Simulating DVB-T to DVB-T2 Migration Opportunities in Croatian TV Broadcasting

Emil Dumic, Sonja Grgic
Department of Wireless Communications
University of Zagreb, Faculty of Electrical Engineering and Computing
Zagreb, Croatia
emil.dumic@fer.hr

Domagoj Frank
Department of Multimedia, Design and Application
University North
Varaždin, Croatia
domagoj.frank@unin.hr

***Abstract*— In this paper we analyzed possible capacity gains in transition from DVB-T to DVB-T2 standard. We compared minimum C/N ratio needed for quasi error free reception of DVB-T and DVB-T2 systems with similar transmitting parameters currently used in Croatia. C/N was calculated using simulations developed in Matlab for those standards, in three commonly used channel models: Gaussian, Ricean and Rayleigh. Results show bandwidth increase of about 63% without significant increase of the minimum C/N. By using newer compression techniques and statistical multiplexing in large pools, it can be concluded that up to 10 times more TV channels (with the same quality) can be transmitted in the same occupied frequency bandwidth.**

Keywords—DVB-T, DVB-T2, Channel models, LDPC

I. INTRODUCTION

In Croatia, analog television was turned off in 2010. Because in DVB-T in one channel there can exist more programs, some parts of radio-frequency spectrum had become free and could be used for other purposes - for mobile broadcast services (LTE). This free part of the spectrum (790-862 MHz) is called the "first digital dividend" and is nowadays used by two national mobile operators. Croatian Digital Terrestrial Television networks are currently divided in 9 Single Frequency Networks (SFNs). In each SFN, 5 multiplexes are allocated: Multiplex A and Multiplex B for Free-To-Air (FTA) national channels, Multiplex D for FTA national and regional channels and Multiplex C and E for pay-tv platform. Multiplexes A, B and D are using DVB-T, while multiplexes C and E are using DVB-T2 standard. In DVB-T2, four regions are connected in two, which effectively gives 7 SFNs.

24 countries in the world (including Croatia) are commercially using DVB-T2 standard and 10 other countries are experimentally using it or are planning to use DVB-T2 standard [1].

Croatia was the 15th European country to switch of analog television, and because of such early digitalization H.262 (MPEG-2 Part 2) video coding standard was used, together with DVB-T standard, although more advanced DVB-T2 standard already existed, as well as more advanced H.264/AVC compression (MPEG-4 Part 10), which could be implemented even in DVB-T. Such approach was used also by other countries that had early digitalization, primarily because of couple of times higher cost of set top boxes (STBs) and TV sets with newer H.264/AVC decoder type. DVB-T2 TV sets or STBs were not commercially available at that time.

Because of the higher spectral efficiency of the DVB-T2 standard, higher compression of newer standards H.264/AVC and especially HEVC (MPEG-H Part 2) compared to H.262, and statistical multiplexing gains in large pools, it is likely that FTA multiplexes will migrate to the newer standards that are already used for pay-tv multiplexes. Also, by introducing newer standard, the "second digital dividend" will become free and could be again used for mobile broadband and other purposes.

This paper is organized as follows. Section II gives an overview of related work. Section III discusses about technical description of DVB-T and DVB-T2 standard. Section IV explains three commonly used channel models which will be used in later simulation. Section V gives simulation results with similar transmitting parameters like existing DVB-T and pay-tv DVB-T2 Croatian networks. In section VI, practical gain in number of different TV channels will be discussed and finally section VII gives important conclusions.

II. RELATED WORK

In [2] digital dividend after the transition to DVB-T2 has been discussed, from the technological advances such as DVB-T2 standard and H.264/AVC. Paper [3] gives review of DVB-T2 standard in detail, along with its benefits and trade-offs. This paper also presents a comprehensive review of the laboratory and field trial results in Spain and in Northern Germany. In [4] authors discuss about possible advances in OFDM based multicarrier systems by using Faster-than-Nyquist (FTN) signaling, which may improve many existing and upcoming broadband access technologies such as WLAN, LTE and DVB. Similar work was presented in [5], where authors concluded that FTN can transmit up to twice the bits as ordinary modulation at the same bit energy, spectrum, and error rate. The method is directly applicable to orthogonal frequency division multiplex (OFDM) and quadrature amplitude modulation (QAM) signaling.

