On the Provisioning of Mobile Digital Terrestrial TV Services to Vehicles with DVB-T

Jaime López-Sánchez, David Gómez-Barquero, David Gozálvez, Narcís Cardona

***Abstract*—Most of the DVB-T (*Digital Video Broadcasting - Terrestrial*) networks deployments worldwide have been designed for fixed rooftop antennas and high transmission capacity, not providing good coverage level for vehicular mobile reception. This letter analyzes how to combine different technical solutions, so far studied individually, in order to increase the robustness of the transmission for vehicular reception to provide in-band mobile services. In particular, we consider: receive antenna diversity, hierarchical modulation, and Application Layer – Forward Error Correction (AL-FEC). Performance evaluation results have been obtained by means of simulations, laboratory tests, and field measurements in the commercial DVB-T network of the city of Valencia (Spain). 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, Doppler shift, the poor coverage at ground level and the utilization of lower gain antennas; being possible to provide mobile DVB-T services to vehicles in networks dimensioned for fixed rooftop reception.**

***Index Terms*—Antenna diversity, application layer forward error correction, hierarchical modulation, mobile DVB-T.**

I. INTRODUCTION

Most commercial digital terrestrial TV DVB-T (*Terrestrial*) networks deployments have been designed for fixed rooftop antennas and high transmission capacity (e.g., mode FFT 8K, guard interval GI 1/4, non-hierarchical 64QAM modulation, code rate CR 2/3, which provides an approximate channel capacity of 22 Mb/s); no being possible to provide mobile services to vehicles. Vehicular reception is characterized by the utilization of lower gain antennas and the reception at ground level, which results in a penalization of about 15 dB [1]. In addition, DVB-T does not implement time interleaving, and suffers an important degradation under mobility conditions due to multipath (fast) fading [2].

In order to improve the mobile performance of DVB-T, DVB-H (*Handheld*) added an optional forward error correction (FEC) scheme at the link layer known as MPE-FEC (*Multiprotocol Encapsulation – Forward Error Correction*) [3]. However, in order to provide good coverage levels for mobile reception, it is necessary to deploy a dedicated DVB-H network and allocate an entire multiplex (RF channel) for the provision DVB-H services.

This letter investigates the feasibility of providing mobile services to vehicles in a DVB-T network dimensioned for fixed rooftop reception by reusing the existing wireless infrastructure and without the need of allocating a dedicated multiplex. The simultaneous provision of fixed and mobile services in the same multiplex with a single network it is considered nowadays as key to alleviate the investments required to start providing mobile services.

In order to increase the coverage level for mobile reception, three technical solutions have been considered: receiver antenna diversity, hierarchical modulation, and application layer forward error correction (AL-FEC). The utilization of two or more receiving antennas is a decision of the receiver manufacturer. The hierarchical modulation is an optional feature of the DVB-T standard. AL-FEC can be introduced in a backwards-compatible way in existing networks and terminals without affecting legacy receivers.

The main contribution of this letter is to assess the joint performance of receiver antenna diversity, hierarchical modulation, and AL-FEC in a realistic scenario by means of field measurements, laboratory tests, and computational simulations. Although these techniques have been previously studied in the literature in a separate manner ([3], [5] and [3]), a joint investigation like the one presented in this paper is necessary since the overall gain is not the sum of the individual gains. The commercial DVB-T network of the city of Valencia (Spain) and some bus routes along the city center have been chosen as reference scenario.

The rest of this paper is structured as follows. In Section II, antenna diversity, hierarchical modulation, and AL-FEC are briefly explained. In Section III, we explain the performance evaluation methodology and the measurement set-up. Section IV presents and discusses the results obtained with field measurements, laboratory tests, and dynamic simulations. Finally, the paper is concluded with Section V.

