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Power management for SVC video over wireless networks

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Abstract— **The main idea of this paper is to study how the emerging H.264 SVC standard can be utilized for more efficient power management in wireless video transmissions. Our proposal uses a cross-layer approach which adapts the power transmission level of the sender according to the SVC information regarding the priority of the SVC NAL frame. Our aim is to improve transmission statistics, and therefore user experience, without unnecessary power consumption. We use extensive experimentation on the ns2 network simulator, which we have specifically modified for this purpose, in order to verify this approach.**

Keywords-component; power management, video transmission, wireless, H.264 SVC, cross-layer

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 not only improved transmission quality, but also reduced power consumption is desired.

Various researchers have studied and experimented with H.264 video transmission, which is defined as Part-10 of MPEG-4 standard. The latest and most promising mechanism for wireless transmission of H.264 video is SVC (Scalable Video Coding). SVC [1] 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. These functionalities provide enhancements to transmission and storage applications. SVC has achieved significant improvements in coding efficiency with an increased degree of supported scalability relative to the scalable profiles of prior video coding standards.

In our work, we 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 main idea of this paper 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.

The tradeoff between increased power consumption and improved signal strength has been explored by various researchers studying TCP modifications ([10], [11], [12]) trying to combine reduced power consumption with increased data throughput. Wireless standards such as IEEE 802.11 specify power saving mechanisms [13], although studies have shown that PSM (Power Saving Mode) and other similar mechanisms carry a significant performance penalty in terms of throughput ([14], [15], [16], [17]).

The rest of the paper is organized as follows. Section II describes the H.264 SVC extension. Section III introduces the proposed cross-layer design and section IV describes the proposed mechanisms that aim to achieve improved quality and power consumption trade offs. Section V presents the simulation testbed that was used for evaluating the proposed mechanisms and section VI discusses the obtained results. Finally section VII concludes the paper with a summary of our proposal and ideas for future work in this area.

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II. Scalable video coding

Scalable video coding (SVC) is a highly attractive solution to the problems posed by the characteristics of modern video transmission systems. As a result of the Scalable Video Coding extension, the standard contains three additional scalable profiles: Scalable Baseline, Scalable High, and Scalable High Intra.

- Scalable Baseline Profile which is mainly targeted for conversational, mobile, and surveillance applications.
- Scalable High Profile: Primarily designed for broadcast, streaming, storage and videoconferencing applications.
- Scalable High Intra Profile: Mainly designed for professional applications.

Scalable Video Coding 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) [6].

A. *Video Coding Layer*

In H.264/AVC, each video frame to be encoded will be partitioned into smaller coding units called macroblocks [6]. A macro-block will cover a rectangular picture area of luminance samples. Not all macro-blocks are fully encoded, most of them can be spatially or temporally predicted before being fed into the VCL encoder. Outputs of the VCL are slices: a bit string that contains the macroblock data of an integer number of macro-blocks (making a full frame) which are normally organized into slices according to the frame scanning order; and the slice header (containing the spatial address of the first macro-block in the slice, the initial quantization parameter, and similar information)[7]. In both H.264/AVC and SVC, there are three main types of slices:

- I slice: intra-picture coding using intra-spatial prediction from neighboring regions. This type of slice is self-contained and can be decoded without the reference to any other slice.
- P slice: intra-picture predictive coding and inter-picture predictive coding with one prediction signal for each predicted region. This type of slice can only be decoded with reference information from previous I or P frame.
- B slice: inter-picture bi-predictive coding with two prediction signals that are combined with a weighted average to form the region prediction. This type of slice can only be decoded with reference information from the previous and successive I or P frame.