In [6], authors have analyzed DVB-T and DVB-T2 performance in fixed terrestrial TV channels, using classical Ricean and Rayleigh multipath fading channels with 20 independent paths. In [7], authors have evaluated performance of DVB-T2 in a SFN Network and compared it with DVB-T, with similar parameters as in their country (France).

III. Technical Description of DVB-T and DVB-T2 Systems

A. Technical description of DVB-T system

DVB-T transmitter shown in Fig. 1. consists of several signal processing blocks [8], [9]: Source coding and MPEG-2 multiplexing, Splitter, Multiplex adaptation and energy dispersal, External encoder (RS encoder), External interleaver (Convolutional interleaver), Internal encoder (Punctured Convolutional Code), Internal interleaver, Mapper (+ pilots and Transmission Parameter Signaling (TPS) carriers), OFDM Transmitter and Guard Interval Insertion, DAC (digital to analogue converter) and front-end. DVB-T transmitter diagram is shown on Fig. 1.

The receiving STB (Set-Top Box) adopts techniques which are dual to those used in the transmission. Its practical performance depends on hardware construction (it is not standardized like encoder).

In Croatia, DVB-T system is currently used for several national and regional television channels. Transmission parameters which are used in multiplexes A and B: 64-QAM, code rate 3/4, guard interval 1/4, H.262 video compression, 8k FFT and useful bitrate 22.4 Mbit/s. In multiplex D, depending on the region, some other transmission parameters may have been used, depending on the territory and number of regional TV channels. Later in the paper, parameters which are used in multiplexes A and B will be used for comparison with DVB-T2 standard.

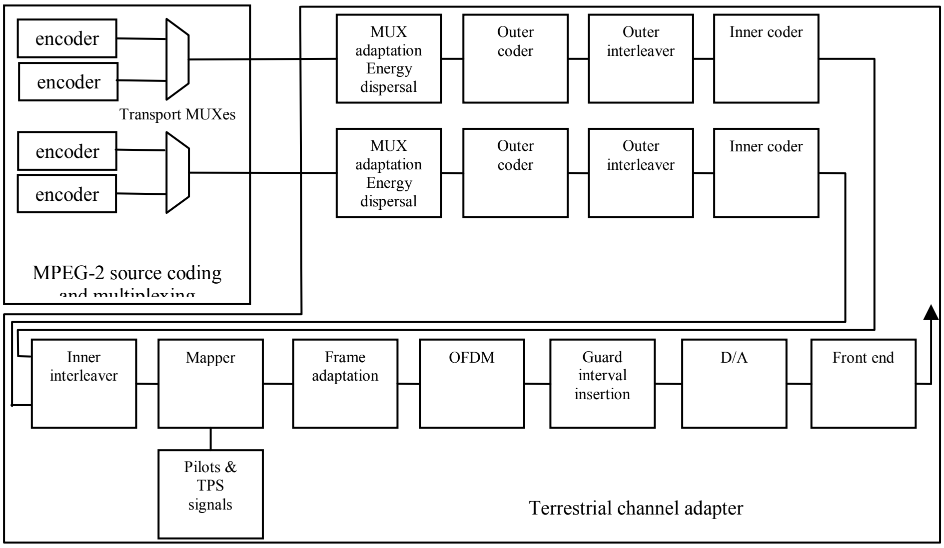

Fig. 1. DVB-T transmitter block diagram

B. DVB-T2 system description

Main benefit of the DVB-T2 over DVB-T is the possibility to increase the capacity in digital terrestrial television (DTT) [10], [11]. It provides a minimum increase in capacity of at least 30% in comparison to the DVB-T standard in equivalent reception conditions. 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.

The DVB-T2 transmitter shown in Fig. 2 consists of several signal processing blocks. First novelty in the DVB-T2 standard are Low-density parity-check (LDPC) codes [12] 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, as well as spectrum capacity increase.

