station increases H_RQ by 1 if minislot 1 is collided
Each station increases N_RQ by n where n is the number of collisions in minislots 2-4.

Case 7: |H_TQ| = 0, |N_TQ| = 0, |H_RQ| > 0, |N_RQ|-DC

DTR: New high priority arrivals transmit in the data slot.

RTR: Stations that have the first entry in H_RQ resolve collision using minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station increases H_TQ by n which is the number of successes in minislots 2-4.
Each station increases H_RQ by n where n is the number of collisions in minislots 1-4.

Case 8: |H_TQ| = 0, |N_TQ| = 0, |H_RQ| = 0, |N_RQ|> 0

<table>
<tr><th rowspan="2">CASE</th><th colspan="5">Usage of Slots</th></tr>
<tr><th>Data</th><th>CMS 4</th><th>3</th><th>2</th><th>1</th></tr>
<tr><td>Case 1. |H_TQ|>0,|H_RQ|>0,|N_TQ|,|N_RQ| - Don't Care</td><td>High</td><td>H</td><td>H</td><td>H</td><td>H</td></tr>
<tr><td>Case 2. |H_TQ|>0,|H_RQ|=0,|N_TQ|-DC,|N_RQ|>0</td><td>High</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
<tr><td>Case 3. |H_TQ|>0,|H_RQ|=0,|N_TQ|-DC,|N_RQ|=0</td><td>High</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
<tr><td>Case 4. |H_TQ|=0,|H_RQ|>0,|N_TQ|>0,|N_RQ|-DC</td><td>Normal</td><td>H</td><td>H</td><td>H</td><td>H</td></tr>
<tr><td>Case 5. |H_TQ|=0,|H_RQ|=0,|N_TQ|,|N_RQ|-DC</td><td>Normal</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
<tr><td>Case 6. |H_TQ|=0,|H_RQ|=0,|N_TQ|>0;|N_RQ|=0</td><td>Normal</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
<tr><td>Case 7. |H_TQ|=0,|H_RQ|>0,|N_TQ|=0,|N_RQ|-DC</td><td>High</td><td>H</td><td>H</td><td>H</td><td>H</td></tr>
<tr><td>Case 8. |H_TQ|=0,|H_RQ|=0,|N_TQ|=0,|N_RQ|>0</td><td>High</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
<tr><td>Case 9. |H_TQ|=0,|H_RQ|=0,|N_TQ|=0,|N_RQ|=0</td><td>High/Normal</td><td>N</td><td>N</td><td>N</td><td>H</td></tr>
</table>

Figure 2. Extra-Slot Priority Rules

Table 1. Delay Performance for Extra-Slot PDQRAP

Offered Load		Delay		Average Delay
High Priority	Normal Priority	High Priority	Normal Priority	
10%	80%	2.63201	8.44779	7.80159
20%	70%	2.85083	8.94663	7.59203
30%	60%	3.08984	9.66986	7.47652
40%	50%	3.36167	10.8472	7.52031
50%	40%	3.68157	12.5768	7.635
60%	30%	4.07379	15.3171	7.82156
70%	20%	4.64013	19.5788	7.95983
80%	10%	5.61106	27.9336	8.09134

DTR: New high priority arrivals transmit in the data slot.

RTR: Stations that have the first entry in N_RQ resolve collision using minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: Each station increases N_TQ by n which is the number of successes in minislots 2-4.
Each station increases H_RQ by 1 if minislot 1 is collided.
Each station decreases N_RQ by one.

Each station increases N_RQ by n where n is the number of collisions in minislots 2-4.

Case 9: |H_TQ| = 0, |N_TQ| = 0, |H_RQ| = 0, |N_RQ|= 0

DTR: New high priority arrivals transmit in the data slot. New normal priority arrivals transmit in the data slot.

RTR: New normal priority arrivals make requests using minislots 2-4. New high priority arrivals make requests in minislot 1.

QDR: IF more than one minislot used do the following else do nothing.
Each station increases H_TQ by 1 if minislot 1 is successful.
Each station increases N_TQ by n which is the number of successes in minislots 2-4.
Each station increases H_RQ by 1 if minislot 1 is collided.
Each station increases N_RQ by n where n is the number of collisions in minislots 2-4.

