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Quality of Service Measurements of Video Encoded Sequences Over an Emulated Ka Band Satellite Environment[♦]

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Abstract. A well equipped laboratory environment has given the opportunity to measure in an objective way the quality of H.261 video coded streams when transmitted over a noisy satellite channel. Two different transmission chains have been implemented, based on IP and DVB platforms, respectively. The unavailability of the Italsat satellite obliged us to perform the experiment in an emulated environment at intermediate frequency (IF) level. The results obtained are quite interesting, showing that DVB always performs better than IP, and they open the way for further experiments for the investigation on packet video transmission over a rain faded satellite link.

1. Introduction

In view of the commercial exploitation of the Ka satellite band that is foreseen for the near future, an increasing number of applications are being experimented, involving multimedia communications in the satellite environment. Among others, the Italian National Consortium for Telecommunications (CNIT) has undertaken a number of projects in this field, whose synergy has contributed to create its private networking infrastructure, based on the TCP/IP protocol suite, over a heterogeneous transport platform. This platform is constituted by Ka band satellite links and bandwidth leased by national operators. In particular, two projects are providing advanced applications over this network, namely, the *Teledottorato* [1] and *LABNET* [2] ones. Of these, the former is focused on the creation and delivery of distance learning advanced short courses (10 hours each), dedicated to PhD students in Information and Communications Technology all over Italy, by using multicast audio-video Internet applications, with Quality of Service (QoS) guarantees. The latter is setting up and experimenting hardware equipment and software tools for the remote access to sophisticated laboratory instrumentation, for measurement and testing purposes.

The multimedia applications employed in these projects make extensive use of video encoding techniques, like H.261 and MPEG2-MPEG4, which are transported over a RTP/UDP/IP platform. Recently, some experiments have been conducted with CNES(1) in France, by connecting their Toulouse site with the CNIT Network Operating Center in Naples, via an IP-IP tunnel through the Internet over which the multicast flows generated by the *Teledottorato* lectures are encapsulated. On the French site, CNES utilizes PCNS (Plate-forme de Communication Numerique par Satellite), its experimental, widely-open DVB-S European platform over the Ku Hot Bird satellite transponder. The received multimedia flows, after decapsulation, are handled by CNES in two ways: i) by decoding audio and video at the application level and re-encoding them via MPEG2; ii) by directly passing the IP packets over to PCNS. Both flows (MPEG and IP) are transmitted simultaneously in the DVB-S

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(1) Centre National d'Etudes Spatiales

frame, and become available all over Europe, through the use of either a commercial IRD (Integrated Receiver Decoder; TV-mode only) or dedicated PC boards (TV- and IP-mode).
The above described situation includes many aspects that are common to the satellite environment. In particular we may have different video encoders whose frames can be segmented in various ways, according to the network and data link layer characteristics. The latter may range from IP over HDLC-like data link protocols, to IP over DVB, or to direct transmission of MPEG or H.261 over DVB.
As a matter of fact, in an environment characterized by a non negligible bit error probability (BER), these different scenarios may have a strong impact on the quality of the decoded video sequence. Within this setting, we have undertaken an evaluation of the impact of the satellite channel characteristics over the performance of H.261 video coded streams, derived from TV news, in different satellite channel quality conditions. The goal is to quantify the quality of the received video stream in an objective mode. This paper presents the measured results of an evaluation of H.261 video sequences over both IP and DVB, performed in a laboratory test bed, where an accurate emulation of the Italsat Ka band satellite channel is carried on(2).

