# A Dynamic Spectrum Access Case Study: Secondary User Coexistence in the FM Band

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## Background and Motivation

The explosion of wireless everything in recent years has placed a strain on the radio spectrum, and has led to the so-called 'spectrum crunch', where the spectrum is described as being nearly at capacity [1]. It is widely accepted that in reality this is not the case, as great numbers of 'allocated' bands are underutilized or not in use at all. In other words, the radio spectrum is not used as efficiently as it could be.

Commonly, bands (containing many channels) are classified by spectrum regulators for a particular type of use, such as those for FM Radio, Digital TV and cellular services. If there are not enough Primary Users (PUs) to use all of the channels in these bands, they lie empty. Using new spectrum access techniques, these channels can be targeted for 5G and IoT applications.

This work focuses on targeting the FM Radio band (88-108 MHz). Signals broadcast at these frequencies have excellent propagation characteristics, and are able to diffract around objects such as hills, and penetrate through buildings well. Recent studies [2] have shown that a significant portion of the 100 individual 200 kHz-wide FM Radio channels are unused at any given location.

Average findings across the USA suggest that in urban regions with populations between 100,000 and 1 million, only 25% of the channels are in use [3]. When FCC rules on minimum distances are taken into account, the amount of 'available' spectrum is lower, however the findings do provide a strong argument that the FM band is a suitable candidate for enabling Secondary User (SU) access.

The aim of this work is to build a radio that is capable of scanning the band, identifying which channels are unused, automatically building a channel mask, and establishing multicarrier SU communication channels using a FBMC scheme, as shown in Figure 1.

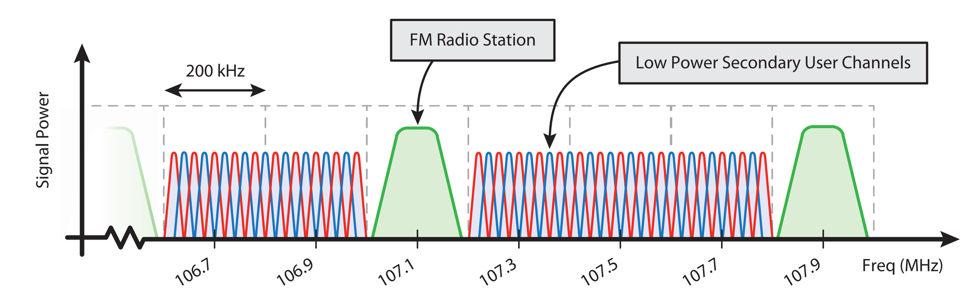



Figure 1: Secondary Users broadcasting in available channels of the FM Radio Band

## PHYDYAS FBMC Transmitter PHY Overview

SU radios designed to mould around existing PUs must have very low Out Of Band (OOB) leakage. This will ensure that the radio does not interfere with PU signals by broadcasting energy in 'off' bands. These interference limits are set by regulators under various names (adjacent channel leakage ratio, OOB leakage, co-channel interference).

OFDM has become the defacto standard of choice in the latest generations of wireless digital communications. By inputting complex zeros to the OFDM transmitter IFFT, it is possible to 'disable' subchannels, creating a Non Contigous (NC) OFDM signal with 'spectral holes'. However, due to the fact the scheme uses rectangular pulse shaping, there is very high OOB leakage in these disabled subchannels [4,5].

An alternative scheme which is gaining popularity is FilterBank Multicarrier (FBMC). Here, pulse shaping filters are used because of their better spectral containment. The filters are designed based on an overlapping factor $K$. The higher the $K$ value the more complex the radio, however the smaller the OOB leakage. This has led to the $K$=4 PHYDYAS filter becoming a popular choice [6].

