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FBMC Modulation as a Possible Co-existence Facilitator for LTE Mobile Networks in 800 MHz Band

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ABSTRACT

This paper proposes filter bank multicarrier transmission technique (FBMC) as means to minimize adjacent band interference from long-term evolution (LTE) user equipment operating in the frequency band 792−862 MHz to short-range devices in the band 863−870 MHz. Main FBMC benefits are presented through comparison with reference case of orthogonal frequency-division multiplexing. The key advantage of FBMC modulation in reported electromagnetic compatibility studies is derived from its low out-of-band leakage, which guarantees minimum harmful interference level between stations using adjacent channels. The problem was evaluated in two aspects: first, theoretical analysis using minimum coupling loss method, complemented with statistical Monte-Carlo analysis (using SEAMCAT software tool) in order to verify results obtained in theoretical approach.

Keywords:
Interchannel interference, Electromagnetic compatibility, Spectral analysis, 4G mobile communication, Monte Carlo methods.

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1. INTRODUCTION

In today's world, there is a growing mobile technology development, thus increasing demand for radio frequencies to mobile services. Mobile technology is spreading at staggering rates, but network operators are often faced with the problem of spectrum scarcity [1]. To address this challenge, the newly formed 800 MHz band was designated for mobile services. One of the main problems for deploying mobile services in 800 MHz band is influence of out-of-band (OOB) emission to low-power short-range devices (SRDs) operating in adjacent band 863−870 MHz [2], which include intruder alarms, cordless headphones, radio microphones, smart utility meters, telemetry, etc.

The effect of OOB emission of mobile services to SRD operation has been actively examined in working group SE24 of electronic communications committee (ECC) in European context [3]. This paper builds on our earlier work presented in SE24 working group on the subject [4,5]. Filter bank multicarrier transmission technique (FBMC) is considered to be a possible solution in minimizing adjacent band interference from long-term evolution (LTE) user equipment (UE), since it offers significant improvements in spectral and transmission domains over orthogonal frequency-division multiplexing (OFDM) − better frequency selectivity, spectrum efficiency, no cyclic prefix, offset quadrature amplitude modulation (OQAM) modulation, etc. [6−10].

In this paper, we investigate a possible reduction of interference using FBMC transmission technique in 800 MHz band coexistence scenarios. A study of critical scenario of LTE UE vs. SRD coexistence is included, in which an LTE UE device is in the same room with an SRD unit. Situation was modelled using SEAMCAT software, employing statistical Monte-Carlo analysis, as well as theoretical compatibility analysis using minimum coupling loss (MCL) method.

2. OFDM AND FBMC PHYSICAL LAYER

The main idea of OFDM is channel separation into the finite number of sub-channels. Sequential data stream is divided into parallel data blocks and each sub-channel transmits only a part of original information (Figure 1). As shown in Figure 1, initial data signal passes through digital filters $h(t)$ with rectangular impulse response, and then to each input signal is applied inverse fast Fourier transform (iFFT) function, summation operation, modulation, etc.

Unlike OFDM, FBMC uses a well-localized filter $h(t)$ such that it requires orthogonality for the neighbouring sub-carriers only. There are different concepts of OFDM and FBMC: OFDM exploits given frequency bandwidth with a number of carriers, while FBMC divides this given bandwidth into a number of sub-channels. In order in the same time to guarantee the orthogonality of sub-channels and the maximum bit rate, OQAM

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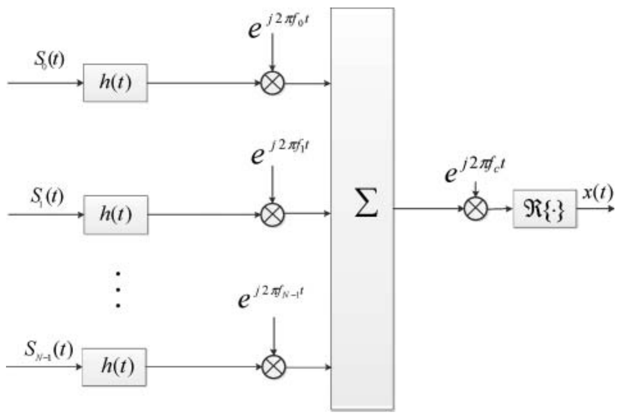

Figure 1: OFDM structure.