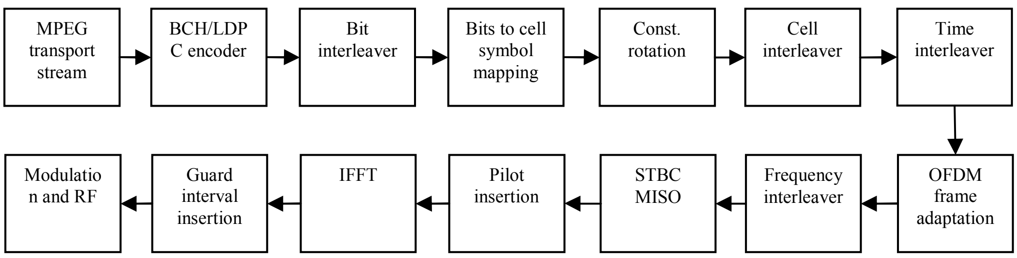

Fig. 2. DVB-T2 transmitter block diagram

Additionally, a new technique called rotated constellations 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 the 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. Rotation angles have been experimentally determined to be 29°, 16.8°, 8.6° and 3.6° for QPSK, 16QAM, 64QAM and 256QAM respectively [13].

Similarly to the DVB-T, the DVB-T2 uses Coded Orthogonal Frequency Division Multiplex (COFDM), with new modulation - 256QAM. This 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, because of the longer useful OFDM symbol duration, than in 8K mode. This allows broader SFN (Single Frequency Network) networks in DVB-T2 standard. Alternatively, if guard length with the same duration is used, as in DVB-T, this results in useful capacity increase (in DVB-T2).

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 results in increased data capacity, while not increasing channel bandwidth.

To compensate for changes in channels as a result of time and frequency, the DVB-T2 standard uses scattered pilot patterns. Additional flexibility in comparison with DVB-T 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. However, only some combinations of guard interval, FFT size and pilot patterns are possible.

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 and can have different physical parameters, like coding rate or constellation. The DVB-T2 standard allows the transmission of multiple PLPs simultaneously.

Simple comparison of available modes in DVB-T and DVB-T2 specifications is shown in Tab. 1. Bolded numbers in DVB-T2 column mean that they are newly introduced in this standard.

In Croatia, parameters which are used in multiplexes C and E are: 256-QAM (rotated), code rate 2/3, guard interval 19/256, pilot pattern 4, 32k FFT (extended) with useful bitrate of 36.6 Mbit/s. Also, H.264/AVC is used as video compression, together with statistical multiplexing. In comparison with H.262, H.264/AVC is approximately twice as efficient as H.262, while maintaining same visual quality. By using statistical multiplexing, depending on the number of channels in one multiplex, gain can be up to 50% (in comparison with constant bitrate case) [14].

TABLE I. DVB-T AND DVB-T2 SYSTEM COMPARISON

	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

IV. CHANNEL MODELS

We compared DVB-T and DVB-T2 systems using 3 commonly used channel models: Gaussian, Ricean and Rayleigh channel models. Gaussian channel model describes only one ray with line of sight. Ricean channel has one direct and several delayed rays, while Rayleigh doesn't have direct ray. Characteristics of Ricean and Rayleigh channels can be found in [2] and their parameters are given in Tab. 2.

When comparing DVB-T and DVB-T2 standards, we used 'ideal channel estimation', which means that pilot signals were not actually used to estimate channel frequency response. Instead, inverted characteristic of the 'known' channel was multiplied with received symbol. For lower degradations in the channel frequency response, C/N can be expected to be similar as in Gaussian channel scenario, while for higher degradations, higher C/N values will be needed for decoder. In real channel measurements, minimum C/N should be even higher [9], [11], because in that case channel frequency response is not known, but is calculated from pilot signals. In some cases, channel degradations can be too severe to be able to decode the signal, with any C/N.

