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ABSTRACT: A digitized video application was used to help determine minimum quality of service parameters for asynchronous transfer mode (ATM) over satellite. For these tests, binomially distributed and other errors were digitally inserted in an intermediate frequency link via a satellite modem and a commercial gaussian noise generator. In this paper, the relationship between the ATM cell error and cell loss parameter specifications is discussed with regard to this application. In addition, the video-encoding algorithms, test configurations, and results are presented in detail.

Introduction

NASA Lewis Research Center is the lead center for commercial satellite communications and hybrid satellite/terrestrial networks. As such, Lewis has been asked to assist the commercial satellite communications industry with hybrid satellite/terrestrial networks and interoperability issues. One of the major topics of interest is the satellite link requirements for asynchronous transfer mode (ATM) quality of service (which is application dependent). Voice quality may be acceptable with bit error rates (BER's) of 10^{-6} or higher. For medical imaging, BER's of 10^{-7} may be acceptable. For file transfers that are not delay sensitive, high-level protocols will resolve many problems resulting from transmission errors. Thus, the question to be resolved is "What link quality will satellites have to provide in order to be globally interoperable with terrestrial systems?"

Digitized Video

As an interim step in determining the satellite link quality requirements, we chose to use FORE Systems' AVA–200 Video [1,2] to digitize video over ATM since this equipment was already available. Future tests will use MPEG–2 (Moving Pictures Experts Group). The uncompressed digitized video rate used in these tests was approximately 19 Mbps, giving a "pseudocompression" ratio of approximately 20:1. Here, pseudocompression refers to the lossy compression resulting from encoder parameter settings such as video resolution, picture size, and frame rate. For comparison, MPEG–2 can compress video at ratios as high as 90:1 for quality videos, such as sports and movies.

For the AVA–200 uncompressed video, the picture frame was split into and transmitted as a sequence of tiles, where each tile was an 8- by 8-pixel segment of a video frame. Figure 1 shows the common part convergence sublayer (CPCS) packet. Each asynchronous transfer mode adaptation layer 5 (AAL5) frame consisted of an integral number of bytes of encoded pixel data, a variable-length pad, a 2-byte tile trailer, and a 2-byte AAL5 trailer. The pad ensured that the AAL5 protocol distribution unit (PDU) frame would be an integral number of cells (48 bytes) in length. The tile trailer contained the coordinates of the first tile in the tile dimension units and a 32-bit picture frame number that stated which frame the tile belonged to. The AAL5 trailer contained a 2-byte pad, a 2-byte code, and a 4-byte cyclic redundancy check (CRC) code. For the particular encoding parameters used in these tests, the AAL5 CPCS packet consisted of 66 ATM cells.

The following encoder parameters were used in our test, resulting in a pseudocompression ratio of approximately 20:1, as given by equations (1) and (2):

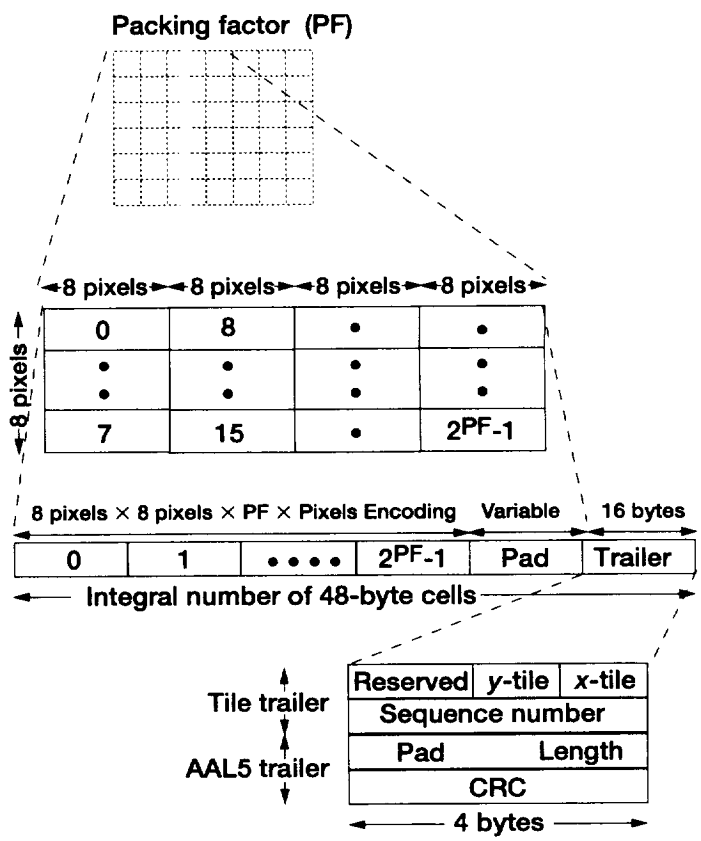

Figure 1.— Video tile encoding.

