Improving performance of Device to Device Communication Using Underlay Cognitive Radio Principle

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Abstract– In this report, we analyze the performance of the device to device communication in terms of throughput of the secondary network using the underlay cognitive radio principle. The unlicensed secondary network with multiple D2D pair can share the frequency band of a licensed network which is known as the primary network[1]. We assume that the interference temperature limit (ITL) is the maximum interference that can be allowed by the secondary users to the primary network[2]. To keep the transmitted signal from the primary network unaffected, the interference to the primary receiver should not exceed the ITL[3]. We demonstrate that below ITL it is advantageous to operate both secondary networks and primary network simultaneously. By user selection method the user with minimal interference is selected[4]. Here it is shown that as we increase the number of D2D pair in a secondary network and select the best pair for transmission, the throughput increases accordingly. Computer simulations demonstrate the accuracy of the derived expressions. The results have been obtained by the Monte Carlo simulation which has been simulated using MATLAB.

I. INTRODUCTION

The exponential growth in the number of mobile devices and their need for spectrum in recent days realizes a tough constraint on the spectrum as a resource. The idea of cognitive radio (CR) network gives better performance of the device to device communication by increasing the spectrum utilization efficiencies or so to say it reduces spectrum redundancy[5],[6].

By introducing CR to the fifth generation (5G) mobile networks, the primary users (base station (BS) and mobile users served by the BS) and the secondary users (mobile users non-served by the BS) can coexist in the same licensed band[4],[7],[8]. In such an underlay approach, the primary transmitted signal can be affected by the secondary interference and thus the interference should be below a certain level i.e. ITL. This approach makes the throughput to be maintained at the desired level. So, in the underlay CR mode of operation, both primary and secondary users co-exist and transmit simultaneously[9],[10].

A. Related work

Researchers have given the idea of simultaneous secondary transmissions earlier where two or more low-power cellular base station reuse the spectrum of a macro-cell (i.e. cell in a mobile phone network that provides radio coverage served by a high power cell site)[11]. The major obstacle faced to implement this underlay scheme is the increasing interferences among secondary users and dealing with interferences from secondary transmitters to the users of the primary network.

Researchers have derived an expression for the selection probabilities of cognitive users with opportunistic scheduling[12]. This technique exploits the time-varying nature and the spatial diversity of the wireless channel to make effective use of the available system bandwidth. It is shown that the equal chance for transmission amongst all cognitive users can only be achieved when the fraction of distances between the cognitive transmitter and cognitive receiver, and cognitive transmitter and primary receiver is identical for each of the cognitive transmitters.

In another work sum throughput and sum ergodic rate of two co-existing downlink multiuser underlay secondary network has been done in the scenario where ITL is apportioned and is based on the statistical parameters of the channel[2].

B. Motivation and Contribution

In this report, we assume that the secondary networks can directly share a part of a licensed spectrum as long as the interference to the primary users by the secondary transmitters is controlled under an acceptable interference temperature limit.

In the previous papers, the interference caused by the secondary network has been considered only. But it may also happen for a weak channel that the secondary power becomes higher than the interference limit. The problem is resolved here.

We show that throughput increases as the number of devices (i.e. D2D pairs) in co-existing secondary network increases. So, initially, we determine the throughput for simultaneous transmissions by up to two D2D nodes in the same frequency band as that used by the macro-cell and it is shown that as we increase the number of D2D pairs the throughput increases. It leads to an increase in spectrum utilization efficiency. The main contributions of our paper are as follows:

1) We present the expression for multiple numbers of D2D pairs. In that case maximum SNR of each of them is taken and then the pair which has the maximum SNR is considered. Such analysis gives insight for better spectrum utilization.

2) In this report, we propose a scheme where the interference level is naturally maintained which was not focused till now in the other works which were done previously.

3) We show that sum throughput improves with the increasing number of D2D pairs in a secondary network and by user selection method among multiple numbers of D2D pairs.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Initially, we consider only one D2D pair in the secondary network. Then all the N number of D2D pairs are considered to be transmitting in the same frequency band.

A cognitive underlay downlink network, where two secondary transmitters $S1$ and $S2$ transmit symbols at a fixed rate in the range of a primary network. We assume that the secondary network is located relatively far apart so that the same frequency can be reused by $S1$ and $S2$ concurrently. We ensure that the total secondary interference caused to the primary receiver R_p is below ITL. We assume that all the channel experience with independent Rayleigh fading. We assume that the primary transmitter is located far away from the secondary receivers. Hence the primary interference at the secondary node can be neglected. Noise at all the terminals is assumed to be additive white Gaussian noise with zero mean and variance of σ_n^2. In every signalling interval, S_1 transmits with power P_{S1} and 2 transmits with power P_{S2}.