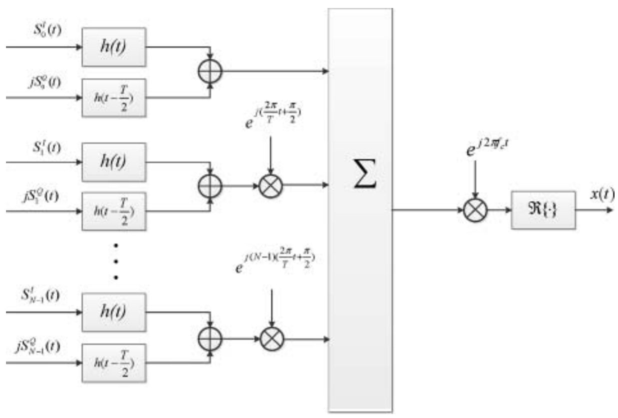

Figure 2: FBMC structure [11].

modulation has to be used instead of quadrature amplitude modulation on each sub-channel [10−13]. A combination of filter banks and OQAM leads to the maximum bit rate, whereas there is no need for a guard time or cyclic prefix as in OFDM. The principle of FBMC operation is presented in Figure 2 [11−13].

Meanwhile, the formation of sub-carrier channels in FBMC is performed slightly different. In this case, real and imaginary parts of $S_k[n]$ are separated and shifted by $T/2$ (according to OQAM), while the spacing between the adjacent sub-carriers is $1/T$. Since FBMC is an evolution of OFDM, FBMC systems are likely to coexist with those of OFDM. Compatibility covers sampling frequency, sub-channel spacing, FFT parameters, and other generalities of multi carrier systems [11−13].

3. OFDM AND FBMC SPECTRA COMPARISON

Since the main problem in 800 MHz mobile networks is OOB emission of OFDM sub-carriers, FBMC transmission technique is considered to be a promising solution

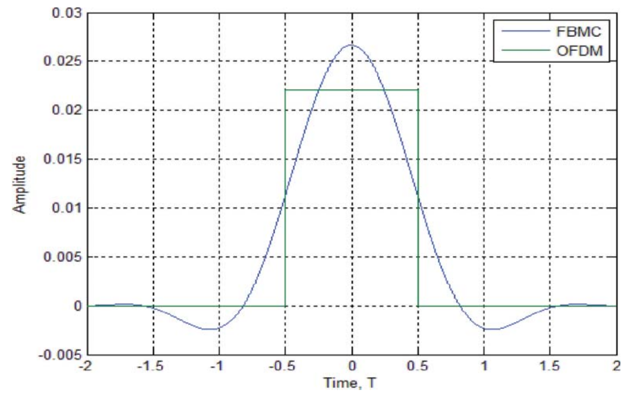

Figure 3: Time representation of OFDM rectangular window and FBMC cardinal sine function filter impulse responses.

to facilitate this problem. Its differences over OFDM are revealed in Figures 3 and 4.

Impulse response of filters in FBMC continues through a number of symbols what makes its frequency response narrower. Consequently, the spectrum of each sub-carrier covers only a small part of the adjacent sub-carrier, what allows effectively exploit available spectrum and meet the demands of traffic management and multi-user systems. However, it should be noted that this technique requires long data blocks, what causes long start-up time, whereas channel estimation and equalization are much more complex than these in OFDM [10].

As can be seen in Figure 4, the side lobs in FBMC are lower and narrower than these in OFDM due to the different patterns of filters in OFDM and FBMC. The analysis of these two systems was carried out by using standard LTE channel, the parameters of which are presented in Table 1.

