RECOMMENDATION ITU-R S.1420

PERFORMANCE FOR BROADBAND INTEGRATED SERVICES DIGITAL NETWORK ASYNCHRONOUS TRANSFER MODE VIA SATELLITE

(Questions ITU-R 78/4 and ITU-R 75/4)

(1999)

The ITU Radiocommunication Assembly,

considering

a) that satellites operating in the fixed-satellite service play an important role in providing reliable international digital communications;

b) that, therefore, satellite performance must comply with performance objectives as specified by ITU-T Recommendation I.356-B-ISDN ATM layer cell transfer performance;

c) that in defining performance criteria, it is necessary to take into account all the specific characteristics of the transmission medium used for asynchronous transfer mode (ATM) transmission,

recommends

1 that connection portions including satellite links carrying broadband integrated services digital network (B-ISDN) ATM transmission meet the objectives set forth in ITU-T Recommendation I.356 (see Note 1);

2 that these objectives should be met only during the time that the satellite link is in the available state (see Note 2);

3 that the reference model, set forth in Annex 1 of this Recommendation, be considered a basis for developing methods and techniques for meeting the objectives of ITU-T Recommendation I.356 in the above context;

4 that the allocations of ATM performance objectives to connection portions including satellite links forming part of a hypothetical reference connection (HRX) for B-ISDN ATM systems be according to the allocations set forth in Annex 1 of this Recommendation;

5 that the translation methods detailed in Annex 1 of this Recommendation be used in the assessment of performance levels of satellite systems designed to carry ATM traffic (see Note 3);

6 that the following Notes are regarded as part of this Recommendation.

NOTE 1 – Satellite transmission systems that carry ATM traffic but are not part of an international connection are outside the scope of ITU-T Recommendation I.356. In this case, performance objectives derived from ITU-T Recommendation I.356 may not apply.

NOTE 2 – The B-ISDN ATM availability objectives for semi-permanent connections are specified in ITU-T Recommendation I.357. The availability of B-ISDN ATM switched connections is for further study. Satellite system ATM availability parameters and objectives are the subject of Recommendation ITU-R S. 1424.

NOTE 3 – Annex 2 contains informative material regarding the general performance of ATM over satellites.

ANNEX 1

(Normative)

B-ISDN ATM layer performance objectives and translation methods for satellite links

1 Scope

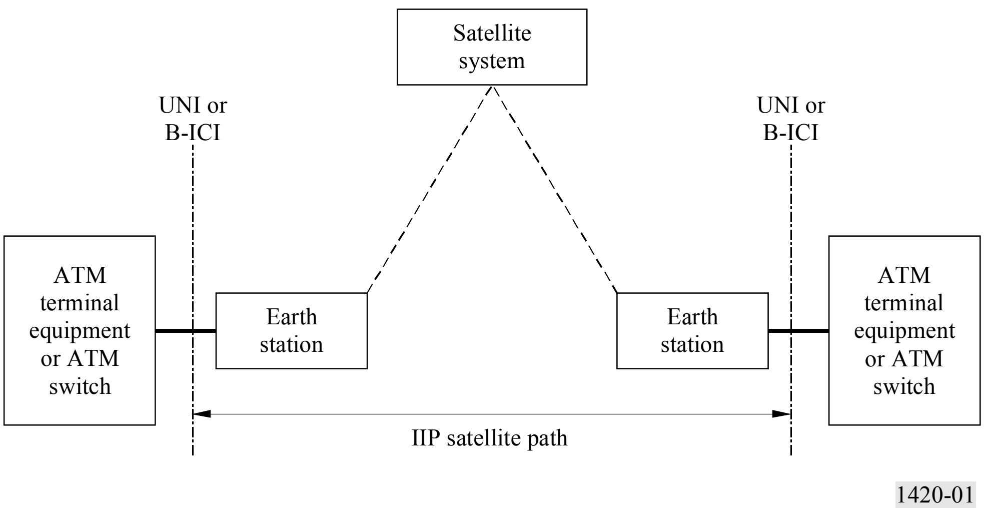
This Annex describes a reference model for the international portion of ATM satellite connections and details the methods for translating between the required ATM layer performance parameters and the satellite link bit error ratio (BER). Both the HRX definition and the ATM performance parameters of the various parts of the HRX are given in ITU-T Recommendation I.356. The use of satellite systems in other connection portions is a subject for further study.

2 Reference model

To interpret the allocation of performance objectives given to satellite portions of an ATM connection a reference model is provided in Fig. 1. Notice that the satellite path may comprise the earth stations and a single transparent (bent-pipe) satellite or a series of satellites. Some satellite systems may include on-board processors (OBPs), ATM switching, and inter-satellite links (ISLs). The terrestrial segment of the ATM satellite path comprises the earth station equipment (antennas, amplifiers, up-converters, down-converters, modems, etc.) and any satellite specific ATM equipment that may be used within a satellite path. The demarcation point between the domestic ATM network and the international ATM network is known as the measurement point international (MPI). The MPI can be a user-network interface (UNI) or a broadband inter-carrier interface (B-ICI). The portion between the two MPIs is known as the international inter-operator portion (IIP).

FIGURE 1

Reference model for an ATM satellite path



One use of satellites is to provide connectivity between separate ATM networks located in different countries. In such case, the terrestrial ATM network will generally interface with the satellite subnetwork through an UNI (or B-ICI). Since this interface point may not always be co-located at the satellite earth station, there may be a terrestrial distance between the terrestrial gateway node and the earth station.

3 ATM performance objectives for satellite links

This section provides an interpretation of the performance objectives defined in ITU-T Recommendation I.356 and the corresponding requirements for the satellite portion(s) of an ATM connection.

The end-to-end ATM layer network performance parameters and objectives for public B-ISDN are defined in ITU-T Recommendation I.356. To accommodate the characteristics and the requirements of various traffic types, ITU-T Recommendation I.356 defines various classes of service. Class 1 (stringent class) is a delay-sensitive class and it is intended to support constant bit rate (CBR) and real-time variable bit rate (VBR) services such as telephony and videoconference. Class 2 (tolerant class) is a delay-tolerant class and supports available bit rate (ABR) and non-real-time VBR services such as video and data. Class 3 (bi-level class) supports VBR and ABR services such as high-speed data. Finally, Class 4 (unspecified class) supports unspecified bit rate (UBR) services such as file transfers and e-mail. Table 1 provides the ATM layer performance objectives for the various service classes (see Note 1). These objectives may be revised in the future based on operational experience (see Note 2).

NOTE 1 – During a recent meeting (June 1998) of Telecommunication Standardization Study Group 13 a new stringent bi-level quality of service (QoS) class was provisionally accepted for inclusion in the next version of ITU-T Recommendation I.356. This new class will have bounds for cell transfer delay (CTD), cell delay variation (CDV), cell loss ratio 0 (CLR0), cell error ratio (CER), cell misinsertion rate (CMR), and severely errored cell block ratio (SECBR), but none for CLR0 + 1.

NOTE 2 – Performance objectives designated by U are unspecified and the ITU will not establish an upper bound for these parameters.

TABLE 1

QoS class definitions and network performance parameters

	CTD	2-pt. CDV	CLR_{0+1}	CLR_0	CER	CMR	SECBR
Default objectives	No default	No default	No default	No default	4×10^{-6}	1/day	1×10^{-4}
QoS classes:							
Class 1 (stringent class)	400 ms	3 ms	3×10^{-7}	None	Default	Default	Default
Class 2 (tolerant class)	U	U	1×10^{-5}	None	Default	Default	Default
Class 3 (bi-level class)	U	U	U	1×10^{-5}	Default	Default	Default
U class	U	U	U	U	U	U	U

The QoS class required by each application is part of the contract negotiation procedure between the user and the network. If the network can provide the requested service level, the connection will be established. If there is any performance objective that cannot be met, the connection will be denied. Once a connection is established, the network must ensure that the performance objectives of the QoS class are met during the connection.

3.1 ATM performance allocation principles

ITU-T Recommendation I.356 specifies upper bounds on ATM transmission performance objectives. It allocates parts of the end-to-end objectives to the national and international portions of an HRX ATM connection. Geostationary satellites have a special allocation based on the assumption that satellites will replace significant terrestrial distance, multiple

ATM nodes and transit country portions. These performance allocations are defined between ATM measuring points as they refer to ATM transmission performance and not to individual items of transmission equipment such as satellite systems. Thus the allocation to the IIP includes terrestrial plant and may include ATM switching nodes as well as the satellite system.

This Recommendation assumes that the terrestrial plant does not introduce significant errors and that all the allocation can be given to the satellite system. Thus the objectives given in terms of ATM layer parameters at ATM measurement points simply need translation to the BER objectives of the satellite link. This assumption may not be valid, however, for all circuit configurations. Table 2 summarizes the allocation of objectives as specified in ITU-T Recommendation I.356 to connection portions with satellite links.

TABLE 2

Allocation of ITU-T Recommendation I.356 objectives to connection portions with satellite links

	SECBR et CER (classes 1, 2 and 3 (%)	CLR (class 1) (%)	CLR (classes 2 and 3) (%)
National	42	35	34.5
IIP(0)	35	25	1
International transit portion	36	30	9
IIP(1)	38	30	11
IIP(2)	42	33	21
IIP(3)	48	42	31

According to ITU-T Recommendation I.356, the abbreviation IIP (x) ($x = 0, 1, 2 \ldots$) is used to indicate a virtual channel (VC) IIP with x intervening transit countries, each providing virtual path (VP) switching or cross-connect functions.

3.2 ATM performance objectives for satellite systems

Numerical values of ATM performance parameters for satellite systems can be derived by applying the allocations given in Table 1 to the performance objectives given in ITU-T Recommendation I.356. As an illustration, the ATM performance objectives for a satellite link used in the international portion that provides Class 1 service and does not contain switching or cross-connect functions (see Note 1) are shown in Table 3.

NOTE 1 – The allocation of performance objectives for geostationary-satellite systems that include ATM switching and processing is for further study.

4 Translation between ATM layer and physical layer parameters

This section provides a mapping between the CLR, CER and SECBR ATM layer parameters and the BER of the satellite link. This section also discusses the other ATM layer parameters nominally: CMR, CTD and CDV and the impact of the satellite system characteristics on these parameters.

TABLE 3

ATM performance objectives for satellites (Class 1 services)

Performance parameters	ITU objective end-to-end	ITU objective satellite
CLR	3×10^{-7}[(1)]	7.5×10^{-8}
CER	4×10^{-6}	1.4×10^{-6}
SECBR	1×10^{-4}	3.5×10^{-5}
CTD	400 ms	320 ms (maximum)
CDV	3 ms	Negligible
CMR	1 per day	1 per 72 hours[(2)]

(1) It is possible that in the future, networks will be able to commit to a CLR = 1×10^{-8} for Class 1. This is for further study.

(2) The allocation for on-board ATM processing equipment is for further study.

4.1 Characteristics of satellite transmission errors

When geostationary orbit (GSO) satellites and fixed earth stations are used, the satellite transmission channel is Gaussian and transmission errors have a bursty nature owing to the scrambling and coding used in the satellite modems. Generally, the errors that emerge from a decoder tend to cluster in bursts according to the decoding algorithms employed. An error burst is defined by two parameters: the average burst length (L) and average number of bit errors per burst (N). Table 4 provides values of L and N for typical satellite error correction codes.

TABLE 4

Values of L and N for commonly used satellite error correcting codes

Error correcting code	Average burst length (L)	Average bit errors per burst (N)
R 3/4 convolutional coding with Viterbi decoding	29	11.5

The above values were obtained from empirical measurements of burst errors. Analytical derivations are possible for complex coding schemes but it is difficult to derive the results, and therefore measurements are needed to confirm the outcome.

4.2 CLR

The header error control (HEC) mechanism of ATM cells can correct single errors and detect almost all multiple-errors in the 5 bytes that contain the header of an ATM cell.

When the HEC detects errors that it cannot correct, the whole cell is discarded and its payload is lost. These discarded cells are the main component of the overall CLR parameter.

In the presence of randomly distributed errors, the single-bit error correcting code of the HEC is capable of correcting many of the errors encountered. In the presence of burst errors and assuming that the burst affects more than one bit of the header, then, no correction is possible since the HEC is capable of correcting only single bit errors. However, some patterns of multiple errors in the header can be misinterpreted by the HEC as a single error, and therefore an improper correction, or miscorrection, of the header may occur thus resulting in the cell not being discarded. In this case, the ATM cell is either eliminated or transmitted to the wrong destination by the next ATM node (misrouted). Although it is lost from an end-to-end connection, it may be counted as a correct cell by an ATM tester which is only adjusted to measure corrupted cells at the output of a satellite link. Misdirected cells will also contribute to the CLR if they are detected.

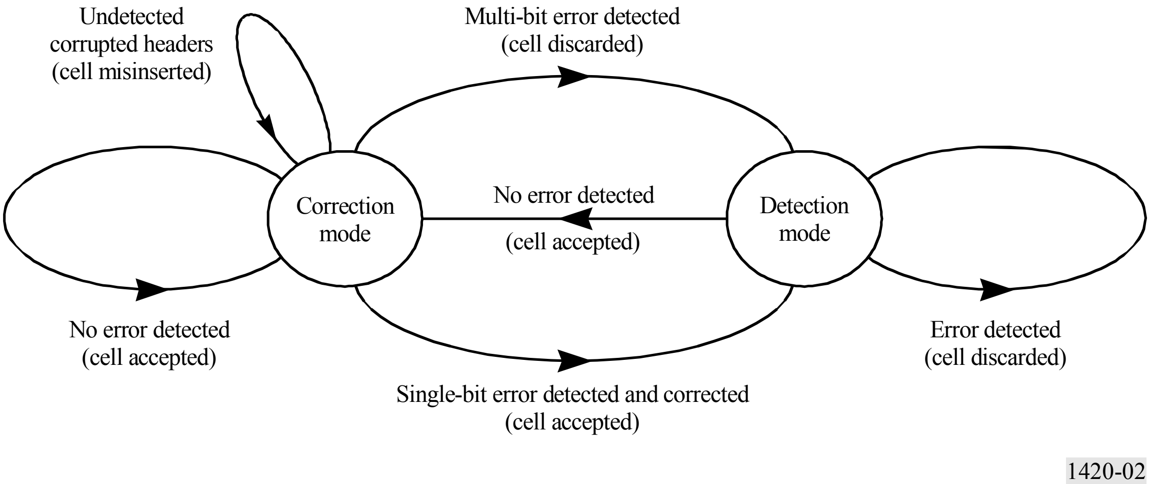
4.2.1 ATM HEC

The last octet in the 5-octet ATM cell header is an HEC byte which is used for header error detection and correction. As shown in Fig. 2, the ATM layer employs an ATM HEC mechanism that can operate in either correction mode or detection mode.

