Next generation of broadcast multimedia services to mobile receivers in urban environments

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Abstract

This paper analyses the possibility of receiving high data rate multimedia services in the non-stationary urban mobile scenario using the digital video broadcast standard DVB-T2. The work focuses on the complex urban mobile environment and presents a comparison between the different configuration parameters and the data rates associated to different video services. The study is based on the experience operating an experimental DVB-T2 network in urban environments, where portable and vehicular reception scenarios have been tested. The results show the system performance and the feasible video quality. The paper explores the coverage for various video services, including HDTV and 3DTV options, and proposes some scenarios for the deployment of broadcasting networks transmitting multimedia services to mobile receivers.

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1. Introduction

Real time consumption of multimedia services has increased over the last years as video services are receivable on mobile devices [1]. Technical and user requirements for mobile reception are quite different from fixed reception and, therefore, specific wireless systems are required. For example, time variant channels in mobile urban reception scenarios require technical systems with advanced physical layers characteristics, while small screen size devices condition multimedia services definition. Nowadays multimedia services to mobile receivers can be achieved with various wireless technologies that range from the cellular systems to the various broadcast systems worldwide [2–4].

Broadcast systems are the most appropriate transport technology to deliver multimedia services to high volumes of simultaneously mobile receivers, using dedicated terrestrial networks or satellite transmissions with auxiliary terrestrial repeaters to provide wide coverage areas. There are different systems approved by ITU [5] that can be considered for broadcasting multimedia and data applications for mobile reception. The most relevant systems are DMB [6–8], ISDB-T “One-seg” [9], ISDB-Tmm [10], ATSC Mobile DTV [11], MediaFLO [12] and the DVB family of standards. Moreover, the DTMB [13] and CMMB [14,15] Chinese systems have also been designed for mobile reception. Most of these standards are enhanced versions of the broadcasting systems to fixed receivers with different available bit rates and reception robustness.

3G cellular Networks are also a feasible platform for multimedia delivery to mobile receivers [16,17]. The 3G unicast streaming has the advantage that network resources are only used when the services are being received. The main problem of 3G delivery is the saturation of transport networks when many individual receivers are connected. The proposed solution is broadcast feature for
3GPP networks, called Multimedia Broadcast and Multicast Service (MBMS). MBMS introduces efficient broadcast capabilities enabling operators to cope with a wide simultaneous audience [18–20].

Regarding the DVB family of standards, broadcasting of multimedia services to mobile receivers started with the development of DVB-H [21] as an enhancement, optimized for handheld terminals, of the DVB-T system [22]. With the DVB-SH system [23] mobile coverage of large regions was achieved using hybrid satellite/terrestrial networks. Recently, the development of the second generation of DVB broadcasting systems has improved multimedia transmission in terms of capacity and robustness. For terrestrial networks, the new DVB-T2 system [24] outperforms previous broadcasting systems for all three receiving conditions: fixed, portable and mobile.

Moreover, considering than the consumption of Rich Media Applications using a variety of devices will increase in coming years, a new specification for the next generation of broadcasting to handheld and mobile devices, called DVB-NGH, is being under development within the DVB consortium [25]. The DVB-NGH will be designed in two phases, the first one as an advanced version of DVB-T2 and the second one aligned with the 3GPP broadcast mode.

This paper is structured as follows. Section 2 introduces the characteristics of the video services in mobile scenarios. Section 3 analyses the DVB-T2 system for content delivery to mobile receivers. Sections 4 and 5 describe the experimental network and the field trials carried out to test mobile performance using DVB-T2 system. Coverage results are used in the last section to propose real deployment scenarios for delivering multimedia services to mobile users.

2. Video services for mobile broadcasting

Requirements of video services broadcasted to mobile receivers depend on the devices used for reception. These devices range from battery operated handheld receivers with small screen sizes and low resolutions, to higher picture resolution and less power-constrained portable and vehicular receivers [5].

