UTILIZING VIDEO ENCODING FOR POWER MANAGEMENT OVER WIRELESS NETWORKS

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Abstract: Power management is especially important in wireless networks because of the emergence of energy constrained mobile devices. This paper examines the ways that video encoding information can be used for more efficient power management. In particular, we propose and evaluate cross layer mechanisms that fine-tune transmission power depending on the video frame being encoded and we examine how this mechanism may be combined with algorithms that adjust transmission power based on feedback reports when TCP Friendly Rate Control (TFRC) is used as the transport protocol. Since typical video encoding uses frames of varying importance for the overall quality, this approach can improve received video quality and make better usage of available power.

1 INTRODUCTION

Packet losses in wired networks mainly occur due to congestion in the path between the sender and the receiver, whereas in wireless networks the packet losses mainly occur due to corrupted packets. That is a result of the low Signal to Noise Ratio (SNR), the multi-path signal fading and the interference from neighbouring 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.

H.264/AVC is an essential component in wireless video application due to its excellent compression efficiency and network-friendly design. Typical video encoding standards define various types of frames (Stockhammer T., 2005) with varying importance in terms of information and compressibility. The main picture types as presented in Figure 1 are I-frames, P-frames and B-frames. I-frames are independent of other frames, P-frames are dependent on previous frames, and B-frames are dependent both on previous and future frames. Therefore, a video stream is expected to suffer more quality degradation when an I-frame is lost or delayed instead of a B-frame. The latest standard H.264/MPEG-4 defines slices instead of frames, which are more fine-grained elements that make part of a video picture.

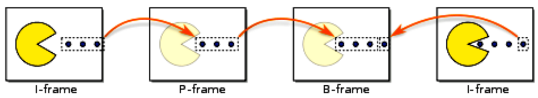


Figure 1: Dependence of various video frame types.

Cross layer design refers to protocol design done by actively exploiting the dependence between protocol layers to obtain performance gains. This is unlike layering, where the protocols at the different layers are designed independently. In particular, cross layer techniques allow the exchange of information between different network layers for the sake of improved performance. Power management in particular can significantly benefit from application layer information related to the type of frame being encoded and its importance in the decoding of the video stream at the receiving end of the transmission. A theoretical discussion of the cross-layer problem framework can be found in (Van der Schaar, 2005).

The trade-off between increased power consumption and improved signal strength has been explored by various researchers studying Transmission Control Protocol (TCP) modifications (Tsaoussidis, 2000, Zhang 2001, Jones 2001) trying to combine reduced power consumption with increased data throughput. Wireless standards such as IEEE 802.11 specify power saving mechanisms (IEEE 802.11 PSM Standard), although studies have shown that PSM (Power Saving Mode) and other similar mechanisms carry a significant performance penalty in terms of throughput (Molta, 2005, Chen, 2004, Anastasi, 2004, Simunic, 2005). The goal of this paper is to present a mechanism for cross layer power management for video transmission over wireless 802.11 networks utilizing the information about video encoding.

The rest of this paper is structured as follows: Section 2 describes the proposed mechanisms that aim to achieve improved quality and power consumption trade offs. Section 3 presents the simulation testbed that was used for evaluating the proposed mechanisms and section 4 discusses the obtained results. Finally section 5 concludes the paper with a summary of our proposal and ideas for future work in this area.

2 POWER MANAGEMENT UTILIZING VIDEO FRAME INFORMATION

In this section we describe how the information about video encoding can be utilized for the adjustment of power levels at the transmitting node and how this mechanism can be combined with a power management mechanism we refer to as Binary (Bouras, 2011).

2.1 Binary Mechanism

In this section for the sake of completeness we present the basic characteristics of the Binary mechanism which is described in detail in (Bouras, 2011), and which is tested in combination with the new approaches presented in this work. The mechanism is used by the sender of the video which is transmitted over TFRC. The reason TFRC is selected is because of its attractive properties in combining TCP characteristics of good behaviour towards other flows and UDP-type (User Datagram Protocol) throughput. At the same time, it defines a set of report metrics that are sent back to the sender of the traffic. Every time the sender receives a TFRC report from the receiver changes its state according to the state it is in and the new data. The mechanism after receiving the first report, if packet loss is not satisfactory, defines a region in which it will try to approximate the optimum power. The optimum power is that which produces a desired value of packet loss. After defining the region, the sender will increase its power to the maximum possible in that region and send the next TFRC packet with that power (state A: Expanding Power Region). When the sender receives the next report, it tests whether there has been a significant improvement (state B: Improvement and Constraint testing). If there has been an improvement and packet loss is below a predetermined threshold, goes to state C (Lower Consumption) or else repeats the actions of state A. In state C, the mechanism sets the power to the middle of the defined region and the sender goes to state D (Constraint Testing). In state D the algorithm tests whether the packet loss constraints are still satisfied and, if this is the case, it repeats state C. If this is not the case the algorithm goes to state E (Backtracking to Last Known Acceptable Value), where it goes back to the previous known acceptable power value. The mechanism stays at state E while the packet loss value is acceptable and, if not, it goes back to state A.

