REPORT 1210

ERROR-PROTECTION STRATEGIES FOR DATA BROADCASTING SERVICES

(1990)

1. Introduction

Certain extensions of the display capabilities of existing teletext and subtitling services (e.g. the inclusion of non-latin based alphabets and non-alphabetic writing systems [CCIR, 1986-90a] as well as new data services, some of which are already identified in CCIR Report 802, require the adoption of error-protection strategies able to guarantee a high degree of confidence in the recovered message without undue repetition.

Sophisticated and powerful decoding strategies are now feasible thanks to progress in consumer microelectronic technology and can be implemented today, at low cost in commercial receivers. Thus, additions of a means of forward error correction will allow data to be corrected before they are decoded when the data packets are organized as an error correcting code [CCIR, 1982-86a]. Provided adequate buffer storage exists and time between data acquisitions permits sophisticated software programming techniques for error correction can also be used to acquire the service components correctly [CCIR, 1986-90b].

Section 2 outlines the general considerations for error protection strategies. Section 3 reports some studies of error protection strategies applied to present terrestrial broadcasting systems. Section 4 reports examples of error protection strategies for data transmission using satellite broadcast channels.

2. General considerations on error protection methods

The quality of a data broadcasting service depends mainly on the influence of transmission errors on the correctness of the recovered information message and appropriate error protection methods used. The following factors should be taken into account:

- the nature of the data to be transmitted;
- the quality of the transmission path;
- the unidirectional nature of the transmission path;
- the use of common strategies for the broadcast environment and their extension, if possible, to other media;
- efficiency of the coding technique.

Major methods for error protection can be divided into the following categories:

- Parity Check
- Forward Error Correction (FEC)
- Cyclic Redundancy (CRC)
- Majority Logic (ML)
- Bit Variation (BV)
- Error Concealment

Generally one or more of the above error control methods may be combined to provide satisfactory error performance.

For teletext services, in severe reception conditions, a residual error probability is usually tolerated for alphabetic and syllabic writing systems due to the high redundancy in the displayed text. In particular this applies to those systems where data synchronization is maintained and the displayed character position is fixed. Hence decoding can use a simple parity check at character level, combined with a cyclic transmission sequence without penalizing the majority of the audience served by satisfactory reception conditions. In other systems, simple FEC in each data packet both improves the reception and provides a check against errors. A high level of confidence can be provided by including a CRC at page level.

The quality requirements are more severe as regards enhanced teletext services, teletext for non-alphabetic writing systems and services such as telesoftware and transparent data services, either with cyclic or non-cyclic transmission. For these services, a high degree of confidence is of utmost importance and, in principle, no residual error probability can be tolerated because of the effect of these errors on the decoded message. The addition of suitable redundancy for error control, often associated with message repetition, is necessary in order to ensure a satisfactory reception quality in severe reception conditions. In such conditions, an eventual increase of the access time, resulting from the need for repeated message acquisitions to recover the correct information, will generally be acceptable, provided that the decoding strategy allows a high probability of success at the first attempt for the majority of the audience.

3. Studies based on the transport mechanism derived from CCIR teletext systems

3.1 Studies in France

It is shown /¯CCIR, 1986-90c_/ that the use of a CRC on the packet level of the DIDON data broadcasting system is effective in reducing the residual bit rate. Majority logic and error detection by CRC (e.g., a family and strategy as well as error correction by the CRC was studied through computer simulation of a transmission channel. The results show that the error processing can be adapted to yield a desirable residual BER for a range of input BERs (Table I).

TABLE I

INPUT bit error rate	Minimum number of repetitions for a residual bit error rate $\angle 10^{-8}$ C.R.C. processing: error detection	error correction
10^{-3}	4	2
$5x10^{-4}$	2	2
$2x10^{-4}$	2	1
10^{-4}	2	1
$5x10^{-5}$	2	0
$2x10^{-5}$	1	0
10^{-5}	1	0
$5x10^{-6}$	1	0

3.2 Studies in Italy

Laboratory tests and field trials have been carried out in Italy [Cominetti et al. 1986] [CCIR, 1986-90d] to assess the performance of error-protection strategy used in the telesoftware system developed by the RAI and using the structure of CCIR teletext system B.

This strategy is based on the adoption of a (40,34) Hamming code, for forward correction of any single error in a block of 4 bytes, associated with a cyclic redundancy check (CRC) for the detection of residual errors on each data row /Cominetti and Morello, 1985/.

From the results the following conclusions have been drawn:

- The telesoftware service requires a reception quality higher than a teletext service (level 1), both for the high sensitivity to transmission errors and for the greater length of the data "files" (e.g. about 10 pages for a 10 kbyte telesoftware file).

- The use of a (40,34) Hamming code represents a satisfactory compromise between transmission efficiency (80%) error correction/detection capability and decoding implementation economy.

- The efficiency of the error-correcting code against the occurrence of repetitive critical data patterns can be improved by masking the transmitted data with pseudo-randon sequences.
  With the above error protection strategy it was possible to recover 1 kByte file, error free, at the first acquisition with 85% probability of success at BER of about 10^{-3}.
  Without using this error protection strategy the same probability of success was achieved at a BER of about 2×10^{-5}.

3.3 Studies in the Federal Republic of Germany

A technique called bit variation has been studied in the Federal Republic of Germany. It is a highly effective error correction control scheme in the case of poor reception conditions. The technique is based on a two-fold transmission of data. Where the received bit values differ at the same position within two acquisitions of a data block, the bit values are successively modified until the error check is satisfied. In combination with a low-redundancy FEC (about 5%) and error detection by CRC, such a correcting strategy will provide 99.9% probability of correct reception of subtitles, teletext pages and 10 kbyte data files at bit-error rates up to 5.10^{-2} [CCIR, 1986-90e].

3.4 Studies in Japan

Error-protection schemes for data broadcasting has been extensively studied in Japan since 1977, bearing in mind application to teletext services. Using error pattern data collected in field tests, simulations on the performance of many kinds of error-correcting codes have been carried out. Field experiments to compare the error-correcting capabilities of several kinds of proposed codes have also been carried out. Based on these simulations and experiments, the (272, 190) difference set cyclic code was adopted for the data broadcasting system for the CCIR teletext system D. This code has an efficiency of 70% and an estimated capability of correcting 11 incorrect bits in a 272-bit block [CCIR, 1982-86b]. A block error rate of 10^{-5} can be obtained at a bit-error rate of 10^{-2}.

In addition to the (272, 190) code, the use of the continuity index in packet transmission and the cyclic redundancy check (CRC) in the data group level have made the transport mechanism of the system a very reliable one. Figure 1 shows the error protection capability of the (272, 190) code and CRC.

In general, reliable transmission can be expected when the above mentioned strategies are applied to services other than teletext whether they are transmitted terrestrialy or by satellite. Studies are being carried out on the application of the error-protection strategies on various types of data broadcasting services (Figure 2).

