CATV Digital Compression Systems Interoperability: A Paradigm for the Future

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Abstract

Digital video compression is poised for initial CATV deployment in 1994. An important consideration for the cable operator contemplating the deployment of the new digital technology is the interoperability of different vendors' compression systems. Interoperability offers the potential advantages of interworking between different vendors' equipment, increased maintainability and reduced maintenance costs. Most significant is the creation of an extensible digital infrastructure that can readily support future interactive, networking applications.

This paper outlines the major areas that must be addressed to provide interoperability in an end-to-end compression system: the types of video and audio compression employed, specification of transport formats and transmission system characteristics (including signaling channels) for various media (e.g., satellite, coax, fiber), access control and encryption, and equipment interfaces and interconnection protocols.

INTRODUCTION

The notion of interoperability is fundamental to the creation of integrated communications networks supporting a wide variety of services. As CATV networks continue to evolve from analog to digital, from coax to fiber, and from one-way broadcast to two-way interactive services such as Impulse Pay Per View (IPPV), interactive multimedia and Personal Communications Services (PCS), the need for end-to-end system interoperability specifications will intensify.

Traditional CATV systems, based primarily upon broadcast services, have tended to be geographically localized and isolated from other systems. There has been no need to ensure compatibility of equipment deployed in different systems, making incompatibility the rule rather than the exception. Local optimization of equipment and resources has been an appropriate and accepted paradigm. Interoperability between systems — and between the elements that make up each end-to-end system — has not been a requirement.

The traditional CATV architecture is rapidly facing obsolescence with the tremendous increase in the breadth of services that cable operators are now introducing or planning to offer. Interactive and transaction based services will require the capability to support communications between different CATV systems, as well as external communications systems such as public telephone and data networks. The future success of the new service offerings critically depends upon the adoption of a new paradigm of interoperability.

Benefits of Interoperability

In the near term, interoperability offers the cable operator the potential for interconnecting equipment produced by different vendors to create fully operational end-to-end systems. Provided that the necessary conditions — outlined below — are met, source material can be appropriately processed at a point of origination (such as a satellite uplink site), be transported through a network consisting of a variety of equipment and transmission media, and be reconstructed at the receiving end in a manner that is totally transparent to the information consumer.

Operations and maintenance considerations also support the notion of digital interoperability. The new generation of digital equipment will be significantly more complex than today's analog equipment. Moreover, in order to access the received analog signal that will actually be seen by the end customer, the digital bit streams must be demultiplexed, decrypted and decompressed. Standard techniques for testing analog video equipment will be of little help in diagnosing the problems of digital systems.

Testing, maintenance and fault isolation of digital systems will require special equipment with the capability to properly analyze bit streams and provide status and error indications to test personnel. Interoperability will reduce equipment needs to a practicable level and eliminate a needless proliferation of incompatible test gear. Side benefits also include reduced maintenance time and the requisite amount of training required by maintenance personnel.

The first opportunity to adopt the interoperability paradigm is the deployment of the new digital compression technology. Because the new technology encompasses virtually all aspects of an end-to-end system, the equipment that is deployed today will have a long lasting effect and will continue to influence the ability — or inability — of CATV networks to support new services for years to come. Interoperability will greatly enhance future network extensibility and will favorably influence the economics of new service offerings by allowing them to be deployed incrementally, supported by a solid digital infrastructure. Of course, interoperability also demands the mutual coexistence of the new digital technology and the existing analog technology that will continue to be used for many years to come.

Thus, the long term value of interoperability is the capability to grow networks easily and seamlessly to support new services without the need to replace the existing infrastructure of equipment, coax and fiber. In effect, interoperable design criteria can ensure that the digital infrastructure that is first put in place to provide IPPV and EPPV services in the near term can be evolved into digital highways of the future. Through the establishment of appropriate criteria, it will also be possible for CATV systems to interconnect with other digital communications systems, such as Local Area Networks (LANs) and Wide Area Networks (WANs) and even digital telephony networks. The time for the new paradigm has now arrived.

Interoperability Defined

Interoperability may be defined as the design and deployment of consistent functionalities and interfaces throughout an end-to-end information delivery system to ensure operation at an expected level of performance. The most significant characteristic of an interoperable system is the ability to easily accommodate compatible equipment at any point in the communications path from satellite uplink to cable head end to the home terminal. Moreover, an infrastructure of compatible equipment provides a clear path to the future, readily supporting the introduction of new services.

Interface compatibility includes the specification of signal levels and wave forms, bit rates, bit framing and packet formats, protocols and standard message sets. Key dimensions of functional interoperability are compression, encryption, multiplexing, modulation, error correction and other transmission signal processing. Other significant network attributes are signaling modalities, return channel characteristics and the many aspects of access control.

