Digital Cinema

Using Satellite CDN as Delivery and Transport Platform

By Augusto Villasenor
Globecomm Systems, Inc.

When the term "digital cinema" is used, the first thing that may come to mind is a movie theatre filled with the latest, cutting-edge electronic cinematic gizmos. One may expect pristinely sharp pictures to be projected onto the big screen and sound systems that carry the viewers into the thick of action with deep aural depth and clarity.

While that notion is not far from the truth, digital cinema is much more than just impeccable images and sounds. Digital cinemas are not simply digital capture, post-production, delivery or projection, but the combination of all these phases into a complete digital network, a value chain, that offers a myriad of possibilities on how the movie-watching experience is set to change.

In brief, digital cinema impacts how the movie is actually made, how it gets from the production company to movie theaters and how the theaters present the movie. Digital cinema encompasses the production, delivery and projection of full-length motion pictures, trailers, advertisements and other audio/visual "cinema-quality" presentations to theatres using digital technology.

Digital cinema technology uses a "store-and-forward" concept to distribute motion pictures, which have been digitized, compressed, encrypted and delivered to theatres using either physical media distribution (such as DVD-ROMs, or hard disk, etc) or through other electronic transmission methods, which can be satellite, fiber or other broadband connections. The main advantage of digital technology (such as a CD, DVD, etc) is that it can store, transmit and retrieve a huge amount of information exactly as it was originally recorded. Analog technology (such as an audio tape, cassettes, open reel, etc) loses information in transmission, and generally degrades with each viewing. Digital information is also a lot more portable and flexible than analog information. A computer can manipulate bytes of data very easily, but it can't do much with a streaming analog signal.

Digital cinema is simply a new approach to mastering and showing movies. The basic idea is to use bits and bytes (strings of 1s and 0s) to record, transmit and replay images, rather than using chemicals on film.

The main focus of this paper is to examine the distribution *transport and delivery systems* (via satellite) and workflow implementation with aim of overcoming possible hurdles and obstacles that content creators' and distributors now face. This paper describes the packaging, distribution, transmission, encryption and exhibition of motion pictures in digital form. It does not specify how these motion pictures are originated, produced and finished. However, it does present in an exploratory manner, the basic realities for implementation of a complete digital cinema system. Some other components are discussed briefly including playback systems and video servers, and Digital Light Processing (DLP) projectors.

Introduction

Recent advances in high-resolution, real-time, digital technology have revolutionized feature film production. The cinema mastering workflow has become one based on the storage and manipulation of high-resolution digital images. And, because these digital images represent the intellectual property and value of a production, it is of utmost importance to protect the integrity and quality of this data at every step in the production pipeline[1]. Production staging is considered one of the most monotonous processes, capturing the best possible picture image, that one can ever imagine. Director, artist, creative consultant, and crews are all geared to one common objective: Capture the best possible shot in every action. This paper does not focus on film electronic field production (Film EFP) and image capturing. The context of EFP is out of this topic.

Traditionally, filmmakers convert film footage to digital format for post-production and then back to film again for its theatrical release. This conversion process is expensive and time-consuming. Digital video however, does not have to go through this conversion process. As soon as they shoot digital footage, filmmakers can immediately play it back and start editing it.

Editing is a no non-sense workflow under the guidance of producers, directors, writers, editors, and effect artists in the editing suite. This is the brainstorming phase for critique and consultants from marketing to merchandising, from advertising to product packaging point of view.

Sharing soft-copy visual information is increasingly important in business and will likely become equally so for consumers[2]. With traditional film, content owners and distributors need to strategize where they send their movie to print. Given the high costs, they risk making a loss if the cost of duplicating film prints far outweighs cinema earnings. Digital cinema's low distribution costs on the other hand, allow movies to be sent via broadband channels or transmitted via a satellite Content Delivery Network (CDN). Because of logistical attributes and processing delays during film printing, business is clamoring for innovative approach to providing duplication with little planning and without an extensive asset tracking system. The key for a better distribution network is portable digital copy of the content. With digital cinema, once the editing is completed, the content is actually ready for Motion Picture Association of America (MPAA) review submission. After approval, the final cut theoretical release is set for distribution. Thanks to digital asset management (DAM) associated with digital technology, automated tracking and control of content distribution is an additional benefit when implemented.

Transport of valued content is not an easy task. In fact, it is the most sensitive undertaking of all, because *content is king*. All material must be labeled relative to the last royalty of ownership before leaving the plant. The metadata chucks are extensive since anyone and everyone who had anything to do in the creation of the content has to be included in the listings. In addition, the producing firm expects that their ownership rights are protected from the first to the last frame of the picture. Since distributing digital media is the final possession stage, it requires strategic management attention. The groundwork for sophisticated digital infrastructure must have a tool for DAM control, encryption and conditional access, and that reliable delivery of the data stream is protected from unauthorized users.

Production

As filmmakers begin to use digital technology throughout the production process, developers of hardware systems and software applications used in the film industry are challenged with creating new products and methodologies that raise the bar in quality and productivity. As such, there are significant technical requirements that must be met to support this workflow[3].

Mastering

Once the motion images are captured, the goal is to create a digital intermediary using the highest quality images possible. This digital intermediary forms the basis for production. These acquired high quality images are stored as data in a format easily manipulated by the post-production tool suite. This universal mastering format offers the highest possible spatial resolution and wide aspect ratio that permits all the final distribution formats, as well as digital dailies and lower resolution preview proxies, to be generated from a single copy of the original image data[4]. This data enters the workflow from possible sources such as:

- Film scanner/telecine
- Digital Camera
- Image data
- Data recorder/VTR

The most common content acquisition tools available today are the telecine and digital camera, therefore this paper will discussed briefly the data resulting from telecine and digital HD cameras.

Film scanner/telecine

The telecine transfer process digitizes the selected shots from the original negative or an interpositive (I/P). An offline session dictates exactly which frames are scanned from a Edit Decision List (EDL). This generates Digital moving Picture Exchange (DPX)[5] files, each containing a 10-bit LIN/LOG RGB image with up to a 2K (2048 x 1556) resolution[6], along with the header, and can be as large as 12 Mbits in size. Once scanned, image files are transferred to digital archival, where they become immediately available for post-production. The real time transfer of these images requires approximately 300 Mbits/sec of sustained bandwidth. Meanwhile, Sony during the NAB2005 show (Las Vegas Nevada,) presented the world with the first 4K film-processing projector[7]. With this introduction, the industry is moving toward the acquisition of 4K (4096 x 3038) film plates, with the end goal of moving 4K data with 2K proxies through the entire workflow pipeline. This change quadruples the amount of data generated for each film frame.

