Frequency Planning for Digital Terrestrial Television (DTT) in South America

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Abstract

In South America, the migration from analogue television to Digital Terrestrial Television (DTT) is on-going without any international agreement for the frequency allocation in the region such as the Geneva 2006 regional agreement (GE06) for Europe. Furthermore, there are several DTT technologies on air. Most countries have adopted the Japanese-Brazilian standard ISDB-Tb (Integrated Services Digital Broadcasting – Brazilian version) but Colombia adopted the European standard DVB-T2 (Digital Video Broadcasting – Terrestrial Second Generation). Another characteristic is that the digital dividend band (700 MHz band in the Americas), which was used in many countries for the simulcast transition period, has been already allocated in many countries for mobile broadband (4G LTE) and hence it is not available. This paper reviews the frequency planning problem for DTT and presents a first proposal for a frequency allocation agreement in South America.

Keywords: 4G LTE; analogue switch-off; digital dividend; digital terrestrial television; DVB-T; DVB-T2, ISDB-Tb, frequency planning; network planning; NTSC; single frequency networks.

1. Introduction

The introduction of Digital Terrestrial Television (DTT) offers great advantages compared to analogue television, making a very efficient use of the scarce radioelectric spectrum. Firstly, it allows to transmit several TV services in a single radio frequency (RF) channel. Secondly, it enables to transmit national, local and mobile services in Single Frequency Networks (SFN) consisting of several transmitters transmitting the same content at the same frequency [1]. Thirdly, DTT also allows to work in adjacent RF channels. The spectrum efficiency achieved with DTT allows to release the upper part of the UHF band traditionally used for terrestrial TV broadcasting for mobile broadband [2]. This is known as Digital Dividend (DD), and corresponds to the 700 MHz band in the Americas. This band has been allocated for 4G LTE in several countries [3], and hence it is not available during the simulcast period when analogue and digital transmissions must co-exist.

In Latin America several DTT standards have been adopted, and in South America, region in which the present work focuses, there are two DTT technologies. All countries have adopted the Japanese-Brazilian standard ISDB-Tb (Integrated Services Digital Broadcasting – Brazilian version) [4], except Colombia that has adopted the second-generation European DTT standard DVB-T2 (Digital Video Broadcasting – Terrestrial Second Generation) [5]. DVB-T2 is the actually state of art of DTT transmission. For the typical ISDB-Tb mode adopted in South America (64 QAM, 3/4, FFT 8K), DVB-T2 offers a capacity gain of about 58% for the same coverage (CNR 20.1 dB), and a coverage gain of about 7 dB for the same capacity (18.26 Mbps). DVB-T2 was adopted in Colombia with the particularity that it was the first time that it operates with 6 MHz channelization instead of 8 MHz or 7 MHz commonly used in Europe.

Today many countries have completed the DTT transition process. But in South America the process is still underway, and at the date of writing this paper no country has performed the analogue TV switch-off. Most countries are planning to finish the analogue switch by the end of this decade [6].

The Geneva 2006 (GE06) rules the frequency distribution for DTT in Europe [7], but in South America there is nothing similar. There are some bi-lateral agreements regarding the frequency allocation for analogue TV. Therefore, all the countries in the region have started the deployment of DTT network without any coordination for the whole region. Ideally, an international frequency plan for all countries must be first performed before planning the national frequency plans for each country taking into account the restrictions derived from the international planning. In South America, there are only some bilateral broadcasting spectrum allocation agreements between neighboring countries (e.g. between Colombia and Ecuador, a border where that DVB-T2 and ISDB-T should coexist [8]), by which each country can use the even or odd RF channels, as long there is no interference from a third country.

The main objective of regional planning is to determine which frequencies can be use by each country on its borders, such that there are no interferences (in practice, the planning process tries to ensure that the level of interference from a neighbor is lower than a given level). In such arrangements are usually defined: coordination areas in which incidentally the signal from a country can reach another one, coordination distances for each coordination zone, and minimum electric field to protect within the coordination distance. In the case of national frequency planning, countries large enough can use all the frequencies into the country. However, for small countries the available frequencies are restricted by the border agreements.

