Optimization of DVB-T Networks for the Provision of Local and Mobile Services

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Abstract

Nowadays, the main standard around the world for digital terrestrial TV broadcasting is Digital Video Broadcast - Terrestrial (DVB-T). Most of DVB-T networks deployments have been designed for fixed rooftop antennas and high transmission capacity, without providing good coverage level for vehicular mobile reception. These networks also make use of either a Single Frequency Network (SFN) or a Multi Frequency Network (MFN), but none of these topologies is ideally suited for delivery of both global and local services in an efficiently way. This article discusses the use of the hierarchical modulation, the Scalable Video Coding (SVC), antenna diversity reception, Application Layer Forward Error Correction (AL-FEC) and time slicing techniques for the optimization of DVB-T networks in two different issues: the provision of mobile digital television in vehicles and the transmission of local services in SFN topologies. The paper shows that the combined usage of these solutions can compensate the impairments caused by the mobility of the receivers, such as signal fast fading due to Doppler shift, and the poor coverage at ground level. Furthermore, our results show that it is possible to enable Local Services Areas (LSAs) in SFNs without affecting the availability of neither global services nor any of its all advantages. Performance evaluation results have been obtained through field measurement campaigns, laboratory testing and dynamic simulations in the city of Valencia (Spain).

Keywords: Mobile DVB-T, hierarchical modulation, Local contents, application layer forward error correction, dynamic simulations, single frequency networks

1. Introduction

The most popular digital terrestrial television technology worldwide is DVB-T. It is adopted by more than 120 countries of the five continents. DVB-T transmits compressed digital audio, video and data in an MPEG-2 Transport Stream, using Coded Orthogonal Frequency Division Multiplexing (COFDM) modulation. Most commercial DVB-T networks deployments have been designed for fixed rooftop antennas and high transmission capacity (e.g., mode FFT 8K, GI 1/4, non-hierarchical 64QAM, CR 2/3, which provides an approximate channel capacity of 20 Mb/s [1]) without good coverage level of mobile services to vehicles. The first cause is the poor coverage at ground level. The difference in link budget between fixed rooftop reception and vehicular mobile reception is in the order of 15 dB due to antenna gain, antenna height, and channel type (static Line-of-Sight channel vs. mobile Non-Line of Sight channel). In addition to the link budget issue, DVB-T signals suffer an important degradation under mobility conditions due to multipath, fast fading and Doppler effects. The reason is that DVB-T was primarily designed for fixed and portable reception, and it incorporates a very short time interleaving that cannot cope with the impairments of mobile channels [1] .

Otherwise, different types of TV services may be transmitted over a broadcast networks depending on the target area. Some services are consumed by many users throughout the whole network, possibly covering a whole country, (called global services). Alternatively, some services attract enough users for efficient broadcasting only in a certain sub-region of the network, for example in a city (referred to as local services) [2]. Current digital broadcast networks such DVB-T enable the composition of two different types of networks: MFN or SFN. In an MFN all transmitters make use of different transmitting frequencies and this approach makes both global services similar in all cells as well as localized services possible. The drawback is that a huge amount of the scarce frequency spectrum is then needed. In an SFN multiple synchronized transmitters and repeaters broadcast the same signal at the same frequency. However, the insertion of local services in an SFN has particular problems. On the one hand, content needs to be different from locality to locality. On the other hand, all transmitters in an SFN must transmit the same information at same time and thus must be synchronized. Local service insertion entails either the replacement of a national service with a local content or superposition of a local content over a national service in certain transmitters, affecting the coverage area of one or more adjacent SFN transmitters [2]. This is an inefficient use of the network.

This article analyzes some technical solutions for the optimization of DVB-T networks in two different issues: first, the provision of mobile services to vehicles in a realistic DVB-T network dimensioned for fixed rooftop reception by combining antenna diversity, hierarchical modulation and AL-FEC using Raptor codes. Secondly, the provision of global and local services in SFN topologies using hierarchical modulation and time slicing techniques. The analysis has been performed by means of field measurements, laboratory tests, and simulations. Some bus routes along the city of Valencia and the commercial DVB-T network of the Valencian Community have been chosen as reference scenario.

The rest of this paper is structured as follows. In Section 2, the technical solutions to improve mobile DVB-T reception: antenna diversity, hierarchical modulation, and AL-FEC are briefly explained. The techniques and transmission schemes using hierarchical modulation and time slicing for the provision of global and local services in SFN are described in the section 3. In the section 4 we explain the performance evaluation methodology. Section 5 presents some field measurements result of coverage level of the commercial DVB-T network of the city of Valencia and some illustrative results of the joint performance of the technical solutions for mobile reception obtained by lab tests. An example of dynamic simulations for reception of DVB-T in public buses routes in Valencia and coverage estimation are also included. Section 6 presents the simulations results in fixed reception of the technical solutions proposed for broadcasting global and local services in SFN topologies. An example of coverage estimation for both local and global services in Valencian community is also included in this section. Finally, Section 7 draws the results and conclusions of this research.

