Energy Efficiency and Sum-Rate Performance Improvement of 5G and Beyond Cooperative Cognitive Radio Network with MIMO Antenna

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Abstract: In this paper the system model of MIMO-CCRN shows cooperative communication using MIMO antennas at the secondary networks of 5G wireless communication systems. This secondary network acts as the relay and helps to communicate with the primary network which is at a far distance away. According to our simulation results we get to know the parameter which causes degradation to the sum-rate. We have seen that distance affects the sum-rate, with increase in distance the sum-rate decreases. On the other hand the power seems to be directly proportional to the sum-rate performance. On the basis of the precoding technique the SVD gives out the overall best performance for the MIMO-CCRN in 5G and beyond wireless communication systems.

Key Word: Energy efficiency, Sum-rate, 5G, Cooperative Cognitive Radio Network and MIMO.

1. Introduction

Communication is a method of sending information from sender to receiver and vice versa. Communication technology is a rapidly growing field, where different technologies are being introduced every day due to the need for the growing generation. Out of which wireless communication have an important role. The wireless communication use transmitter and receiver as the communicating device and communicating medium may be space and air. The MIMO antenna is an advance antenna type which is used for wireless communication; it has multiple transmitters at the transmitter side and multiple receiving antennas at the receiver side. This MIMO antenna can transmit and receive multiple signals simultaneously and increase the throughput of the channel and performance. The growing no of wireless communication technology using different frequency spectrum has led to the congestion of spectrum.

The central government gives authorization to the licence user (primary user) for a specific spectrum. This authorized spectrum cannot be used by another licensee or any unlicensed user (secondary user). According to the survey of Federal Communications Commission (FCC), the actual licensed spectrum is highly underutilized while there is high congestion in the unlicensed frequency due to the high number of the unlicensed user. This spectrum need leads to the introduction of cognitive radio. It was first introduced by Joe Mitola in 1999 [1], and it is the next step up for self-monitoring software defined radios that are emerging today. While continuously monitoring the spectrum utilization if it detects empty spectrum holes, it quickly jumps into them, so cognitive radio can improve the spectrum utilization significantly.

To give very good spectrum efficiency to both the licensed and unlicensed, and also the interference to the licensed user is being avoided; the cognitive radio must also be able to perform spectrum conditions flexibly. Hence, dynamic frequency selection, spectrum sensing and transmit power control are some important abilities which is provided by the cognitive radio [3]. To bring the cognitive radio systems in practical environment, many numbers of cognitive networks must be able to coexist. However, the coexistence of many cognitive users will produce interference to each other's users, which will lead to the hidden terminal problem. This problem happens when the cognitive radio is in the shadow of any physical object, or with high path loss while a primary user is in reachable area. In order to deal with the hidden problem in cognitive networks, cognitive users can help to detect the spectrum as well as share the spectrum without causing interference to the primary user.

Spectrum utilization is being improved to a greater extent by letting a secondary user to utilize a licensed frequency band when the primary user (PU) is not present. Cognitive radio (CR), as a smart radio technology, has been introduced to promote the increase in utilization of the spectrum [5]. Without disturbing the PU a CR can fill in unused spectrum and serve its users by continuously monitoring and adapting to the environment. To avoid the interference to the PU the CR must continuously lookup the spectrum for the presence of the primary user. If the PU is found, the CR must be removed from the spectrum so as to lessen the interference it may cause. This is difficult as the PUs will be using different modulation schemes, transmission powers, and data rates in the existence of flexible propagation environments and interference generated by other secondary users. The hidden terminal problem is also a great challenge for executing spectrum sensing, it happens when the CR is shadowed by opaque with a high penetration loss or in high multipath fading while a PU is present in the vicinity. Cooperative communications is powerful and an emerging solution that will solved the limits of wireless systems.

The main motive of cooperative transmission lays on the observation that, in a wireless channel the signal transmitted or broadcast by a source toward a destination antenna is also received by other antennas in between, which forward the signal to the destination antenna. This are often referred to as relays or partners. The relays receive the signal, process it and transmit the signals they receive toward the destination. The destination then collects the entire signal coming from different relays and partners, by taking the advantages of the multipath. The interference between the nodes can be reduces by distributed spatial processing technology. By letting many CRs to take part in spectrum sensing, the hidden terminal problem can be addressed. In CR each sensor makes an own decision and those decision results are combined together at the centre to make a final [8]. With smart and rapid sensing ability, CR can opportunistically occupy the spectrum holes to better the spectrum occupancy utilization. But if the PU returns to use the licensed band, the CR should instantly stop using the PU licensed band. This rapid switching off of the CR can guarantee minimum interference to the primary system. However, from the point of view of the cognitive system, the interruptive transmissions will lead to a discontinuous data service and intolerable delay. To deal with this issue, we suggest a cognitive relay network with many spread out cognitive users cooperate with each other and they share their spectrum bands. By employing a cognitive space–time–frequency (STF) coding in the relay cognitive network, smooth data transmission in the cognitive system can be observed.