This paper provides an overview of the DTT frequency planning activities performed by the iTEAM research institute of the Universitat Politecnica de Valencia. The results presented constitute a first approach for an international agreement of DTT frequency assignment in the region.

The rest of the paper is structured as follows. The state of the DTT deployment in South America is presented in Section II. Section III describes the generic requirements for frequency planning. In Section IV, an efficient frequency planning at the country borders in South America are presented. In Section V, the frequency planning for a specific country, Colombia, is introduced. Finally, Section VI concludes the paper.

2. State of the DTT in South America

In South America, DTT networks are in deployment stage in most of the countries. Brazil was the first country that adopted the ISDB-Tb standard in 2006. In December 2007, it started the first DTT transmissions, and in 2012 448 cities were covered, equivalent to the 46% of the population. Argentina adopted ISDB-Tb in March of 2012, and there are currently 18 commercial DTT channels. The switch-off is planned for the end of 2019. Colombia, unlike the other countries, adopted in 2008 DVB-T instead ISDB-Tb, but thanks to the introduction of DVB-T2, Colombia decided to upgrade its DTT standard in 2011. The DTT transmissions have been divided in two groups, one for public operators (RTVC) and other one for private operators (CCNP), both of them working over big SFN networks for national services [9]. In the case of regional services, in Colombia there are four regional services distribute across the country. Ecuador adopted ISDB-Tb in 2010, and today there are commercial DTT services in the most important cities (7 in Quito and 8 in Guayaquil). Bolivia adopted ISDB-Tb in May 2012, year that started the transmission of the public broadcaster in La Paz. Peru adopted ISDB-Tb in 2012, and today there are 15 commercial transmissions in Lima. Finally, Venezuela adopted ISDB-Tb in 2009. In 2013 DTT transmissions started in 15 states.

The analogue switch-off in the region is currently in progress, being Brazil and Ecuador the countries that expect to end the analogue TV transmissions by the end of the next year (See Table 1). However, postponing the analogue switch-off has become a common practice in the region.

Regarding the auction of the 700 MHz band, Brazil, Chile, Colombia and Peru had started the auction of the DD band. Brazil was the first country in South America to complete the auction in September 2014. In Chile, the 700 MHz band auction finished in 2014, in this country the first DTT transmission in the DD band was performed in 2015. Colombia is planning the auction of 90 MHz of the DD band by the end of 2017 [10]. In Peru, the auction of three blocks of the DD started in September 2015. In Uruguay, the action is being planned for 2018.

Country	Technology	Start DTT transmissions	Analogue switch-off	AuctionDD
Argentina	ISDB-T	2010	2019	Not defined
Bolivia	ISDB-T	May 2012	2019	Not defined
Brazil	ISDB-T	December 2007	2020	2014
Chile	ISDB-T	June 2010	2020	2014
Colombia	DVB-T2	January 2010	2019	2017
Ecuador	ISDB-T	May 2013	2018	Not defined
Paraguay	ISDB-T	2011	2022	Not defined
Peru	ISDB-T	March 2010	2028	2015
Uruguay	ISDB-T	August 2012	2020	2018
Venezuela	ISDB-T	June 2011	2021	Not defined

Table 1. Deadlines for DTT implementation in South America.

In the rest of countries in the region, the auction has not been defined yet. Table 1 shown the stablished deadlines for the implementation of DTT in South America. The early assignment of the 700 MHz band to 4G LTE involves a much complex scenario for the frequency planning, because there is less spectrum for the simulcast phase where both analogue and digital transmissions co-exist [11], [12].

