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Broadband Video/Audio/Data Distribution Networks — The Need for Network Management

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Abstract

Audio-visual/data service delivery systems are based on complex network, distributed system and application architectures that enable the wide-area coordination, control, and delivery of audio, video, and data. One of the central logical components of these architectures are the transport/program/service streams used in storage and transmission of audio, video, and data. The composition of the transport/program/service streams is standardized by the Motion Picture Experts Group (MPEG) in the MPEG-2 standard.

In this paper we give an overview of the issues involved in managing MPEG-2 based audio-visual/data distribution networks and present a brief analysis of the applicability of different architectural management frameworks and standards.

Keywords

Integrated management, broadband, MPEG-2, audio-visual service delivery.

1. OVERVIEW

Carriers today, Local Exchange Carriers (LECs), Interexchange Carriers (IXCs), Competitive Access Providers (CAPs), or Multiple System Operators (MSOs) are seeking new geographic and demographic markets. The nature of their services is rapidly changing from static packaged, scheduled programming to dynamic, interactive services such as: Video-On-Demand (VOD), near-VOD (NVOD), interactive shopping, interactive gaming, etc. There remains considerable debate over network architectures and distribution technologies. Clearly substantial sums of money will be spent on plant and infrastructure (in North America some estimates

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are in the order of $75 billion) (Tankin, 1996).

Due to the cost and nature of some high-bandwidth distribution architectures, cost recovery from subscribers is a significant issue. Consumer selection of network operator and carrier service is less of a technology issue, and more of a reflection of programming content, service availability, service quality, service flexibility and cost. Services are becoming a commodity nature with content changed frequently. Therefore the ultimate challenge for the carriers is to provide these services (telephony, video, gaming, shopping, data and telemetry) at competitive cost, minimize subscriber churn and keep service areas intact.

For the traditional LECs, IXCs, and some CAPs, this may not be much of a challenge. For the MSO community at large, the ability to control and manage network resources against acceptable levels of service availability and quality is a new dimension of the competitive contest. Promoting telephony and data services based on a network that lacks appropriate management technology and operational practices are bound to result in disaster for the MSOs. The management of broadband networks and network services is a prerequisite for success. All carriers, regardless of network management experience, are required to develop and deploy new generation management systems. This is due to the cost of distribution technology, the competitive environment, network and service complexity, and increased treatment of services as commodity.

The video, audio, and data service delivery systems deployed and operated today are an order of magnitude more complex then those deployed and operated only a few years ago. Today's systems are based on complex network, computing, and service architectures. They provide a wider variety of program delivery capabilities and services, use new technologies and vastly more complex types of equipment to enable the wide-area coordination, control, and delivery of audio, video, and data (Weiss, 1996).

The new video-audio-data-distribution networks can no longer be managed by the patch-work of management applications that have been created in an ad-hoc fashion to solve the problems of the day. Satellite Uplinks today may consist of several hundred Encoders with dozens of IP nodes each, controlled by several hundred control computers. Satellite Downlinks and Cable Headends may be on top of a pyramid of several HFC distribution networks; each with thousands of network elements serving different overlaid logical RF distribution networks; each multiplexing a variety of services ranging from digital video, to digital telephony, to Internet services. This increased complexity of managed equipment and services coupled with today's market requirements, necessitate powerful architectural solutions. These solutions should facilitate the use of off-the-shelf management technologies and tools for non-video-audio-data-distribution specific management tasks while enabling the seamless integration of newly developed video-audio-data-distribution networks.

In this paper we give an overview of the tasks and possible architectural solutions for management of video-audio-data distribution networks. First, we introduce an architectural framework based on networks deployed or planned today. Within that framework we specify common services and applications. We then outline management requirements and relate them to a combination of different off-the-shelf technologies, capable of supporting the specified common services and applications. We concentrate only on the Uplink side of the distribution network and just briefly consider the requirements of the Downlink distribution plant and Headend.

2. MPEG-2 BACKGROUND

The central logical components of audio-visual/data architectures are the transport/program/service streams used for storage and transmission of audio, video, and data. The composition of the transport/program/service stream is standardised by the Motion Picture Experts Group (MPEG) in MPEG-2 standard (ISO 1-4, 1994).

MPEG-2 streams are created by Encoders from other such streams and/or elementary audio/video/data/control information. Decoders recreate the elementary audio/video/data from MPEG-2 streams.

An MPEG-2 Transport Stream consists of one or more programs each containing one or more elementary streams and other streams multiplexed together. Each elementary stream consists of access units, which are the coded representations of presentation units. The presentation unit for a video elementary stream is a picture. The corresponding access unit includes all the coded data for the picture. The access unit containing the first coded picture of a group of pictures also includes any proceeding data from that group of pictures. The presentation unit for an audio elementary stream corresponds to samples from an audio frame.

Elementary stream data is carried in PES packets, which are inserted into transport packets. Transport packets are carried in Packet Identifier (PID) Streams, which correspond 1-to-1 with PES streams. The contents of the data contained in the transport packets is identified by their PID via the Program Specific Information (PSI) tables. The PSI tables are carried in the Transport Stream as additional PID streams. The PSI tables listed below contain the information required to demultiplex and present programs:

- Program Association Table
- Program Map Table
- Network Information Tables
- Conditional Access Table

While the PES layer transports the video, audio and isochronous data, additional PID streams are defined for other PSI that may include messages related to access control, text services, asynchronous data services, subtitles, etc.

