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A New MAC Algorithm for QoS Support in Ad hoc Networks

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Abstract: Supporting real-time traffic in wireless LANs is one of the interesting QoS (Quality of Service) issues. However, the wireless ad hoc networks are severely affected by bandwidth, and establishing a QoS in these networks face problems. In this paper, we have proposed a fully distributed MAC algorithm to support the QoS in ad hoc networks. This algorithm provides delay fairness and delay differentiation for real-time flows. This algorithm also uses the fixed and/or less stationary nodes for the transmission of real-time flows by increasing the QoS of the multimedia flows. By simulation, we show that our mechanism achieves delay fairness and differentiation, and functions adequately to support real-time traffic in practical environments where real-time traffic and non-real-time traffic coexist in an identical wireless Ad hoc networks.

Key words: Ad hoc, Quality of Service, Differential Service, Back-off mechanism.

INTRODUCTION

A wireless ad hoc network consists of a number of nodes communicating with each other on wireless links without infrastructure support. Considering the comfortably establishing ad hoc networks, the use of this type of network is increasing day to day. So, real-time applications such as telecommunications and video conferences will be popular in these networks. Therefore, supporting real-time traffic in wireless LANs (Local Area Network) is an interesting QoS issue.To support real-time traffic in wireless LANs, concentrated control mechanisms are utilized in several previous researches (Brian P. Crow, 1997; 1. Brian P. Crow, 1997; Constantine Coutras, 2000; Malathi Veeraraghavan, 2001; Kazuyoshi Saitoh, 2001). The mechanisms proposed in them use PCF (Point Coordination Function) of IEEE802.11(Wireless LAN Medium Access Control, 1999) to support real-time traffic. Although these mechanisms can provide bounded delay service, they cannot be used in ad hoc mode. On the other hand, distributed control mechanisms can be used in ad hoc mode. So, a distributed control mechanism supporting real-time traffic is required.To give the finite transmission opportunities to flows having variousfeatures, distributed control mechanisms provide fairness and differentiation for flows.In multi-class service, fairness shall be provided for flows belonging to the same service class and differentiation shall be provided for flows belonging to different service classes. Take into account that real-time applications are sensitive to delay rather than throughput, we believe that fairness provided for real-time flows should be delay fairness and that differentiation provided for real-time flows should be delay differentiation.

Many distributed control mechanisms supporting real-time traffic have been proposed for ad hoc networks (Michael Barry, 2001; Andras Veres, 2001; Joao L. Sobrinho, 1996). Although these mechanisms provide higher-priority service for real-time traffic by differentiating real-time traffic from non-real-time traffic they can provide neither delay fairness and delay differentiation.

In this paper, a fully distributed MAC mechanism is proposed for supporting the QoS of the flows in the network that provides delay fairness and differentiation for flows. To achieve delay fairness, we introduce a back-off algorithm that controls back-off time based on waiting-time, the time a frame has experienced since it was it was entered to the link interface. To achieve delay differentiation, we introduce weighted parameter into the back-off algorithm. This algorithm is preferred to others because it classifies the flows in the network without overhead and any control packet.

The rest of this paper is organized as following. Section 2 describes the DCF method of IEEE 802.11, Section 3 concerns with the QoS frameworks, algorithms and works done to classify the flows and support QoS of flows. In Section 4, By simulation, we confirm that our mechanism functions adequately for supporting real-time traffic in wireless Ad hoc networks, and Section 5 is associated with conclusion.

2. IEEE802.11 Standard-DCF:

IEEE802.11 standard describes MAC layer and physical layer specifications for IEEE802.11 wireless LAN (1999). Two access control methods are defined in the MAC layer specifications. One is DCF (Distributed Coordination Function), and the other is PCF (Point Coordination Function). In the following we describe the DCF method (PCF method usable in infrastructure mode of IEEE 802.11).

DCF (Distributed Coordination Function) is a distributed control method based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). DCF must be implemented in all IEEE802.11 stations. In DCF, if a station

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has frames to be transmitted, the station decides back-off time of the frame, which is used to resolve a contention. Back-off time is calculated using a back-off algorithm. DCF adopts BEB (Binary Exponential Back-off) as a back-off algorithm. In BEB, back-off time is calculated using the following expressions:

$$CW = (CW_{\min} + 1)2^{RC} - 1 \quad (1)$$

$$CW = \min(CW, CW_{\max}) \quad (2)$$

$$B = \lfloor CW * rand() \rfloor * Slot\_Time \quad (3)$$

Where CW is contention window, RC is retransmission count of a frame, which RC=0 when the frame is to be transmitted at the first time and RC=n when the frame is to be retransmitted at the n-th time, $CW_{\min}$ is the minimum value of CW, which is equal to CW when RC=0, $CW_{\max}$ is the maximum value of CW, min(a,b) is the function that returns the smaller number of a and b, rand() is a function that returns a value chose n randomly from the interval from 0 to 1, B is back-off time. While the station determines the medium in idle state, for a time interval greater than a DIFS (DCF Inter Frame Space; IFSs are detailed in Table1) then, decrements the Back-off time. When the back-off time reaches to 0, the station transmits a frame. After transmitting the frame, if the node receives the ACK for the transmitted frame, the station resets RC and repeats the above procedures for the next frame. If the node does not receive the ACK, it repeats the above procedures for the same frame with incremented RC.

