A Contention Channel Access Control Policy - Retreatable Dual Mean Collision Density Control Policy (REDME) for Random Channel Access Control

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Abstract - A random multiple access channel control policy to improve delay and throughput performance of the minislot ALOHA reservation protocols is proposed and studied. A prioritised multiple access scheme derived from the study is also simulated. The policy permits channel access according to two estimated values of the mean collision density based on the previous l (l = 1, 2, 3..., called *history length*) request access (RA) channel feedbacks. It is shown that the policy reduces collisions in the RA channel and better performance is provided by applying optimal policy parameters to the access control process. It is also shown that the policy can prioritise a random multiple access process.

1 Introduction

In a wireless packet network, the medium access control (MAC) protocol is designed to increase throughput and reduce average packet delay. The medium access delay should be minimised and the stability of the protocol should be strengthened. Demand assignment reservation protocols with explicit frame-by-frame RA channel collision feedback are considered here. Some MAC protocols use packet reservation multiple access (PRMA) [1-4]; others use separate RA minislots for the mobile terminals (MTs) to reserve bandwidth from the base station (BS), possibly in contention with other MTs. We classify these protocols as minislot reservation mac (MRMA) protocols. The MRMA protocols with a slotted ALOHA RA chanel are refered to as ALOHA MRMA protocols in this paper.

The basic wireless architecture considered in this paper is called a cell with a BS serving a number of MTs through a shared radio channel. The BS is connected to a fixed network. The downlink (DL) channel consists of a transmission permission (Xmt_Perm) slot, an RA acknowledgement (ACK) slot and one data slot. The uplink (UL) channel consists of a data slot, a piggyback bit and an RA minislot for requesting access. The BS acknowledges a collision (or no-collision) in the immediate next DL ACK slot. If a collision occurs, the MTs will backoff some frames and retry. If no collision occurs, the MT will wait for its Xmt_Perm to be announced in one of the following DL Xmt_Perm slots. After "hearing" its Xmt_Perm, the MT will transmit a packet in the following UL data slot and set the piggyback bit if it has more data to transmit.

When a cell has many MTs, collisions in the RA channel can be high. To remedy this, many techniques have been proposed, e.g. (1) slotting the RA channel [5]; (2) converting idle UL data channels into multiple RA channels and piggybacking a short update RA request along with a data packet [6]; (3) controlling RA channel access permission [7]; etc. We extend the method of controlling the RA channel access permission and propose our REDME policy for the ALOHA MRMA protocols. An optimised RA channel access control policy can regulate reservation traffic to reduce blind RA contention.

Section 2 describes REDME. Section 3 describes evaluating the minimum average delay minimum the MRMA/REDME protocol. Section 4 presents a REDME prioritisation scheme. Section 5 reports the simulation environment. Section 6 interprets the simulation results. Section 7 concludes the paper.

2 REDME Description

Figure 1 shows the operation states of the MRMA/REDME protocol. In traditional MRMA, an MT changes from the empty state to the reservation state when it needs service. But the REDME requires that the state transition be conditional, depending on an entry condition A. We chose an average collision density value e called *entry threshold*, calculated using previous l RA channel feedbacks (collision or no-collision). Only when average collision density is less than e, is the state transition allowed. The calculation of e requires that each MT has a set of binary registers of length l. A right history length leads to an accurate estimation of the average collision density, which is expected to reduce more blind contention in the RA channel. The right history lengths are different under different traffic loads. Hence, the l is a variable.

In traditional MRMA, an MT is not allowed a transition from the reservation state to the empty state. MTs in the reservation state will continue sending RA requests with a backoff algorithm until success. This persistence could increase collision levels and worsen the protocol delay performance. Hence, REDME requires that some blocked MTs return (retreat) to the empty state when the average collision density in the RA channel is larger than a threshold h called *retreat threshold,* in order to reduce contention and keep the use of RA channel efficient. The difference between the h and the e is called *control width* w ($w = h - e$, $h > e$).

It is not necessary to force all MTs in the reservation state to retreat. We consider that it is a fair scheme to make the newer arrivals to retreat because, by doing so, the delay difference between the newer arrivals and the older arrivals which already have longer delays will not be further increased. The number of retries shows how new an RA request is. We select a threshold c (c = 0, 1, 2...) called *retreat ceiling*. We also define another parameter p called *retreat probability.* REDME stipulates that an MT will retreat with probability p when its number of retries < c. The retreat condition **B** in the Figure 1 is expressed as that the collision density is larger than ($e + w$) while the number of retries is less than c. The delay performance caused by the number of retreating MTs shows in the simulation by tuning p.

