# Dynamic Bandwidth Allocation in DVB-T Networks Providing IP Services

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***Abstract*—The combination of high capacity, signal robustness, and worldwide acceptance have made digital terrestrial broadcasting (DVB-T) one of today's more promising technologies, while newly adopted standards support the integration of digital television programs and data services within a single multiplex, offered to both stationary and mobile end users. This paper addresses the issue of optimal bit rate allocation among DTV and IP services within the DVB-T multiplex, and demonstrates a novel configuration providing real-time sharing of the available bandwidth via an algorithm based on service hierarchy and perceptual quality assessment. The architecture and performance of a fully functional DVB-T testbed developed on this concept is also presented.**

***Index Terms*—Dynamic bandwidth allocation, IP over DVB, picture quality assessment.**

## I. INTRODUCTION

A NEWLY introduced trend in network design and implementation is the convergence of fixed, mobile and broadcasting technologies in order to create a new environment that will enable citizens to access broadband services wherever they are and whenever they want. It has become apparent that there is a need of synergy (better than convergence) between broadcasters and telecom operators in order to enable the provision of new affordable services to users. This is the reason why the introduction of the Digital Terrestrial Broadcasting system (DVB-T) as a carrier not only of digital television programs, but also of interactive IP services, has accented the role of this contemporary technology in the formation of modern fourth generation networks. Many research and development activities have been focused on the design and implementation of hybrid networks, combining DVB-T with fixed and mobile cellular wireless access systems (WLAN, GSM/GPRS, UMTS), using for example optimum receivers for the mobile terminals [1]. In this way, a wireless access network with broadband downlink can be realized, able to offer high-speed Internet services to both stationary and mobile users [2].

In order that the ability of the DVB networks to combine DTV (Digital Television) programs and IP data in a single multiplex can be fully exploited, an optimal bandwidth allocation between these two types of services must be achieved. Contemporary rate control mechanisms have been designed separately for DTV and IP services [3], [4]. However, within a composite multiplex combining television and IP traffic, there is a need of a more generalized bandwidth management scheme which can be in real time applied to all services, regardless of their nature.

This paper presents a novel approach to the this issue, which proposes the integration of a real time Bandwidth Allocation Management (BAM) module [5] into the multiplexing kernel of the DVB-T platform. This module uses a dedicated algorithm to optimally and in real-time allocate bandwidth to each service, either DTV or IP.

The combination of the BAM with a system measuring the perceived picture quality of the DTV streams (PQMS—Perceived Quality Management System) and an MPEG-2 Real-time Transrater allows the realization of a real time feed back loop bandwidth optimization mechanism. This mechanism ensures that the overall multiplex rate is at any moment optimally shared among the different services without significantly degrading the picture quality of the DTV programs.

The aforementioned modules (BAM, PQMS, MPEG-2 Transrater) have been developed and integrated in a fully functional DVB-T platform in the frame of the European IST (Information Society Technologies) MAMBO project *(MAMBO: Multi-Services Management Wireless Network with Bandwidth Optimization)*.

## II. THE CONCEPT OF DYNAMIC BANDWIDTH ALLOCATION

The term "dynamic bandwidth allocation" in a DVB-T system providing IP services refers to the real-time adjustment (regulation) of the incoming bitrates of both IP and DTV services in an optimal way following a prioritization scheme, so that the fixed rate of the final MPEG-2 Multiplex is fully exploited—and of course is not exceeded.

At present, integration of data services in a DVB multiplex is undertaken by IP encapsulator modules, based on opportunistic data insertion techniques. These modules eliminate the presence of null MPEG-2 transport packets within the transmitted multiplex, by replacing them with others carrying useful IP payload. It is self-evident that this approach leaves the IP traffic at a "best-effort" priority. The architecture proposed in this paper can support prioritization of IP traffic over DTV programs, so that data services, in the case of increased traffic, can claim in real time bandwidth from television streams, without significantly degrading the perceived picture quality. This architecture has been fully implemented to form a functional Demonstrator. Fig. 1 shows how a typical DVB-T platform supporting IP services (Fig. 1(a)) is enhanced with additional modules, thus realizing a real-time bandwidth management system (Fig. 1(b)).