3. Methodology for Frequency Planning

As a first step in the elaboration of a frequency plan, it is necessary to define: i) the radio propagation model, ii) Reference Planning Configuration (RPC), iii) Reference Network (RN), iv) Coordination areas, and v) coordination distances. Also, the service areas must be defined. Then, Using a frequency planning algorithm, the frequency plan could be synthetized. In which each service area has one or a group of frequencies allowed. Finally, a coverage estimation should be performed in order to test the proposed frequency planning. If the interferences are under the maximum allowable interferences (5% of the coverage area), the frequency planning could be considered complete. If the interferences are not admissible, the process must be repeated as shown in Fig. 1.

In order to maximize the spectrum efficiency, the services areas should be defined taking into account the maximum SFN size in each country. This is achieved by determining the minimum number of SFN networks that can cover the country, or what is the same the minimum number of frequencies needed to cover the country (one frequency for each SFN), which lead to an acceptable level of inter-SFN interference.

Regarding the radio propagation model, it is important to use a representative model for the area under study. A global model for DTT widely used is the ITU-R 1546 propagation model [13]. This is the model considered in this work. However, it should be pointed out that the model ITU-R 1546 was defined from measurements in Europe and North America. Therefore, due to the difference propagation conditions this model may not represent the South American scenario. In fact, the model that best fits the predicted and field measurements made in Colombia for two specific scenarios (Cucuta and

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Cartagena) is the model ITU-R 525 and ITU-R 525/526, with attenuation by diffraction based on rounded shape and sub path with fine attenuation [14]. However, it should be noted that due to the extensive area and very different topography of South America, it is difficult that a single model is representative for the entire region.

3.1. Reference Planning Configuration (RPC)

Table 2 shows the reference planning configurations assumed, taking into account that the predominant reception condition in South America is portable indoor reception. The transmission modes for ISDB-Tb and DVB-T2 are actually used in commercial deployments in South America, in Brazil and Colombia, respectively. For the modes of Table 2, DVB-T2 offers up to 5 dB gain in terms of coverage compared with ISDB-Tb. Also, the capacity is improved due the use of a larger FFT of size 16K (instead of 8K, maximum value possible para ISDB-Tb), and the use of extended bandwidth that increases the number of the OFDM subcarriers (1 % for 8k and 16K and 2% for 32K).

Standard		ISDB-Tb	DVB-T2
Modulation		64QAM	64QAM
Code rate (CR)		3/4	2/3
Guard Interval (GI)		1/8	1/8
FFT		8K	16KE
Bit rate		18.1 Mbps	18.1 Mbps
CNR (dB)	AWGN	20.1	13.6
	Rice	21.1	16.1
	Rayleigh	22.8	17.9
Emin (dBμV/m)		55.7	46.6
Locations %		95	95
PR inside country (Rayleigh)		21	16
PR borders (Rayleigh)		20	15
Bandwidth		6 MHz	6 MHz

Table 2. Reference planning configurations assumed.

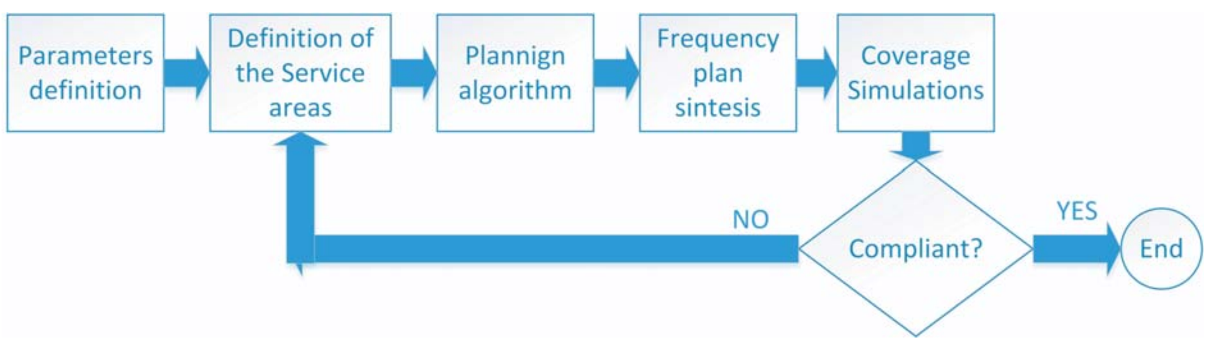

Figure 1. Steps for the frequency planning.