$P_{s1} \leq \frac{Ip}{|h1c|^2}$ and

$P_{s2} \leq \frac{Ip}{|h2c|^2}$ should be maintained where and h_{1c} and h_{2c} are channel gain from secondary network to primary network

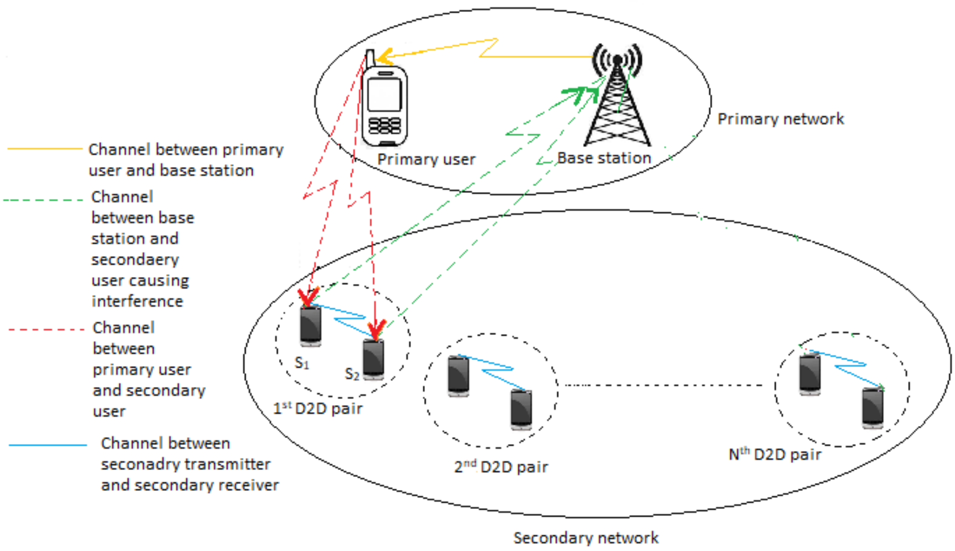

Fig.1 System model of co-existing underlay CR network

All N number of D2D pair share spectrum of primary network and IP denotes the ITL. Maximum possible SNR among this pair is to be taken to determine the outage probability.

The outage probability of D2D link:

$P_{Out} = P_r\left(\frac{Ip\,|hc|2}{\sigma n2\ min\ (|h1c|2,|h2c|2)} \le \gamma_{th}\right)$, where $\gamma_{th} = 2^R - 1$ and R is the transmission rate of secondary network and $\frac{Ip\,|hc|2}{\sigma n2\ min\ (|h1c|2,|h2c|2)}$ is the instantaneous signal-to-interference-plus-noise ratios (SINRs).

As a separate case, when more than two secondary users reuse the primary spectrum and perform concurrent transmissions i.e. say N number of D2D pairs are considered then the outage probability corresponding to the best D2d pair is being chosen out of N such pairs is: $P_{Out} = P_r(max_{i\,\epsilon[1,N]}\,(x_i) \le \gamma_{th})$.
Fig. 1: System model of co-existing underlay CR network

Here we use peak interference power control at $S1$ and $S2$ instead of limiting the transmit powers with a peak power because secondary devices have a limited capacity of power because they are battery operated. So, the secondary communications are short-range communications. If the channel is very weak, then the power may shoot up very large.

Thus, the minimum among the peak power (P) and Ps is considered in the underlay cognitive radio network.

So, For a single device, $P_s = P$ when $|h_{sp}|^2 \le \frac{Ip}{P}$

And $P_s = \frac{\mathrm{Ip}}{|\mathrm{hsp}|2}$ when $|h_{sp}|^2 > \frac{Ip}{P}$

$\therefore\ P_s = min(P, \frac{Ip}{|hsp|2})$

$\therefore$ SNR at the receiver will be:

$\gamma_{D1} = (min(P,I_p/|h_{D2C}|^2)\ |h_D|^2)/((P_C/|h_{CD1}|^2)+\sigma_n^2)$; when S_2 is transmitting.

$\gamma_{D2} = (\mathrm{min}(P,I_p/|h_{D1C}|^2)\ |h_D|^2)/((P_C/|h_{CD2}|^2)+(\sigma_n)^2)$; when S_1 is transmitting.

