Best Path Selection in a Multi-Relay Node System under the Concept of Cognitive Radio

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Abstract: The main purpose in this work is to enhance relay technique in underlay cognitive radio scheme through estimating the best path between the secondary source and the secondary destination under the power interference constraint of the primary user. A protocol is proposed based on the cooperation process between the secondary relay nodes in the system in order to establish the best path at low complexity without exceeding the interference threshold of the primary user. Performance analyses, through simulation, of the suggested protocol shows great enhancement in network outage probability when compared with direct path model and one relay node based-model.

1 INTRODUCTION

In the last years, wireless communications systems have experienced sharp growth, as there are around seven billion users around the world. Providing the service of mobile access in wireless communications systems to such a large number of users requires a solution to the wide spectrum issues from both scientific and economic aspects. New technologies in wireless communications systems must be developed in order to enhance the quality of service (QoS), the throughput and the reliability of communication networks (Goldsmith, 2005).

One of the basic challenges that face the developers is supplying high throughput at the cell edge (Goldsmith, 2005), (Mikio, 2010). Relay technology provides solutions that have been applied to improve the coverage at the cell edge (Klaus, 2010).

The main idea behind the relay technology is a cooperation process that depends on the nodes located in the distance between the source and the destination. These relay nodes receive the signal from the source and they transmit it to the receiver as shown in figure1, where P_{SR}, P_{RD} and P_{SD} represent the paths between the source and the relay, the relay and the destination and the source and the destination respectively.

On the other hand, to overcome the shortage on the frequency spectrum and to enhance its utilization, cognitive radio technology has been developed in the past few years. Cognitive radio is simply one of the forms of wireless communications where in one of its three well-known schemes, the basic scheme (called interweave), the secondary user (the unlicensed user to use the spectrum) can intelligently detect and distinguish the frequency channels that are used and others which are unoccupied, and instantly move into vacant channels while avoiding the occupied ones. This process is done without coordination with the primary user who owns the channel (the licensed user) (Juncheng, 2009). In the second scheme (overlay) a cooperation between the primary user and the secondary user occurs by allowing the primary user to send uses specific information and code-storing documents (codebooks), this method enables the primary user to assist the secondary user to transmit simultaneously with the primary user through occupying a portion of its transmitting power. However, in the last scheme (underlay) which is our interest in this work, both the secondary user and the primary user transmit in a simultaneous fashion, i.e., transmitting at the same time, while keeping an interference threshold, this means that the primary user's receiver must have an interference threshold that the secondary user must not pass to be able to transmit data without interfering with the primary user.

More interest in Cognitive Relay Systems (CRS) has appeared to take advantages from the integration

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of relay and cognitive radio technologies (Guo, 2010), (Rahul, 2013).

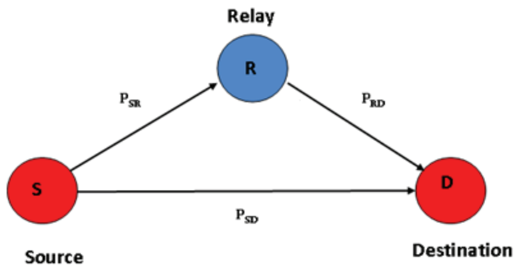

Figure 1: Relay Technology Structure.

Some previous studies have worked on specific type of cognitive relay system. One of these works (Han, 2009) introduced a two phase cooperative decode-and-forward relay system based on the concept of the cognitive radio, the secondary user access the spectrum along with the primary user, in return the primary user use the secondary user as a relay node. In (Ding, 2011) and (Duong, 2012) the authors proposed amplify-and- forward relay system with underlay cognitive radio and in the same concept of using the secondary user as a relay node for the primary user. The authors in (Tran, 2013) agitate a new topic that is the relay technology principle in the secondary system for the underlay cognitive radio, where it depends on one relay node system model between the secondary source and the secondary destination, this principle is adopted in this paper, in which we assume the existence of multi-relay nodes between the secondary source and the secondary destination and the best path between will be selected through our developed best path selection protocol.

This paper introduces relay technique under the concept of underlay cognitive radio, figure 2 illustrates this principle.

