

ENERGY-EFFICIENT TRANSMISSION OF H.264 SCALABLE VIDEO OVER IEEE 802.11E

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ABSTRACT

Achieving low energy consumption is one of the main challenges for wireless video transmission on battery-limited devices. Moreover, the bandwidth is scarce and must be shared efficiently among users. The focus in this paper is on the timely delivery of multiple delay-sensitive video flows over a distributed access wireless LAN with minimal energy cost. This is done taking into consideration the Enhanced Distributed Channel Access (EDCA) mode and the Scalable Video Codec (SVC). In this context, a method is presented for energy-efficient resource allocation across the physical layer and medium access layer, by properly leveraging transmission modes and the available prioritization mechanisms. Global energy savings around 60% are achieved with respect to state-of-the-art EDCA under a wide range of network loads.

Index Terms— energy-efficient, scalable video, prioritization

1. INTRODUCTION

The efficient transmission of video over wireless local area networks (WLANs) is a challenging goal, especially when considering multiple mobile users on an error-prone channel and sharing the same channel resources. To address this challenge and provide Quality of Service the WLAN IEEE 802.11e standard [1] proposes the Hybrid Coordination Function (HCF) with two different access schemes, namely HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). Both schemes support user mobility and provide high data rates but face the limitation of the high energy consumption. As wireless stations are battery-powered, achieving the required performance at minimal energy consumption becomes a critical issue. In this paper we address this challenge and focus on energy minimization in the EDCA scheme.

Several authors have already addressed the problem of energy consumption in WLAN networks. In [2] and [3] the authors proposed improvements to the Power Saving Mode of 802.11. In [4] a power saving strategy is developed for both HCCA and EDCA schemes to maximize the sleep mode. However, the majority of the work on EDCA focuses on analyzing the QoS characteristics of EDCA and neglects

its energy consumption. In [5] we proposed a real-time scheduler to minimize the energy consumption of multiple users in a centralized context of HCCA. In this paper, we use the energy-performance models derived in [5] to minimize the transmission energy in the EDCA context. Moreover, we use the Scalable Video Codec (SVC) to exploit the EDCA prioritization mechanisms and further reduce the energy by efficiently allocating the transmission power between video layers. This yields similar savings as in [6] and [7] where Unequal Error Protection is applied on MPEG-4 Fine Granular Scalability.

The remainder of this paper is organized as follows. Section 2 introduces our previous work on HCCA mode. This is extended to the EDCA context in Section 3. Section 4 introduces SVC and the energy-efficient prioritization. Finally Section 5 presents the results and we draw the conclusions in Section 6.

2. ENERGY OPTIMIZATION IN HCCA

In [5], we introduced a cross-layer optimization methodology for energy-efficient and reliable delivery of delay-sensitive network flows over a HCCA WLAN. A run-time scheduler, located in the access point, optimally allocates the network resources and controls the system configuration of each station. Its goal is to minimize the overall energy consumption of the network while meeting the performance requirements under varying wireless channel conditions. The scheduler's decision capitalizes on design-time performance-energy models. These models provide for each transmission configuration K the Energy and Time (defined as Transmission Opportunity: $TXOP$) required to transmit a specific amount of data under certain channel condition (CS). The models are given in [5] but we briefly introduce them here.

Let E_K be the energy needed to send a packet of size L , with the current wireless transmission configuration K . A configuration is typically a setting of transmission rate and power. The 802.11a/g PHY for instance allows the use of 8 different transmission rates. Varying the output power is considered jointly with the power amplifier linearity settings to achieve true energy scalability. Obtaining such values of the energy cost for a given packet size is easily achieved through a simple calibration step where each of the configurations is used once and the energy required is

measured. Hence, in this paper, we do not repeat the models of [5] and assume we have obtained those energy costs through calibration. Similarly, we can determine the transmission time T_K . Let E_{ACK} and T_{ACK} be the energy and time needed to receive an ACK packet. E_{Header} and T_{Header} are the energy and time for the MAC and PHY headers. The energy and time needed for a successful and failed frame transmission is then determined using parameters in Table 1:

$$E_{good}(K) = E_K + E_{Header} + (2 \times T_{sifs} \times P_{Idle}) + E_{ACK} \quad (1)$$

$$E_{bad}(K) = E_K + E_{Header} + ((2 \times T_{sifs} + T_{ACK}) \times P_{Idle}) \quad (2)$$

$$T_{good}(K) = T_K + T_{Header} + (2 \times T_{sifs}) + T_{ACK} \quad (3)$$

$$T_{bad}(K) = T_{good}(K) \quad (4)$$

MAC Model	Control Dimensions from [4]
$L_{frag} = 1024B$	Back-off (dB) {6 to 16}
$T_{ACK} = 52\mu s$	P_{out} (dBm) {0 to 20}
$T_{Header} = 20\mu s$	Modulation {BPSK, QPSK, 16-QAM, 64-QAM}
$T_{SIFS} = 16\mu s$	Code Rate {1/2, 2/3, 3/4}

