# CHANNEL-AWARE RATE ADAPTATION FOR ENERGY OPTIMIZATION AND CONGESTION AVOIDANCE*

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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 needs to be properly shared amongst different users. Congestion in the network can result in packet losses, with a significant impact on video quality. In this paper we propose the use of a channel-adaptive rate control mechanism in a multi-user WLAN up-link scenario. The benefit is twofold: the communication energy is reduced and congestion is strongly alleviated allowing an increase of the video quality or a network capacity increase for a similar quality.

***Index Terms***— Rate Control, Channel Adaptation, Scheduling, Communication Energy, Congestion

## 1. INTRODUCTION

The efficient transmission of video content over wireless communication networks is a challenging goal, especially when considering multiple mobile users equipped with handheld devices and sharing the same channel resources. Moreover, energy on the battery-powered devices is a limited resource, and achieving the required performance at minimal energy consumption becomes a challenge. In addition, the wireless medium is highly error-prone and network congestions cause extra packet losses, which can have a dramatic impact on the video quality making the error-prone transmission even more challenging.

In general, congestion in the network is avoided by informing the higher transport layer when it should decrease the packet transmission rate [1]. However, these techniques result in burst transmission of the data which is typically not acceptable for video applications, and many solutions are proposed to improve this [2]. To complement this, approaches exist to adapt the video compression rate as a function of the network condition [3],[4]. Considering congestion control for wireless networks, most research focuses on solving the problem of random packet losses that are misinterpreted as congestions losses [5].

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Next, cross-layer approaches exist that adapt the communication strategy to optimize distortion given the congestion level of the network [6]. None of these schemes however focuses on the energy cost. We have proposed a scheme to minimize energy for a given distortion in [7].

To control both the energy cost and the congestion level in the network, it is imperative to adapt jointly the communication and video encoding. In this paper we propose a channel-adaptive rate control that makes it possible to decrease both congestion and energy cost of the video transmission. The scheme extends a channel-adaptive run-time scheduling algorithm so as to achieve a cross-layer adaptation for energy and congestion control.

The remainder of this paper is organized as follows. Section 2 introduces the considered scenario. The channel-adaptive rate control is introduced in Section 3, capitalizing on our previous work [7] and in Section 4 the network scheduler is presented. Section 5 describes the simulation results and Section 6 draws the conclusions.

## 2. SYSTEM DESCRIPTION

The considered setup consists of multiple independent users equipped with mobile terminals (MT) who want to upstream real-time video traffic to the access point (AP) of a wireless local area network (WLAN). These users transmit their data over a shared wireless channel, assumed to be slowly fading (typical of indoor propagation conditions). A WiFi- based WLAN is considered: the IEEE 802.11a standard (1999) is taken for the physical layer (OFDM-based transmission in the 5 GHz band), and the QoS-enabled IEEE 802.11e standard is considered for the MAC (Medium Access Control) functionalities.

As mentioned already, several challenges need to be addressed simultaneously:

1. sharing of network resources
2. transmission of delay-sensitive data such as video
3. dealing with an error-prone channel
4. dealing with congestion
5. use of energy-constrained devices

To meet these challenges we implement an energy-efficient PHY-MAC cross-layer run-time scheduler located at MAC-level of AP side. The aforementioned scheduler enables guaranteeing the per-flow QoS constraints for multiple users while minimizing energy consumption. In addition, we use channel-adaptive encoders at the MT.

## 3. CHANNEL-ADAPTIVE RATE CONTROL

The Video encoder at each user is steered by the rate control (RC) mechanism and produces a data bit rate which is passed to lower communication layers (network, link and physical layers). The energy invested in the lower layers to guarantee a successful delivery, is highly dependent on both the channel conditions and on the amount of bits transmitted during varying conditions. The worse the channel conditions are, the higher the energy invested per bit is. Additionally, the more bits are transmitted, the higher the energy consumption is. In [7] we presented a cross-layer approach in which the video codec becomes network aware so as to decrease the communication energy. The channel state (CS) is feedback to the RC of the encoder that steers the output rate accordingly. Under bad channel conditions, when the communication energy per bit is high, the RC reduces the output rate to save energy. On the contrary, if the channel conditions are good, communication energy is low, and the channel-adaptive RC steers the encoder to a higher instantaneous output rate, while the average target bit rate and video quality are maintained.