Figure 2 shows the usage of the data slot and the minislots for cases in the Extra-slot format. Several simulations were run using different sets of High/Normal priority traffic combination while the total

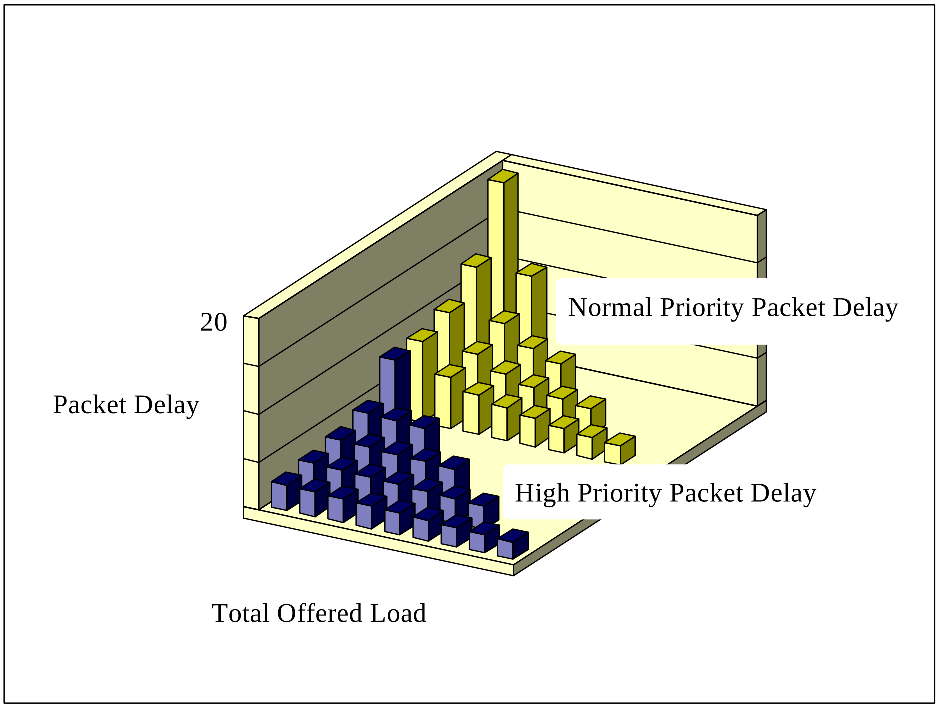

Figure 3. Delay Characteristics for Extra-Slot (Dixon) PDQRAP

offered traffic was maintained at 0.9. Table 1 shows the high, normal, and average packet delay performance.

Table 1 shows that the overall delay reaches a minimum when the range of high priority load is .30 to .50 and the range of normal load is .60 to .40. This is to be expected since all high priority traffic enters the system through one minislot and the probability of collision on the first attempt rises dramatically when we pass the slotted Aloha maximum of 0.368. However the high priority packets utilize all four minislots to resolve a collision thus there is not too much increase in delay. Conventionally the proportion of high priority traffic, relative to normal traffic, is small thus a single minislot suffices. Lin considers the delay performance of the situation where the two loads (high and normal) are more balanced. In this case two minislots are assigned to each of high and normal traffic [3].

The low delay of a high priority packet is impressive considering the total offered traffic is 90%. Xu and Campbell [1] employing three and four minislots under single priority load of 90% report delays of 8.2555 and 7.5451 slot times respectively. We use these values as a reference point. Figure 3 shows packet delay performance of the Extra-slot format for high priority and normal packets under a variety of high/normal load combinations. This figure shows graphically the low absolute delay of high priority packets under the various combinations of high and normal priority traffic.

Some qualitative properties of the Extra-slot format:

1) This approach does not guarantee first-come first-serve transmission at an individual station. For example, a station might have a series of high priority packets to send. It is possible that the first packet collides and joins the H_RQ. However, the second packet could use the exclusive minislot to reserve a spot in H_TQ prior to the first packet leaving H_RQ. The property of FIFO may or may not be important in some applications.