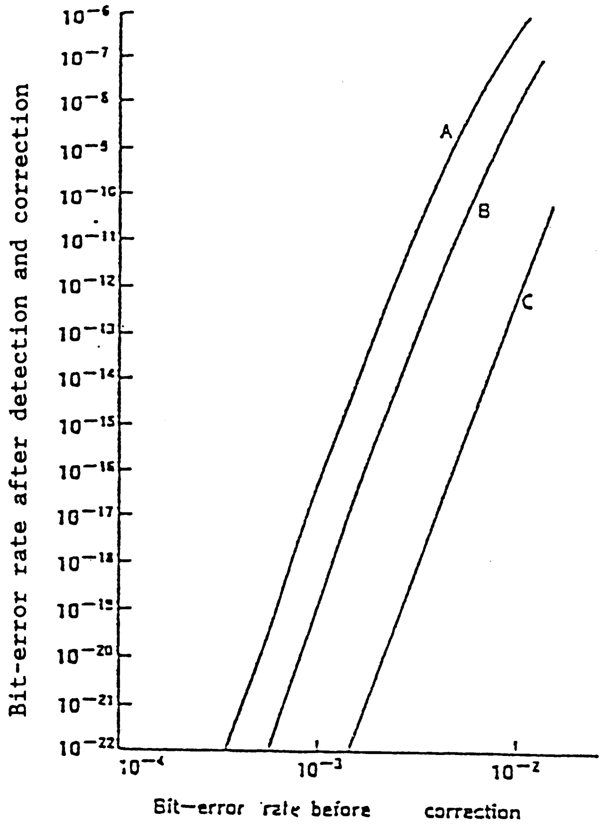


FIGURE 1

<u>The error protection capability of (272, 190) code and CRC</u>

curve A: error correction capability of the (272, 190) code

curve B: error detection capability of the (272, 190) code

curve C: error detection capability of the (272, 190) code combined with CRC

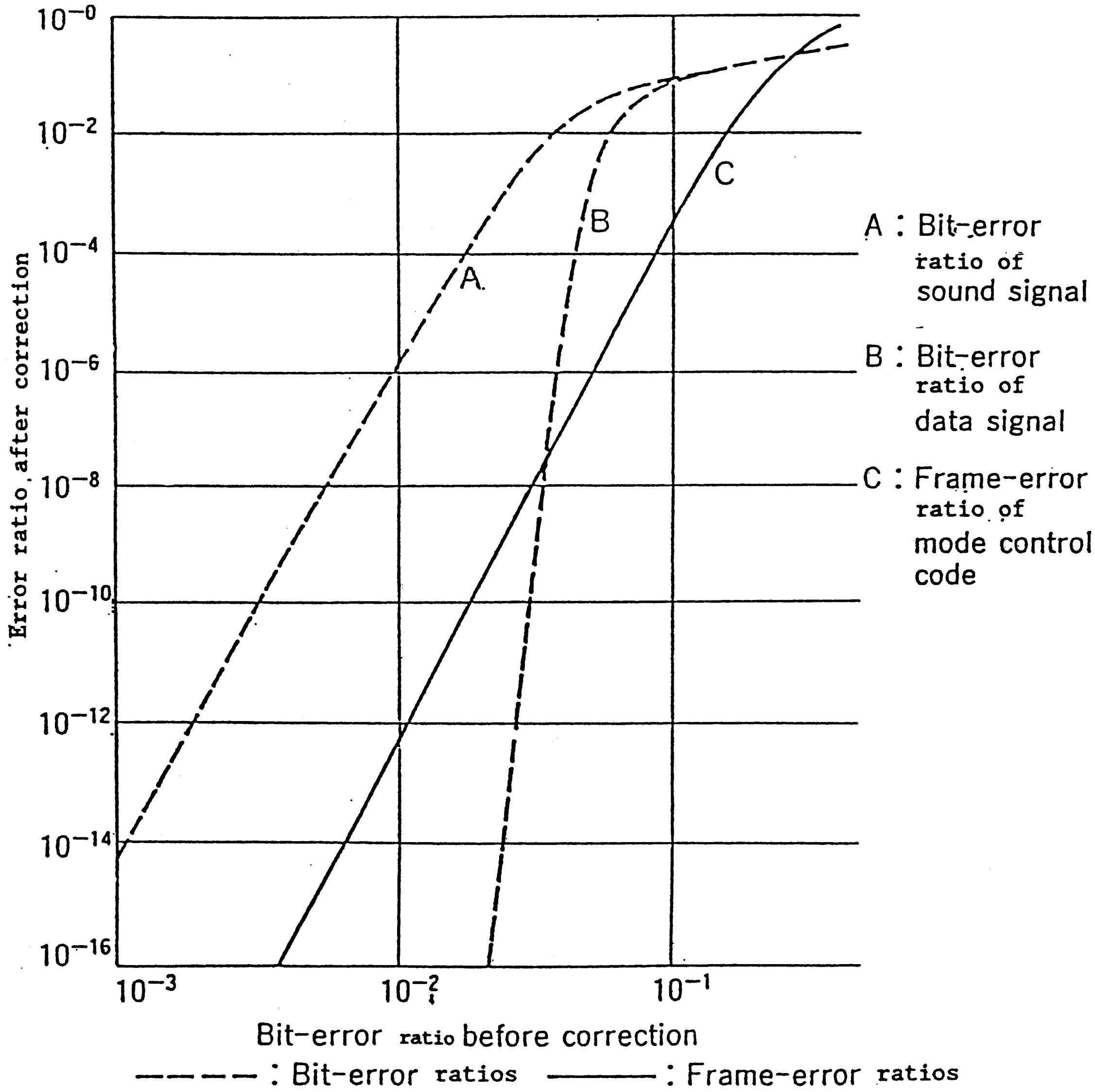


Fig. 2 **Performance of the error-correction strategy**

4. Examples of error protection strategies for data broadcasting using satellite broadcasting channels

4.1 Data transmission in the MAC/packet digital multiplex

The EBU has studied various error-protection schemes [CCIR, 1986-90f] for standardization of a suitable transport mechanism for data services in the digital multiplex of the MAC/Packet family of systems [CCIR, 1982-86c, d]. These strategies may be applicable to other transport mechanisms than those of the MAC/Packet digital multiplex.

Two particular error protection schemes have been defined by the EBU [CCIR, 1986-90g] for the transport of teletext of CCIR Systems A and B in the MAC/packet digital multiplex. The first level utilizing cyclical redundancy check coding alone is primarily intended for cycled data services where error correction can be provided by using majority logic or bit variation at the receiver. The second level —— utilizes (24,12) Golay forward error correction to provide a high level of protection on a single transmission of teletext data.

4.1.1 Error protection strategies

Various error-protection strategies have been proposed [Cominetti and Morello, 1985] and [Eitz and Moell, 1988] which make use of one or more of the following main error-control elements:

- cyclic redundancy check (CRC)
- error correction by majority logic (ML) or bit variation (BV)
- forward error correction (FEC).

Depending on the error-protection strategy chosen, both at the transmitter and at the receiver, different decoder behaviour in the presence of errors can be achieved whereby the error performance under non-satisfactory reception conditions could be moved between the following two extremes: high level of confidence that a data message will be error-free at the first acquisition, at the expense of an additional amount of redundancy for forward error correction, or the need for message repetition and multiple acquisitions to obtain error-free reception.

While error detection can be efficiently implemented by low-redundancy codes, forward error correction in poor reception conditions (BERs greater than 10^{-3}) requires a large amount of additional redundancy.

When the offered service is not inherently cyclic, the adoption of powerful FEC codes often gives better error performance than multiple transmissions and majority logic [BSB, 1989] or bit variation decoding, provided that the transmission efficiency is kept constant. However, when the service is cyclic, the repetition does not involve a reduction of transmission efficiency. In this case, it could be more appropriate to exploit the message repetition rather than introduce very powerful FEC codes thus avoiding an increase in access time in regions where receiving conditions are good.

It is important to point out that, when the error rate on the channel exceeds the error-correcting capability of the code, the forward correcting procedure may occasionally introduce new errors. In contrast, error correction by majority logic can usually operate in such conditions, thereby reducing the channel error rate.

The behaviour suggests combining majority logic, or error correction by bit variation, with forward error correction; the first will reduce the BER to an acceptable level for the code correcting capabilities, and the second will eliminate the residual errors; in this way, it is possible to keep the additional redundancy to a low level, while assuring the required service quality. The choice of the optimum error-protection strategy in the receiver is then a trade-off between the exploitation of cyclic message repetition and the use of forward error correction. In general it seems necessary to identify some basic strategies and compare their correcting capabilities as a function of the channel bit-error rate.

4.1.2 Typical values of data content

The EBU has used the following values of data content to characterize and assess service quality:

- a typical teletext page: 1 kbyte
- a typical two-row subtitle: 80 bytes
- a typical unit of telesoftware: 10 kbytes

4.1.3 Criteria for satisfactory performance

The following limits of a service conveyed in the digital multiplex of the MAC/Packet family of systems have been considered:

- teletext : at a random BER of 3×10^{-3}, two or three acquisitions will provide an error-free display with a probability of success larger than 97%
- subtitling : a two or threefold repetition of each subtitle will provide error-free subtitles at a random BER of 3×10^{-3}
- telesoftware: to assure an adequate probability of success in acquiring a 10-kbyte telesoftware message at a random BER of 3×10^{-3}, a fivefold acquisition may be required.

It is reasonable to choose a protection scheme that provides satisfactory data service quality at a random BER of 3×10^{-3}. For MAC/packet DBS systems, this figure corresponds to a sound and vision quality worse than CCIR grade 3 ("fair").

4.1.4 Decoding strategies

The decoding strategies described in the annex, refer only to the useful part of the message (data block), assuming that all the complementary information needed for the correct reconstruction of the message (packet header) are correctly recovered by the receiver. In the MAC/packet system, this information is highly protected by forward error correction codes, such as the Golay (23,12) code and the Hamming (8,4) code. As reported in the MAC/packet family specification /EBU, 1986/, the Golay (23,12) code is able to correct up to three errors in a group of 23 bits, and the packet loss probability is about 7.5×10^{-5} at a BER of 10^{-2}, and 4.5×10^{-3} at a BER of 3×10^{-2}.

A proposed protocol for the General Purpose Data (GPD) type of MAC/packet service component [CCIR, 1986-90h] allows the optional use of error detection by data segment CRC, optional error correction by FEC coding, and an optional format extension to provide an extended data segment continuity index to support error correction by repetition. A theoretical study of the error performance of the GPD type of service component is presented in [BSB, 1989].

4.1.5 Conclusions of the EBU studies

These studies provide some general indications on the choice of an efficient error correcting strategy:

- To guarantee good service quality in the case of high BERs (up to 10^{-2}), it would be necessary to combine error-correction methods using multi-acquisition, such as majority logic or bit variation, with forward error correction (e.g. BCH codes) which does not need to be very powerful (e.g. a code able to correct up to two errors).

- In such a case, the additional amount of redundancy for error control should not significantly penalize the capacity for data transmission (redundancy 5%).

- Under good or satisfactory reception conditions, forward error correction should eliminate residual errors at the first acquisition, thereby reducing the access time.

- Under poor reception conditions, additional acquisitions (T = 2 or 3) will be necessary in order to obtain error-free data message.

- In the case of subtitles, a very high probability that the text rows will be displayed without errors could be assured by arranging a consecutive twofold transmission of each subtitle.

The choice between the above-mentioned strategies, and the many variants that can be imagined to improve their performance, is still under EBU study.

