Video Quality monitoring in digital TV networks

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DTV services have rapidly developed in the last few years, based on advances in digital signal-compression technology. However, QoS issues – which are often the most critical parameter to evaluate in a DTV system – have not developed at the same pace. In order to ensure the Quality of Service provided to the end-user, there is an urgent need to develop appropriate methods and tools.

This article presents a reference model that is a generic framework for describing any automatic video-quality assessment method. The issue of in-service video-quality monitoring in DTV networks is addressed, and an effective method of monitoring the QoS is presented. This method has been implemented and tested in a range of situations – on both simulated and real DVB broadcasting networks.

1. Introduction

Digital television systems provide an unprecedented level of flexibility. As a drawback, each system element may influence the perceived video quality by introducing specific impairments which affect the decoded signals. Those impairments fall into one of two categories. Firstly, MPEG-2 compression – as a lossy and non-linear process – essentially leads to a coder- and content-dependent audio and video quality. Secondly, digital transmission systems generate binary errors when the automatic correcting threshold is reached.

The impact of digital impairments on signal quality cannot be predicted simply from the encoded bitstream. Indeed, the picture content, the receiver performance and the decoder processing (e.g. error-masking strategy) may have a strong influence. Consequently, the usual "provider-oriented" bitstream-level parameters – such as bit or packet error rates – are inadequate for monitoring the signal quality in digital systems. Specific additional methods must be used to measure the perceived quality.

Many objective (automatic) audio- and video-quality assessment methods have been proposed, with the goal of predicting the quality level as given by a panel of viewers in subjective approaches. In this article, we address more specifically the video quality, which we believe to be an important component of QoS. We present a generic model for in-service video-quality monitoring. This model has been submitted to standardization bodies and is intended to serve as a structuring tool in the field. The second part of the article presents an effective video-quality assessment method developed by TDF-C2R, applicable to DTV networks. This method has been tested in various applications. We will more specifically address the monitoring of DTV networks in real time.

2. Measurement strategies

Most video-quality assessment methods rely on comparing the measured distortion at the input with that at the output of the TV system. This configuration requires some information about the input (reference) pictures to be carried along with the normal video signals to the distant measurement point in the broadcasting network. Naturally, the amount of reference information carried along with the normal video should be minimized. Three measurement strategies are applicable, depending on the application domain and the requirements [1][2].

1) Strategy 1

The *full reference* approach requires the availability of both the reference video pictures and the impaired decoded pictures. The quality assessment is based on the distortion measured at pixel level. However, unlike SNR, the integration of complex human visual system models, and/or the a priori knowledge of the impairments, aim at providing a quality evaluation well correlated with the subjective evaluation of a panel of viewers.

The drawback is that a full-bandwidth reference video – that is to say, several Mbit/s per programme – has to be transmitted, leading to important bandwidth consumption and processing complexity. Finally, precise spatial and temporal synchronization of the reference and the impaired pictures is necessary, at the pixel level. Although these conditions can eventually be met during laboratory tests, they are not realistic for in-service operation and for use throughout a DTV network – without applying strong compression and/or sub-sampling to the reference data. Clearly, the trade-off between cost and performance is a disadvantage of this first strategy.

2) Strategy 2

The second strategy is a *reduced reference* approach (*Fig. 1*). The quality assessment methods rely on the measured distortion for a small set of parameters only, instead of for each pixel. Those parameters are designed to highlight specific impairments observed in

DTV pictures. The parameters are processed at the entrance to the DTV chain (Entrance Control) and at each measurement point (Final Control). A linear combination of the distortion usually provides the final objective quality evaluation. The combination model is tuned to maximize correlation with the subjective test results [3].

This strategy may provide results less accurate than the full reference one. However, it offers the advantage of surveying the transparency of transmission links, using a very low bit-rate of the order of 10 kbit/s for the reference data. Additionally, the processing complexity is lower, making real-time implementations affordable. Consequently, this second strategy is well adapted for an automatic and continuous monitoring of signal quality on DTV networks.