2. The Experimental Environment

The video coding techniques (such as MPEGx and H.26x families), described in the main international standards, are highly sensitive to errors during transmission. The process of removing spatial and temporal redundancy [3] means that the remaining data are very important to the correct reconstruction of the video sequence in the decoder. It means that if any part of the coded data is lost or corrupted, the decoded sequence may be significantly distorted. An error during transmission of a coded video sequence can have a very significant effect, because decoding and decompressing the coded data may lead to a magnification of the error. The resulting distorted area may propagate spatially and temporally through the decoded sequence, leading to a large area of distortion in a series of frames, thus significantly reducing the visual quality and, in some cases, ending up in a decoded sequence that disturbs the observer s sight.
In order to evaluate the effect of different levels and patterns of errors on the quality of the decoded video, it is necessary to use subjective and/or analytical testing methods to determine the visual quality of the sequence. The commonly used subjective assessment is the perceptual quality, called the *mean opinion score* (MOS)(3), which requires several observers and many tests in order to provide a reasonable statistical spread of results.
The reference measures used for an objective video quality assessment are the *mean squared error* (MSE), calculated on the difference signal between the original error-free sequence and the received decoded sequence, and the *peak signal to noise ratio* (PSNR), measured in dB, defined as:

$$PSNR = 10 \ \log_{10} \frac{(2^n - 1)^2}{MSE} \qquad [dB]$$

where n is the number of bits required to represent each pixel.
To evaluate MSE and PSNR it would be necessary that the transmission medium deliver the whole content of the video stream, including the corrupted parts, without discarding data blocks affected by errors that cannot be recovered by the FEC code. This is possible in a MPEG-over-DVB environment, where the receiver can also accept corrupted packets without discarding them, and the video decoder is still able to operate even on a corrupted sequence. Unfortunately, this situation does not apply in the H.261 case, because the video decoder is not able, in general, to handle all types of errored sequences. Thus, even though the data link protocol would deliver the entire received bit stream, synchronization losses might occur at the video decoder, which would require a synchronization recovery mechanism. The temporary loss of data in this situation also requires a choice on the strategy to apply in substitution of a missing data block. One possible solution is to freeze the previous Macro Block (MB) [4, 5] correctly received and to repeat it for substituting the missing one. In this case, the evaluation of the PSNR is still possible.

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(2) At the time of writing, the Italsat satellite was no longer available

(3) Recommendation 500-5 of the ITU-R

H.261 video is organized into a hierarchy of layers. The defined layers are, from top level: Picture, Group Of Blocks (GOB), Macro Block, and Block. Each layer is built from the lower one, and it contains its data payload and a header composed by the parameters used for the bit stream generation. As a result of this hierarchical structure, in order to decode a MB, the knowledge of the picture and GOB headers the MB belongs to is sufficient.

A Picture or even a GOB can sometimes be too large to fit into a single packet. Therefore it is reasonable to choose the MB as unit of fragmentation: packets have to start and to end on a MB boundary. To allow independent processing of packets, some state information from the frame and the GOB headers is carried within each packet, to allow the MBs in the packet to be decoded. Such information includes: GOB number, macro block address predictor, and quantizer value. In our experiment we have chosen both the MB as fragmentation unit and the freezing of the MB in case of loss.

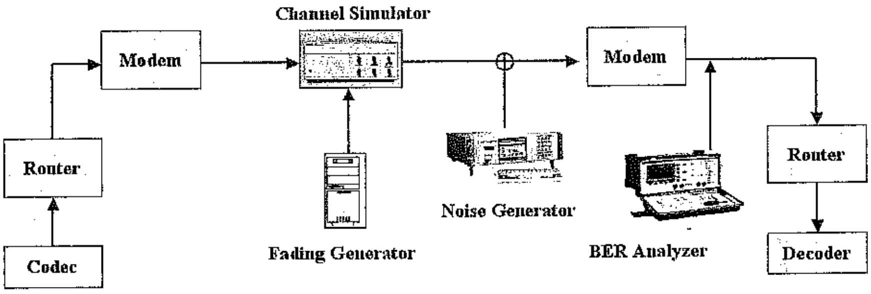


Fig. 1. The laboratory experimental setup.

