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Broadband DVB-T2 Channels at a Physical Level – Simulation Analysis

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***Abstract*—Digital video broadcasting (DVB) decreases the proportion of broadcasting channels used for existing programmes. Second-generation DVB standards offer increased bit rates, enabling more programmes per broadcasting channel than in case of the first generation. On the other hand, increased bit rate needed for high definition programmes requires combining of the capacity of few single channels producing a broadband one. Also, statistical multiplexing allows more efficient usage of capacity. Terrestrial broadcasting standard DVB-T2 enables the time frequency slicing (TFS), as a way of connecting channels at the media access control (MAC) level. This paper deals with the two types of a broadband channels at physical layer. Compared to the TFS mode, method proposed here utilizes the allocated bandwidth in a more efficient way.**

***Index Terms*—Digital video broadcasting, statistical multiplexing, time frequency slicing, physical level combining, FFT multiplying, adjacent channel combining.**

I. INTRODUCTION

The participation of high-definition programmes within the DVB-T2 packet, taken in high-definition format, with a typical flow rate of 7 Mb/s–8 Mb/s have been increased. Broadcasting of an ultra-high definition (HD) 1080p/50 programme with a data rate of about 10 Mb/s [1] will be widely used throughout the globe. In the same time, 3D programmes with almost doubled data rate [2], compared to 2D ones, will be introduced in the majority of the broadcasting networks. The introduction of new interactive services and high-resolution TV formats require broadband channels.

Improved DVB-T2 performances, as terrestrial standard, allow more than 40 Mb/s within a broadcasting 8 MHz channel depending on the transmission parameters [3], [4]. Performances of DVB-T2 solutions for mobile users, are analysed and tested [5]. The choice of the transmission mode automatically specifies the capacity per multiplex, which is important in the process of defining the spectrum requirements.

High HD data rates reduce the number of programmes within the multiplex. So, it is not possible to achieve the traffic balance or optimal utilization, without introducing of the efficient compression technique, as well as by applying the statistical multiplexing and Physical Layer Pipe (PLP) data slicing [6], [7].

All these require aggregation of multiple channels creating a broadband statistical multiplex, as a consequence. The DVB-T2 standard proposes the time frequency slicing, as a channel combination at the MAC level [8]. TFS allows the sub-slices of a PLP to be sent over the multiple non-adjacent RF frequencies, providing multiplexes with, for instance, up to 6 frequency channels. Software implemented in traffic scheduling over multiple channels [9] is rather complex.

The creation of broadband multiplex, which includes frequency bands of several adjacent broadcasting channels at the physical layer, has been assumed in the proposal for technologies for DVB-C2 standard, as well. Orthogonal Frequency Division Multiplex (OFDM) technique enables its realization in two ways:

– By generating a single multiplex covering multiple broadcasting frequency channels, without changing of the space between them, and keeping the symbol and guard interval duration [10] unchanged compared to the one in single channel case;

– Due to the orthogonality of the carriers, adjacent single band channels can be placed *side-by-side* without need for guard frequency interval between them [11].

Compared to the TFS in the DVB-C2 transmission, as cable standard, the advantages of both of the models in reducing the complexity and increasing of the overall capacity are provided in [12].

In this paper the capability of the models mentioned above for implementation in case of DVB-T2 transmission is analysed. It is performed by taking into account the differences in the multiplex performances, as well as already defined parameters for the transmission modes, planned for future DVB-T2 broadcasting for fixed, portable and mobile services [13].

First, we obtain the requirements for a large number of different services by merging a few single RF channels (broadcasting channels) into a common broadband one. Therefore, the channel utilization increases. In case of

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statistical multiplexing, this is the well-known *statistical multiplexing gain*.

Second, merging of the capacities on the physical layer, enables its increase, introducing the *capacity gain*, and in the same time increasing cumulatively the overall gain. This gain is a characteristic of the channel merging at a physical layer and will be discussed later.

