REGIONAL CONTENTS IN A NATIONAL DVB-T2 SFN: A NOVEL APPROACH BASED ON DVB-SIS

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ABSTRACT

To include regional contents in a national Single Frequency Network (SFN), Rai has studied and tested in the laboratory a system configuration that benefits from the multiple Physical Layer Pipes (PLP) of DVB-T2. According to the proposed solution, in each region the national programmes are transmitted in one PLP, while other k PLPs convey the regional contents of macro-regional SFN, formed by a region and the (k-1) surrounding ones. The DVB Single Illumination System standard (DVB-SIS) can be a valid technical solution to distribute such complex signals to SFN transmitters via satellite or terrestrial contribution links in a cost-effective way.

The paper presents the rules adopted to map content into DVB-T2 PLPs and their application to the Italian case. Furthermore, it describes the end-to-end laboratory set-up and the results of tests carried out, showing that a national SFN can broadcast both national and regional contents with high flexibility and spectrum efficiency.

INTRODUCTION

DVB-T2 is the candidate DVB technology to complement (or replace) the current DVB-T terrestrial transmission format in Italy after the release of the 700 MHz band in 2022, allowing us to compensate for the reduction of available spectrum resources.

Large Single Frequency Networks (SFN) are recognised by EBU and ITU studies [1] [2] as the best configurations for the optimal exploitation of spectrum resources, with respect to Regional SFNs or Multi Frequency Networks (MFN). However, a national SFN would normally not allow the inclusion of regional contents, since different contents from adjacent SFN transmitters would interfere.

The paper presents a possible solution to broadcast regional programmes (21 for Italy) in a national SFN, along with national ones, while keeping a good spectrum efficiency (much higher than the trivial solution of simulcasting the 21 regional contents all over the national SFN network).

DVB-T2 MULTI-PLP TO CARRY REGIONAL CONTENT IN A NATIONAL SFN

With respect to DVB-T, the second-generation standard DVB-T2 offers, among other features, a method of transporting individual data services in separate logical channels,

known as physical layer pipes (PLPs), within the physical layer, where the error-correction coding and interleaving are applied separately to each PLP. This allows for the implementation of independent “transmission channels”, separated in time/carrier position instead of frequency (as it is the case in MFNs).

The Multi-PLP (MPLP) configuration, originally proposed to allow for the implementation of service-specific robustness, is exploited here, to broadcast regional contents in a national SFN, without generating interference problems in neighbouring regions, while at the same time keeping good spectrum efficiency.

According to the proposed solution, in each region the national programmes are transmitted in PLP#0, while k PLPs convey the regional contents of a macro-regional SFN, formed by a region and the (k-1) surrounding ones (k<<21 Italian regions).

To minimise interferences, the regional content of each individual region is assigned to the same PLP number also in the transmitters located in the surrounding regions, thus complying with the non-interference SFN rule for that PLP. In Figure 1 this is represented for an ideally infinite hexagonal network. In the example, 7 PLPs are used (analogous to the 7 frequencies required for MFN planning): the content of PLP#1 is the one of Region 1 also in the surrounding regions (2 to 7), while in regions far from Region 1 (e.g. Region 8) PLP#1 is reassigned to another regional content (e.g. the one of Region 22). The process is implemented according to a sliding SFN approach. This solution allows to maximally exploit the frequency spectrum, without the need to switch from a national SFN to a regional one, thus avoiding the adoption of multiple frequency channels.