2. Literature Survey

In [2] has evaluated MIMO antenna system getting high data transmission which eventually establishing a high capacity communication system without need to increase the transmitted power or the channel bandwidth. Gain in capacity can be considerably improved by manipulating the number of antennas on both sides. They have evaluated for different number of antennas. Considering, system capacity, different MIMO system configuration is obtained at both side of the system (transmitter and receiver) by changing the number of antennas.

To overcome the problems of analogous to spectrum sensing and removing of interference for cognitive radio systems in both centralized and decentralized networks, a broad study on cooperative communications is discussed in [3]. They also propose a new important technique to secure the working of incumbent, licensed radio services. Their studies suggest that collusion may improve the usage and spectrum sharing while causing no interference to the primary system. They have analysed the use of cooperation in both centralized and decentralized networks. They have proposed some methods for securing the incumbent users from the harmful interference by controlling the transmit power of the cognitive transmitter and dynamically allocating the cognitive users to the available channels using scheduling schemes.

In [4] proposed a precoding scheme based on the interference minimization for multiple-input multiple-output (MIMO)-based cognitive (CR) networks. The proposed precoder is to get the highest sum capacity through the reduction of interference power. With the lowest singular value of the interference channel, by choosing a channel with the proposed pre-coder, the transmitter transmits the information signals through the channel which produce the lowest interference in the system.

A novel model of MIMO cognitive radio for single primary transmitter was exploited in [5]. They design a MIMO-CCRN structure by seeing both the temporal and spatial domains to increase the efficiency of spectrum. They have formulated a model using a Stackelberg game to get highest utilities of PUs and SUs. The results show that both primary and secondary users obtain maximum utility by leveraging MIMO spatial cooperation in MIMO CCRN than with ordinary schemes.

In [10] has exploit the MIMO design using FPGA Based with suitable Signal Processing Algorithms which will improve Channel capacity, Bandwidth, High data rate transmission, Power requirement, Bit Error Rate, Size, Complexity and Reliability of connectivity in available limited frequency resources.

3. System Model

Our system will be consisting of two transmitter-receiver pairs of primary user (PU) and in between this primary transmitter and receiver we have four transmitter-receiver pair of secondary users (SU).We consider a secondary network consisting of K = |S| transmitter-receiver pairs, which is denoted by (STi, SRi) respectively, $i \in S$. SUs are equipped with three MIMO antennas. And two main primary user (PU) with a single antenna each. The complete transmission of the primary transmitter to the primary receiver is divided into two frames and we use T to represent the frame duration (FD). The primary transmitter can select any pairs of secondary transmitter-receiver pairs to help as relay in the cooperative transmission, denoted as R. Either secondary transmitter (ST) or secondary receiver (SR) in each pair can be the selected relay. Figure-1 shows the frame structure that we will use.

By allowing the secondary relay to participate in cooperative transmission the primary users share its spectrum in return for relaying its transmission. During this cooperative communication of primary and the secondary relays, the frame duration of the transmission is time-divided into two phases. In the phase one with duration αT, the primary transmitter (PT) transmits the signal of primary transmitter to the selected secondary relays(R). Then in the phase two with a time duration of (1 − α)T, those selected secondary relays transmits the data to the Primary Receiver (PR). The SUs' cooperation, the channel will be granted to the relays for their own traffic.

Phase-I:

Figure-1 shows the system architecture. In this model, there are $|R| = 4$ pairs of SUs. We assume the primary transmitter selects SR1, SR2, ST3 and ST4 for the cooperative relays. In phase-I, PT transmits its signals to the selected relays. For the secondary network, the pairs with selected SR as the relay can access the channel of the primary user in this phase in a time division multiple access fashion. In our model, we select the following pairs (ST1, SR1) and (ST2, SR2). We use S1 to denote the set of such pairs. Thus, Phase-I is further divided into |S1| sub slots (|S1| = 2 in our model), one for each pair. In a symmetric way, the selected pairs ST2 and SR2 work as a relay, denoted by S2. This pairs have the permission to access the channel in Phase-II. It is obvious that S1 and S2 are disjoint sets and $S1 \cup S2 = R \subseteq S$.

