Cognitive Radio Relay Network Performance Analysis by using Game Theory

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Abstract—Cognitive radio plays a vital role in wireless communication. The cognitive radio composed of a transceiver which is used to check the channel vacancy for communication and avoids busy channels by shifting into unused channel. The scope for spectrum vacancy and area of coverage is increased by using cognitive radio. In cooperative relay network to transmit the primary traffic the primary users (PUs) will nominate some of the secondary users (SUs) so as to relay PUs data. To drive the secondary users to co-operate with the primary user, the primary user who owns the channel have to rent some of the channel to the secondary user for relaying PUs data transmission. This cutback the performance of the primary usersand secondary users. Therefore in co-operative cognitive relay network, MIMO system is implemented to increase its performance. Beam formingis used over the MIMO antenna in space domain which permits multiple data streams and minimizes the interference. The game model called Nash Equilibrium is used forpower control in secondary users and PUs and SUs utilities are obtained in MIMO-cooperative cognitive radio network. In multipleinput multiple output technique the secondary users can co-operatively relay the data for the primary users while concurrently accessing the same channel to transmit its own data. To improve the spectrum usage both Time and space domain are examined for arranging the MIMO co-operative cognitive radio networks.

IndexTerms—*Beamforming,Co-operative cognitive relay network [CCRN], multiple input multiple output [MIMO], Game Theory, Nash Equilibrium (NE).*

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I. Introduction

The benefits of cognitive radio networks have been well recognized with the development of the wireless applications. The users in a cognitive radionetwork are classified into two groups: primary users (PUs) and secondary users (SUs). The primary users have authorized licensed spectrum bands and the secondary users can sense the unusedspectrum bands and share them with primary users to improve the spectrum utilization [1].The system belongs to overlay method, where thesecondary users allocate part of their power forsecondary transmissions and remaining powerto relay the primary transmissions [2].Beam forming is a Signal Processing technique used in sensor arrays for directional signal transceivers. Beam forming can be used at both the transmitting and receiving ends in order to achieve spatial diversity[1]. This can be achievedin such a way that signals at particular angles have constructive interference while others have the destructive interference. In multiple stream, beamforming makes it possible to direct the energy of the antenna array in the independent spatial directions associated with both data streams, while avoiding interference[6].

In CCRN secondary users are totally transparent to primary users.The Primary users are aware of the existenceof secondary users, and lease some part of the spectrum which is provided to secondary users is called spectrum leasing. In return primary user is allowed to leverage secondary users as cooperative relays, by exploiting cooperative diversity, transmission rate of primary link is improved , as a result spectrum access opportunity increased ,which is left to secondary users which can transmit relatively high signal.[3].

Although CCRN benefits both the PUs and SUs, the inadequacy exists. To compensatethe SUs for cooperation the PU must completely give out its spectrum access to the SUs for their transmission.[4] To solve this problem MIMO system is used.Consider there will be multiple secondary users competing for accessing the spectrum which will cause jamming of spectrum. As a result, the rate of each secondary links performance is limited.To resolve the above issue, MIMO-CCRN is used for cooperation between SUs and PUs by exploiting MIMO antennas on SUs' transceivers.

In MIMO there are multiple antennas and they are used for simultaneous transmission as well as reception.MIMOhas theadvantage through multiple antennas and advanced signal processing [5].Multipledata streams can be transmitted or received over the MIMO antenna elements independently. The MIMO-CCRN provides cooperation among SUs and PUs by exploiting MIMO on SUs .By beam-forming, a MIMO receiver can suppress interference from neighboring transmitters and a MIMO transmitter can null out its interference to other receivers.[7]

The primaryuser targets at maximizing transmission rate while secondary users compete with each other when accessing the