3. QoS Framework:

3.1. Desirable Network Modification:

Our aim is to realize the QoS of the real-time flows in the ad hoc networks vis-a-vis best-effort flows. Many routing protocols in the ad hoc networks do not differentiate between fixed nodes, less mobile and mobile nodes for the transmission of the flows in multi-hop environment. Though, the fixed nodes and/or less mobile nodes offer better quality in the flow transmission. Thus, it is suggested fixed routers and/or less mobile routers be taken into account in special places of vast environments, so that the transmission can be done with better quality. The utilization of fixed wireless routers in these networks will greatly improve the quality of real-time traffic by the elimination of intermediate link breaks.

3.2. Find_Fix_Router for Real-timeTtraffics:

When a node wants to send a real-time flow, it must, first of all, call for Find_Fix_Router process in order to find a valid path. Find_Fix_Router() process based on the modified AODV routing protocol. The modified protocol prefers the selection of stationary routes for real-time traffics. When a source node initiates route discovery for real-time traffic with strict quality requirements, only the fixed routers respond to the control packets by either forwarding the RREQ, or unicasting a RREP. The mobile nodes do not respond to these packets, unless they are the destination.

Find_Fix_Router also enables effective admission control when the network utilization is saturated. This requires accurate estimation of channel utilization and prediction of flow quality, i.e., throughput or transmission delay. The proposed QoS approach is based on model-based resource estimation mechanism, called *MBRP* (Sun, 2004). By modeling the node back-off behavior of the MAC protocol and analyzing the channel utilization, MBRP provides both per-flow and aggregated system wide throughput and delay (Yuan Sun, 2004).

3.3. Distributed MAC for Real-time Flows:

In Ad hoc networks, priority scheduling algorithms are based on IEEE 802.11 (IEEE Computer Society, 1999). Currently, there are several approaches that have been proposed to provide service differentiation to different types of traffic based on 802.11, by either assigning different minimum contention window sizes ($CW_{\min}$), Arbitrary Inter Frame Spacing (AIFS), or back-off ratios. There are algorithms that differentiate between different flows through these techniques, but this differentiation is static. To achieve service differentiation, as well as to adapt to the current usage of network, we combine the collision rate and current QoS of flows with the exponential back-off mechanism in IEEE802.11. To do it, classifies flows into two types: delay-sensitive flows and best effort flows. Upon receiving the first packet from the flow related to one of those classes, each node, without any overhead in the network, locally builds a queue for that flow. Then it inserts this packet and subsequent packets related to that flow in this queue. It is noted that contrary to real-time flows where a separate queue is built in every node for each flow, only a queue is built for all best-effort flows in every node. Figure 1 shows the queues built in each node to manage different flows.

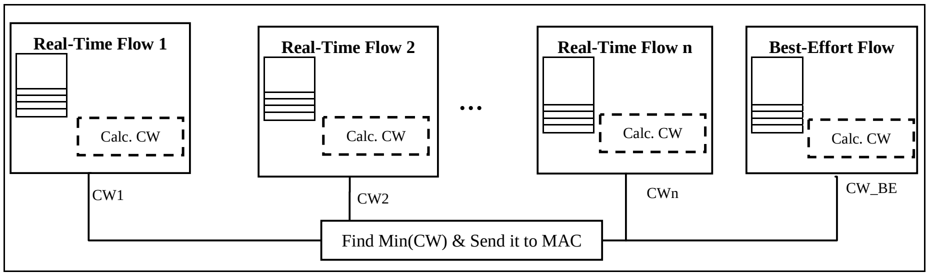

Fig. 1: Queues in each node (Network Layer).

3.4 Mechanisms Used to Support QoS of Flows:

A distributed MAC mechanism supporting real-time traffic in Ad hoc networks should satisfy the following requirements:

- Delay fairness: A distributed control mechanism is required to give the finite transmission opportunities to flows fairly. In addition, delay is very important factor to be considered for real-time traffic, becausereal-time applications are sensitive to delay rather than throughput. Thus, all the real-time flows supported by a distributed MAC should be provided with delay fairness.
- Delay differentiation: Delay differentiation is useful to support real-time flows according to their QoS requirements. Real-time applications have different level of requirements on delay according to the characteristics of them. For example, voice requires tighter delay than moving picture, and interactive communication requires tighter delay than one-way communication.