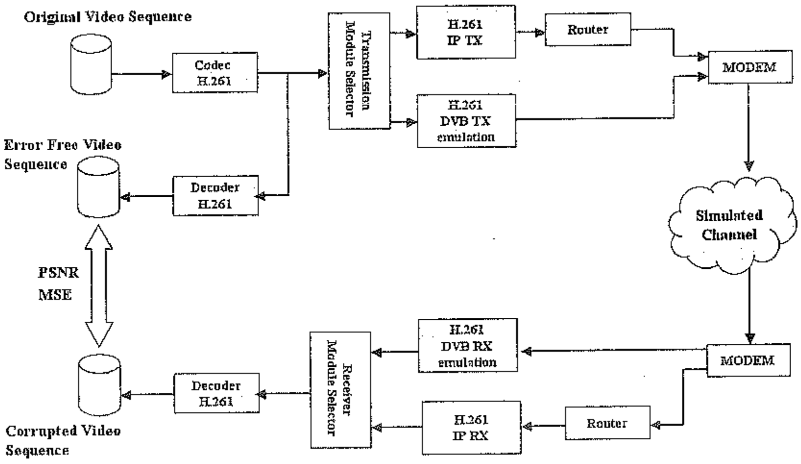


Fig. 2. The logical data flow diagram of the experiment.

Due to the unavailability of the Italsat satellite, we have emulated the experiment by using the telecommunication systems testbed of the CNIT National Laboratory for Multimedia Communications in Naples. The experimental layout is shown in Fig. 1. We have set various signal to noise ratio (S/N) values suitable for evaluating PSNR and MSE at constant bit rates. Furthermore, taking the Italsat satellite characteristics [6] and the CNIT earth station parameters (1.8 m antenna and a 1 W SSPA), we derived the link budget, which then resulted of up-link noise predominant type. We also assumed that the up-link fade were perfectly compensated by the up-link power control, and we applied real attenuation data on the down-link by means of the fading generator. The modems used were of FAIRCHILD SM290 type, operating in QPSK, at an information rate of 2048 Kbps, with a sequential FEC (forward error correction) of 3/4.

The logical data flow diagram of the experiment is shown in Fig. 2, which highlights both situations of transmission chains that have been implemented: i) relatively long IP packets (1500 byte Maximum Transfer Unit - MTU, with average length of 347 bytes), carried within a PPP (point-to-point protocol) data link, which discards corrupted PDUs; ii) DVB frames, carrying a payload of 184 bytes per packet. In this second case, packets in error are not discarded but, for the previously said synchronization loss reason, the H.261 decoder is generally unable to decode them.

3. The Measurement Results

Several tests have been performed over the emulated environment. The video sequence utilized is taken from a 5 minutes recording of a TV news. The chosen sequence is particularly critical, as it contains moving and still images, text (headline news), and it is characterized by a number of zooming movements. Figures from 3 to 6 refer to measurements done under a constant BER level during the entire duration of the transmission.

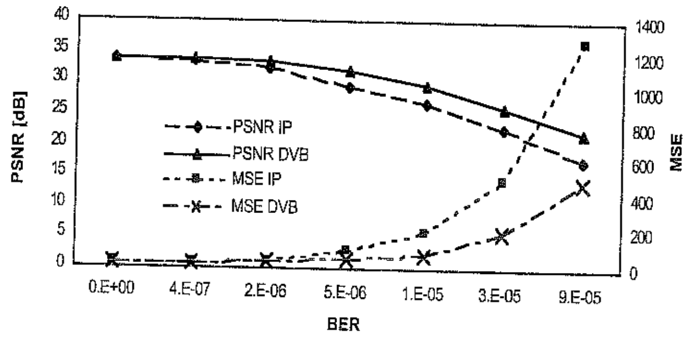


Fig. 3. PSNR (left axis) and MSE (right axis) vs. BER for transmissions of a H.261 coded sequence. Two cases are reported: the first one refers to an IP stream over PPP, while in the second one the stream is directly packetized according to a DVB format.

