

Spectral Efficient Cognitive Radio Transmission using Full Duplex Communication

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Abstract

Background/Objectives: The rapid growth of demand for ever-increasing data rate and wireless services results in spectrum scarcity. Cognitive radio technology is used as solution for this problem. **Methods/Statistical Analysis:** Spectrum sensing is the key mechanism used to share the spectrum in cognitive radio which will solve the spectrum scarcity problem. Conventional cognitive radio is operated in half-duplex mode which first sense the spectrum hole and transmit if spectrum hole is found. This listen and talk approach has the constraint of losing transmission opportunities during sensing or has the Risk of undetectable collisions during transmission. This problem can be rectified by operating the cognitive radio in full duplex mode. **Findings:** Modern full-duplex wireless radio transceivers will be capable of simultaneous spectrum sensing and transmission. But one of the main issues in the full duplex simultaneous sensing and transmission is the residual self-interference. In this paper a full duplex cognitive radio with two antennas (2x2 MIMO) which will provide for higher physical isolation is proposed with the self-interference cancelling technique. The technique consists of a power control and interference cancellation filter or self-interference whitening filter. Since the full-duplex system, radios transmit and sense simultaneously in the same frequency band at the same time, providing improvement in spectral efficiency over a half-duplex system. **Applications/Improvements:** The result shows that the proposed full duplex cognitive radio provides spectral efficiency of 5.2 bits/Hz/sec at 11dB SNR but the conventional half duplex cognitive radio provides only 2 bits/Hz/sec.

Keywords: Cognitive Radio, Full Duplex, MIMO, Power Control, Spectrum Sensing

1. Introduction

The conventional cognitive radio is operated in half duplex mode where the radio will be either in sensing mode or transmission mode. The problem associated with the system is in sensing mode the radio will miss the transmission opportunity even the spectrum is free similarly it will inject interference to primary in transmit mode suppose the primary started to use the spectrum that is not able to be detected by CR in the transmit mode⁹.

Full duplex communication is the one of the key technology proposed for spectral efficiency and high data rate for the next generation of wireless network. Spectrum sensing on full duplex mode will improve the spectral efficiency of cognitive radio, increases the data rate of CR and reduces the interference to primary by quickly leaving the

band whenever the primary getting in to the band. One of the challenges under full duplex CR system is the self-interference handling. Passive and active techniques are used to handle interference. Passive techniques involve cancelling the interference in wireless channel itself before it get in to hardware^{1,2}, but active interference cancellation technique cancels it by processing the received signal data³. Active cancellation technique can be further classified in to two categories. 1. Analog domain cancellation. 2. Digital domain cancellation; digital cancellation techniques are lowest complex one among the two. But the performance of digital cancellation technique is limited in performance due to the hardware imperfection⁴. There are few work that analysis the interference cancellation effect in presence of hardware impairment. In⁵ analysis of oscillator phase noise effects on the self-interference cancellation capability of

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full-duplex direct-conversion radio transceivers is carried out and proved that a severe effect on self-interference cancellation. For cognitive radio spectrum sensing, an adaptive window design based and the BER variation tracking based spectrum sensing algorithm is proposed⁶. Energy detection for spectrum sensing in full-duplex cognitive radios in the presence of residual self-interference is presented with two antennas, one for transmitting and other for sensing and the effect on the probability of missed detection is analyzed⁷. A waveform-based sensing method that detects the PU signal in the presence of self-interference (and noise) is proposed with analyze of sensing performance in the simultaneous transmit and sense mode by deriving the false-alarm and detection probabilities⁸.

This work involve spectrum sensing of cognitive radio in full duplex mode with self-interference by using correlation of receive signal with the CR transmitted signal and thresholding the correlated output with a threshold value.

2. System Model

The study of full duplex sensing system consist of three node one primary transmitter, one secondary receiver and one secondary user with two RF chain and antenna to sense and transmit the data when the spectrum is free as shown in Figure 1.

The above system model is used for the simulation. The primary transmitter is designed to transmit OFDM symbol after mapping the data bits by using QAM-4 and the secondary is designed to transmit only QAM-4 modulated symbol.

The received signal at the secondary user with presence of self-interference.

$$y(n) = x(n) + \sum_{i=0}^{L-1} SS(n-l) * h(l) + w(n) \quad (1)$$

Where the is the received signal from the primary user; is the self-interference signal; is the channel response of self-interference signal; is the additive white noise signal.

