# Simulation and Measurement of DVB-T2 Channel Characteristics

Dijana Tralic, Emil Dumic, Josip Vukovic, Sonja Grgic
University of Zagreb, Faculty of Electrical Engineering and Computing
Department of Wireless Communication
Unska 3, 10000 Zagreb, Croatia
*dijana.tralic@fer.hr*

*Abstract* **-** This paper describes a simulation and measurement of digital television signal transmission according to the DVB-T2 standard in Single-Frequency Networks (SFN) over few models of the fading channels. Simulation was done using a software implementation of the DVB-T2 standard with parameters defined for the DVB-T2 test signal that is transmitted in Croatia. Different types of fading channels were used including Gaussian, Ricean, and Rayleigh channels simulating fixed, portable and mobile reception. Besides the simulation, measurement of a typical signal reception in urban zone was done. Results from simulation and measurement were compared and analyzed.

***Keywords*** - DVB-T2; Digital Television; Fading Channels; Carrier-to-noise Ratio; BER

## I. INTRODUCTION

The analogue switch-off in Europe resulted in availability of new frequencies in the Ultra-High Frequency (UHF) band and new opportunities for services such as video-on-demand, High Definition Television (HDTV), and mobile television. Limited by frequency capacity, the terrestrial television platform, defined in DVB-T standard [1], needed more efficient transmission system to fulfill the demands of market and allow launch of new services. Induced by the request to maximize spectrum efficiency, the DVB Project developed the second-generation digital terrestrial television standard, the DVB-T2 [2].

New specification includes the latest coding, interleaving and modulation techniques which provide capacity and robustness in the terrestrial transmission environment. Thanks to all configurable parameters of the new standard, the transmission can be adapted to the characteristics of the actual channel conditions. In this paper the performance of the new standard is analyzed and evaluated through simulation and measurement.

The behavior of the DVB-T2 standard is studied in SFN for different types of fading channels (Gaussian, Ricean, and Rayleigh). Provided results show the improvement achievable by applying algorithms and techniques defined in the DVB-T2 specification.

This paper is organized as follows. Section II depicts the components of the DVB-T2 system and its improvements in comparison to the DVB-T system. In Section III, fading channels, simulation and results for all cases of simulation are described. Section IV presents measurement of DVB-T2 signal transmission in real conditions in urban zone. Finally, the conclusions are summarized in Section V.

## II. DVB-T2 SPECIFICATION

Main benefit of the DVB-T2 is the possibility to increase the capacity in digital terrestrial television (DTT). It provides a minimum increase in capacity of at least 30% in comparison to the DVB-T standard in equivalent reception condition using existing receiving equipment [3]. Although it has been fundamentally designed for fixed reception, the DVB-T2 standard is also feasible in portable and mobile devices if appropriate set of parameters is used.

### A. *Technical description*

The DVB-T2 transmitter, shown in Fig. 1, consists of several signal processing blocks. First novelty in the DVB-T2 standard are Low-density parity-check (LDPC) codes [4] combined with Bose-Chaudhuri-Hocquengham (BCH), used as protection against interference and noise. They offer excellent performance resulting in a very robust signal reception in various signal transmission condition. Another benefit is improved forward error correction (FEC) which gives a major capacity increase.

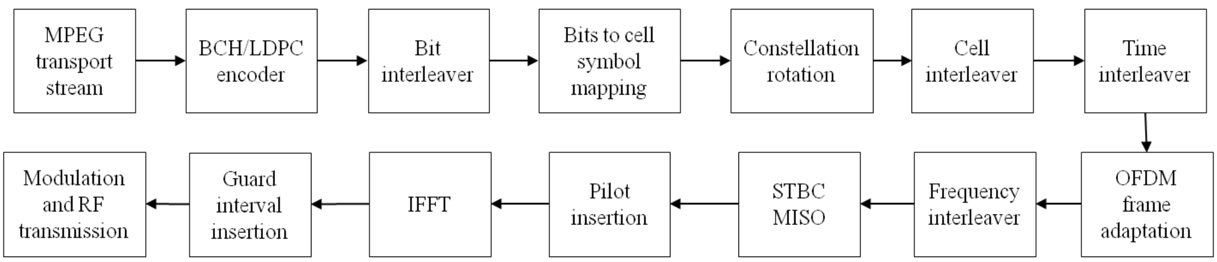


Figure 1. DVB-T2 transmitter block diagram

An important innovative feature is also the use of four cascaded forms of interleaving: bit, cell, time, and frequency interleaver. The purpose of these interleaving stages is to avoid error bursts, giving rise to a random pattern of errors within each LDPC FEC frame.

