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Integration of a GFDM Secondary System in an OFDM Primary System

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Abstract: Concepts of cognitive radio are yet in an early stage of development. They aim at improving the efficiency of spectrum utilization by exploiting locally and temporally vacant parts of the spectrum. When hierarchical spectrum access is considered, secondary users are authorized to use spectrum white spaces on a non-interfering basis, where minimal impact on the primary systems has to be ensured. GFDM is a digital multi-carrier transceiver concept that employs pulse shaping filters to provide control over the transmitted signal's spectral properties, a cyclic prefix that enables an efficient FFT-based frequency domain equalization scheme as well as tail biting as a way to make the prefix independent of the filter length.

In this paper, two setups of uncoded AWGN transmission are analyzed through simulation. Both setups have in common that an OFDM primary system is overlaid by a secondary system. For that purpose, resources are made free artificially. First, a non-synchronized OFDM system is inserted into the white space. Then, the results are compared to the case when the secondary system operates with the GFDM scheme. Both setups are reviewed under the aspect of bit error performance in dependence of guard bands and various pulse shaping filter parameters. Conclusions for the primary and secondary system are drawn.

Keywords: OFDM, GFDM, Multi-Carrier Systems, Software Defined Radio, Hierarchical Spectrum Access, Vertical Spectrum Sharing

1. Introduction

The concept of variable transmit and receive parameters in combination with smart spectrum sensing is applied in cognitive radio (CR) systems. Such technology is still at an early stage of development and formulates a promising approach to enhance the efficiency of spectrum utilization by today's wireless communications systems. The unlicensed TV white spaces from the Digital Dividend offer a scenario, where temporally or locally vacant frequency regions can be exploited on a non-interfering basis [1], to achieve optimal use of the spectrum. In another possible setup, a fraction of the resources of a licensed system, e.g. a mobile network, could be temporally assigned for secondary use. Then, minimal impact from the secondary system on the primary system is crucial. The other way around, secondary users need to be able to handle interference that might be received.

Despite numerous advantages, the well-known OFDM approach has proven unfavorable in this context because of its spectral properties in its conventional form. This is mainly due to bad side lobe attenuation of cardinal sine (sinc) pulses in frequency domain, which makes additional measures like side lobe suppression through filters and/or the use of guard bands necessary. Two approaches aiming to address the issue

of efficient spectrum utilization are the Generalized Frequency Division Multiplexing (GFDM) scheme [2] as well as Filter-Bank Multi-Carrier (FBMC) technique [3,4]. While latter has been extensively studied in the scope of the PHYDYAS project [5], the GFDM approach will be discussed in this paper.

GFDM is a digital multi-carrier transceiver concept that provides the means to contain out of band radiation through pulse shaping with adjustable matched filters. For this purpose, filters with the raised cosine (RC) and root-raised cosine (RRC) shape have proven suitable properties. However, sharp edges in frequency domain response have to be traded for a greater spread of the signal in time domain. This is especially an issue, when an efficient FFT based block equalization is desired. In that case, the transmit and the receive filter have to be included in the cyclic prefix (CP). However, from the information theory point of view, CP is pure redundancy, while from energy efficiency point of view it increases the power requirement per bit. For these reasons it should be kept minimal. Tail biting (TB) filters allow to keep the length of the CP the same as in OFDM, while still having the means for spectral shaping.

In the next section, a system model is defined for GFDM. Subsequently, two setups of spectrum overlay are introduced and the simulation results are discussed. Conclusions and outlook follow in the last section.

2. Generalized Frequency Division Multiplexing

Let $d[k, m] \in \mathbb{C}$ be an information symbol. The $K \times M$ matrix

$$\underline{\underline{D}} = \begin{pmatrix} d[0, 0] & \dots & d[0, M-1] \\ \vdots & \ddots & \vdots \\ d[K-1, 0] & \dots & d[K-1, M-1] \end{pmatrix} \quad (1)$$

will be addressed as an information block. Therein, $k = 0, \dots, K-1$ shall denote a subcarrier while $m = 0, \dots, M-1$ refers to a time slot. With the intention to distribute the data symbols in time and frequency, the discrete impulse response of the pulse shaping transmit filter $g[n]$ needs to be movable in those dimensions. Mathematically, the expression