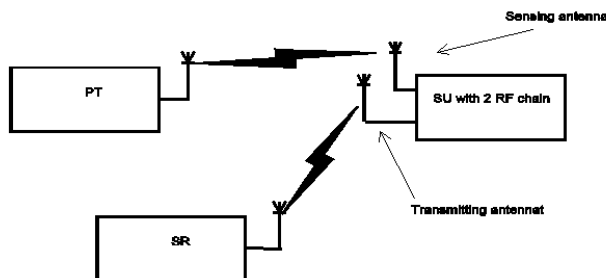


Figure 1. Full Duplex sensing system model.

The primary user transmitter is designed to transmit the OFDM after mapping the binary data using QAM-4 modulations. The secondary radio transmitter is designed to have simple QAM-4 modulation to transmit the data.

The autocorrelation and cross correlation plays important role in this work of full duplex cognitive radio transmission. The autocorrelation of primary user signal $\gamma(i)$ is defined as below

$$\gamma(i) = \text{autocorrelation}(x(n)) \quad (2)$$

$$\gamma(i) = 1/N \sum_{k=0}^{N-1} x(i+k) * x(k)^* \quad (3)$$

The cross correlation between the received signal $y(n)$ and the transmitted signal of secondary user $\beta(i)$ can be calculated since both are available with secondary user.

$$\beta(i) = \frac{1}{N} \sum_{k=0}^{N-1} y(i+k) * SS(k) \quad (4)$$

This cross correlation parameter is used as decision variable for the spectrum sensing in this proposed full duplex spectrum sensing approach. When only secondary signal present i.e. in the absence of primary signal.

$$\beta(i) = \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{L-1} [SS(i-l+k) * h(l) + w(i+k)] * SS(k)^* = D_1 \quad (5)$$

When both secondary signal and primary signal present

$$\beta(i) = \frac{1}{N} \sum_{k=0}^{N-1} \sum_{l=0}^{L-1} [SS(i-l+k) * h(l) + w(i+k) + x(i+k)] * SS(k)^* = D_0 \quad (6)$$

The hypothesis of the spectrum sensing using $\beta(i)$ as decision variable is given below

$$H_0 : D_{\text{emt}} = 1 \text{ if } \beta(i) < \text{th}_{\text{corr}} \quad (7a)$$

$$H_0 : D_{\text{emt}} = 1 \text{ if } \beta(i) \geq \text{th}_{\text{corr}} \quad (7b)$$

The above hypothesis formulated based on the fact that when the primary signal is not present then the signal received will be the only the signal component of secondary user only then the correlation $\beta(i)$ value will be large in magnitude since it compute the correlation between the same signal component. When the primary signal is present in the channel then the received signal will be having both secondary and primary signal components when it

correlated with secondary signal the value will be small in comparison with secondary alone signal correlation.

Similarly the additive noise and self-interference signals are uncorrelated

$$1/N \sum_{l=0}^{N-1} w(i+k) *_{ss}(k)^* = 0 \quad (8)$$

So the additive noise component will not affect the decision process.

The probability of detection under the scheme is defined as below

$$P_d = \text{Prob}(D_0 < th_{corr}) = 1 - F_{D_0}(th_{corr}) \quad (9)$$

The probability of false detection under the scheme is defined as below.

$$P_f = \text{Prob}(D_1 < th_{corr}) = 1 - F_{D_1}(th_{corr}) \quad (10)$$

$F_{D_1}(th_{corr})$ and $F_{D_0}(th_{corr})$ are the CDF of the random variable D_1 and D_0 .

3. Result and Discussion

The simulation is carried out by using the system model given in the Figure 1. The simulation set up that is used to simulate the system is given in the Table 1.

The spectral efficiency is calculated based on sensing and transmitting time of the secondary user. If the sensing time is more, then the data transmit time is less. In order to compute the spectral efficiency the sensing time of the proposed algorithm is computed by profiling the sensing code. The sensing time is function of no of transmitting bits used for the transmission. The sensing time for various transmit bits are calculate by simulating for various transmit bits and tabulated in Table 2. These values are calculated for the fixed observation time duration of 20 seconds. Within this 20 sec based on sensing time the actual time for transmit the data is calculated.