B. *Network Abstraction Layer*

If the VCL is the interface between the encoder and the actual video frames, the Network Abstraction Layer (NAL) is the interface between that encoder and the actual network protocol, which will be used to transmit the encoded bit-stream. The NAL encoder encapsulates the slice output of the VCL encoder into Network Abstraction Layer Units (NALU), which are suitable for transmission over packet networks or used in packet oriented multiplex environments [8]. In order to generate proper NAL units, we must pre-define the network protocol that we want to use to transmit the video bit-stream. H.264/AVC and SVC support encapsulating VCL slices into a number of network protocols (H.320, MPEG-2, and RTP...) [9], in which RTP is mostly used because of its popularity. SVC extended the H.264/AVC standard by providing scalability. 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 strict requirement for a bit-stream to be called temporally scalable is that, when we remove all access units of all temporal enhancement layers with a temporal layer identifier higher than k ($1 < k <$ maxlayer), then the remaining layers still form a valid bit-stream for a SVC decoder (when k=1, then we have a base layer 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. However, among layers, inter-layer prediction mechanisms are applied to improve the coding efficiency and rate-distortion efficiency by using as much lower layer's information as possible. Lower layer pictures do not need to be present in all access units making it possible to combine spatial and temporal scalability.
- 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. In CGS, inter-layer prediction is also used. A higher quantization step size will be provided by the enhancement layers to provide a better quality for the lower layers. However, this multi-layer concept for quality scalable coding only supports a few selected bit rates in a scalable bit stream. In general, the number of supported rate points is identical to the number of layers. Switching between different CGS layers can only be done at defined points in the bit stream. Furthermore, the multi-layer concept for quality scalable coding becomes less efficient, when the

relative rate difference between successive CGS layers gets smaller. MGS provides a better coding efficiency for bit-streams that have to provide a variety of bit-rates. With MGS, any enhancement layer NAL unit can be discarded from a quality scalable bit stream and thus packet-based quality scalable coding is provided. Fine-grain quality scalable (FGS) provides a coding prediction structure mechanism that completely omits drift (the motion-compensated prediction loops at encoders and decoders are not synchronized because quality refinement packets are discarded from a bit-stream).

- Combined scalability: In some cases, quality, spatial, and temporal scalability can be combined.

III. CROSS-LAYER DESIGN TO EXPLOIT SVC EXTENSION

In this section we introduce the proposed concept of utilizing the SVC frame priority for power adaptation at the physical layer.. 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 SVC NALU header is being presented in the following figure:

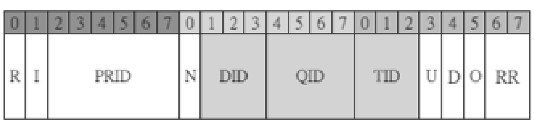

Figure 1. SVC NALU's header

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 [8].

This proposal is essentially a cross-layer mechanism involving the application and physical layers. Many cross-layer design proposals can be found in the literature (Figure 2). 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.

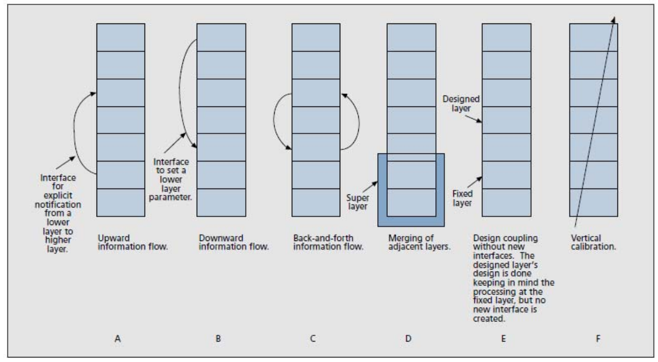

Figure 2 Illustrating the different kinds of cross-layer design proposals. The rectangular boxes represent the protocol layers [18].