The ATM layer receiver normally operates in the correction mode, whereby all single bit errors are detected and corrected. All double and quadruple bit errors are only detected, and result in the cell being discarded. A small fraction of triple bit errors is mistakenly corrected as single bit errors. When in the correction mode, if a header error is detected (or corrected), the receiver switches to detection mode. In the detection mode, the ATM layer receiver is capable of detecting all single, double, and triple-header bit error patterns. It can also detect most quadruple bit error patterns. In the detection mode, no error correction is performed; all detected header errors result in cell discards. If no header errors are detected, when in the detection mode, the receiver switches to correction mode.

FIGURE 2

ATM cell header modes of operation



4.2.2 Calculation of relationship between CLR and BER

In order to calculate how CLR relates to the BER, the following assumptions have been made about the cell loss outcome in the correction and detection modes:

– In correction mode, all multiple header error events result in cell loss. This assumption ignores the probability that undetected multiple errors, or multiple errors which are mistakenly corrected as single errors, may result in valid values in the header (and consequently a cell misinsertion outcome).

– In detection mode, all single or multiple header error events result in cell loss.

Based on the above assumptions:

$$P[\text{cell loss} \mid \text{correction mode}] \cong 1 - P[\text{no errors}] - P[1 \text{ error}]$$

$$P[\text{cell loss} \mid \text{detection mode}] \cong 1 - P[\text{no errors}]$$

and

$$P[\text{cell loss}] = P[\text{correction mode}] \times P[\text{cell loss} \mid \text{correction mode}] + P[\text{detection mode}] \times P[\text{cell loss} \mid \text{detection mode}]$$

Since the receiver will be in detection mode after every header error correction or detection:

$$P[\text{detection mode}] \cong 1 - P[\text{no errors}]$$

$$P[\text{correction mode}] \cong P[\text{no errors}]$$

Substituting in the above equation gives:

$$CLR = P[\text{cell loss}] \cong 1 - P[\text{no errors}] - P[\text{no errors}] \times P[\text{1 error}]$$

Random error channel

For the random error channel:

$$P[\text{no errors}] = (1 - BER)^{40}$$

$$P[\text{1 error}] = 40 \times BER \times (1 - BER)^{39}$$

Burst error channel

A first order characterization of the burst error channel is by the average burst length, L, and the average number of bits in error per burst, N. The probability of occurrence of a burst in a small interval corresponding to K bits may be approximated by $K \cdot BER/N$. Then, the probability that a burst overlaps a given bit ($K = 1$) may be approximated by:

$$P[\text{burst}] = BER/N$$

Assuming that only a single burst will impact the header, and error bursts do not extend over more than a single ATM header, the probability of no errors in the header is given by:

$$P[\text{no errors}] \cong 1 - (BER/N)\,(L - 1 + 40)$$

The probability of a single bit error in the header may be written as:

$$P[\text{1 error}] = \sum Pe(i)\, P[\text{burst}]$$

where $Pe(i)$ represents the occurrence of a single error in a certain bit i, given that a burst hits that bit; the summation must consider all the cases where the burst overlaps the header.

Figure 3a) illustrates the situation where a single error in the header at position $i \le$ minimum $(L - 1, 39)$ corresponds to the last (errored) bit of the burst. (Note that an error burst begins and ends with a bit in error).

Assuming a uniform and independent distribution of errors within the burst (excluding the first and last bits), for the case in Fig. 3, $Pe(i) = [1 - P(EB)]^i$, where $P(EB)$ is the probability of a bit being in error between the first and last bits of the burst. This is given by:

$$P(EB) = (N - 2)/(L - 2)$$

A symmetric topology may be obtained by considering that the single error at position i is produced by the first (errored) bit in the error burst, as also illustrated in Fig. 3b). Then, the probability of a single error in the header is given by:

$$P[\text{1 error}] \cong (BER/N) \times 2 \times \sum [1 - P(EB)]^i$$

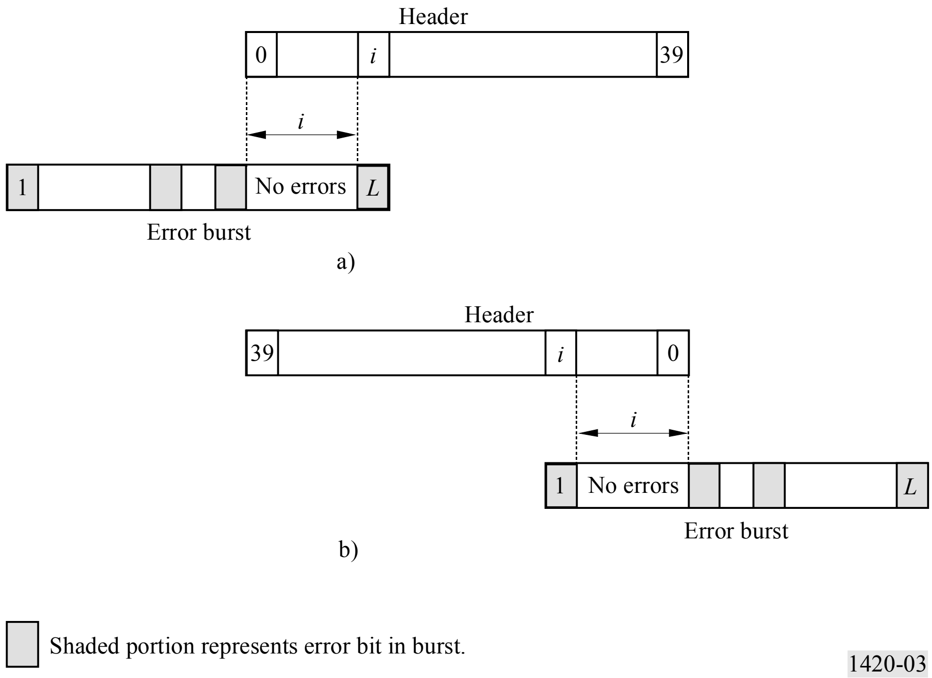
where in the above summation, $i = 0, 1, \ldots,$ minimum $(L - 1, 39)$. For typical values of N and L (N, $L >> 1$):

$$P[\text{1 error}] \cong (BER/N) \times 2/P(EB)$$

Note that, if $L > 40$ and the header is entirely contained in the burst, there may be a possibility of a single error being produced by a bit error not corresponding to the first or last bit in the burst. The probability of this event is much smaller than the one described previously and is neglected. Also note that if $L \le 40$ and $L - 1 < i \le 39$, the burst is entirely inside the header and, in that case, at least two errors will occur.

FIGURE 3

Single error in header produced by the last and first (errored) bits in the burst

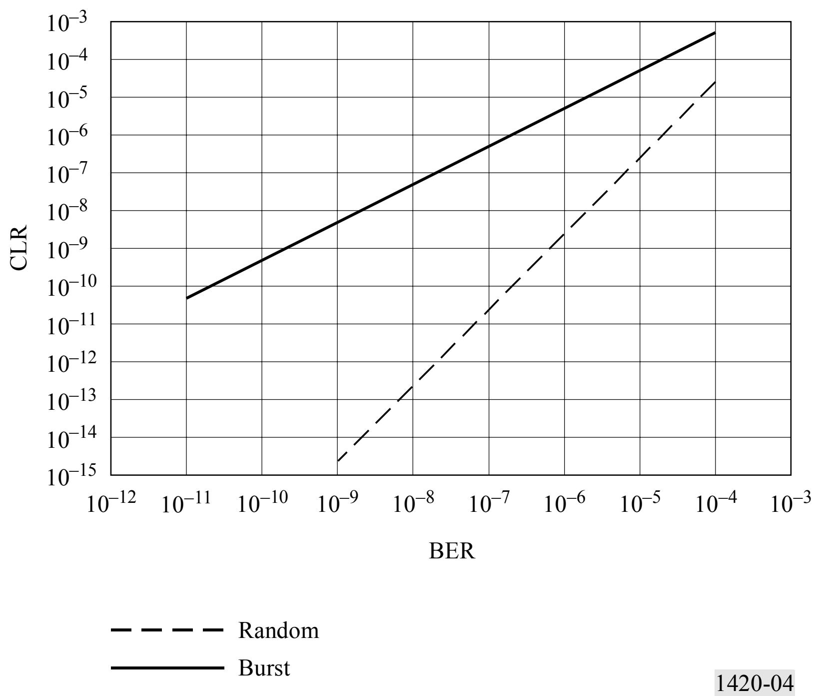


4.2.3 Numerical results

A plot of CLR versus BER is provided in Fig. 4. This plot shows CLR for a random error environment and for a burst error environment where $L = 29$ and $N = 11.5$ (typical of rate 3/4 convolutional encoding with Viterbi decoding).

FIGURE 4

Plot of CLR as a function of BER for a burst error channel with average length, $L = 29$ and average number of bits in error per burst, $N = 11.5$



Some measured results for concatenated codes may be found in § 3 of Annex 2.

4.3 CER

The CER is defined as the ratio of errored cells to the total number of successfully transferred errored and non-errored cells. A successfully transferred cell is defined as a cell that is received with a correct (virtual path identifier/virtual channel identifier) (VPI/VCI) and a valid HEC byte. Therefore, not counting misinserted cells, an errored cell event would occur if:

– the cell header contains detected errors;

– the cell HEC corrected a multiple bit error as a single bit error which resulted in an incorrect VPI/VCI; and

– the cell header is correct while the cell payload contains one or more bit errors.

The probability of the first two events has been ignored in comparison with the probability of a payload error event. Taking into account the receiver header error correction mode and detection mode, the CER can be expressed as:

$$P[\text{cell error}] = P[\text{cell error} \mid \text{correction mode}] \times P[\text{correction mode}] + P[\text{cell error} \mid \text{detection mode}] \times P[\text{detection mode}]$$

where:

$$P[\text{detection mode}] \cong 1 - P[\text{no header errors}]$$

$$P[\text{correction mode}] \cong P[\text{no header errors}]$$

4.3.1 Calculation of relationship between CER and BER

– In order to calculate how CER relates to BER, the same assumptions used to derive the CLR relationship to BER were used: In correction mode, all multiple header error events result in cell loss.

– In detection mode, all single or multiple header error events result in cell loss.

Based on these assumptions, the probability of a cell error in correction and detection modes is:

$$P[\text{cell error} \mid \text{correction mode}] = (1 - P[\text{cell loss} \mid \text{correction mode}]) \times$$

$$P[\text{payload error} \mid \text{correction mode}] \cong P[(\text{no header errors}] + P[1 \text{ header error}]) \times$$

$$P[\text{payload error} \mid \text{correction mode}]$$

$$P[\text{cell error} \mid \text{detection mode}] = (1 - P[\text{cell loss} \mid \text{detection mode}] \times$$

$$P[\text{payload error} \mid \text{detection mode}] \cong (P[\text{no header errors}]) \times$$

$$P[\text{payload error} \mid \text{detection mode}]$$

The CER is:

$$P[\text{cell error}] = P[\text{payload error} \mid \text{correction mode}] \times (P[\text{no header errors}] +$$

$$P[1 \text{ header error}]) \times P[\text{no header errors}] + P[\text{payload error} \mid \text{detection mode}] \times (P[\text{no header errors}]) \times$$

$$(1 - P[\text{no header errors}])$$

Random error channel

For the random error channel:

$$P[\text{no header errors}] = (1 - BER)^{40}$$

$$P[1 \text{ header error}] = 40 \times BER \times (1 - BER)^{39}$$

$$P[\text{payload error} \mid \text{correction mode}] = P[\text{payload error} \mid \text{detection mode}] = 1 - (1 - BER)^{384}$$

Burst error channel

For the burst error channel with average burst length L and average error bits per burst N:

$$P[\text{no header errors}] \cong 1 - (BER/N) \times (L - 1 + 40)$$

$$P[1 \text{ header error}] \cong (BER/N) \times \left[\sum (1 - PEB)^{i} + \sum (1 - PEB)^{39-i}\right]$$

where in the above summation, $PEB = (N - 2)/(L - 2)$ and $i = 0, ...,$ minimum $(L - 1, 40 - 1)$.

