Simulating MPEG-2 Transport Stream Transmission over Wireless ATM

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ABSTRACT

Within this paper we simulate the transmission of MPEG-2 Transport Stream (TS) Packets over a wireless ATM network. Based on a finite state radio channel model for the physical layer of a wireless ATM link including the characteristics of the ATM and MAC layer, different packing schemes are evaluated for encapsulating MPEG-2 Transport Stream packets in ATM Adaptation Layer 5 (AAL5) PDUs. We analyze the performance with respect to both delay and visual quality in terms of PSNR based on a calculated cell error ratio (CER) for each given state of the radio model. The statistics show, that the 1TP (one MPEG-2 TS per AAL5 PDU) scheme outperforms all other packing schemes in terms of visual quality. At medium channel quality (38 dB), quality is judged to be good, although the CER may be as high as 25 %.

1. INTRODUCTION

MPEG-2 is the emerging industry standard for high quality video and audio compression applicable both to Video on Demand (VoD) scenarios and high quality real-time conferences based on specialized hardware. Spatial as well as temporal redundancy is exploited to provide compression ratios up to 200:1. Different profiles and levels can be used to provide different quality levels ranging from standard MPEG-1 up to HDTV quality. The MPEG-2 standard defines two ways for multiplexing different elementary stream types (audio, video or private like subtitles) to form a program: the MPEG-2 Program Stream Format and the MPEG-2 Transport Stream (TS) Format [10]. Transport streams consist of multiplexed streams which do not have a common time base, whereas program streams do have such a common time base. Additionally, transport streams are made of fixed length (188 bytes) packets which simplifies efficient error detection and recovery techniques.

Wireless ATM combines broadband communication, scalability and guaranteed Quality of Service (QoS) with mobility and extends the ATM-concept onto the wireless link. The Magic WAND system [8] provides seamless integration of the wireless access facility into the fixed ATM network emphasizing a combination of high bandwidth, low delay and guaranteed QoS. This is achieved by using the 5.2 GHz band and providing different connection types according to the ATM concept with available bandwidth up to 20 Mbit/s. Mobility is supported by building a scalable architecture based on Access Points and Mobile Terminals. Therefore, wireless ATM provide a good basis for high quality video transmission. However, the wireless transmission link is not error free and several mechanisms are build into the WAND system to cope with transmission errors. Nevertheless, an error free channel cannot be guaranteed and it is of major importance to study the effects of errors on the visual quality given the characteristics of the wireless ATM link and the special behavior of MPEG-2 transport stream de-multiplexing and decoding.

This paper is organized as follows. In Section 2 we discuss different packing schemes and AAL alternatives for MPEG-2 TS encapsulation and introduce our simulation setup. In Section 3 we then analyze the results of our simulations. Finally we summarize our major findings and outline future work.

2. MPEG-2 TRANSPORT STREAM TRANSMISSION

The MPEG-2 TS was designed for transporting MPEG-2 over noisy environment. Synchronization and continuity is assured by inserting timestamps (PCRs, Program Clock References), which also facilitates clock recovery at the decoder. The first four byte (header) of a MPEG-2 TS packet start with a unique sync-byte (0x47). The packet identifier (PID) determines, to which program a TS packet belongs to. The PID is unique for each program. The transport error indicator (TEI) can be used to notify the decoder about possible errors so that error concealment techniques can be employed. The payload contains the actual audio, video or data for the MPEG-2 decoder to be used. When transmitting MPEG-2 TS over ATM, several issues must be addressed [1] like the choice of an adequate AAL, the encapsulation of MPEG-2 TS packets in AAL5 packets, the impact of different scheduling methods within the ATM network for controlling delay and jitter, and error concealment techniques at the decoder to cope with packet loss.

Basically, several methods exist how to transmit MPEG-2 TS packets over networks based on ATM. Real-time applications like video conferences or Video-on Demand (VoD) impose stringent requirements on the overall end-to-end delay and can tolerate some information loss. The most effective way to transmit MPEG-2 TS over ATM is to use directly a suitable AAL.