In Fig. 1(a) (standard platform) an IP to DVB Gateway performs segmentation of IP datagrams and encapsulation to

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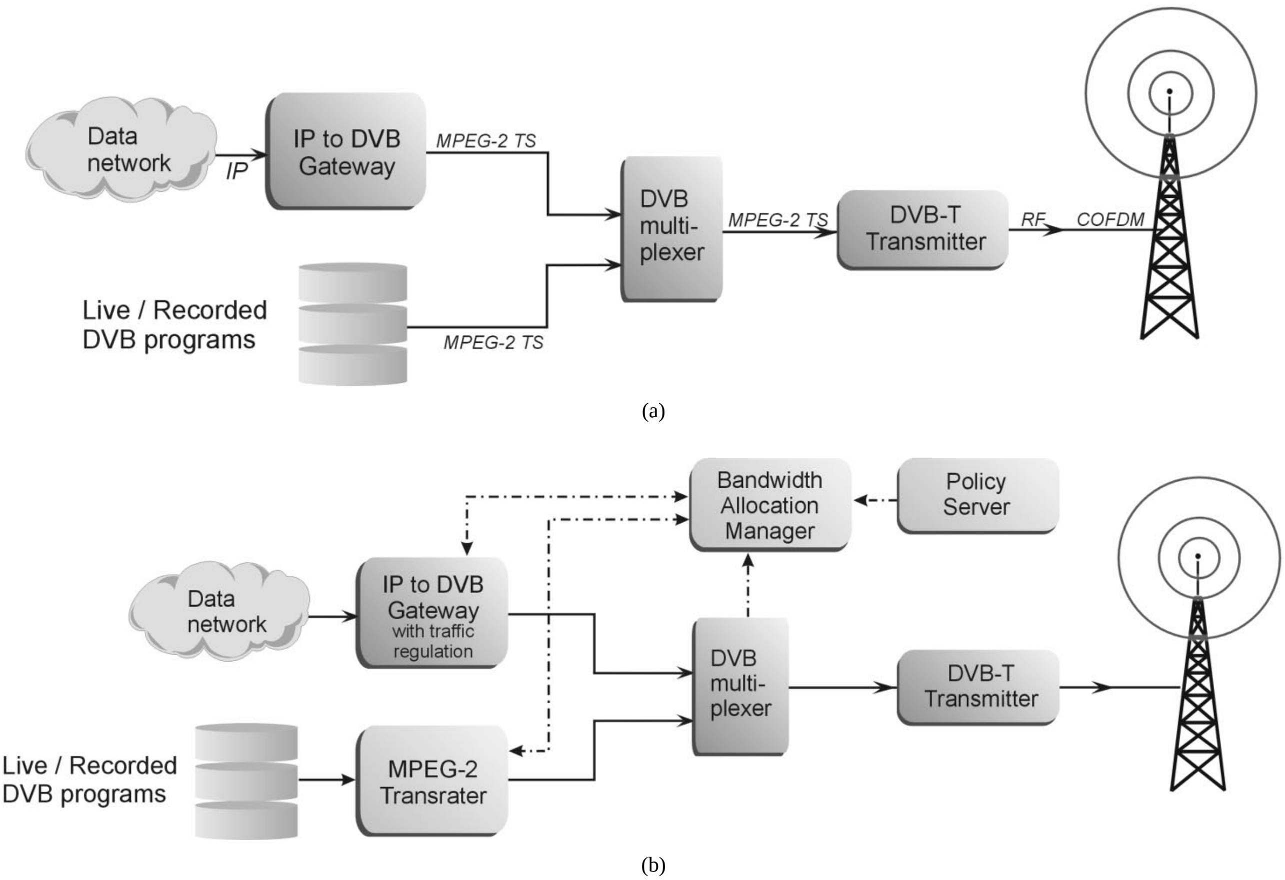


Fig. 1. (a) Typical DVB-T configuration with IP service provision. (b) Platform enhancement with bandwidth allocation subsystem.

MPEG-2 transport packets, so they can be multiplexed in a DVB compliant Transport Stream. In the proposed configuration (Fig. 1(b)), this Gateway is further enhanced with a traffic regulation feature, which enables for dynamic management of the bandwidth assigned to IP traffic.

Furthermore, the enhanced IP to DVB Gateway offers the feature of classifying the incoming IP traffic into various Channels, based on parameters contained in the IP header, such as the source or destination IP address, or the port number. After this classification has been performed, the different IP Channels can be prioritized and each one can be assigned a certain priority level, so it can have precedence over others.