The spectral responses of the two schemes are shown in Figure 2. OFDM subcarriers have high powered sidelobes; the first of which is only 13 dB lower than the in-band power level. After 3 subcarrier spacings, this only drops to -20 dB. With the PHYDYAS filter, the power in the first disabled subchannel is around 40 dB lower than in-band levels, and within 3 subchannel spacings, the OOB attenuation is over 80 dB. A PHYDYAS FBMC transmitter, unlike NC-OFDM, is capable of coexisting with the PUs of the FM band.

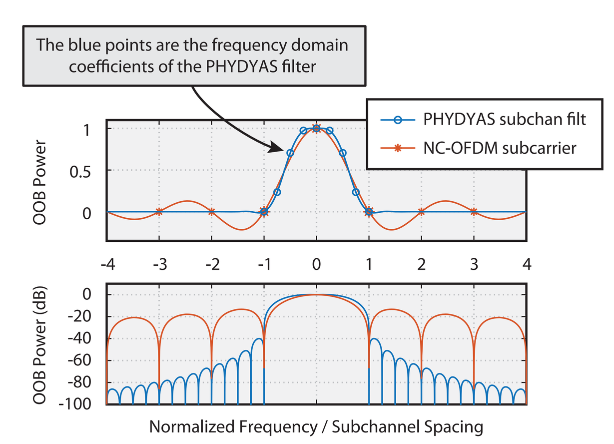



Figure 2: Comparison of the OOB power in PHYDYAS FBMC and NC-OFDM schemes

A high level overview of the radio that has been developed is shown in Figure 3. On switch-on, the radio begins by automatically developing a SU channel mask that protects ambient PU transmissions. The mask is applied to data symbols arriving from the host computer, and these undergo the processing required to generate FBMC symbols. The Frequency Spreading FBMC (FS-FBMC) architecture was chosen for this initial investigation. The radio was developed using MathWorks *HDL Coder* tools, so that it could be targeted to a ZynqSDR.