Additionally, a new technique called rotated constellations [5] resulted in improved robustness against loss of data cells. This technique is very important for achieving better performance in difficult propagation scenarios because it ensures that loss of information from one channel component can be recovered in another channel component. It maps data on QAM axis and rotates them in the I-Q plane where I and Q components are sent at different time slots using different cells.

Similarly to the DVB-T, the DVB-T2 uses Coded Orthogonal Frequency Division Multiplex (COFDM), but new modulation and coding techniques are introduced. The possibility of using the 256QAM mode allows higher number of bits to be carried per data cell, which increases the spectral efficiency and bitrate. The support for the 16K and 32K transmission modes allowed increase of the guard interval length without decreasing the spectral efficiency of the system. It is also possible to choose between normal or extended carrier modes. The extended carrier mode gives the possibility to use more carriers per symbol which result in increased data capacity. Comparison of available modes in DVB-T and DVB-T2 specifications is shown in Table I [6].

TABLE I. COMPARISON OF PARAMETERS IN DVB-T AND DVB-T2 SPECIFICATIONS

| | DVB-T | DVB-T2 |
|---|---|---|
| **FEC** | Convolutional Coding + Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8 | LPDC + BCH 1/2, **3/5**, 2/3, 3/4, **4/5**, 5/6 |
| **Modes** | QPSK, 16QAM, 64QAM | QPSK, 16QAM, 64QAM, **256QAM** |
| **Guard Interval** | 1/4, 1/8, 1/16, 1/32 | 1/4, **19/256**, 1/8, **19/128**, 1/16, 1/32, **1/128** |
| **FFT size** | 2K, 8K | **1K**, 2K, **4K**, 8K, **16K**, **32K** |
| **Scattered Pilots** | 8% of total | **1%**, **2%**, **4%**, 8% of total |
| **Continual Pilots** | 2,6 % of total | **0,35%** of total |

To compensate for changes in channels as a result of time and frequency, the DVB-T2 standard uses scattered pilot patterns. Additional flexibility is provided by the possibility to choose between one of eight scattered pilot patterns, depending on the selected Fast Fourier Transform (FFT) size and guard interval, in order to maximize the data payload. Each service can have different robustness and protection level with a unique modulation mode through the use of Physical Layer Pipes (PLPs). Each PLP carries one or more logical data streams (the DVB-T2 services and higher layer signaling data) and can have different physical parameters, like coding rate or constellation. The DVB-T2 standard allows the transmission of multiple PLPs simultaneously.

Optionally, the DVB-T2 standard can support Multiple Input Single Output (MISO) systems which can improve coverage in small scale SFNs using a transmitter diversity technique based on Alamouti encoding [7]. Also, two techniques for Peak to Average Power Ratio (PAPR) reduction are proposed: Active Constellation Extension (ACE) [8] for lower order constellations, and Tone Reservation method [9] for higher order constellations.

## III. SIMULATION

Simulation was done using publicly available DVB-T2 Common Simulation Platform (CSP) [10, 11] simulator version 030100 (Revision 11 from [11]), implemented in MATLAB. Verification and validation (V&V) reference model VV004-8KFFT [12] was tested with parameters adopted for Croatian terrestrial DVB-T2 emitting service. Table II shows only modified parameters in comparison to this reference model.

TABLE II. DIFFERENCES BETWEEN VV004-8KFFT REFERENCE MODEL AND CROATIAN DVB-T2 EXPERIMENTAL TELEVISION SERVICE

| | VV004-8KFFT | Croatian DVB-T2 |
|---|---|---|
| **Scattered pilots pattern** | PP5 | PP4 |
| **Symbols per frame (including closing symbol)** | 81 | 60 |
| **PLP Code rate** | 3/4 | 2/3 |
| **FFT size** | 8k | 32k |
| **PLP Constellation** | 64-QAM | 256-QAM |

### A. *Transmission Channel Models*

Eight fading channel models were used in the DVB-T2 simulation. Each model represents channel conditions between a transmitter and a receiver with different number of signal paths, attenuation, delay, phase and Doppler frequency shift.