II. MOBILITY SOLUTIONS FOR DVB-T

A. Antenna Diversity

In this paper, we consider the use of several antennas at the receiver[1]. The basic idea of receive antenna diversity is that

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[1] Transmit antenna delay diversity has been investigated in the context of mobile DVB-T reception in [6]. Results show that very important gains are feasible, although the gain is not as high as with receive antenna diversity, especially at low Doppler. Receive antenna diversity is also a more practical approach for vehicular reception, because there is no need to modify existing DVB-T transmitter installations.

the combined signal from several transmitters exhibit less fading than the signals provided by each individual antenna.

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 their instantaneous Signal-to-Noise Ratio (SNR) before combining. The diversity gain depends on the correlation factor (ρ) between the received signals. In this way, the maximum diversity gain (up to 8 dB) is obtained with no correlation $\rho = 0$, and the minimum gain (3 dB) with completely correlated signals $\rho = 1$ [4]. However, there is no big loss when ρ varies from 0 to 0.7 (less than 1 dB). Therefore, $\rho = 0.7$ is considered the practical limit for determining the distance between antennas (i.e., $\lambda/5$, where λ is the wavelength of the signal) [4]. Note that in the frequency range operation of DVB-T this separation is feasible for vehicles, but not for mobile phones (12.7 cm @ 470 MHz and 6.9 cm @ 862 MHz).

B. Hierarchical Modulation (HM)

This DVB-T transmission mode allows combining two MPEG-2 transport streams into a single stream, each having a specific modulation and code rate. One stream, called the High Priority (HP) stream, is mapped on the two most significant bits, identifying the quadrant of the constellation (i.e., its modulation QPSK). The remaining bits (i.e., least significant bits) are used by the second stream, called the Low Priority (LP) stream, to determine the exact position of the symbol into the quadrant (i.e., 16QAM or 64QAM modulation) [1].

The HM suffers from inter-layer interference because the LP stream acts as noise to the HP stream. The susceptibility to noise of the HP stream can be reduced by increasing the spacing between HP constellation states (α) [5]. Permitted values of the constellation ratio α are: 1 (reference), 2 and 4. However, increasing the value of α degrades the performance of the LP stream because the spacing between LP constellation points is reduced. Another possibility to increase the robustness of the HP stream is to use a lower code rate, at the expense of a reduced capacity. The HM 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 to fixed receivers.

The HM can be nicely combined with Scalable Video Coding (SVC) in order to efficiently provide the same content to all receivers. SVC is an amendment to the H.264/AVC video codec and it encodes the video information into a base layer and one or several enhancement layers [7]. The combination of hierarchical modulation and SVC would allow the simultaneous provision of fixed and mobile services while reusing the content in the base layer.

C. Application Layer Forward Error Correction (AL-FEC)

DVB-T implements in the physical layer a FEC scheme based on a concatenated Reed-Solomon (RS) and convolutional code, which corrects bit errors within MPEG-2 TS packets [2]. The physical layer of DVB-T was designed to cope with noise and interference, but not for mobility and hence, it provides frequency interleaving but no time interleaving. Although DVB-T itself does not incorporate any protection mechanism above the physical layer, an additional FEC protection can be introduced at the application layer in a fully backwards compatible way [3].

With AL-FEC, a particular TV program is 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. Raptor codes have been previously standardized in DVB systems for the provision of link and application layer FEC protection [8] and they can be decoded in generic software processors without upgrades in hardware [3].

The protection provided by AL-FEC depends on the code rate and the interleaving duration. With AL-FEC it is possible to provide longer time interleaving durations than MPE-FEC in DVB-H[2], increasing the robustness of the transmission in the presence of shadowing. The longer the time interleaving duration, the larger the memory requirement at the receivers and the network latency and zapping times. The network latency is not critical for the majority of services, whereas in some specific cases, the zapping time may not be an issue (e.g., public transport with only one TV channel). Fast zapping techniques allows FEC protection with long time interleaving durations and zapping times within tolerable values [3].

