# Comparison and Evaluation of Packing Schemes for MPEG-2 over ATM using AAL5

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## Abstract

Due to the technological advances in video/audio compression and networking, residential broadband services can be supported by carrying MPEG-2 streams over ATM networks as the ATM-to-the-home (ATTH) architecture. Two packing schemes, the 2/2 and 1/2 schemes, have been proposed to constitute AAL5-PDUs from MPEG-2 transport packets at ATM adaptation layer (AAL). In this paper, we compare the two packing schemes in several aspects including packing jitter introduced at the AAL and respective implementation costs. We suggest three possible modifications (enhancements) of the 2/2 scheme which eliminate packing delay and have relatively low cost and complexity versus the 1/2 scheme. We also examine the possible queueing jitter occuring at the ATM layer. It is shown that in the worst case the 1/2 scheme produces significant queueing jitter as compared to the packing jitter it saves in the AAL while no queueing jitter is caused by either the basic or modified (enhanced) 2/2 schemes.

*Key words: AAL5 Encapsulation, Buffer Budget, Jitter, MPEG-2 Transport Packets, Packing Schemes, Time Recovery*

## 1 Introduction

Today's residential broadband services are supported by separate networks including cable and telephone networks with limited interactive capabilities [4]. Among many alternatives, ATM technology is acknowledged as the most promising solution to provide the residential services with a single integrated network due to its flexibility. Moreover, standard bodies and industrial forums are currently very active in defining how to use ATM platforms for various applications/services, including, carrying CBR MPEG-2 transport streams over ATM networks. For example, the ATM Forum recently determined on relative issues regarding transfering CBR MPEG-2 transport streams over ATM networks for VOD applications. Note that although ATM can support both constant bit rate (CBR) and variable bit rate (VBR) MPEG-2 streams over an integrated network, carrying VBR MPEG-2 over ATM networks entails several problems such as clock recovery, jitter removal, and resource management which are not addressed yet. Therefore, currently only CBR MPEG-2 services are considered. In this paper, all MPEG-2 streams are assumed to be CBR if not explicitly stated otherwise.

In general, MPEG-2 streams require lossless connections with constant end-to-end delay. On the other hand, ATM networks may introduce cell delay variations which can destroy the temporal relationship within an MPEG-2 stream. Therefore, some functions must be added to the AAL and/or higher layers to accommodate cell delay variation and clock drift between source and destination. As will explained in Section 2, the PCR-PLL approach is currently implemented at the transport layer to solve these two problems – delay jitter and clock drift.

In the ATM adaptation layer, AAL5 is selected by the ATM Forum to produce PDUs from MPEG-2 transport packets. The reasons for this selection are

- The wide acceptance of AAL5 from both the computer and telecommunication industries,
- No requirement for extra hardware,
- (Possibly) Easy extension to support VBR MPEG-2 transport,
- Effective error handling [2].

Two possible packing schemes have been considered for creating AAL5-PDUs from MPEG-2 transport packets. These two approaches are well-known as the 2/2 and 1/2 schemes, respectively. As pointed out in [6], the 2/2 scheme introduces packing jitter that costs more buffer space due to timing recovery at the destination. Therefore, the 2/2 scheme could cause discontinuous playback if the destination has a tight buffer budget. On the other hand, the 1/2 scheme reduces the packing jitter at the cost of higher system complexity [3, 5].

This paper is organized as follows: In Section 2, we briefly explain the two packing schemes. In Section 3, several possible modifications (enhancements) of the basic 2/2 scheme are examined. We demonstrate the performance of these modified (enhanced) 2/2 schemes through simulation. Moreover, we show that the basic packing scheme performs well in certain scenarios. In Section 4, we analyze how these two packing schemes affect the queueing jitter at the multiplexer of the ATM layer of the source. Finally, we conclude the paper in Section 5.