$$g[n - mN]e^{j2\pi\frac{kn}{N}} \quad (2)$$

accounts for these shifts, where given a sampling time T_S , the length of one symbol in time is NT_S and $\frac{1}{NT_S}$ denotes the spacing of two neighboring subcarriers in frequency domain. The transmit signal

$$x[n] = \sum_{m=0}^{M-1} \sum_{k=0}^{K-1} d[k, m]g[n - mN]e^{j2\pi\frac{kn}{N}}, \quad 0 \leq n \leq NM. \quad (3)$$

results for one block from the superposition of all shifted impulse responses that are weighted with the respective information symbols $d[k, m]$

In order to be able to perform equalization at the receiver in frequency domain, $x[n]$ is prefixed with a cyclic extension and yields $\tilde{x}[n]$, which is the signal that is going to be sent through the radio channel. The received signal is given by

$$\tilde{y}[n] = \tilde{x}[n] * h[n] + n[n], \quad (4)$$

where $*$ denotes convolution with respect to n . Removing the CP, provides $y[n]$ and assuming the channel response $h[n]$, is known perfectly at the receiver, one block of $K \times M$ information symbols is equalized by

$$\bar{y}[n] = \mathcal{IDFT} \left[\frac{\mathcal{DFT}[y[n]]}{\mathcal{DFT}[h[n]]} \right], \quad (5)$$

with $\mathcal{DFT}[\cdot]$ being the discrete Fourier transform and $\mathcal{IDFT}[\cdot]$ denoting its inverse. However, in order to ensure the cyclic structure of $y[n]$ that is a prerequisite to (5), the cyclic prefix of the system requires to account for the channel, as well as the transmit and receive filter.

Assuming T_h denotes the length of the channel impulse response in time domain and T_g the length of the matched filter, then the cyclic prefix needs to be of length $T_{CP} = T_g + T_h + T_g$ to prevent interference between subsequent blocks and to make frequency domain equalization (FDE) possible. The resulting decrease of the data rate is of factor $\frac{T_b}{T_b + T_{cp}}$ and the increase of the power required to transmit one bit of information is its reciprocal for $T_b = MT_d$. Clearly, from this point of view it is desirable to keep T_{CP} as short as possible, while at the same time for spectral shaping large values for T_g are favorable. Tail biting [2] has been introduced as one way to reduce the length of the CP without cutting short on the pulse shaping filter length. It is based on the idea of preserving a circular structure within each transmitted block, which allows to keep the length of the CP independent from the length of the transmit filter.

While in [2], tail biting is only used on the transmitter side, this paper applies the concept also to the receiver. Therefor each subcarrier is received and processed using the matched filter $g[n]$ according to

$$\bar{y}_k[n] = \bar{y}[n] e^{-j2\pi \frac{kn}{N}} \circledast g[n], \quad (6)$$

with a circular convolution \circledast with respect to n . By keeping every N th sample, the information symbols $\bar{d}[k, m] = \bar{y}_k[mN]$ are retrieved and passed to the detector.

The complete GFDM system model is depicted in Figure 1.

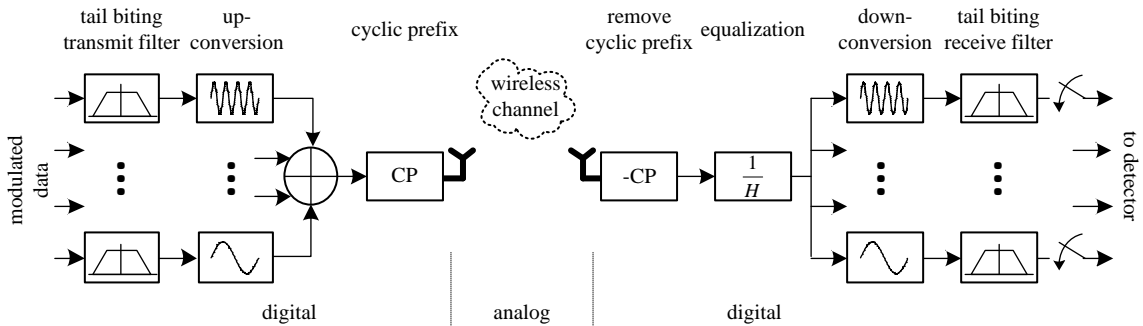


Figure 1: GFDM baseband transceiver model.