Third, merging of few channels enables the third type of gain representing the robustness towards the frequency selective fading, as a consequence of content spreading over the wider frequency range. As it produces the increase of content utilization based on Forward Error Correction (FEC) decrease, this gain can be seen as *network planning gain*. It is much higher in case of TFS connection, as the RF channel spacing's increase. So, it is less sensitive to frequency selective fading.

Further, the comparison of the capacities obtained in case of TFS connectivity, the analysis should show which of the models at physical layer corresponds to a particular DVB-T2 transmission mode. Simulation is performed in the software package [14]. It confirms the assumptions and the adequate conclusions have been derived.

The analysis justified the worthiness of generating of a broadband channel for both of the models mentioned above. Their performances and all of the main parameters such as: carrier, carrier spacing, symbol duration, guard interval duration and modulation type have been considered.

The results quantified the increase in capacity compared to the corresponding TFS connections based on the full use of the allocated frequency space.

Simulation results, diagrams and figures are expected to show how the broadband channel affects the transmission quality, as well as to confirm the resulting BER in presence of Additive White Gaussian Noise (AWGN) noise.

The paper is organized as follows. The second chapter is devoted to the channel integration on physical layer. The third chapter represents the simulation results, and in the last one conclusions are derived.

II. Channel Integration at the Physical Level

A common broadband frequency channel will be created by TFS technique at the MAC level, and its capacity will be equal to the sum of the separate single channels capacities. Table I contains the basic parameters and capacities per multiplex in a single channel, which can be achieved for several scenarios of DVB-T2 transmission mode, proposed for future implementation.

The RF channels are separated by frequency guard band in order to avoid interchannel interference. Thus, in the 8 MHz band, in case of normal mode the useful bandwidth is 7.6 MHz wide, whereas in the extended carrier mode it takes 7.71 MHz. In case of 16 K and 32 K modes, the bandwidth is 7.77 MHz. Note that it is expected that extended carrier modes will be used in future.

Therefore, in each channel there is a residual of at least 0.23 MHz guard frequency band unused. The heritage of the well-known analog transmission mode is seen through the current RF broadcasting channels (8/7/6 MHz wide). They are followed by filters supporting the frequency guard intervals. OFDM technique allows us both: to use the frequency guard band and to avoid the adjacent channels interference (by achieving carriers' orthogonality). Subsequently, the influences among the carriers within the channel are avoided. Furthermore, adjacent channels can be connected in a common wide channel, enabling the sharing of such a huge band.

TABLE I. CAPACITIES OF A SINGLE MULTIPLEX FOR FIXED MFN, FIXED SFN AND PORTABLE/MOBILE SFN (DVB-T2) FOR A SINGLE BAND CASE.

Transmission mode	**Fixed MFN**	**Fixed SFN**	**Portable SFN**	**Mobile SFN**
FFT mode	32 K	32 K	16 K	16 K
Channel Bandwidth	8 MHz	8 MHz	8 MHz	8 MHz
Carrier mode	Extended	Extended	Extended	Extended
Guard interval	1/128 (28 μs)	1/16 (224 μs)	1/8 (224 μs)	1/8 (224 μs)
Modulation	256 QAM	256 QAM	64 QAM	16 QAM
Code rate	2/3	2/3	2/3	2/3
Capacity per multiplex	40.2 Mbit/s	37.0 Mbit/s	26.2 Mbit/s	19,65 Mbit/s

Table II contains the *capacity gains* achieved by utilization of frequency guard intervals, depending on the number of combined channels. The increase that has been obtained is calculated and expressed compared to the extended versions of the single FFT (Fast Fourier Transform) modes, since these modes are planned for future implementation.

TABLE 2. MAIN PARAMETERS AND THE CAPACITY INCREASE DUE TO INCREASE OF NUMBER OF FREQUENCY CHANNELS USED, FOR EXTENDED 8K, 16K AND 32K *FFT* MODES.