Respectively, regulation of incoming DTV services is undertaken by an MPEG-2 Transrater module, which is able to decrease the bit rate of each DTV service within an MPEG-2 MPTS (Multi-Program Transport Stream). The transrating procedure, at the simplest approach, can be realized through a full-decode-full-encode scheme, implemented by cascading a decoder and an encoder. More sophisticated implementations have also been proposed, most of them based on the concept of partial decoding and requantization of the Discrete Cosine Transform (DCT) coefficients within the MPEG-2 video stream [6].

In order that the Transrater can be used in real-time applications, it provides the capability of bit rate adjustment on-the-fly, so that the final DVB stream, when decoded, will not suffer from picture pauses or artifacts. The Transrater is used before the DVB multiplexer to decrease the bit rate of the television programs by an appropriate amount, according to the commands of the BAM. In this way, the valuable bandwidth which is freed can be used for IP data provision, or for additional DTV services.

The Bandwidth Allocation Manager monitors in a per-second basis the overall bandwidth utilization within the DVB multiplexer, and adjusts the rate of the incoming services so that: i) the sum of the service bit rates does not exceed the multiplex rate (which could result in a multiplexer overflow) and ii) no bandwidth is wasted, i.e., the amount of null packets in the final Transport Stream is kept at a minimum level. The BAM issues commands to both the Transrater, which adjusts every second the bit rate of the DTV services, and to the IP to DVB Gateway, which restricts the overall IP load which is forwarded to the multiplexer so that it does not exceed a certain threshold.

The decision of the BAM is based on a prioritization hierarchy among the different DTV/IP services. The Policy Server, a separate module, containing the service priority database, provides the platform administrator with the ability to categorize the different DTV and IP services into various QoS classes. The BAM uses this database to classify the DTV and IP streams into "Guaranteed" and "Best effort" services, each assigned a different priority. With this innovation, the concept of QoS classification which until recently was used exclusively in data networks, can now be extended to DVB platforms and include digital television streams in addition to IP services. The flexibility and configurability of the Policy Server database allows for virtually innumerable scenarios which can be set up by the broadcaster, giving priority to individual services, either DTV or IP.

## III. Open-Loop Dynamic Allocation of Bandwidth for IP Services

A simple scenario demonstrating the functionality of the bandwidth allocation subsystem can be derived from the need to incorporate interactive (e.g., TCP/IP based) data services into a DVB-T multiplex, typically containing television programs. A fixed-rate multiplex, e.g., at 12 Mbps, can contain two high quality digital television programs, namely Program A and Program B, which consist of constant bit-rate (CBR) streams at 6 Mbps. If no other stream is included in the multiplex, the two programs occupy the entire bandwidth. Assuming that the platform administrator assigns higher priority to Program A than Program B, it could be desired that the bit rate of the latter is decreased to allocate some bandwidth for the IP services, when there is need to do so. Thus, when and only when there exists some IP traffic to pass through the multiplexer, the Bandwidth Allocation Manager senses the input activity (through its interface with the IP/DVB Gateway) and issues a command to the Transrater to decrease the bitrate of Program B, so that the IP load can be inserted into the multiplex. Under this concept, an IP over DVB stream can be assigned a minimum guaranteed rate $(\mathrm{BR}_{\mathrm{IPMIN}})$. This trade-off cannot exceed a pre-defined limit, i.e., Program B cannot be transrated below a certain threshold (4 Mbps in this example). This algorithm is analytically expressed in the following formulae

$$\mathrm{BR}_A \in [0, \mathrm{BR}_{\mathrm{TOTAL}} - \mathrm{BR}_{\mathrm{BMIN}}, \min\{\mathrm{BR}_{\mathrm{IPMIN}}, \mathrm{BR}_{\mathrm{IP\_IN}}, \}] \quad (1)$$

$$\mathrm{BR}_{\mathrm{IP}} = \min\{\mathrm{BR}_{\mathrm{IP\_IN}}, \mathrm{BR}_{\mathrm{TOTAL}} - \mathrm{BR}_{\mathrm{BMIN}} - \mathrm{BR}_A\} \quad (2)$$

$$\mathrm{BR}_B = \mathrm{BR}_{\mathrm{TOTAL}} - \mathrm{BR}_A - \mathrm{BR}_{\mathrm{IP}} \quad (3)$$