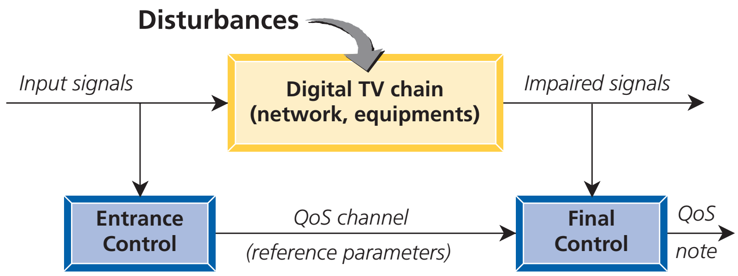


Figure 1
Methodology with reduced reference data.

3) Strategy 3

The third class works *without reference* information transmitted from the input to the measurement point. Instead, it focuses on the measurement of the most characteristic impairments of DTV – usually blocking effects generated by the encoding equipment [4][5]. Thus, the "quality" assessment is quite limited to just these few impairments. This strategy can be used for checking the quality of received signals when no reference video is available. Its advantage is a relatively straightforward implementation.

3. Generic model

The variety of available quality-assessment methods makes a comparison of their respective designs difficult. However, a generic model – within the framework of ITU-R JWP 10/11Q – has now been proposed. It describes a general structure for the measurement methods, in order to progress the standardization of just one measurement method [6]. This generic model is designed for in-service video-quality monitoring applications over DTV networks.

3.1. General concepts

The design and development of a video-quality meter brings us to consider a general structure for the measurement procedure. It comprises several layers:

- ⇨ **Measurement methodology** defines the class or the strategy relative to the application requirement (see *Section 2*);

- **Measurement method** is composed of a set of modules implemented to process inputs such as the original signals, and to provide output results such as processed reference data, level of impairment or quality assessment;
- **Algorithmic module** is the basic building block of the signal-processing functions that the method is composed from. It comprises the core of the method from which the final objective qualification is delivered;
- **Associated module** is an additional function that aids the algorithmic modules in their operation, by addressing such issues as dating, synchronization, presentation of data, etc.

3.2. *Measurement Method*

A typical configuration for the measurement method is shown in *Fig. 2*.

The method is composed from algorithmic modules (**ALM**) and associated modules (**ASM**). On the diagram, **N** indicates that the module is located at the Entrance Control measurement point; **N´** indicates that it is located at the Final Control point.