When the receiver is in the correction mode, a valid cell is received if there are 0 or 1 header error bits. The probability of a payload error depends on whether a HEC occurred. When there are 0 header error bits, the probability of a payload error is the probability of a burst error within the payload, which is approximated by:

$$PB \cong 384 \times BER/N$$

On the other hand, when there is 1 header error bit which is corrected by HEC, the single error bit will be either the first bit or the last bit of an error burst. When the header error bit is the first bit of an error burst, the probability of a payload error is approximately equal to 1. When the header error bit is the last bit in an error burst, the probability of a payload error is PB. Therefore, in correction mode:

$$P[\text{payload error} \mid \text{correction mode}] \cong P[\text{no header errors}] \times PB + P[\text{1 header error}] \times [0.5 + 0.5PB]$$

In detection mode, a valid cell is received only if no header errors occurred. The probability of a payload error is given by:

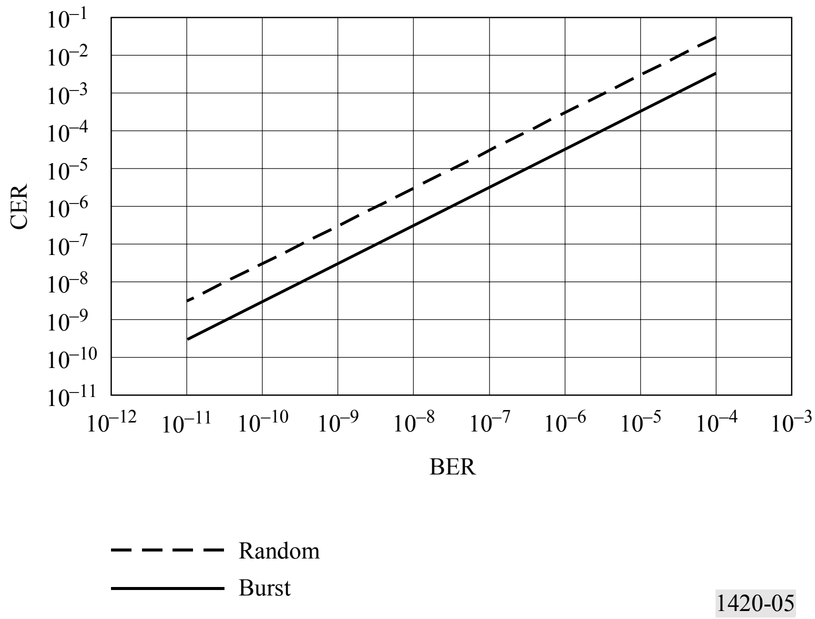
$$P[\text{payload error} \mid \text{detection mode}] \cong P[\text{no header errors}] \times PB$$

4.3.2 Numerical results

A plot of CER versus BER is provided in Fig. 5. This plot shows CER for a random error environment and for a burst error environment where $L = 29$ and $N = 11.5$ (typical of rate 3/4 convolutional encoding with Viterbi decoding).

FIGURE 5

CER vs. BER for a burst error channel with average length, L = 29 and average number of bits in error per burst, N = 11.5



Some measured results for concatenated codes may be found in § 3 of Annex 2.

4.4 SECBR

The SECBR parameter is defined in ITU-T Recommendation I.356 as the ratio of total severely errored cell blocks to total cell blocks in a population of interest. A severely errored cell block outcome occurs when more than M errored cells, lost cells, or misinserted cell outcomes are observed in a received cell block. A cell block is a sequence of N cells transmitted consecutively on a given connection. The values of M and N are rate dependent and are given in Table 1 of ITU-T Recommendation I.356.

4.5 CMR

Certain patterns of multiple errors in the header node may be recognized by the HEC as single errors and hence the affected cell can be miscorrected instead of being discarded. In this case, the next ATM node may either drop the cell or send it to the wrong destination (misrouted). Within ITU-T Recommendation I.356, the parameter that accounts for the total number of misinserted cells observed during a specified time interval is the CMR.

4.6 CTD

The overall CTD or latency within a satellite connection results from various sources. The main source of delay is free-space propagation. The next contributor is the delay due to coding and decoding done at the satellite channels (modems). Generally, coding delays vary depending on the type of coding and the transmission bit rate. Finally, another source of delay may be the satellite specific ATM equipment located at the earth station or on board the spacecraft as they may introduce queuing, switching and/or routing delays.

4.7 CDV

The CDV or jitter that may arise in a satellite link depends on several aspects. First, CDV depends on the traffic load structure or the number and proportion of virtual path (VP) and virtual channels (VC) that may be used within the ATM channel. CDV also depends on the switch buffering capacity and mechanism. Next, CDV will increase with the number of ATM nodes within a connection (this may be a critical component of satellites that use OBP and ISL). Finally, CDV will depend on the amount of internal switch operations (queueing, switching, routing) resulting from satellite specific ATM equipment. The use of multiple access schemes may have an impact on CDV.

5 Relationship between ITU-T Recommendations G.826 and I.356 performance parameters

While the ATM layer performance parameters and objectives are specified by ITU-T Recommendation I.356, the physical layer performance parameters and objectives for connections that will carry ATM traffic are given in ITU-T Recommendation G.826 – Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate. The ITU-T Recommendation G.826 performance parameters are errored seconds ratio (ESR), severely errored seconds ratio (SESR), and background block error ratio (BBER). Furthermore, the performance objectives of ITU-T Recommendation G.826 are rate dependent. A satellite link within a ITU-T Recommendation G.826 connection is allocated 35% of the overall end-to-end objectives.

Studies and measurements on channels affected by error bursts have shown that a satellite system designed to just meet ITU-T Recommendation G.826 may not meet the ITU-T Recommendation I.356 objectives for ATM Class 1 services. Thus, it is essential that satellite links that will carry ATM traffic be designed to meet ITU-T Recommendation I.356 requirements with additional margin to ensure compliance with ATM QoS requirements.

ANNEX 2

(Informative)

Simulated and measured performance of ATM over satellites

1 Introduction

This Annex describes the results of simulations, laboratory measurements, and field trials of ATM transmission over satellite systems.

2 ATM performance parameters in satellite systems

The performance of the ATM layer over satellite links depends on the BER and the bit error burst statistics. Bit errors due to thermal noise in satellite communications are assumed to be randomly distributed. However, if FEC techniques are used to improve the BER then errors generally occur in bursts when the FEC error correction mechanism fails. An undesirable consequence of error bursts on the transport of ATM traffic is that they can result, with significant probability, in two or more bit errors in the ATM cell headers. This causes the ATM cells to be discarded by the HEC mechanism. Analytical results and field trials have shown that the CLR originated by the transmission link tends to be linearly proportional to the BER. For this reason, the CLR is much higher than that achieved in the presence of random errors where the CLR tends to be proportional to the square of the BER.

The error bursts introduced by satellite modems, due to error correction failures, have different lengths and error occurrences according to the different FEC schemes, scrambling methods and interleaving techniques employed. Thus, formulating general rules for the relationships between the physical layer performance and the ATM layer performance is impractical. Relationships that are specific to particular schemes may however be derived either by measurements and/or simulation.

2 CER

2.1 CER performance for concatenated codes

2.1.1 Concatenated FEC codes

The various candidates for concatenated codes include Reed-Solomon (RS) outer codes and conventional trellis codes and rotationally invariant (RI) codes for the inner codes. QPSK modulation with coherent detection and conventional trellis coding has been assumed as the basic transmission system to which FEC has been applied.

2.1.1.1 RS codes

The RS block code is among the most efficient class of codes that can be implemented using state-of-the-art hardware and software technology. Concatenating RS outer coding schemes with convolutional inner-codes achieves higher quality, cost-effective satellite transmission links. Block codes, as their name implies, process data in blocks. Each block is processed as a single unit by both the encoder and the decoder. A particular RS code is described as an (n, k) code. The code rate (efficiency) of a code is given by $R = k/n$. Codes with high code rates are generally desirable because they efficiently use the available channel for information transmission. RS codes typically have rates greater than 80%. RS codes are typically large block length, high code rate codes.

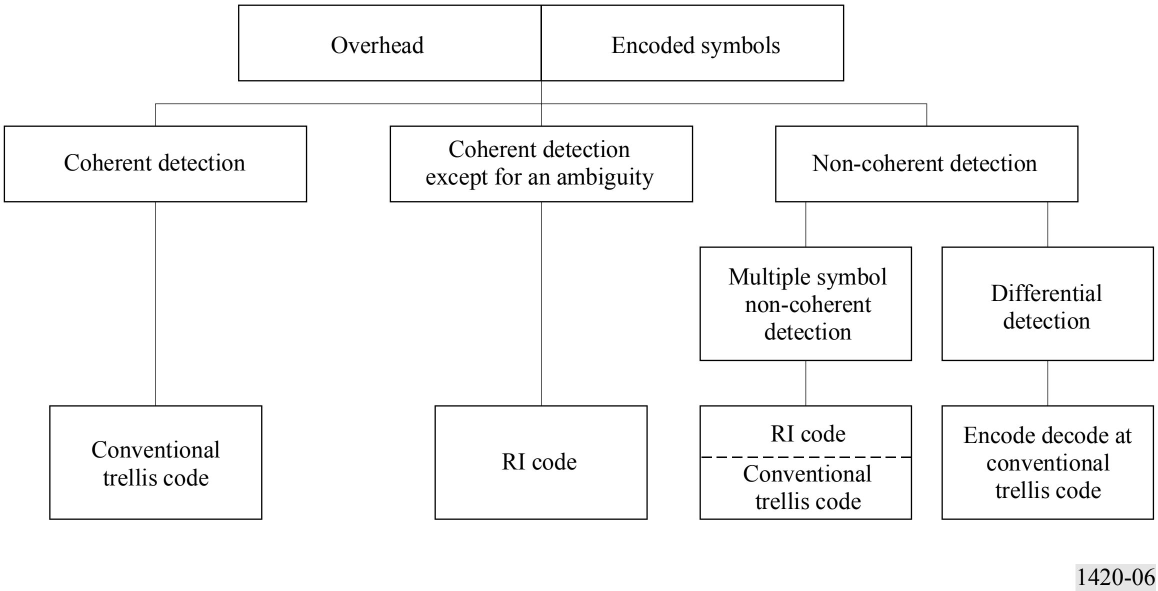
RS codes work well when the message block length and the code block length are matched. For instance, in a multipoint configuration with a TDMA scheme, the code block length can be adapted to an integer number of ATM cells, so as to obtain flexibility in terms of traffic allocation to different earth stations.

2.1.1.2 Inner codes

Figure 6 shows the various options for the inner codes.

FIGURE 6

Synchronization and coding candidates for inner codes

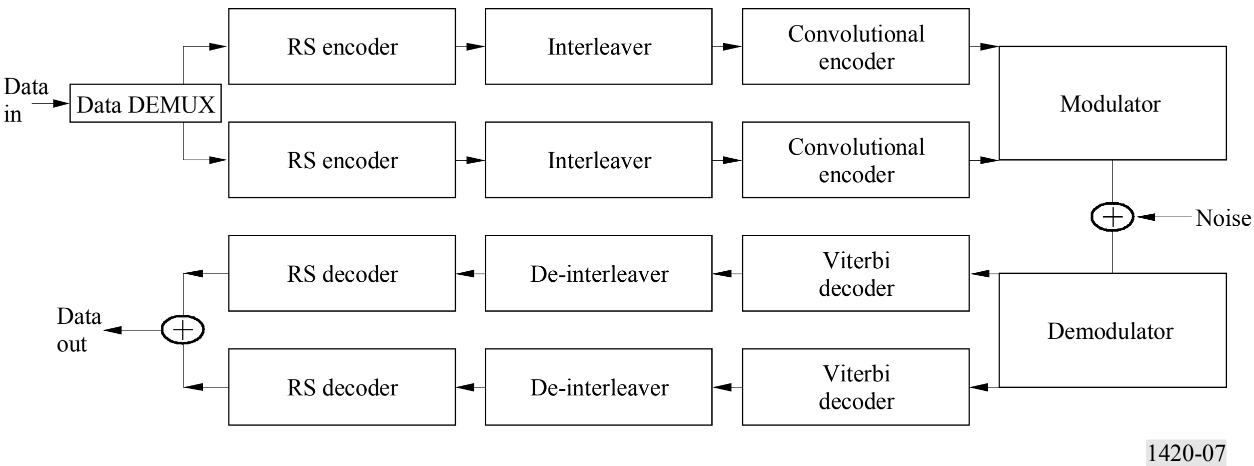


Interleaving options are also considered between the outer and inner codes. For the outer RS codes, the block length is considered in ATM cell quanta. Specifically, 53 symbols and 106 symbols data sequences.

Analysis indicates that implementation of nearly perfect interleaving requires enormous buffer size, especially for multiple access FDMA/TDMA satellite services. Therefore, the performance with no interleaving between the outer and inner codes has also been studied.

FIGURE 7

Block diagram of an on-board ATM switching satellite communications system

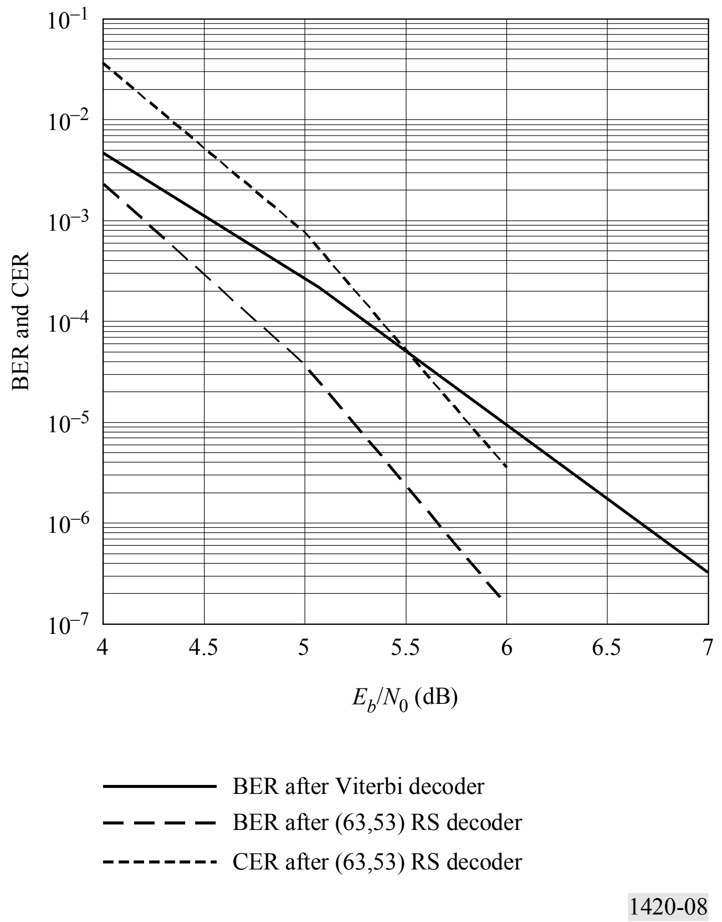


2.2 Simulation results with respect to satellite E_b/N_0

The BER and CER performance simulation results as a function of E_b/N_0, for a specific case of rate 3/4 punctured convolutional inner code and (63,53) RS outer code are plotted in Fig. 8. This Figure shows that for an E_b/N_0 of 6 dB, the CER is about 3×10^{-6} and BER is about 1×10^{-7}.