3.2. Reference Network (RN)

Figure 2 shows the reference network considered for the synthesis of the frequency plan. The main reason to select an open network, is due to the need to establish the worst case, this is with a reference network that does not present antenna discrimination. The distance between transmitters considered was 90 km and 60 km for DVB-T2 and ISDB-T, respectively. The choice of the distance was motivated by the maximum SFN distance allowed for the reference configurations shown in Table 2. The values of transmit power and antenna height shown in Table 3 were chosen as the average transmitter power planned in Colombia, assuming that they are typical for the whole region. It should be noted that the values presented in Table 2 are for portable indoor reception. If a different type of reception is considered, e.g. fixed outdoor reception, the requirements in terms of Carrier-to-Noise Ratio (CNR), the minimum field strength required in reception for a correct decoding of the signal Emin, and protection ratios are lower. The protection ratio is defined as the minimum value of wanted-to-unwanted signal ratio, usually expressed in decibels at the receiver input. This aspect also influences the re-use distance for planning frequencies.

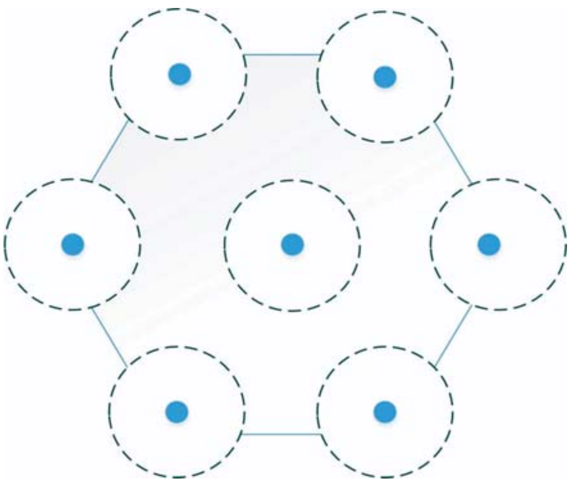

Figure 2. Reference Network (RN) used for frequency planning.

Parameter	Value
Network type	Closed
Distance between Tx	60 km
Height	150 m
Central Tx Power	100 W
Radiation Pattern Central Tx	Omni
Power of others Tx	1kW
Radiation pattern other Txs	Omni

Table 3. Reference planning configurations RPC assumed.

4. Frequency Planning at Country Borders in South America

4.1. Coordination Distance

It is necessary for each boundary to determine coordination areas in which one or other frequencies can be used. The number of coordination areas needed in each border are directly related to the border length and geographic conditions (i.e. mountains, valleys, etc.), and the possible existence of high power transmitters, involving interferences in a coordination zone. As is