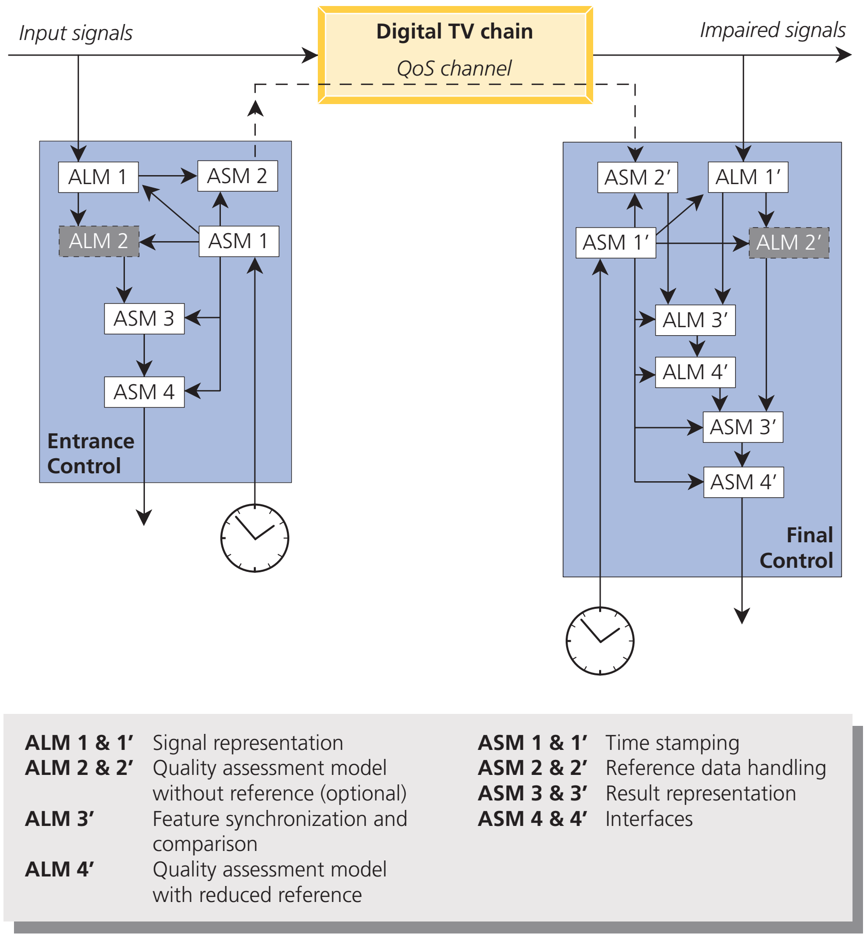


Figure 2
Detailed structure of the generic measurement method.

3.3. Algorithmic modules

3.3.1. Signal representation (ALM 1 & 1′)

ALM 1 & 1′ are modules which extract specific features from the signal. This occurs at Entrance Control (EC) or Final Control (FC), depending on the position of the measurement point or on the retained measurement methodology. Subsequent modules use the extracted features to provide an indicator of the video quality.

Signal representation is one transformation or a set of transformations applied to the video in order to change its representation from pixel values to another domain. This latter domain can be a new matrix of transformed values, or a smaller vector of features. How the appropriate signal representation is chosen depends not only on its perceptual relevance, but also on the bit-rate of the extracted information to be transmitted. This representation will be transmitted from EC to FC in the two methodologies which provide some form of reference data (Strategies 1 and 2 in *Section 2*).

3.3.2. Feature synchronization and comparison (ALM 3′)

In case the proposed quality assessment method is a comparative one, then the monitoring of one or several links in the network requires the comparison of two signal representations, operated at different points. This process demands a precise synchronization between the measurements done at the Entrance Control point and those realized at the Final Control points. To this end, time-stamping information about each measurement is used.

After the synchronization, the comparison result is computed on a sample-by-sample, frame-by-frame or component-by-component basis, depending of the signal representation (matrix or vector). The amplitude of the comparison signal and its statistical properties carry information about the characteristics of the generated distortions. The results are a representation of the degradation between the two video sequences. This output is fed to the next module, i.e. the perceptual model (ALM 4′).

3.3.3. Quality assessment models (ALM 2, 2′ & 4′)

The quality assessment models ALM 2, 2′ or 4′ merge the previously defined features into a single quality score. Since several impairment types can occur simultaneously and influence the subjective judgement, the most relevant measurements of individual impairments must be jointly used [7]. To this end, a combination model is set up as shown in *Fig. 3*. The impairment features are the result of either the signal representation modules (cases ALM 2 and 2′), or the distortion measurement between two representations (case ALM 4′).

Several kinds of models can be implemented in this module. A common solution is a learning approach, which consists of two phases. The learning phase optimizes the model distortion between objective features and a subjective quality database, on a large set of sequences. The operational phase uses the model to assess the quality. The most common model is a linear combination of the individual impairment measurements [8]. Other advanced learning techniques such as neural networks can also be employed [9].

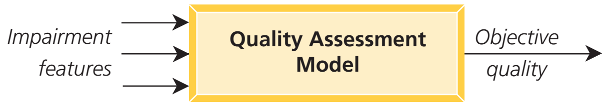


Figure 3
Synopsis of the quality assessment algorithmic module.