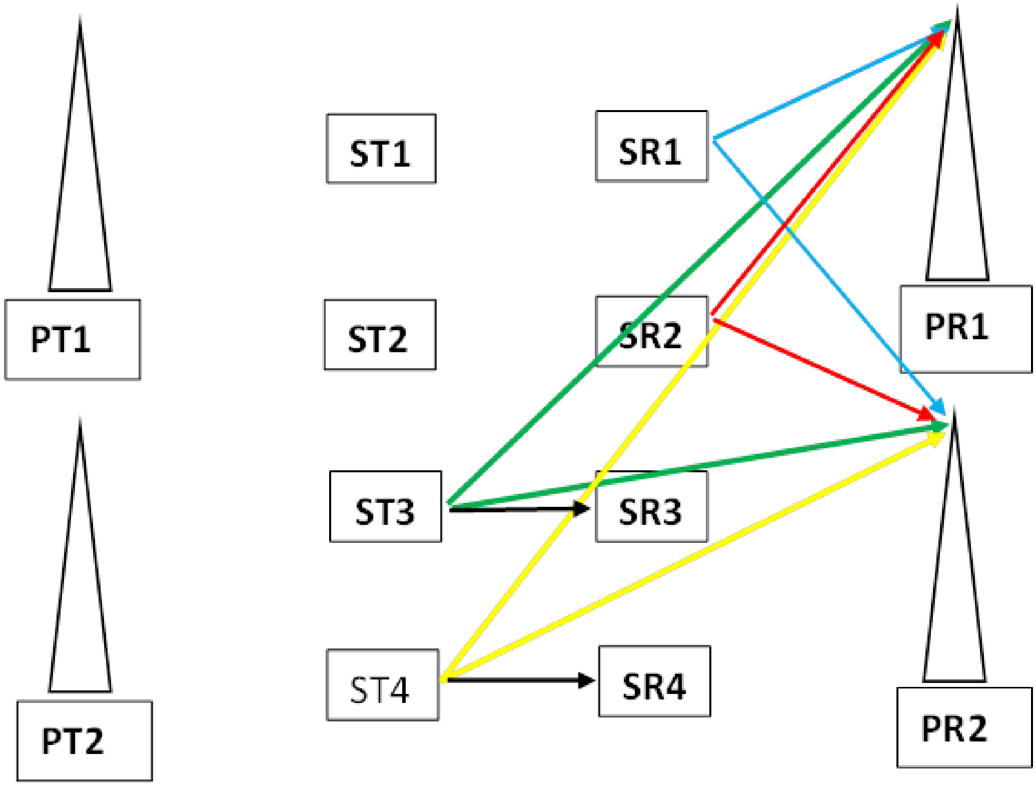

Figure-1: Phase one transmission.

We use h_{1r} and h_{2r} to represent the channel coefficient vector from PT_1 and PT_2 to the relay node r, ∀r ∈R. Note this node stands for SRr if r ∈ S1 and STr if r ∈ S2. The channel coefficient from STi to the relay node r, ∀i ∈ S1, r ∈ R is represented by matrix H_{ir}. If a frame of time duration of length $T_k^{(1)}$ is allotted to the pair (ST_k, SR_k), k ∈ S1 in Phase-I. By virtue of multiple antennas, SR_k can receive both streams from PT_1, PT_2 and ST_k simultaneously in this sub slot. We further denote the primary stream as *sp* and the stream transmitted by ST_k in this sub slot as *sk*. The transmission powers of PT and ST_k are P_p and $P_{(s)}{}^k$ respectively. Each PT applies an encoding vector α_1 and α_2 respectively for PT_1 and PT_2. If ST_k applies an encoding vector $u(s)^k$ on *sk*, then the received signal on each relay r in this sub-slot is

$$S_{r,k}^{(rec)} = \alpha_1 h_{1r} sp + \alpha_2 h_{2r} sp + H_{kr} u_k^{(s)} sk + n, \quad \forall r \in R, k \in S1 \dots\dots\dots\dots (1)$$

Then each of the relay *r* can use a decoding vector $v^{(p)}{}_{r,k}$ for decoding the primary signal, by letting $v^{(p)\dagger}{}_{r,k} H_{kr} u_k^{(s)} = 0$. The resulting primary signal on r is then

$$S_{r,k}^{(p)} = v_{r,k}^{(p)\dagger} \alpha_1 h_{1r} sp + v_{r,k}^{(p)\dagger} \alpha_2 h_{2r} sp + v_{r,k}^{(p)\dagger} n, \quad \forall r \in R, k \in S \dots\dots\dots\dots (2)$$

Then the SR_k relays, uses different decoding vector $v^{(s)}{}_k$ for decoding the secondary signal for itself. By letting $v^{(s)}{}_k \alpha_1 h_{1r}$ *sp*= 0, and $v^{(s)}{}_k \alpha_2 h_{2r}$*sp*= 0 its own stream sent by ST_k can be decoded as

$$s_k = v_k^{(s)\dagger} H_{kk} u_k^{(s)} s_k + v_k^{(s)\dagger} n, \ \ k \in S_1 \qquad (6.3)$$

As in phase-I we can see that, the selected relays incessantly receive the primary signals from the PT, simultaneously those selected pairs in set S1 accomplish their own transmissions in their respective sub slots.

Phase Two:

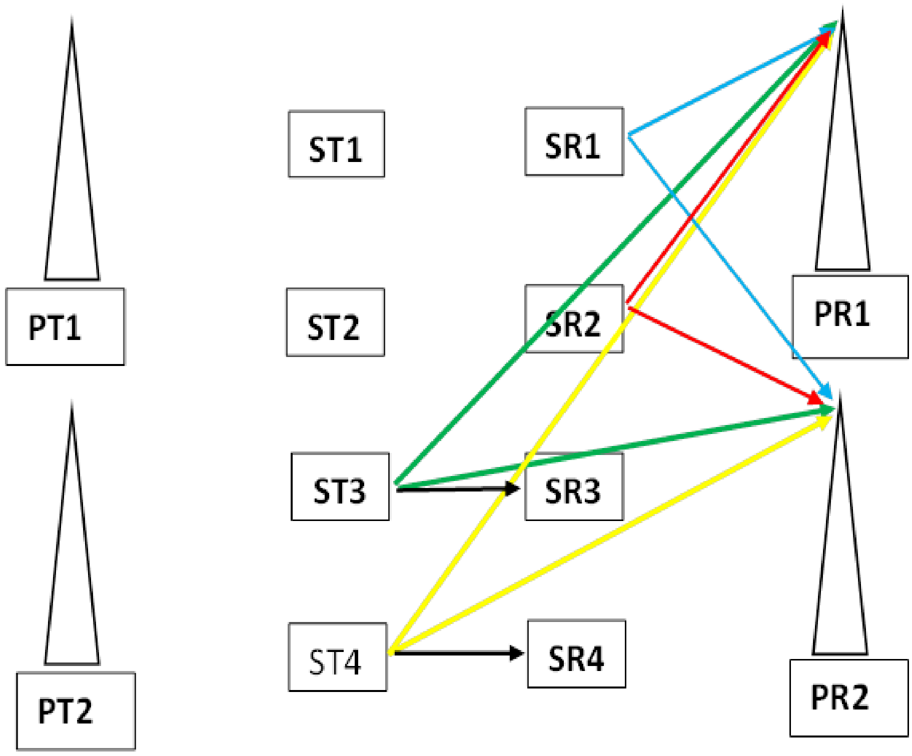

Figure-2: Phase two transmissions.

In Phase Two, similar idea can be applied as in Phase One. The selected relays all together forward the primary data to the respective PR, and at the same time the pairs in the sub set S2 will use the channel spectrum in a TDMA fashion. As in Figure-2 (ST3, SR3) and (ST4, SR4) share the channel by dividing it into two sub slots, one for each pair. We use Hri to denote the channel coefficient matrix from relay r to SRi, ∀r ∈R, i ∈ S2, and h_{r1}, h_{r2} is used to represent the channel coefficient vector from relay r to PR_1.and PR_2. Also, the node r stands for SRr if r ∈ S1 and STr if r∈S2.Without ambiguity, we keep using *sp* and *sk* to represent the primary signal and the secondary signal ST_k sends. Suppose a sub slot of length $T_k^{(2)}$ is allocated to the pair (ST_k, SR_k), k ∈ S2. Since ST_k has three antennas, it can send both secondary and primary signals to the primary transmitters and SR_k respectively without causing much interference. Precisely, each relay r (including ST_k) send *sp* encoded by $u_{r,k}^{(p)}$. Simultaneously, ST_k also sends its own signal *sk* encoded with vector $u_k^{(s)}$ using power $P_k^{(s)}$, which is united with the primary signal it sends. We use *Pr*, r ϵ R to represent the transmission powers used by relay transmitter for relaying. If $u_k^{(s)}$ is taken so that $H_{rk}u_k^{(s)}= 0$, the secondary signals from ST_k is totally removed at the PR. The signal received by PR is then

$$s_k = \sum_{r\in R} \sqrt{Pr_k}\alpha_1 h_{r1} sp u_{r,k}^{(p)} + \sum_{r\in R} \sqrt{Pr}\,\alpha_2 h_{r2} sp u_{r,k}^{(p)} + n \qquad (6.4)$$

Moreover, the received signal for SR_k in this sub-slot is

$$s_k^{(rec)} = \sum\nolimits_{r\in R} \sqrt{Pr_k} H_{rk}\alpha_1 u_{rk}^p sp + \sum\nolimits_{r\in R} \sqrt{Pr}\, H_{rk}\alpha_2 u_{rk}^p sp + H_{kk}u_k^s sk + n \qquad (6.5)$$

The first two terms in above Eqn. is the primary signal summed over all the relays. The third term is the secondary signal transmitted by ST_k. The secondary signal stream *sk* can be decoded by taking a decoding vector v(s) k so that the primary signal will be cancelled. These results in

$$s_k = v_k^{(s)\dagger} H_{kk} u_k^{(s)} sk + v_k^{(s)\dagger} n, \qquad k \in S2 \qquad (6.6)$$

In phase two the relays incessantly forward the primary signal to the PR, while those pairs in S2 complete their own transmissions in their particular sub slots.

1) Primary Link:

Since in phase one there are many relays during the downlink, the sum-rate can be represented by the worst channel in the subset r ∈ R. Then according to Eqn. (6.3), in the sub slot when STk is transmitting, the downlink rate is:

$$R_k^{(PS)} = log_2\left(1 + \frac{min_{r\in R}\left|V_{r,k}^{(p)\dagger}\alpha_1 h_{1r} sp + V_{r,k}^{(p)\dagger}\alpha_2 h_{2r} sp\right|^2 Pr}{N_0}\right) \quad k \in S1 \quad (6.7)$$

In phase two the effective SNR of primary receiver equals the sum of all the SNRs from the secondary relays. Based on Eqn (6.7), the total sum-rate at the receiver is given as

$$R_k^{(PS)} = log_2\left(1 + \sum\nolimits_{r\in R}\left|\frac{\alpha_1 h_{1r} u_{rk}^{(p)} + \alpha_2 h_{2r} u_{rk}^{(p)}}{N_0}\right|^2\right) \quad k \in S2 \qquad (6.8)$$

