The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

DIGITAL MOTION IMAGERY

RECOMMENDED STANDARD

CCSDS 766.1-B-2

BLUE BOOK

August 2016

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FOREWORD

This document identifies which television and video industry standards should be utilized for interoperability between spacecraft, spacecraft-to-ground, ground-to-spacecraft, and ground-to-ground applications. The international television and video industries have many standards and interfaces for acquiring, recording and distributing live and recorded video. That flexibility can lead to complexity when attempting to share or monitor video from acquisition to monitoring or recording locations. This document provides system designers a sub-set of the larger industry set of standards to choose from, depending on the application and purpose of the video system.

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DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 766.1-B-1	Digital Motion Imagery, Recommended Standard, Issue 1	May 2015	Original issue, superseded
CCSDS 766.1-B-2	Digital Motion Imagery, Recommended Standard, Issue 2	August 2016	Current issue: adds support for MPEG4 recording and JPEG2000 transmission.

NOTE – Substantive changes from the previous issue are indicated by change bars in the inside margin.

CONTENTS

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to provide a common reference and framework of standards for digital motion video and imagery, and to provide recommendations for utilization of international standards for sharing or distributing motion video and imagery between spacecraft elements and ground systems.

The scope of this document includes traditional real-time streaming video and television, including human and robotic spacecraft-to-spacecraft and spacecraft-to-ground systems, as well as video recorded and distributed later, either as a real-time stream or as a file transfer. In this context, real-time streaming includes all modes where video is sent from a spacecraft in a continuous stream and is intended for immediate use when received, regardless of the latency of the transmission path. Other specialized motion imagery applications, such as high-speed scientific motion imagery and multi-spectral motion imagery, are not addressed in this document. However, if a specialized imagery camera system has a requirement to interface to spacecraft systems in a video mode, it would be required to match these interfaces.

Ground-systems-to-ground-systems video distribution is obviously a key component of the entire video system. However, this is not the primary focus of this document. Currently, there are significant differences in the ways mission video products are exchanged between the various space agencies on the ground. This is the result of differences in network topologies between space agencies, and agreements for video sharing. Those differences preclude there being a standard methodology for delivering video imagery between agencies. Prior to the commencement of video transmission between space agencies, system design reviews and performance testing should be done between the ground systems in use to assure operability when video imagery comes from spacecraft.

1.2 APPLICABILITY

This document is a CCSDS Recommended Standard. It is intended for all missions that produce, consume, or transcode video imagery from low-bandwidth video such as web streaming through high-bandwidth video such as high-definition television imagery.

1.3 NOMENCLATURE

1.3.1 NORMATIVE TEXT

The following conventions apply for the normative specifications in this Recommended Standard:

a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;

b) the word ‘should’ implies an optional, but desirable, specification;

c) the word ‘may’ implies an optional specification;

d) the words 'is', 'are', and 'will' imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.3.2 INFORMATIVE TEXT

In the normative sections of this document, informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

1.4 REFERENCES

The following publications contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the publications indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS publications.

[1] *Studio Encoding Parameters of Digital Television for Standard 4:3 and Wide Screen 16:9 Aspect Ratios*. ITU-R BT.601-7. Geneva: ITU, 2011.

[2] *Television—SDTV Digital Signal/Data—Serial Digital Interface*. SMPTE ST 259:2008. White Plains, New York: SMPTE, 2008.

[3] *Digital Interfaces for HDTV Studio Signals*. ITU-R BT.1120-8. Geneva: ITU, 2012.

[4] *1.5 Gb/s Signal/Data Serial Interface*. SMPTE ST 292-1:2012. White Plains, New York: SMPTE, 2012.

[5] *High-Definition Multimedia Interface Specification*. Version 1.4. Sunnyvale, California: HDMI Licensing, LLC, 2009.

[6] *Electrical Characteristics of Low Voltage Differential Signaling (LVDS) Interface Circuits*. Revision A. TIA/EIA-644-A. Arlington, Virginia: TIA, February 2001.

[7] *Serial Digital Interface-Based Transport Interface for Compressed Television Signals in Networked Television Production Based on Recommendation ITU-R BT.1120*. ITU-R BT.1577. Geneva: ITU, 2002.

[8] *Television—Serial Data Transport Interface (SDTI)*. SMPTE ST 305:2005. White Plains, New York: SMPTE, 2005.

[9] *Teletext Systems*. ITU-R BT.653-3. Geneva: ITU, 1998.

[10] *Television—Time and Control Code*. SMPTE ST 12-1:2008. White Plains, New York: SMPTE, 2008.

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[12] *Ancillary Data Packet and Space Formatting*. SMPTE ST 291:2011. White Plains, New York: SMPTE, 2011.

[13] *Vertical Ancillary Data Mapping of Caption Data and Other Related Data*. SMPTE ST 334-1:2007. White Plains, New York: SMPTE, 2007.

[14] *Metadata Element Dictionary Structure*. SMPTE ST 335:2012. White Plains, New York: SMPTE, 2012.

[15] *Metadata Dictionary Registry of Metadata Element Descriptions*. SMPTE RP 210.10:2007. White Plains, New York: SMPTE, 2007.

[16] *Ultra High Definition Television—Mapping into Single-link or Multi-link 10 Gb/s Serial Signal/Data Interface*. SMPTE ST 2036-3:2010. White Plains, New York: SMPTE, 2010.

[17] *1280×720, 16:9 Progressively-Captured Image Format for Production and International Programme Exchange in the 60 Hz Environment*. ITU-R BT.1543. Geneva: ITU, 2001.

[18] *1280 x 720 Progressive Image 4:2:2 and 4:4:4 Sample Structure—Analog and Digital Representation and Analog Interface*. SMPTE ST 296:2012. White Plains, New York: SMPTE, 2012.

[19] *Parameter Values for the HDTV Standards for Production and International Programme Exchange*. ITU-R BT.709-5. Geneva: ITU, 2002.

[20] *Television—1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates*. SMPTE ST 274:2008. White Plains, New York: SMPTE, 2008.

[21] *Dual Link 1.5 Gb/s Digital Interface for 1920 x 1080 and 2048 x 1080 Picture Frames*. SMPTE ST 372:2011. White Plains, New York: SMPTE, 2011.

[22] *Television—3 Gb/s Signal/Data Serial Interface*. SMPTE ST 424:2006. White Plains, New York: SMPTE, 2006.

[23] *Ultra High Definition Television—Image Parameter Values for Program Production*. SMPTE ST 2036-1:2009. White Plains, New York: SMPTE, 2009.

[24] *Ultra High Definition Television—Audio Characteristics and Audio Channel Mapping for Program Production*. SMPTE ST 2036-2-2008. White Plains, New York: SMPTE, 2008.

