Power Management Mechanism Exploiting Network and Video Information over Wireless Links

Christos Bouras[1,2], Savvas Charalambides[1,2], Kostas Stamos[1,2,3], Stamatis Stroumpis[1,2], Giannis Zaoudis[1,2]
[1]Computer Technology Institute and Press "Diophantus", Greece
[2]Computer Engineering and Informatics Dept., University of Patras, Greece
[3]Technological Educational Institute of Patra, Greece
E-mail: {bouras, charalampides, stamos, stroumpis, zaoudis}@cti.gr

***Abstract*—This article examines the ways in which cross-layer information from higher network layers may be utilized for more efficient power management in wireless networks and energy constrained mobile devices. In particular, we present and evaluate mechanisms that fine-tune transmission power according to information received from the transport (feedback reports from TFRC) and application (type of the video frame encoded) layers. Further improvements may be applied if the video encoding is done using capabilities of the SVC standard. We also describe power management adaptation techniques for wireless video transmission using the TFRC protocol that take into account feedback about the received video quality and try to adapt transmitting power accordingly. The purpose of the mechanisms is to utilize TFRC feedback and thus achieve a beneficial balance between the power consumption and the received video quality. The mechanisms proposed, offer significant improvements when used in terms of both power consumption and received video quality. All proposals are compared and evaluated using simulation.** [1]

***Index Terms*— cross-layer, SVC, TFRC, power management, wireless, video transmission**

I. Introduction

Dealing with networking architecture by dividing functionality in layers is a tested and successful concept, especially for wired networks. It reduces complexity and makes issues more manageable and architectures more flexible and upgradeable. However, it may lead to suboptimal designs, since operations of one layer are not always aware of information available to different layers. 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 important ways from wired communication. 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 (Transmission Control Protocol) 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 Mechanisms) and other similar mechanisms carry a significant performance penalty in terms of throughput ([6], [7] [8], [9]).

In this context, 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 SNR (Signal to Noise Ratio), the multi-path signal fading and the interference from neighboring transmissions. This is information that may potentially be utilized for adjustment of transmission power. The sender of a traffic flow can be informed for packet losses through a transport protocol that provides such feedback, such as for example TFRC (TCP Friendly Rate Control) [10]. TFRC is more suitable for applications such as telephony or streaming media where a relatively smooth sending rate is important.

The same consideration applies for application-layer traffic of video. Typical video encoding standards define various types of frames with varying importance in terms of information and compressibility. 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,

[1] This article is an extended version of the paper titled "Utilizing Video Encoding for Power Management over Wireless Networks", which has been presented in the 8th International Joint Conference on e-Business and Telecommunications (ICETE 2011).

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which are more fine-grained elements that make part of a video picture. 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. SVC [25] 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 the possibility for bit rate, format, and power adaptation.

In this paper we investigate the above possibilities and propose cross layer mechanisms for wireless scenarios and in particular WiFi transmission scenarios. The main objective of the mechanisms is to limit WiFi power consumption while maintaining satisfactory user experience and low computational complexity. The rest of this paper is organized as follows: Section 2 gives an overview of related work in the area of cross layer optimization, and section 3 provides an introduction to the SVC standard. Section 4 describes the main proposals of the paper related to utilization of information from transport and application layers. Section 5 presents the test bed setup that was used for the experiments, which are presented along with their results in in section 6, while section 7 concludes the paper and discusses possible future work. Source code for our implementation and installation instructions can be found at [14].

II. Related Work

Many cross-layer design proposals can be found in the literature. It is worthwhile to present how the layers are coupled, in other words, what kind of architecture change has taken place in a particular cross-layer design. The layered architecture can be bypassed in several ways, including the creation of new interfaces, the merging of adjacent layers, the design coupling without new interfaces and the vertical calibration across layers [1].

The cross-layer design approach in this paper is categorized in “Creation of new interfaces” category. The cross-layer approach is useful for wireless networks, because of the unique problems created by wireless links, the possibility of opportunistic communication on wireless links, and the new modalities of communication offered by the wireless medium.