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channel. Assumed that both primary and secondary users are rational and selfish, which are interested in maximizing their utility, the stackelberg model can be applied in game theory. Through backward induction concept, we can prove that there exists a unique Nash Equilibrium (NE) point for this Stackelberg game under some particular constraints. An analytical result of the NE point is discussed and to analyzethe constraint under which primary user tends to share a portion of transmission time and secondary users tends to cooperate. Results show that primary user and secondary user have the motivation to cooperate with each other under some circumstances and the performance of both systems are dramatically improved if they cooperate.[9]

II. SYSTEM MODEL

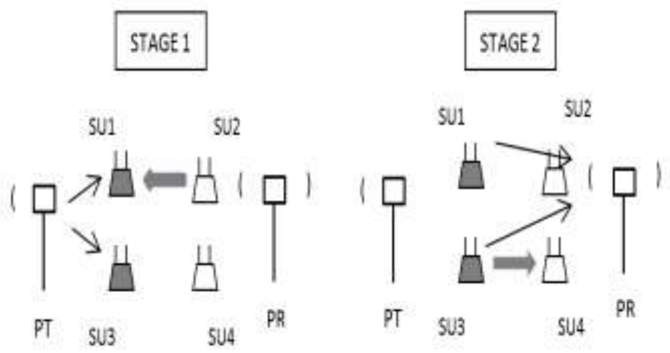

Figure: 1 Structure of MIMO-CCRN

Consider SUs are equipped with two MIMO antennas,while PU is assumed to have one antenna. The number of SUs participating is selected by the PU for cooperative communication which is called relays. The Figure.1 shows the structure of MIMO-CCRN. In this model two stages are used.In first stage the Primary User(PU) transmits signal to the secondary relays.Then in the second stage the relays transmit the data to the primary receiver. For the SUs cooperation of transmitting primary signal, the channel is provided to the relays to transmit their own data. The assumption is possible due to using MIMO antennas for simultaneous transmission and reception by the users.

Y_i = H X+ N (1)

Where H represents the Channel gain, ndenotes the AWGN (Additive White Gaussian Noise) and X is the information signal. The MIMO transmission is explained into two stages.

In first stage: the primary user selects SU1 and SU3 as the relaysr for cooperation; SUsare generally denoted as R. We use h_{1r} to represent the channel coefficient of primary signal$X_1$and H_{Rr} to represent the channel vector of secondary signal X_2 .The users apply precoding vectors;they are denoted as u for encoding vector and v for decoding vector. The received signal in the stage 1 on each relay is a combination of primary and secondary signals.

Y_r $=h_{1r}X_1$ $+H_{Rr}\,u^s X_2$+n(2)
The each relay applies a decoding vector $v^{p\dagger}$ to decode the primary signal by making $H_{Rr}\,u^s X_2$ = 0. And to obtain the secondary data, the SU applies $v^{s\dagger}$ to make $v^{s\dagger}h_{1r}$ = 0.

And the received secondary stream at the SU after decoding is

$\widetilde{Y_r}$ = $v^{s\dagger}H_{Rr}\,u^s X_2$ $+v^{s\dagger}$ n (3)

And decoded primary signal at relay is denoted as Y_p

Y_p $= v^{p\dagger}h_{1r}\,X_1$ $+v^{p\dagger}$ n (4)
Where u^s and u^p are used to denote the encoding vector of secondary signal and primary signal respectively. Then $v^{s\dagger}$ and $v^{p\dagger}$ are used to the decoding vectors of secondary signal and primary signal respectively.

In second stage: The chosen relays transmit the primary data to the primary receiver PR. We useh_{r1} to represent the channel vector form relay r to PR and H_{rR} to represent the channel vector from relay r to SU.At the PR secondary signal is nulled so $H_{rR}\,u^s X_2$ = 0. The signal received at PR is

$\widetilde{Y_p} = \sum_r h_{1r}\,X_1\sqrt{P^r}u^p$ + n (5)
Where, P^rRepresents the power used for relays. The values of P^r are found using game theory.