[25] *2048 × 1080 and 4096 × 2160 Digital Cinematography Production Image Formats FS/709*. SMPTE ST 2048-1:2011. White Plains, New York: SMPTE, 2011.

[26] *2048 × 1080 Digital Cinematography Production Image FS/709 Formatting for Serial Digital Interface*. SMPTE ST 2048-2:2011. White Plains, New York: SMPTE, 2011.

[27] *Parameter Values for Ultra-High Definition Television Systems for Production and International Programme Exchange*. ITU-R BT.2020-1. Geneva: ITU, 2014.

[28] *Information Technology—Coding of Audio-Visual Objects—Part 10: Advanced Video Coding*. 8th ed. International Standard, ISO/IEC 14496-10:2014. Geneva: ISO, 2014.

[29] *Advanced Video Coding for Generic Audiovisual Services*. ITU-T H.264. Geneva: ITU, 2012.

[30] *Data Services in Digital Television Broadcasting*. ITU-R BT.1301-1. Geneva: ITU, 2011.

[31] *Interface for Digital Component Video Signals in 525-Line and 625-Line Television Systems Operating at the 4:2:2 Level of Recommendation ITU-R BT.601*. ITU-R BT.656-5. Geneva: ITU, 2007.

[32] *Information Technology—JPEG 2000 Image Coding System: Motion JPEG 2000*. 2nd ed. International Standard, ISO/IEC 15444-3:2007. Geneva: ISO, 2007.

[33] *Information Technology—Generic Coding of Moving Pictures and Associated Audio Information—Part 7: Advanced Audio Coding (AAC)*. 4th ed. International Standard, ISO/IEC 13818-7:2006. Geneva: ISO, 2006.

[34] *Digital Audio Interface—Part 3: Consumer Applications*. Edition 3.1 (2009-12-10). IEC 60958-3:2006+AMD1:2009 CSV. Geneva: IEC, 2009.

[35] *IP over CCSDS Space Links*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 702.1-B-1. Washington, D.C.: CCSDS, September 2012.

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[37] *CCSDS File Delivery Protocol (CFDP)*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 727.0-B-4. Washington, D.C.: CCSDS, January 2007.

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2 OVERVIEW

In the early days of human spaceflight, motion imagery was accomplished with motion picture film cameras, set at varying frame rates depending on lighting conditions. Upon safe return the film was processed and eventually shared with the world via documentaries or television. Inevitably live video became operationally desirable for situational awareness and to satisfy the public's interest in high-profile events such as the Moon landings or the Apollo-Soyuz test project. Compromises were made with those first video systems to fit within the constraints of bandwidth, avionics, and transmission systems. Even in the modern era, video systems on spacecraft are a hybrid of analog and digital systems, typically made to work within the existing spacecraft's avionics, telemetry, and command/control systems.

With the advent of digital cameras, encoding algorithms, and modulation techniques, it is desirable to treat video as data and to utilize commercially available technologies to capture and transmit live and recorded motion imagery, possibly in High Definition (HD) or even better. Thus the Recommended Standard addresses:

– Video Interfaces and Characteristics

– Video Formats and Characteristics

  Video data has a number of characteristics which need specification such as frame rate, aspect ratio, bandwidth and compression standards, color sampling, the inclusion of audio, etc.

– Encapsulation and Transmission Protocols

  Video data needs to be encapsulated, transported, and distributed. Although the choice of mechanisms and protocols may not be specific to video data, certain aspects need addressing because of the high bandwidth typically required for video. Thus this part will address encapsulation schemes (e.g., IP), transport protocols, and use of CCSDS Encapsulation Packets.

– Interoperability of Standards

  Future Human Spaceflight endeavors are expected to be collaborations between many agencies, with complex interactions between spacecraft and non-Earth surface systems, with intermediate locations (EVA crew, habitats, etc.) requiring the ability to view video generated by another agency's systems. Therefore interoperability between these systems will be essential to mission success and in some cases crew safety. Such interoperability will only be achieved by use of common references and joint agreement on international standards, either commercial or CCSDS or a combination of the two.

This Recommended Standard does not cover video quality. The intention of this document is to provide a framework of standards to ensure interoperability, not to define a level of quality. What is acceptable video quality varies widely with the application and requirements of users. A science experiment, for example, may have video quality requirements beyond what is available, or practical, within a spacecraft avionics system. The science team for that experiment might elect to record video on board at high quality and transfer that video as a digital file after the conclusion of the experiment run. They might elect to do that and have a real-time downlink of lesser quality as a confirmation the experiment is working properly. A requirement for real-time video to support a docking event might sacrifice spatial resolution to lower the latency of the real-time video feed. Within the parameters listed in this document and the capabilities of any given spacecraft, users and controllers can determine how equipment should be configured for the best match to requirements.

3 SPECIFICATION

3.1 OVERVIEW

There are many system configurations that can be implemented in spacecraft video systems. Choices of interface standards, resolutions, and frame rates are based on the application, user requirements, available equipment, and spacecraft capability. There are multiple ways for signals to flow from the image source through to the spacecraft avionics system and on to the ground (see figures 3-1 and 3-2). Application of this Recommended Standard limits the overall number of options by limiting the interfaces to those that are in most common use. It should be noted that, while scientific imaging systems are excluded from this Recommended Standard, should a scientific imaging system need to interface to the spacecraft video system, the same interfaces would apply to them. It would be the responsibility of the user to provide a matching interface from the user's imaging system.

3.2 GENERAL

Users shall select from the following interfaces and standards when designing and implementing new video systems for spacecraft.

3.3 INTERFACE STANDARDS

3.3.1 NON-COMPRESSED STANDARD DEFINITION TELEVISION SIGNALS

The interface for non-compressed Standard Definition (SD) television signals shall be Serial Digital Interface (SDI), conforming to

– ITU-R BT.601-7 (reference [1]);

– SMPTE ST 259:2008 (reference [2]).

3.3.2 NON-COMPRESSED HIGH DEFINITION TELEVISION SIGNALS

The interface used for non-compressed high definition television signals shall be one of the following:

– High Definition-Serial Digital Interface (HD-SDI), conforming to

  • ITU-R BT.1120-8 (reference [3]);

  • SMPTE ST 292-1:2012 (reference [4]);

– High Definition Multimedia Interface (HDMI) 1.4 or higher, as defined by the HDMI Founders and licensed by HDMI Licensing, LLC (reference [5]);

– Camera Link Low Voltage Differential Signaling (LVDS) Interface Standard, as defined by the Camera Link Participating Companies (reference [6]).