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 [17] 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 [18] 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”.

The work in [19] summarizes the recent developments in optimization based approaches for resource allocation problems in wireless networks using a cross-layer approach. Paper [20] deal’s with 802.16 WiMax (Worldwide Interoperability for Microwave Access) networks. This paper presents an adaptive cross-layer scheduling algorithm for the IEEE 802.16 BWA (Broadband Wireless Access) system. The algorithm uses adaptive modulation and coding (AMC) scheme at the physical layer according to the SNR on wireless fading channels. In [21], the gap between existing theoretical cross-layer optimization designs and practical approaches is examined.

Power management in wireless networks is surveyed in [13] and techniques classified according to the layer where they are applied (application, transport, network, data link, MAC or physical). The authors in [15] propose a power management scheme for intra-frame refreshed image sequences of the wireless video service in code-division multiple-access (CDMA) systems, while [16] introduces coordinated power management policies for video sensor networks. In [23] , transmission power is one of the parameters that were jointly optimized in order to minimize power consumption. A thorough survey of power-awareness in mobile multimedia transmissions can be found in [24]. To the best of our knowledge the cross-layer design presented in this paper, is the first one taking into consideration parameters such as receiver’s perceived video quality, while using TFRC in wireless video transmission.•

III. Scalable Video Coding

Scalable video coding (SVC) is a highly attractive solution to the problems posed by the characteristics of modern video transmission systems. It was standardized as an extension of H.264/AVC. Deriving from H.264/AVC, it maintains the concepts of using a Video Coding Layer (VCL) and a Network Abstraction Layer (NAL). There are three main kinds of scalability that SVC can support:

- Temporal scalability: A bit-stream provides temporal scalability when the set of access units (a set of NAL units that always contains exactly one primary coded picture) can be partitioned into a temporal base layer and one or more temporal enhancement layer(s). A strictly requirement for a bit-stream to be called temporal scalable is that, when we remove all access units of all temporal enhancement layers with a temporal layer identifier higher than k (1 < k < max-layer), then the remaining layers still form a valid bit-stream for a SVC decoder (when k=1, then we have a baselayer bit-stream which must be compatible with conventional H.264/AVC decoders). Due to its non-reference property, B slices are often used to form temporal enhancement layers.

Spatial scalability: A bit-stream contains of multiple layers, in which each layer corresponds to a supported spatial resolution and can be referred to by a spatial layer with a dependency identifier. In each spatial layer, motion-compensated prediction and intra-prediction are employed as in single-layer video coding.

- Quality (SNR) scalability: This scalability can be considered as a special case of spatial scalability with identical picture sizes of base and enhancement layers. Quality scalability comprises of coarse-grain quality scalable (CGS) coding, medium-grain quality scalable (MGS) coding and fine-grain quality scalable (FGS) coding.
- Combined scalability: In some cases, quality, spatial, and temporal scalability can be combined.

IV. POWER MANAGEMENT MECHANISMS

The target of the mechanisms presented in this section is to minimize or eliminate packet losses, with an emphasis on packets containing crucial information, 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.

This section is divided in two subsections dealing with the utilization of transport layer feedback (we call the relevant mechanism "binary") and two subsections dealing with the utilization of application layer information.

A. The Binary Mechanism

Combined with TFRC's limited variation in transmission rates, we aim for improved media parameters such as PSNR (Peak Signal-to-Noise Ratio) and MOS (Mean Opinion Score), which better represent the end user experience. At the same time, we have to make sure that power consumption will be bounded and will only increase when this results to noticeably improved video quality. A new interface has been provided to TFRC in order to set the power transmission accordingly.

The Binary mechanism, originating from our previous work [27], 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.

The essence of the mechanism is to provide a better and quicker convergence to efficient power levels in scenarios where the mobile nodes follow more random movement patterns. We have to note that the objective of the binary mechanism is therefore to accommodate rapidly changing movement patterns, but not necessarily fast-moving nodes. The "binary" name comes from the dichotomic ("divide and conquer") nature of the mechanism, since it tries to divide the possible power level ranges through their middle, as will be shown below.