Figure 1 below illustrates the structure of MPEG-2 communications represented as a OSI-style layered architecture:

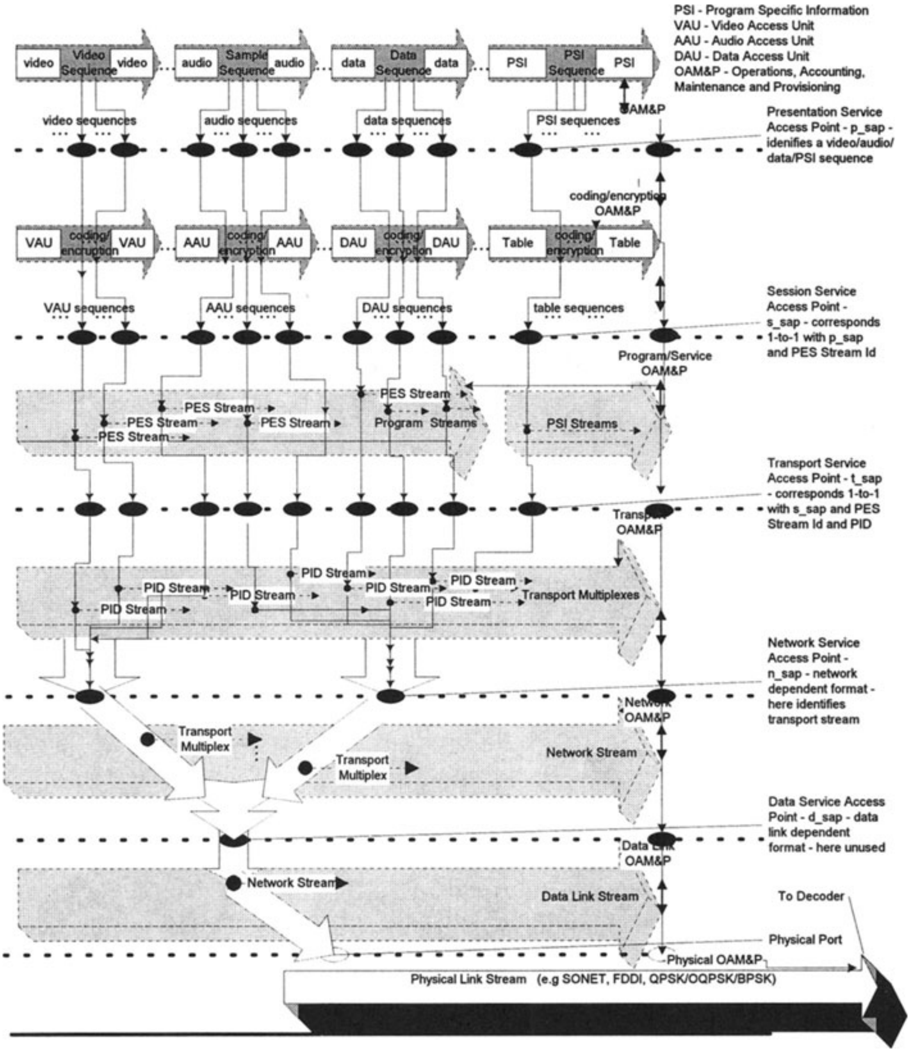

Figure 1. MPEG-2 Communications Architecture

3. PHYSICAL ARCHITECTURE

MPEG-2 streams are created by Encoders from other such streams and/or from elementary audio/video/data/control sources. Decoders recreate the elementary audio/video/data from MPEG-2 streams. Commonly, the communications system underlying MPEG-2 based audio-visual/data distribution networks can be subdivided into the following functional domains illustrated in Figure 2:

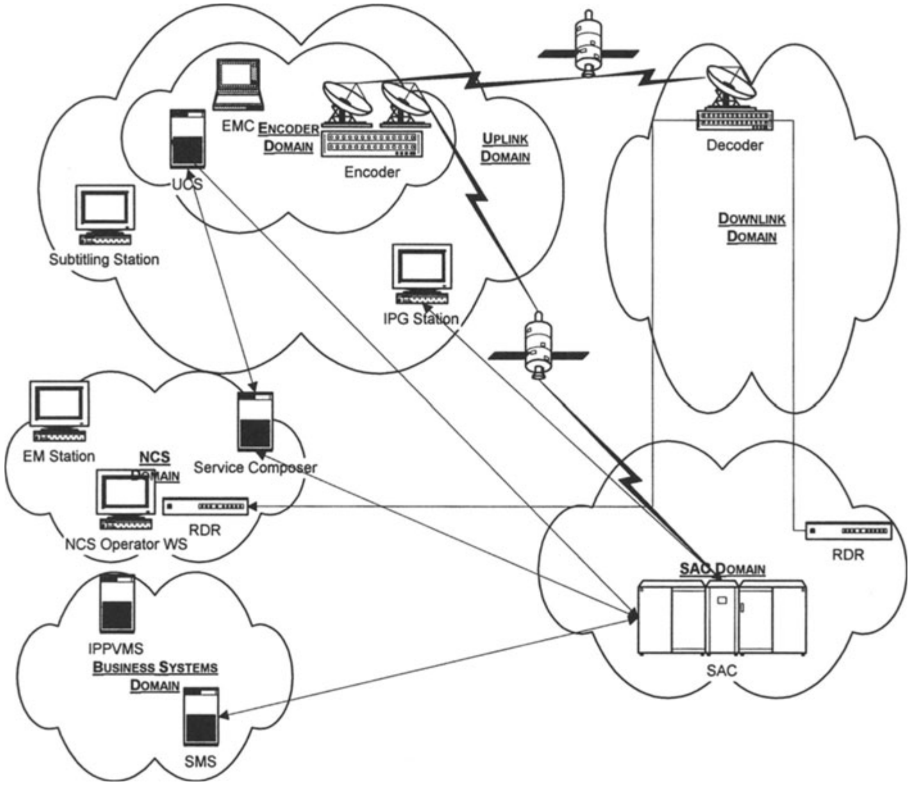

Figure 2. Sample Video/Audio/Data Distribution Comm. Architecture

- Network Control System (NCS) Domain — consists of program authoring stations, network management systems, entitlement management systems, etc.
- Uplink Domain — consists of a number of encoders controlled by Uplink Control Systems (UCSs) and other systems used to support the encoders such as video servers, automatic audio/video feeder networks to encoders, subtitling stations, etc. The Uplink Domain is usually subdivided into multiple:
  * Encoder Domain — consists of encoders and devices supporting encoders. Encoders are devices that generate MPEG-2 transport multiplexes from video/audio/data sources in a variety of different input formats and other transport multiplexes.
- Business Systems Domain — consist of a number of systems dealing with subscriber management and billing.
- Subscriber Authorization (SA) Domain — consists of a number of systems dealing with subscriber authorizations, key management, etc.
- Downlink Domain — can be of two types:

  * Direct Broadcast System (DBS) consisting of end-user consumer Integrated Receiver Decoders (IRDs)
  * Commercial IRDs feeding a CATV network

- Cable Headend Domain — usually overlaps with the Downlink Domain and can be of varying complexity. The Downlink Domain can include commercial IRDs, Head End Transcoders, Encoders, management systems for the Headend, and distribution plants. Optical or RF equipment is used to feed the distribution plants.
- Distribution Plant — from the Cable Headend Domain a variety of different access network technologies can be employed; these include Hybrid Fiber Coax (HFC) and Switched Digital Video (SDV).

The NCS Domain consists of Service Composers, which create programming services, schedule programs, and manage UCSs accordingly. Entitlement Management Systems (EMSs) contain the commercial IRD authorisation database, Reportback Data Receivers (RDRs) for Private Networks (using IRD diagnostic Reportback capabilities), and Network Management Stations. Commercial IRDs may be Headend receivers or a private network where all IRDs are treated as commercial units.

The main applications within the NCS domain are: defining program schedules, commercial access control, scripting using the authoring station, and management including RDR-based commercial IRD fault management.

The main components of the Encoder Domain are the Uplink Control System (UCS) and the Encoder. The UCS performs several functions (not required to be co-hosted). These functions include: Encoder control, generating required PSI, and generating messages related to access control. It consists of one or more UCSs, and one or more Encoders. The main application facilitated by the Encoder Domain is the Encoder programming and management.

Elements of the Encoder Domain interact closely with other elements of the Uplink Domain that are mostly used to create, store, and provide content for Encoders. Elements of the Encoder Domain also closely interact with elements of the Network Control System Domain. They are used to control all elements of the Uplink Domain and most significantly to provide UCSs with the program schedules and information necessary to manage Encoders. Finally, elements of the Service Access (SA) Domain interact with both UCSs and Encoders.

Figure 3 below illustrates a possible Encoder Domain configuration with the major computing and networking components:

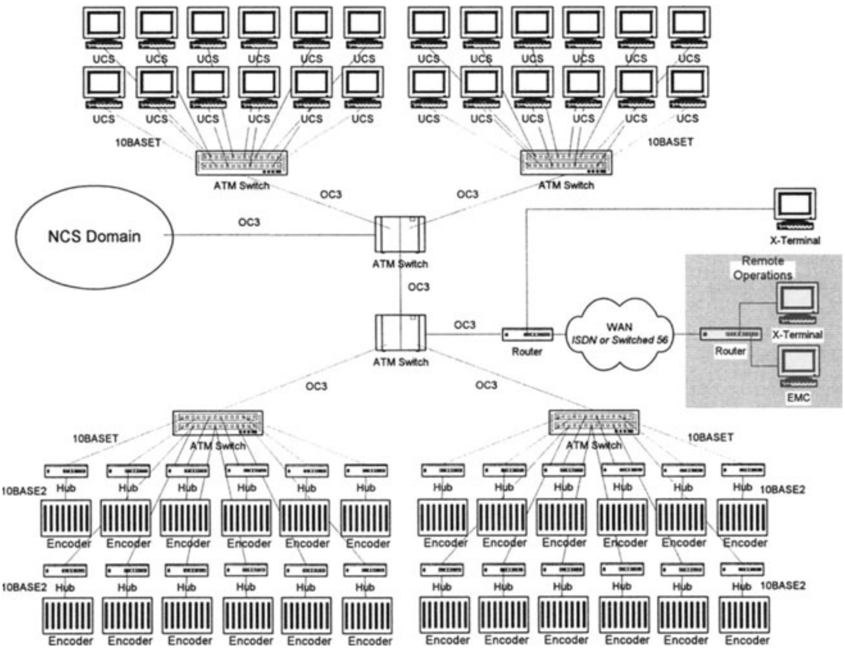

Figure 3. Encoder Domain Example: Switched Virtual LANs with ATM

The Uplink Domain includes, at a minimum, the Encoder Domain and possibly Interactive Program Guide (IPG) stations. The Uplink Domain may include different types of source equipment for video/audio, isochronous and asynchronous data, subtitles. and text services. Systems, such as the source traffic control system, automation system, and authoring station may be included as well. The main application is the generation of transport multiplexes. The UCS-s, source equipment and auxiliary data services are managed by the NCS domain.

The Business Systems Domain consists of Subscriber Management Systems (SMSs) and Instant Pay-Per-View Management Systems (IPPVMSs), which are used by the operator to bill IRD owners for their programming. The main application here is subscriber management. Business Systems communicate with the SA.

The SA Domain consists of Subscriber Authorization Systems (SASs), which authorize and manage all consumer IRDs, and RDRs for consumer IRDs. The main application here is subscriber management and consumer access control.