Besides, from the view point of practicability, a distributed MAC mechanism supporting real-time traffic is desired to coexistence with a MAC mechanism for non-real-time traffic. Because real-time traffic and non-real-time traffic coexists in a practical wireless LAN, a MAC mechanism of wireless LANs is required to support both real-time traffic and non-real-time traffic. Now, DCF of IEEE802.11 is the most widely used wireless LAN protocol and is the standard for non-real-time traffic. Therefore, a MAC mechanism for real-time traffic is required to coexist with a MAC mechanism for non-real-time traffic such as DCF.

To meet the requirements described above, we propose a new MAC mechanism. DCF cannot supportdelay fairness or differentiation, because BEB (Binary Exponential Back-off), the back-off algorithm have been used in DCF, decides back-off time of a frame regardless of how long the frame is kept waiting to be transmitted. Then, to achieve delay fairness, we introduce “waiting-time” defined as the time a frame has experienced since it was it was entered to the link, and we give smaller back-off time to a frame having larger waiting-time. To achieve delay differentiation, we also introduce weighting parameter that is used to adjust back-off time independently of waiting-time, and give different waiting parameters to differentiated frames.

The delay-sensitive flows, such as conversational audio/video conferencing, require that packets arrive at the destination within a certain delay bound. The best effort flows, such as file transfer, can adapt to changes in bandwidth and delay. Due to the different requirements of flows, each type of flows has its own contention window adaptation rule, as flows:

1) Delay-Sensitive Flows: Delay-sensitive flow adopts the back-off algorithm presented by the following expressions:

$$CW = (CW_{\min} + 1)2^{RC} - 1 \quad (4)$$

$$CW = \min(CW, CW_{\max}) \quad (5)$$

$$B = \lfloor CW * rand() \rfloor \quad (6)$$

$$B = \lfloor B * K / (t / w) \rfloor \quad (7)$$

$$B = \max(B, B_{\min}) \quad (8)$$

$$B = \min(B, B_{\max}) \quad (9)$$

Where t is waiting-time, K is a constant value of which is the same in any station, w is a weighting parameter that the value of which may vary in every station.

This back-off algorithm is composed of 2 steps. In the first step, the BEB procedure decides B according to the expressions (4), (5) and (6). (4), (5) and (6) are equivalent to (1), (2) and (3), respectively. We utilize the contention resolution functionality of BEB in this step. In the second step, B is adjusted according to the expressions (7), (8) and (9).

This step decides B to be inversely proportional to t, whereby a frame of larger waiting time has higher transmission priority. That is, this step supports delay fairness. In addition, by making stations have different w values, this step can support delay differentiation. Expressions (8) and (9) limit B in the range from $B_{\min} to\ B_{\max}$.

2) Best Effort Flows: Best effort flows are tolerant to changes in service levels and do not have any hard requirements about bandwidth or packet delay. The purpose of updating the back-off size of best effort flows is to prevent best effort flows from congesting the network and degrading the service level of real-time flows and this is done by controlling the network congestion.

$$CW^{(n+1)} = CW^{(n)} \times (1 + \gamma(f - F^{(n)})) \qquad (10)$$

Where *f* is a *congestion threshold* for idle channel time, *F* is the actual idle channel time and *γ* is a positive constant (*γ=0.1).*

When the average idle channel time *F* is smaller than the threshold value *f*, the network is considered congested and the contention window size of the best effort traffic is increased to avoid decreasing the service level of real-time traffic. On the other hand, if the network is lightly loaded so that the idle channel time is larger than *f*, the contention window size of best effort traffic is decreased so that the idle bandwidth can be utilized.

The pseudo-code of back-off computation is as follows:

Back-off_Time():

{

If (TypeOf(Flow)='Real-Time') **then**

$$CW = (CW_{\min} + 1)2^{RC} - 1$$

$$CW = \min(CW, CW_{\max})$$

$$Back-off = \lfloor CW * rand() \rfloor$$

$$Back-off = \lfloor Back-off * K/(t/w) \rfloor$$

$$Back-off = \max(Back-off, Back-off_{\min})$$

$$Back-off = \min(Back-off, Back-off_{\max})$$

Else If (TypeOf(Flow)='non-Real-Time') **then**

$$CW^{(n+1)} = CW^{(n)} \times (1 + \gamma(f - F^{(n)}))$$

$$Back-off = Rand[0,(2^{r} + R_{col}) * CW] * Slot\_Time$$

}

Where R_{col} denotes the collision rate between a station's two successful frame transmissions and r is a positive number.