Due to Maximum Ratio Combining MRC, the effective SNR at PR equals to the sum of all SNRs from all the secondary relays. The transmission power of primary transmitter PT is denoted asP^p , the data rate of primary stream at selected relay is

DR^{ps} $=\log_2(1 + h_{1r}v^{p\dagger})$^2 P^p/N_0 (6)

In the PR sum of SNR of all relays are done by MRC method, thus rate of primary signal at PR is given by

DR^{sp} $=\log_2(1 + \sum_r h_{r1}u^p)$^2 P^p/N_0 (7)

For the secondary data rate, the transmission power of SUs given asP^r , thus the resulting secondary rate is

DR^{ss} $=\log_2(1 + v^{s\dagger}H_{Tr}\,u^s S_s)$^2 P^r/N_0 (8)

Here the data rate of secondary signal is less than primary due to self-interference caused by large number of SUs. And in MIMO-CCRN more importance is given to primary users compared to secondary users.

A .*Power Allocation Using Game Theory:*

In this system two stages are used. By using TDMA(time division Multiple Access) we are denoting the time duration as T^i while for first stage asαT^i,the second stage as (1-α)T^i and the time length as α, and we are denoting the secondary pair which are participating in stage 1 as Q_1 and the pair in stage 2 as Q_2.Since in CCRN the secondary users are followers of primary user for cooperation. Hence all theusers are selfish aiming to maximize the utilities.

In order to find the best P^rin equation (8) the Nash Equilibrium is used to find primary users utility and P_k is the secondary user's power, here k denotes secondary users. The utility of each secondary pairis the difference between the data rate (DR_i) and the cost of the power. The utilityof secondary pair is denoted M_1 .

M_1= T^i(DR_i-ωP^r)- ωP_k(1-α)T^i (9)

Where ω represent the cost for a unit transmission.

The energy consumed by the relay of secondary users are denoted as

T_k^i=$F_i.\frac{P_k}{\sum_{j\epsilon Q_i}P_j}$(10)

Where F_i= αT^i for Q_1 and F_i=$(1-\alpha)T^i$forQ_2.

The secondary users in each pair are players. For non-cooperative power allocation game, the strategy is achieved by Nash Equilibrium for each relay. Based on the equation (9), the utility of the secondary user in Q_1 is

M_1=$\alpha T^i\frac{P_k}{\sum P^r}DR_i^{ss}$- ωP_k(1-α)T^i(11)

In this we are Nash Equilibrium (NE) is analyzed for secondary pairs inQ_1. Similar method Q_2 can be analyzed.

Now to solve the power for secondary pairs with unique Nash equilibrium for the first stage $Q_1$is

P_k^*=$\frac{\alpha}{(1-\alpha)}a_k$ (12)

Where

a_k=$\frac{(|Q_1-1|)}{\omega\sum_{i\epsilon Q_1}\frac{1}{DR_i^{ss}}}$(1-$\frac{(|Q_1-1|)}{DR^{ss}\sum_{i\epsilon Q_1}\frac{1}{DR_i^{ss}}}$) (13)

P_k^*Represent the power for each relay inQ_1.

Similarly using NE the secondary power among the relays in Q_2 is b_k as

P_k^*=b_k=$\frac{(|Q_2-1|)}{\omega\sum_{i\epsilon Q_2}\frac{1}{DR_i^{ss}}}$(1-$\frac{(|Q_2-1|)}{DR^{ss}\sum_{i\epsilon Q_2}\frac{1}{DR_i^{ss}}}$)(14)

B.*Utility Analysis for Primary User:*

The secondary power can obtained from equation (12) and (14).To solve the time scale αsubstitute equation (12 and (14) in (7), thus the resulting data rate is

A= $\sum_{k\epsilon Q_1}\frac{|h_{r1}u^p|\text{^}2.a_k}{N_0}$ and B=$\sum_{k\epsilon Q_2}\frac{|h_{r1}u^p|\text{^}2.b_k}{N_0}$