The transmit frame duration of secondary radio is set based on amount of bits to be transmitted. For 100000 bits of information bits frame time is set as 5 sec, for

Table 1. Simulation set up

Parameter	PR node value	SR node value
No of bits	100 to 10000	100 to 10000
FFT length	64	-
Modulation employed	QAM-4	QAM-4
Channel model	Rayleigh	Rayleigh

10000 bits of information bits it is set to 0.5 sec and for the remaining information bits size it is set to 0.05 sec. This time duration is set because of the constrain the entire PR and SR transmit code and sensing code has to be executed in the simulation code.

The spectral efficiency of the secondary user is calculated and compared with the half duplex mode of the secondary user and it is given in the Figure 2. From the Figure 2 we can observe that spectral efficiency i.e. capacity for Hz is more for full duplex mode for the various SNR comparing the half duplex mode. The peak spectral efficiency achieved in full duplex is around 5.2 bits/Hz/sec but for the half duplex it is around 2 bits/Hz/sec. Full duplex system achieves this rate at 5dB SNR, that means full duplex system provides 6dB gain over half duplex system.

The probability of correct detection for various SNR of the secondary user is calculated since the self-interference signal power will be effecting the signal correlation value and plotted in Figure 3 from the Figure it is observed that the probability of accuracy various from 1 to 0.79. The reduction of detection probability happen because of the increased self-interference signal power with increased SNR of secondary user for the given threshold of correlation.

Table 2. Sensing and data transmit time for 20 sec duration

No of transmit bits	Sensing time (sec)	Data transmit time (sec)
100	0.02	14.25(FT-0.05 sec)
1000	0.039	11.2(FT-0.05 sec)
10000	0.255	12.5(FT-0.5 sec)
100000	4.989	10(FT-5 sec)

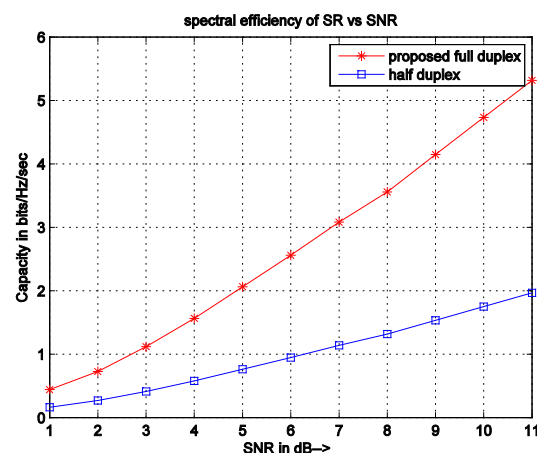


Figure 2. Channel capacity y secondary radio for various SNR in half duplex and full duplex system.

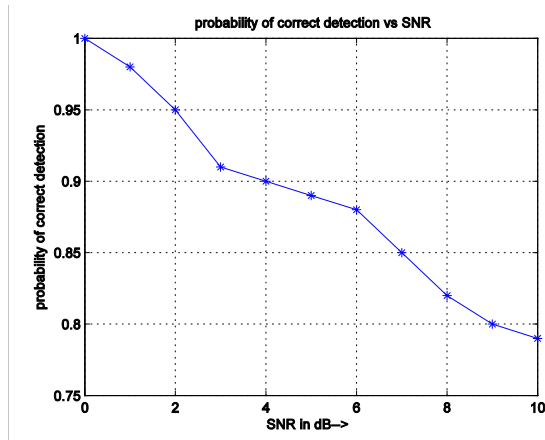


Figure 3. Probability of correct detection for various SNR in full duplex system.

4. Conclusion

Full duplex based spectral sharing is used in cognitive radio to change the half-duplex sense and talk approach in order to improve spectral efficiency of the secondary radio and to achieve high data rate of the secondary radio system. But the self-interference is main issue in the full duplex system that affects the sensing accuracy. In this paper a correlation threshold based sensing algorithm with different wave form design at primary and secondary system is proposed and proved that the system can high spectral efficiency with gain of 6dB comparing to the half-duplex mode. Sensing detection accuracy of 100% at 0 dB to 79% at SNR of 10 dB is achieved by the proposed correlation threshold based full duplex based sensing algorithm.

5. References

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