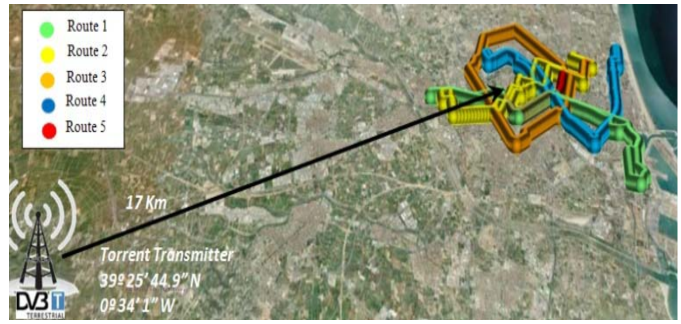

Fig. 1. Public bus routes measured in the city of Valencia (Spain).

III. Evaluation Methodology

A. Field Measurements

Field measurements of the commercial DVB-T network of Valencia (Spain) were performed for vehicular reception conditions with single and antenna diversity. The typical speeds were in the range of 0 to 60 km/h, on channel 59 (770 MHz @ bandwidth 8 MHz). The DVB-T transmission mode used in Spain is: FFT 8K, GI 1/4, non-hierarchical 64QAM, CR 2/3. Fig. 1 shows the TV tower that covers the city (situated around 17 km from the city center, antenna height of 100 m and PIRE 42.94 dBw), and the five selected bus routes. The routes covered mainly urban and sub-urban zones with wide and medium roads in all directions.

The measurement set-up employed consisted of one

[2] The MPE-FEC of DVB-H provides a time interleaving duration in the order of 100-400 ms (one time-sliced burst duration), which is enough to cope with fast fading but not with long shadowing effects.

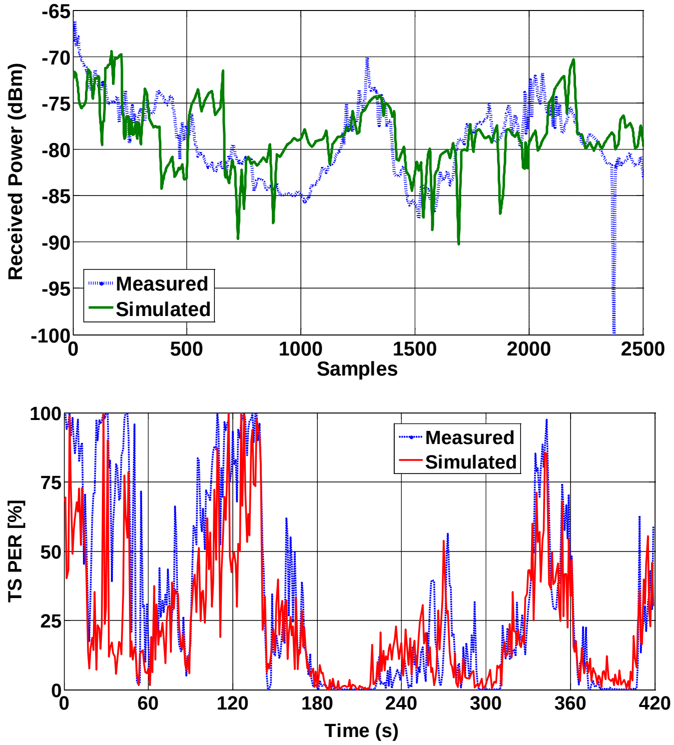

Fig. 2. Comparison between measured and simulated received power (top), and between measured and simulated TS Packet Error Rate (bottom). Route 5.

professional DVB-T receiver with two RF input signals for antenna diversity, two external antennas, and a GPS receiver to record the terminal position and speed. The receiver measured and stored the Transport Error Indicator (TEI) of each MPEG-2 TS packet of the whole multiplex. With this information, it was possible to estimate the coverage level and emulate AL-FEC protection in order to reproduce the Quality of Service (QoS) experienced along the measured trajectories.

B. *Laboratory Tests*

Laboratory tests were performed to evaluate and model the performance of different DVB-T transmission modes with HM and receive antenna diversity. The same professional receiver and set-up used in the field measurements was used in the lab tests. Measurements were performed using a low power DVB-T transmitter and a channel emulator for the Ricean and TU6 channel models, representative for fixed rooftop and mobile reception, respectively [2].