The AAL5 CPCS packet size *PKS* is given by equation (1):

$$PKS \text{ bytes/AAL5-CPCS} = \left[PE \text{ bytes/tile } \left(PF \text{ tiles/AAL5-CPCS}\right)\right] + \text{pad bytes/AAL5-CPCS} + \text{trailer bytes/AAL5-CPCS} \quad (1)$$

where *PE* is a pixel encoding of 24 rgb and 3 bytes and *PF* is a packing factor of 64 tiles per AAL5 CPCS.

The video bit rate *VBR* can be determined from equation (2):

$$VBR \text{ bits/sec} = FR \text{ frames/sec} \left(\frac{PS \text{ tiles/frame}}{PF \text{ tiles/AAL5-CPCS}}\right) \times PKS \text{ bytes/AAL5-CPCS} \left(\frac{424 \text{ bits/ATM-Cell}}{48 \text{ bytes/ATM-Cell}}\right) \quad (2)$$

where *FR* is the frame rate and *PS* is the picture size.

No audio was used in these tests because it was not deemed necessary at the time. In hindsight, it would have been useful to have included the audio channels in these tests to see if they degrade gracefully and at what point their degradation is unacceptable.

ATM Quality of Service Measurement Parameters

Each of the following six parameters give a particular measure of the ATM quality of service:

- CER cell error ratio
- CLR cell loss ratio
- CDV cell delay variation
- SECBR severely errored cell block ratio
- CTD cell transfer delay
- CMR cell misinsertion rate

Cell error ratio, cell loss ratio, and cell delay variation are the most important quality of service parameters to consider when one is testing digital video applications over ATM. Cell error rate and cell loss ratio are of greatest concern. With the test setup and equipment on hand we were able to obtain reliable, repeatable measurements for the cell error ratio and cell loss ratio, as well as for the severely errored cell block ratio.

Severely errored cell block ratio measurements were readily obtained but were not particularly meaningful for our tests. They are used primarily as an availability measurement to identify bursts of errors.

Digital video is not delay sensitive; therefore, the cell transfer delay will not affect the ATM quality of service. For instance, the round-trip delay for a geostationary satellite is

