MPEG STANDARD CONFORMANCE TESTING FOR INTEROPERATILITY

Mukta Kar, Majid Chelehmal, Rich Prodan
Cable Television Laboratories, Inc.

Abstract

An important objective of the MPEG standardization effort is to define a set of video and audio compression techniques and to increase interoperability among various digital audio/video devices made by different manufacturers. To further this effort, the MPEG committee has defined a set of normative compliance requirements in a part of the MPEG standard which sets forth procedures and bitstreams to test MPEG-2 related products.

Many manufacturers, particularly small ones, do not have enough resources to test their product thoroughly for compliance. To help cable operators and the cable industry, Cable Television Laboratories, Inc. (CableLabs®) has set up a conformance testing laboratory. These efforts should minimize concern about incompatibility among MPEG products and should assist in the development of a multivendor base of interoperable equipment.

This paper reviews some of the background of the MPEG-2 Standard and its compliance requirements. Discussion about non-realtime and realtime conformance testing is also included. The current conformance testing capabilities at CableLabs and the results of bitstream analysis from several manufactures realtime encoding system are discussed.

INTRODUCTION

As digital information delivery to the consumer is becoming reality, millions of devices will be interconnected to handle telecommunications and entertainment services. Interoperability among the equipment of various manufacturers will increase the speed of deployment while decreasing cost. For this reason, it is particularly important for cable companies to adopt interoperable standards.

In the wake of the Telecommunication Deregulation Bill recently passed by Congress, one can expect competition in the future encompassing various service providers. Without sufficient interoperability among equipment, the opportunities for timely, cost-effective mass deployment of video services may be impeded in a highly competitive marketplace.

Interoperability is a key issue. It helps stimulate strong competition for product innovation in the marketplace. Competition ensures more reliable products at lower prices. With the tremendous advances in hardware and software technology, the analog video and audio equipment makers are changing to digital design. In the analog world, most of the audio/video equipment manufactured by various vendors was not interoperable. Some of the audio/video equipment (e.g., analog settop boxes) cannot be moved and plugged into different cable systems in different regions of the country.

The interoperability of digital television utilizing the MPEG-2 audio-visual compression standard is examined in this paper. A brief history and overview of this standard is provided. The role of conformance testing to determine compliance to the definition of the standard and to allow interoperability at the baseband compressed program multiplex level is discussed. The MPEG-2 conformance laboratory established at CableLabs facilities is described. Some results of conformance testing of several vendors MPEG video encoder are provided. Future work and conclusions are summarized.

Compression Standards

To promote interoperability, equipment manufacturers, broadcasters, cable operators and government entities have expressed a desire for broader standardization. Various standardization committees have been formed under the administrative umbrella of the International Organization for Standardization (ISO). These standardization committees are know as JPEG (Joint Picture Experts Group) and MPEG (Moving Picture Experts Group).

The JPEG committee created a document for compressing still pictures. A picture can be compressed and decompressed without any reference to other pictures. So a picture can be compressed in non-realtime and then be stored or transmitted. The first document from the MPEG Committee is known as MPEG-1. MPEG-1 is optimized for moving pictures of SIF (352X240) format with a bitrate of about 1.5 Mbits/s used in single program application (e.g., CD ROM). Later, the MPEG committee extended its MPEG standardization work to include CCIR-601 broadcast quality images. The extended standard is known as MPEG-2. Also, it added a new system layer including a transport stream layer for realtime delivery of multiple programs over error-prone channels. Using MPEG-2 compression and transport syntaxes, interoperability among equipment of various vendors is possible. This paper deals with the MPEG-2 standard and the conformance testing of encoded bitstreams.

MPEG-2 OVERVIEW

In the second phase of work, the main goal of the MPEG committee was to extend the MPEG-1 standard such that it could be applied to a wide class of applications involving audio, video and other data with broadcast resolution and bitrates up to 15 Mbits per second. Major requirements were (a) forward compatibility with MPEG-1, (b) good picture quality, (c) flexibility in input format, (d) random access capability, (e) inclusion of VCR controls (fast forward, reverse play and slow motion), (f) bitstream scalability, (g) low delay for two-way isochrouous communication, and (h) the capability of multiplexing several programs in a single bitstream with resilience to transmission errors. Bitstream scalability is defined as the ability to discard a portion of the bitstream, but decoding the remaining bitstream will produce a recognizable picture of lower quality. Soon it was realized that a bitrate restriction of 15 Mbits/s is not required and the MPEG-2 standard can be applied to higher bitrate applications such as high-definition television.

The MPEG-2 standard is divided into three principle parts; video compression, audio compression, and system multiplexing and transport. MPEG-2 is basically a collection of tools defined in such a way as to satisfy the requirements of a wide variety of applications. All the tools are not needed for a specific application. A subset of tools is enough to implement a particular application while maintaining full interoperability among the equipment manufactured by various vendors that support that application.

