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MPEG-2 Over Asynchronous Transfer Mode (ATM) Over Satellite Quality of Service (QoS) Experiments: Laboratory Tests

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MPEG-2 OVER ASYNCHRONOUS TRANSFER MODE (ATM) OVER SATELLITE QUALITY OF SERVICE (QOS) EXPERIMENTS: LABORATORY TESTS

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ABSTRACT

Asynchronous transfer mode (ATM) quality of service (QoS) experiments were performed using MPEG-2 (ATM application layer 5, AAL5) over ATM over an emulated satellite link. The purpose of these experiments was to determine the free-space link quality necessary to transmit high-quality multimedia information by using the ATM protocol. The detailed test plan and test configuration are described herein as are the test results. MPEG-2 transport streams were baselined in an errored environment, followed by a series of tests using MPEG-2 over ATM. Errors were created both digitally as well as in an IF link by using a satellite modem and commercial gaussian noise test set for two different MPEG-2 decoder implementations. The results show that ITU-T Recommendation I.356 Class I, stringent ATM applications will require better link quality than currently specified; in particular, cell loss ratios of better than $1.0\text{x}10^{-8}$ and cell error ratios of better than $1.0\text{x}10^{-7}$ are needed. These tests were conducted at the NASA Lewis Research Center in support of satellite-ATM interoperability research.

INTRODUCTION

The current version of ITU-T Draft Recommendation I.356 (B-ISDN ATM Layer Cell Transfer Performance) provides quality of service (QoS) class definitions and end-to-end network performance objectives. These objectives are given, for each performance parameter, as upper bounds (worst-case values) that need to be met on a virtual channel (VC) or a virtual path (VP) for the duration of the connection. Many of these parameters are still being debated—in particular, the class I, stringent class, QoS parameters. In an attempt to address some of these issues and relate the ITU-T I.356 objective requirements to satellite performance characteristics, this paper presents empirical data and a proposal for the requirements of cell loss ratios (CLR) and cell error ratios (CER).

We performed laboratory experiments with MPEG-2 (ATM application layer 5, AAL5) over asynchronous transfer mode (ATM) over an emulated satellite link. The purpose of these experiments was to determine the free-space link quality necessary to use the ATM protocol to transmit high-quality multimedia information. The compressed video standard, MPEG-2, was chosen as the baseline application in order to stress the overall link quality. All equipment and protocols are directly traceable to international specifications for clarity, consistency, and repeatability by other researchers.

BACKGROUND

MPEG-2 Audio/Video Compression and Transportation

When we speak of MPEG-2 in this paper, we are referring to the combination of the compressed video and audio signals, the program element streams (PES), and the associated multiplexing, which is the transport stream (TS). The MPEG-2 detail specifications can found in references 1–3.

MPEG-2 video can be compressed up to approximately 90:1 with good quality results, obtained through a combination of spatial and temporal compression techniques. The spatial compression techniques are the same as those used in JPEG including discrete cosine transformation, quantization, and entropy coding. The temporal compression technique uses three types of pictures, with each using different coding methods. An intra-coded (I) picture is coded using information only from itself. The I-pictures are the reference pictures and are intended to assist random access into the video sequence for applications such as fast-forward and fast-reverse playback. The predictive-coded (P) picture is coded using motion-compensated prediction from the past I- or P-picture. The bidirectionally predictive-coded (B) picture is coded using motion-compensated prediction from a past and/or future I- or P-picture. The Nuko Information Systems Highlander encoder used in our tests produced the following I-, P-, and B-picture mix repeated every 15 frames (IBBPBBPBBPBBPBB) independent of encoding rate. Table I shows the approximate amount of data contained in the video access unit size of a typical B-picture.

Transport Stream

The MPEG-2 transport stream is a complicated multiplexing protocol that allows multiple programs of video, audio, mixed video and audio, and user-specific data to be transmitted in a single stream. The transport stream is composed of 188-byte packets containing program-specific information such as the program association table (PAT), program map tables (PMT), conditional access tables (CAT), network information table (NIT), program clock reference (PCR), and program element stream (PES) packets. The PES packets contain the element stream data as well as the program time stamp (PTS) indicating the time that a presentation unit is presented in the system target decoder, and the display time stamp (DTS) indicating the time that an access unit is decoded in the system target decoder.