Digital HD Cameras

In addition to the traditional telecine transfer of images from film, the image may also be acquired through the use of digital camera technology. This option has become more prevalent with the increased availability of digital film cameras that support the direct capture of 10-bit RGB 4:4:4 images. Standard digital film cameras are capable of frame rates of up to 150 frames/sec. A digital camera with comparable parameters would produce a data rate of 64.8 Gbits/sec. Given that this is currently impractical, a more realistic rate was adopted using lossless compression technology to limit this rate to 425 Mbytes/sec[8]-[9].

In the past, HD video cameras results were stored as HDCAM, D-5, or D-6 materials for later transfer to the post-production system. The use of HDCAM and D-5 has limited the data captured to a compressed YUV 4:2:2 data sampling; D-6, though uncompressed, has still limited the captured data to YUV 4:2:2 format. New digital cameras specifically designed for film, now permit the direct capture of 10-bit 4:4:4 RGB, with the uncompressed results stored immediately on disk for later transfer to the digital archive. This technique requires the support of a dual link HD I/O standard[10] and sustained disk bandwidth of 300 Mbits/sec. In addition to the data essence, time code information and other ancillary data must also be captured. Comparisons that were run for 24P scan format 2K versus 4K assumed that no significant data or quality loss is incurred from processing or downstream of the digital data creation during capture. However, independent film or camera manufacturer noted better depth of field for higher capture 4K systems. Their argument relies on simple geometrical comparisons of camera optical paths and sensor formats combined with measurements of camera and lens modulation transfer function (MTF) losses[11]-[12]-[13]. The economics of 4K processing is likely to improve as processing power increases and disk storage costs drop in the future. Still, in the current film environment, almost all-digital film work is being done at 2K, mainly due to the time and economic constraints associated with 4K work[14]. In other words, the improved performance is not generally considered to be worth the cost by the industry's financial gurus.

The transfer of 2K and 4K image data within a production facility, with a goal of real time or better transfer rates, requires high-bandwidth communications at every step in the digital cinema mastering workflow. At 12 Mbits/frame, 300 Mbits/sec is required to transport 2K data in real time. Moving 4K data in the future will require more that 1 Gbits/sec of bandwidth for real time transfer (300 Mbits x 4).

Post-Production

The second stage in the process is post-production. This is a series of processes that are performed on the original source material to produce the single final set of images from which all distribution formats are produced. In the digital production phase, software tools running on general and special purpose computer systems and workstations implement these processes, which includes (a) color correction and color grading, (b) Dust busting grain matching, and noise reduction, (c) Editing and compositing applications, (d) Paint and effects applications as well.

During post-production, high bandwidth, low-delay data communications is required between the digital archive and post-production systems, so that devices operating on the data can access it directly within the digital archive, without making secondary local copies. Making copies of the data introduces a risk to its integrity and security, and at the same time, creates multiple versions that subsequently need to be tracked[15].

Post-production software applications may indeed extract the image data from larger DPX files and buffer it within an application for direct manipulation. During the process, the data is extracted and converted to another format for easier manipulation; thus it is not a true copy. When an operation on the data is complete, it is imperative that the core image data be returned to the archive file, and each frame and the metadata associated with each image updated to reflect and changes that were made[16].

Advances in post-production technology make it easier to manipulate captured images in new ways to perform functions such as the changing of frame rates and the insertion of virtual objects. However, such processes could be improved or made significantly easier by capturing additional data at the camera[17].

Distribution

The Internet and other two-way mediums pose a challenge for content delivery; since they often have inherent latencies and raw error rates that make them unsuitable for use in real-time video delivery. For example, while an error rate of 3-nines is normal on an IP network, the resulting gaps in a video stream would be unacceptable for a movie viewer[18]. By implementing Satellite CDN for digital cinema transport and delivery, the quality of service (QoS) can ensure that all theaters have received a flawless copy of the movie on time[19].

Once all post-production processes are complete, the single digital master is ready for distribution. In today’s environment, this distribution includes not only the final feature film recording, but also DVD, TV broadcast HD and SD, data archiving, and DTV. Later, the data may also be repurposed for the creation of a sequel, or toys and other merchandise. These activities will utilize the same single resolution-independent universal digital assets[20].

Secure and Flexible Transport

Digital Cinema facilitates the display of high quality studio masters anywhere in the world. Although these masters will be compressed, the bit rate available will be such that they can be considered to be clones of the master files. This means that the distribution system has to be secure across chosen transport mechanism[21]. Transport can be via satellite, data tape, hard disk, fiber optic, etc. The focus of this paper is present a distribution transport system using satellite CDN for digital cinema. The remainder of this material will outline the requirements of this pipeline and explain how the current technologies can be employed to realize the digital cinema within the realms of satellite content delivery.

Content Delivery Network

Satellite CDN is the transport service delivery that enables the bridge between the distribution center, post-production house and the movie theaters. The Satellite CDN infrastructure, where applicable, duplicates the media (DVD, Data Tape, HD drive), stores (*store*) the content in an edge server and then manages routing and transport of content to the theatres (*and forward*) through satellite link broadcast channels. Satellite content delivery technology performs simultaneous one-to-many content distribution using IP multicast[22] or broadcast. Unlike point-to-point methods, which send multiple streams, each to a separate network client, Satellite multicast, which mimics IP LAN protocol, sends a single stream that is directed to all or only those recipients needing the information.

Reliability

In this architecture, the CDN uses Forward Error Correction (FEC) to provided reliable file delivery without relying on receiver responses via a backchannels. FEC technology provides reliable and efficient transmission by sending data files with intelligent repair packets, which can be used to reconstruct lost or damaged data without retransmission and without relying on a return communications path. FEC eliminates the cost and complexity of installing a hardware based reliable content delivery distribution solution applicable only to digital cinema.