The REDME policy is described by 5 parameters: (1) *l - history length* (2) *p - retreat probability*; (3) *c - retreat ceiling*; (4) *e - entry threshold*; (5) *w - control width.* The notation (*l*100 *p*0.02 *c*7 *e*0.4 *w*0.1) means a REDME policy with *history length* 100, *retreat probability* 0.02, *retreat ceiling* 7, *entry threshold* 40% and *control width* 10%. There are special meanings for special notations, eg., in *l*100 *p*0 *c*7 *e*1+ *w*0.1. The *e*1+ means no channel access control - any RA request can access the UL RA channel and no *retreat*; in other words, the behaviour of the *e*1+ REDME completely equals to a traditional MRMA protocol.

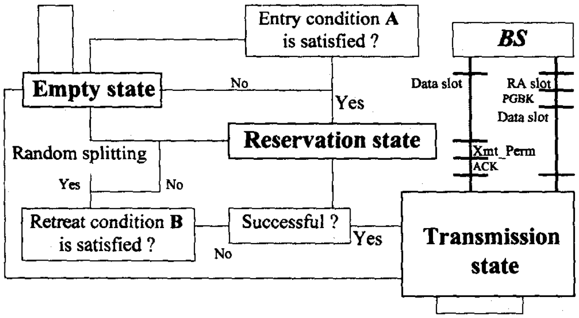

Figure 1 The MRMA/REDME protocol operation states and frame structure

The average delay d of the MRMA/REDME protocol is generally expressed as

$$d = f(l, p, c, e, w, u) \qquad (1)$$

u is the UL data channel normalised throughput. Other variables have been introduced previously. f is not known analytically. The dependencies among the variables are shown by simulation below.

3 Search for Average Delay Minimum Value

Because formula (1) embodies multiple parameters, finding the minimum d is not straightforward. We estimate, by changing one of the five REDME parameters under a given throughput, the minimum average packet delay. Figures 2 - 6 show the first round searching results of an instance which starting point was arbitrarily selected at (*l50 p0.5 c6 e0.01 w0.1*) and the path was *l -> p -> c-> e->w* under the data channel throughput at 50%. Figures 2 - 6 prove the existence of the minimum. After repeatedly searching until the variation of the minimum average delay is less than 1 frame, the minimum itself trends to 82.58 frames, the corresponding optimal parameters are (*l34 p0.02 c6 e0.32 w0.15*). Using the same method but along the reverse path (*w->e->c->p->l*) with the same starting point, the minimum tends to 81.42 frames, the corresponding optimal parameters are (*w*0.12 *e*0.37 *c*5 *p*0.6 *l*37). Both the optimal parameters and the minimal extreme values do not converge together. This is a general characteristic of the MRMA/REDME protocol.

Our simulation shows that the minimum delay also depends on starting points. It tends to 76.29 frames with another starting point at (*l50 p0.028 c4 e0.51 w0.01*) and with the path along *l -> p -> c-> e->w* under 50% data channel throughput. The corresponding optimal REDME parameters are (*l*20 *p*0.33 *c*4 *e*0.385 *w*0.01) which are different. This makes the search for the minimum average delay more difficult.

Our simulation also shows that the optimal REDME parameters are different under different data traffic loads. As shown in Figure 7, under 90% data channel throughput, the delay performance of (*l*10 *p*0.33 *c*4 *e*0.385 *w*0.01) which has a shorter *history length* is better (less) than that of (*l*20 *p*0.33 *c*4 *e*0.385 *w*0.01). This suggests that the REDME should adopt a shorter *history length* under higher data traffic loads. The absolute accuracy of the average delays are less than 1 frame when data throughput is less than 95%, suggesting a very small relative error. The relative accuracy of all average delay values is less than 5%.

4 Developing Prioritised REDME Multiple Access Schemes

As shown in Figures 2, 4, 5 and 6, the delay is sensitive to the parameters *l, c, e.* Although the delay is not sensitive to the *retreat probability p* (Figure 3), it is in Figure 8 with different parameters. It shows that p can influence the delay in some cases and is an important parameter in REDME.