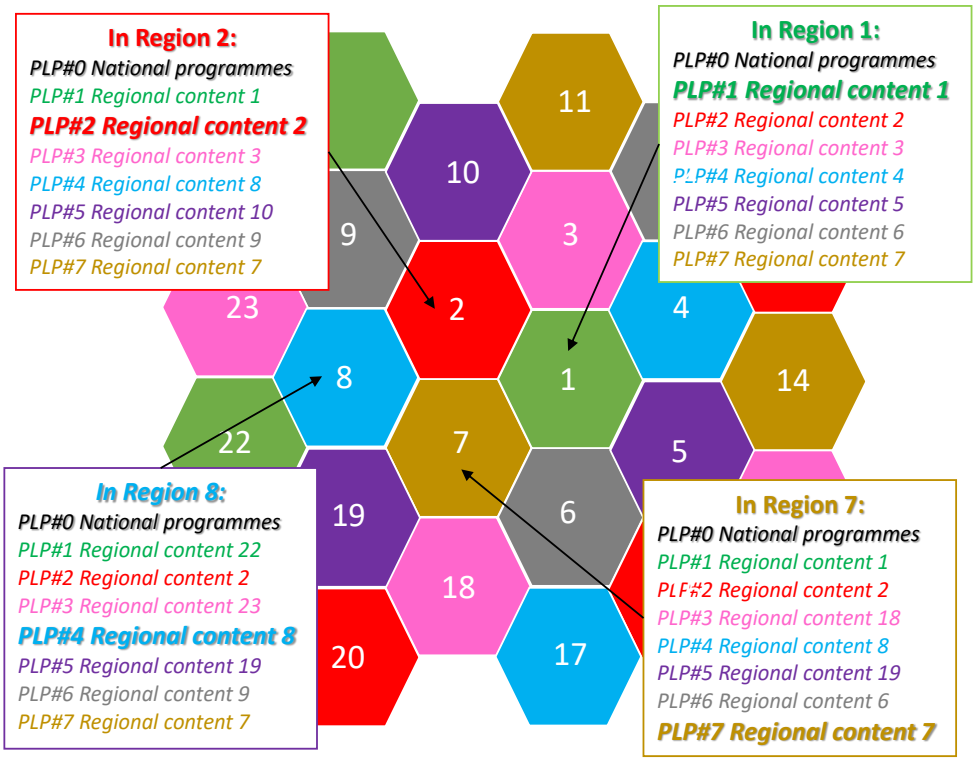

Figure 1 – MPLP configuration of DVB-T2 to broadcast regional content in a national SFN

CONFIGURATION OF THE REGIONAL SERVICES FOR THE ITALIAN CASE

The Rai public-service multiplex contains 2 national programmes, Rai 1 and Rai 2, plus Rai 3, that broadcasts regional News during some portions of the time. So far, in order to accommodate 21 regional variants, the Rai public-service multiplex has been planned as a regional SFN: according to traditional implementations, it is necessary to allocate from 3 up to 7 frequencies for the regional multiplex, hence the need to elaborate a more efficient configuration in order to deliver the same content using only one frequency. To keep the same coverage currently achieved by the Rai/Rai Way network infrastructure with DVB-T, a possible DVB-T2 system configuration could be as follows: 256QAM 3/5 with a guard interval of 224 µs (and using PP4), achieving a bit rate of 33.18 Mbps with a target Signal-to-Noise Ratio (SNR) for Quasi Error Free (QEF) performance of about 18 dB [3] (equivalent to DVB-T 64QAM 2/3). Alternatively, for a SNR of 20 dB, the use of 256QAM 2/3 would increase the available bit rate to 36.92 Mbps.

The result of the mapping of a full country is given in Figure 2 for the case of Italy, where 5 regional PLPs are considered, in addition to the national PLP. This allows us to map PLPs for the wanted region and 4 neighbouring ones. To cope with cases where the number of neighbouring regions is larger than 4 and to avoid the need to increase the number of PLPs in each region (resulting in a reduction of the available bit rate per PLP), the transmitters in a region may contain differentiated content for some of the PLPs of the neighbouring regions. This is for example the case of Lombardia, where PLP#5 contains regional content of Alto Adige in transmitters covering the north-east territories, while in the west territories of the region PLP#5 brings regional contents of Piemonte.

With a capacity of about 35 Mbps, a basic configuration of the Rai public-service multiplex could be configured to contain:

- PLP#0 (National): Rai 1 and Rai 2 in HD at 5 Mbps each (HEVC encoding);
- PLP#1-PLP#5 (Regional): Rai 3 regional service in HD at 5 Mbps (plus 4 Rai 3 regional services of neighbouring regions).

This results in 3 HD programs over a single UHF channel, instead of 7 HD programs over 4 UHF channels (which would be required using a regional SFN approach), with an efficiency gain of 70%. A further optimisation could also be considered reconfiguring the SFN network when Rai 3 content is national: PLP#1 would carry Rai 3 (national) and PLP#2-PLP#5 would carry other national programmes (but these programmes would be periodically interrupted by regional news).