3.3.3 COMPRESSED DIGITAL TELEVISION SIGNALS

The interface used for compressed digital television signals shall be Digital Video Broadcasting-Asynchronous Interface (DVB-ASI), conforming to

– ITU-R BT.1577 (reference [7]);

– SMPTE ST 305:2005 (reference [8]).

NOTE – DVB-ASI would be used with compressed digital video while still in the serial digital domain. For interfacing to spacecraft systems, Internet Protocol (IP) (see 3.6) is the preferred interface.

3.3.4 TELEVISION TIME CODE AND METADATA

3.3.4.1 Television time code and metadata may be inserted in non-compressed video. If time codes and/or metadata are inserted into non-compressed video, one of the following standards shall be used:

– ITU-R BT.653-3 (reference [9]);

– SMPTE ST 12-1:2008 (reference [10]);

– SMPTE ST 12-2:2008 (reference [11]);

– SMPTE ST 291:2011 (reference [12]);

– SMPTE ST 292-1-2012 (reference [4]);

– SMPTE ST 334-1:2007 (reference [13]);

– SMPTE ST 335:2012 (reference [14]);

– SMPTE RP 210.10:2007 (reference [15]);

– SMPTE ST 2036-3:2012 (reference [16]).

NOTE – The standards listed above are primarily concerned with the serial digital standard-definition and high-definition interfaces listed in 3.3.1 and 3.3.2. Metadata inserted at a camera conforming to HDMI or Camera Link interfaces conform to the serial digital interfaces when those signals are converted.

3.3.4.2 Compressed video signals in 3.3.3, per the standards listed in 3.3.3, shall carry all television time code and metadata information inserted into a non-compressed video stream.

3.4 VIDEO FORMAT AND CHARACTERISTICS

3.4.1 VIDEO RESOLUTIONS

3.4.1.1 Overview

Traditionally, video resolution has been categorized as low resolution, standard definition, high definition, or high resolution. Low resolution is generally defined as less than 640 × 480, standard definition as 640 × 480 and 768 × 576, high definition as 1280 × 720 and 1920 × 1080, and high resolution as anything beyond 1920 × 1080 such as 4K and 8K resolutions. Low resolution was used for streamed Internet video. Standard definition was used for broadcast (pre-HD) and security camera systems. High definition was limited to high-end television broadcast. High resolution was practically non-existent unless it was film based. Now, however, the distinctions are less clear. Laptop computer cameras are now often high definition, with options to stream from 320 × 240 up to 1280 × 720. Standard definition is now in limited use for broadcast television, web streaming, and monitoring applications. High definition has become the norm for broadcast and cable television. High resolution or ultra-high-definition cameras are replacing 35mm motion picture film for imaging requirements beyond HD. Therefore it is more difficult to classify video in terms of resolutions than in terms of application. A given application can have a broad range of resolutions, depending upon the requirements of the user, available equipment, and bandwidth constraints. The specifications below reflect the diversity of choices available for video systems. Higher resolution applications (e.g., ‘public affairs’, critical operations) can be used to fulfill lower resolution applications (e.g., ‘personal video conferencing’).

3.4.1.2 Personal Video Conferencing

Personal video conferencing video resolution should be selected from the following range:

– 320 × 240 to 1280 × 720, progressive scan.

NOTE – Selection of resolution is dependent on immediate requirement and available bandwidth.

3.4.1.3 Medical Conferencing

Medical conferencing video resolution should be selected from the following range:

– 320 × 240 to 1280 × 720, bandwidth-dependent progressive or interlace scan:

  • standard definition legacy systems may be 525 or 576 interlace;

  • 640 × 480 and 768 × 576 systems shall conform to ITU-R BT.601-7 (reference [1]) or SMPTE ST 259:2008 (reference [2]).

NOTE – Lower resolution personal video conferencing and medical conferencing applications are most likely to be performed using a personal computer or tablet-type device. All video encoding would be handled internally. Connection to the spacecraft avionics system would be through wired or wireless data connections independent of any video systems. Transmission to the ground would also be handled as part of standard data protocols and also independent of dedicated video transmission.

3.4.1.4 Situational Awareness

Situational awareness video resolution should be selected from the following range:

– 640 × 480 to 1280 × 720, bandwidth dependent:
  - interlace scan for legacy SD systems shall conform to
    - ITU-R BT.601-7 (reference [1]); or
    - SMPTE ST 259:2008 (reference [2]);
  - progressive scan for HD systems shall conform to
    - ITU-R BT.1543 (reference [17]); or
    - SMPTE ST 296:2011 (reference [18]).

NOTE – Situational awareness may be required in situations where only low-bandwidth transmission is available, such as S-Band, which would likely limit resolution to as low as 320 × 240. In cases such as this, best effort is acceptable. The requirement to have visual confirmation of events may be higher than a specific resolution. This should be considered the exception and not the norm.

3.4.1.5 Public Affairs

3.4.1.5.1 Public affairs video resolution should be selected from the following range:

– 640 × 480 to 1280 × 720, bandwidth dependent:
  - Interlace scan for legacy SD systems shall conform to
    - ITU-R BT601-7 (reference [1]); or
    - SMPTE ST 259:2008 (reference [2]);
  - Progressive scan for HD systems shall conform to
    - ITU-R BT.1543 1280 (reference [17]); or
    - SMPTE ST 296:2011 (reference [18]).

3.4.1.5.2 Multiple resolutions may be used to accommodate mission requirements.

NOTE – There are situations where HD formats are not required. It saves considerable bandwidth to use SD systems. Whether these are US or European standard resolutions and frame rates is not an issue. Regardless of the actual video format, the interface standards allow virtually all current equipment to route and encode the video. Once encoded and packetized, it is not an issue for spacecraft avionics as the video is compatible data packets. That part of the system is format agnostic. Regardless of the interface chosen for a particular spacecraft, routing and encoding utilize the same components.

3.4.1.6 High Resolution Digital Imaging

3.4.1.6.1 High resolution digital imaging video resolution should have a minimum resolution of 1920 × 1080, progressive scan:

- 1080 HD systems shall conform to
  - ITU-R BT.709-5 (reference [19]); or
  - SMPTE ST 274:2008 (reference [20]);
- Up to 30 FPS systems shall conform to
  - ITU-R BT.1120-8 (reference [3]); or
  - SMPTE ST 292-1:2012 (reference [4]);
- Above 30 FPS shall conform to
  - ITU-R BT.1120-8 (reference [3]); or
  - SMPTE ST 372:2011 (reference [21]); or
  - SMPTE ST 424:2006 (reference [22]).

