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Performance analysis of a threshold-based dynamic TXOP scheme for intra-AC QoS in wireless LANs

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HIGHLIGHTS

- A threshold-based dynamic TXOP scheme is proposed to address the intra-AC QoS.
- The scheme dynamically adjusts TXOP according to the queue length and threshold.
- An analytical model is developed to evaluate the performance of the TBD-TXOP.
- NS-2 simulation experiments validate the accuracy of the proposed analytical model.
- Results show that the TBD-TXOP can effectively support the intra-AC QoS.

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ABSTRACT

The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) protocol has been proposed for provisioning of differentiated Quality-of-Service (QoS) between various Access Categories (ACs), i.e., inter-AC QoS, in Wireless Local Area Networks (WLANs). However, the EDCA lacks the support of the intra-AC QoS provisioning, which is indispensable in practical WLANs since the network loads are always asymmetric between traffic flows of ACs with the same priority. To address the intra-AC QoS issue, this paper proposes a Threshold-Based Dynamic Transmission Opportunity (TBD-TXOP) scheme which sets the TXOP limits adaptive to the current status of the transmission queue based on the pre-setting threshold. An analytical model is further developed to evaluate the QoS performance of this scheme in terms of throughput, end-to-end delay, and frame loss probability. NS-2 simulation experiments validate the accuracy of the proposed analytical model. The performance results demonstrate the efficacy of TBD-TXOP for the intra-AC QoS differentiation.

1. Introduction

The Distributed Coordination Function (DCF) ratified in the IEEE 802.11 standard [1] is the popular Medium Access Control (MAC) protocol deployed in Wireless Local Area Network (WLAN) devices. However, due to the lack of support for real-time services, DCF is unable to provide the Quality-of-Service (QoS) required by multimedia applications. With the ever-increasing demand of various wireless services, the provisioning of differentiated QoS has become a critical issue of future wireless multimedia communication.

In order to support multimedia applications subject to the differentiated QoS constraints, IEEE 802.11e has been standardized [1]. It introduces a contention-based channel access protocol, referred to as the Enhanced Distributed Channel Access (EDCA). The EDCA provides service differentiation by classifying the traffic flows into four Access Categories (ACs) [1], each of which is associated to a separate transmission queue and behaves independently. These ACs are differentiated through adjusting the parameters of Arbitrary Inter-Frame Space (AIFS), Contention Window (CW), and Transmission Opportunity (TXOP) limit [1].

Although the EDCA provides the QoS differentiation between various ACs, i.e., inter-AC QoS, it lacks the support of the intra-AC QoS provisioning [2–4]. The EDCA assigns the same MAC parameters to the traffic flows belonging to the same service class regardless of their traffic arrival rates and QoS requirements, which leads to the throughput fairness among the flows in the same class. However, in practical WLANs with multimedia applications, the network loads are always asymmetric between traffic flows of ACs with the same priority. Therefore, it is desirable to provide intra-AC QoS differentiation between those flows, which belong to the

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same service class but have different traffic arrival rates and QoS requirements.

We use the TXOP limit as a way of intra-AC QoS differentiation in this study. The default TXOP scheme assigns a fixed TXOP limit to all the flows of the same service class [1]. We propose that each flow in the same class can have a dynamic TXOP limit that depends on its traffic arrival rate. Bearing in mind that if a flow has a higher traffic rate than the others of the same class, the transmission queue length of this flow should be larger than the others, we take the queue length as an indicator for the traffic rate. It is thus desirable to dynamically adjust the TXOP limits according to the status of the transmission queue.

In order to support intra-AC QoS differentiation in IEEE 802.11e networks, in this paper, we propose a Threshold-Based Dynamic TXOP (TBD-TXOP) scheme and further develop a new analytical model to evaluate this scheme in WLANs. The main contributions of this paper include

(1) A threshold-based dynamic TXOP scheme is proposed to address the intra-AC QoS differentiation in IEEE 802.11e networks. This scheme dynamically adjusts the TXOP limits according to the current status of the transmission queue and the pre-setting threshold.
(2) A new analytical model is developed to evaluate the performance of the TBD-TXOP scheme. To make this challenging problem tractable, we use a Markov chain to solve the bulk service queueing system arising from the burst transmission. NS-2 simulation experiments validate the accuracy of the proposed analytical model. The performance results demonstrate that the TBD-TXOP scheme can effectively support the intra-AC QoS differentiation.

The rest of this paper is organized as follows. Section 2 introduces the EDCA protocol. Section 3 entails the TBD-TXOP scheme. Section 4 reviews the related work in the literature. The analytical model for the proposed scheme is developed in Section 5. Section 6 presents the validation and performance analysis. Finally, the paper is concluded in Section 7.

