Physical Layer Statistical Multiplexing for the Second Generation Digital Terrestrial TV Standard DVB-T2

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Objectives — This thesis aims to develop a physical layer statistical multiplexing algorithm for the second generation of terrestrial TV standard, DVB-T2. This new service allocation method should take advantage of the advanced physical layer concept present in this new standard where it is possible to configure different physical layer modulation, coding and time interleaving per service. With this new statistical concept of physical layer statistical multiplexing efficient bandwidth utilization and service buffering reduction are achieved.

Methodology — The new physical layer statistical multiplexing algorithm is compared with the traditional statistical multiplexing methods and also with fixed multiplexing methods in order to study the potential gain in terms of bandwidth saving or service number transmission. The evaluation is done over a DVB-T2 simulation platform that performs all the transmission chain until the modulators, including since the video content generation until the service allocation. These simulations take place under typical DVB-T2 deployed scenarios to make more practical the results.

Theoretical developments — A previous multiplexing techniques study has been performed before designing the physical layer statistical multiplexing algorithm. These techniques have been developed for the first generation of DVB standards and were designed to work with upper layer packets to perform the scheduling. By this way, the new algorithm proposed takes the advantages of the previous studies in this field and it adapts them to the new concept at physical layer level.

Prototypes and lab tests — The studied multiplexing algorithms are developed over Matlab language in order to simulate the best allocation methods for a real use case of DVB-T2. In addition, the HD video traffic generator to work as simulation platform input is performed in Matlab.

Results — Simulation results show the gain obtained by the physical layer statistical algorithm proposed in terms of bandwidth utilization, services transmission and buffering reduction. The results have been achieved in a typical DVB-T2 configuration, such us the UK deployed network.

Future work — The scheduling algorithms designed and performed in this thesis and analyzed with computer simulations are the basis for their inclusion in the MCG DVB Encapsulation platform. One of the goals of this work is to be the starting point for the new release of the existing encapsulation platform which should include the second generation of DVB standards, DVB-T2, DVB-S2 and the almost finished DVB-NGH.

Publications — The results of this work will be included in a planned journal paper.

Abstract — DVB-T2 (*Digital Video Broadcast – Second Generation Terrestrial*) is the new specification for the second generation of digital television. Currently, this standard is commercially deployed in UK, Sweden, Italy and Finland. Within the new features of this specification it should be noted the capacity improvement (close to 50%) with respect to DVB-T. On the other hand, the main changes are found in the physical layer where DVB-T2 incorporates a new concept, the Physical Payer Pipe (PLP). Each PLP contains an individual configuration of modulation, coding and interleaving. This new concept allows a transmission with multiple PLPs (MPLPs) where each service can be transmitted with different physical layer configuration. To perform this MPLPs configuration a physical layer service allocation is needed. By this way, in DVB-T2 the service allocation should be efficiently improved at the physical layer, not in the upper layers like in the first generation of DVB standards. This thesis work aims to study the statistical multiplexing methods in the upper layers to design a new algorithm in the physical layer. This algorithm seeks to enhance the bandwidth utilization, reduce the service buffering delay and increase the number of services in the transmission. In order to achieve the objective a simulation platform has been developed to analyze different multiplexing methods with a real DVB-T2 network configuration, verifying the potential gain of the new proposal.

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I. Introduction

I.1. *Motivation*

Nowadays, the video traffic contents are consuming the largest part of the available networks bandwidth. The constant increasing of the video popularity makes users demand more quality in the video content.

This video quality is strongly linked with the video encoding method performed. From this point of view, a Variable Bit Rate (VBR) video is preferred against a Constant Bit Rate (CBR) compression. The VBR provides a quasi-constant quality of the encoded video with a similar average bit rate at the expense of more resources in terms of transmission and processing time.

Variable bit rate character of the contents to be delivered by a communication network involves an additional difficult to allocate every service in the available bandwidth. When several VBR video services needs to be transmitted in a shared bandwidth simultaneously a multiplexing method based on the statistical properties of the service data flow can improve the efficiency. In systems where CBR is used as a video compression method the service multiplexing could be performed statically because each service bandwidth needed is known a priori. However, in a system performed with several services encoded with VBR, a statistical multiplexing algorithm is needed in order to achieve the maximum performance of the available bandwidth.

Following this concept, the newest digital television broadcasting standards are implementing different methods of statistical multiplexing to increase their bandwidth efficiency. This service multiplexing usually has been made by the scheduler. The scheduler has the mission to allocate the different services and organize it in order to guarantee the individual service and the overall system restrictions. Traditionally, this service scheduling is performed in the upper layers within the transmission chain. In the *Digital Video Broadcasting - Terrestrial* (DVB-T) [1] standard, the main digital TV broadcasting in Europe, this service multiplexing is done at the link layer level, allocating MPEG2-TS (Transport Stream) packets.

Nevertheless, the second generation of DVB standards has introduced a new physical layer vision, the Physical Layer Pipes (PLP) [2], providing more flexibility in terms of transmission robustness, allowing different modulation, codification and time interleaving configuration per service. In this manner, the service scheduler has fallen in the transmission chain until the physical level. Due to this, an adaptation of the existing multiplexing methods is needed in order to get the maximum bandwidth optimization.

I.2. *Digital Video Broadcasting – Second Generation Terrestrial (DVB-T2)*

The digitization of the TV signal has opened a wide range of applications and services. Highlight the transmission of HDTV (High Definition TV, HDTV) television services and new raising interest for the 3D contents. The emergence of these new services substantially increases the bandwidth required for signal transmission, which is not enough despite the increased availability of bandwidth that emerged after the analogue switch-off. This limitation of spectrum will be improved by the second generation of DVB standards such as DVB-T2.

DVB-T2 [3] introduces the most advanced modulation and coding techniques to improve spectral efficiency to reduce the bandwidth required between 30% and 50% [4] for the transmission of HD-TDT. This would enable, to transmit in HD channels or TV 3D [5], solving the limitations in the radio spectrum.

The DVB-T2 standard [6] was formally published in 2009 and the first commercial transmissions began in the UK in December of 2009 and in 2010, Italy and Sweden has seen the launch of DVB-T2 services. Recently in 2011, Finland has started their DVB-T2 HD services, while advanced trials are taking place in Austria, Denmark, the Czech Republic and Germany.

DVB-T2 incorporates a large number of new features over DVB-T in order to provide better robustness, capacity and flexibility [7]. While DVB-T was entirely based on the transmission of MPEG-2 transport streams (TS), DVB-T2 also supports generic streams (GS) as input format. The utilization of generic stream encapsulation (GSE) provides a more efficient encapsulation of IP packets and results in less overhead due to packet headers. TS or GSE packets are encapsulated inside baseband frames (BB frames) before being modulated and transmitted over the air. Each BB frame constitutes a code word and has a constant size of 16200 or 64800 bits depending on the selected code word length.

Among other things, DVB-T2 uses the combining LDPC coding with BCH encoding, which offers excellent performance in presence of high levels of noise and interference, resulting in a sign of great strength. DVB-T2 provides greater variety in terms of number of carriers, guard interval and pilot signals to reduce overheads. A new technique of rotated constellations provides a significant additional robustness in adverse conditions of reception. It also provides a mechanism to adjust independently the robustness of each service to meet the required conditions of reception, also allowing for transmission to the receiver can decode only save energy required program instead of the entire multiplex.

DVB-T2 also introduces the utilization of physical layer pipes (PLPs) in order to achieve per-service specific robustness. In this regard, DVB-T2 defines two different PLP transmission modes. While the input mode A only supports the transmission of a single PLP, the input mode B allows multiple PLPs to be transmitted in the same frequency channel. In the first case the different services are multiplexed into one data stream (e.g. TS or GS) and are transmitted in the same PLP over the air. In the second case, each PLP carries one data stream and can be transmitted with a particular set of transmission parameters, including constellation size, code rate and time interleaving. This allows the transmission of multiple data streams targeting different user cases: fixed, portable and mobile, in the same frequency channel. In this regard, the utilization of multiples PLP for the transmission require to allocate the service scheduler at the physical layer level. With this physical layer multiplexing it is possible to achieve a better efficiency in terms of bandwidth utilization due to a specific allocation in function of the modulation, codification and time interleaving configuration of the different PLPs.

In addition, DVB-T2 specifies a method of diversity reception, known as Alamouti coding, enhancing coverage in SFN networks by means of multiple antenna reception.

On the other hand, DVB-T2 also includes an optional new feature known as time-frequency slicing (TFS) [8]. This new scheme for data transmission provides a great flexibility for the system design. By means of the combination of multiple radio frequency (RF) channels it is possible to dispose of a high-capacity channel to exploit the benefits of the statistical multiplexing algorithms. Thanks to TFS it is possible to implement a two-dimensional statistical multiplexing over the service to optimize the overall broadcasting system.

Following this topic, in the DVB-T2 system the set of blocks that includes the video input processing and the resources allocation is the T2-Gateway. This subsystem has the mission of manage all the services inputs until the modulator's input and it is the responsible of the efficient scheduling of all the information.

Currently, the Mobile Communication Group of the iTEAM is developing a software implementation of the T2-Gateway. With this software development and the utilization of the MGC DVB-T2 modulators and demodulators it will be possible to analyze all the researching topics concerning to this new technology and testing them in a practical environment.

Moreover, all this studies over DVB-T2 are the base of new specifications of the DVB standardization forum, T2-Lite and DVB-NGH *(Digital Video Broadcast – Next Generation of Handhelds*) [9]. T2-Lite is a less complex DVB-T2 version that enables the transmission of contents both for fixed as portable terminals. On the other hand, DVB-NGH will be a new standard which physical layer is based on DVB-T2 with several enhancements and the most advanced transmission techniques in order to allow the reception of the new TV concept in the handheld terminals.

II. T2-Gateway

The entire DVB-T2 system is composed by five subsystems beginning by the video/audio coder. This subsystem is usually grouped with the next subsystem. The T2-Gateway is the subsystem that processes all the input services signals (commonly since the video/audio encoders) until the modulators before the transmission. Following to the gateway there are the modulators ending the transmission side of the system. Finally, in the reception side there are the corresponding demodulators and the last subsystem, the audio/video decoders.

