A Cognitive Overlay System Based on FBMC

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***Abstract*—In this proposal, we provide details on our approach for the design of a cognitive overlay system which is implemented on a heterogeneous Software Defined Radio (SDR) platform consisting of an off-the-shelf consumer laptop and a USRP X310. To ensure high flexibility, spectral efficiency and low out-of-band radiation, we chose Filter Bank Multicarrier (FBMC) as physical layer waveform. For the cognitive aspect we propose a hybrid solution based on learning of Primary User (PU) transmission parameters and behavioral patterns as well as continuous, low-delay channel monitoring. To achieve a low delay and to improve performance, we implement critical signal processing components on an FPGA. Detection thresholds are optimized by using feedback information on the PU error rate.**

I. System overview

The proposed system is an evolved version of [1]. We implement an overlay system that focuses on the fast and reliable detection as well as efficient usage of transmission opportunities. Besides the description of the existing system we want to highlight which improvements we are implementing in order to demonstrate a competitive system at the DySPAN 2017 Spectrum Challenge [2]. The overall design, however, is targeted at a relatively generic scenario in which a Secondary User (SU) is trying to communicate in presence of a Primary User (PU) who must not be interfered with.

II. Waveform

It is imperative to avoid any interference with the PU and at the same time make efficient use of transmission opportunities in the time-frequency domain. Therefore we chose Filter Bank Multicarrier (FBMC) as physical layer wave form. FBMC is also a contender for the next generation of mobile communications, 5G [3]. Its outstanding features comprise a high spectral efficiency and very low out-of-band radiation. An example for the spectral properties of FBMC in comparison with OFDM is given in Fig. 1. This allows for very narrow guard bands while maintaining a low co-channel interference, which in turn increases the spectral efficiency of FBMC even further. Also, the multi-carrier system allows to selectively deactivate subcarriers as needed to mitigate interference with the PU.

In comparison to the system demonstrated at DySPAN 2015, synchronization and equalization algorithms were improved. The synchronization was adapted in accordance with the latest advances in the literature [4]. The chosen approach offers a reduced signaling overhead and employs a Constant Amplitude Zero Autocorrelation (CAZAC) sequence. For the equalization, we use scattered pilots and linear interpolation between subcarriers throughout the transmission frame to enable a reliable tracking of the channel state.

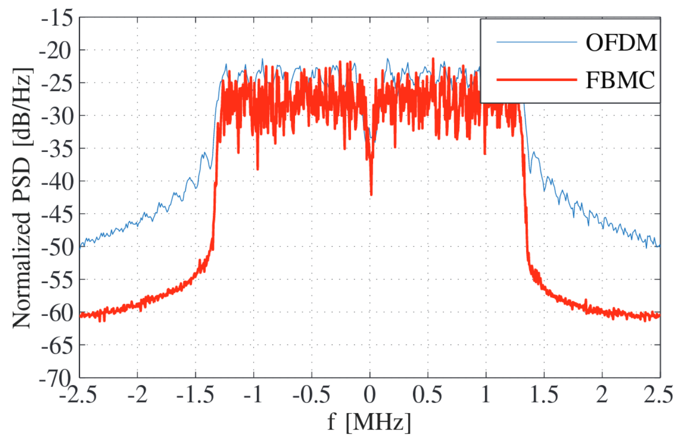

Fig. 1. Comparison of FBMC and OFDM spectrum. FBMC shows much lower sidelobes and therefore much less co-channel interference.

To make use of the available antennas, we employ Maximum Ratio Combining (MRC) at the detector in the receiver [5, p. 986]. The additional diversity gain of up to 3 dB can be used to either increase the reliability of the link or to reduce the transmission power and therefore the potential interference depending on the transmission scenario.

III. Medium access control and situational awareness

Presence detection algorithms such as Energy Detection (ED) and Preamble Detection (PD) are employed in order to reliably detect transmissions of the PU. It is very important to ensure a very low probability of misdetection P_{MD} and, at the same time, keep the false alarm rate P_{FA} low as well. By carefully adjusting the threshold and observation period of the ED using feedback information on the packet loss of the PU due to interference, the sensitivity is improved.

