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An IEEE 802.11 energy efficient mechanism for continuous media applications

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ABSTRACT

The widespread deployment of wireless mobile communications enables an almost permanent usage of portable devices, which imposes high demands on the battery of these devices. Indeed, battery lifetime is becoming one the most critical factors on the end-users satisfaction when using wireless communications. In this work, the optimized power save algorithm for continuous media applications (OPAMA) is proposed, aiming at enhancing the energy efficiency on end-users devices. By combining the application specific requirements with data aggregation techniques, OPAMA improves the standard IEEE 802.11 legacy Power Save Mode (PSM) performance. The algorithm uses the feedback on the end-user expected quality to establish a proper tradeoff between energy consumption and application performance. OPAMA was assessed in the OMNeT++simulator, using real traces of variable bitrate video streaming applications, and in a real testbed employing a novel methodology intended to perform an accurate evaluation concerning video Quality of Experience (QoE) perceived by the end-users. The results revealed the OPAMA capability to enhance energy efficiency without degrading the end-user observed QoE, achieving savings up to 44% when compared with the IEEE 802.11 legacy PSM.

1. Introduction

The opportunity to connect mobile equipment, sensors, actuators and other devices to the Internet, usually referred as Internet of Things (IoT) [1], raises new challenges in the deployment of those equipment. The battery lifetime is still one of the most relevant challenges, since it is directly affected by the device communication capabilities. Despite numerous efforts to create alternative low power radio technologies, IEEE 802.11 seems to be the *de facto* standard for wireless communications in most common scenarios. Therefore, it is crucial to investigate and propose mechanisms aimed at saving energy while providing Internet access through an IEEE 802.11 ready interface.

Furthermore, the massive deployment of high demand continuous media applications, namely Video on Demand (VoD) or Internet Protocol Television (IPTV), also enforces new requirements with respect to the equilibrium between energy efficiency and application performance. Besides specific application constraints, other aspects may be considered, such as end-user guidelines about whether or not energy saving is mandatory. For instance, the end-user configuration can be related with daily mobility or traveling patterns. As the end-user battery lifetime expectations are extremely hard to predict, the inclusion of end-user feedback in the optimization process will bring relevant benefits.

This work extends the optimized power save algorithm for continuous media applications (OPAMA) [2]. OPAMA improves devices' energy consumption considering both end-user and application specific requirements, together with an optimized IEEE 802.11 power saving scheme and frame aggregation technique. Apart from using distinct application sources in the performance assessment, this paper also describes additional performance evaluation results concerning OPAMA algorithm parameters configuration. Additionally, a novel hybrid (simulation and testbed) Quality of Experience (QoE) measurement methodology is proposed, allowing the discussion about end-users' perceived quality along all studied scenarios.

The remaining sections of this paper are organized as follows. Section 2 discusses the related work, followed by the OPAMA proposal presentation in Section 3. The assessment of OPAMA performance, in the OMNeT++simulator and using the developed hybrid video quality assessment methodology, is described in Section 4. Finally, Section 5 presents the conclusions.

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2. Related work

This section introduces the background of the proposed algorithm, and presents the most relevant related work concerning IEEE 802.11 energy efficiency improvements for continuous media applications employing power saving techniques.

An IEEE 802.11 station (STA) under Power Save Mode (PSM) [3] (also known as Legacy-PSM) is able to switch off the radio during a certain period, aimed at saving energy during that time. A STA must inform the Access Point (AP) about the current power management mode by defining the corresponding power management fields in the control frames. When the power saving mode is enabled for a STA, the AP buffers all the packets to that station. If the AP has packets buffered to a certain STA, it will send a notification using the Traffic Indication Map (TIM) field within the *Beacon* frames. In PSM, a STA must wake-up regularly to receive the *Beacon* frames. By performing this action, a STA that does not have any data buffered on the AP will be required to wake up recurrently, resulting in unnecessary energy consumption. To overcome this limitation, IEEE 802.11e [4] introduced the Unscheduled Automatic Power Save Delivery (U-APSD) algorithm. The main difference between the PSM and the U-APSD is related to the proactivity implemented in the U-APSD scheme. Unlike PSM, where only the Access Point (AP) is able to inform the station about pending packets, in U-APSD, the STA can itself ask the AP for new downlink messages pending in the queue. More recently, IEEE 802.11n [5] also announces two contributions to the power saving schemes, namely the spatial multiplexing (SM) power save and the power save multi-poll (PSMP) techniques.