SERVICE DISCOVERY

In the basic scenario, the Rai 3 services conveying national content or the regional variant are carried in different PLPs and identified by a different transport_stream_id. To allow users to select, during the initial receiver installation, the service carrying their preferred regional variant, all the services are signalled with the same LCN (Logical Channel Number) value, so triggering an LCN conflict and driving the manual selection based on the service name (for example “Rai 3 Lombardia”).

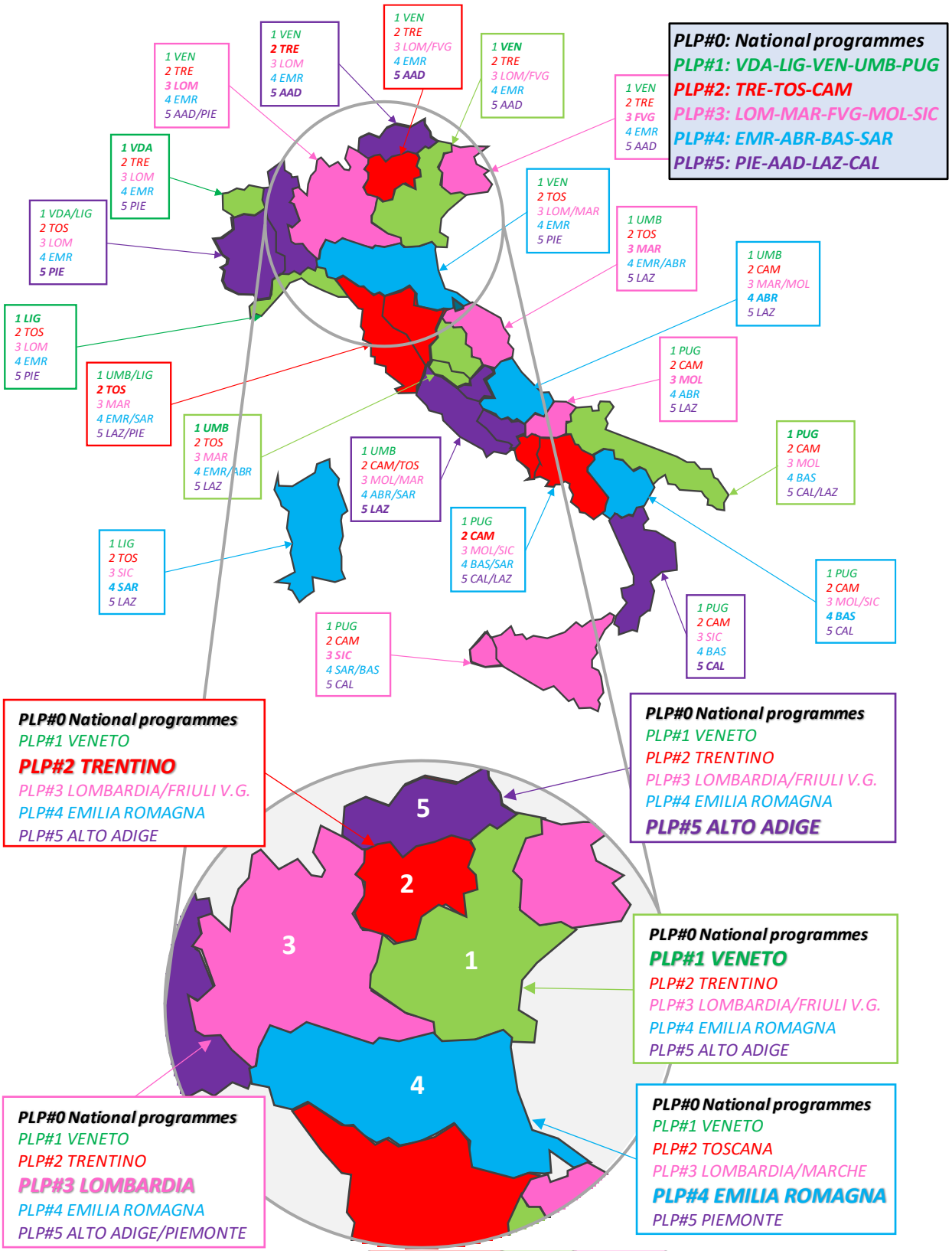

Figure 2 – MPLP configuration for Italy

In an alternative scenario, since the regional schedule counts less than 10% of the overall daily schedule, the regional variants could be carried in dedicated PLPs with a lower capacity, while the national Rai 3 service could benefit from a higher capacity, shared with other national services to improve statistical multiplexing efficiency. In this scenario, the receiver has to switch between the national Rai 3 service and another service carrying the regional variant. The switching mechanism uses the DVB "service replacement" functionality which is based on the addition of proper linkage descriptors in the Service Description Table (SDT) of the national Rai 3 service. To allow the selection of the preferred regional variant (through an LCN conflict) it is necessary to declare as many national services "copies" as the total number of regional variants, each referring to the elementary streams of the same service. According to the schedule, in the SDT of the national PLP the running status is toggled from "running" to "not running" to automatically tune the receiver to the regional replacement service. The receiver, once tuned to the replacement service, listens to the SDT other (which lists the services transmitted in national PLP) in order to tune back to the national Rai3 service, when running status of the origin service becomes "running" again, at the end of the regional news program. In this regards, the Ultra HD Book 1.0 [4] mandates the support of linkage descriptor with linkage type "service replacement service" in receivers for the Italian market.

PRIMARY DISTRIBUTION TO THE TRANSMITTING SITES LEVERAGING DVB-SIS