MPEG video compression is based on discrete cosine transform with motion compensation (DCT-MC) algorithms. DCT is a block orthogonal transform which reduces spatial redundancies inherent in a picture by compacting most of the energy into lower order coefficients of a block. Coefficients are quantized and higher order terms are truncated. The technique of motion compensation provides further compression by taking advantage of temporal redundancies of successive frames. Only motion compensated (spatially offset) differences between pictures are transformed. The resulting motion vectors and quantized DCT coefficients are variable length coded using entropy coding including Huffman coding and run-length coding.

The MPEG video coding support is divided into profiles and levels. A profile is defined as a subset of the entire bitstream syntax. Within a profile, there could be various levels (picture resolutions). There are five profiles: simple, main, SNR scalable, spatially scalable, and high profile. There are also four levels: low (SIF), main (CCIR601), high-1440, and high (HDTV resolution). Using the combination of these profiles and levels, 11 different types of decoding are defined. A decoder could have one or more of these capabilities. MPEG audio compression uses the MUSICAM (masking pattern universal sub-band integrated coding and multiplexing) algorithm and supports mono, stereo, and surround quality audio.

In the MPEG-2 system document, the syntax and semantics are defined for multiplexing multiple programs in a single bitstream. In the system/transport stream layer, bitstreams are split into 188 byte packets (184 byte payload and 4 byte header) as shown in Figure 1. The header carries various information fields. The PID (packet identifier) is the most important one. The PID is a unique integer number associated with an elementary stream in a single or multi-program transport stream. The packets can carry various video and audio channels and other information, such as synchronization and timing, encryption, program information, access control, etc. The PID numbers help sort the packets into specific streams to which they belong.

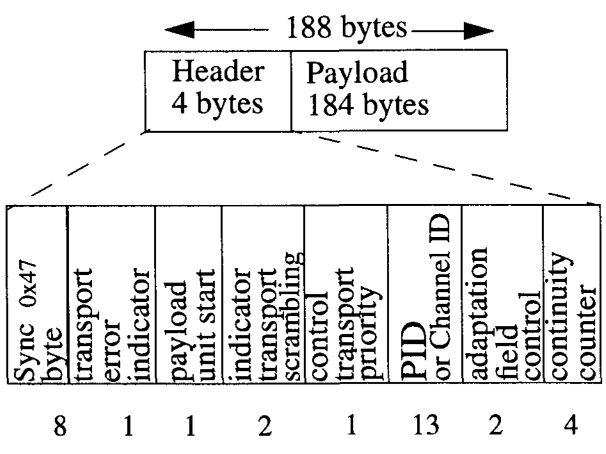

Fig. 1 MPEG-2 Transport Packet

Conformance Testing

Interoperability is the main goal behind creation of MPEG standard documents. It is assumed that equipment designed complying with the rules stipulated in the three documents (audio, video, and systems) will be interoperable, at these levels.

The MPEG-2 committee realized there were questions on how to test compliance and the degree of compliance, so it added a fourth document known as Part 4, Compliance. Part 4 specifies tests for ensuring compliance with video, audio, and systems specifications. The document recommends that a number of bitstreams be used for the test. These bitstream files have been carefully designed to test various characteristics of MPEG equipment. They will be especially useful for testing settop (decoder) boxes. These bitstream files are stored in various FTP (file transfer protocol) sites around the country and can be downloaded by anyone using FTP or similar software. CableLabs is an active participant in the MPEG standardization process and has provided the FTP site for system-related bitstream files.

Equipment manufacturers designing MPEG-2 related equipment (encoders, decoders, etc.) should test their equipment using the procedures specified in Part 4 so that they can specify their equipment as MPEG-2 compliant. Many companies do not have sufficient resources to test their equipment extensively. Such equipment may run into interoperability problems. This situation could be avoided by submitting equipment to a neutral laboratory that would test MPEG-2 equipment and check the degree of compliance. To assist cable television operators in evaluating MPEG-2 equipment, CableLabs has set up a conformance testing laboratory to test encoders and decoders. The main goal of conformance testing is to broaden the scope of interoperability among the equipment produced by various vendors.

CableLabs plans to test bitstreams both in non-realtime and in realtime. A set of software tools has been designed and developed to analyze bitstreams captured from an encoding system (video encoder and system multiplexer). A schematic block diagram of the hardware configuration for the CableLabs non-realtime conformance verifier is shown in Figure 2. A set of software analysis tools checks the syntax and semantics of such bitstreams at the system and video layers. The second approach employs realtime testing of encoders and decoders using specific hardware. Currently, video bitstreams can be stored over a short time only (several seconds, maximum). If an encoding system generates bitstreams with infrequent problems, observing such problems using a non-realtime method will be difficult. In that case, the encoder bitstream has to be analyzed in realtime over a considerable time interval.