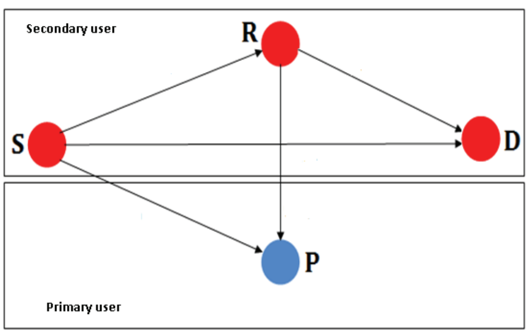

Figure 2: Relay Technique with Underlay Cognitive Radio Technology.

At a glance we will use a system model that consists of primary users and secondary users, whereas the relay nodes will be located between the secondary transmitter and the secondary receiver, the first relay node receives the signal from the source, process it then retransmit it to the next relay which in its turn will do the same or it will retransmit it to the receiver. The developed protocol is working on detecting the best path between the secondary source and the secondary receiver through cooperation between the relay nodes in the system under the interference constraint of the primary user.

In the next section, the system model is presented. Then, the system procedure is explained in the third section. In the fourth section, simulation results will be shown. Finally, conclusions are drawn at the end of the paper.

2 SYSTEM MODEL

In this work we adopts the same basic model in (Tran, 2013), in which the concept of decode and forward relay technique with underlay cognitive radio is assumed. Here, the permission is given to the secondary users to use the primary users' channels under the condition of not overcoming the allowable maximum transmitted power constraint on the primary users, to avoid interference.

Without loss of generality, in our model we assume the existence of maximum three relay nodes (R1, R2 and R3) in the distance between the secondary source (S) and the secondary destination (D). Figure 3 illustrates the used system model with different links between each relay, the source and the destination. For paths: (S to D), (S to P), (R to D), (S to P) and (R to P) the links are denoted by d_0, d_1, d_2, d_3 *and* d_4, respectively, and the channel coefficients are given as h_0, h_1, h_2, h_3 *and* h_4 respectively. Channel coefficients are considered as Rayleigh fading in the form (Tran, 2013):

$$\gamma_i = |h_i|^2, i = \{0,1,2,3,4\} \quad (1)$$

Ultimately, γ_i is an exponential random variable with a parameter λ_i. To include the path-loss in consideration, the parameter λ_i can be modelled as in (Duy, 2012) by:

$$\lambda_i = d_i^{-\beta} \quad (2)$$

β is the path-loss exponent which varies from 2 to 6, and we consider it 3 (Tran, 2013).

We reflect the network topology on the X-Y plane, and assume that the coordinates of the (S),(D),(R_i) and (P) are (0,0),(1,0),(XR_i,YR_i) and (XP,YP) respectively, where ($0 < XR_i, 0 < YR_i$) and (XP<1,

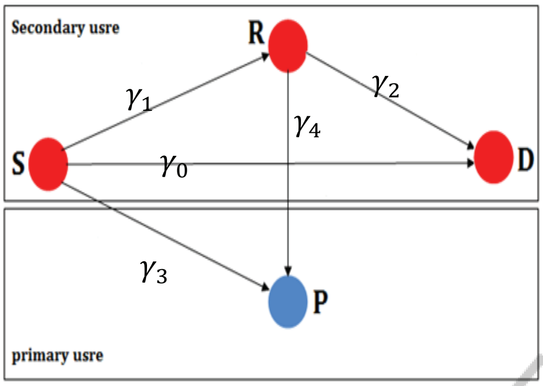

Figure 3: One Relay System Model.

YP<1), here for R_i, $i \in \{1,2,3\}$ which represents the different relay nodes see figure 4. The distances between the system components are:

$$d_0 = 1 \tag{3}$$

$$d_1 = \sqrt{(XR_i)^2 + (YR_i)^2} \tag{4}$$

$$d_2 = \sqrt{(1 - XR_i)^2 + (0 - YR_i)^2} \tag{5}$$

$$d_3 = \sqrt{(XP)^2 + (YP)^2} \tag{6}$$

$$d_4 = \sqrt{(XP - XR_i)^2 + (XP - YR_i)^2} \tag{7}$$

In addition to the mentioned links, in this system model we assume the existence of communication links between the three relay nodes (R1-R2),(R2-R3) and (R1-R3). The idea behind these connections is to find the best relay path between the secondary source and the secondary destination by creating cooperation process between the relay nodes to calculate the best path as shown in figure 4 and explained in the next section.