Table 1: Parameter values used in the experiment

We next introduce a channel model to determine when a packet is received correct or not, as function of the configuration K and channel state CS . The burst-error wireless channel is modeled with an 8-state Markov model [5]. Knowing the Packet Error Rate (PER) as function of CS and configuration K , and the retransmission model, we can then compute the expected time $E\{TXOP\}$ and energy $E\{Cost\}$ for a transmission of an L -sized fragment. Our quality constraint is expressed as the job failure rate (JFR), this is, the ratio of frames not successfully delivered before the deadline. From the many possible outcomes in *Energy-TXOP* that satisfy the desired JFR , we only retain those that are Pareto-optimal for future decisions. It is out of the scope of this paper to fully describe the energy modeling performed in [5] but the readers can refer to the paper for the full details.

3. ENERGY OPTIMIZATION IN EDCA

We extend the work in [5] to the Enhanced Distributed Channel Access (EDCA) mode in the HCF. We first briefly introduce the EDCA CSMA/CA mechanism. Before transmission, the node senses the medium. If the channel is sensed to be idle for at least the Arbitration Interframe Space (AIFS) time interval, then the station invokes a backoff procedure. The node selects, in a contention window (CW), a random backoff counter, which will be decremented each time when the channel is idle for a backoff slot. The first node with a zero backoff interval accesses the medium while other backoff counters are suspended until the channel has been idle again for an AIFS interval. An unsuccessful attempt to transmit data results in incrementing one of the retransmission counters and in selecting a new random

backoff interval in an incremented contention window. Once the station acquires channel access, it can initiate multiple frame transmissions without additional contention as long as the total transmission time does not exceed a specified limit; the so-called EDCA transmit opportunity limit duration (*TXOPLimit*). In our work in [5] the HCCA central scheduler allocates the resource per user (*TXOP*) and decides upon the user configuration based on the energy-performance models (*Energy-TXOP*). To extend our work to the EDCA case, as there is no central coordinator, we consider a local scheduler at each mobile terminal. To simulate real time transmission at 30 frames per second we select a scheduling period of 33 ms, in which all users schedule one video frame. To perform the scheduling and select a transmission configuration K a user needs to estimate its available *TXOP* within the scheduling period, which is variable and depends on:

- the number of accesses N to the channel that the user may have within its delivery deadline,
- the *TXOP* limit per access to the channel.

The steps to schedule a video frame during each scheduling period are the following:

STEP 1: the video frame is fragmented in L MAC packets of 1068 bytes.

STEP 2: the user estimates the available resources during scheduling period i , this is, the number of expected channel accesses $E\{N_i\}$. Note that $E\{N_i\}$ is both a function of the channel load (due to other user's request), and our own traffic demand. We assume that $E\{N_{i=1}\} = 1$ and update the expectation $E\{N_i\}$ where $i > 1$, based on the statistics from previous periods:

L_k : MAC fragments in queue to be scheduled in period k

S_k : number of MAC fragments scheduled during period k

N_k : number of accesses realized during period k

$$\left. \begin{array}{l} E\{N_{i-1}\} > N_{i-1} \\ S_{i-1} < L_{i-1} \end{array} \right\} \rightarrow E\{N_i\} = E\{N_{i-1}\} - 1$$

$$\left. \begin{array}{l} i-1 \leq k \leq i-1 \\ E\{N_k\} = N_k \\ \sum_{k=i-j}^{k=i} S_k = \sum_{k=i-j}^{k=i} L_k \end{array} \right\} \rightarrow E\{N_i\} = E\{N_{i-1}\} + 1$$

$$\left. \begin{array}{l} E\{N_{i-1}\} > N_{i-1} \\ \sum_{k=i-j}^{k=i} S_k = \sum_{k=i-j}^{k=i} L_k \end{array} \right\} \rightarrow E\{N_i\} = E\{N_{i-1}\}$$

$$\left. \begin{array}{l} S_{i-1} = L_{i-1} \\ \sum_{k=i-j}^{k=i} S_k < \sum_{k=i-j}^{k=i} L_k \end{array} \right\} \rightarrow E\{N_i\} = E\{N_{i-1}\}$$

The values of j and l are chosen as 30 and 5 scheduling periods. These values are chosen experimentally to average out the influence of channel attenuation and load variations.

