PS-WP4 Scorecard

...the GA System meets PS-WP4 recommendations...

PS-WP4 Recommendation		Grand Alliance System
All-digital layered architecture	√	Fundamental basis of interoperability
Headers and descriptors	√	Sequence Header, Packet ID Header
Transmission in progressive scan format	√	5 progressive, 1 I/P block adaptive
Flexible packet data transport	√	GA/MPEG-2
Transparent channel re-allocation	√	provided by Packet ID header
Low-cost ATV receivers	√	
Low cost ATV VCR	√	
Extensions with backward compatibility	√	packet extensibility, enhancement coding
Square pixels or square pixel option	√	
Compatible with international standards	√	GA/MPEG-2 compression &transport
Still/motion multi-window transmission	√	

JEGI Doc.-026

RECEIVED

NOV 2 9 1993

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

INTEROPERABILITY ASPECTS

OF THE

GRAND ALLIANCE HDTV SYSTEM

INTERIM REPORT

SEPTEMBER 30, 1993

RECEIVED

NOV 2 9 1993

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

EXECUTIVE SUMMARY

The Grand Alliance HDTV System is being developed with interoperability as one of its design goals. The system provides powerful flexibility by using two fundamental system principles that were recognized in the previous work of PS-WP4: a layered digital system architecture, and headers/descriptors. In addition, the GA HDTV system provides interoperability at all of its layers. This includes interoperability among a variety of transmission media, packet formats, compressed video and audio data streams, and picture and sound formats.

LAYERED SYSTEM ARCHITECTURE WITH HEADER/DESCRIPTORS

The layers of the GA HDTV System, and some of their most important capabilities, are:

- The Picture layer provides multiple picture formats and frame rates (supported by header/descriptors at the compression layer) in the 16x9 wide aspect ratio.
- The Compression layer is based on MPEG-2 video compression with Grand Alliance syntax extensions for AC coefficient leaky prediction, and *(not yet determined)* audio compression
- The Transport layer is a packet format with packet header/descriptors that is based on MPEG-2 transport, and provides the flexibility to deliver a wide variety of picture, sound and data services
- The Transmission layer is a signal that delivers a net data rate of approximately 18 Mbps in the 6 MHz simulcast channel

The GA HDTV system's layered digital system approach with header/descriptors will create interoperability among a wide variety of consumer electronics, telecommunications, and computing equipment. While all of the GA HDTV system's layers operate in unison as an effective simulcast system, each layer has also been designed to have outstanding interoperability.

TRANSMISSION LAYER

Interoperability at the transmission layer is facilitated by the nature of digital systems. Although different modulation techniques are used to meet the characteristics of different physical channels (e.g., terrestrial simulcast, cable, satellite, fiber, etc.), the serial bit stream forms the basis for transcoding among modulation techniques and achieving interoperability among delivery media.

TRANSPORT LAYER

The transport layer separately packetizes video, audio and auxiliary data and allows their mix to vary dynamically, providing the flexibility needed to innovate new services and new kinds of programming. Important capabilities include:

- The basic service provided by the GA HDTV system includes video, five-channel surround-sound audio and a nominal auxiliary data capacity.
- The GA HDTV system offers great flexibility in the mix of video, audio and data services that can be provided to appropriately-featured receivers. It separately packages each type of data (e.g., video, audio, etc.) in its own set of transmission packets. Each packet has a *Packet ID* header that identifies the content of the data stream. This capability enables the creation of new services, such as: many stereo channels of audio, to broadcast distribution of computer software, to the transmission of very high resolution still images to computers.
- The mix of services can be dynamically allocated. This capability will allow rapid burst-mode addressing of receivers. It will also enable broadcasters to send multiple "streams" of video, audio and data programming to their audience, all complementing or enhancing the basic program content. This capability can fundamentally change the nature of television programming, since it enables software to be broadcast to "smart receivers" that can operate in conjunction with the HDTV picture and sound. With this capability, HDTV will likely become

a more interactive medium than today's television, enabling new forms of educational and entertainment programming and games.

At the transport layer, the GA HDTV system has attributes that contribute to interoperability with computers, multimedia systems and broadband networks:

- The GA packet format is a subset of the MPEG-2 transport protocol.
- The GA/MPEG-2 packet format is simply related to the Asynchronous Transfer Mode (ATM) broadband data network packet format. The 4x larger GA/MPEG-2 packet provides for simple encapsulation and/or transcoding between GA/MPEG-2 packets and ATM cells, with the resulting capability to achieve cost-effective delivery of HDTV over ATM links.

COMPRESSION LAYER

The compression layer transforms the raw video and audio samples into a coded bit stream -- essentially a set of computer instructions and data that are executed by the receiver to recreate the pictures and sound. At the compression layer, the GA HDTV system has attributes that contribute to interoperability with computers, multimedia systems, and other media:

- The GA video compression syntax is based on the ISO-MPEG (International Standards Organization — Moving Picture Experts Group) MPEG-2 video data compression draft standard. Additionally, the GA includes certain syntax extensions for AC coefficient leaky prediction that are not part of MPEG-2.
- The use of GA/MPEG-2 video compression will allow many HDTV receivers to interoperate with MPEG-2 and MPEG-1 computer multimedia applications directly at the compressed bit stream format.
- MPEG compression was designed for digital storage media. It can contain certain periodically occurring frames that are spatially coded. This approach provides the ability to reconstruct pictures in fast-forward and reverse scanning modes from digital storage media, including disks and VCRs.
- Although the Grand Alliance has not yet selected its audio subsystem, each of the candidate systems (Dolby AC-3, MUSICAM Surround, and MIT AC) provides different interoperability advantages.