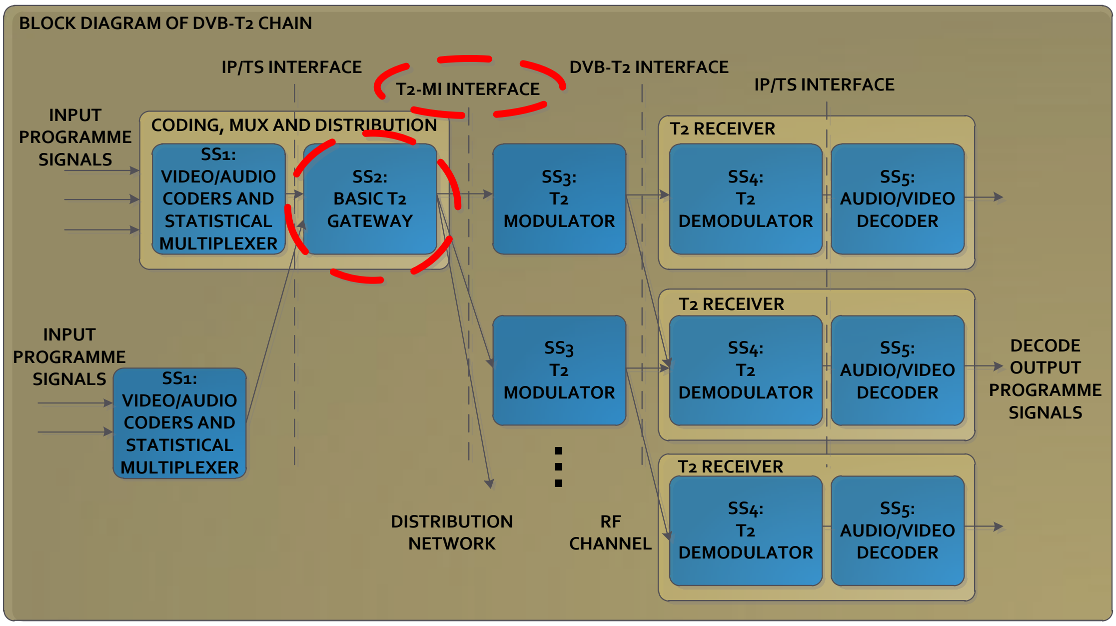

Fig.1. DVB-T2 chain block diagram

The T2-Gateway contains the responsible blocks of the input interface adaptation (input pre-processing), the input processing module (with the mode and stream adaptation) and finally the T2-MI block (T2 Modulator Interface) before their transmission through the modulators.

II.1. *Input Pre-Processing*

The pre-processing takes the input flows, which would be basically MPEG2-TS (Transport Stream) or Generic Stream Encapsulation (GSE). These different input systems are accepted to provide more flexibility with the typical broadcasting formats and the new and more advanced protocols. In one side there is MPEG2-TS, with a fixed packed length (188 bytes) and a fixed header, and in the other side there is GSE, with a variable packet length. This last encapsulation protocol it is a complement protocol for MPEG2-TS designed to provide an efficient IP (Internet Protocol) content transmission. GSE is the DVB second generation option to transmit IP contents against the

Multiprotocol Encapsulation (MPE) used over TS in the first generation of DVB standards for this proposal. On this topic, GSE introduces less encapsulation overhead (2-3%) than IP over TS through MPE (10-15%) [10].

These input flows are grouped in only one output PLP (Mode A or Single PLP) or in several output PLPs (Mode B or Multiple PLP). The Mode A it is the equivalent of DVB-T. The Mode B allows allocate as many PLPs as input flows plus another common control PLP, enabling different physical layer configuration for each service.

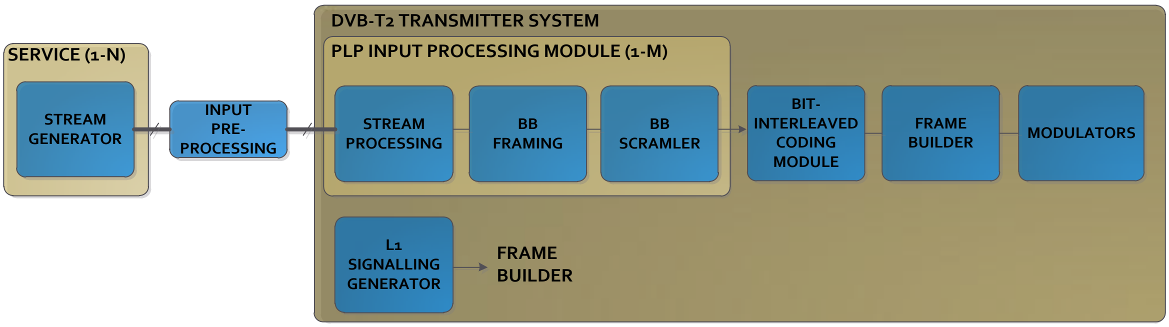

Fig.2. DVB-T2 Transmitter side blocks diagram

Otherwise, working with a Multiple PLP configuration whether the input flows are encoded with VBR and encapsulated in MPEG2-TS it is necessary to guarantee a constant bit rate per service before the input processing. To achieve this constant bit rate the TS flows are filled by a dynamically amount of NULL TS packets without information depending of the VBR encoder data output. By this way, the multiplexing algorithm ensures that the total bit rate don’t overflow the maximum PLP capacity.

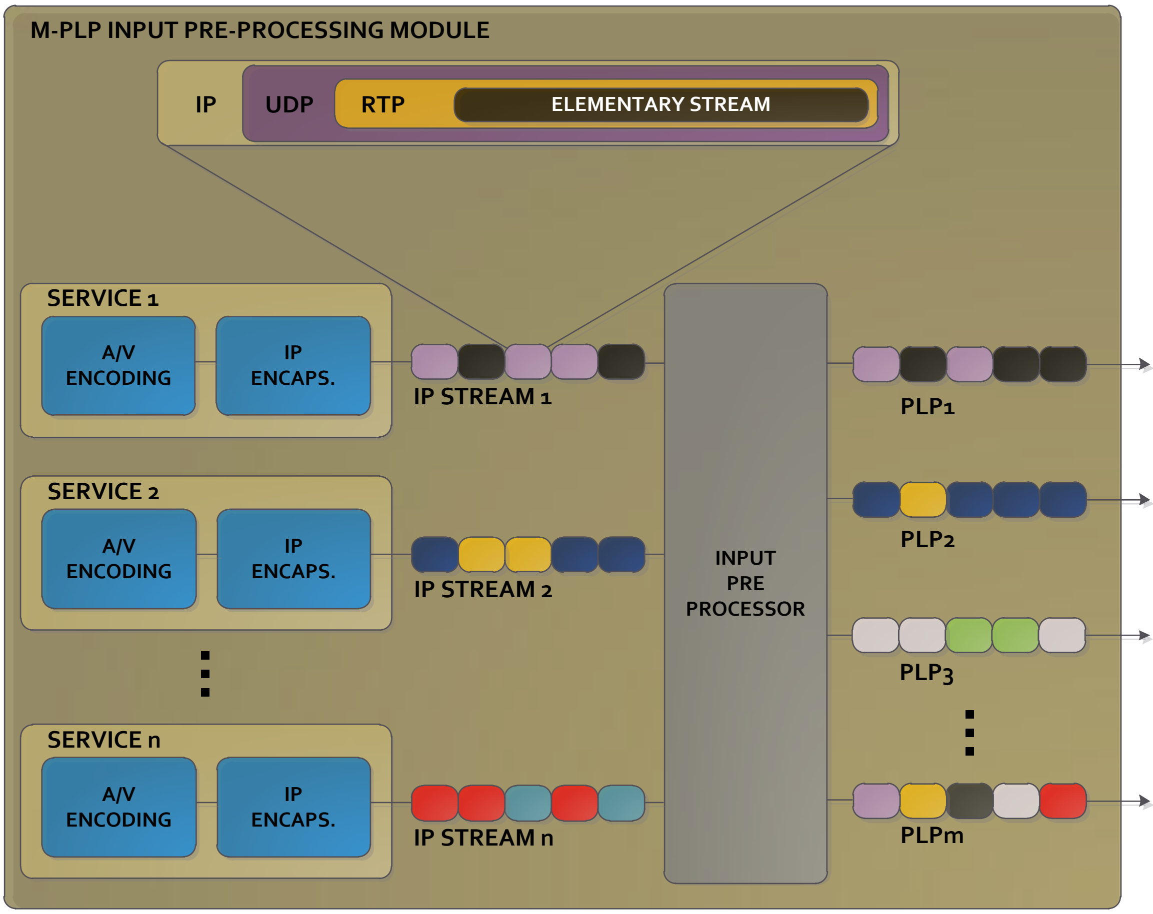

Fig.3. Stream Generator and Input Pre-Processing (Mode B)

II.2. *Input Processing*

After the pre-processing, the PLPs should be mapped in Baseband Frames (BB Frames). To achieve this, it is necessary to perform two adaptation of the information in the input processing module. In this module, the PLPs will suffer the Mode Adaptation and the Stream Adaptation.

The *mode adaptation* is the responsible of the data encapsulation in physical layer packets BB Frames for the each input PLP. In addition, the mode adaptation implements a null packet deletion and a delay to synchronize the PLPs.

The BB Frames are the physical layer unit that substitutes the MPEG2-TS packets of DVB-T and the other first generation broadcasting standards. This new concept of physical layer unit was adopted firstly by DVB-S2 and now is the base of all the second generation DVB standards.

BB Frames have a fixed length of K_{bch} bits and are composed by a 10 bytes Header, the Data Field (with a variable length) and Padding or In-band Signalling to complete it. BB Frame length depends of the LDPC word length N_{ldpc} (16200 or 64800 bits) and the code rate CR (1/2, 3/5, 2/3, 3/4, 4/5, 5/6).

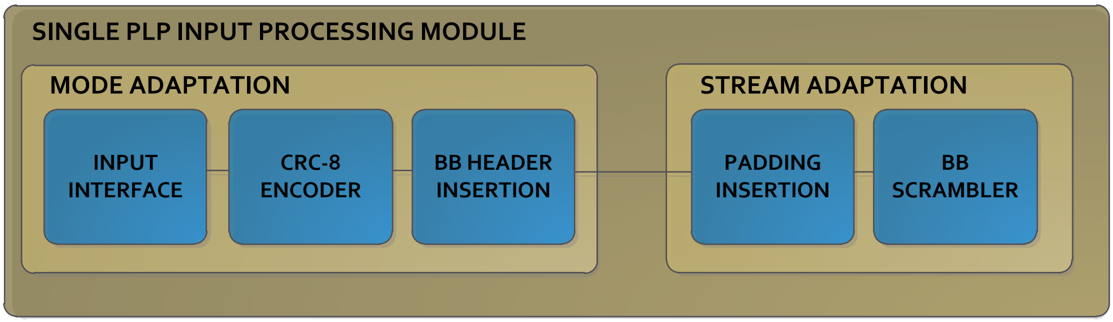

Fig.4. DVB-T2 Basic Input Processing Module (Single PLP)

The basic implementation of the mode adaptation is depicted in the Fig.4 and includes the following three blocks: the Input Interface, a CRC-8 and the BB Header Insertion. The first one generates the data BB Frames (with or without packet fragmentation) with a maximum length of K_{bch} if in-band signalling is not used. The second one, the CRC-8 block, replace the TS packet sync byte with a CRC used to detect erroneous packets. Finally, the last block composes the BB Frame Header of 80 bits (10 bytes).