Gaussian (AWGN) channel consists of a single signal path with only Gaussian noise present. It provides best signal reception, however, it is usually not the only one affecting terrestrial transmission. Gaussian channel with high C/N ratio was used as a reference.

Two channels used in the simulation were defined in ETSI EN 300 744 [1]. Ricean channel, named DVBT-F, simulates fixed signal reception. It consists of a direct path component and 19 components with variable attenuation, delay, and phase. Rayleigh channel named DVBT-P simulates portable signal reception with heavy multipath and no direct signal. It does not include the Doppler effect, which appears at higher speeds. The channel consists of 20 scattered, phase shifted and time delayed multipath components.

Two channels defined in COST 207 project [15], TU06 and TU12, provide simulation of mobile reception conditions and include the Doppler effect. Channel response for TU12 is shown in Fig. 2. In the time domain channel response is uneven and in the frequency domain there are signal drops of more than 40 dB.

The remaining three used channels, DTGlong, DTGmedium and DTGshort were defined by Digital Television Group [11]. First two have Ricean, and the last one Rayleigh distribution. Each of them consists of 6 signal paths. Table III shows signal attenuation and Table IV shows signal delay for these channels.

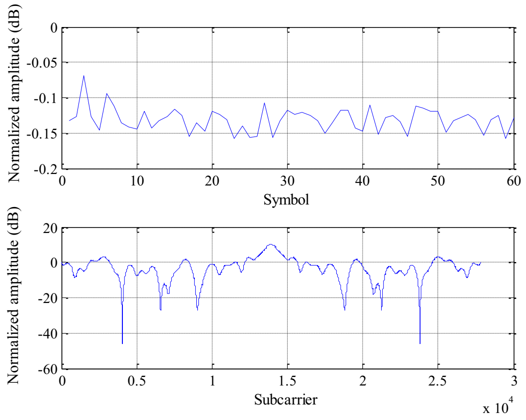


Figure 2. TU12 channel response in time and frequency domain

TABLE III. SIGNAL ATTENUATION FOR THREE TYPES OF CHANNELS

| Path | DTGlong [dB] | DTGmedium [dB] | DTGshort [dB] |
|---|---|---|---|
| 1 | 0 | 0 | 2.8 |
| 2 | 9 | 8.6 | 0 |
| 3 | 22 | 12.6 | 3.8 |
| 4 | 25 | 18 | 0.1 |
| 5 | 27 | 20.7 | 2.6 |
| 6 | 28 | 22.2 | 1.3 |

TABLE IV. SIGNAL DELAY FOR THREE TYPES OF CHANNELS

| Path | DTGlong [µs] | DTGmedium [µs] | DTGshort [µs] |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 5 | 1 | 0.05 |
| 3 | 14 | 5 | 0.4 |
| 4 | 35 | 8 | 1.45 |
| 5 | 54 | 12 | 2.3 |
| 6 | 75 | 21 | 2.8 |

DTGlong represents conditions where one signal path is a direct one and others are highly attenuated, with delay reaching 75 µs. Its channel response is shown in Fig. 3. In time domain, channel response is even. Frequency response varies often from minimum to maximum, but the lowest value is not lower than -8 dB. DTGmedium channel is similar to DTGlong, with signal delay up to 21 µs. DTGshort channel has much lower path delays, reaching only 2.8 µs, but components signals are attenuated, which complicates reception.

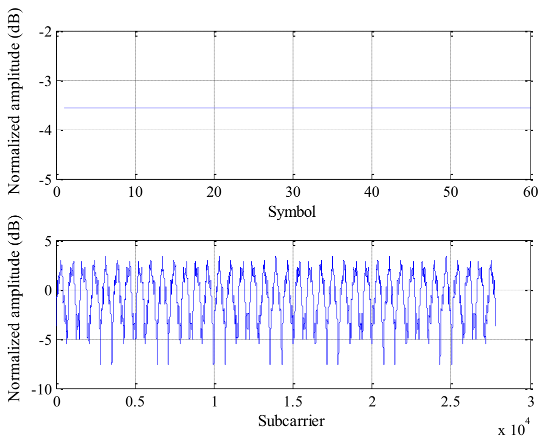


Figure 3. DTBlong channel response in time and frequency domain

Difference between used channels, especially Ricean and Rayleigh channels, can be seen in Fig. 4. Ricean channels provide much better signal reception for the same C/N. Constellation diagram in demapper for DTGlong channel is shaped similarly to reference AWGN channel constellation diagram, while TU12 constellation diagram in demapper has constellation points spread far away from the ideal shape.

