Cognitive Spectrum Optimization

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***Abstract*— A suite of novel, complementary technologies is used to enable dynamic, cognitive optimization of communications spectrum usage in congested and dynamic radio frequency environments. The term Transpositional Modulation (TM) is used to refer to this set of technologies for smart, adaptive management and optimization of existing spectrum. TM enables sizeable increases in data rates of traditional communications systems and enables obfuscated communications (if desired) without using additional spectrum. Adaptive spectral monitoring is used to identify and exploit room under spectral emissions masks to add additional, non-interfering channels of communication; customized digital pre-distortion (DPD) linearization techniques increase the room under the emissions mask by removing intermodulation distortion. In addition, self-interference cancellation techniques allow overlaying additional, non-interfering communications to existing systems in the same frequency band at the same time. Customized coding and encryption techniques enhance the reception of TM signals from challenging and dynamic channels and provide secure communications. The data rate increase achieved is implemented transparently with insignificant effects on the original waveform. Hardware test results with a modern software defined radio platform confirm increases in data rate by over 50%.**

Keywords—cognitive radio; adaptive signal processing; RF communications; high data rate; spectrum monitoring; interference cancellation; digital pre-distortion linearization; obfuscated communications; LPI; LPD; 5G

I. Overview of the Technique

Indiscriminately adding waveforms to existing communications systems can adversely affect the spectral spreading and signal-to-noise ratio (SNR) of the system and present significant co-channel interference problems. In contrast, Transpositional Modulation (TM) cognitively adds non-interfering, orthogonal channels of communication to legacy communications systems to enable sizeable increases in data rates without interfering with or degrading the original, legacy communications.

The amount of headroom available for adding TM channels under regulatory power limits and the resulting SNR of the system determine how much of an increase in communication capacity can be achieved. Equation (1) below quantifies the percent improvement in achievable data rate (*% Improvement*) as a function of the current measured SNR of the system ($SNR_{measured}$), the allowable attenuation of the added TM signal ($TM_{attenuation}$), the minimum SNR required for the specified modulation density (SNR_{min}), the delta SNR corresponding to the difference in modulation density (ΔSNR), the number of legacy system subcarriers ($nData_{legacy}$), and the number of TM system subcarriers ($nData_{TM}$):

$$\% \, Improvement = \frac{nData_{TM} * \dfrac{SNR_{measured} - TM_{attenuation} - SNR_{min}}{\Delta SNR}}{nData_{legacy} * M_{legacy}} \tag{1}$$

Dynamic spectrum monitoring is used to continuously monitor these key parameters in congested RF signal environments to identify and exploit underused areas of spectrum to add additional TM channels. Sideband TM channels (e.g., within the unused mask shoulders) can be used to add system capacity (see test results below), for example, by using customized digital pre-distortion (DPD) linearization to reduce sideband spectral leakage due to intermodulation distortion [1]. The improvement to the legacy system is optimized by detecting the noise and distortion in a system and adaptively changing the modulation order, bandwidth, and signal level of the TM signals.

In addition, in-band SNR headroom can be exploited to add non-interfering TM signals in the same frequency at the same time as the original, legacy signal (e.g., using customized self-interference cancellation techniques).

Customized coding techniques are also used to enhance the bit error rate of the added TM signals, which is particularly important since the additional TM signals are attenuated and in the presence of noise, distortion, and interference in congested environments. For example, Intelligent Poly Key Zero Overhead Encode is an enhanced coding technique with the extra benefit of Physical Layer encryption via dynamically changing codes (vs. static codes that provide no security benefits) [2].

Obfuscated communications are further provided by the inherent waveform structure of the added TM signals since they resemble noise and distortion. In addition, techniques such a Unitary Braid Division Multiplexing further obfuscates the added TM signals by transforming them have a Gaussian noise distribution, making them difficult to detect or intercept [3].