FIGURE 8

BER and CER performance for inner rate 3/4 FEC with concatenated RS (63,53) outer coding



The outer code block size was varied from one ATM cell to two ATM cells. The BER and CER results for RS (126,106) outer code with no interleaving between the outer and inner code (rate 3/4 punctured convolutional) are shown in Fig. 9.

Note that there is a significant performance improvement as the block length is increased from one ATM cell to two ATM cells (with the same code rate). For an E_b/N_0 of 6 dB, the CER decrease from 3×10^{-6} to about 3×10^{-8}. Therefore, where possible, using multiple cells to perform outer coding, improves performance with minimal increase in implementation complexity.

2.3 CLR

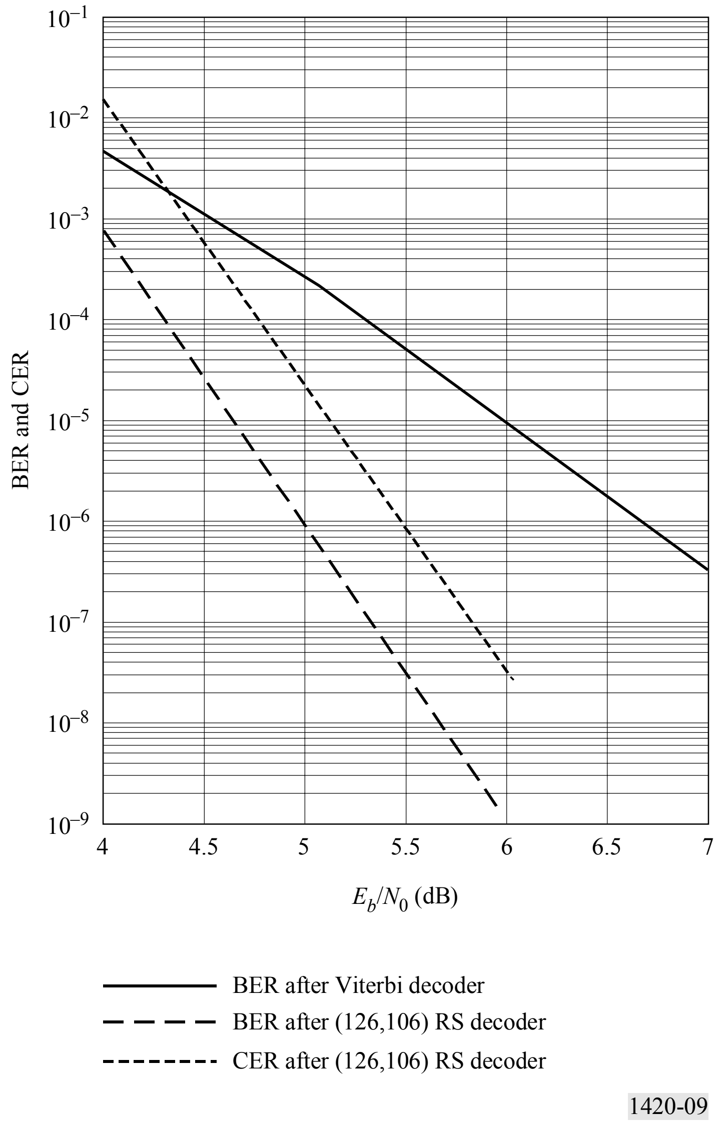
Measurements of CLR versus BER are described in § 3.1, 3.2 and 3.3. Information on the impact of on-board processing and ground segment cell processing systems is for further study.

2.4 SECBR

Measurements of SECBR versus BER are described in § 3.1.

FIGURE 9

BER and CER performance for inner rate 3/4 FEC with concatenated code RS (126,106) outer coding



2.5 CTD

The specific characteristics and the impact of on-board cell processing systems as well as the impact of ground segment cell processing equipment on CTD are for further study.

2.6 CDV

The specific characteristics and the impact on CDV of on-board cell processing systems, ground segment cell processing equipment and TDMA framing are for further study.

2.7 CMR

The specific characteristics and the impact of on-board cell processing systems as well as the impact of ground segment cell processing equipment on CMR are for further study.

3 Measured results of physical versus ATM layer performance

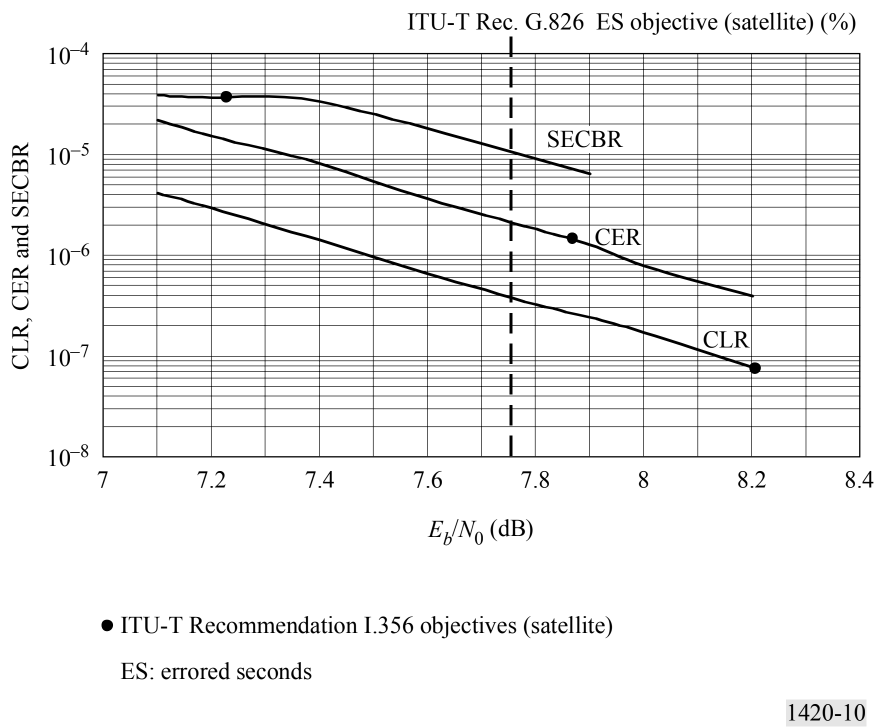
This section summarizes measured results. These results provide verification of the calculated performance of ATM over satellite links and its relation to the performance of the physical layer. Subsection 3.1 contains measured results of ATM parameters versus the E_b/N_0 of a modem. Subsection 3.2 contains field test results of intermediate data rate (IDR) performance at 45 Mbit/s. Subsection 3.3 contains test results of 120 Mbit/s TDMA performance (with and without R 7/8 BCH coding) and 34.368 Mbit/s IDR performance. Subsection 3.4 contains test results for IDR performance at 2.048 Mbit/s (with and without RS coding).

3.1 Measured results at 45 Mbit/s

Laboratory measurements (by AT&T) of 45 Mbit/s IDR satellite modems demonstrate the relationship between the modem's E_b/N_0 versus the ATM layer performance parameters: CLR, CER, and SECBR. The test set-up consisted of two IDR satellite modems, a noise injector, and an ATM test set. The test set measured the CLR, CER and SECBR according to the definitions of ITU-T Recommendation I.356. These results are shown in Fig. 10.

FIGURE 10

Measurement results of CLR, CER and SECBR vs. E_b/N_0 for a 45 Mbit/s IDR modem



The Figure includes the ITU-T Recommendation I.356 objectives for CLR, CER and SECBR for a satellite carrying Class 1 ATM services. These results provide the relationships between the modem operating point and the ATM layer performance for a widely used modem that employs rate 3/4 convolutional encoding and Viterbi decoding. These results also show that a modem that just meets all ITU-T Recommendation G.826 parameters does not meet the Class 1 ATM performance objectives allocated in ITU-T Recommendation I.356.

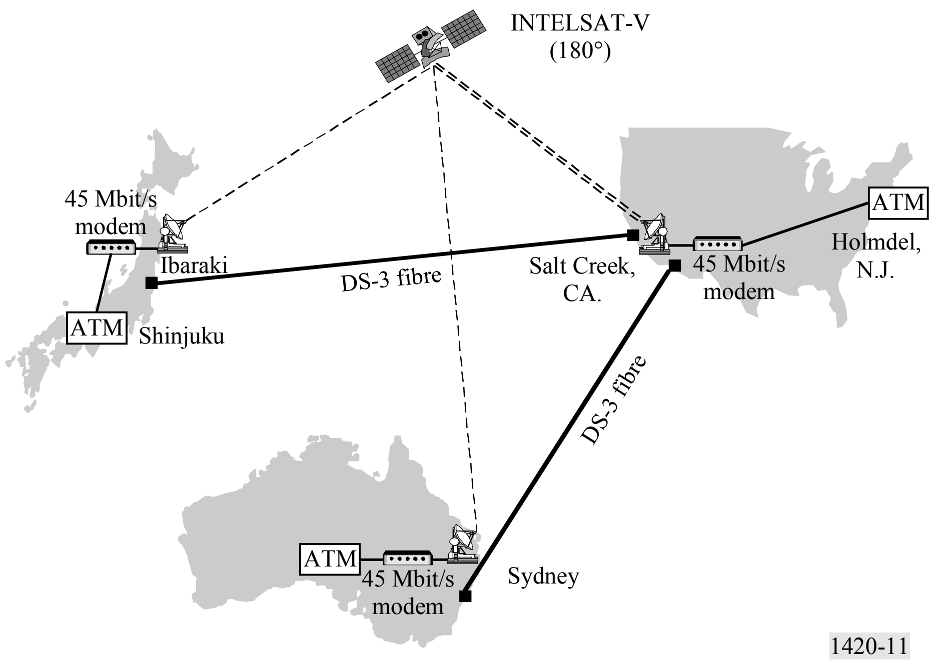
3.2 Test between AT&T and KDD

This subsection presents the results of a field trial involving AT&T (United States of America), KDD (Japan), and Telstra (Australia). The trial involved a mix of fibre and satellite connections. The objective of the tests was to characterize the long-term performance of DS-3 (45 Mbit/s) facilities by measuring various physical layer and ATM layer parameters. The field tests were conducted from 24 April through 5 December 1995.

Figure 11 illustrates the field trial architecture. One full 72 MHz C-band transponder, and two half transponders, on the INTELSAT 511 spacecraft located at 180° East longitude and operating in an inclined orbit of about 3° were employed.

FIGURE 11

AT&T-KDD-Telstra ATM trial - test architecture



The satellite portion of the trial employed a pair of DS-3 IDR carriers between the Salt Creek and Ibaraki earth stations and another pair of DS-3 links between Salt Creek and the Sydney earth station, located in Australia. Each earth station was connected to a terrestrial fibre facility carrying the DS-3 information streams to and from the three test-beds, located in Holmdel (United States of America), Tokyo (Japan) and Sydney (Australia). All satellite links were properly equalized and lined-up to achieve a clear-sky BER value of 1×10^{-10}, according to performance specifications for IDR carriers (without RS codec) operating on INTELSAT-VII satellites.

The results presented pertain to the AT&T-KDD link only since this link was tested for a longer period of time, and it exhibited greater rain impairments than the AT&T-Telstra link. This greater level of rain impairments was considered more representative of other links in the Pacific ocean region. The physical layer tests between the Salt Creek (AT&T) and Ibaraki (KDD) earth stations were conducted for a period greater than 30 days. Once those tests were completed, the ATM cell transfer performance was measured by ATM test instruments installed at the earth stations. After excluding abnormal events, the test data was processed to obtain results in terms of Recommendation ITU-R S.1062 and ITU-T Recommendation G.826. The ATM layer data was collected by ATM test sets located at the earth stations. Again, after excluding abnormal events, the test data was analysed to compute the values of various parameters including those defined in ITU-T Recommendation I.356.

Table 5 shows the main performance parameters, the performance objectives used for evaluating the physical and ATM layer performance, and the results obtained with the IDR links. The performance objectives were adjusted according to the allocation given to GSO satellites that are used in the international portion of an end-to-end connection.