It is important to note that this level of interoperability does not preclude the possibility of advanced, value-added features that can serve to differentiate different vendors' products. Indeed, a truly interoperable digital infrastructure can serve as the vehicle for providing a great variety of new features and services that can be designed in accordance with a well-defined set of interoperability criteria.

DIMENSIONS OF INTEROPERABILITY

Although the new digital technology affects virtually every aspect of system operation and performance, it is important to recognize that it is compatible with the existing infrastructure of fiber, coax and analog transmission equipment. Conceptually, a new layer of digital functionality is being placed upon — and supported by — the present analog CATV plant. However, it is equally important to note that the nature of the new digital overlay will essentially determine the capability to support future interactive services.

The key dimensions of interoperability are the functional elements that determine end-to-end system performance. They include compression, transport formats, modulation, error correction and various other transmission signal processing, downstream and upstream signaling, return channel characteristics, and access control and encryption. The interoperability requirements of each of the key dimensions is described in more detail below.

Digital Compression

Digital compression of video and audio signals constitute the foremost enabling technologies for the new IPPV and EPPV services that will also serve as the foundation for many future services. Many different — and incompatible — compression techniques have been proposed, creating a difficult challenge for cable operators and equipment vendors alike in choosing an appropriate compression technique.

Video compression algorithms can be described in terms of their specific feature sets and their syntax. Features refer to the definition of elements used to represent compressed video and the rules for using these elements to reconstruct decompressed video images. Examples include motion vectors, discrete cosine transform coefficients, quantization matrices and other mathematical constructs that are typically utilized by compression algorithms. Syntax is the set of rules used to efficiently represent the various elements in a binary form that can be decoded by an appropriate digital receiver. Similar comments also apply to audio compression algorithms.

Fundamental to digital CATV interoperability is the use of video and audio compression algorithms, or families of algorithms, with common features and syntax. A digital cable converter will not be capable of decoding a compressed video or audio signal that has been compressed with an incompatible compression algorithm. In addition to various proprietary compression schemes that have been proposed, considerable effort has been expended in the development of digital compression standards. Most notable in the context of CATV is the MPEG2 standard.

An interesting aspect of MPEG2 video compression is the proposed support of distinct "profiles", each corresponding to a specific feature set. Different profiles may be best suited to different applications, based on required functionality and cost considerations. For example, the creation of a profile optimized for CATV applications has been proposed. All profiles will employ the same syntax and some profiles may include other profiles as subsets. Nevertheless, for interoperability any particular MPEG2 decoder would have to support the profile (or a superset of the profile) used by the video encoder.

Essential elements for compatible video compression include the syntax and feature set, as well as the range of compressed bit rates supported and any constraints that are placed upon compression parameters, such as motion vector ranges or limits on receiver buffer sizes. In addition to feature set and syntax, compatible audio compression requires definition of auxiliary data channels and specification of any built-in error correction parameters, such as those that are built into some existing algorithms. However, as discussed below, interoperability is better served by including error correction with medium specific transmission equipment and logically separating the compression and transmission functionalities.

Transport Formats

Associated with the introduction of digital compression technology is the deployment of a new digital overlay to the existing analog infrastructure. The definition and specification of every aspect of this digital overlay is critical to interoperability and system extensibility.

Because every bit in a digital communication system appears superficially to be indistinguishable, formats for organizing digitally encoded information must be established. The definition of these transport formats can either facilitate or severely limit the future networking potential of CATV systems, including the ability to interwork with other communication networks.

Closely associated with the transport format definition is a plethora of issues related to timing, framing and synchronization of bit streams, means for associating and synchronizing video, audio and any associated data within a bit stream, and many more related concerns. There is also a number of issues related to separating digital streams associated with different points of origination and recombining them for targeted redistribution. Broadcast based approaches are generally not amenable to supporting this type of networking.

Flexible networking is also needed to support different bit rates associated with varying degrees of compression and to accommodate the different capacities of various transmission media, including satellite, coax and digital fiber. Moreover, flexible networking and extensibility to future services demands the use of compatible transport formats that can be used regardless of the actual transmission media, as discussed more fully below.

All the issues noted above must be satisfactorily resolved in order to ensure interoperability. The definition of transport formats is another area of active standardization activity, particularly within MPEG2.