4.2 Data transmission in the digital sub-carrier NTSC system

The digital sub-carrier NTSC system described in Report 1073 used for operation of the satellite broadcasting television services in Japan has a transmission capacity for use as a satellite broadcasting data channel.

4.2.1 Error protection strategies in the sound/data multiplex

The sound/data multiplex carried by the 5.73 MHz digital subcarrier has a bit rate of 2.048 Mbps and a frame structure the length of which is 1 ms (i.e. 2.048 bits). The frame has a matrix structure of 32 by 64 bits. The bits contained in each row of the matrix except the first bit, which is a sync or control bit, comprise the (63,56) BCH code. Since the transmission sequence of bits in the matrix is in the column by column direction, successive errors likely to occur in differential QPSK demodulation do not affect the error protection scheme with the BCH code.

The data channel area is defined as the remaining area in the matrix not used for the transmission of sound, range control, frame sync, frame control and error protection [CCIR, 1986-90i].

4.2.2 Error protection strategies in data transmission scheme

A set of nine frames comprises a super frame which has a matrix structure of 288 X 64 bits. A packet having a fixed length of 288 bits (32 x 9 = 288) is arranged in the data channel area in the super frame in a manner similar to a sawtooth pattern so that the bit sequence of the packet is orthogonal to the bit transmission sequence as well as the bit sequence of the error correction code given below. Thus concentration of errors on a packet can be avoided.

The packet is composed of a header and a data part. The header, having a length of 16 bits, is a code word of the (16,5) BCH code which can correct all errors up to three bits and detect errors up to four bits.

No particular error protection scheme is specified for the data part; however, a (272, 190) majority logic decodable difference set cyclic code (see section 4.3) can be applied.

The frame control code contains five bits to indicate the mode of sound transmission and two bits for suppressing sound and data used in such transtions as changing the sound mode or switching the earth transmission station. The data channel mode is identified by the bits indicating the mode of sound transmission.

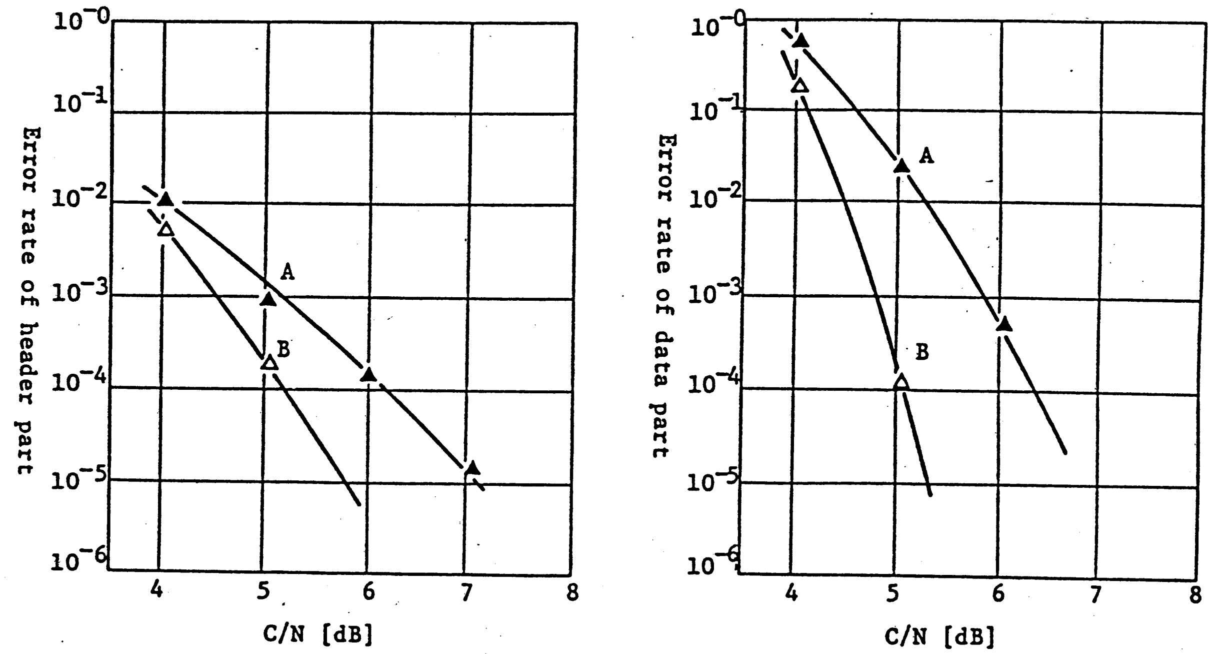
To strengthen these control bits, 36 repeated transmission in a master frame, of which the interval is 36 mS, is specifieda. One bit in the control code is used to indicate the master frame period. At the receiving end, a majority decision of more than 19 out of 36 in the master frame is recommended.

4.2.3 Results of satellite transmission experiments

Using the operational direct broadcasting satellite BS-2b, packet transmission experiments through the data channel have been carried out.

Figures 3 (a) and (b) show the error rate of the header and the data part respectively. The (272, 190) cyclic code is applied for the data part. Also shown is a product effect with the (63, 56) BCH code.

A block error rate of 10^{-3} was obtained at a C/N ratio of 4.5 dB for the header part and one of 10^{-2} at the same C/N ratio for the data part. As the C/N ratio increased to 8 dB, the error rate became negligibly small (less than 10^{-9}).



A : (16, 5) BCH code only

B : Combination of (16, 5) BCH code and (63, 56) BCH code

(a) Header part

A : (272, 190) cyclic code only

B : Combination of (272, 190) cyclic code and (63, 56) BCH code

(b) Data part

Figure 3 Block error rate of header and data part of packet transmitted through satellite broadcasting data channel

C/N : carrier to noise ratio (27 MHz band)

4.3 Data transmission in the sound-only satellite broadcasting system DSR

The Digital Satellite Radio system DSR recommended in Recommendation 712 and specified in Report 1228, Annex 1, used for the transmission of 16 high-quality stereophonic or 32 monophonic sound channels in the Federal Republic of Germany has the potential for use for satellite data broadcasting [Assmus, 1989]. Each of the 32 monophonic sound channels offers 352 kbit/s of protected and 96 kbit/s of unprotected data capacity. The protected part uses the 11 MSBs in combination with a (63,44) BCH-Code.

This code can correct two bit errors within a 63 bit coding block. The measured corrected BER versus C/N in a broadcasting satellite channel in the 12GHz range is outlined in Table II. The final entry in the table shows the uncorrected BER for a C/N of 12 dB.

TABLE II

C/N (dB)	7	8	9	10	12	12 uncorrected
BER	4.3×10^{-4}	6.0×10^{-5}	6.6×10^{-6}	6.9×10^{-7}	8.1×10^{-5}	3.6×10^{-5}

A comparison of the BERS's of C/N = 12 for protected and unprotected data transmission indicates the substantial improvement of the BER in the protected channel of about 4×10^{-3} In other words, the reduction of the BER achieved by the (63,44) block coding method corresponds to an improvement of the C/N by about 4dB.

5. Error-protection strategies for FM multiplex broadcasting on other types of data broadcasting services

5.1 FM multiplex broadcasting system

An FM multiplex broadcasting system capable of transmitting digital sound and data signals has been developed. The system multiplexes a 48 kbps digital signal and is suitable for stationary reception [CCIR, 1986-90 j]. The digital multiplex signal has a frame structure which consists of an 18 bit framing code, a 16 bit mode control code and 34 blocks of (272, 190) majority logic decodable difference set cyclic code (See Section 3.4).

The sound signals are protected by the (272, 190) code, while the data signals are protected by the product of two (272, 190) codes.

The mode control code which defines the contents in the frame is protected by the (16,7) extended BCH code which has a 2-bit error-correction capability and a 3-bit error-detection capability in a 16-bit block. It is recommended in the studies to decode this code after a majority decision made on each bit of 5 continuous mode control codes, because the same mode control code is transmitted in the same FM multiplex broadcasting program.

Sampled digital sound signals are arranged orthogonally on the error-correcting codes and the bit transmission sequence in the frame to avoid concentration of errors in both the error-correction blocks and the sampled sound data.

The performance of the error-correction strategy used in the system is shown in Figure 1 as described in section 3.4.

5.2 Facsimile broadcasting multiplexed with FM-FM sound system using television system M

As to the signal format of digital broadcast facsimile system, the system employs a packet type signal which incorporates a majority logic decodable (272,190) shortened difference set cyclic code for error correction. In addition, the signal is supplemented with a 16 bit mode control code to identify the content of the transmission channel; and then is further written into a frame with 32 lines and 288 columns. When reading out the signal, a bit interleaved transmission method is used to prevent signals being affected by burst errors due to multipath propagation.

As to the controlling signal format of analogue broadcast (272,190) shortened difference set cyclic code is incorporated [CCIR 1986-90k].

REFERENCES

ASSMUS, U. [February 1989] - Data distribution by Digital Satellite Radio (DSR) via broadcasting satellite. EBU Review, Technical, No. 233.

BSB [1989] - An analysis of the effect of bit errors on MAC/packet General Purpose Data (GPD) services. British Satellite Broadcasting, April 1989.

COMINETTI, M. and MORELLO, A. [September, 1985] - Telesoftware - Sistemi di protezione dagli errori di transmissione. RAI Research Centre, Technical Report No. 85/10/I.