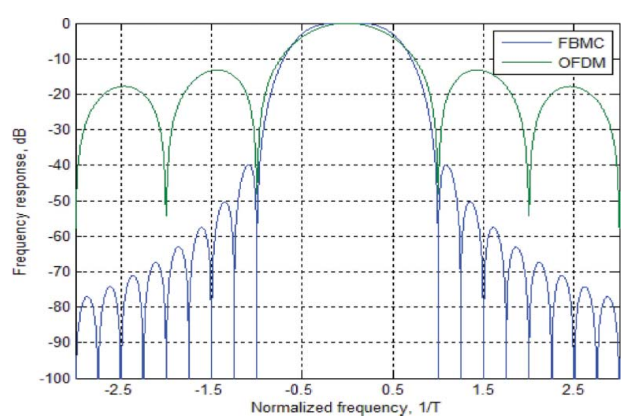

Figure 4: Frequency representation of OFDM rectangular window and FBMC filter response.

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Table 1: LTE channel parameters [14]

Channel bandwidth (MHz)	5	10	15	20
Frame duration (ms)		10		
Sub-frame duration (ms)		1		
Sub-carrier spacing (kHz)		15		
Sampling frequency (MHz)	7.68	15.36	23.04	30.72
FFT size	512	1024	1536	2048
Occupied sub-carriers (inc. DC sub-carrier)	301	601	901	1201
Occupied channel bandwidth (MHz)	4.515	9.015	13.515	18.015

It was simulated the worst case scenario, which assumes that one user occupies the whole channel and emits maximum allowed power by 3GPP recommendation. Figure 5 shows that OOB emission level in FBMC is approximately 20 dB less than that in OFDM, which

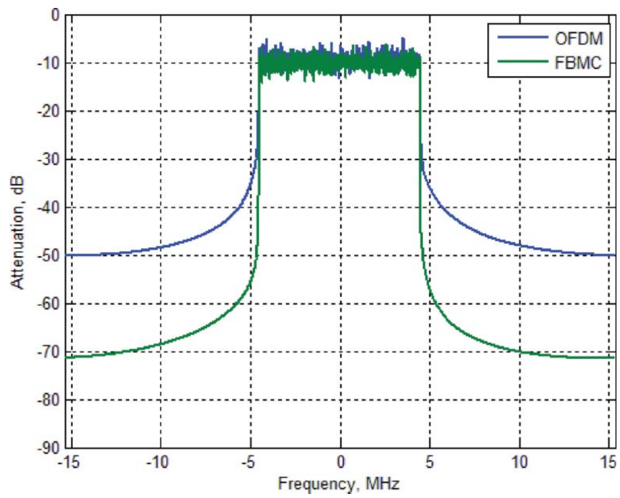

Figure 5: OFDM and FBMC spectrum comparison (10 MHz channel).

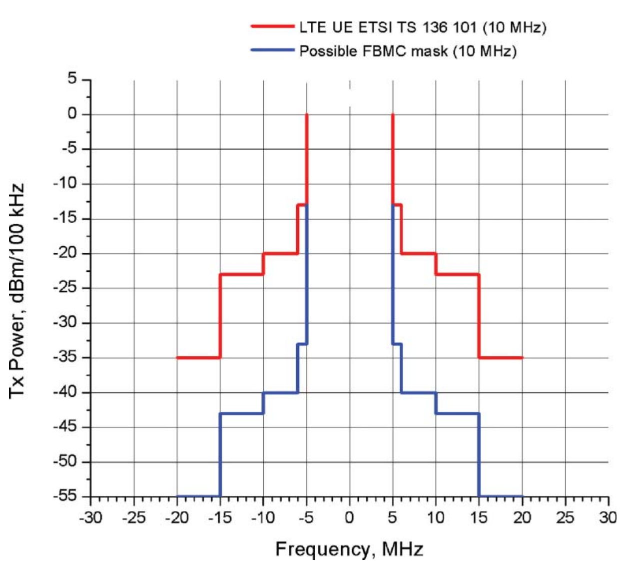

Figure 6: LTE emission mask based on TS 136 101 and possible FMBC emission mask (RBW 100 kHz).