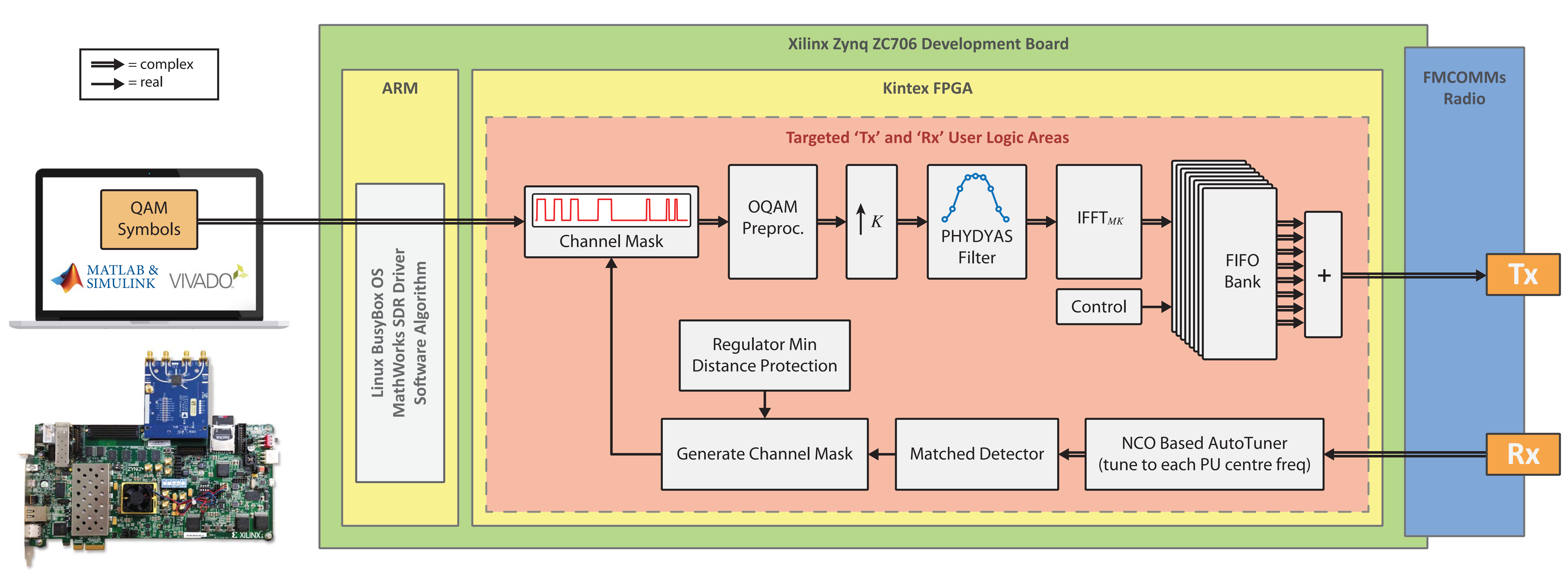



Figure 3: Block diagram of the FBMC transmitter with auto-mask generator, targeted to a ZynqSDR (Xilinx Zynq dev board + FMCOMMs Radio)

## Field Test Simulation Results

As it is not currently permitted to broadcast SU signals in the FM Radio band, it was decided that synthetic 'field test' simulations would instead be performed to investigate how well the SU could coexist with the PU; in terms of the level of interference caused by the SU to the PU. Both PHYDYAS FMBC and NC-OFDM transmitters would be compared. Recordings of the entire FM band were made in the centre of Glasgow, and these were applied to the 'Rx' input of the radio. 22 stations were received. Greater Glasgow has a population of around 1.2m, so this is in line with the findings of [3].

The radio generated a suitable channel mask, with 300 kHz wide guardbands either side of active stations. It is evident from Figure 4 that, at this low transmit power of 0.1 W, the NC-OFDM signal's OOB leakage is significantly more powerful than many of the PU FM channels. However, the PHYDYAS FBMC signal fits well around them, actually having an OOB leakage level below the noise floor of the FM band.

The average power for each of the FM and SU signals and in active FM Radio channels under various transmit power levels were found, allowing the Signal to Interference Ratio (SIR) to be calculated. Figure 5 shows the average SIR experienced across all FM Radio channels, plotted against SU transmit power. It shows that overlaying the PHYDYAS FBMC signal on the FM spectrum results in ~47 dB improvement in PU SIR when compared with overlaying the NC-OFDM signal.

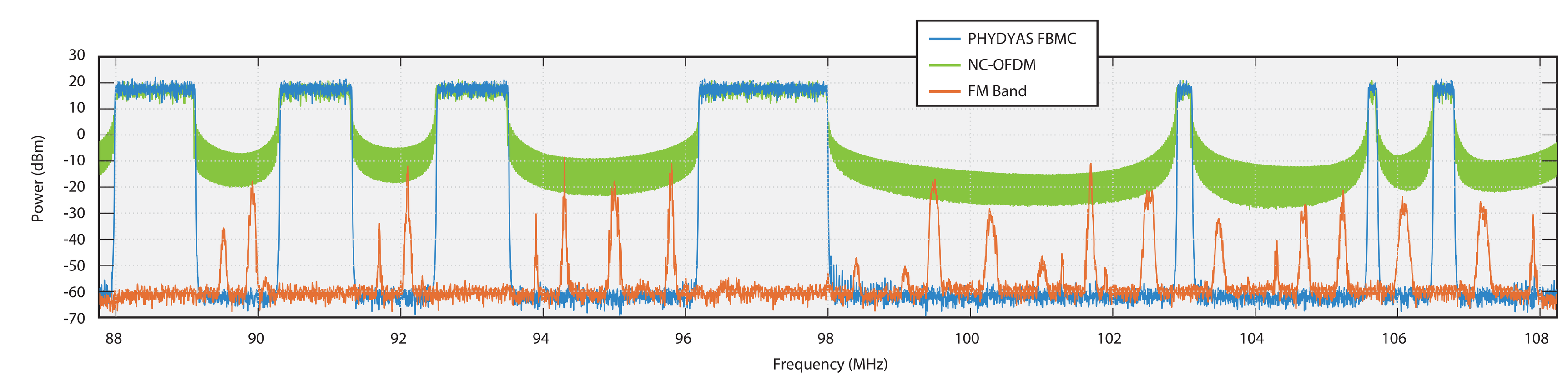



Figure 4: Spectrum Analyzer window showing the PHYDYAS FBMC, NC-OFDM and recorded FM radio signals — SU transmit power = 0.1W/ 20dBm