PICTURE LAYER

The picture layer consists of raw pixel data, organized as pixels, scan lines and frames. The GA HDTV system provides for multiple 16x9 formats and frame rates, *all of which will be decoded by any GA HDTV receiver.* This approach allows program producers and application developers to make their own tradeoffs among resolution, frame rate, compression artifacts and interlace artifacts, and to choose the format that is best for their particular use. The formats are:

Spatial Format (X x Y active pixels)	Temporal rate
1280 x 720 (square pixels)	23.976/24 Hz progressive scan
1280 x 720 (square pixels)	29.97/30 Hz progressive scan
1280 x 720 (square pixels)	59.94/60 Hz progressive scan
1728 x 960 (square pixels) *(or other ≈1000 line, TBD)*	23.976/24 Hz progressive scan
1728 x 960 (square pixels) *(or other ≈1000 line, TBD)*	29.97/30 Hz progressive scan
1728 x 960 (square pixels) *(or other ≈1000 line, TBD)*	59.94/60 Hz interlaced scan

Each of these multiple formats have attributes that contribute to interoperability with current television standards, film and computers:

- All formats have 16x9 aspect ratio
- All formats have square pixels *(as of this writing; the ≈1000 line format is still under consideration, as explained in Chapter 6)*
- All formats have simple vertical and/or scan rate relationships to NTSC
- All formats at the 23.976/24 Hz temporal rate are progressive scan. This provides a frame rate identical to film, which is currently an extremely important source of television material. (Note that film will most likely be converted to 60 Hz for studio handling, with the 3:2 frame repetition detected and removed by the compression encoder).
- All formats at the 29.97/30 Hz temporal rate are progressive scan. This provides compatibility with 30 Hz film, and can be an extremely useful format for computer multimedia applications.
- At the 59.94/60 Hz temporal rate, there is a choice of either ≈1000 line interlaced or 720 line progressive formats, reflecting the fundamental tradeoffs between spatial and temporal resolution in a data rate-limited channel.
- At the ≈1000 line resolution, there is a choice of either 29.97/30 or 23.976/24 Hz progressive scan or 59.94/60 Hz interlaced scan, reflecting the fundamental tradeoffs between spatial and temporal resolution in a data rate-limited channel.

OTHER INTEROPERABILITY CONSIDERATIONS

Creating a mass consumer market for HDTV will require low cost receivers and VCRs, both initially and in the future, as the market matures and consumer expectations rise. Also, interactive applications that will build on basic HDTV capabilities must be accommodated. The GA system provides for these considerations:

- Since the display is the highest cost element of a receiver, the approach of transmitting multiple formats to a decoupled display facilitates the production of cost-effective receivers, and the migration to higher quality displays over time.
- Since data rate is the most important factor in VCR cost, low-cost digital VCRs will be possible due to the low 18 Mbps data rate of the GA HDTV system
- Low-latency encoding is important to reduce the end-to-end delay of interactive applications. While the GA/MPEG-2 compression approach allows B-frame encoding for higher quality (with higher latency), B-frames are not required. A GA/MPEG-2 encoder may be built as a (or switched into a mode of) low-latency, no B-frame encoding, and produce a completely standard GA/MPEG-2 bit stream with a slight reduction in picture quality.

EXTENSIBILITY AND MIGRATION PLAN

One of the first improvements to be implemented in HDTV will be the migration from today's 59.94 Hz based frame rates to a true 60 Hz family of frame rates. All GA HDTV receivers will be capable of receiving six different temporal rates (60, 59.94, 30, 29.97, 24 and 23.976 Hz).

- The initial 59.94 Hz based frame rates (59.94, 29.97 and 23.976 Hz) facilitate transcoding with NTSC that is required in a simulcast environment — this eliminates temporal artifacts and the need for frame synchronization in mixed NTSC/HDTV production and broadcasting environments.
- The 60 Hz based frame rates (60, 30 and 24) capability that will be provided in all HDTV receivers allows the migration to these rates, which are better suited to production editing and computer multimedia.

The development of new services and applications will require extensibility, to ensure that new products and services can be compatibly introduced within the framework of an established standard. The GA HDTV system provides this extensibility through its Transport layer header/descriptors:

- An GA HDTV receiver will disregard any packet with a PID header that it does not recognize or cannot process. This will eliminate future "backward-compatibility" problems in the installed base of receivers, removing a crucial constraint from the introduction of new services.

With the constraints of current compression technology, 6 MHz transmission bandwidth and simulcast power limitations, it is not possible to deliver the ≈1000 line progressive scan and square pixel format with the 60 Hz frame rate that is ultimately desirable. Future improvements to compression efficiency and the relaxation of simulcast bandwidth and/or power requirements as NTSC stations go off-air will allow digital enhancement data to be transmitted. Enhancement coding can be based on any of the multiple formats in the GA HDTV system, providing several paths for a backward compatible migration.

CONCLUSIONS

The GA HDTV system has the flexible operating characteristics that allow it to provide broad interoperability needed to form the basis for new and innovative services and applications of HDTV in many industries.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

1. BACKGROUND 1
   - 1.1 Interoperability Introduction 1
   - 1.2 Scope of HDTV Standards and their Impact 2
   - 1.3 Grand Alliance Goals 3
   - 1.4 PS-WP4 Recommendations 4

2. SYSTEM INTEROPERABILITY OVERVIEW 7
   - 2.1 Layered Digital System Architecture 7
   - 2.2 Headers/Descriptors 10
   - 2.3 System Interoperability Overview Summary 12

3. TRANSMISSION LAYER INTEROPERABILITY 13
   - 3.1 Constraints of the Simulcast Environment 13
   - 3.2 Cable Interoperability 14
   - 3.3 Satellite, Packet networks and Other Delivery Media Interoperability 14

4. TRANSPORT LAYER INTEROPERABILITY 15
   - 4.1 Transport Design Issues -- Why Not ATM? 15
   - 4.2 GA/MPEG-2 transport 16
   - 4.3 ATM Interoperability 17
   - 4.4 System Level Multiplex -- a Header/Descriptor Tree 18
   - 4.5 Transport Layer Interoperability Summary 20

5. COMPRESSION LAYER INTEROPERABILITY 21
   - 5.1 Compression Design Issues 21
   - 5.2 The MPEG-2 Compression Family: Levels and Profiles 23
   - 5.3 GA/MPEG-2 compression 24
   - 5.4 MPEG-2 Interoperability 24
   - 5.5 MPEG-1 Interoperability 25
   - 5.6 H.261 Interoperability 25
   - 5.7 Computer Interoperability at the Compression Layer 25
   - 5.8 **AUDIO** compression 26
   - 5.9 Compression Layer Interoperability Summary 27

6. PICTURE LAYER INTEROPERABILITY 29
6.1 A Plethora of Picture Formats 29
6.2 Format Conversion -- Spatial Interpolation and Deinterlacing 30
6.3 GA Picture Formats 32
6.4 The ≈1000-line Format Issue 34
6.5 Film Interoperability 35
6.6 NTSC Interoperability 36
6.7 HDTV Production Interoperability 36
6.8 30 fps Film Interoperability 37
6.9 Computer Interoperability 37
6.10 Picture Layer Interoperability Summary 39

7. OTHER INTEROPERABILITY CONSIDERATIONS 41
7.1 Low Cost HDTV Receivers 41
7.2 Low Cost HDTV VCRs 42
7.3 Low Latency Encoding 42

8. EXTENSIBILITY AND MIGRATION PLAN 45
8.1 Migration to 60 Hz 45
8.2 Migration to ≈1000 Line Progressive at 60 Hz 45

9. SUMMARY 49

1. BACKGROUND

A successful HDTV standard will be used for HDTV delivery to the public by terrestrial broadcasting and a variety of alternate delivery media, and it will also form the basis for new services and new applications of HDTV across a wide range of industries. In order for the enormous potential impact of digital HDTV to be realized, a high degree of interoperability is an essential attribute of an American standard.