A parameter's effect on the delay provides the possibility of forming a prioritised multiple access scheme based on allocating different values of the parameter among the MTs in a cell. Hence, each of five REDME parameters can form a prioritised multiple access scheme. Here, we provide the study results of a priority scheme which is based on *retreat ceiling c*.

4.1 A Prioritised Multiple Access Scheme based on the Retreat Ceiling *c*

Figure 4 shows that the packets of a MT with a smaller c will experience a smaller delay. Hence, an MT with a higher prioirty should be assigned a smaller c. We simulated a two level priority scheme among the MT population in a cell. The high priority MTs are assigned $c = 0$ constantly, which means that the MTs will not retreat regardless of the RA collision density. The c of low priority MTs is changed to show the degree of the advantage obtained by the high priority MTs. The fraction of the high priority MTs in the population is 50% constantly. The UL data channel throughput is 70%. The results are shown in Figure 9 and Table 1 provides 95% confidence intervals.

In Table 1, when $c = 7$, both the high priority packets and the low priority packets have the minimum delay. Hence, $c = 7$ is a notable value which provides the maximum advantage to the high priority packets (e.g., realtime traffic) whilst keeping the delay of the low priority packets as small as possible. In this case, the average delay of the high priority traffic $d_1 = 49.86$ frames. The high priority traffic occupies 35% of the UL capacity. In the unprioritised scheme, 35% UL throughput leads to an average packet delay $d_2 = 22$ frames (Figure 7). $d_2 = 22$ is the ideal value for d_1 here.

With $c = 7$, the prioritisation characteristic curve shown in Figure 10 is obtained by changing the amount of the high priority MTs in the population. The curve can be used to compare with other multiple access schemes with priority.

5 Simulation environment

Each MT generates bursts of packets at the same rate and provides 1% G load of UL data traffic. The Burst interval is exponentially distributed with burst length = 1 packet constantly. One successful reservation request reserves one data slot in the UL. Each data packet piggybacks an update RA request according to the real time buffer situation (empty or not).

Only 1-slot ALOHA[8][9] is used in the RA channel of the MRMA and in the MRMA/REDME protocols as the random access protocol. The backoff retry algorithm is 1/2 1/4, 1/6, 1/8, 1/10, 1/12 ....

In the BS, the scheduling algorithm is token-generator-like. When the BS receives a successful reservation request or a piggybacked update RA request, an Announcement Token (AT) recording the aID of that MT is generated and put into a FIFO queue, called an AT queue. For each DL frame, the BS will check the AT queue; if the AT queue is not empty, the BS will, via the *Xmt_Perm* channel, announce the MT's aID recorded on the first token in the AT queue and then delete it.

The number of MTs used in the simulations ranges from 10 to 100. Average UL data packet delay statistics are calculated from at least 3,000,000 packets. The simulation program is written in C++.

6 Simulation Results

1 slot ALOHA is equivalent to a pure ALOHA, of which delay-throughput performance is shown by the curve 1 in Figure 7. The average packet delay of the pure ALOHA is not stable around 30% UL throughput. This poor performance is greatly improved by the piggyback channel. The improved performance is shown by the curve 2 in Figure 7.

The plateau in the curve 2 is caused by the piggyback channel. The reason is that, when the average packet delay rises, the probability of more than one packet queued in the MT buffer rises too. Hence, more bandwidth reservation requests are sent through the piggyback channel free of contention. The plateau in the curve 3 and 4 is also caused by the same reason.

It is not be concluded that the REDME policy can improve the throughput performance of a pure ALOHA from 30% to 98%. The piggyback mechanism and REDME, to a lesser extent, contribute to this improvement.

7 Conclusions

This paper presented a retreatable dual mean collision density RA channel access control policy for MRMA protocols. Simulations show that (1) The REDME policy reduces the average packet delay of the minislot ALOHA reservation protocols. (2) Better performance is provided by applying optimal policy parameters to the access control process. (3) Under heavy traffic load conditions, a shorter collision *history length is to be used;* under mild traffic load conditions, a longer collision *history length is to be used.* (4) The stability of the MRMA protocols is improved by the use of REDME. (5) The REDME policy has multiple parameters to prioritise random access.