The learning methods have the great advantage of being simple and easily implemented, once the model has been set up. A general drawback is that the performance of the model is linked to the relevance of the training sequences used to set up the model.

3.4. Associated modules

3.4.1. Time stamping (ASM 1 & 1′)

ASM 1 & 1′ are the pilots of the quality meters at the measurement points. They provide time stamps for:

- ⇨ the reference data handled through the QoS channel with the inserter and extractor modules (respectively ASM 2 & 2′);
- ⇨ the QoS information transmitted to the supervision system by means of ASM 4 & 4′.

The time-stamping information allows the synchronization in ALM 3′. The operations achieved at the input and output equipments are then synchronous, and ready to carry out the comparison of the parameters.

The time-stamping modules have to use a common unified clock, retrievable throughout the DTV network chain. One example of a unified time reference is the MPEG-2 internal system time clock (STC) [2].

3.4.2. Reference data handling (ASM 2 & 2′)

In order to make signal reference information available throughout digital television networks, it must be transmitted to the final control stations. For this purpose, inserter and extractor means have to be implemented as ASMs at the entrance and final measurement points (ASM 2 & 2′ respectively). An example of this implementation has been proposed [10][11][12].

One solution is to transmit input parameters in-band with the digital TV programmes, within a dedicated QoS channel multiplexed into the MPEG-2 Transport Stream. The bit-rate required to transmit the parameters has to be of the order of a few kbits/s, to be affordable. In this way, the parameters are easily broadcast to all final control measurement points [2]. For this purpose, the creation of a QoS channel has been proposed and standardized within the DVB framework. DVB has edited the recommendations for the use of specific MPEG-2 Packet Identification (PID) numbers, reserved to the QoS channel. Several other applications are also allowed to use this QoS channel [13].

3.4.3. Result representation (ASM 3 & 3')

The ASM 3 module is needed to set up the measurement representation: graphical charts, plots, etc. Depending on the application, a short- or long-term statistical representation is required.

3.4.4. Interfaces (ASM 4 & 4')

ASM 4 concerns the connection of the quality meter to the supervision system. This will allow the gathering of quality information for network monitoring. To achieve the interfacing, HTML page server with JAVA applets is one possible solution. Another solution is to use SNMP (Simple Network Management Protocol) agents, or specific external proxies [14].

4. Quality assessment method

Strategy 2 in *Section 2* (i.e. reduced reference) was the chosen methodology for network monitoring (*Fig. 1*). The approach developed by TDF-C2R relies on an estimation of the amount of each type of impairment by means of a specific feature. The picture-quality comparative features are based on a set of parameters which seek to represent the loss or addition of content from/to the picture, in order to track typical MPEG-2 impairments (blocking, loss of details, blur, frozen pictures). Those parameters are sensitive to both the spatial and temporal content of the video. Additionally, they have been designed to allow real-time implementation of the video analysis, in response to the randomness of transmission errors.

The quality assessment model combines the relevance of the various video impairment features in order to predict the global quality. To this end, an optimization procedure, carried out with subjective data, is used to set up the model. Subjective data are derived from a panel of viewers according to the standard SSCQE protocol [15].

The device which implements the method is called MAEVA (Model for AssEssment of Video and Audio quality). The input parameters are transmitted in-band with the digital TV programmes, in a dedicated QoS channel multiplexed into the MPEG-2 Transport Stream, as shown in *Fig. 4* [13]. The processing of the input and output equipments are synchronous, in order to compare the parameters. The system labels all the measurements with specific time-stamps, which are present in the MPEG-2 stream.

The quality meter allows us to evaluate the video quality in real time. It has been used for assessing the quality of numerous video sequences. Globally, on a 30-minute video sequence, the method provides a predicted Mean Opinion Score (pMOS) which matches the subjective quality MOS evaluation (see *Fig. 5*). A linear correlation coefficient of the order of 0.8 is obtained by this method.