3.4.1.6.2 Systems above 1920 × 1080 shall conform to

- SMPTE ST 2036 Standards Suite, ST 2036 1–3:
  - ST 2036-1:2009 Image Parameter Values for Program Production—Ultra High Definition Television (reference [23]);
  - ST 2036-2:2008 Ultra High Definition Television—Audio Characteristics and Audio Channel Mapping for Program Production (reference [24]);
  - ST 2036-3:2010 Mapping into Single-link or Multi-link 10 Gb/s—Ultra High Definition Television Serial Signal/Data Interface (reference [16]);

– SMPTE ST 2048 Standards Suite ST 2048-1–2:

  • ST 2048-1:2011 2048 × 1080 and 4096 × 2160 Digital Cinematography Production Image Formats FS/709 (reference [25]);

  • ST 2048-2:2011 2048 × 1080 Cinematography Production Image FS/709 Formatting for Serial Digital Interface (reference [26]);

– ITU-R BT.2020-1 (06/2014) Parameter Values for Ultra-High Definition Television Systems for Production and International Programme Exchange (reference [27]).

NOTE – 1920 × 1080 and above is to accommodate users with special requirements. Typically, these systems will have on-board recording and downlink video as file transfers. Any real-time requirement will include that the video system provide a compatible signal to spacecraft video systems.

3.4.1.7 Spacecraft to Spacecraft

Spacecraft-to-spacecraft video resolution should follow 3.4.1.2–3.4.1.6.

NOTE – Selection of spacecraft-to-spacecraft video resolution is dependent on mission requirements.

3.4.2 FRAME RATE

3.4.2.1 Video frame rates shall be selected from the following ranges for the following applications:

a) personal video conferencing: 10 – 60 Frames Per Second (FPS);

b) medical video: 10 – 60 FPS;

c) situational awareness: 25 – 60 FPS;

d) public affairs: 24, 25, or 60 FPS;

e) high resolution digital imaging: 24 – 120 FPS.

NOTE – These are considered optimum frame rates for these applications. However, bandwidth constraints may not allow even the lower frame rates to be utilized. In these cases, best effort should be made to accommodate the recommendations based on available bandwidth for imaging applications.

3.4.2.2 Spacecraft-to-spacecraft frame rates should be selected from 3.4.2.1 a)–e), above, depending on application.

NOTES

1 Spacecraft-to-spacecraft frame rates are dependent on mission requirements.

2 The listing of specific video applications above does not necessarily imply discrete equipment sets dedicated for each application. Most cameras, for example, can be used at multiple resolutions and frame rates allowing them to be used for multiple applications.

3.4.3 ASPECT RATIO

Aspect ratio of original material shall be maintained from origination through delivery to end user.

NOTE – By definition within industry standards, HDTV resolution video has an aspect ratio of 16:9.

3.4.4 VIDEO COMPRESSION

3.4.4.1 Overview

The two compression standards listed below have different applications. MPEG-4 Part 10 is primarily intended for real-time applications where live, or nearly live, video needs to be monitored at a ground location during an event or experiment. MPEG-4 may also be used for recording applications where the quality level is determined to be sufficient. JPEG2000 is intended for requirements for higher quality or where each individual frame needs to be maintained intact. The data rate required for JPEG2000 would normally preclude JPEG2000 from being used for live transmission. The normal operating mode for JPEG2000 is to record the video and downlink it later as a data file. However, if the bandwidth is available, live transmission of JPEG2000 offers very low latency and may be preferable for operations where low video latency is preferable.

3.4.4.2 Compression Standards

The following video compression standards shall be used as indicated:

- MPEG-4 Part 10 (references [28] and [29]) for real-time transmission and recording:
  - 0.5 to 25 Mb/s—application and user requirement-driven data rates;
  - 8-bit sampling;
  - constant bit rate or variable bit rate acceptable—defined by interface to spacecraft system;
  - Group of Pictures (GOP) from 1 – 30—defined by user requirement;

        - Constrained Baseline Profile for conferencing type applications (Personal and Medical Video Conferencing);
        - Main Profile for SD applications;
        - High Profile for HD applications;
        - metadata as required by user:
            - shall conform to
                - ITU-R BT.1301-1 (reference [30]); or
                - SMPTE ST 291:2011 (reference [12]); or
                - ITU-R BT.656-4 (reference [31]) for ancillary data; or
                - SMPTE ST 335:2001 (reference [14]); or
                - SMPTE RP 210.10:2007 (reference [15]);
            - shall be read and passed by encode/decode systems;
            - may include system status and control feedback data;
            - may include embedded television time code conforming to
                - ITU-R BT.1301-1 (reference [30]); or
                - SMPTE ST 12-1:2008 (reference [10]); or
                - SMPTE ST 12-2:2008 (reference [11]).

        NOTE – Per specification and established practice, embedded television time code is used as the time reference for the MPEG transport stream time code value.

    – JPEG2000 (reference [32]) for analysis and high-quality recording requirements for video stored and transferred as files and real-time transmission:
        - 45 to 140+ Mb/s—application and user requirement-driven;
        - 10-bit (or greater) Sampling;
        - metadata as required by user:
            - shall conform to
                - SMPTE ST 291:2011 (reference [12]); or
                - ITU-R BT.653-3 (reference [9]) for ancillary data; or
                - SMPTE ST 335:2001 (reference [14]); or
                - SMPTE RP 210.10:2007 (reference [15]);

- ▫ shall be read and passed by encode/decode systems;
- ▫ may include system status and control feedback data;
- ▫ may include embedded television time code.

3.4.5 COLOR SAMPLING

Color sampling should be as follows:

- 4:2:0 for real-time requirements;
- 4:2:2 for high resolution digital imaging:
  - science and engineering;
  - production and digital cinema applications;
- 4:4:4 for special applications.

3.4.6 DISCUSSION—VIDEO SYSTEM BLOCK DIAGRAMS

The diagrams below illustrate typical video system connectivity and what interfaces are associated with each stage in the system for a typical human spaceflight video system. These diagrams assume separate components for each of these functions. While the same functions occur with the use of a laptop- or tablet-based video system used for medical or personal video conferencing, they are internal with an IP connection to the spacecraft avionics system for transmission.

