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Kalman Filtering: Estimate of the numbers of active queues in an 802.11e EDCA WLAN

Igor Kadota [a,*], Andrea Baiocchi [b], Alessandro Anzaloni [a]

[a] Instituto Tecnologico de Aeronautica, Departamento de Engenharia Eletronica, Praca Marechal Eduardo Gomes 50, 12.228-900, Sao Jose dos Campos, SP, Brasil
[b] Universita di Roma "Sapienza", Dipartimento di Ingegneria dell'informazione, elettronica e telecomunicazioni, Via Eudossiana 18, 00184 Roma, Italia

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ABSTRACT

Many schemes that aim to tune the IEEE 802.11e EDCA transmission parameters have been proposed in the literature. Based on them, we notice that the knowledge of the numbers of active transmission queues of each Access Category has an important role in modeling and optimizing the network. In this paper, we propose a simple and standard-compliant mechanism that processes easily obtained traffic measurements into a novel Extended Kalman Filter to obtain estimates of those numbers. For validating the filter, we simulate three network scenarios. The first two comprehend an application of the filter under saturated traffic and the third one refers to non-saturated conditions. Assessing the network performance impact promoted by the application and analyzing the EKF behavior in diverse traffic conditions we find out that under saturation the filter is precise and accurate enough to match closely the ideal performance and under non-saturated traffic the estimates track the short-term average numbers of active queues.

1. Introduction

The increasing usage of all kinds of services available to mobile devices is pushing massive deployment of wireless access technologies, including IEEE 802.11 WiFi. However, this technology has serious limitations in offering media streams with a quality comparable with their wired counterparts due to the comparably poorer performance as regards bandwidth variability and delay jitter of contention based wireless communications. To address this issue, an enhanced version of the standard was developed in [1]. The so called IEEE 802.11e has been defined as an amendment of the basic WLAN 802.11.

Within the QoS stations (QSTAS) employing IEEE 802.11e there is a distinct queue for handling each of the four Access Categories (AC). Those queues operate independently and are classified according to their state: active or idle, whether they have a backlogged frame to send or not, respectively.

For prioritizing traffic, the contention based mechanism of the IEEE 802.11e, the Enhanced Distributed Channel Access (EDCA), sets different transmission parameters to each of those four ACs. This adds degrees of freedom, over previous standards such as 802.11a/b/g. Category specific parameters are used to benefit high priority traffic over low priority ones. This mechanism cannot actually guarantee QoS, but only manipulate transmission advantages, achieving a differentiated QoS among categories.

With the aim to improve QoS even further, an optional Admission Control mechanism is described in [1]. As the name suggests, its purpose is to restrict traffic growth, with the AP controlling the access to high priority categories (AC_0 and AC_1), aiming to prevent QoS degradation due to an excess of "greedy" streams. For more information on the mechanism we refer the reader to [1–3]. Notice, however, that the objective of this auxiliary mechanism is not to provide information about the number n_i of active queues of $AC_i, i = 0, 1, 2, 3$.

The main difficulty of the degrees of freedom introduced by IEEE 802.11e is the added complexity. The number of variables which need to be set in order to attain an intended network operation point is greatly increased with EDCA. A lot of effort has been made for creating means to tune those parameters in a simple manner aiming to optimize network performance. Some of those works are introduced next.

2. Related work

The standard in [1] only recommends fixed values for the transmission parameters of each AC, what is not sufficient to adapt transmissions to a time varying number of active flows. Hence, it leaves tuning open for research. We identify two main working areas.

Adapting the EDCA. In [4] a sliding Contention Window scheme based on heuristics and aiming to adapt the parameters to the

* Corresponding author. Tel.: +55 11 99413 8566.
E-mail addresses: igor.kdt@gmail.com (I. Kadota), andrea.baiocchi@uniroma1.it (A. Baiocchi), anzaloni@ita.br (A. Anzaloni).

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traffic conditions was proposed. [5] proposed a Proportional Integrator controller to tune the network based on several approximation of the network model in [6], that led to a collision probability independent of the numbers of active flows at the optimal operation point. In [7] it was proposed a heuristic algorithm for adjusting the parameters based on information, such as bandwidth of each packet stream, obtained from the Admission Control mechanism. Assessing these and other works we can see that the lack of knowledge of the numbers of active queues is compensated in different forms when adapting the parameters of EDCA: heuristic methods, several model approximations and/or dependence on the Admission Control mechanism.

Optimizing the EDCA. In addition to proposing models, [8,9] also devise optimization mechanisms based on them. For gathering the information of the numbers of active flows in the network, which are input to the optimization processes, both works use the Admission Control mechanism. In [10] the transmission parameters are regulated to traffic also based on the numbers of active queues. These are obtained through a partially explained procedure that has as input the category identifiers (AC number) and source addresses of the transmitted frames.

As we can see from previous works, n_0, n_1, n_2 and n_3 have a crucial role in optimizing the performance of the EDCA. To the best of our knowledge, there is no mechanism aiming to provide this information in the EDCA scenario, even if other works have addressed the problem of estimating the number of active queues in the plain IEEE 802.11 DCF framework [11–14]. The goal of our work is to fill this gap by proposing a mechanism that estimates these values and that is practically realizable in an EDCA wireless access.