Table 2: LTE frequency use in 800 MHZ band

Band (MHz)	Bandwidth (MHz)	Downlink (MHz)		Uplink (MHz)		Duplex spacing (MHz)
		Low	High	Low	High	
800	30	791	821	832	862	11

occurs due to the different physical layer mechanisms, which were presented in previous section. Figure 6 represents this gain by comparing possible FBMC spectrum emission mask with 3GPP standard. This finding will be used in the next sections.

4. ELECTROMAGNETIC COMPATIBILITY STUDIES: LTE UE (USING OFDM/FBMC) vs. SHORT-RANGE DEVICES in 800 MHZ BAND

We focused on most critical scenario of LTE vs. SRD coexistence, in which a LTE UE device is in the same room with an SRD unit. In 2009, it was decided (CEPT Report 31 [15]) that the chosen frequency plan in 790−862 MHz band should be based on the FDD mode (see Table 2).

LTE mobile networks in 800 MHz band may influence digital video broadcasting-terrestrial (DVB-T) networks in the lower adjacent band and to SRD in 863−870 MHz and in the upper adjacent band. Since LTE bandwidths can vary up to 20 MHz, the usage of such channels can produce high levels of OOB emissions. According to Table 2, SRD devices can be interfered by uplink of LTE networks, i.e. LTE UE emissions.

It was estimated that LTE UE uses the closest 10 MHz channel (852−862 MHz) according to SRD band, maximum emitted power −23 dBm (all possible resource blocks allocated). In Table 3, the LTE UE spectrum emission mask used in simulations according to 3GPP TS 36.101 is shown (corresponding ETSI reference number TS 136 101) [14].

In the previous section, it was analysed that FBMC has approximately 20 dB less in the OOB emission. In the

Table 3: 3GPP TS 36.101 LTE UE spectrum emission mask

	Spectrum emission limit (dBm)/channel bandwidth			
Δf00B MHz	5 MHz	10 MHz	15 MHz	Measurement bandwidth
± 0−1	−15	−18	−20	30 kHz
± 1−2.5	−10	−10	−10	1 MHz
± 2.5−2.8	−10	−10	−10	1 MHz
± 2.8−5	−10	−10	−10	1 MHz
± 5−6	−13	−13	−13	1 MHz
± 6−10	−25	−13	−13	1 MHz
± 10−15		−25	−13	1 MHz
± 15−20			−25	1 MHz

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Table 4: Parameters of victims receivers and their values used for simulation [16–19]

	SRD type according CEPT/ERC/Rec. 70–03			
Parameter	Annex 1	Annex 7	Annex 10	Annex 13
Bandwidth (kHz)	100	25	200	50
Sensitivity (dBm)	−101	−107	−90	−104
$C/(I+N)$ (dB)	8	8	17	8
Selectivity	EN 300 220	EN 300 220	EN 301 357	EN 300 220
Power EIRP (dBm)	14	14	14	10
Antenna	Omni directional 0 dBi gain			
Frequency (MHz)	868.1	869.65	864.25	864.975

following sectors, it will be analysed what could be the benefit of stricter emission mask, which can be achieved by using FBMC modulation.

SRD devices in the band 863–870 MHz are defined in ERC recommendation 70-03 [16]. In this analysis, four different SRD applications were used as described in the following annexes of CEPT/ERC/REC 70-03 [16], the parameters of which are listed in Table 4:

- Annex 1 non-specific SRDs.
- Annex 7 social alarms/alarms.
- Annex 10 radio microphones including aids for the hearing impaired.
- Annex 13 wireless audio applications.

All of these types of SRDs were used in statistical Monte-Carlo simulations.