Because of the complexity of the MPEG-2 video and audio encoding and the transport stream multiplexing, it is extremely difficult to determine the video quality resulting from random errors inserted in the transport stream. In some instances an error could corrupt an unused portion of a transport stream, an insignificant bit of some timing information, or a portion of an audio or video access unit, and produce no noticeable effect on the program quality. In other cases, a significant timing bit or a critical pointer could be corrupted, which results in loss of decoder synchronization. In addition, many of these errors can be masked through innovative decoder implementation. Thus, an intricate knowledge of the decoder implementation and the video and audio encoding and multiplexing are required to determine exactly why the program content degrades or the decoder loses synchronization. However, a detailed discussion and evaluation of the effects of error on the failure mechanism of the MPEG-2 decoding process is beyond the scope of this study.

TABLE I.—APPROXIMATE B-PICTURE AU SIZE

Video Encoding Rate (MHz)	Video Access Unit Size (Bytes)
3	10000
10	40000
15	50000

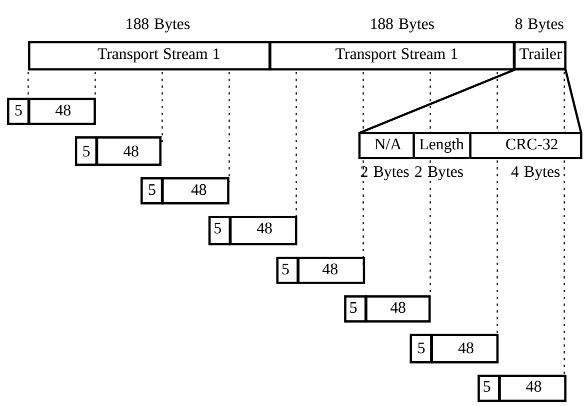

Figure 1.—AAL-5 common part convergence sublayer.

MPEG-2 over ATM

The MPEG-2 transport stream can be segmented and placed into ATM cells using either AAL-1 (ATM application layer) or AAL-5. For these experiments, the AAL-5 segmentation was used (fig. 1) (ref. 4).

Whether or not a corrupt AAL-5 datagram is dropped completely or passed on to the application is optional (ref. 5). Thus, one ATM cell drop can result in the loss of two transport stream packets or a total of 376 bytes. Dropping the last cell in a datagram that contains the end of the datagram flag, could cause four packets to be dropped. We used two different decoders in our tests. Both passed corrupted AAL-5 packets.

TESTBED SETUP

The testbed setup is shown in figure 2. Some of the major equipment is listed below.

Tektronix MTS100 MPEG-2 Generator/Analyzer
Hewlett Packard HP-4210B Broadband Series Test Equipment

- Hardware
  - OC3 Line Cards E1697A
  - T1/T3 Line Cards E1616A
  - Protocol Processor Module E4212A
  - Network Impairment Module E4219A
- Software
  - MPEG-2 Protocol Viewer Software E4226A
  - MPEGscope E6271A

Hewlett Packard HP-3708A Noise Generator
EF-Data SDM-9000 IDR Modem
Adtech AX4000 ATM Analyzer
Adtech SX/14 Data Channel Emulator
FORE systems Forerunner 200 ATM switch
Nuko Systems VF-1000E MPEG-2 Encoder with ATM multiplexer
Nuko Systems VF-1000D MPEG-2 Decoder
Nuko Systems VF-1000DM ATM-to-MPEG2 demultiplexer
Stellar 1000 MPEG-2 Decoder
Panasonic Laserdisc player
Panasonic VCR