On the other hand, if the system is using a Mode B configuration (MPLPs) the mode adaptation module includes three new elements and it is replicated as times as PLPs there will be. These blocks are the Input Stream Synchronizer, the Compensating Delay block and a Null Packet Deletion module.

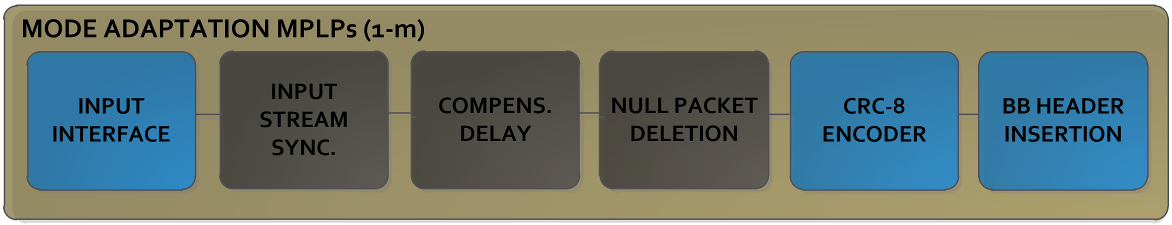

Fig.5. Mode Adaptation for Mode B (Multiple PLP)

The Input Stream Synchronizer (ISSY) adds 2 or 3 bytes to every TS packet to provide a mechanism to recover the original temporization of the data due to the DVB-T2 temporal delays are very variable and the Transport Streams have high restrictions concerning to that. The second block aims to compensate the different temporal configuration in each PLP (Sub-slicing, Inter-Frame Interleaving and Frame Interval) by means of a specific delay. This delay helps to reduce the receiver's memory thanks to synchronize the PLPs with a maximum difference of 1ms. Finally, the Null Packet Deletion replaces (and deletes) the Null TS packets by null packet counter byte. All the null packets are deleted and in the receiver recovered by means of the (Deleted Null Packets) DNP counter.

After all mode adaptation blocks we found the *stream adaptation*. This set of blocks is composed by the scheduler, a frame delay block, padding or in-band signalling inserter and BB scrambler.

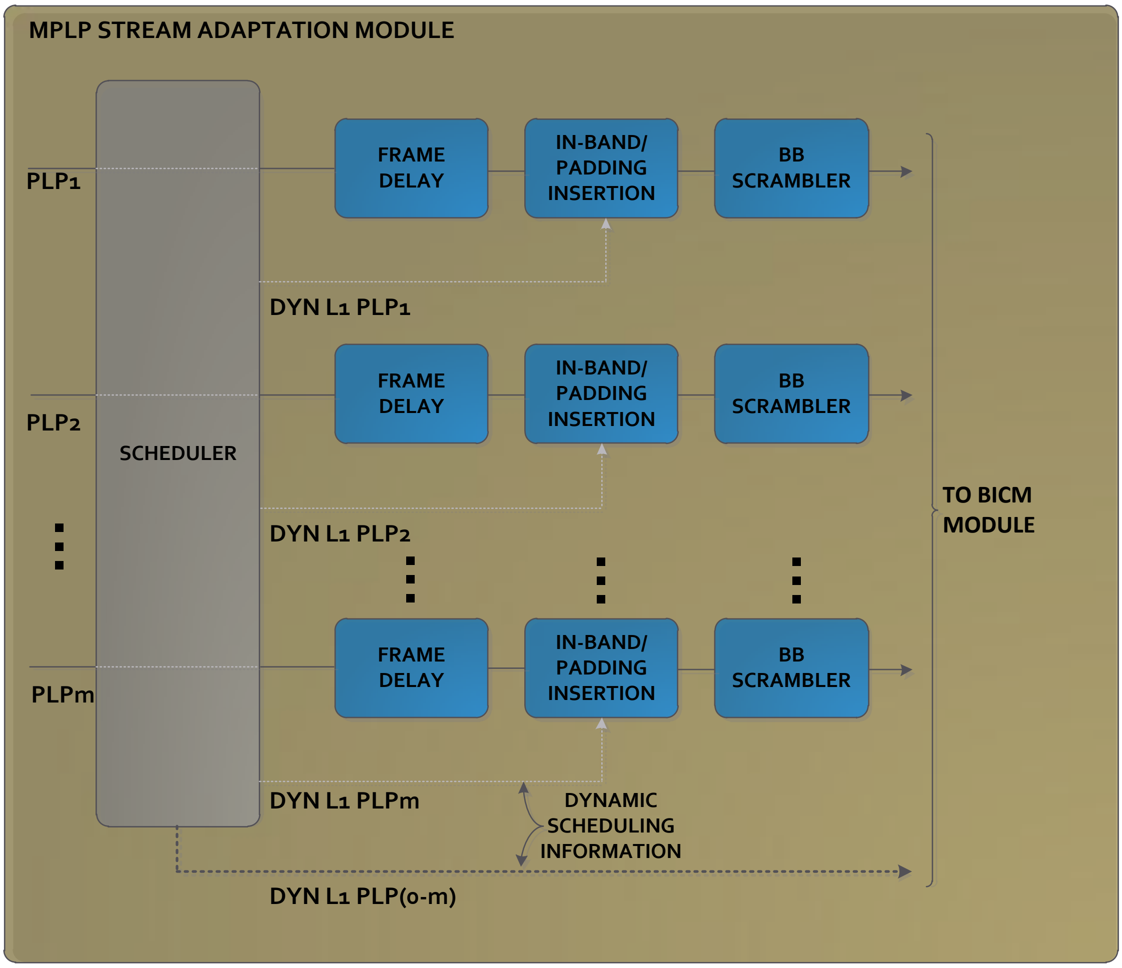

Fig.6. Stream Adaptation Multiple PLP Module

The scheduler aims to mapping data BB Frames into cells. Working with MPLPs the scheduler is the most important agent in order to perform the service multiplexing. To do that, the scheduler generates the physical layer signalling information, the L1 and assign for each PLP the cells number to fill with data. Following there is a frame delay block and the in-band and and/or padding insertion. In this block it is possible to fill the last bits of the BB Frames with dynamic physical layer information in the or simply complete the BB Frame with padding. And finally, the last stream adaptation block is a scrambler for the complete BB Frame to increase information diversity. This scrambling is applied separately BB Frame per BB Frame.

II.3. *T2-Modulator Interface (T2-MI)*

In SFN network it is necessary to feed different transmitters with the same information. In this case, T2-MI [11] presents an interface to deliver the data with the appropriate synchronization. This interface provides a new encapsulation structure that allows the receivers to generate synchronized frames. In addition, the T2-MI contents could be replaced in the distribution network by other local or regional contents. To make easy the distribution of these new T2-MI packets it is possible to encapsulate them in MPEG2-TS packets or encapsulate those IP packets to exploit the IPTV protocols or even do a RF distribution.

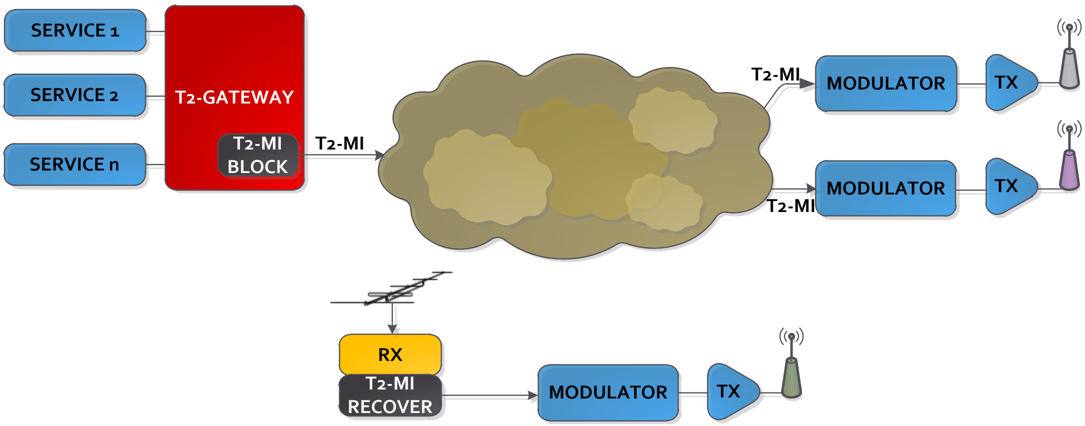

Fig.7. SFN network fed by T2-MI interface.

The T2-MI is ruled by the “ETSI TS 102 773 T2-MI Modulator Interface” and there, is defined the appropriate T2-MI protocol stack to deliver the DVB-T2 content to the corresponding modulators.

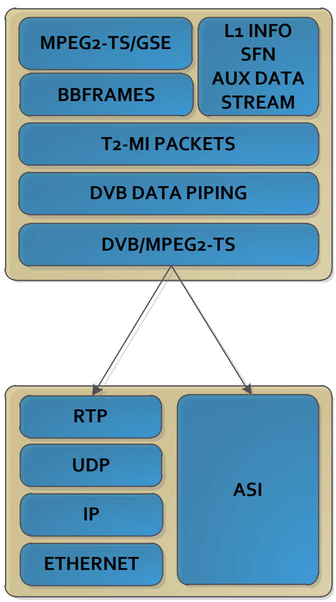

Fig.8. T2-MI Modulator Interface stack protocol.

III. Video Encoding

III.1. *Constant Bit Rate (CBR)*

Constant Bitrate, or CBR, refers to video or audio encoding where the bitrate used doesn't fluctuate. While CBR audio is actually rather common, being used for such technologies as CD-A (standard audio CDs), Dolby Digital, and even many MP3 files. For video it's less common, as Variable Bitrate (VBR) encoding generally offers far greater quality at a comparable bitrate.

In terms of service allocation, CBR provides as advantage, the a priori knowledge of the resources needed for each service. When all the services are sharing a common bandwidth it is preferred to know beforehand in every temporal instant the service requirements because the scheduling is easier.

However, a constant bit rate codification for video contents it is not appropriate in terms of quality. In the video compression the quantization parameter (QP), which determine the grade of faithfulness between the uncompressed content and the final video stream, vary in the time to achieve the constant bit rate output. This variation is due to the video scenes with more bit rate requirements needs to be compensated with a quality diminution ruled by the QP. By this way, to guarantee an acceptable quality of the whole video it is necessary to increase the bit rate limit. The most popular option for video content compression is the VBR which achieve a better quality with a similar bit rate average.

III.2. *Variable Bit Rate (VBR)*

In streaming applications usually VBR video bit streams are used [12]. VBR video bit streams generally provide higher visual qualities and compression performances than constant bit rate video bit streams at the expense of more resources in terms of transmission bandwidth and delay.