2. Technical solutions for mobile DVB-T

2.1 Antennas diversity reception

In this technique the receiver should have several versions of the same transmitted signal, where each version is received through a distinct channel. In each channel the fading is intended to be mostly independent, so the chance of deep fading (and hence loss of communication) occurring in ail the channels simultaneously is very much reduced. The combining technique that yields a larger reduction of the fading is Maximum Ratio Combining (MRC), which synchronizes the signals in phase and weights them according to their instantaneous signal-to-noise ratio before combining [3]. The diversity gain is in the range of 3 to 8 dB depends on the correlation factor (ρ) between the signals received [4]. The lower the ρ value, the higher the diversity gains. Otherwise, the antenna diversity not only reduces the minimum Carrier to Noise Ratio (CNR) required, but it overcomes the problem of dependence on speed because it is able to maintain the CNR almost constant by increasing the Doppler. It is important to point out that in the frequency range operation of DVB-T the separation between antennas required is feasible for vehicles, but not for mobile phones (12.7 cm @ 470 MHz and 6.9 cm @ 862 MHz).

2.2 Hierarchical modulation

Hierarchical modulation is a DVB-T transmission mode that separates the RF channel in two virtual channels, each able to carry a Transport Streams (MPEG-TS) with a different bit rate, modulation and code rate in the physical layer. One stream, called the "High Priority" (HP) stream is always modulated in QPSK and defines the quadrant of the symbol into the constellation. The second one, either in the QPSK or 16QAM cases is introduced as an over modulation of the HP one and determine the exactly position of the symbol in the quadrant. This is named "Low Priority" (LP) stream and depending on the hierarchical configuration, its robustness is comparable with the one obtained for the whole constellation (i.e.: regular 16QAM or 64QAM). Additionally, in hierarchical modulation an important parameter known as the constellation ratio (α) is used to characterize the system. The value α is the ratio of the spacing between the groups to the spacing between individual points within a group. Permitted α values are 1, 2 or 4 [1].

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The hierarchical modulation can be used to increase the robustness of the transmission for mobile services with the HP stream, while the LP can stream can be used to broadcast information for fixed receivers [5]. The hierarchical modulation can be nicely combined with SVC in order to efficiently provide the same service to all receivers. SVC is an amendment to the H.264/AVC video codec to provide efficient scalability options on top of the high coding efficiency of H.264/AVC [6]. SVC encodes the video information into a base layer and one or several enhancement layers. The hierarchical modulation can be used in DVB-T to transmit the SVC base layer with the HP stream, and the SVC enhancement layers with the LP stream. This way, users with good reception conditions (i.e., fixed receivers) can receive all layers, whereas those with poorer reception conditions (i.e., mobile receivers) only receive the base layer.

2.3 AL-FEC

DVB-T implements Forward Error Correction (FEC) mechanisms designed to cope with noise and interference only on the physical layer. MPEG-2 packet loss in physical layer can be retrieved in upper layers (link layer or application layer) [7]. With AL-FEC, the audio and video of a particular TV program are encoded at the application layer, and the parity data generated is transmitted in a dedicated elementary stream. Legacy receivers would simply discard that stream, but robust receivers would make use of it in order to reconstruct lost audio and video data [8]. Different codes may be used in order to provide AL-FEC protection for DVB-T services. Raptor codes have been previously standardized in DVB systems for the provision of link and application layer FEC protection [9].

The protection offered by AL-FEC depends on two parameters: the coding rate and protection period. These parameters determine the trade-off between the desired level protection and the reduction in capacity, zapping time and latency introduced. With AL-FEC it is possible to provide longer time interleaving durations than MPE-FEC in DVB-H, increasing the robustness of the transmission in the presence of shadowing.

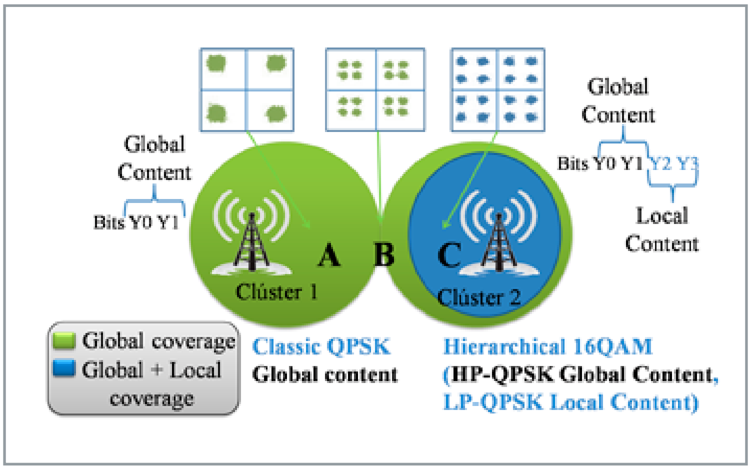


Figure 1 *SFN topology where one transmitter use hierarchical modulation for the provision of local contents.*

