Performance Analysis and Comparison of QoS Provisioning Mechanisms for CBR Traffic in Noisy IEEE 802.11e WLANs Environments

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Abstract

In order to reach better Quality-of-Service (QoS) requirements for multimedia application, the 802.11e task group was formed and has proposed EDCA (Enhanced Distributed Channel Access) for contention period and HCCA (HCF Controlled Channel Access) for contention-free period in the HCF (Hybrid Coordination Function) to enhance the original IEEE 802.11 Medium Access Control (MAC) protocol. However, the problem of choosing the right set of MAC parameters and strict QoS mechanism to provide guaranteed QoS in IEEE 802.11e Wireless Local Area Networks (WLANs) remains unsolved. In this paper, a pragmatic Call Admission Control (CAC) scheme with a novel polling based uplink scheduling policy for CBR traffic in IEEE 802.11e WLANs is proposed. The proposed CAC scheme computes the expected delay variation of every session upon arrival of new connection for admission decision. In addition, the proposed packet based delay constrained scheduling policy can derive sufficient conditions such that all accepted sources satisfy their time constraints to provide deterministic QoS guarantees. In addition to theoretical analysis, simulations are conducted to evaluate the performance of the proposed scheme. As it turns out, our design works very well in providing performance improvement in the noisy IEEE 802.11e WLANs environment.

Key Words: Delay Variation, EDCA, HCCA, CBR, IEEE 802.11e

1. Introduction

In WLANs, the MAC protocol is the key component that provides the efficiency in sharing the common radio channel while satisfying the QoS requirements for real-time traffic. However, frames in Distributed Coordination Function (DCF), the basic access method in the IEEE 802.11 MAC layer protocol [1], do not have priorities, and there is no other mechanism to enforce a guaranteed access delay bound. As a result, real-time applications such as voice transmissions may suffer from unacceptable delay with this protocol. The alternate access mode of the IEEE 802.11 MAC layer protocol, Point Coordination Function (PCF), offers a “packet-switched connection-oriented” service, which is well suited for real-time traffic. However, in order to poll the stations an Access Point (AP) must maintain a polling list, which is implementation dependent. What this means is that end-to-end QoS requirements still cannot be satisfied in this scheme since it does not include any access control policy.

Since the demand for the use of packet-switched techniques for transferring delay-sensitive data in wireless environments is inevitable for multimedia applications, the IEEE 802.11 working group is currently working on a new standard called 802.11e [2] to enhance the original 802.11 MAC sublayer to support applications with QoS requirements. In order to reach better QoS requirements for real-time application, the 802.11e task group has proposed EDCA for contention period and HCCA for contention-free period in the HCF to enhance
the original IEEE 802.11 MAC protocol. However, the problem of choosing the right set of MAC parameters and strict QoS mechanism to provide guaranteed QoS in IEEE 802.11e Wireless LANs remains unsolved.

Although in the literatures there have been adequate excellent discussions on the issue of QoS and delay analysis in IEEE 802.11 WLANs [3–6], none of the above studies proposed a complete solution and performance evaluation to fulfill a strict QoS guarantees for multimedia traffic in IEEE 802.11e WLANs.

In paper [7], the authors proposed an adaptive EDCF scheme. One problem of the basic EDCA ad-hoc mode is that the size of contention window and backoff function of each queue is static and does not take into account dynamicity of wireless channel conditions. In AEDCF, relative priorities are provisioned by adjusting the size of the contention window of each traffic class taking into account both application requirements and network conditions. After each successful transmission, AEDCF does not reset the contention window size.

In paper [8], the authors introduced a per-flow differentiation scheme. All packets are put in the same queue, independent of their priorities. However, this scheme introduces mutual interferences between priorities: when the AP serves a low priority of slow flow, the global speed and efficiency of AP depends on the occupation time of the slow flow. If most of the time the flow occupies the AP, even if there are other high-priority fast flows, hence, the AP has to be slow, and service differentiation gets lower.

Based on the above observations, the need for providing Quality of Service (QoS) for real-time applications in 802.11e networks has been driving research activities and standardization efforts for some time. However, current research results offer some mechanisms to provide basic levels of QoS differentiation to aggregate flows mainly in the form of priority services. In addition, to the best of our knowledge, very little work has been dedicated to providing per-session/per-packet QoS guarantees in WLANs, a necessary feature for most multimedia applications.