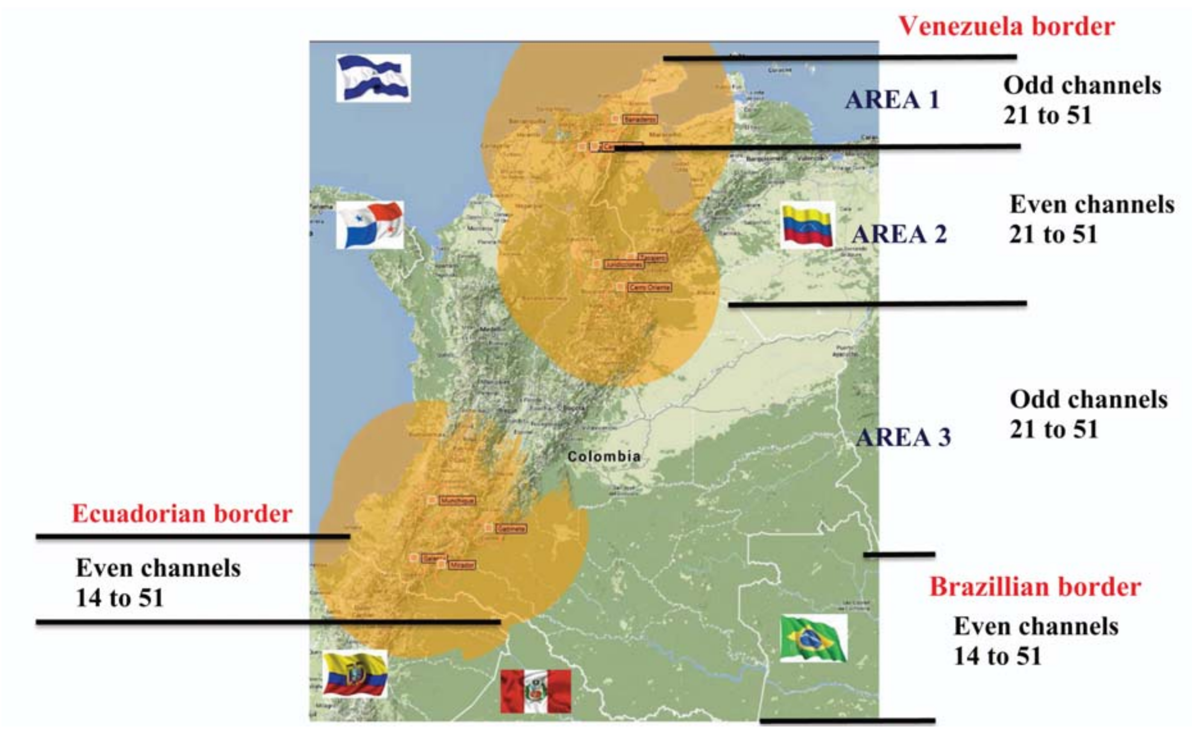

Figure 3. Coordination areas for Colombian borders.

shown in the Fig.3, in the case of Colombia, for example, for the borders Colombia-Ecuador, Colombia-Brazil and Colombia-Panama one single coordination area is enough. However, in the case of the Colombia-Venezuela border more coordination areas are needed, this is due to the greater border.

In each coordination area, the transmitter inside the coordination distances must be analyzed. The coordination distance is the distance from the border of each country within the deployment of a transmitter could lead to interferences to another country. The calculate coordination distances for South America are 16 km and 21 km for countries with DVB-T2 and ISDB-Tb, respectively.

4.2. Re-use Distance

The re-use distance is defined as the distance that the same frequency could be used for other transmitter of the same network. It was calculated from the reference network positioning two reference networks at a starting distance of 100 km. Later the received power was calculated for each point between them. Using the adequate PR (see Table 2) the points in which exist interferences was computed. Finally, the distance between the two networks was reduced in steps of 10 m. until the appearance of interference. The calculated re-use distance for frequency planning in South America are shown in Table 4.

Ambit	Technology	Re-use distance (km)
National	DVB-T2	66
	ISDB-Tb	70
Borders	Countries with DVB-T2	65
	Countries with ISDB-Tb	69

Table 4. Re-use distance for frequency planning in South America.

4.3. Service Area

The services areas must be determined within the border of the countries, usually following administrative or political conditions. Fig. 4 shows the possible service areas for national services in the border of South America.

In addition, it should be noted that in order to optimize the spectrum usage, it is desirable to deploy large SFN networks. Hence, services areas shown in Fig. 2 can be grouped, so that two adjacent areas can use the same frequency forming an SFN. The coverage scope of the networks is a very important factor, and it is recommended to define independent groups of service areas for national, regional and local networks.