where $\mathrm{BR}_{\mathrm{A}}, \mathrm{BR}_{\mathrm{B}}, \mathrm{BR}_{\mathrm{IP}}$ are the instantaneous bit-rates of the two DTV services (Program A and B) and the IP traffic, respectively. $\mathrm{BR}_{\mathrm{IP\_IN}}$ is the incoming IP rate (before the regulation process), $\mathrm{BR}_{\mathrm{BMIN}}$ is the minimum bit rate of Program B (lower bound) and $\mathrm{BR}_{\mathrm{TOTAL}}$ is the overall multiplex rate. Note that the $\mathrm{BR}_{\mathrm{A}}$ is not defined by the algorithm, as Program A is included in the multiplex "as-is". Its rate must always be within the limits shown in (1), so that there is a minimum space in the multiplex reserved for the other two services.

This adjustment is illustrated in Fig. 2 which depicts a view of the realtime BAM graphical user interface. For demonstration purposes, CBR DTV sources are used as inputs to the system, along with a single "on-off" IP traffic source.

When the multiplexer is loaded with IP traffic, Program B is transrated in accordance to (3) ("Best Effort" service class), while Program A is left at its original rate ("Guaranteed" service class).

Via the Policy Server, the platform administrator can easily extend this scenario to support higher multiplex rates as defined by the DVB-T specification (up to 31.67 Mbps useful rate depending on the transmission mode used), multiple IP Channels with different QoS parameters and more DTV services, both Constant Bit-Rate (CBR) and Variable Bit-Rate (VBR). If many "Best Effort" DTV services exist, having different priority settings, in the case of bandwidth shortage they are all transrated by amounts proportional to their prioritization. Lower priority streams will be transrated to proportionally lower bit rates.

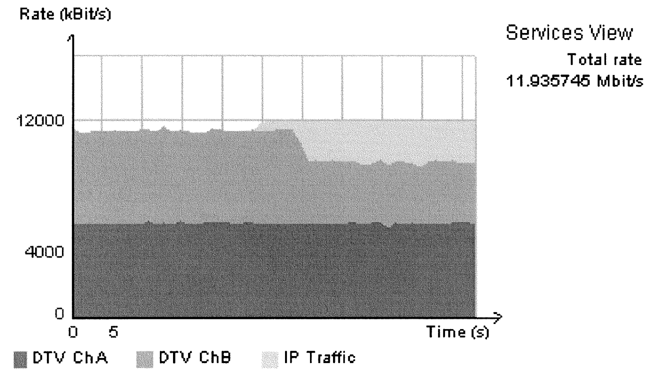


Fig. 2. Transrating a DTV service to free bandwidth for IP traffic.

## IV. Closed-Loop Bandwidth Allocation With Perceptual Quality Assessment

It is well known that when the bit rate of an MPEG-2 program decreases, the perceived picture quality is also degraded, with the amount of degradation depending on the content of the video sequence. When the spatial and temporal dynamics of the video are high, picture degradation is steeper as the bit rate is decreased. In order to retain the perceived picture quality at a pre-defined (acceptable) level, the Bandwidth Allocation Management System is complemented with a Perceived Quality Management System (PQMS), applying realtime digital image processing algorithms and used to estimate the quality degradation caused by the Transrater (Fig. 3).

Various algorithms have been proposed for assessing the degradation caused by lossy MPEG encoding [7], [8]. A detailed report presenting performance and accuracy tests among ten quality assessment methods is included in [9]. Most of them are too complicated to perform in real-time and moreover they require both the initial and the processed sequence, presented in frame-accurate synchronization. The PQMS integrated in the proposed system is designed for real-time analysis of the original and the transrated content independently. The initial Quality Metering (QM) module analyzes the original MPEG-2 program (before transrating) and extracts in real-time parameters concerning the content and the complexity of the picture. These values are derived from two-dimensional spatial filtering of a certain frame with a high-pass filter (to specify the spatial complexity of the image), along with a cross-frame analysis across sequential frames, which shows the temporal activity of the video sequence. These parameters, along with synchronization data, are fed into the multiplexer as ancillary data, occupying a dedicated PID at a very low bandwidth (no more than 10 Kbps). The final quality meter analyzes the transrated program contained in the multiplexer output. At the same time it extracts the ancillary data inserted in the Transport Stream by the initial QM, and, based on the synchronization