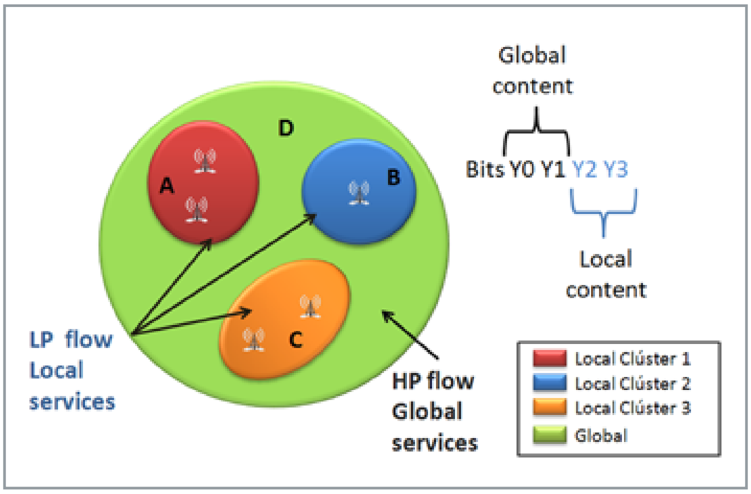


Figure 2. *SFN topology where all transmitters use hierarchical modulation for broadcast global and local contents.*

3. Technical solutions for the provision of global and local services in SFN

3.1 Hierarchical modulation

The hierarchical modulation also can be used to provide local services in a SFN topology. In this transmission mode the HP bit stream can be used to transmit global service due to them require wide coverage area and the LP stream can be used to transmit local contents.

Hierarchical modulation cells convert them from a low order QAM to higher order QAM, e.g. from QPSK (global service) to 16-QAM (global + local service). Depending on the need for a transmitter of broadcast local contents or not, we will analyze two topologies.

In the first topology one transmitter (Tx1) broadcast only global contents and the adjacent transmitter (Tx2) broadcast global and local contents in hierarchical modulation as it is showed in the figure 1. The transmitter without local contents must use the same configuration than the HP stream used by the other transmitter in order to obtain constructive combination of the global bits (Y0, Y1). Within the coverage area of Tx2, reception of the local service would require a higher SNR than the global service. In the border zone is possible receive the global contents only due to the gain SFN between the signals QPSK plus HP stream. Finally, within the coverage area of Tx1, the receiver can decode the global contents only because the signal is basically QPSK constellation.

The second topology is when all transmitters broadcast global and local contents simultaneously and it is shown in the figure 2. The zones A, B and C are LSAs and their local contents transmit into the LP stream are different, global contents also can be decoded through the HP stream. In these LSAs the LP stream from the others LSAs are considered interference limiting the maximum coverage area allowed. Outside the LSAs (zone D) only reception of global content is possible and it takes advantage of the SFN gain to increase de maximum coverage area, whereas reception for local services is interfered.

3.2 Time slicing techniques

The other technique that we propose to provide local content in SFN is the Time Slicing. Time Slicing is a technique included in DVB-H which consists of temporal multiplexing of services to be transmitted [10]. The sending of each of the services is done using all the bandwidth that provides the channel during a period of time. The main idea of Time Slicing in DVB-T is to define 2 time periods in each cycle, one for global services and other for local services, the figure 3 illustrate this idea.

Figure 3. *Time slicing technique.*

During the global services period all transmitters in the network broadcast the same content and it presents SFN gain in those zones with two or more versions signals received (assumed good synchronization). Otherwise, during the local services period each transmitter broadcast its contents belonging to the target area (LSA) and different between LSAs. The coverage during local period is limited by the levels of interference generated by the other transmitters and the minimum Signal to Interference plus Noise Relation (SINR) required for good reception for each transmission mode. A receiver located close to transmitter could decode global and local services all time. On contrary if receiver is located so far, it will decode the information of the global time slot only because local time slot will have high interference from the other transmitters.

DVB-T included a short interleaving time in order to cope with noise, interference and effects produced by the channel [1]. If data of both local and global contents were transmitted in an OFDM symbol on one of its carriers simultaneously, the signals of this carrier send out by transmitters from the other LSA would be different. The solution to this problem is to insert a period between the global and local services called protection interval. This interval contains stuffing data identical for all transmitters of the network. Such protection intervals ensure that no data from the global services is send out mixed with data from the local services. This interval is inserted between global and local time slots as show the figure 3. Its duration depends on the physical layer parameters [11]. Keep in mind that by varying the size of the FFT (2K or 8K) and the constellation (QPSK, 16QAM and 64QAM) got put more or less bits in each OFDM symbol and this varies the size of the adaptation intervals.

3.3 Hierarchical modulation combined with time slicing techniques

So far we have used the time slicing and hierarchical modulation separately, however, the following topology use the two technologies together. The proposal is to use hierarchical modulation in all transmitters in the network constantly, HP stream carries global information and LP stream carries local and global information multiplexed by time-slicing. In this way, two slots are defined in the LP stream, one dedicated to global services and other local services. This is very useful when there are not enough local content to broadcast in LP stream or these contents are broadcast at certain times of the day only. Therefore, our proposal increases the total bit rate available for global services and provides more flexibility to the system.