1.1 INTEROPERABILITY INTRODUCTION

The formation of the Grand Alliance moves the HDTV standardization process from a competitive phase into a new collaborative phase. The previous competitive phase stimulated the rapid development of technology, as well as broad industry debate over various attributes in which the proposed systems differed. In the new collaborative phase, the Grand Alliance and the Advisory Committee must rapidly establish a national consensus and move forward into laboratory and field performance verification, and the documentation of a standard for FCC approval. Failure to achieve these objectives will harm every industry that is potentially advantaged by the deployment of HDTV systems and technology.

It must be understood that interoperability among systems does <u>not</u> require them to be identical. During its previous work, PS-WP4 defined interoperability as:

> *"The capability of providing useful and cost-effective interchange of electronic image, audio and associated data: among different signal formats, among different transmission media, among different applications, among different industries, among different performance levels."*

This means that systems can be made to interoperate across an appropriate interface. In this context, interoperability cannot be viewed as a binary characteristic that simply exists or does not exist. The degree of a system's interoperability must be evaluated in a complex multidimensional space that considers the established standards and practices of various industries, as well as the technical feasibility and cost impact of providing interfaces at different operational boundaries between applications or industries.

Because HDTV will have an important impact on many industries, there are many questions and concerns about interoperability from a diverse collection of potential users. These concerns impact virtually every aspect of the HDTV system. Those aspects of HDTV that concern different interests sometimes create conflicting desires for interoperability with established systems and/or practices in different industries that cannot be satisfied simultaneously.

Grand Alliance

In some cases where the Grand Alliance confronted the dilemma of conflicting interoperability goals, it was technically feasible and reasonably cost-effective to allow a multiplicity of modes within the system. In these cases, the presence of modes favored by a particular industry do not preclude the inclusion of modes that are more favorably viewed by a different industry. The result is a system that is maximally useful to all industries, rather than one that burdens one industry at the expense of another.

In other cases where the Grand Alliance confronted the dilemma of conflicting interoperability goals, a choice had to be made among the conflicting alternatives. In these cases, there are good technical reasons for the choice that was made, and careful consideration has been given to interface requirements that bridge the differences between the approaches of different industries and make the system interoperable.

In this document, we will discuss the interoperability aspects of the Grand Alliance HDTV system, identify areas in which conflicting interoperability desires occur, and explain the technical rationale behind our solution in such cases.

1.2 SCOPE OF HDTV STANDARDS AND THEIR IMPACT

HDTV technology will not only revolutionize the television industry, but it will have a profound impact across a wide range of industries. The proliferation of high speed digital communications needed to deliver HDTV to the home will make the associated industries a key part of our National Information Infrastructure. Further, the core capability of cost-effectively delivering full-motion high resolution pictures and high-quality surround-sound will become a cornerstone of image communications that may be adopted by a variety of industries and applications.

However, it is important to understand the scope of the GA HDTV System, which is a proposed transmission standard that is under consideration by the FCC through its Advisory Committee on Advanced Television Service (ACATS). The Grand Alliance HDTV system (and presumably the FCC standard) is NOT a production standard, or a display standard, or a consumer equipment interface standard. In fact, a digital compression and transmission system effectively DECOUPLES these various elements of the end-to-end imaging chain.

A digital HDTV transmission standard must specify sufficient information that allows any manufacturer to build a receiver that can receive a radio frequency (RF) transmission, and from it, produce pictures and sound. For a digital system, this means specifying the meaning of a bit stream and the signal format for transmitting those bits in a 6 MHz television channel. Thus, the picture formats, the compression syntax, the packet format and the RF signal format are examples of items that require standardization. While these standardized elements establish a minimum

functionality for HDTV encoders and receivers, they do not specify encoder or receiver implementation. In the opinion of the Grand Alliance, this traditional approach to transmission standards is highly desirable, because it enables natural competitive and economic forces to influence the implementation of encoders and receivers, which can evolve over time as underlying technology as cost changes take place.

1.3 GRAND ALLIANCE GOALS

Since we are considering a proposed HDTV transmission standard that contains many complex tradeoffs, it is important to state the design goals that the Grand Alliance established for itself. These goals essentially summarize the selection criteria that were established by ACATS during the competitive phase of the standards process. The Grand Alliance design goals are to provide:

- High quality HDTV pictures and sound
- An effective simulcast system that:
  - Provides wide HDTV service area for terrestrial broadcast
  - Avoids unacceptable interference to existing NTSC service during its lifespan
- A cost effective solution for consumers, producers and all users at the time of introduction and over the life of the HDTV standard
- Interoperability with other media (e.g., cable, satellite, computers, etc.) and applications
- The potential for a worldwide standard

In this simple list of design goals, there are many conflicting desires. For example, there is a three-way tradeoff among HDTV picture quality, HDTV service area and interference to existing NTSC service. In order to have outstanding HDTV picture quality, a high data rate is desired. But achieving a high data rate over a large HDTV service area requires high power transmission that results in too much interference to existing NTSC service. Reducing the HDTV service area is unacceptable, because there would be insufficient audience to make the service economically viable. Fortunately, with some balancing of objectives and associated engineering tradeoffs, the combination of video compression technology and digital transmission technology is sufficient to enable the creation of an HDTV simulcast service.