Initial requirements for video consumption in mobile receivers were restricted to QCIF and CIF resolutions in the 1.5” hand-sets. Nowadays mobile receivers are becoming more advanced in terms of multimedia capabilities and with larger screens offering high video quality. Ranging from high-end 4” SVGA touch screen mobile phones and 7” HDTV resolution Tablet PCs to portable notebooks and wide-screen TV sets in public transportation, mobile receivers have increased video requirements in terms of image resolution and frame rate [4].

Advanced coding techniques designed for multimedia services allow high quality video services to be delivered in the streaming bit rates defined by the broadcasting systems [2].

Emerging 3D video services can also be delivered in broadcasting networks to 3D terminals [26–28]. Depending on the specific content and the device screen size, a bit rate increase in the range of 10–30% more than the 2D services should be considered for 3D services [29,30].

3. DVB-T2 to mobile receivers

DVB-T2 is a new broadcasting standard approved in September 2009. Although DVB-T2 was mainly design for stationary reception of high data rate services (up to 50.3 Mbps in 7.77 MHz), this standard can also be used for delivering multimedia services to portable and mobile devices [31]. DVB-T2 uses the latest advances in channel coding and OFDM techniques to improve reception performance. Fig. 1 shows a block diagram of the DVB-T2 signal generation process.

3.1. Input formats and streams

One of the main novelties of DVB-T2 is the possibility to transmit different streams of video, voice and data as independent streams (PLPs) with their own parameters, allowing a better system capacity allocation. DVB-T2 considers four potential input formats, besides the traditional MPEG-TS container, the system offers three additional generic data formats with fixed or variable packet lengths: Generic Stream Encapsulation (GSE), Generic Continuous Stream (GCS), or Generic Fixed-length Packetized Stream (GFPS).

3.2. Modulation and coding

DVB-T2 uses OFDM modulation. Larger FFT modes (16 K, 32 K) and the inclusion of high order 256-QAM constellations increase the number of bits per symbol and in consequence the throughput of the system. This paper will make use of these features in order to match the capacity demands of 3D and HDTV content. For the mobile urban scenario, higher order constellation (256-QAM) and larger FFT size (32 K) are not considered suitable.

In the same way as DVB-S2 standard [32], DVB-T2 uses LDPC in combination with BCH codes improving the FEC module. The specification makes also use of scattered pilot patterns where the number of patterns available has been increased providing higher flexibility and maximizing the
data payload depending on the FFT size and Guard Interval adopted. This paper will propose a selection of modulation and FEC parameters based on the required bit rates and the desired coverage probability for mobile urban reception.

3.3. Physical layer pipes

The DVB-T2 physical layer data is divided into logical entities called the physical layer pipe (PLP), each PLP carrying one logical data stream each one with specific code rate constellation mapping and time interleaving. The PLP architecture is designed to be flexible so that arbitrary adjustments to robustness and capacity can be easily done. Thanks to the PLP concept, different robustness modes can be selected for different services improving the system performance and flexibility. This feature has provided the tool to include applications targeting fixed and mobile services using the same RF channel with an adequate configuration suite for each receiver type.

3.4. DVB-T2 lite profile

Although DVB-T2 can be configured for mobile reception, a new profile was approved by the DVB consortium in June 2011 [33]. This new profile is the T2-Lite. The subset of parameters selected for this profile has been designed to improve mobile performance and allow simple receiver designs for low bit rate services (up to 4 Mbps). The commercial equipment including this profile is expected for the beginning of 2012.

The T2-Lite services can be transmitted in the DVB-T2 signal using the Future Extension Frames (FEF). The FEFs are special time frames, inserted between the T2 frames, that may carry data with different FFT size, Pilot pattern and Guard Interval than the other T2 frames.