2.1 ATM Adaptation Layer Alternatives

Currently, four different types of AAL are defined: AAL1, AAL2, AAL3/4 and AAL5 offering different types of functionality. Each AAL is divided into two sublayers: the Segmentation and Reassembly (SAR) sublayer, which segments outgoing user data into ATM cells and reassembles incoming ATM cells into Protocol Data Units (PDUs) and a Convergence Sublayer (CS). When transmitting MPEG-2 TS over wireless ATM, the special characteristics of MPEG-2 TS with respect to error detection and correction, support for CBR or VBR connections, jitter issues and end-to-end delay for real-time scenarios have to be considered and two main candidates can be identified: AAL1 and AAL5 (AAL2 is not yet completed, whereas AAL3/4 functionality has been replaced by AAL5).

When analyzing the networks impact on the overall delay, AAL1 seems to be an ideal candidate for CBR connections. Several dejittering mechanisms at the receiver lead to a nearly constant delay, because the original clock timing can be regenerated at the receiver. Missing cells can be detected and an MPEG-2 TS demultiplexer can set the TEI bit for the decoder to use error-concealment techniques. The additional overhead bytes in AAL5 can be used to provide forward error correction (FEC). However, AAL1 does not support VBR MPEG-2 TS which will become more important in the future. Furthermore, signaling in the network is based on AAL5, so a NIC has to provide both AALs. Additionally, MPEG-2 maintains its own clock recovery mechanisms, so jitter removal at AAL level (typically performed ba a phase locked loop, PLL) is redundant [5].

The most studied AAL for MPEG-2 over ATM is AAL5 [1], [6], [9] which is also the recommendation of the ATMForum (specifically, two MPEG-2 TS should be encapsulated in a single AAL5 PDU). Several advantages make AAL5 the first choice: almost all NIC manufacturers provide drivers for AAL5, AAL5 supports variable length PDUs, it supports VBR traffic making it suitable for VBR MPEG-2 TS. However, there is no support for removing jitter in AAL5 ([1]) because no timing information is included. Furthermore, if an AAL5 PDU is lost or corrupted, there is no way to recover it in contrast to AAL1 with FEC possibility. AAL5 can detect errors due to a CRC field but an erroneous AAL5 PDU is discarded. So if more than one MPEG-2 TS are encapsulated in a single AAL5 PDU and the AAL5 PDU is corrupted or lost, all MPEG-2 TS packet contained in the AAL5 PDU are lost, which might have severe impact on the visual quality of the decoded video or audio data. These problems might be alleviated by better clock recovery mechanisms build into the MPEG-2 decoders. For the second disadvantage, there is a proposal to turn of the AAL5 error-detection discard scheme [3] so that if the CRC inside the AAL5 determines an error, the payload is not discarded but forwarded to the MPEG-2 multiplexer.

2.2 Packing Scheme Alternatives

Several issues arise, when packing MPEG-2 TS packets in AAL5 PDUs and varying the number of TS packets per AAL5 PDU. Additionally, there are different options on how to align the TS packets inside the PDU (i.e. to use padding between the single TS packets or to use padding at the end of the last TS packet in case the last ATM cell is not filled. For example, if each TS packet is encapsulated in a distinct AAL5 PDU, then five ATM cells are needed at the ATM layer and the last cell is only partially filled. From the point of efficiency, encapsulating $2+12k$, $k=0,...$ TS packets in a single AAL5 PDU results in the last cell of the PDU being filled up, all other combinations result in partially filled last cells. Here, we only consider the so called nTP-Tight schemes [6], where all n MPEG-2 TS packets are packed in one AAL5 PDU directly. The efficiency of the packing scheme calculates to

$$N_{nTP-Tight} = \frac{Sys \times n}{\left\lceil \frac{n \times 188 + 8}{48} \right\rceil \times 53}$$

at MPEG-2 system level (Sys = 184) or at AAL 5 level (Sys = 188) and includes 4 Byte TS header, 8 Byte AAL5 trailer and 5 Byte ATM cell header. The additional buffer for holding the AAL5 payload calculates to $n \times 188 + 8$ bytes.

