Power management of video transmission on wireless networks for multiple receivers

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Abstract: **The main idea of this paper is an efficient power management mechanism in order to transmit to multiple receivers. The proposed mechanism consists of a module for efficiently managing the power when transmitting video over wireless networks by using the TFRC protocol reports and then adjusts transmission power using a binary-like approach. In order to extend to multiple receivers, several methods are proposed for calculating an appropriate power transmission level based on all TFRC reports and adjust the server's transmission power accordingly.**

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

1. INTRODUCTION & RELATED WORK

Over the last years a number of new protocols have been developed for multimedia applications in the whole OSI layer's scale. In wireless networks the multimedia data transmission inherits all the characteristics and constrains related to the propagation to the free space. An important difference between wired and wireless networks is the cause of packet losses. 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 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, since reduced signal power due to node movement may affect reception quality.

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. The transport/session layer can play important role in cross layer adaptation for wireless networks, as a number of adopting mechanisms in this layer have been extensively evaluated in wired networks. A cross-layer approach between transport and physical layer seems to be revealing many adaptation opportunities in wireless networks because of their special characteristics as described above.

Another major issue related to the transmission of multimedia data is the "TCP-friendly" behavior of the underlying transport protocols so that TCP-based applications that share the same network links with bandwidth-consuming and typically UDP-based multimedia applications will not be effectively denied access to network resources. TFRC is a protocol that attempts to combine some of the best characteristics of both TCP and UDP protocols. The basic characteristic of TFRC in order to achieve better performance than TCP is its slow throughput variation, which might however affect the overall network performance in case of a real congestion scenario as it is presented in [1]. TCP seems to react quite fast, in a congestion scenario, decreasing its transmission rate rapidly, while TFRC decreases its rate much slower, which leads in reduced TCP-friendliness.

On the other hand TFRC's slow variation seems to be an advantage for multimedia applications, compared with TCP, making it thus more suitable for applications such as telephony or streaming media where a relatively smooth sending rate is important.

Therefore, TFRC is a good candidate protocol to be used for transporting multimedia data in an environment where frequent variations are possible. Such an environment is the case we are dealing with in the context of this paper, where wireless nodes may adapt their transmission power in order to increase signal strength.

The tradeoff between increased power consumption and improved signal strength 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 (Power Saving Mode) and other similar mechanisms carry a significant performance penalty in terms of throughput ([6], [7], [8], [9]).

In [10], an approach for cross-layer adjustment of transmission power based on TFRC reports was presented. The binary adaptation algorithm was shown to be more efficient than other approaches in achieving reduced power consumption and improved video quality reception. These ideas are extended in this paper for multiple receivers.

Most researchers use for their simulations the ns-2 simulator software. A drawback of those simulations is that they were not based on any multimedia traffic generation model and in the best case trace files were used instead. Therefore, the only quality indicators were purely based on the usual network metrics. However, different multimedia encodings can result in different perceived video quality, although the transmission is done with exactly the same set of protocols and under the same network conditions. Therefore, it is important to study the performance of any proposed solution by using real video files and to associate simulation results with video QoS metrics.

This paper presents the issues related to efficient transmission of encoded video (such as H.264) over wireless links using the TFRC protocol. The main idea is to extend previous work on efficient power management in order to transmit to multiple receivers.

The rest of this paper is structured as follows: Section 2 presents the proposed algorithms. Section 3 lists the experiments that were carried out in order to evaluate the proposals and comparatively evaluates them. Finally, section 4 presents our conclusions and our plans for future work.

2. POWER MANAGEMENT MECHANISM EXTENDED FOR MULTIPLE RECEIVERS

2.1 Problem statement

In this section we present a mechanism that extends the power management approach when there are multiple wireless receivers. In this case, the transmitting station has to calculate the most efficient transmission rate, so that a maximum number of receivers experience a satisfactory quality.

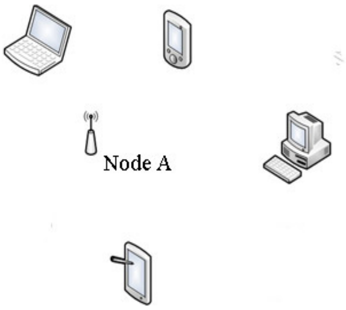

Figure 1. *Broadcast transmission of video*

We assume that the transmitting node has a variety of nodes within its transmission range, which all wish to receive the same broadcast transmission, as shown in Figure 1. The problem in this case is for the transmitting node to decide on an optimal strategy for all their varying reception capabilities.

2.2 Proposed mechanisms

The original power management algorithm presented in [10] considers only a constant number of previous packet losses, so that it is more adaptive to the most recent conditions of the network. It is based on information received by TFRC reports in order to perform its calculations. The improved cross-layer mechanism (called from now on the "binary" mechanism) also uses information provided by the TFRC protocol but performs more complex calculations in order to produce a more optimal result. TFRC is a transport layer protocol, and the mechanisms need 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. Below we describe the binary mechanism, which forms the basis for the variations suitable for multiple wireless receivers, since [10] has demonstrated its improved performance.