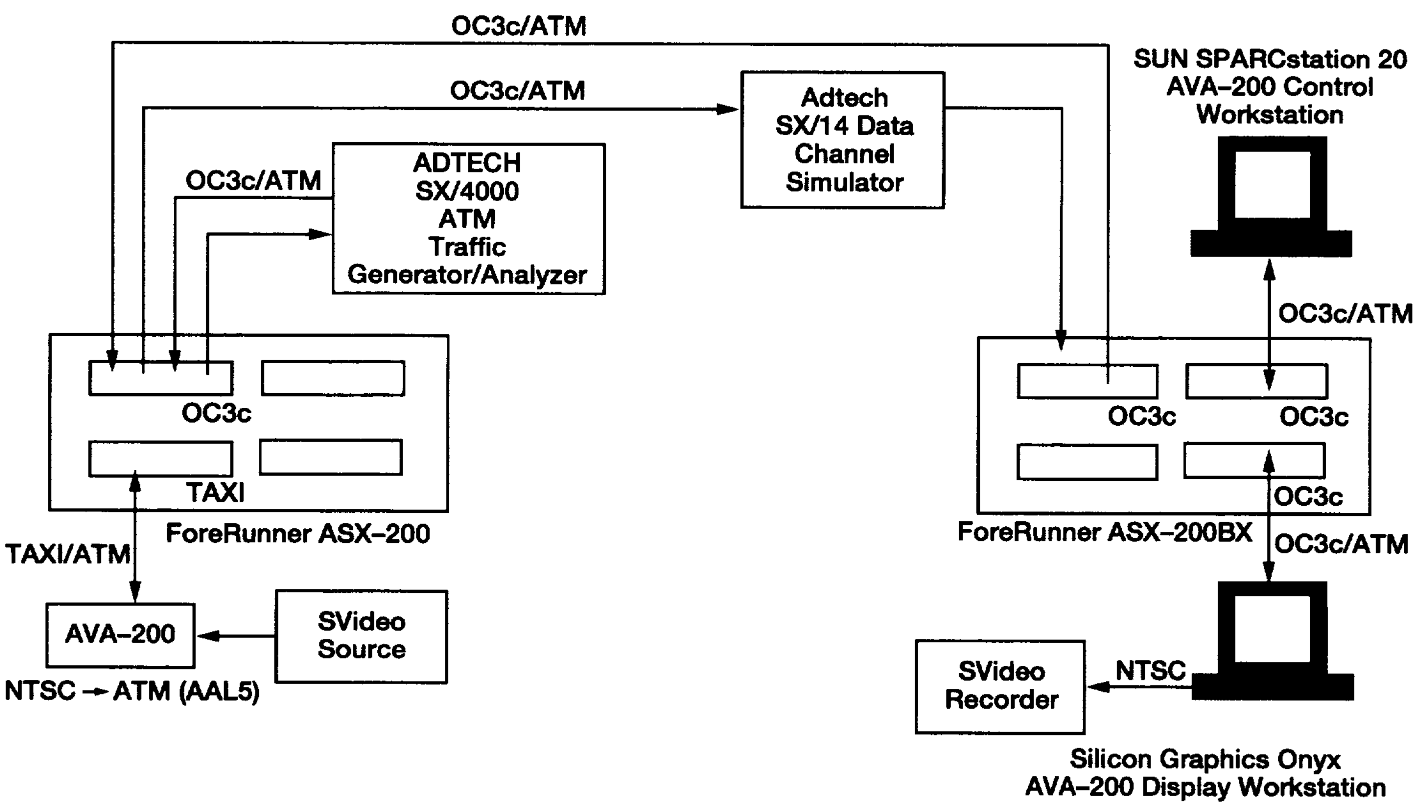

Figure 2.—Binomially distributed errors. (NTSC, National Television System Committee Video; TAXI, transparent asynchronous transceiver/receiver interface; OC3c, optical carrier 3c.)

approximately 250 msec. This delay has no effect on the video quality seen at the receiving node. Thus, the cell transfer delay did not affect the video quality.

Cell delay variation (jitter) was not measured during these tests because of test equipment limitations. The only way we could have produced jitter effects with the equipment on hand would have been to insert additional ATM traffic into the ATM switch. We believe that such a test would have been valid for only the specific traffic scenario implemented.

Cell misinsertion also was not measured during these tests because this measurement is only significant for complex, fully loaded networks. Even then, the probability of misinserted cells is quite rare.

Test Configurations

Two test configurations were used. The first (Fig. 2) provided for fixed delay and random, binomially distributed errors inserted digitally with an Adtech SX/14 Data Channel Simulator as the satellite link. This test shows digitized video versus BER. The second configuration (Fig. 3) used the EFData SDM–9000 modem and the Hewlett Packard HP 3708A noise test set to simulate the satellite; the Adtech SX/14 provided a fixed delay only. This test shows digitized video as a function of the energy-per-bit to normalized-noise-power ratio E_b/N_0.

Results

Figure 4 uses GIF pictures to visually show the results of the digitized video testing. The digitally generated noise test is relative to the BER. When an actual quadrature phase shift keying (QPSK) modem was used at a 44.736 Mbps transmission rate, the test results for analog generated noise were relative to the E_b/N_0. The digitized video parameters were set to provide a digital video data stream at approximately 19 Mbps. Video clips of these tests have been stored as MPEG–1 files and are available on the World Wide Web at NASA Lewis' Satellite Networks and Architectures Branch site [3]. Also a short, 8-min video is available upon request.

Table I shows the relative range of readings obtained from the FORE ATM network interface card at the video sink. The output measurements for AAL5 packets provided from this card were the number of CRC errors, the number of congested packets, and the number of dropped packets. The update rate was set for 1-sec intervals. For this test, each AAL5 CPCS packet contained 66 ATM cells. The results for the digitally generated errors show that the number of cells dropped was an integral multiple of the AAL5 CPCS packet except for extremely high BER's of 10^{-5}. At this point, the AAL5 CPCS packets contained enough errors that the measurement circuitry considered the packets lost because of congestion. This was even more apparent for