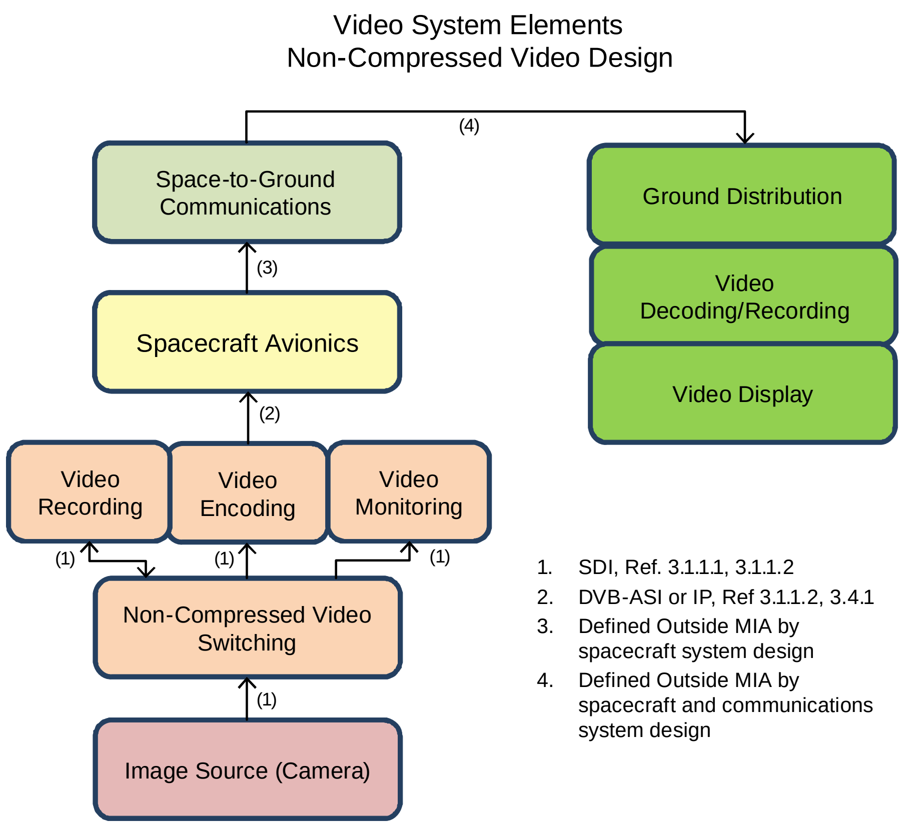

Figure 3-1: Video System Elements—Non-Compressed Video Design

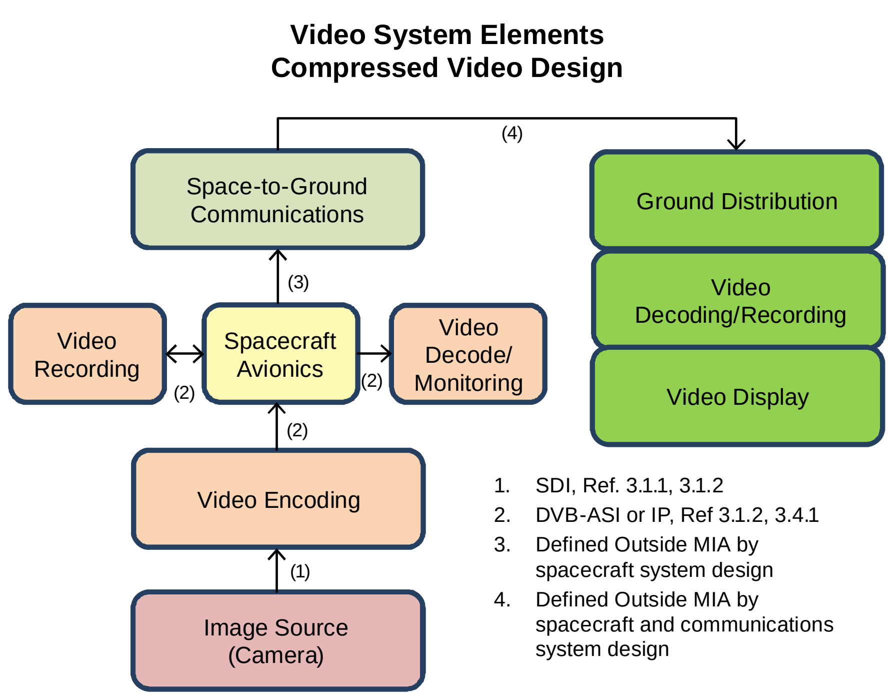

Figure 3-2: Video System Elements—Compressed Video Design

3.5 AUDIO

3.5.1 AUDIO AS PART OF VIDEO STREAM

Audio as part of a video stream should conform to the following standards:

– Advanced Audio Codec (AAC) (reference [33]) for compressed audio;

– AES/EBU-3 (reference [34]) for uncompressed audio.

NOTE – Generally, audio as part of a compressed bitstream for live applications (MPEG-4) will be compressed. There are several different audio codecs available. AAC was chosen as the highest quality, most widely used audio codec for this application. Non-compressed AES/EBU-3 is another possibility supported by a number of audio/video codecs. It is less common, but might be a requirement based on user needs.

3.5.2 DISCUSSION—AUDIO SEPARATE FROM VIDEO STREAM

For those applications where audio is distributed separately from video, audio/video synchronization (lip sync) is handled on the ground. Time stamps in the audio stream, corresponding to time stamps in the video stream, are recommended to aid in synchronization.[1]

3.6 REAL-TIME VIDEO ENCAPSULATION AND TRANSMISSION[2]

3.6.1 INTERNET PROTOCOL TRANSPORT STREAM

3.6.1.1 MPEG-4-encoded video shall be formatted as Transport Stream (TS) with Packet Identification (PID) for transport in IP datagrams.

3.6.1.2 JPEG2000 for transmission shall adhere to Video Services Forum (VSF) TR-01 Transport of JPEG2000 Broadcast Profile video in MPEG-2 TS over IP (reference [38]).

NOTE – TR-01 maps JPEG2000 encoding to an MPEG2 Transport Stream. This makes JPEG2000 compatible with the same IP connections used for MPEG-4 compression.

3.6.1.3 IP datagrams shall be encapsulated for transmission over the CCSDS space link as specified in reference [35].

[1] It is anticipated the Voice Working Group standard will address this issue with standard practices to be employed for audio/video synchronization.

[2] Delay Tolerant Networking is being standardized as an internetworking layer for CCSDS missions. Future missions may want to consider transmitting real-time video encoded with MPEG-4 or file-based video encoded with JPEG2000via DTN Bundle Protocol (reference [D9]) bundles. Annex C presents a narrative of the classes of real-time video transmission still under development by the DTN working group.

3.6.2 ELEMENTARY STREAM

3.6.2.1 Real-time video and audio elementary streams may be transmitted via User Datagram Protocol (UDP) (reference [36]).

3.6.2.2 IP datagrams containing User Datagrams with real-time video and audio elementary streams shall be encapsulated for transmission over the CCSDS space link as specified in reference [35].