The Downlink Domain contains the population of Direct Broadcast System (DBS) IRDs, which may be consumer or commercial units. The Downlink Domain intersects with the Cable Headend Domain and the cable access plants. Currently two architectures are favored among carriers (Pugh, 1995). They are:

- Subcarrier Modulated Fiber Coax Bus (also known as Hybrid Fiber Coax) — is mostly an extension of the existing CATV fiber-coax topology.
- Baseband Modulated Fiber Bus (also known as Switched Digital Video) — closely resemble the Fiber-to-the-Curb architecture.

We consider only the HFC architecture. The Downlink Domain CATV for a large metropolitan network typically consists of a primary Central Office (CO) or Head End (HE) containing Encoders and Transcoders interconnected via multiple fiber optic links with distribution hubs. Each distribution hub is the root of a typical HFC access network to subscriber premises. The CO or HE also interfaces local digital telephony switches.

The HFC networks consist of optical fibers from the distribution hub to each fiber node, and the coaxial distribution plant from each fiber node to the subscriber premises. Two separate optical fibers between the distribution hub and the fiber node carry the downstream RF spectrum (typically, 50 to 550 or 750Mhz) or upstream RF spectrum (typically, 5 to 40 MHz). The Downlink network may be shared by different product classes such as digital telephony, switched digital service (e.g., ISDN), interactive multimedia, etc. This is accomplished by RF spectrum allocation and management over the same physical network.

Network elements of the distribution plant today do not have sufficient computing resources to utilize any of the standard network management protocols such as CMIP or SNMP. It is therefore necessary to manage the distribution plant by proxy where the actual management protocol between the proxy control unit and the network elements is most frequently RF based.

Within the HFC networks, RF Spectrum needs to be managed and coordinated with configuration management, performance management, traffic management, and fault management systems of Head End and distribution plant (Ahmed, 1996). The purpose of RF Spectrum management is to allocate the RF spectrum of the physical HFC subnetworks to multiple vendor's products supporting digital services. These products are supported using multiple logical HFC subnetworks in the same physical HFC subnetwork. The downstream and upstream RF spectra need to be coordinated.

The different domains interact for a number of different purposes. The most significant interaction types are:

- UCS/Service Composer—used mostly for communicating control information such as schedules to the UCS and reporting events to the Service Composer,
- SAS/Encoder broadcast — used mostly for communicating control information to the decoders through the encoders by means of MPEG-2 control messages.
- Encoder/Decoder broadcast — the main distribution mechanism for the MPEG-2 transport multiplexes to the consumers; all services and applications involving the Decoder rely on this link.
- Decoder/RDR — used for subscriber control and billing for services such as Impulse Pay Per View (IPPV).
- UCS/SAS — used for applications such as IPPV.

- Service Composer/SAS — used for synchronization of system wide data.
- Business Systems/SAS — used for applications such as consumer access management.

4. VIDEO/AUDIO/DATA SERVICES

Any MPEG-2 service can contain audio, video, data, text, control, and even executable components. A control stream is present for every service in the transport multiplex. That stream includes the MPEG-2 Program Map message. This channel may optionally also contain related text. The components of any service may be encrypted to strictly limit access. The following subsections give a brief overview of Video, Near Video on Demand (NVOD), Radio, and Data services.

4.1 Television Service

Television service includes at least one video component, one audio or subtitling component, and a service control component. Access to these components can be selectively controlled for each user. Additional components may include:

- Additional audio components for additional language tracks
- A data channel can supply information to augment video and audio (educational applications, or statistics related to a sporting event, for example)
- additional video components can be present to support synchronous commercial insertion

Near Video on Demand (NVOD), although a service in the sense of a consumer offering, is not handled as a transport multiplex service. By staggering the start time of multiple instances of the same service, the consumer can be transparently directed to the service that starts next.

4.2 Radio Service

Radio service includes at least one audio component and a control channel; typically it will also include text backdrop for display while tuned to service. Other components may include:

- A still frame compressed video component could be present for display
- Additional textual information
- A data channel component could supply information meant to augment the audio (such as title, artist, etc.), if a PC is connected to the Decoder data port
- Additional audio component could supply other language soundtracks

4.3 Data Service

Data service includes at least a single data component and a control channel; the control component includes the information defining the data channel to be isochronous or asynchronous. Other components may include:

- A text component could supply encrypted text, meant for display, perhaps conveying instructions or for advertising.
- A still frame video component may be present for display.
- An audio component may be present to provide instructions or advertising.

4.3.1 Textual Information

Two basic types of text systems are commonly supported, depending on the application:

- The main text system, which can be based on an extensible object-oriented scripting language; this system supports on-screen displays beyond the level of character-based text systems;
- Character-based text using the Latin ISO character set — used for specific message field definitions, rather than for definitions of on-screen displays with graphics.

Textual information originates at the UCS, at the SAS, or Auxiliary Data Systems that send the data to the Encoder. The Encoder acts as a gateway converting the input data to the MPEG-2 protocol for transport. Textual information commonly supported include barker messages, personal messages, or multicast messages.

4.3.2 IPG Service

An Interactive Programming Guide (IPG) service is similar to the text information service but can be transmitted at a low rate and stored internal to the Decoder. The IPG service may have both background trickle components and high speed demand components. Interactive Programming Guides provide the consumer with the allusion of rapid access to a large IPG database through a combination of IPG broadcast techniques.

IPG data is based on program schedule information given to the IPG provider by one or more program sources. The program source is usually a business entity different from the IPG provider, but may also be a network operator. The source program schedule will typically give at least the name and scheduled broadcast time of a program. It may contain additional information, such as program ratings or descriptive information.

4.3.3 Data Carousel

The data carousel service replays the same data over and over, e.g. weather reports.