COMINETTI, M., MORELLO, A., PASTERO, N., TABONE, D. and TOSONI, N.S. [1986] - Campagna di misure per l'introduzione del Telesoftware. RAI Research Centre, Technical Report No. 86/9/I.

EBU [October 1986] - Specification of the systems of the MAC/packet family. EBU Doc. Tech. 3259.

EITZ, G. and MOELL, G. [1988] - Fehlerschutzstrategien für die Satellitenübertragung von Fernsehtext (Error protection strategies for the transmission of teletext via satellite). Rundfunktechnische Mitteilungen 6/1988.

CCIR Documents

[1982-86]: a. 11/129 (Japan); b. 11/29 (Japan); c. 10-11S/164 (EBU); d. 10-11S/165 (EBU).

[1986-90]: a. JIWP 10-11/5-13 (China (People's Rep. of)); b. JIWP 10-11/5-15 (Germany (Fed. Rep. of)); c. JIWP 10-11/5-11 (France); d. 11/101 (Italy); e. JIWP 10-11/5-39 (Germany (Fed. Rep. of)); f. JIWP 10-11/5-7 (EBU); g. JIWP 10-11/5-36 (EBU); h. JIWP10-11/3-117 (UKIBA); i. 11/420 (Japan); j. 10/204 (Japan); k.

ANNEX

THE CLASSIFICATION AND ASSESSMENT OF
ERROR PROTECTION STRATEGIES

This annex gives the method of classification of error protection strategies and relationships used to evaluate these strategies.

A. Classification of error protection strategies

As shown in Table I, the various error-protection strategies can be grouped into three basic families which are identified by the amount of additional redundancy introduced at packet level.

TABLE I

FAMILY	REDUNDANCY	BYTE CODING	APPLICATION
A	Parity check at character level	7 + 1 bit	Conventional teletext and subtitling
B	CRC (16 bits)	8 bits	Enhanced teletext systems A and B, subtitling, telesoftware, transparent data services
C	CRC (16 bits) + FEC		

Assuming that the performance of error protection based on a parity check at character level, as used in present CCIR teletext systems A and B, does not require further study, attention will be concentrated on new protection strategies based on 8-bit coding. However, the basic relationships for 7-bit coding + parity are given in the Annex, together with those for 8-bit coding.

The results presented in Figures 1 - 7 relate to transport by the MAC/packet multiplex with a data block length of 90 bytes. The result is given as the probability of correctly displaying a page (or recovering a file) after T acquisitions (P(s,T) where s=success, T= number of acquisitions.

a) Strategy of family A

Strategy (A-1)
(PARITY CHECK)

Applied to conventional teletext and subtitling (7-bit coding + parity) and adopted in CCIR teletext systems A and B:

- Error detection is carried out at character level by a parity check bit. Parity check failure leaves blanks in the page memory.

- Error correction is obtained by successive acquisitions of the page by filling the empty spaces with characters estimated as being error free. This mechanism does not avoid displaying wrong characters in the occurence of even errors. The degree of confidence in the displayed page can be increased significantly by including an error detecting code (CRC - cyclic redundancy check) in any data row or page.

b) Strategies of family B

For the case of enhanced teletext, subtitling, telesoftware and transparent data services (8-bit coding), two strategies of this family have been identified. Each data packet (90 bytes) is protected by a 16-bit suffix (CRC).

Strategy (B-1)
(CRC)

The following decoding procedure is adopted:

- The data blocks are accepted when the CRC is correct and are rejected in the other cases.

- In the presence of channel errors, the information unit (e.g. a teletext page, a two-row subtitle, a data file, etc.) is recovered error-free after several consecutive acquisitions.

As shown in Fig. 1, this strategy is only suitable for very good reception conditions.

Strategy (B-2)
(CRC + ML + CRC)

The decoding procedure is the following:

- The data blocks are accepted when the CRC is correct, otherwise they are stored in the receiver's memory for further processing. The memory locations reserved for consecutive acquisitions of the same data block affected by errors are different (no over-writing).

- After 3 (or 5) acquisitions affected by errors, the receiver performs majority-logic error-correction on a bit-by-bit basis.

- A final CRC error detection allow validation of the decoded message.

This strategy, which is an improvement upon strategy (B-1), allows correct message decoding at the first attempt in good reception conditions, and presents a higher ruggedness in the case of high BER (see Fig. 2).

These results have been verified by laboratory tests /Cominetti and Morello, 1985/ carried out by an intelligent receiver (see Table II). The probabilities for display (or file recovery) with a residual BER (i.e. before final validation by the CRC) are also given.

TABLE II

TYPE OF SERVICE	REPETITION T	MAX BER	PROBABILITY OF DISPLAY (RECOVERY)	RESIDUAL BER
TELETEXT (1 KBYTE)	3 3	5×10^{-3} 10^{-3}	100% 97%	10^{-4} 0.
SUBTITLING (80 BYTES)	3 3	10^{-2} 3×10^{-3}	100% 98%	3×10^{-4} 0.
TELESOFTWARE (10 KBYTES)	3 5	3×10^{-4} 3×10^{-3}	97% 97%	0. 0.

c) Strategies of family C

In this series of error-protection strategies, each data packet is protected by a forward error-correcting code (e.g. Hamming or BCH codes) in addition to the suffix (CRC).

Strategy (C-1)
(FEC + CRC)

The decoding procedure is as follows:

- Through the error-correcting capabilities of the FEC code in use, the receiver performs a forward error correction.
- A final CRC error detection on each data block assures the necessary degree of confidence.

Depending on the error-correcting capabilities of the FEC code, a high probability of confidence that data messages will be error-free at the first acquisition could be achieved at the expense of an additional amount of redundancy for the FEC (see Figs. 3, 4 and 5).

Strategy (C-2)
(FEC + CRC) + (ML + FEC + CRC)

Use of majority-logic error-correction in combination with forward error correction.

The decoding procedure is the following:

- The first two steps are the same as for strategy C-1, but the data packets with CRC failure are stored as received (without FEC).
- After 3 (or 5) unsuccessful acquisitions, the receiver performs, in sequence, majority-logic error-correction and forward error correction of the residual errors.
- A final CRC error detection on each data block allows validation of the decoded message.

Compared with strategy B-2, some additional redundancy for the FEC needs to be inserted into the message; however, the correcting code does not need to be very powerful since the residual bit-error rate after the majority-logic processing is normally low.

The strategy is especially suitable for severe reception conditions (see Fig. 6).

Strategy (C-3)
(FEC + CRC) + (BV + FEC + CRC)

In place of the majority logic, the FEC is preceded by an error-correction process using bit variation (BV) at each position within a data packet at which two successive acquisition attempts give different results. In these positions, the bit values are varied until the CRC on the data packet is found to be correct.

The decoding procedure is as follows:

- The first two steps are the same as for strategy C-1, but the data packets with CRC failure are stored as received (without FEC).
- On the packets where the above steps failed, the receiver performs, in sequence, bit-variations, forward error correction and CRC error detection. When the CRC is correct, the data block is accepted.

In common with strategy C-2, some additional redundancy for the FEC needs to be inserted into the message, but in contrast to majority logic, only two acquisition attempts are needed. With regard to practical limits for the computing power in the decoder, bit variation would probably allow the correction of up to 9 or 10 errors (corresponding to a maximum of 2^9-2 or $2^{10}-2$ variations respectively) within a data packet.

This strategy is similar to strategy C-2 and is especially suitable for severe reception conditions; particularly in the case of subtitles, the probability of decoding the data error-free can be considerably improved when a consecutive twofold transmission of the corresponding data packets is provided (see Fig. 7).

