Video Transmission over TFRC using cross-layer power management

Christos Bouras, Apostolos Gkamas, Vaggelis Kapoulas, Vassilis Papapanagiotou, Kostas Stamos and Giannis Zaoudis
Research Academic Computer Technology Institute, Greece,
and Computer Engineering and Informatics Dept., University of Patras, Greece
E-mail: {bouras, gkamas, kapoulas, papapana, stamos}@cti.gr
zaoudis@ceid.upatras.gr

***Abstract*. This paper presents the issues related to efficient transmission of encoded video (such as H.264) over wireless links using the TFRC protocol. It proposes a novel mechanism that utilizes cross-layer approaches for adaptation of the power transmission level of the sender and feedback information regarding the wireless connection status from the receiver for improved transmission statistics and therefore user experience without unnecessary power consumption. The mechanism is tested through simulations using ns2. Compared to the operation of the video transmission without the mechanism, we observe that it has benefits in terms of video quality.**

1. INTRODUCTION

Networking complexity has led to the modularization of network architecture in layers. Traditional approaches focus on wired networks and try to separately optimize each network layer such as the physical, the medium access, the routing and the transport layer. This approach reduces the complexity and makes issues more manageable and architectures more flexible and upgradeable, but it may lead to suboptimal designs. Under this layered approach, communication occurs between two adjacent layers without taking into consideration the specific characteristics of multimedia applications. Although this layered approach has been the fundamental factor for the growth of the wired networks and the World Wide Web it seems to pose constrains when attempting to adapt protocol's behavior to multimedia applications characteristics and to wireless network conditions. Therefore, a careful cross-layer approach, where selected communication and interaction between layers is allowed, can have performance advantages without negating the successful layer separation that has guided network design so far. A theoretical discussion of the cross-layer problem framework can be found at [1].

Wireless transmission differs in an important way from wired communication, in that the notion of the link is not as fixed and can vary depending on the movement of the communicating nodes, the intermediate interferences and the transmission characteristics of the communicating nodes, most notably their transmission power. While increased power generally correlates with a stronger signal and therefore improved transmission characteristics, in many wireless scenarios reduced power consumption is desired. This tradeoff has been explored by various researchers studying TCP modifications ([2], [3], [4]) trying to combine reduced power consumption with increased data throughput. Wireless standards such as IEEE 802.11 specify power saving mechanisms [5], although studies have shown that PSM and other similar mechanisms carry a significant performance penalty in terms of throughput ([6], [7], [8], [9]).

An important issue for the efficiency of wireless networks is to accurately determine the cause of packet losses. Packet losses in wired networks occur mainly due to congestion in the path between the sender and the receiver, while in wireless networks packet losses occur mainly due to corrupted packets as a result of the low Signal to Noise Ratio (SNR), the multi-path signal fading and the interference from neighboring transmissions. A second difference between wired and wireless networks is the "mobility factor". Mobility in wireless networks introduces a number of additional barriers in multimedia data transmission. Channel fading and handover time are the most important factors that cause packet losses as they introduce additional delays when the mobile user changes its location from one Access Point (AP) to another.

According to its specification, TFRC [16] is a congestion control mechanism for unicast flows operating in a best-effort Internet environment. It aims to be reasonably fair when competing for bandwidth with TCP flows, but at the same time achieving a much lower variation of throughput over time compared with TCP, making it thus more suitable for applications such as telephony or streaming media where a relatively smooth sending rate is important. However, TFRC is slower than TCP in responding to in the available bandwidth.

This paper presents a mechanism for cross layer power management for video transmission over wireless 802.11 networks using the TFRC protocol. The rest of this paper is organized as follows: Section 2 gives an overview of related work in the area of cross layer optimization. Section 3 describes the main idea of the paper and section 4 the testbed setup. Experiments and their results are presented in section 5, while section 6 concludes the paper and discusses possible future work. Source code for our implementation and installation instructions can be found at [24].

2. RELATED WORK

Several researchers have focused on various issues of cross layer optimization for wireless ad hoc networks, when there is no infrastructure assumed. The author in [10] proposes a jointly optimal design of the three layers (physical, MAC, routing) for wireless ad-hoc networks and studies. several existing rate-maximization performance metrics for wireless ad-hoc networks in order to select appropriate performance metrics for the optimization. In [11] the authors propose an application adaptive scheme based on priority based ARQ (Automatic Repeat Request) together with a scheduling algorithm and FEC (Forward Error Correction) coding combined with RLP (Radio Link Protocol) layer granularity. In [1] the need of a cross-layer optimization is examined and an adaptation framework is proposed amongst the application (APP), the Medium Access Control (MAC) and the Physical (PHY) layers. In the same publication a number of different methodologies for cross-layer adaptation are proposed, named “top-down” approach, “bottom-up”, “application centric” and “MAC centric”.