3. Proposed solution

The novel filter defined in Section 3.2 *provides a simple and standard-compliant manner of dynamically estimating the numbers of active queues in the EDCA*. It uses easily obtained traffic parameters, for example the number of idle slots, to estimate n_0, n_1, n_2 and n_3. A significant advantage of this estimate mechanism over others such as [11–14] is that it has been built upon the IEEE 802.11e, thus accounting for the nuances of the standard. Some accomplishments of the filter are listed next:

1. it is based on a well-established analytical model [6] and approach [11], but it has been built in a novel manner, more suited for the scenario;
2. it does not need management nor control packet exchanges;
3. it runs on the Access Point (AP), so easing deployment and compatibility; in fact, it requires that the QSTAs are EDCA compatible only, while they can ignore any detail of the estimate process and AP functions based thereof;
4. it works independently from Admission Control or any other side mechanisms of the IEEE 802.11e.

With this filter estimating the values of n_0, n_1, n_2 and n_3, mechanisms that need this information, such as those purported in [8,9], can operate independently of the Admission Control being forced on all ACs or even being enabled in the WLAN. In Section 6 we discuss this and some other possible applications for this filter, like in Industrial Wireless Sensor Networks.

The remainder of this work is organized as follows. In Section 3.1 we briefly review the EDCA and the analytical model that grounds the filter design. Next, in Section 3.2, the Extended Kalman Filter (EKF) used for dynamically estimating the numbers of active queues is described. Following, in Section 4, the filter is assessed in two different contexts: (i) under saturated traffic and applying it to a throughput optimization mechanism; (ii) under non-saturated traffic. Then, in Section 5, the implementation cost of the EKF is discussed. Finally, in Section 6, we cover other possible applications and further work. In A we give details of the development of the EKF.

3.1. IEEE 802.11e Description and modeling

In this section we give a brief review of the EDCA, that is part of the Hybrid Coordination Function (HCF) and is an enhancement of the contention based Distributed Coordination Function (DCF).

Along with EDCA, another important modification brought by the IEEE 802.11e concerns the Beacon Frame (BF) role in the network. In IEEE 802.11, BF main purpose is stations synchronization. In the new standard, BFs have the additional function of periodically communicating the AC queues transmission parameters (which can be static or dynamic) to the QSTAs. Also, in order to prevent that network events disturb the BF periodicity, the HCF does not allow queues to transmit across a Target Beacon Transmission Time (TBTT).

The Contention Window (CW) optimization procedure presented in Section 4.1 takes advantage of this new BF functionality.

3.1.1. EDCA overview

The main differences between EDCA and legacy DCF are the added queues and the per class parametrization. While the DCF supports only one transmission queue per STA, the QSTAs have four independent queues, one for each AC, with their own transmission parameters.

The standard 802.11e EDCA envisages a Binary Exponential Backoff (BEB) mechanism to update the CW size W_i of AC_i when a collision is detected, i.e., failure to receive an ACK frame following the transmitted data frame. BEB means that W_i is doubled after each collision until it attains a maximum value $W_{max,i}$, and is reset to $W_{min,i}$ after successful transmissions or expiration of the maximum number of retransmission attempts (max_retry counter).

The same access procedure of the DCF is maintained with EDCA, except that BEB parameters may be different for each of the four queues in a QSTA. The backoff procedure begins with each queue of AC_i choosing the backoff counter randomly in the integer interval $[0, \ldots, W_i - 1]$. However, for the backoff countdown to start, each queue must first detect the medium being idle for an $AIFS_i$ period. $AIFS_i$ can be chosen different for each $i \in \{0, 1, 2, 3\}$ according to $AIFS_i = SIFS + \sigma \cdot AIFSN_i$ with $AIFSN_i$ an integer not less than 2 and σ the duration of an Idle Slot time. It is always $AIFS_i \geqslant DIFS$.

When the backoff countdown associated to the queue of AC_i reaches zero and an Idle Slot time has elapsed, the queue is granted channel access and is allowed to transmit multiple packets for a $TXOP_i$ time interval. In a WLAN with no legacy stations, $\max_i(TXOP_i)$ sets the limit of time a queue can uninterruptedly retain the right to channel access.

Within all QSTAs, each active queue runs the described procedure independently. Thus, in the case of a QSTA with multiple active queues, there is the possibility of an internal packet collision. This is addressed in the QSTA by a scheduler that grants channel access to the frame with highest priority. The colliding queues with lower priority behave as if a regular collision had occurred.

On a final remark on the EDCA, we recall that the parameters $AIFS_i, TXOP_i, W_{min,i}$ and $W_{max,i}$ $(i = 0, 1, 2, 3)$ are periodically communicated to the QSTAs by the AP through BFs. For a more detailed description we refer the reader to [1,15]. Following we introduce and comment on the EDCA model that grounds the EKF defined in this work.

3.1.2. Assumptions and analytical model

In this section we briefly present the well-established analytical model of the IEEE 802.11 proposed in [6], which was employed in