TABLE 5

Physical and ATM layer performance test results of 45 Mbit/s IDR links between AT&T and KDD

	Physical layer April-June, 1995					ATM layer August-December, 1995	
Parameters	ES (ITU-T Rec. G.826) (%)	SES (ITU-T Rec. G.826) (%)	BBER (ITU-T Rec. G.826)	Average BER	Threshold BER (0.2% of time) (Rec. ITU-R S.1062)	CLR ITU-T Rec. I.356 (Class 1)	CER ITU-T Rec. I.356 (Class 1)
ITU Objectives	2.62	0.07	7×10^{-5}	–	4.0×10^{-6}	7.5×10^{-8}	1.4×10^{-6}
KDD to AT&T	0.014	0.008	1.5×10^{-8}	4.8×10^{-6}	4.5×10^{-9}	1.9×10^{-6} (1)	5.4×10^{-6} (1)
AT&T to KDD	0.0056	0.0027	7.6×10^{-9}	2.6×10^{-6}	3.0×10^{-9}	3.9×10^{-6} (1)	8.8×10^{-6} (1)

SES: severely errored seconds

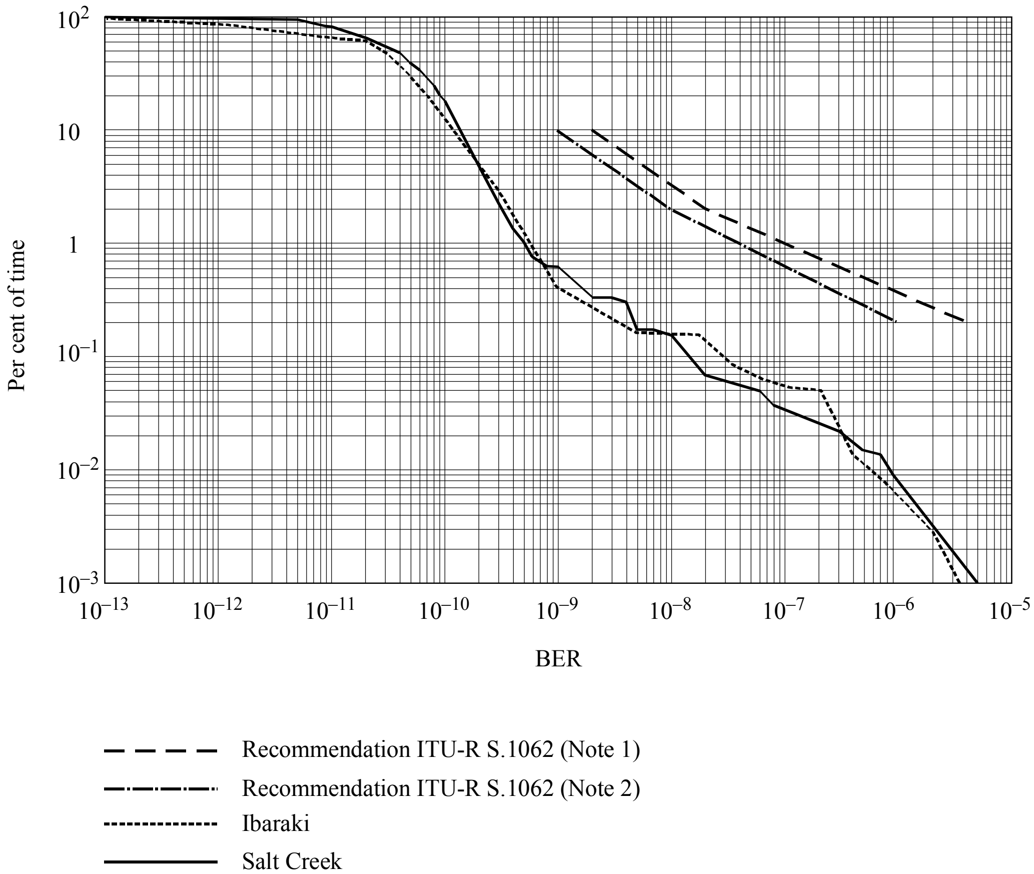
(1) These are the average values and not the upper bounds specified by ITU-T Recommendation I.356.

The results show that the performance in both directions met the ITU-T Recommendation G.826 objectives by a margin of 1 to 2 orders of magnitude.

Figure 12 shows the cumulative statistical distribution of the bit error events recorded for a period greater than 30 days. Also, Fig. 12 shows, as reference, the performance masks of Recommendation ITU-R S.1062. The Note 1 mask represents the mask that just meets ITU-T Recommendation G.826 objectives. Note that the measured BER curves for both links, AT&T to KDD and KDD to AT&T, are very similar. Furthermore, the measured BER curves are about 1 to 2 orders of magnitude better than the Recommendation ITU-R S.1062 masks.

FIGURE 12

Per cent of time vs. BER for DS-3 IDR link between AT&T and KDD



1420-12

The ATM layer tests were conducted after the physical layer tests were completed. The ATM layer objectives listed in Table 5 correspond to the new allocation given in ITU-T Recommendation I.356 to GSO satellite systems used in the international portion. Notice that the measured CLR and CER are average values obtained during the total measurement interval as opposed to the upper-bound (worst-case numbers) specified in ITU-T Recommendation I.356. The IDR link averages were better than the ITU-T Recommendation I.356 upper-bound values, but only by a small margin.

The results presented should be representative of the performance that may be achieved on many 14/11 GHz band DS-3 IDR links throughout the world. They show that a carefully conditioned and operated IDR link can comfortably meet Recommendation ITU-R S.1062 and ITU-T Recommendation G.826 objectives. However, the results also show that this level of performance may not be sufficient for ATM traffic since the upper bound objectives of Class 1 services defined in ITU-T Recommendation I.356 will require BER thresholds near 1×10^{-9}. Consequently, the AT&T-KDD results may have barely met the ITU-T Recommendation I.356 objectives. Link enhancement techniques, such as the RS outer coding and interleaving, can provide improved performance that may meet the ATM requirements (see § 6).

3.3 ATM tests by EUTELSAT

EUTELSAT conducted ATM and physical layer measurements on TDMA and IDR links in the EUTELSAT system to characterize the relationship between the ITU-T Recommendations G.826 and I.356 parameters as a function of the link performance. The results show the link BER as a function of the E_b/N_0 performance of the satellite modem. The results are plotted in Figs. 13 to 16 for a 2.048 Mbit/s interface to the 120 Mbit/s TDMA system, and in Figs. 17 to 20 for a 34.468 Mbit/s IDR link.

Figure 13 shows ITU-T Recommendation G.826 performance parameters versus E_b/N_0 for the TDMA system. The ITU-T Recommendation G.826 objectives are indicated. Two sets of results are illustrated, one set is for rate 7/8 BCH coded links, and the other set is for links with no FEC coding.

FIGURE 13

ITU-T Recommendation G.826 (physical layer) performance parameters and objectives vs. E_b/N_0 at the demodulator input for a 2.048 Mbit/s interface of the EUTELSAT 120 Mbit/s TDMA system

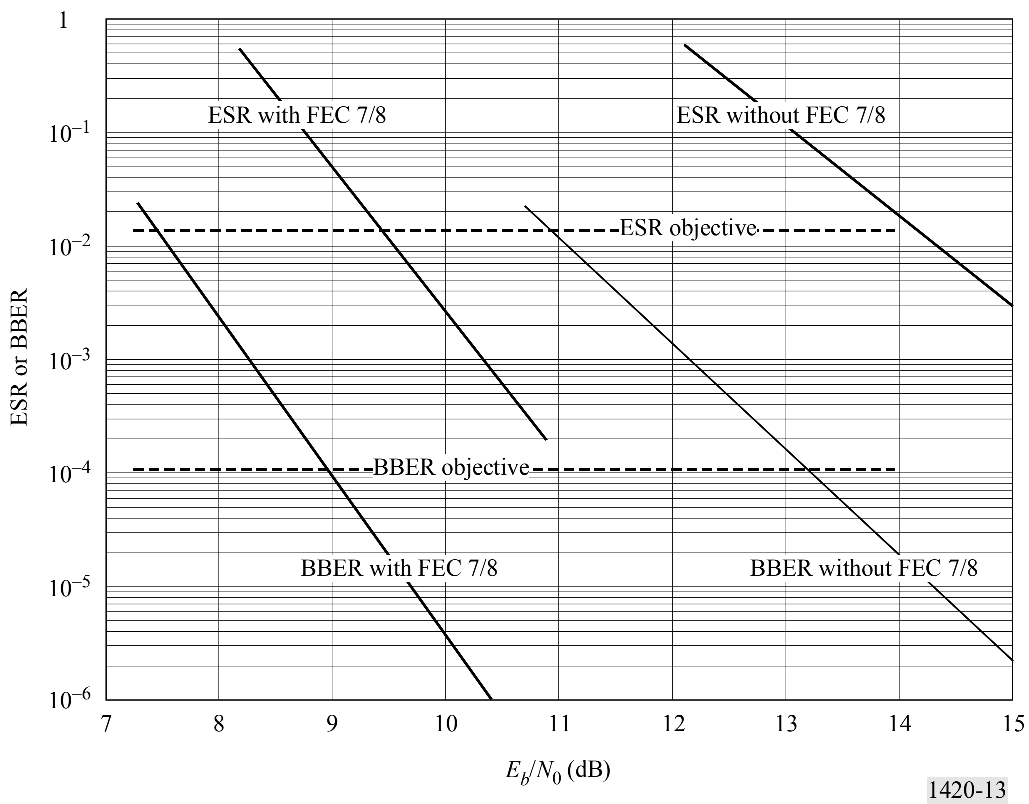
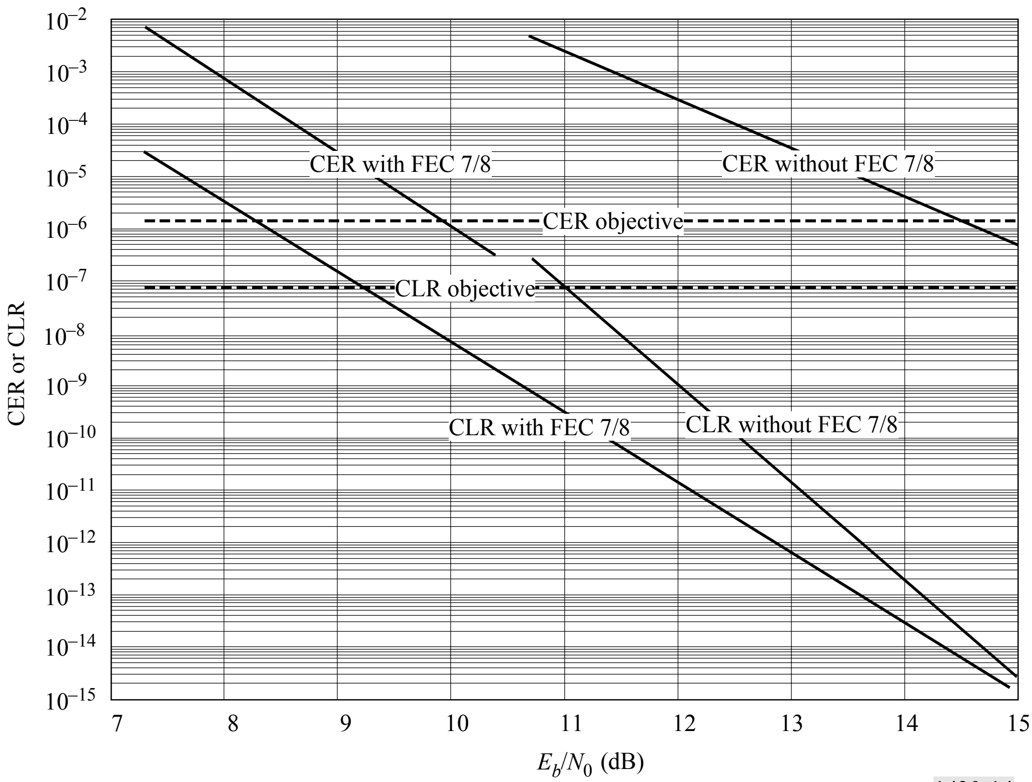


Figure 14 shows ITU-T Recommendation I.356 performance parameters versus E_b/N_0 for the TDMA system. The ITU-T Recommendation I.356 objectives are marked. As in Fig. 13, two sets of results are illustrated. One set is for rate 7/8 BCH coded links, and the other set is for links with no FEC coding.

FIGURE 14

ITU-T Recommendation I.356 (ATM layer) performance parameters and objectives vs. E_b/N_0 at the demodulator input for a 2.048 Mbit/s interface of the EUTELSAT 120 Mbit/s TDMA system



1420-14

Figure 15 shows ITU-T Recommendation G.826 performance parameters versus BER for the TDMA system. ITU-T Recommendation G.826 objectives are marked.

FIGURE 15

ITU-T Recommendation G.826 (physical layer) performance parameters and objectives vs. BER at the demodulator output for a 2.048 Mbit/s interface of the EUTELSAT 120 Mbit/s TDMA system

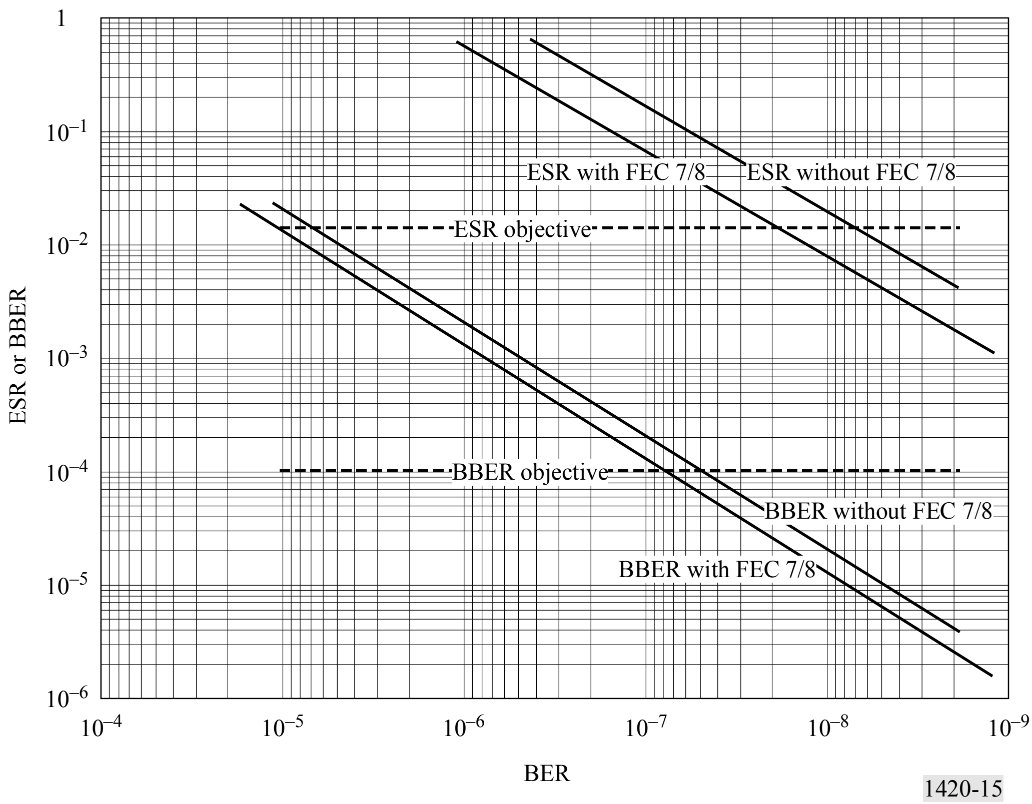
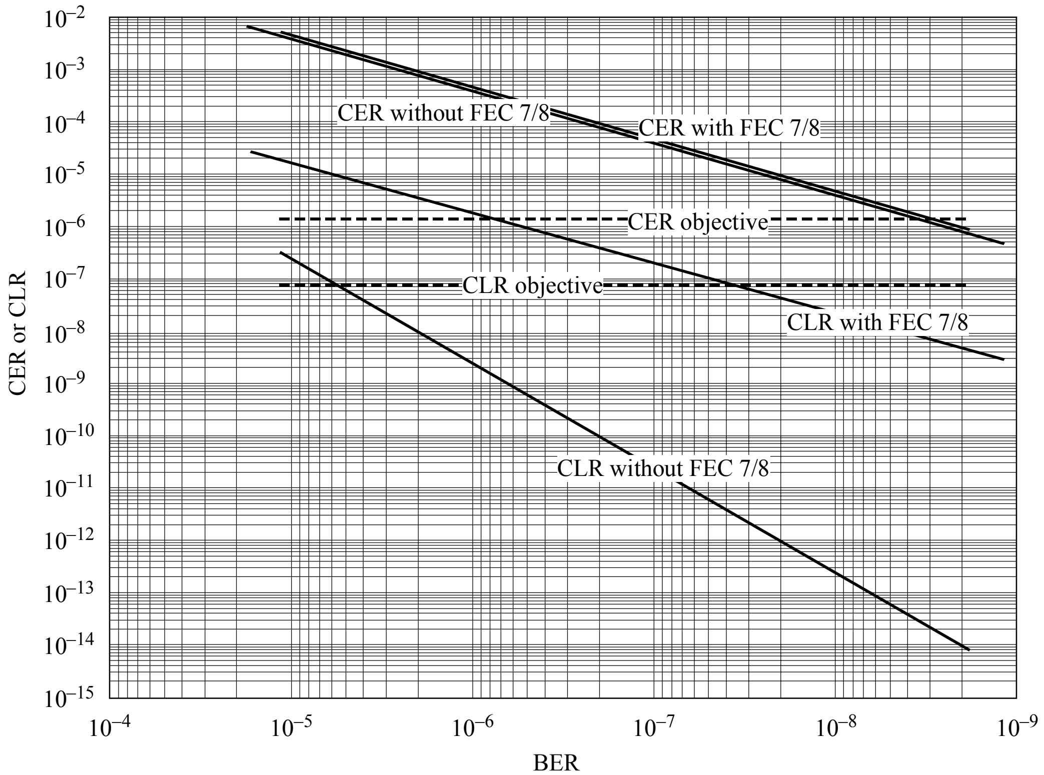