Thus the resulting data rate in stage 2 is

DR_i^{sp}=$\log_2(1+A.\frac{\alpha}{(1-\alpha)}+B)$(15)

Similarly rate for DR_i^{ps} can be obtained. In order to maximize the utility, the data rate of stage 1 $T_{k\epsilon Q_1}^i DR_k^{sp}$and stage 2 $T_{k\epsilon Q_2}^i DR_k^{ps}$is maintained equally. Therefore

$T_{k\epsilon Q_1}^i DR_k^{sp}$= $T_{k\epsilon Q_2}^i DR_k^{ps}$ (16)

Substituting equation (10)and(15) in equation (16) and rewriting, we get.

$\sum_{k\epsilon Q_2}E_k\log_2(1+A_k.\frac{\alpha^*}{(1-\alpha^*)}+B_k)=F.\frac{\alpha^*}{(1-\alpha^*)}$(17)

Where $F=\frac{\sum_{k\epsilon Q_1}P_k^*DR_k^{ps}}{P_k^*}$in this substitute a_k for P_k^* to get the equation as $F=\frac{\sum_{k\epsilon Q_1}a_k DR_k^{ps}}{a_k}$and E_k=$\frac{P_k^*}{\sum_{i\epsilon Q_1}P_k^*}$ substituting b_k for power we get E_k=$\frac{b_k}{\sum_{i\epsilon Q_1}b_i}$. α^*. Where α^* denotes the peak time length scale .

III. BLOCK DIAGRAM

a)Transmitter Block Diagram of Primary:

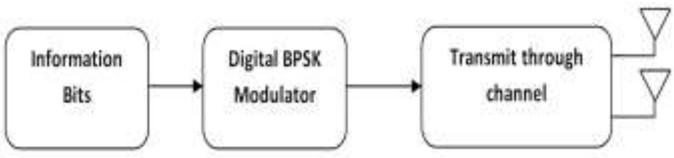

Figure: 2 Primary Transmitter

In the transmitter Block diagram, the Information bits are modulated using Binary Phase Shift Keying (BPSK) technique before transmitting through channel .Channel is used is for transmission is Rayleighchannel and Additive White Gaussian Noise (AWGN) is added to signal. Using Beam forming technique the PU selects SUs for cooperative communication and the selected SUs are relays. The Primary Transmitter broadcasts the modulated signal through the channel to the selected Secondary users.

b) Transmitter Block Diagram of Secondary:

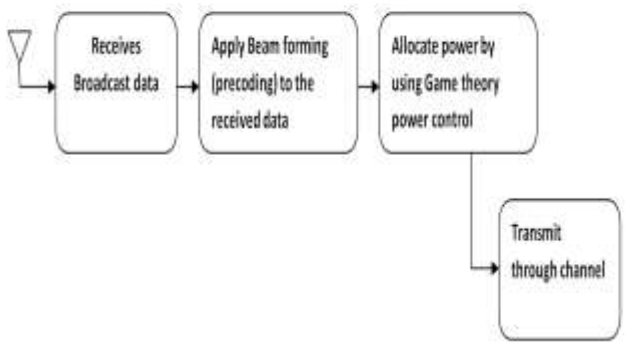

Figure:3 Secondary Transmitters and Relay

Beam-forming can be used at both the transmitting and receiving ends in order to achieve spatial diversity. In this Figure:3 block diagram beam forming technique is performed. The secondary user applies decode and forward method to transmit the signal. Then orthogonal signal are used to decode the signal at the receiver. Each PU and SU has its own precoding vectors. This method is based oneach user chooses its combining vector to maximize its own SNR entirely based on its own channel matrix without considering the channel of the other user. Using NE the power control is performed to secondary pairs.

c) Receiver Block Diagram for primary and secondary:

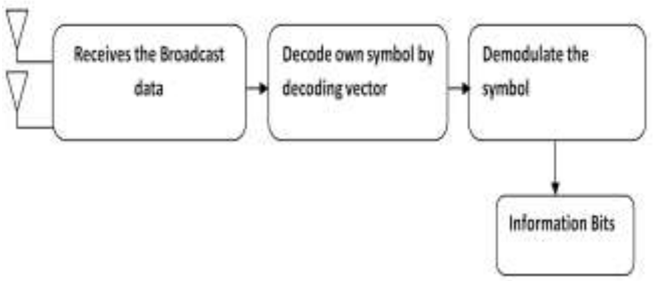

Figure:4 Secondary Receiver and Primary Receiver.

In the receiver block diagram SR and PR receives thedata;the received symbol is decoded by each secondary and primary receiver respectively. The secondary users send its information bits by combining separate encoding vector to its data and a decoder to extracts the information bits. Similarly the PUs has the encoding and decoding vectors to receive the data.The decoded symbol is provided to demodulate the symbol and then the information bits are extracted at the receiver.

IV. SIMULATION RESULTS

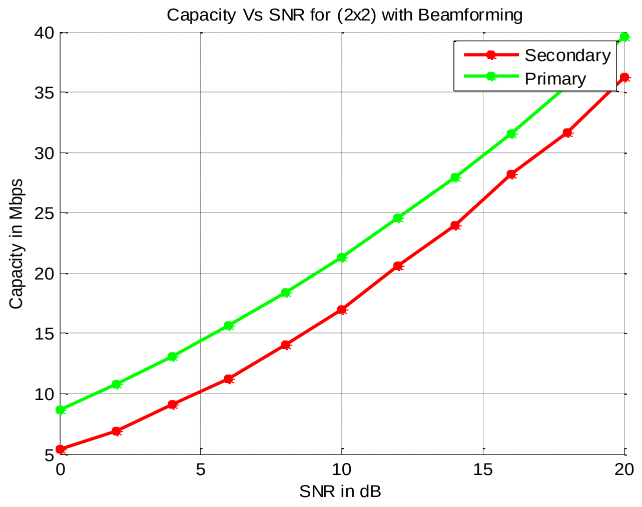

Figure: 5 Capacity vs. SNR for 2x2 MIMO systems with Beam forming technique.

The above figure illustrates the performance of 2x2 MIMO system using beam forming technique, where both primary and secondary users are plotted. From figure the performance of primary user is better than secondary user.

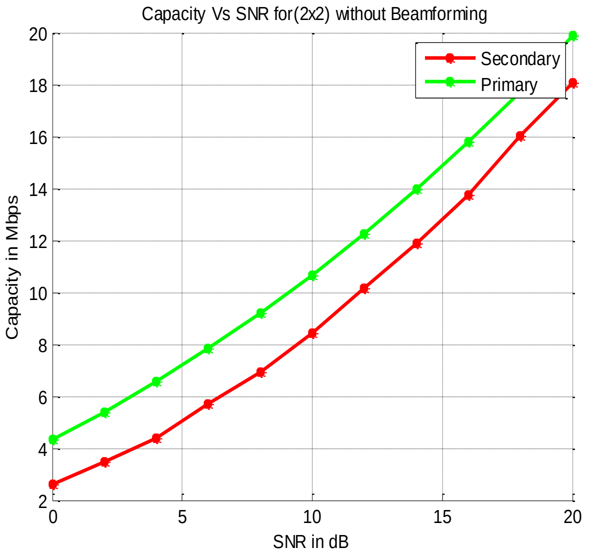

Figure: 6 Capacity vs. SNR for 2x2 MIMO system without Beam forming technique.

The above figure illustrates the performance of 2x2 MIMO systems without using beam forming technique. From the figures 5 and 6 we can infer that the

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performance of o 2x2 MIMO system with beam forming technique is high than without beam forming technique.