As another example of conflicting goals, even when considered solely as an entertainment medium, the HDTV transmission standard must have a high degree of interoperability with its common production sources, in order to ensure economical operation from production through delivery to the home. Even in this limited context, interoperability of one kind may be in conflict with interoperability of another kind. The production sources for HDTV transmission will include: the HDTV production standard, film, computer graphics, and NTSC video. The conflicting

interoperability desires are that while the HDTV production standard will likely be interlaced with square pixels at 59.94 Hz, the desire for NTSC interoperability argues for preserving non-square pixels and the 59.94 Hz temporal rate, while the desire for film interoperability argues for a 24 Hz temporal rate, while the desire for computer interoperability argues for square pixels, progressive scan and possibly a frame rate higher than 70 Hz. Furthermore, film, TV, and HDTV have different picture aspect ratios (the ratio of the image width to its height). Clearly, these conflicting interoperability desires are mutually exclusive, yet the interoperability of an HDTV transmission standard with all of these sources is important. A solution can be found that takes into account existing and widely accepted interoperability practices, such as the conversion of 24 Hz film to 59.94 Hz through a combination of a 1000/1001 slowdown to 23.976 Hz and a 3:2 frame repeat sequence to speed up the temporal rate to 59.94 Hz. Windowing and pan-and-scan are traditionally used to overcome aspect ratio differences while preserving artistic content. In addition, the conversion between square pixels and non-square pixels must take place at some interface boundary; the question is simply where. Understanding the technical difficulty and cost of one conversion compared to another is an important element of the complex tradeoffs that must be made in the design of an HDTV system.

To further complicate our decision space, we observe that HDTV is on the vanguard of an explosion in digital technology. HDTV products will exist in a world where digital delivery of television by cable, satellite and pre-recorded media are proliferating; where the availability of low cost computational power and digital data networks are enabling the creation of a National Information Infrastructure; and where the development of new interactive services and applications will drive the creation of information appliances and products that may be hybrids of today's products, or entirely new products based on technologies that rapidly cross the computing, communications and consumer electronics industries.

Thus, the interoperability of the GA HDTV system must be evaluated in a context that considers the scope of a transmission standard, the currently existing standards and practices with which interoperability is important, and the characteristics that are desirable to foster interoperability with new systems and applications in the future.

1.4 PS-WP4 RECOMMENDATIONS

At the conclusion of its previous work, ACATS PS-WP4 developed a list of recommendations that "contribute significantly to Interoperability, Scope of Services and Features, and Extensibility." They are:

1. An all-digital implementation based on a layered architecture model
2. The use of universal headers and descriptors (as agreed by industry standards group)

3. Transmission of the signal in progressive scan format
4. Use of a flexible, packet data transport structure
5. Viewer transparent channel re-allocation (limited picture and sound while most of the channel capacity is devoted to data transmission for conditional access addressing or other purposes)
6. Ability to implement lower performance low-cost ATV receivers (comparable price/performance options to current NTSC receivers)
7. Ability to implement low cost ATV consumer VCR
8. System architecture and implementation that will allow improvements and extensions to be incorporated as technology advances while maintaining backward compatibility
9. Square pixels or at least the option to select square pixel presentation
10. Compatibility with relevant international standards or commitment to this objective
11. Easily implementable and user-accessible "still/motion multi-window transmission"

In the remainder of this document we will attempt to explain how the GA system is highly interoperable, and in concert with these recommendations.

2. SYSTEM INTEROPERABILITY OVERVIEW

The Grand Alliance HDTV system employs two fundamental system principles that make it a highly interoperable system. First, it is designed with a layered digital system architecture[1], that results in the ability to interface with other systems at any layer. This means that many different applications can make use of various layers of the HDTV architecture. In addition, the Grand Alliance has designed each individual layer of the system to be highly interoperable with other systems at corresponding layers. Secondly, the Grand Alliance HDTV system takes full advantage of the potential flexibility offered by a digital approach by using header/descriptor design principles that allow maximum flexibility to be achieved[2]. As a truly flexible digital system, the Grand Alliance HDTV system provides the basis for an HDTV standard that will have a revolutionary impact on many industries and applications that are well beyond the scope of television today.

2.1 LAYERED DIGITAL SYSTEM ARCHITECTURE

The GA HDTV system is a layered digital system that consists of four primary layers: the Picture layer, the Compression (video and audio) layer, the Transport (packetization) layer and the Transmission layer. These layers are conceptually illustrated in Figure 2.1.

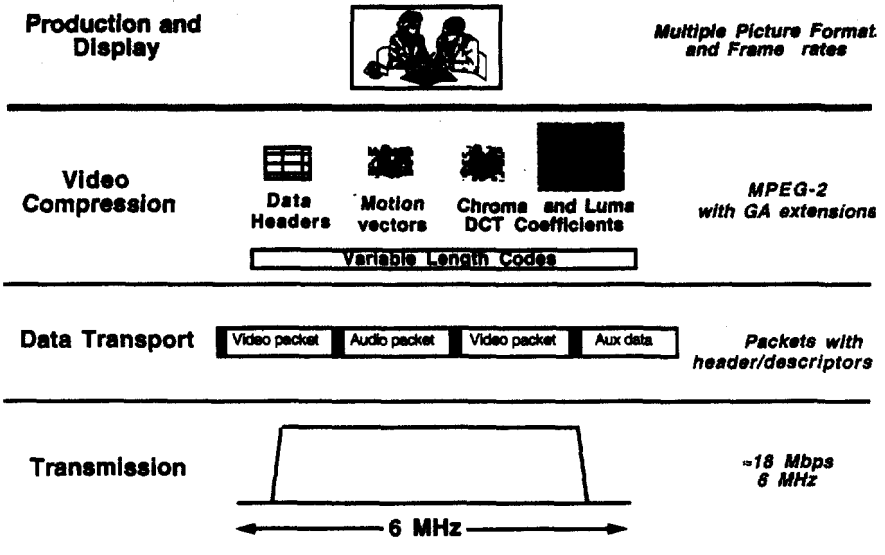

Figure 2.1 - The GA HDTV system's layered architecture and the PS-WP4 reference model.

While Picture layer Production and Display standards are not within the scope of a transmission standard, header/descriptors in the compression layer of the GA system support the

---

1 In accordance with PS-WP4 recommendation # 1.

2 In accordance with PS-WP4 recommendation # 2.

transmission of multiple picture formats and frame rates that are related to both high-definition video and film production, and that are also appropriate for computer-based applications. At the Video Compression Layer, the GA HDTV system is based on MPEG-2 compression, with a GA syntax extensions for AC coefficient leaky prediction. At the transport layer, the GA HDTV system is also based on MPEG-2, which uses a flexible ATM-like packet protocol with headers/descriptors[3]. At the Transmission Layer, the GA signal will provide a net user data rate of over 18 Mbps delivered in the 6 MHz terrestrial simulcast channel.

