Efficient Power Management Adaptation for Video Transmission over TFRC

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Abstract— **In this paper, we describe a power management mechanism for wireless video transmission using the TFRC protocol that takes into account feedback about the received video quality and tries to intelligently adapt transmitting power accordingly. The purpose of the mechanism is to utilize TFRC feedback and thus achieve a beneficial balance between the power consumption and the received video quality. We use simulation in order to compare and evaluate our approach.**

Keywords: cross-layer, TFRC, power management, wireless, video transmission

I. Introduction

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.

According to its specification, TFRC (TCP Friendly Rate Control) [9] 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 (Transmission Control Protocol) 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 that tries to quickly adapt to network and mobility changes that affect wireless link performance. The mechanism is compared with simpler mechanisms and the lack of power management through a large variety of simulated experiments. The rest of this paper is organized as follows: Section II gives an overview of related work in the area of cross-layer optimization. Section III describes the main idea of the paper and Section IV the testbed setup. Experiments and their results are presented in Section V, while Section VI concludes the paper and discusses possible future work. Source code for our implementation and installation instructions can be found at [17].

II. Related Work

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.

The tradeoff between increased power consumption and improved signal strength has been explored by various researchers studying TCP modifications ([1], [2], [3]) trying to combine reduced power consumption with increased data throughput. Wireless standards such as IEEE 802.11 specify power saving mechanisms [4], although studies have shown that PSM (Power Saving Mode) and other similar mechanisms carry a significant performance penalty in terms of throughput ([5], [6], [7], [8]). Several researchers have dealt with the issue of optimized video transmission using power management techniques ([19] [20]), but these approaches do not utilize feedback available from protocols such as TFRC.

Previous work in [18] introduced a power management mechanism for TFRC, which operates in a MIMD (Multiplicative Increase, Multiplicative Decrease) fashion. In general, when the packet loss increases above a preset threshold, then the power is also increased, else if the packet loss falls below the threshold, the power consumed is decreased. 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 mechanism (called MIMD approach) is compared in the next sections to the mechanism proposed in this paper (called Binary approach).

III. Power Management Mechanism

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 (Peak Signal-to-Noise Ratio) and MOS (Mean Opinion Scores), 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. 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.

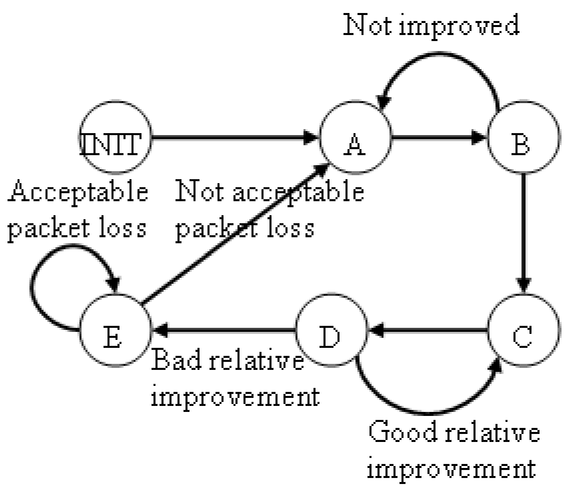

Figure 1. Finite automaton for the proposed mechanism for the sender.

The finite automaton presented in Figure 1. is the mechanism used by the sender of the video via TFRC. 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 the one that 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). When the sender receives the next report, it tests whether there has been as significant improvement. If there has been an improvement and packet loss is below a predetermined threshold goes to state C 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. 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 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. Below there is a summary of the states of the automaton:

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INIT: initializations

A: Expand "power region" and apply region-maximum power, then goes to state B

B: Improvement and constraint testing. If qualified, goes to state C, else it goes to state A

C: Lowers consumption to the middle of the defined power region and goes to state D

D:If all the constraints are satisfied, goes to state C, else goes to state E

E: Backtracks to the last known acceptable power value and stays there while packet loss is acceptable, else it goes to state A.
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IV. Testbed Setup

For our experiments we have used the Network Simulator 2 (ns-2.30) [10] 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 ([11], [12]). 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 [13].

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 2. The akiyo sample video found in [14] was used for video streaming for the purposes of our experiments.

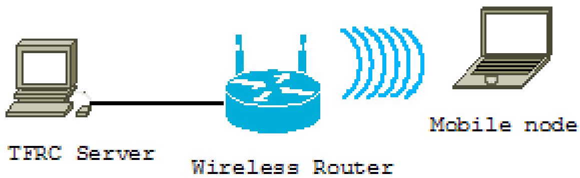


Figure 2. Topology in experiments

Firstly, the video file was preprocessed and many video files were produced of different quality and resolution using the ffmpeg tool [15] 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.