The DVB-T2 signal can carry multiple PLP with different robustness, but all PLP should be transmitted in the T2 frames with the same FFT size, Pilot Pattern and Guard Interval. These parameters have different optimization values if the performance is optimized targeting fixed or mobile reception. As different values for these parameters may be used in the T2 frames and in the FEFs, the new T2-Lite profile allows the transmission of services for mobile reception in the FEFs, multiplexed with other services for fixed reception in the T2 frames. For example, high bit rate services for fixed reception may use high FFT sizes in the T2 frames, and low bit rate services for mobile reception may use low FFT sizes in the FEFs with the T2-Lite profile.

4. Experimental network

4.1. Coverage environment description

This section describes the environment where the measurements for this study have been gathered. The measurements were taken in the city of Vitoria, located in the northwestern part of Spain. The area of the city is 276.81 km² with an average altitude of 525 m. The

![Coverage simulation result for Vitoria.](image)
transmitter is located 425 m above this average altitude and its distance to the measurement points ranges from 5.5 to 10 km. In this area there are no line-of-sight coverage problems as it is shown in Fig. 2, where the entire city is in the yellow area corresponding to more than 90 dB $\mu$V/m.

The buildings are generally high-rise residential blocks between wide avenues crossed by narrow roads. The historical center of the city has a bigger building density and has been considered as a separate environment from the Urban case, and called Dense Urban. These two types of environments are shown in Fig. 3.

In both environments there is a high concentration of traffic. In the Dense Urban case there are many traffic lights and crossings so the traffic is very discontinuous, while in the case Urban traffic decreases and roundabouts predominates allowing more fluid traffic, although the existence of numerous pedestrian crossings also disrupt this traffic quite often.

Measurements had been taken in these environments at pedestrian speed (5 km/h) and at mobile speed (in the range of 5 km/h and 50 km/h). The results of the analysis are provided for these two types of non-stationary reception scenarios and can be applicable for network planning of a city that meets the particularities described in this section.

4.2. Network infrastructure

The transmitter center (Fig. 4) was located on a mountain, 450 m higher than the average altitude of the city and 9 km far from the city center. This center is used to broadcast the main digital terrestrial TV commercial channels to the city. The radiating system consisted on two array panels and the frequency is 706 MHz (channel 50) with a transmitted power of 300 W and an antenna gain of 13 dBi.

4.3. Measurement system

Receiving the T2 signals in motion implies several devices to be used while measuring the signal, some of them dedicated to the reception of the services (antenna, T2 receiver, etc.) and other devices for further and deeper signal analysis (GPS, tachometer, IQ recorder, etc.). Fig. 5 shows the measurement system.

The reception system used has a 0.5 dBi gain dipole antenna ($K_{factor}=26.7$ dB 1/m) set to the transmission frequency. This antenna is on the roof of the mobile unit and is located 2 m high from the ground. Table 1 summarizes the specifications of the dipole.

This type of antenna is the most commonly used for mobile reception because it has an almost omni-directional radiation pattern that allows a correct reception of signals regardless of where the user is located from the
transmitter. This type of antenna is easy to integrate into mobile handsets, especially in cases of motor vehicles.

The received signal is divided as shown in Fig. 5, thus being simultaneously delivered to the IQ recorder (noise figure $= 10.4$ dB), the DVB-T2 set top box and the TV. The total attenuation due to this setup is 10.1 dB. Captured IQ sample files are stored on an external hard drive through a high-speed eSATA port. At the same time that the RF signal is captured it is essential to store other information needed for the subsequent analysis. The speed of the receiver is measured by a tachometer and the position is provided by a GPS. All this is controlled by a custom software that synchronizes the process and generates the logs with the desired information.

5. System performance analysis

5.1. General procedure description

The required infrastructure for evaluating a variety of video sources in different formats and throughputs was out of the scope of the trial. Under this assumption a different approach was taken. First the appropriate DVB-T2 mode selection was carried out aiming at covering a wide range of available bitrates and system robustness. Associated to each configuration, coverage and quality of service were measured in the field. Later, the results were analyzed in comparison with the bitrates associated to different video resolutions and formats (SDTV, HDTV, 3D).