Video encoding at constant data rate leads to quality variations both in terms of subjective and objective measures, if the video content differs, for example, in the amount of details in the scene, movement of objects in the scene, or changes of lighting. Especially different video source material such as movies, cartoons, or computer generated content, can have a big influence on the data rate requirements [13]. Fig. 9 shows an example of the resulting video quality (decoding all scalable layers) in terms of the peak signal-to-noise-ratio (PSNR, blue lines) with respect to the data rate of the encoded video (red lines) for eight well-known test sequences. The solid lines mark the results for encoding using a fixed quantization parameter QP, while the dashed lines mark the results of constant bit rate (CBR) encoding. For CBR encoding, the PSNR values vary heavily depending on the video contents, while for encoding with constant QP the data rate fluctuates and the PSNR values vary much less. The latter strategy is also referred to as variable bit rate (VBR) encoding.

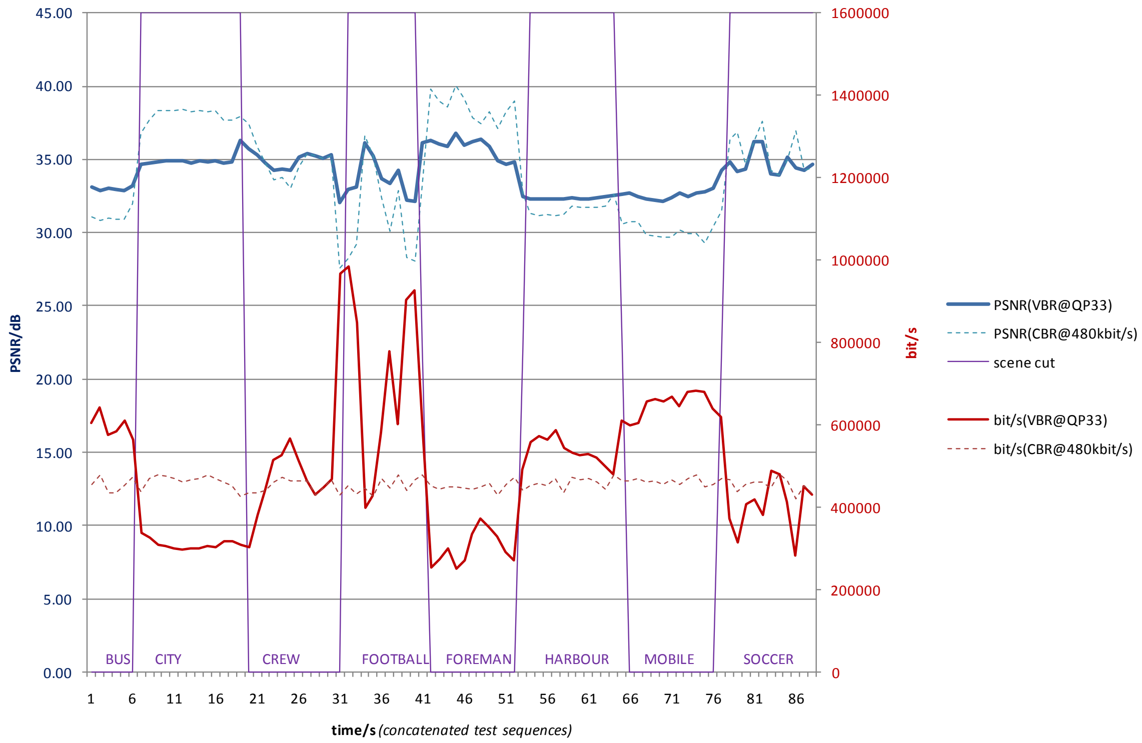

Fig.9. CBR vs. VBR in terms of quality (PSNR) and bit rate for different video sequences.

Encoding VBR video can be open-loop (uncontrolled) or closed-loop (controlled). In uncontrolled encoding, the video pictures are encoded with an almost constant quantization (QP) to provide a relative constant quality for encoded video regardless of coding complexity of video source. In controlled encoding, the bit rate of encoded bit stream is controlled by a VBR rate controller according to feedback signals from encoding results and coding complexity of video source. The rate controller imposes some constraints on the degree of variability allowed in the bit rate.

For example, in video streaming over the first generation of DVB standard such as *Digital Video Broadcasting – Handhelds,* DVB-H [14], the closed-loop VBR encoding method is preferred for several reasons [15][16][17]. First, for a given percentage of bandwidth utilization, unlike the open-loop encoded bit streams that need a relatively high buffering delay, the required buffering delay of constrained bit streams is limited. While the end-to-end delay is a serious bottleneck in DVB-H, the constrained bit streams are preferred to guarantee a limited end-to-end delay. Second, for a given transmission delay, the controlled encoded bit streams provide a higher bandwidth utilization than uncontrolled bit streams. Finally, although the bandwidth utilization can be improved by a statistical multiplexing of broadcast services, due to small number of DVB-H services that can be multiplexed to one DVB-T channel, the performance of statistical multiplexing is not as much as in other applications in which a large number of services are multiplexed.

Therefore, the required resources in terms of bandwidth and delay should be controlled by the closed-loop encoding before multiplexing.

Otherwise, in DVB-T2 is also preferred a controlled VBR encoding method in order the make more easy the service allocation. In addition, depending of the transmission mode configured for the DVB-T2 system (Mode-A/Single PLP or Mode-B/Multiple PLP) the service allocation it is similar to the DVB-T and the benefits are similar. However, if the system use a MPLP configuration, the VBR content to be allocated needs to be analyzed in the physical layer level because the multiplexing is done at cell level.

III.3. HD Video Traffic Model

The HD video traffic model used in this thesis as input data source is based on [18] developed jointly with Nokia and the Tampere University of Technology. This model is performed to generate video sequences composed by several scenes and each scene includes a number of video frames from different types such as I, P and B frames. The model proposed use a Gamma distribution to get the frame number in the video scene for each frame type. Gamma function was chosen for this model because it fits well enough with the practical results and simplifies the modeling approach [19]. According to the model, a Gamma PDF for the size of frame (x) of type I in scene s is considered as:

$$Gamma\ (x, k_{is}, \theta_{is}) = x^{k_{is}-1} \frac{e^{-x/\theta_{is}}}{\theta^{k_{is}}\Gamma(k_{is})}, x > 0 \quad (1)$$

where $k_{is} > 0$ is the shape parameter and $\theta_{is} > 0$ is the scale parameter of Gamma distribution, i stands for I, P or B frame type and $s = 1, \ldots, S$ denotes the scene index. On the other hand, it is necessary to define several parameters to configure the simulator to generate synthetic video traffic. These main parameters are the total number of frames per video sequence (*N*), Group of Pictures (GOP) structure, the number of P and B pictures (N_P, N_B) in the GOP, the length of video scenes as well as their parameters (k_{is}, θ_{is}), average bit rate (*B*), frame rate (*F*) and smoothing buffer size (S_B).

With these configuration parameters this model based on a Gamma distribution is capable of provides long video sequences of HD video traffic with VBR properties. In the Fig.10 it is possible to see the gamma distribution of the generated frame histograms. For each type of frame it is obtained the distribution of sizes that combined with the GOP structure, allows the generation of a video sequence (Fig.11).

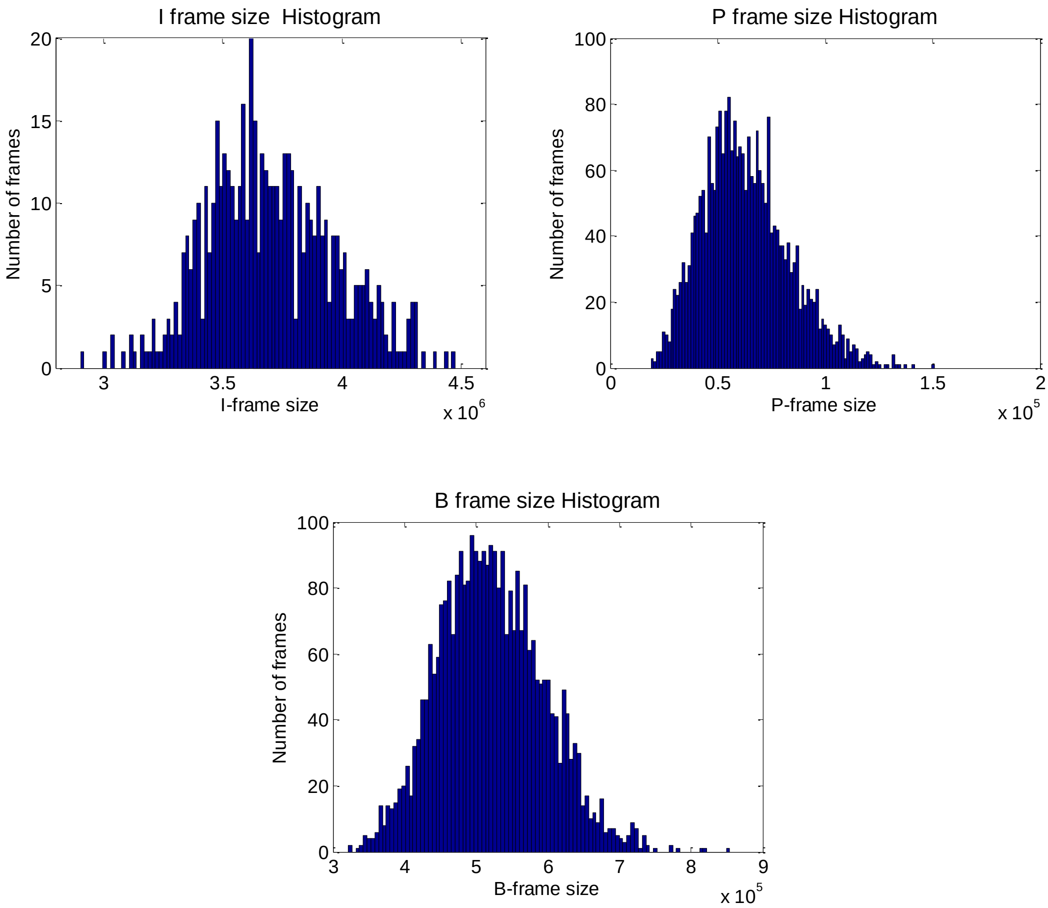

Fig.10. I, P and B frame size histograms

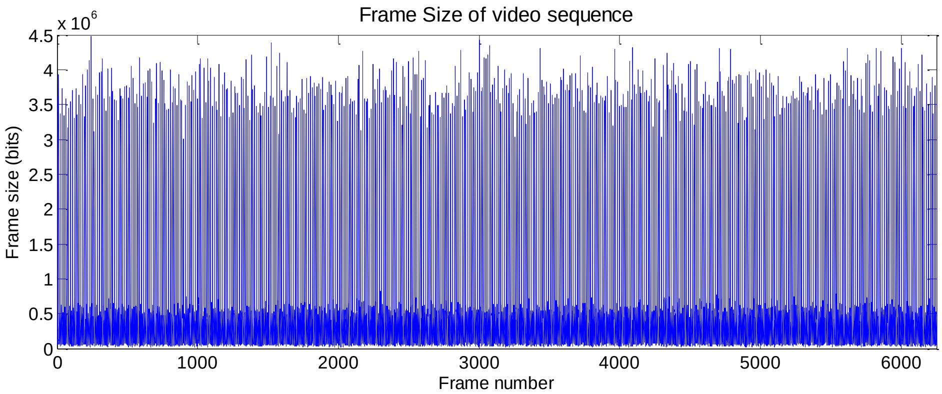

Fig.11. Video sequence frame size distribution

IV. TRADITIONAL STATISTICAL MULTIPLEXING

IV.1. *Multiplexing overview*

When set of services shares the same resources it is necessary to implement multiplexing mechanisms to allocate properly and efficiently the different data flows. In broadcasting services this multiplexing is performed by a scheduler who traditionally maps the upper layer packets into a shared flow previously to the transmission.