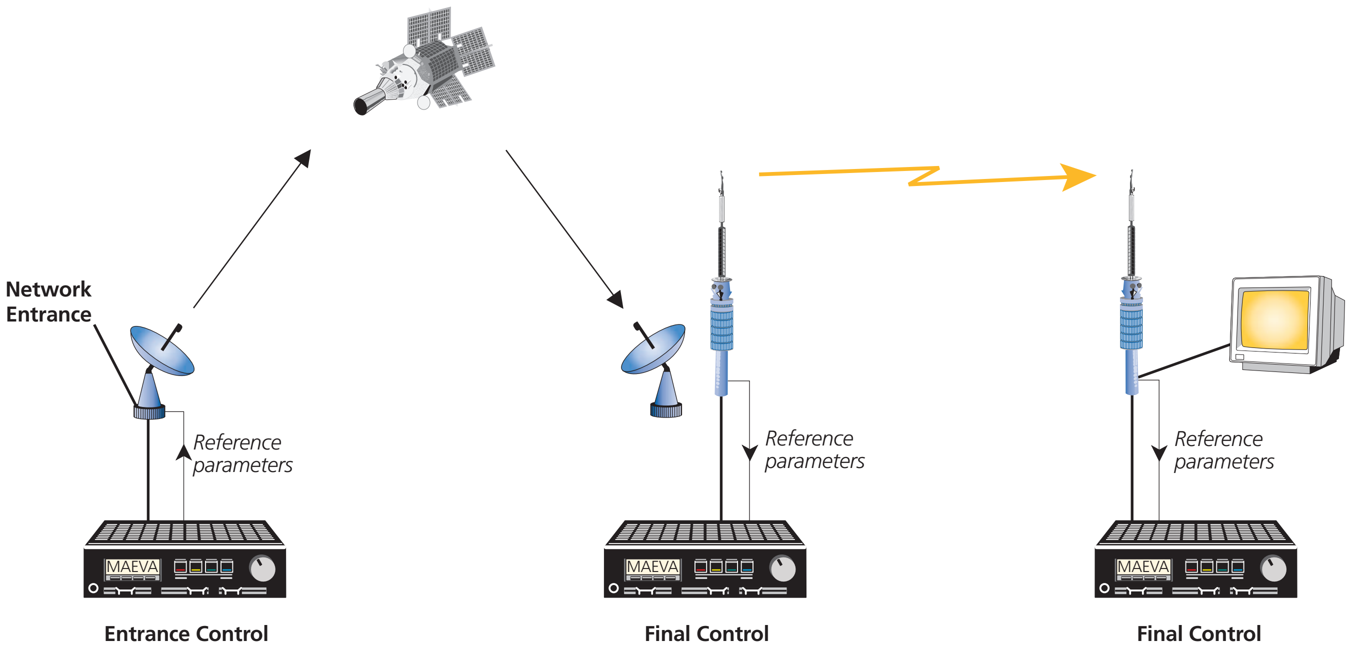


Figure 4
The quality assessment method applied to network monitoring.

