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ANALYSIS OF OUTAGE PROBABILITY, THROUGHPUT IN HYBRID COGNITIVE RADIO NETWORKS WITH AND WITHOUT TRANSCEIVER IMPAIRMENTS

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ABSTRACT

Cognitive radios in wireless networks is the efficient way of sensing and accessing the spectrum dynamically. In this paper we analyze the outage probability and capacity of hybrid network model in cognitive radios considering transceiver impairments. Every physical device has hardware impairments which degrades the performance of the system. Majority of technical contributions in wireless communications neglect transceiver impairments, assuming ideal hardware. Transceiver impairments like IQ imbalance, phase noise etc. have greater effect on system performance. A hybrid overlay/underlay transmission scheme has been proposed. This transmission method takes the effect of transceiver impairments into consideration and finds the best channel; best relay and best relay power. In this we develop a simulation test model to evaluate the performance and outage probability of hybrid model considering transceiver impairments. The manuscript provides how the effect of hardware impairments can be modeled. The manuscript also provides the analysis of the proposed hybrid cognitive radio model with the help of a case study, which considers various practical aspects.

Keywords: hybrid network, hardware impairments, outage probability, IQ imbalance, phase noise, non-linearity, overlay, underlay.

1. INTRODUCTION

Unavailability of bandwidth is not due to the scarcity of spectrum but it is due to inefficient utilization of spectrum. Advances in recent wireless technologies provided means for efficient spectrum utilization through dynamic spectrum access techniques. Cognitive radio technique is one of such type. Cognitive radio has three major implementation paradigms interweave, underlay and overlay [1-2]. Among these overlay and underlay are two transmission techniques which allow secondary users to exist with the primary users simultaneously. In this paper wedesigned a hybrid overlay/underlay spectrum access strategy consists of both traditional overlay and underlay strategy features.

In interweave paradigm, the spectrum of primary user is sensed by the secondary user and identifies holes in the spectrum i.e. frequencies that are not used by the primary users. Decision regarding best channel is taken by receiver [3].

In underlay approach primary and secondary user transmission occur concurrently. Secondary users transmissions are limited by interference threshold kept to shield primary user's transmissions. The interference generated by the secondary user transmission should not be more than the interference thresholds set by the primary receiver [4] .Only secondary users are benefited by this mode of transmission as they do not provide any service to primary user.

In overlay paradigm secondary users are used as relays for relaying primary user data. Concurrent transmission happens with highest priority to primary users and least priority to secondary users. Thus there is no need for setting an interference threshold. Interference caused by secondary users is compensated by the SNR produced by secondary users to primary users [5]. Hence both primary and secondary users are benefited equally in overlay paradigm.

In this paper the proposed hybrid underlay/overlay model provides method for selecting best channel, best relay and best relay power. This protocol takes into consideration power of primary user transmitter, interference threshold and spectral distances between primary and secondary user channels and distance between primary and secondary user channels.

Most recent studies in this area of study consider that the transceiver hardware as ideal one. But, in practice every transceiver hardware suffers from some impairment which degrades the performance of the system like IQ imbalance, amplifier amplitude-amplitude non linearity's, phase noise etc [6-9]. Impairments create capacity limitation which cannot be overcome by increasing transmitting power. Thus hardware impairments have a significant role mainly in high power systems. Despite the importance of hardware impairments only limited works investigate their effect on transceivers [10-11].

In this paper we design a hybrid underlay/overlay model. Unlike the previous work done on hybrid models which maximize the secondary user throughput we aim to maximize the primary user power and to avoid detrimental interference. While maximizing the throughput we also considered transceiver impairments of transmitter and receiver for attaining accurate throughput results.

The remaining of this paper is structured as follows: Section II, analyze the system model of hybrid cognitive network describing its primary and secondary users and method of relaying as both overlay and underlay methods. Section III, presents the throughput calculation of the hybrid model without considering hardware impairments. Section IV, presents throughput and outage probability calculation for hybrid model considering

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transceiver impairments. Section V, we have considered a case study which provides a model for hybrid underlay/overlay cognitive radio considering TV spectrum as a primary network and different secondary users. Section VI presents simulation results for hybrid model with and without hardware impairments; this section also gives the results of above mentioned case study with interference and power constraints.