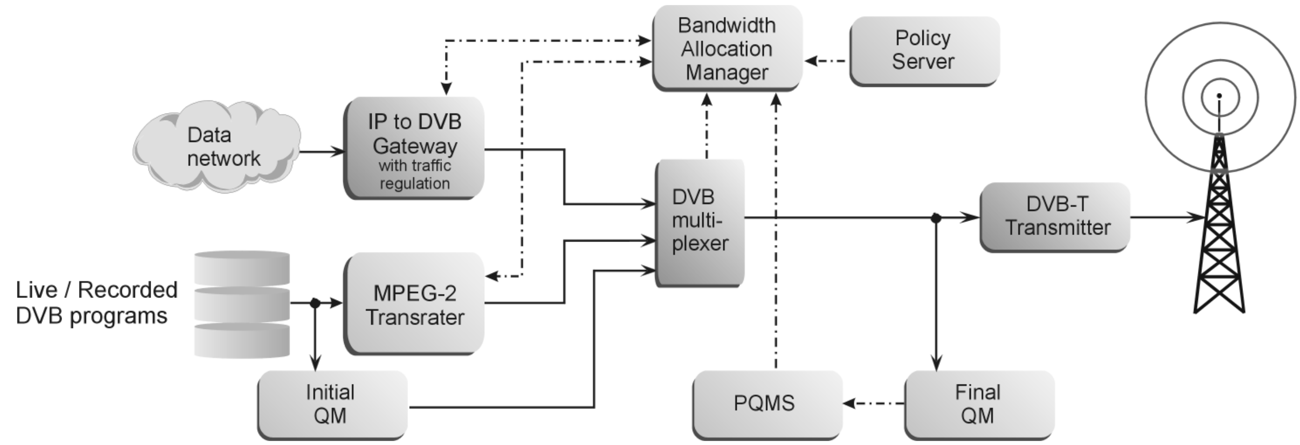


Fig. 3. Bandwidth Allocation Management with perceptual quality assessment.

data, compares the numerical results to produce a Perceptual Quality Score, in the range of 0–100. This score indicates how much the picture quality has been degraded by the transrating process. In order that this indication approximates the human estimation of the average viewer, several subjective quality tests were conducted, involving several nonexpert viewers who were asked to evaluate the picture degradation caused by the transrater. The viewers were presented both the original and the transrated versions of a connection of test clips with various content and scored the perceptual difference in picture quality. The evaluation procedure followed complies with the Double Stimulus Impaired Scale (DSIS) method described in the ITU-R document BT.500-10 [10]. The results obtained from the statistical processing of the viewers' scores were used to fine-tune the QM assessment so that it is as close as possible to the human perception.

The calculated score is forwarded to the PQMS (Perceptual Quality Management System), which acts as an interface to the BAM. The BAM takes into account the PQMS estimation and restricts the decrease of the bitrate, trying to keep the perceived quality of the television programs always at a desired level.

This closed-loop feed back mechanism ensures that no bandwidth is wasted for video sequences with relatively low temporal and spatial detail, such as talk shows or weather forecasts, that can be presented with high quality at relatively low bit rates. Fig. 4 shows the application of the scenario of Section III, with the addition that the rate of Program A is adjusted by the BAM, as its quality is monitored by a pair of quality meters. Thus, this service is substantially converted from CBR to constant-quality VBR and the rule in formula (1) becomes

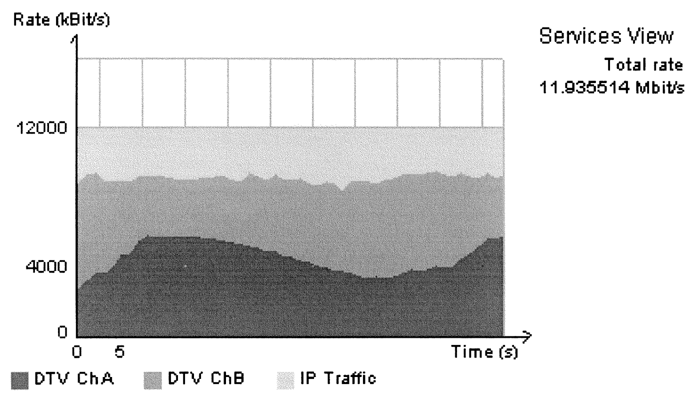


Fig. 4. Rate adjustment on Program A to maintain constant quality.