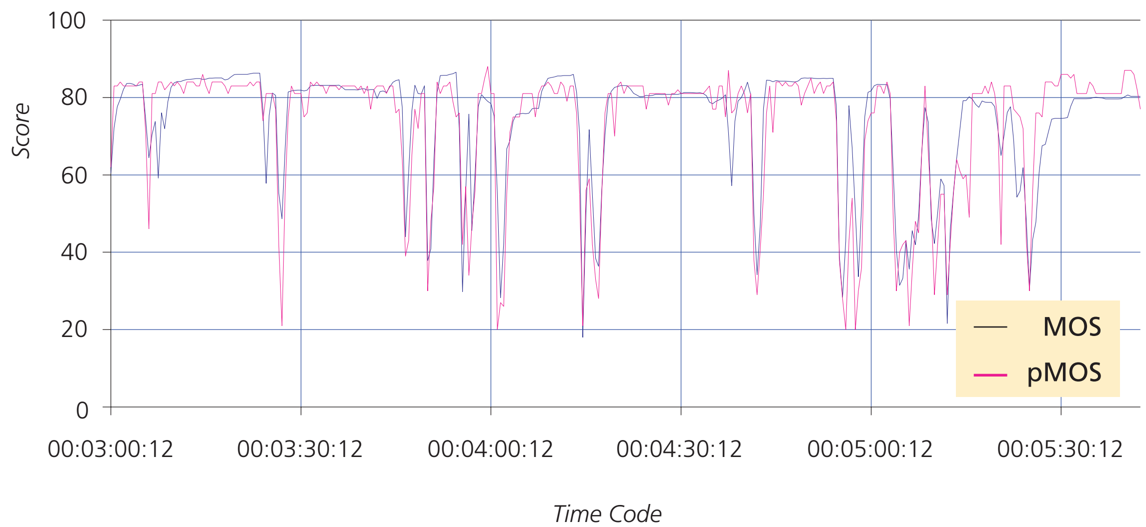


Figure 5
The objective (pMOS) and subjective (MOS) quality of a sequence affected by transmission errors.