II. Test Results

An example TM-enabled system was configured to demonstrate data rate increases provided by exploiting spectral capacity in the sidebands of a legacy communications system. The configuration used was:

Hardware Testing Configuration:

- Xilinx Zynq UltraScale+ RFSoC ZCU216

System Configuration:

- 256 Point FFT
- Total Bandwidth 50 MHz
- Subcarrier spacing = 195.3125 kHz
- Data Interval Time = 5.12 µs
- 18 Point Cyclic Prefix
- Guard Interval Time = .36 µs
- Subframe Consists of 8 OFDM Symbols, 7 Data, 1 Sync Symbol
- Base signal: 148 data subcarriers, 4 pilots, QPSK
- Base signal occupied bandwidth: 30 MHz
- Base Data Rate: 54.015 MBits/s
- Base Signal Spectral Efficiency: 1.08 bits/s/Hz
- Data Rate with TM: 89.051 Mbits/s
- Spectral Efficiency with TM: 1.78 bits/s/Hz
- Data Rate and Spectral Efficiency Improvement: 64.86%
- TM signal occupied bandwidth: 10 MHz
- TM signal: 48 data subcarriers, 4 pilots, 16-QAM
- TM Signal level 10 dB below base signal

As discussed above, these configuration settings for the additional sideband TM signals are configured and continuously updated according to changes in the dynamic spectrum environment. Figure 1 depicts the frequency plan of the test system, including the legacy communications signal (spanning -15 to +15 MHz) and two TM signals in the side channel areas (-15 to -20 MHz and +15 to +20 MHz).

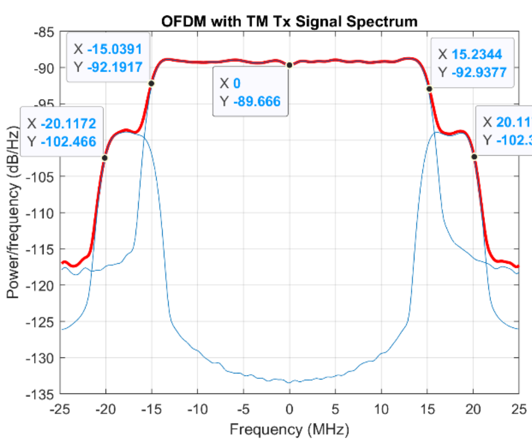

Fig. 1. Frequency configuration of the example TM-enabled system using two side channel TM signals to increase the data rate.

Both the legacy and TM communications protocols are configured in the hardware (Xilinx ZCU216 RFSoC), and testing and validation are performed in MATLAB. A channel model was configured as following for this analysis:

Channel Model:

- AWGN, SNR = 35 dB
- 3-tap Multipath Rayleigh Fading Channel
  - Path delays = [0 100 ns 200 ns]
  - Path gains = [0 -8 -15]
  - Max Doppler Shift = 80 Hz

Figure 2 show the received constellation plots for the legacy (QPSK, left) and TM signals (16-QAM, right). The addition of the orthogonal TM signals does not affect the fidelity of the legacy signal.

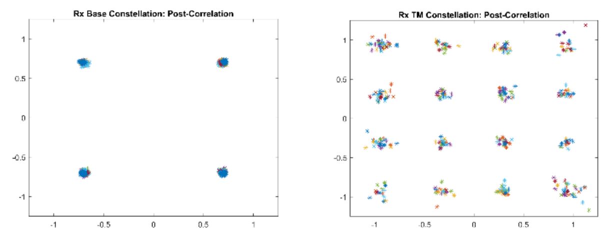

Fig. 2. Received constellation plots for the legacy QPSK signal (left) and the added TM 16-QAM signal (right).

For this system, the optimal improvement to the spectral efficiency was 64.86%, a significant increase. The legacy system contained 148 data subcarriers with QPSK modulation ($M_{legacy} = 2$). The bandwidth constraints for the TM signal dictated the number of TM data subcarriers to be 48. The TM signal attenuation is set to 10dB below the legacy signal and the SNR for the system was measured to be 31.1dB. The minimum SNR threshold for the system is 9.1dB and the SNR delta is 3dB. The result is as follows:

$$\%\ Improvement = \frac{48 * \frac{31.1 - 10 - 9.1}{3}}{148 * 2} = 64.86\% \tag{2}$$

References

[1] S. R. Velazquez, D.H. McIntire, “Transpositional Modulation (TM) for Spectrum Efficiency and Obfuscated Communications” in Proceedings of GOMACTech Conference 2022, March 2022.

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