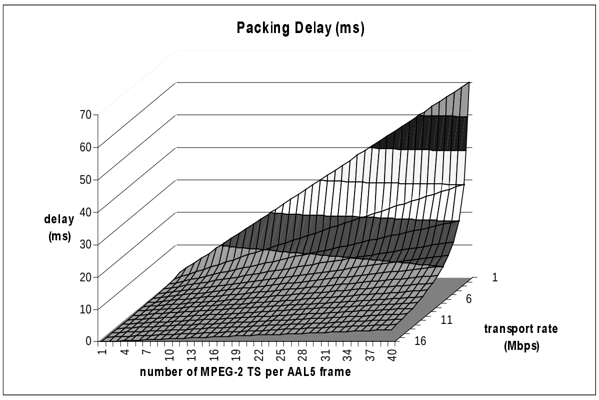

Figure 1. Packing delay vs. number of MPEG-2 TS packets and transport rate of the MPEG-2 TS

As can be seen from Figure 1, the additional packing delay depends on the number of MPEG-2 TS packets encapsulated and on the transport rate. It varies from 1 ms (for 16 Mbps transport stream rate and one MPEG-2 TS per AAL5 PDU) up to 60 ms (1 Mbps, 40 TS per AAL5 PDU). The more TS packets are carried inside a single AAL5 PDU, the more efficient the packing scheme is, but the more packing delay is introduced and the more TS packets a bit error affects.

2.3 Simulation Setup

Based on the WAND system different sources of influence like fluctuations or different transceiver and the indoor environment are combined to form a Stochastic Radio Channel Model (SRCM). The model describes a mobile terminal moving around an access point at fixed distance with a velocity of 1 m/s. The carrier frequency was 5.2 GHz. The mean number of paths was set to 8 with a random distribution. The standard deviation of the path energy was 2.0 allowing to model the shadowing effects. A delay spread of 50 ns was adopted for simulating a typical indoor environment. Time variant multi-path propagation was taken into account for modeling of fast and slow fading (shadowing) and it was assumed that there was no path loss [1].

The signal power of the continuous state model was discretized [7] in order to generate a Finite State Radio Channel Model (FSRCM). A semi-Markov process is used to describe the time-variant behavior of the SNR at the receiver side. A relationship between the SNR and the BER or the CER can be found by applying the OFDM (Orthogonal Frequency Division Multiplexing) coding scheme for the WAND radio modem. The last step is to use a model of the WAND MAC protocol to get the AAL5 PDU loss rate and distribution based on the semi-Markov process, which defines the FSRCM. Each state (based on a radio SNR) then corresponds to a certain BER or CER resulting in a certain AAL5 PDU loss rate. The mean state holding time equals 13 ms. We base our simulations directly on the BER/CER calculated from this model. We can then interpret the results of our simulations given a channel, which does not tolerate any additional delay, so all the cells send from a mobile terminal to an access point (or vice versa) are not re-transmitted at lower layers in the case of bit-errors at the PHY-layer. Similarly, no forward error correction (FEC) is applied.

We have run simulations based on three different radio conditions: the three set-ups showed a mean radio SNR of (30;38;44) dB corresponding to a distance of (32;21;15) m between the mobile terminal and the access point and a mean CER of ($9.85x10^{-2}$; $9.5x10^{-3}$; $8x10^{-4}$). Momentarily high CER values of (0.89; 0.44; 0.041) may persist over longer period of time due to shadowing effects. The transmission of a MPEG-2 TS was simulated based on the test sequence susie_015 at 1.5 mbps The MPEG-2 TS contains only the compressed video data in the format 352x288 at 25 fps.