Through interpreting current and past observations, PU patterns will be learned by employing machine learning algorithms such as Decision Trees or Support Vector Machines. Furthermore, the estimated PU packet length in combination with the inter arrival time between frames can be used to optimize the SU packet length. Therefore, our design detects and adapts to the frequency hopping pattern of the PU. This knowledge will then be used to predict transmission opportunities in the time-frequency domain.

As these predictions can never be perfectly certain, we also implement continuous spectrum monitoring as a ”safety net” in order to immediately shut down any ongoing SU transmissions if an unexpected PU communication is detected. As this

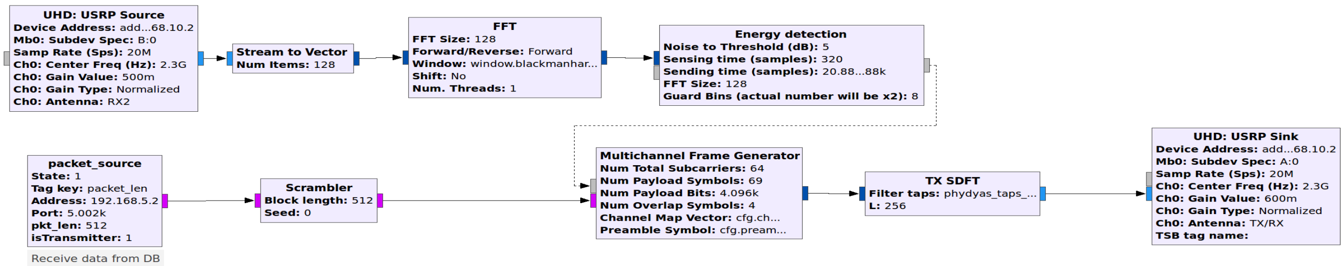

Fig. 2. Part of the FBMC modulator flow graph in GRC as it was demonstrated in the previous Spectrum Challenge.

needs to happen within a short time, the functionality is also implemented on the FPGA to ensure a low and deterministic processing delay.

IV. Implementation and Hardware

To cope with challenging latency and bandwidth requirements, we decided to use a heterogeneous SDR platform. It consists of a Universal Software Radio Peripheral (USRP) X310 by Ettus Research and a consumer laptop, which is connected using Gigabit Ethernet. In this configuration, the X310 supports an instantaneous bandwidth of up to 25 MS/s in full duplex mode and is therefore capable of continuous monitoring of the whole 10 MHz band used in the Spectrum Challenge.

As the network connection as well as the off-the-shelf Linux operating system of the laptop may introduce (non-deterministic) latency that exceeds the required timing constraints, the presence detection algorithms are implemented on the FGPA of the USRP, a Xilinx Kintex-7. Another reason to utilize the FPGA is its computational performance, which is why we also realize the synchronization for the FBMC signal on the FPGA.

On the host side, GNU Radio [6] is employed to realize modulation and demodulation of the (synchronized) FBMC signal as well as connectivity with the database for sending and receiving layer-2 packets and feedback from the PU. GNU Radio is a free and open source Software Defined Radio framework. It features a multi-threaded scheduling of signal processing components as well as access to Single Instruction Multiple Data (SIMD) instructions through the Vector Optimized Library of Kernels (VOLK) [7] which makes it a suitable candidate for high-rate and computationally expensive applications.

The cognitive component, which is responsible for learning and detecting the different transmission scenarios is also implemented on the host computer, while the extraction of the relevant features can be implemented on the FPGA for performance reasons.

The integration of modules running on the FPGA is done with the use of RF Network on Chip (RFNoC) by Ettus Research and integrated into GNU Radio Companion (GRC). An example flow graph showing our FBMC modulator can be seen in Fig. 2.

References

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