The DVB-SIS (Single Illumination System) specification, published in August 2018 as an ETSI standard [5], enables using a single satellite signal to provide at the same time DTH (Direct-To-Home) coverage, with TV reception by means of conventional DVB-S/S2/S2X consumer receivers, and primary distribution to DVB-T/T2 terrestrial transmitters, including DVB-T2 MPLP and in SFN. In the absence of such specification, a dedicated satellite transponder should be allocated to feed the DVB-T2 transmitters with streams in T2-MI (Modulator Interface) format, not accessible by consumer DTH receivers. With DVB-SIS, the T2-MI signal is reconstructed locally by the DSA (Daughter Site Adapter), based on regular TSs delivered via satellite and additional framing and timing information inserted centrally by the CSG (Control Stream Generator) at the satellite head-end.

Clearly, this standard allows achieving the 'single illumination' feature, with maximum satellite capacity saving, if the TV services use the same audio/video encoding parameters in both satellite and terrestrial broadcast networks. However, even in cases where this would be impractical (e.g., in some markets, limitations in the available spectrum may require a more efficient video coding standard on terrestrial networks) and dedicated transponders for primary terrestrial distribution would be needed anyway, DVB-SIS proves to be a cost effective solution for the use case described in the present paper.

Table 1 reports a comparison between a traditional solution, based on a centralised generation of all regional T2-MI streams, and a decentralised solution based on DVB-SIS[1],

[1] With reference to the configuration in previous Section, the following assumptions are made in Table 1:
- 21 different regional variants of T2-MI streams are configured, to be delivered via satellite;
- Calculation of required satellite capacity does not include overheads (e.g., TS and T2-MI headers);

for the configuration proposed in previous Sections. The saving in terms of satellite capacity is about 84%, at the cost of additional equipment at the terrestrial transmitting sites.

		Centralised generation of all T2-MI regional streams	Decentralised reconstruction of T2-MI regional streams (DVB-SIS)
Required satellite capacity		735 Mbps ⇨ [21((2x5)+(5x5))]	115 Mbps ⇨ [1(2x5)+21x5]
Equipment	**Head-end**	21 T2-gateways	2 CSGs
	Each Tx site	1 satellite receiver	2 satellite receivers + 1 DSA

Table 1 – Comparison of the requirements of the distribution network (centralised vs. decentralised solution)

