NTT Technology Supporting Digital Cinema

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Abstract

This article describes Hollywood's 4K digital cinema specifications, which are based on NTT super-high-definition image technology, and describes the equipment and technology that NTT developed for use in the ongoing joint "4K Pure Cinema" trial of the implementation of these specifications, which involves actual secure distribution and exhibition of 4K feature films (e.g., Harry Potter 4 and The Da Vinci Code) in Japan.

1. Hollywood's DCI specifications

The DCI (Digital Cinema Initiatives, LLC) digital cinema specifications [1] were finalized in July 2005. They include specifications for 4K images, which are based almost entirely on NTT's eight-million-pixel super-high-definition image technology [2]. Standardization of digital cinema specifications based on the DCI specifications is currently in progress in the Society of Motion Picture and Television Engineers (SMPTE). The DCI specifications are intended to achieve extensibility and image quality that will remain usable into the future, with particular importance placed on maintaining security and compatibility. Their features are described below.

1) Image resolution

The specifications define two formats that differ only in resolution: 1) 2048 × 1080 pixels, referred to as 2K, and 2) 4096 × 2160 pixels, referred to as 4K. Thus, the 2K format provides resolution equivalent to current high-definition television while the 4K format, which has four times the resolution, provides digital images with quality as good as conventional 35-mm film, although the images shown in theaters could actually look better because digital data does not degrade in quality when copied, unlike conventional film.

2) Image color reproduction

The image is quantized at a depth of 12 bits for each color in the absolute color space represented as XYZ. Using an unlimited XYZ color space will ensure compatibility with future display devices that will have wider color ranges. In addition, true color reproduction can be achieved regardless of the exhibition conditions by adjusting the color to match the specific color characteristics of the projector. The frame rate is the same 24 frames per second (fps) as is conventionally used for film. For the 2K format, however, a 48-fps mode is specified to allow for other display styles, such as three-dimensional (3D) display.

3) Image compression method

An image compression method based on JPEG2000[*1] for intra-frame encoding is used. JEGP2000 produces a high-quality image without the block distortion that occurs with ordinary JPEG or MPEG compression. An additional feature is that 2K-resolution data can easily be extracted from 4K-resolution data. The maximum bit rate is specified as 250 Mbit/s, which corresponds to about 200 to 300 giga-

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*1 JPEG2000: An international standard specification for still image compression as a successor to the JPEG format currently used in digital cameras. The most basic core encoding system was standardized internationally in December 2000 as ISO/IEC 15444-1 Part-1. It is based on the wavelet transform and arithmetical encoding and features various levels of scalability.

bytes for a two-hour movie.

4) Audio signal

Audio is quantized with a sampling frequency of 48 or 96 kHz at a resolution of 24 bits, which allows for the use of up to 16 channels simultaneously. No audio compression is used.

5) Subtitles

The XML format is specified for subtitle data. Two subtitling methods can be used: the superimposition of still image files and the specification of timed-text data.

6) Data encryption

The image and audio data are wrapped in a multimedia data exchange format known as MXF (material exchange format) and then encrypted with the AES (advanced encryption standard) cryptosystem (128 bits, cipher block chaining mode). Because the DCI specifications forbid the storage of data in unencrypted form, the decryption must be performed in real time as the movie is shown.

7) Decryption key distribution

The encryption key, which is also used for decrypting the data, is encrypted by the RSA (Rivest-Shamir-Adleman) cryptosystem using a key pair consisting of the private key of the theater exhibition equipment and a public key. It is delivered to the theaters together with license period information in a message format called KDM (key delivery message). High security is maintained because the data encryption key is valid only on a particular exhibition device. A high level of security is required for the exhibition equipment that stores the private key and decrypts the data.

8) Data package distribution and management

The content is sent to theaters as a digital cinema package (DCP) that comprises multiple data files containing image, audio, and subtitle data. The specifications do not prescribe a specific data distribution method, but secure distribution is required, and a secure network is a promising means of accomplishing it. Another matter included in the specifications is the generation and management of an exhibition log.

9) Digital watermarking

To prevent content theft, the exhibition equipment must embed information that specifies the exhibition time and place as a digital watermark. The digital watermarking method must ensure that the image quality remains high and must prevent re-photographing of the exhibited film.

2. NTT's 4K digital cinema distribution system

The overall configuration of the 4K digital cinema distribution system that NTT developed for the 4K Pure Cinema trial [3] is illustrated in **Fig. 1**. This is the first network distribution system capable of satisfying the DCI specifications in Japan. The components of our system are described below.