## 2 Packing Schemes

In this section, we introduce the system model and two basic packing schemes. As shown in Figure 1, the encoder at the transport layer of the source generates CBR MPEG-2 transport packets and sends them to the AAL. The encoder is also responsible for inserting 44-bit program clock references (PCRs) into the MPEG-2 transport packets periodically. Each transport packet is 188 bytes in size. The MPEG-2 transport packets generated by the encoder are packed into PDUs in the AAL. Depending on which packing method is used, the following results:

Using the 2/2 packing scheme produces an AAL5-PDU every 2 transport packets, regardless of the locations of PCR-

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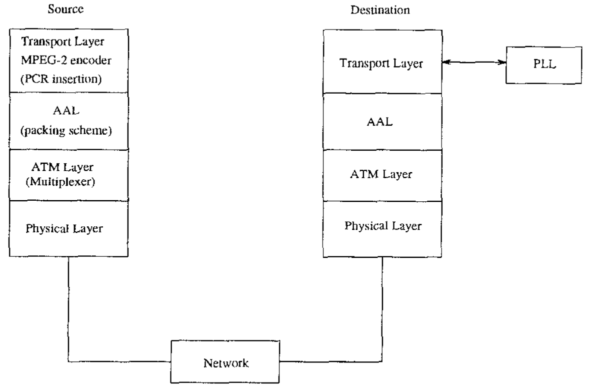

Figure 1: System Model.

bearing transport packets. In addition to two transport packets, each PDU consists of an 8-byte trailer. Therefore, the size of all AAL5-PDUs is 384 bytes if the 2/2 scheme is used. Alternatively, the 1/2 packing scheme could be utilized which ensures that PCR-bearing transport packets are always the last packet of the PDU. In other words, if the first transport packet carries a PCR, then the AAL makes that packet a PDU by itself with a 44-byte padding and an 8-byte trailer. So, the size of an AAL5-PDU could be either 384 or 240 bytes depending on the locations of PCR-bearing transport packets.

Note that the 2/2 scheme may introduce additional jitter as shown in [6] because the PCR-bearing transport packets sometimes wait at the AAL for PDU packing while the 1/2 scheme reduces this jitter at the cost of slightly decreased bandwidth efficiency due to the 44-byte padding. Regardless of the packing scheme used, the AAL5-PDUs are then sent to the ATM layer where they are segmented into cells consisting of a 48-byte payload and a 5-byte header.

To model the ATM layer multiplexing, we assume the cells are scheduled for transmission using a first-come-first-served scheduling discipline. This is a reasonable assumption given the nature of the source traffic is CBR. There is no statistical variation in the aggregated input traffic to cause queueing delay jitter. If the input traffic is VBR, then a first-come-first-served assumption would not be valid. In that case new or more complex scheduling disciplines are needed.

The cells sent to the physical layer by the multiplexer are received by the ATM layer at the destination. The ATM layer removes the headers from these cells and sends them to the AAL which assembles the cells into PDUs. Upon reassembly, the packets are sent to the transport layer. At the transport layer, a demultiplexer is used to parse out PCRs for input to a phase lock loop (PLL) where MPEG-level timing recovery occurs. The PLL operates through detection of the phase errors between the values of its local counter and the PCR values recovered from the incoming MPEG-2 transport packets in the transport layer. The PLL uses the detected errors to adjust the frequency of its local clock to match that of the source clock.

# 3 Modifications of the 2/2 Scheme

As mentioned above, since the 2/2 scheme can present packing jitter, it requires a longer time for the PLL to lock onto the source's clock. Therefore, the receiver could require slightly more buffer to compensate. In order to avoid this additional requirement, we suggest three possible modifications using the 2/2 schemes in Section 3.1 to 3.3 and identify their performance in Section 3.4.

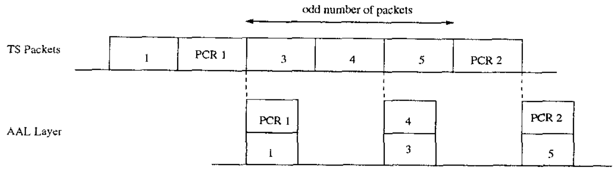

Figure 2: Case 1.