Moreover, denote the channel gain from PT to PR as h_P. Then in the trivial case when the secondary cooperation is not applied, the rate of the direct transmission from PT to PR is

$$R_{dir} = log_2\left(1 + \frac{|hp|^2 Pp}{N_0}\right) \qquad (6.9)$$

2) Secondary Link:

We assumed that for each secondary relay pair, secondary transmitter will have a fixed power level $P^{(s)}$ k for communicating the secondary data. Based on Eqn. (6.1) and Eqn. (6.2), the transmission sum- rate of secondary relays (ST_k, SR_k) in the both the phases can be shown as

$$R_k^{(s)} = log_2\left(1 + \frac{\left|V_k^{(s)\dagger} H_{kk} u_k^{(s)}\right|^2 P_k^{(s)}}{N_0}\right), \quad \forall k \in R \qquad (6.10)$$

4. Simulations Results and Analysis:

In this paper we have analysed the simulate results of the sum-rate performance for the proposed system model by varying its different parameters such as, the distance between the primary transmitter and the secondary receiver, and also observing the sum-rate performance for different power level while keeping the distance constant.

4.1 Downlink System Sum-Rate Results:

Here we have considered the path loss exponent *n*=3.8, and the thermal noise level is -96dBm and also for the observation the downlink power is kept constant for the whole observation at 10dB. Taking these parameters, we observe the result for three different type of precoding technique i.e., SVD, ZF and MMSE by varying the distance between the primary transmitter PT1 and the secondary relay receiver in our system model. The figure-3 shows the total sum-rate performance of primary transmitter PT1 toward the entire primary relay receiver for different distances between them. As we can see from the graph that if the distance between the primary transmitter and the secondary relay receiver is increased the data rate decreases irrespective of precoding schemes. For this transmission the SVD precoding give the best performance, while ZF and MMSE gives the approximately the same results.

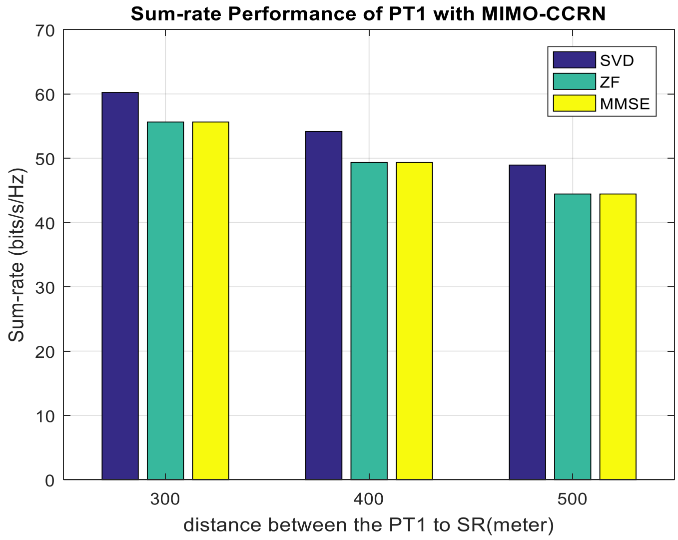

Figure-3: Average sum-rate performance of PT1 to the all secondary receiver.

Here also the parameters values of the thermal noise level, downlink power path loss exponent of the system is same as mentioned figure-3. Similarly, the total sum-rate of the primary transmitter PT2 to all the selected secondary relays in the cooperative cognitive radio network is shown in the figure-4. The sum-rate of the transmitter is observed by varying the distance between the PT2 and the SRs for different precoding technique. The SVD precoder gives the highest performance.

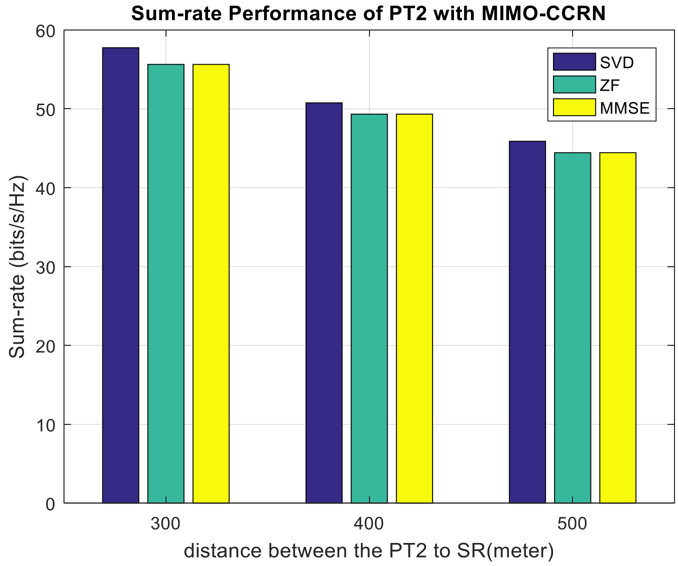

Figure-4: Average sum-rate of primary transmitter PT2 to the entire secondary relay receiver.