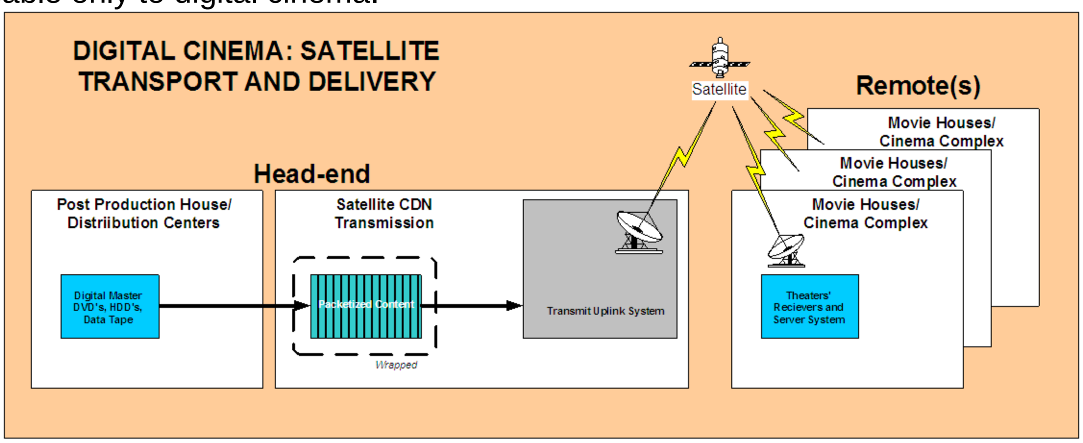

Figure 1.1 Distribution of Content via Satellite to Multiple Receivers

Prior to sending files, the sender multicasts a message to a group of pre-determined receivers, informing them that data is forthcoming. The recipients then register to receive the information. During the data transmission, files are broken into blocks and frames, and then sent across the Satellite CDN network to each recipient simultaneously. A block consists of multiple frames. As lost or bad frames are recorded by the receiver, the sender requests status of only lost or bad frames on a block by block basis using a efficient negative acknowledgement scheme. On subsequent passes, the sender retransmits only those lost or bad frames. In this way, Satellite CDN offers complete reliability with minimal network overhead. Details on the use of the return path channel are discussed later in the Return Communications Path section.

Packaging

The packaging requirements for satellite distribution must be format agnostic. Included among other things to remember is the process to acquire the content and maintain every piece of sensitive data included in the final recording. As shown in Figure 1.1, the final (digital master) film recording is broadcast from the satellite to multiple theaters, which have compatible receivers. The broadcast transmission is a coordinated transfer of content to these theaters, secure without delay, through a process known as "Reliable File Delivery". The vehicle that carries the content on time is the MPEG-2 Transport Stream (TS).

The program acquisition stage of the CDN treats all incoming content as raw data. The content needs to be packaged prior to delivery in order to assign destinations, schedules, and insure secure and reliable delivery. This phase of ingesting the content (or the digital master) includes assignment of various tags in conformance to a set of metadata[23] guidelines. The complete package is composed of the data essence (the digital master), the associated metadata and transport tables[24].

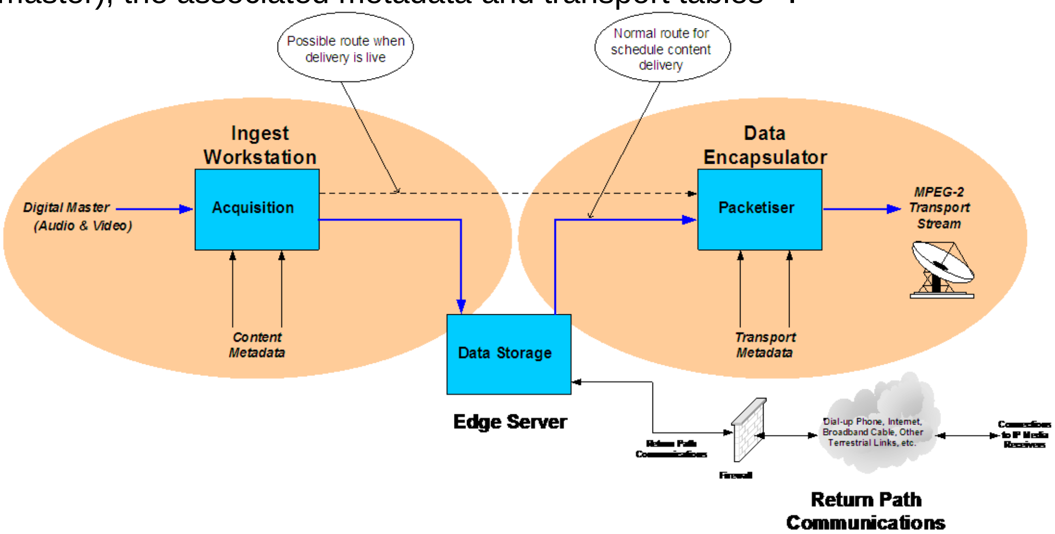

Figure 1.2 The Content Delivery Basic Workflow process

Upon arrival of digital master content from postproduction house, an ingest workstation sitting in the Satellite CDN facility tags the incoming content. Metadata tagging[25] is needed for content identification and proper handling through the entire phase of the delivery process. Identification includes movie title(s), event(s), schedule(s), and other delivery important metadata information. During the ingestion process, the metadata will be included as part of the compressed package. Metadata is extensive and includes the require MXF wrapper established by SMPTE[26]. Once ingest of the movie content has started, the necessary encoding and transcoding of the transport format will take place to synchronize the video, audio and metadata files together to form the processed streams (see Figure 1.2). Delivery metadata such as Video –type of compression, Audio type (–Dolby AC-3, DTS, THX, other surround sound), second audio program (SAP) – when applicable, Video Packet Identifier (PID), Audio PID, Packet Headers, Time and Date, Versions #, Video Frame sampling rate (24 frame per sec for progressive scanned, for film), Video bit-rate, Audio bit-rate, Audio Mode, Royalty, Actors, Actresses, Directors, Producers, Editor, Creators, Date of Release, etc.[27]-[28] The packaged content in the form of wrapped file will then be pushed (data) to an Edge server where delivery to the satellite link will take place. A Fiber Channel (FC) loop between the Ingest workstation and the Edge server carries an enormous amount of data traffic transparently up to speeds of 1 Gbits/sec. A commonly used version now available is 1000 LAN (Gigabit Ethernet)[29].

