Encoding and Encryption of Digital Cinema Package

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Abstract

During the past decade it became the use of digital formats became widespread in the production, post production, and distribution process in the film industry. Digital cinema package is one of the widely accepted and commonly used formats in the distribution of digital cinema. This paper specifies the key details and attributes of digital cinema package along with the encoding and encryption process used in digital cinema package creation. Most commonly used approaches in digital cinema distribution are discussed in the later section of the document. The evaluation of encoding of the digital cinema package is based on a practical approach and the experimental results obtained are also discussed.

Keywords : Delivery message encryption, digital cinema package, key, multimedia security

I. INTRODUCTION

A. What is Digital Cinema Package (DCP) ?

Digital Cinema Package (DCP) is a format used in digital cinema (DC)to store, and convey the contents of the film to be projected. A typical DCP consists of a set of files that contain images, sound, subtitles, and additional files to control playback and optional encryption of the content.

Images and sound are stored in separate files (track files) and in most cases the entire movie is possibly divided into several reels. Therefore, the entire set of images and sound data along with the subtitles are split into several files of arbitrary duration. The order of playback of these files is controlled by a Composition Playlist (CPL) which is in XML format which references the image, sound, and subtitle files.

The DCP also contains Packing List (PKL) that contains information about all the files that belong to the DCP.

The picture track files in DCP are compressed using JPEG2000 codec and the audio track file is represented using a 24-bit linear PCM uncompressed multichannel WAV file. Encryption can optionally be applied to the track files with AES 128-bit in CBC mode to protect the contents from unauthorized use.

B. Basic Technologies and Standards

Two versions of DCP compositions are used. The original and commonly introduced version is called Interop DCP. Another specification was published by SMPTE (SMPTE ST 429-2 Digital Cinema Packaging - DCP Constraints), in 2009, which is commonly referred to as SMPTE DCP. Although both of them share similar properties, SMPTE DCP is not backwards compatible with Interop DCP. Newer film productions are mostly encouraged to be distributed in SMPTE DCP.

SMPTE standards for digital cinema have been adopted by the ISO in its technical committee TC36. Newer and emerging technical aspects of digital cinema are specified in SMPTE standards and can be found on their website [4] for references. These documents contain specifications for key aspects of digital cinema such as D-Cinema Distribution Master (DCDM, SMPTE 428). D-Cinema Packaging (DCP, SMPTE 429), D-Cinema operations (including key management for encrypted packages, SMPTE 430) and D-Cinema quality for projection (SMPTE 431).

These documents also contain references to the other core technical details and standards specified by SMPTE, ISO, and other organizations. A major part of the technical details included in the DCI Digital Cinema

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System specification [5] is also included in the related SMPTE standards specification, and can be downloaded for reference purposes. The DCI specification contains details about encryption and content security which serves as an operational guide for the users involved in DCI related operations. Individual organizations can develop software that is compatible with SMPTE / DCI D-Cinema standards as all technologies that are specified in SMPTE / DCI D-Cinema are openly available and can be used free of license and without any patent related issues.

II. DESIGN OF THE DIGITAL CINEMA PACKAGE

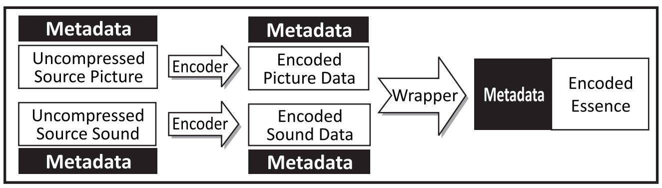

Fig. 1. Encoding and Wrapping Process of Picture and Sound with Metadata

DCP serves as a flexible and secure format for the delivery and projection of digital movies without the loss in its quality levels. The encoded and wrapped form of DCP consists of mainly MXF and XML files which correspond to the actual contents and its various attributes used in the representation process.

MXF stands for Material eXchange Format which is a container or wrapper format used in digital video and audio for the representation and distribution process as defined by a set of SMPTE standards. This format supports different streams of encoded data (mainly video and audio, also called essence) with metadata wrapper which describes the material contained in the MXF file. The MXF file can contain images and sound compressed using various systems or even uncompressed image and sound data in a representable format. The representation of the internal structure of an MXF file and itsencoding and wrapping process is shown in Fig. 1.

The wrapped MXF file consists of metadata as file header and the encoded essence as file body. To reduce storage space and to speed up the transmission of DCPs, images are compressed using JPEG 2000 codec (at very high quality). Sound stored is normally kept uncompressed. Subtitles can be stored as XML files that contain timed text or subpictures. In case of timed text, the text is stored with timecode that corresponds to the time that the text is to be shown in the picture. The text is rendered and combined with the image in the projection system during playback. In case of subpicture a pre-rendered image with sufficient transparency (containing subtitles) is kept stored and is combined with the image (actual movie content) at playback time. The time synchronization in this case is also done by an XML file. An example of a video trailer encoded as DCP is shown in Fig.2.

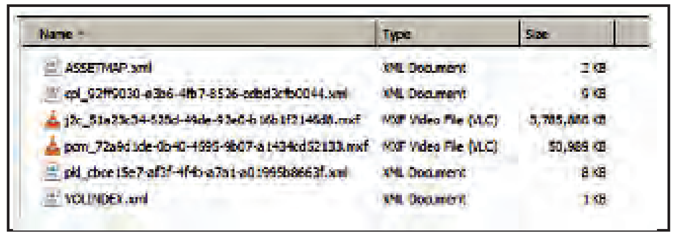

Fig. 2. Video Trailer File Encoded as DCP

The other major attribute file that is contained in a DCP is the Packing List (PKL). The PKL is stored in XML format which contains hashed value of all the files used in the composition. This file is commonly used in the ingestion process to the digital cinema server which verifies whether the provided data has been corrupted or tampered. Apart from PKL, a DCP may contain multiple Composition Playlist (CPL), which specifies the order of execution of the encoded essence (actual data). The DCP also contains an Asset Map file which holds the identifiers that correspond to the mapping process of the storage that links the actual data to the file system on the disk. An optional volume index can also be used to identify the order of volumes in a multi volume DCP (DCP stored in multiple hard disks).