The GA HDTV system has been designed to provide interoperability at every layer of its architecture, and the PS-WP4 reference model provides an excellent framework to explain its interoperability features. Figure 2.2 shows the protocol stack that consists of the layers of the GA HDTV system (shown on the left) expanded in a form that corresponds to the reference model established by PS-WP4 (shown in the middle) as a basis for evaluating interoperability. Also shown is the ISO Open Systems Interconnect (OSI) reference model for data communications (on the right).

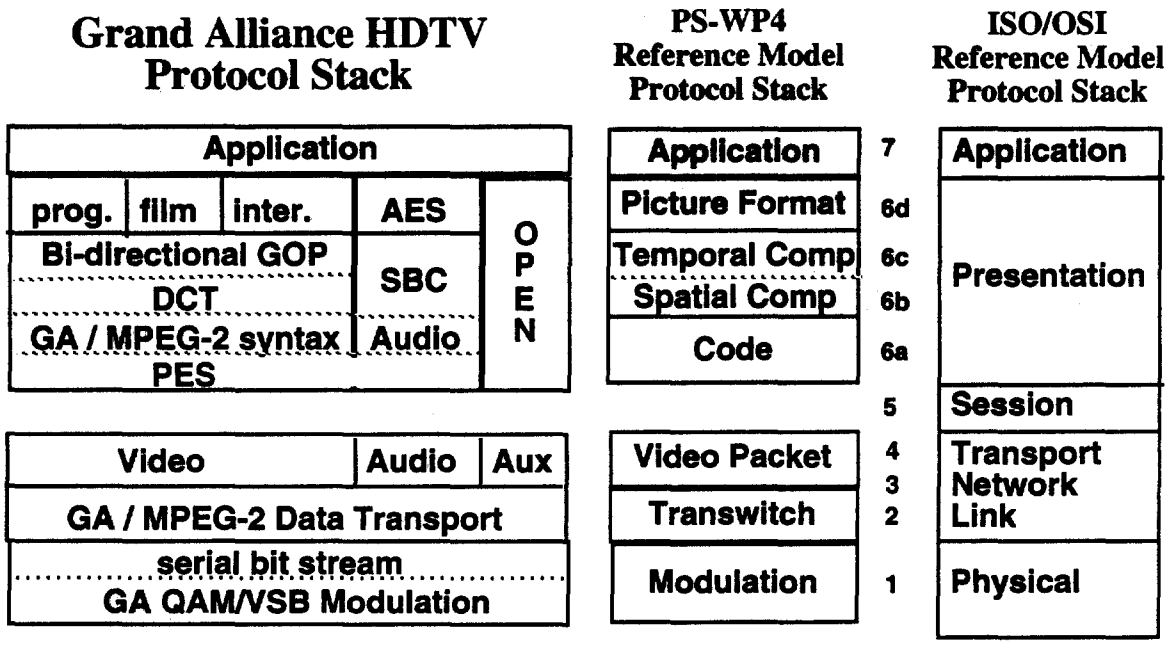

Figure 2.2 - The GA HDTV system's layered architecture and the PS-WP4 reference model

At the Picture layer, progressive scan formats are provided at both video and film frame rates[4], in addition to an interlaced format. The compression layer conceptually consists of temporal compression, spatial compression and code (syntax) sublayers. For temporal compression, the

---

3 In accordance with PS-WP4 recommendation # 4.

4 In accordance with PS-WP4 recommendation # 3.

MPEG Group of Pictures (GOP) approach is used to allow bi-directional motion-compensation across a block of frames. An additional AC coefficient leaky prediction mode is used by the GA. Spatial compression is achieved through the Discrete Cosine Transform (DCT). For the compressed code representation, the GA compression syntax is based on MPEG-2, but has additional syntax required to support AC coefficient leaky prediction. The Program Elementary Stream (PES) layer is the fundamental data stream that comprises a compressed video bit stream. At the video packet/transwitch layer, the GA system uses the MPEG-2 packet format, which provides the capability to synchronize the delivery of video, audio and auxiliary data packets in an ATM-like multiplexing environment. Finally, at the transmission layer, the serial bit stream is converted to a 6 MHz signal by an appropriate modulation technique *(the GA has not yet made the transmission signal format selection)*. Subsequent chapters of this document will describe the interoperability that is provided at each layer of the architecture.

The layered digital system architecture of the GA HDTV system means that at the application layer, many different applications can be enabled in addition to terrestrial broadcasting. These applications can take advantage of any or all of the GA HDTV system layers. Figure 2.3 shows four examples, each of which is represented as a layered protocol stack. In the first example, an intelligent Personal Digital Assistant could be built into the HDTV receiver, and make use of all of the GA system layers to acquire data from the broadcaster and present information to the consumer. In the second example, an electronic Publishing and Shopping application could deliver compressed video, audio and data on a computer disk, that can be plugged into an HDTV receiver (with an appropriate interface). In the third example, an Interactive Education and Training application could be delivered over a high speed ATM/SONET fiber network, but make use of the GA compression and picture formats. In the fourth example, a Medical Image delivery application could compress large format medical images with JPEG compression, and use the GA transport and transmission layers to deliver the data to a computer-based medical workstation.