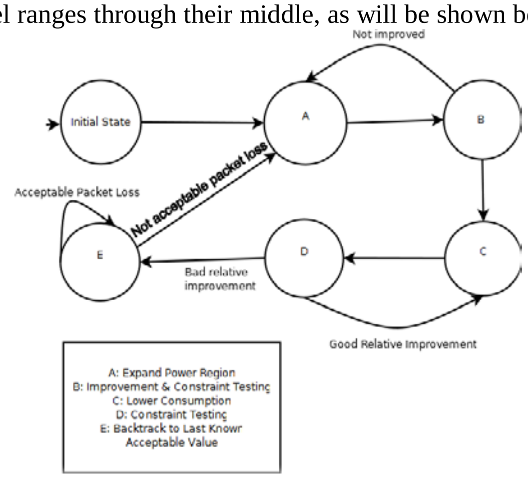


Figure 1. Finite state machine for the proposed mechanism for the sender.

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.

B. Power Management Mechanism Extended for Multiple Receivers

In this section we consider the implications of having multiple wireless receivers and present a mechanism that extends the power management approach for efficient operation in such a scenario. 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.

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

Several approaches can be examined for generalizing the original binary mechanism for the multiple receivers' problem. Every case follows the binary mechanism described above, 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.

B: Improvement and constraint testing according to the TFRC reports with the most packet losses. If qualified, go to state C, else go to state A

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.

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

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.

B: Improvement and constraint testing, taking into account the median value from the TFRC reports of all receivers. If qualified, go to state C, else go to state A

C. 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)
}
```

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 the test-bed and experiment sections we present the selected values for the type of encoding that was simulated and tested.

The proposed approach for selecting the values of the values for the P_I, P_P, P_B parameters is to make them dependent on the statistical distribution of the I, P and B frames of the video respectively, so that average consumption does not exceed the theoretical consumption if all frames were treated identically. In other words, the P_I, P_P, P_B values are also constrained by the fact that we want the sum $N_I*P_I+N_P*P_P+N_B*P_B$, where N_I, N_P, N_B are the percentage of I, P and B frames respectively, to equal one.

Since power adaptation in this case is dependant upon information available at the sender (frame type), no special considerations for multiple receivers are needed in this case.

The combinations of the above mechanism with the binary mechanism lead to a new cross-layer design between Application-Transport-Physical layers.

D. SVC Mechanism

In case where the transmitted video is encoded using H.264 SVC, we propose to exploit Network Abstraction Layer (NAL frames), which are segmented into a number of smaller UDP packets before feeding them to a real or simulated network. The video server component is responsible for the above procedure. In the case of a simulated transmission, this component also logs video frame number, frame type, frame size, number of segmented UDP packet, and timestamps down to a video trace file, which can then be used to simulate video transmission.

The objective of the SVC standardization has been to enable the encoding of a high-quality video bit stream that contains one or more subset bit streams that can themselves be decoded with a complexity and reconstruction quality similar to that achieved, using the existing H.264/AVC design with the same quantity of data as in the subset bit stream.

The most important part of the NALU header for our purposes is the PRID field, which designates the priority of the specific frame, as considered by the video encoding algorithm. A lower value of PRID indicates a higher priority [26]. The proposed cross-layer design creates an interface from the application layer to the physical layer, by taking into consideration the priority information from the application layer of the transmission and passing this info to the physical layer which then adjusts its transmission power in order to achieve minimum packet loss for important SVC frames that heavily influence the perceived end-user experience.

The main idea is to exploit the video bit stream at the physical layer according to the priority of the packet that will be transmitted as specified by the SVC architecture. This information may then be used to adjust the transmission power of the sender node, making sure that frames of higher importance are transmitted with higher average power, while balancing overall power consumption with low importance frames. According to the SVC standard packets with higher priority are considered quit important for the decoding process, so our approach focuses on these packets that will lead to better end-user experience. The mechanism is actually improving the overall quality of a video especially in cases where the distance between the nodes is above a certain threshold and is increasing.

We consider beneficial a power transmission increase only in packets that carry payload information for NAL units with higher priority. Since NAL units with higher priority are important for the decoding procedure, additional transmission power will typically result in a decrease in packet loss ratio of this kind of packets which will lead to improved end user experience.

The proposed mechanism's goal is twofold. On the one hand PSNR values will increase and on the other hand transmission power will be used efficiently.