5. ARCHITECTURAL FRAMEWORKS

A number of different standardization bodies and consortia have created architectural frameworks applicable to the audio-visual problem domain. These include DAVIC, IETF, ITU-T, ISO, Network Management Forum (NMF), the

Object Management Group (OMG), Telecommunications Information Network Architecture Consortium (TINA-C), and many others.

The Digital Audio-Visual Council[1] (DAVIC) (DAVIC1, 1995), (DAVIC2, 1995) specified a system reference model for audio-visual system (see DAVIC 1.0). According to DAVIC, the structure of the DAVIC 1.0 specification is motivated by applications, the driving factor in the audio-visual industry. It defines the essential vocabulary and provides the initial system reference model which is then used as follows:

- Physical architectural descriptions of the three major components of the audio-visual system:
  * Service Provider System (SPS)
  * Delivery System (DS)
  * Service Consumer System (SCS)
- A "toolbox" of the following:
  * High- and mid-level protocols (represented in the DAVIC system as vertical stacks). In addition, modulation, coding, and signaling techniques (pertinent to horizontal physical interfaces between entities of the DAVIC system; this is specially useful for content creators and service providers).
  * Application notes rehearse the steady state and dynamic operation of the system at each reference point. and define the protocol to be used in each case; this is especially useful for equipment vendors and system designers.

Although DAVIC 1.0 is the only widely recognized model for audio-visual systems and some parts of the DAVIC model are defined in great detail and well beyond a conceptual description, the specification is still not mature enough. Therefore, we do not relate the architectural concepts introduced here to the DAVIC Model.

It is important to understand the historical perspective of network management within broadband distribution networks. There are two fundamentally different communities providing these services. The telcos have developed sophisticated network management systems and an infrastructure to support high availability services, but have traditionally not been a major player in the general distribution of video services. The MSO community developed essentially standalone systems that are predominately reactive. Outages of service, although not desirable, were tolerated. The MSO community does not have a current network management infrastructure., and is largely unwilling to spend large sums of money for complex management features. The MSOs have been the traditional buyers of the broadband video/audio distribution equipment, and consequently the infrastructure of broadband video equipment has very little network management technology.

The challenge is thus to evolve a network management system that meets the

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[1] DAVIC is a non-profit association based in Geneva, Switzerland. The purpose of DAVIC is to favour the success of emerging digital audio-visual applications and services, in the first instance of broadcast and interactive types, by the timely availability of internationally agreed specifications of open interfaces and protocols that maximise interoperability across countries and application services.

needs of both communities. An evolutionary approach is required that will allow the requirements of both communities to be met. As equipment from different companies must interface, paradigm shifts can be difficult to introduce. It would be unreasonable to expect the telcos to degrade their expectations of network management. Therefore, the MSOs will need to become more sophisticated and network management technology must offer the appropriate cost to benefit ratio.

In the following sections we rely on these considerations to sketch a framework and outline technologies suitable for the management of audio-video-data-distribution networks.

5.1 Information Model

TMN (ITU-T, 1992) is based on the Q_3-Interface for the Operations System to Network Element communication and for the Operations System to Operations System communication. The NMF sees the communications between the layers of TMN (i.e. business, service, network, and element management) as via the Q_3-Interface. The Q_3-Interface is based on OSI Systems Management and is not a feasible solution for embedded controllers with only EEPROM as non-volatile memory and with only 1-2 MB RAM. On the other hand, TMN is the only management standard including an object-oriented management information model with provisions for business and service management and with a wealth of standardized management functionality such as state, event, alarm, log, and test management. Thus, a feasible solution for the support of the TMN model is one of the critical requirements.

Use of the TMN management information model is the key to the successful development of a network management architecture for Video/Audio/Data Distribution networks.

While the Q_3-Interface may be supportable on the business, service, and network level, in most cases SNMP (Case 1-3, 1996) is the only viable solution for the network element level. Given the excellent work of XoJIDM (JIDM], 1995) which defined translators between SNMP SMI, CORBA IDL, and OSI GDMO, it is feasible and desirable to support the TMN information model by mapping between SNMP SMI, CORBA IDL, and OSI GDMO (Q_3-Interface basis). This paves the path for increasingly more sophisticated network management products.

5.2 Computing Paradigm

Object Oriented (OO) programming technology and methodology appear to be a significant break-through for software reuse and provide the foundation for the flexible software factory. Using object oriented technology, software parts could be made available for portable operations systems platforms, multimedia graphical interfaces, corporate data bases, and the domain specific code needed for the operations system.

Over the last several years the information technology industry has been rapidly developing object-oriented software-development environments (languages, library tools, databases, etc.) for the realization of object-oriented designs in computer systems. Of those environments OMG CORBA (OMG, 1995), and UNO have emerged as the standard incorporated in numerous other standard frameworks such as NMF OMNIPoint 2, TINA-C, and ISO/ITU-T ODP. The DAVIC 1.0 specification includes OMG UNO. All major computing manufacturers are currently supporting the OMG standards.

5.3 Element Management Technology

Due to the popularity of the Internet technologies and the lack of comparable simple network management standards, SNMP has become the de-facto standard for network management. Almost any type of computing and networking equipment comes today with SNMP agents. SNMP management platforms are more mature and 5-10 times less expensive than comparable CMIP platforms. Embedding CMIP into resource scarce network elements may be prohibitively expensive if feasible at all. That leaves only SNMP as an open, standards based network management solution.