The criteria used to determine the service areas was based on the politic division for each country, and the maximization in the size of possible SFN networks. In addition, it was considered the minimization of coordination areas needed in the borders of each country.

Figure 4. Service areas for national services in South America.

4.4. Frequency Plan Synthesis

After determining the conditions for the frequency plan (service areas, re-use distance of frequencies, coordination distances, coordination zones, restrictions on border agreements), it can be performed the synthesis of the frequency plan. With this aim, a graph that correspond to the adjacency of each service area at the borders of each country was defined. The sequential coloring algorithm was used, that consists of assigning a frequency sequentially, starting with the service areas with more adjacencies, to this service area a color (frequency) is assigned. Then is analized the next service area with less degree of adjacencies, if the distance between the already assigned service areas is greater than the re-use distance, the same color could be assigned, otherwise a new color must be used. This process is repeated for all service areas. The frequency distribution obtained is presented in Fig. 5 and Table 5.

■ **Figure 5.** Colouring for national services in South America.

It should be noted that for national services in South America, five frequencies are required as shown in Table 5. In the case of regional services, the number of required frequencies is increased up to 6.

5. National Frequency Planning

Once frequency planning at the borders of the countries were determined, then national frequency plans should be developed for each country.

The case of Colombia is presented as an example. For the frequency plan analysis, it was assumed that the entire band assigned to DTT can be used; taking into account the restrictions of each country and the considerations in border areas. This means that at the borders, the frequencies assigned in the regional frequency plan can not be used in the national frequency plan.

For national services, in Colombia three frequencies are required to cover the whole country for each multiplex. For regional services, four frequencies are necessary. For local services only one frequency is required, although it was recommended that nine local services should be multiplexed in the same RF channel for the capital Bogota.

Conclusions

The particularity of having adopted two different DTT standards in South America should be taken into account for the frequency planning. In the case of countries with

	Bolivia	**Brazil**	**Chile**	**Argentina**	**Colombia**	**Ecuador**	**Guyana**
Bolivia	-	1,3	1,4	4	-	-	-
Brazil	2,4	-	-	3	2		3
Chile	2	-	-	1,2,3	-	-	-
Argentina	3	-	1,3	-	-	-	-
Colombia	-	3	-	-	-	1,2	-
Ecuador	-	-	-	-	2,3,5	-	-
Guyana	-	1	-	-	-	-	-
Guiana Fr.	-	1	-	-	-	-	-
Paraguay	2	2	-	2,4	-	-	-
Perú	3,4	1,3	3		1	1,4	-
Suriname	-	2	-	-	-	-	2
Uruguay	-	2	-	1,2	-	-	-
Venezuela	-	4,5	-	-	1,5	-	4
	Guiana Fr.	**Paraguay**	**Perú**	**Suriname**	**Uruguay**	**Venezuela**	
Bolivia	-	3,4	1	-	-	-	
Brasil	3	1,3	2	3	1	2	
Chile	-	-	2	-	-	-	
Argentina	-	3	-	-	3	-	
Colombia	-	-	2,3	-	-	2,3	
Ecuador	-	-	2,3,5	-	-	-	
Guyana	-	-	-	1	-	1	
Guiana Fr.	-	-	-	1	-	-	
Paraguay	-	-	-	-	-	-	
Perú	-	-	-	-	-	-	
Suriname	2	-	-	-	-	-	
Uruguay	-	-	-	-	-	-	
Venezuela	-	-	-	-	-	-	

■ **Table 5.** Frequency assignment for national services at borders in South America.

small border, around 700 km (e.g. Ecuador-Colombia border), only one coordination area is necessary, but for larger borders (e.g. Brazil-Bolivia border), more coordination areas must be defined. The coordination distances needed in South America are 16 km and 21 km for countries with DVB-T2 and ISDB-Tb, respectively. This means that countries with DVB-T2 are less vulnerable against interferences. In other hand, the recommended re-use distances at the borders are 65 km and 69 km for countries with DVB-T2 and ISDB-T, respectively.