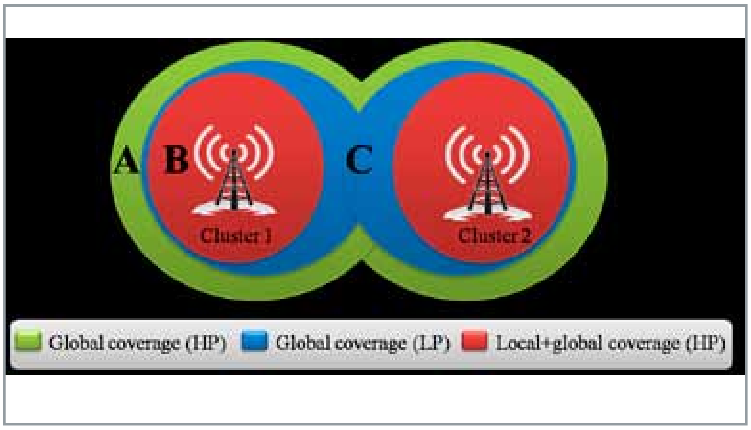


Figure 4. *Coverage areas obtained with hierarchical modulation and time slicing for the provision of global and local contents.*

The use of time slicing in LP stream for carrying global content implies that there are two different coverage areas for global services, see figure 4. A coverage area for global services carried in HP stream and other coverage area for global services carried in LP stream. It is also important to note that our proposal can efficiently transmit the global services using SVC. The base layer of video is carried in the HP stream and the enhancement layer is carried in the LP stream. Thus, users with bad reception conditions can be able to view the global content with basic quality (HP stream only) and users with good reception can decode both HP and LP streams and obtaining temporal, spatial or quality scalability.

4. Evaluation methodology

4.1 Field measurements

The measurement set-up employed is shown in the figure 5. it consisted of one professional DVB-T receiver that allow up to two RF input signals, a demodulator in order to capture the trace of correct or erroneous transport stream packets, common external antennas and a GPS receiver to record the terminal position and speed. Basically, the measurements consist of MPEG-2 TS packet error information at the physical layer of the whole multiplex recording whether the packets have been correctly received or not with sample rate of 100ms. Field measurements were performed in vehicular reception conditions of the DTT network (64QAM non-hierarchical, 8K, CR2/3, GI 1/4) in the city of Valencia. The frequency tuned was 770MHz (channel 59) which is broadcast from the Torrent transmitter (39º 25′ 44.9″ N, 0º 34′ 1″ W, 1710 m.a.s, 17 km from Valencia city) with Effective Isotropic Radiated Power (EIRP) of 42.94 dBw and height antenna of 100m. Five bus routes have been selected in the urban zones, which include high buildings, offices, and residential halls. The typical height of these buildings is 30 m and the areas include several trees. Several locations are in LOS with the transmitter antenna array. The measurements were carried out in the morning on a weekday with typical speeds in the range of 0 to 60 Km/h (average of 28Km/h). It should be mentioned that the measurements were repeated two times on the same routes, one using single antenna and the other one using antenna diversity reception.

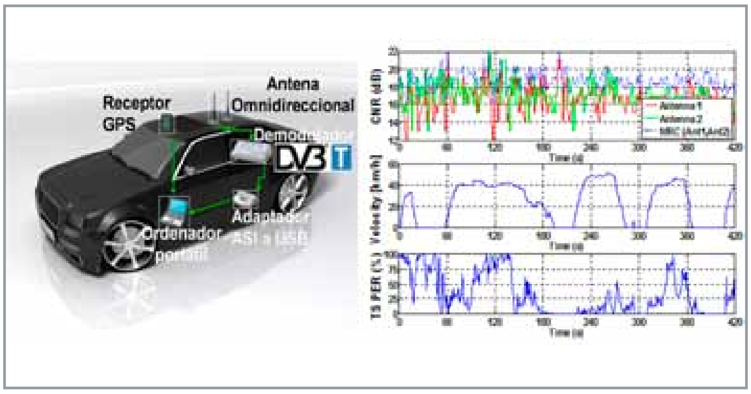


Figure 5. *measurement system and example of field measurement in the city of Valencia*

4.2 Laboratory tests

Laboratory tests were performed to evaluate and model the performance of different DVB-T transmission modes including hierarchical modulation and receive antenna diversity. Professional DVB-T modulator, channel emulator and the same receiver used in the field measurements was used in the lab tests. Measurements were performed for the Ricean and Typical Urban - 6 taps (TU6) channel models. The TU6 channel models the time variant small-scale fluctuations of the received signal due to receiver mobility (i.e., fast fading), and it proven to be representative for the typical mobile reception with Doppler frequency above 10 Hz in the studies carried out in the EU-COST207 project [12]. The automated DVB measurement system development by iTEAM stores the MPEG-2 TS packet information from the professional DVB-T receiver and obtaining the physical layer performance used in dynamic simulations.