```
while (true) {
   nalu = processNALU();
   prid = getPRID(nalu);
   currPower=getCurrentPower();
   if (prid < HIGH)
          setPower(P_H)
   else if (prid < MEDIUM)
          setPower(P_M)
   else
          setPower(P_L)
}
```

Since packets with high PRID contain the most important information compared to the rest of the packets, 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.

We expect this approach to be beneficial in cases where the distance between the nodes is large (and signal strength is correspondingly small), and especially when the receiving nodes tend to further distance themselves from the transmitting node. In such cases, signal weakness is harmful for the overall quality of the perceived video. On the other hand, we want our approach to use transmission power efficiently, even when signal strength is adequate, so that no excessive power consumption takes place.

The P_H, P_M, P_L 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 $P_H >= P_M >= P_L$. The interaction of these parameters is explained in the pseudo-code above. Their absolute values are related to the absolute power levels available at a specific environment, with P_M typical being chosen close to the average power used in a default setting, and P_H and P_L symmetrically above and below the P_M power level.

V. TESTBED SETUP

For our experiments we have used the Network Simulator 2 (ns-2.34) 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]. Evalvid-RA supports rate-adaptive multimedia transfer based on trace file generation of an MPEG video file. 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 MOS can be calculated. An example implementation is illustrated in [12]. For experiments using SVC video transmission, we used the extension EvalvidSVC ([2], [3]). Evalvid SVC supports scalable video coding extension of the H.264 mechanism based on trace file generation of an MPEG video file, similarly to Evalvid-RA.

Figure 2. Topology in experiments

In our experiments we used the network topology illustrated in Figure 2. . The akiyo sample video found in media.xiph.org was used for video streaming for the purposes of our experiments.

The simulation environment consists of three parts and is depicted in the Figure 2. . During the pre-processing phase, a raw video file, which is usually stored in YUV format, is encoded with the desired video encoder into 30 different encoded MPEG-4 video clips with quantizer scale values in the range 2–31. Quantizer scale 2 provides an encoded video with the highest quality. We use the ffmpeg free video encoder for the creation of the video clips. For our simulations, all video clips have temporal resolution of 25 frames per second and GoP (Group of Pictures) pattern IBPBPBPBPBPB, with a size of 12 frames. The frame size of all clips is 352x288 pixels, which is known as the Common Intermediate Format (CIF). After all the video files are encoded they are then traced to produce 30 frame-size traces files. At the end of the pre-processing phase, we thus have 30 m4v files with their associated frame size files.

Briefly, the video file was preprocessed and many video files were produced of different quality and resolution using the ffmpeg tool and shell scripts included in the Evalvid-RA toolset. Then, trace files were generated for all these files and by using these trace files 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 trace files were obtained which then were used to reconstruct the videos as it would have been sent over a real network.

The third part of the simulation environment consists of the reconstruction of the transmitted video and the measurement of the performance evaluation metrics. The reconstruction of the received video traces is implemented off-line by comparing the transmitted and the received traces with those of the original video sequence of all the transmitted simulcast streams. In this phase, several measurements and calculations can be done involving network and video metrics such as PSNR, MOS, jitter, throughput and delay. With the above described procedure we are able to make extensive comparisons between algorithms and reach conclusions about the efficiency of each one.