The use of even frequencies by one country and odd frequencies by another one, has been widespread in South America. However, it has been found that having freedom in the choice of frequencies between countries decreases the number of necessary frequencies. Therefore, optimizes the use of radioelectric spectrum. This implies that, the existing agreements for analogue TV should be reviewed and modified if necessary. Regarding frequency planning for all borders of South America, 5 and 6 frequencies are necessary for national and regional services, respectively.

In the case of national frequency planning, the size of the country takes an important role. This is because small countries could not use all the frequencies into the country. It means that, all the national frequency planning will be restricted by the border frequency planning.

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Biographies

Jefferson Ribadeneira Ramírez received the Electronic and Computation Engineering degree in 2008 from the Escuela Superior Politécnica de Chimborazo (ESPOCH), Riobamba, Ecuador. In 2010, he was recipient of a scholarship for studies of excellence, granted by the SENESCYT (Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación) of Ecuador. In 2013, he obtained the M. Sc. degree in Technologies Systems and Telecommunications networks from the Universitat Politècnica de València (UPV), Valencia, Spain. In 2016, he received his Ph.D. degree in telecommunications from UPV. Actually, he work at Institute of Telecommunications and Multimedia Applications (iTEAM). He has worked in investigation and cooperation projects between iTEAM and the Colombian spectrum regulator (ANE). He is also with the Escuela Superior Politecnica de Chimborazo (ESPOCH), Riobamba, Ecuador. His research activities are focused on spectrum optimization, DTT network planning, compatibility studies between DTT and other mobile technologies as LTE, as well the implementation of 4G communications in the Digital Dividend.

David Gómez-Barquero received the double M.Sc. degree in telecommunications engineering at the Universitat Politècnica de València (UPV), Valencia, Spain, and at the University of Gävle, Sweden, and the Ph.D. degree in telecommunications from UPV, in 2004 and 2009, respectively. Since 2008, he has been actively participating in the European digital television standardization forum DVB. He also participated in the validation of DVBT2, and in the standardization processes of its mobile profile T2-Lite and its handheld evolution DVB-NGH. He also contributed to the DVB-T2 implementation guidelines, and co-edited the implementation guidelines for upper layer forward error correction. He is the Vice-Chairman of the Modulation and Coding Ad-Hoc Group of the ATSC 3.0 standardization process. He is currently a Senior Researcher (Ramon y Cajal Fellow) at the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV, where he leads a research group working on multimedia broadcasting, in particular on the optimization of 3GPP multimedia broadcast multicast services (MBMS) and digital video broadcasting (DVB) systems.

Prof. Narcís Cardona received the M.Sc. degree in Communications Engineering from the ETSI Telecommunications at the Polytechnic University of Catalunya in 1990, and the Ph.D. in Telecommunications from the Polytechnic University of Valencia in 1995. Since October 1990, he is with the Communications Department of the Polytechnic University of Valencia (UPVLC). Prof Cardona is in head of the Mobile Communications Group at the UPVLC, with 30 researchers including assistant professors & research fellows. Additionally he is the Director of the Mobile Communications Master Degree (since 2006) and Vice-Director of the Research Institute of Telecommunications and Multimedia Applications (iTEAM) since 2004. Prof Cardona has led and participated to National research projects and to European projects, Networks of Excellence and other research forums, always in Mobile Communications aspects. At European scale, he has been Vice-Chairman of COST273 Action, Chair of the WG3 of COST2100 in the area of Radio Access Networks, and he is currently the Chairman of the EU Action COST IC1004 since May 2011. From his research work, Prof Cardona has authored eight patents, several books and above 160 research papers. His current areas of interest include mobile channel characterization; planning and optimization tools for cellular systems, RRM techniques applied to personal communications and broadcast cellular hybrid networks.