3.6.3 JITTER AND BIT ERROR RATES

Real-time video delivery jitter and Bit Error Rate (BER) shall be limited as follows:

– jitter (packet delay variation) not to exceed 10 ms (assumes 300 ms decoder buffer);

– BER not to exceed 1×10^{-6}.

NOTES

1 Use of elementary streams is possible for lower bandwidth video applications, such as personal video conferencing. However, commercial hardware decoders do not recognize elementary streams, so transport stream should be used exclusively for video systems interfacing directly to spacecraft avionics. Also, audio cannot be embedded with video when using elementary stream for compressed video transport. Audio and video in an elementary stream are not synchronized for transmission.

2 Real Time Protocol (RTP) and Hypertext Transfer Protocol (HTTP) are commonly used for video transmission. HTTP is common for computer-based applications, such as family video conferencing. In this application it is not only acceptable, but may be the only methodology available on that type of platform. However, for higher bandwidth video transmission where transport streams are utilized, HTTP is not efficient. RTP is acceptable, but UDP offers better performance over space based networks. The use of TCP for video over space based networks is also not recommended.

3.7 RECORDED VIDEO AND AUDIO

3.7.1 ACQUISITION AND STORAGE OF VIDEO DATA

3.7.1.1 Recordings shall be file based.

NOTE – This is required to allow for transfer of recorded video data via established file transfer methodologies. This standard does not dictate how an application might create a video file, and specific file formats will vary based on systems being used.

3.7.1.2 Encoding shall be MPEG-4 or JPEG 2000, dependent upon the application.

3.7.1.3 Specific file formats will change based on systems being used. Data rates to be used for recording shall be determined by user requirements.

3.7.2 FILE TRANSFER OF RECORDED VIDEO

3.7.2.1 Recorded File Transmission

Recorded video shall be transmitted as files via the CCSDS File Delivery Protocol (CFDP) Class 1 or Class 2 (reference [37]).

3.7.2.2 Discussion—CFDP

CFDP supports four classes that are distinct from the three video classes:

– Class 1—Unreliable CFDP Transfer;

– Class 2—Reliable CFDP Transfer;

– Class 3—Unreliable Transfer Via One Or More Waypoints In Series;

– Class 4—Reliable Transfer Via One Or More Waypoints In Series.

When using CFDP to transfer video, one of the following mechanisms is used:

– Class 1—Unreliable CFDP transfer over a reliable UT layer;

– Class 2—Reliable CFDP.

3.8 DISTRIBUTION OF VIDEO DATA

3.8.1 REAL-TIME DISTRIBUTION

Real-time video shall be distributed as MPEG-4 program streams with resolution and frame rate dependent on available bandwidth and user requirements.

3.8.2 DELAYED DISTRIBUTION

Video files should be distributed on the ground via established file distribution methodologies.

NOTE – For file transfer of video, this will likely be recorded JPEG 2000, as MPEG-4 will be used for real-time distribution.

3.8.3 END USER CAPABILITIES

End user capabilities should include:

– decoding capability for real-time video distribution:

format conversion as required to meet local user requirements for display (i.e., conversion from 525i to 625i and vice versa, 50/60 Hz frame rate conversion, up-conversion or down-conversion);

– ability to record data stream from real-time applications;

– ability to participate in and store video files from transfer operations;

– ability to decode and play the stored files.

ANNEX A

PROTOCOL IMPLEMENTATION CONFORMANCE STATEMENT (PICS) PROFORMA

(NORMATIVE)

A1 INSTRUCTIONS FOR COMPLETING THE PICS PROFORMA

A1.1 OVERVIEW

A1.1.1 Columns

A1.1.1.1 General

In order to reduce the size of tables in the PICS proforma, notations have been introduced that have allowed the use of a multi-column layout, where the columns are headed ‘Status’ and ‘Support’. The definition of each of these follows.

A1.1.1.2 Status Column

The ‘Status’ column indicates the level of support required for conformance to the standard. The values are as follows:

M Mandatory support is required.

O Optional support is permitted for conformance to the standard. If implemented, it must conform to the specifications and restrictions contained in the standard. These restrictions may affect the optionality of other items.

O.*n* The item is optional, but support of at least one of the options labeled with the same number *n* is mandatory. The definitions for the qualification statements used in this annex are written under the tables in which they first appear.

C.*n* The item is conditional (where *n* is the number which identifies the applicable condition). The definitions for the conditional statements used in this annex are written under the tables in which they first appear.

n/a The item is not applicable.

A1.1.1.3 Support Column

The ‘Support’ column is completed by the supplier or implementer to indicate the level of implementation of each feature. The proforma has been designed such that the only entries required in the ‘Support’ column are:

Y Yes, the feature has been implemented.

N No, the feature has not been implemented.

– The item is not applicable.

A1.1.2 Item Reference Numbers

Within the PICS proforma, each line that requires implementation detail to be entered is numbered at the left hand edge of the line. This numbering is included as a means of uniquely identifying all possible implementation details within the PICS proforma. The need for such unique referencing has been identified by the testing bodies.

The means of referencing individual responses is to specify the following sequence:

a) a reference to the smallest subclause enclosing the relevant item;

b) a solidus character, ‘/’;

c) the reference number of the row in which the response appears;

d) if, and only if, more than one response occurs in the row identified by the reference number, then each possible entry is implicitly labeled a, b, c, etc., from left to right, and this letter is appended to the sequence.

A2 COMPLETION OF THE PICS

The implementer shall complete all entries in the column marked ‘Support’. In certain clauses of the PICS proforma, further guidance for completion may be necessary. Such guidance shall supplement the guidance given in this clause and shall have a scope restricted to the clause in which it appears. In addition, other specifically identified information shall be provided by the implementer where requested. No changes shall be made to the proforma except the completion as required. Recognizing that the level of detail required may, in some instances, exceed the space available for responses, a number of responses specifically allow for the addition of appendices to the PICS.

A3 REFERENCED BASE STANDARDS

Motion Imaginery and Applications (MIA, this document) is the only base standard referenced in the PRL. In the tables below, numbers in the Reference column refer to applicable subsections within this document.

A4 GENERAL INFORMATION

A4.1 IDENTIFICATION OF THE PICS

Date of statement (yyyy-mm-dd)	
PICS version	
System Conformance Statement cross-reference	
Other information	

A4.2 IDENTIFICATION OF THE SYSTEM SUPPLIER / TEST LABORATORY CLIENT

Organization name	
Contact name	
Address	
Telephone	
E-mail	
Other information	

A4.3 IDENTIFICATION OF THE IMPLEMENTATION UNDER TEST

Implementation name	
Implementation version	
Encoder name	
Decoder name	
Camera	
Software viewer	
Special configuration	
Other information	

A4.4 EQUIPMENT CONFIGURATION FOR VIDEO FORMAT IN DETAILS (ENCODER/DECODER)

Source Device IP address	
Source Device Netmask	
Source Device Gateway	
Destination IP Addresses	
Network Protocol	
Source /destination UDP ports	
Bandwidth	

A4.5 GLOBAL STATEMENT OF CONFORMANCE

Are all mandatory features implemented? (Yes or No)	

NOTE – If a positive response is not given to this box, then the implementation does not conform to the standard.