For SVC experiments, we used the DownConvertStatic resampler. This tool is used for spatial/temporal resampling of video sequences. In our procedure we used it to spatially resample our video to a resolution of 176x144 at 30 Hz, from 352x288 in order to have the same video sequence but with two different spatial characteristics. The next step was to encode the two separate video sequences into one spatial scalable bit-stream. To accomplish this we used the H264AVCEncoderLibTestStatic AVC/SVC encoder. The encoder is used for generating AVC or SVC bit-streams depending on the encoding mode you select in the main configuration file of the encoder. The parameter that defines the encoding is AVC mode. After defining the parameters of the encoder’s configuration files and encoding our video sequences we get a spatial scalable bit-stream. Following the encoding we used the MP4Box tool that came with the EvalSVC tool to create an ISO MP4 file which will contain the video samples and a hint track to describe how to packetize the frames for transport. Furthermore we used we used the mp4trace tool from EvalSVC to create the mp4 file.

The output of the mp4trace tool was used as an application in ns-2 to produce traffic in our simulated scenario and by enabling tracing we produced the needed trace file.

We used the EvalSVC toolset to generate the appropriate trace files for transmission over the network simulator ns-2. Through EvalSVC toolset we exported the PRID of the NALU header, by using of a modified version of mp4trace tool. The trace files that were used had spatial scalability, where two resolutions of the same video were used.

Several modifications of the network simulators were needed in order to build a working instance of the proposed mechanisms. Firstly, a module that implements the logic of the proposed mechanisms 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.

Furthermore, the module that implements the UDP protocol was modified in order to retrieve the video frame and priority information. The mechanisms run constantly throughout the whole simulation process at the agent of the transmitting node, which is an integrated agent of the toolset in ns2, where PRID info is available with the modifications we made.

Additionally, by using the EvalvidSVC toolset the total noise introduced can be measured (in dB PSNR) as well as Mean Opinion Scores (MOS) can be calculated. Objective PSNR measurements can be approximately matched to subjective MOS according to the standardized TABLE 1.

TABLE I. ITU-R QUALITY AND IMPAIRED SCALE AND POSSIBLE PSNR TO MOS MAPPING [22]

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

VI. PERFORMANCE EVALUATION EXPERIMENTS

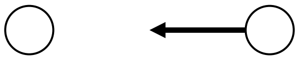
For our experiments, we transfer H.264 video over TFRC over a wireless link and in particular over a single hop in a wireless ad hoc network. Selection of P_I, P_P, P_B values for this specific video encoding was 1.3, 1.1 and 0.9 respectively. In order to model various instances of network degradation, 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



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 II. STATIONARY NODES

Power management	Triple cross-layer	Binary	None
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.

TABLE III. ONE NODE MOVING AWAY

Power management	Triple cross-layer	Binary	None
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)

This time, the proposed mechanism displays a noticeable performance advantage over the approach 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 IV. ONE NODE MOVING CLOSER AND THEN AWAY

Power management	Triple cross-layer	Binary	None
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.

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.

TABLE V. ONE NODE MOVING CLOSER

Power management	Triple cross-layer	Binary	None
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)

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. Figure 3. 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.

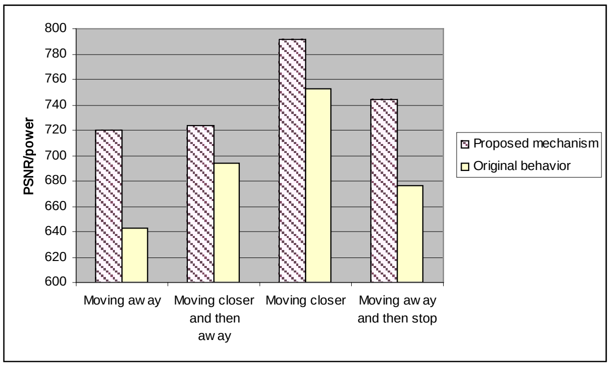


Figure 3. PSNR/power ratio

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.

A. Experiments with SVC Encoding

In this set of ns-2 experiments, we transfer H.264, in particular SVC extension, video over UDP using the same network setup described above. 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.