4.3 Dynamic simulations

Dynamic system-level simulations were performed to assess the coverage level for vehicular reception of the commercial DVB-T network in the city of Valencia taking into account the technical solutions proposed in this research (receive antenna diversity, hierarchical modulation, and AL-FEC). The architecture of the dynamic simulator developed in the iTEAM uses the DVB-T performance results obtained with field and laboratory measurements and it has four models: mobility model based on the SUMO (Simulation of Urban Mobility) model [13] , coverage model which use the calibrated Xia-Bertoni propagation model [14], DVB-T physical layer performance models [15] and AL-FEC model [16]. The simulator computes the Quality of Service (QoS) experienced by each mobile user in terms of TS packet error rate (TS PER), erroneous second ratio (ESR), and ESR5(20).

The main simulations for mobile services have been performed assuming a DVB-T physical layer configuration used in Spain: FFT 8K, guard interval 1/4, non-hierarchical modulation 64QAM and coding rate 2/3. This transmission mode gives a total bit rate of approximately 19.91 Mbps. Additionally hierarchical 64QAM modulation with coding rate 2/3 for both LP and HP streams and $\alpha=1$ has been evaluated. These hierarchical parameters were selected in order to keep the same total bit rate and approximately the same coverage level for fixed services (LP stream) compared with non-hierarchical transmission mode. Finally, for the evaluation of AL-FEC in DVB-T services, the HP stream (a service of 6.64 Mbps) has been protected by an ideal FEC implementation. All cases have been simulated for vehicular reception with single and two omni-directional antennas placed on the car roof. Typical speeds emulated were in the range of 0 to 60 Km/h over a Digital Terrain Map (DTM) of the city of Valencia.

Otherwise, the performance of DVB-T for broadcast local and global services in SFN topologies has been obtained by simulations in Ricean channel (typically used for emulate good reception with a roof top antenna) from two different transmitters. This performance in terms of minimum SINR required for quasi error free (QEF) was evaluated for different power relations (Pw1/Pw2) between signals received from both transmitters which we have called XPD. In this way, XPD value defines the power relation between signal received from the main transmitter (Tx1) and the constructive or destructive signal received from the other transmitter (Tx2). On the one hand, the transmitter was simulated with FFT 8K, GI 1/4 and classic QPSK CR 2/3 if it transmit global services only or hierarchical 64QAM, $\alpha=1$, CR 2/3 (for both HP and LP streams) if it transmit global and local services. In these LSAs the LP stream from the others LSAs are considered as interference, therefore, the coverage area for reception of local services will be limited to those points with higher SINR. On the other hand, both transmitters have been set to the current configuration used in Spain (64QAM non-hierarchical) but including the time slicing technique with two time slots each with 50% of the total capacity and a protection interval between them (52 transport stream packets) [11]. In order to obtain the performance without influence of the total power transmitted, it has been normalized to 1 in all simulations.

5. Results and discussions

5.1 Results for mobility solutions

5.1.1 Coverage Estimation of the Commercial DVB-T Network for Single and Diversity Antenna Reception

The coverage level measured in the field trials for single and diversity antennas reception antennas (separated 14.8 cm, optimum distance for 770 MHz) and using different QoS criteria are showed in the table 1. We assumed the coverage level obtained with ESR5(20) as target level to increase because this QoS criterion takes into account the time distribution of the errors. It can be seen that the coverage level is not enough (29% and 48% fulfillment of the ESR5(20) criteria for single and diversity reception, respectively). Figure 6 shows the covered areas across the five public bus routes. Positions farther from the transmitter, downtown and dense buildings areas have low coverage.

5.1.2 Laboratory Tests of Hierarchical Modulation + Antenna Diversity for Mobile Receivers

Figure 7 shows a summary of the overall mobile performance of DVB-T under TU6 channel model with hierarchical modulation and two antenna diversity obtained by lab tests. In this figure we can see that the curves have a CNR floor, which gives the minimum signal requirement for good mobile reception, and a maximum Doppler frequency at which reception is possible, which determines the maximum supported terminal speed (usually, for network planning purposes it is considered up to 3 dB more than the minimum CNR value). In order to not reduce the capacity of the LP stream, in the following we assume a coding rate of 2/3 and a constellation ratio α = 1, which implies a very small coverage degradation for fixed rooftop reception.

Figure 7. DVB-T mobile performance in TU6 channel model with hiearchical modulation (α = 1), antenna diversity and AL-FEC (CR 3/4, Δt 5 s). QoS criteria TS PER 1%. FFT 8K, GI 1/4.

First, in this figure we compare the mobile performance of current transmission mode in Spain for single antenna (hereinafter called the reference transmission mode) and two antennas reception combined by MRC. In this case, the gain brought by the introduction of two antenna

Routes	Coverage level (%)					
	Mean TS PER 1%		Mean ESR		ESR5(20)	
	Single	Diversity	single	diversity	single	diversity
1	64.41	83.59	63.65	82.71	37.95	61.68
2	69.24	84.14	68.29	82.52	41.89	61.35
3	58.52	80.28	58.68	81.06	36.46	52.26
4	47.70	69.61	47.11	67.62	19.61	34.12
5	48.33	71.91	48.39	70.43	10.24	31.66
Total	57.64%	77.91%	57.22%	76.87%	29.23%	48.22%

Table 1. *Coverage level measured in the field trials in the city of Valencia for different QoS criteria.*