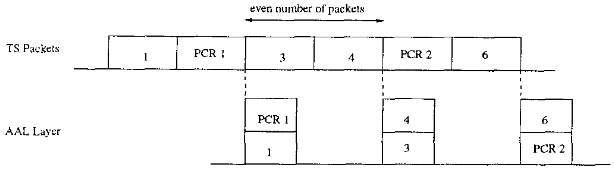

Figure 3: Case 2

## 3.1 Control of PCR-bearing Packet Generation

The first modification considered is to control the generation of the PCR-bearing packets. Based on the value of the bit rate of transport stream and the PCR transmission frequency, we observe that the following three cases with respect to the position of PCRs within the transport stream may occur.

- **Case 1:** The number of packets between two PCR-bearing packets is odd. In this case, all PCR-bearing packets will always be odd numbered or even numbered as shown in Figure 2.
- **Case 2:** The number of packets between two PCR-bearing packets is even. Subsequent PCR-bearing packets will have alternating (odd-even) indices as shown in Figure 3. In this case, the receiver can compute the deterministic delay jitter.
- **Case 3:** Based on the typical PCR frequency values, we will encounter case (i) or (ii). Rarely, following an odd (even) period, the number of packets may be even (odd). Although the frequency of this event is deterministic, this case is not desired.

## 3.2 Destination Packet Delay

The additional packing delay only occurs when the PCR is in the first transport packet because, in this case, the PCR packet needs to wait for the second packet to constitute a PDU. Therefore, if we can compensate for this additional packing delay at the destination by letting the second packet wait at the AAL until the first packet is transferred to the transport layer, there will be no jitter due to packing.

## 3.3 PLL Enhancement

Since the PLL is implemented at the transport layer at the destination, it is possible for the PLL to know that a PCR-bearing packet is from the first transport packet or the second one in an AAL5-PDU. If the PCR is in the first packet, the PLL can substract a deterministic term from its local counter to compensate for the packing delay at the source. Hence, the jitter can be eliminated.

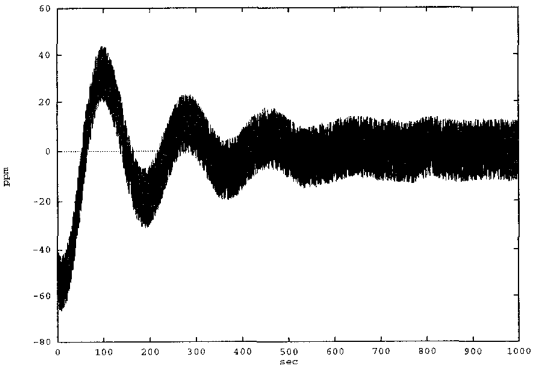

Figure 4: Frequency Error for Basic 2/2 Packing (R= 1.536)

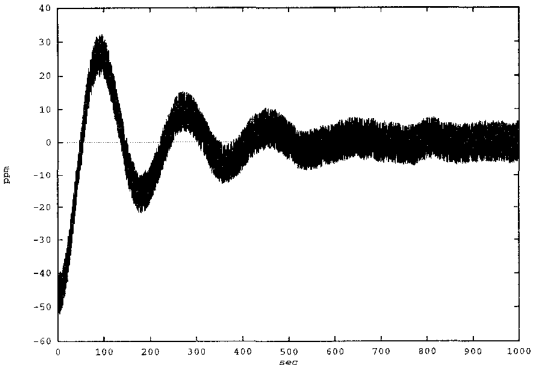

Figure 5: Frequency Error for Enhanced 2/2 Packing (R= 1.536)

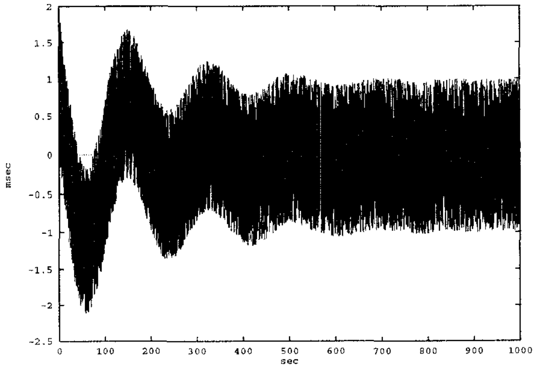

Figure 6: Phase Error for Basic 2/2 Packing (R= 1.536)