Figure 16 shows ITU-T Recommendation I.356 performance parameters versus BER for the TDMA system. ITU-T Recommendation I.356 objectives are marked.

FIGURE 16

ITU-T Recommendation I.356 (ATM layer) performance parameters and objectives vs. BER at the demodulator output for a 2.048 Mbit/s interface of the EUTELSAT 120 Mbit/s TDMA system

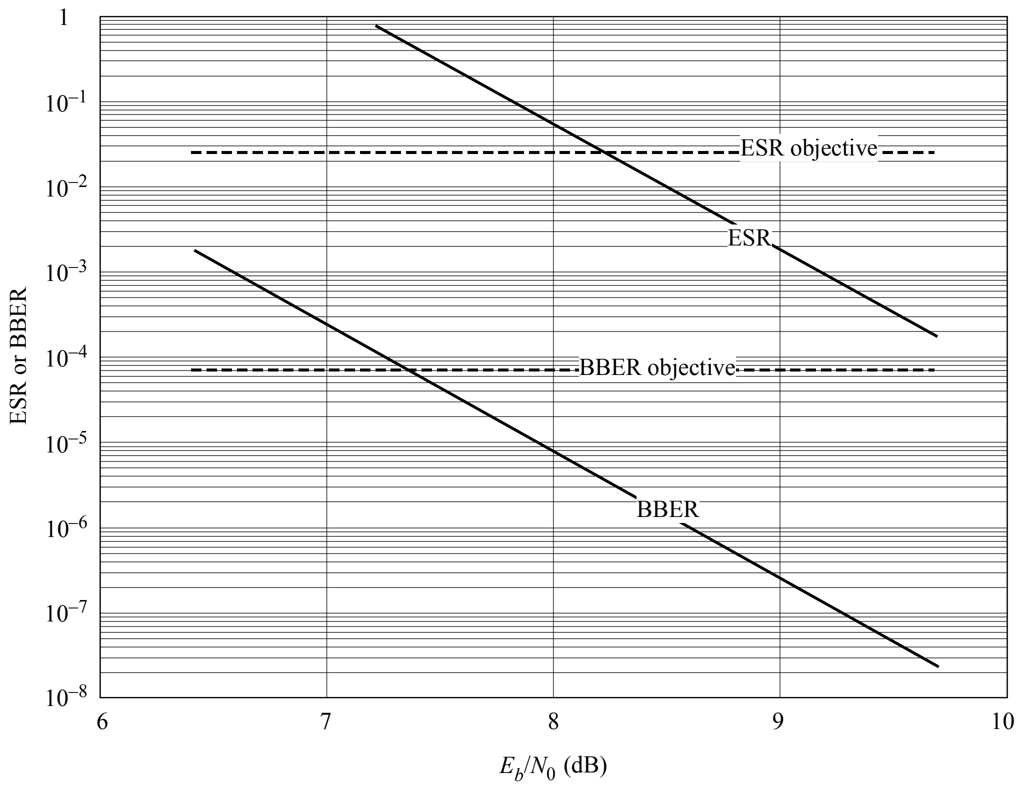


1420-16

Figure 17 shows ITU-T Recommendation G.826 performance parameters versus E_b/N_0 for IDR (with rate 3/4 convolutional coding and Viterbi decoding). ITU-T Recommendation G.826 objectives are marked.

FIGURE 17

ITU-T Recommendation G.826 (physical layer) performance parameters and objectives vs. E_b/N_0 at the demodulator input for an IDR modem working at an interface rate of 34.368 Mbit/s

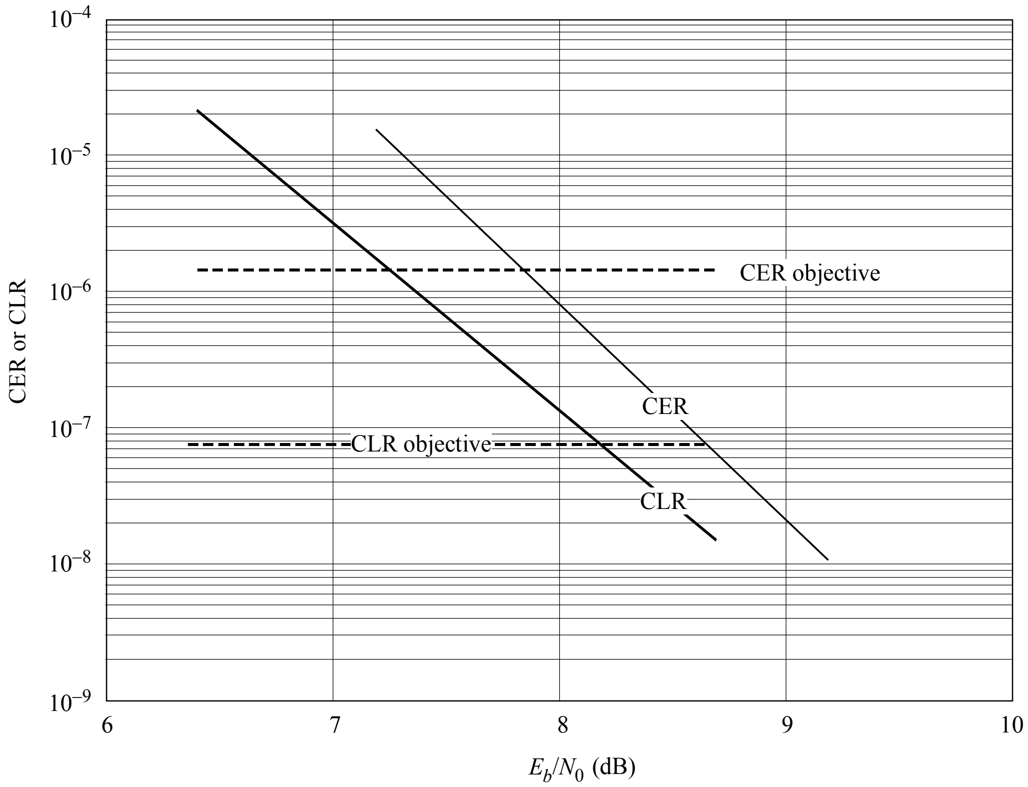


1420-17

Figure 18 shows ITU-T Recommendation I.356 performance parameters versus E_b/N_0 for IDR (with rate 3/4 convolutional coding and Viterbi decoding). ITU-T Recommendation I.356 objectives are marked.

FIGURE 18

ITU-T Recommendation I.356 (ATM layer) performance parameters and objectives vs. E_b/N_0 at the demodulator input for an IDR modem working at an interface rate of 34.368 Mbit/s



1420-18

Figure 19 shows ITU-T Recommendation G.826 performance parameters versus BER for IDR (with rate 3/4 convolutional coding and Viterbi decoding). ITU-T Recommendation G.826 objectives are marked.

FIGURE 19

ITU-T Recommendation G.826 (physical layer) performance parameters and objectives vs. BER at the demodulator output for an IDR modem working at an interface rate of 34.368 Mbit/s

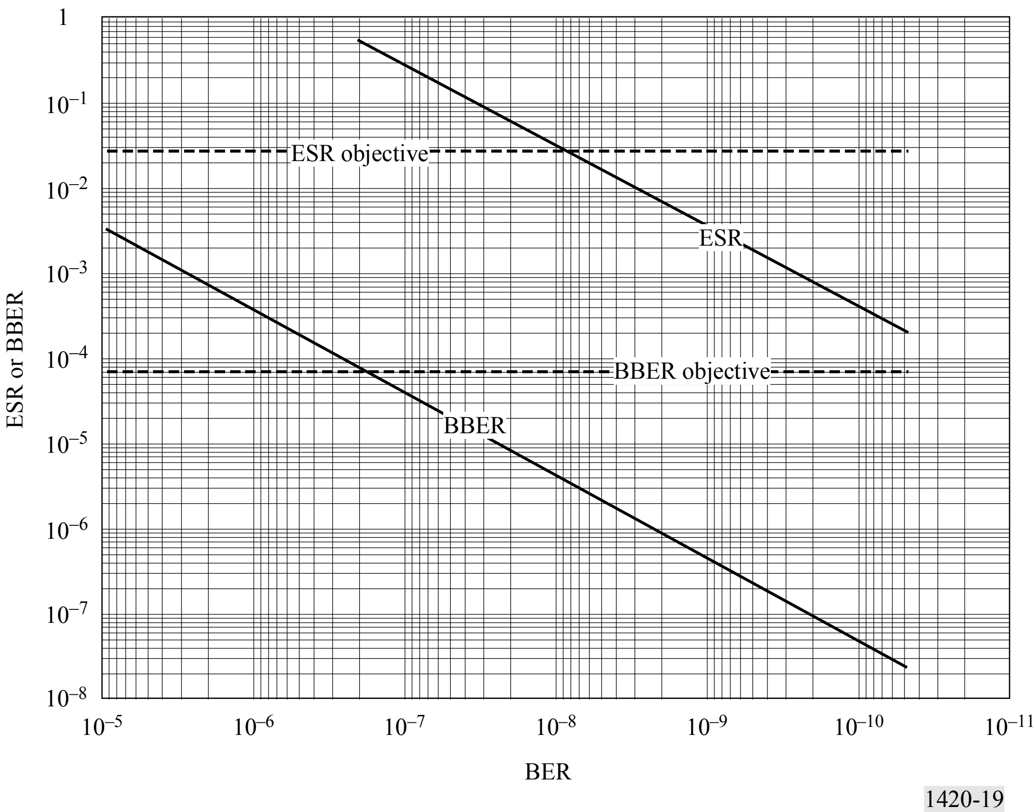
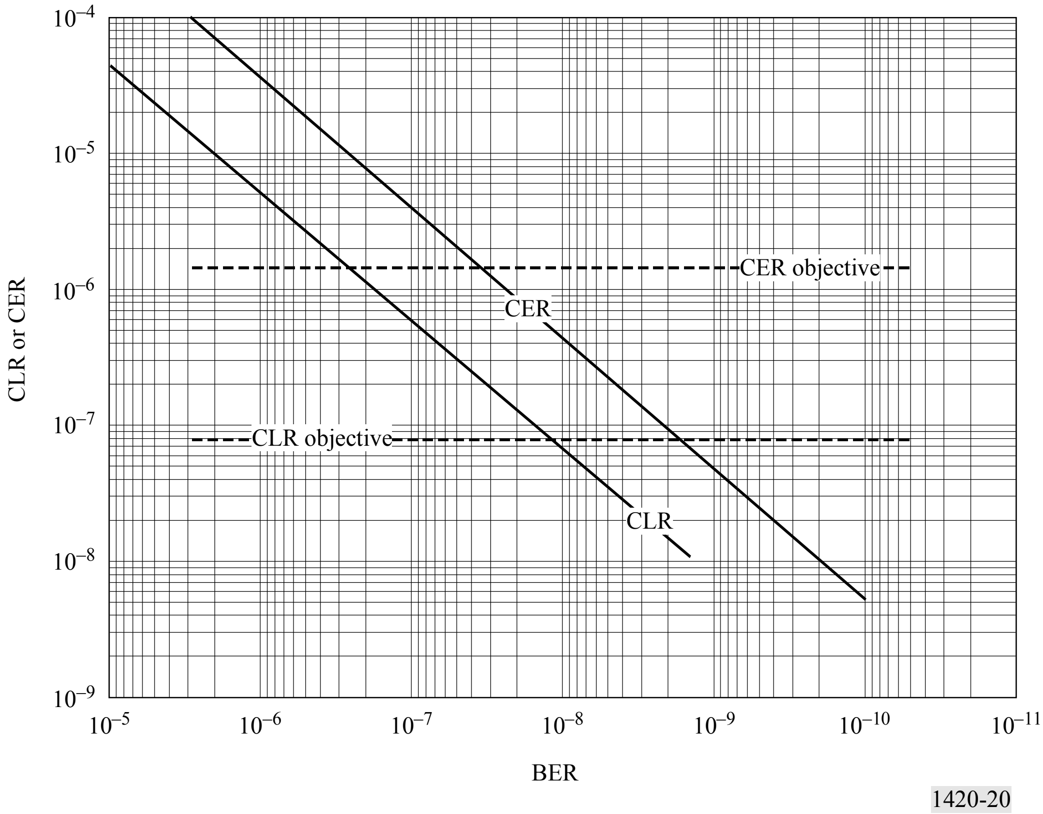


Figure 20 shows ITU-T Recommendation I.356 performance parameters versus BER for IDR (with rate 3/4 convolutional coding and Viterbi decoding). ITU-T Recommendation I.356 objectives are marked.