5.2. DVB-T2 test configurations

DVB-T2 coding schemes greatly outperforms the FEC techniques used in DVB-T. It also introduces a higher order constellation, 256-QAM, which increases the spectral efficiency and bit rate, although this new feature is not compatible with the mobile reception scenario. The flexibility of DVB-T2 offers other configurable parameters that could be usable for this purpose, like rotated constellations, the introduction of a flexible time interleaver and new modulation schemes with more options for FFT size, bandwidth, guard interval and pilot pattern.

Although the new version of DVB-T2 standard that includes T2-Lite profile will be officially published shortly, it is not possible to work with T2-Lite signals yet, so this experimental studio has been focused on different DVB-T2 modes summarized in Table 2.

These configurations have been selected based on the following criteria:

- A and B modes provide greater robustness against Doppler spread thanks to FFT sizes of 2 K and 4 K, and against the multipath caused by reflected signals received with the omnidirectional antenna in a high traffic and high building density scenario thanks to the use of code rates 2/3 and 1/2.
- C mode increases the bit rate compared to B in 3 Mbps at the expense of losing some robustness against errors with a code rate of 4/5 versus 1/2. Suitable for environments less dense in terms of traffic and buildings.
- Finally, D mode maximizes the bit rate up to 21.62 Mbps using 64QAM modulation scheme, which optimizes the mapping of data in the OFDM symbol but at the cost of robustness. It has been selected to evaluate the reception of high capacity services in urban environments with different degrees of density of traffic and buildings.

5.3. Processing methodology

The signal recorded as IQ samples during a measurement route is played back at the laboratory by using an IQ player. The reproduced signal is connected to a DVB-T2 set-top box and the video quality is measured by continuously monitoring a pin of the DVB-T2 decoder. In this setup, additional noise can be easily added over the entire signal to simulate the effect of decreasing the transmitter power. The setup is depicted in Fig. 6.

In the mobile reception scenario it is not feasible to obtain an accurate single C/N value for a measurement.
interval since the received signal power varies extremely within few milliseconds as shown in Fig. 7. Furthermore, the video monitoring output has an additional stochastic delay between 70 ms and 120 ms, which could lead to a several dB error because of measuring the received power at the incorrect time instant.

Because of this received signal power variability, we have decided to refer the percentage of correct reception time to the transmitted power. But in order to provide results as general as possible, instead of referring to the transmitter power directly, which is very dependent on the transmission setup, the reception quality results have been referred to the field strength measured at the city center. This value has been measured at a rooftop location with direct vision to the transmitter. Considering only free space loses, this value varies 2 dB when reaching the furthest point of the city.

In order to provide a reception threshold, the transmitted power is decreased in 1 dB steps. It would not be feasible to accomplish this on the field, but is straightforward in this IQ playing setup. The power of the reproduced samples could be decreased in 1 dB steps, but we have decided to increase the noise level instead in order to make the measurement independent on the receiver sensitivity. The internal noise of the IQ recorder has been characterized \( \langle N_i \rangle = -96.6 \text{ dB m} \) so the external noise \( \langle N_e \rangle \) that should be added to decrease the signal C/N a given amount \( x \) in dB is given by the following equation:

\[
N_e = 10 \cdot \log 10(10^{x/10} - 1) + N_i
\]

5.4. Measurement results

A total number of 528 intervals of 2 s have been analyzed for mobile and pedestrian reception for the whole set of modes.

A reception threshold of no video error during 95% of the time has been considered. In urban environment at pedestrian speed all the modes considered in Table 2 achieve this threshold, but only modes A and B reach it in mobile urban. When considering dense urban environments none of the modes pass this threshold and the use of gap-fillers is recommended. Table 3 summarizes the reception results for all the modes and environments. The results for mode A are also shown in Fig. 3 (red color indicating incorrect reception and green color correct reception).