Data Encapsulation

The IP Encapsulator (IPE) plays an integral role in an IP data broadcast head-end by encapsulating IP packets into an MPEG-2 transport stream per DVB and ATSC specifications[30] for transmission over Satellite networks. An IPE receives IP packets from an Ethernet connection and encapsulates selected packets into an MPEG-2 TS. Once the encapsulator has encapsulated the data, it forwards the data packets based on the user-defined routing tables (IP Multicast Addresses) and performs Quality of Service (QoS) on a route-by-route basis. The IPE outputs the MPEG TS on one of the user selected hardware interfaces. Satellite transmission uses Asynchronous Serial Interface (ASI) format as the physical connection[31]. The output transport stream can then be forwarded to a multiplexer or directly to a modulator for the high-performance and cost-saving transmission of IP data. Enhanced performance in IP Encapsulators now allow data rates up to 213 Mbps and Ethernet packet rates in excess of 148 Kbps.

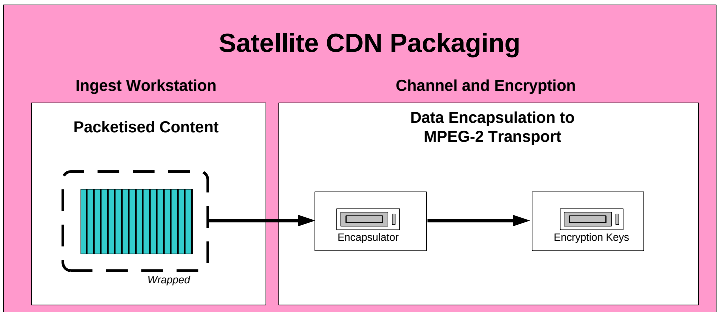

Figure 1.3 Data Conditioning prior to Transmission over Satellite

After the packaged is completely wrapped (conditioned for transport), the IP Encapsulator residing in the edge network, prior to the modulator, actually receives the data files (in IP format) and provides a medium (a channel route) to where the content is to be delivered (Refer to Figure 1.3). The IP Encapsulator follows MPEG-2 Transport Stream standards[32] to fill up the payload of the TS with IP data packets (blocks) from the incoming IP data stream. The MPEG-2 transport stream as shown in Figure 1.4 is 188-bytes long. It is commonly use to carry compressed TV and radio signal and was standardized by the DVB consortium[33]. The TS byte carries any form of data blocks as payload in the stream as shown in the figure. The carriage system is properly synchronized and time stamped so that the receiver on the other end of the pipe can actually reconstitute the packets to the original file (as wrapped) once transfer is complete.

The IP Encapsulator routes are actually multicast addresses (i.e. 240.0.0.1) where the incoming stream will be broadcast or multicast to designated receivers (which sit in the theater’s facility). Multiple routes can be created, scheduled, edited, deleted or halted. Thanks to dynamic nature of MPEG-2 systems, there is an easy way of managing and tracking distribution of content.

Scheduling
After the transport conditioning process is completed and the set date and time finalized, the delivery mechanism of the satellite will stream out the MPEG file stored in the server to the IPE input to form a MPEG-2 transport stream service as shown in Figure 1.2. The transport stream which has a payload of data (the packetized content) will be sent to the modulating signal carrier for uplinking to satellite. The receivers in the theaters, which are calibrated (and pre-authorized) to tune to the satellite broadcast, will then receive the content in blocks of packets. These packets of content are the payload of the MPEG transport stream (Refer to Figure 1.4). After receiver buffering is completed, the content was automatically push to theater central server for local repository in the Theater's Central Server system.

Encryption
Another concern of the Film Industry is the piracy issue. The content must be accorded with a high degree of protection against unscrupulous content hackers. This is the major apprehension that needs careful consideration in dealing with a Satellite CDN transmission system. The very nature of satellite architecture is one to many. The beam coming from the geo-stationary orbit actually illuminates everybody below its footprint. This fear of piracy is primary in the mind of the content creator from day one. This need for protection through some form of encryption must be taken seriously and address each underlying technology before satellite transmission of content commences.

Conditional Access
Before file transfer actually happens, the Conditional Access (CA) subsystem of the satellite network comes into play. As shown in Figure 1.5, the CA assigns vital encryption keys in the form of Entitlement Management Message/Entitlement Control Messages (EMM/ECMs) and control word (CW) scrambling the entire transport stream and/or the associated program in it. Encryption keys are dynamically changed automatically at appropriate times once the transmission cycle begins. The present SimulCrypt Standard established by DVB specifies the system architecture, timing relationships and messaging structure[34] in implementing a CA system. The Entitlement Management Message is private CA message, which for example, specifies the authorization levels of theater subscribers (receivers' population) or group of theaters subscribers, for services or events. Entitlement Control Message (ECM) is a private CA message, which carries the CW in a secure manner, and private entitlement information. Since the CW is scrambled and also encrypted, there is no way upon which an illegitimate receiver can intercept the packaged delivery. The transport stream is carrying encrypted payloads of packets. A package is composed of huge number of packets, timing information updated to that particular stream, and a Conditional Access Table (CAT)[35]. Leakage of multiple numbers of packets, block of packets, the entire payload, or the complete package does not give pirates any advantage to the information. A package still requires a de-encryption mechanism for EMM/ECMs combinations before they actually decode the intelligence of the data. Aside from these layers of protection, the IP media receiver needs to be pre-authorized before it can tune to the satellite signal. Another layer of security is the playback systems password level

protection for users in the theaters. Only licensed JPEG2000 capable playback decoders can reconstitute the image on screen.

The movie package upon reception at the theater's central server is encrypted and cannot be open (decoded) unless the posted time for presentation is due. The number of times the movie can be presented is also enumerated by royalty metadata embedded in the stream itself during the package wrapping in the transmission head-end (Satellite CDN Packaging, refer to Figure 1.3). This information is invisible to the user because the embedded metadata only lives within the packaged file itself[36] and not within the theater's playback system storage unit. Lastly, the IP media receiver is directly under control by the Satellite CDN transmission system at the far end. It can be disabled at any time upon sensing of compromised reception.