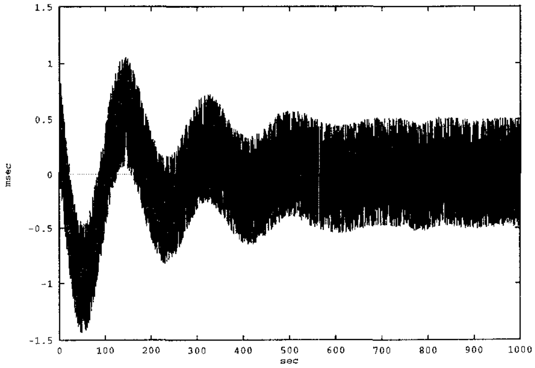

Figure 7: Phase Error for Enhanced 2/2 Packing (R= 1.536)

## 3.4 Experimental Results

The first method in Section 3.1, the control of PCR-bearing packets, is an encoding implementation requirement for material provided by a VOD (Video-on-Demand) server which may also represent a relatively significant change to current encoder designs. The other two methods identified in Sections 3.2 and 3.3 represent components of potential set-top implementation options. Beyond this implementation difference, all proposed methods perform the same, i.e., all of them eliminate packing jitter introduced in the basic 2/2 scheme.

In this subsection we identify the performance of the three enhanced 2/2 schemes and compare them to the basic scheme. Our experimental scenario is very similar to the one in [6]. We assume that the initial clock drift in the receiver PLL is 40 ppm and the maximum peak-to-peak network delay jitter is 1 ms. The rate of the transport stream packets is $R = 1.536$ Mb/s. PCRs are sent periodically with a period of 100 msec. For the original 2/2 scheme, packing delay is equal to one transport stream packet time which is approximately 1 msec at the above rate. We assume that the network jitter is distributed uniformly between 0 and 1.

In the experiments, delay compensation is used at the receiver. If a PCR value arrives at the destination during the odd numbered TS packet, one packet time delay is added into the PCR value, as if it had been placed into the next even numbered TS packet.

Figures 4, 5, 6 and 7 show the frequency and phase errors for the basic and the enhanced 2/2 schemes, respectively. We note that the performance of the enhanced scheme becomes the same as the 1/2 scheme performance. However, we find the basic 2/2 scheme performs well in some scenarios. For example, in Figures 8 and 9 we show the phase errors for the basic and enhanced 2/2 schemes given the same simulation parameters except that the rate of the transport packets increases to $R = 4$ Mb/s. Note that their performance is almost identical. The reasons for this phenomenon are explained as follows.

The first reason is the decreased packet time. Since the packing jitter is equal to one packet time for the basic 2/2 scheme, the packing jitter becomes smaller if the packet rate increases. In particular, when compared to the network jitter which remains the same regardless of the packet rate, the packing jitter could be less significant for high packet rates. For instance, given the 4 Mb/s packet rate, a packet time is 0.376 msec.

The second reason is that the packing jitter does not occur frequently. Let us denote the PCR period, e.g., the 100 msec used in the simulation, and the packet time by $T_{PCR}$ and $T_p$, respectively. As shown in Figure 10, there exists a difference between PCR values and their associated packet boundaries. These differences are multiples of a constant, denoted by $\alpha$, from PCR 2 to PCR 24. The constant $\alpha$ can be computed by

$$\alpha = \lceil \frac{T_{PCR}}{T_p} \rceil T_p - T_{PCR} \tag{1}$$

As shown in Figure 10, $\alpha = 0.016$ msec for $R = 4$ Mb/s and $T_{PCR} = 100$ msec. By observing Figure 10, we notice that the PCRs are in even-numbered packets (PCR 2-PCR

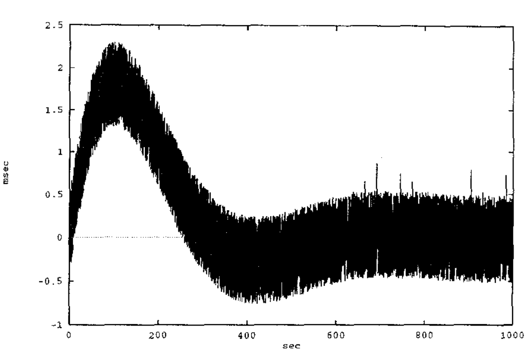

Figure 8: Phase Error for Basic 2/2 Packing (R= 4)