The results in Table 3 show that the behavior of all tested modes is very different for pedestrian and mobile. The difference between mode A and the rest of the choices is the number of carriers and thus the intercarrier separation. This mode provides similar results as mode B, suggesting that the Doppler spread does not have a strong impact on the final performance. Also, it is noticeable that modes C and D are not adequate for this mobile scenario if the EIRP wants to be kept low. Fig. 8 plots the percentage of correct reception as a function of the additional attenuation applied (as detailed in Section 5.3). Using modes A and B, the 95% of correct reception could be achieved using 6.6 dB less transmission power. The rest of the analysis shown here refers to mode A. Similar results were obtained with mode B.

Referring this transmission power to the field strength value in a rooftop reception at the center of the city, mode A would cover Vitoria (without considering the dense urban historic quarter) with 81 dB.

6. Mobile video services over DVB-T2

Previous sections have described the DVB-T2 physical layer performance as a function of different configurations and under different mobile reception conditions. This section aims at converting physical layer parameters

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Table 3

<table>
<thead>
<tr>
<th>Att (dB)</th>
<th>Mobile</th>
<th>Pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>64.4</td>
<td>52.7</td>
</tr>
<tr>
<td>D</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

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Fig. 7. Received power variation (RMS 100 ms).

Fig. 8. Percentage of correct reception for mode A.
into a list of feasible video service types and video configurations.

6.1. Capacity requirements

Data rate requirements related to different video services are presented in this section. Table 4 shows a summary of the capacities that are needed for 2D and 3D video transmission as a function of different definitions: HD and QVGA to SD. Also, the associated resolution values and a description of the typical devices that can support each type of service have been included along with a reference code defined for the sake of the brevity.

The previous bit rate ranges are a compendium of values derived from a set of reports [30,34–42] that present results for a codification MPEG-4 AVC and frame rates between 15 and 30 fps. In the cases A3D and B3D, a 3D video format commonly known “2D+Delta” which is based on transmitting additional depth information compressed at 20% of the necessary bit rate to encode the color video [43–45] has been considered due to its compatibility with the existing 2D displays.

It should be noted that for practical purposes, the allocation of video services over DVB-T2 presented in next subsections was done taking a representative bit rate of 10 Mbps for an A2D service of resolution 1920 × 1080 [30]. In the same way, a value of 0.5 Mbps was considered to account for the reception of a service B2D in mobile phones [2,46]. Finally, the increase on the capacity requirements necessary for the transmission of depth information in the 3D cases, led to assume data rates of 12 Mbps and 0.6 Mbps per A3D and B3D service respectively.

6.2. Service scenarios

In practice, at least at the introductory stages of mobile broadcast services, not all the DVB-T2 signal resources will be allocated to mobile video services. It is envisaged that the video programs targeting mobile receivers represent only part of the whole multiplex. According to this, a limited number of real deployment scenarios, as well as the capacity of the system is able to provide for each one of them, is defined in this section.

Table 5 shows four different situations starting from the case where the allocation to mobile services in the DVB-T2 ensemble is the 15% of the whole multiplex to the case of a dedicated UHF channel to mobile receivers. Bit rate values have been calculated considering two PLPs for mobile and fixed reception respectively. The PLP dedicated to mobile services corresponds to the tested DVB-T2 configuration that provided a higher percentage of coverage in Vitoria (2 K, GIF 1/4, PP1, 16QAM, 2/3). In the case of fixed reception, the mode that provided maximum capacity for the same FFT value was selected (2 K, GIF 1/4, PP1, 256QAM, 2/3).

As it can be seen, assuming representative bit rates of 10 Mbps and 12 Mbps for A2D and A3D services respectively, it would be feasible to transmit 1 or 2 two-dimensional or three-dimensional HDTV fixed services in the first three scenarios. In fact, exception made for the case of 2A3D services transmitted in a scenario S 85/15, several B2D and B3D fixed services could also be delivered. Obviously, the final configuration for fixed reception will depend on commercial factors and broadcaster’s business models.