TABLE II. NORMALIZED AMPLITUDE (OVERALL POWER 0 DB), PHASE AND DELAY VALUES FOR SIMULATED RICEAN AND RAYLEIGH CHANNEL

I	$\rho_{i\ (Ricean)}$	$\rho_{i\ (Rayleigh)}$	τ_i(μs)	θ_i (rad)
0	0.953462	-	0	0
1	0.016187	0.053687	1.003019	4.855121
2	0.049635	0.164620	5.422091	3.419109
3	0.114301	0.379093	0.518650	5.864470
4	0.085224	0.282656	2.751772	2.215894
5	0.072647	0.240941	0.602895	3.758058
6	0.017358	0.057568	1.016585	5.430202
7	0.042204	0.139975	0.143556	3.952093
8	0.014467	0.047981	0.153832	1.093586
9	0.051955	0.172315	3.324866	5.775198
10	0.112561	0.373324	1.935570	0.154459
11	0.083017	0.275336	0.429948	5.928383
12	0.098485	0.326639	3.228872	3.053023
13	0.073805	0.244784	0.848831	0.628578
14	0.063414	0.210321	0.073883	2.128544
15	0.048003	0.159207	0.203952	1.099463
16	0.042031	0.139401	0.194207	3.462951
17	0.067413	0.223585	0.924450	3.664773
18	0.032729	0.108549	1.381320	2.833799
19	0.062084	0.205908	0.640512	3.334290
20	0.072913	0.241824	1.368671	0.393889

V. SIMULATION RESULTS

Practical example of useful bitrate increase between DVB-T and DVB-T2 system is shown on Fig. 3. Parameters that were used in simulations:

- DVB-T: 64QAM, guard interval 1/4, FFT mode 8k; code rates: 1/2, 2/3, 3/4, 5/6 and 7/8
- DVB-T2: 256QAM (rotated), guard interval 19/256, FFT mode 32k extended, Pilot Pattern 4; code rates: 1/2, 3/5, 2/3, 3/4, 4/5, 5/6; other parameters are the same as in verification and validation (V&V) reference model VV004-8KFFT [15]

Simulated channel types were, as described earlier, Gaussian, Ricean and Rayleigh. For DVB-T C/N (Carrier to Noise) ratio, results were obtained from [9] (simulation was implemented in Matlab, Simulink) for Gauss and Rice, while for Rayleigh channel minimum C/N was taken from [2]. For DVB-T2, C/N was calculated using publicly available DVB-T2 Common Simulation Platform (CSP) simulator version 030202 [16], also implemented in Matlab. C/N values represent minimum values to obtain quasi error free reception, which means BER (Bit Error Rate) $<2*10^{-4}$ after internal decoder in DVB-T and BER$<10^{-7}$ after internal decoder in DVB-T2.

It should be noted that guard interval is set to 1/4 in DVB-T system, 8k mode, in Croatia, which equals to 1/16 in DVB-T2, 32k mode, because of the 4 times longer useful OFDM symbol duration in 32k mode. However, 19/256 mode is used in DVB-T2 in Croatia so we compared those values (guard interval 19/256 gives just slightly lower useful bitrate, comparing to 1/16). C/N ratio factor can change somewhat if other simulators would be used, or in real channel measurements. It can be found however that similar C/N values (for our used parameters) are in [2] for DVB-T and [17] for DVB-T2 system. On Figure 3, beside overall results, specific parameters which are used in Croatia for DVB-T (multiplexes A and B) and DVB-T2 (multiplexes C and E) are shown with horizontal lines. It can be seen that, for relatively similar C/N, gain in useful bitrate is about 63% for DVB-T2, comparing to DVB-T (22.4 Mbit/s in DVB-T versus 36.6 Mbit/s in DVB-T2).