Transport Packet Structure

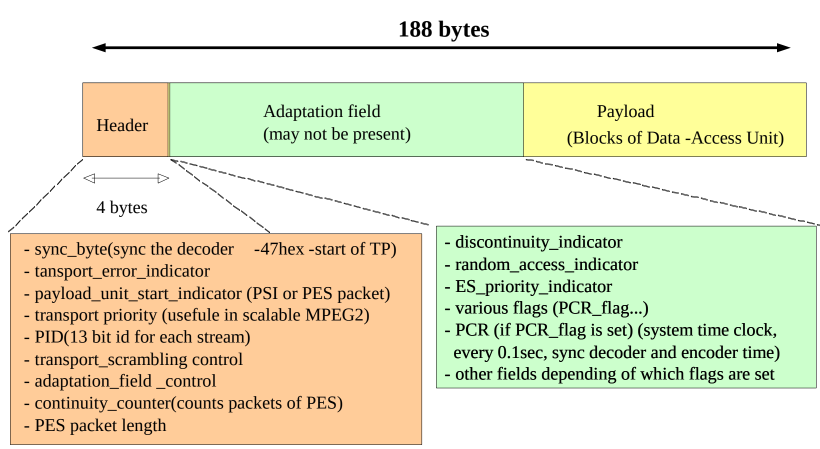

Figure 1.4 How MPEG-2 Transport Stream carries data,
Reference: ISO/IEC 13818-1 System, Standard 1994

Digital Watermarking

Content rights owners are now able to stamp their videos invisibly and indelibly, possibly tagging independently the versions passed to each licensee and the copies delivered to each recipient. The watermark is used as a root link in the essence of the content for digital media rights management, dissuasion against piracy, statistics and respect of contracts. The application of such a robust recipient ID provides forensic tracking to protect Rushes, Master copies, Awards screeners, and Browsing versions.

The electronic representation and transfer of digitized multimedia information (image, video, audio and text) has increased the potential for misuse and theft of such information, and significantly increases the problems associated with enforcing copyrights on multimedia information such as film. Digital watermarking technology opens a new door to authors, producers, publishers, and service providers for protecting their rights and interests in multimedia data.

Watermarking the content is in effect an invisible fingerprint embedded within the video during post-production and/or transmission. That is, watermarking is a tool that allows the information owner and provider to secretly embed robust invisible or inaudible copyright labels (watermarks) in the multimedia material for designating its copyrightrelated message such as origin, owner, use, content, rights, integrity, or destinations. In order to prevent any copyright forgery, misuse and violation, the embedded watermark fingerprint is perceptually invisible or inaudible, unalterable, and furthermore survives processing, which does not affect the quality of the multimedia data[37]. All relevant information of original data remains intact. A virtual barcode is embedded in the essence of the video. Each copy of a given content can contain a unique identifier. This invisible and robust stamp can then be read whatever the video format changes. Any video sample can be traced back to its source[38].

Original data is not required to retrieve embedded copyright watermarks. The watermark is robust against lossy compression, format conversions, low pass filtering, printing and scanning, analog to digital conversion, re-sampling, color reduction, and cropping. Software has flexible adjustment between robustness, perceptual noticeability, and size. Figure 1.6 illustrates the digital watermarking system for content security.

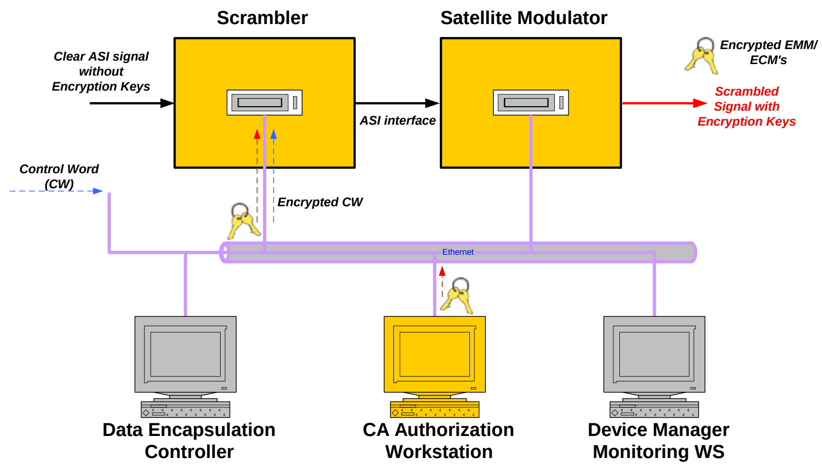

Figure 1.5 Implementation of SimulCrypt Conditional Access Encryption System, Reference: DVB SimulCrypt Standard, ETSI TR 102 035 V1.1.1 (2002-04)

Digital watermarking capabilities includes (a) Repeated (redundant) watermarking -It is the process when the same watermark can be embedded into one digitized data more than one time. This will increase the robustness of the embedded label. The retrieval of watermark requires 16-digit encrypted key. (b) Hierarchical watermarking embeds multiple watermarks into one data such that all of them are extractable independently for the purpose to track and identify a multimedia copyright transaction chain. A 16-digit key is required to check each independent frame or frames. (c) Regional watermarking embeds a watermark within or outside a specific region of multimedia data. This process also requires 16-digit key. (d) Public copyright watermarking embeds a watermark in such a way that anybody can read it without a secret key[39].

Data De-encapsulation

Only those properly authorized IP media receivers can actually receive the multicast streams. Receivers who do not have prior authorization cannot actually receive the satellite signal. The IP media receiver performs the data de-encapsulation process and buffers the package to its memory. The IP media receiver does not have enough storage capacity to take the entire stream. Once buffering is full, the data will be forwarded directly to the central server for ingestion to its storage device (in this case, an internally attached RAID drive). The encrypted content will remain in the storage bins of the central server until the presentation to the screen. Central servers that do not have dynamic keys to open up the package (during presentation-playback to DLP projectors) cannot decode the data. Decoding is requiring before the fragmented data packets are rebuild to its original form. During this time, the movie presentation on the screen is actually happening.