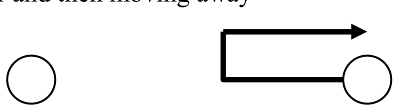
V. Performance Evaluation Experiments

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 a series of experiments with various scenarios, with both stationary and mobile nodes:

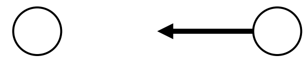
- Scenario 1: Two nodes, both stationary

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

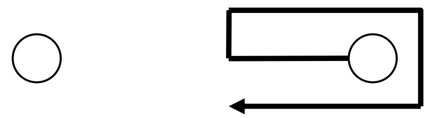
- Scenario 3: Two nodes, one stationary, one moving closer and then moving away



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

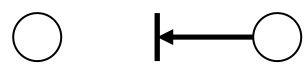


- Scenario 5: Two nodes, one stationary, one moving closer and then moving away and then moving closer again



- Scenario 6: Two nodes, one stationary, one moving away and then stops moving

- Scenario 7: Two nodes, one stationary, one moving closer and then stops moving



- Scenario 8: Two nodes, one stationary, one moving randomly

Each scenario was run in three variations, one without any power management, one with MIMD power management algorithm and one with Binary power management algorithm. Each experiment lasted almost 1 minute (the transmitting node was sending video for 40 seconds). Each experiment was repeated several times and the average values were calculated. 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 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 MIMD method's performance varied according to the values of the thresholds chosen, while the Binary Method is insignificantly susceptible to thresholds' change. The Binary Method's performance however, depends on the initial desired power that one wants to use.

TABLE 1. PSNR TO MOS MAPPING

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

A. Experiments

We ran the 7 scenarios described above and took the ratio average PSNR over average power per experiment. The purpose is to maximize this ratio as the larger its value the better the performance. Indeed a large value means larger average PSNR or lower average power or both. The Binary method clearly outperforms the MIMD method and the version without mechanism.

TABLE 2. SCENARIO RESULTS

Scenario	Normal (PSNR/Power)	MIMD (PSNR/Power)	Binary (PSNR/Power)
1	669,2	813,1	790,1
2	666,4	769,4	782,5
3	662,2	759,8	798,8
4	676,2	798,9	814,8
5	671,8	800,3	789,7
6	666,4	769,4	782,5
7	669,2	813,1	790,1
8	919,3	902,3	968,4
Average	**700,9**	**803,3**	**814,6**
stddev	**88,66**	**45,06**	**63,02**

We also present a detailed graph for each scenario, and provide trend lines in order to illuminate the behavior of each mechanism under different conditions. It is worthwhile to note that in many cases as shown in the following figures the Binary method achieves Excellent Mean Opinion Score (see Table 1) whereas the other methods achieve at most Good Mean Opinion Score.

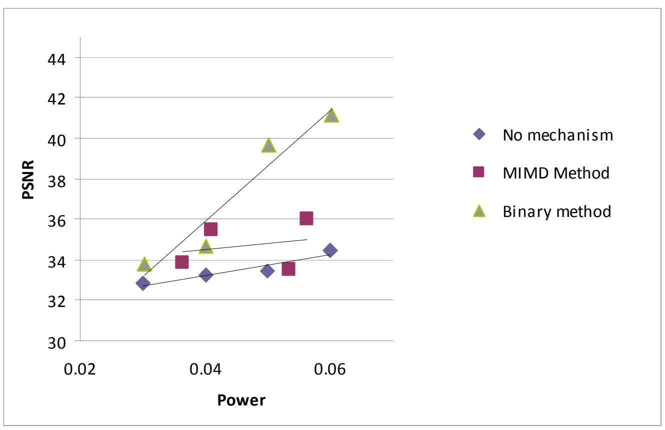


Figure 3. Scenario 1: Two nodes, both stationary

In the first scenario, both nodes are stationary, so power requirements do not vary. Nevertheless, power management mechanisms offer a better ratio of PSNR to transmission power. The proposed mechanism proves especially capable in taking advantage of the available transmission power. For a given amount of transmission power, the proposed mechanism significantly outperforms both the MIMD method and the original transmission approach, in terms of achieved video quality (as measured by the PSNR metric).