2. SYSTEM MODEL

The proposed hybrid model we designed consists of primary transmitter, primary receiver and a set of cognitive users. These secondary users are of two kind's idle secondary users and active secondary users. The primary user is well conscious of the secondary nodes. This protocol helps in selecting best relay and best power constraints for primary user transmissions. The secondary user idle nodes acts as relays and helps in relaying primary user data while the secondary active users transmits simultaneously. [12-18] Consider X number of idle cognitive users and Y number of active cognitive users. Out of these X cognitive users one cognitive user is preferred as superlative relay for relaying between primary transmitter and secondary transmitter. Only inactive relays involve in relay selection process, active relays does not involve in relay selection. Active secondary user transmits data while the idle secondary user is in relay selection procedure causing interference to primary transmission and also idle secondary user [19-22]. Out of available K channels and X secondary idle users best channel and best relay are selected such that secondary transmissions cause minimal interference to primary transmission.

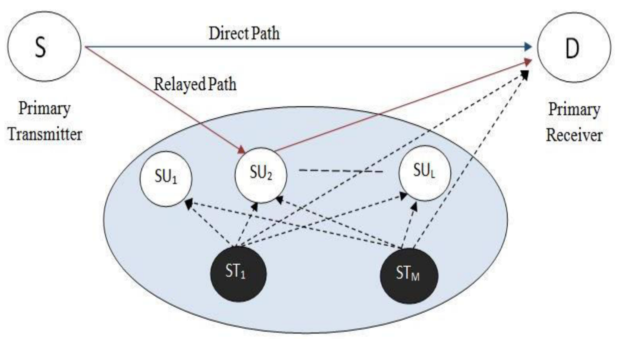

Figure-1. System model of hybrid networks.

3. THROUGHPUT

In this section we calculate the capacity for the hybrid overlay, underlay networks considering hardware impairments. The below is the algorithm which is used to calculate capacity. We consider the channels over links $P(TR)_x$-$P(RE)_x$, $S(TR)_i$-$P(RE)_x$, $P(TR)_x$-$S(UR)_j$, $S(UR)_j$-$P(RE)_x$ and $S(TR)_i$-$S(UR)_j$ are subjected to Rayleigh flat fading plus AWGN. Here P stands for primary user, S stands for cognitive user, TR stands for transmitter, RE stands for receiver and UR stands for user. Let P_{pt} be the primary transmitter power, P_{st} be the secondary transmitters transmit power. The following is the notations for link gains of the channels $\alpha_{(p(tr)x-p(re)x)}$ is the link gains over the link $P(TR)_x$-$P(RE)_x$. $\alpha_{(s(tr)i-p(re)x)}$ is the link gain over the link $S(TR)_i$-$P(RE)_x$. $\alpha_{(p(tr)x-s(ur)j)}$ is the link gain over the link $P(TR)_x$-$S(UR)_j$. $\alpha_{(s(ur)j-p(re)x)}$ is the link gain over the link $S(UR)_j$-$P(RE)_x$. $\alpha_{(s(ur)j-p(re)x)}$ is the link gain over the link $S(TR)_i$-$S(UR)_j$. 'n' is the distance dependent path loss factor. The power strength of the received signal P_{pr} is given by

$$P_{pr} = \frac{(\alpha(ptrx-prx)*Ppt)}{(d(ptx-prx))^\wedge(n))} \quad (1)$$

If ST_i are active cognitive users, then the strength of interference power P_i^1 at the $P(RE)_x$ can be associated to power transmitted by P_{sti} by secondary transmitter $S(TR)_i$ is given by

$$P_i^1 = \frac{(\alpha(sti-prx)*Psti)}{d(sti-prx))^\wedge(n)} \quad (2)$$

for the links $P(TR)_x$-$P(RE)_x$, SNIR at primary receiver can be defined as

$$SNIR_{p(tr)x-p(re)x} = \frac{Ppr}{\sigma p^2+\sum_{i=1}^{Y} Pi^1} \quad (3)$$

σ_p^2=variance of awgn on primary TRx to RExlink. So the attainable rate R_{target} for the links $P(TR)_x$-$P(RE)_x$ is given by