FIGURE 20

ITU-T Recommendation I.356 (ATM layer) performance parameters and objectives vs. BER at the demodulator output for an IDR modem working at an interface rate of 34.368 Mbit/s



3.4 ATM tests by INTELSAT

Measurements to investigate the relationship between CLR and CER as a function of BER were conducted by COMSAT. Figures 21 (CLR versus BER) and 22 (CER versus BER) demonstrate these relationships at the E1 rate, with and without RS coding. These Figures assist in the translation of the CLR and CER requirements in ITU-T Recommendation I.356 to the BER requirements used in the design of satellite links.

4 ATM application requirements and physical layer performance

This section presents application performance results over satellite ATM from various experiments and trials.

The cell transport mechanism of ATM is only one layer of the 3-layer ATM transmission system. Above the cell transport layer is the ATM adaptation layer (AAL). There are four types of AAL defined at this time, AAL-1, AAL-2, AAL-3/4, and AAL-5. AAL-5 provides a transparent path between ATM switches whereas AAL-1 provides buffering to reduce CDV and AAL-3/4 includes error detection and correction. Above the AAL are two other layers, the segmentation and reassembly service specific convergence sublayer and the convergent sublayer that provides a mapping between the AAL and the application. An AAL-5 connection has been employed for all the results reported or derived in this Recommendation.

FIGURE 21

ATM CLR versus BER for an IDR channel at E1 rate

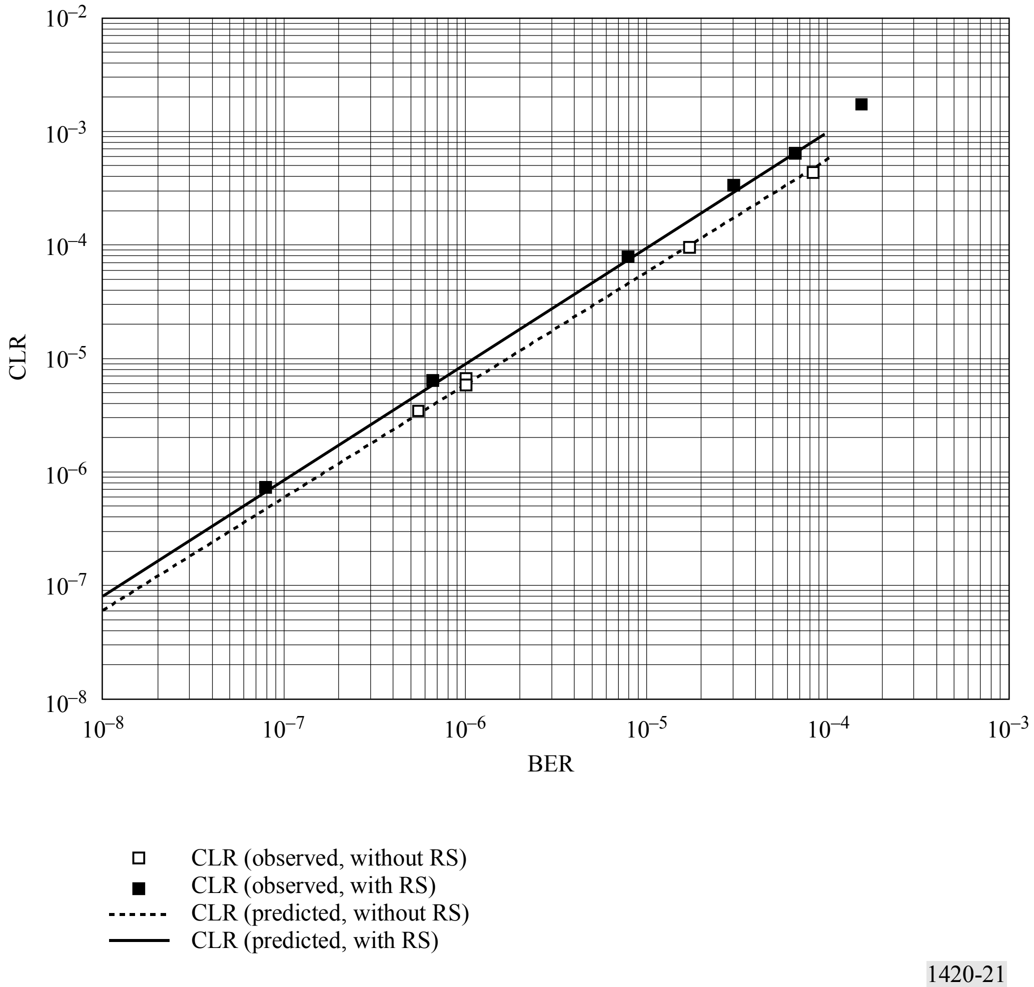
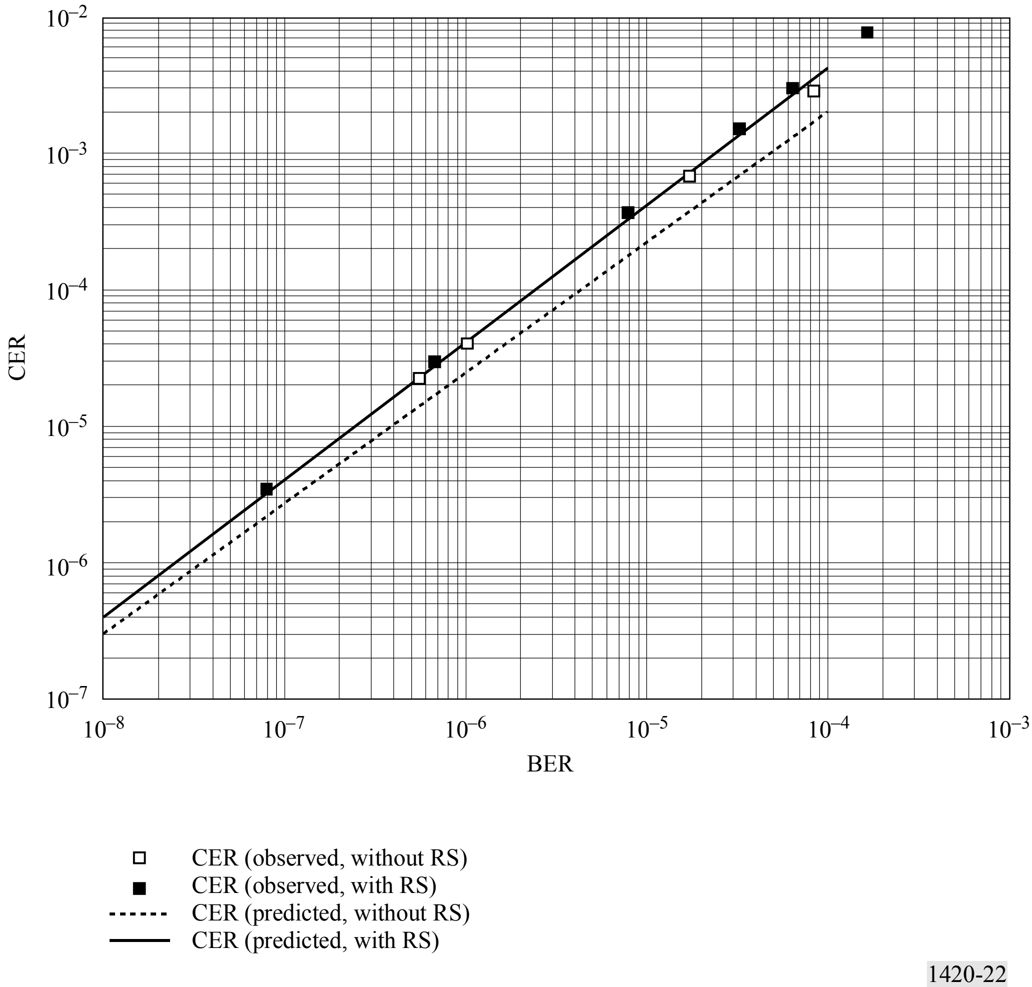


FIGURE 22

ATM CER versus BER for an IDR channel at E1 rate



4.1 Voice and voiceband data applications

The error performance required to support speech and voiceband data is not as demanding as that needed for compressed video but high CLR and high end-to-end delay will impact on the quality of these services. New compression techniques for speech allow many more speech samples to be carried in each ATM cell. Thus the loss of even a single cell will impact many speech channels or insert a long break in a single channel.

4.2 Video applications

4.2.1 MPEG-2 audio/video compression and transport over ATM

MPEG-2 signal transmission over ATM refers to the transport of combined compressed video and audio signals, program element streams (PES) and the associated multiplexing, and the transport stream (TS). Video can be compressed up to approximately 90:1 with MPEG-2. Table 6 shows the approximate amount of data contained in a typical B-picture video access unit size.

TABLE 6

Approximate B-picture access unit size

Video encoding rate (MHz)	Video access unit size (Bytes)
3	10 000
10	40 000
15	50 000

4.2.2 The MPEG-2 TS

The MPEG-2 TS is a 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 TS is composed of 188 byte packets containing program specific information such as the Program Association Table (PAT), the Program Map Table (PMT), Conditional Access Table (CAT), the Network Information Table (NIT), the program clock reference (PCR), and 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 TS multiplexing it is extremely difficult to determine the video quality resulting from random errors inserted in the TS. In some instances an error could corrupt an unused portion of a TS, 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 resulting in loss of decoder synchronization. In addition, many of these errors can be masked through innovative decoder implementations. Thus, an intricate knowledge of the decoder implementation and the video and audio encoding and multiplexing is required to determine exactly why the program content degrades or the decoder loses synchronization.

4.2.3 MPEG-2 over ATM

The MPEG-2 TS can be segmented and placed into ATM cells using either AAL-1 or AAL-5. Figure 23 illustrates the AAL-5 segmentation.

Whether or not a corrupt AAL-5 datagram is dropped completely or passed on to the application is optional. Thus, one ATM cell drop can result in the loss of two TS packets or a total of 376 bytes. Dropping the last cell in a datagram, which contains the end of datagram flag, could cause four packets to be dropped.

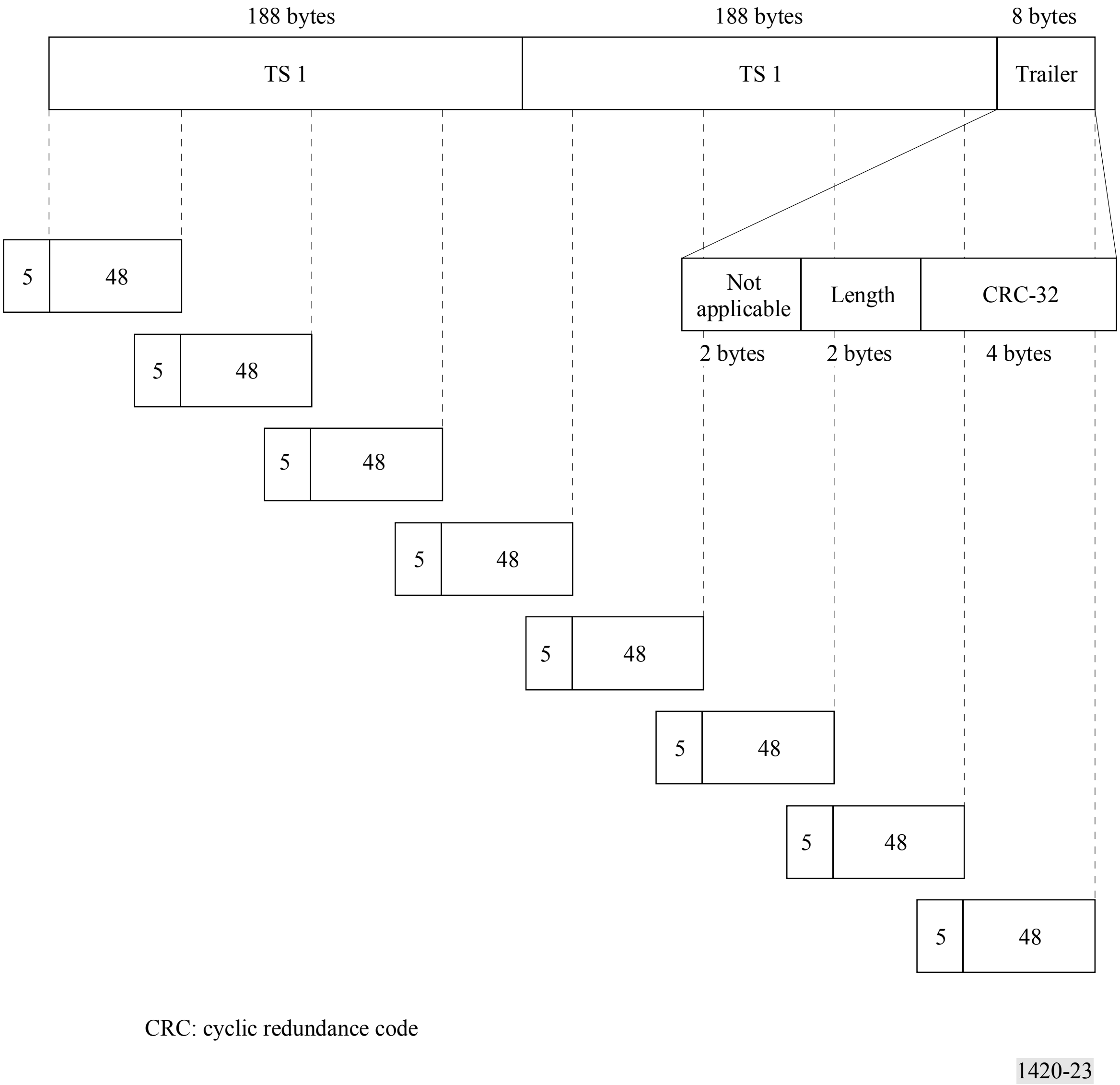
4.3 Data application

4.3.1 Internet traffic over satellite ATM

The transport of Internet traffic over ATM networks is an important application area to consider in satellite ATM. Satellite systems can be used to provide high-speed backbone transport as well as direct access and connectivity to distant users around the world.