In [12] a joint cross-layer design for QoS content delivery is presented. The central concept of the proposed design is that of adaptation. A new QoS-awareness scheduler with a power adaptation scheme is proposed and is applied at both uplink and downlink Medium Access Control (MAC) layer to coordinate the behavior of the lower layers for resource efficiency. The work in [13] summarizes the recent developments in optimization based approaches for resource allocation problems in wireless networks using a cross-layer approach. [14] deals with 802.16 (WiMax) networks. The 802.16 standard provides four kinds of multimedia data services with QoS parameters but does not define any QoS scheduling algorithm. This paper presents an adaptive cross-layer scheduling algorithm for the IEEE 802.16 BWA system. The algorithm uses adaptive modulation and coding (AMC) scheme at the physical layer according to the Signal to Noise Ratio (SNR) on wireless fading channels. In addition the cost function is defined for each kind of multimedia connection based on its service status, throughout the deadline in MAC layer. The simulation results provided show that the scheduling algorithm achieved an optimum tradeoff between throughput and fairness. In [15], the gap between existing theoretical cross-layer optimization designs and practical approaches is examined.

3. POWER MANAGEMENT MECHANISM

Over the last years a number of new protocols have been developed for multimedia applications in the whole OSI layer’s scale. The MPEG protocol family includes the encoding and compression of multimedia data. The MPEG-4 protocol with the enhancements of the FGS (Fine Granularity Scalability), AVC (Advanced Video Coding) and SVC (Scalable Video Coding) provides adaptive video coding by taking into account the available bandwidth and is expected to be used by many multimedia applications. Moreover, congestion control and TCP-friendliness pose additional design requirements as highly fluctuating (“shark teeth”-like) transmission rates may be too difficult to be followed by Audio-Video (AV) encoders and decoders. TCP congestion control produces high fluctuations in the transmission rate which are not suitable for the current audio-video codecs which expect predictive and stable bandwidth allocation. Therefore, the development of protocols such as TFRC can be seen as a step to improve multimedia transmission. TFRC aims to achieve UDP’s throughput efficiency, without stifling other network TCP flows. One way to cope with transient fluctuations of the transmission rate is with the use of buffers at the clients. However, an initial data pre-fetch in a buffer of more than 8 seconds before the player starts playing the stream is not easily accepted by the end user. Moreover, in real time video applications and conversational media large pre-fetch buffers are not acceptable. For multimedia applications smooth and steady transmission rates and low delay are more important attributes than guaranteed and on order delivery of data packets.

The target of the proposed mechanism is to minimize or eliminate packet losses, since even a small packet loss rate can result to important reduction of multimedia quality in the end user and result to a bad end user experience. Improvements in the above two areas will lead to improved media parameters such as PSNR and MOS, which better represent the end user experience. At the same time, it has to make sure that power consumption will be bounded and will only increase when this results to noticeably improved video quality.

The proposed mechanism uses the TFRC receiver’s reports to the sender in order to calculate the packet loss rate percentage. The algorithm considers only a constant number of previous packet losses, so that it is more adaptive to the most recent conditions of the network. In addition, if the packet loss rate increases above a preset threshold, then the power is also increased by a percentage, else if the packet loss falls way below the threshold, the power consumed is decreased for reasons of power efficiency. Moreover the power consumed has a lower bound to prevent the base station from halting the transmission and an upper bound to prevent excessive consumption. This cross-layer mechanism uses information provided by the TFRC protocol which is a transport layer protocol and needs to act upon the physical layer to adjust the transmission power. The parameters involved by each layer include the transmission power at the physical layer, and the packet loss information at the transport layer. The interaction of these parameters is explained in the pseudocode below.

Below the mechanism is expressed in a more compact form using pseudocode (PL stands for Packet Losses (as a percentage) and TP for Transmission Power, while A>1 and 0<B<1):

```
while (true) {
  retrieve last TFRC report
  set PL = Average of last N reports
  if (PL > Threshold_1) and (TP < Upper_Bound)
      then set TP = A * TP
  else if (PL < Threshold_2) and (TP > Lower_Bound)
      then set TP = B * TP
}
```

After extensive experimentation with the values A,B and the thresholds we concluded with the values A=1.05, B=0.05, Threshold_1=0.1, Threshold_2=0.075 which led to both good PSNR values and limited energy consumption. The values for Upper_Bound and Lower_Bound are discussed in the Experiments section.

4. TESTBED SETUP

Evaluation and testing of new cross-layer techniques in real networks would require big investments in software development and very often hardware development. In addition, a lot of equipment would be needed to conduct experiments on a large scale having multiple sources and destinations of different types. Therefore, real network testing is too costly for most research institutes at least in the first phases of development. Testing in a simulation environment is a more appropriate and inexpensive solution for evaluating novel cross-layer architectures. In this paper the Network Simulator 2 (ns-2.30) [17] was used as a basic tool of our simulation environment to simulate multimedia data transmission over wireless networks.