2.1 Digital cinema packager

The packager is an application program that transforms the content to be exhibited into a DCP for distribution through a process that involves image data compression, MXF wrapping, and encryption.

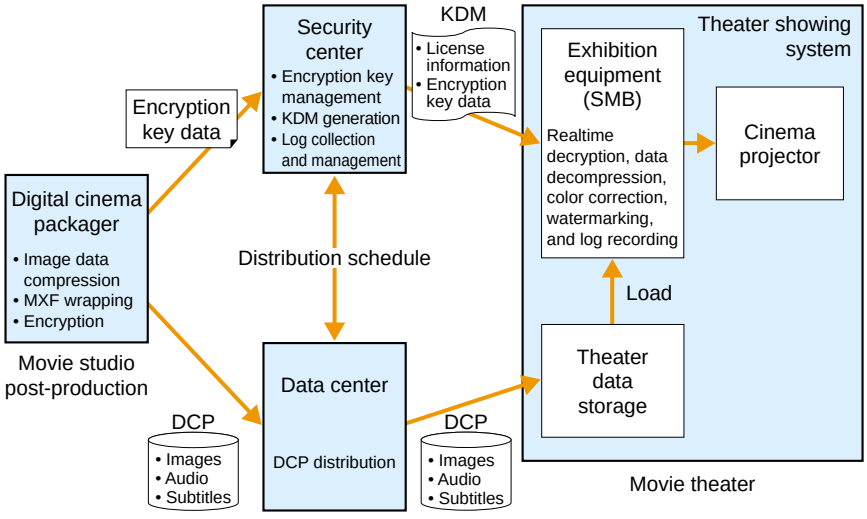


Fig. 1. Overall configuration of the 4K digital cinema distribution system.

2.2 Security center

The encryption key used by the packager in creating the DCP is sent to the security center, which forwards the key in KDMs to the exhibition equipment of various theaters according to the distribution schedule. A secure communication path that includes certification and encryption processing is used to transmit the encryption key and KDM.

2.3 Data centers

The DCP created by the packager is sent to a data center and the encryption key is distributed to theaters by a different path according to the distribution schedule. The distribution of large volumes of data to multiple destinations requires a high-speed optical network.

2.4 Theater showing system

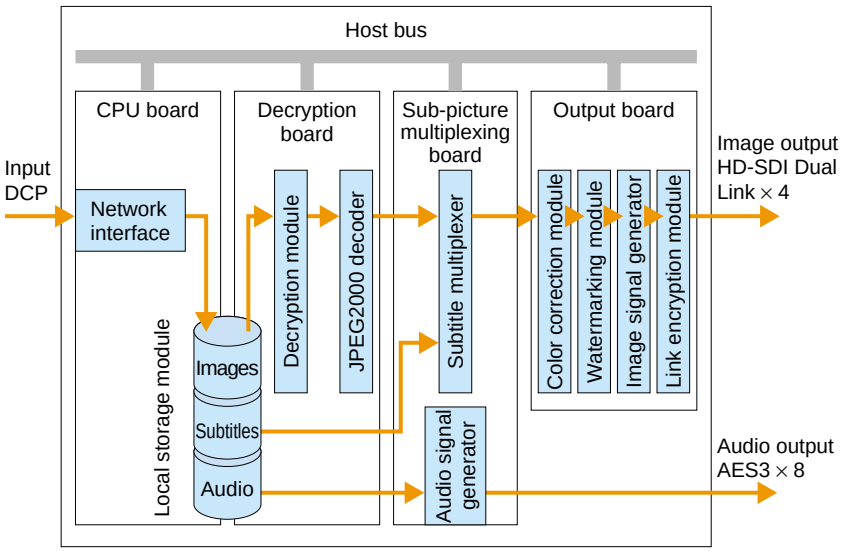
The theater showing system comprises an exhibition device (secure media box (SMB)), a data storage device, and a projector. The SMB is described in detail in the next section.

3. Secure media box

The SMB is the central component of the theater exhibition system in the 4K digital cinema distribution scheme. The implementation is based entirely on NTT technology. It receives the DCP via a Gigabit Ethernet line. The DCP contains JPEG2000-encoded image data, linear PCM audio data, subtitles, and other sub-picture data, all of which are MXF-wrapped by the packager. The SMB stores the DCP temporarily on a hard disk drive. Then, it extracts the encryption key from the KDM, decrypts and decompresses the data, and performs other processing such as subtitling, watermarking, and color correction in real time, so it requires high-speed decryption and data decompression functions. It also stores the encryption key, performs decryption, and maintains an exhibition log, so it must have a high degree of resistance against external attacks on security. A photograph of the SMB is shown in **Fig. 2(a)** and its functional block diagram is shown in **Fig. 2(b)**.