In this paper, a pragmatic CAC scheme with a novel polling based uplink scheduling policy for CBR traffic in IEEE 802.11e Wireless LANs is proposed. Under such a scheme, the CBR session was characterized by its traffic rate and tolerable jitter. The proposed transmit-permission policy for HCCA access method can derive sufficient conditions such that all the CBR sources satisfy their time constraints to provide deterministic QoS guarantees. In addition to theoretical analysis, simulations are conducted to evaluate the performance of proposed scheme for CBR traffic. We also compared the proposed scheme with the other two QoS provisioning mechanisms with respect to blocking rate, average access delay, and achievable throughput under different offered traffic load. As it turns out, our design indeed provides good performance improvements over the IEEE 802.11e standard.

The remainder of this paper is organized as follows. Section II describes the proposed scheme in detail. Simulation and experimental results are reported in Section III. Section IV concludes this paper.

2. The Proposed Scheme

In what follows, we present the proposed scheme in detail. Our method involves two basic components: (1) a call admission control scheme for access decision; (2) a packet based delay constrained up-link scheduling policy.

2.1 Call Admission Control for Access Decision

Upon arrival of a new user, the call admission control unit decides to grant or deny admission permit. The decision is made based on the current information of the system and the analytical model for estimation of expected delay variation. If admission of the new user does not degrade the achievable performance below their requirement, the new user can be admitted into the system.

The CBR traffic is characterized by two parameters \( r, \delta \), where \( r \) is the rate (number of packets per second) of the source and \( \delta \) is the maximum tolerable jitter (packet delay variation) for this session. Assume there are \( n \) CBR sources (indexed by \( i = 1, 2, \ldots, n \)). We denote \( (r_i, \delta_i) \) as the traffic parameters of the \( i \)-th CBR source. In the following theorem, we provide sufficient conditions for all the CBR packets to satisfy their maximum jitter constraints.

**Theorem:**

Define \( \delta^* \) to be the parameter calculated by CAC unit. The CAC unit uses this parameter to decide whether the AP accepts a CBR connection or not. Let \( \delta^*_i = t_{PIFS} + t_p + \sum_{i=1}^{n} \left[ \frac{r_i t_{PIFS}^2}{t_i} \right] \times t_p, i = 1, 2, \ldots, n \) and \( t_{PIFS} \) be the duration of PCF interframe space, and \( t_p \) be the time to transmit a
packet. If $\delta^* < 1/r_i$ and for all $i = 1, 2, \ldots, n$, then all the packets generated by the $i^{th}$ CBR source meet their jitter constraints.

**Proof:**

Suppose that the first token generated from the $i^{th}$ CBR source has a maximum waiting time $\delta_i$. We want to prove that $\delta_i \leq \delta^*$, for $1 \leq i \leq n$.

Considering the first CBR source, i.e., $i = 1$, its maximum waiting time is for the channel to be cleared since we assume a nonpreemptive priority. The channel will be cleared within a packet transmission time $t_p$. Thus, $\delta_1 \geq t_{PIFS} + t_p = \delta^*$. Since $\delta^*_i < \frac{1}{r_i}$ and $\delta^*_i \leq \delta_i$ (by our assumption), we have $\delta_i \leq \delta^*_i$, which establishes the induction basis.

Suppose our induction hypotheses holds up to the $(i-1)^{th}$ CBR sources, i.e., $\delta_j \leq \delta^*_j$ for $1 \leq j \leq i - 1$. Now we consider the $i^{th}$ CBR source. Let the arrival instant of a polling token as time 0. Suppose $\delta_i > \delta^*_i$. Then it means that up to time $\delta^*_i$, the channel must be serving all the CBR sources from 1 to $i-1$. Since the total amount of packets that can be served within $(0, \delta^*_i)$ for these $i-1$ voice sources is at most $t_{PIFS} + \sum_{j=1}^{i-1} r_j \cdot \delta^*_j$. Adding $t_p$ for nonpreemptive priority, hence, the total amount of time to serve these packets is bounded above by $t_{PIFS} + \left(\sum_{j=1}^{i-1} r_j \cdot \delta^*_j\right) + 1) \cdot t_p$, and since we assume $\delta^*_i < \frac{1}{r_i}$, we have $t_{PIFS} + \left(\sum_{j=1}^{i-1} r_j \cdot \delta^*_j\right) + 1) \cdot t_p \leq t_{PIFS} + \left(\sum_{j=1}^{i-1} \frac{r_j}{r_i}\right) + 1) \cdot t_p = \delta^*_i$. Thus, the channel cannot be busy all the time in $(0, \delta^*_i)$ and this contradicts our assumption. This shows $\delta_i \leq \delta^*_i$. Hence, $\delta_i \leq \delta^*_i$. Based on the principle of induction, the statement of the theorem follows. Q.E.D.