By the Back-off-Time(), all flows dynamically manage their contention parameters to meet their own QoS needs. A real-time flow that did not get its required QoS in the past due to competition from other flows try to lower back-off and so, give media as soon as possible. A best effort flow, on the other hand, increases its contention window size when the network is considered busy and hence releases the channel to the real-time flows (Eq.(10)). The random generated back-off counter ensures that the channel access attempts from different flows are spread out and do not cause a lot of collision. More importantly with attention to flow's current status, traffics with same class will have different back-off value when collisions occur. Specifically, after a collision occurs, low priority traffic will back-off for longer, and subsequently high priority traffic will have a better chance of accessing the channel. Contrary to (Kanodia, 2001; Haiyun Luo, 2002), in our proposed algorithm, no piggy-backed schedule information and neighborhood scheduling tables are needed. Therefore, there is no control message overhead imposed by our proposed algorithm.

In next section, the simulation of the proposed algorithm is proved.

4- Simulation:

In this section we evaluate the proposed MAC mechanism by simulation. The simulation is done in ns-2 and network size is 1000m*1000m. In the simulation environment n senders transmit frames destined for an identical receiver at constant bit rate. The configurations are shown in Table 1.

In this paper, we use fairness index (Raj Jain, 1996) to evaluate accuracy of delay fairness and differentiation. Fairness index is defined by the:

$$fairness\ index = \frac{(\sum_{i=1}^{n} d_i / w_i)^2}{n\sum_{i=1}^{n} (d_i / w_i)^2}$$

Where n is the number of senders, d_i is the delay of sender i, and w_i is the weight of sender i. Fairness index is greater than 0, and less than or equal to 1. It approaches to 1 as $d_1 / w_1, d_2 / w_2, \ldots, d_n / w_n$ are becoming the same.

Table 1: Configuration

Sender	CW_{min}	CW_{max}	K	B_{min}	B_{max}	W	IFS	Queue length	Frame Size	Bit rate
1-n	31	1023	0.0005	1	1023	1	DIFS	16 KBytes	1024 byte	1000 kbps

We evaluate the proposed MAC mainly by comparing the simulation results of the proposed MAC with those of DCF. To evaluate the fairness of the proposed MAC mechanism, we use Configuration that has described in Table 1, as a simulation configuration. In the configuration, n senders all implement the proposed MAC mechanism and have the parameters in the table. For the purpose of the comparison of the proposed MAC and DCF, we have all the senders implement DCF too. In the case, they have the parameters in the table except K, B_{min}, B_{max} and w . Figure 2 shows the delay characteristics obtained in the simulation of Configuration in table 1. The figure shows simulation results in the case where the n sender all implement the proposed MAC or in the case where the n senders all implement DCF. The lines of "min" present delays of the sender having the smallest delay of the n senders, the lines of "max" present delays of the sender having the largest delay of the n senders, and the lines of "ave" present the average values of the delays of the n senders. Both in the proposed mechanism and in DCF, if $n \leq 6$, all the senders experience little delay because the medium load is light. On the other hand, if $n \geq 7$, the average delay of the n senders increases as n grows larger. Additionally, there are two features when $n \geq 7$. One is that the average delay in the proposed mechanism is smaller than that in DCF. The other is that the difference between the maximum delay and the minimum delay in the proposed mechanism is much smaller than that in DCF. In other words, the proposed MAC is a better mechanism to achieve low delay and delay fairness than DCF. This advantage is derived from our original procedure (7), where larger waiting-time leads to smaller back-off time.

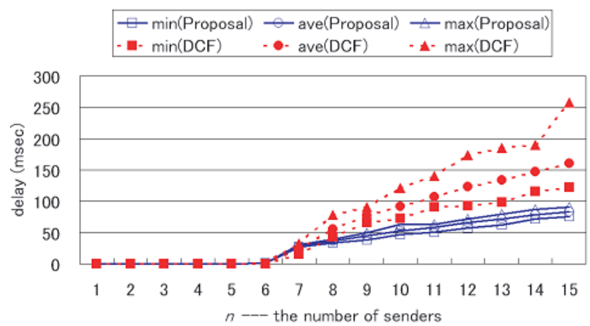

Fig. 2: Delay of Flows.

5- Discussions:

In this paper we introduce a new distributed MAC protocol that support from QoS, this protocol could be run in large-scale ad hoc networks, which this protocol is simple, fully distributed and use no control packets. An important benefit of this protocol is that it does not need resource reservation and therefore, it does not have the problems related to the use of in-bound and out-bound signals to reserve and free the resources, and the network bandwidth is not occupied by reserving and freeing the resources.

In the future, we will investigate the effect of different values t, w, f, r on the throughput and delay related to different classes.

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