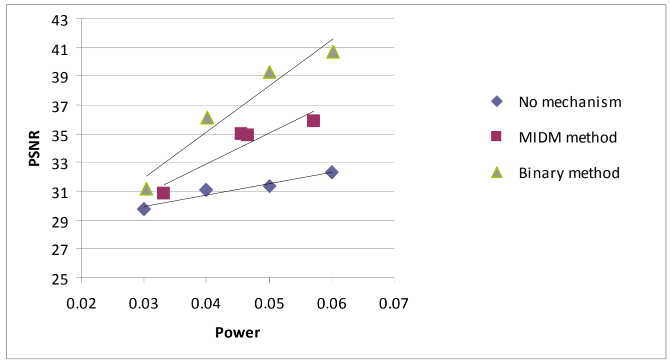


Figure 4. Scenario 2: Two nodes, one stationary, one moving away

The same observations apply also when one of the nodes is moving away. This time, the MIMD mechanism also displays a noticeable performance advantage over the simple approach. The Binary Method converges faster and closer to an optimum value of power needed to decrease packet, therefore achieves better PSNR values for the same average power.

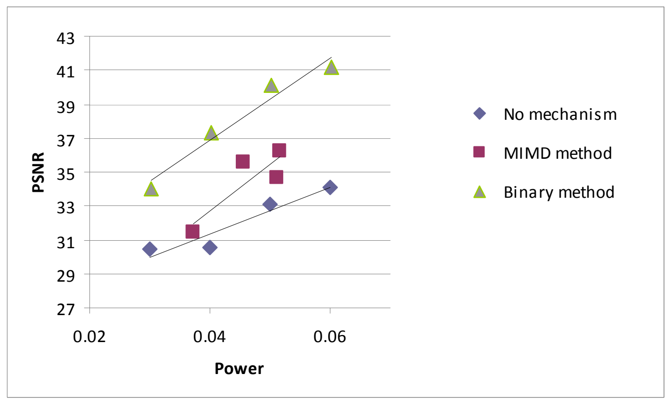


Figure 5. Scenario 3: Two nodes, one stationary, one moving closer and then moving away

Because of the increased proximity of the nodes in Scenarios 3 and 4, the simple transmission approach is able to achieve better performance, without however being able to match either the MIMD or the Binary power management approach because of their adjustment of power according to the packet loss.

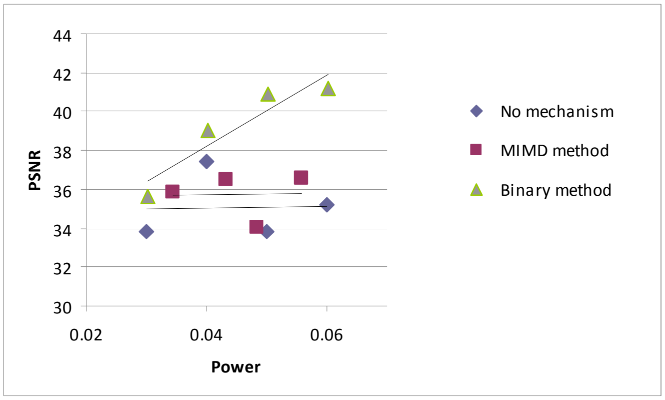


Figure 6. Scenario 4: Two nodes, one stationary, one moving closer

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. Also, the Binary method achieves Excellent Mean Opinion Score for power over 0.04.

In Scenarios with more complicated movement patterns, the basic conclusion seems to be the same: the proposed Binary approach demonstrates a significant performance lead, which often results in the received video quality to be excellent. The MIMD method provides intermediate benefits, while the original transmission approach without active power management lacks behind both in terms of video quality and consumed power.

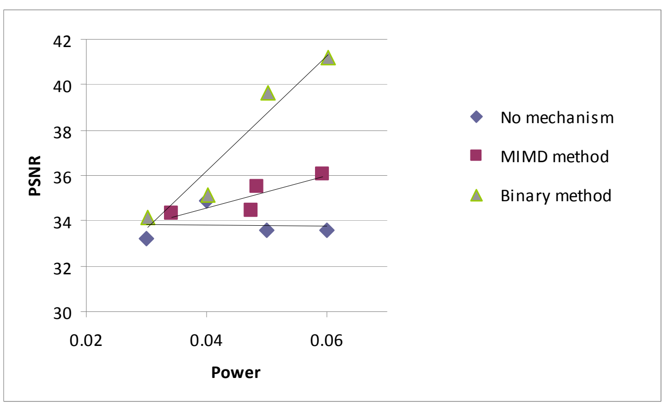


Figure 7. Scenario 5: Two nodes, one stationary, one moving closer and then moving away and then moving closer again