The IP media receiver is the main piece of hardware acting as content catcher for the theater's central server. The IP media receiver is directly connected to a satellite small disk antenna on the movie house roof via a coaxial cable (See Figure 1.7). The IP media receiver has an assigned IP multicast address to listen to during transmission. This pre-configured IP address is valid for reception of data files. The right RF frequency and satellite Network Information Table (NIT)[40] as well as other parameters are also provided so that the receiver actually gets the signal designated for reception.

Once data reception commences, the IP media receiver automatically forwards the buffered packets by blocks to the theater's central server for storage. It is estimated that digital cinema will use a file of 100GB for each film transfer. At a speed of 24 Mbps per sec, the approximate time to complete transfer of a digital master will be about 11.5 hours (1000/86.4).

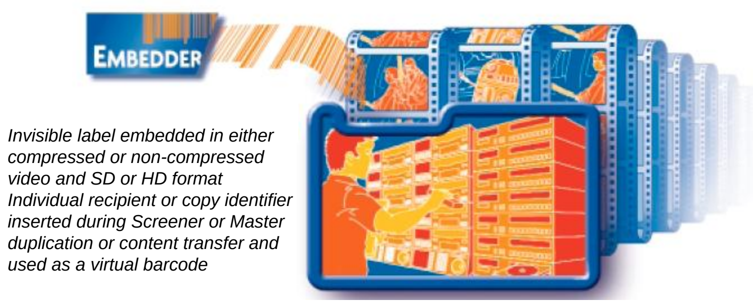

Figure 1.6 How Digital Watermarking Technology can meet your Content Security, Source: Nextamp's Content Security Solution

Return Communications Path

Following the arrival of the files, the IP media receiver communicates in echo mode to the satellite CDN networks' edge server system (Refer to Figure 1.2 and Figure 1.7). This communication is required so that the edge server at the transmit side can inquire about the package reception status and if there is a need for re-transmission. The acknowledgement from theater's central server system confirms the transmission is successful by sending positive echo (ACK) back to the transmit side Edge server. As mentioned in previous sections, the Satellite CDN already has a FEC mechanism in place, however, it is sometimes possible that due to severe noise (inherent in Satellite Broadcasting) and other interference, the packets needs to be rebroadcast. In this case a negative (NACK) acknowledgement is expected from the theater's server system requiring re-sending of the loss packets. Based on experience, a FEC of 10-15% of actual payload has virtually eliminated any packet loss upon arrival. The communication return path is secure using IP level tunneling and 128-bit AES encryption. The server systems of both the theaters, and the satellite CDN transmission system are in DMZ (Demilitarized Zone) protection isolated from any external Internet threats through a firewall. The terrestrial connection use to response back is physically isolated from main reception network (see Figure 1.7). This degree of protection is used in satellite broadcast CDNs because of the high need to content security.

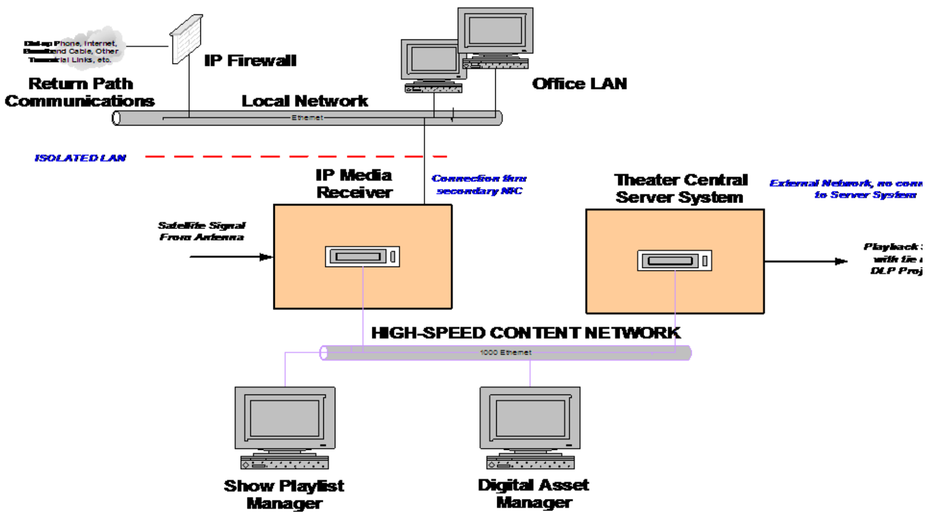

Figure 1.7 Return Path Communications from Remote Site Receiver

Projection

The digital cinema system in the movie houses is made up of several elements. Among them are: Central server, Playout server and DLP projectors.

Central Server

The Central server is the main repository for the multiplex movie theatre. The Central server manages the intake of new features from tape, DVD-ROM, satellite or fiber networks. It manages a very large storage capacity and the timely distribution of content to each screen of the multiplex, according to the show program. Once transfer of digital master (copy) is completed in the central server, the scheduling administrator kicks in the time and date of the playlist. The assignment of theater screens, as well as, the duration of the show plus associated ads and merchandising plugs are listed in the particular playlist. The central server automatically updates each playout servers' content reflecting the schedule(s) made in the Central server[41]. A complete digital cinema system is shown in Figure 1.8 (Source: EVS Digital Cinema Technology)[42]

The Playout Server

The Playout Server is a local server placed beside each projector in the multiplex. It ensures the local play-out of the show on one screen at a time. The playout server receives its content and playlist instructions from the Central server system. It allows the simultaneous loading of new film and the play-out of the current show. The playout server provides a reliable playback solution to deliver digital cinema efficiently to theater screens. Playout server technology employs a highly secure, 128-bit AES encryption scheme during the mastering process that provides reliable protection of content throughout the entire show and display projection chain. Simple and easy-to-use show list and scheduling tools provide unsurpassed flexibility and control. Plus twelve channels of AES/EBU digital audio and support for multiple subtitling and watermarking standards make the playout server the ideal cinema playback system. A playout server, being digital, has unsurpassed image quality to the silver screen using wavelet technology and the recently adopted JPEG2000 compression for digital cinema. To accommodate today's projectors, the playout server must provide transparent real-time playback of a 2K image from a 4K master or vice-versa. In addition to a resolution independent playback, the playout server needs to support current video broadcast standards including Standard Definition (SD) and High Definition (HD) playback at a guaranteed quality level at first time and every subsequent time[43].