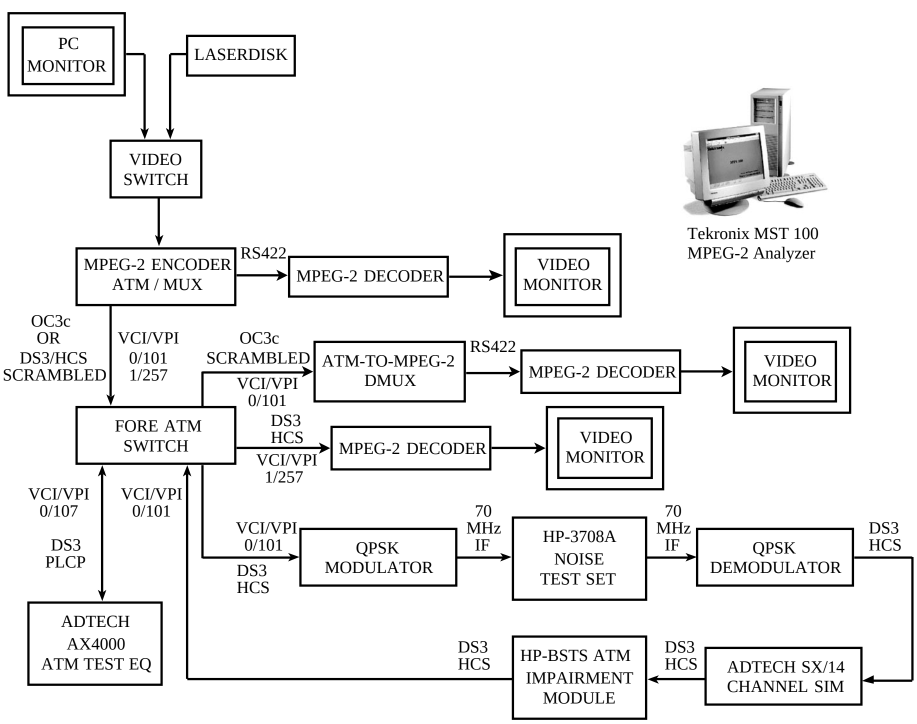

Figure 2.—MPEG-2 Over ATM test setup.

This testbed is extremely flexible and can easily be expanded to run over actual satellite and terrestrial links because we have direct ATM connections to NASA's Advanced Communication Technology Satellite (ACTS) high data rate (HDR) terminal and the NASA Research and Education Network (NREN). Some of the major features of this testbed are embedded in the equipment and its integration into the system. The video switch provides a mechanism for placing markers in the recorded video so we can identify which test configurations were set for each test. The Nuko encoder has three MPEG-2 transport stream channels that output through either RS-422 or TAXI ports as well as an OC3 optical ATM connection. This aids in monitoring the encoded video before it passes through the test network. Errors can be generated using three different pieces of equipment. Errors can be generated in the IF link using the HP 3708A noise test set, or digitally using the Adtech SX/14 or HP Impairment module. ATM link statistics can be obtained with either the Adtech AX/4000 or the Hewlett Packard Broadband Series Test System (BSTS). Generally, we chose to use the AX/4000 because it provides CER and CLR simultaneously. The Tektronix MST 100 allows us to capture or playback MPEG-2 transport streams as well as analyze these streams off line. A laser disk is used for the video source in order to repeat specific, short video segments without degrading the video the way a video tape would.

The video takes the following path through the ATM network. It is first encoded and passed on to the ATM switch—the Nuko encoder can provide up to 3 channels of ATM-encapsulated MPEG-2 video. The video then passes through a combination of video impairment equipment including the satellite modem, the Adtech SX/14, and the HP BSTS impairment module. The video returns to the ATM switch and is forwarded to either the Stellar 1000 settop box decoder which has a DS3 interface built in or to the Nuko ATM-to-MPEG-2 demultiplexer and then on to the Nuko decoder. The Adtech AX/4000 produces ATM test cells which are simultaneously passed through the impairment path and returned for analysis.

TEST CONFIGURATIONS

A series of tests were run to baseline the MPEG-2 video in an error-free and in an errored environment for both transmissions of MPEG-2 transport streams directly over an emulated satellite channel, and for MPEG-2 transport streams using ATM AAL-5 over various emulated satellite channels. The variables shown in table II were introduced into the test in a systematic and controlled manner in order to determine which parameters were affected by errored channels. The systematic reduction of variables was necessary in order to reduce the number of permutations needed for complete and accurate results. The following tests were performed:

(1) Encoding rate testing

(2) MPEG-2 transport stream with errors

(3) MPEG-2 over ATM with errors

(4) MPEG-2 over ATM over satellite channel (emulated)

(5) MPEG-2 over ATM channel characteristics

TABLE II.—TEST VARIABLES

Parameters/Variables	Range
Encoding Rate	3, 5.5, 10, 15 Mbps
Decoder Type	Nuko VF-1000D, Stellar 1000
Channel Characteristics	
BER	10^{-5} - 10^{-9}
Error Distribution	Binomial, Burst (Modem), Payload Only, Header Cell Loss Only
Modulation Format	QPSK 3/4 Conv. Code, QPSK 3/4 Conv. And R/S Code, 8-PSK w/RS Code*
ATM AAL Type	AAL-5, AAL1*

*Not performed during this study period

Decoded Video and Decoder Terminology

A series of tables was generated to describe the video quality and MPEG-2 decoder operation. In order to efficiently complete these tables, we created some terminology and acronyms to describe the results. These acronyms and their associated terminology are listed below.

BE Block error. Noticeable small squares in a portion of the screen—sometimes with changing colors.

CBE Continuous block error. This occurs only in severely errored conditions.

CDR Continuous decoder resynchronization. This occurs only in severely errored conditions.

DR Decoder resynchronization. The decoder freezes the picture and resynchronizes.