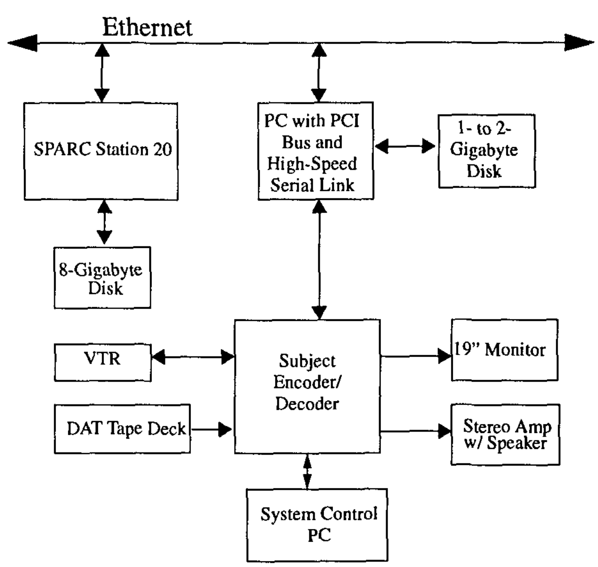

Fig. 2: Non-realtime Conformance Verifier

Non-Real-Time Conformance Verifier

At present, the non-realtime version of the conformance verifier is operational. A brief description of various components shown in Figure 2 is given below.

A Unix SPARC Station 20 serves as the main computer for the various MPEG-2 software tools used to create and to analyze MPEG-2 bitstreams. The 8-Gigabyte disk stores large bitstream files as captured from encoders or provides input to decoders. A PC has a PCI bus, a fast Ethernet card, and a specialized serial card. This serial card is used to send/receive data to or from an encoder or decoder, respectively. The 1-2 Gigabyte hard disk, connected to the PC provides a fast SCSI link for fast storage/retrieval of data. The SPARC-20 and PC are connected to Ethernet for networking. The VTR is digital D-5 or a D-1 tape recorder, or could be a video realtime disk. A DAT tape deck is used as the audio source material.

In a non-realtime configuration, a bitstream from a realtime encoder is captured using the PC with a high-speed serial link and stored on the hard disk. Then the bitstream is transferred to the SPARC-20 and analyzed using a set of conformance checking tools. The software tools are designed such that each tool reads a parameter file where various flags, such as buffer-verification, PSI (program specific information) checking, etc., are set to desired values. The analysis output can be displayed on the screen and be logged into a file at the same time, if desired.

The software tools have been primarily divided into two parts: transport stream multiplexer/demultiplexer and video elementary stream encoder/decoder. The demultiplexer tool reads PSI (Program Specific Information) from the transport stream and separates the elementary streams into individual stream files for video, audio, and private data. The video decoder tool checks the syntaxes and semantics of the video elementary stream file while reconstructing the picture. It also displays a frame once it is complete, and can send the decoded frames to other devices.

There are a significant number of syntax elements and parameter values to be checked in a transport stream. CableLabs demultiplexer checks about 300 syntax elements, and important parameters like buffer level verifications for all three buffers specified for T-STD model, bitrate, PCR frequency, etc., applicable to MP@ML. The demultiplexing tool has the capability of reading PSI information from a bitstream or can read a user-supplied one (if the stream has no PSI or erroneous PSI). Features are incorporated such as setting initial offset into the bitstream, logging program output to a file for later investigation, information display level for diagnostic output level of detail, etc. The video decoder checks 73 important syntax elements including timing parameters (validity of Presentation Time Stamps [PTS] and Decoding Time Stamps [DTS]), motion vector search ranges, valid temporal references, etc. The decoder handles both Main Profile and Simple Profile at Main Level, including Dual-Prime prediction mode. Additional software tools have been created to support conformance test activities. For example, the software video encoder and transport stream multiplexer may be used to create transport stream.

CableLabs has been performing conformance testing of bitstreams from a number of encoder vendors. Errors and warnings are tabulated and provided to the vendor company for appropriate action to correct the problems. The bitstreams captured from several realtime encoders under test have been analyzed and sample results presented below.

The conformance verifying decoder found the following problems in several bitstreams: 1) In the Dual Prime mode, forward prediction vectors were not pointing to the adjacent previous picture. 2) In the field prediction mode for a B-picture, the motion vectors violated the picture boundary limit. 3) Video access unit (AU) was not aligned with the PES packet in some transport stream packets. 4) The continuity counter did not increment in some transport packets. 5) The PTS time-stamp value was different from the expected value.

Future Research

With the current conformance testing software tools, syntax and semantics can be checked methodically in non-realtime. But if problems occur infrequently or intermittently, much time and storage will be required for post-analysis. A realtime verifier would alleviate these bottlenecks in such a situation.

CableLabs is designing and developing a realtime conformance testing tool. The realtime verifier will not make the previously developed non-realtime software tools obsolete. Checking syntax and semantics in detail is easier to do in non-realtime. A thorough checking of syntax and semantics will be very computationally intensive. Hence, we believe that realtime and non-realtime tools will complement each other. Filtering bitstream violations using hardware without detailed analysis will greatly reduce this computational burden.

Conclusion

Digital television utilizing the MPEG-2 audio-visual compression standard facilitates interoperability of equipment for cable distribution of entertainment programs. The CableLabs conformance testing laboratory has been established to foster a multiple vendor universe of interoperable products. The current non-realtime and future realtime components can assist in solving ambiguities and verify adherence to the established MPEG-2 standard, as well as industry established standards unique to the cable environment.

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The authors are employees of Cable Television Laboratories Inc., Louisville, Colorado. The conformance tools have been jointly developed with DiviCom Corporation of Milpitas, California.