Energy saving mechanisms for IEEE 802.11 can consider cooperation between the energy aware mechanisms at the lower (e.g. MAC layer aggregation) and upper layers. Camps-Mur et al. [6] have studied the impact of IEEE 802.11 MAC layer aggregation on both PSM and U-APSD schemes. The authors proposed a Congestion Aware-Delayed Frame Aggregation (CA-DFA) algorithm, which is divided into two logical parts: congestion estimation and dynamic aggregator. Congestion estimation is responsible for assessing the network capabilities and uses these values as near real-time input for dynamic aggregation. Being able to measure accurately network congestion, it allows the algorithm to dynamically adapt the maximum frame aggregation size when the network congestion goes below a certain limit. When compared with the IEEE 802.11 standard aggregation schemes, the CA-DFA performance is superior, particularly in terms of energy consumption. However, the CA-DFA algorithm does not support any end-user feedback.

Tan et al. [7] proposed a cross-layer mechanism based on the standard PSM, but using information provided by the upper layers. The algorithm, named PSM-throttling, aims at minimizing energy consumption for bulk data communications over IEEE 802.11. The PSM-throttling concept is based on the idea that there are already many Internet based applications performing bandwidth throttling and, as a result, there is an opportunity to improve energy efficiency at the client side. PSM-throttling uses the under-utilized bandwidth to improve the energy consumption of bandwidth throttling applications, such as video streaming. Nonetheless, it neither considers the inclusion of dynamic aggregation, nor the possibility that the end-user controls the maximum allowed delay. Ding et al. [8] also investigate the standard PSM capabilities and identify considerable differences between static and dynamic PSM approaches. By using preliminary results, the authors proposed a system named Percy, which uses the best of both static and dynamic methods. The Percy proposal is deployed as a transparent web proxy in the Access Point, and its main idea is to buffer the information in the local proxy, while the clients are running the PSM algorithm. The Percy solution does not consider the end-user feedback or frame aggregation, which could boost the 40% energy savings reported by the authors. Moreover, the trace-driven evaluation conducted does not assess the impact of the proposed mechanism on the end-users' Quality of Experience while receiving the application data.

An adaptive-buffer power save mechanism (AB-PSM) for mobile multimedia streaming was proposed by Adams and Muntean [9] to maximize the STA sleep period. The proposal includes an application buffer, able to hide the frames from the Access Point and, consequently, to avoid the TIM reports with pending traffic indication. The authors argue that the amount of packets to store in that buffer could be dynamic, but they do not explain how to overcome this issue. Moreover, AB-PSM aims to be an application-based approach, but the mechanism to be used by the STA to provide feedback to the AP was not defined. Additionally, aggregation mechanisms were not employed and the testbed study is very limited, since only battery lifetime was analyzed. This is an important parameter, but it should always be correlated with the drawbacks introduced in the end-user application (e.g., extra delay or jitter). Another user-aware energy efficient streaming strategy for video application on smartphones was suggested by Shen and Qiu [10]. The system was modeled as stochastic process, and a Gaussian mixture model was built to forecast the end-user demands regarding the video playback time. The resulting predictive model enables a more efficient control of video download, allowing a superior control of the power states. The authors argue that energy savings of around 10% can be attained. Nevertheless, an important limitation regarding this stochastic approach is related to the need to have information about the actual user habits. Since the model uses end-user habits information as input, it is crucial that such historical information is always available. Additionally, the simulation study was performed using only a mathematical tool, where several network stack aspects are not modeled. Therefore, the obtained results are limited to the wasted energy, and do not include an analysis of network quality of service related parameters nor the end-users perceived quality.

According to Palit et al. [11] the feasibility of employing aggregation is strongly related with the scenario and/or application. In order to understand the typical packet distribution in a smartphone data communication, the authors have analyzed mobile device traffic. The main observations are that around 50% of the packets have a size less than 100 bytes and 40% have an inter-arrival time of 0.5 ms or less. These conditions enable a good opportunity to perform aggregation. Using this motivation, the authors have studied the aggregation impact in the smartphones' energy consumption. The proposed aggregation scheme uses a buffering/queuing system in the AP together with PSM in the client side. The proposed packet aggregation mechanism, named Low Energy Data-packet Aggregation Scheme (LEDAS), receives packets from the different applications through the logical link control sub-layer and performs the aggregation. This approach showed some good results, but application requirements, such as the maximum tolerable delay, were not taken into account. With the native support for frame aggregation in IEEE 802.11n [12], which includes two distinct approaches to perform MAC frame aggregation, named Aggregated MAC Service Data Unit (A-MSDU) and Aggregated Mac Protocol Data Unit (A-MPDU), various studies concerning aggregation performance have been done [13]. Kennedy et al. studied the adaptive energy optimization mechanism for multimedia centric wireless devices [14] and concluded that significant energy saving could be achieved when performing application-aware optimization. Pathak et al. [15] have proposed an application level energy consumption profiling tool for mobile phones and reported issues concerning high energy usage in I/O operations. The software-based energy methodologies were early surveyed by Kshirasagar [16].

Although others in the literature [9,17] have also proposed energy optimization for continuous media applications, none takes

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