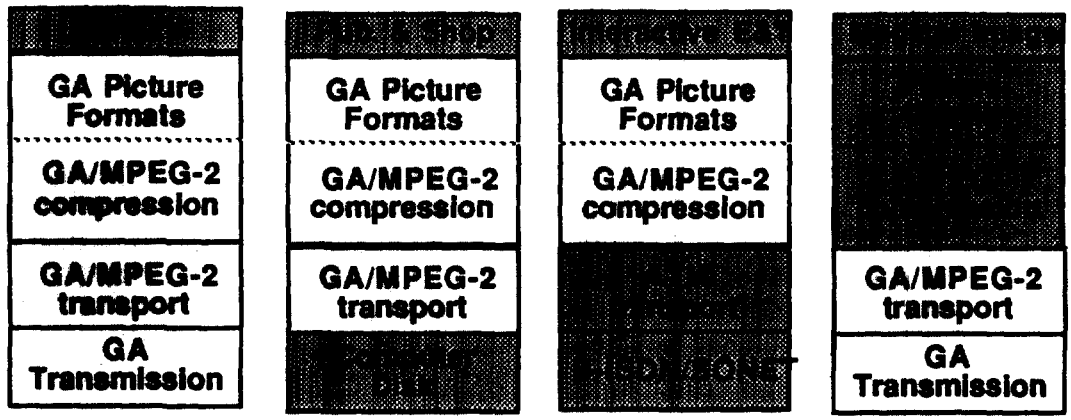

Figure 2.3 - Other Applications can be built on or around the GA HDTV system

Grand Alliance

In order to deliver applications such as those discussed above, it is desirable for consumer products to accommodate a variety of interfaces. Ideally, every HDTV product would provide standardized logical and physical interfaces at each layer of the system architecture. This approach is not cost-effective for all consumer products, which must span a broad spectrum of capability/performance and cost. Further, the FCC usually does not mandate the existence of any interface other than the RF input of a television receiver. Fortunately, in a digital system, a "virtual port" can be provided at any layer of the architecture through appropriate interface electronics. This approach is lossless and transparent to both the application and the HDTV receiver. For example, in the Interactive Education and Training application discussed above, even a low-cost HDTV receiver with only an RF interface could be used by providing a set-top box that inputs an ATM packet stream and produces an RF output. A set-top box would probably have to be used in any event, since the application would likely require a down-loadable microprocessor for running appropriate software.

Thus, the layered digital system approach of the GA HDTV system achieves flexibility and enables a wide variety of applications to leverage the system in many ways. The layered digital system approach ensures that regardless of the physical interfaces that are provided by various consumer products, applications can be built on or around consumer products.

2.2 HEADERS/DESCRIPTORS

In order to achieve powerful flexibility, the GA HDTV system incorporates a header/descriptor approach in two layers of its architecture. The function and capability of these header/descriptors are conceptually shown if Figure 2.4. (More detailed description about header/descriptors is provided in the discussion of each particular layer.)

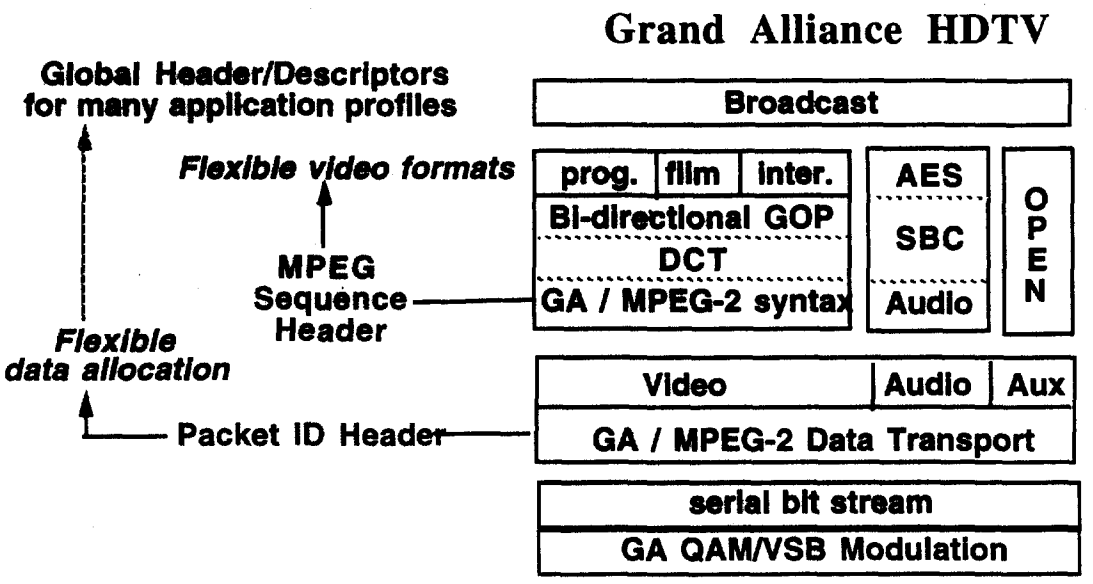

Figure 2.4 - Header/Descriptor approaches used in the GA HDTV system

At the picture format level, the GA HDTV system has format flexibility that supports both video and film frame rates, and both interlaced and progressive scanning, with square pixels in all formats *(as of this writing; video formats are not yet finalized, per the discussion in Chapter 6)*. This capability is provided by MPEG, which contains a Sequence Header that describes the video format that is represented by the subsequent compressed codewords. Furthermore, the MPEG-2 compression approach represents units of frames, which on an adaptive block by block basis may be coded as a single set of pixels or two sets of (interlaced) pixels. The result of this approach is that both interlaced and progressively scanned formats are supported by the MPEG-2 syntax, and the decompression of both formats can be practically handled in economical GA HDTV receivers. Note that this multiple format approach is practical due to the presence of frame store memory for decompression in the receiver. This allows picture format and display frame rate conversions to be performed in the receiver for minimal cost, and it provides receiver manufacturers with a variety of product options.

At the transport level, each of the GA HDTV Transport packets contains a Packet ID (PID) header/descriptor. The PID header/descriptor classifies the contents of the cell as a member of a particular data stream (e.g., video1, video2, audio1, audio2, aux data 1...aux data N). The overall GA HDTV data stream thus consists of many data streams, that are asynchronously multiplexed in an ATM-like approach. Through its header/descriptor approach, the GA HDTV system provides flexibility of services, interoperability with packet networks, and extensibility with freedom from backward-compatibility constraints.

The flexibility of the GA HDTV system may be extended even further by designating one packet ID type to carry a global header/descriptor data stream. This approach would allow great flexibility in expanding and describing the range of data streams that can be carried by the transport and transmission layers. If included as part of the final HDTV standard, the global header/descriptor can provide a mechanism to further extend the multiple data stream capability of the GA HDTV system by defining application profiles for different industries and/or delivery media. It could also provide a standard means for defining different optional approaches at each layer of the architecture.

2.3 SYSTEM INTEROPERABILITY OVERVIEW SUMMARY

The GA HDTV system, with its layered architecture, powerful use of header/descriptors, and capabilities for broad interoperability at each layer, ensure that it will be useful in a broad spectrum of applications.