A. Track Files (Images and Sound)

1) Image Track Files

Over the years, different standards have been adopted by D-Cinema in its representation of images and sound to achieve higher levels of quality. All of these standards follow advances in technology to achieve higher levels of quality by focusing on details like image compression, spatial resolution, and colour fidelity.

According to the current advances employed in digital cinema projection, two basic resolutions are followed as standards: 2K with 2048 x 1080 pixels and 4K with 4096 x 2160 pixels. Although these correspond to the maximum frame size representations which is possible while projection, most standards use different formats and frame sizes according to their needs (as according to the formats standards specification). In most cases the resolution shall extend to the maximum of either the horizontal or the vertical resolution the projector can achieve. For example, a movie with aspect ratio of 2.39:1 in a 4K container shall have the image resolution of 4096 x 1716 (active pixels), which fills the horizontal resolution of the container. Most common formats used as standards, as of now, by SMPTE and Interop in digital cinema reproduction and projection are specified next.

a) SMPTE (JPEG 2000)

- Flat (1998 × 1080 or 3996 × 2160), = 1.85:1 aspect ratio
- Scope (2048 × 858 or 4096 × 1716), ~2.39:1 aspect ratio
- HDTV (1920 × 1080 or 3840 × 2160), 16:9 aspect ratio (~1.78:1) (although not specifically defined in the DCI specification, this resolution is DCI compliant per section 8.4.3.2).
- Full (2048 × 1080 or 4096 × 2160) (~1.9:1 aspect ratio, officially named as Full Container by DCI which is not widely accepted in cinemas.)

b) MXF Interop (MPEG-2) which is currently deprecated

- *Full Frame (1920 × 1080)*

Apart from frame sizes, the need for higher frame rates other than the standard 24fps and 48fps are also discussed over these years [2], [3], and the successful experimental results of these added to their support as standards in the specification document. Frame rates that are supported as standards, as of now, by SMPTE and Interop DCP are specified as follows:

i) SMPTE (JPEG 2000) supported frame rates

- 24, 25, 30, 48, 50, and 60 fps @ 2K
- 24, 25, and 30 fps @ 4K
- 24 and 48 fps @ 2K stereoscopic

ii) MXF Interop (JPEG 2000) supported frame rates which is currently deprecated

- 24 and 48 fps @ 2K (MXF Interop can also be encoded at 25 frame/s but support is not guaranteed)
- 24 fps @ 4K
- 24 fps @ 2K stereoscopic

iii) MXF Interop (MPEG-2) supported frame rates which is currently deprecated.

- 23.976 and 24 fps @ 1920 × 1080

Even though standards have been extended to support additional frame rates like 25, 30, 50, and 60 fps, the most commonly used primary frame rates that are supported and used by SMPTE / DCI D- Cinema systems are 24fps and 48 fps.

The images to be played back during projection need to follow XYZ colour space which uses 12 bits per component and per pixel with a gamma correction value of 2.6. XYZ is a device independent colour space that includes all the possible colours in the visible spectrum. A colour conversion needs to be done while projection as all the projectors work in the RGB colour space.

To achieve better transparency in this issue the standards also define a minimum RGB colour space value for the projectors and include specifications for colour accuracy, and screen luminance.

Because of the high resolution images which use 12 bits per component while representation, a single uncompressed 4K DCP image needs 39.8 Mbytes of storage space which then leads to a file size of 955.5 Mbytes/s or 7.6 Gbit/s [1]. This amount of data is too large for distribution and projection. To overcome this difficulty, compression needs to be done without loss in the quality levels of representation to reduce portability issues. The most common standard followed and used widely by digital cinema which is based on SMPTE standards uses JPEG 2000 compression algorithm for the compression of images.

The maximum allowed bit rate for JPEG 2000 images while encoding a DCP is 250 Mbit/s (1.3 MBytes per frame for a 24 frame per second DCP). In such a case, a DCP which is encoded in its maximum data rate (250 Mbit/s) would result in a 1 hour movie to be stored with a file size of 115 GBytes in size. For most practical situations, a DCP is encoded with a maximum bit rate of 200 Mbit/s to avoid playback issues in the DCP projection server, thereby, achieving compatability across a wide range of projection equipments.

As an entire movie may contain several tens of thousands of single images, it is a tedious task to handle file management if stored in its native format (individual image by image). To override this problem, all the image files are wrapped together using a container format. DCP uses Material eXchange Format (MXF) for this purpose. MXF files normally contain a header part which specifies the technical details of all the images and a body part which contains all the actual images to be projected.

2) Sound Track Files

Sound Track Files in a DCP are also encoded and stored in the wrapped MXF files. Sound data is sampled at 48 kHz or 96 kHz according to the preference. Each sound track file can represent upto 16 discrete audio channels which are used for multi-channel audio representation and reproduction. For the playback of multi language films, there can be more than one sound track file present per reel in a DCP. The execution of the sound track file which corresponds to each of the languages is done by the Composition Playlist (which holds references to the images, sound and subtitle files).

B. Package

The Digital Cinema Package is a combination of image track files, sound track files, subtitles, Composition Playlists (CPL), Packing List (PKL), an Asset Map, and an optional Volume Index file.

