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Leveraging 802.11n frame aggregation to enhance QoS and power consumption in Wi-Fi networks

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ABSTRACT

The Wi-Fi technology, driven by its tremendous success, is expanding into a wide variety of devices and applications. However, many of these new devices, like handheld devices, pose new challenges in terms of QoS and energy efficiency. In order to address these challenges, in this paper we study how the novel MAC aggregation mechanisms developed in the 802.11n standard can be used to enhance the current 802.11 QoS and power saving protocols. Our contribution is twofold. First, we present a simulation study that illustrates the interactions between 802.11n and the current 802.11 QoS and power saving protocols. This study reveals that the 802.11n MAC aggregation mechanisms perform better when combined with the power save mode included in the original 802.11 standard than with the 802.11e U-APSD protocol. Second, we design CA-DFA, an algorithm that, using only information available at layer two, adapts the amount of 802.11n aggregation used by a Wi-Fi station according to the level of congestion in the network. A detailed performance evaluation demonstrates the benefits of CA-DFA in terms of QoS, energy efficiency and network capacity with respect to state of the art alternatives.

1. Introduction

After more than a decade from its initial design, the Wi-Fi technology is expanding nowadays into a wide number of applications and devices. Handheld devices (e.g. smartphones) are a clear example of this expansion as confirmed by the Wi-Fi Alliance [1] who has recently forecasted that by 2014 more than 90% of the new smartphones will be equipped with Wi-Fi connectivity [2]. In addition, the presence of Wi-Fi in handheld devices is already becoming a key feature for operators, who leverage this capability in order to offload data traffic from their cellular networks to Wi-Fi Hotspots [2].

However, the success of the Wi-Fi technology in handheld devices depends on its ability to cope with two fundamental requirements: QoS and energy efficiency. In addition, new types of Wi-Fi devices and applications are arising that also have stringent requirements on QoS and energy efficiency. Smart Grid and Machine-to-Machine communications are relevant examples of these new types of applications [3].

Being aware of the importance of both QoS and energy efficiency, the IEEE 802.11 group developed in the recent years a set of technologies tailored to fulfill these requirements. Regarding the need for QoS provisioning, the IEEE 802.11 working group developed the 802.11e standard [4]. This standard defines the Hybrid Coordination Function (HCF), that includes two different access methods: a contention-based channel access method called the Enhanced Distributed Channel Access (EDCA) and a contention-free channel access method referred to as HCF

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Controlled Channel Access (HCCA). A thorough overview of the 802.11e QoS enhancements can be found in [5].

Regarding power saving mechanisms to extend battery life, IEEE 802.11 defines a power save mode that allows stations to switch off their radio during inactivity periods in order to save power. When this protocol is used, an Access Point (AP) buffers incoming data for the sleeping stations, and periodically notifies them about their buffered data using the Beacon frame. A power saving station wakes up to receive the Beacon frame and retrieves its buffered data by sending a PS-Poll frame to the Access Point. A detailed overview of this protocol can be found in [6] and references thereof. In the rest of the paper we will refer to this power save mode as *802.11 PSM*.

In addition, IEEE 802.11e defines the Automatic Power Save Delivery (APSD) protocol, that takes advantage of the QoS mechanisms of 802.11e in order to provide an improved QoS experience when this power saving mode is used. Two modes of operation are available under APSD: *Unscheduled* APSD (U-APSD) that can be used in combination with EDCA, and *Scheduled* APSD (S-APSD) that can be used with both access mechanisms, EDCA and HCCA. In particular, relevant to the work presented in this paper is the U-APSD protocol. The main difference between U-APSD and 802.11PSM is that U-APSD stations proactively trigger the AP, instead of waiting for the Beacon frame, in order to retrieve their buffered data. U-APSD thus is specially suited for applications with tight delay requirements, like VoIP. A detailed description of both U-APSD and S-APSD can be found in [6].

Orthogonally to the previously mentioned technologies, the IEEE 802.11 group recently developed the 802.11n standard [7] which defines improvements to both physical and MAC layers, and is meant to replace the traditional 802.11a/b/g technologies in order to become the baseline technology in next generation WLANs [8]. Specially relevant to our work is the Aggregated-MPDU (A-MPDU) scheme proposed in 802.11n, which allows a transmitter to aggregate several MAC data frames (MPDUs) addressed to the same receiver in a single physical frame. This mechanism significantly reduces channel access overhead and is expected to increase the efficiency of next generation Wi-Fi networks. A thorough overview of 802.11n MAC aggregation mechanisms can be found in [9].

The work presented in this paper focuses on the study of how the new MAC features defined in 802.11n can be used to complement and enhance the existing Wi-Fi QoS and power saving protocols. Our main contributions are as follows:

- Analysis of the effect of 802.11n MAC aggregation on the performance of 802.11 PSM and U-APSD. Our study reveals that U-APSD, currently used when battery operated devices require real-time applications like Voice, is poorly suited to benefit from the 802.11n aggregation mechanisms. Instead, 802.11 PSM significantly benefits from aggregation and can outperform U-APSD when congestion in the network increases.
- *Congestion Aware – Delayed Frame Aggregation (CA-DFA)* our proposed algorithm that, using only information available at layer two, adapts the amount of aggregation used by a Wi-Fi device according to the level of congestion in the network. CA-DFA significantly outperforms alternative solutions in the state of the art in terms of QoS, energy saving and network capacity, and can be easily implemented in current 802.11n devices.

This paper is organized as follows: Section 2 describes the results of a simulative study that evaluates the combined performance of the 802.11n aggregation mechanisms and the current Wi-Fi QoS and power saving protocols. Section 3 presents the design and evaluation of our CA-DFA algorithm, and Section 4 evaluates its performance. Finally, Section 5 discusses relevant related work in the state of the art and Section 6 summarizes and concludes this paper.

2. Effect of 802.11n frame aggregation on Wi-Fi QoS and power saving protocols

In this section, we present the results of a simulative study that evaluates the effect of the 802.11n MAC aggregation mechanisms on the current Wi-Fi QoS and power saving protocols. Our focus is in protocols currently deployed in the market and thus, we consider in our evaluation EDCA for QoS, 802.11 PSM and U-APSD for power saving, and 802.11n A-MPDU as MAC aggregation technique. We start this section by describing our simulation framework in Section 2.1, and then discuss the results obtained in our study in Section 2.2.

2.1. Simulation framework

Our evaluation is based on packet level simulations using OPNET [24]. In particular, we extended an 802.11n OPNET model contributed by Intel [25], to include the 802.11 PSM and U-APSD power saving protocols. The original model in [25] was used for internal evaluation of competing proposals in the IEEE 802.11 TGn group, and has also been used in previous related works as [21], [22] and [23].

We consider the *HotSpot* scenario defined by the TGn group in [26], where stations are stationary and randomly placed within a 30 m radius from the AP. In addition, we consider that stations implement 2×2 MIMO, which is becoming increasingly available even for mobile devices [17]. In our simulations though, stations do not transmit using a fixed data rate but instead adapt their data rate according to the varying radio conditions. In addition, since the performance of the protocols under study is affected by error-prone wireless channels, we model the radio channel using the *TGn Channel Model E* in the 5 GHz band which was also defined by the TGn group, and has been proved to faithfully model realistic channel conditions [27].

In order to evaluate the combined performance of the Wi-Fi QoS and power saving protocols and the frame aggregation mechanisms defined in 802.11n, we define a basic *cluster* of stations, and increase the number of clusters present in our HotSpot scenario until the network starts to saturate. Our basic cluster is comprised of four types of stations which generate a traffic mix