FFT mode	**8K extended**	**16K extended**	**32K extended**
Number of carriers K_{total}	6913	13921	27841
Symbol duration T_U	0.000896	0.001792	0.003584
Carrier spacing (Hz)	1116.071	558.0357	279.0179
Gain in % – 2 single bands	1.844351	1.490554	1.492403
Gain in % – 4 single bands	2.766527	2.235831	2.238605
Gain in % – 6 single bands	3.073919	2.484256	2.487339

As the frequency guard band in case of extended 8 K mode is higher than in 16 K or 32 K cases, the resulting gain is higher and it increases with the number of combined channels. The capacity increase obtained by merging of the channels is higher than the gain produced by introducing the extended mode. In general, compared to the normal mode used in DVB-T2 system, the obtained increase goes from 2.6 % for two channels up to the 4.3 % for six channels. According to the Table II, compared to the extended version of 8 K FFT mode, the increase is from 1.8 % for two channels, up to the 3.1 % for six connected channels. The extended version of 16 K to 32 K FFT mode produces 1.5 % for two, up to 2.5 % for six connected channels.

It should be pointed out that OFDM multiplex supports the modes in which the increase of carrier numbers produces the symbol duration increase, as well as an intercarrier spacing decrease. So, different number of FFT carriers should be selected in a way to minimize the expected interference (caused, for example, by the Doppler effect or multiple reflections in free space) and intersymbol interference. Fortunately, this technique supports the single frequency network type, thus eliminating the self-interference.

Let us start with the assumption that most important network parameters have been selected in accordance with the expected network performances. Hence:

– spacing between carriers (which are important for interchannel interference),
– symbol duration (important in case of pulse noise presence),
– guard interval duration (defining the self-interference conditions) and the
– modulation type (which is important for the robustness of the detection process)

have already been selected. So, these parameters under the assumptions explained, even in an attempt to increase the bandwidth in the broadcasting channel, would not be changed. Therefore, there are two possible ways how to increase the bandwidth that will be analysed below.

The first method is based on adjusting of the bandwidth by increasing the FFT size. According to ETSI specification [8], the symbol duration is $T_U = T * FFT$ and the intercarrier spacing is $cs = 1/T_U$. To avoid increasing of the symbol duration and changing of the intercarrier spacing, that are the main principles in DVB-T2, it is necessary to simultaneously decrease elementary period T [8]. In order to increase the bandwidth n times, $FFT_n = FFT * n$ should be taken simultaneously with $T_n = T/n$. Then the symbol duration T_{Un} is same as T_U, as

$$T_{Un} = FFT * T_n = FFT * T = T_U, \tag{1}$$

which means that carrier spacing

$$cs_n = \frac{1}{T_{Un}} = \frac{1}{T_U} = cs, \tag{2}$$

also remains unchanged.

For 8 MHz single channel in DVB-T2 [8], $T = 7/64$ μs is chosen. The bandwidth, *Bw = 8 MHz*, can place the whole number of carriers N_{total}

$$N_{total} = \frac{Bw}{cs} = Bw * T_U = Bw * T * FFT = \frac{7}{8} FFT. \tag{3}$$

The same way, the n times increased bandwidth, *Bwn*, can place the number of carriers

$$N_{n\_total} = \frac{Bwn}{cs_n} = \frac{n * Bw}{cs_n} = n * N_{total}. \tag{4}$$

Both sides of the obtained wideband channel have the same number of unactive OFDM carriers, so the frequency guard bands are the same as in case of single channel in accordance to [8]. All carriers in the available bandwidth are used for data transmission. Consequently, depending on value *n*, the *Capacity gain* is represented in Table II.

Thus the expression for power spectral density $P_k(f)$, of the *OFDM* symbols with: total duration T_s, the maximum number of active subcarriers K, subcarriers frequency indexed by f_k, where k indicates the subcarriers distance (enabling the subcarriers orthogonality) from the *RF* carrier frequency f_c, becomes

$$P_k(f) = \left[\frac{\sin ®(f - f_k)T_s}{®(f - f_k)T_s} \right]^2, \tag{5}$$

where

$$f_k = f_c + \frac{k}{T_U}, \tag{6}$$

where $-\frac{K-1}{2} \le k \le \frac{K-1}{2}$. For the FFT chosen, parameters k, f_k, T_U and T_S are kept unchanged. The only one that is going to be changed is the maximum number of active subcarriers K (N_{total} to N_{n_total}), producing the corresponding changes in the broadcasting channel. As a consequence, the power spectral density (PSD) is changed only in the broadcasting channel.