A5 SIGNAL INTERFACES

Item	Protocol Feature	Reference	Status	Support
1	Non-Compressed Standard Definition Television Signals	3.3.1	O.1	
2	Non-Compressed High Definition Television Signals	3.3.2	O.1	
3	Compressed Digital Television Signals	3.3.3	O	

A6 SUPPORTED VIDEO RESOLUTIONS

Item	Protocol Feature	Reference	Status	Support
1	Personal Video Conferencing	3.4.1.2	O.2	
2	Medical Conferencing	3.4.1.3	O.2	
3	Situational Awareness	3.4.1.4	O.2	
4	Public Affairs	3.4.1.5	O.2	
5	High Resolution Digital Imaging	3.4.1.6	O.2	

A7 INTEROPERABILITY

Item	Protocol Feature	Reference	Status	Support
1	Acquisition and storage of video data	3.7.1	M	
2	Real time distribution	3.8.1	C	
3	Delayed distribution	3.8.2	O	
4	End User Capabilities	3.8.3	M	

A8 COMPRESSION

MPEG-4	High Definition 720p			
Item	Protocol Feature	Reference	Status	Support
1	Mpeg 2 /TS stream (7 TS packet /UDP Frame) Transmisson Only	3.6.1	O.3	
2	Elementary Stream	3.6.2	O.3	
3	Codec Mpeg-4, part 10	3.4.4	M	
4	Color code 4:2:0/4:2:2	3.4.5	O.4	
5	Video Format (720p)	3.4.1.2-3.4.1.5	O.4	
6	HD H.264 High profile. Level 4.0	3.4.4.2	O	
7	GOP < 31	3.4.4.2	O	
8	Constant Bit Rate (CBR)	3.4.4.2	O	
9	Embedded audio	3.5.1	O	
JPEG2000	High Definition 720p			
Item	Protocol Feature	Reference	Status	Support
1a	Mpeg 2 /TS stream (7 TS packet /UDP Frame) Transmission Only	3.6.1	O.3	
2a	Color code 4:2:0/4:2:2	3.4.5	O.5	
3a	Codec JPEG2000	3.4.4	M	
4a	Video Format (720p)	3.4.1.2-3.4.1.5	O.5	
5a	CBR	3.4.4.2	O	
6a	Embedded Audio	3.5.1	O	

A9 SUPPORTED OPERATIONS

Item	Protocol Feature	Reference	Status	Support
1	Personal Video Conferencing	3.4.1.2	O.6	
2	Medical Conferencing	3.4.1.3	O.6	
3	Situational Awareness	3.4.1.4	O.6	
4	Public Affairs	3.4.1.5	O.6	
5	High Resolution Digital Imaging	3.4.1.6	O.6	

ANNEX B

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

B1 SECURITY CONSIDERATIONS

B1.1 INTRODUCTION

Aside from the generic security needs of computing systems, security concerns are applicable to motion imagery where there are specific requirements to ensure that transmitted imagery not be disclosed, altered, spoofed, or redistributed without authorization.

Robotic space systems that transmit imagery frequently need the capability to control access to the imagery, whether for proprietary reasons or for national security. Human space applications frequently have the additional requirements to provide private video teleconferencing capabilities for communications with families, physicians, ground operations personnel, and/or news media outlets. Ground systems that receive and/or redistribute motion imagery have additional threats and countermeasures as well.

The focus of this discussion is on the specific protocols and methods recommended earlier in this document. It may be necessary to implement security services at other layers within the protocol stack, to account for distributed processing and cross support, to account for different classes of data or end users, or to account for protection of data during unprotected portions of the complete end-to-end transmission (e.g., across ground networks). The specification of security services at other layers is outside the scope of this document.

B1.2 SECURITY CONCERNS WITH RESPECT TO THE CCSDS DOCUMENT

The most common method of applying security to digital video and audio streams is through the use of multimedia *container* formats. Containers provide a file-based mechanism for exchanging, processing, and storing interleaved fragments of video, audio, metadata, and/or other data such as subtitles and still images. Most container files may be read or written by ordinary computer systems in the same manner as other files.

The 'MP4' standard, ISO/IEC 14496-14 (reference [D6]), is a multimedia container format standard specified as a part of MPEG-4. The 'Secure JPEG 2000' standard, ISO/IEC 15444-8 (reference [D7]), is a multimedia container format standard specified as a part of JPEG 2000.

B1.3 DATA PRIVACY

The first major area of security concern is *privacy*, the requirement that the imagery not be disclosed to any other than the intended recipient(s). Limited privacy can be achieved through the use of data *scrambling*, which weakly obfuscates the data stream using a reversible non-cryptographic mechanism, or through employment of protected data transport at lower layers and restricting distribution.

Better privacy can be achieved using cryptographic techniques, which may be applied to all or part of a container format. Since any transcoding or decoding system must be able to read and pass metadata in order to process the stream, imagery metadata must be visible at these points. It is therefore highly desirable to have the capability to perform selective encryption of container file fields (e.g., imagery but not metadata, or imagery and imagery metadata but not cryptographic metadata). ‘Secure JPEG 2000’ includes mechanisms for selective encryption of JPEG 2000 image content and metadata. Various proprietary methods also exist for encrypting MP4 streams.

B1.4 DATA INTEGRITY

The second major area of security concern is *data integrity*, the requirement that the imagery not be altered, whether to introduce false imagery or to interfere with decoding. Integrity verification mechanisms can be used for data validation to prevent security problems due to non-compliant malignant data. Like privacy, data integrity is commonly provided at other layers of the protocol stack or through a container format. ‘Secure JPEG 2000’ includes mechanisms for cryptographic verification of JPEG 2000-compliant data.

B1.5 AUTHENTICATION OF COMMUNICATING ENTITIES

Source authentication is the requirement that the imagery be attributable to a known origin. Closely related to data integrity, it can also be used for data validation. Source authentication, if provided, is commonly provided at other layers of the protocol stack or through a container format. ‘Secure JPEG 2000’ includes digital signature mechanisms for authentication of JPEG 2000-compliant data.