We note that the layered architecture can be bypassed in the following basic ways according to Srivastava et al. [18]:

- Creation of new interfaces. Several cross-layer designs require the creation of new interfaces between layers. The new interfaces are used for information sharing between the layers at run time.
- Merging of adjacent layers. Another way to do cross-layer design is to design two or more adjacent layers together such that the service provided by the new superlayer is the union of the services provided by the constituent layers.
- Design coupling without new interfaces. Another category of cross-layer design involves coupling two or more layers at design time without creating any extra interfaces for information sharing at run time.
- Vertical calibration across layers. The final category in which cross-layer design proposals in the literature fit is what we call vertical calibration across layers. As the name suggests, this refers to adjusting parameters that span across layers.

The cross-layer design approach in this paper is categorized in the 'Creation of new interfaces' category for cross-layer proposals, which was introduced above. The reason that this cross-layer approach is used is that, as has been extensively argued in the literature, although layered architectures have served well for wired networks, they are not suitable for wireless networks. There are three main reasons for this: 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. Another example is, for instance, if the end-to-end TCP path contains a wireless link, errors on the wireless link can trick the TCP sender into making erroneous inferences about the congestion in the network, and as a result the performance deteriorates. Creating interfaces from the lower layers to the transport layer to enable explicit notifications alleviates such situations. For example, the explicit congestion notification (ECN) from the router to the transport layer at the TCP sender can explicitly tell the TCP sender if there is congestion in the network to enable it to differentiate between errors on the wireless link and network congestion [19].

The proposed cross-layer design creates an interface from the application layer to the physical layer, by taking into consideration the priority information (Figure 1) 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. Our cross-layer design is presented below:

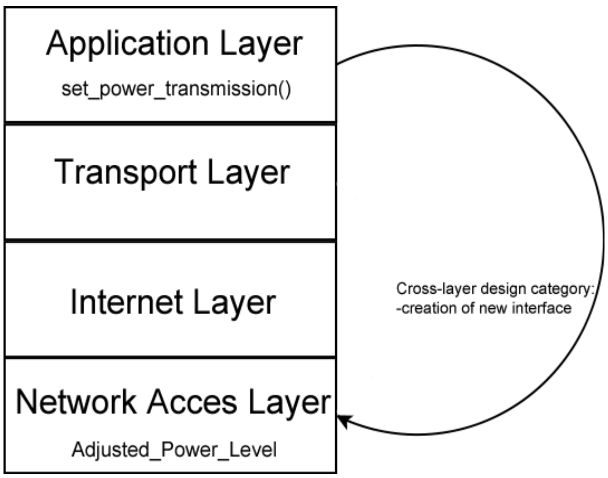

Figure 3. Proposed cross-layer design

As we can see from Figure 3 our cross-layer design belongs in the cross-layer category, creation of new interface, since the transmission power cannot be adjusted in the application layer and we need to create a new interface between these two layers.

IV. MECHANISM ARCHITECTURE

The target of the mechanism presented in this section is to minimize or eliminate packet losses, especially on important packets for the decoding process, since even a small packet loss rate can result in important reduction of multimedia quality for the end-user and result in a bad end-user experience. We aim for improved media parameters such as peak signal-to-noise ratio (PSNR) and mean opinion score (MOS), 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 in noticeably improved video quality. A new interface has been provided to the application layer in order to set the power transmission accordingly.

A NAL unit comprises of a header and a payload. PRID (priority ID) specifies a priority identifier for the NALU. We therefore 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 pseudocode 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 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.

Firstly 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 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. The procedure described above is presented in a flow chart in the figure below.

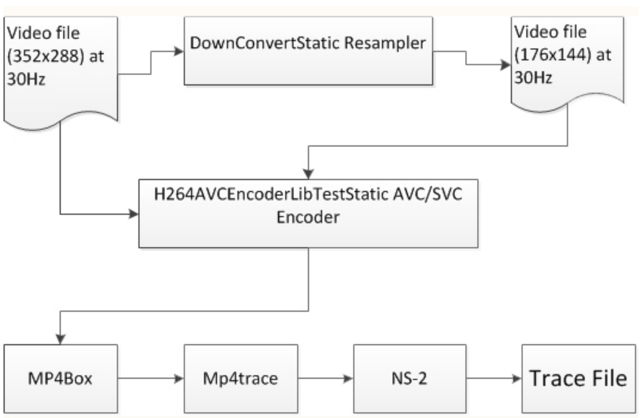

Figure 4. Simulation procedure

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 mechanism. Firstly, a module that implements the logic of the proposed mechanism was added in the simulator. The mechanism sets 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.