FIGURE 23

AAL-5 common part convergence sublayer



Although most Internet applications run successfully over satellite, there is a concern that high-speed applications may not work efficiently when transmitted over a satellite due to the potential packet losses and the latency (delay) effects on the data protocols used by the Internet. The main problems with the current version of transmission control protocol (TCP) are its inefficiency to handle high-speed data streams over long-delay links and how it responds to network loss and congestion conditions. This problem is not unique to satellites, but also, it is of concern to some data services that are transmitted at gigabit rates over fibre networks.

There are two broad categories for enhancing the current TCP: the limitation on how much bandwidth can be transmitted over a satellite path, and the manner in which packets are acknowledged and re-transmitted. The throughput of a single application using a TCP connection may be limited by the window size of TCP, which is constrained so that:

– fast transmitters do not overrun slow receivers, and

– transmitters will slow down if there is congestion in the network.

One way of increasing the throughput is by increasing the window size, regardless of the type of transmission facility, since this will allow more data to be sent before waiting for an acknowledgement message. While extended windows may allow greater throughput, under no-loss conditions, there are other aspects that need to be considered as well. These include the retransmission algorithms and the congestion control mechanism of TCP. Some potential solutions that have been proposed thus far include:

– running multiple parallel connections,

– extending the window size (RFC-1323),

– use of selective acknowledgement mechanism (RFC-2018), and

– use of the slow start algorithm (RFC-2001).

TCP/Internet protocol (IP) implementations over ATM may be additionally impacted by ATM cell losses or cell misinsertions that may lead to data retransmissions and by the nature of the ATM protocol. Techniques to improve the use of TCP/IP over ATM are being investigated.

When designing these networks, several system design parameters have to be taken into account to achieve high throughput efficiency. These parameters include buffer sizes, switch drop policies, end-system policies, error recovery algorithms, and congestion control mechanisms.

Some preliminary simulation results, submitted to Radiocommunication Working Party 4B, on a satellite that is being planned to carry ATM unspecified bit rate (UBR) traffic addressed this issue and showed that an optimum buffer size of about $0.5 \times$ RTT (round-trip transmission time) is sufficient to provide 98% throughput to infinite TCP traffic sources.

4.4 QoS measurement results of applications using ATM

4.4.1 AT&T-Telstra QoS results of ATM applications over an IDR link

During the AT&T (United States of America), KDD (Japan) and Telstra (Australia) ATM Trial, AT&T and Telstra performed various tests including QoS measurements of some services and applications. The ATM applications were transmitted between research laboratories, located at New Jersey and Sydney, over fibre-based networks and 45 Mbit/s IDR satellite links. The results presented below correspond to four ATM applications:

– EMMI (a motion Joint photographic Experts Group (JPEG) video);

– communiqué (desktop videoconferencing);

– PCM voice; and

– G3 facsimile.

Some major characteristics of these systems are shown in Table 7.

TABLE 7

Applications tested

Application	Description
EMMI	A motion-JPEG video that was set to operate at a quality level of 50. This produces a VBR signal from about 10 to 20 Mbit/s
Communiqué	A desktop videoconferencing system that was set to operate at 15 frames/s. This produces a VBR signal from 0.5 to 1.5 Mbit/s
Voice	A 64 kbit/s PCM voice channel connected to a private branch exchange (PBX) and linked by a DS1 CBR trunk
Facsimile	A G3 facsimile (without enhanced error correction capability) connected to a voice channel of the PBX and linked by a DS1 CBR trunk

People experienced with each respective application assessed the applications subjectively for audible and/or visual impairment. The results are shown in Table 8. For this particular example, the results show that the end-to-end objectives proposed in ITU-T Recommendation I.356 (CLR = 3×10^{-7}, CER = 4×10^{-6} and SECBR = 1×10^{-4}) were met by a small margin. Any further degradation resulted in unacceptable performance.

TABLE 8

Test results

Test interval (min)	E_b/N_0	BER(1)	CLR(1)	EMMI	Communiqué	Voice	Fax
3	10.3	5×10^{-11}	0	Excellent	Video and audio OK	Excellent	Excellent
14	9.4	5.7×10^{-10}	0	No change	No change	No change	No change
8	8.7	6×10^{-9}	0	Maybe flickering on solid colour. Still excellent quality	No change	No change	No change
7	8.2	5×10^{-8}	0	Small amount of shimmering on skin tones. Still very good quality	Smear	No change	Small font difficult to read
5	7	5×10^{-7}	2.8×10^{-7}	Small amount of shimmering. Acceptable quality	OK	No change	Small font difficult to read
14	6.5	4.2×10^{-6}	7.7×10^{-6}	Movement is jerky at times. Some shimmering	Few black streaks, smears, white streaks	Heard noise burst then lost call. Re-established call, quality is good when call is up. Heard 2 to 3 s of very choppy speech then call dropped	Third page did not come through and had to be re-transmitted. Slight loss of sharpness
5	5.4	7.5×10^{-5}	8.2×10^{-5}	Movement breaking up quite a bit. Freezing on video. Bouncing ball appears to freeze in mid bounce and pause as it bounces Shimmering on skin tones. Blur on letters and name signs	Streaks, tearing. Audio beginning to break up	Breaking up. Noise bursts, then connection gone. Now unusable. Stays up less than one minute	Receive stop. Could not transmit
3	4.5	2.99×10^{-3}	1.2×10^{-2}	Video freeze. Maybe 5% of frames received. Audio breaking up	Picture is frozen	Cannot set up a call (five attempts). Secondary dial tone, but no ring back or ringing	Could not transmit

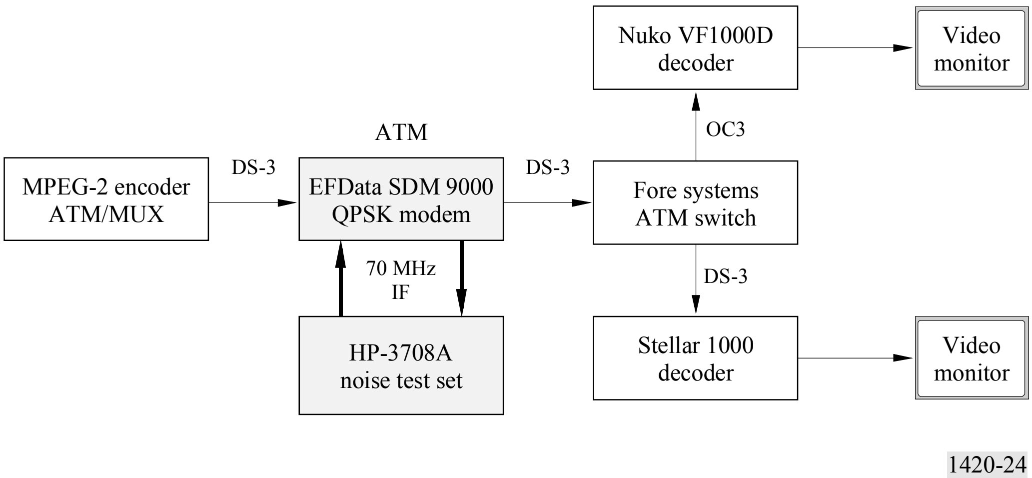
(1) BER measured by the satellite modem. CLR is the uncorrected or discarded cell ratio (DCR) i.e. all cells with two or more errors in the header. Notice that at low BERs there is not enough statistical confidence on the CLR measurement.

4.4.2 NASA MPEG-2 over satellite ATM laboratory tests

ATM QoS experiments were performed by NASA Lewis Research Center using MPEG-2 (AAL-5) 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 using ATM. MPEG-2 TS were baselined in an errored environment (binomial distribution) followed by a series of tests of MPEG-2 over ATM. Errors were created both digitally as well as in an IF link using a satellite modem and commercial Gaussian noise test set, for two different MPEG-2 decoder implementations. The test configuration is shown in Fig. 24.

FIGURE 24

MPEG-2 test configuration for long duration dual decoder tests



The results of the tests are shown in Table 9. The results indicate that CLR and CER should be at least 1×10^{-8} and 1×10^{-7} respectively, and may require even better performance in order to acceptably carry such services as MPEG-2 compressed video. These results appear to be due, however, to a general need for better MPEG-2 decoding BER quality rather than on the ATM transport mechanism, as indicated by the baseline testing of errored MPEG-2 TSs versus errored ATM cells carrying MPEG-2 TSs.

TABLE 9

Test results

E_b/N_0 (dB)	BER	CLR	CER	Decoder resynch	Block errors	Total visible errors	Run time (s)	VEPS
7.5	4.23×10^{-7}	1.40×10^{-6}	9.95×10^{-6}	18	8	26	420	6.19×10^{-2}
8.0	7.05×10^{-8}	2.93×10^{-7}	1.76×10^{-6}	12	17	29	2 315	1.25×10^{-2}

– The BER, CLR and CER measurements are for test patterns which were transmitted through the link simultaneously with the video. They are indicative of the link but are NOT measurements of the video stream itself.

– Modem setting: rate 3/4 convolutional coding/Viterbi decoding and QPSK modulation.

– Decoder resynch: the decoder freezes the picture and resynchronizes.

– Block error: noticeable small squares in a portion of the screen – sometimes with changing colours.

– VEPS: visible errors per second.

The results of this study were based on systems that had ATM to MPEG-2 demultiplexer portions that passed corrupted AAL-5 datagrams to the video decoder portions. Also, both decoders utilized in these tests were implemented with C-Cube[R] CL9100 decoder chips. Further work is required to evaluate the impact on QoS of other decoders and more robust MPEG-2 systems.

5 Performance measurement considerations

To measure the B-ISDN ATM layer ITU-T Recommendation I.356 performance parameters at the closest point to the satellite link, the two ATM network nodes on either side of the satellite link will have to be identified. ATM test equipment must be able to measure the long-term ATM performance (CLR, CER, SECBRs, etc.) in both non-invasive and out of service cases. If a point-to-multipoint topology is involved then the test equipment may have to be able to identify individual or groups of VPs and VCs. The methods employed for measuring these parameters are the subject of other ITU-T Recommendations.

6 Techniques to enhance ATM performance over satellite

This section describes techniques used to improve the performance of satellite links in order to accommodate the various ATM classes of service. These techniques may include enhanced coding, interleaving, and adaptive power control.

6.1 Reducing CER, SECBR and CLR

6.1.1 Selective interleaving

Interleaving enhances the random-error correcting capabilities of a code to the point that it can also become useful in a burst-error environment. The interleaver rearranges the encoded bits over a span of several block lengths. The amount of error protection, based on the length of burst encountered on the channel, determines the span length of the interleaver. The overall effect of interleaving is to spread out the effects of long bursts so they appear to the decoder as independent random bit errors. The probability of discarding ATM cells over links characterized by error bursts is of the orders of magnitude higher than over links with random errors due to the single-bit error correction capability of the HEC mechanism. For this reason, bit interleaving may be used to improve performance over coded satellite links.

6.1.2 FEC

The power of FEC is that the system can, without retransmissions, find and correct limited errors caused by the transmission system. Extra code symbols are added to the transmitted message to provide the necessary detection and correction information. FEC coding techniques that may be used in satellite systems include sequential, convolutional, BCH, trellis, turbo and RS codes.

6.1.3 Adaptive power control

Adaptive power control may be used on the uplink or downlink or both, to compensate for fading due to rain.

6.1.4 Adaptive rate control

Adaptive rate control can be achieved by adaptive coding which allows a satellite system to be throughput efficient while at the same time conserving its most valuable resource-satellite power. The principle relies on powerful modern coding techniques that allow adaptation and maximization of the user data throughput based on the link conditions. Special algorithms can be used to dynamically monitor the link performance degradation or improvement. This capability allows the development of system protocols that allocate more or less data throughput on a per-link basis. One way of adapting throughput is to control the coding rate; this is defined as the number of user data bits transmitted per channel symbol. The channel symbol can be a QPSK symbol or a generalized time and/or frequency of a waveform.

6.1.5 Site diversity

Site diversity of ground stations enables the ground subsystem of a satellite system to have multiple geographically dispersed communication links to the space subsystem. The space subsystem may consist of one or more satellites providing multiple communication links with differing angles of elevation with respect to the ground stations. The performance for each communication link will vary depending on the atmospheric conditions and the distance through which the communication links travel, but by combining the signals from the better paths a good signal can be recovered. Thus the satellite system could comply with the availability required to support the ATM transport services.

7 Digital transmission formats employed by satellite systems for ATM

ATM traffic can be carried over satellite systems in various digital transmission formats that include the synchronous digital hierarchy (SDH), plesiochronous digital hierarchy (PDH), cell-based systems, and MPEG-2 based systems.

7.1 SDH

Refer to ITU-T Recommendations G.707 and I.432 Series of Recommendations.

7.2 PDH

Refer to ITU-T Recommendation G.804.

7.3 Cell-based systems

Refer to ITU-T Recommendations G.707 and I.432 Series of Recommendations.