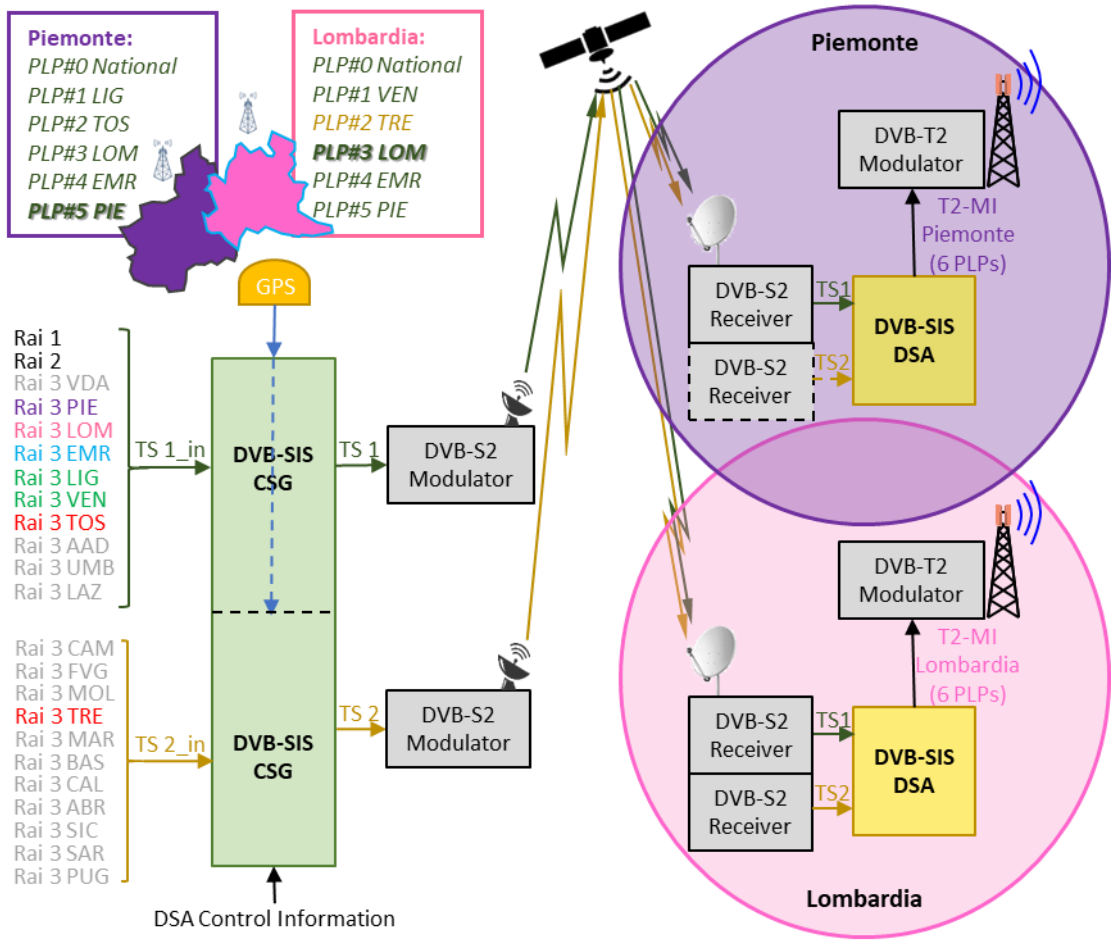

Figure 3 – Primary satellite distribution and local reconstruction of regional DVB-T2 multiplexes leveraging the DVB-SIS standard

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- In the decentralised solution, all contents (national and regional), summing up to 115 Mbps, can be delivered in two satellite transponders (e.g., DVB-S2). In some of the regions, all services are picked from the same satellite transponder (see also Figure 3).

Figure 3 shows the end-to-end distribution architecture in the described use case (for simplicity, only two regions are depicted). Being entirely based on DVB standards, this solution guarantees cross-vendor interoperability and is therefore preferable to equivalent proprietary solutions. The same architecture is applicable also to other distribution networks, e.g., fibre or radio links (in this case, further optimisations could be considered, e.g., splitting the distributed TSs into smaller streams).

LABORATORY TESTS

A thorough laboratory investigation has been carried out in order to verify the performance of receivers in the proposed system configuration. During the tests various aspects were analyzed using a great variety of different approaches. For the sake of brevity, only the most important laboratory set-up and results are described here.