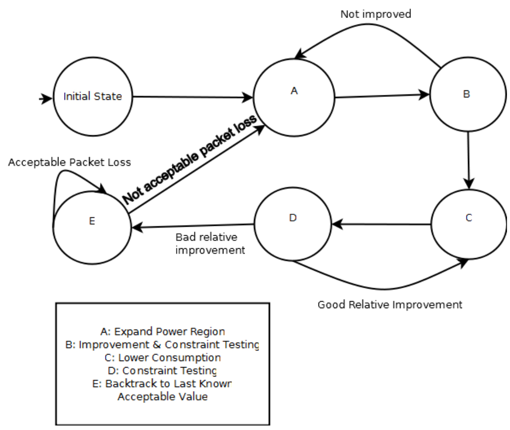


Figure 2: Binary mechanism.

2.2 Exploiting Video Frame Information

Since I-frames contain the most important information compared to the rest of the frames, and their loss may affect multiple frames before and after in the frame sequence, it is reasonable to make sure that they reach their destination. If the receiving mobile node has moved further away from the transmitting node, a transmission power increase may mitigate weak signal reception problems. However, packet losses may also be due to other factors, such as channel congestion, and then power increases offer no benefit. This is where the binary mechanism is needed: its operation is to quickly identify the optimal level of power for a given network condition depending on available information about packet losses. However, since the identification of an efficient power level unavoidably has to examine several iterations of packet loss reports, it is complemented by direct changes depending on the frame type as discussed below.

We therefore introduce a modification to the adaptive algorithm presented above that tries to heuristically increase power levels only when it is expected to produce some tangible beneficial effect.

```
onBackground(BinaryMechanism())

while (true) {
    frameType=checkMPEG4FrameType()
    currPower=getCurrentPower()
    if (frameType == I) {
        setPower(P_I*currPower)
    } else if (frameType == P){
        setPower(P_P*currPower)
    } else {
        setPower(P_B*currPower)
    }
}
```

Figure 3: Triple cross-layer power management.

The P_I, P_P, P_B values are fixed for a transmitting node and quantify the amount of importance that each type of frame has relative to the rest. It is therefore imperative that $P_I >= P_P >= P_B$. In section 4 we present the selected values for the type of encoding that was simulated and tested.

2.3 Triple Cross-layer Approach

The combinations of the above mechanism with the binary mechanism lead to a new cross-layer design between Application-Transport-Physical layers (Srivastava, 2005). This approach is being described in Figure 4.

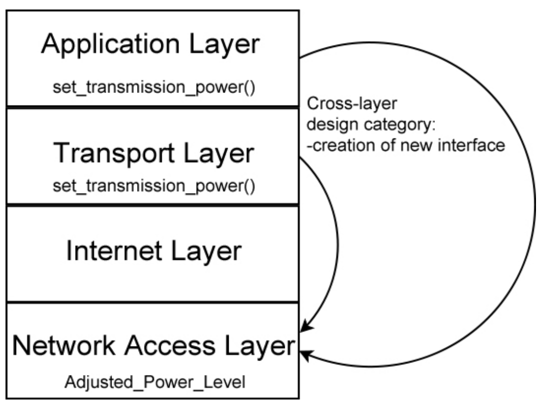


Figure 4: Proposed cross-layer design.

3 TESTBED SETUP

For our experiments we have used the Network Simulator 2 (ns-2.34, www.isi.edu/nsnam/ns/) as a basic tool for simulating 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 (Lie, 2008, www.item.ntnu.no/~arnelie/Evalvid-RA.htm).
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 Scores (MOS) can be calculated. An example implementation is illustrated in (Haukass, 2007). Objective PSNR measurements can be approximately matched to subjective MOS according to the standardized Table 1. The MOS scores reported below are derived from the automatic PSNR to MOS mapping according to the following table.

Table 1: ITU-R Quality and impaired scale (ITU-R, 2002) and possible PSNR to MOS mapping (Klaue, 2003).

PSNR [dB]	MOS	Impairment
>37	Excellent (5)	Imperceptible
31-37	Good (4)	Perceptible, but not annoying
25-31	Fair (3)	Slightly annoying
20-25	Poor (2)	Annoying
<20	Bad (1)	Very annoying

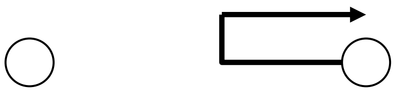
4 EXPERIMENTS AND RESULTS

In our experiments we used the akiyo sample video found in http://media.xiph.org/video/derf/ for video streaming. We transfer H.264 video over TFRC over a wireless link and in particular over a single hop in a wireless ad hoc network. Selection of P_I, P_P, P_B values for this specific video encoding was 1.3, 1.1 and 0.9 respectively. In order to model various instances of network degradation, we have performed a series of experiments with various scenarios, with both stationary and mobile nodes:

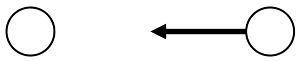
- Scenario 1: Two nodes, both stationary

- Scenario 2: Two nodes, one stationary, one moving away

- Scenario 3: Two nodes, one stationary, one moving closer and then moving away



- Scenario 4: Two nodes, one stationary, one moving closer



- Scenario 5: Two nodes, one stationary, one moving away and then stops moving

In all scenarios, the nodes communicate wirelessly using 802.11 MAC protocol and the distributed coordination function (DCF) from the Carnegie Mellon University. Propagation model used was two-ray ground reflection model.