Since the proposed packet based delay constrained scheduling policy can derive sufficient conditions such that all accepted sources satisfy their time constraints to provide deterministic QoS guarantees, all admitted CBR sources are starvation-free. However, as the numbers of CBR connections increases, they tend to grab the channel. Hence, from the performance viewpoint, it is equally important to guarantee a minimum bandwidth for data traffic in order to maintain a reasonable bandwidth usage. To achieve this goal, we can leave a minimum bandwidth for data traffic simply by changing the value of $t_p$ (the total time of transmits a CBR packet in a contention free period) to keep data traffic from starvation.

Finally, we still need to analyze the complexity of the proposed theorem. In the worst case, the call admission control unit makes n-1 comparisons before making the decision, and each comparison take n steps calculations. Hence, its complexity is $O(n^2)$.

### 2.2 Packet Transmit Permission Policy

In what follows, we propose a delay constrained scheduling scheme for HCCA access method in contention-free period to support CBR sessions. In one Basic Service Set (BSS) of IEEE 802.11e infrastructure network architecture, the AP implements a token bucket for each CBR source. In token buckets for CBR sources, the one with the smallest tolerable jitter constraint has the highest priority among all CBR sources. For each CBR source, its polling token is generated every $1/r_i$ second in the AP. In order to gain control of the medium, the AP performs the function of the point coordinator by transmitting a beacon frame at the beginning of the CFP after sensing the medium to be idle for a PIFS period. Once the AP has the control of the medium, it performs the following algorithm.

**Function** Packet_Transmit Policy

repeat

scan the token buffer of CBR sources

if a token found in CBR source then

Transmits a CFP_Start Beacon after a PIFS period

remove one token from this token bucket

poll corresponding CBR source and transmit one packet

if not the last packet then

generate next token after $(1/r_i) \cdot t_p$ sec

else remove this token bucket

else scan the next token bucket

until no token bucket found in token buffer

Transmits a CFP_End Beacon

end.

As the pseudo code illustrates, AP scans the token buffers of CBR sources according to the preset priority order. If a token is found, it removes one from this token buffer and polls this CBR terminal. On receiving a poll
the Station transmits its packet, and the AP will generate the next token for this CBR after $\frac{1}{t_i} - t_p$ second if it is not the last packet. When an end-of-file signal is received, the BS will remove this token bucket from token buffer. If there is no token found in all token buffers, the AP will not know which, if any, of the stations have real-time packets to transmit, then, it can end the CFP by transmitting a CF-End frame, and, for assuring the time constraint of admitted real-time traffic, the AP shall announce the beginning of the next CFP interval by observing the token buffer constantly.

3. Performance Evaluation

Our simulation model is built using the network simulator NS2 [9]. The model represents a BSS in the IEEE 802.11b standard WLANs with all stations in the BSS (Basic Service Set) capable of directly communicating with the remaining parties. Figure 1 shows an overview of the simulated system topology. In our simulations environments, the ns-2 802.11 wireless link is extended to generate an error probability by employs the Gilbert-Elliot (GE) error model [10] to characterize fading in the communication channel. The rate at which errors occur in the GE model is dependent on the channel condition. As illustrated in Figure 2, in the good state, $G$, losses occur with a low probability, $P_G$, whereas in the bad state, $B$, the channel operates in a fading condition and the loss probability, $P_B$, is correspondingly higher. Steady state probabilities of being in states $G$ and $B$ are given by $\pi G = P_{BG} = (P_{GB} + P_{BG})$ and $\pi B = P_{GB} = (P_{GB} + P_{BG})$, respectively. The average packet loss rate produced by the GE channel is $P = P_{G} + P_{B}$.

To focus on the access control issue and to reduce the complexity of the simulation, what follows are the basic assumptions in our simulation environment. First, the “hidden terminal” and the “exposed terminal” problems are not addressed in the simulation model. Second, no stations operate in the “power-saving” mode. Third, no interference is considered from nearby BSSs. Fourth, transmission errors are generated according to the Gaussian channel assumption. Finally, the transmitted propagation delay is $1 \mu s$. The evaluation is made with respect to the frame blocking rate, average access delay, and
achievable throughput under different offered traffic load. We also compared the proposed scheme with the other two QoS provisioning mechanisms [7, 8].

CBR applications are used as traffic generators. The default values used in the simulation are listed in Table 1. The values for the simulation parameters are chosen carefully in order to closely reflect the realistic scenarios as well as to make the simulation feasible and reasonable. All the simulations are conducted on FreeBSD 6.0 on a Xeon 3.4 GHz Server with 2 GB memory. The version of NS2 is ns-2.29, and each simulation run lasts for 100 simulation seconds.

Simulation results are shown below in the form of plots. Figure 3 depicts the frame blocking rate as the traffic load increases. Since we allow the admitted CBR sources to use bandwidth exclusively with priority over other traffic, the blocking rate of the proposed scheme will be kept lower than the legacy IEEE 802.11e protocol, besides, the proposed scheme outperforms the other two schemes in most cases.