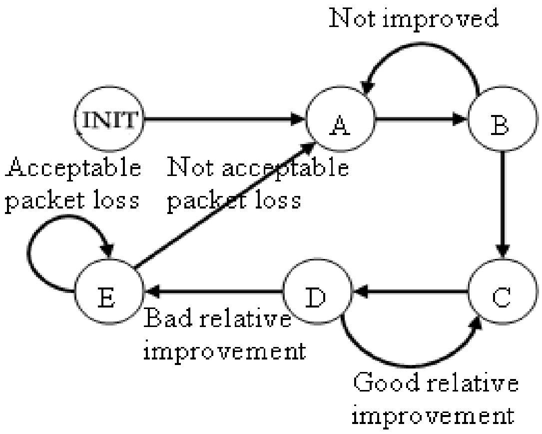

Figure 2. *Finite automaton for the original binary mechanism for the sender*

After receiving the first TFRC report, and if packet loss is not satisfactory, the binary mechanism defines a region in which it will try to approximate the optimum transmission 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, the sender transitions to state C, otherwise it repeats the actions of state A. In state C, the mechanism sets the power to the middle of the defined region and the sender transitions 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 transitions 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.

Figure 2 summarizes the above description. Below is a summary of the states of the automaton displayed in Figure 2:

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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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Several approaches can be examined for generalizing the original binary mechanism for the multiple receivers' problem. Every case follows the above mechanism where step B changes accordingly.

Follow the worst-case receiver

Calculating an average does not guarantee that nodes with high mobility and bad channel characteristics will receive fair quality video. On the other hand taking into account extreme values could lead to high energy consumption.

This mechanism variation is used in order to be efficient for every wireless node, which is included in the hop. Such an approach is suitable for a set of receivers that do not have wide differences in reception quality and capabilities, or do not quickly distance from each other or approach the transmitting node. In any case, this approach is expected to maintain a minimum quality level for every one participating node. However, the existence of outlier nodes that for some reason are not able to receive the stream properly may have a large influence on the performance of the whole system. Such an approach may be more suitable when minimum quality thresholds should be guaranteed.

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B: Improvement and constraint testing according to the TFRC reports with the most packet losses. If qualified, goes to state C, else it goes to state A
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Calculate an average

In this scenario the mechanism variation calculates the transmission power based on every the TFRC report from all the wireless and mobile nodes, thus making our mechanism less power-consuming, although some nodes may experience transmission problems due to wireless transmission characteristics.

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B: Improvement and constraint testing, by calculating the average amount of packet losses from the last five TFRC reports. If qualified, goes to state C, else it goes to state A
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Follow the median

Sometimes the median can be a more robust estimator than the mean in the presence of outliers, so we investigate its applicability as a criterion for feeding the power management mechanism.

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B: Improvement and constraint testing, taking into account the median value from the TFRC reports of all receivers. If qualified, goes to state C, else it goes to state A
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3. EXPERIMENTS AND RESULTS

All the above described mechanisms are implemented and evaluated using ns2. In our ns-2 experiments, we transfer H.264 video over TFRC over wireless links. TFRC's throughput equation is a slightly simplified version of the throughput equation for Reno TCP:

$$X_{TFRC} = \frac{s}{R\sqrt{\frac{2bp}{3}} + t_{RTO}(3\sqrt{\frac{3bp}{8}})p(1+32p^2)}$$

where X_{TFRC} is the transmit rate in bytes/second, s is the packet size in bytes, R is the round trip time in seconds, p is the loss event rate, between 0 and 1.0, of the number of loss events as a fraction of the number of packets transmitted, t_{RTO} is the retransmission timeout value in seconds, and b is the number of packets acknowledged by a single acknowledgement. The value of b is typically set to 1.

For the purpose of this work we have extended a previous work named Evalvid-RA ([11], [12]) in order to integrate the required sources into ns-2 and thus enabling us to conduct a number of realistic experiments with real video files. Evalvid-RA supports rate-adaptive multimedia transfer based on trace file generation of an MPEG video file. A typical trace file 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 trace file and not the actual binary multimedia content. The simulator keeps its own trace files holding information on timing and throughput of packets at each node during simulation. Combining this information and the original video file Evalvid-RA can rebuild the video file 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.

The simulation topology includes one base station and four wireless nodes. Moreover, five different scenarios where tested using various parameterization on nodes mobility and settings. Scenarios include single-hop cases with various channel characteristics. Below, there is a brief description of the basics scenario tested.

In order to compare the results PSNR and MOS were used. Moreover, 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.

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

Scenario 1: Results from two nodes moving randomly and the other two approaching the transmitting node are summarized in Table 2.