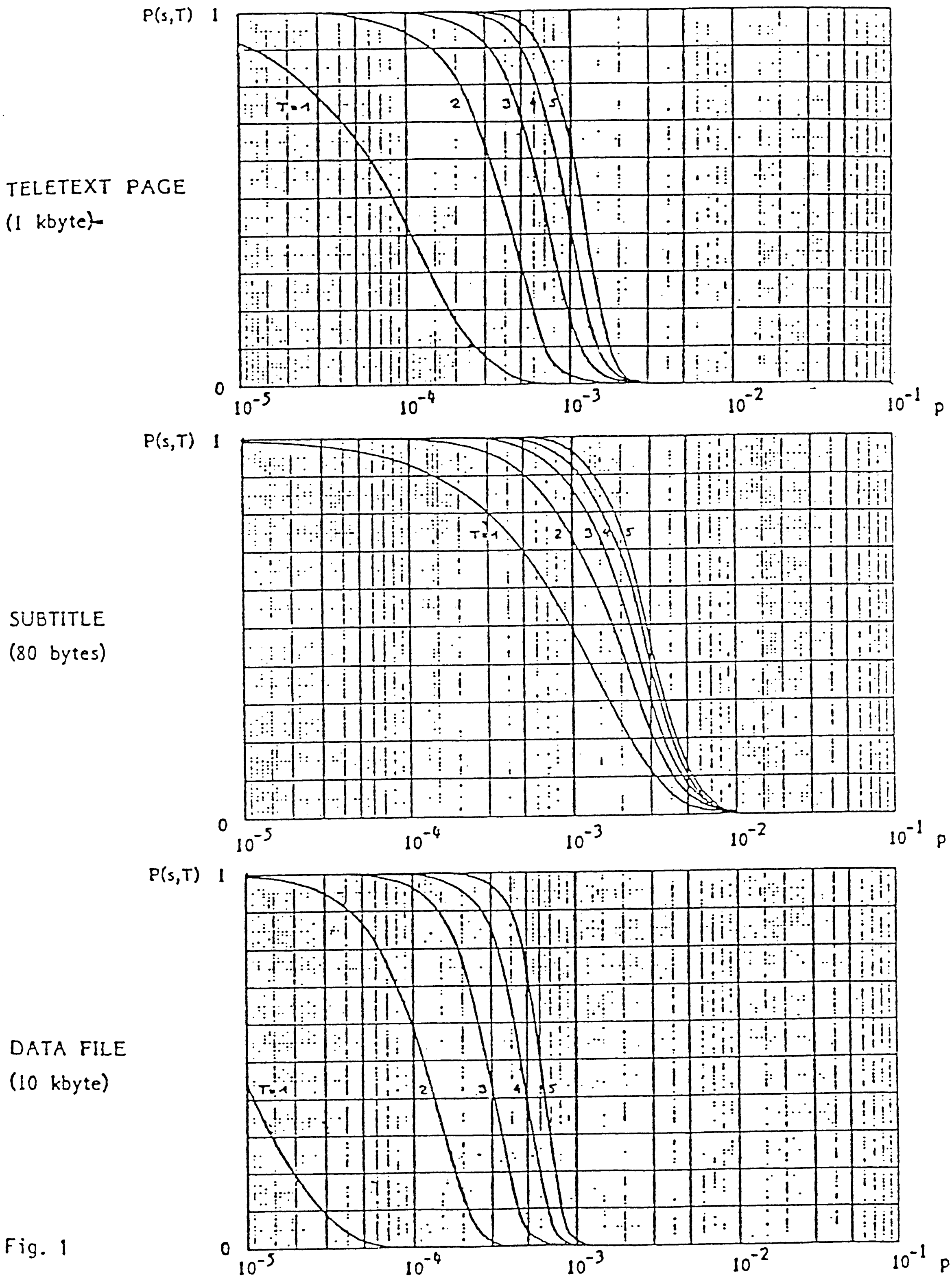


Fig. 1

Strategy B-1 : Probability of correctly accepting the three basic Information Units with CRC error detection

Block length: 90 bytes, CRC: 2 bytes

TELETEXT PAGE
(1 kbyte)

SUBTITLE
(80 bytes)

DATA FILE
(10 kbyte)

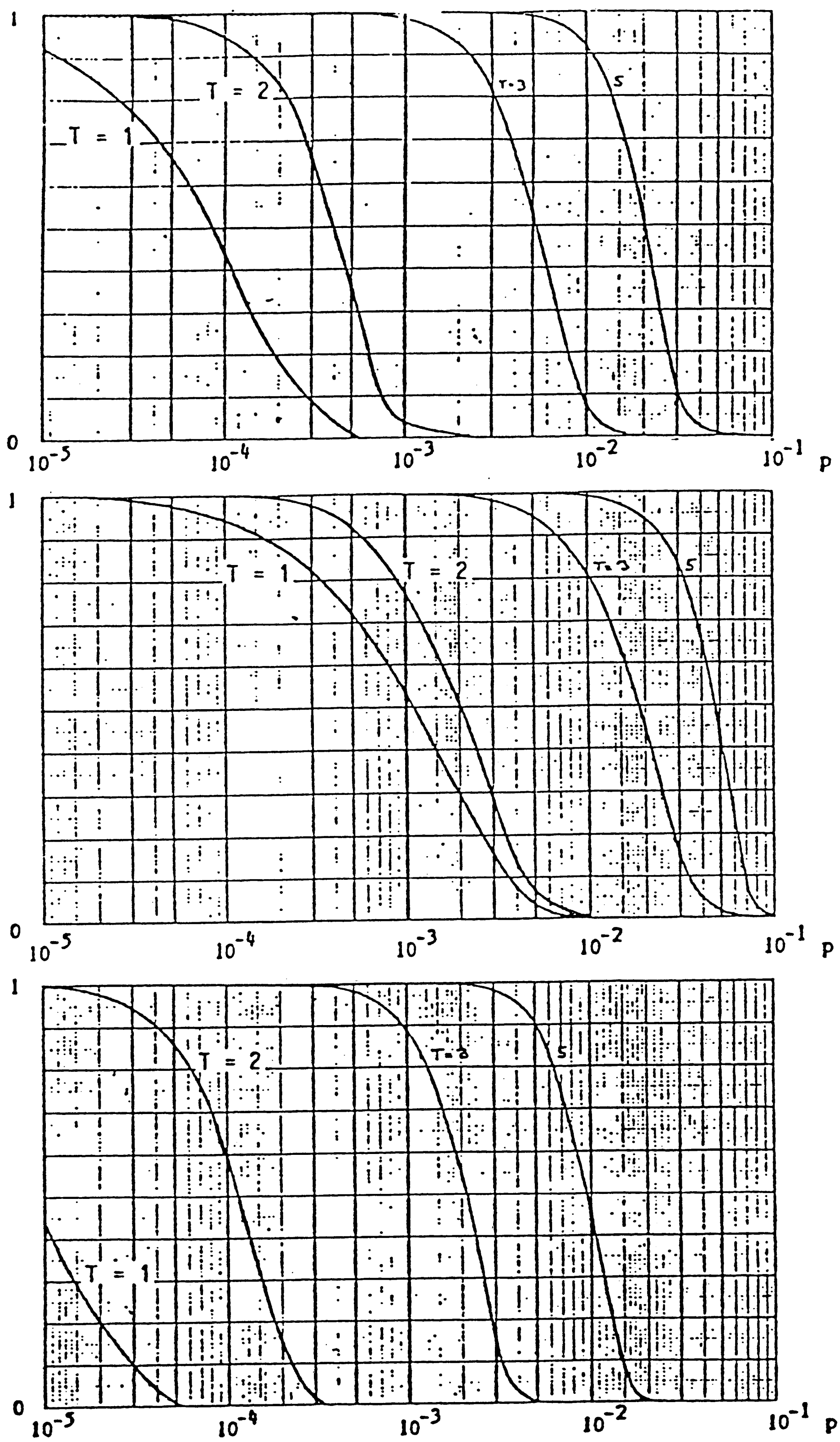
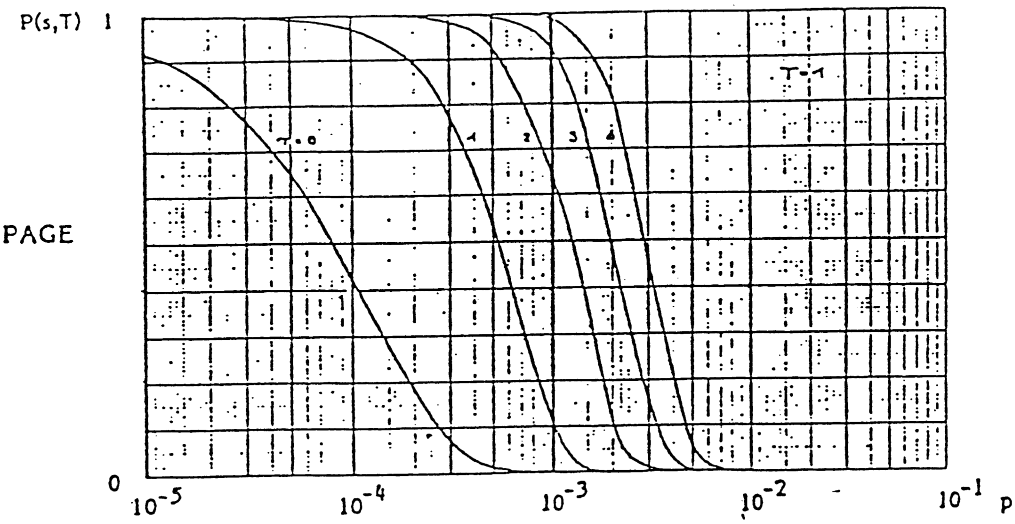


Fig. 2

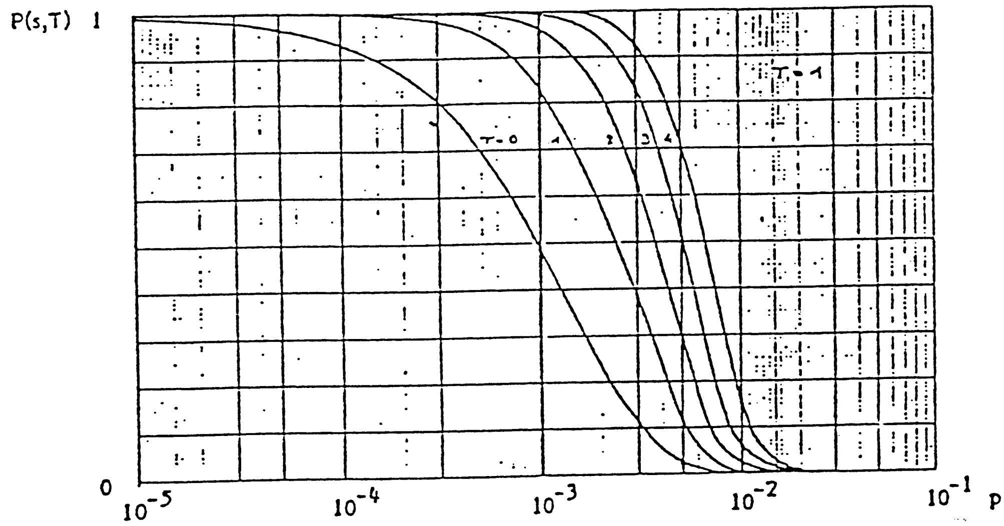
Strategy B-2: Probability of correctly accepting the three basic Information Units with Majority Logic error correction after T acquisitions and CRC error detection