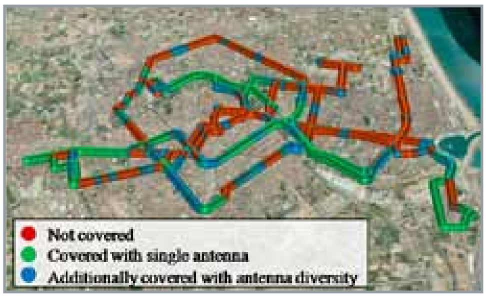


Figure 6. *Measured coverage level for single and diversity antenna reception in the city of Valencia.*

diversity in DVB-T receivers is very significant in terms of CNR (6 dB in TU6) and the gain in Doppler frequency is also significant (approx 70%). We can also see that the performance of HP stream of hierarchical modulation is very similar to the performance of reference transmission mode using antenna diversity, although the gain of antenna diversity is 0.8 dB of CNR and about 5 Hz of frequency Doppler higher than HP stream. Then, when antenna diversity and hierarchical modulation are combined, the CNR gain is around 11 dB and the maximum Doppler frequency is doubled up to 100 Hz with respect to reference transmission mode. In this way, the combination of these technical solutions allows

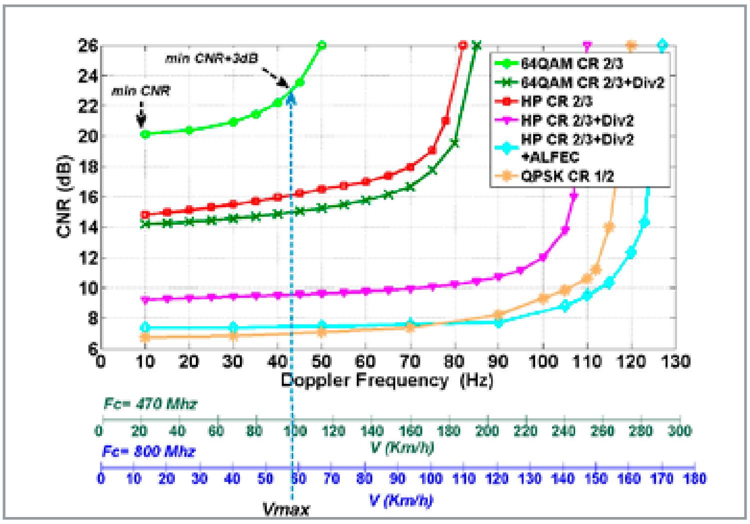


Figure 7. *Simulated coverage map of the DVB-T network in Valencia using antenna diversity, hierarchical modulation (a=1) and AL-FEC (CR 2/3,Δt 5 s).*

up to 135 km/h driving speeds in the highest part of the UHF band (channel 62) available for DVB-T.

5.1.3 Laboratory Tests of Hierarchical Modulation + Antenna Diversity + AL-FEC for Mobile Receivers

With AL-FEC it is possible to increase even further the gain in terms of CNR and maximum Doppler frequency achieved so far with hierarchical modulation plus antenna diversity. The AL-FEC gain depends on the interleaving duration and the code rate selected. Figure 7 also presents the performance of HP stream with antenna diversity reception and applying AL-FEC (CR 3/4, Δt 5 seconds). The additional gain in CNR obtained by the introduction of this AL-FEC configuration is 1.8 dB and it extends the maximum Doppler frequency up to 120 Hz. It can also observe that setting this configuration we can achieve a performance similar to classic QPSK CR 1/2; but with these three technical solutions we are transmitting contents for fixed reception in the LP stream simultaneously and keeping the coverage level provide with the reference transmission mode. This shows that AL-FEC works in conjunction with physical layer FEC to produce a more efficient overall configuration. By operating above the physical layer, it is possible to provide protection against longer losses with larger interleaving depths that physical layer cannot support. Nevertheless, higher interleaving durations of AL-FEC can be of interest to compensate temporary signal outages [8].

5.1.4 Simulated Mobile Coverage with Dynamic System-Level Simulations

The simulated mobile coverage for the commercial DVB-T transmission mode across five public bus routes in the city of Valencia was 29% for single antenna reception and 50% with two antenna reception. These values correspond quite well with the results obtained in the field measurement campaign. Combining antenna diversity with uniform hierarchical modulation (constellation ratio α = 1, code rate 2/3), the coverage level obtained was 75.3%. Figure 8 shows the simulated coverage map.