In the first generation of DVB standards such as DVB-T, the multiplexing is done allocating the different MPEG2-TS flows from each service in the same transmission flow. This kind of allocation seeks the gain, minimizing the buffering delays and improving the bandwidth utilization al high level in the encapsulation chain.

In DVB-T2 it is possible working in the same way that the previous standards. If the system is using a Mode A configuration with a single PLP the multiplexing is equivalent to DVB-T. As an example, in the Fig.12 it's possible to see the typical service allocation for single PLP where the upper layer packets (in this case IP packets) are sharing the same transmission resource.

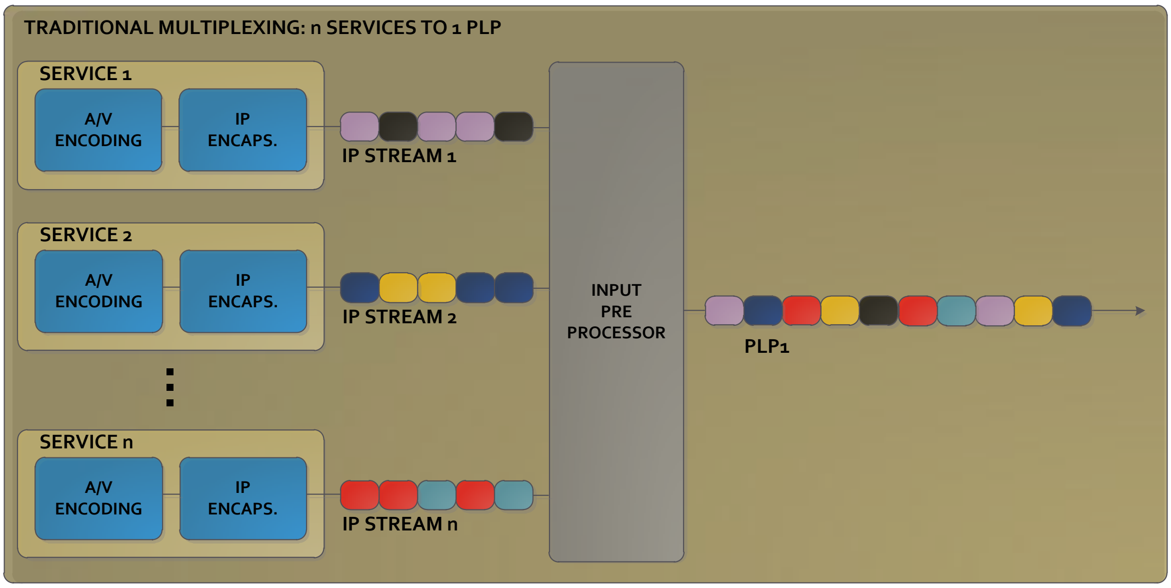

Fig.12. Traditional multiplexing n services to 1 PLP (like DVB-T)

Despite that this configuration is valid for DVB-T2 this is not taking advantage of the new standard features such as the MPLP, with different physical layer configuration per service. In Mode B DVB-T2 configuration, this service allocation needs to be done at physical layer level.

IV.2. *Statistical Multiplexing Concept*

Independently where the service multiplexing is done, it is possible distinguish two different concepts in terms of how is performed this multiplexing. Considering the available resources allocation evolution along the time are found the static multiplexing and the statistical multiplexing.

The first one multiplexing algorithm performs a beforehand service allocation in the shared bandwidth. This allocation will be fixed and invariant during all the transmission without any adaptation. In terms of management complexity this option is preferred because of it not requires additional processing and real-time video analysis. However, this multiplexing method is not enough efficient combined with VBR video encoding. Whether the bit rate per service is not constant, in the pre-allocation of each service in the shared bandwidth an extra margin will be needed in order to cover the worst case when all the services will have the highest rate.

On the other hand, with the statistical multiplexing it is possible to exploit the properties of the video content by means of real-time analysis of the encoded content. This analysis allows the adaptation of the transmission to the set of services bit rates. Nevertheless, this improvement is not free. Statistical multiplexing requires a complex real-time analysis of the video content and processing to allocate the appropriate the optimal amount of information of each service in each time interval. This processing complexity implies usually extra buffering in the transmitter and indeed more end-to-end delay.

In the Fig.13 is depicted a typical configuration of a statistical multiplexing system where the scheduler block allocates the services into a shared resource. To perform the allocation, the scheduler establishes a rate control for each service. This rate control is also combined with a quality control analyzer which provides a feedback to the video encoders. The video encoders are joint managed this quality/rate analyzer in order to satisfy the scheduler rate restrictions without losing quality.

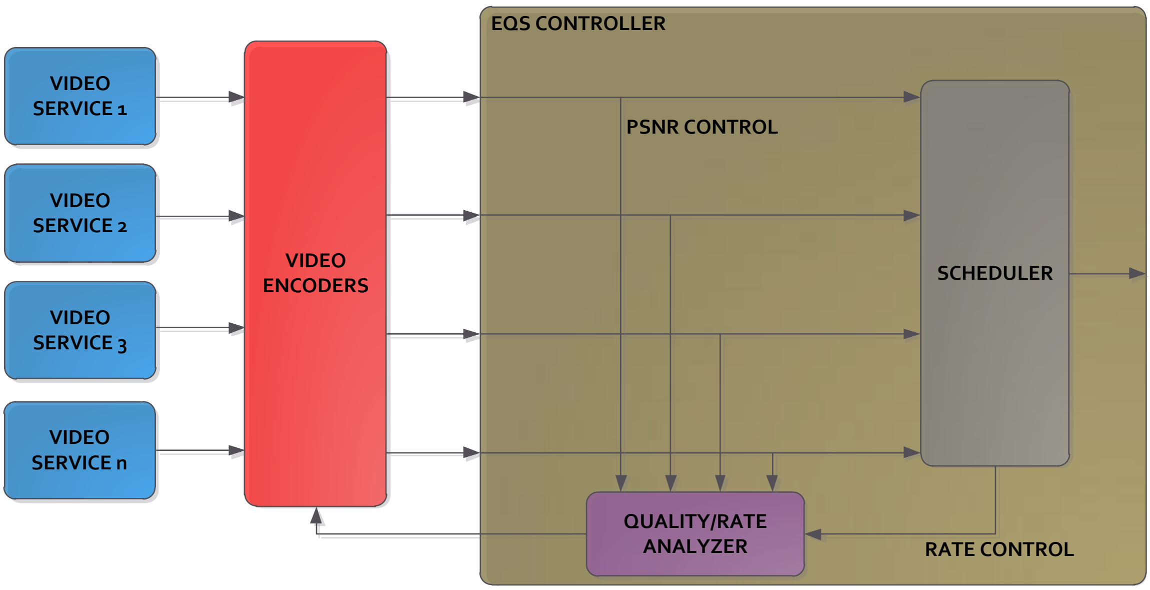

Fig.13. Scheduler with quality/rate feedback to the video encoders

V. ADVANCED STATISTICAL MULTIPLEXING FOR DVB-T2

V.1. *New Multiplexing Concept*

DVB-T2, as a second generation of broadcasting standards, includes new advanced transmission concepts. Regarding service allocation and multiplexing, the most powerful advantage is the possibility introduced by the multiple PLP configuration with a per service physical layer setup.

This new physical layer configuration per-service implies that the encapsulation is done in lower layers in comparison with previous standards. In the section II it has been described the T2-Gateway, the main component in transmission in terms of bandwidth and service management. In the T2-Gateway the scheduler, as part of this DVB-T2 system, is the responsible to map the different services in a MPLP configuration.

This scheduler presents several differences with its equivalent components in the first generation of DVB standards. Previously, the schedulers had to work with upper layer packets as inputs and usually the output was the same kind of packets. However, in this new standard the scheduler has physical layer units in its input, the BB Frames, and the allocation units are cells.

A new allocation concept is needed to achieve an efficient service multiplexing because of the significant of the input units is not the same depending of the associated physical layer configuration. The input BB Frames always have the same size however their conversion to cells will differ in function of the service physical layer set up. By this way, the buffering analysis will be characterized by the BB Frame equivalence in cells which will be different in the different PLPs.

In the DVB-T2 system, the cells structure of the transmission symbols in the frame is depicted in the Fig.14. In this structure, in the first place there is space for the preamble symbols (P1 and P2) which allow the receiver synchronization with signaling information. Afterward, there is space for the common PLP and later there are the data PLPs. These data PLPs contains the different information of the services previously encapsulated. In MPLP, each PLP may have a particular configuration occupying more or less cells. Finally, the frame is closed by an amount of dummy cells without information.