5. THEORETICAL INTERFERENCE ANALYSIS

5.1 Interference Scenario

The general idea for simulating coexistence scenario between LTE UE and SRD devices is shown in Figure 7. It reflects the assumption that these devices function in close proximity from each other – from zero to a few metres. Such a scenario could be recognized when both devices operate in the same room. This idea could be

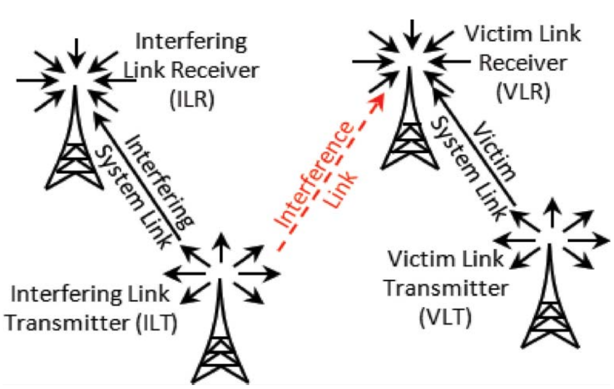

Figure 7: SEAMCAT simulation area [19].

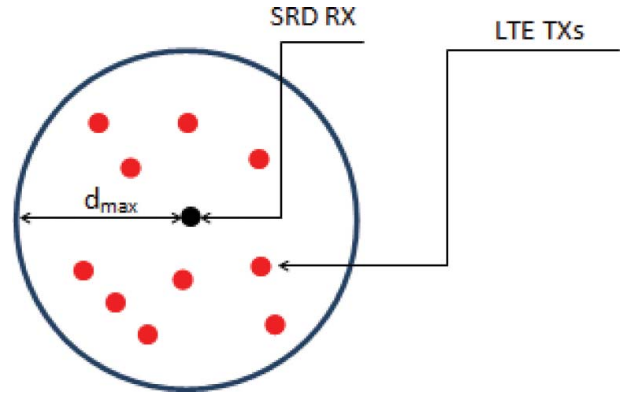

Figure 8: Coexistence scenario of LTE UE vs. SRD.

considered as worst case scenario, but it is logical that SRD devices and LTE UE can be indoor [2]. The simulation radius $d_{\max}$ was up to 10 m in order to reflect the same room coexistence scenario (see Figure 8) [2].

Annexes 1, 7, 10, and 13 reflect majority of SRD devices that are currently worldwide operational.

5.2 Theoretical Evaluation of Interference Potential

First of all, the MCL method was examined, which evaluates what spatial separation distance is needed between the interferer and victim in order to avoid interference:

$$\text{RPC} = \text{Ptx} - \text{Srx} + \text{Grx} + \text{UEBC} \tag{1}$$

where RPCis the required path loss, Ptx is the equivalent isotropically radiated power (EIRP) of interferer, Srx is the victim sensitivity level, Grx is the victim antenna gain, and UEBC is the unwanted emissions bandwidth conversion or C/I value.

This method was applied in this situation for, e.g., non-specific SRD devices. Consider two cases of adjacent channel interference: (a) OFDM emission mask and (b) FBMC emission mask.

$$\begin{aligned}\text{RPC}_{\text{OFDM}} = & (-23\ \text{dBm}/100\ \text{kHz}) \\ & -(-101\text{dBm}) + 0 + 8 = 86\ \text{dB}\end{aligned} \tag{2}$$

$$\begin{aligned}\text{RPC}_{\text{FBCM}} = & (-43\ \text{dBm}/100\ \text{kHz}) - (-101\ \text{dBm}) \\ & + 0 + 8 = 66\ \text{dB}\end{aligned} \tag{3}$$

We can translate the calculated RPC value to spatial required distance using free space loss propagation model. This model is suitable in this case, because the LTE UE and SRD device are always in line of sight. So, the required separation distances are 389 and 39 m for OFDM and FBMC cases, respectively.