In many cases, the individual elements have only minimal resources for management. That type of environment is best suited for the SNMP based Master-Agent/Subagent (e.g. AgentX - Daniele 1996, DPI -Winjen 1990, SMUX, EMANATE) for the following reasons:

- resource consumption - SNMP agents are minimalist in nature with most overhead going on ASN.1 encoding/decoding. Subagents usually don't use ASN.1 (e.g. the new IETF AgentX Draft Standard).
- Element synchronization - an SNMP set request is required to either set all variable bindings contained in the request or none. That means that if the set variables are distributed over multiple subagents, a protocol like AgentX would automatically take care of the roll-backs needed in case of errors.

The SNMP MIB design can follow the TMN management information model to allow an element manager to pass information to the next level manager using other protocols such as CORBA or Q_3 The use of proxy agents allows the use of a SNMP interface, even before the element design has matured to the next generation.

5.4 Data Base Technology

The extensive use of RDBMS engines has evolved from the historical view of MSOs. The requirements for persistent data storage have largely been program schedules, customer lists, authorization status, purchase records and various other tables. The needs have been largely met by RDBMS systems.

RDBMS technology is stable mature technology. Most products today include support for distributed, replicated, heterogeneous data bases. This allows geographic distribution along with replication of data that allows continued operation in the prescience of network faults. There are many tools that allow rapidly building client GUIs for the operators. The standard SQL interface in combination with access libraries from DBMS vendors allows various business systems to interoperate. The use of this approach eliminates the need to develop protocols for the transfer of data from one machine to another, which had previously been a significant developmental effort.

Current OO design efforts are using the RDBMS for persistent storage, largely because of the maturity of the environment. While there are many constraints on storing objects in a RDBMS, the perception has been that OODBMS are not yet mature. As OODBMS technology matures, its use is expected to become more predominant. The size of the installed base of RDBMS ensures that backward compatibility of SQL would be a requirement.

As applications become more complex, the use of standard management applications will become the only feasible choice, as the cost of a custom development will become prohibitive. It is expected that persistent storage would be provided by a OODBMS with a CORBA/IDL interface, the management information model would be TMN based, and applications would be standardized, such as those under development by the NMF.

6. MANAGEMENT REQUIREMENTS

The management architecture must be service driven and must be able to support a variety of proprietary systems and protocols. Distributed applications and management systems within the management architecture must include:

- Service Creation and Network Operations (NCS Domain)
- SA Domain Management
- Uplink Domain Management
- Decoder access control
  - * Consumer access control
  - * Commercial access control
- Virtual Channel Map distribution
- Headend Management
- Distribution Plant Management
- Logical RF Access Network Management

The following subsections give a brief overview of the first five.

6.1 Service Creation and Network Operations (NCS Domain)

An operations center responsible for program authoring, service creation, network operations, and frequently also entitlement management. Created services are downloaded to Uplink Control Systems (UCSs) which then program the Encoders. Simultaneously, operations of the various Uplinks are monitored and controlled and are coordinated with the services supported. For that purpose the following distributed databases are maintained:

1. The database related to the programming of services carried by the transport multiplexes; the main components needing access to this database are the

Service Composer, which creates the services; the UCSs, which are instructed by Service Composers to generate the services; and SASs and Entitlement Management Systems (EMSs), which control consumer and commercial access to the services.

2. The database related to commercial Integrated Receiver Decoders and their authorizations; the main component needing access to this database are the Entitlement Management Systems (EMSs).
3. Network and system configuration information and other network and distributed system and application management related information; all components need access to at least the management information reflecting the configuration of the particular system itself.

The tasks of service creation and network operations are distributed in nature over local and wide area networks and need to be supportable by a heterogeneous computing and communications environment. The size of the data is in the order of gigabytes. The data is distributed and replicated and requires frequent updates over potentially unreliable media. The most stable and mature technology capable of satisfying this requirement is RDBMS technology. A variety of architectural scenarios are possible:

- distributed, replicated DBMS only as persistent storage with a corporate wide information model using a variety of distinct database views for the different application types; the actual applications can rely on a variety of different computing and control paradigms;
- distributed, replicated, isolated DBMSs with applications utilizing other computing and control paradigms linking the DBMSs.
- distributed, replicated DBMS with a corporate wide information model and most applications (including network management) utilizing SQL and triggers as the main means of control and asynchronous notifications (do to the lack of maturity of network management technology even the use of RDBMS clients in embedded controllers is considered as a viable monitoring and control application).

6.2 SA Domain Management

The basic management requirements of the SA Domain are:

- Management of the Decoder Database - this can be done through DBMS applications.
- Management of decoder access control, and decoders; the SAS maintains the database related to consumer Integrated Receiver Decoders and their authorizations; the main components needing access to this database are the SAS and Business Systems.
- Configuration and monitoring of communications links and service providers - that can be accomplished through SNMP.
- Management of RDRs which submit decoder unit transaction reports - this can be done with SNMP.

A feasible architecture for the SA Domain would include a CORBA based SA

Domain Manager communicating with the RDBMS applications and SNMP Element Managers using UNO.

The information model is based on the TMN information model. This is independent from the individual realization of specific architectural components such as agents, element managers, network managers, and their communications infrastructure. The individual architectural components can be CORBA, SNMP, TMN, or other. All of these support the same information model which is TMN based.

In case of SNMP agents the NMF has specified a translation of GDMO to SNMP SMI. That translation is not regarded as a desirable basis for SNMP MIB design do to the complexity of generated SNMP MIBs. Instead, alternative approaches more in line with SNMP management paradigm are commonly used which still allow an easy mapping on element manager (or Q_3 Proxy) level between GDMO and SNMP SMI.