According to the second solution, orthogonality between the carriers enables the two adjacent channels to use carriers from the frequency guard band. Further, precise carrier spacing between adjacent channels is needed. The spacing must be equal to, or be a multiple of carrier spacing in channels itself. So, the so-called *Side-by-side* combining of single broadcasting channels, create a wide band suitable for a broadband multiplex realization.

Let the carriers occupy the entire frequency range of a broadcasting channel (for example 8 MHz), and let they are indexed by $k \in [K_{\min}; K_{\max}]$. Carriers in a single channel are determined by $K_{\min} = 1$ and $K_{\max} = N_{total}$. If the lower channel is labelled with an index *A*, and the upper one labelled with index *B*, then the spacing between channels is determined by the spacing between carriers $K_{A\max}$ and $K_{B\min}$. Carrier spacing between $K_{A\max}$ and $K_{B\min}$ have to satisfy next relation

$$cs_{AB} = cs_A = cs_B. \tag{7}$$

The fact that number of carriers in 8 MHz broadcasting channel (3) is integer, means that it is enough to tune the RF frequencies with the exact spacing of 8 MHz in order to achieve interchannels orthogonality. For example, if we define the broadband channel central frequency f_C, central frequencies for four single channels merged in the broadband one will be:

$$\begin{cases} f_{c1} = f_c - 3\cdot\left(\dfrac{N_{total}}{2}\right)\cdot cs, \\ f_{c2} = f_c - \left(\dfrac{N_{total}}{2}\right)\cdot cs, \\ f_{c3} = f_c + \left(\dfrac{N_{total}}{2}+1\right)\cdot cs, \\ f_{c4} = f_c + 3\cdot\left(\dfrac{N_{total}}{2}+1\right)\cdot cs, \end{cases} \quad (8)$$

where the N_{total} is defined by (3).

In fact, the orthogonality can be obtained if any of these values is multiplied by n, with $n=1,2,3,...$ This means that, in principle, orthogonality will be enabled even if the adjacent channels do not use the same FFT mode, since this combining introduces additional flexibility, taking into account changes of the symbols duration T_U and guard interval T_G and receiver's operation complexity. In this paper, we will assume that the adjacent side-by-side channels use the same FFT mode. The carrier allocation is the same as one used in a common FFT block (in previous model) with n times lower sampling rate.

Parameters in the single broadband channel configuration planned for future implementation, according to the type of network and the transmission conditions, were kept in each method. Both analysis and simulation results, given in Chapter III, will show the potential impact on the transmission quality.

In case of increased number of FFT carrier's calculation complexity slightly increase. Theoretically, the intercarrier spacing increase [6], [8]. This enabled the extended mode implementation which is a part of DVB-T2 standard. In our case, the FFT block increased, though the intercarrier spacing was not changed. Hence, by applying this technique the interference decreases.

Nevertheless, it should be noted that the model based on increasing of the IFFT and FFT carriers, has administrative limitations. According to the DVB-T2, standard maximal FFT size is 32 K, and only for the purposes of transmitter identification [13], it uses a 64 K size. *Side-by-side* model represents technological challenge with the requirement of maintaining carriers' orthogonality in both the frequency and time domain.

From the implementation standpoint, both methods require new terminal equipment. Theoretically, both could be implemented in the transient period, by using the existing equipment. In that case, additional activation of FFT carriers would be used for advanced services. The existing receivers would offer standard, and new ones could be used for services with enhanced quality. This will enable capacity gain, only. However, each of the services could be transmitted only within a single channel, thereby producing the unused capacity in each of the connected channels. In this way, the main purpose of merging of the channels, i.e. the broadband capacity for traffic utilization and selective frequency, would not be achieved.