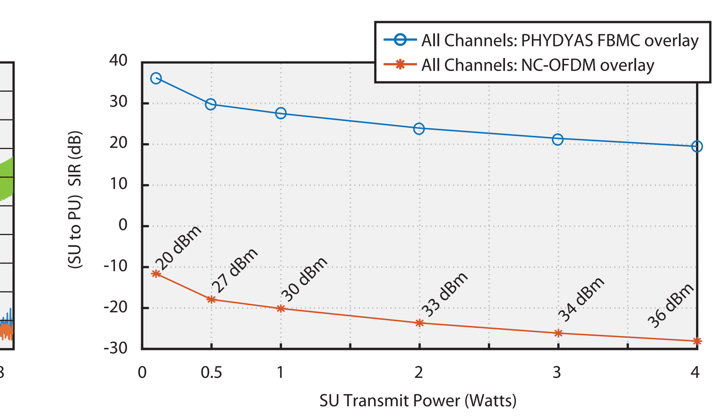
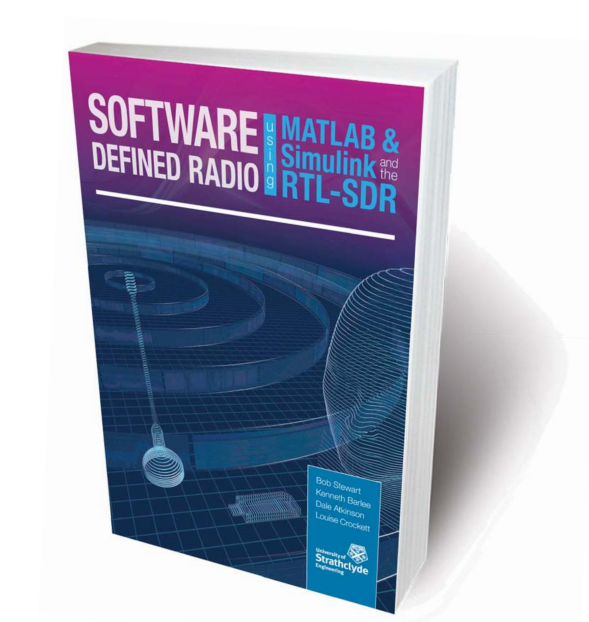



