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Source: Alexander MacInnis (Chair of MPEG Systems Sub-Group), Sakae Okubo (Rapporteur for Q.2/15 in ITU-T SG15)
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1. Introduction

MPEG Systems, which is Part 1 of MPEG-2 (ISO/IEC 13818) as well as Part 1 of MPEG-1 (ISO/IEC 11172) is the specified coding method and set of constraints for packaging and synchronizing compressed audio and video. It is the result of about four years of intensive work on this subject by a broad representation of companies, and it reflects the realization of the substantial set of real-world problems that need to be solved to combine and transport audio-visual data.

MPEG Systems addresses a significant set of problems which are not addressed either by compression coding of audio or video, nor by communications standards such as ATM or other networks. MPEG-2 Systems was designed with ATM in mind, and the MPEG Transport stream is intended to be carried over ATM where such services are appropriate.

ATM promises to provide widespread essential communications and switching capabilities to homes and businesses, with the ability to carry wide bandwidth real time audio-visual data, as well as other services such as voice telephony and traditional computer data in a flexible way. ATM is expected to provide a powerful and popular mechanism for transporting MPEG and other audio-visual information.

ITU-T SG-15 has recently decided to use a "common text" approach for H.222.0 and MPEG-2 Systems (ISO/IEC 13818-1), meaning that the same document will be used for both. H.222.1 will include additional recommendations for adaptation within ATM applications.

This paper intends to clarify the relationship between the MPEG Systems and ATM with their overviews and techniques to cope with particular characteristics of ATM - cell delay variation.

2. Overview of MPEG Systems

MPEG-2 Systems coding provides a packet and time-stamp based method for multimedia multiplex synchronization and timebase recovery. Each elementary bitstream is segmented into PES Packet (Packetized Elementary Stream), and the respective packets are multiplexed into either a Program Stream or a Transport Stream. PES packets contain the Presentation and Decoding Time Stamps (PTS and DTS), as well as other data fields that are specific to individual elementary streams such as video and audio. The resulting stream also contain clock reference time stamps: Program Clock Reference (PCR) in case of the Transport Stream, or System Clock Reference (SCR) in the case of Program Stream.

MPEG-2 Systems specifies two stream types;

- "Program Stream" which is a multiplex of variable length PES packets and is similar to MPEG-1 Systems in functionality. This is designed for use in error free environments, for compatibility with MPEG-1 Systems, and for relative ease in software processing of the system layer.

- "Transport Stream" which consists of 188 byte fixed length packets and has the functionality of multiplexing multiple programs (typically for broadcasting applications, each program having independent clock reference). This is designed for use in error prone environments.

The MPEG-2 Systems Transport Stream definition ("Transport") is designed to maximize interoperability of multi-vendor digital audio-video terminals, while providing robust operation in a variety of environments. It is optimized for real-time communications of audio-visual data in environments in which bit errors and packets losses have some significant probability. "Real time" in this sense means that late data is as bad as wrong data, and re-tries are not acceptable. In rough correspondence to the OSI model, MPEG Transport provides transport services but not data-link, although it is also suited to operation under other transports such as ATM. After adding the appropriate data link coding, i.e. forward error correction, it is suitable for RF modulation for CATV, satellite, and terrestrial services, as well as wired telephony and LAN services including ADSL and ATM. It may also be carried on consumer electronics LANs.

Some of the problems that are addressed by MPEG Systems, in particular MPEG-2 Systems Transport streams, include:

1) Accurate synchronization of presented audio and video, with no frame-slipping in decoders

2) Accurate recovery of sample clock timing, sufficient for chroma sub-carrier reconstruction and undistorted audio, without requiring any particular relationship between the transport clock and pertinent sample clocks nor a common network clock .

3) Guaranteed management of coded data buffers in decoders, with no overflow or underflow; these constraints apply to a variety of multiplexed and non-multiplexed scenarios. Includes a separate small, high speed buffer for high communication rate applications.