During the stage of preparing for exhibition, the

(a) External appearance



(b) Configuration

Fig. 2. Secure media box.

different media contained in the DCP received via the Gigabit Ethernet network interface of the CPU board are separated and placed in a local storage device. The image and audio data are encrypted using AES (advanced encryption standard). The keys for decrypting those files are received and stored in a secure location within the SMB.

At the time of exhibition, the encryption keys are used for software decryption of the audio data and hardware decryption of the image data in real time. The image data is further processed for JPEG2000 decoding by the decompression board. The image then has subtitle data superimposed on it by the sub-picture board and it is color-corrected to match the projector by the output board. The resulting image is then output through the HD-SDI (high definition serial data interface) Dual Links. The audio is output as an AES3 signal[*2] through multiple channels (up to 16) to multiple speakers.

In future, the signal output to the projector is also expected to be protected by link encryption, but current 4K projectors do not have link encryption functions, so security is currently maintained through physical protection of the signal input/output modules.

Because the quality of a 4K digital cinema image is so high, tolerable quality could be obtained by someone in the audience using even a camcorder to re-photograph the image projected on the screen (content theft). To discourage that, the SMB inserts a digital watermark that is specific to the exhibition time, which enables the source of the data stream to be identified. The watermarking technology used for that purpose must be reliable and trusted as a forensic marker for use as proof of content theft. There are still various other technical hurdles to overcome, such as the need to be able to identify multiple watermarks embedded in the data by the movie studio, data distribution centers, and other authorities. Furthermore, identification of the exhibition time requires that the SMB at least generate and embed a different watermark pattern for each exhibition in real time.

4. Distribution system for the trial

The main targets of the 4K Pure Cinema trial are secure distribution to movie theaters in Japan and direct reception of DCP data from Warner Bros. in the USA. Below, we describe the configuration of the networks used for those purposes in the trial and the network for distributing the license keys from the security center in the Dojima Building in Osaka (**Fig. 3**). We also describe the attempts to satisfy the security requirements at the beginning of the trial.

4.1 Data distribution network

Movies produced by Warner Bros. in Los Angeles are stored in the Los Angeles studio. For this trial, that movie data is directly transferred from the USA to NTT Yokosuka Data Center via a secure, large-capacity network. The main network used is GEMnet2, NTT's large-capacity network testbed for global R&D. For the link from Seattle to Los Angeles, the CineGrid network was used to connect to the Warner Bros.' network. For higher security, virtual private network (VPN) equipment was set up between the transmitting data server at Warner Bros. and the data server in Yokosuka to configure a secure high-speed network.

Once the DCP data has been accumulated in the Yokosuka Data Center, it is immediately sent to the Dojima Data Center and transferred to movie theaters in the metropolitan area. From the Dojima Data Center, the data is transferred to movie theaters in the Osaka area. This allows efficient data transfer in western Japan and provides a duplicate set of the data. The two data centers are connected to the theaters by 1-Gbit/s access lines. The Yokosuka Data Center is inside the NTT Yokosuka R&D Center and the Dojima Data Center is in the Dojima Building in Osaka.

4.2 License key distribution network

The license keys are distributed from a security center that has been set up in Osaka. The keys are distributed over the same network as is used to transmit the movie data, but a VPN is established within that network for higher security. The KDMs are distributed directly from the security center to the SMB in each theater via the VPN. After confirmation of KDM distribution, the movie data is downloaded from the storage server to the SMB and the movie can then be shown for the time period specified in the license.

4.3 Data center and security center

The Dojima Data Center was originally designed to be a data center, so it is equipped for strict security. On the other hand, the Yokosuka Data Center was constructed in NTT Yokosuka R&D Center, so extra

*2 AES3 is a digital audio standard defined by the Audio Engineering Society. It should not be confused with the advanced encryption standard mentioned before.