3. Simulation Setups

3.1 Spectrum Overlay

Spectrum overlay is a mode of hierarchical spectrum access, that requires to distinguish primary and secondary users [6]. While the primary system typically has the highest priority in a given frequency range, this policy imposes constraints to communication activities of secondary users regarding time and geographic location, such that the primary user is faced with minimal interference. The goal is to increase spectral efficiency by allowing overlay systems to use parts of the spectrum that are temporally and locally not in use. In order to identify to what extent GFDM is suitable as a secondary system and how it performs compared to an OFDM secondary system, two setups are analyzed in the following sections.

In the considered setups, the primary system employs an OFDM scheme that is based on IEEE 802.11a as shown in Table 1. Within the bandwidth of the transmitted signal of the primary system, a white space is artificially created by replacing the data symbols on a given number of subsequent subcarriers with a sequence of zeros.

3.2 Setup 1: OFDM secondary system

The first step is to evaluate how conventional OFDM satisfies the requirements of a secondary system. For doing so, the secondary system is designed to match the white space of the primary system. Thereby, a given number of subcarriers are left silent, to serve as a guard band and mitigate the impact of spectral leakage.

Both systems are designed with the same set of parameters regarding sampling frequency and subcarrier spacing. Additionally, a mutual frequency offset of half a subcarrier distance is introduced. This ensures that both OFDM systems are not orthogonal and allows the consideration of two systems that are independent. On the other hand, if both systems are perfectly synchronized, they do not interfere.

3.3 Setup 2: GFDM secondary system

In the second setup, the white space is occupied by a GFDM signal and the primary and secondary system are not orthogonal. The GFDM system requires additional parameters like pulse shaping filter type, roll-off factor, block size and filter length to be specified (Table 1), which exceed the scope of traditional OFDM.

4. Results

As a basis for performance evaluation, numerical simulations of bit error rates (BER) of uncoded transmission in additive white Gaussian noise (AWGN) and Rayleigh channels are chosen. The signals are considered in baseband and the total systems' bandwidth is divided into 64 subcarriers from which 48 are assigned to the primary system, while the remaining 16 are granted to the secondary system. If guard bands are employed, then they are deducted from the primary system.

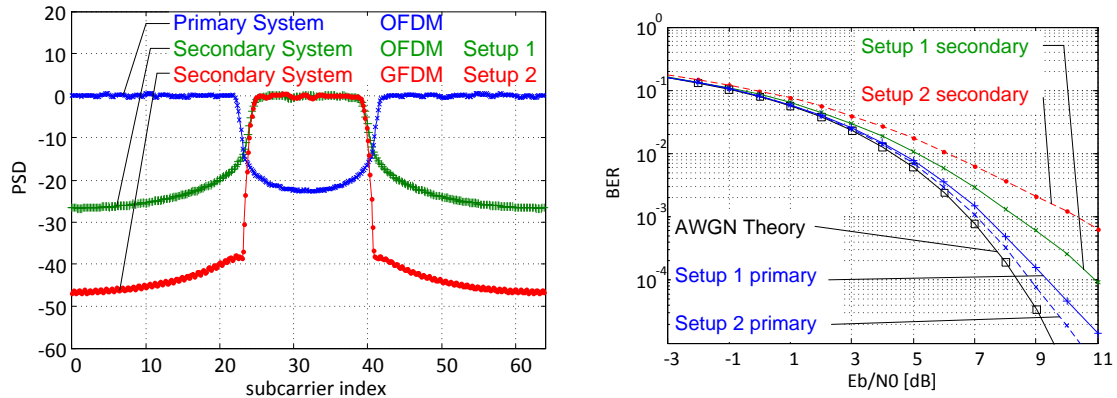
4.1 Setup 1 vs. Setup 2

In Figure 2, the OFDM and GFDM secondary system are compared regarding their impact on the BER of the primary OFDM system. The results show, that for high SNR and with the given set of parameters, the GFDM secondary system produces less interference to the primary system than the asynchronous OFDM system. This