We then compare the achieved throughput in terms of PSNR and power consumption. Objective PSNR measurements can be approximately matched to subjective MOS according to the standardized TABLE I.

During the preprocessing phase a raw video file, which is usually stored in YUV format, is encoded with the desired video encoder. For our simulations, all video clips have a spatial scalability where the frame size of clips is 352x288 and then is down sampled and merged with 177x144 frame size using the EvalSVC toolset.

TABLE VI. EXPERIMENTS WITH STATIONARY NODES

Measurement	Nalu mechanism	Without mechanism
PSNR average	32.76	31.81

Measurement	Nalu mechanism	Without mechanism
Energy Consumption	0.272W	0.28W
MOS	Good (4)	Good(4)

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.

TABLE VII. EXPERIMENTS WITH ONE NODE MOVING AWAY

Measurement	Nalu mechanism	Without mechanism
PSNR average	27.53	23.49
Energy Consumption	0.272W	0.28W
MOS	Fair (3)	Poor(2)

This is a scenario where the cross-layer mechanism significantly affects perceived end-user experience. Its handling of higher priority frames leads to noticeably better PSNR values for the same average power consumption. We observe that the optimization also leads to an upgrade of the PSNR-equivalent MOS score. The improvement in the result can be understood if we consider the fact that while the moving node is distancing itself from the transmitting node, it crosses at some point the threshold where signal strength is no longer adequate for proper packet reception. Due to the increased power allocated to high importance packets, the proposed mechanism is able to keep video transmission at an acceptable level for a significantly longer time period.

TABLE VIII. EXPERIMENTS WITH ONE NODE MOVING CLOSER

Measurement	Nalu mechanism	Without mechanism
PSNR average	34.67	32.65
Energy Consumption	0.272W	0.28W
MOS	Good (4)	Good(4)

Since a node is moving closer it is natural to achieve a better PSNR value compared to the other scenarios. Usage of the proposed mechanism again achieves better results occur, without adversely affecting power consumption.

TABLE IX. EXPERIMENTS WITH ONE NODE MOVING CLOSER AND THEN MOVING AWAY

Measurement	Nalu mechanism	Without mechanism
PSNR average	30.25	28.76
Energy Consumption	0.272W	0.28W
MOS	Good (4)	Good(4)

In this case the node changes its movements rapidly but our mechanism seems to react better in terms of PSNR values though MOS level is the same. In cases where the receiving node is moving away our mechanism leads to better overall video quality.

TABLE X. EXPERIMENTS WITH ONE NODE MOVING CLOSER THEN MOVING AWAY AND THEN MOVING CLOSER AGAIN

Measurement	Nalu mechanism	Without mechanism
PSNR average	32.23	29.65
Energy Consumption	0.272W	0.28W
MOS	Good(4)	Fair(3)

The proposed approach demonstrates a significant performance lead for the cross-layer approach, including an upgrade of the PSNR-equivalent MOS score compared to the default approach.

TABLE XI. EXPERIMENTS WITH ONE NODE MOVING CLOSER AND THEN STOPS MOVING

Measurement	Nalu mechanism	Without mechanism
PSNR average	33.14	32.02
Energy Consumption	0.272W	0.28W
MOS	Good(4)	Good(4)

In this case both mechanisms achieve comparable results, with no benefit of the mechanism but also no negative effects.

The results from all scenarios demonstrate that in almost all cases the proposed mechanism outperforms the default behavior (without any power management mechanism) as it achieves higher video quality reception, with negligent increase of average power levels. The results from all scenarios are summarized in Figure 4. , 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.

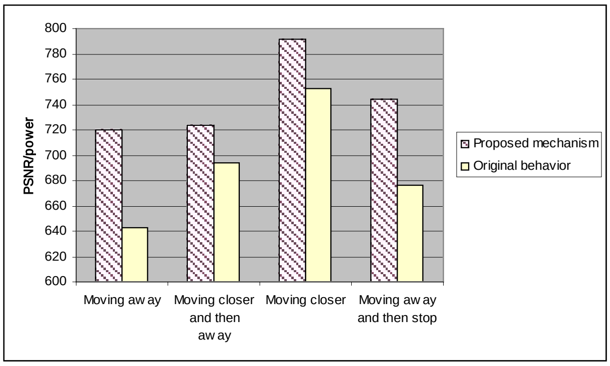


Figure 4. Test results

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.

B. Multiple Receivers

In the last set of experiments we transfer H.264 video over TFRC over wireless links. In this set of experiments we assume that the video is received by multiple mobile nodes, so that we can verify that the proposed mechanism scales satisfactorily. We simulate various patterns of movement for the sending and receiving nodes as detailed below. We compare the results depending on the type of policy for configuring the cross-layer mechanism as explained in the relevant part of section 4.