Digital Modulation and Error Correction

Digital compression and transmission lead naturally to the use of digital modulation techniques. Particular forms of modulation may be more or less appropriate for a given transmission medium, depending upon the fundamental limitations of that medium. It is essential to note that the type of modulation technique is logically independent of the transport format specification. Specifically, in the case of IPPV services, all bit streams must ultimately be decoded by a large number of home terminals, regardless of the route by which the digital programming actually traverses the system. It is therefore imperative that medium specific transmission equipment be designed to serve as digital highways that transport bits *without* altering their transport format. This logical separation of functionality is a cornerstone of system interoperability.

Forward Error Correction (FEC) techniques are also designed to accommodate the transmission limitations of a specific transmission medium, such as degraded signal to noise ratio or channel dispersion. The particular technique employed and the specific number of error correction bits that is used can vary significantly between, for example, satellite and cable transmission. Interoperability demands that the medium dependent error correction functionality be logically separated from the medium independent transport format.

The interoperability of transmission components requires not only compatible modulation and error correction techniques. Transmission equipment must designed to a common set of specifications, including well-defined external interfaces and input and output signal characteristics.

Transmission Interfaces

Transmission interoperability requires common specifications for the various interfaces that exist within an end-to-end system. At the most fundamental level are physical interfaces, which are specified by physical connectors, acceptable ranges of signal levels and wave form variations (defined by masks), impedance levels, spectral shaping, frequency plans and channelizations supported. Additional measurable signal characteristics that must also be specified for compatible operation include frequency and phase stability over time and temperature, the degree of permissible linear and nonlinear distortions, and bit stream jitter generation, transference and tolerance, to name but a few.

Return Channels

The introduction of interactive services will necessitate the specification of *all* the interoperability dimensions described above for *both* downstream and upstream channels. Consideration must be given to the natural evolution toward greater upstream capacity, the impact of transmission performance upon interactive services, and the protocol aspects associated with interfacing to other external networks.

Signaling Channels

In addition to their physical interfaces, transport formats, and modulation and error correction techniques, signaling channels are characterized by their protocols and message sets. The minimum requirement for interoperability is the adoption of a standard set of protocols that can support any type of control message. The prospects for interoperability will be further enhanced with the definition of a basic set of universal control messages that apply to all foreseeable applications. Examples could include commands for initializing the state of the home terminal, performing built in self tests, and so on; and creating queries for operational status or consumer usage information on an addressable terminal basis.

Access Control and Encryption

Security and access control are essential to the viability of value-added services. At present there is no single access control standard, although most approaches utilize the same basic principles. The existence of a number of proprietary access control systems is perhaps the greatest barrier at present to complete system interoperability. What is needed is a more general framework which encompasses all existing systems as well as potential future access control schemes.

A minimum requirement for system interoperability is the logical separation of access control from the other end-to-end system functions. In addition, as in the case of signaling, interoperability would be aided by a set of standard interfaces, including connectors, signal levels and so forth. The establishment of a basic protocol scheme would provide a further means of communicating access control messages of any desired format *without* compromising the security of a system. These factors are important to the development of low cost home terminals with universal access control capability.

Digital encryption is a fundamentally simple operation involving only the performance of a logical "exclusive or" of the data to be encrypted with a secure pseudo random sequence that can be updated in near real time. The paramount issue here is the absence of a standard relationship between the encryption process and the transport format. This subject is also being addressed by the MPEG2 systems working group, along with the definition of transport formats.

THE ROLE OF STANDARDS

Interoperability is also facilitated by the development of industry standards and adherence to these standards in equipment design and operation. Although a number of standards already exist for digital video and audio formats, most other important aspects of an end-to-end digital CATV system have not yet been standardized. As noted above, many interoperability aspects of particular relevance to the CATV industry will be addressed by the emerging MPEG2 standard, which is presently being defined by the International Standards Organization (ISO) in conjunction with the International Electrotechnical Commission (IEC). MPEG2, which is an extension of the MPEG1 standard, encompasses video and audio compression and transport formats (known as "systems" in MPEG parlance).

A major issue with any evolving standard, including MPEG2, is the timeliness of final standardization and subsequent availability of low cost VLSI implementations in relation to perceived market needs for deployment. Although short term deployment of non-standard technology may address immediate opportunities, this approach carries the risk of creating a digital infrastructure with limited extensibility to support future applications.

SUMMARY

The deployment of digital video compression systems marks the dawn of a new era for the CATV industry. The new technology will create a digital overlay, supported by the existing analog plant, the characteristics of which will critically determine the ability of cable operators to introduce future services. Many new interactive, two-way services will require the ability to interoperate with other systems, including other types of communications networks.

Thus, with the new digital era comes the opportunity to adopt a new paradigm of system interoperability: a paradigm with a path to the future.