The Composition Playlist (CPL) is a representation of the complete Digital Cinema work. It specifies the order in which the essence (actual content like image,

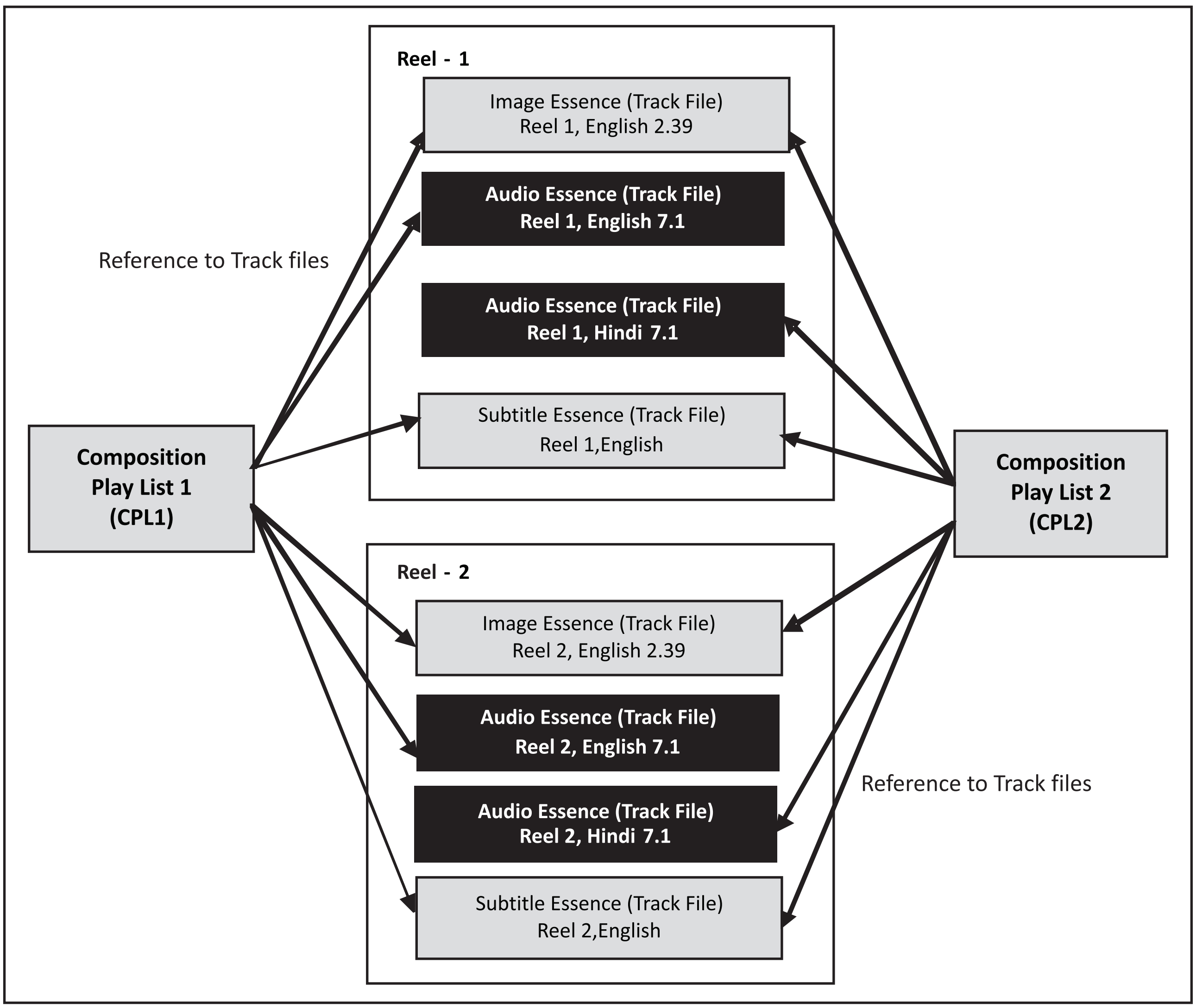

Fig. 3. Composition Playlists and Their Relation to Track Files

sound and subtitles) is to be played back while projection. The CPL is stored in XML format.

A DCP can have multiple CPL, and it is possible that the same track file can be referenced from more than one CPL. This makes it possible to create multi-language DCP which shares the same set of image files for all languages and with different set of sound track files, one for each of the languages. In a scenario like this, all of the CPL files share references to the same image track files and to the separate sound track files, each of which thereby, refers to different languages. There is also the possibility of multi-language DCP where some parts of the image sequences differ for each of the languages.

In this scenario the differing scenes need to be rendered on separate image track files for the CPL to refer to. An example of two Composition Playlists, each of which belongs to a Multilanguage DCP having a difference in the sound track files being played is shown in Fig.3.

In this case, both of the composition playlists, CPL1 and CPL2 share the same image track files and subtitle track files for the two reels and differ in their reference to sound track files. So CPL1 which represents two reels (Reel 1 and Reel 2) references to the image track files, sound track files, and subtitle files all of which correspond to the language English. In the case of CPL2, which also represents two reels (Reel 1 and Reel 2) has its references to the image track filesand subtitle files that correspond to the language English and with sound track files which corresponds to the language Hindi.

In real case scenarios, if CPL1 is invoked for playback, the image track, sound track, and subtitle will show contents that correspond to the language English. If CPL2 is invoked for playback, then the image track and subtitle track will show contents that correspond to the language English but with sound track files that correspond to the language Hindi.