4) Seamless support for variable bit-rate (VBR) services, and multiplexing of services with differing data rates, with no changes required to the stream definition nor to decoders

5) Independence of the sample clock frequencies from the coded data rates and the transport data rates, allowing widespread distribution of signal and coding sources without requiring a common clock

6) Error resilience for real-time services, via mechanisms such as the packet Continuity Counter, the Packet Error Indicator, support for redundant information packets for critical coded data, use of short packets, and CRC error detection for critical meta-information and user data

7) Random access performance, including a data sync byte and other necessary information

8) Support for meta-information needed in broadcast services, such as program and packet identification (up to 8192 in one Transport stream), which can change dynamically

9) Support for conditional access security mechanisms

10) Support for seamless splicing of streams while retaining guaranteed decoder buffer behavior

11) Support for "trick modes" such as fast forward and rewind, again while ensuring proper decoder buffer behavior

12) Copyright indication and description

13) Relatively easy conversion to and from other stream types such as the Program Stream for disk applications

14) Support for cascaded re-multiplexing of streams while retaining decoder timing recovery and guaranteed decoder buffer behavior.

15) Relatively low overhead given the above functionality, e.g. 2.17%.

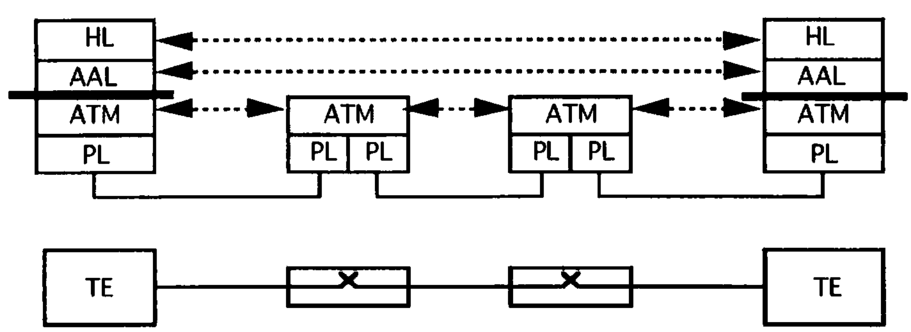
MPEG Transport is not intended as a competitor to ATM; rather, the intention of is to support applications that use ATM as the network transport layer.

MPEG Transport does not contain any form of user addressing (although one could be added privately for user data), and it is not intended for generic virtual connection operation. While there will be MPEG Transport multiplexers, these are used for different applications than most ATM switches.

3. Overview of ATM

Asynchronous Transfer Mode (ATM) is a variable rate, service independent transport mechanism in which user information is transported in fixed length packets, called cells. An ATM cell consists of a 5 Byte cell header containing routing information, and a 48 Byte payload containing user data.

An ATM connection consists of a concatenation of ATM layer links. The ATM layer does no processing of the user payload. Figure 1 shows an example of an ATM connection in terms of the B-ISDN Protocol Reference Model. Service specific functions reside above the solid line at the network edge.



HL Higher Layers
AAL ATM Adaptation Layer
ATM Asynchronous Transfer Mode
PL Physical Layer
TE Terminal Equipment

Figure 1. B-ISDN Layered Protocol Communication

An ATM virtual channel connection can be viewed as a cell pipe. Cells arrive at the receiver in the order in which they were transmitted but with some delay variation. ATM errors are such that some cells may be missing due to congestion in the network, and some cells may be incorrectly sent to the receiver due to bit errors in the ATM cell header. In addition the user data in some cells may contain errors.

ATM operates in a connection oriented mode. At connection set-up the user of the ATM layer negotiates a traffic contract with the network. The network may allocate resources at the start of the call to meet the required Quality Of Service. The network may not accept the connection if the Quality Of Service of existing connections cannot be maintained. Throughout the connection duration the network polices the user traffic such that the traffic contract is not violated. Network resources are released at the end of the call.