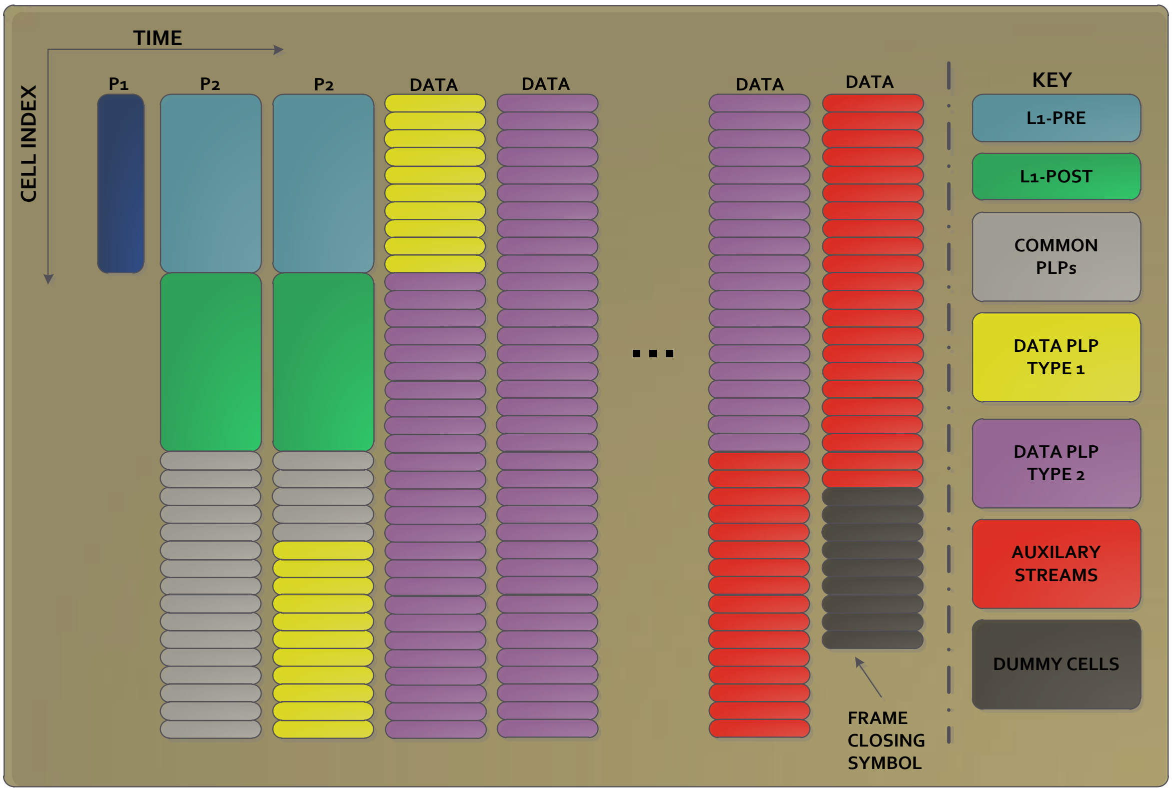

Fig.14. Cell mapping in DVB-T2

The proposed algorithm is an approximation to the ideal statistical multiplexing case. In the ideal case, the available bandwidth is distributed between the services proportional to their temporal required bandwidth. By this way, the algorithm aims to allocate the input BB Frames from N services into the shared amount of cells B_{CELLS}, in the corresponding time interval. On the other hand, this B_{CELLS} number depends on the individual physical layer configuration of all the PLPs and the Time-Frequency Slicing (TFS) set for the DVB-T2 system. To perform the statistical multiplexing analysis the buffer occupancy B_i for each service it is taking in consideration. In addition another variable taking in account is the bit rate R_i of each service. With these variables it is possible to get, for each time interval, the amount of information to extract for each buffer as

$$b_i = \frac{B_{CELLS} B_i / R_i}{\sum_{j=1}^{N} B_j / R_j} \qquad (2)$$

Input information to the scheduling block are BB Frames. However, to achieve a better performance in the algorithm, all the analysis is done in terms of cells. By this way, every input buffering information is always treated in cells, with the corresponding equivalence depending of PLP they belong.

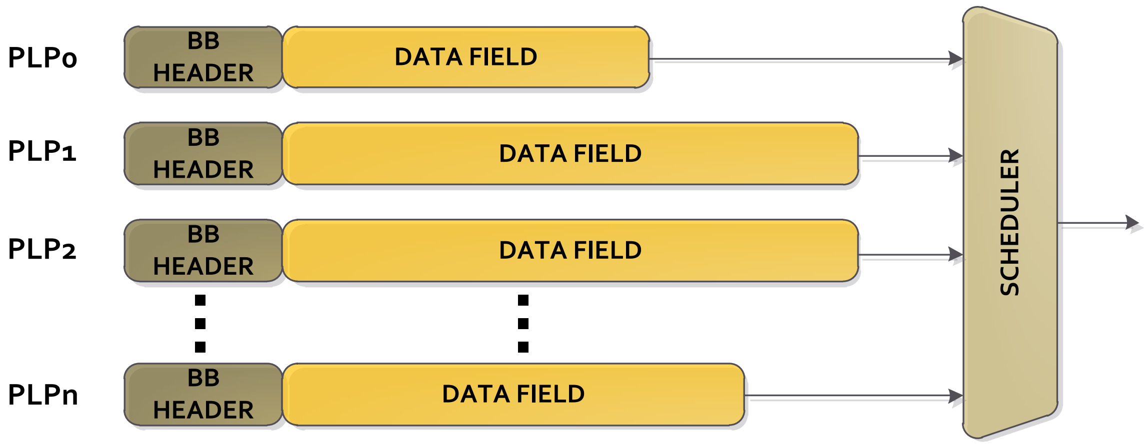

Fig.15. Different BB Frame size due to different physical layer configuration per PLP.

VI. RESULTS

VI.1. *MCG Statistical Multiplexing Simulation Platform*

To accomplish this statistical multiplexing analysis a simulation platform has been developed within the Mobile Communication Group (MCG) of the iTEAM. This simulation platform is composed by three differentiated systems depicted in the Fig16.

In the first term there is the traffic model block. This system generates, through the HD video traffic model explained in the section III.3, the input information for the whole simulation platform. Thanks to the model it is possible to generate a big number of video sequences with VBR encoding method of different average bit rates.

The output video frames of the traffic model are the input of the DVB-T2 encapsulation system. This set of blocks has the mission to simulate the different encapsulation protocols from the upper layers until the physical layer, ending in the BB Frames. To perform the analysis of this master thesis an IP profile was chosen against the TS profile. This option was done because at the beginning of this study this branch seemed more interesting that use the traditional MPEG2-TS.

Once the BB Frames flow per service is achieved these are the input of the multiplexing simulator. This system has implemented the different algorithms for the service allocation. In addition, this block also contains the output analyzer that recovers all the multiplexing information to generate the appropriate results.

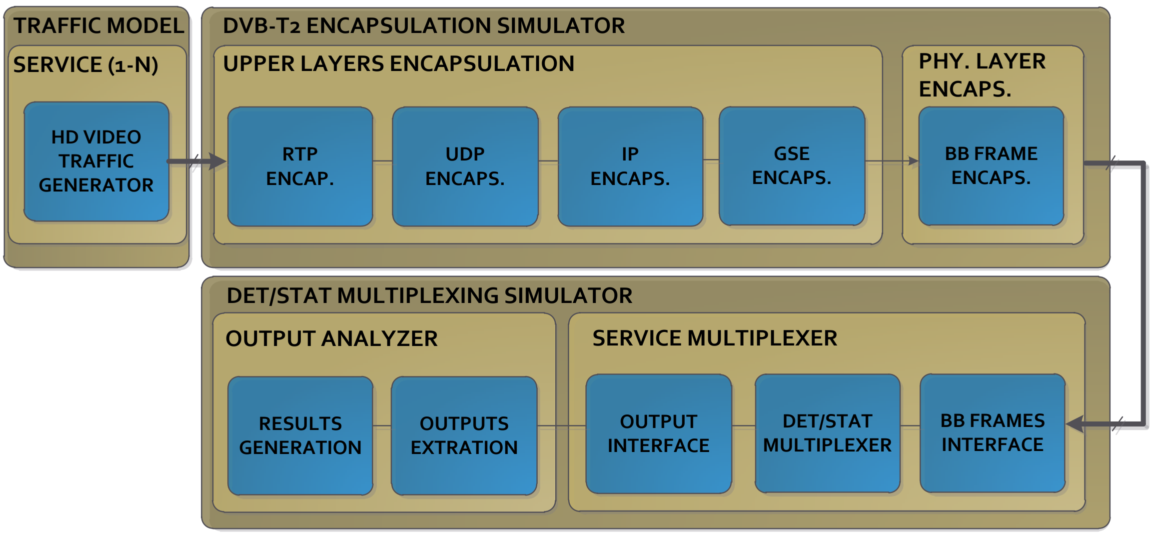

Fig.16. MCG Statistical Multiplexing Simulation Platform

VI.2. *Simulation Results*

To evaluate the performance of the physical layer statistical multiplexing algorithm proposed a real scenario for the simulations has been tested. This real scenario is based on the UK DVB-T2 setting, with as main parameters the 256-QAM modulation, FFT size of 32K, guard interval of 1/128, FEC configuration of 3/5 LDPC + BCH and 64K LDPC word size. With this reference, different studies have been developed in order to analyze the enhancements presented by the new service allocation method.

On the other hand, the input services have been generated by the HD traffic video generator giving a mean of 6 Mbps per service. In addition, these input flows have been encapsulated in the upper layers following an IP profile in RTP, UDP, IP and finally in GSE packets. The GSE packets have been allocated in the BB Frames to be later allocated in the transmission cells.

BW Utilization Analysis

In order to study the benefits of using the new physical layer statistical multiplexing a set of simulation has been run to compare the bandwidth utilization when each algorithm is transmitting the maximum number of services. In the Fig.17 case, it should be noted a benefit of at least the 20% between the statistical multiplexing algorithm proposed and a fixed multiplexing. In this simulation, for one DVB-T2 multiplex with a fixed multiplexing method it is possible transmit until 3 HD services, reaching a 60% BW utilization, while the statistical multiplexing algorithm allows 4 HD services, with a BW utilization close to the 90%.

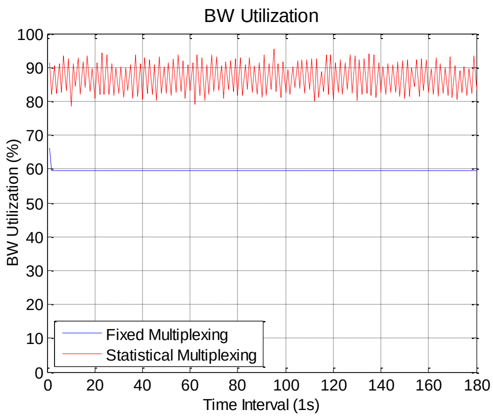

Fig.17. Bandwidth utilization comparison between fixed and statistical multiplexing.

Buffer Occupation Analysis

Buffer occupation analysis shows how the algorithm affects data information queues before their transmission. In the couple of pictures in the Fig.18 it is possible to compare the difference between a fixed assignation of the available resources and one dynamic scheduling algorithm adapted to the statistical features of the inputs.

Fig.18. Buffer occupations for fixed and statistical multiplexing with 3 services.

On the other hand, in the next Fig. 19 it is possible to check how the statistical multiplexing algorithm is capable to transmit 4 services while fixed multiplexing buffers do not are able to guarantee a more or less constant behavior within an acceptable margins.

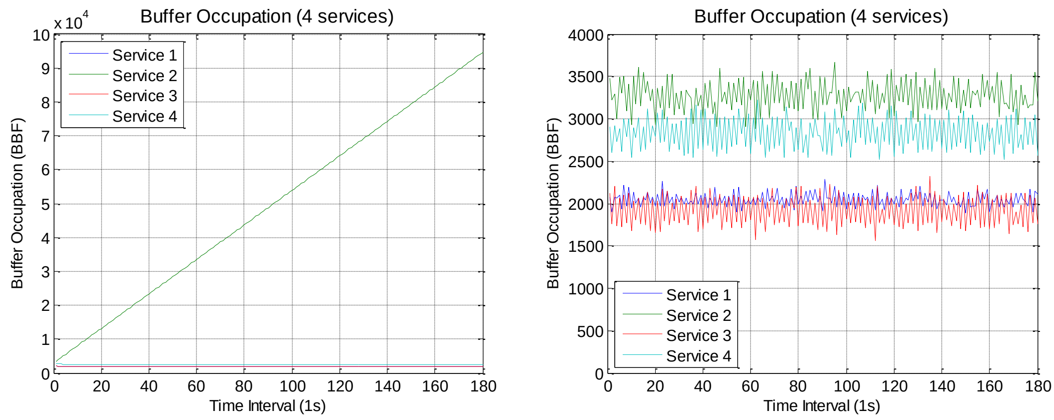

Fig.19. Buffer occupations for fixed and statistical multiplexing with 4 services.