C. *Dynamic System-Level Simulations*

Dynamic system-level simulations were performed to assess the coverage level for vehicular reception in the commercial DVB-T network across the same 5 bus routes measured using receive antenna diversity, hierarchical modulation, and AL-FEC [9]. The architecture of the simulator has four main models: mobility model, coverage model, DVB-T physical layer performance model, and AL-FEC model. The simulator computes the QoS experienced by each user in terms of overall packet error rate (TS PER), erroneous second ratio (ESR), and ESR5(20), which represents the percentage of the time intervals of 20 seconds with at most 1 erroneous second (i.e., 5% errors).

The mobility model is based on the mobility platform SUMO (Simulation of Urban Mobility) [10]. This model calculate the average velocity using the following parameters: maximum speed 60 km/h, maximum acceleration 15 m/s^2, traffic congestion of 25%, 1.5 meters as minimum distance between vehicles, traffic light duration of 30 seconds in red and 60 seconds in green. This model has been compared with the traffic data registered in the field measurements and calibrated to resemble quite well the mobility pattern of vehicles in cities.

The coverage model estimates the received signal level taking in account path loss and correlated shadowing[3] (standard deviation 5.5 dB, correlation distance 20 m, typical values for outdoor broadcasting signals in the UHF band). The path loss model is based on the Xia-Bertoni propagation model [11], calibrated with the data recorded during the field measurements. Table I shows the statistical parameters of the error between measurements and predictions. It can be noted that the calibrated model provides quite accurate results: mean deviation 0.39 dB, standard deviation 4.66 dB, and correlation factor of 0.78. Fig. 2 shows the comparison between path loss measurements and predictions using the calibrated model for the route 5 in Valencia.

TABLE I.
STATISTICAL PARAMETERS OF THE ERROR BETWEEN MEASUREMENTS AND PREDICTIONS. XIA-BERTONI MODEL.

	Non-calibrated			Calibrated		
Route	Mean (dB)	Std. Dev. (dB)	Correlation factor	Mean (dB)	Std. Dev. (dB)	Correlation factor
1	18.2	6.8	0.23	1.4	3.5	0.77
2	14.6	9.3	0.01	0.3	5.1	0.71
3	17.1	6.5	0.36	0.1	3.8	0.86
4	16.2	5.2	0.41	0.2	5.4	0.69
5	11.1	8.3	0.18	0.0	4.0	0.87
Total	15.4	6.0	0.23	0.4	4.7	0.78

The DVB-T physical layer performance model emulates which TS packets are correctly received for each user dynamically over time, based on the velocity and received signal level given by the mobility and coverage models, respectively. This model is based on aggregated Markov processes with 4-states, and it was originally proposed in [12].

The performance model was validated with the field measurements, by comparing the measured TS error traces to those obtained from simulations using the measured signal strength and vehicle speed values as inputs to the model. Fig. 2 shows an example of measured and simulated TS packet error rates over time for a measured trace in Valencia. It can be seen that the time-variant packet error rate of the simulated error trace follows very closely the measurement.

The AL-FEC model emulates protocol de-capsulation and FEC decoding at the application layer. An ideal FEC implementation has been assumed. The size of the source and repair symbol used is 184 bytes, which corresponds to the payload of one TS packet. In a practical implementation some

[3] Fast fading is taken into account in the DVB-T physical layer performance model [9].

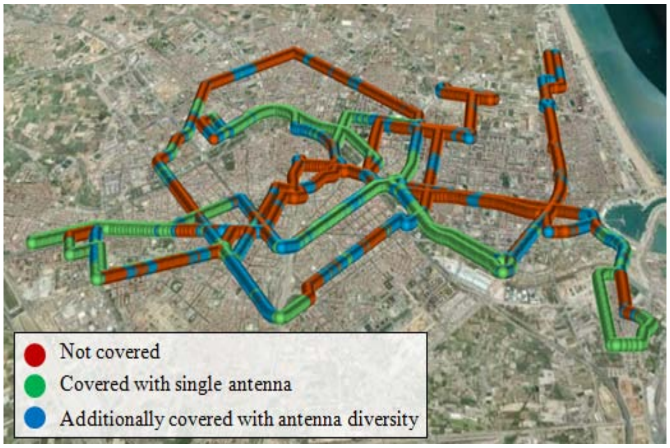

Fig. 3. Measured coverage level for single and diversity antenna reception.