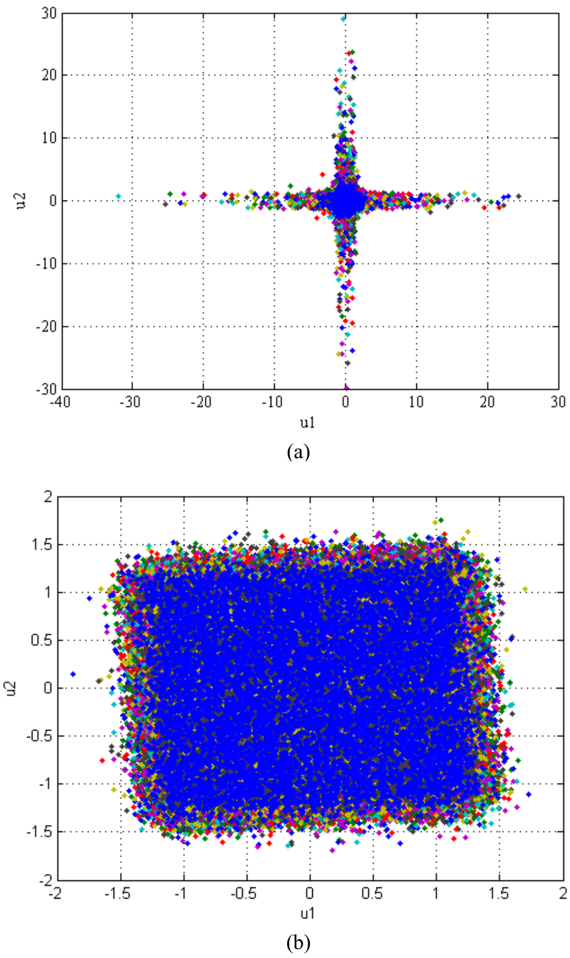


Figure 4. Constellation diagrams for 2 different channels: (a) demapper, TU12 (SNR=21.43 dB), (b) demapper, DTGlong (SNR=18.58 dB)

## B. *Simulation Description*

Simulation results were obtained using the DVB-T2 test 'dvbt2bl_ber_snr_VV_dico' which performed dichotomic search for SNR (Signal to Noise Ratio, e.g. added Gaussian noise) at target BER (Bit Error Rate) of $10^{-7}$ (after LDPC decoder) [13]. It starts from widely spaced SNR values guaranteed to bracket the desired BER and performing interval bisection. Only one frame is simulated at each SNR value and so the procedure rapidly homes in on the approximate SNR achieving the target BER. It is possible to calculate more precise SNR value using similar test and testing SNR by small increments, however, it takes much longer to calculate desired SNR which will be around 0.1 dB different than SNR obtained by using dichotomic search. Also, current receiver channel estimator uses only ideal channel estimation, which means that the channel response is obtained from the channel itself and not the pilot signals. Real channel estimation should be done using pilot signals and interpolating channel characteristic, thus increasing required SNR (in comparison with ideal channel response). For static multipath channels, frequency response is calculated directly from channel parameters. On the other side, for channels with Doppler shift, channel frequency response is calculated by loading the transmitted signal after the fading channel has been applied but before noise is added, and dividing it by the clean transmitted signal before the channel is applied. This means that it provides the best estimate of the frequency response at each frequency and on each symbol [10] (channel(*f*) in Eq. (1)). Inverted characteristic of the 'known' channel was multiplied with symbol (Zero forcing method), so final signal in the receiver, after channel estimation, will be defined as

$$input(f) = \frac{F(F^{-1}(X(f) \cdot channel(f)) + AWGN(t))}{channel(f)}, \qquad (1)$$

$$input(f) = X(f) + \frac{F(AWGN(t))}{channel(f)}, \qquad (2)$$

where *X(f)* marks output from the transmitter, and *input(f)* marks input in the receiver.

### C. Simulation Results

Results for TU06 and TU12 channel models were tested with 0.4 km/h moving velocity proposed in [14], which at 730 MHz (channel K53 on which the DVB-T2 signal is emitting in Croatia, in one allotment) equals 0.27 Hz Doppler frequency shift. At 10 Hz (velocity about 15 km/h at 730 MHz) any SNR would produce BER much higher than required for stable reception, which means that 256QAM cannot be used for mobile reception.