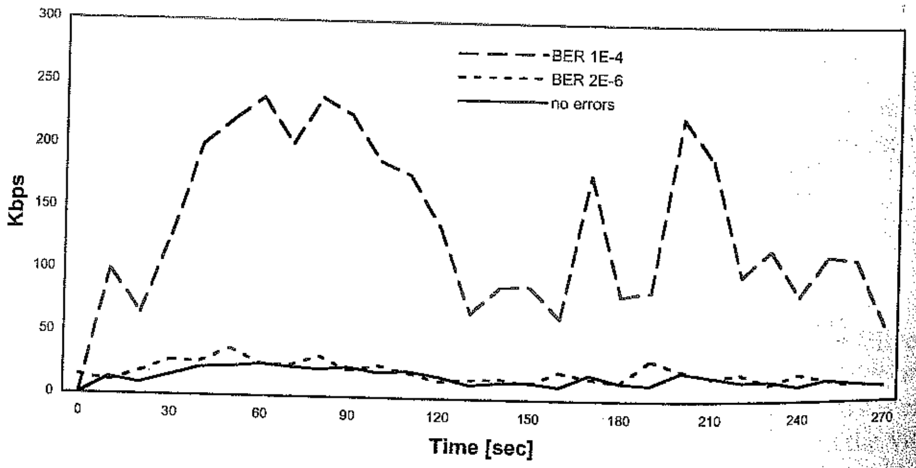
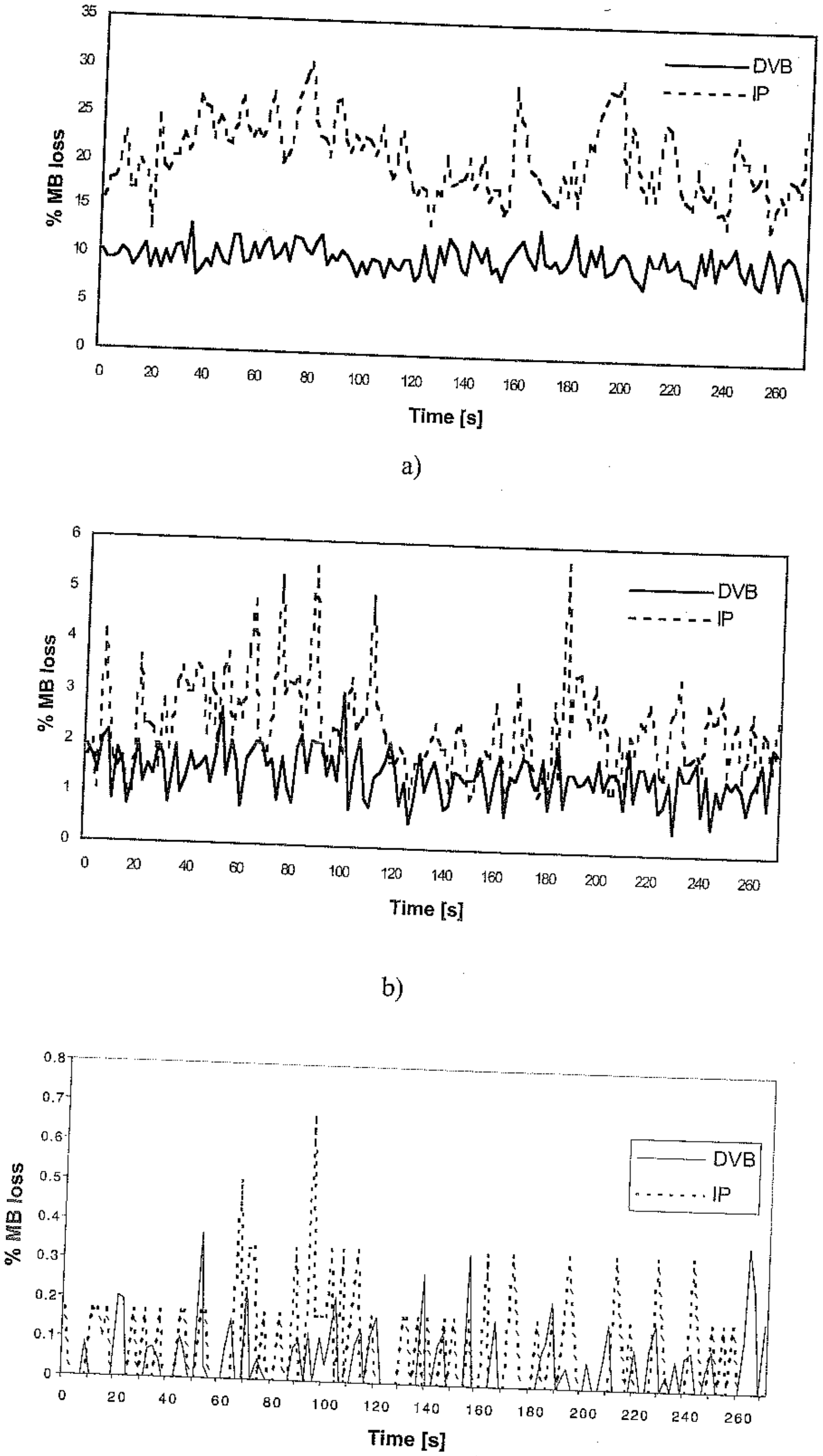