Block length: 90 bytes, CRC: 2 bytes

TELETEXT PAGE
(1 kbyte)



SUBTITLE
(80 bytes)



DATA FILE
(10 kbyte)

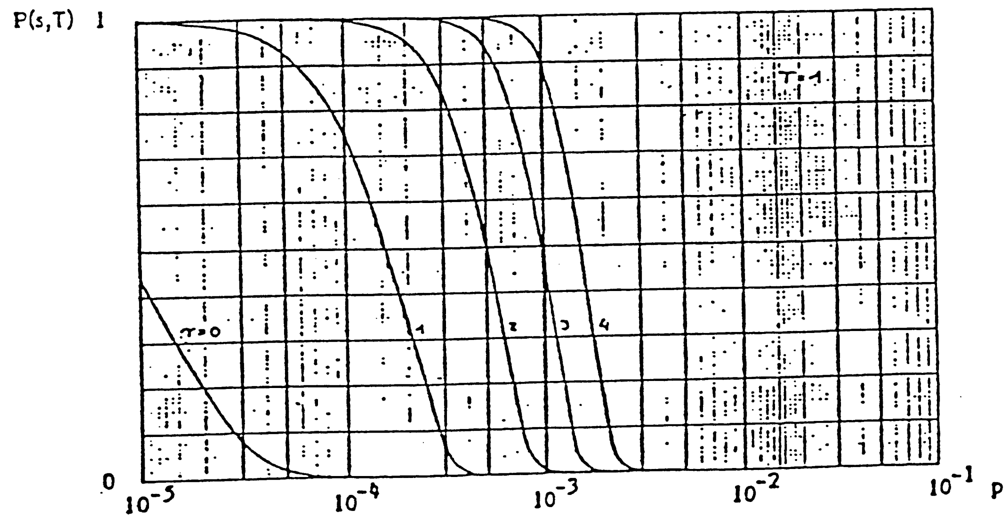


Fig. 3

Strategy C-1 (1): Probability of correctly accepting the three basic Information Units after 1 acquisition with FEC (correcting 0, 1, 2, 3, 4 errors) and CRC error detection

Block length: 90 bytes, FEC: 0, 10, 20, 30, 40 bits, CRC: 2 bytes

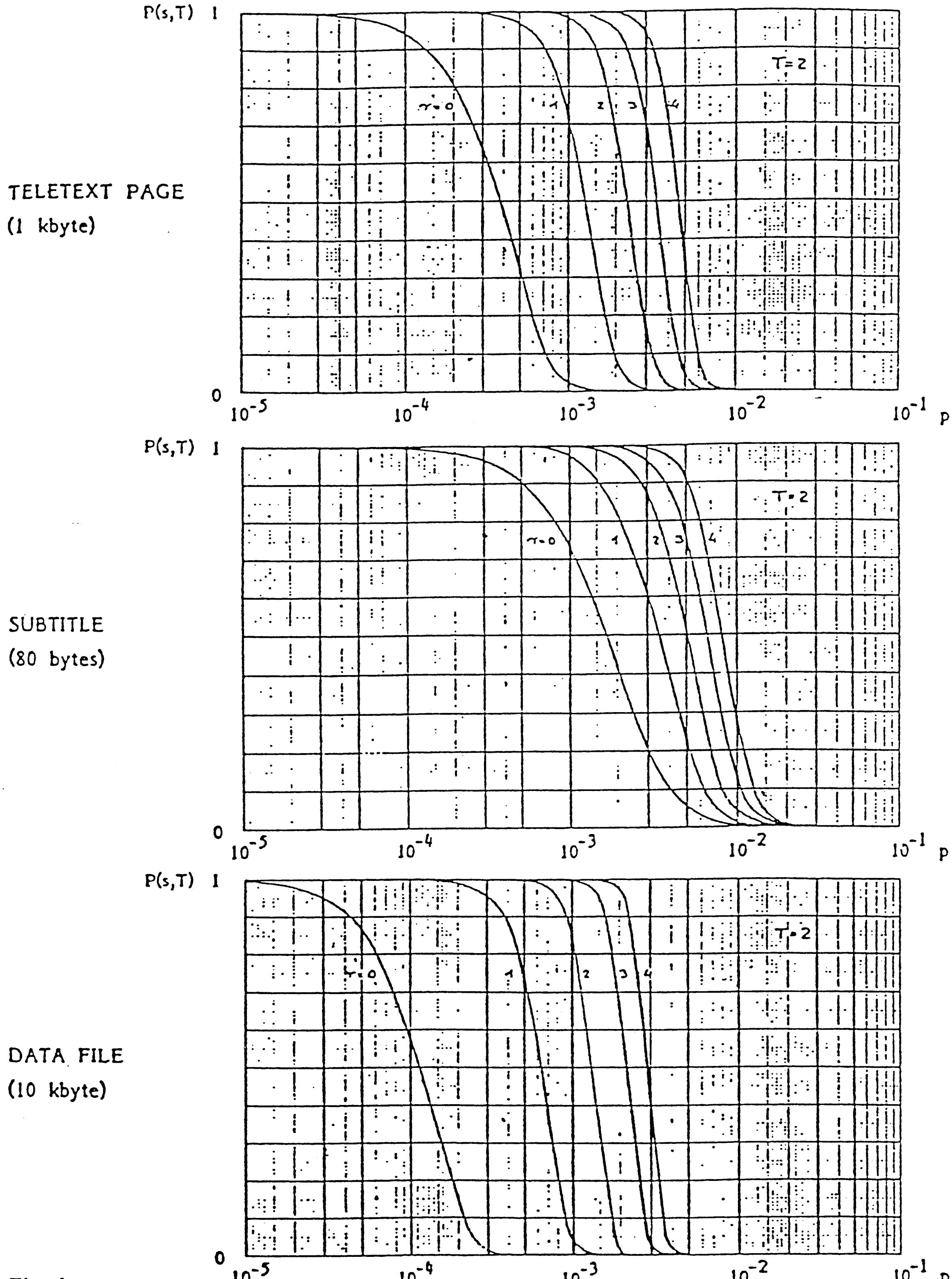


Fig. 4

Strategy C-1 (2): Probability of correctly accepting the three basic Information Units after 2 acquisitions with FEC (correcting 0, 1, 2, 3, 4 errors) and CRC error detection