Results for all 8 channels are presented in Table V, for target BER that equals $10^{-7}$ ($\pm\ 0.2 \cdot 10^{-7}$). BER calculations are presented after 5 key points in receiver after:

- demapper (BER1),
- inner deinterleaver (BER2),
- inner decoder (BER3),
- outer decoder (BER4) and
- stream adaptation (BER5).

It should be noted that final BER was in all cases 0, because only 1 frame was tested and for 0.01 dB lower SNR BER was again higher than $10^{-7}$. This case is presented in Table VI. Table VII presents BER for SNR ~0.1 dB lower than marginal (for target BER3 smaller then$10^{-7}$).

From Table V it can be concluded that, using ideal channel estimation, marginal BER1 for all tested channels is about 0.1. With that BER1, BER3 results were equal to 0, although it is possible that by using more testing frames, BER3 would be somewhat higher. From Table VI, it can be seen that only slight change in SNR produces much higher change in BER3, although BER1 remained practically the same. This means that most of the error correction is done in LDPC decoder (BER2 → BER3), while BCH decoder corrects only smaller amount of errors (BER3 → BER4).

By reducing SNR for only about 0.1 dB (Table VII) it can be seen that, with BER3 between $10^{-4}$ and $10^{-5}$, BER5 would be in the same range as BER3. Values of BER5 different than zero indicate that some errors occur in transmission. These conclusions will be presented in measurement results also.

TABLE V. SIMULATED SNR RESULTS FOR 8 DIFFERENT CHANNEL FREQUENCY RESPONSES, TARGET BER3<$10^{-7}$

| | AWGN | DTGlong | DTGmedium | DTGshort | DVBT-F | DVBT-P | TU06 | TU12 |
|---|---|---|---|---|---|---|---|---|
| **SNR (dB)** | 18.08 | 18.58 | 18.85 | 20.36 | 18.49 | 20.42 | 20.05 | 21.43 |
| **BER1** | 0.0974 | 0.0986 | 0.1 | 0.1 | 0.0981 | 0.104 | 0.103 | 0.104 |
| **BER2** | 0.0974 | 0.0986 | 0.1 | 0.1 | 0.0981 | 0.104 | 0.103 | 0.104 |
| **BER3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **BER4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **BER5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE VI. SIMULATED SNR RESULTS FOR 8 DIFFERENT CHANNEL FREQUENCY RESPONSES, 0.01 DB LOWER SNR THAN REQUIRED

| | AWGN | DTGlong | DTGmedium | DTGshort | DVBT-F | DVBT-P | TU06 | TU12 |
|---|---|---|---|---|---|---|---|---|
| **SNR (dB)** | 18.07 | 18.57 | 18.84 | 20.35 | 18.48 | 20.41 | 20.04 | 21.42 |
| **BER1** | 0.0976 | 0.0988 | 0.1 | 0.1 | 0.0983 | 0.104 | 0.103 | 0.105 |
| **BER2** | 0.0976 | 0.0988 | 0.1 | 0.1 | 0.0983 | 0.104 | 0.103 | 0.105 |
| **BER3** | 1.39E-6 | 4.63E-7 | 4.63E-7 | 4.63E-6 | 1.85E-6 | 3.24E-6 | 1.4E-6 | 9E-7 |
| **BER4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **BER5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE VII. SIMULATED SNR RESULTS FOR 8 DIFFERENT CHANNEL FREQUENCY RESPONSES, ~0.1 DB LOWER SNR THAN REQUIRED

| | AWGN | DTGlong | DTGmedium | DTGshort | DVBT-F | DVBT-P | TU06 | TU12 |
|---|---|---|---|---|---|---|---|---|
| **SNR (dB)** | 17.99 | 18.57 | 18.77 | 20.24 | 18.28 | 20.34 | 19.95 | 21.35 |
| **BER1** | 0.0987 | 0.1 | 0.101 | 0.102 | 0.0983 | 0.105 | 0.104 | 0.105 |
| **BER2** | 0.0987 | 0.1 | 0.101 | 0.102 | 0.0983 | 0.105 | 0.104 | 0.105 |
| **BER3** | 3.64E-4 | 3.86E-4 | 4.50E-4 | 6.14E-4 | 5.76E-3 | 8.83E-4 | 4.8E-4 | 2.2E-4 |
| **BER4** | 3.56E-4 | 3.84E-4 | 4.44E-4 | 6.08E-4 | 5.73E-3 | 8.70E-4 | 4.8E-4 | 2.2E-4 |
| **BER5** | 3.55E-4 | 3.83E-4 | 4.42E-4 | 6.07E-4 | 5.71E-3 | 8.67E-4 | 4.7E-4 | 2.2E-4 |