The mechanism runs 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. Since priority info can be retrieved only one more modification is needed in order to set the transmission power of the packet at the physical layer for improved end-user experience. We inserted the appropriate methods in order to create the cross-layer design described in section III, thus having the ability to set transmission power according to the needs of the application.

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. The MOS scores reported below are derived from the automatic PSNR to MOS mapping according to the following table.

TABLE I. ITU-R QUALITY AND IMPAIRED SCALE [4] AND POSSIBLE PSNR TO MOS MAPPING [5]

PSNR [dB]	**Subjective Metrics**	
	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. EXPERIMENTS AND RESULTS

In our ns-2 experiments, we transfer H.264, in particular SVC extension, video over UDP over a wireless link 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.

We then compare the achieved throughput in terms of PSNR and power consumption. Objective PSNR measurements can be approximately matched to subjective MOS (Mean Opinion Score) according to the standardized Table 1. The simulation environment consists of three parts and is depicted in Figure 5.

Figure 5. Topology in experiments

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 II. EXPERIMENTS WITH STATIONARY NODES

Measurement	Nalu mechanism	Without mechanism
PSNR average	32.76	31.81
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 III. 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 IV. 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 V. 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 VI. 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 VII. EXPERIMENTS WITH ONE NODE MOVING AWAY AND THEN STOPS MOVING

Measurement	Nalu mechanism	Without mechanism
PSNR average	28.59	26.23
Energy Consumption	0.272W	0.28W
MOS	Fair(3)	Fair(3)

Since the node is moving away our mechanism increases power and therefore results in an overall PSNR to power ratio higher than the transmission without any mechanism.

TABLE VIII. 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 6, 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.

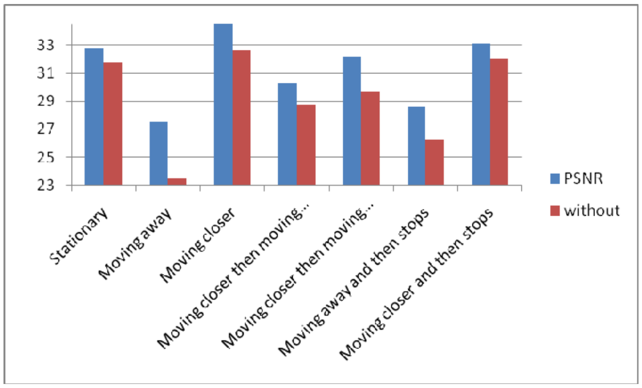

Figure 6. Test results

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.

VII. CONCLUSIONS AND FUTURE WORK

From our results we concluded that using a cross-layer technique exploiting information from the application layer for optimizing power management yields higher PSNR values than using any of the other coverage schemes described in this paper. We have seen that by inserting a simple cross-layer exploitation mechanism for power management in wireless UDP transmission, we can improve the objective quality of the transmitted video. The complexity cost of the mechanism is quite small, and slightly larger power consumption in measurements seems to be the only remaining trade-off.

The proposed cross-layer mechanism could be further improved in a wide range of ways. Firstly, we could estimate power consumption by taking into account both power consumption for the computational complexity of encoding and the power consumption for the transmission. The most interesting aspect though is to create a rate adaptive mechanism. In the future the current mechanism could be extended to support temporal, snr and combined scalability. Furthermore power adaptation mechanisms could be implemented, in wireless scenarios, in order to minimize or eliminate packet losses, since even a small packet loss rate can result in an important reduction of multimedia quality for the end-user and result in a bad end-user experience.

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

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