$$R_{target} = \log_2(1 + SNIR_{ptx-prx}) \quad (4)$$

When power transmitted by the primary transmitter is P_{pt}, the received power at relay $S(UR)_j$ is

$$P_{suj} = \frac{(\alpha(ptx-suj)*Ppt)}{(d(ptx-suj))^\wedge(n))} \quad (5)$$

Active cognitive users cause interference to the idle secondary users. Interference power strength P_{ij}^1 of $S(UR)_j$ is given by

$$P_{ij}^1 = \frac{(\alpha(sti-suj)*Psti)}{(d(sti-suj))^\wedge(n))} \quad (6)$$

from user i to user j the amount of interference induced is defined as P_{ij}^1. In order to send data to different relays, different channels are sensed by primary transmitter. The rate attained at idle cognitive users is given by

$$R_{p,s(ur)j} = \frac{1}{2}\log(1 + \frac{Ps(ur)j}{\sigma j^2+\sum_{i=1}^{Y} Pij^1}) \quad (7)$$

σ_j^2=variance of AWGN on idle cognitive users link, primary transmitter. $P_{j,k}^{rate}$ is the rate on transmitter to relay link and relay to receiver link , it is stated as follows:

$$\frac{((2^{2Rp,s(ur)j}-1)(\sigma j^2+\sum_{i=1}^{M} Pij^1)d_{s(ur)j-p(re)x})}{\alpha_{s(ur)j-p(re)x}} \quad (8)$$

σ_k^2=variance of AWGN on primary user and inactive cognitive users link. For every relay 'j' and channel 'k', for every relay, we found the maximum allocate power by using

$$P_{j,k}^{max}=\frac{I_{th}}{\Omega_{j,k}} \quad (9)$$

Where $\Omega_{j,k}$= channel interference factor ;I_{th} = interference threshold;α= channel gain; T_s= sampling time; d_k=distance between the subcarrier k and channel of primary user, B=channel bandwidth of primary user.

Therefore, final allocated power for every relay $s(ur)_j$ over the channel k is

$$p_{j,k}=\min(P_{j,k}^{max},P_{j,k}^{rate}) \quad (10)$$

Optimal pair (j,k) is given by

$$(j^{opt},k^{opt})=\text{argmax}\ (Power_{j,k}^{re}) \quad (11)$$

The throughput rateof the signal that arrives at the PU receiver over the best relay link and channel pair is

$$R=\frac{1}{2}\log(1+\frac{power_{jopt,kopt}^{re}}{\sigma k^2+\sum_{i=1}^{Y}Pi^1}) \quad (12)$$

if$R_{p(re)x}$>R_{target}, we prefer the relay path considering that the primary user channel is ruined due to fading or shadowing.

4. TRANSCIEVER IMPAIRMENTS

Distortion models are existing for different sources of transceiver impairments for example IQ imbalance, phase noise etc in [13] for detailed description of hardware impairments. The combined influence is well modeled in a general way in [13].This model is supported by many studies [13-14].

We considered system parameter K. These design parameters K_T,K_R characterizes the level of impairments in respec0tive systems.

$$K_T,K_R \geq 0. \quad (13)$$

K_T indicates impairment levels in transmitter and K_R indicates level of impairments in receiver. These values are taken as Error Vector Magnitudes (EVM).It is a quality measure of RF transceivers which measures the joint impact of different hardware impairments, it can be measures directly [15]. Error vector magnitude is the ratio of the magnitude of distorted signal to the magnitude of average signal. As in [11] it will be sufficient to calculate the aggregate level of impairments $K=\sqrt{K_T^2+K_R^2}$ of the channel without specifying the exact contribution from the transmitter and receiver hardware's. In an ideal hardware case K=0, which represents K_T=0 and K_R =0.The level of impairments K_I depends on SNR [16-17]. Thus in our analysis we consider fixed SNR_i thus considering fixed K_i value. Thus taking a range of EVM values of a system we have considered k value to be 0.2 as at that value system experiences highest distortion. By considering the effect of hardware

