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 Broadcasting - 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 Mbaud [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 ground 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 as DVB-T enable the composition of two different types of networks: MN or SFN. In an MN 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, some 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 results of coverage level at the service area of 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 and portable 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 all 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 p 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 (≥72 cm or 470 MHz and 6.9 cm or 862 MHz).

2.2 Hierarchical modulation

Hierarchical modulation is a DVB-T transmission mode that separates the FH channel in two virtual channels, each able to carry a transport stream (MPEG-15) 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 compatible with the one obtained for the whole channel (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 of the α parameter is the spacing between the groups to the spacing at the bit rate that cannot cope with the impairments of mobile channels.
MPEG-2 packet loss in physical layer can be retrieved in upper layers (link layer or application layer). With AE-FC, 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. Different codes may be used in order to provide AE-FC 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 AE-FC 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 AE-FC 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.

Hierarchical modulation cells convert them from the network broadcast the same content and it presents SFN gain in those zones with two or more versions signals received (assumed good synchronisation). 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 Ratio (SINR) required for good reception for each transmitter mode. A receiver located close to transmitter could decode global and local services all time. On contrary if receiver is located 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 the LP stream for carrying global information and LP stream carries local information. DVB-T provides more flexibility to the system. 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 local services carried in LP stream. It is also important to note that our proposal can efficiently transmit the global content with basic quality (HP stream only) and users with good reception conditions can be able to view 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

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

Figure 2. SNF topology where all transmitters use hierarchical modulation for broadcasting global and local contents.

Figure 3. Time slicing technique.

Figure 4. Coverage areas obtained with hierarchical modulation and time slicing for the provision of global and local contents.
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. The performance of adjacent transmission bands (e.g., frequency reuse, hierarchical modulation, and AL-FEC) is essential to the design of the DVB-T network. The architecture of the dynamic simulator developed in the ITAE 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 [11], 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 (PER), erroneous second ratio (ESR), and ESR(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 α = 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 receivers, the HP stream (a service of 6.64 Mbps) can be protected by an ideal FEC implementation. All cases have been evaluated for different power relations (Pw1/Pw2) between the transmitter and the other transmitter (Tx2). On the one hand, the reference transmission mode for fixed services (LP stream) in the city of Valencia 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 Kmph (average of 28Kmph). It should be mentioned that the measurements were repeated two times on the same route, one using single antenna and the other one using antenna diversity reception.

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.

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

The combination of these technical solutions allows up to 135 km/h driving speeds in the highest part of the UHF band (channel 62) available for DVB-T. 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 interfering duration and the code rate selected. Figure 7 also presents the frequency is doubled up to 100 Hz with respect to reference transmission mode. In this way, the performance of current transmission bands (e.g., frequency reuse, hierarchical modulation, and AL-FEC) is essential to the design of the DVB-T network.
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 interfering depths that physical layer can not support. Nevertheless, higher interfering 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. 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 SNIR 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.

5.2 Results for Global and Local services in SFN topologies
5.2.1 Performance using hierarchical modulation
Figure 9a 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 three different cases. Case 1 (blue line), both transmitters use hierarchical modulation and Tx2 does not use it and only transmits global 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 when Tx1 is active and 10.7 dB of SINR when Tx2 is active, 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 9b. 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. The additional gain in CNR obtained when 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 SINR required for good reception. XPD values above 10 represent high interference and it is impossible decoded local services.

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 arrive 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. Figure 9b 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 SNIR 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 considered 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 10 represent high interference and it is impossible decoded local services.

5.2.3 Coverage estimation on real scenario
The simulated network consists of two LSAs in the Valencia region, both with SFN topologies and local areas. The local service area is 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.

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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 (through hierarchical modulation) and forward error correction could achieve a better performance for 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 (OPSK embedded in 64QAM with $n=1$), physical layer code rate 2/3 for both LP and HP, AL-FEC code rate 2/3 and interleaving duration of 5 s. This configuration would provide a bit rate of 13.3 Mbps for fixed reception (one HDTV or three SDTV programs codified with MPEG-2) and 4.4 Mbps 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 efficient 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 areas and efficient use of the spectrum. Time slicing techniques assign with more flexibility the bit rate dedicated to local services compared with hierarchical modulation which uses rigidly 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 other 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.

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References


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