6.3. Allocation of mobile video services

In order to provide the potential video service offer, the maximum number of B2D and B3D mobile services have been calculated for each one of the previous scenarios.

Table 5
Service scenarios.

<table>
<thead>
<tr>
<th>Code</th>
<th>Mbps for fixed reception</th>
<th>Mpps for mobile reception</th>
<th>A2D and A3D Services for fixed reception</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 85/15</td>
<td>24.07</td>
<td>2.13</td>
<td>2A2D or 2A3D</td>
</tr>
<tr>
<td>S 75/25</td>
<td>21.24</td>
<td>3.56</td>
<td>2A2D or 1A3D</td>
</tr>
<tr>
<td>S 50/50</td>
<td>14.26</td>
<td>7.13</td>
<td>1A3D</td>
</tr>
<tr>
<td>S 0/100</td>
<td>0</td>
<td>14.26</td>
<td>No A2D or A3D</td>
</tr>
</tbody>
</table>

Fig. 9. Number of B3D and B2D mobile video services for different scenarios.

Table 4
Data rates for different video service types.

<table>
<thead>
<tr>
<th>Code</th>
<th>Service description</th>
<th>Bit rate (Mbps)</th>
<th>Resolution</th>
<th>Typical devices type/diagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3D</td>
<td>3D (HD)</td>
<td>7.2–21.6</td>
<td>From 1280 × 720 to 1920 × 1080</td>
<td>TV ≥ 15”</td>
</tr>
<tr>
<td>A2D</td>
<td>HD</td>
<td>6–18</td>
<td></td>
<td>Tablet PC ≥ 5.6”</td>
</tr>
<tr>
<td>B3D</td>
<td>3D (QVGA to SD)</td>
<td>0.12–13</td>
<td>From 320 × 240 to 720 × 576</td>
<td>Phone ≥ 4.3”</td>
</tr>
<tr>
<td>B2D</td>
<td>From QVGA to SD</td>
<td>0.1–2.5</td>
<td></td>
<td>TV ≤ 32”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tablet PC ≤ 7”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phone ≤ 4.3”</td>
</tr>
</tbody>
</table>
scenarios. Results were obtained considering the capacity values allocated to mobile services as well as the data rate requirements and representative bit rates for the different service types defined in Section 6.1. Fig. 9 summarizes the possible combinations.

The most remarkable conclusion is that even in the case of allocating only the 15% of the multiplex to mobile reception, a significant number of services with definitions that range from QVGA to SD could be transmitted either in 2D or 3D formats. In an initial situation, only 3B\textsubscript{2D} or 4B\textsubscript{3D} services could be delivered respectively. However the possibilities of the system increase significantly for higher multiplex percentages dedicated to mobile reception.

On the contrary, the perspective for HDTV transmission is very different, since the Table 5 leads to deduce that a complete UHF channel will be required for the transmission of one A\textsubscript{2D} or A\textsubscript{3D} mobile service. In that case, the rest of the PLP defined for mobile reception could include up to 7B\textsubscript{2D} or 8B\textsubscript{3D} services depending on the video configurations.

7. Conclusions

Broadcasting of multimedia services to mobile receivers has been tested using the DVB-T2 system. In the tested area of the city of Vitoria (Spain) coverage probabilities have been obtained for different DVB-T2 configuration parameters. The most adequate DVB-T2 configuration mode for mobile reception would cover a city like Vitoria with a single transmitter of 65.6 W except the densest part which would require the use of gap-fillers.

Considering this DVB-T2 configuration for mobile reception, a total bit rate of 14.26 Mbps can be used for delivering different video services. With this DVB-T2 mode four scenarios for transmitting video services have been analyzed, proposing the maximum number of 2D and 3D video services that could be delivered to mobile receivers. In these scenarios different percentage of bit rate allocation in the delivered multiplex have been assumed for these mobile services considering terrestrial networks that could also deliver HDTV and 3D-HDTV video services to fixed receivers.

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