In the cooperative communication the secondary users act as the relay between the distant primary transmitter and primary receiver. In our observation we have varied the distance between the primary to secondary while keeping the secondary system unchanged i.e. the distance between the secondary transmitter and the secondary receiver for self-communication is fixed to 50m, the sum-rate for both the secondary pairs in the phase one is shown below.

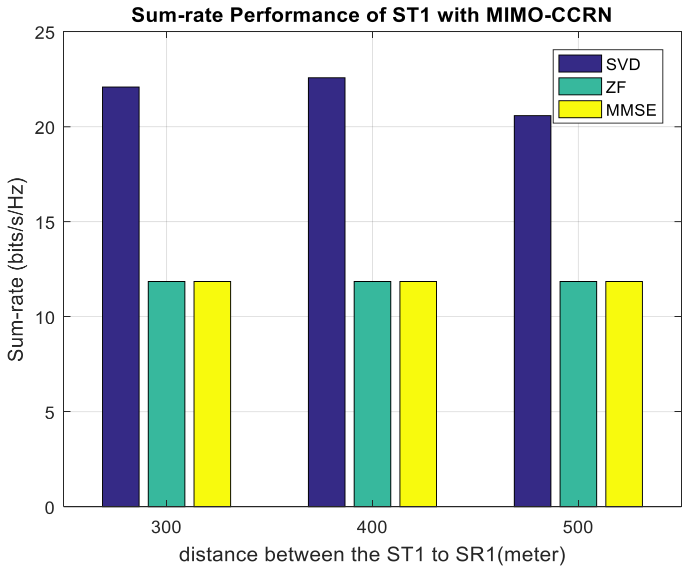

Figure-5: Average Sum-rate of ST1 to SR1

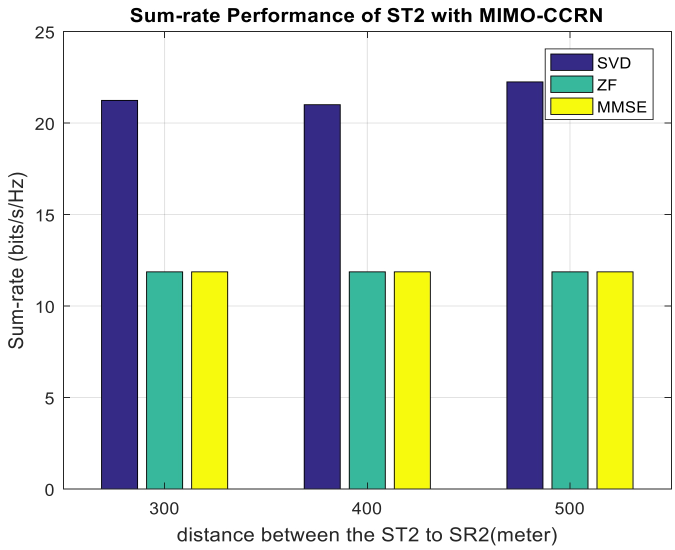

Figure-6: Average Sum-rate of ST2 to SR2

In both the figure-5 and figure-6 we can see the sum-rate for the secondary transmission. Here we can see in both graphs that varying the distance between the PT and the secondary relay does not affect the secondary transmission unless the distance between the ST and SR is changed.

Now we will set the distance between the primary transmitter and the secondary relay receiver to 400m and vary the downlink power from 0dB to 20dB and observe the sum-rate performance of all the transmitters. The channel parameter is same as before.