STEP 3: the scheduling of the L packets is distributed during the expected channel accesses as $L_{access} = L/E\{N_i\}$

STEP 4: each time the user is granted access to the channel, it selects a configuration k^* that minimizes the energy while meeting the timing ($TXOP \leq TXOPLimit$) and quality constraints ($JFR \leq TargetJFR$) under current channel state CS_i :

$$k^* = \arg \min \{E(k^*) : TXOP(k^*) \leq TXOPLim, JFR(k^*) \leq TargetJFR\}$$

The selection of the optimal k^* configuration capitalizes on the available Energy- $TXOP$ models. Hence, from the Energy-Performance models described in Section 2, we extract the Energy- $TXOP$ curve corresponding to the transmission of L_{access} fragments under CS_i conditions, while meeting the performance requirements in terms of JFR . To minimize the energy, the user chooses a configuration that scales the transmission in time, i.e., maximizing $TXOP$ while not exceeding the $TXOPLimit$ (maximum allowed $TXOP$ per access). In Figure 1 the Pareto optimal energy versus time for 1 MAC fragment is plotted, as achieved by the EDCA local scheduler. Depending on the current channel state (CS) and $TXOPLimit$, the energy-optimal operation point can easily be extracted from that curve.

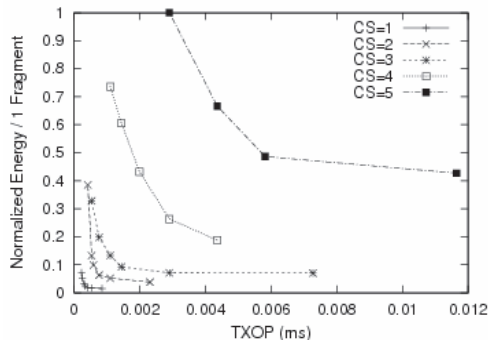


Figure 1: Energy – $TXOP$ tradeoffs in EDCA for $JFR=10e-4$

In contrary, state-of-the-art wireless systems such as 802.11a devices function at a fixed set of operating points and assume the worst-case conditions at all times. The highest feasible physical rate is always used and the power amplifier operates at the maximum transmit power [8]. This translates in Figure 1 to points with the lowest $TXOP$ and highest transmission energy. Figure 2 shows the impact of the JFR

requirements on the Energy-performance tradeoffs. The lower the JFR required, the higher Energy and $TXOP$ values are.

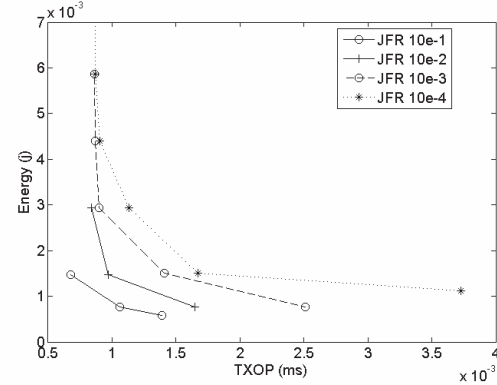


Figure 2: Energy – $TXOP$ tradeoffs versus JFR for 1 fragment and $CS 4$. Choosing a user's configuration with increased transmission time ($TXOP$) reduces the transmission energy but this causes other users to wait longer in idle state for the channel to become idle. To avoid this idle energy increase, we use the network allocation vector (NAV) technique [10] to send other users to sleep during one user's transmission. To consider the impact of the energy spent during idle and sleep states we assume an idle and sleep state power of 131 mW and 10 mW respectively [9].