3. SIMULATION RESULTS

When MPEG-2 TS are encapsulated using different packing schemes, the 8-byte AAL5 trailer inserted by the network card contains a cyclic redundancy check (CRC) and length information at the end of the PDU, which is then segmented into ATM cells. The radio model calculates for each state a CER and drops the whole AAL5 PDU (and therefore all *n* TS packets encapsulated) in case of errors. The receiver then reassembles all cells of the PDU to form a TS train of *n* (possibly corrupted) TS packets, which are then forwarded to the demultiplexer and decoder. The typical behavior of AAL5 is to drop a whole AAL5 PDU in case of a CRC error. Single bit errors in the ATM header are correctable. For real-time conferencing scenarios, a re-transmission of a corrupted AAL5 PDU is impossible, so it is interesting to see, how a decoder reacts on receiving either only parts of TS packets or erroneous TS packets.

The quality of the 44 dB sequence was very good, whereas the 38 dB sequence was acceptable. Errors over longer period of time very visible for the 30 dB simulation. Figure 2 shows frame 84 for the 30 dB and 38 dB run. Clearly, the better radio channel showed better performance The errors are localized to macroblock level due to the MPEG-2 video coding behavior. The same frame for the 44 dB run was almost perfect. During our runs we found all kind of errors especially in the 30 dB case: motion jerkiness, frame freezing, color cycling, error blocks and tiling or pixelation.

Figure 3 shows the average loss ratio based on transport packet statistics and on frame statistics. A cell loss results in the loss of a whole AAL5 frame and thus in a loss of *n* TS packets depending on the packing scheme. The MPEG-2 demultiplexer has no knowledge about frames. This information is available only at elementary stream (ES) level. In case the AAL5 PDU contains TS packets which include a frame header at ES level, the whole frame is lost by a decoder and error concealment techniques are necessary. A simple technique would then replace the current (corrupted) frame by the previous frame. A more intelligent decoder system would replace at macroblock level and use temporal, spatial or frequency concealment techniques.

Figure 2. Frame number 84 obtained from the simulation runs for the 2 TS scheme (left: 30 db, right: 38 dB)

Figure 4 presents the PSNR curves for the 1-, 2- and 8 TP schemes based on the CER for the 38 dB radio model. It can be seen that the image quality decreases as the radio channel quality decreases. The PSNR curves are based on the luminance channel and show that in general the 1-TS scheme is the best. However, no significant difference is noticeable, because the scenes are played at 25 fps. In some situations, the 2 TS scheme shows better visual quality than the 1 TS scheme, whereas in other situations the 8 TS scheme is better than the 2 and 1 TS scheme. This depends on the wireless channel characteristics. The more TS packets are encapsulated and no errors occur the better the quality. But if errors occur more frequently, encapsulating less TS packets gives better results. As a consequence, a wireless ATM system could also operate more efficiently and use the 8 TP scheme without sacrificing the quality too much, if the radio quality is good enough. Our simulations showed, that at least 38 dB signal strength are necessary for acceptable video quality, which corresponds to a distance of 21 meters (mobile - access point). Typically, wireless ATM systems operate indoor due to the high frequency and the limited ground speed and 21 meters are still acceptable.