III. SIMULATION RESULTS

A. *The FFT Size Increase*

Table I contains the FFT mode, carrier mode, guard interval and modulation parameters that can be applied in DVB-T2 networks in the near future. As noted above, one way of taking multiple single channels bandwidth, while keeping the parameters of a particular network configuration unchanged as much as possible, is to decrease the elementary period. For instance, in the Matlab simulations performed here, we use parameters for Portable SFN (Single Frequency Network) network.

The elementary period for 8 MHz channel, which is 7/64 µs, decreases by two and four times. Consequently, the IFFT and FFT blocks' sizes (16384) increase twice and four times. Carrier frequency spacing (~558 Hz), symbol duration (1792 µs), as well as the guard interval duration (224 µs) remain unchanged. Two and four times wider bandwidth has been occupied. Number of carriers has been defined according to (3) and (4), and reduced for carrier positions belonging to the left and right frequency guard intervals at the channel ends (1232 and 1231 carrier positions respectively), planned for 16 K single channel extended mode. The increase of number of carriers for the 16 K extended mode is represented as *capacity gain* and expressed in percentage, Table II.

Power spectral density (PSD) plots, calculated for 16 K FFT extended mode and the single 8 MHz channel, are presented in upper part of Fig. 1. Simulations presented in the lower part of Fig. 1 have been performed for 32 MHz broadband channel containing 64 FFT block. Portable SFN type network Based on parameters from Table I has been assumed. The only difference in the two diagrams is frequency bandwidth (all other performances are identical).

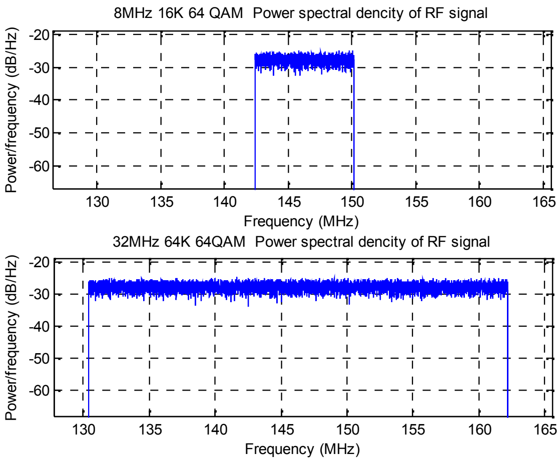

Fig. 1. PSDs for single and four FFT multiplied channels.

Figure 2 contains the bit error rate (BER) simulation results for 16 K FFT extended single mode and four combined channels (64 K FFT), given for the portable SFN case in presence of additive white Gaussian noise (AWGN). The two curves are identical.

According to the DVB-T2, the maximum FFT size can be 32 K, and for specific testing of SFN network maximum is 64 K. FFT size is the limiting parameter. Therefore, the applications in which wide frequency spacing is necessary cannot be modelled by including more than two channels.

During the steady state transmission mode, the frequency spacing is not critical as a result of the carrier orthogonality. On the one hand, the 32 K FFT mode is planned for both MFN *(Multi Frequency Network)*, as well as SFN fixed network types. On the other hand, portable and mobile transmission modes are sensitive to Doppler effect, so the 16 K and 8 K FFTs are usually planned. In that case, four or eight channels can be connected via the 64 K FFT block. Note that more than 64 K carriers can be expected in the future.

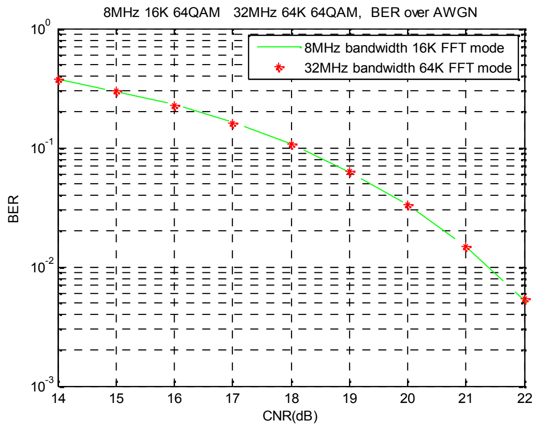

Fig. 2. BERs for single and four FFT multiplied channels.