$$\Omega_{j,k}=\alpha T_s\int_{(dk)-(\frac{B}{2})}^{(dk)+(\frac{B}{2})}\left(\frac{\sin(\pi f Ts)}{\pi f Ts}\right)^2 df \quad (14)$$

impairments we have calculated the capacity for the hybrid model in the same manner as we have done in section (ii). In this section we have calculated capacity and outage probability for paradigms underlay, overlay and hybrid models. Capacity for a hybrid model calculated using

$$R_{PR_x}=\frac{1}{2}\log(1+\frac{power_{jopt,kopt}^{Re}}{\sigma_k^2+\sum_{i=1}^{M}p_i'}) \quad (15)$$

For the above equation when we consider hardware impairments, the capacity of the system slightly changes in detail the capacity of system decreases because of the impairments considered. Considering these we can formulate that design parameter K which represents hardware impairments is inversely proportional to capacity and as SNR varies with K value this also exhibits similar characteristics.

$$R_{target}=log_2(1+k^2*SNIR_{PT_x-PR_x}) \quad (16)$$

$$\text{And}R_{PR_x}=\frac{1}{2}\log(1+\frac{power_{jopt,kopt}^{Re}}{\sigma_k^2+k^2*\sum_{i=1}^{M}p_i'}) \quad (17)$$

Though the effect of k value is minimal in overall system performance it should not be neglected. Significance of K value is to be recognized to analyze the exact performance of the system. Though the hardware impairments shows a minimum effect at low SNR's but are very interrupting at high SNR's. Outage probability of SINR at input of the primary receiver is below the certain threshold value is known as the outage probability. Outage analysis of the system is performed by using

$$p_{outage}=prob[SINR<th] \quad (18)$$

p_{outage}=outage probability; SINR=signal to interference plus noise ratio; th=interference threshold value. As we consider the transceiver impairments the probability of occurrence of outage is significantly high.

5. CASE STUDY

We considered a real time scenario to analyze the performance of the hybrid cognitive radio networks. In this case study, we considered four inactive secondary sources and two active secondary sources along with the primary transmitter and receiver. We designed a hybrid network model, considering the following: TV transmitter as primary transmitter at coordinates (0, 40), TV receiver as primary receiver at coordinates (50,40), for idle secondary users we considered short wave radio at (1, 40), baby monitor at (3, 40), walkie talkie at (14, 40), wireless microphone at (20, 40). Family radio service at (15, 20)

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and mobile phone at (30, 20), are taken as the two active secondary users. Throughput for direct path remains same as 5.5614e+05 with varying interference threshold values. For varying powers throughput at a node remains constant for direct path.

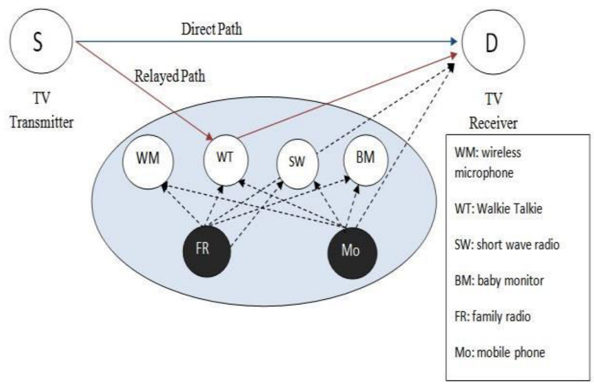

Figure-2. System model for case study.

In the above model each transmitter and receiver were selected considering their hardware impairments so asto provide with exact throughput and capacity calculations for the hybrid model.

Table-1. Throughput for all the idle secondary users for varying interference threshold.