Fig. 4. Goodput difference between DVB and IP transmissions for two BER levels. The no errors line represents the overhead introduced in the DVB case.

Figure 3 reports the results of MSE and PSNR, calculated at different BER values, by averaging the same quantities over all video frames in the sequence. The 33 dB PSNR that can be observed at BER=0 is caused by the coding/decoding process, which is lossy. For all other BER values, the DVB case exhibits a lower degradation.



a)

b)

c)

Fig. 5. Percentage of lost Macro Blocks vs. time during a transmission of IP over PPP and direct DVB on a satellite link with BER 10^{-4} (a), 10^{-5} (b) and 10^{-7} (c).

In order to explain this result, we have to make the following considerations. In the IP case, packets affected by at least one errored bit are discarded, and the decoder looses all the MBs they contain. In the DVB case, packets in error are not discarded; however, the decoder looses the corresponding MBs, owing to the possible synchronization loss mentioned above. As DVB packets have shorter length, the number of unused MBs will be anyway less than in the previous IP case. The gain resulting from this effect actually justifies the additional overhead that is necessary in order to make the MBs contained in a DVB packet identifiable (i.e., attributable to the corresponding GOB and Picture). As a matter of fact, the corresponding goodput (in terms of MBs actually available to the decoder) is always in favour of the DVB case, as evidenced in Fig. 4 for two BER values.

Figure 5 shows the behaviour of the percentage of lost MBs, averaged over 2-second intervals, at different BER values. The comparison is practically always in favour of DVB.

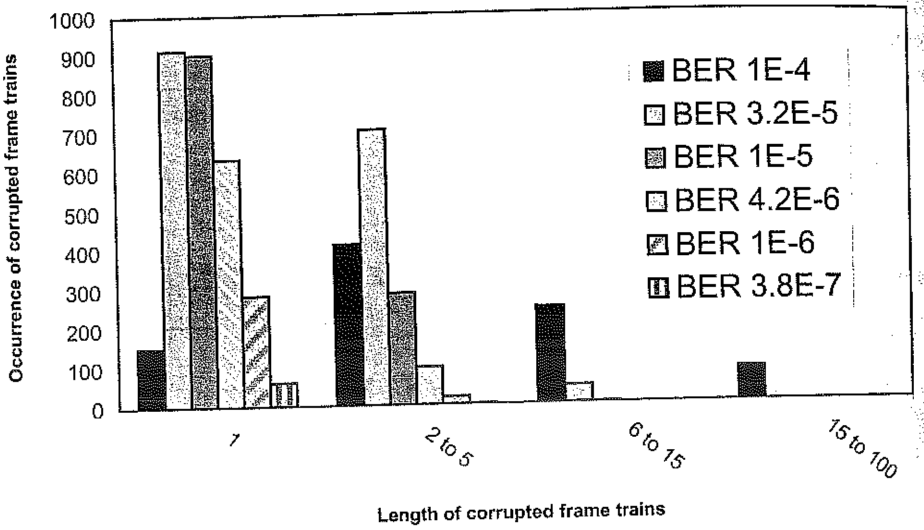


Fig. 6. Number of occurrences of consecutive corrupted frames for different levels of BER.