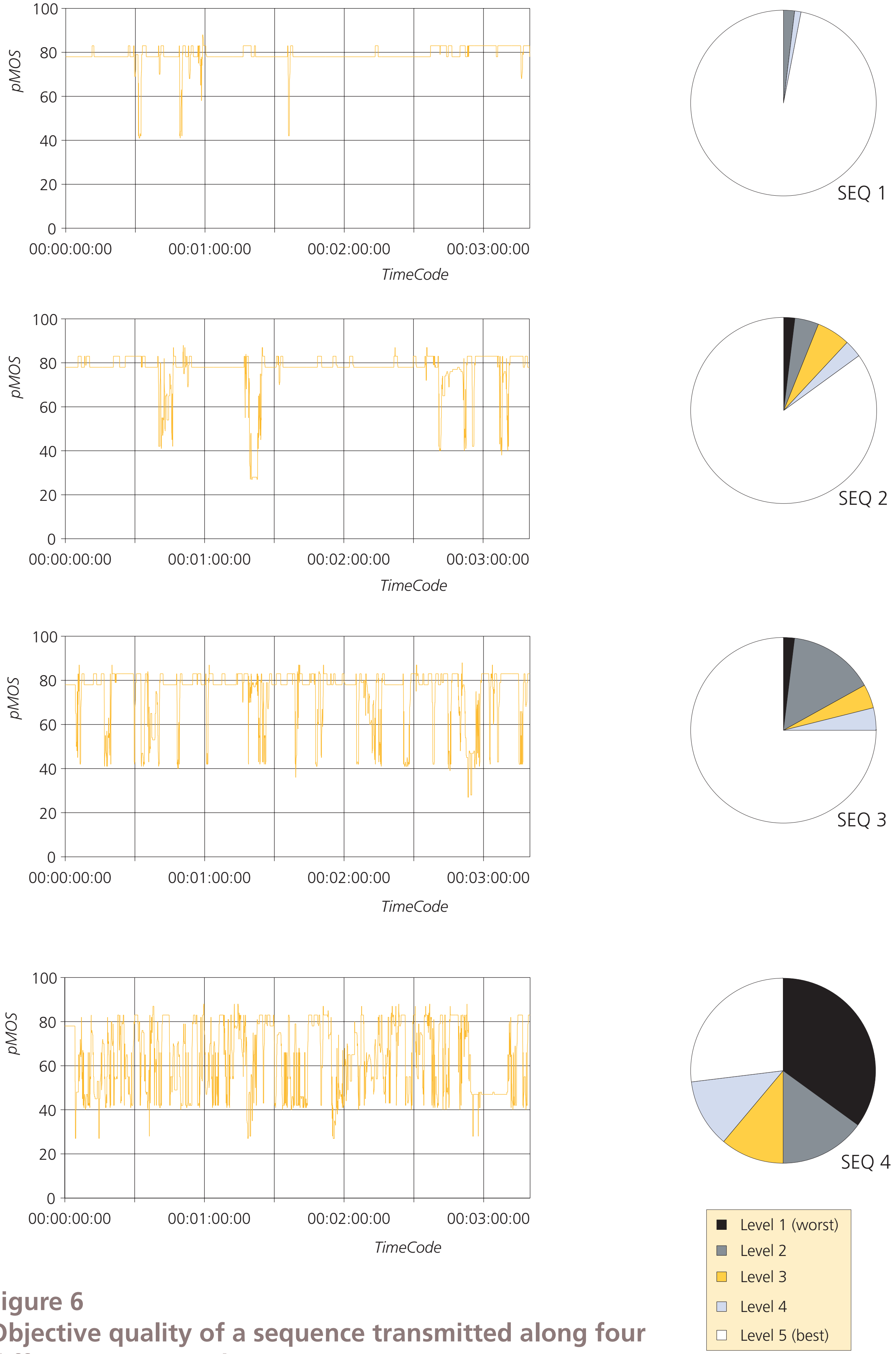


Figure 6
Objective quality of a sequence transmitted along four different DVB-S paths.

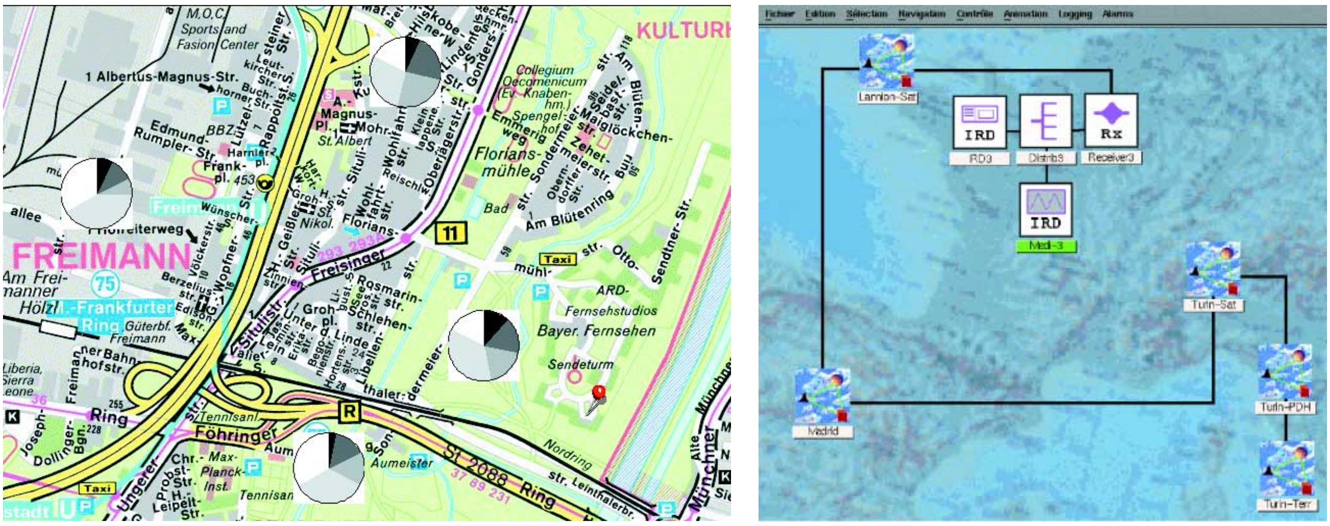
5. Network monitoring

The main application for the designed quality meter is network monitoring. In the framework of the fifth ACTS QUOVADIS and MOSQUITO projects, several field tests have been carried out, in order to validate the equipment on a wide range of video content, transmission conditions, and network configurations (DVB-T, DVB-S, DVB-C, and ATM in a distribution network). For each of these tests, the measurements have been made according to the configuration in *Fig. 1*.