Ith / Node	2*10^-3	3*10^-3	4*10^-3	5*10^-3	6*10^-3	7*10^-3
1(WIRELESS MICROPHONE)	3.6033e+05	4.8523e+05	5.8916e+05	6.7785e+05	7.5497e+05	8.2303e+05
2(WALKIE TALKIE)	3.6663e+05	4.9297e+05	5.9786e+05	6.8722e+05	7.6483e+05	8.3323e+05
3 (SHORT WAVE RADIO)	4.0872e+05	5.4415e+05	5.7146e+05	5.7146e+05	5.7146e+05	5.7146e+05
4 (BABY MONITOR)	3.2141e+05	3.2141e+05	3.2141e+05	3.2141e+05	3.2141e+05	3.2141e+05

Table-2. Throughput for all idle secondary users as function of varying power.

P / Node	10	20	30	40	50	60
1(WIRELESS MICROPHONE)	8.3730e+05	8.3730e+05	8.3730e+05	8.3730e+05	8.3730e+05	8.3730e+05
2(WALKIE TALKIE)	8.3323e+05	8.3323e+05	8.3323e+05	8.3323e+05	8.3323e+05	8.3323e+05
3 (SHORT WAVE RADIO)	5.7146e+05	8.6236e+05	8.9934e+05	8.9934e+05	8.9934e+05	8.9934e+05
4 (BABY MONITOR)	3.2141e+05	5.3455e+05	6.9251e+05	1.7423e+05	9.1909e+05	1.0051e+06

4. SIMULATION RESULTS

In this section, we compared the performance of overlay, underlay and hybrid networks by considering the direct path and relay path. To achieve this we used the MATLAB software for simulation purpose Rate achieved by system is shown as the function of the interference threshold and power of transmitter by considering with and without transceiver impairments for overlay, underlay, hybrid networks.

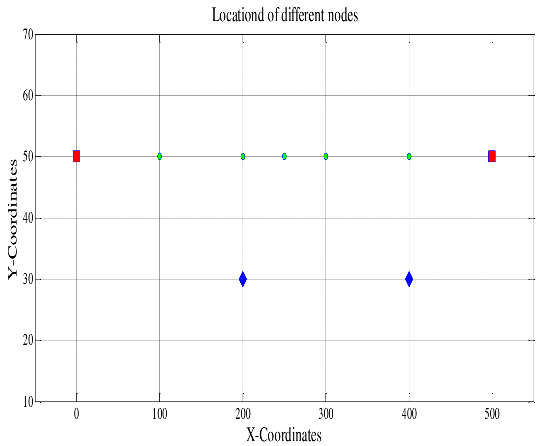

Figure-3. Location of different nodes.

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As to improve the performance of the cognitive radio networks, A Hybrid model is designed by considering two primary users and two active users. In this hybrid network we assume inactive secondary users; these users are used by the primary users to maximize their throughput. In Figure-3 at coordinates (0, 50) and (500, 50) primary user transmitter and receiver are present and at coordinates (200, 30), (400, 30) we considered the active secondary users. At coordinates (100, 50), (200, 50), (250, 50), (300, 50) and (400, 50) considered the inactive secondary users .These users act as the relays for transmitting the data from primary transmitter to the primary receiver. In this hybrid model the primary receiver search for the channel and best relay for transmission when the data rate on the direct link is less, when compared to the relay path.

In Figure-4 (i) and (ii) for Hybrid cognitive radio networks Throughput rate achieved through the direct path as function of power of transmitter and rate achieved through the relay path as a function of interference threshold are shown by considering with transceiver impairments and without transceiver impairments.

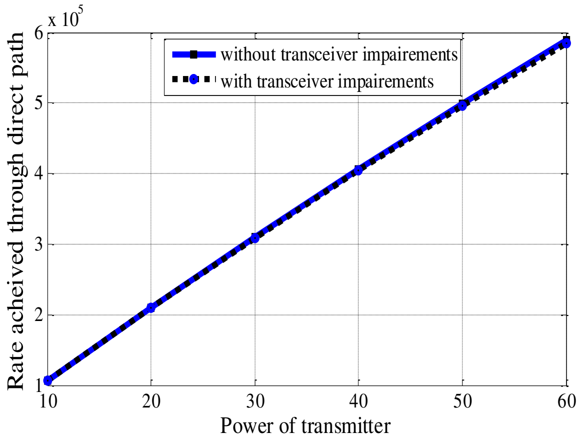

Figure-4(i). Rate achieved through direct path vs power of transmitter.