Another attribute file included in the DCP is the Packing List (PKL), which is an XML file that is stored along the package that contains information about all the files that are present in the DCP. The PKL stores attributes like identifiers for all files, information related to the issuer of the package, system type that was used for package creation etc. The main use of PKL in distribution process is for storing hash values which relate to each asset in the package. So, in order to check the integrity of a package, a playback server could recalculate the hash values from the original distributed asset files and compare them with the hash values in the PKL.

The included attribute file called the Asset Map file contains the location of each asset with an entry that maps the UUID of the asset to the actual path in the file system used for storage.

For the operation of large files it may require the contents to be stored in multiple storage mediums. In cases like these, the asset map contains the location to find all the scattered parts of a file on a multi-volume storage. To specifically identify each of the volumes in a multi-volume storage, an attribute file called *volume index* is used. Volume index specifies the list of all volumes in a multi-volume storage.

C. DCP and KDM Encryption Process

A major security feature that is employed while creating a DCP is the encryption of the content which is done after the encoding stage is complete. The process of encryption is made available as an optional possibility in the DCP creation process. So every DCP creating program does have the provision to create the DCP either as signed or as encrypted. If a DCP is created as signed, then open access permission is enabled by default to access the content. It is a known fact that a DCP created in such a way can only be used for testing purposes internally in a production facility and may not be used for distribution purposes due to lack of security in its access control mechanisms. So in most cases, the distribution of a film is to be done in such a way that the encoded content needs to be encrypted to provide sufficient access control mechanisms so that it can only be decrypted on the intended playback server. The complete list of access control and content security measures used in a DCP creation process is available in the DCP specification as a guideline to help through this process.

The specification also describes mechanisms to ensure that the encrypted content needs to be only accessed by authorized playback systems for better security in the distribution process. To achieve better transparency in the actual data encryption and distribution, the process of DCP encryption is done as a two stage process. The actual track files containing the essence were encoded as MXF files and encrypted using AES system with 128-bit keys. Since AES employs a symmetric encryption system, the same key is used to encrypt and decrypt a file. This creates a security loophole for the fact that anyone having the actual key which was used for the encryption can easily hack the content by decrypting it with the same key.

So for providing better safety, the AES keys which were used in the encryption process need to be encrypted before distributing them. This is normally achieved by using a second entirely different cryptographic algorithm called the RSA public key algorithm which is represented in 2048 bits. The RSA algorithm is asymmetric so that it makes use of a pair of keys for encryption and decryption. The receiver of an encrypted message holds a private key which is kept secret and is used only in the decryption process. The second key, which is the public key, can only be used to encrypt the message (in this case the 128 bit AES keys which were used for the encryption of the actual content) and cannot be used to decrypt the encrypted message.

The asymmetric key pair is created and encryption is made possible by following a list of operations. Every playback server holds a unique set of public/private key pair. The manufacturer of the playback server stores the private key in a dedicated hardware part of the server meeting FIPS-140 security standards, which is tamper-proof and can be set to automatically erase itself if some manipulation is done.

So, it is designed in such a way that not even the operator or the owner of the playback server can get the secret private key hidden inside the hardware.

The second key called the public key belongs to the private key of a playback server and is made available by the manufacturer of the playback server. It is distributed along with the server. The public key which is made available is shared with the distributor and is used to create Key Delivery Messages (KDM) for DCPs which are specific to playback servers. The KDM is another major security aspect used in the distribution of DCP which is defined specifically for the purpose of secure transmission along with reuse restriction locks to achieve better security. The KDM holds the RSA encrypted AES keys which are used to decrypt a DCP.

A KDM generated is normally associated with particular composition playlists (CPLs) and can contain keys for more than one playback server. Each playback server needs a uniquely generated KDM to work properly. A common practice followed while creating multi-language DCPs is to generate different KDMs for each language. KDM also provides the feature to assign date/time validity window so that access control management is done properly. Playback systems are not allowed to operate or use the KDM outside of this specified time window. So, it allows the distributors to safely distribute the content (DCP) so that it cannot be unlocked prior to the release date.

The creation and distribution of DCP with KDM encryption is shown in Fig. 4.

III. DCP CREATION AND DISTRIBUTION : THE PRACTICAL APPROACHES USED

For most of the films produced for theatrical releases, post production facilities follow strict guidelines to ensure that all the quality control checks are accomplished, so that the final package must follow all the compatibility with a variety of digital cinema projection equipments. For bigger studio release films, the initial process is to create a DCDM (Digital Cinema Distribution Master), which is a post production step prior to making a DCP.

A DCDM normally holds the picture contents in XYZ TIFF format along with the sound data, which are not yet wrapped to MXF files. The major advantage of creating a DCDM is that it can be used for archival purposes and its sharability feature allows it to be sent for international re-versioning purposes. For smaller release films, the post production facility skips the creation of a DCDM and instead relies on a DSM (Digital Source Master), which can be used to encode a DCP. DSM can be exported as a variety of formats along with variable colour spaces. So, encoding to a DCP needs to be done carefully, with colour space standards and with the use of 3D LUTs so that the colour reproduction of the end product need not vary from the original DSM. Quality control checks of the final encoded and encrypted DCPs are done and approved with the presence of major people involved in films like directors, editors, colorists, sound mixers etc.

The distribution process of the DCP makes use of hard disks commonly attached on a CRU DX115 drive enclosure. The CRU DX115 drive enclosure was designed initially for military purposes, and was later adopted for digital cinema distribution because of its reliable characteristics. The hard drive itself is formatted with the Linux ext2 or ext3 file system for better compatibility as most of the digital cinema servers are Linux based. Usually, the inode is set to 128 bits to reduce compatibility issues. FAT32 and NTFS file systems are occasionally used for this purpose. Other common methods of digital cinema distribution are by dedicated satellite links or through the use of high speed internet connections.