Fig. 6 (previous page) synthesizes the results obtained for a 3-minutes sequence extracted from a live commercial programme, and transmitted on a satellite link with QPSK modulation in four different noisy environments. The variations in quality over a given time period, as well as its distribution on a 5-point quality scale are represented. Depending on the transmission conditions, the impact on perceived quality can vary over a great range. The resulting impairment features and the predicted quality are displayed instantaneously at the network measurement point.

The quality meter has also been deployed on a wide broadcasting network, to test the integration of the device into an experimental supervision system using the SNMP protocol. This gives us the opportunity to build up a global view of the network operational status. The system has given us very satisfactory results, showing the relevance of monitoring the video quality to complement the usual bitstream-level parameters. The comparative approach is well adapted since it has a moderate technical complexity, and it informs us of any distortion in the network. Thus, it is useful for a broadcaster to reserve a small bit-rate in the transport stream for reduced reference information, in order to monitor the video quality remotely.

Fig. 7a shows the application of the quality meter to measurements at several locations within a DVB-T broadcasting area. In cases where a supervision network already exists,



(a) (b)

Figure 7
Quality monitoring at several locations (a), and the supervision display (b).

the quality measurement can be centralized in order to enable an efficient global network monitoring system (*Fig. 7b*).

Beyond network monitoring, the quality meter has been applied successfully in other applications. One of them used the quality meter during a measurement campaign to determine the coverage area of a DVB-T network. The quality level induced by transmission errors was taken into account when determining the service area.

6. Conclusions

In the field of video quality monitoring, some techniques are beginning to emerge from the research area. Several groups within the international standardization bodies are working on this topic. Indeed, the field of network monitoring requires very concise and simple quality indicators. We have proposed here a generic model for video-quality assessment methods, for the monitoring of DTV networks. This model is currently

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In 1996 Gabriel Goudezeune joined TDF-C2R as manager of the Digital Signal Processing department. His fields of interest currently lie in audio and video signal processing aimed at perceptual quality measurements, audio and video watermarking and also digital communications for broadcasting or wireless applications.

under study within ITU-R JWP 10/11Q. This should lead us to find common agreement and consensus over this generic approach which is well adapted to cover a large set of solutions. The proposed method and generic structure can be extended to describe quality meters for audio and video signals, to provide a global audio-visual monitoring service: but that will be tomorrow's work!

TDF-C2R has designed its own quality meter in response to QoS issues for in-service DTV networks. The MAEVA quality meter is a solution for end-to-end measurement strategies, based on a "double-ended with reduced reference" approach. The quality meter has been tested and validated in various real broadcasting network applications and on several signal types. The choice of a reduced reference approach is the most efficient one for network supervision, as it provides a good trade-off between complexity and measurement performance.

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Abbreviations

ACTS Advanced Communications Technologies and Services

ALM Algorithmic module

ASM Associated module

ATM Asynchronous transfer mode

DTV Digital television

DVB Digital Video Broadcasting

DVB-C DVB - Cable

DVB-S DVB - Satellite

DVB-T DVB - Terrestrial

EC Entrance Control

FC Final Control

HTML Hypertext markup language

ITU-R International Telecommunication Union, Radiocommunication Sector

JWP Joint Working Party

MAEVA Model for AssEssment of Video and Audio quality

MOS Mean Opinion Score

MOSQUITO Management Of Service QUality In Television Operations

MPEG Moving Picture Experts Group

PID (MPEG) Packet Identification Number

pMOS predicted Mean Opinion Score

QoS Quality of service

QPSK Quadrature (quaternary) phase-shift keying

QUOVADIS QUality Of Video and Audio for DIgital television Services

SNMP Simple Network Management Protocol

SNR Signal-to-noise ratio

SSCQE Single-stimulus continuous quality evaluation

STC System time clock