Statistical Multiplexing Gain

To analyze the statistical multiplexing gain versus the fixed multiplexing a run of simulation have been performed in order to check the improvement achieved.

The methodology used in this simulation has been focused to evaluate for each multiplexing method, the maximum number of services that is possible to transmit in the available bandwidth. In this case, the starting point was a real case of DVB-T2 network, such as the UK configuration. In addition, to make more interesting the analysis, the utilization of TFS has been added to the simulations. Thanks to TFS it is possible to combine more than one RF channel increasing the available bandwidth and thus the number of services to transmit.

This statistical multiplexing gain was measured with the following expression:

$$StatMux_{Gain}\,(\%) = \frac{StatMux_{ServicesNumber} - FixMux_{ServicesNumber}}{StatMux_{ServicesNumber}} x100 \qquad (3)$$

Combining the simulation results with this expression and taking into account different bandwidths depending on the RF channels number, it has been evaluated the statistical multiplexing gain.

RF Channels	1	2	3	4	6
FixedMux Services Nr	3	5	8	11	16
StatMux Services Nr	4	8	13	17	24
Gain (%)	**25**	**37.5**	**38**	**41.18**	**36**

Table 1: StatMux gain in different TFS RF channels number

In the Fig.20 is depicted the statistical multiplexing gain evolution when the number RF channels and the available bandwidth increases. In this figure, the gain trend raises quickly when the number of services to allocate are relatively low. When this number increases, for more than 3-4 RF channels, the gain tends to saturate because the algorithm needs allocate too many information sources and the efficiency decrease.

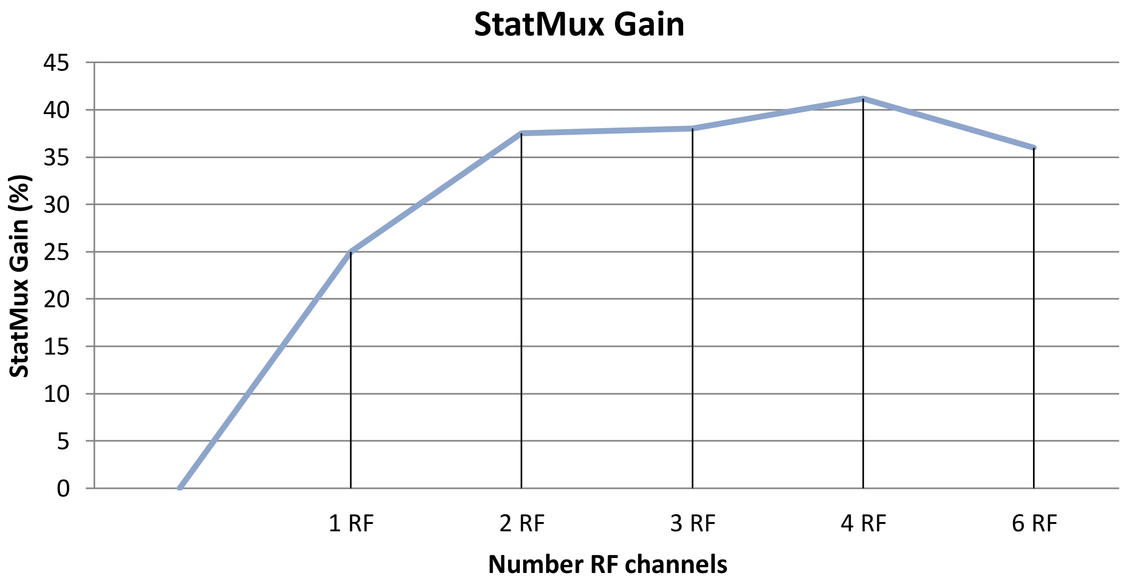

Fig.20. StatMux gain representation for TI (1s).

Otherwise, in the Fig. 21 is depicted the same gain in terms of service number, comparing the maximum number of services that is possible to transmit depending of the number of RF channels of the TFS frame.

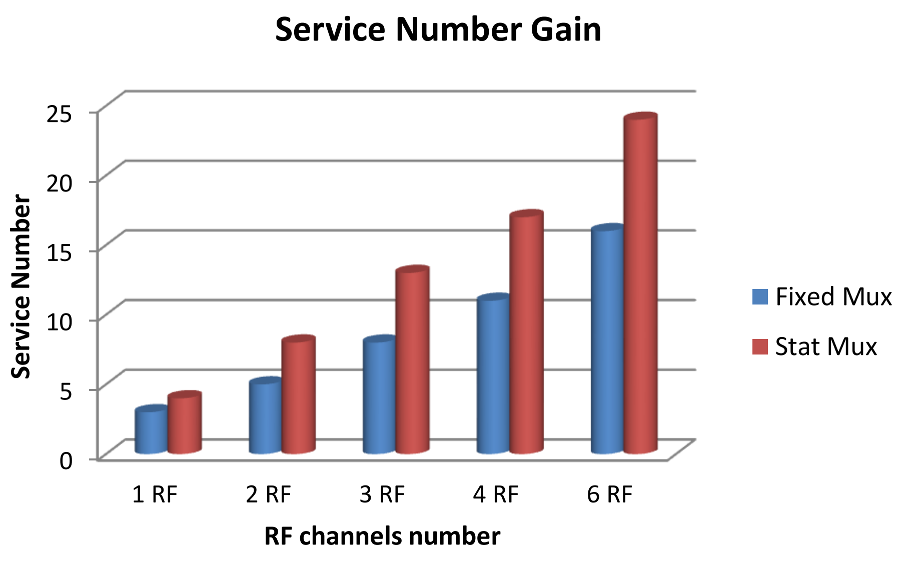

Fig.21. Gain in terms of service number

In addition, the same simulations have been performed with different a different time interval. This time interval is the minimum buffering period in order to determine how many information of each service has to be transmitted in the next interval.

To simplify, almost all simulations have been developed with 1 second time interval. However, it is interesting to test other configurations of decision time interval. In the Fig. 22 and Fig. 23 are depicted the statistical multiplexing gain in terms of (3) and services number, respectively, for a 0.5 seconds time interval.

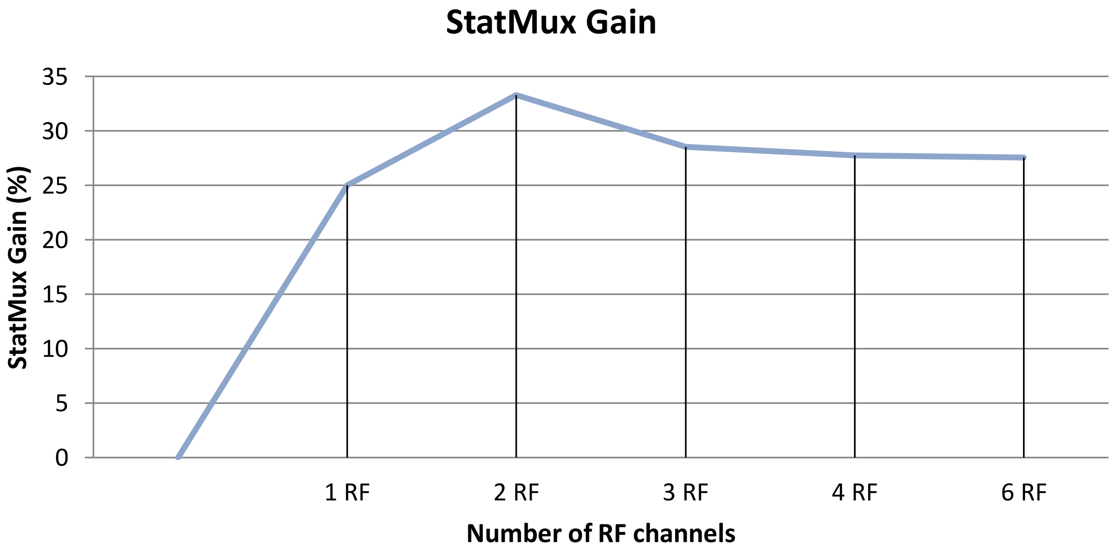

Fig.22. StatMux gain representation for TI (0.5s).

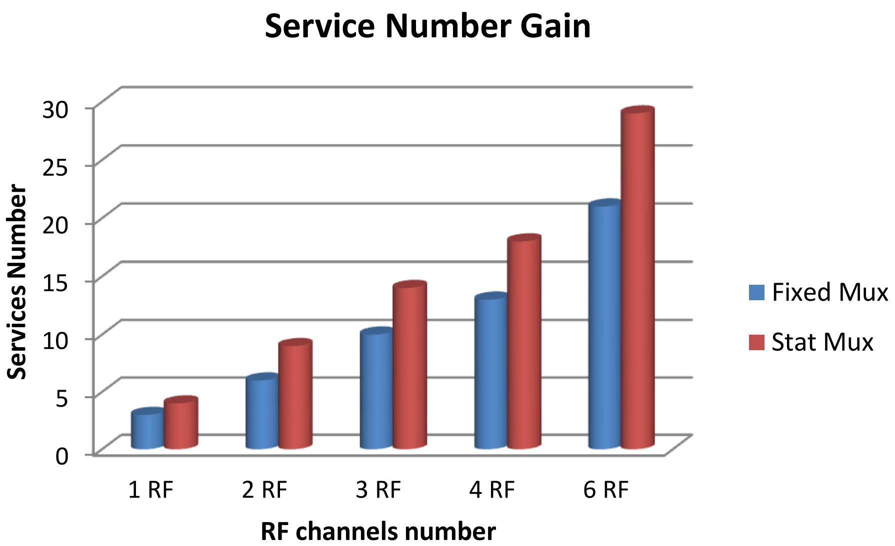

Fig.23. Gain in terms of services number

If these results are compared with 1 second time interval it is possible to see that then number of services to transmit has increased. With the same bandwidth and less buffering time, the algorithm has less buffering congestion and it works a little bit better. This gain is achieved because of the more dynamically adaptation of the algorithm to the statistical behavior of the service flows. In the simulations performed with more time interval, 2 seconds, the number of services that is possible to transmit decrease in comparison with 1 or 0.5 seconds from the utilization of 2 RF channels.