Figure 4 compares the average access delays of CBR traffic from the proposed scheme with the legacy IEEE 802.11e protocol and the other two schemes. If the request is successfully received and scheduled by the AP, the CBR connection may transmit its packet by using HCCA access mode in contention free period when it is polled by the AP. Otherwise, it can still transmit its packet by using EDCA access mode in contention period. We can see that although there is not much difference in the values of the performance measures when load is light, however, the proposed scheme provides significantly better performance at heavy load.

Figure 5 depicts the achievable throughput as the traffic load increase in noisy environments. As shown in the figures, the throughput improvement can be as much as about 20% in congested wireless environments. It reveals that our proposed scheme could reduce the dropping probability without sacrificing the overall system performance.

Figure 6 show the BER performance and the traffic load versus the achievable throughput for the proposed scheme. As shown in the figure, it can be seen that the throughput of our proposed scheme is not affected by

![Figure 3](image-url)  
**Figure 3.** Blocking rate versus traffic load in noisy environments.

### Table 1. Default attribute values used in the simulation

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Meaning &amp; Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{DATA}$</td>
<td>11 Mb/s</td>
<td>Maximum data rate (WaveLAN DSSS)</td>
</tr>
<tr>
<td>$T_{slot}$</td>
<td>20 us</td>
<td>Time needed for each time slot</td>
</tr>
<tr>
<td>$T_{SIFS}$</td>
<td>10 us</td>
<td>Duration of short interframe space (SIFS)</td>
</tr>
<tr>
<td>$T_{DIFS}$</td>
<td>50 us</td>
<td>Duration of DCF interframe space (DIFS)</td>
</tr>
<tr>
<td>$L_{DATA}$</td>
<td>1000 bytes</td>
<td>Mean payload size</td>
</tr>
<tr>
<td>$L_{ACK}$</td>
<td>112 bits</td>
<td>Ack frame size</td>
</tr>
<tr>
<td>$L_{H_DATA}$</td>
<td>224 bits</td>
<td>MAC overhead</td>
</tr>
<tr>
<td>$T_p$</td>
<td>25 us</td>
<td>Duration of a PLCP preamble</td>
</tr>
<tr>
<td>$T_H$</td>
<td>4 us</td>
<td>Duration of a PLCP header</td>
</tr>
<tr>
<td>$\tau$</td>
<td>1 us</td>
<td>Propagation Delay</td>
</tr>
<tr>
<td>$W$</td>
<td>31 slots</td>
<td>Minimum contention window size</td>
</tr>
<tr>
<td>$m$</td>
<td>5</td>
<td>Maximum backoff stages</td>
</tr>
<tr>
<td>$d$</td>
<td>250 meters</td>
<td>Simulation topology 250 m × 250 m</td>
</tr>
<tr>
<td>$r$</td>
<td>10–100 Kb/s</td>
<td>CBR set rate (corresponds to interval of 3.75 ms)</td>
</tr>
<tr>
<td>$L$</td>
<td>210 bytes</td>
<td>CBR packet size</td>
</tr>
</tbody>
</table>
channel BER between $10^{-8}$ to $10^{-5}$. Besides, the throughput of our proposed scheme changes little as the traffic load varies. This indicates that the proposed scheme is quite resistant towards influences from wireless environments.

In Figure 7, we investigate and analyze the fairness of the proposed scheme. We use the fairness index defined by Jain [11] to evaluate how fair it is. The fairness index is defined as

$$\text{Fairness Index} = \frac{\left( \sum_{i=1}^{n} T_i \right)^3}{n \times \sum_{i=1}^{n} T_i^2}$$

where $n$ is the number of connections, and $T_i$ is the throughput of connection $i$. From Cauchy-Schwartz inequality, we obtain Fairness Index $\leq 1$, and the equality holds if and only if all $T_i$ are equal. As shown in the figure, as the number of connections and channel BER increases, the difference of throughput also increases.

4. Conclusion

Currently, many wireless applications and devices are emerging, and this trend is expected to continue in the foreseeable future. Many problems remain further intensive investigation and need to be solved. In this paper we have propose a pragmatic CAC scheme with a novel polling based uplink scheduling policy for CBR traffic in
IEEE 802.11e WLANs, offering easily implemented and yet flexible criteria for traffic prioritization in a wireless environment. The scheduling algorithm for CBR traffic is performed at each AP in a distributed manner. Through extensive simulations, we have demonstrated a satisfactory performance of our proposed scheme in a quantitative way. It shows that the proposed scheme has proven its satisfactory superiority in most cases.

References


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