K Click sound noticeable in some portions of the audio.

MBE Minimal block errors. Block errors occur infrequently.

MDR Minimal decoder resynchronization. Decoder resynchronization occur infrequently.

NNE No noticeable errors.

NS No synchronization. Decoder cannot synchronize consistently if at all.

S Shaking or jittering of the entire video picture that is possibly caused by the decoder being slightly out of lock.

VEPS Visible errors per second.

\+ Slightly better QoS (i.e., DR+ indicates a decoder resetting maybe 3 times in 5 min versus 5 to 10 times in 5 min.).

\- Slightly worse QoS (i.e., MBE- indicates a noticeable block error occurred 5 times in 5 min verses once or twice in 5 min.).

Encoding Rate Testing

The purpose of the encoding rate test was to baseline the effects of the compression on the decoded signal. No system degradations were included as part of this test. Table III shows the quantitative results. For these tests, a Nuko Information Systems VF1000E decoder was used to decode the video scene from the bicycle race segment of the IMAX movie, “Speed.”

TABLE III.—ENCODING QUALITY

Rate (Mbps)	Video Resolution	Description	Quality
1.5	352 x 480	microblocks are very noticeable in all areas of change	fair
2.0	352 x 480	microblocks are slightly noticeable in all areas of change	good
3.0	352 x 480	microblocks are barely noticeable in select areas of change	very good
5.5 - 15	352 x 480	No noticeable degradation	excellent
1.5	704 x 480	microblocks are very noticeable over the entire screen	bad
2.0	704 x 480	microblocks are very noticeable over much of the screen during fast changing frames	poor
3.0	704 x 480	microblocks are barely noticeable in select areas of change	very good
5.5 - 15	704 x 480	crisp, well defined picture	excellent

MPEG-2 Transport Stream With Errors Test

The purpose of the MPEG-2 transport stream with errors test was to determine if the quality of MPEG-2 video, that had been transmitted using the MPEG-2 transport stream and had errors inserted in the physical channel, was dependent on the encoding rate as well as the decoder implementation. This provides a baseline to which MPEG-2 over ATM can be compared. A simplified test setup is shown in figure 3.

Tests were run using both a Nuko Information Systems VF1000D and a Stellar 1000 MPEG-2 decoder. The data encoder rates were varied from 3 to 5.5 Mbps. Higher encoder rates were not possible because the RS422 interface cards in the Adtech SX14 channel simulator cannot operate above 10 Mbps and the Stellar 1000 cannot operate above 6.144 Mbps. The channel simulator was configured to produce a binomial error distribution which best represents random gaussian noise in an analog channel. These test runs were relatively short, (less than 5 min) and were used to get an understanding of where the decoders' acceptable operation threshold resided. The results are shown in table IV and indicate that a BER of at least 1.0×10^{-8} or higher in the MPEG-2 transport stream is definitely unacceptable. Also, the Stellar and Nuko decoders have approximately the same QoS threshold of acceptability. Finally, there is a slightly better quality for higher compressed video. We hypothesize that this may be because the video access unit sizes are smaller for video with higher compression and the I-frames repeat more quickly. Further investigation is necessary to fully understand this phenomenon.

MPEG-2 over ATM With Errors Test

The purpose of the MPEG-2 over ATM with errors test was to determine if the quality of MPEG-2 video that had been transmitted using ATM AAL5 and that had errors inserted in the physical channel was dependent on the encoding rate as well as the decoder implementation. Both the Stellar 1000 decoder with DS3 ATM interface and the NUKO VF-1000DM ATM-to-MPEG2 demultiplexer passed AAL5 CRC errors. Figure 4 shows the simplified test setup.

As in the previous tests, both a Nuko Information Systems VF1000D and a Stellar 1000 MPEG-2 decoder were used to acquire data. The channel simulator was configured to produce a binomial error distribution and the test runs where relatively short (less than 5 min). ATM QoS parameters were simultaneously measured while video was recorded. This was accomplished by passing ATM test patterns through the same link over a different VC/VP. CER and CLR measurements were taken using the Adtech AX/4000.[1] The results are shown in table V and are

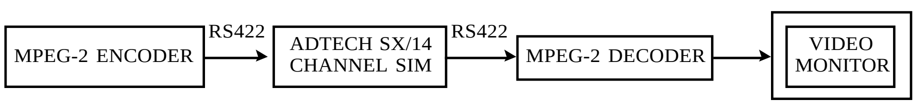

Figure 3.—MPEG-2 transport stream with errors test.