Figure 5: Plot of average SIR (SU to PU) for various SU transmit powers

## Other SDR Projects from the University of Strathclyde

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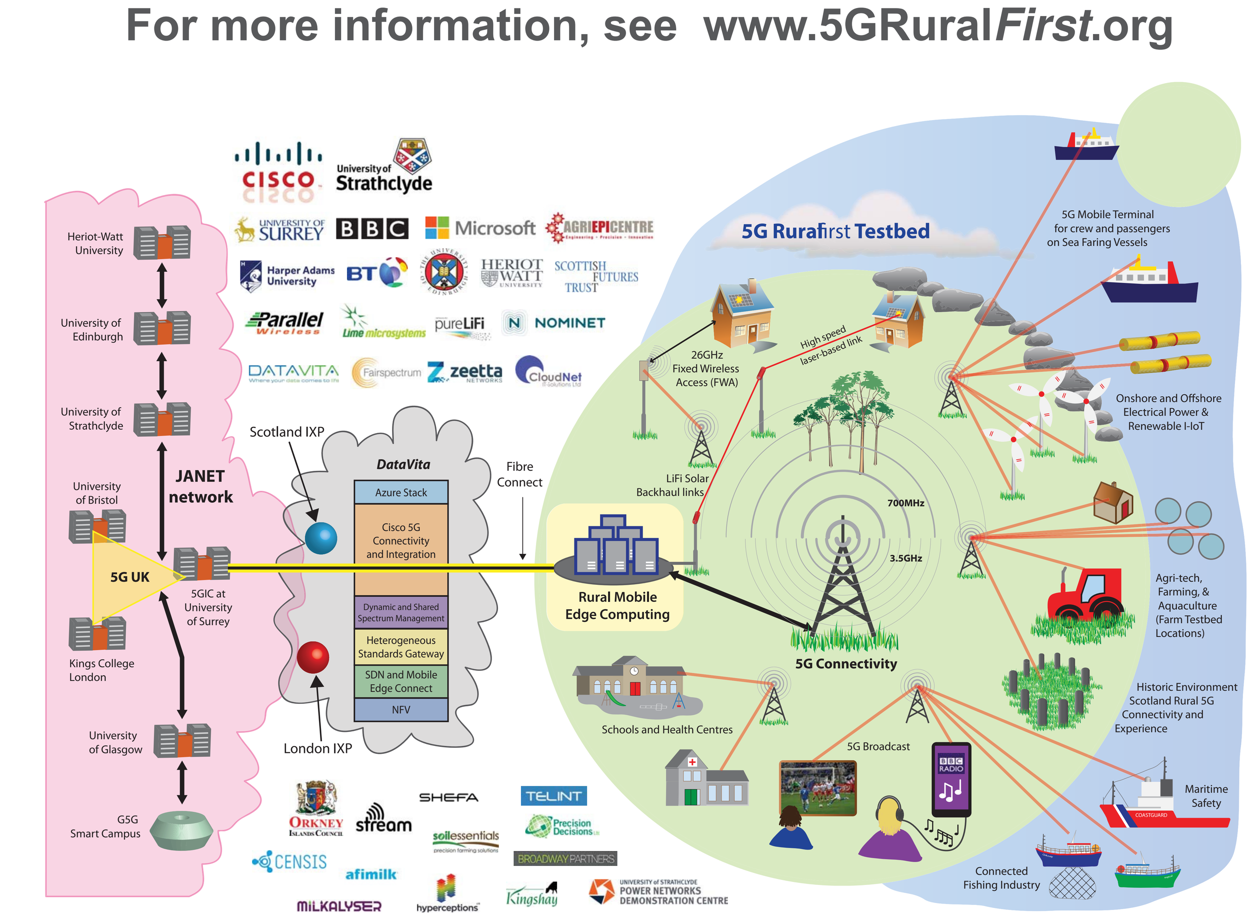
Back in 2015 we launched a 670 page, 12 chapter textbook titled *Software Defined Radio using MATLAB & Simulink and the RTL-SDR.* Aimed at beginners, hobbyists and professionals, the book introduces readers to SDR, and demonstrates through a series of theoretical and practical exercises how the low cost RTL-SDR can be used to implement a series of analog and digital receivers in MATLAB and Simulink.

It has been widely received, with over 23000 downloads from over 150 countries around the world. It is used heavily in academia, and its teachings will feature as a core class in the new 5G MSc course offered at Strathclyde.

The university has been actively working in the areas of 5G, IoT, Dynamic Spectrum Access, Sofwtare Defined Radio and TV White Space for some time, and was recently awarded a £7.3m ($10.3m) UK government grant for our new 5G Rural*First* project.

5G Rural*First* will help the UK take a leading position in 5G, enabling some of the UK's disconnected, remote and rural communities to be the first to benefit from the new technology. Project partners include Cisco, Microsoft, BBC, BT, AgriEpi, Parallel Wireless, LimeMicro, Nominet, Fairspectrum, CloudNet and the Scottish Futures Trust.


For more information, see www.5GRural*First*.org

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*References:*
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