In Fig. 6 the corrupted frames are grouped in four classes according to the length of corrupted sequences. The first class takes into account isolated corrupted frames, the second class contains sequences formed by consecutive corrupted frames from 2 to 5, and so on.

The set of figures from 7 to 13 refer to the situation where a specific fading pattern, taken from real Ka band data, has been applied.

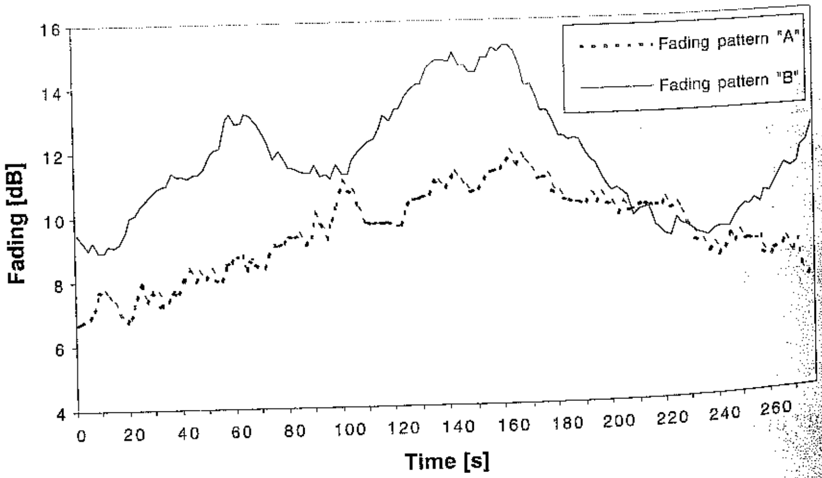


Fig. 7. Plot of the fading vs. time in the two cases studied: the pattern indicated as „B", which corresponds to a quite severe fading, causes a temporary sync loss at the demodulator

Figure 7 shows the two rain attenuation patterns used, which are taken from the results of the propagation experiment carried out in Ka band on the Olympus satellite by the CSTS (Centro Studi sulle Telecomunicazioni Spaziali) Institute, on behalf of the Italian Space Agency (ASI).

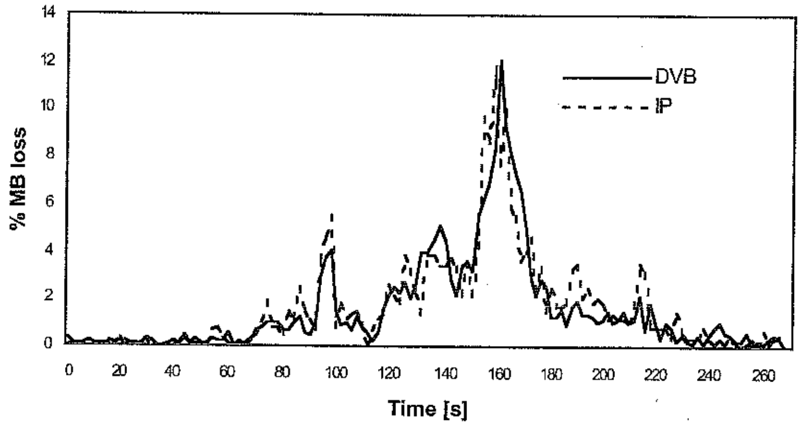


Fig. 8. Percentage of lost Macro Blocks vs. time for a transmission of IP over PPP and direct DVB, when the satellite link is affected by the fading pattern A reported in Fig. 7.