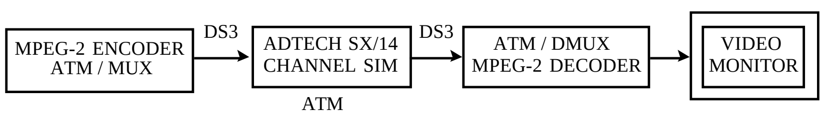

Figure 4.—MPEG-2 over ATM with errors test.

TABLE IV.—MPEG-2 TRANSPORT STREAM WITH BINOMIAL ERROR DISTRIBUTION TESTS (SHORT TEST, LESS THAN 5 MINUTE RECORD TIMES)

	Stellar 1000			Nuko VF1000D		
\Encode \Rate BER\	3.0	4.0	5.5	3.0	4.0	5.5
10^{-5}	CDR, CBE	CDR, CBE	CDR, CBE, K	CDR-, CBE	CDR-, CBE	CDR-, CBE
10^{-6}	DR, BE	DE, CBE, K	DR, CBE, K	DR, CBE	DR, CDE, S	DR-, CBE
10^{-7}	NNE	MDR, MBE	DR, BE	BE	MDR, BE, S	MDR, BE
10^{-8}	MBE	NNE	MBE	MBE	MBE	MDR, BE+
10^{-9}	NNE	NNE	NNE	NNE	NNE	NNE

[1]Note, the version of DS3 line cards used on the FORE switch operated in header error detection mode only. Therefore, cells with single header errors would normally be dropped, not corrected. However, since the ATM cells pass-through the Hewlett Packard E4219A Impairment Module (the Hewlett Packard E1616A T3 line card is in pass-through mode not monitor mode), single header errors are corrected at this point (see fig. 2).

nearly identical to the results for the MPEG-2 transport stream with binomial error distribution tests. This is to be expected since both the Stellar and Nuko ATM-to-MPEG2 demultiplexer portions of the decoding process passed errored ATM AAL5 cells while ATM cells with single header errors were corrected. Therefore, the probability of a dropped ATM cell is insignificant relative to the effects of errors in the MPEG-2 transport stream.

MPEG-2 over ATM over Satellite Channel (Emulated) Tests

The purpose of the MPEG-2 over ATM over a satellite emulated channel test was to evaluate the quality of MPEG-2 video that had been received and had errors inserted in the physical channel RF link. This test was performed using an EFData IDR (ref. 6) modem model SDM 9000 with $\frac{3}{4}$ rate convolutional forward error correction (FEC) coding. The tests were also performed using combined $\frac{3}{4}$ rate convolutional coding concatenated with a Reed-Solomon code. Both FEC techniques produce bursts of errors when the correction capabilities of the code are exceeded. The simplified test setup is shown in figure 5 and the characteristics of this modem relative to ATM QoS parameters are shown in figure 6.

TABLE V.—MPEG-2 OVER ATM WITH BINOMIAL ERROR DISTRIBUTION (SHORT TEST, LESS THAN 5 MINUTE RECORD TIMES)

	Stellar 1000				Nuko VF1000D				
\Encode \Rate BER\	1.5	3.0	4.0	5.5	3.0	5.5	10.0	12.0	15.0
10^{-5}	CDR-	CDR-	CDR-	CDR-	CDR-	CDR-	CDR-	CDR-	CDR-
10^{-6}	K, DR, BE-	CDR+, CBE	CDR, CBE	CDR, CBE	DR-, CBE	CDR+, K, CBE	CDR+, CBE	CDR, CBE	CDR, CBE
10^{-7}	DR+, MBE	BE	BE	DR+, BE	DR	DR-, MBE-	DR-, MBE-	DR-, CBE+	DR-, CBE+
10^{-8}	NNE	NNE	NNE	MBE+	MBE+, S	MDR+, MBE	MBE, S	MDR, MBE	MDR, MBE
10^{-9}	NNE	NNE	NNE	NNE	NNE	NNE	NNE	NNE	NNE

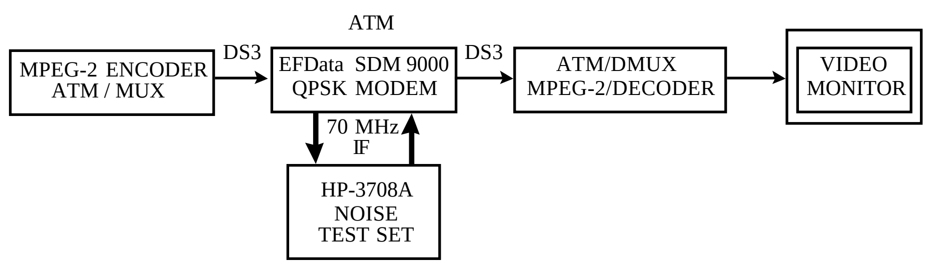

Figure 5.—MPEG-2 over ATM over an emulated satellite channel tests.