2. Enhanced distributed channel access

EDCA has been designed to support multimedia applications with stringent QoS requirements in WLANs [1]. Traffic of different classes in terms of voice, video, best-effort, and background is assigned to one of four ACs, which is associated to a separate transmission queue and behaves independently. The QoS of these ACs is differentiated through assigning various EDCA parameters including AIFS values, CW sizes, and TXOP limits. In the EDCA protocol, the channel is sensed before an AC attempts to transmit frames. If the channel is detected idle for an AIFS, the transmission starts. Otherwise, the AC defers until the channel is detected idle for an AIFS, and then generates a random backoff counter. The value of the backoff counter is uniformly chosen between zero and CW, which is initially set to $CW_{\min}$ and doubled after each unsuccessful transmission until it reaches the maximum value $CW_{\max}$. It is reset to $CW_{\min}$ after the transmission succeeds or the number of retransmission attempts reaches a retry limit. The backoff counter is decreased by one for each time slot [1] when the channel is idle, halted when the channel becomes busy and resumed when the channel is idle again for an AIFS. An AC transmits when its backoff counter becomes zero.

When an AC wins the contention for the channel, it transmits the frames available in its buffer successively provided that the duration of transmission does not exceed the specified TXOP limit [1]. Each frame is acknowledged by an Acknowledgement (ACK) after a Short Inter-frame Space (SIFS) interval. The next frame is transmitted immediately after receiving the ACK and waiting for an SIFS. If the transmission of any frame fails the burst is terminated and the AC contends again for the channel to retransmit the failed frame. The TXOP scheme is an efficient way to improve the network utilization because the backoff overhead is shared among all the frames transmitted within a burst.

3. Related work

A significant amount of work has been reported on the performance analysis of DCF [5–9] and EDCA [10–14,2,3,15,4,16–24]. THe majority of the studies for EDCA were focused on the AIFS and CW schemes [10,13,14,3,18,22,24]. For instance, Xiao [22] presented a bi-dimensional Markov chain model for the CW differentiation scheme. Huang and Liao [13] analyzed the performance of saturation throughput and access delay of EDCA with AIFS and CW differentiation. Ramaiyan, Kumar, and Altman [18] proposed the fixed point analysis to capture AIFS and CW differentiation and established a condition for the uniqueness of the fixed point solution. Gas et al. [10] presented a 3D EDCA model implementing CW and AIFS built on an existing comprehensive model in [11].

As the TXOP scheme cannot only support service differentiation but also improve the network utilization, performance evaluation of this scheme has also received many research efforts recently [11,12,2,15,25,4,16,17,19,20,23]. Most existing analytical models for TXOP have been developed under the assumption of saturated traffic loads and thus excluded any need to consider queueing or traffic models for performance analysis [15,17,20,23]. For instance, Tinnirello and Choi [20] compared the saturation throughput of the TXOP scheme coupled by different ACK policies. Li, Ni, and Xiao [15] analyzed the TXOP scheme with the block ACK policy under saturated traffic loads and noisy channel conditions. Xu, Sakurai, and Vu [23] proposed an access delay model for EDCA with the AIFS, CW, and TXOP schemes under saturated conditions. Since the realistic network conditions are often unsaturated, it is important to evaluate the performance of the TXOP scheme under unsaturated traffic loads [11,12,25,16,19]. Tickoo and Sikdar [19] used a discrete-time $G/G/1$ queueing system with infinite buffer capacity to model the DCF and extended the queueing model to analyse the TXOP scheme under unsaturated conditions. Hu et al. [11,12] developed a comprehensive EDCA model with the combination of AIFS, CW, and TXOP schemes under unsaturated traffic loads.

The aforementioned work on EDCA was primarily focused on the QoS differentiation between various ACs, namely, inter-AC QoS. However, since the network loads are always asymmetric between traffic flows in practical WLANs, it is desirable to provide the intra-AC QoS between the traffic flows of ACs with the same priority, regarding their traffic arrival rates and QoS constraints. To tackle the intra-AC QoS issue, several TXOP-based approaches [2–4] have been reported in the literature. Ksentini et al. [2] proposed an enhanced TXOP scheme where each traffic flow monitors the MAC queue and computes at runtime the TXOP limit according to the flow's AC and the queue length. However, the TXOP limits for the ACs with video traffic is set to the number of arriving frames between two successful transmission attempts, which is obtained through simulations [2]. Liu and Zhao [4] introduced a new TXOP scheme, which takes into account the frame size and the transmission queue length to tune the TXOP limit to improve the QoS support for VBR video transmission over the IEEE 802.11e WLANs. However, the performance of this scheme [4] was evaluated through simulations and no theoretical analysis was given. Kosek-Szott [3] develops an analytical model to evaluate the throughput performance for IEEE 802.11aa intra-access category prioritization including virtual collision handling, backoff differentiation, and Arbitration Inter-Frame Space differentiation. Distinguished from the existing solutions for the intra-AC QoS issue, we propose a threshold-based TXOP scheme that dynamically adjusts