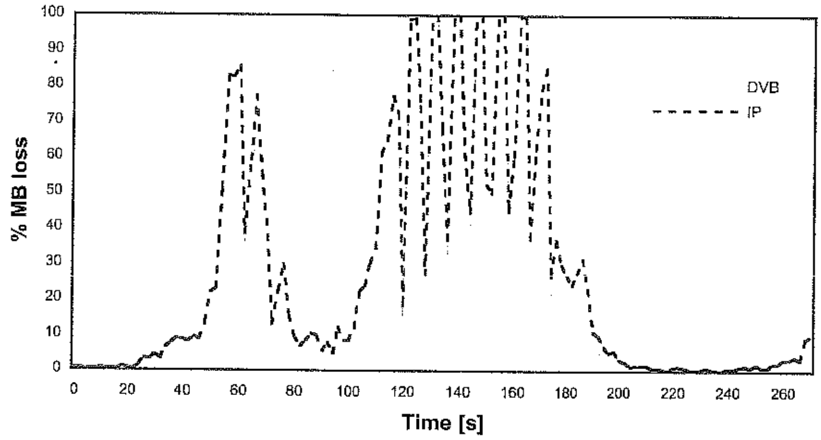


Fig. 9. Percentage of lost Macro Blocks vs. time for a transmission of IP over PPP and direct DVB when the satellite link is affected by the fading pattern B reported in Fig. 7.

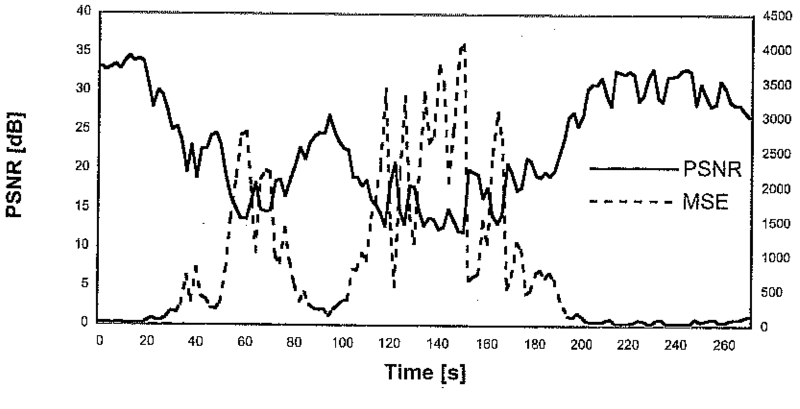


Fig. 10. PSNR and MSE vs. time for a DVB transmission when the satellite link is affected by the fading pattern B reported in Fig. 7.

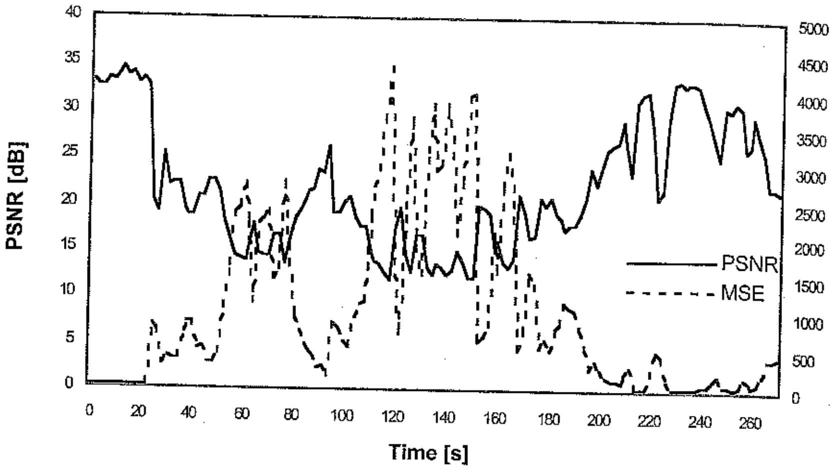


Fig. 11. PSNR and MSE vs. time for an IP over PPP transmission, when the satellite link is affected by the fading pattern B reported in Fig. 7.