Block length: 90 bytes, FEC: 0, 10, 20, 30, 40 bits, CRC: 2 bytes

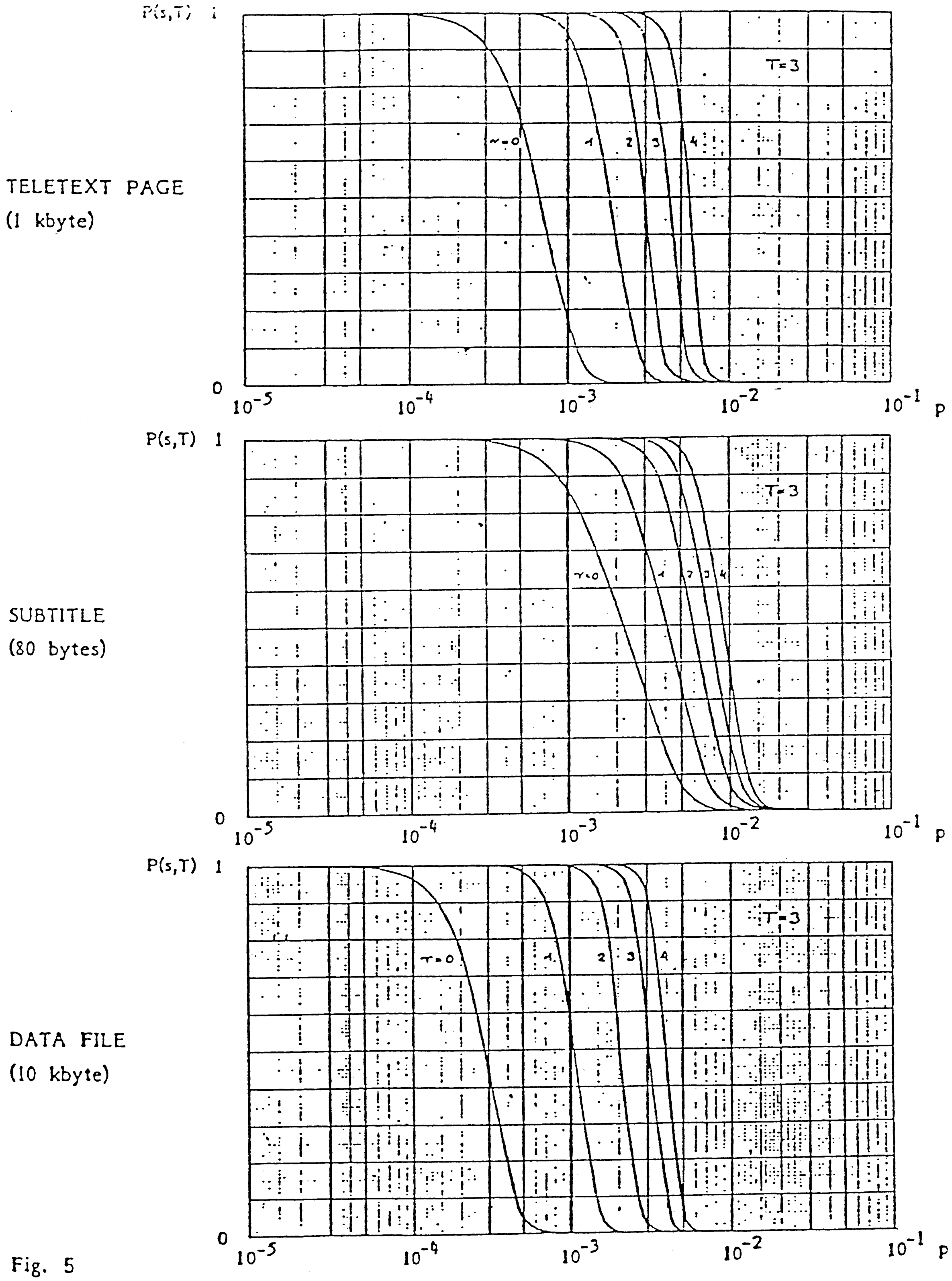
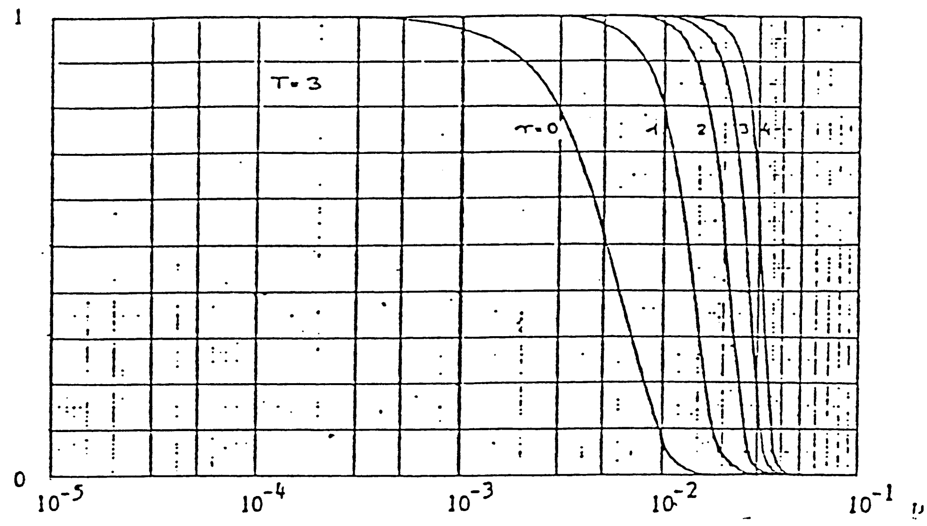


Fig. 5

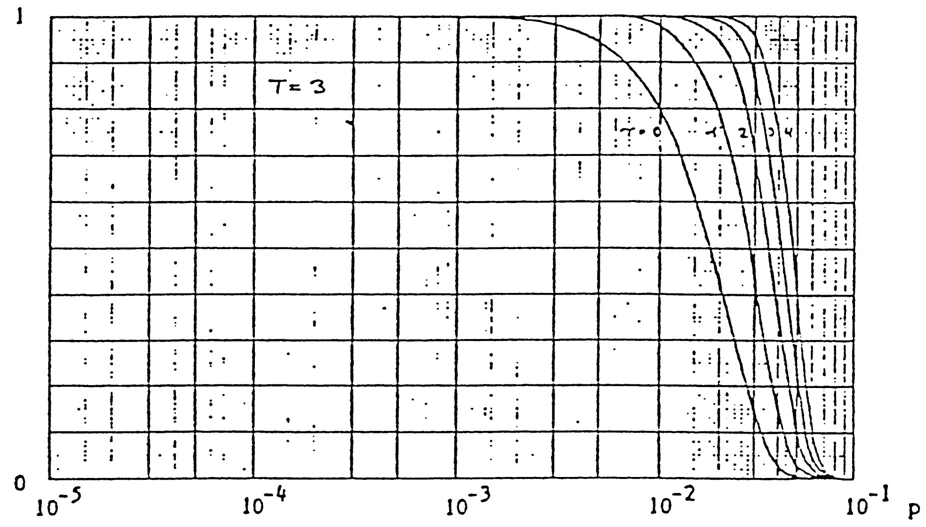
Strategy C-1 (3): Probability of correctly accepting the three basic Information Uni after 3 acquisitions with FEC (correcting 0, 1, 2, 3, 4 errors) ar CRC error detection

Block length: 90 bytes, FEC: 0, 10, 20, 30, 40 bits, CRC: 2 bytes

TELETEXT PAGE
(1 kbyte)



SUBTITLE
(80 bytes)



DATA FILE
(10 kbyte)

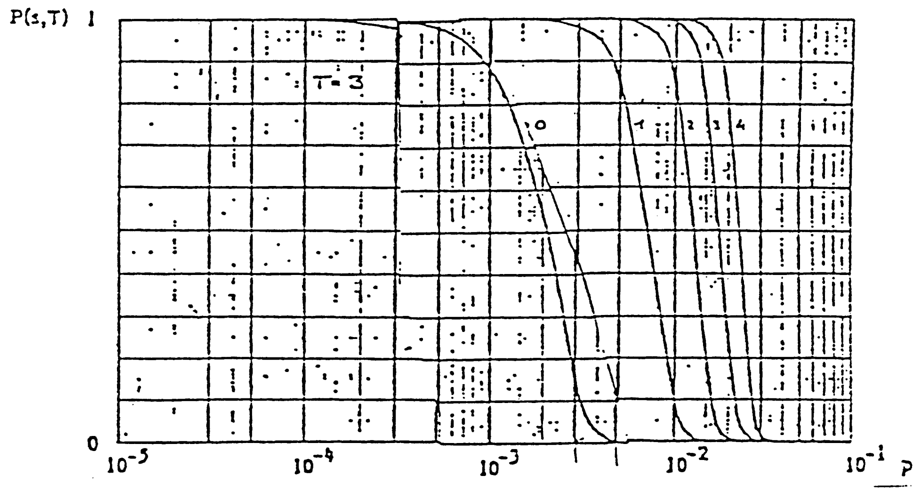


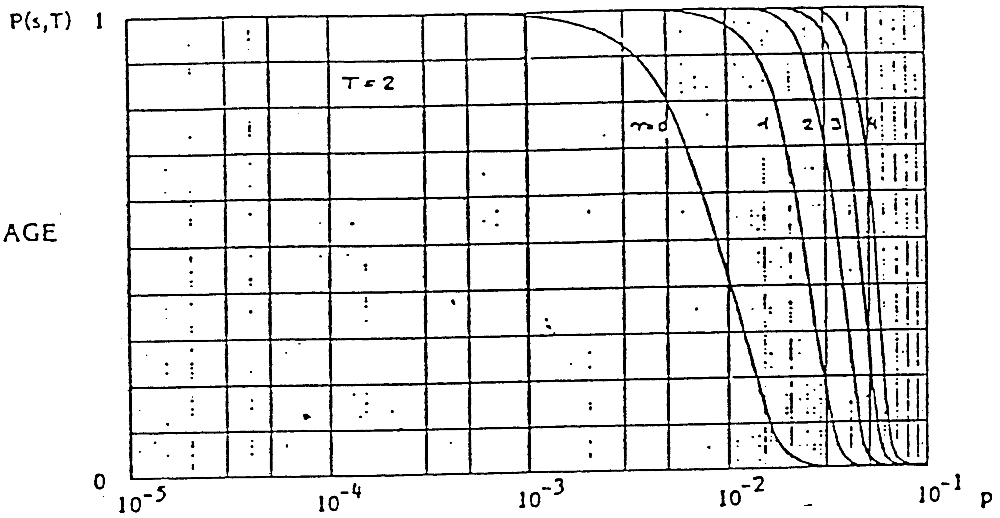
Fig. 6

Strategy C-2: Probability of correctly accepting the three basic Information Units with Majority Logic error correction, FEC (correcting 0, 1, 2, 3, 4 errors) and CRC error detection