This paper also provided a prioritisation characteristic curve of one of the REDME prioritisation schemes. The curve can be used for comparison with other multiple access protocols with priority.

The policy increases the amount of computing at the MT side; but this is not a significant problem. The REDME policy can be used in future wireless packet networks with multiple priority levels.

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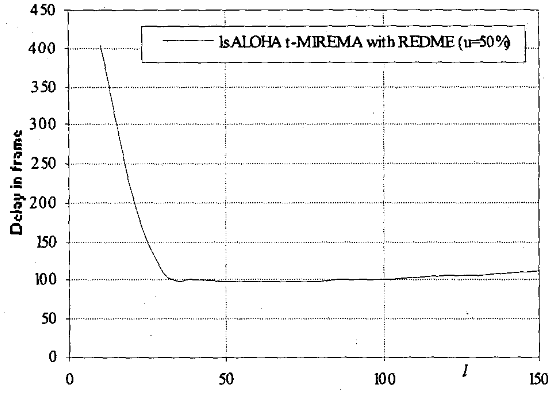

Figure 2 Ave. delay extreme value when changing *l* (*l-- p0.5 c6 e0.51 w0.01*)

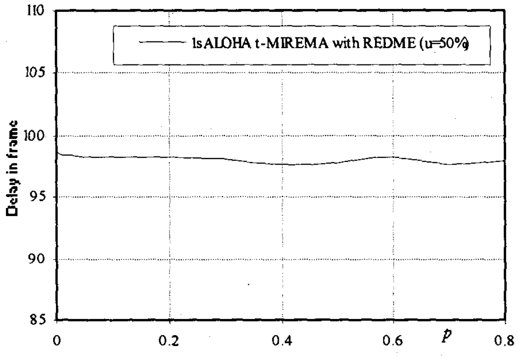

Figure 3 Ave. delay extreme value when changing *p* (*l60 p-- c6 e0.51 w0.01*)

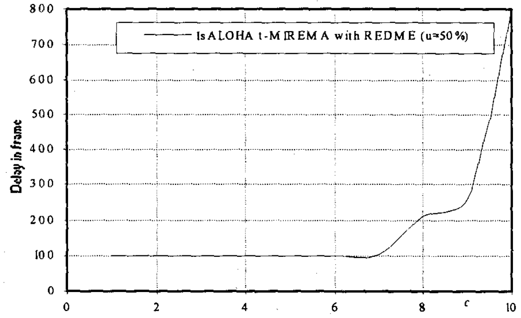

Figure 4 Ave. delay extreme value when changing *c* (*l60 p0.4 c-- e0.51 w0.01*)

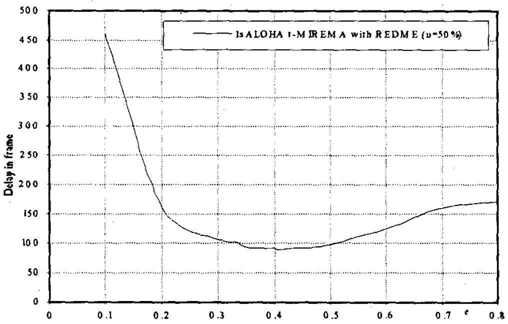

Figure 5 Ave. delay extreme value when changing *e* (*l60 p0.4 c6 e-- w0.01*)

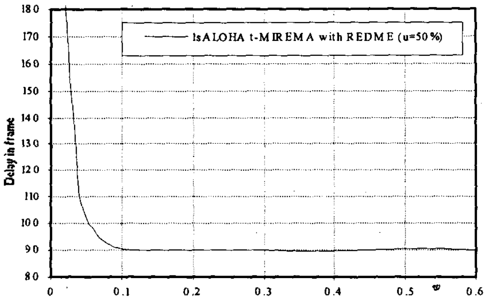

Figure 6 Ave. delay extreme value when changing *w* (*l60 p0.4 c6 e0.41 w--*)