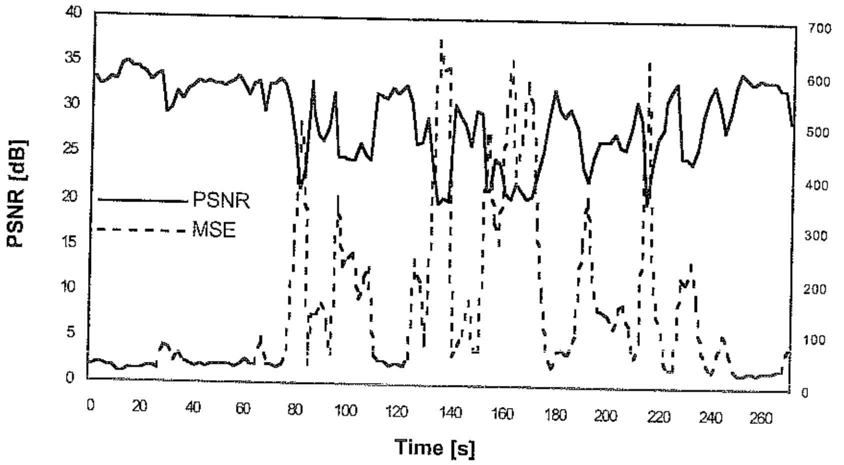


Fig. 12. PSNR and MSE vs. time for an IP over PPP transmission, when the satellite link is affected by the fading pattern A reported in Fig. 7.

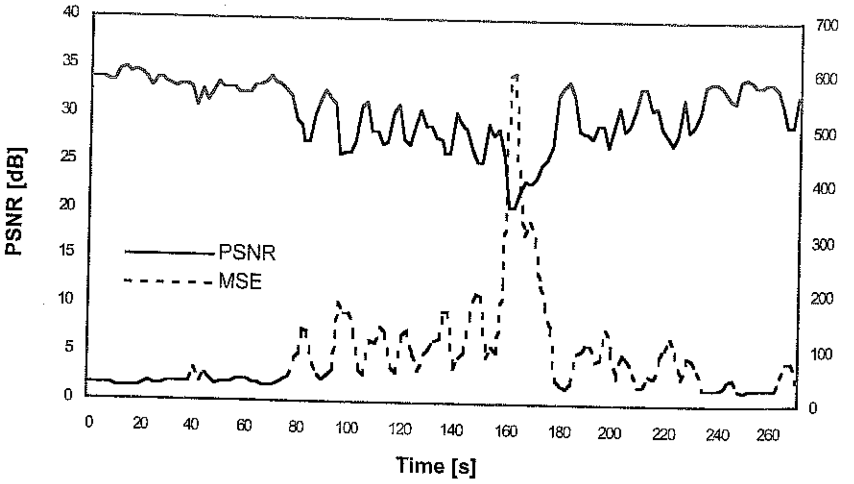


Fig. 13. PSNR and MSE vs. time for a DVB transmission, when the satellite link is affected by the fading pattern A reported in Fig. 7.

The attenuation samples considered were 1-second averages, expressed in dB, of the signal power attenuation with respect to clear sky conditions. Patterns A and B are taken from data recorded at the Spino d Adda (Northern Italy) station on September 21st and 23th, 1992, respectively. These patterns have been used in the experiments whose results are reported in Figs. 8-13 below. In Figs. 8 and 9 the MB loss is reported in the IP and DVB cases for both fade patterns, while Figs. 10-13 show the calculated MSE and PSNR. When fade pattern B is present, the modem experiences periods of synchronization losses lasting 5 seconds on average. In general, the results confirm the better performance of the DVB case.

4. Future Work

At the moment, only the H.261 video stream coder was taken into account through all our experiments: surely a larger set of video coders (e.g., MPEG2), as well as audio coders should be considered for testing in Ka band satellite links. In particular, the results so far obtained encourage the comparison with MPEG2 over DVB. The research carried out in the image coding field also suggests the (partial) re-implementation of some classic audio/video coders, with the aim of improving the robustness of the streams transmitted over the satellite channel [7]. Furthermore, since PSNR is often not completely adequate to express the actual quality of a video stream perceived by the user, some subjective metrics, such as MOS, should be employed, in order to evaluate the effects of fading on multimedia transmissions. Finally, when access to a Ka band satellite will become again available, some of the tests previously presented should be repeated on a real satellite link.

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