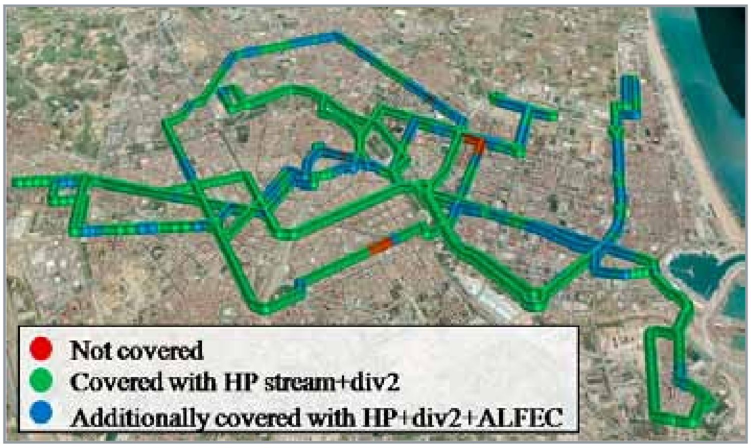


Figure 8. *Simulated coverage map of the DVB-T network in Valencia using antenna diversity, hierarchical modulation (a=1) and AL-FEC (CR 2/3,Δt 5 s).*

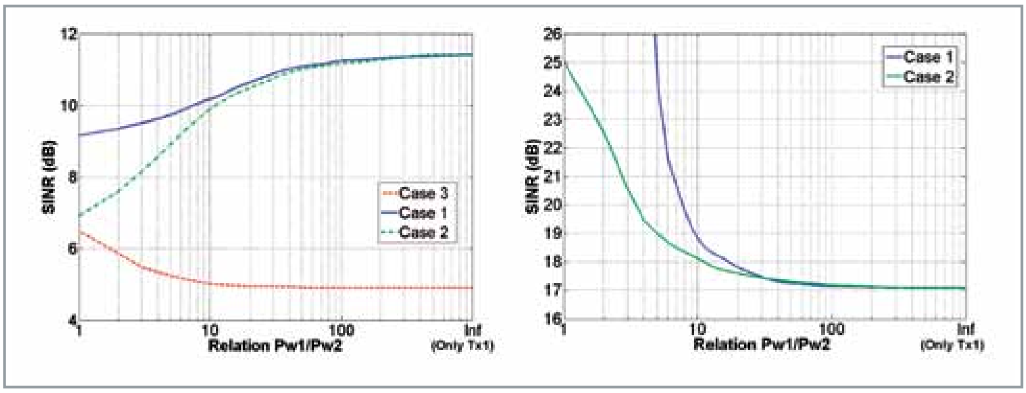
It can be seen that the areas without coverage correspond to city center, where there is greater density of buildings, and the northeast part of the city, which is the area furthest away from the DVB-T transmitter. As described previously, the introduction of AL-FEC reduces the minimum SINR and therefore it can increase the coverage level. Simulation results show that the combination of antenna diversity, HP stream and AL-FEC (CR 3/4, Δt 5 seconds) achieved a 95.4% of coverage level for mobile DVB-T services. This coverage is also shown in the figure 8.

5.2 Results for Global and Local services in SFN topologies

5.2.1 Performance using hierarchical modulation

Figure 9.a depicts the minimum SINR required for good reception of global services (HP stream) as a function of the relation power between signals received XPD. The curves represent the decoding performance of signal received from the main transmitter (Tx1) in the follow three different cases. Case 1 (blue line), both transmitters use hierarchical modulation for transmitting global and local content; Case 2 (green line): Tx1 uses hierarchical modulation and Tx2 does not use it and only transmits global content; case 3 (red line): Tx1 only transmits global content and Tx2 transmits global and local content with hierarchical modulation. In the case 1, a stationary receiver requires 11.3 dB of SINR for good reception when Tx1 is active only. A reduction up to 2.2 dB in this SINR is obtained when the Tx2 is active and its power is similar to Tx1. This positive effect is due to the combination of LP streams, which are bits in different position into the same quadrant and therefore, the sum is a symbol moved toward to center. Comparable performance was obtained in the case 2, although the reduction in SINR is up to 4.5 dB due to Tx2 transmits in classic QPSK and it forces even more the symbols toward to center of the quadrant. In the case 3, the main signal is QPSK and it is penalized with up to 1.5 dB of SINR by effect of LP stream hierarchical modulation when the signals received from both transmitters have the same power.

Furthermore, local services are transmitted in the LP stream and their decoding performances are shown in the figure 9.b. In the case 1, a receiver requires 17 dB for good reception of local services without interference from the other transmitter. The higher the interference level from the Tx2, the higher the SINR required for good reception. We can see that XPD values above five represent high interference and it is impossible decoded local services. In the case 2, the main signal is LP stream of the hierarchical modulation and it is combined with classic QPSK from the Tx2. The signal from the Tx2 force the symbols toward to center of quadrant affecting the decoded of LP stream. In general, the interference causes by others LP stream reduce the coverage of local contents, and there are edge areas where it is impossible to receive local content. However, this is not usually a problem because

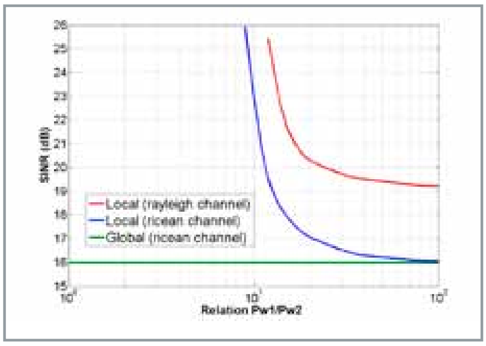


■ **Figure 9.** *DVB-T stationary reception in Rician channel using hierarchical modulation. A) Performance of global services and B) Performance of local services.*

these areas are remote from the transmitter and only require receive global content.