A. Non Linear Editors and MXF Support

Since DCPs became a standard for Digital Cinema distribution, the use of a container and wrapper format like MXF also became common with most of the Non

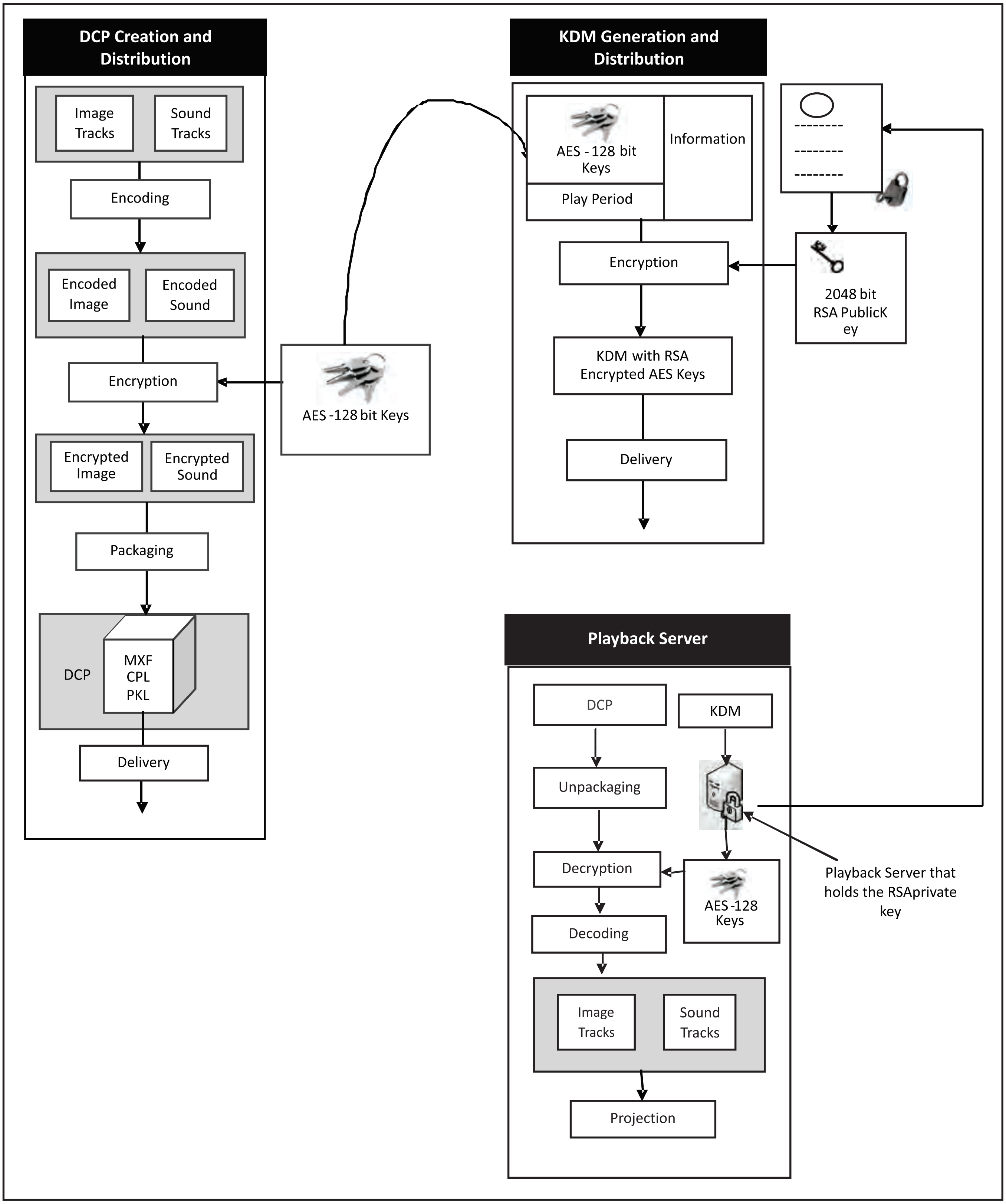

Fig. 4. Creation and Distribution of DCP with KDM Encryption

Linear Editing (NLE) programs. Most commonly used NLEs like Avid Media Composer, Final Cut Pro X, Adobe Premiere Pro 3.1 or above, DaVinci Resolve, Sony Vegas Pro, and GrassValley EDIUS all natively support the use of MXF files. The latest version of Avid Media Composer, which is one of the most commonly used and industry standard NLEs in Hollywood films, stores media in its native format, Avid MXF Op-Atom, and has capabilities for importing and exporting in MXF Op1a format.

IV. EXPERIMENTAL RESULTS

To evaluate the encoding process of creating a DCP, a test trailer project was created in Avid Media Composer [7], which is one of the widely used Non Linear Editing program in film post production. The test project had a sequence of resolution 1920 x 1080 running at 24 frames per second with a duration of 3 minutes. The video files used in the project were shot with a Canon EOS 5D Mark IV camera. The actual contents shot were with Chroma sub-sampling applied as most consumer level cameras lack the feature of shooting in raw formats without any sub-sampling. Therefore, the footage used was shot with a resolution of 1920 x 1080 at 24 frames per second and with a chroma sub-sampling of 4:2:0 encoded with Rec 709 colour space using YCbCr colour model. The footage were reencoded within Avid Media Composer using its built in engine to the codec Avid DNX HD 120, which stores the content as MXF files. The encoded file now holds a better chroma representation with a sub-sampling value of 4:2:2. As the editing process was completed, the final colour corrected project was exported as a movie file (.mov) without any further compression. So, the resulting file holds the actual picture file along with its audio content having data stored in 2 channels (stereo) sampled at 48.0 KHz and represented in 16 bits. The representation of the final test sequence which was created using the NLE software Avid Media Composer is shown in Fig.5.