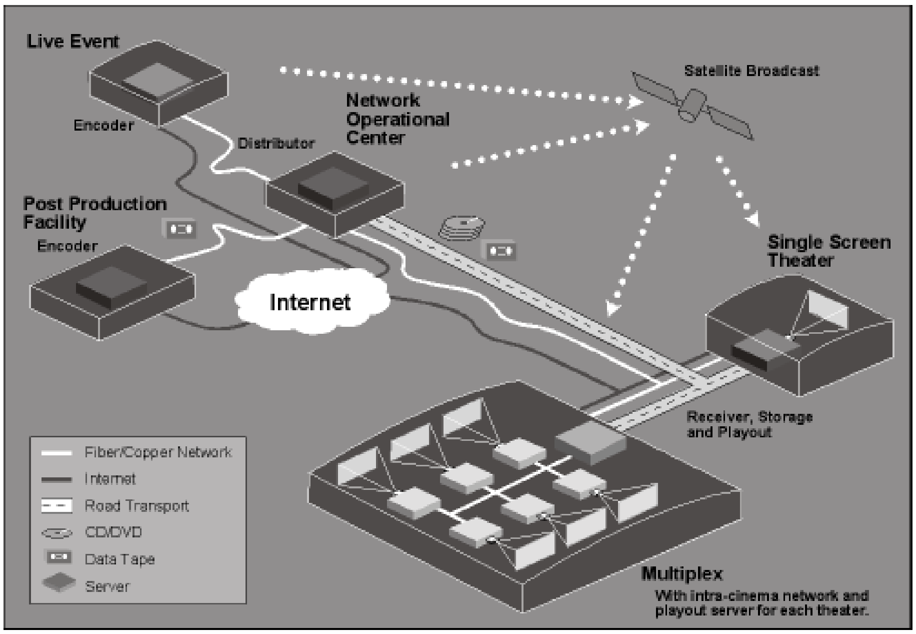

Figure 1.8. A typical digital distribution workflow envisions servers at all key locations, connected directly or with the help of Internet and satellite transmission. Courtesy: EVS Digital Cinema.

The redundant internal storage archive can hold up to 20 hours of high quality content. The movies are securely stored within an original encrypted form until playback time. At that time they are decrypted on the fly by the internal decoder. The show editor assembles detailed play-lists with pre-show adverts, logos, teasers, trailers and movies. It incorporates all the cues for theatre automation; sound, light level, intermission, curtains, etc.

The playback server automatically manages multiple content formats, title versions, languages and subtitling. An advanced monitoring system informs the projectionist of any potential issues including the projector. An automatic system health report can be generated and sent to the remote monitoring center providing proactive preventative maintenance.

Interfacing
Playback servers can receive interoperable content (MXF Interop Initiative)[44] on a standard hard drive connected through Ethernet, Fire Wire or USB2 link, as well as on

the advanced removable CineDisk media newly developed by XDC[45]. It interfaces with any DLP Cinema™ projector with the CineLink™[46] or any other video projector. The system application GUI manages all connections (GPI I/O, Ethernet or Serial) with the theatre automation systems. It provides a Gigabit Ethernet link to interconnect with the digital cinema network and exchange content with central server libraries.

DLP Projector

The projector is seen as the key element of digital cinema success. Currently, the market-share leader is Texas Instruments (TI). TI's Digital Micromirror Device (DMD) technology (aka DLP or Digital Light Processor) is based on a chip composed of a 1.3 million tiny moving mirrors, each representing a pixel on the screen. A projector system consists of three such chips, one for each primary color. TI consulted with cinematographers in the design of the chip and continues to improve it with higher resolution and improved color range (gamut) and contrast using something called "dark chip" technology, which creates better blacks. The technology is licensed to three projector manufacturers: Christie Digital, Digital Projection, Inc. and Barco. The system was developed as a bolt-on device to retrofit existing 35mm lamp houses, replacing the mechanical part of the projector.

Micromirror technology initially encountered resistance because the display chip was originally only 1,280 high by 1,024 wide and required the use of anamorphic projector lenses to display widescreen aspect ratios. Critics pointed out that film has at least a 4,000-line resolution and balked at sacrificing image quality for an electronic display.

JVC has come up with a CMOS-chip projector, the QX1. Their technology is less expensive to produce than the TI micromirror chip, and offers the higher, QXGA resolution of 2,048 by 1,536 pixels. So far, there are no installations using this technology, but both Sony Electronics and Eastman Kodak announced that they would license it for future products. NEC and Panasonic are also introducing TI-based projectors without dark chip technology but adding proprietary color management and video processing that produce images that are competitive[47].

DLP Technology

A digital projector based on DLP Cinema™ technology transfers the digitized image file onto three optical semiconductors known as Digital Micromirror Devices, or DMDs. Each of these chips is dedicated to one primary color- - red, green, or blue. A DMD chip contains a rectangular array of over one million microscopic mirrors. Light from the projector's lamp is reflected off the mirrors and is combined in different proportions of red, green and blue, as controlled by the image file, to create an array of different colored pixels that make up the projected image. The DMD mirrors tilt either toward or away from the light source thousands of times per second to reflect the movie onto the screen. These images are sequentially projected onto the screen, recreating the movie in front of you with perfect clarity and a range of more than 35 trillion colors[48].

Other Development

Researchers at Fraunhofer Institute for Computer Architecture and Software Technology (FIRST) and the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Intitut HHI are developing a more affordable alternative. The idea is based on using multiple, lower cost electronic playback devices instead of a costly, single projector[49].

Conclusion

Digital Cinema is intended to enhance the Cinema Theater experience. Implementation of Digital Cinema will revolutionize the cinema workflow from mastering to post production thru distribution channels. Creation of universal digital data (as a single digital master) would bring reliable and flexible content tracking. The transport and delivery of finished product (digital master) requires more than careful handling. To meet the demanding requirements of the entertainment industry and moviegoers, it must provide reliable, scaleable and secure delivery of a superior theatrical experience. The content security must be thorough and consistent with strict implementation of conditional access system to prevent any content spillage to unauthorized users. The satellite transmission network plays an important role in harnessing this method. Satellite CDN facilities must conform to high-bandwidth communications, flexible digital storage at edge network, secure data transfer thru the use of conditional access, and network management control of remote receivers in order to efficiently realize the benefits of this new methodology.