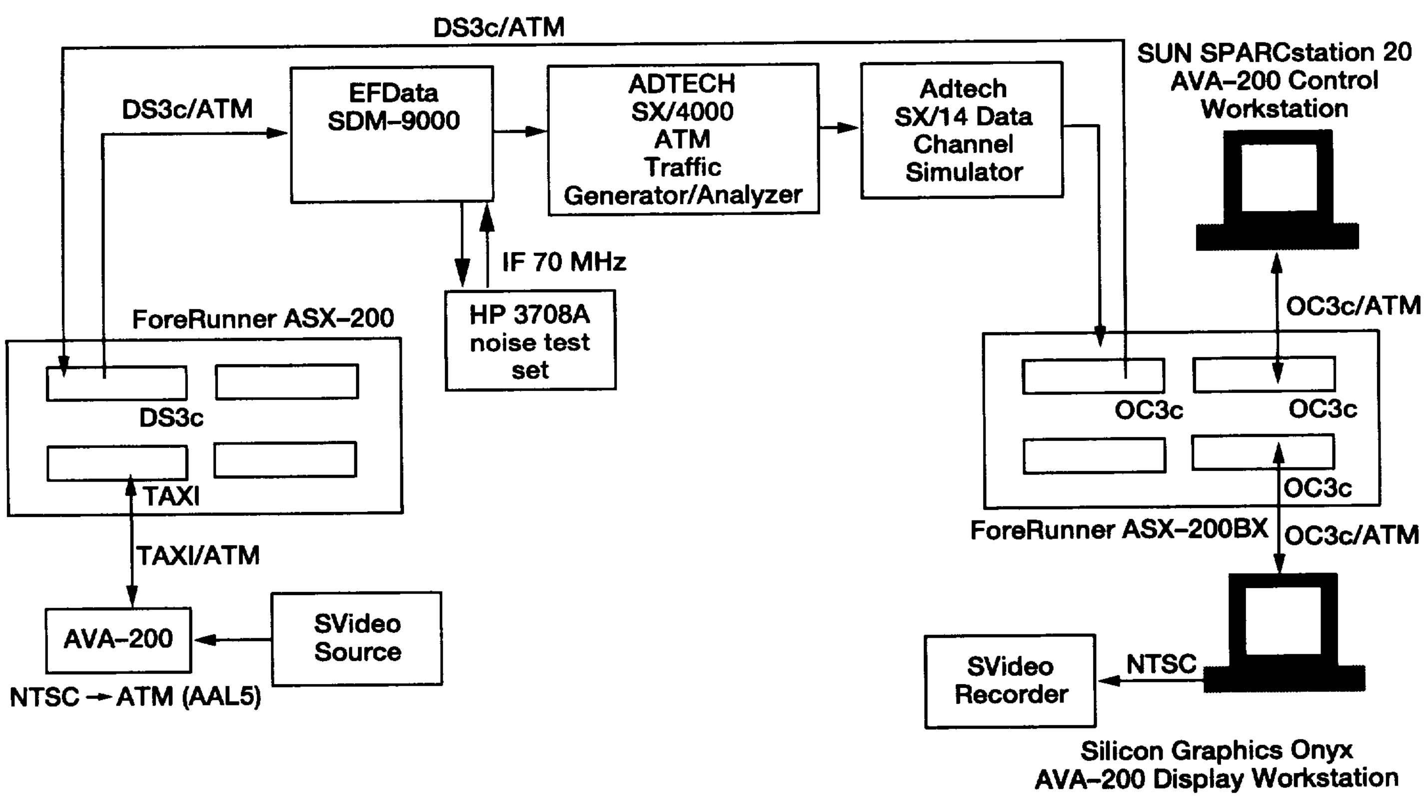

Figure 3.—Errors inserted by using average white gaussian noise. (NTSC, National Television System Committee Video; TAXI, transparent asynchronous transceiver/receiver interface; OC3c, optical carrier 3c.)