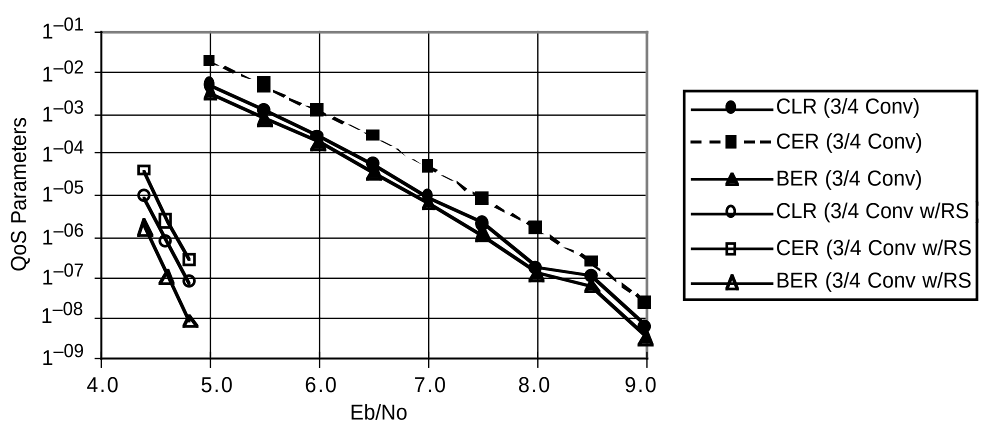

Figure 6.—EF-DATA modem model SDM 9000 ATM characterisitcs.

The qualitative results shown in table VI indicate that an Eb/No of less than 8.0 dB for convolutional encoding and an Eb/No of less than 4.8 dB for combined RS and convolutional encoding provide an unacceptable link quality. These values roughly correspond to BER's of $1.0x10^{-8}$, CLR's of $1.0x10^{-7}$, and CER's of $1.0x10^{-6}$.

Long Duration Dual Decoder Tests

The purpose of the long duration dual decoder tests was two-fold. First, we wanted to determine if decoders from various manufacturers react to the same errored transport stream similarly. Do these decoders have approximately the same failure threshold? Second, we wanted to quantify the video degradations in relatively low-errored environment. Thus, the tests had to be run for a long duration. Also, since the video degradation had to be determined by human observers with a reasonable degree of confidence, the errors had to occur often enough to provide some reasonable statistical information. Thus, one visible error per day or week would not be practical to measure. Instead, the link was set up such that visible errors occurred approximately every 30 sec to a few minutes.

The simplified test setup is shown in figure 7. The video encode rate was 5.5 Mbps with the video resolution set for main level, main profile (704 by 480 pixels). In order to compare the decoders, the recorded video was synchronized and displayed in a split screen. The audio source used was from the Stellar decoder as was the left half of the video. The right half of the video was from the Nuko decoder. This setup allowed the viewer to simultaneously compare the decoders.[2]

The results of these tests showed that both decoders degraded at the same point (table VII) For the same impaired MPEG-2 transport stream, both decoders would lose synchronization simultaneously. Often, both decoders would display block errors simultaneously. However, sometimes the block error would only occur in a small portion of the video and it would be difficult to determine if both decoders reacted to that particular errored stream. In general, however, the link-error-threshold for which the video signal out of the decoders is unacceptable is identical for both decoders. Also, the human tolerance indicates block errors are far more tolerable than decoder resynchronization. The results of this test are shown in table V.

At this time we have insufficient data to determine an exact relationship between the QoS parameters and the video quality. However, from these results we can conclude that CLR's of $3x10^{-7}$ and CER's of $4x10^{-6}$ are unacceptable for MPEG-2 compressed video and that a least an order of magnitude improvement is required if not more.