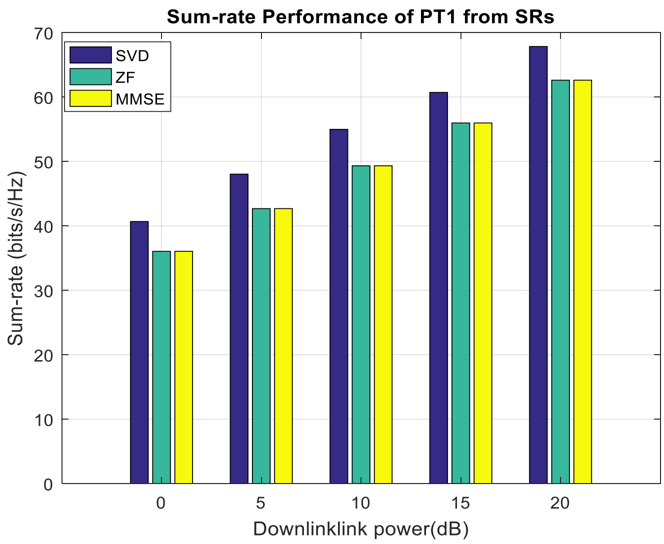

Figure-7: Average sum-rate of PT1 to SRs

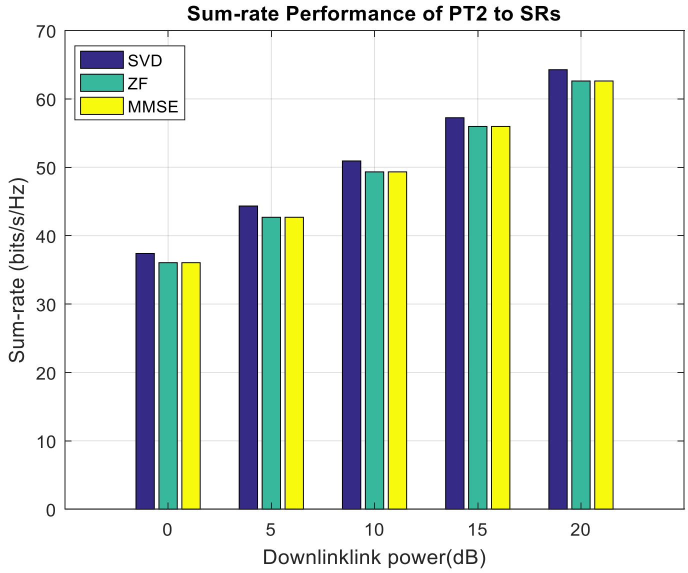

Figure-8: Average sum-rate of PT2 to SRs

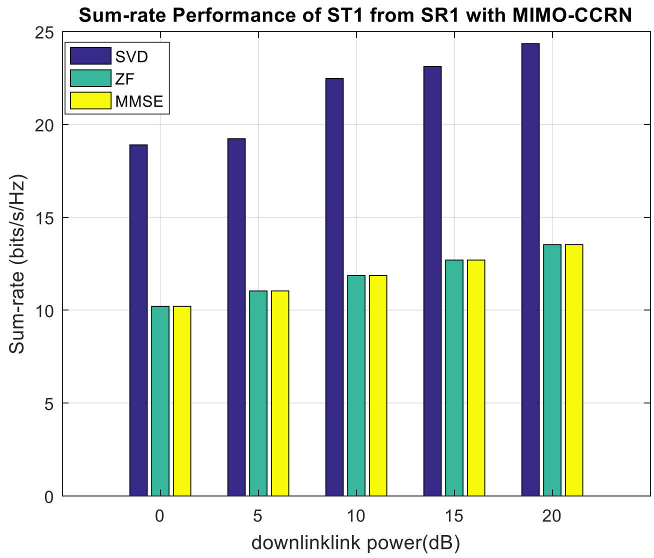

Figure-9: Average Sum-rate ST1 to SR1

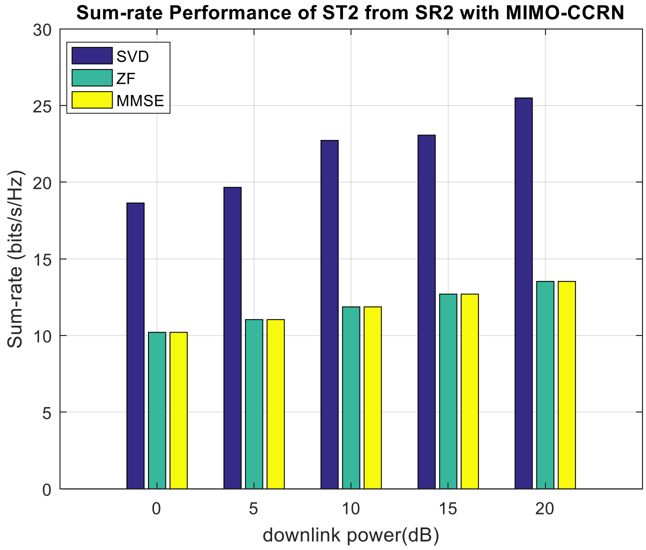

Figure-10: Average Sum-rate of ST2 to SR2.

The above figure-7, 8, 9 and 10, show the sum-rate of transmitters PT1, PT2, ST1 and ST2 respectively. Here we have observed that sum-rate is proportional to the transmission power. If the distance between the transmitter and receiver is fixed, the sum-rate increases with increase in power.

Considering the channel noise level to be 1 and also assuming the distance between the primary transmitter and the secondary relay to be unity we find the sum-rate by varying the SNR values of the transmission path.

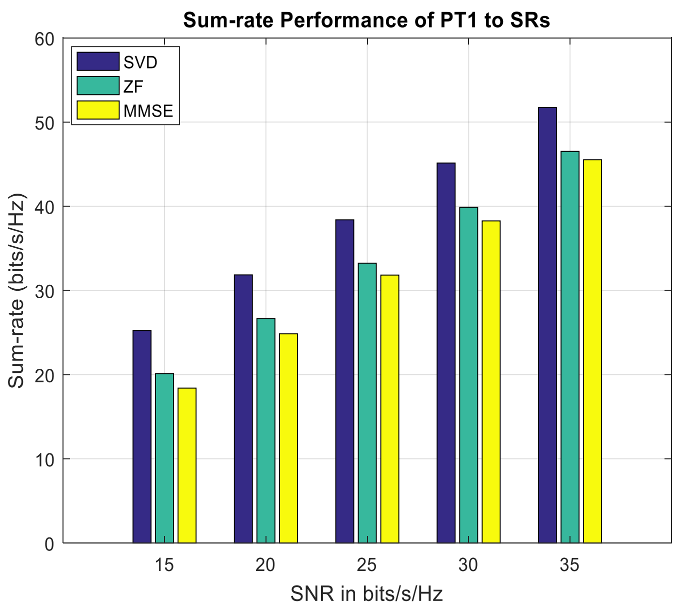

Figure-11: Average Sum-rate of PT1 to the secondary relays.