B1.6 CONTROL OF ACCESS TO RESOURCES

The third major area of security concern is *access control*, the requirement that the imagery be restricted from unauthorized further use by the recipient(s). Access control is commonly provided at other layers of the protocol stack. Various methods also exist for attempting access control through the inclusion of proprietary metadata in a container format, although it should be noted that many similar techniques in the past have been defeated by determined attackers. As discussed in B1.3 above, some protocols provide for selective encryption of imagery (e.g., high-resolution imagery encrypted while metadata or a low-resolution preview is unencrypted). This method may be used to provide controlled access to imagery.

B1.7 AUDITING OF RESOURCE USAGE

Auditing of imagery usage falls under the controversial category of so-called *Digital Rights Management* (DRM), i.e., 'copy protection'. As discussed with respect to access control in B1.6 above, copy protection is commonly an application of proprietary techniques to container formats. A more robust mechanism is the use of digital *watermarking* to embed identifying data within imagery or metadata in order to provide legally actionable evidence of the data's origin that is difficult to remove from second- or later-generation copies. 'Secure JPEG 2000' includes digital watermarking mechanisms for JPEG 2000-compliant data.

B1.8 POTENTIAL THREATS AND ATTACK SCENARIOS

It is possible to interfere with the decoder at the receiving end by injecting non-compliant data streams. This attack can result in a denial of service (if the decoder crashes) or a system compromise (if the decoder is software-based). Deliberate overflow of receiving buffers is a widespread attack method in ground-based computing systems.

With some digital imagery formats, it is possible to embed arbitrary data within the metadata sent as part of the overall imagery stream, and thereby use the ancillary data as a covert channel for transmitting other, unrelated information. This technique is called *Steganography*.

B1.9 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

If confidentiality is not implemented, imagery might be visible to unauthorized entities resulting in disclosure of sensitive or private information.

Without source authentication or integrity verification, valid imagery could be corrupted or invalid imagery substituted in its place. Without access controls, authorized entities might be able to redistribute sensitive or proprietary information to unauthorized third parties.

B2 SANA CONSIDERATIONS

The recommendations of this document do not require any action from SANA.

NOTE – The systems described in this document are either standalone or connect to existing communications facilities. Those communication facilities, however, would require a SANA registry entry. Motion Imagery is another service among many utilizing a given spacecraft's communication system and therefore does not require an additional SANA entry.

B3 PATENT CONSIDERATIONS

It is expected that implementation of this Recommended Standard by space-agency users will occur through the use of commercial off-the-shelf equipment that implements the referenced standards, and that patent-rights issues for such equipment will have been settled between the equipment manufacturer and the patent-right holders. It is not expected that space-agency users will develop new equipment based on the standards referenced herein. Therefore patent rights for the referenced standards are outside the scope of this Recommended Standard.

ANNEX C

DTN BUNDLE PROTOCOL FOR VIDEO TRANSMISSION

(INFORMATIVE)

C1 MODE 1 REAL TIME DELIVERY, BEST EFFORT

Mode 1 provides best-effort delivery of data and should be used for unicast or multicast data delivery when the data is to be utilized immediately upon arrival (perhaps for near-real-time decision making). The data will be forwarded using the DTN Bundle Protocol without custody transfer and will be available to the receiving CODEC/application on a best-effort basis. Therefore the data will be ‘played’ in the order it is received. Missing, damaged, or out-of-order packets will be ignored with subsequent CODEC responses being typical. Additional items such as excessive latency or jitter may be deleterious to the CODEC response.

C2 MODE 2 DELAYED DELIVERY, WITH PACKET RESTORATION

Mode 2 provides delivery of data with the prospect of no packets dropped and should be used for single or multi-transport of data when the data can be utilized after a sufficient latency to allow reassembly of the data. The data will be available to a CODEC/application once the underlying protocol has sufficient time to reassemble the data stream.

Therefore the data will be ‘played’ in its entirety subject to data being wholly lost on a frame basis. Missing and damaged bundles will be forwarded prior to reassembly with out-of-order bundles to be made available to the end CODEC/application. Additional items such as excessive latency or jitter will not affect CODEC/application response.

C3 STORE AND FORWARD ISSUES

The Delay Tolerant Networking Bundle Protocol (DTN-BP) enables store and forward operation when multiple hops or links are required to send data from source to receiver. There is an additional space link reliability protocol available known as Licklider Transmission Protocol (LTP), which will note loss of DTN bundles (which would contain $1-n$ video frames depending on system design) and request retransmission of missing bundles.

Use of the LTP reliability mechanism will result in delivery of out-of-order video frames to the application layer (because of the lag in retransmitting missing bundles). This may or may not be acceptable to the end-user application, and consideration of this out-of-order condition must be made.

In current lab experiments, it has been seen that an effective use of DTN to transmit video is to transmit bundles unreliably, accept the consequences of missing data for the real-time viewing of the video stream, and use another mechanism for recovery of missing data. This mechanism could be an application buffer to store retransmitted bundles separately for later reconstruction of the video stream in non–real time, or to record the video on board and later transmit as a video file for playback after the file is completely received without errors. Further experimentation is required to provide definite parameters for the transmission of video using DTN.[3]

[3] As this is refined, it will be added to the MIA specifications.

ANNEX D

INFORMATIVE REFERENCES

(INFORMATIVE)

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[D7] *Information Technology—JPEG 2000 Image Coding System: Secure JPEG 2000*. International Standard, ISO/IEC 15444-8:2007. Geneva: ISO, 2007.

[D8] *Licklider Transmission Protocol (LTP) for CCSDS*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 734.1-B-1. Washington, D.C.: CCSDS, May 2015.

[D9] *CCSDS Bundle Protocol Specification*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 734.2-B-1. Washington, D.C.: CCSDS, forthcoming.

ANNEX E

ABBREVIATIONS

(INFORMATIVE)

AAC	Advanced Audio Codec
BER	Bit Error Rate
CBR	Constant Bit Rate
CFDP	CCSDS File Delivery Protocol
DRM	Digital Rights Management
DTN	Delay Tolerant Networking
DTN-BP	Delay Tolerant Networking Bundle Protocol
DVB-ASI	Digital Video Broadcasting-Asynchronous Interface
EVA	Extra-Vehicular Activity
FPS	Frames Per Second
GOP	Group of Pictures
HD	High Definition
HDMI	High Definition Multimedia Interface
HD-SDI	High Definition-Serial Digital Interface
HTTP	Hypertext Transfer Protocol
IP	Internet Protocol
LTP	Licklider Transport Protocol
LVDS	Low Voltage Differential Signaling
PID	Packet Identification
RTP	Real Time Protocol
SD	Standard Definition
SDI	Serial Digital Interface
TS	Transport Stream
UDP	User Datagram Protocol
UT	Unitdata Transfer