The burst-error wireless channel is modeled with an 8-state Markov model [8]. Based on experiments for indoor WLAN [9] we take a channel coherence time of 120ms. This is, the channel remains constant for 3 or 4 video frames of the video sequence (encoded at 25 or 30 frames per second), while the RC adapts on a frame time basis. We assume a wireless environment with a feedback channel where an a priori probabilistic model of the channel behavior is available at the encoder.

To steer the output bit rate, while preserving the overall target bit rate, the adaptive RC uses the CS probabilities in the initialization phase and computes initial target frame sizes in bits (2) for frames transmitted under different CS *i* as a scaled version of the hypothetical average Frame size (1):

***AverFrameSize=Total_bit_rate/frame_rate (1)***

***AverFrameSize_i = AverFrameSize* Factor_i (2)***

The scaling factor is smaller than 1 for bad channels so as to reduce the produced bits during bad conditions and slightly bigger than 1 during good channel conditions. Experimental values are chosen in [7]. Finally, the QP of the current frame is computed based on the target frame size, QP and MAD (Mean Absolute Difference) of the previous frame. In addition to QP variation, our approach uses frame skipping, as also allowed in the MPEG-4 coding scheme. During the worst CS the frame rate is reduced to produce less bits. As bad CS occur with very low probability (around 2% of the time) the frame rate is only slightly reduced from 30 frames per second (fps) to around 29 fps. We refer the readers to [7] for more details. Timely feedback of the CS at the MT can be available. If channel reciprocity is assumed, the CS can be computed at the transmitter with no incurred delay. If the CS is feedback from the receiver, the delay is piggybacked in the ACK and bounded by 3 ms due to the transmission at 6Mbps of maximum data length (Maximum Transmission Unit) and ACK plus the SIFS (Short Inter Frame Space) [10].

The channel-adaptive RC in [7] steers the instantaneous encoding rate according to the network conditions and achieves energy savings over 20% under quality constraints (barely 0.1 dB degradation of average PSNR). Moreover, the mechanism is of low complexity and suitable for real-time applications.

## 4. RUN-TIME SCHEDULER

The goal of our run-time cross-layer scheduler is to ensure reliable and timely delivery of the different real-time video streams over the wireless links, while minimizing the total energy consumption of the mobile terminals under varying wireless channel conditions. Conventional energy management techniques in the present context belong to two major categories, i.e. focus on the baseline power cost or the transmission power cost:
(1) Sleeping (MAC centric), i.e., minimizing the baseline energy consumption of the transceiver circuit by transmitting at the highest rate, maximising the sleep duration.
(2) Scaling (PHY centric), i.e., scalable transmission control with variable transmission rate, coding and power, spreading the transmission in time, so as to minimize the transmission energy costs.
These two conflicting energy-management approaches present a trade-off in minimizing the overall system energy and are to be jointly optimized. To solve this, a cross-layer run-time scheduler was developed [8]. This scheduler is located at the AP and relies on the HCF functionality of the IEEE 802.11e MAC protocol. Its goal is to optimize the performance (expressed as a job failure rate) [8], while minimizing the overall energy consumption in the mobile terminal. In this context a job is defined as the reliable delivery of the information that has to be transmitted by a terminal during an MAC scheduling period. Depending on the current channel state, the scheduler uses more sleeping or scaling so as to minimize the energy cost for a given channel bandwidth requirement (expressed as time needed to transmit the job). In Figure 1 the optimal energy/job versus time/job is plotted, as achieved by the cross-layer scheduler. Depending on the current channel state, and current access time left on the channel, the energy-optimal operation point can easily be extracted from that curve. It

can be seen that for bad channel states, more energy is needed for a given job. To gain even more energy, it is hence required to decrease the amount of video packets to be transmitted during those bad channel states.