Parameter	Variable	Value (OFDM)	Value (GFDM)
Modulation scheme		QPSK	
Samples per symbol	N	64	
Total number of subcarriers	K	64	
Block size	M	1	$M > 1$
Filter length	L	1	$1 < L \leq M$
FFT size	N_{FFT}	64	$M \cdot 64$
Sampling frequency	f_s	20MHz	
Subcarrier distance	Δf_k	312, 5kHz	
Symbol duration	T_d	$3.2\mu s$	
Block duration	T_b	$3.2\mu s$	$M \cdot T_d$
Cyclic prefix duration	T_{CP}	$0.8\mu s$	
Filter duration	T_g	$3.2\mu s$	$L \cdot T_d$
Filter type (time domain)		RECT	RC, RRC
Roll-off factor	α		$0 \dots 1$

Table 1: Primary and secondary system parameters based on IEEE 802.11a.

observation appears natural, as the pulse shaping filters that are introduced by GFDM have the purpose of creating a signal with small spread in frequency domain (Figure 2(a)). The results further show, that the above advantage to the primary system has to be traded for an increase in error rate of the secondary system. This however complies with the spectrum overlay policy.



(a) Power spectral density (PSD) of primary and secondary systems.

(b) Comparison of Setup 1 and Setup 2.

Figure 2: Power spectral density and bit error rates in Setup 1 and Setup 2 in AWGN, where the GFDM system operates with an RC filter.

4.2 Guard Bands

Another relevant aspect that directly influences the performance of both systems, is the size of guard bands between primary and secondary system. Figure 3 shows the error rates of the primary system from Setup 1 and Setup 2 in dependence of the number of subcarriers that are turned silent in between. Again, the advantageous spectral properties of the pulse shaped GFDM signal lead to an overall equal or better

performance. This is especially the case, when the results with guards bands of one or two subcarriers are compared. As a direct result, it can be constituted that in Setup 2, guard bands of size $B_G > 1 \cdot B_S$ do not contribute a significant improvement, which is positive regarding spectral efficiency. Another interesting finding is the fact, that in the case of guard bands not being present, GFDM actually produces stronger interference to the primary system than OFDM.

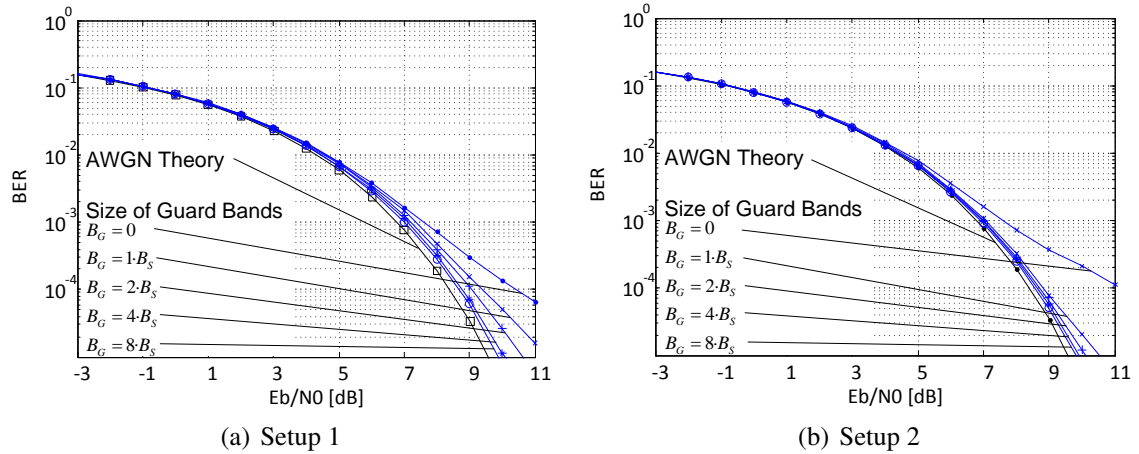


Figure 3: Comparison of the primary system's error rates under varying size of guard bands B_G (in multiples of the subcarrier distance B_S). The GFDM system operates with an RC filter.