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According to 3 dB, optional margin and $C/(I+N) =$ 8 dB interference criterion are used regarding to EN300220 standard [17]. So, the MCL method shows that the LTE UE can have interference influence to SRD devices in adjacent band at distances of up to 389 m if OFDM mask is used and at distances of up to 39 m. The following calculations show the great potential influence of possible FBMC emission mask utilization – spatial distance could be reduced from 389 to 39 m.

These two proposed spectrum emission masks were used in Monte-Carlo analysis section subsequently.

5.3 Monte-Carlo Simulation of Interference

In this subsection, the Monte-Carlo statistical simulations of above-described coexistence scenario were conducted using SEAMCAT software tool [19]. SEAMCAT is an electromagnetic compatibility tool based on Monte-Carlo method. The workspaces of this tool contain three main links as given below.

- Interfering system link with transmitter and interfering link receiver.
- Victim system link with victim link transmitter and victim link receiver.
- Interference link is described using interference criterion in accord with simulation scenario – carrier to interference ratio C/I, carrier to interference and noise ratio $C/(I+N)$, interference to noise ratio I/N, noise and interference to noise ratio $(N+I)/N$, and various propagation models – free space model, extended hata, extended hata-SRD, ITU-R P.1546, spherical diffraction, longley rice propagation, IEEE 802.11 model C, and winner propagation [19].

In this simulation, the maximum separation distance between LTE UE transmitter and SRD receiver was varying stochastically up to 10 m radius. In SEAMCAT, we can use propagation model for very close operating distances called extended hata SRD. The simulations were carried out for four types of SRD devices, always 20,000 calculations were done. The LTE cell area was modelled with reference to real cellular network in Vilnius city, e.g. average cell radius was up to be 350 m. The maximum cell radius is important for LTE UE power control function [2].

Table 5 shows the simulation results using Monte-Carlo method in terms of probability of interference (PoI) from LTE UE to different victim SRD devices. Here, the PoI less than 5% is considered to be a sufficient level.

The obtained results show a significant change in the level of PoI using FBMC. The SRDs which correspond to Annexes 1 and 7 could coexist in the same room assumption (simulation radius d_{max} up to 10 m) if FBMC emission mask was used in LTE mobile networks. The level of PoI is strongly reduced for SRDs which correspond to Annexes 10 and 13. In these simulations, the interference criterion $C/(I+N) = 8$ dB or 17 dB for Annex 10 (as described in: EN 300 220 [17], EN 301 357 [18], and ECC Report 037 [20]) was used.

Table 5: Simulated LTE UE to SRD adjacent band interference probability

	SRD types according ERC/Rec 70–03			
Parameter	Annex 1	Annex 7	Annex 10	Annex 13
$d_{max} = 10$ m				
PoI with OFDM (%)	21.11	17.76	50.52	32.27
PoI1 with FBMC (%)	4.02	2.85	20.22	9.68
$d_{max} = 20$ m				
PoI with OFDM (%)	13.85	10.62	34.30	19.92
PoI with FBMC (%)	2.20	1.76	11.27	4.85
$d_{max} = 50$ m				
PoI with OFDM (%)	7.66	4.41	15.07	8.52
PoI with FBMC (%)	1.04	0.81	4.72	2.22

6. CONCLUSION

This paper proposed FBMC modulation as a possible facilitator in order to avoid LTE UE 800 MHz interference to SRD operating in the band of 863–870 MHz. FBMC modulation is more spectrum efficient – OOB emissions are approximately 20 dB according to OFDM.

Simulations were done with OFDM and FBMC. The obtained results of simulations show the significant level of PoI using OFDM – between 18% and 32% depending on the type of SRD victim. Results with FBMC can reduce interference level to 4%–20%. The SRDs which correspond to Annexes 1 and 7 could coexist in the same room assumption (simulation radius d_{max} up to 10 m) if FBMC emission mask was used in LTE mobile networks (with assumption – PoI less than 5% is considered like a sufficient level).

As an overall conclusion, it may be recommended that the limits of LTE UE OOB emissions may need to be revised in order to ensure the reasonable degree of adjacent band coexistence with SRDs.

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