5.2.2 Performance using time slicing

When time slicing technique is used for the provision of local contents, the SFN topology will have to different time slots. One slot when all transmitters broadcast the same information (global contents) and other when each transmitter broadcast different information (local contents). Assuming that all signals arrived into the guard interval and perfect synchronization, the time slot dedicated to global services has SFN gain in the coverage area because the receiver doesn't have interference and all signals will be combined constructively. The figure 10 shows the decoding performance of global and local services in a SFN topology formed by two transmitters set to 64QAM, FFT 8K, CR 2/3, GI 1/4 and time slicing technique. On the one hand, we can see that the minimum SINR required for decoding global services is 16 dB. This value is constant by increasing XPD due to SFN gain and that the total power transmitted has been normalized. On the other hand, all signals received from the other transmitter are considerate interference in the time slot dedicated to local services. Without interference from the Tx2 transmitter, a receiver requires 16 dB for decoded local services from the Tx1 in Ricean channel as show the figure 10. The higher the power interference from the Tx2, the higher the minimum SINR required for good reception. XPD values above of 10 represent high interference and it is impossible decoded local services.



■ **Figure 10.** *DVB-T stationary reception of global and local services in Rician channel using time slicing techniques. Transmission mode 64QAM, FFT 8K, CR 2/3 and GI 1/4.*

5.2.3 Coverage estimation on real scenario

The simulated network consists of two LSAs in the Valencia community (Spain), one in the city of Alicante (transmitter with 50m of height antenna and EIRP of 5Kw) and other in the city of Valencia (transmitter with 40m of height antenna and EIRP of 4Kw). These transmitters are separated 89 km and currently they broadcast DVB-T signals. The simulation is based on signal propagation estimation using the extended Okumura-Hata propagation model at frequency of 770 Mhz. The coverage area is determined for outdoor reception with rooftop antenna and using hierarchical modulation solution for transmits global and local contents. The coverage estimation of LSAs and GSAs (Global Services Area) for fixed reception is defined as those areas where the SINR is higher than the minimum SINR required as function of power received relation between transmitters XPD, these thresholds have

■ **Figure 11.** *Coverage area for global and local services in Valencia community (Spain).*

been obtained in the section 5.2. Depending on the relative delay (Δt) between signal received, these signals can contribute both useful and/or interference to the total signal at the receiver. This contribution is defined by the weighting function W(Δt) specified in [11].

Figure 11 illustrates the resulting coverage for both global and local areas. The local service areas are limited to respective cities and maximum radius coverage is 55 Km for Alicante Transmitter and 38 km for Valencia transmitter. The global services have total coverage in both cities and additional coverage in rural areas located between transmitters due to SFN gain.

6. Conclusions

In this article we have analyzed some technical solutions for the optimization of DVB-T networks in two different issues: first, the provision of mobile services to vehicles in a realistic DVB-T network dimensioned for fixed rooftop reception and second, the provision of local services in SFN topologies. The results demonstrated that combining antenna diversity reception, hierarchical modulation, and additional forward error correction at the application layer (AL-FEC), it is possible to deliver digital TV services to vehicles in such networks without impacting the coverage of fixed rooftop reception. For the scenario analyzed in this work, the current commercial DVB-T network in Valencia (Spain), good mobile coverage could achieve with antenna diversity and uniform hierarchical modulation (QPSK embedded in 64QAM with $\alpha = 1$), physical layer code rate 2/3 (for both HP and LP), AL-FEC code rate 2/3 and interleaving duration of 5 s. This configuration would provide a bit rate of 13.3 Mb/s for fixed reception (one HDTV or three SDTV programs coded with MPEG-2) and 4.4 Mb/s for mobile reception (one SDTV or four Low Definition TV programs for small screens using MPEG-2).

Current broadcast digital networks use either an SFN or an MFN. None of these networks topologies is ideally suited for the delivery of both global and local services in an efficiently way. This research also shows that the traditional approach of SFNs can be enhanced for the provision of local services using hierarchical modulation and/or time slicing technology and maintaining all SFN advantages like higher coverage area and efficient use of the spectrum. Time slicing techniques assign with more flexibility the bit rate dedicated to local services compare with hierarchical modulation which uses in rigid way the LP stream in each LSAs for transmitting different local services. The coverage area of each LSA is limited by the interference perceived from the others LSAs in the time slot dedicated to local contents or in the LP stream of the hierarchical modulation. On contrary, taking into account that the global contents are the same in HP stream or time slot dedicated to global services, they take advantage of the SFN gain and increase the total coverage area. Finally, we have made an estimation coverage simulation for a real scenario in order to show that the local service areas are reasonably large and enable efficient usage in real life applications.

Acknowledgement

This work won the first prize in the research contest "Valencia idea 2010" in the category "Information and Communication Technologies (ICT)" organized by the Concejalía de Juventud del Ayuntamiento de Valencia, in October 2010. This work has been partiality supported by the Spanish Ministry of Industry, Tourism and Trade under project Redes Hibridas TSI-020307-2010-165 and the FEDER founds.

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