additional issues need to be addressed. A main issue is the transmission of the signaling information required for the configuration and assembling of the source blocks in reception. This information is sent into the PSI/SI tables in a way that ensures that legacy receivers could drop the repair data without altering its proper operation.

IV. Results

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

Table II shows the coverage level measured in the field trials for different QoS criteria for single antenna and diversity antenna reception (two antennas separated 14.8 cm, optimum distance for 770 MHz). The selected QoS criteria is the ESR5(20), as it takes into account not only the overall amount of errors but also its time distribution. It can be seen that the coverage level is not enough (29% and 48% for single and diversity reception, respectively). Fig. 3 shows the covered areas across the five public bus routes.

TABLE II.
COVERAGE LEVEL OF MOBILE DVB-T MEASURED IN THE FIELD TRIALS IN THE CITY OF VALENCIA.

	Coverage level (%)					
Routes	Mean TS PER 1%		Mean ESR		ESR5(20)	
	single	diversity	single	diversity	single	diversity
1	64.4	83.6	63.6	82.7	37.9	61.7
2	69.2	84.1	68.3	82.5	41.9	61.3
3	58.5	80.3	58.7	81.0	36.5	52.3
4	47.7	69.6	47.1	67.6	19.6	34.1
5	48.3	71.9	48.4	70.4	10.2	31.7
Total	57.6%	77.9%	57.2%	76.9%	29.2%	48.2%

B. Laboratory Tests of Hierarchical Modulation for Static Receivers

Fig. 4 shows the required CNR for quasi error free (QEF) reception in a Ricean channel (characteristic of rooftop antenna reception), as a function of the constellation ratio (α), and the FEC overhead percentage generated by the physical layer code rates. According to the results, a stationary receiver requires a CNR of approximately 18 dB for the current transmission mode of Spain. With hierarchical modulation and

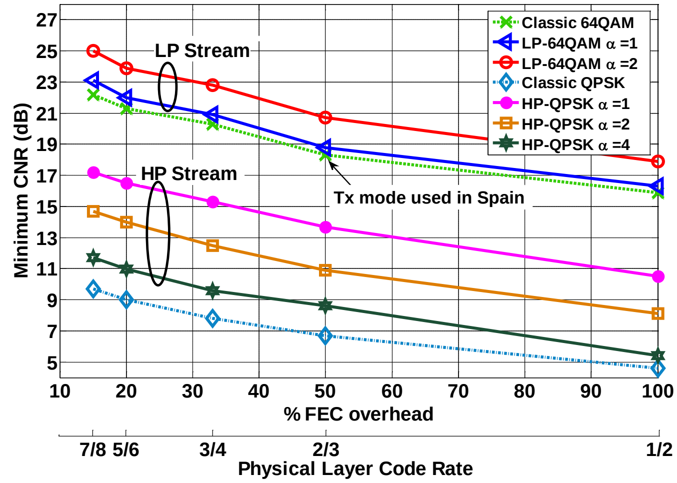

Fig. 4. Measured performance of hierarchical modulation in a Rice channel. Minimum CNR as funtion of the phisycal layer code rate.

α =1, the degradation of the LP stream is only 0.5 dB. On the other hand, the HP stream requires almost 7 dB more than non-hierarchical QPSK. For α = 2, the degradation of the LP increases up to 2 dB, and the degradation of the HP is reduced down to 4 dB. For α = 4, the performance of the LP is very poor (not shown in the figure).