4.3 Pulse Shaping Filter

GFDM offers a degree of freedom by allowing to choose its pulse shaping filter. In Figure 4, the impact of raised-cosine (RC) filtering is compared with root raised-cosine (RRC) filtering. The graphs show, that the primary system is faced with less interference, when an RC matched filter is used in the GFDM secondary system. The reason for this can be found in the better spectral properties of the RC pulse compared to the RRC, which allows to contain the secondary system's signal within the white space.

Further, the roll-off factor α directly influences the frequency localization of RC/RRC-based pulses. From Figure 4(a) it can be concluded, that reducing the value of this parameter also protects the primary system. But this measure also leads to weaker side lobe attenuation in time domain, which might make a trade off with the filter's length necessary. However, a guard band of one subcarrier allows the use of short filters with a high roll-off factor. According to Figure 4(b), this parameter has no significant impact on the primary system's error rates. This is because the RC has sharper edges in frequency domain compared to the RRC.

4.4 Tail Biting

In this section, the primary system is considered silent and the secondary systems from Setup 1 and Setup 2 are compared regarding the performance degradation that originates from the cyclic prefix. For this purpose, a Rayleigh fading channel with exponential power-delay-profile is assumed and in Figure 5 error rates for various configurations are compared. To illustrate the advantage of tail biting, a long ($L = 11$) and

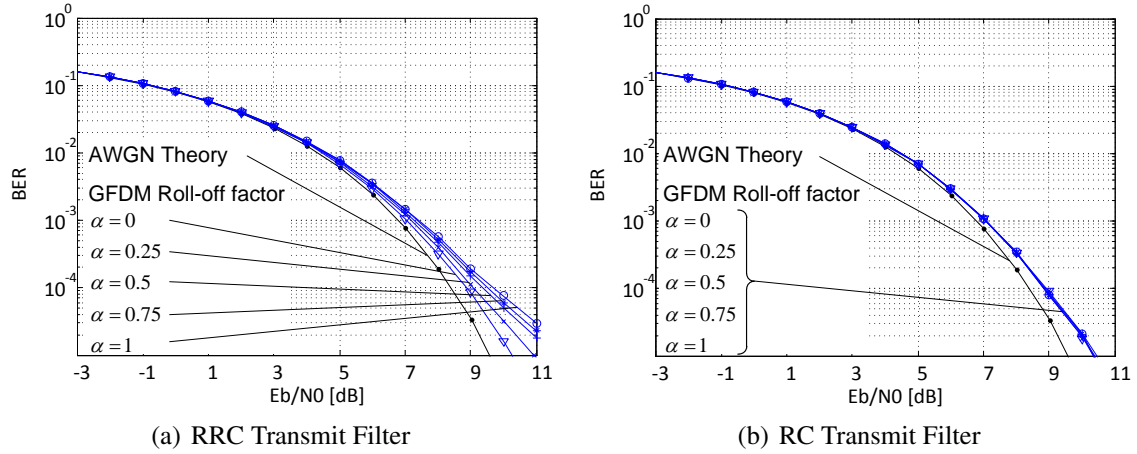


Figure 4: Primary system BER depending on GFDM secondary system pulse shaping filter with different roll-off factors. One subcarrier is omitted as guard band.

a short ($L = 1$) filter are compared. Without tail biting, the filter has to be included twice in the cyclic prefix in order to maintain the circular structure of the transmitted signal and allow for equalization according to (5). However, this directly leads to a shift of the error rate curves to the right (Figure 5(b)), which increases with growing length of the prefix. On the other hand, long filters allow better spectral shaping and therefore, the advantage of tail biting is that the length of the CP becomes independent from the length of the filters. It becomes especially efficient when sharp filter edges and long filters are required.