6.3 Uplink Management

The four main Uplink Management requirements are:

1. Encoder Programming - this is mainly accomplished by programming the UCS from the Service Composer;
2. Encoder Management - this is mainly accomplished by the UCS;
3. Uplink Network Management - the Uplink may be spread over a metropolitan area and may consist of several 1000 IP nodes, interconnected by a variety of technologies including ATM, FDDI, Ethernet, etc.
4. Source Equipment Management- various different types of source equipment (for example, video servers, video machines, etc.) are used on the Uplink side to generate the programming material. Two types of systems are used to deal with this complexity:
   a) Traffic control systems—include detailed program schedules and control the automation system; interact with Service composers
   b) Automation systems—used to automate the source equipment control; for example, to route source signals from video machines video servers, etc. to the Encoder

6.3.1 Encoder Programming

Encoder Programming is highly data intensive, distributed, replicated with different types of data views ranging from abstract views suitable for creating new services without regard to their implementation to concrete allocation and configuration of television service processors. Two candidate technologies are suitable for accomplishing this task.

Data Base - The type of data base selected in the architectural framework is a RDBMS. The RDBMS server could be located on the Service Composer with RDBMS clients on the UCS, network management stations, the SAS, etc. The advantages of the RDBMS approach include:

- data distribution - data can be easily distributed over a variety of Uplink Domain elements using mature RDBMS Client/Server technology. This enables the different Uplink Domain elements to have uniform access to the same data base.
- data replication - multiple synchronized copies of data can coexist with off-the-shelf RDBMS technology. This would enable the Service Composer to keep pieces of the programming information on the different UCSs which control the Encoders.
- multiple data views - different Uplink Domain elements need different views of the same data depending on their function.
- security - robust systems with possible C2/B1 level security
- standard interfaces - SQL.
- development cost - use of a mature technology with a large labor pool.

MIB - The information model selected for management information in the architectural framework is TMN. A natural solution would be to develop the TMN business and service layers for Encoder Programming using the TMN information model. Possibly concepts of TINA-C service architecture could be used. Assuming a CORBA based TMN information model implementation the advantages include:

- information model integration - the network management and the Encoder programming information model are different pieces of the same picture. The Service Composer could be realized as a CORBA/TMN manager managing UCSs which are CORBA/TMN agents via GIOP where the UCSs would be proxying Encoders.
- monitoring and control paradigm - the basic paradigm here has been created for monitoring and control with special emphasis on the temporal aspects of the processes managed. This is an especially important factor in comparison to Data Base solutions.
- open architecture - the architecture is based on international standards such as TMN and CORBA.
- data distribution, data replication, security, development cost - depend on the CORBA/TMN products selected.

6.3.2 Encoder Management and Uplink Network Management

The Encoder is usually realized as a complex extensible architecture with dozens of independent processors needing frequent configuration with large groups of service-specific parameters. Sometimes, Encoders are distributed over local area networks and are connected to UCSs via wide-area links. The Encoder CCAs have usually only minimal resources for management. That type of environment is best suited for SNMP based Master-Agent/Subagent (e.g. AgentX - Daniele 1996, DPI - Winjen 1990, SMUX, EMANATE) for the following reasons:

- resource consumption - SNMP agents are minimalist in nature with most overhead going on ASN.1 encoding/decoding. Subagents usually don't use ASN.1 (e.g. the new IETF AgentX Draft Standard).
- CCA synchronization - an SNMP set request is required to either set all variable bindings contained in the request or none. That means that if the set variables are

distributed over multiple subagents, a protocol like AgentX would automatically take care of the roll-backs needed in case of errors.

- MIB replication - the new Entity MIB (McCloghrie, 1996) enables an agent to have multiple MIB modules of the same type. That enables MIB replication in the CCAs and enables the manager to set the same variable to the same value in two different subagents in an atomic fashion.
- open architecture - SNMP is an IETF standard.
- development cost - off-the-shelf technology.
- management integration - almost any networking equipment in existence is SNMP manageable which would allow an integrated management of all Uplink Equipment.

6.3.3 Uplink and Source Equipment Management

Much of the Uplink computing equipment and network equipment such as routers, bridges, hubs, switches, etc. are commonly managed with SNMP. This integrates nicely with the SNMP Encoder management.

Both traffic control and automation systems could be easily managed by SNMP for the same reasons as indicated above.

6.4 RDR/Subscriber Management

RDR/Subscriber management is ideally not developed in-house but customized from one of the off-the-shelf products such as Small World which support CORBA and industry's standard management platforms such as OpenView. That would allow either application specific integration or CORBA based integration between the SAS, the Uplink , and the Subscriber Management System.

Subscriber management depends on the type of subscriber access but will likely be SNMP based.

A subscriber management application is illustrated in Figure 4:

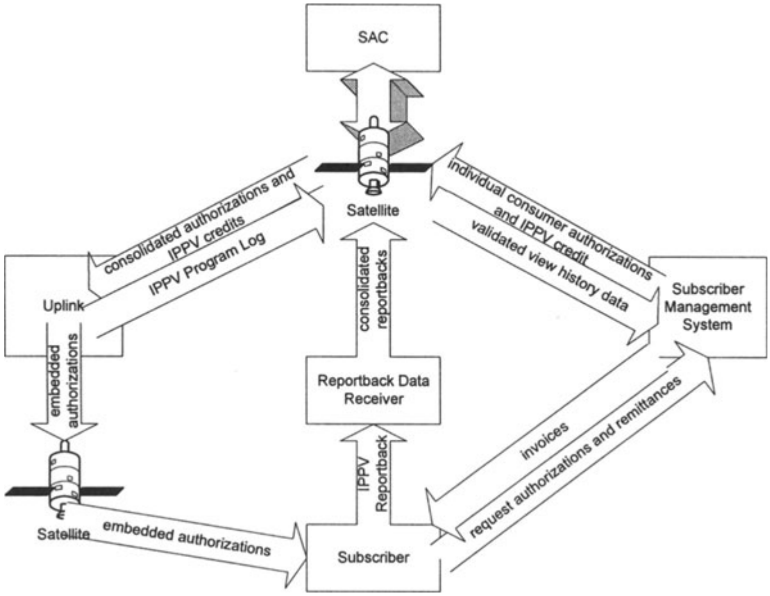

Figure 4. Subscriber Management and Reportback Data Receiver Application

The Subscriber Management application assumes the following sequence of actions in the case of the Impulse Pay Per View service:

1. A subscriber requests program authorization from a program packager (program packagers may, or may not, also be programmers).
2. The program packager uses a Subscriber Management System (SMS) to set up an account for the subscriber and transmit the authorization request to the SAS.
3. The SAS adds the new subscriber IRD unit address to its database, turns on the appropriate tiers, and inserts the IRD's authorization into the SAS authorization stream.
4. The Uplink sites feed the authorization stream into the Encoders, which multiplex it with the video programs. The IRD will receive its authorization as long as it is tuned to any Encoder receiving the SAS's authorization stream. It should take less than 5 seconds from the time the SMS sends the authorization request to the SAS to when the IRD receives its authorization.
5. After the subscriber purchases an IPPV program, a reportback is generated and sent to the RDR operating on a small VAX computer. The reportback can be via modem or via history cards. There can be multiple RDRs.
6. The RDRs consolidate and transmit the reportback data to the SAS.
7. The SAS regularly retrieves from each Uplink system the IPPV program log, listing the IPPV programs that have been broadcast; the SAS uses this information to validate the reportback information received from the RDRs and create View History data for the program packagers.
8. The program packagers use their SMSs to retrieve the validated View History data from the SAS.

9. Upon retrieving the View History data, the program packagers extend additional IPPV credit to their subscribers.
10. The packagers can use the SMS billing system or their own billing system to invoice the customer for their subscription and IPPV purchases.
11. The subscriber pays the program packager.

6.5 Decoder Access Control

Access control is frequently managed through a tiering structure, coupled with encrypted key delivery. Each Decoder is authorized for a set of services. The Decoder manages these services in the form of a bit vector called the authorization vector. The position of a bit within the vector identifies the service to which the bit corresponds. If a bit in the vector is set to zero, the Decoder is not authorized for the corresponding service.

Usually a hierarchy of secret keys is used whose distribution and maintenance creates a major synchronization issue. At the root of the hierarchy is secret information which is placed into the secure access control device in the Decoder when it is manufactured. Such information is unique to the access control device and lasts for the lifetime of the unit. The hierarchy usually consists of multiple levels.

For an IRD to be able to access a service, the two ends of the hierarchy must be linked by a complete chain. The keys for each level in the chain are generated by the Decoder using information delivered uniquely to it in a control channel message. Secret data delivered in the control channel is protected by encrypting it under a strong cipher such as the Data Encryption Standard (DES).

Access control is likely to remain a proprietary application for some time to come.

6.6 Virtual Channel Maps

The transport multiplex carries a large number of video, audio, text, and data service components. The concept of virtual channels offers the user a consistent view of services available, and provides a reference mechanism for various combinations of services (e.g. television with secondary audio). Each virtual channel number defines the access point for a particular service, and represents a particular combination of components. The access point is described in terms of its transport multiplex location and MPEG service number. Transport multiplex location is given as satellite and transponder (for satellite IRDs) or its carrier frequency (for cable).

The consumer set-top box upon acquisition of the transport multiplex obtains virtual channel information through the Virtual Channel Map (VCM). A VCM is a data structure that contains entries for each virtual channel in the map. Each entry has the name of the virtual channel, an identification of the RF channel and multiplex relevant to that bitstream, the service number in the multiplex, and various sub-identifiers. Set-tops usually reference a single VCM but may also reference multiple as is done for multisatellite C band configurations.

VCMs originate at the Service Composer, or at the UCS if there is no Service

Composer. The channel number space between a VCM may be partitioned between several originators, so that each originator is a designated controller of a virtual channel number. There may be different classes of VCMs such as:

- Commercial VCMs—intended for commercial broadcast users
- Consumer VCMs—intended for consumer broadcasts
- Private VCMs—intended for private network users

In addition, there may be local copy modifications to a VCM that are to be distributed only to users of the current multiplex to which they apply.

Virtual Channel Maps largely rely on simple data distribution and synchronization which can be easily accomplished through RDBMS or CORBA based applications.

7. CONCLUSIONS

An overview of the tasks and possible architectural solutions for management of video-audio-data distribution networks has been given. The architectural framework sketched is planned for the next generation of systems. The two fundamentally different communities providing or planning the services outlined have historically very different approaches to network management. While the telcos have developed sophisticated network management systems and an infrastructure to support high availability services, but have traditionally not been a major player in the general distribution of video services, the MSO community developed essentially standalone systems that are predominately reactive with lower service reliability. That leads to the current status-quo in which the MSO community does not have a current network management infrastructure, and is largely unwilling to spend large sums of money for complex management features.

Considering those restrictions, it is quite difficult to completely embrace complex architectures such as TMN or TINA-C. However, we also concluded that use of the TMN management information model is key to the successful development of a network management architecture for Video/Audio/Data Distribution networks.

In this paper we have sketched the architectural framework and architectural requirements of a feasible solution. While the Q_3-Interface may be supportable on the business, service, and network level, in most cases SNMP is the only viable solution for the network element level. Thus, the TMN Information Model has to be supportable through the SNMP information model. Given the excellent work of XoJIDM which defined translators between SNMP SMI, CORBA IDL, and OSI GDMO, it is feasible and desirable to support the TMN information model by mapping between SNMP SMI, CORBA IDL, and OSI GDMO (Q_3-Interface basis). This paves the path to sophisticated yet feasible and achievable management solutions.

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