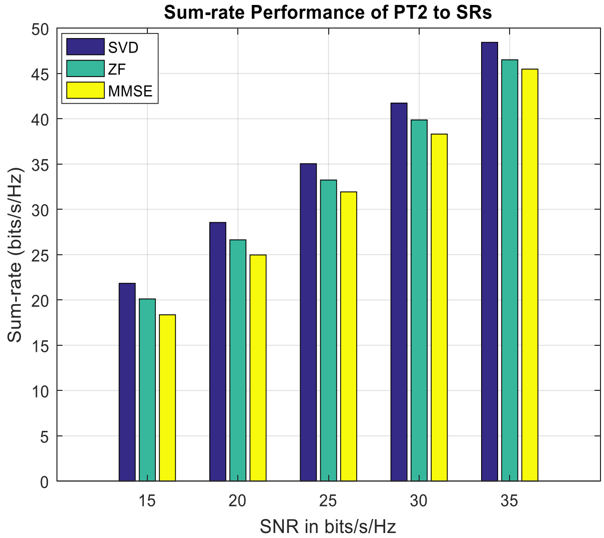

Figure-12: Average Sum-rate of PT2 to secondary relays.

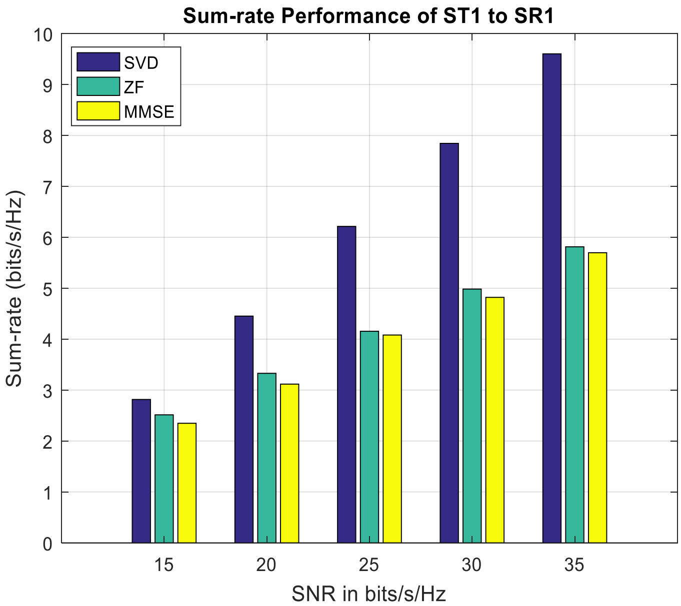

Figure-13: Average Sum-rate of ST1 to SR1

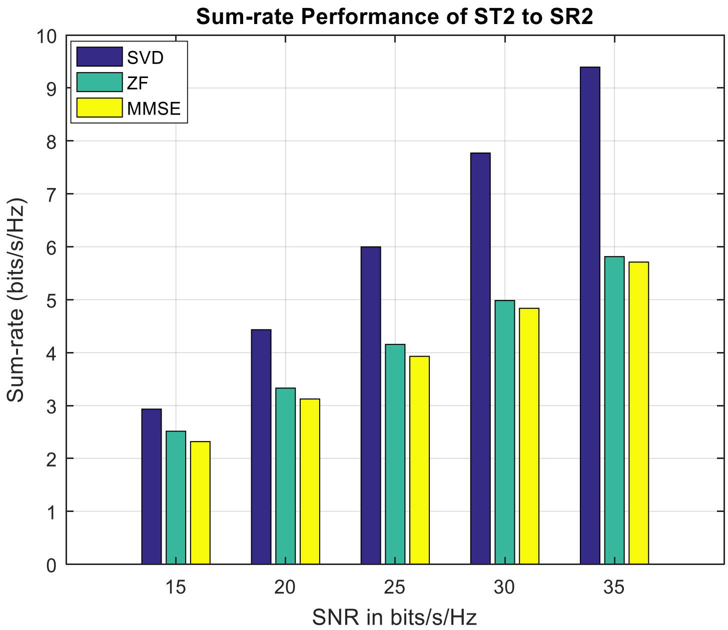

Figure-14: Average Sum-rate of ST2 to SR2

From simulation results we get that with increase in the SNR value we get a higher average sum rate.

CONCLUSION

This system model of MIMO-CCRN shows the cooperative communication using MIMO antennas at the secondary networks. This secondary network acts as the relay and helps to communicate the primary network which is at a far distance away. According to our simulation results we get to know the parameter which causes degradation to the sum-rate. We have seen that distance affect so much to the sum-rate of a transmission, with increase in distance the sum-rate decrease. On the other hand the power seems to be directly proportional to the sum-rate performance. On basis of the precoding technique the SVD give out the overall best performance for the MIMO-CCRN.

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