2) The Extra-slot format has an exponential growth of the number of states with increasing number of priority levels. This section has shown that two level priority requires nine states to treat all possible situations. This is probably not too serious since in a practical world two levels of priority often suffice.

III Extra-bit (Lin) Format PDQRAP

The Extra-bit format utilizes a single type bit in each minislot to indicate priority class. Just as the Extra-slot format can be extended to multiple priority classes with extra slots the Extra-bit format accommodates multiple priority classes with extra bits. As with the Extra-slot format, this discussion is restricted to two priority classes. For discussion purposes a 0 in the type bit means the packet is high priority, a 1 indicates normal priority. In an implementation the complement of these values could be used.

The packet and system organization is shown in Figure 4. In this configuration, H_TQ is used as a queue for transmitting High Priority packets and N_TQ is used for transmitting Normal packets. RQ is used, as usual, to resolve collisions for both High Priority and Normal packets.

Some of the original DQRAP rules are changed to achieve prioritized transmission. These rules are summarized as follows:

Case 1: When |H_TQ| > 0, |RQ| > 0, |N_TQ| - DC
DTR: The station that has the top position of H_TQ transmits a high priority packet.
RTR: Stations which have the first position of RQ resolve their collision through minislots.
QDR: Table 2 shows the possible outcome and action for each minislot feedback state.

Case 2: When |H_TQ| > 0 , |RQ = 0|, |N_TQ| - DC.
DTR: The station that has the top position of H_TQ transmits a high priority packet.
RTR: Stations with high priority or normal packets ready to transmit make their request through minislots.
QDR: Same as case 1.

Case 3: When |H_TQ| = 0, |N_TQ| > 0, |RQ| > 0
DTR: The station that has the top position in N_TQ transmits a normal packet.
RTR: Stations that have the first position in RQ resolve their collision.
QDR: Same as case 1.

Case 4: When |H_TQ| = 0, |N_TQ| = 0, |RQ| > 0
DTR: No high priority or normal packet is waiting therefore the slot is left empty
RTR: Packets that have the first position in RQ resolve their collision.
QDR: Same as case 1.

Case 5: When |H_TQ| = 0, |N_TQ| > 0, |RQ| = 0
DTR: The station that has the first position in N_TQ transmits a normal packet.
RTR: Stations that have high priority or normal packets ready to transmit make their request using minislots.
QDR: Same as case 1.

Case 6: When |H_TQ| = 0, |N_TQ| = 0, |RQ| = 0

DTR: Stations that have high priority or normal packets transmit in the data slot.

RTR: Stations that have high priority or normal packets transmit in minislots.

QDR: If no collision in the data slot, no action . Otherwise, same as case 1

This priority scheme is preemptive in that packets in H_TQ are always transmitted. For cases 3 and 4, the state of N_TQ does not matter since |N_TQ| > 0 will result in successful transmission in the data slot. However, if |N_TQ| = 0 the data slot remains empty. Figure 5 shows the usage of the data slot and minislots for cases using the Extra-bit format.

Table 3 shows the delay of the Extra-bit PDQRAP format as measured by simulation.

In Extra-slot PDQRAP a minimum average delay occurs in the 0.3-0.5/0.6-0.4 high/normal load configuration. In the Extra-bit format a maximum occurs in the same region. Overall though there is little to choose between the two approaches with respect to delay performance. When the high and normal priority loads are approximately equal one would expect the overall delay to be close to the delay of conventional DQRAP. Table 3 shows this to be so. The overall delay is slightly higher than with the Extra-slot format because the latter utilizes four minislots into which traffic funnels instead of three in the Extra-bit format. Indirectly this confirms results shown by Xu and Campbell [1] and Zhang and Campbell [4] that increasing the number of minislots beyond three does improve performance, but not appreciably. Lin [3] does show results with four minislots in the Extra-bit format to provide a comparison with the four minislot Extra-slot format. Figure 6 shows packet delay performance of the Extra-bit format for both high priority and normal packets under different high/normal load combinations.