B. Merging of the Adjacent Channels

The capacity of the side-by-side type is the same as that in case of FFT blocks number increase. Actually, in the second case *n* connected channels have *n*-1 active carriers less than in the former one, as each channel has its own RF carrier. The only difference that are worth mentioning, among the gains in Table II, could be with a rather good approximation kept as valuable.

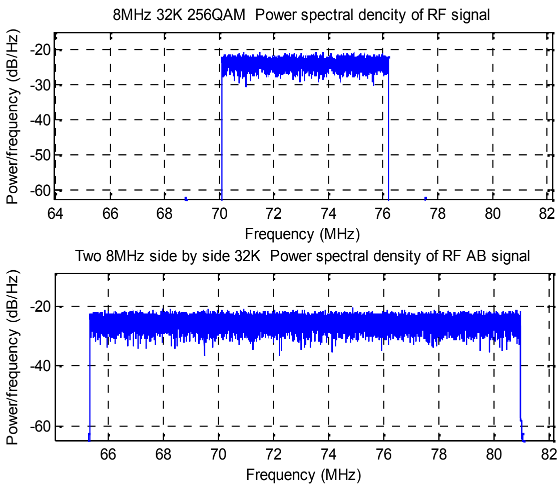

Fig. 3. PSDs for single and two side-by-side channels.

DVB standards define the integer number of carrier spacing in a broadcast channel, see (3). For instance, the 8 MHz channel contains exactly 28672 carriers (32 K FFT mode). Further, it is enough to fit the RF frequencies into 8 MHz bandwidth, and the highest carrier from a previous channel will differ from the lowest carrier of next channel exactly *cs*, i.e. for the spacing between carriers.

The *Matlab* simulation has been performed for two single channels, relative to a RF central frequency f_C, [8]. The simulations have been performed for the *MFN* fixed reception, Table I. Combined channels have the same configuration parameters as a single one. However, on the right side of lower channel the 2464 carriers, and left side of upper channel the 2463 carrier positions in guard band between channels are used.

Power spectral densities for single channel and two side-by-side channels are presented in Fig. 3. PSD of side-by-side combined channels is slightly higher, because of the absence of guard filters between channels and more carriers used for data transport. This figure gives the results for BER (Bit Error Rate) with four side-by-side connected channels in presence of AWGN. BER is calculated for each channel, as well as for the common broadband channel. The simulation has been performed for 16 K FFT portable mode. The inner channels have maximum capacity of 14 335 carriers. This value is in accordance with relation (3) reduced by 1 (produced by the RF channel carrier location). Left and right channels have guard bands, so the number of subcarriers is reduced by 1232/1231, respectively, in accordance with DVB-T2 recommendations for extended 16 K mode. BER for particular channels in a group, as well as BER for the common broadband channel are identical.

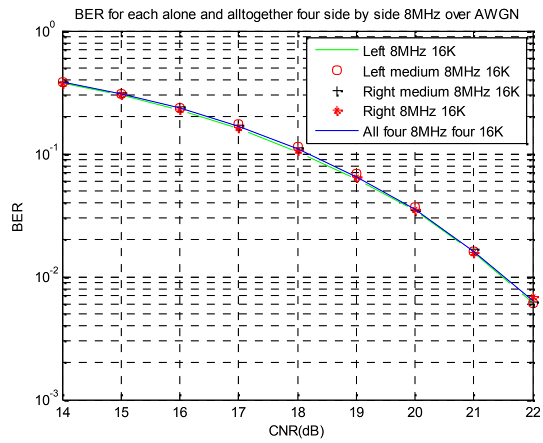

Fig. 4. BERs for four *side-by-side* combined channels separately and for a broadband channel.