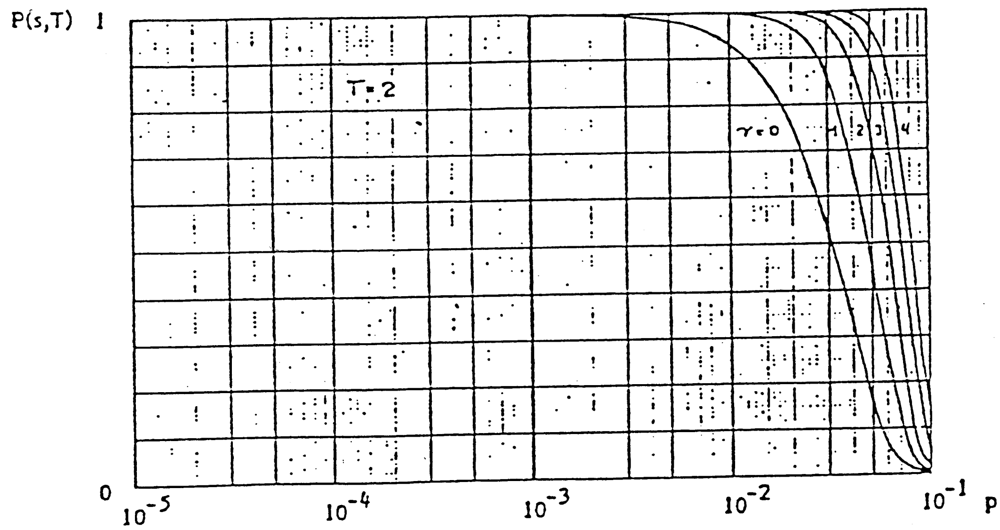
Block length: 90 bytes, FEC: 0, 10, 20, 30, 40 bits, CRC: 2 bytes

The values of P(s,T) for T = 1 and 2 are given in Figs. 3 and 4 respectively

TELETEXT PAGE
(1 kbyte)



SUBTITLE
(80 bytes)



DATA FILE
(10 kbyte)

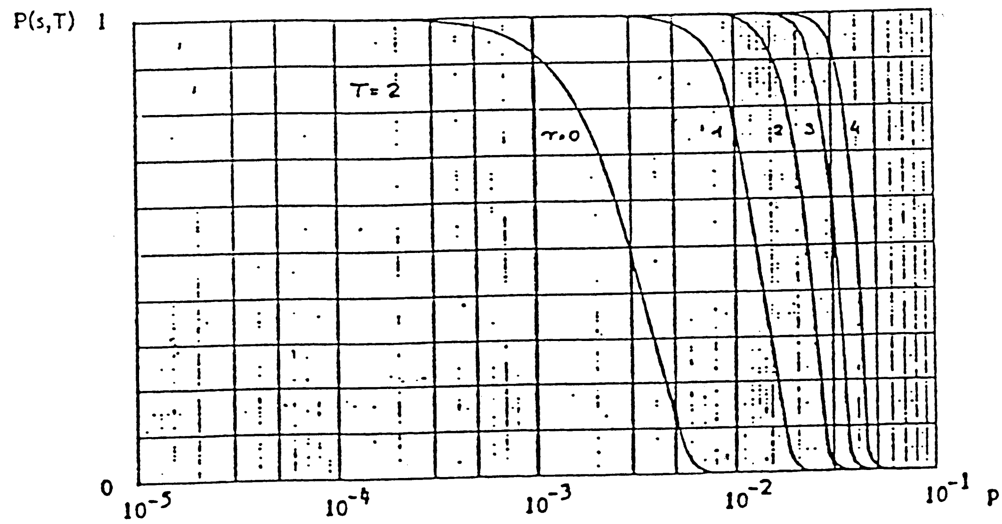


Fig. 7

Strategy C-3: Probability of correctly accepting the three basic Information Units with error correction by bit variation, FEC (correcting 0, 1, 2, 3, 4 errors) and CRC error detection

Block length: 90 bytes, FEC: 0, 10, 20, 30, 40 bits, CRC: 2 bytes
The values of P(s,T) for T = 1 are given in Fig. 3

B. Relationships used for the assessment of error protection strategies

The statistical independence of the errors (memoryless, binary, symmetrical channel) is assumed.

The following notation is used:

P = bit-error rate on the channel
M = number of bytes per data block
R = number of data blocks per file (or teletext page)
T = number of tentatives of acquisition
P(s,T) = probability of success (correctly recovering the file or the teletext page) after T tentatives.

FAMILY (A): PARITY BIT AT CHARACTER LEVEL

7-bit coding + parity: conventional teletext page.

Strategy (A-1)
(PARITY CHECK)

Probability of error-free data message, after T tentatives:

$P(s,T) = Pn\ (1-Pu)$

Where:

Pn = parity check success on the M bytes of the teletext page

$Pn = (1 - Poe^{T})^{MR}$

Poe = probability of odd errors

$Poe = 8p\ (1-p)^{7} + 56\ p^{3}\ (1-p)^{5} + 56\ p^{5}\ (1-p)^{3} + 8\ p^{7}\ (1-p)$

Pu = probability of unrecognized errors on the page

$Pu = 1 - (1-Pee)^{MR}$

Pee = probability of even errors

$Pee = 28\ p^{2}\ (1-p)^{6} + 70\ p^{4}\ (1-p)^{4} + 28\ p^{6}\ (1-p)^{2} + p^{8}$

FAMILY B: 16-BIT CRC

8-bit coding: teletext with enhanced presentation features, telesoftware.

Strategy (B-1)
(CRC)

$$P(s,T) = (1-\langle 1-(1-p)^{8M}\rangle^{T})^{R}$$

Strategy (B-2)
(CRC + ML + CRC)

$$P(s,T) = P\,(dc,T)^{R}$$

where:

$P(dc,T)$ = probability of correct data block, after T tentatives -

$$P(dc,T) = P(CRC/OK) + \langle 1-P(CRC/OK)\rangle\ P(ML/OK)$$

$$= 1-\langle 1-(1-p)^{8M}\rangle^{T} + \langle 1-(1-p)^{8M}\rangle^{T}\ .\ (Q_{BT})^{8M}$$

where:

Q_{BT} = Probability of error-free bit after majority-logic error-correction

$$Q_{B3} = (1-p_1)^3 + 3p_1\ (1-p_1)^2$$

$$Q_{B5} = (1-p_1)^5 + 5p_1\ (1-p_1)^4 + 10\ (p_1)^2\ (1-p_1)^3$$

where:

p_1 = BER on the data blocks with CRC not correct

$$p_1 = p\ /\ \langle 1-(1-p)^{8M}\rangle$$

FAMILY C: 16-BIT CRC + FORWARD ERROR CORRECTION

8-bit coding: teletext with enhanced presentation features, telesoftware.

Strategy (C-1)
(FEC + CRC)

$$P(s,T) = \langle 1-(1-Pa)^{T}\rangle^{R}$$

where:

Pa = probability that the errors of the data packet can be corrected by the code (r or less errors)

$$Pa = P_0 + P_1 + \ldots + P_r$$

$$P_0 = (1-p)^n$$

$$P_1 = n\, p\, (1-p)^{n-1}$$

$$P_2 = \frac{n\,(n-1)}{2}\, p^2\, (1-p)^{n-2}$$

$$P_r = \frac{n!}{(n-r)!\, r!}\, p^r\, (1-p)^{n-r}$$

r = error-correcting ability of the code

n = number of bit in the code word

Strategy (C-2)
(FEC + CRC) + (ML + FEC + CRC)

Probability of error-free data message, after T tentatives:

$$P(s,T) = \left\{ P(FEC + CRC/OK) + \langle 1-P(FEC + CRC/OK)\rangle . \langle P_{m0} + P_{m1} + .. + P_{mr}\rangle \right\}^R$$

where:

$$P_{m0} = (1-p_m)^n$$

$$P_{m1} = n\, p_m\, (1-p_m)^{n-1}$$

$$P_{m2} = \frac{n\,(n-1)}{2}\, p_m^2 (1-p_m)^{n-2}$$

$$P_{mr} = \frac{n!}{(n-r)!\, r!}\, p_m^r\, (1-p_m)^{n-r}$$

with:

$$p_m = 3\, p_1^2 - 2\, p_1^3 = 1 - Q_{B3}.$$

$$p_1 = p \,/\, \langle 1-P(FEC + CRC/OK)\rangle = p \,/\, (1-Pa)^T$$

$$P(FEC + CRC/OK) = 1-(1-Pa)^T$$

Pa = <see strategy (C-1)>

Strategy (C-3)
(FEC + CRC) + (BV + FEC + CRC)

Probability of error-free data message, after T tentatives:

$$P(s,T) = \left\{ P(FEC + CRC/OK) + <1-P(FEC + CRC/OK)> (P_{b0} + P_{b1} + .. + P_{br}) \right\}^{R}$$

where :

$$P_{b0} = (1-p_b)^n$$

$$P_{b1} = n\ p_b\ (1-p_b)^{n-1}$$

$$P_{b2} = \frac{n\ (n-1)}{2}\ p_b^2\ (1-p_b)^{n-2}$$

$$P_{br} = \frac{n!}{(n-r)!\ r!}\ p_b^r\ (1-p_b)^{n-r}$$

with:

$$p_b = p_1^2$$

$$p_1 = p/\ (1-Pa)^T$$

P(FEC + CRC/OK) = <see strategy (C-2)>
Pa = <see strategy (C-1)>

REFERENCES

COMINETTI, M. and MORELLO, A. [September, 1985] - Telesoftware - Sistemi di protezione dagli errori di transmissione. RAI Research Centre, Technical Report No. 85/10/I.