The ATM Adaptation Layer (AAL) enhances the ATM layer to support the functions required by the next higher layer, in a service specific manner. AAL functions are typically:

- error control of transmission errors in the information field
- segmentation and reassembly of higher layer information into ATM cells
- handling of cell loss and misinserted cells in the ATM layer
- handling of cell delay jitter
- transfer of timing information.

In order to minimise the proliferation of AAL protocols, four service classes, based upon end to end timing relationship, constant or variable bit rate, and connection mode, are recognised. Class A and Class B cover real time services. The former class is for constant bit rate services, while the latter is for variable bit rate service.

Particular AAL types being considered for audiovisual/multimedia communications are type 1, type 2 (yet to be defined) and type 5. Methods of network adaptation which covers those layers between ATM and elementary streams, including MPEG Transport and Program Streams as part of it are now under study by ITU-T SG15 toward developing Recommendations for audiovisual communications in the ATM environments.

4. Delivery of digital video and audio over ATM

MPEG Systems is generic standard for multiplexing, synchronizing, and otherwise packaging digital audio and video. While it is was designed in conjunction with MPEG audio and video, it is equally applicable to other compression formats.

Both the MPEG-2 Program Stream and the MPEG-2 Transport Stream are suitable for use with ATM. Table 1 shows multiplexing possibilities for MPEG-2 Systems on one ATM virtual channel.

Table 1. Multiplexing possibilities for MPEG-2 Systems on ATM.

in one Virtual Channel	Program Stream	Transport Stream
multiple programs		√
single program	√	√
one elementary stream	√	√

The Program Stream maps easily to the service offered by an ATM Adaptation Layer, whether that be a byte oriented Service Access Point (SAP) as in AAL type 1, or a packet oriented SAP. In the latter case the PES packet in the Program Stream is a natural Service Data Unit to be dealt with by a packet oriented SAP. Where a single program, or a single elementary stream, is carried by one ATM virtual channel the Program Stream may offer simpler implementation than the Transport Stream due to its software implementability.

MPEG Transport streams should be used to carry compressed audio and video, of whatever format, with the appropriate lower network layers. In the case of ATM, Transport packets should be carried within ATM cells with an appropriate simple AAL. While the AAL for generic audio-video applications has not be chosen yet, AAL type 1 using FIFO fullness control used for smoothing of network jitter (adaptive clock recovery) is appropriate for constant bit rate (CBR) applications. AAL type 1 also provides cell loss detection and indication, which assists in localizing errors in the received bit stream. AAL type 1 provides a byte oriented SAP; alignment between the Transport Stream packet may be neither possible nor required.

AAL type 5 can be used to carry MPEG Transport packets, however the unit of data that is lost when AAL type 5 detects an error is typically 2 or more transport packets, and there is no provision for smoothing of network jitter in the existing specifications. Variable bit rate (VBR) operation is provided by MPEG Transport without the need for a specialized AAL, however smoothing of network jitter would assist in interoperability with generic MPEG Transport processors. There is ongoing discussion regarding the options for an AAL for VBR operation.

The Transport Stream implementation generally includes hardware processing to handle the short packets and provides the full error resilient functionality, and thus is thought to be more expensive than Program Stream at the moment, but it is expected that its cost will be rapidly reduced due to wide support of it from various applications and industries. It is expected that Transport Stream will form a ubiquitous common interface between audiovisual equipment and a variety of transmission/storage media.

While Transport Streams can carry multiple programs multiplexed together, they can also carry a single program or a single elementary stream per Transport Stream, such that multiple Transport Streams carry a complete program. Putting audio and video streams in separate Transport Streams is viable for applications that may require such flexibility. The resulting Transport Streams can also be carried in separate ATM VCs.

It may appear that there is a some overlap in the functionalities of ATM and MPEG Transport; the small size and fixed length packet, the simple header functionality to support high speed links, and large multiplexing capacity. However, very little of the actual functions are duplicated. The only apparent cost of such overlap is a fraction of MPEG System's already low overhead which is the equivalent of one byte per ATM cell. Another way to look at the situation is that despite this commonality the Transport Stream may be viewed as an end to end transport system, in which an ATM connection forms but one link out of a whole connection.