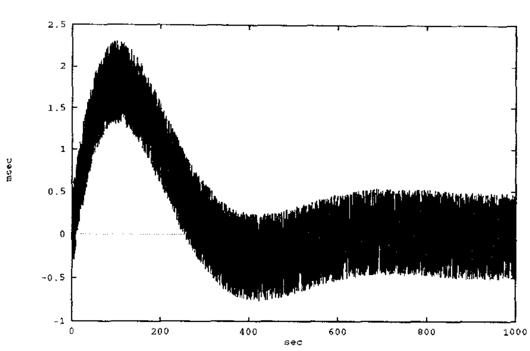

Figure 9: Phase Error for Enhanced 2/2 Packing (R= 4)

24) for a certain period, then they switch to odd-numbered packets, or vice versa. We refer to this behavior of PCRs as a pattern switch. It is clear from Figure 10 that the reason for pattern switch is that the difference between PCR 25 and the boundary of the 6384-th packet, $24\alpha = 0.384$ ms, exceeds one packet time, $T_p = 0.376$ msec. Hence, PCR 25 is in the odd-numbered packet, the 6383-th packet, and the difference between PCR 25 and the boundary of the 6383-th packet is $0.384 - 0.376 = 0.008$ msec. After the pattern switch, this difference, 0.008 msec, will increase by $\alpha$ for each $T_{PCR}$ until it exceeds one packet time and causes the next pattern switch. Note that in the basic 2/2 scheme packing jitter only occurs when pattern switch occurs. We denote $\beta$ as the number of PCRs between pattern switches. $\beta$ is a random number and is bounded by inequality (2).

$$\lfloor \frac{T_p - \alpha}{\alpha} \rfloor \leq \beta \leq \lfloor \frac{T_p}{\alpha} \rfloor \qquad (2)$$

The derivation of inequality (2) is straightforward. As we mentioned, the pattern switch occurs when the difference between PCR values and packet boundaries exceeds one packet time. However, we also need to take into account the initial difference between the first PCR-bearing packet right after a pattern switch and the packet boundary which may vary from time to time. For example, in Figure 10, the initial difference is 0.008 ms for PCR 25 and the boundary of the 6383-th packet. Therefore, the upper bound represents the case that the initial difference is 0. On the other hand, the initial difference must be less than $\alpha$, otherwise the packet is not the first PCR-bearing packet right after a pattern switch. The lower bound for $\beta$ is derived from this constraint.

Due to the increased packet rate and infrequent pattern switch, the basic 2/2 scheme may work well for high packet rate connections. Also, if we select appropriate $T_{PCR}$ such that $\beta$ is maximized, then the basic 2/2 scheme could also work for low packet rate connections.

# 4 Effects of Packing Schemes on Cell Scheduling Performance

Here we present a cell scheduling methodology which can be implemented in the multiplexer located in the VOD server. We also performed simulation experiments to determine the effects of the packing disciplines on the performance of the multiplexer.

## 4.1 Cell Scheduling

ATM networks are capable of multiplexing VBR cell traffic to take advantage of statistical multiplexing. As support for carrying jitter-sensitive VBR traffic within an ATM network has not yet been finalized, the ATM Forum has decided in the near-term to consider CBR cell streams in the ATM layer for MPEG-2 VOD applications. This is now the basis of the AMS Phase 1.0 traffic shaping requirement.

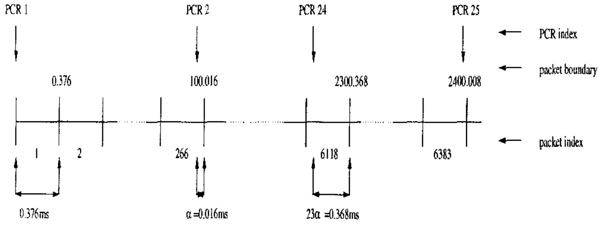

Figure 10: PCRs Pattern Switch

Thus, our scheduling discipline in the multiplexer assumes that the arriving cell streams from individual channels are CBR. When the arrival process to a multiplexer is perfect CBR, the delay jitter due to queueing becomes zero. Individual connections will not experience any delay variation since the aggregate arrival process is periodic. It is possible that cells from different connections can experience different queueing delays, but the delay for the cells of a specific connection remain constant during the lifetime of the connection.