Table 2: Stationary nodes.

	Triple cross-layer power mgmt	Binary power mgmt	Without power mgmt
PSNR average	37.8	37.6	37.1
Energy Consumption	0.051 W	0.046 W	0.046 W
MOS	Excellent (5)	Excellent (5)	Excellent (5)

In this scenario both nodes are stationary, so power requirements do not vary. Nevertheless, power management mechanisms offer a better PSNR with slightly increase in transmission power.
This time, the proposed mechanism displays a noticeable performance advantage over the approach

Table 3: One node moving away.

	Triple cross-layer power mgmt	Binary power mgmt	Without power mgmt
PSNR average	35.3	34.8	30.2
Energy Consumption	0.049 W	0.047 W	0.047 W
MOS	Good(4)	Good(4)	Fair (3)

without any mechanism. We observe that it actually achieves Good Mean Opinion Score while the value for the same scenario without any power management mechanism in fair.

Table 4: One node moving closer and then away.

	Triple cross-layer power mgmt	Binary power mgmt	Without power mgmt
PSNR average	36.2	36.1	33.3
Energy Consumption	0.050 W	0.048 W	0.048 W
MOS	Good(4)	Good(4)	Good (4)

The same applies to this scenario, where the power management mechanisms significantly improve received video quality as shown by the PSNR values. Power increase is non-existent or very small in both cases. The reason is that both mechanisms are capable to adapt to the changing distances between the nodes and tweak the power levels accordingly.

Table 5: One node moving closer.

	Triple cross-layer power mgmt	Binary power mgmt	Without power mgmt
PSNR average	38.8	37.9	34.6
Energy Consumption	0.049 W	0.046 W	0.046 W
MOS	Excellent (5)	Excellent (5)	Good (4)

When a node is moving closer it is natural to achieve a better PSNR value in all methods. By also using rapid adjustment of power even better results occur, whereas power consumption again stays relatively low.

In this case where the node stops after moving, the power management mechanisms adjust themselves to be as power saving as possible without making a reduction to the quality of video image transmitted by giving greater weight to the most important frames.

Table 6: One node moving away and then stop moving.

	Triple cross-layer power mgmt	Binary power mgmt	Without power mgmt
PSNR average	37.2	36.8	31.8
Energy Consumption	0.050 W	0.047 W	0.047 W
MOS	Excellent (5)	Good(4)	Good (4)

The results from all scenarios demonstrate that in all cases the proposed mechanism significantly outperforms the default behaviour (without any power management mechanism) as it achieves higher video quality reception, with only slight increases of average power levels. The following figure summarizes the results of the experiments in terms of the ratio PSNR/power which gives us an estimation of how well the trade-off between power consumption and video quality is balanced.

We can see that the proposed mechanism achieves a significantly improved trade-off, which means that the mobile nodes may gain in either quality or power consumption or both, compared to the original approach that does not utilize the cross-layer information.

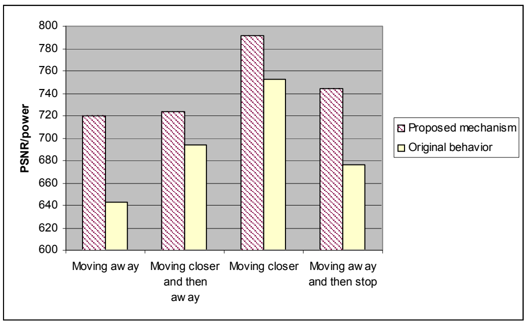


Figure 5: PSNR/power ratio.

5 CONCLUSIONS AND FUTURE WORK

In this paper we have proposed an advanced power management cross-layer mechanism for power management in wireless TFRC transmission, which significantly improves both the objective quality of the transmitted video, and makes more optimal usage of available power utilizing information from three different layers of the TCP/IP stack. In this paper we have seen that minor tweaks to the algorithm can achieve both goals and can be fine-tuned depending on the specific requirements of each particular situation. Most of the presented approaches have their strong and weak points, depending on the specific type of movement performed by the nodes.

The proposed cross-layer mechanism could be further improved in a wide range of ways. Firstly, we could estimate power consumption by taking into account both power consumption for the computational complexity of encoding and the power consumption for the transmission. Furthermore, 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. Finally, the latest and most promising mechanism for wireless transmission of H.264 video is SVC (Scalable Video Coding). SVC (Schwarz, 2006) enables the transmission and decoding of partial bit streams to provide video services with lower temporal or spatial resolutions or reduced fidelity while retaining a reconstruction quality that is high relative to the rate of the partial bit streams. Hence, SVC provides functionalities such as graceful degradation in lossy transmission environments as well as bit rate, format, and power adaptation, so another step could be to use our proposed power management mechanism, while exploiting features the structure of H.264 video.

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