An SFN has been emulated in the laboratory in the presence of multiple PLPs, with one or more conflicting PLPs. For simplicity, and without this in any way representing a limitation to the validity of the test performed for more complex networks, a SFN with only two regions was built based on two PLPs, PLP#0 common to the whole network and PLP#1 in conflict. With reference to Figure 3, PLP#0 could contain the national programmes and one regional programme common to Piemonte and Lombardia, while PLP#1 one of the conflicting programmes. In order to generate a MPLP DVB-T2 SFN signal, two IQ files were produced using the Dektec T2Xpress software. The adopted system configuration is 256QAM 3/4 (FFT 32k, PP4).

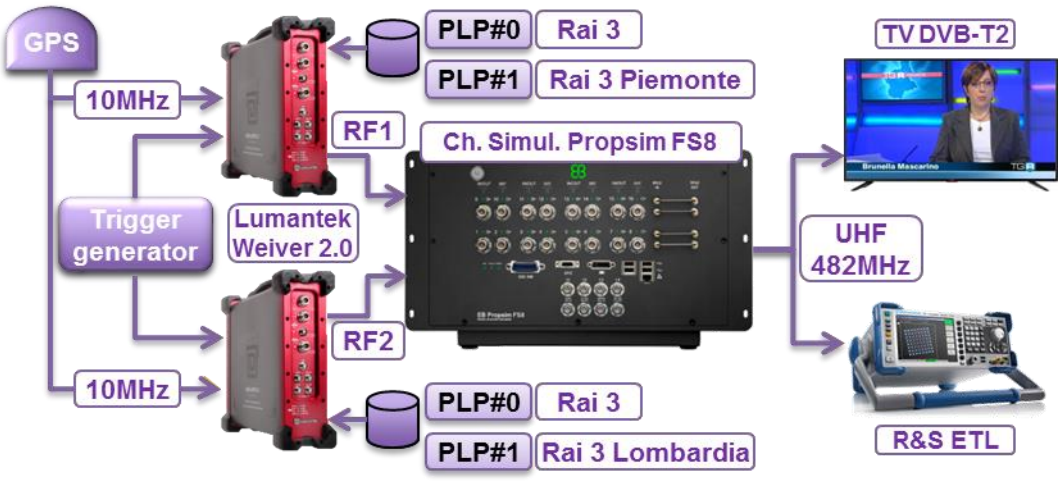

Figure 4 – Laboratory test bench

The two IQ files were loaded, after appropriate resampling and harmonization of the file formats, on two RF players (Lumantek *Weiver 2.0*). These devices allow to playback IQ files in synchronous mode using a common time and frequency reference. The two signals, passed through a hardware channel emulator (Propsim F8) applying various delays and C/N, were then combined and supplied to a number of consumer DVB-T2 receivers and to a professional analyser (R&S ETL). The measurement bench is shown in

Figure 4.

First of all, the reference receivers' performance in the absence of PLP conflicts was assessed by loading the two RF players with the same file. The results for two sample receivers are reported in Table 2 for several channel profiles.

	C/N@TOV [dB]									
			Echo parameters							
	Gaussian		200 μs, 0 dB		200 μs, -5 dB		10 μs, 0 dB		10 μs, -5 dB	
	RX1	RX2	RX1	RX2	RX1	RX2	RX1	RX2	RX1	RX2
PLP#0/1	20.9	21.0	25.2	25.3	22.5	23.2	25.0	24.6	22.5	22.5

Table 2 – C/N@TOV without PLP conflict

Then, the conflicting configuration was tested and it was verified that PLP#0, the one not in conflict, could still be received correctly without further degradation. This confirms the validity of the proposed solution: in each region the national programmes and the specific regional one can be correctly received, because, according to the adopted MPLP configuration, they belong to non-conflicting PLPs in the region.