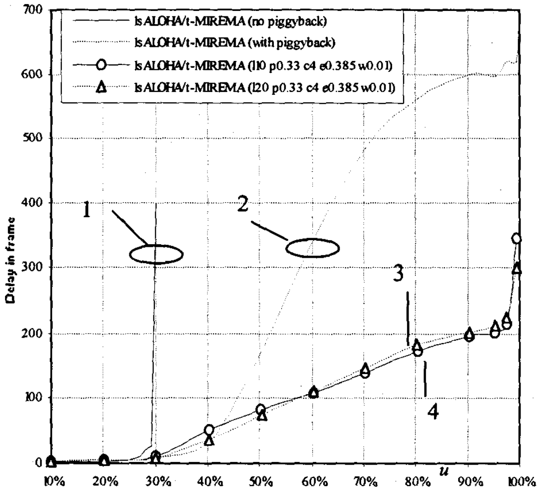

Figure 7 Delay comparison (1 pkt/ burst)

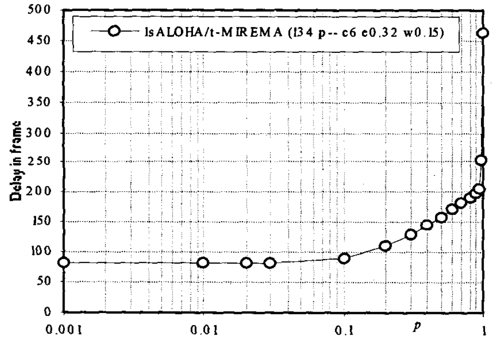

Figure 8 An instance that the delay is sensitive to the *retreat probability*

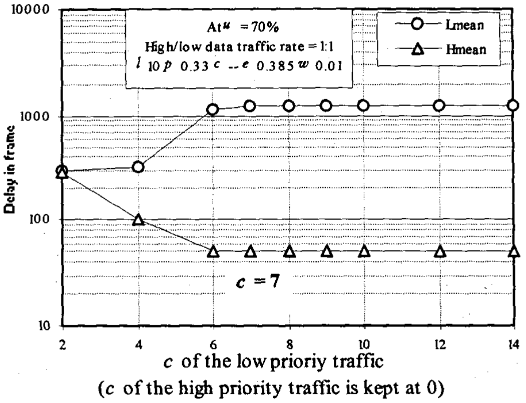

Figure 9 The differences in *c* cause the differences in ave. packet delay

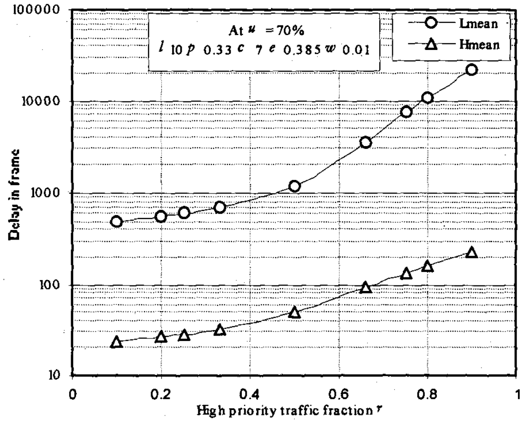

Figure 10 The delay prioritisation characteristic curve related to *c* at *u* = 70%

Table 1 The difference in *c* causes the difference in ave. packet delay (controlled by the following REDME parameters: *l10 p0.33 c- e0.385 w0.01*)

a: *c* of high priority traffic; b: *c* of low priority traffic; r: High priority traffic fraction in the uplink data flow.

(a, b, *r*)	Low priority traffic delay			High priority traffic delay		
	2.5% percentile	Mean	97.5% percentile	2.5% percentile	Mean	97.5% percentile
(0, 2, 0.5)	12.00	295.61	1405.00	12.00	287.43	1397.00
(0, 4, 0.5)	14.00	327.88	1142.00	7.00	101.35	462.00
(0, 6, 0.5)	32.00	1140.16	4183.00	5.00	50.76	209.00
(0, 7, 0.5)	**34.00**	**1222.33**	**4482.00**	**5.00**	**49.86**	**203.00**
(0, 8, 0.5)	34.00	1237.78	4582.00	5.00	49.76	203.00
(0, 9, 0.5)	34.00	1226.06	4513.00	5.00	49.68	202.00
(0, 10, 0.5)	35.00	1235.46	4514.00	5.00	49.82	202.00
(0, 12, 0.5)	35.00	1238.58	4585.00	5.00	49.97	203.00
(0, 14, 0.5)	34.00	1227.28	4532.00	5.00	49.76	202.00