Since most of the DCP creating tools available in the market restrict their extensive toolsets to be only available in their commercial versions, the encoding and creation of DCP in this experiment was done with a free and open source program called DCP-o-matic. The program consists of most of the commonly needed feature sets for the creation of a DCP. The program is freely available to download from the official website [6].

The exported file from the editing software is imported as input to the DCP creation program. The exported content with the resolution 1920 x 1080 (16:9)was then rescaled to 2048 x 858 to achieve the wide aspect ratio used in modern movies (2.39 : 1 or 21:9). The re-scaling process can either be done within the editing software before exporting to the final movie (.mov) file or by the DCP creation program. In most cases of post production it is done within the video editing programs. In this case, the DCP creating program was used to do this to check the transparency of the undergoing process.

The content settings window in DCP-o-matic specifies the scaling and colour conversion attributes along with crop operations (useful in removing any cinemascope/mask applied previously).The DCP settings window in DCP-o-matic specifies attributes like the naming scheme, content type (trailer, advertisement, feature, teaser etc.), number of reels, and type of standards used for encoding (SMPTE or Interop). Other attributes are specific for videos like Container (DCI Scope which is 2048 x 858), Resolution (2K, 4K etc.), Frame Rate (24, 25, 30, 48, 50, 60), and audio attributes (like the number of channels (2-16)).There is also a section which specifies the bandwidth of the converted data which is normally encoded as JPEG2000.

The main security aspect in a DCP distribution process, which is the KDM encryption is also done in this stage. There is an option to create a DCP as signed or as encrypted. The process of generation of a KDM is done if the DCP is created as encrypted. Here in this test, the DCP is only created as signed and not as encrypted because of the limitations in availability of a practical cinema playback server to check the exact decryption process. The actual attributes and specifications used for encoding the DCP are given as follows:

Content Type : Trailer (Signed)
Reels : Single Reel
Standard : SMPTE
Container : DCI Scope (2048 x 858)
Resolution : 2K
Frame Rate : 24
JPEG 2000 bandwidth : 200 Mbit/s

A representation of the actual content settings window and the DCP settings window of the DCP created in DCP-o-matic is shown in Fig.6. A representation of the DCP encoding process is shown in Fig. 7. The attributes of the created DCP package along with the file size is shown in Fig.8.

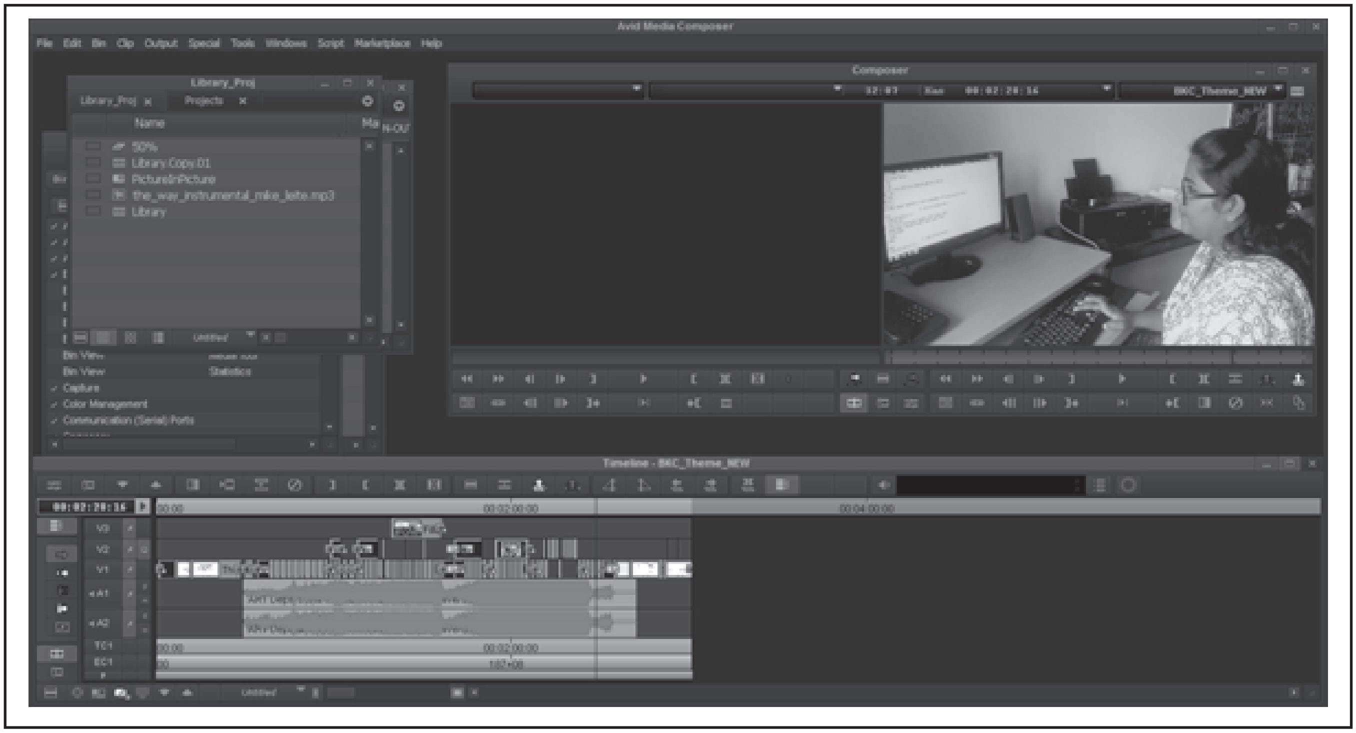

Fig. 5. Test Sequence Representing the Trailer File Created in the Non Linear Editing Software Avid Media Composer