Mechanism	PSNR average	Energy Consumption	MOS
None	30.1	0.034	Fair
Worst case	30.8	0.041	Fair
Median	30.7	0.035	Fair
Average	32.3	0.034	Good

Table 2 Scenario 1

In this scenario, we observe that the average approach obtains clearly superior results (the only one that gets a “Good”-equivalent in the MOS scale), while it also ties for best energy consumption.

Scenario 2: Two nodes move randomly, one node is stationary and the other is leaving the hop.

Mechanism	PSNR average	Energy Consumption	MOS
None	31.0	0.038	Good
Worst case	31.2	0.040	Good
Median	30.8	0.035	Fair
Average	28.4	0.035	Fair

Table 3 Scenario 2

As we can see in Table 3 the average approach did not excel in the quality of the transmitted video, although it did achieve the best energy result among compared approaches. We conclude that the average approach is not aided by a scenario where the behavior of the nodes varies widely. On the other hand, the median approach in this case was able to achieve the best results as it weighs down extreme values that heavily influence the calculation of the average.

Scenario 3: Two nodes move randomly, one node is stationary and the other is approaching the base station.

Mechanism	PSNR average	Energy Consumption	MOS
None	28.2	0.031	Fair
Worst case	33.4	0.041	Good
Median	29.5	0.035	Fair
Average	29.6	0.033	Fair

Table 4 Scenario 3

The best behavior in this scenario in terms of video quality was displayed by the worst-case approach, although its energy consumption was the highest among all tested mechanisms, as we can see in Table 4. This behavior was common for all scenarios, and is due to the worst-case approach’s tendency to favor video quality guarantees for all nodes at the cost of increased energy consumption, sometimes just for the benefit of a single node.

Scenario 4: Two nodes move randomly and the other two are moving away.

Mechanism	PSNR average	Energy Consumption	MOS
None	27.1	0.031	Fair
Worst case	28.7	0.042	Fair
Median	30.4	0.036	Fair
Average	29.8	0.032	Fair

Table 5 Scenario 4

Since half of the nodes are moving away from the transmitting node in this case, this has been the most adversive scenario for almost all mechanisms. Especially the worst-case approach displayed heavily increased energy consumption, as it tried to accommodate nodes that were moving out of transmission range. The average approach was though able to obtain fair quality results with very low energy consumption. Overall results are presented in Table 5.

Scenario 5: Three nodes move randomly and the one left is stationary.

Mechanism	PSNR average	Energy Consumption	MOS
None	27.3	0.031	Fair
Worst case	29.6	0.038	Fair
Median	31.2	0.037	Good
Average	29.7	0.033	Fair

Table 6 Scenario 5

In our final experiment more nodes than ever performed random movements. The results, which are summarized in Table 6, were similar with most of the previous scenarios, in that the median and average approaches yielded best results. This time however differences were somewhat diminished, as the random movements did not allow a single approach's advantage on specific type of movements to sum up.

The results from all scenarios are summarized in Figure 3 which displays the ratio of PSNR/Power for all mechanisms and scenarios. A higher value means that the mechanism achieved better video quality with lower power consumption, which is our main objective. As we can see, the worst case approach obtained a relatively low ratio in all cases. This is an expected result, as this is the trade-off that we have to pay in order for all receivers to achieve high video quality. On the other hand, selecting the average approach yields the best results in most cases, while only scenario 2 outcomes favor the median approach.

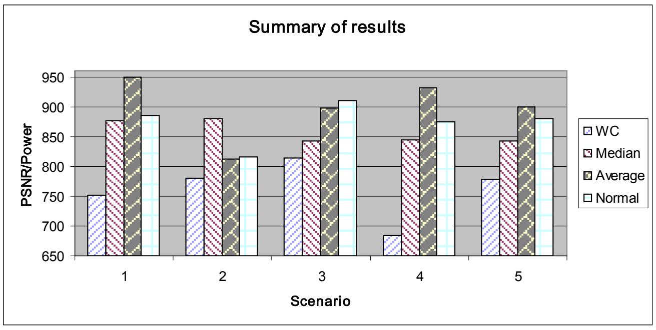

Figure 3. Summary of results

4. CONCLUSION 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. Having multiple receivers does not change this conclusion, although a new trade-off is introduced, namely whether we want all receivers to obtain a minimum level of video quality, which hinders overall results, or whether we want to focus on improving average video quality. 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 improved in a wide range of ways. Firstly, the power management scheme could calculate the optimal power transmission considering the type of frame being sent next (I, P or B-frame). Furthermore other algorithms can be used in order to calculate an average excluding extreme values, or taking into account the worst case receiver excluding extreme values. In both of these approaches, the effects of few outlier nodes are mitigated, although no quality guarantees can then be provided. 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. Also other topologies could be applied, we could additionally run experiments where mobile nodes move randomly between two hops, using various parameterization scenarios.

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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