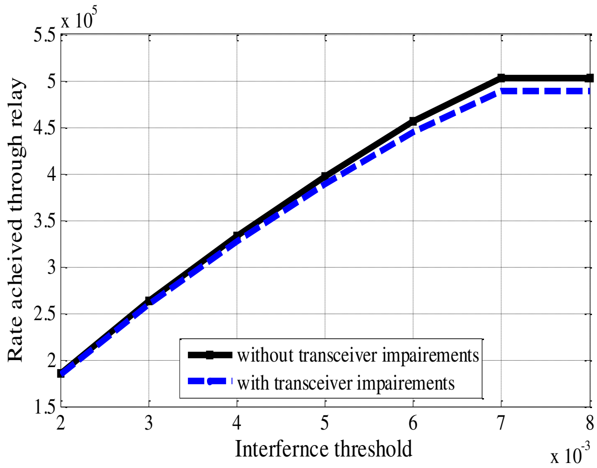

Figure-4(ii). Rate achieved through relay path vs interference threshold.

In Figure-4(i) the interference threshold is taken as the constant and throughput of the system through the direct path is calculated by varying the power of transmitter (considered in db). By considering the transceiver impairments the throughput of the network is decreasing compared to without transceiver impairments. At higher values of power of transmitter the difference between the throughput of the network with and without transceiver is significantly large. Figure-4 (ii) gives the variation in the throughput of the network by varying the interference threshold where the transmitter power is constant and equal to 10dB. After the value of interference threshold equal to 7×10^3 the throughput rate of the system remains constant in both the with transceiver impairments and without transceiver impairments is observed.

When compared to the throughput of the overlay and underlay networks individually the throughput rate of the hybrid cognitive radio network is significantly high in both, with and without transceiver impairments. Fig5 implies the comparison between the overlay, underlay and hybrid networks in both, with and without transceiver impairments. When the interference threshold value is less than the 3×10^3 w overlay approach is better for transmitting the data.

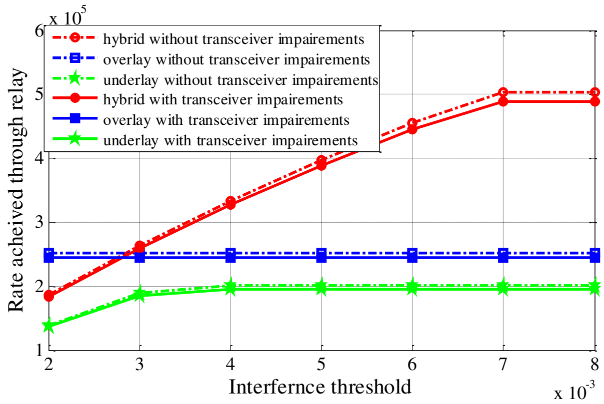

Figure-5. Rate achieved vs. interference threshold.

For interference threshold greater than 3mw hybrid overlay/underlay network model is preferred to transfer the data from primary transmitter to the primary receiver. In overlay paradigm as there is power sharing between the primary and secondary users we did not consider any interference threshold. So the throughput rate achieved by the system is constant for all the varying threshold values. In hybrid network model throughput rate of the system remains constant after the threshold level exceeds the value of 7×10^3 w.

Outage probability calculation for hybrid network model considering the with and without transceiver impairments:

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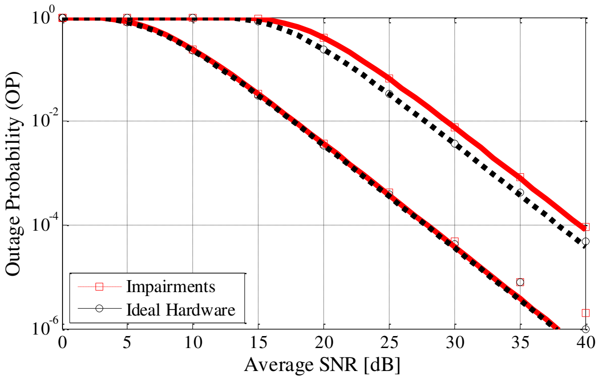

Figure-6. Outage probability vs. average SNR (dB).