3. TRANSMISSION LAYER INTEROPERABILITY

Interoperability at the transmission layer is influenced by existing and emerging standards in many media, including cable, satellite, and ATM networks. A special interoperability relationship exists between broadcasting and cable, since over 60% of viewers currently receive their television over cable. The Grand Alliance RF signal can be carried *directly* in a standard 6 MHz cable channel, and the current practice of frequency translation for rearrangement of channel assignments will work transparently. Modulation techniques for each delivery media must take into account the special characteristics of each medium, and the Grand Alliance simulcast transmission system is no exception. Fortunately, a serial bit stream provides the basis for simple interoperability despite these differences in modulation.

3.1 CONSTRAINTS OF THE SIMULCAST ENVIRONMENT

Many of the choices made by the Grand Alliance were constrained by the FCC mandate for 6 MHz simulcasting in the existing NTSC spectrum, with all of the associated problems of co-channel (city-to-city) interference between HDTV and NTSC sharing the same channel: each reduces the coverage area of the other, especially in large market areas.

For example, consider the goal of broadcasting ≈1000 line progressively scanned images at 60 frames per second. With today's video compression technology, this would require increasing the current 18 Mbit/sec bit rate by about 30-40%. Achieving this data rate would make the RF signal more fragile, with a corresponding loss in HDTV service area. To reclaim this area, the HDTV signal power would have to be increased, reducing the coverage area of existing NTSC broadcasters to unacceptable levels. The technical design tradeoffs in a simulcast transmission system are complex and multidimensional, involving:

- carrier-to-noise ratio
- co-channel interference from NTSC to HDTV
- co-channel interference from HDTV to HDTV
- upper adjacent-channel interference from NTSC to HDTV
- lower adjacent-channel interference from NTSC to HDTV
- upper adjacent-channel interference from HDTV to HDTV
- lower adjacent-channel interference from HDTV to HDTV
- co-channel interference from HDTV to NTSC
- upper adjacent-channel interference from HDTV to NTSC
- lower adjacent-channel interference from HDTV to NTSC

Furthermore, the balancing of technical compromises has important regulatory policy implications. The Grand Alliance has established a process (based on analysis and possibly hardware tests) to determine the best transmission technique. The four approaches under consideration (QAM, SS-QAM, 6-VSB with trellis coding, and 4-VSB) are all very close in performance.

3.2 CABLE INTEROPERABILITY

As established during the competitive round of testing, any of the four proposed GA transmission techniques can be carried *directly* on a standard 6 MHz cable channel. As digital standard definition television on cable emerges, cable companies may choose other transmission techniques that they consider best for their medium. Primarily because of the lack of a co-channel interference constraint, cable operators may be able to achieve as much as 40 Mbps in a 6 MHz channel. Interoperation between the GA system and such a high-speed cable system would be achieved at the Transport Layer, where the GA packet stream would be merged into the higher-speed cable packet stream, as shown in Figure 3.1.

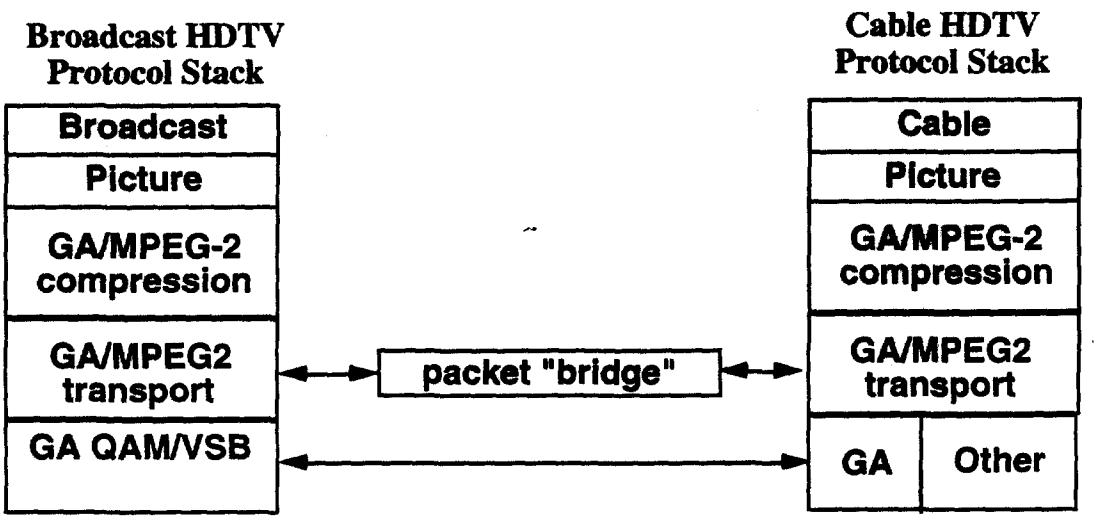

Figure 3.1. **Interoperation between cable and broadcast** will occur at the transmission layer in the case of direct RF translation, or at the transport layer in the case of high-speed cable data transmission.

3.3 SATELLITE, PACKET NETWORK AND OTHER DELIVERY MEDIA INTEROPERABILITY

Systems that do not share common modulation approaches at the Transmission layer may interoperate simply by the exchange of serial bit streams, as long as there is no need to multiplex the HDTV bit stream with other bit streams in a much higher capacity channel. Should this be the case, the systems will interoperate at the Transport layer (as described above for high-speed cable transmission), using a packet bridge to manage the appropriate packet multiplexing and demultiplexing tasks.

4. TRANSPORT LAYER INTEROPERABILITY

The Grand Alliance has adopted a packetized data approach with headers/descriptors[5]. This approach allows service providers to have total flexibility in deciding the mix of video, audio and auxiliary data that comprise the HDTV data stream. The GA HDTV system accomplishes this by specifying a Packet ID (PID) header for each packet. This same approach provides the extensibility needed to introduce future enhancements and new services, which will be assigned new PIDs. This capability will enable broadcasters to send multiple streams of video, audio and data programming to their audience, all complementing or enhancing the basic program content.

4.1 TRANSPORT DESIGN ISSUES -- WHY NOT ATM?

The terrestrial broadcast channel is limited in data rate and subject to severe error rates under poor reception conditions. The bit rate that can be achieved in the 6 MHz simulcast channel is preciously little for providing outstanding HDTV picture quality. Therefore, the picture quality of an HDTV simulcast transmission system is highly sensitive to transport overhead (header-to-payload size ratio) and error correction overhead. Yet the flexibility provided by packet header/descriptors are an extremely important capability, and powerful error correcting codes are essential in the severe error rate environment of terrestrial transmission.