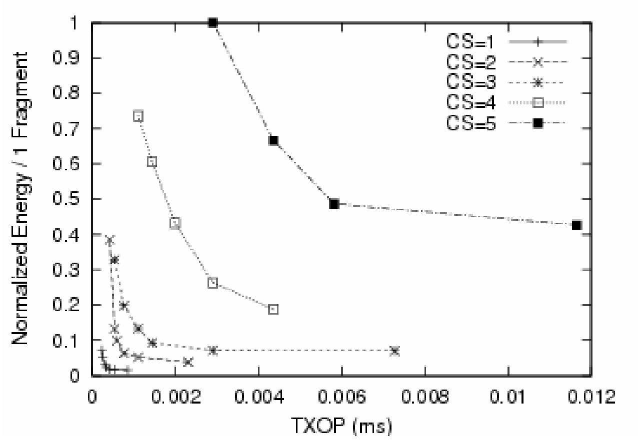

Figure 1: Energy – TXOP tradeoffs

## 5. SIMULATION TESTS

For our tests we use the Mobile and Foreman video sequences encoded at 2 Mbps and 1 Mbps respectively. We use the scheduler of [8] as described in the previous section. Under congestion the scheduler drops the biggest queue and no priority queues are considered for our tests. We gradually increase the number of video users that are being scheduled till the video load is higher than the available bandwidth and congestion occurs. The channel adaptive rate control mechanism is used in each transmitting video user. As explained in [7], the adaptive RC reduces the output rate when bad channel conditions occur and increases it when the channel conditions are good.

We explore if the adaptive RC can bring an overall benefit in a multi-user scenario under congestion. When the user demands are higher than the available bandwidth, congestion occurs and the scheduler reacts by dropping video packets till it is able to fit the remaining video packets in the available bandwidth. In this study, to focus on the congestion mechanism, we will only consider packet losses due to congestion and not those of transmission errors. To do this the scheduler configures the transmission parameters so as to guarantee always a very low Job Failure Rate.

We distinguish as well three cases in our study:

- Use of non-adaptive terminals: their output rate is independent of their individual channel condition.
- Use of partial adaptation: half of the terminals adapts its output rate to the channel conditions while the other half does not.
- Total adaptation: all users adapt their rate to their individual channel conditions.

Figure 2 shows the total normalized communication energy for multiple users transmitting Foreman at 1 Mbps in the described setup and with different degrees of adaptation.

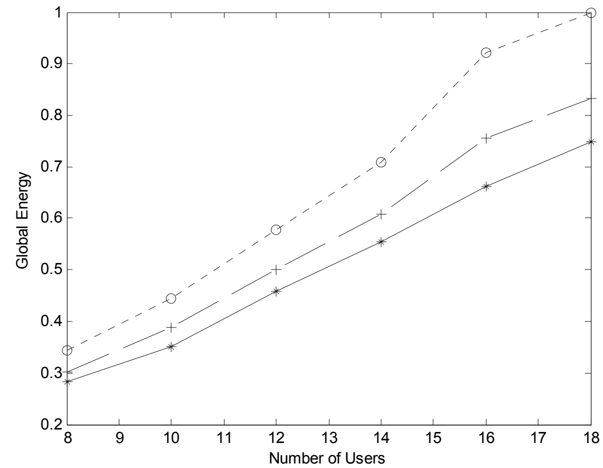

Figure 2: Totally adaptive scheme saves 25% of energy

The dotted line represents the non-adaptive system, the dashed one the partially adapted system and the solid one the fully adaptive system. Table 1 shows the average energy savings obtained. We can see how the higher the number of adaptive terminals the lower the communication energy spent, achieving average savings of around 15% when half of the terminals are adaptive and around 25% independently of the number of users (and network congestion) when all terminals are adaptive.

| ***Nb Users*** | ***8*** | ***10*** | ***12*** | ***14*** | ***16*** | ***18*** |
|---|---|---|---|---|---|---|
| | | ***Partially Adaptive*** | | | | |
| *Saving* | 11% | 12% | 13% | 14% | 18% | 16% |
| | | ***Totally Adaptive*** | | | | |
| *Saving* | 17% | 20% | 20% | 21% | 28% | 25% |

Table 1: Energy savings with respect to non-adaptive one

Figure 3 shows the average video quality per user for an increasing number of users in the system.