There are two solutions to compensate the degradation of the LP stream, such that the coverage level of existing services is not reduced. One solution is to increase its robustness by reducing the code rate down to 1/2. This would allow for a constellation ratio α = 2, but at the expense of reducing 16.6% the available capacity of the multiplex (the capacity of the LP would be reduced from 13.3 Mb/s down to 10 Mb/s, it is still possible to transmit a HDTV program). The other alternative is simply to take advantage of the fact that the coverage of the HP stream would be actually higher than the reference case, although with a lower quality (e.g. SDTV instead of HDTV). Otherwise, if the same content is transmitted to fixed and mobile receivers, the SVC techniques would be used in order to offer HDTV in areas with good reception conditions (decoding HP and LP streams) and SDTV in areas with poorer conditions (decoding only HP stream).

C. Laboratory Tests of Hierarchical Modulation for Mobile Receivers

Fig. 5 shows the measured mobile performance (TU6 channel@ 30 Hz of Doppler) of the DVB-T transmission mode used in Spain and for the HP stream with hierarchical modulation using different values of the constellation ratio α. It can be seen that around 21 dB of CNR are required for the reference mode established TS PER 1% as QoS criteria. Almost 5.5 dB and 9 dB gain in the link budget can be achieved with hierarchical modulation for α equal to 1 and 2, respectively. This gain varies as function of the Doppler frequency and the use or not of antenna diversity as is analyzed in the next sub-section.

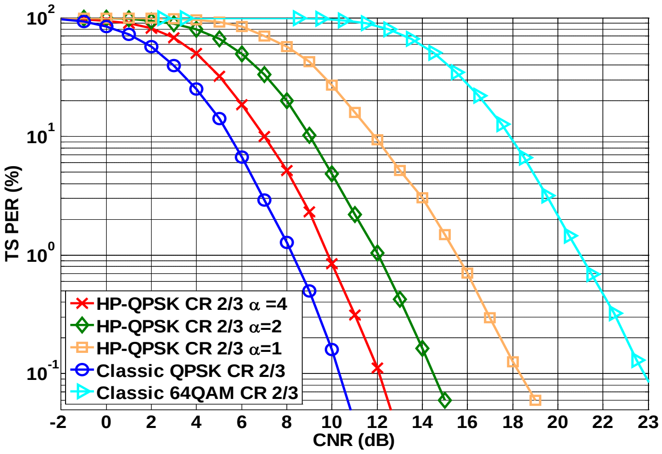

Fig. 5. Measured performance of HP stream embedded into a 64QAM hierarchical modulation in TU6 channel model (Doppler frequency 30 Hz).

D. *Laboratory Tests of Hierarchical Modulation for Mobile Receivers with Antenna Diversity*

Fig. 6 shows a summary of the overall mobile performance of DVB-T under TU6 channel with HM and two antennas diversity. In order to not reduce the capacity of the LP stream, in the following we assume a constellation ratio α = 1, which implies a very small coverage degradation for fixed rooftop reception. Fig. 6 depicts the required CNR as a function of the Doppler frequency. It can be observed 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 the Fig. 6, we can also show the important gain achieved using antenna diversity with respect single antenna reception (around 6 dB CNR and about 70% maximum tolerated Doppler). A close performance can be achieved using the HP stream (CR2/3, α=1, embedded in 64QAM) alone, although the gain of antenna diversity is 0.8 dB of CNR and about 5 Hz of frequency Doppler higher than it. When antenna diversity and HM are combined, the CNR gain is around 11 dB, and the maximum Doppler frequency is doubled up to 100 Hz. This configuration allows speeds up to 135 km/h in the highest part of the UHF band (channel 62) available for DVB-T.