Figures 11 and 12 show the input traffic from a single source for the 1/2 and 2/2 schemes. As it can be seen in Figure 12, the cell stream for the 2/2 scheme is perfect CBR due to the presence of the CBR transport stream and constant size AAL PDU's. On the other hand, when the 1/2 scheme is used the resulting cell stream is not perfect CBR due to the PCR-bearing TS packets being fragmented into 5 cells with 44-byte padding. In the next section, we show the effects of this imperfect CBR stream on the jitter per-

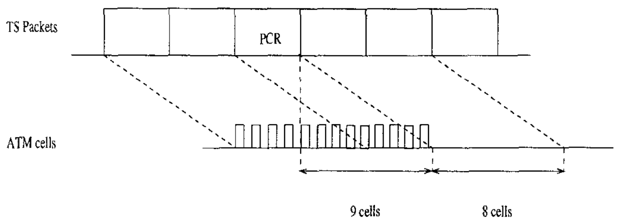

Figure 11: Input Traffic from a Source using 1/2 Scheme

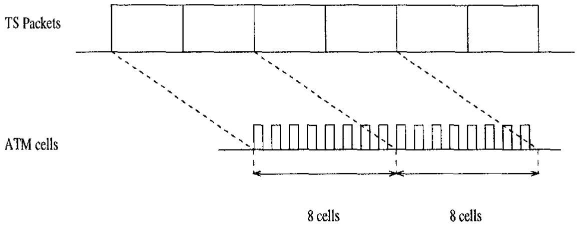

Figure 12: Input Traffic from a Source using 2/2 Scheme

| | Packing Jitter (ms) | Queueing Jitter (ms) |
|---|---|---|
| 1/2 Scheme | 0.280 | 0.237 |
| 2/2 Scheme | 0.959 | 0.0 |
| Enhanced 2/2 Scheme | 0.0 | 0.0 |

Table 1: Packing and queueing jitter for various packing scheme

formance of the multiplexer.

### 4.2 Experimental Results

In this section, we evaluate the jitter characteristics of the 1/2, 2/2 and enhanced 2/2 schemes for a multiplexer with output capacity of 120 Mbps. Input to the multiplexer is 76 MPEG-2 connections with individual TS rates of 1.536 Mbps. In Table 1, we present packing and queueing jitter components individually for different packing schemes.

The worst scheme among the three is the basic 2/2 scheme due to the packing jitter. The enhanced 2/2 scheme is better than the 1/2 scheme. The jitter occurs in the 1/2 scheme when a single transport stream packet is divided into 5 ATM cells.

Note that in the simulations all sources are synchronized, i.e., all sources produce the same number of cells at the same time instant. This is apparently the worst case scenario since the aggregate traffic rate changes abruptly when a PCR-bearing TS packet is sent using 5 ATM cells.

## 5 Conclusion

In this paper, we examined and compared the performance of the 1/2 and 2/2 packing schemes. We identified in Section 3 several enhancements to the basic 2/2 approach that can remove (ideally all of) the packing jitter. Furthermore, we find that the 1/2 scheme introduces some source jitter at the ATM layer. This source jitter is comparable to the packing jitter saved by the 1/2 scheme in the AAL.

On the other hand, no source jitter at the ATM layer is caused by the 2/2 scheme. In addition, the 1/2 scheme increases the bandwidth requirement for each connection by a small fraction due to its stuffing requirement. Though the increment on bandwidth is small per connection, it can represent several hundred kilobits per OC-3 multiplex, depending on the frequency and relative location of PCRs in the transport stream. In conclusion, we think that the 1/2 scheme offers a marginal performance gain in light of its relative complexity versus the 2/2 scheme. Note that the ATM Forum reached a decision to use the 2/2 scheme for packing MPEG-2 streams at AAL5 in its October 1995 meeting [1].

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