3 PROTOCOL PROCEDURE

This paper adopts the one relay system protocol calculation that has been applied in (Tran, 2013) as a base point to enhance and develop choosing the best path protocol from multiple relay node system.

The cooperative protocol (C) is the relay node protocol that has been used in the relay technology. This protocol works according to comparison process for the signal to noise ratio (SNR) between the direct path and the relay node path, the higher SNR will be chosen as a best path. As we know the (SNR) depends on the channel conditions and for this paper the channels conditions had been assumed randomly to be close to the reality as much as possible.

Figure 4 shows the distances and the channels coefficient for our system model. We assumed that the source (S) and each relay node (R) have knowledge in the channel information h_3 and h_4 so that they have the ability to adapt their transmitted power to satisfy the interference constraint at (P) as (Guo, 2010).

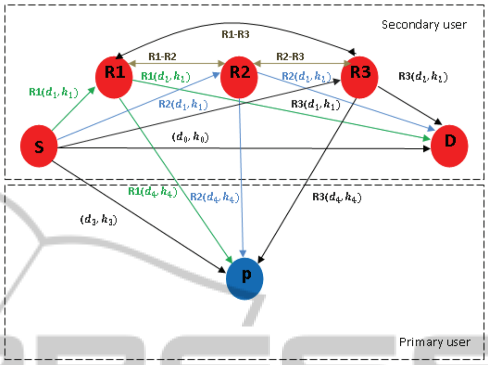

Figure 4: Best Relay System Model.

Before the source transmits its data, a media access control (MAC) layer operation which is similar to the way in (Liu, 2006) is applied on the system channels.

The source begins the process with a request-to-send (RTS) message to the relay point and the destination. Since the source is aware of the channel informationh_3, if is possible to add the parameters to the (RTS) message. It is possible for the secondary destination (D) to estimate the channel h_0 and reacts to the source by sending a clear-to-send (CTS) message to it, and the destination includes the value of h_0 in this message. The relay node decodes the (RTS) and (CTS) messages that have been received from the secondary source to extract the needed information while estimating h_1 and h_2.

The relay node (R) makes a full conclusion to all channels information; to calculate the (SNR) of the relay links h_1 and h_2 and the direct link h_0 in the following stages:

- Direct link is used (DL):

According to (Guo, 2010), the source adapts its power with the allowable maximum transmitted power $I_P, P_S^D = I_P / \gamma_3$. And the (SNR) to this link will be

$$\gamma^D = \frac{I_P/h_0/^2}{N_0/h_3/^2} = \frac{Q\gamma_0}{\gamma_3} \tag{8}$$

Where $Q = I_P / N_0$ and N_0: is Gaussian noise (assumed to be same at all receivers R and D).

- Relay link is used (R):

In this paper we assumed that node has one antenna and each one will operate in half duplex mode and the system used time division multiple access (TDMA).

According to (Liu, 2006) the transmitted powers of the relay link (S to R to D) are: $P_S^C \le I_P/\gamma_3$ and $P_R^C \le I_P/\gamma_4$, where P_S^C and P_R^C are the transmitted powers of (S) and (R), respectively.

The total transmitted power of (S) and (R) must be under this condition:

$$P_S^C + P_R^C = P_S^D = I_P/\gamma_3 \tag{9}$$

The SNR for this relay link, decode and forward relaying mode can be represented in a similar fashion to (Laneman, 2004):

$$\gamma^C = min\left(\frac{P_S^C\gamma_1}{N_0}, \frac{P_R^C\gamma_2}{N_0}\right) \tag{10}$$

Depending on (Tran, 2013) we can formulate the optimal γ_{max}^C as in (11).

By comparing the SNR of both the direct link and the relay link, the relay node detects whether if it will cooperate with the source or not.

If $\gamma^D > \gamma_{max}^C$, then the relay will send to the source and destination a *not help to send* message (NHTS). In this case the source will use the direct path between itself and the destination.

In the other cases the relay will send *help to send* (HTS) message to inform that it will assist in the source forwarding the data to the destination, and the message includes the transmitted power of the source P_S^C which was calculated in the (11), and the source will adapt its power follows the P_S^C. (Tran, 2013) (Laneman, 2004).