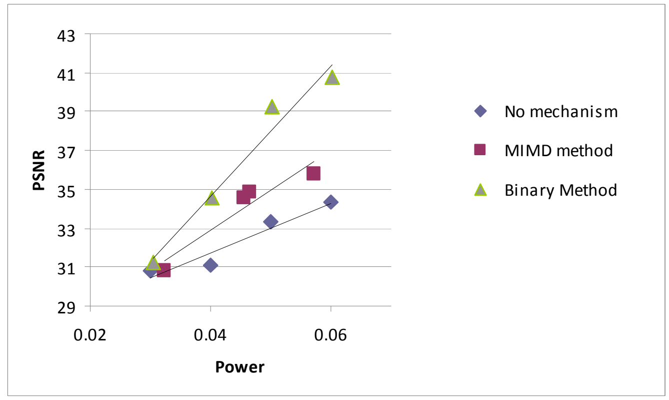


Figure 8. Scenario 6: Two nodes, one stationary, one moving away and then stops moving

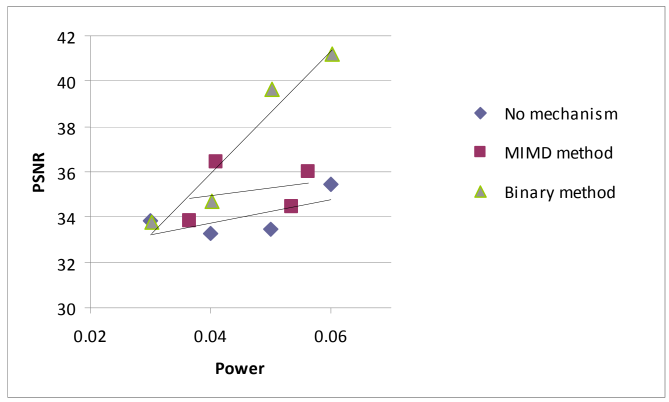


Figure 9. Scenario 7: Two nodes, one stationary, one moving closer and then stops moving

In the cases where the nodes stop after moving, the MIMD and Binary methods adjust themselves to be as power saving as possible without making a reduction to the quality of video image transmitted. In fact, for the same PSNR values the MIMD and Binary methods consume less energy than when using no mechanism and when the Binary method uses power 0.05 and over achieves excellent results.

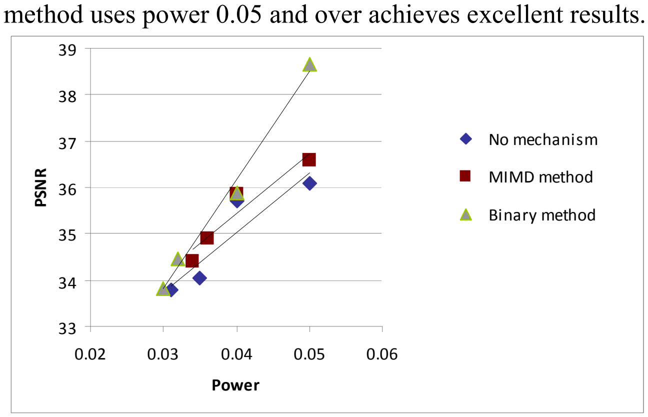


Figure 10. Scenario 8: Two nodes, one stationary, one moving randomly

When one node moves randomly the results show that all mechanisms tend to display similar behavior, for power values up to 0.04. Above this value the Binary method again gains a significant advantage and achieves excellent results. The fact that in this scenario the performance gains are not as pronounced as in previous scenarios can be attributed to the fact that the adaptive methods need some time to adjust (they adjust every time they receive a TFRC report). Random motions tend to quickly change the assumptions upon which adaptive behavior is based. Therefore, the adaptive methods (MIMD, Binary) tend to perform best in situations where there are movement patterns and changes in movement direction occur slower than the round-trip time of a TFRC report.

VI. 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. A much simple MIMD power management approach also has performance benefits, albeit significantly smaller. The complexity cost of the binary mechanism is relatively small, as our implementation in the ns2 simulator has shown.

The proposed cross-layer mechanism could be further improved in a wide range of ways. Firstly, the method to find the optimal power needed for transmission in order to minimize packet loss 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. 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.

VII. References

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