5. Techniques to cope with particular ATM characteristics

One of the ATM transmission impairments is cell delay variation which may cause buffer overflow or underflow and incomplete timebase recovery. In general, three kinds of technical solutions are available to cope with this (see Annex K to ITU-T Rec. H.222.0 | ISO/IEC 13818-1 for more details).

One way to model the transmission of a system stream (MPEG-2 system stream referring to both MPEG-2 Transport Streams and MPEG-2 Program Streams) across a jitter-inducing network is shown in Figure 2.

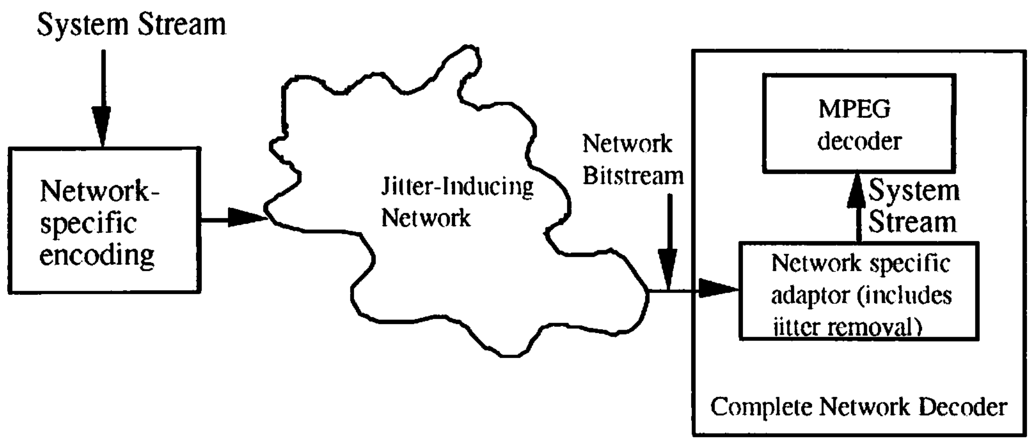


Figure 2 Sending system streams over a Jitter-Inducing Network

The system stream is input to a network-specific encoding device which converts the system stream into a network specific format. Information to assist in jitter removal at the network output may be part of this format. The complete decoder comprises a network-specific adaptor and an MPEG-2 decoder. The MPEG decoder is modeled after the System Target Decoder mathematical model in the MPEG-2 Systems standard but has additional capability to handle the residual jitter which is not removed by the network adaptor. The network-specific adaptor removes any additional data added by the network-specific encoder and smoothes the jitter imposed by the network. The output of the network-specific adaptor is an MPEG system stream, with slightly more jitter than the original bitstream.

Network specific solution

The ATM Adaptation Layer (AAL) deals with characteristics of the ATM layer so as to provide the required Quality Of Service to the AAL user. An AAL to deal with variable bit rate, real time signals is required. Such an AAL must provide a mechanism that removes the effects of ATM layer cell delay jitter, to provide the expected Quality Of Service to the AAL user. The mechanism can be based on higher layer (MPEG Systems) coding, or network specific time stamps, or possibly other methods.

Integrated decoder solution

In one example decoder implementation, two clock recovery stages are required; one for smoothing network induced jitter and the other for recovering the MPEG timebase by processing PCR or SCR time stamps. An alternative solution integrates the dejittering and decoding functions in a single system. The timebase is directly recovered from received PCR or SCR values.

6. Conclusion

This paper has summarized the current status of the MPEG Systems and its use in ATM environments which are being studied in WG11 ad ITU-T Experts Group. MPEG Systems will be standardized by the end of 1994. Choice of network adaptation alternatives or their profiling will be worked out in ITU-T SG15 to make Recommendations H.222.1 and H.32X by the end of 1995.

END