## IV. MEASUREMENT

Measurement site had a clear view to the transmitter, situated 11030 m away on Sljeme, Croatia. Position of the transmitter was higher than position of the receiver which was situated at 11th floor in a high building in urban zone. Antenna with 11 dB gain, at the relative height of 1.5 m from the floor, was used. Test DVB-T2 signal, with 730 MHz frequency and the same parameters used in the simulation, was received. Measurements were conducted using two devices: Agilent N9010A EXA Signal Analyzer and Sefram 7865HDT2.

Table VIII shows measurement results:

- the error named LDPC calculated after the signal went through demodulator, and before entering LDPC procedure (corresponds to BER2 error in simulation results),
- the BCH error calculated between LDPC and BCH decoders (corresponds to BER3 error in simulation results),
- Frame Error Rate (FER) calculated after BCH procedure, and before MPEG decoding,
- Modulation Error Ratio (MER),
- Carrier-to-Noise (C/N) ratio.

FER is defined as the ratio between erroneous and total number of received frames. On the other side, MER (in dB) is defined as the ratio between Root Mean Square (RMS) power of ideal transmitted signal divided by the RMS power of the error vector. Error vector is a vector in the I-Q plane between the ideal constellation point and the point received by the receiver. C/N ratio is difference between the amplitude of an RF signal and the amplitude of noise present in the transmission path of the RF signal.

Measurement results are shown for two cases. The first measurement was conducted in ideal conditions, with no obstacles between the transmitter and the receiver's antenna (first row in Table VIII). Afterwards, signal was attenuated using attenuation elements between the antenna and the receiver. Attenuation was gradually increased by 1 dB until decoding became impossible. Second row in Table VIII shows results for signal attenuated as much as possible, while decoding was still possible. This attenuation was equal to 10.2 dB from ideal receiving conditions.

Results demonstrate that LDPC of $8.6 \cdot 10^{-2}$ is very similar to BER2 results obtained in the simulation. C/N in simulation is on average 10 dB lower than in the measurement. Reason for that is usage of ideal channel estimation in all simulation cases.

TABLE VIII. MEASUREMENT RESULTS OF REAL DVB-T2 SIGNAL

| | LDPC | BCH | FER | MER [dB] | C/N [dB] |
|---|---|---|---|---|---|
| **Measurement 1** | $2 \cdot 10^{-4}$ | $1 \cdot 10^{-9}$ | $1 \cdot 10^{-5}$ | 35.9 | 39.9 |
| **Measurement 2** | $8.6 \cdot 10^{-2}$ | $1 \cdot 10^{-8}$ | $2 \cdot 10^{-5}$ | 19.2 | 29.7 |

Amplitude of the received signal normalized in a way that mean value equals 1 is shown in Fig. 5, and phase of the same signal is shown in Fig. 6.