E. *Laboratory Tests of Hierarchical Modulation + Antenna Diversity + AL-FEC for Mobile Receivers*

With AL-FEC it is possible to increase the gain in CNR and maximum Doppler frequency even further. The gain depends on the interleaving duration and the code rate. Fig. 6 also presents the performance of HP stream, with antenna diversity and applying AL-FEC (CR 3/4, Δt 5 seconds). The additional gain in CNR obtained is 1.8 dB and it extends the maximum Doppler frequency up to 120 Hz. Fig. 7 shows the CNR required by the HP stream with antenna diversity as a function of the AL-FEC interleaving duration and code rate. We can compare the performance of classic QPSK CR 1/2 and HP stream (CR 2/3, α=1) with AL-FEC CR 3/4 and antenna

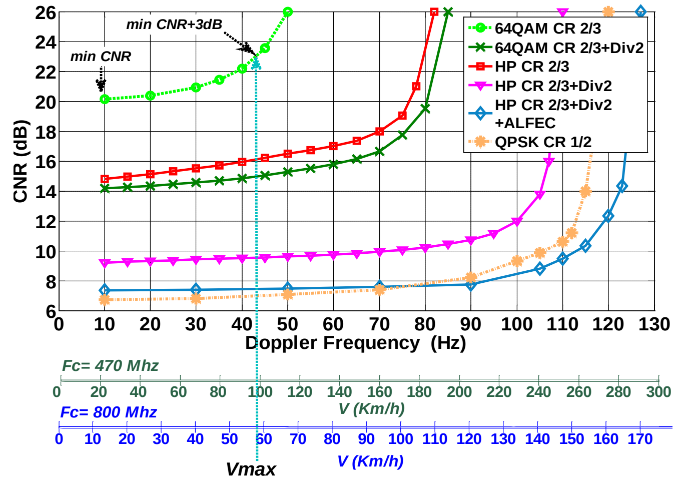

Fig. 6. DVB-T mobile performance in TU6 channel model with hiearchical modulation (α = 1), antenna diversity and AL-FEC (CR 3/4, Δt 5 seconds). QoS criteria TS PER 1%. FFT 8K, GI 1/4.

diversity. It should be pointed out that both configurations have the same overall bit rate. In this case, the use of antenna diversity and AL-FEC with interleaving duration above 12 seconds can compensate the lower performance of the HP stream, achieving a performance similar to classic QPSK. Lower code rates of AL-FEC provide the same or better performance with shorter interleaving durations. For example, the use of AL-FEC with code rate 1/2 provides an additional CNR gain up to 1 dB with only 3 seconds of interleaving.

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. Therefore, higher interleaving durations of AL-FEC can be of interest to compensate temporary signal outages caused by the mobility of the receivers.

F. *Simulated Mobile Coverage with Dynamic System-Level Simulations*

The simulated mobile coverage for the commercial DVB-T transmission mode across the five public bus routes in the city center of Valencia was 29% for single antenna reception and

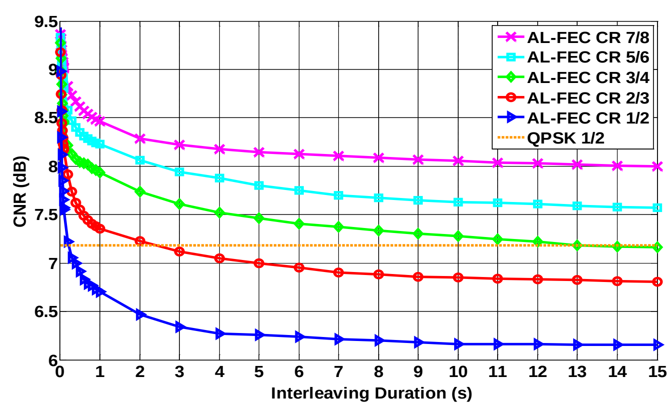

Fig. 7. Measured performance of AL-FEC in a TU6 channel with 50 Hz Doppler (115 km/h at 470 MHz, 68 km/h at 800 MHz) with HM (HP-stream, CR 2/3, α = 1, FFT 8K, GI 1/4) and antenna diversity.