ATM's short 53 byte packet size results in a large header overhead: the 5 byte ATM header comprises about 10% of the bits that make up its packet stream. This level of overhead is very wasteful of precious bits in a situation where the channel is bit-limited and the picture quality is very sensitive to bit rate. Consider that in a channel of approximately 18 Mbps capacity, the loss of about 1.8 Mbps of data rate would result in a significant degradation in picture quality. A longer packet size with lower overhead is clearly desirable from a picture quality point of view.

The packetized data must survive transmission under poor conditions, so the overhead due to Forward Error Correction (FEC) coding is also a concern. Reed-Solomon (or other block-based) FEC codes are more powerful and efficient when applied to longer packets, so the selection of longer packets also provides increased transmission robustness. Stated another way, for a given error correction capability, a longer packet size requires less FEC overhead than a shorter packet. Once again, reducing overhead in order to improve picture quality is an overriding consideration.

Finally, the ATM protocol does not provide certain services that are essential for an HDTV system, such as timing recovery, media synchronization, and encryption control.

---

5 In accordance with PS-WP4 recommendation # 4.

4.2 GA/MPEG-2 TRANSPORT

The transport layer of the GA HDTV system encapsulates the video and audio bitstreams into fixed-size transport packets. This packetization solves many problems: it packages the data into fixed-size units suitable for Forward Error Correction encoding (FEC), it multiplexes the various elements of the program (video, audio, data, etc.), it provides time synchronization for those elements, and through the use of packet identifiers (PID) header/descriptors, it provides flexibility and extensibility with backward compatibility. As shown in Figure 4.1, the GA system delivers a stream of packets, where each packet contains a single type of data (e.g., video, audio, program guide, etc.) identified by the packet's ID number, the PID. There is no predetermined mix of data required, and furthermore the mix can change *dynamically* from moment to moment[6].

video	TEXT	video	audio 1	video	video	audio 2	video	video	PGM GD	video

Figure 4.1. **Packet Multiplexing.** The GA HDTV System separately packages video, audio and auxiliary data in fixed-length packets. This enables data multiplexing, Forward Error Correction, time synchronization, and extensibility with backward compatibility.

This packet structure allows great flexibility in the services that can be provided. For example, a secondary video program can be introduced, such as another camera angle during a baseball game, that would appear in a window on the receiver at the viewer's option. Multiple language broadcasts can be facilitated through the introduction of a new audio packet stream. Program-related software can be downloaded to "smart receivers". Pay-per-view television can be serviced through decoder addressing and scrambling control bits. A significant portion of the channel capacity can be momentarily diverted for use other than video[7], such as to provide rapid addressing of subscriber terminals, during periods of relatively easy-to-compress images (e.g. stills). The extensibility provided by the PID header/descriptors is also key to enabling the eventual introduction of higher resolution formats (see the discussion in Chapter 8) in a backward-compatible way[8]. Many other applications will undoubtedly be invented as HDTV becomes part of our infrastructure.

The Grand Alliance has chosen to use a fully compatible subset of the MPEG-2 Systems Transport[9]. The MPEG-2 packet is 188 bytes long, consisting of 184 bytes of payload and 4 bytes of header, as shown in Figure 4.2. The packet length was chosen to easily interoperate with

---

6 In accordance with PS-WP4 recommendation # 5.

7 In accordance with PS-WP4 recommendation # 5.

8 In accordance with PS-WP4 recommendation # 8.

9 In accordance with PS-WP4 recommendation # 10.

ATM using a 4:1 ratio. The header contains the packet sync byte, a 13-bit service identifier (PID), a 4-bit continuity counter to help in the event of packet loss or mis-ordering, bits for control of scrambling systems (e.g. pay-per-view) and an optional priority bit to indicate the relative priority of the data. The payload may optionally contain an Adaptation Header (which is counted as part of the 184-byte payload). The Adaptation Header contains information to distribute timebase reference to decoders, indicate random access locations for decoders, and to indicate bit stream splice points for affiliate/headend insertion equipment. The Adaptation Header also provides the facility for sending private user data, such as conditional access messages.

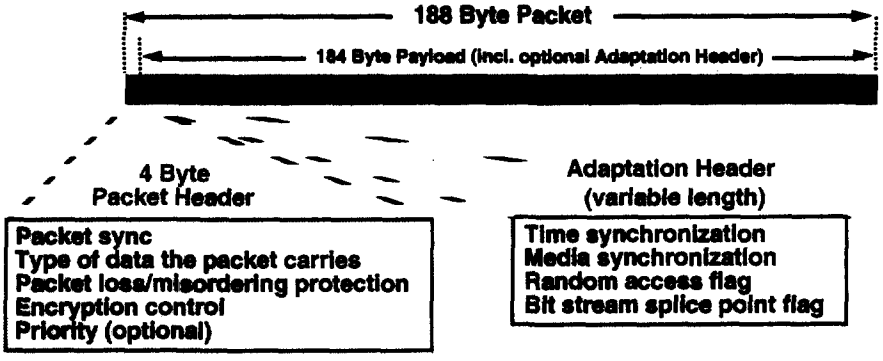

Figure 4.2. **The Grand Alliance (MPEG-2) packet.** The Grand Alliance (MPEG-2) packet is 188 bytes long consisting of 184 bytes of payload and 4 bytes of header. The payload may optionally contain a Adaptation Header (which is counted as part of the 184-byte payload). The packet length was chosen to interoperate with ATM using a 4:1 ratio.

4.3 ATM INTEROPERABILITY

There are several ways to easily achieve interoperability between the Grand Alliance Transport Layer and ATM. By the clever choice of payload/header ratios, the GA/MPEG-2 transport format facilitates ways to either *encapsulate* or *convert* MPEG-2 packets to ATM cells.

As shown in Figure 4.3, the GA/MPEG-2 packet may be encapsulated within four ATM packets by using only 1 optional ATM AAL byte, which leaves 47 usable payload bytes per ATM packet. Since 4 x 47 is 188, this provides an exact fit for the entire GA/MPEG-2 packet. An important advantage of encapsulation is that it is a simple way to retain the full functionality of both the MPEG-2 Transport stream (as defined in its header) and the ATM transport stream (as defined in its header). By encapsulation, ATM's 8 bit service type header is *multiplied* with MPEG's 13 bit PID header. Thus, an ATM stream can carry 2^8 MPEG streams, each of which can carry 2^{13} data streams, for an effective multiplexing capability of 2^{21} data streams.