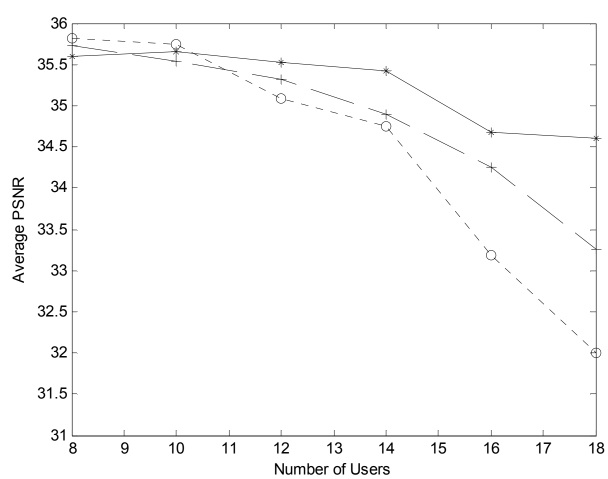

Figure 3: Adaptive approaches reduce congestion

Up to 8 users, the video of each user is received without any distortion as no packet losses occur (JFR imposed is very low). Moreover, no congestion happens in the network and all video packets can be scheduled on time. From 10 users on, however, the network load increases with the number of users and congestion occurs. To solve the congestion, the scheduler mechanism needs to drop video packets from the transmission queues resulting in packet losses experienced by the decoders.

| ***Non Adaptive*** | | | | | | |
|---|---|---|---|---|---|---|
| ***Nb Users*** | ***8*** | ***10*** | ***12*** | ***14*** | ***16*** | ***18*** |
| *Congested frames* | 0 | 9 | 26 | 51 | 97 | 144 |
| *KB Dropped* | 0 | 31 | 356 | 573 | 2029 | 3027 |
| ***Partially Adaptive*** | | | | | | |
| *Congested frames* | 0 | 4 | 16 | 37 | 74 | 118 |
| *KB Dropped* | 0 | 42 | 138 | 353 | 999 | 1716 |
| ***Totally Adaptive*** | | | | | | |
| *Congested frames* | 0 | 0 | 10 | 23 | 49 | 88 |
| *KB Dropped* | 0 | 0 | 222 | 334 | 576 | 595 |

Table 2: Congestion statistics

Table 2 shows the congestion statistics for each of the three described approaches. From the analysis of Figure 3 and Table 2 we can see how the use of adaptive codecs diminishes the congestion in the network. We observe that the number of frames where congestion happens decreases by more than factor 2 for the totally adaptive approach. The reduction of the number of Kbytes dropped is even higher. This indicates that even when congestion cannot be avoided it is reduced.

This lower number of video packets or bytes that the scheduler needs to drop to solve congestion translates into lower packet loss, so a higher end video quality at the decoder side. The totally adaptive approach (solid line) achieves 1.2 dB gain for 16 users and up to 2.7dB or more gain for 18 users with respect to the non-adaptive approach. Even the partially adaptive approach, where only half of the users implement the adaptive RC, brings from 0.5 to 1 dB gain over the non-adaptive approach. Taking the video quality as a system constraint, the adaptive approach can achieve the same or higher video quality for 18 users than the non-adaptive one for 14 users. This corresponds to a system capacity increase of almost 30%.Tests run for the Mobile sequence at 2 Mbps show similar results.

Congestion or network overload is caused when the resources demand is higher than the available resources. Not only higher rate demand coming from the video users contributes to increase this resource demand. Transmission under bad channel conditions demands as well more resources from the network. Therefore, congestion can be caused by high aggregate rate demand, bad channel conditions or a combination of both. Users with adaptive RC reduce their rate during bad channel conditions. This way, the demand of resources from the network is decreased and the probability and degree of congestion in the network is reduced.

We can conclude then that the use of adaptive RC in some or all of the terminals brings a twofold benefit to all users in the system. Users can save up to 25% of their communication energy independently of the network load. Moreover, under network congestion the end video quality can be increased up to 3 dB with respect to the non-adaptive approach, or equivalently, for the same video quality the system capacity is increased almost 30%.

## 6. CONCLUSIONS

We have analyzed the impact of a channel-adaptive RC mechanism in a multi-user uplink scenario. Users with adaptive RC bring a twofold benefit: the communication energy is reduced around 20% independently of the network load, and the mechanism delays the appearance of congestion. The probability and degree of network congestion is reduced resulting in an increased video quality by several dB or equivalently, the system capacity is increased around 30% for a fixed video quality.

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