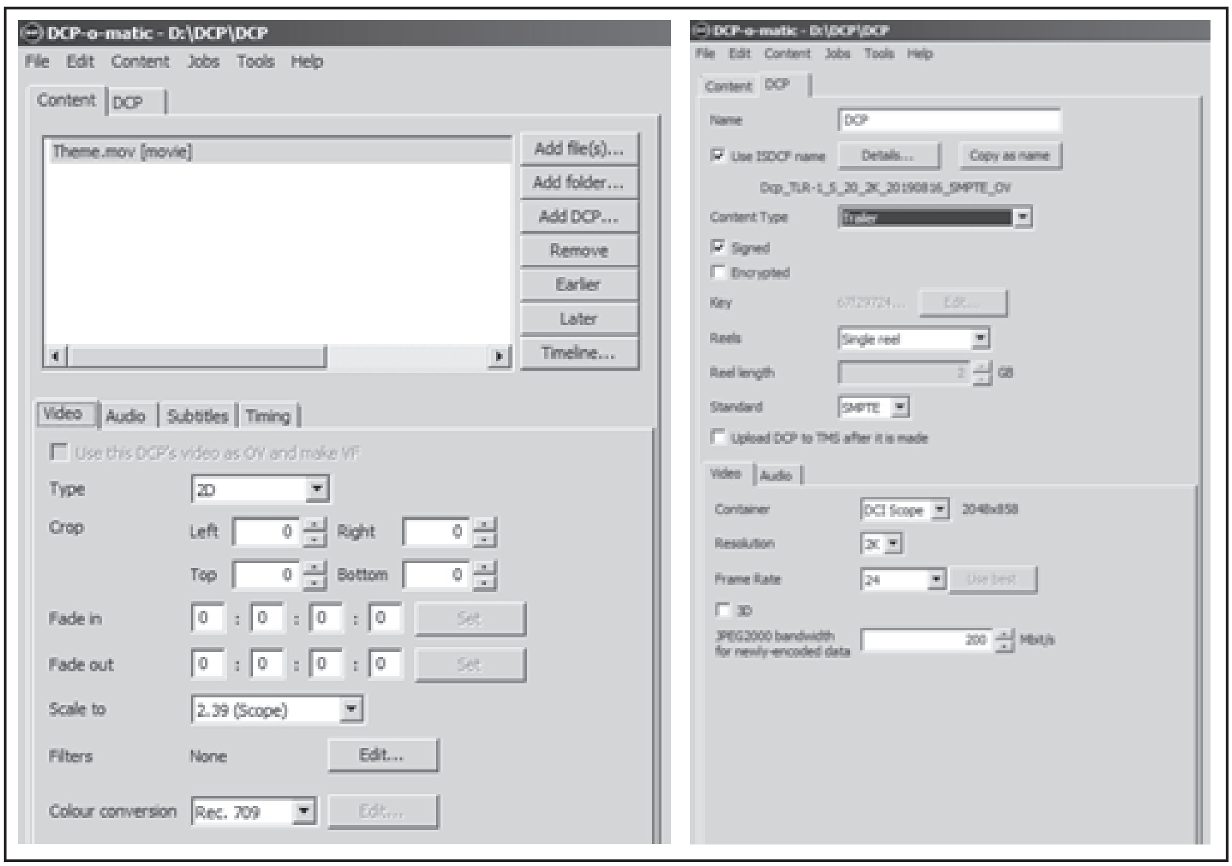

Fig. 6. Representation of the Actual Content Settings Window and the DCP Settings Window of the DCP Creating Software DCP-O-Matic