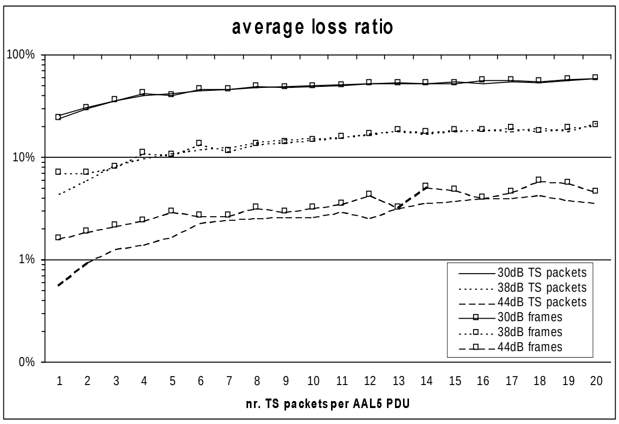

Figure 3. frame loss ratio vs. TS packet loss ratio

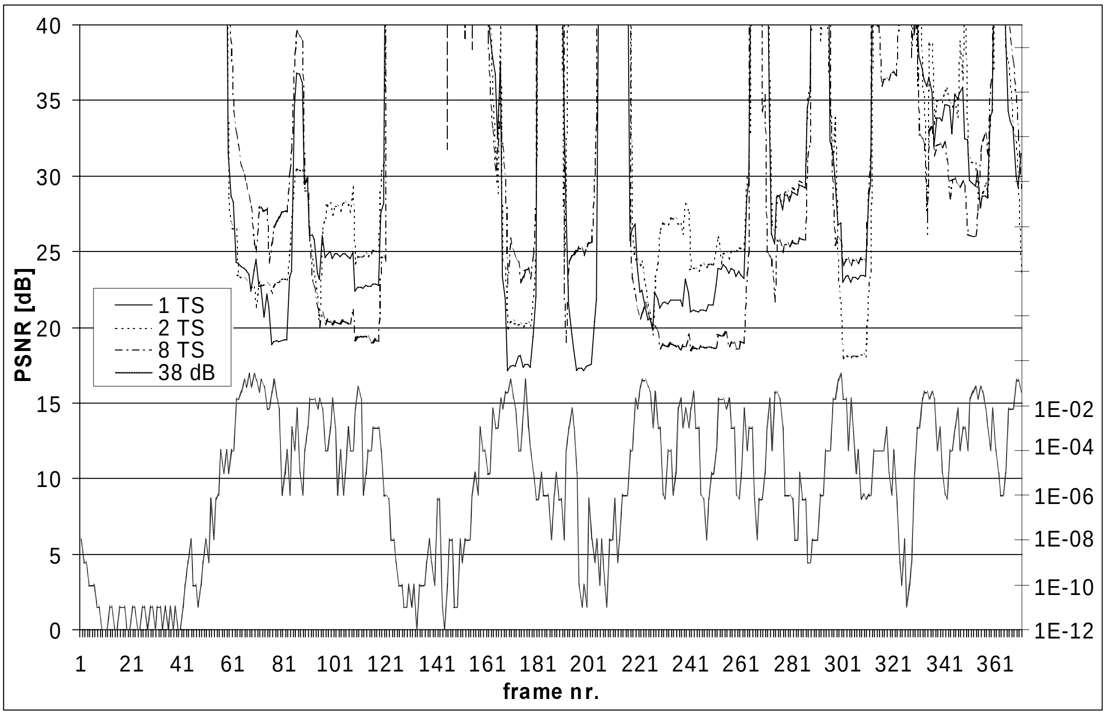

Figure 4. PSNR for different packing schemes based on the 38 dB radio model (CER on right axis)

4. SUMMARY

Within this paper we have studied the effects of cell loss on the video quality given an MPEG-2 Transport Stream. We have simulated the transmission of MPEG-2 TS packets over wireless ATM radio links based on three different radio channel qualities corresponding to a distance (mobile - base station) of 32 m, 21 m and 15 m. We have investigated the suitability of different packing schemes varying the number of MPEG-2 TS packets encapsulated in a single AAL5 PDU. Generally, the less MPEG-2 TS packets are encapsulated, the shorter the AAL5 PDU, the higher the probability that the TS packets are not lost and the higher the video quality. The frame loss ratio is well aligned with the probability of losing TS packets. At a radio quality of 38 dB corresponding to a distance of 21 m, the MPEG-2 video quality at the decoder was judged to be acceptable.

Based on the results of our simulations we conclude that it is necessary to incorporate error concealment techniques into a MPEG-2 TS decoder. If CER are high, a scalable MPEG-2 TS would further improve the performance. The base layer then contains the vital information and the enhancement layer adds detail. Furthermore a wireless Data Link Control layer (WDLC) below the ATM layer would further improve the performance. Depending on the tolerated end-to-end delay, the WDLC could use FEC or retransmit the corrupted cell based on a Go-Back N ARQ scheme.

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