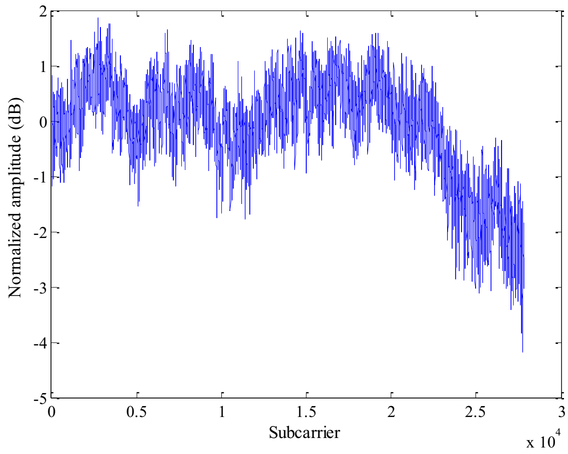


Figure 5. Measured channel - normalized amplitude

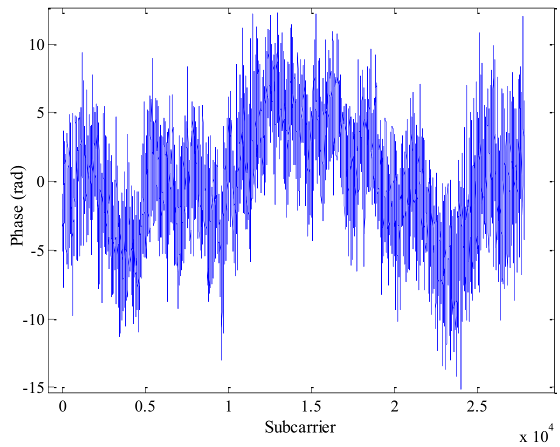


Figure 6. Measured channel - phase

## V. CONCLUSION

In this paper measurements of simulated and real channel characteristics in the DVB-T2 system were presented. Simulation was done in fixed, portable and mobile receiving conditions, which led to conclusion that 256QAM mode cannot be used for mobile reception at higher moving velocity. Results also show that LDPC decoder performs most of the error corrections, while only smaller amount of errors was corrected in BCH decoder.

Measurement results show that C/N ratio was about 10 dB higher than in simulation. Differences in measurement and simulation result are consequence of properties of channel estimator in the receiver. Currently it uses only ideal channel estimation, which means that the channel response is obtained without the pilot signals. Considering the performance of the standard in a SFN scenario, it can be concluded that DVB-T2 allows satisfying reception of the signals in various transmission conditions.

Future research could include simulation of the real channel estimation from pilot signals using more different patterns in DVB-T2 system (PP1-PP8). It is also possible to apply various interpolation techniques (linear, low-pass filter, time domain interpolation) and different methods for calculation of the channel response (zero forcing, minimum mean square error). New technique for better channel equalization is also possible to develop.

## ACKNOWLEDGMENT

The work described in this paper was conducted under the research projects: "Picture Quality Management in Digital Video Broadcasting" (036-0361630-1635) and "Environment for Satellite Positioning" (036-0361630-1634) supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

## REFERENCES

[1] ETSI EN 300 744 (V1.6.1), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television", September 2008

[2] ETSI EN 302 755, "Digital Video Broadcasting (DVB); Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)", V1.1.1, September 2009

[3] DVB BlueBook A133. "Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2) ", DVB Document A133, February 2009

[4] T. Richardson and R. Urbanke, "The Renaissance of Gallager's Low-Density Parity-Check Codes", IEEE Commun. Magazine, vol. 41, pp.126-131, August 2003

[5] K. Boullé and J. C. Belfiore, "Modulation scheme designed for the Rayleigh fading channel", in CISS'92, Princeton, NJ, March 1992

[6] "DVB Fact Sheet: DVB-T2 - 2nd Generation Terrestrial Broadcasting", DVB Project Office, April 2012

[7] S. Alamouti, "A simple transmit diversity technique for wireless communications", IEEE Journal on Selected areas in Commun., vol. 16, no. 8, pp. 1451-1458, October 1998

[8] B. Krongold and D. Jones, "PAR Reduction in OFDM via Active Constellation Extension", IEEE Trans. Broadcasting, vol. 49, pp. 258-268, September 2003

[9] J. Tellado and J. M. Cioffi, "Efficient algorithms for reducing PAR in multicarrier systems", in Proc. 1998 IEEE International Symposium on Information Theory, pp. 191., August 16-21, 1998

[10] DVB-T2: The Common Simulation Platform, BBC R&D White Paper 196, available at http://downloads.bbc.co.uk/rd/pubs/whp/whp-pdf-files/WHP196.pdf

[11] DVB-T2 Common Simulation Platform, available at: https://sourceforge.net/projects/dvb-t2-csp/files/releases, and http://dvb-t2-csp.svn.sourceforge.net/

[12] DVB-T2 Streams Parameter Sets, available at http://www.dvb.org/technology/dvbt2/DVB-T2_Streams_ParameterSets_SPLP.xls

[13] DVB Document A122, "Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)", June 2008

[14] R. Schramm, "DVB-T - C/N values for portable single and diversity reception", EBU Technical review, April 2004

[15] G. Faria, "MOTIVATE Report: Using DVB-T Standard to Deliver Broadcast Services to Mobile Receivers", 36. DVB-TM meeting EBU, January 2000