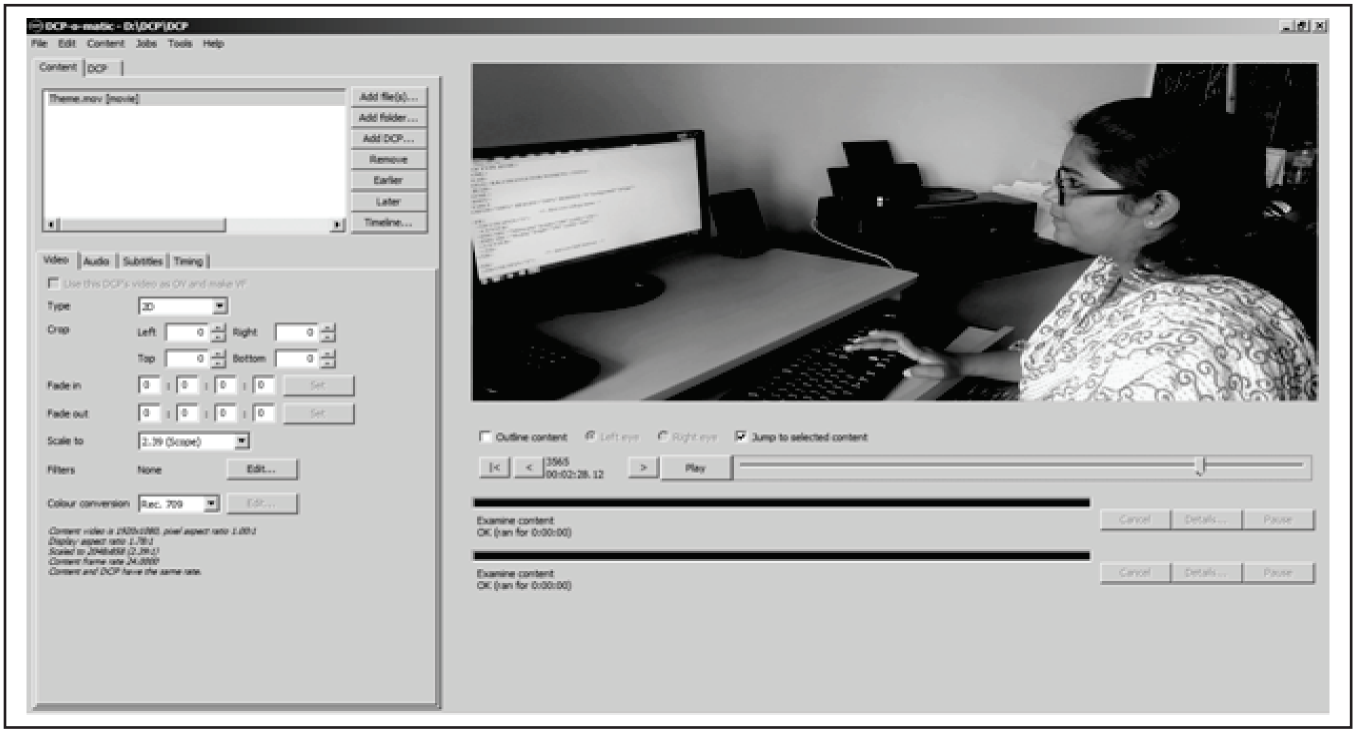

Fig. 7. DCP Encoding Process in DCP-O-Matic

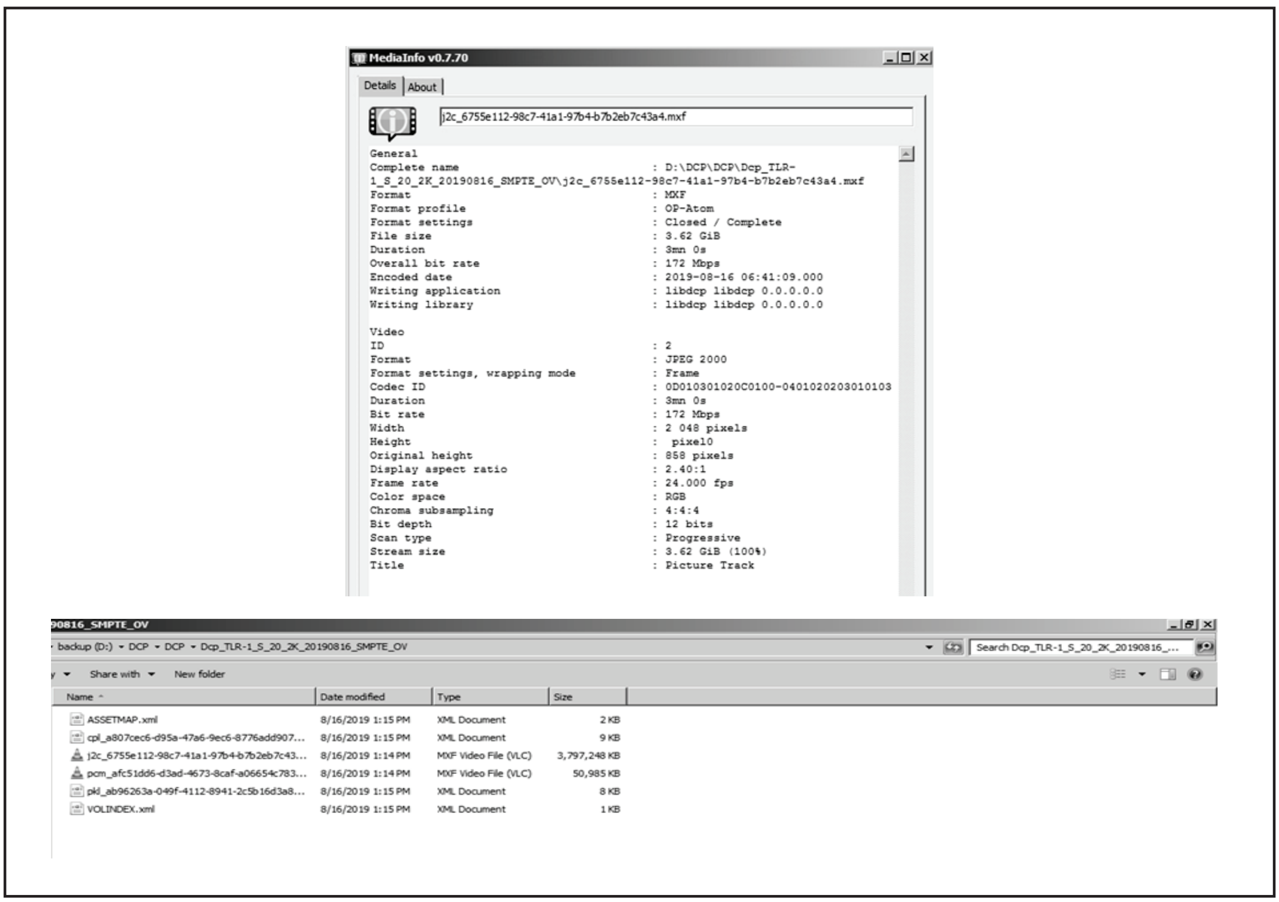

Fig. 8. Attributes of the Created DCP Package with File Size

V. CONCLUSION

The advances in digital technologies over the past years made the possibility of representing film archives in digital format. The digital cinema package serves as one such technology for the easy distribution of film archives in high quality. Security measures like Key Delivery Message encryption which were implemented and upgraded overtime makes it possible to distribute the contents of a film prior to its release safely through dedicated hard disk drives, high speed internet or through satellites.

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