In order to simulate MPEG-4 video transmission using ns-2, another software package is needed, namely Evalvid-RA ([18], [19]). Evalvid-RA supports rate-adaptive multimedia transfer based on tracefile generation of an MPEG video file. A typical tracefile provides information for frame number, frame type, size, fragmentation into segments and timing for each video frame. The multimedia transfer is simulated by using the generated tracefile and not the actual binary multimedia content. The simulator keeps its own tracefiles holding information on timing and throughput of packets at each node during simulation. Combining this information and the original videofile Evalvid-RA can rebuild the videofile as it would have been received on a real network. Additionally, by using the Evalvid-RA toolset the total noise introduced can be measured (in dB PSNR) as well as Mean Opinion Score (MOS) can be calculated. An example implementation is illustrated in [20].

Several modifications of the network simulators were needed in order to build a working instance of the proposed mechanism. Firstly, a module that implements the logic of the proposed mechanism was added in the simulator. Then, the module that implements the TFRC protocol was changed so that it provides information about packet losses to our mechanism. The mechanism calculates the power needed to improve PSNR and then this information is passed to the modified wireless physical layer module that is able to increase or decrease power according to the mechanism.

In our experiments we used the network topology illustrated in *Figure 1*. The akiyo sample video found in [21] was used for video streaming for the purposes of our experiments.

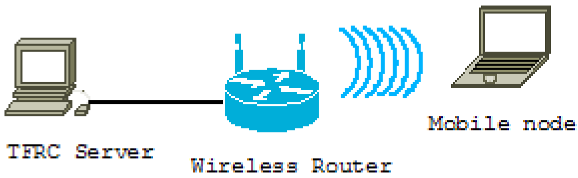

Figure 1: Topology used in experiments

Firstly, the video file was preprocessed and many video files were produced of different quality and resolution using the ffmpeg tool [22] and shell scripts included in the Evalvid-RA toolset. Then, tracefiles were generated for all these files and by using these tracefiles the simulation took place. Ns-2 scripts were created to simulate video transmission over a wireless network over TFRC. After simulating the transfer of the video in several different resolutions, ns-2 tracefiles were obtained which then were used to reconstruct the videos as it would have been sent over a real network. In this phase, several measurements and calculations can be done involving network and video metrics such as PSNR, MOS, jitter, throughput and delay. By using this procedure and another simulation script and algorithm we can make extensive comparisons and reach conclusions about the efficiency of each algorithm.

5. PERFORMANCE EVALUATION EXPERIMENTS

In our ns-2 experiments, we transfer H.264 video over TFRC over wireless links, and in particular over a single hop in a wireless ad hoc network. In order to model various instances of network degradation, we have performed experiments where both nodes are stationary, or where the transmitting node remains stationary, while the receiving node moves with steady speed away from the sender. We then compare the achieved throughput in terms of PSNR, packet losses and power consumption. Objective PSNR measurements can be approximately matched to subjective MOS (Mean Opinion Score) according to the standardized *Table 1*. The MOS scores reported below are derived from the automatic PSNR to MOS mapping according to *Table 1*.

The Lower_Bound ranged from 0.02 to 0.04 and the Upper_Bound from 0.06 to 0.1. In Experiments 1 and 2 we ran a set of experiments with different Lower_Bound and Upper_Bound each time in the above range and increasing by

0.01 in each experiment. The results in *Table 2* and *Figure 2* are from the average of these experiments.

PSNR [dB]	MOS
>37	Excellent (5)
31-37	Good (4)
25-31	Fair (3)
20-25	Poor (2)
<20	Bad (1)

Table 1: PSNR to MOS mapping

Experiment 1

In this scenario, both the transmitting and the receiving node remain stationary. In this experiment we observe a little improvement on PSNR values when using our power management mechanism, yet quality in both cases seems acceptable as they are both subjectively characterized as Good. Energy consumption has increased to optimize the perceived quality of the video as depicted by the average PSNR value.

Measurement	With Power management	Without Power management
PSNR average	35.89	34.16
PSNR standard deviation	10.5	11.97
Energy Consumption	0.0525W	0.048 W
MOS	Good (4)	Good (4)

Table 2: PSNR measurements with the proposed mechanism

Experiment 2

In this scenario, the transmitting node remains stationary, while the receiving node moves with steady speed away from the sender. We have repeated the experiment with and without the proposed power management mechanism, and from the results we observe that our mechanism achieves higher average PSNR measurements, which correspond to a measurable increase in MOS perception of the resulting video (an improvement from 3 – Fair, which is considered quite annoying and most users do not accept it, to 4 – Good, where imperfections can be perceived but is still clear and acceptable by users). Energy consumption increases but leads to a notable increase of the video's quality. Also increased is the PSNR standard deviation, which can also be observed through the higher fluctuation of the PSNR values in *Figure 2*.