Satellite CDN for digital cinema has some notable advantages:

- Since assets can be delivered as files, and not streamed in the clear, there is no chance of the movie pirates consuming the movie through signal leakage.
- Since assets can be delivered as files, and not as live TV streams, theater central server assets are utilized more efficiently, as there is no analog-to-digital conversion (and vice versa) that must happen with caching streams to playout server.
- Since assets can be delivered as files, and not as streams, the theater central server has a fine, pristine quality, movie for multiple playback, as there is no open reel film scratching for loading and reloading that diminish the silver screen presentations.
- Since assets are delivered digitally as files, and stored in the theater's central server or library, there is no need for individual intervention for playing the movie on time and film handling maintenance are completely eliminated.

Digital Cinema is now ready for primetime. Required components are in place and consistent with the requirements for transport and delivery[50] of content reliably and secure to theaters around the world.

Early Birds

- Sony Pictures Entertainment (SPE) has unveiled its plan to streamline the distribution of its film and television content by leveraging a series of new digital entertainment technology and services created by Ascent Media Group (AMG) and HP. By digitizing its library of media assets – both film and TV – SPE can create content once and deliver it to its partners and customers many times, in any standard or format, more securely and quickly than before[51].

- EVS Spin-out XDC raises 9 millions Euros to deploy the first European digital cinema network. XDC aims to digitise 500 cinema screens over the next two years to create the first European digital cinema network. Europe has more than 30,000 screens and XDC is positioning itself as a third party investor between distributors and exhibitors, controlling the digital technology which has made EVS successful. At the same time, XDC is continuing its developments in Asia and America through its subsidiary XDC Inc., based in New York and Hollywood[52].

Definitions of Acronyms

AES	Advanced Encryption Standard with 128-bit cipher strength - AES is a symmetric key encryption technique, which will replace the commonly used Data Encryption Standard (DES). Military Standard FIPS-197.
AES/EBU	Audio Engineering Society/European Broadcasting Union – a standard for Audio transport in baseband with stereo pair in one connection
ANSI	American National Standards Institute
ASI	Asynchronous Serial Interface
ATSC	Advanced Television System Committee – A US version of DVB.
CAT	Conditional Access Table- CA table listing the EMM/ECM for service(s) inside the transport stream. DVB optional table use in implementing CA SimulCrypt
CDN	Content Delivery Network
CW	Control Word – an encrypted control keys for CA's EMM/ECM
D-5	Digital Television Tape Format #5 – for SDTV
D-6	Digital Television Tape Format #6 –for HDTV
DMZ	Demilitarized Zone – a term adopted by IP IETF to emphasize the isolation of piece(s) of device(s) from external environments such as Internet.
DPX	Digital Moving Picture Interchange
DVB	Digital Video Broadcasting – a consortium of European countries that facilitates implementing guidelines for satellite, terrestrial, cable, and television digital emission.
ECM	Entitlement Control Message – encrypted CA private information for controlling receiver's authorization and levels of service access
EDL	Edit Decision List – a mark of in/outs of a frame established during editing session
EFP	Electronic Field Production
EMM	Entitlement Management Message – encrypted CA private information embedded within the transport stream
FEC	Forward Error Correction. A system of correcting transmission packets at the receiving end without a need for complete signal retransmission. Most commonly applied in terrestrial and satellite networks.
FCIP	Fiber Channel of IP (Internet Protocol)
GSN	Gigabit System Network
HD	High Definition format as defined by SMPTE standard 292M with maximum data rates of 1.485 GB/s
HDCAM	Proprietary capture format for camera image acquisition in HD made by Sony Corporation of Japan
HSDL	High Speed Data Link
IETF	Internet Engineering Task Force
IFCP	Internet Fiber Channel Protocol
IP Multicast	IP multicast is a collection of IETF standards for sending information to multiple destinations simultaneously.
JPEG2000	Joint Photographic Expert Group – Digital Cinema officially adopted the JPEG2000 as standard compression technique in capturing image from acquisition
LAN	Local Area Network
LIN/LOG	Linear/Logarithmic. Data values within the file are specified linearly or logarithmically within the utilizing the maximum number of available bits per value.
MPEG	Motion Picture Expert Group. An ISO/IEC committee established to study the compression system for motion picture. Responsible in drafting MPEG standards such as MPEG-2, MPEG-4, MPEG-3 (MP3), MPEG-7, MPEG-21, etc.
NAB	National Association of Broadcasters
NAS	Network Attached Storage
PID	Packet Identifier – a unique ID assign for each packet of payload in the transport (Internet Protocol) adopted by ISO/IEC MPEG TS and DVB consortium.
NIT	Network Information Table – a physical description of the transmission network to help receiver tune to the network's services. DVB Mandatory table for any MPEG transport stream transmission
RF	Radio Frequency
RAID	Redundant Array of Independent Drives
RGB	Red, Green and Blue – primary acquisition colors that a capture prism of the camera were tune to recognize.
SimulCrypt	A DVB standard CA implementation of encryption based on level of service or events. To be implemented at Head-end system.
SMPTE	Society of Motion Picture and Television Engineer
SSL	Secure Socket Layer –an IP tunneling technique to isolate transaction(s) in the public internet.
YUV	Color Model used for encoding video where Y is the luminance of the black and white signals and U and V are color difference signals. U is red minus Y (R-Y) and V is blue minus Y (B-Y)

About the Author

AUGUSTO R. VILLASEÑOR is a principle engineer for Globecomm Systems, with more than 14 years of experience in broadcast engineering design and technical operations. Augusto designed and implemented the SES Americom IP Prime IPTV Network Operations Center in Vernon Valley, NJ, in September 2005. In August of 2006, he started the design and implementation of Showtime's new Network Operations Center file-based playout facility in Hauppauge, NY. From ingest to master control to satellite distribution, Augusto completed the project on time for its June 2007 launch. Presently, he is working on the implementation of the Media Processing Center in Asia for IPTV, DVB-H and DTH operations. Augusto has a Masters degree in Technology Management from Polytechnic University in Farmingdale, NY. He is a licensed electronics and communications engineer, as well as a member of IEEE BTS Society, SBE New York City Chapter 15 and SMPTE New City Region.

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