CAPACITY	Primary Power	Secondary Power
2.0000	2.5352	5.4055
4.0000	3.1626	6.5893
6.0000	3.8884	7.8302
8.0000	4.6437	9.1974
10.0000	5.5191	10.6849
12.0000	6.5557	12.2538
14.0000	7.4724	13.9868
16.0000	8.5455	15.8309
18.0000	9.6006	17.7834
20.0000	10.8590	19.8023

Table: 1 Power allocation of primary and secondary for various values of capacity.

As the table shows that more power is needed for secondary than the primary user, here the power is represented in dB and capacity in Mbps.

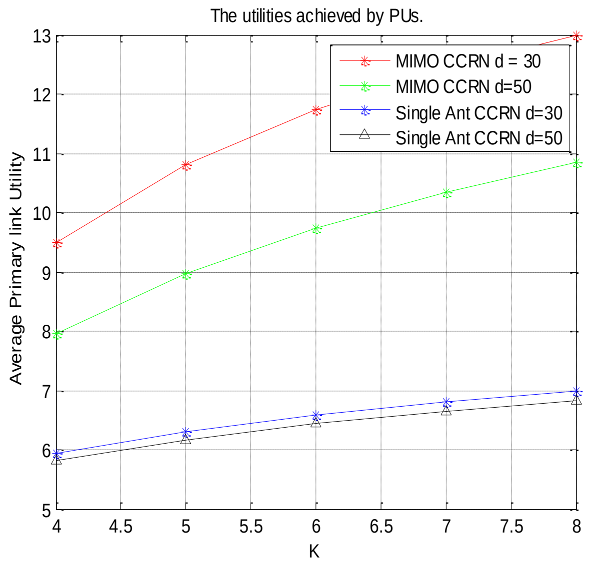

Figure: 8 Graph of Primary Users Utilityvs. Number of relay for CCRN and MIMO-CCRN at different distances.

The above figure shows utility of Primary User for MIMO-CCRN and single antenna CCRN with atotal distance of 100m between them and Here K represents Number of Relays and unit of utility is denoted in Mbps. For lesser distance the channel utilization is more for MIMO-CCRN, whereas for single antenna CCRN the channel utilization varies slightly for various distances.

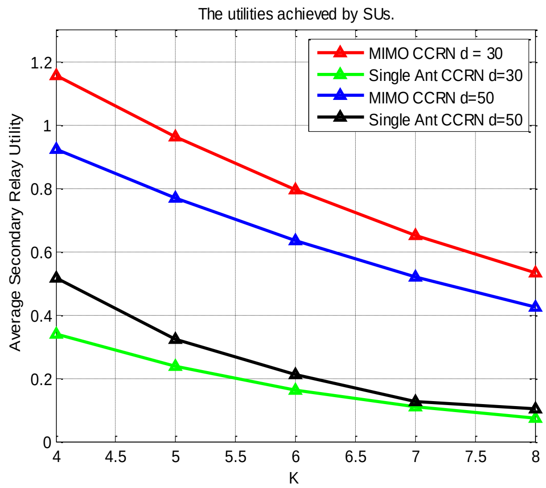

Figure: 9 Graph of Secondary Users Utilityvs. Number of relays for CCRN and MIMO-CCRN at different distances

The above figure shows utility of Secondary User for MIMO-CCRN and single antenna CCRN with a total distance of 100m between them. The unit of utility is Mbps. For lesser distance the channel utilization is more for MIMO-CCRN, whereas for single antenna CCRN the channel utilization varies slightly for various distances. By comparing both Primary and Secondary Users the channel Utilization is more for Primary User.

V. CONCLUSION

Thus Beam forming technique proves to be a promising approach in MIMO-CCRN. The simulation result shows the performance is high for both Primary and Secondary users. Game theory is used to efficiently utilize the channel for both primary and secondary users and to control power among the secondary users.The simulation results show that primary user and secondary user have to cooperate with each other under certain circumstances and the performance of the systems are dramatically improved if they cooperate.

VI. REFERENCES

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