The qualitative properties of the Extra-bit format are:

1) The delay performance is stable under a variety of load configurations.

2) The logic complexity is simpler than using an extra exclusive minislot in terms of states needed. This approach uses six states to represent the system status instead of the nine states in the Extra-slot format.

3) FIFO, with respect to a single station, is guaranteed.

IV Discussion

The delay performance of both the Extra-slot and the Extra-bit formats are very close. Below we summarize the characteristics of the two formats.

1) The delay of the high priority packets using the Extra-slot format is lower than the delay of high priority packets using the Extra-bit format at all offered loads. The Extra-slot format utilizes an extra single minislot thus in effect the comparison is being made between a four minislot system and a three minislot system. Xu and Campbell [1] show that four minislots provides superior performance over three minislots in DQRAP and this is replicated with PDQRAP. The overhead of the extra minislot could adversely impact the overall performance of the protocol in some environments.

2) The average delay of all packets using the Extra-bit format is more stable than the average delay of all packets using the Extra-slot format. The average delay using Extra-slot format is lower than when using Extra-bit format. However, the average delay of all packets and the delay encountered by normal priority packets at all loads is lower than that available with currently available protocols.

3) The Extra-bit format guarantees FIFO at an individual station.

4) The minislots are individual transmissions. In the Extra-slot format, the usage of minislots depends on the state of the protocol. For example, when |H_TQ| = 0, |N_RQ| > 0, the minislots 2-4 are used by normal packets while minislot 1 is used by new high priority arrivals. Successes or collisions in minislots 2-4 will

Table 2. Possible Outcomes and Actions for Each Minislot.

Type \ Mini Pattern\Slot	Collision	Action	No Collision	Action
1	High/Normal Collision	RQ = RQ + 1	Single High	H_TQ = H_TQ + 1
0	High/Normal Collision	RQ = RQ + 1	Single Normal	H_TQ = H_TQ + 1
?	High/Normal Collision	RQ = RQ + 1	Empty Minislot	No Action

change N_TQ or N_RQ respectively while a success or collision in minislot 1 will only change H_TQ or H_RQ respectively. In the Extra-bit format, all minislots can carry both high priority and normal requests. When successful there is no problem distinguishing between the two priorities. However in some environments it could be difficult to identify the type of entries in a minislot after a collision., i.e., two or more high priorities, two or more normal priorities, or a mix of each. Thus, the Extra-slot format utilizes two RQs while the Extra-bit format requires only one RQ.

5) The Extra-bit format can be expanded to a multiple level priority protocol by adding one or more type bits in each minislot, an action that normally has minimal affect on the overhead. The Extra-slot format must add one or more minislots to add priority levels, something that could have an adverse impact on the overhead, especially in an RF environment.

6) Using a single minislot for high priority traffic in the Extra-slot format suggests that if the proportion of high priority traffic approached the equivalent of 35% - 40% of available capacity the well-known slotted Aloha limit of 36.8% would kick in. This doesn't occur since the other three minislots are utilized to resolve collisions occurring in the high priority minislot. Note in Table 1 that even when high priority traffic represents 80% of the total the delay is still 5.6 slots.