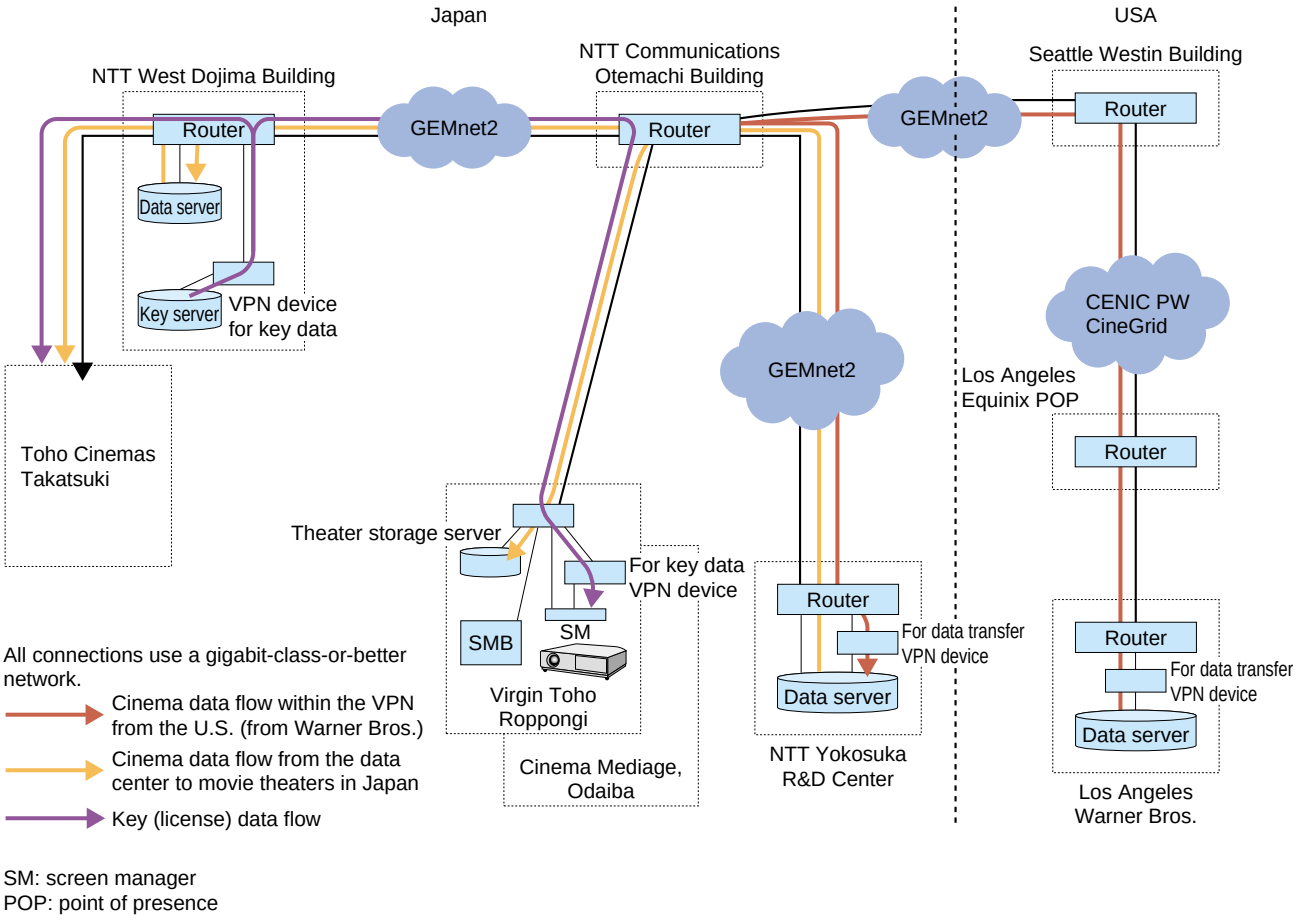


Fig. 3. Configuration of the trial system.

security measures, such as installing surveillance cameras, were taken to meet the security requirements. The movie theaters and 4K cinema systems installed there require the same high security as the data centers. In our system, the encrypted data is read within the SMB, so the content cannot be extracted even if the hard disk on which the data is stored is removed. When both the decryption key and the DCP meet in the SMB, the image data can be extracted from the DCP and exhibited in the theater.

5. Plans for the future

In addition to upgrading the system by reflecting the requirements revealed by this trial, we believe it is necessary to establish technology for scalability in system construction.

References

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[2] K. Shirakawa, K. Ishimaru, T. Fujii, N. Kihara, A. Ogawa, H. Yamane, and A. Akutsu, “8 million pixel digital cinema distribution system,” NTT Technical Journal, Vol. 17, No. 3, pp. 89-92, 2005 (in Japanese).
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