We have run the same scenario multiple times with various values for the Upper and Lower Bound parameters, in order to identify the relationship between power consumption and the effectiveness (in terms of increased PSNR-measured quality) of the proposed mechanism. The results are depicted in *Figure 3*, where our mechanism is compared with the traditional approach, using several static power transmission levels. There it can be clearly seen that in almost every case, for the approximately same amount of energy, we get better PSNR measurements with the proposed mechanism enabled. Furthermore, the higher the average power that the transmitting station is allowed to use, the broader the difference between the usage our mechanism and the traditional approach. Additionally, measurements above 31 on the vertical axis (PSNR) are correlated with good MOS (according to *Table 1*), meaning a qualitative change in the user's experience. In order to increase or decrease energy consumption we used values for Lower_Bound from 0.02 to 0.04 and for Upper_Bound from 0.06 to 0.1. Furthermore, knowing the exact specification of the transmitting station allows us to choose the best combination for Upper and Lower Bound.

In summary, the proposed mechanism is especially beneficial in the case of mobile nodes where packet loss significantly increases due to the node's movement.

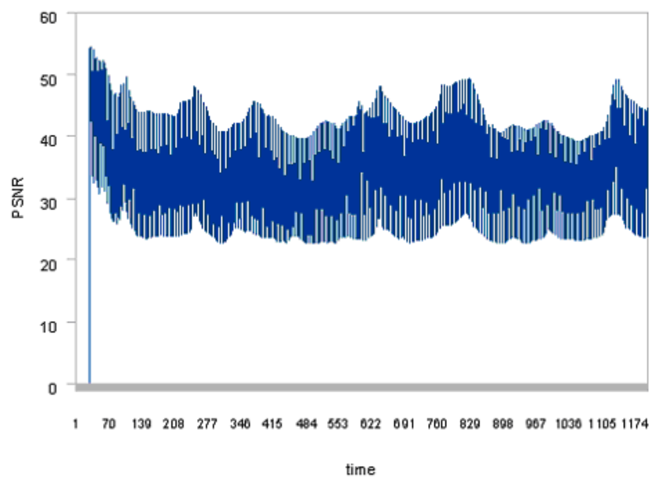

Figure 2: PSNR over time with power management for Experiment 2

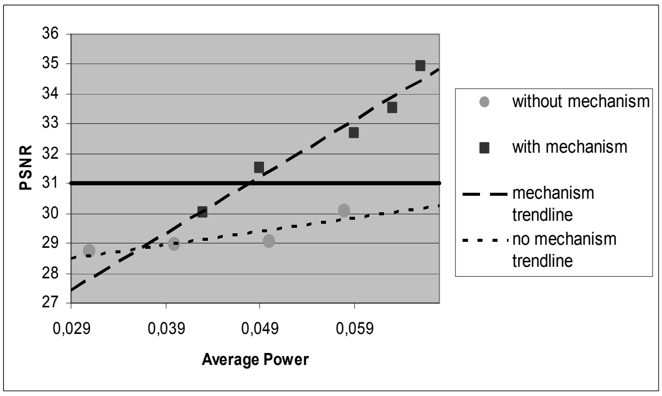

Figure 3. PSNR over average power consumption for the scenario of experiment 2

6. CONCLUSIONS AND FUTURE WORK

We have seen that by inserting a simple cross-layer mechanism for power management in wireless TFRC transmission, we can significantly improve both the objective quality of the transmitted video, and make a more optimal usage of available power. The complexity cost of the mechanism is quite small, and slightly larger fluctuations in PSNR measurements seem to be the only remaining trade-off.

The evaluation and testing procedure suggested in this paper is suitable for further experimentation. By using the codebase created and the testing procedure described, several different algorithms could be easily tested and evaluated. Cross-layer techniques are of particular interest in the area of video transmission (especially combined with enhancements of the H.264 standard) and could be evaluated using the created platform.

The proposed cross-layer mechanism could be improved in a wide range of ways. Firstly, the power management scheme could use a faster method to find the optimal power needed for transmission in order to minimize packet loss. A faster method not only would be more responsive and offer better quality video streaming to a moving node but it would also be more energy efficient. The mechanism could be expanded to take into account the PSNR metric along with packet loss and adjust the transmission rate, the power and the video transmission quality in order to optimize the perceived video quality. Finally, by using the capabilities of H.264 one can change video quality dynamically so that there can be adaptation of the transmission rate according to the available bandwidth.

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