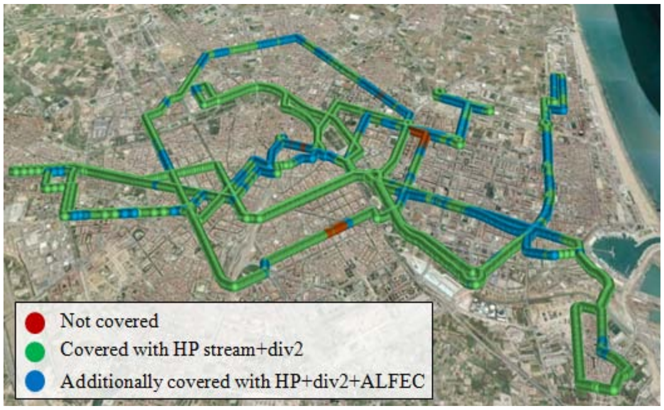

Fig. 8. Simulated coverage map of the DVB-T network in Valencia using antenna diversity, HM (α = 1) and AL-FEC (CR 3/4, Δt 8 seconds).

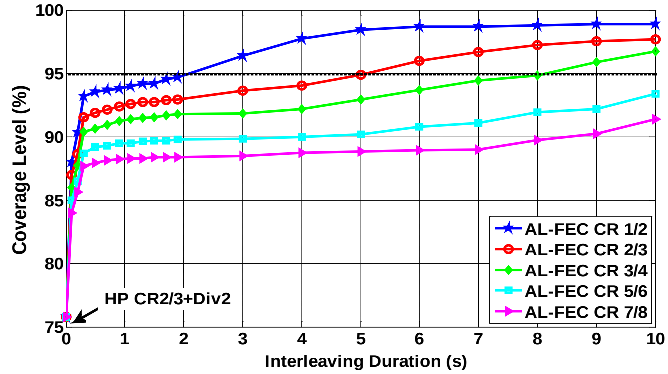

Fig. 9. Simulated mobile coverage of the DVB-T network in Valencia. Coverage level with single antenna (29%), (50%) with antenna diversity and (64%) with HP CR 2/3, α = 1 embeded in 64QAM. QoS criteria ESR5(20).

50% with two antenna reception. These values correspond quite well with the results obtained in the field measurement campaign. Combining antenna diversity with uniform HM (α=1, CR 2/3), the coverage level obtained was 75.3%. Fig. 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 transmitter. AL-FEC can be used to cover these areas with poor coverage.

Fig. 9 shows the coverage level achieved with AL-FEC as a function of the code rate and interleaving duration. The selections of these two design parameters involve a trade-off between protection level, capacity reduction, and network latency for each service. In the figure, it can be seen that a coverage level of 95% can be achieved with a CR of 1/2 for 2 seconds interleaving duration and with a CR 3/4 for 8 seconds interleaving duration. The simulated coverage map of this last configuration is also depicted in Fig. 8.

V. Conclusions and Discussions

In this letter, we have demonstrated that combining antenna diversity reception, hierarchical modulation, and AL-FEC, it is possible to provide in-band mobile services to vehicles in DVB-T networks dimensioned for fixed rooftop reception without impacting the coverage of fixed reception.

Results show that the current commercial DVB-T network in Valencia (Spain) could achieve good mobile coverage using antenna diversity reception, uniform 64QAM HM with physical layer CR 2/3 (for both HP and LP) and AL-FEC (CR 3/4 and interleaving duration 8 seconds). This configuration would provide a bit rate of 13.3 Mb/s for fixed reception and 4.4 Mb/s for mobile reception. The mobile performance of this configuration is similar to classic QSPK CR 1/2, and both will have the same transmission capacity. The benefit of the proposed configuration is that a bit rate of 13.3 Mb/s is available for fixed services with a slight coverage reduction compared with classic transmission mode (require only 0.5 dB more of CNR).

If the content is the same for static and mobile receivers, Scalable Video Coding (SVC) can be used to efficiently offer HDTV quality for fixed reception (capable of decoding both HP and LP streams), and SDTV quality for mobile reception or far away fixed receivers (decoding only HP stream). The benefit of using SVC is that it requires less bitrate than simulcasting the same content in two different video qualities.

Obtained results are of interest not only to update existing DVB-T networks deployments, but also to reduce the investment in infrastructure of emerging networks in countries where mobile reception to public transport systems is a desired feature.

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