4. ENERGY-EFFICIENT PRIORITIZATION OF SVC

The basic idea of the scalable H.264/AVC extension [11] is to extend the hybrid video coding approach of H.264/AVC in a way that a wide range of spatio-temporal and quality scalability is achieved. In this paper, we focus on quality scalability, in concrete on Medium Grain SNR scalability (MGS). Our bit stream is composed of one Base Layer (BL) and one MGS Enhancement Layers (EL). These MGS layer can be added/ dropped for each picture with a limited impact on the video quality, which suits our scenario where packets can be dropped due to congestion or transmission errors. To maximize the end video quality we map the SVC layered structure onto the EDCA priorities. These consist in four different access categories (ACs), this is, multiple backoff entities within a mobile station that contend independently for a $TXOP$. We define the priorities of each AC in medium access by adjusting the EDCA Parameter Set: the $AIFS[AC]$, the contention windows $CWmin[AC]$ and $CWmax[AC]$, and the $TXOPLimit[AC]$. We prioritize the most important video information, BL, by transmitting it with a high priority AC 1 and transmit the EL in a low priority AC 2. We choose the settings in Table 2 to generally guarantee that BL data in AC 1 is scheduled before low priority AC 2 and meets its deadline.

	<i>AIFS</i>	<i>CW_{min}</i>	<i>CW_{max}</i>	<i>TXOP_{Limit}</i>
<i>AC 1</i>	0.034 ms	7	15	6 ms
<i>AC 2</i>	0.079 ms	32	64	6 ms

Table 2: Prioritization via EDCA parameters

This way, in case the user fails to schedule part of its data (due to congestion or overestimation of the available resources at scheduling time), it is the EL, and not the BL data, that is dropped, which highly limits the quality degradation. On top of this, to achieve quasi error-free transmission of the sent data, we must select transmission configurations with very low *JFR* (such as $10e-4$), which requires increased energy consumption, as seen in Figure 2. Once again, in a scalable video codec we can profit from the robustness to losses in the less relevant information. If we deliver the relevant information (BL) error free, we can afford packet errors on the EL and only incur in marginal quality degradation. Hence, we target a low *JFR* of $10e-4$ on the AC1 (BL), while we relax the *JFR* to $10e-1$ on the AC2 (EL). This reduces the required energy for EL transmission and trades off energy consumption with video quality.

5. SIMULATION RESULTS

We compare several approaches for the EDCA transmission of multiple SVC users with a BL and one EL, at a rate of 500 Kbps and target PSNR of 31 dB:

- State-of-the-art EDCA (SoA-EDCA): configuration that maximizes the physical rate. In Figure 1, this is the point with highest energy and lowest *TXOP*.
- Cross-Layer EDCA (XL-EDCA): to minimize energy scales transmission in time within *TXOP_{Limit}* and quality constraint (*JFR* of $10e-4$).
- XL-EDCA with energy-efficient prioritization over SVC (relaxed *JFR* of $10e-1$ on AC2).

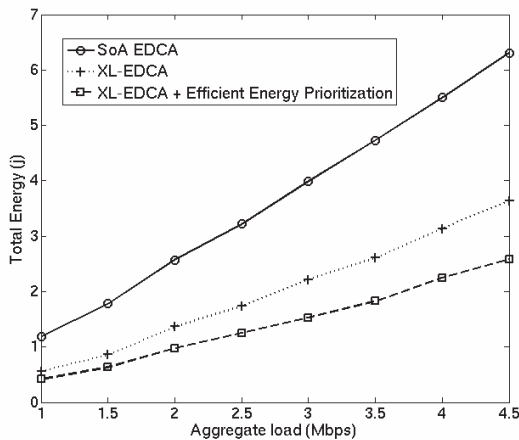


Figure 3: Energy savings above 60% by XL-EDCA with efficient prioritization

Figure 3 shows the total (transmission+idle+sleep) energy consumption for all users in the network. The XL-EDCA

achieves energy savings from 40 to 50% for a wide range of network load. Relaxing the *JFR* requirements on AC 2 brings an extra saving on top of XL-EDCA error free transmission reaching a total energy saving of 60% versus SoA-EDCA. This is achieved at the cost of a marginal average quality degradation of 0.2 dB.

6. CONCLUSIONS

By capitalizing on energy-performance models and the estimated available resources, the EDCA users minimize their energy while meeting timing and quality constraints. Moreover, we use the prioritization mechanisms in EDCA in combination with the SVC scalability. This allows an efficient energy allocation between SVC layers increasing the energy savings. The combination of these two techniques achieves global energy savings around 60% with respect to SoA-EDCA under a wide range of network loads.

7. REFERENCES

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