MPEG-2 over ATM Channel Characteristics Test

The purpose of the MPEG-2 over ATM channel characteristics test was to determine the effect of ATM payload errors *only* and ATM header errors *only* on the quality of MPEG-2 video that has been transmitted using ATM AAL5.[3] The setup was identical to that in the dual decoder tests except that the signal was not degraded

TABLE VI.—MPEG-2 OVER ATM OVER SATELLITE CHANNEL

	Stellar 1000		Nuko VF1000E		
\Encoder\RateEb/No\	3.0	5.5	3.0	5.5	14.0
4.4	—	—	DR, BE	DR	CDR-
4.6	—	—	—	MBE	MDR
4.8	—	—	—	NNE	NNE
6.5	CDR+, BE	CDR, CBE-	S, CDR-	CDR-, CBE	NS
7.0	DR, MBE	CDR+, BE	DR-, S, MBE	DR-, BE	CDR, BE-
7.5	MDR, MBE	MDR, MBE	—	MDR, MBE	DR, MBE-
8.0	NNE	NNE	—	NNE	MDR+

TABLE VII.—VIDEO DEGRADATION (LONG DURATION MPEG-2 OVER ATM OVER SATELLITE)

Eb/No	BER	CLR	CER	Decoder Resynch	Block Errors	Total Visible Errors	Run Time (Sec)	VEPS
7.5 dB	4.23E-7	1.40E-6	9.95E-6	18	8	26	420	6.19E-2
8.0 dB	7.05E-8	2.93E-7	1.76E-6	12	17	29	2315	1.25E-2

*****The BER, CLR, and CER measurements are of test patterns run through the link simultaneously with the video. They are indicative of the link but are NOT measurements of the video stream itself.

[2]Copies of this video are available from NASA Lewis Research Center and can be obtained by contacting: Technology Utilization Office, NASA Lewis Research Center, 21000 Brookpark Road, Mailstop 7-3, Cleveland, Ohio 44135, USA, Phone (216)433-5565.

[3]The HP Network Impairment module can be programmed to either create errors only in the payload section (CER), only in the drop cells (CLR), or both.

through the modem, instead, the Hewlett Packard Impairment module was used. The test setup is shown in figure 8. As in the long-duration dual-decoder tests, the video was recorded simultaneously by both decoders and post-processed to synchronize the video in a split screen display.

Table VIII shows the impairment module settings for both the CER-only tests and the CLR-only tests. A normal distribution was used for these tests as a best approximation to a wireless channel with normal white gaussian noise.

The results of these tests indicate that CLR has far more effect on the video quality than CER (table IX). This is to be expected because at least two MPEG-2 transport streams are dropped as a result of cell loss.

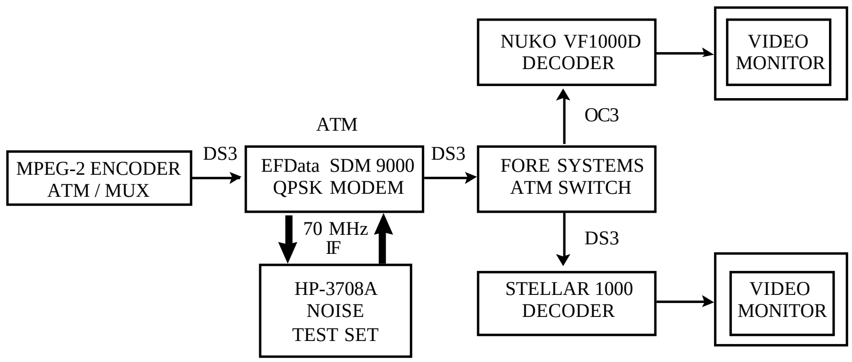

Figure 7.—Long duration dual decoder tests.

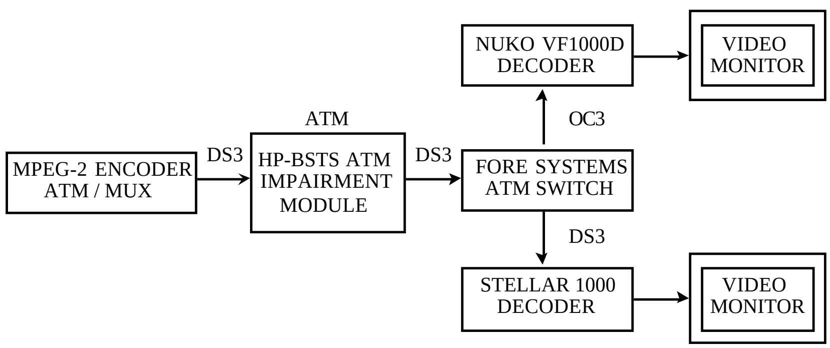

Figure 8.—CLR only and CER only test.