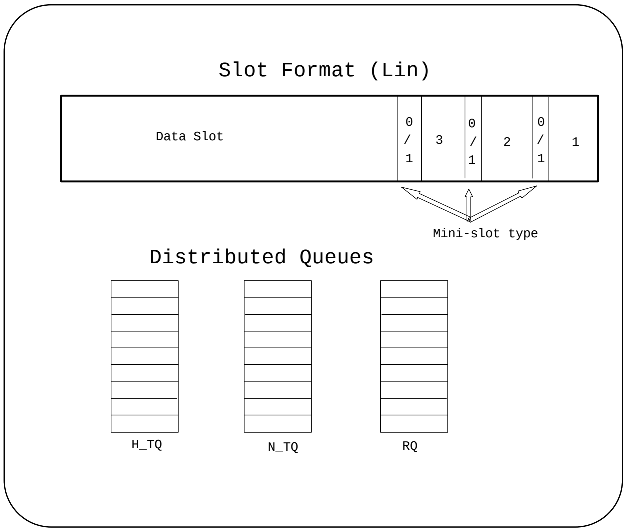

Figure 4. PDQRAP Extra-bit (Lin) Format

The overall performance of the Extra-slot format is slightly better than the Extra-bit performance. As stated previously the main reason for the difference is that the Extra-slot format does utilize four minislots in total as compared to three for the Extra-bit format. However, the most important factor to be considered is the overhead of the two approaches. In actual implementations the minislots utilized in PDQRAP are individual transmissions. They may or may not carry recognizable "bits". A station when writing to a minislot need only transmit some form of signal such that at the receiver(s) ternary feedback is available, i.e., no signal, a single signal, or a presence of two or more signals (a collision). In a baseband digital environment with adequate synchronization DQRAP can be supported by using a minislot consisting of a two-bit pattern. Single high priority PDQRAP can be implemented in such an environment by either adding a single bit to each minislot for a total of three extra bits or by adding an extra minislot at a cost of two bits. Neither method would have an adverse impact on overhead. PDQRAP in an RF broadband environment, e.g., on cable TV, could require a transmission time equivalent to 20, or even more, bit times for a minislot. This is required to overcome the problems in electromagnetic transmission of multilevel coding, ramp-up time, capture effect and the possibility of two transmissions being 180 degrees out of phase and actually canceling out. The solution to these problems is addressed by Campbell [5]. Thus the choice of which priority mechanism to use could very much depend upon the medium.

Table 3. Delay Performance for Extra-Bit PDQRAP (Three minislots)

Load		Delay		Average Delay
High	Normal	High	Normal	
10%	80%	4.29317	9.18598	8.64233
20%	70%	4.35957	9.73857	8.54323
30%	60%	4.40486	10.59016	8.52839
40%	50%	4.51828	11.771	8.54756
50%	40%	4.66318	13.2835	8.49443
60%	30%	4.77584	15.5845	8.37873
70%	20%	5.19356	19.3998	8.3505

PDQRAP is a non-deterministic protocol and as such no guarantees can be made about maximum delay. However, as a matter of interest we logged the maximum delays encountered in simulation runs of 250,000 packets at 90% total offered load with 20% high priority packets. For the Dixon format the maximum delay was 13.9 slots and with the Lin format it was 46.1 slots. A similar length run of normal DQRAP at 90% load produced a maximum delay of 70.2 slots.

Case	Usage of Slots			
	Data	CMS 3	2	1
Case 1. $\vert H\_TQ\vert >0,\vert N\_TQ\vert -DC,\vert RQ\vert >0$	High	H/N	H/N	H/N
Case 2. $\vert H\_TQ\vert >0,\vert N\_TQ\vert -DC,\vert RQ\vert =0$	High	H/N	H/N	H/N
Case 3. $\vert H\_TQ\vert =0,\vert N\_TQ\vert >0,\vert RQ\vert >0$	Normal	H/N	H/N	H/N
Case 4. $\vert H\_TQ\vert =0,\vert N\_TQ\vert =0,\vert RQ\vert >0$	Empty	H/N	H/N	H/N
Case 5. $\vert H\_TQ\vert =0,\vert N\_TQ\vert >0,\vert RQ\vert =0$	Normal	H/N	H/N	H/N
Case 6. $\vert H\_TQ\vert =0,\vert N\_TQ\vert =0,\vert RQ\vert =0$	High/Normal	H/N	H/N	H/N