Then the non-outage probability will be,

$P_{NO}^S = Pr[\{\gamma_{D1} > \gamma_{th}\} \cap \{\gamma_{D1} > \gamma_{D2}\}] + Pr[\{\gamma_{D2} > \gamma_{th}\} \cap \{\gamma_{D2} > \gamma_{D1}\}]$

When multiple secondary users are used, say N no of D2D pairs are transmitting in a secondary network we have to take max SNR of each one of them and then the max of the overall pair and that pair will be used for consideration for outage probability. Then,

$\gamma_D = (max_{i\,\epsilon[1,N]}\,(\gamma_{Di}))$

$P_{NO}^S = Pr[\gamma_D > \gamma_{th}]$

III. SIMULATION RESULTS

We have used Monte-Carlo simulation method in MATLAB for simulating this problem. The number of iterations has been kept at 10^6 times for making the channel random variable working properly as the sample space has to be infinite in this case for proper simulation result to come. The path loss exponent (ple) is taken as 3 for the calculation and simulation purpose. The value of Ip is taken as 20 dB for the simulation purpose. The d which is the normalized distance between device 1 and device 2 in one group is taken as 1 unit. Also, the normalized distances between the base station and two secondary users in the d2d pair are taken as 5 units which is bd1=bd2=5 units. And the distances or normalized values of distances between the primary user and the devices in a device pair which is pd1=pd2 is taken as 4 units for the simulation purposes. Longer the distance, weaker the communication. And also, as target rate increases, the outage probability also increases. In this simulation, the outage probability is clearly shown. These variations with changing the values of different parameters used in the code can be observed by changing the values in the MATLAB code itself. It can also be observed that the throughput at first increases upto a certain value and then decreases to minimum with the change of rate. Overall we have observed a bell-shaped curve in throughput vs rate graph. So we can say that Three different N values are taken which are respectively 5, 10 and 15 and it is observed that throughput increases with increasing number of D2D pair in the secondary network. Overall we can conclude that the performance increases with increase in the number of d2d pairs in the network.

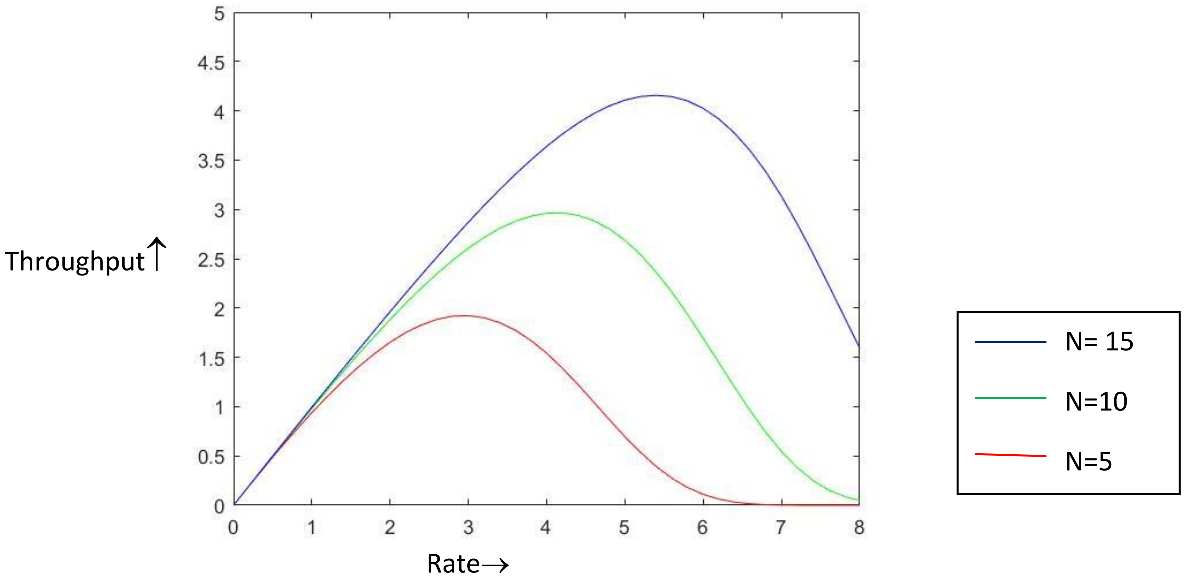

Fig.2 Throughput achieved for three different values of N;

IV. CONCLUSION

This project developed several interesting insights into the selection probabilities of secondary users in D2D communication in underlay cognitive radio networks considering an optimal metric. Throughout this paper, we addressed the spectrum reuse and power assignment issue within D2D communications underlay D2D network. The simulation scenario was chosen according to a realistic underlay cognitive network. The effectiveness of our proposed solution was proved through simulation results. So, the D2D communication enables the devices to communicate directly with each other without the drawbacks regarding interference and power control.

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