Physical Multiplexing Gain

Following with the study of the physical layer statistical multiplexing algorithm, this new proposal has been compared with statistical algorithms at the upper layers. To perform the comparison, a new measurement has been defined in (4) to evaluate the gain due to the physical statistical multiplexing:

$$PhyMux_{Gain}\,(\%) = \frac{PhyStatMux_{ServicesNumber} - TradStatMux_{ServicesNumber}}{PhyStatMux_{ServicesNumber}}\, x100 \qquad (4)$$

To test this gain, new simulations have been run in the same UK DVB-T2 scenario:

RF Channels	1	2	3	4	6
TradStatMux Services Nr	3	6	10	13	19
PhyStatMux Services Nr	4	8	13	17	24
Gain (%)	**25**	**25**	**23.07**	**23.52**	**20.83**

Table 2: PhyMux gain in different TFS RF channels number

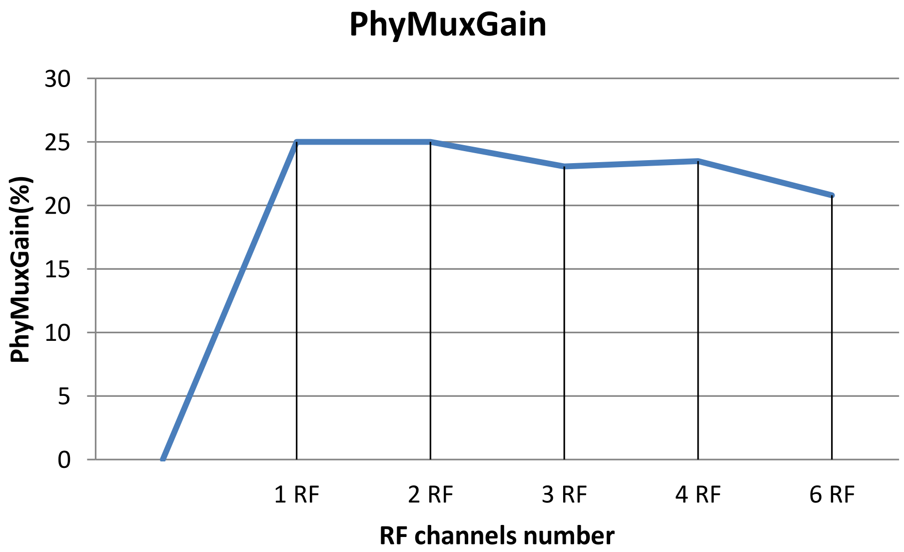

Fig.24. PhyMux gain representation.

In the Table 2 and the Fig. 22 it is possible to see that the new algorithm achieves enhancements close to 25% for the physical layer statistical multiplexing algorithm in comparison with the traditional statistical multiplexing performed in the upper layers. This gain in terms of service number is depicted in the Fig. 25. Thanks to the service allocation in terms of cells at the physical layer, the proposed algorithm is capable to transmit more services than with a conventional multiplexing.

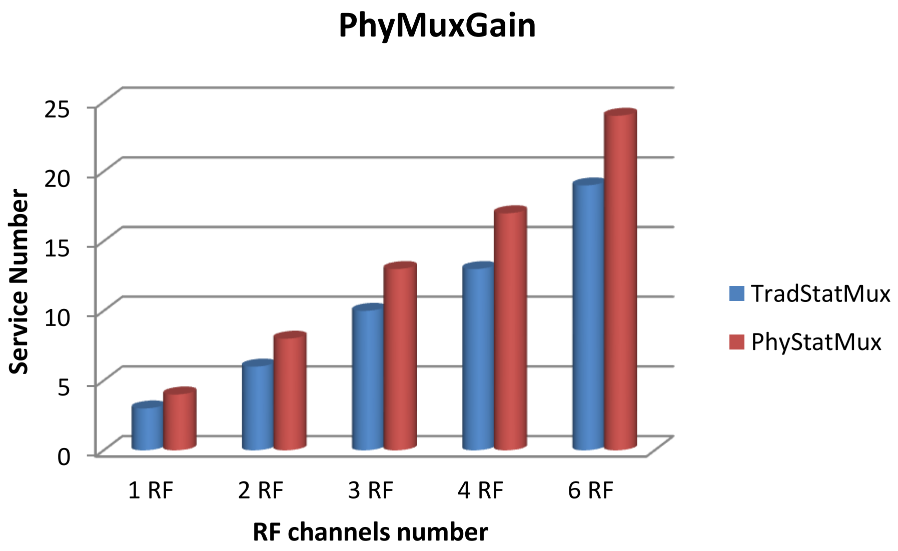

Fig.25. PhyMux gain representation in terms of services number.

On the other hand, another advantage of the physical layer allocation of the services is the per service physical layer configuration. In systems where there are services with different properties, the possibility to set a specific configuration for each type increases the efficiency.

To test these cases, a transmission of High Definition TV (HDTV) services combined with Standard Definition TV (SDTV) services has been simulated. While in the traditional multiplexing only one physical configuration is allowed for all the services, in the physical layer multiplexing for the HDTV services a 256QAM modulation with a code rate of 3/5 has been used and for the SDTV services a 16QAM modulation with a code rate of 2/3 has been chosen. On the other hand, for the traditional multiplexing the configuration chosen has been the 16 QAM with a code rate of 2/3.

In the Fig. 26 and 27 are depicted the gain achieved thanks to the physical layer multiplexing which allows more services transmission in the same equivalent bandwidth.

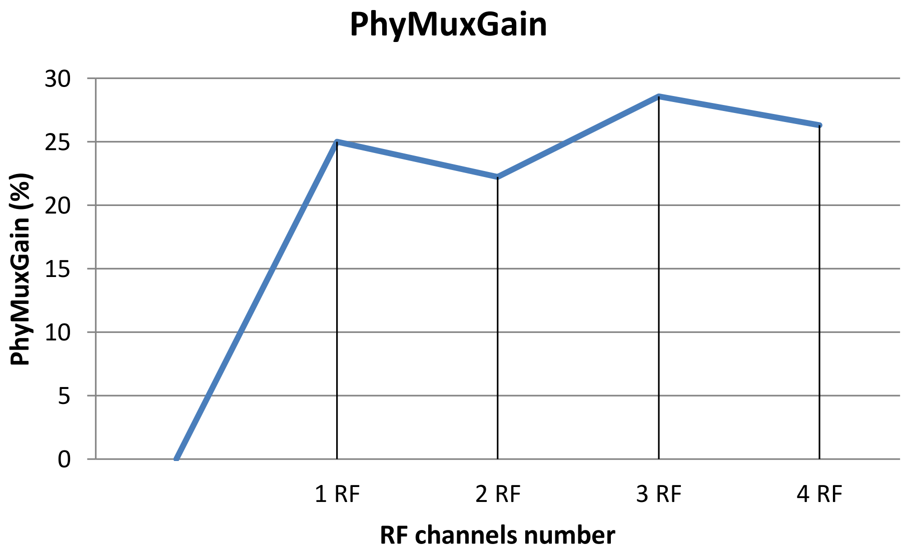

Fig.26. PhyMux gain representation for HDTV and SDTV services.

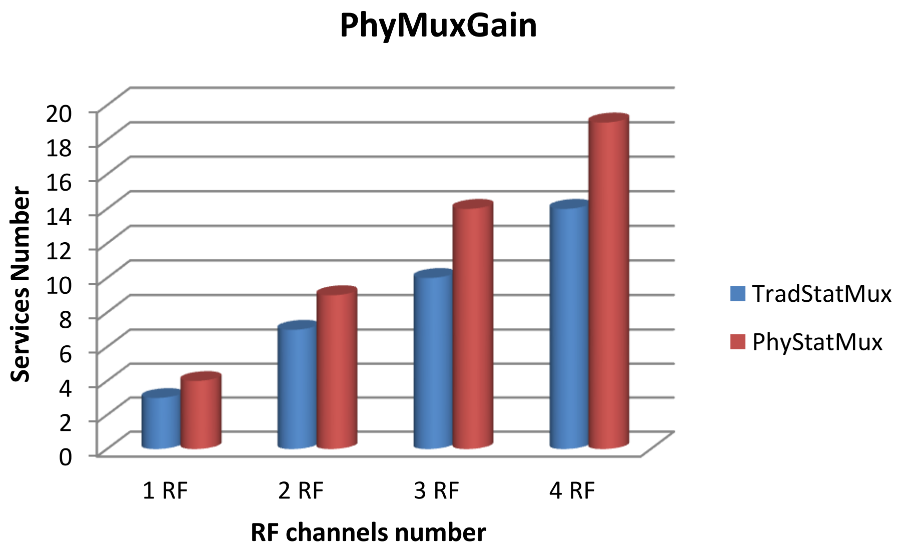

Fig.27. PhyMux gain representation in terms of services number for HDTV and SDTV services.

VII. CONCLUSIONS

This thesis proposes a new concept of service allocation for second generation of DVB standards performed at the physical layer level. The new method studied for DVB-T2 uses the potential of the multiple PLP concept to allocate efficiently the services in the available bandwidth.

Traditional multiplexing algorithms have been performed in the upper layers without taking into account physical layer configurations per service. DVB-T2 allows a per service physical layer configuration which opens the possibility for a new service allocation method. The proposed method aims to work directly with basically allocation units at the physical layer, the cells. Cells allocation has the particularity of enable a more granular data allocation, improving the resources utilization.

The main goal of this thesis has been to enhance the transmission efficiency by means of a services number transmission increasing. To achieve that, a set of simulations have been performed in order to test the potential of the new algorithm. The simulations have shown the benefits of the scheduling algorithm proposed in real cases of DVB-T2 networks, like UK DVB-T2 configuration, in terms of bandwidth utilization and number of transmitted services in comparison with fixed multiplexing algorithms and traditional statistical multiplexing algorithms.

Analyzing the gain achieved against fixed algorithms the improvement achieved is notorious. Like other statistical multiplexing algorithms, for services encoded with VBR compression schemes, the enhancement obtained is several. The statistical multiplexing solution combined with TFS provides more capacity to allocate services in the available bandwidth.

On the other hand, the directly comparison with traditional statistical multiplexing algorithms also shows benefits in terms of number of services transmitted and physical layer flexibility. Thanks to allocate services directly at cell level, the simulation results indicate enhancements in the number of services to be allocated. In addition, the flexibility gained when different types of services need to be transmitted makes the physical layer allocation more interesting. The simulation results show that the flexibility achieved by means of different physical layer configuration allows more services transmission for the same bandwidth with a particular physical layer protection.

It should be noted that the benefits shown by this thesis research have a plus interest for the near launching of DVB-NGH. This new standard for the next generation of handhelds will be based on the physical layer of DVB-T2 and it will include the most advanced encapsulation and transmission techniques to achieve a maximum system optimization. Physical layer statistical multiplexing could be one of these techniques aimed to improve the bandwidth utilization and increase the number of services to transmit.

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Oh the other hand, I would like thanks to David Gómez their support in this thesis development and his help since I came to the MCG. I also want to give thanks to Narcís Cardona for give two years ago the possibility to take part of his research group. I don't want to forget my five months in Tampere with the professor Irek, his help when I was so far of my home and family made me best researcher and person.

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