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

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

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

As we can see in the above table 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

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 the above table. 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

Since half of the nodes are moving away from the transmitting node in this case, this has been the most adverse 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 the above table.

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

In our final experiment more nodes than ever performed random movements. The results, which are summarized in the above table, 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 with multiple receivers are summarized in Figure 5. , 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.

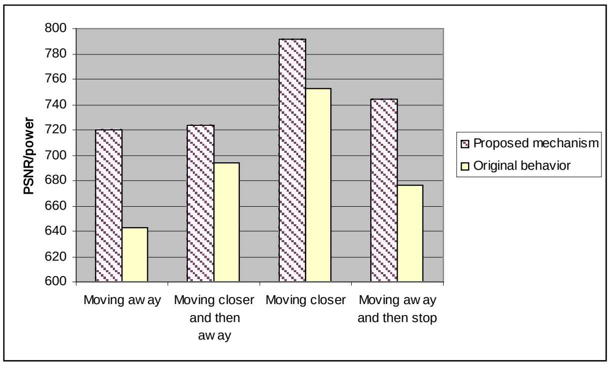


Figure 5. Summary of results

VII. CONCLUSIONS AND FUTURE WORK

In this paper we have proposed some advanced power management cross-layer mechanisms for power management in wireless TFRC and UDP transmission, which significantly improve both the objective quality of the transmitted video, and make more optimal usage of available power utilizing information from three different layers of the TCP/IP stack.

Utilizing the video encoding properties of H.264 and the SVC extension we can manage power in order to favor the most important packets. Furthermore, exploiting feedback information from the transport layer, allows the algorithm to benefit from the knowledge of the network status. When feedback is provided by multiple receivers, we have seen that minor tweaks to the algorithm can achieve better results 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 complexity cost of the mechanisms is quite small, and slightly larger power consumption in measurements seems to be the only remaining trade-off.

The proposed cross-layer mechanisms could be further improved in a wide range of ways. We plan to estimate power consumption by taking into account both power consumption for the computational complexity of encoding and the power consumption for the transmission, create an SVC rate adaptive mechanism that could be extended to support temporal, snr and combined scalability and extend the mechanism 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. We are also working on real implementations of the algorithms in order to more accurately estimate any computational performance trade-offs.

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Christos Bouras is Professor in the University of Patras, Department of Computer Engineering and Informatics. Also he is a scientific advisor of Research Unit 6 in Computer Technology Institute and Press - Diophantus, Patras, Greece. His research interests include Analysis of Performance of Networking and Computer Systems, Computer Networks and Protocols, Mobile and Wireless Communications, Telematics and New Services, QoS and Pricing for Networks and Services, e-learning, Networked Virtual Environments and WWW Issues.

Savvas Charalambides was born in Pafos, Cyprus in 1987. He entered Computer Engineering and Informatics Department in 2007 and joined RU6 in 2011. He is interested in Network Design, Network Protocols and Wireless Networks.

Kostas Stamos was born in Patras, Greece in 1978. He has received his Diploma, Master Degree and PhD from the Computer Engineering and Informatics Department at the University of Patras. Since July 2001 he works as a R&D Computer Engineer with Research Unit 6 of CTI. His research interests include multicast video transmission, QoS, bandwidth on demand and network applications and protocol design.

Stamatis Stroumpis was born in Chios, Greece in 1989. He entered Computer Engineering and Informatics Department in 2007 and joined RU6 in 2010. His research interests include wireless video transmission (mpeg4-h264) and network technologies.

Giannis Zaoudis was born in Chios, Greece in 1987. He entered Computer Engineering and Informatics Department in 2004. His interests include Web Technologies, Network programming and Network Protocols. Currently he is a post-graduate student in CEID and he is doing research on cross-layer techniques over wireless networks.