TABLE VIII.—NETWORK IMPAIRMENT MODULE SETTINGS

Settings	CLR Only	CER Only
Distribution	Normal	Normal
Mean	1.0E+6	1.0E+6
Standard Deviation	10,040	10,040
Cell or Byte	Byte	Byte
Consecutive Error Probability		
Single Errors	0.7	0.7
Double Errors	0.2	0.3
Triple Errors	0.1	0.1
Quadruple Errors	0.0	0.0

TABLE IX.—VIDEO DEGRADATION (CER ONLY AND CLR ONLY TESTS)

Test	BER	CLR	CER	Decoder Resynch	Block Errors	Total Visible Errors	Run Time (Sec)	VEPS
CER Only	1.77E-7	0	4.82E-5	4	16	20	460	4.35E-2
CLR Only	0*	1.36E-6	0	14	0	14	660	2.12E-2

*92 cell drops and 71 pseudo-random pattern resynchronizations
*The BER, CLR, and CER measurements are of test patterns run through the link simultaneously with the video. They are indicative of the link but are NOT measurements of the video stream itself.

OBSERVATIONS AND DISCUSSION

Throughout months of testing and viewing MPEG-2 video in various degraded stages, the following observations were made:

(1) Human tolerance for block errors is far greater than for decoder resynchronization where the picture freezes or the screen blanks. This is readily apparent in all tests.

(2) The Stellar and Nuko decoders have approximately the same QoS threshold of acceptability. Generally, the Stellar decoder recovered almost instantaneously, whereas the Nuko decoder would freeze and resynchronize after a second or two. The Stellar decoder requires a continuous bit rate (CBR) whereas the Nuko decoder does not. We suspect that the Stellar implementation may be taking advantage of the CBR and that the Nuko decoder is reading all the presentation and synchronization information in the MPEG-2 transport stream before resynchronizing. During the dual decoder testing we observed that when the Nuko resynchronized, it was in perfect synchronization with the Stellar decoder.

(3) CLR has a far greater effect on the decoder video quality than CER. This was shown in the CLR-only and CER-only tests. This is to be expected as cell losses cause a minimum of two transport streams to be lost.

(4) The results of this study were based on the Stellar and Nuko systems that had ATM-to-MPEG-2 demultiplexer portions that passed corrupted AAL-5 datagrams to the video decoder portions. Further work is required to evaluate the impact on QoS of other, more robust, MPEG-2 systems.

(5) The link-error threshold for which the video signal out of the decoders is unacceptable is identical for both the Nuko and Stellar decoders. This was observed during the dual-decoder testing.

(6) Higher encoding rates require slightly higher quality links. This was observed for both the “MPEG-2 Transport Stream with Errors” and the “MPEG-2 over ATM with Errors” testing. We hypothesize that this is because the video access unit sizes are smaller for video with higher compression and the I-frames repeat more quickly. However, further study is necessary to understand exactly why higher encoding rates require slightly higher quality links.

(7) Further study is necessary in order to determine the relationship between the video quality and the ATM QoS parameters - in particular between the visible errors per second and the CLR and CER, as well as the effect different CER and CLR distributions have on the video. After completion of these tests and during the data analysis phase we realized that there was insufficient data to determine this relationship.

CONCLUSION

ITU-T Rec. I.356 Class I, stringent class, objectives for CLR and CER should be at least 1.0×10^{-8} and 1.0×10^{-7}, respectively, in order to acceptably carry such services as MPEG-2 compressed video and may require even better performance. These requirements are readily met with today’s technology that uses various link enhancement techniques such as concatenated convolutional and Reed-Solomon FEC coding. Further work is required to evaluate the impact on QoS of other, more robust, MPEG-2 systems.

PROPOSAL

ITU-T Rec. I.356 Class I, stringent class, objectives for CLR and CER should be at least 1.0×10^{-8} and 1.0×10^{-7}, respectively, and may require even better performance in order to acceptably carry such services as MPEG-2 compressed video.

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13. ABSTRACT ***(Maximum 200 words)***

Asynchronous transfer mode (ATM) quality of service (QoS) experiments were performed using MPEG-2 (ATM application layer 5, AAL5) over ATM over an emulated satellite link. The purpose of these experiments was to determine the free-space link quality necessary to transmit high-quality multimedia information by using the ATM protocol. The detailed test plan and test configuration are described herein as are the test results. MPEG-2 transport streams were baselined in an errored environment, followed by a series of tests using MPEG-2 over ATM. Errors were created both digitally as well as in an IF link by using a satellite modem and commercial gaussian noise test set for two different MPEG-2 decoder implementations. The results show that ITU-T Recommendation I.356 Class I, stringent ATM applications will require better link quality than currently specified; in particular, cell loss ratios of better than 1.0×10^{-8} and cell error ratios of better than 1.0×10^{-7} are needed. These tests were conducted at the NASA Lewis Research Center in support of satellite-ATM interoperability research.

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