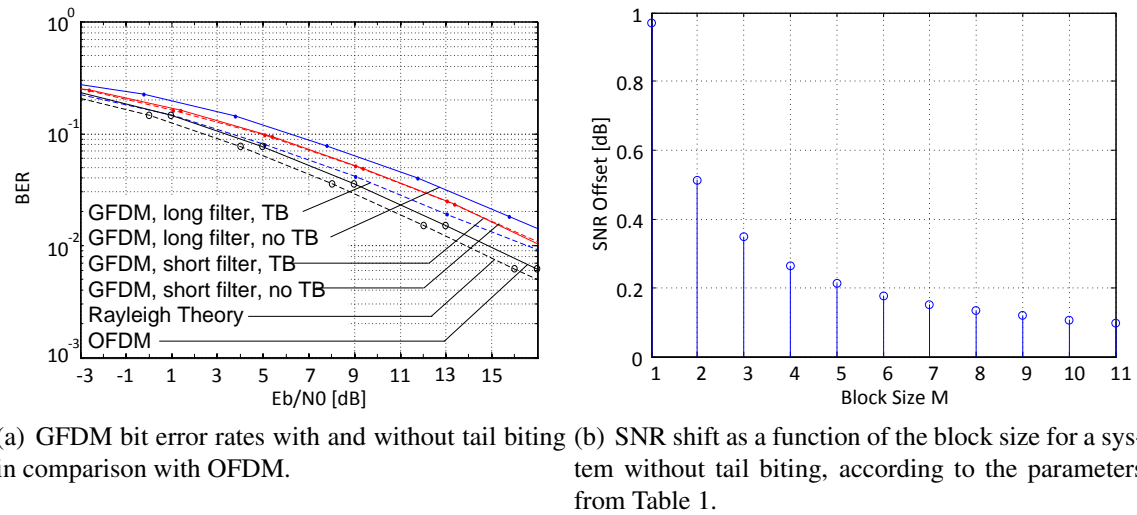


Figure 5: The impact of tail biting on a GFDM system's performance.

5. Conclusions

This paper has shown that in a spectrum overlay scenario where the main goal is to protect the primary system, better results can be achieved with a GFDM secondary system compared to an OFDM secondary system. However, this advantage is traded

for a higher error rate in the secondary system. In the case of GFDM, leaving just one subcarrier silent as a guard band provides reasonable protection. For pulse shaping, choosing raised-cosine filters over root raised-cosine is advantageous and a small roll-off factor can additionally protect the primary system. With tail biting, the length of the cyclic prefix is kept independent from the filter length and this technique allows to bring the performance of GFDM closer to OFDM.

Based on the findings from this paper, various questions unfold. While the results in this paper were obtained from simulations of simple AWGN and Rayleigh channels, further investigation regarding the impact of time and frequency selectivity is necessary. This is especially relevant, as GFDM employs a larger block size per cyclic prefix compared to OFDM and this might impact the equalization. Also, in some areas of communication, the systems are subject to limitations regarding power consumption and complexity. In order to explore if GFDM is applicable in those, studies and optimization regarding those aspects are necessary. Potential for improvement can be also seen in the gap between the performance of the OFDM and GFDM secondary systems, which could be approached with iterative equalization as well as studies on the vulnerability to carrier frequency offset, which is an issue in OFDM. Also, an in depth comparison with FBMC is an interesting study to be made.

References

- [1] "Technical considerations regarding harmonisation options for the Digital Dividend," tech. rep., European Conference of Postal and Telecommunications Administrations (CEPT), 2008.
- [2] G. Fettweis, M. Krondorf, and S. Bittner, "GFDM - Generalized Frequency Division Multiplexing," in *Proc. IEEE 69th Vehicular Technology Conf. VTC Spring 2009*, pp. 1–4, 2009.
- [3] T. Ihalainen, T. Stitz, M. Rinne, and M. Renfors, "Channel equalization in filter bank based multicarrier modulation for wireless communications," in *EURASIP Journal on Applied Signal Processing*, vol. 2007, pp. 140–140, 2007.
- [4] T. Ihalainen, A. Viholainen, and M. Renfors, "On spectrally efficient multiplexing in cognitive radio systems," in *Proc. 3rd Int. Symp. Wireless Pervasive Computing ISWPC 2008*, pp. 675–679, 2008.
- [5] "PHYDYAS Project Deliverables available at <http://www.ict-phydyas.org/delivrables>."
- [6] Q. Zhao and A. Swami, "A Survey of Dynamic Spectrum Access: Signal Processing and Networking Perspectives," in *Proc. IEEE Int. Conf. Acoustics, Speech and Signal Processing ICASSP 2007*, vol. 4, 2007.