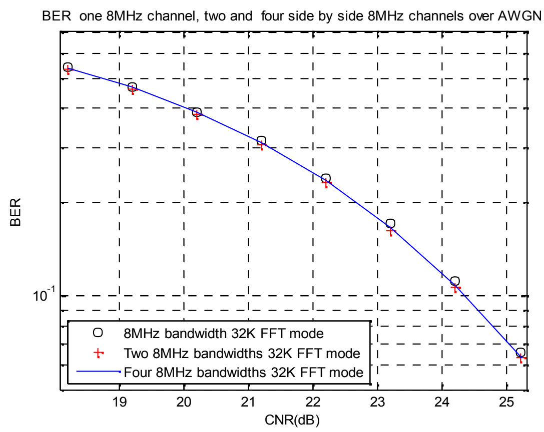

Fig. 5. BERs for single, two and four FFT side-by-side channels.

Performed simulation for BER in case of single mode case, for two and four aggregated channels, in MFN fixed reception case and in presence of AWGN are presented in

Fig. 5. We should point out that curves are identical.

Simulations for two models in case of *portable* SFN reception, based on 16 K *side-by-side* aggregated channels and multiplied 64 K FFT broadband channel are presented in Fig. 6. The conclusion is that power spectral density for side-by-side case is higher. BER calculations presented in Fig. 7 confirm identical results for all of the channels.

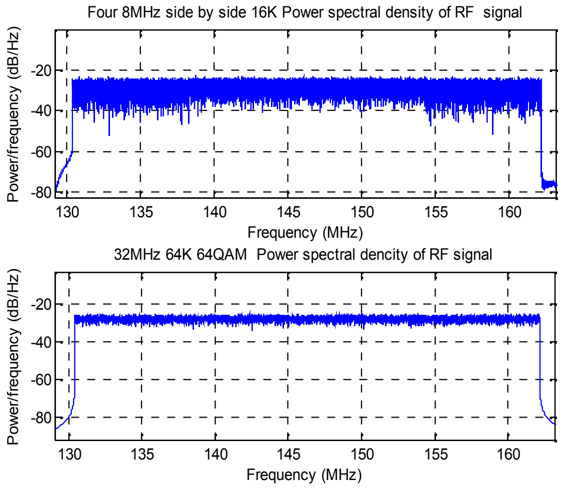

Fig. 6. PSDs for *side-by-side* and *FFT* multiplied channels.

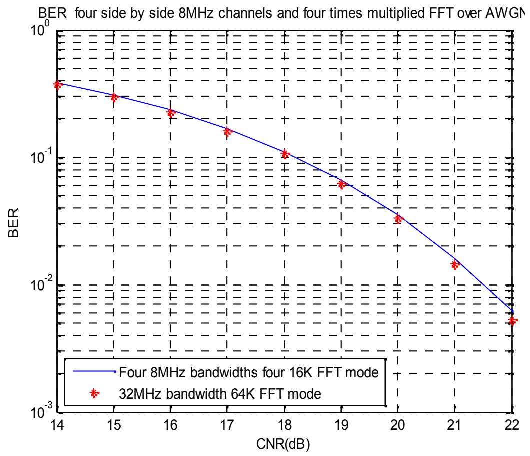

Fig. 7. BERs for four side-by-side and FFT multiplied channels.

It should be noted that deviation from orthogonality among the carriers, in case of increased FFT blocks has not been noticed. Namely, the FFT blocks are huge enough, so the interchannel interference compare to noise effects within the channel is small enough.

IV. Conclusions

The OFDM technique enables the extension of the orthogonality multicarrier principle from one frequency channel to a group of adjacent channels. By channel aggregation at the physical level, broadband channels, being necessary for introduction of high definition, and thus high capacity, digital television programmes can be realized.

This paper proposes two ways of combining the RF channels that have not been analysed in DVB-T2 transmission. The proposed broadband capacity for both models is higher than in case of TFS technique of combining at the MAC level, as they use the complete dedicated frequency bandwidth. On the other hand, the TFS technique enables aggregation of the non-adjacent channels.

Simulation results for both of the proposed models confirm that BER value has not been changed compared to the standard single band RF channel.

Integration performed by merging of the channels is suitable for all types of transmission, but it requires precise time and frequency channel synchronization. Maximum dimension of the FFT block limits the integration which could be done by the FFT block increase. So, it becomes suitable for portable and mobile reception.

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