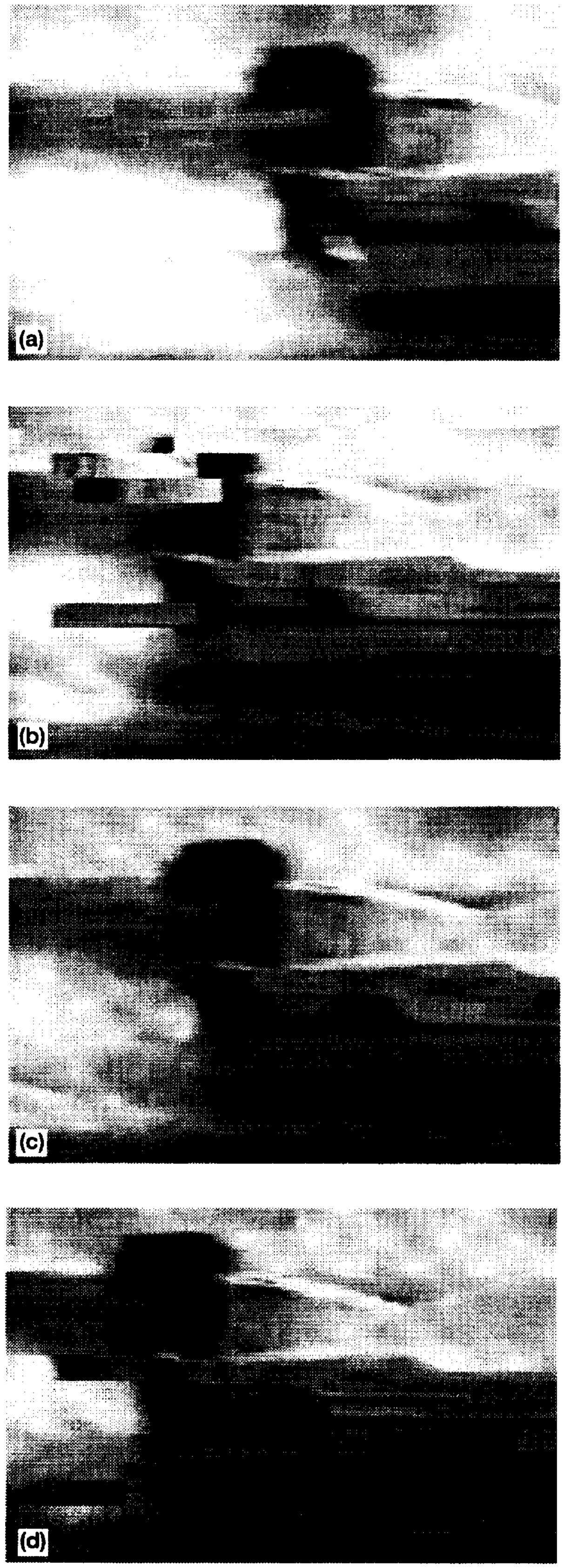

Figure 4.—Digitally generated noise. (a) Bit error rate, 10^{-8}. (b) Bit error rate, 10^{-5}. (c) Signal-to-noise ratio, E_b/N_0, 8.2 dB. (d) Signal-to-noise ratio, E_b/N_0, 6.0 dB.

TABLE I.—RANGE OF READINGS FROM FORE ATM NETWORK INTERFACE CARD

Bit error rate (BER)	AAL5 CPCS packets with CRC errors, range	Congested packets, range	Dropped cells, range
10^{-9}	0	0	0
10^{-8}	0 (1 to 2 occasionally)	0	0 (66 to 132 occasionally)
10^{-7}	1 to 7	0	66 to 462
10^{-6}	15 to 30	0	990 to 1980
10^{-5}	80 to 120	0 to 1	5200 to 12 500
Signal-to-noise ratio, E_b/N_0, dB	**AAL5 CPCS packets with CRC errors, range**	**Congested packets, range**	**Dropped cells, range**
8.2	0 to 1	0	0 to 66
7.5	0 to 3	0	0 to 198
6.0	50 to 120	9 to 29	5500 to 7000

the E_b/N_0 test at a low E_b/N_0. Most likely, this was due to the bursty nature of the errors associated with the intermediate data rate (IDR) modem [4,5]. From the measurements in Table I, it is apparent that an E_b/N_0 setting of 6.0 dB corresponds closely to a BER of approximately 10^{-5}, whereas an E_b/N_0 setting of 8.2 dB corresponds to a BER of 10^{-8} or better.

FORE Systems' AVA–200 uncompressed digital video is very robust in that it continues to operate in the presence of errors. Even extremely errored video is tolerable, and the video decoder does not lose synchronization. This is due mainly to the nature of the encoding and decoding algorithms. If a tile is in error, that tile's information is ignored and the information from the previous frame's file is retained.

Video degradation is perceived at a BER of 10^{-7} and is unacceptable at BER's of 10^{-6} and above. AT&T demonstrated similar results with a JPEG (Joint Photographic Experts Group) video that was set to operate at a quality level of 50, producing a video bit rate signal from 10 to 20 Mbps [6].

Conclusions

Test results indicate that satellite link quality with a bit error rate of at least 10^{-8} should be maintained for stringent asynchronous transfer mode (ATM) applications. Occasional, very short term link degradations that provide bit error rates of 10^{-7} or 10^{-6} may be acceptable for some robust video-encoding schemes.

Quality of service tests for highly compressed data applications are expected to produce more stringent link quality requirements. Applications such as MPEG–2 (Moving Pictures Experts Group) should provide additional input to better identify the necessary quality of service parameters.

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