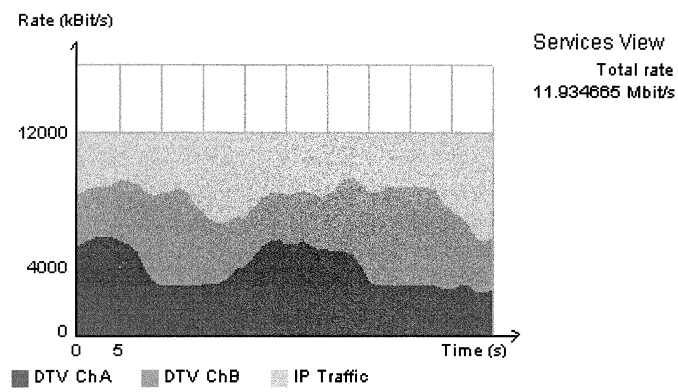


Fig. 5. Combined rate control with quality monitoring for both Program A and B.

$$\mathrm{BR}_A \in [0, \mathrm{BR}_{\mathrm{TOTAL}} - \mathrm{BR}_{\mathrm{BMIN}} - \min\{\mathrm{BR}_{\mathrm{IPMIN}}, \mathrm{BR}_{\mathrm{IP\_IN}},\}] \mid \{Q_A = Q_A^T\} \quad (4)$$

where $\mathrm{Q_A}$ is the measured perceptual quality, and $\mathrm{Q_A^T}$ is the desired quality for Program A, as defined in the Policy Database. The rule (4) implies that $\mathrm{BR_A}$ will be assigned the value which lies within the defined range, and which satisfies the condition $\mathrm{Q_A} = \mathrm{Q_A^T}$. To achieve this, the BAM increases $\mathrm{BR_A}$ if $\mathrm{Q_A} < \mathrm{Q_A^T}$ and decreases it in the opposite case. The amount of $\mathrm{BR_A}$ increase/decrease is proportional to the difference $\mathrm{Q_A^T} - \mathrm{Q_A}$. This adjustment leaves more bit rate to be allocated to the "Best-Effort" Program B, without degrading the perceived quality of Program A.

In order to further optimize the bandwidth sharing between the services, a second pair of quality meters is engaged to monitor the quality degradation of Program B. If both DTV programs contain sequences with low spatial and temporal detail, which can be transrated to low rates without significant quality loss, then their bandwidth can be decreased, leaving more space to IP traffic, which can now get bandwidth beyond its minimum guaranteed amount (Fig. 5). The mathematical expression of this concept is summarized in (5), (6), and (7).

$$\mathrm{BR_{IP}} = \min\{\mathrm{BR_{IP\_IN}}, \max\{\mathrm{BR_{IPMIN}}, \mathrm{BR_{TOTAL}} - \mathrm{BR}_A - \mathrm{BR}_B\}\} \quad (5)$$

$$\mathrm{BR}_A \in [0, \mathrm{BR_{TOTAL}} - \mathrm{BR_{BMIN}} - \min\{\mathrm{BR_{IPMIN}}, \mathrm{BR_{IP\_IN}}, \}] \,\Big|\, \{Q_A = Q_A^T\} \quad (6)$$

$$\mathrm{BR}_B \in [0, \max\{\mathrm{BR_{BMIN}}, \mathrm{BR_{TOTAL}} - \mathrm{BR}_A - \mathrm{BR_{IP}}\}] \,\Big|\, \{Q_B = Q_B^T\} \quad (7)$$

Again, $\mathrm{Q_B}$ is the measured perceptual quality, and $\mathrm{Q_B^T}$ is the desired (target) quality for Program B, as defined in the Policy Database.

The above algorithm can be expanded to include multiple DTV programs belonging in two discrete priority levels by substituting $\mathrm{BR_A}, \mathrm{BR_B}$, and $\mathrm{BR_{BMIN}}$ in (5), (6), and (7) with the sum of the rates of all programs belonging to the same priority level.

## V. Conclusion

This paper presented an enhancement of a typical DVB-T platform providing IP services with innovative modules resulting in a dynamic bandwidth allocation system which is able to provide in real time the optimal sharing of the multiplex rate among the different DTV and IP services. A flexible policy mechanism allows the platform administrator to define the desired QoS level and priority for each IP and DTV service, while a quality monitoring subsystem is used to ensure that the perceptual quality of the digital television programs is kept at a desired level. This concept was realized via the implementation of a fully functional Demonstrator whose operation demonstrated the real-time application of the proposed algorithm.

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