	C/I@TOV [dB]			
	Delay 200 μs		Delay 10 μs	
	RX1	RX2	RX1	RX2
Measure [dB]	24.3	23.4	24.2	23.4
Expected [dB]	20.9	21.0	20.9	21.0
Degradation [dB]	3.4	2.4	3.3	2.4

Table 3 – C/I@TOV with PLP conflict

Instead, for PLP#1 the measured C/I ratio is larger than the C/N in AWGN channel at TOV (Threshold of Visibility), as it could be (erroneously) expected by considering interference as Gaussian noise (see Table 3). The reason behind this result is that, in conflicting PLPs, the receiver channel estimation/equalisation erroneously operates on fully coherent pilot carriers from the wanted and interfering signals, while the correct equalization should consider just the wanted signal. In Figure 5 the constellation diagram after equalization for 256QAM PLP#0 and QPSK PLP#1 case is visible: PLP#0 is well equalized, PLP#1 is badly equalized, thus impairing its C/I and C/N performance. This phenomenon has no negative impact on the three programs addressed to the specific Italian region (Rai 1, 2 and Rai 3 regional), but should be taken into account when planning the network configuration, to minimize the effect of far-away transmitters.

As a second step, the end-to-end chain as in Figure 6 has been set-up, using early implementations of the Single Illumination solution. With respect to Figure 3, only 4 PLPs have been used and the satellite link has been bypassed with direct TS connections.

Two CSGs where fed with one input TS each. The two DSAs picked content from the received TS streams to generate two DVB T2-MI streams, with identical PLP#0, PLP#1 and PLP#2, but different PLP#3 for the two regions. The two T2-MI streams were then sent to two modulators in SFN. Tests with different DVB-T2 TV receivers and the

professional analyser confirmed that services in PLP#0, PLP#1 and PLP#2 can be properly received.

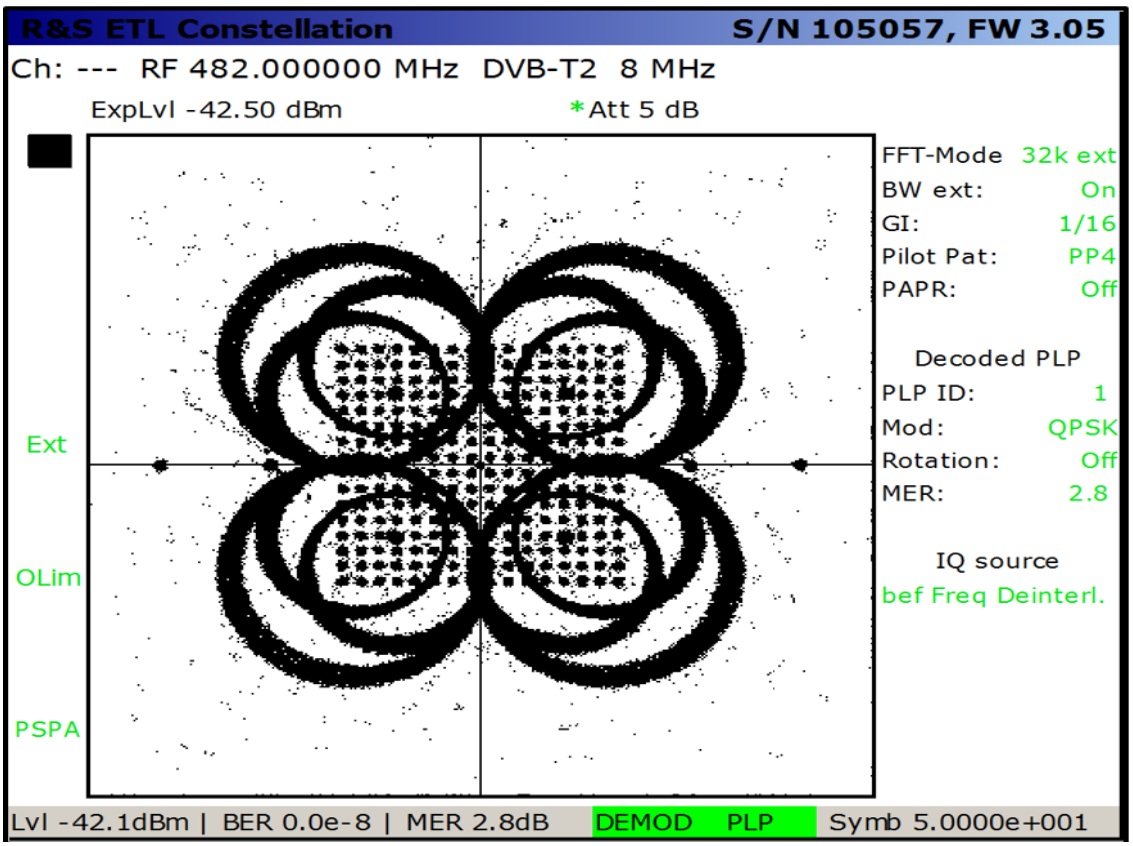

Figure 5 – Constellation diagram:

- PLP#0: non conflicting, 256QAM correct equalization;
- PLP#1: conflicting, QPSK perturbed equalization

CONCLUSIONS

The solution presented in the paper allows us to deliver regional and national content in a national SFN, thanks to the use of the MPLP configuration of DVB-T2. In addition, the adoption of DVB-SIS to transport the content to the transmitters represents a standardized and cost-effective solution for the use case described in the present paper. Extensive laboratory tests demonstrated the feasibility of implementation of the proposed solution, allowing high flexibility and spectrum efficiency in the planning of national SFN with regional and national content.

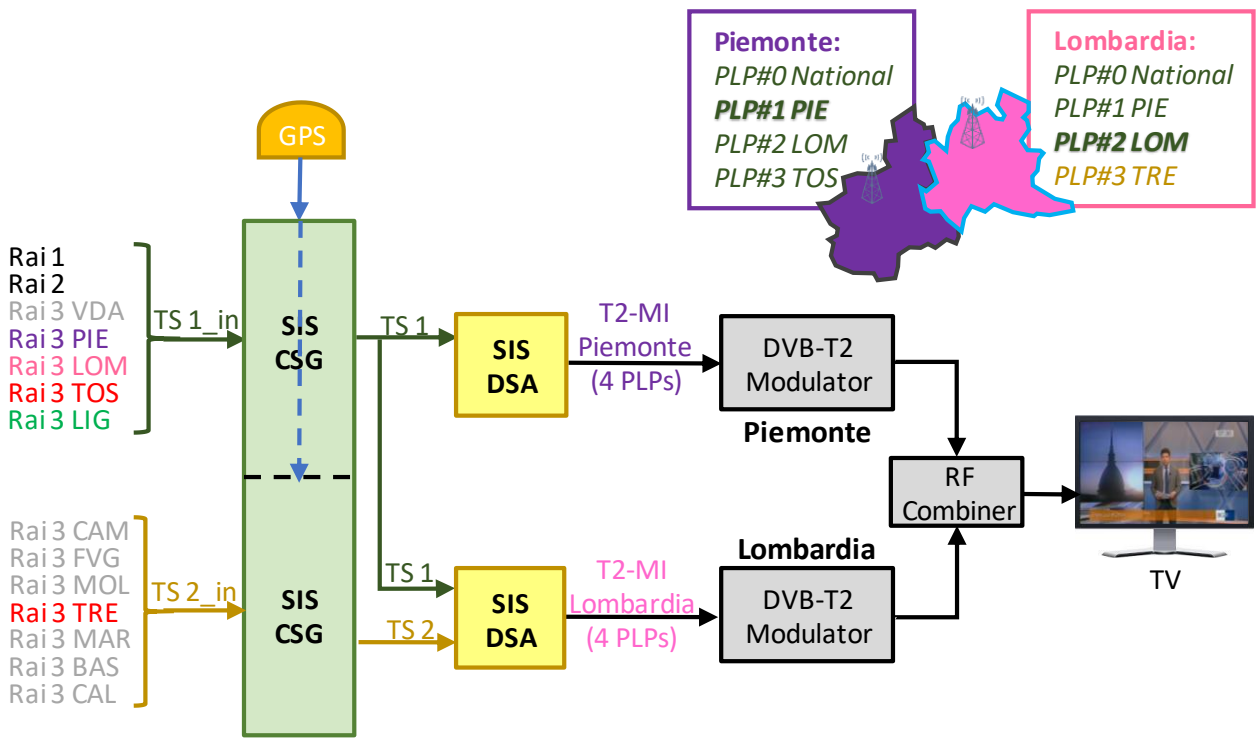

Figure 6 – Laboratory test bed of the end-to-end chain

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