ABSTRACT

The context aware waveform generation is an essential requirement for the next generation hybrid wireless networks, where different types of device and heterogeneous applications demands different Quality of Service (QoS) in such scenario single waveform for handling various demands is impossible. The massive connection of the Internet of Things (IoT) in near future demand more spectrum, which can be addressed through heterogeneous spectrum sharing. This research work proposes a Cognitive Engine (CE) for an optimal waveform selection by analyzing the given current context for the Cognitive Radio (CR) with fuzzy logic controller as decisive system with heterogeneous spectrum sharing in underlay, overlay and interleave modes. As a second component of the research, five different waveforms for five different context is designed, simulated, implemented in SDR platform and their performance is analyzed. The five context for which the waveforms are designed are (i) achieving QoS of secondary user in an underlay DSA suitable for M2M communication (ii) interference free spectrum sharing at subcarrier level for massive narrow band IoT (iii) emergency transmission support spatial coder overlay spectrum sharing for ad hoc critical public safety networks (iv) spectrum sharing for M2M communication in presence of hardware impairment (v) imperfection of Channel State Information (CSI) handling interleave spectrum sharing.

The Fuzzy logic based decisive system is employed in the CE design to (i) make decision with less decision time (ii) avoid the complexity for training the CE (iii) handle imperfection of sensed or measured data that impact the decision process (iv) handle conflict demand of application or context effectively. Quick decision with less complexity is one of the requirements of CE especially when
multiple waveform generation and optimization are involved. Decision time of CE is reduced by analyzing the fuzzy rule set with help of decision tree and removing the don’t care rules for a given context. The 72 rules take 156.82 ms for decision are reduced to 43 rules which take only 93.6 ms. The performance of CE with fuzzy decisive system is analyzed by generating five different random test vectors of size 100 with different probability of supporting the five different context. Two performance parameters namely Success Rate (SR) and Proportions Rate (PR) are measured by applying these test vectors and the decision system capability is tested in the presence of the conflict requirements and with fuzziness of the input values. The real time performance of CE decision making fuzzy controller is analyzed by injecting hardware impairment and it is observed that the decision system switches the waveform to keep better performance. The adaptive switching to optimal waveform is observed when the transmit power of SU radio is -8 dBm and it is also observed that the change in the measured capacity from 4.5 bits/s/Hz to 9.5 bits/sec/Hz for PU, from 4.7 bits/sec/Hz to 6 bits/sec/Hz for SU.

Waveform 1 is designed and generated for underlay spectrum sharing mode. QoS assurance of achieving the target data rate, BER, bandwidth efficiency is formulated as a multiple objective parameter optimization problem which is solved by evolutionary Genetic Algorithm (GA). The GA is designed to find optimal parameters like best transmit antenna, minimum transmit power, modulation scheme and order, parameter of baseband shaping filter and required minimum symbol rate to meet target QOS. The quick convergence of evolutionary GA is addressed to avoid local optimum value of parameters through a designed transform which maps the fitness value of chromosome. The proposed waveform performance is compared with similar kind of waveform and 30% of improved capacity performance is observed.
In waveform 2, the spectral leakage problem that injects interference from SR subcarrier to PR subcarrier when sharing spectrum at subcarrier level is addressed by an optimized low complexity Filter Bank Multi Carrier (FBMC) modulation. The interference performance is analyzed by comparing the PU BER between OFDM and FBMC system. The better PU BER performance is observed by the factor of $10^{-2}$ comparing with the OFDM system. Systolic structure for Multiply And Accumulate (MAC) unit to realize filter bank via IP cores, pipelining and parallel structure by Single Cycle Timed Loop (SCTL) and pipelined FFT IP core for computing FFT are employed to optimize the implementation on SDR platform. The time complexity analysis of the system shows that the system provides response time of 0.025 µs for the 40 MHz clock after the initial latency 6 ms for filling pipeline and other initialization.

In waveform 3, the problem of capacity reduction under spatial coder when the number of SU increases is solved by clustering architecture and selecting best users to transmit by algorithm called Cluster Based Max Signal Power User Scheduling (CBMSPUS). The scheduling algorithm allows two optimal Secondary Users (SU) per cluster. The performance is analyzed in Rayleigh, Rician and Nakagami-m fading channels. When SNR is low, the CBMSPUS algorithm provides 15 dB gain in comparison with FIFO algorithm to achieve a given capacity of 3 bits/sec/Hz and provides 13 dB gain at high SNR to achieve 6.8 bits/sec/Hz.

In waveform 4, the performance of the cognitive radio with minimum interference MIMO precoding in the presence of hardware impairment is analyzed in terms of injected interference power at PU and achieved capacity of PU and SU. The presence of hardware impairment is detected using SVM classifier with 100% accuracy. The hardware impairment is mitigated by a prewhitening scheme. The interference power and capacity measurement results after the prewhitening shows
that elimination of the impact of the hardware impairment can be done with 100% by the proposed scheme. Accurate CSI with a minimum level of Mean Square Error (MSE) is required for power allocation and spatial domain spectrum sharing. In waveform 5, a design of an adaptive training sequence length for target MSE of channel estimation combating the reduction of spectral efficiency with adaptive modulation and power control is given. This waveform will be selected, whenever we require some target accuracy of the estimated channel with a specified MSE value. Least Square (LS) channel estimation algorithm is used for testing the adaptive training sequence design.

Spectrum sensing is an essential component in CR and this research provides spectrum hole information to CE to generate interleaved spectrum sharing waveform. Full duplex CR is used for efficient spectrum utilization by employing sensing and transmission simultaneously. But the performance of full duplex CR suffers from the problem of self-interference. This problem is mitigated by modelling SU self-interference by Wiener filter and cancelling it from received signal. The Probability of Detection (PD) of the proposed system is compared with similar work in the literature. The PD results show that for 100% detection proposed method provide 7 dB gain in Rayleigh fading channel and 5 dB gain in AWGN channel in comparison with the literature. As the second contribution, the sensing time is reduced to 0.025 µs by optimized implementation of the sensing and Wiener filter algorithm thereby increased the spectral efficiency.

Thus this thesis provides the research contribution towards the CE design with less decision time using fuzzy logic that will generate context aware waveform dynamically for five different contexts. The proposed CE tested in real time by using SDR hardware platform.