Figure 5. PDQRAP Extra-Bit Format Priority Rules

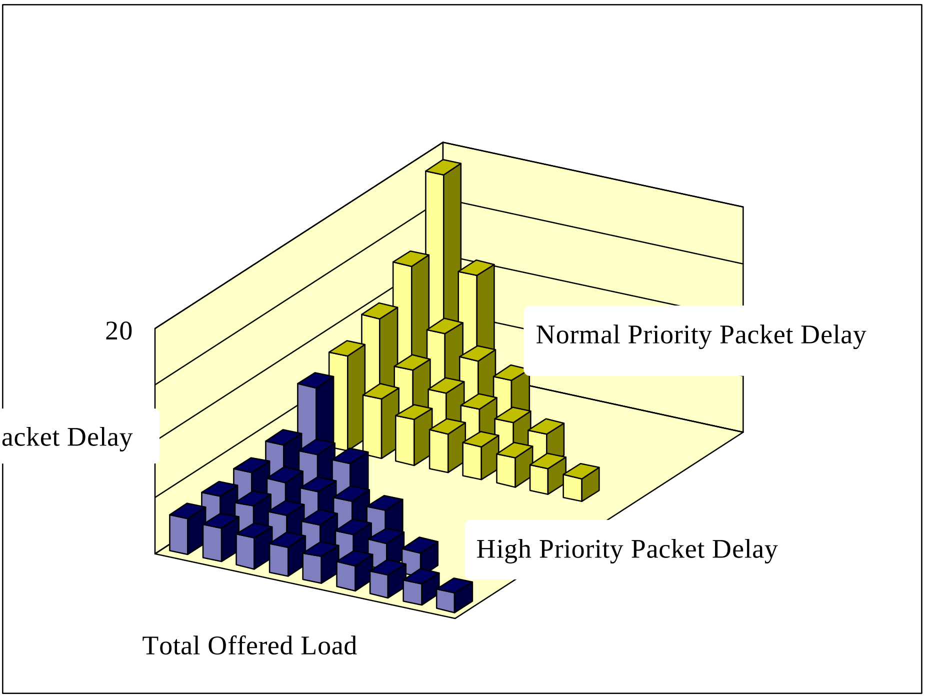

Figure 6. Delay Characteristics for Extra-Bit (Lin) PDQRAP

V Conclusion

We have presented PDQRAP, a priority version of DQRAP. Many MAC priority mechanisms simply provide greater opportunity or probability for high priority packets to transmit. PDQRAP supports a true priority mechanism in that if a high priority packet arrives and one or more normal priority packets have already been scheduled to transmit, the high priority packet preempts and is transmitted at the next slot time. Two variations of PDQRAP: Extra-slot (Dixon) format and Extra-bit (Lin) format, have been described. Simulation results show that the average delay of high priority traffic in both the Dixon and Lin formats is less than five slots when the high priority traffic constitutes up to 50% of total traffic of a 90% offered load. The significance of this is that an ideal protocol has an average delay of 6 slots at 90% offered load.

There is a possibility that in the long run switched cell technology, i.e., ATM, might not prove adequate to the task of transporting real-time traffic associated with multimedia, i.e., voice and video packets. The results presented in this paper suggest that a shared medium approach using PDQRAP at the MAC layer could prove to be a viable solution to transporting this type of traffic in LANs, MANs, and WANs.

References

[1] Xu, W. and Campbell, G.: "A Distributed Queueing Random Access Protocol for a Broadcast Channel," *Computer Communication Review,* Vol. 23, No. 4, October 1993, pp 270-278. (SIGCOMM '93 Proceedings.)

[2] Dixon, O.: "A Proposal for a Two-Level Priority Scheme in the Blocked Access DQRAP Protocol," Master's Project, Illinois Institute of Technology, December 1992.

[3] Lin, H. J.: "Multiple Access Protocols in a Digital Radio Environment," Ph.D. Thesis, Illinois Institute of Technology, August 1993.

[4] Zhang, X. and Campbell, G.: "Performance Analysis of Distributed Queueing Random Access Protocol - DQRAP," DQRAP Research Group Report 93-1

[5] Campbell, G.: "Acquiring Ternary Feedback in a Broadcast Channel," Unpublished.

[6] Towsley, T. and Vales, P.O.: "Announced Arrival Random Access Protocols," *IEEE Transactions on Communications,* Vol COM-35, No. 5, pp 513-521, May 1987.

[7] Stallings, W.: *Data and Computer Communications Fourth Edition,* Macmillan, 1994.

[8] Xu, W.: "Distributed Queueing Random Access Protocols for a Broadcast Channel," Ph.D. Thesis, Illinois Institute of Technology, Dec. 1990.