When the SNR of input signal falling below the predefined threshold, there will be chance of occurrence of outage. In Figure-6 outage probability shown as the function of average SNR (dB) considering, with and without transceiver impairments.

At higher values of the SNR the chance occurring outage will be less when compared to the higher average SNR values. Figure-4 considered the threshold levels as 3mw, 31mw. Chances of outage are more at upper threshold 31 mw.

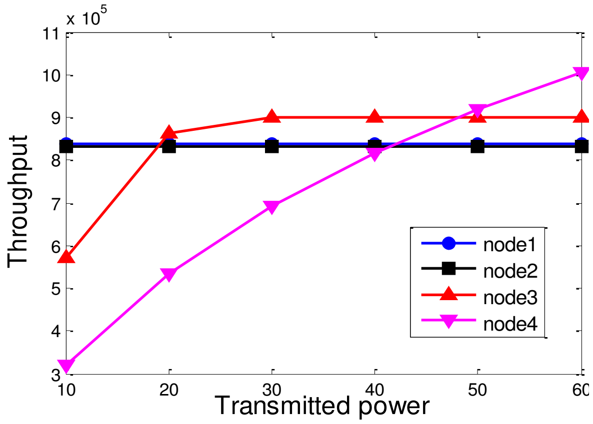

Figure-7(a). Throughput vs. power for secondary network.

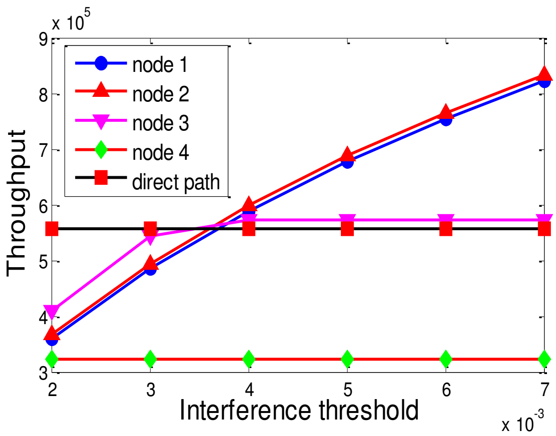

Figure-7(b). Throughput vs. Interference threshold for secondary networks.

In Figure-7 (a) and (b) for all four idle secondary users, SNR is shown as the function of transmitted power and throughput as the function of transmitted power, for transmitted power below 20dB wireless microphone is preferred as relay in hybrid cognitive networks. For the transmitted power ranging from 20dB to 45dB short wave radio is preferred as the relay and for the transmitted power greater than the 45dB baby monitor is used as the relay in hybrid network model.

6. CONCLUSIONS

In this proposed hybrid model, we have done an attempt to increase the throughput of the system when compared to overlay and underlay networks. For this proposed model, we analyzed both the throughput and outage with and without hardware impairment considerations. We have designed an algorithm which is used to identify the best relay, best channel and transmitting power of best relay for the data transmission from primary transmitter to receiver. By considering practical scenario, we designed a hybrid network model considering devices like wireless microphone, short wave radio, walkie talkie, baby monitor as the nodes in the hybrid network model. These devices operate at different frequencies and positioned at different locations. Considering these conditions the highest SNR value for node1 (wireless microphone) is 2.3281, for node2 (Walkie talkie) is 2.3815, for node3 (Short wave radio) is 1.2696, for node4 (Baby monitor) is 0.5743.when ith is the interference threshold and the value of SNR is less then ith then there is a probability of occurring outage. Even though the capacity over relayed path is better than the direct path, there is some delay over the relayed path due to processing at the node. We have to overcome this delay to make the proposed scheme more efficient.

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