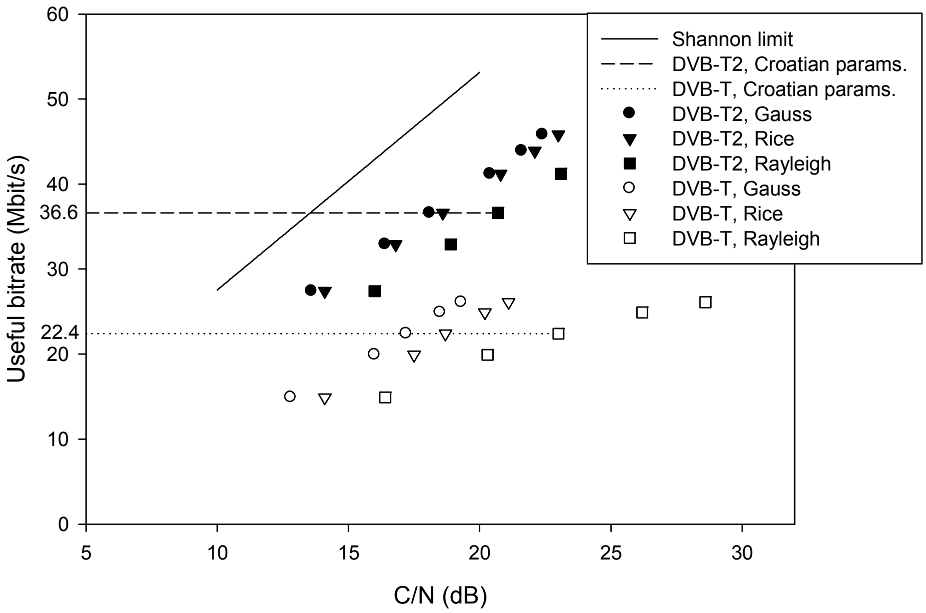

Fig. 3. Simulation results for DVB-T2 and DVB-T system with similar parameters

VI. DISCUSSION OF THE RESULTS

With the same parameters used as in Croatian DVB-T (case with code rate 3/4) and DVB-T2 (case with code rate 2/3), when comparing Gaussian channel, minimum C/N was 17.2 dB for DVB-T standard, while in DVB-T2 it was 18.1 dB. When comparing Ricean channel type, minimum C/N was 18.7 dB in DVB-T versus 18.6 dB in DVB-T2. In Rayleigh channel type, minimum C/N was 23 dB in DVB-T, versus 20.7 dB in DVB-T2. This means that for scenarios with no line of sight path, it could be expected to obtain even better results in DVB-T2 system, than in DVB-T in similar receiving conditions.

With statistical multiplexing and H.264/AVC video compression, it can be concluded that up to 5 times more TV programs could be transmitted in one DVB-T2 multiplex than in DVB-T/H.262 multiplex in Croatia. HEVC compression standard is still in the development phase, but can be expected to be widely commercially available in a few years. It would further increase the density to up to 10 times more TV programs than in current DVB-T/H.262 multiplex. It is expected that HEVC compression could double the data compression ratio compared to H.264/MPEG-4 AVC at the same level of video quality. Alternatively, HD and 3D channels could be implemented, or some frequency spectrum could be used for "second digital dividend" (e.g. for LTE).

By using advances in OFDM based multicarrier systems by using Faster-than-Nyquist (FTN) signaling, DVB-T2 transmission may be further improved by using FTN, in the sense of useful bitrate by 30-100% (in comparison with regular OFDM) with similar C/N [5], but with higher implementation complexity. However, such changes should be implemented on both transmitter and receiver side and require further research about pilot signaling.

VII. Conclusions

In this paper we presented results of minimum required C/N in DVB-T and DVB-T2 systems, with simulated channel characteristics and similar transmitting parameters as in Croatian multiplexes. We tested Gaussian, Ricean and Rayleigh channels as defined in ETSI standard. Results show similar minimum C/N for Gaussian and Ricean channel, while in Rayleigh channel C/N was lower in DVB-T2 system simulation. Useful bitrate increase was about 63%, when comparing Croatian DVB-T and DVB-T2 systems. Depending on the compression method used, 5-10 times more channels with same visual quality could be transmitted. Alternatively, HD and 3D channels could be implemented, or some frequency spectrum could be used for "second digital dividend".

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