By using MATLAB and from all these calculations for each relay node a protocol had been developed to establish a cooperative process between the relay node to produce the best path for the signal from the secondary source and the secondary destination which is passing throw the relay nodes that located in this distance. Where during the procedure, (S) makes its calculations to choose the best node and send the data to the best relay selection in the first time slot. After that, the best relay, which has received the data, will become the new (S) in the system, so it will repeat the previous calculations to detect the new best relay selection in the rest of the system and send to the new best relay selection the data in the second time slot, etc.., until reaching (D).

In this paper, as we mentioned before, three relay nodes system had been adopted that works on the TDMA channel access and half duplex technique as seen in Figure 4 which represents the general plan of the best path selection system model.

The first time slot of the channel has been reserved to the secondary source (S) to send the information to the direct link or to the best relay node which has been detected by the signalling process that was applied on the whole system by the source, after that the second time slot will be reserved to the best relay node and it will be considered as a new (S), after that the same process of signalling was applied to detect the best relay node from the rest of the nodes at the system or to adopt the direct link as a best path between the new (S) and (D), etc… till we get the best path.

We are dealing with each relay node and its channels conditions in isolation from the other nodes in the system. For each node in the first step we are calculating the value of γ_{Ci}, $i = \{1, 2\ and\ 3\}$ for three relay nodes (γ_{Ci} is SNR of the link between S,R and D for each relay node) and γ_D (SNR of the direct link between S and D) and each value of γ_{Ci} must exceed the two conditions : greater than the value of γ_D and greater than the γ_{th} (the minimum value of SNR that the receiver need it to detect the signal) of the destination, to be considered as an active relay node, or we define it by zero value. By comparing the values of the γ_{Ci} with the value of the γ_D, if any value of γ_{Ci} is greater than γ_D then the node which has the greatest γ_{Ci} has the ability to work as a relay node to be the best relay selection and the new secondary source in the same time, at that point the second step will start and all the previous calculations will be repeated on the rest of nodes in the system and the direct link between the new secondary source and the destination till we find the best path, unless the value of γ_D in the first step will be the greatest value of SNR in the system so the protocol will choose the direct path as the best path. We repeated this process for all the relay nodes with the channel conditions for each relay node path and direct path.

$$\gamma_{max}^C = \begin{cases} Q\frac{\gamma_1\gamma_2}{\gamma_3(\gamma_1+\gamma_2)};\ if\ \frac{\gamma_1}{\gamma_1+\gamma_2} < \frac{\gamma_3}{\gamma_4}\ as\ P_S^C = \frac{I_P\gamma_2}{\gamma_3(\gamma_1+\gamma_2)}, P_R^C = \frac{I_P\gamma_1}{\gamma_3(\gamma_1+\gamma_2)} \\ Q\frac{\gamma_2}{\gamma_4};\ if\ \frac{\gamma_1}{\gamma_1+\gamma_2} \ge \frac{\gamma_3}{\gamma_4}\ as\ P_S^C = \frac{I_P}{\gamma_3} - \frac{I_P}{\gamma_4}, P_R^C = \frac{I_P}{\gamma_4} \end{cases} \tag{11}$$

4 SIMULATION RESULTS

As we mentioned before, by using MATLAB the best path protocol had been created. In this part of the paper we present examples of the way that the protocol worked. Also, it presents the system performance calculations which are based on some variable have been taken in the consideration.

For the procedure of the best path selection protocol, the work in this took a lot of cases of implementing the Protocol on different relay nodes points with different values of Q and different positions for the primary user (P). For example:

- Best path with PU at (0.5, 0.5) and $Q = 5$:

In this example, we fixed the position of (P) at (0.5,0.5), and applied the value of $\gamma_{th} = 0.3$, then we chose multiple cases each one depended the relay nodes positions R1(X_1,Y_1), R2(X_2,Y_2), and R3(X_3,Y_3) on (0.9,0.2) (0.75,0.1) (0.82,0), with 5 for the value of Q.

Step1: In this step the system made its calculation to choose the best SNR, where it detected R3 as the best relay node which can be seen in table 1. Figure 5 explains the first step operation.

Table 1: Step one for the path cases at (0.9, 0.2) (0.75,0.1) (0.82,0).

Path	γ	Case
S-R1	0	OFF
S-R2	0	OFF
S-R3	3.11	ON
S-D	0.54	OFF

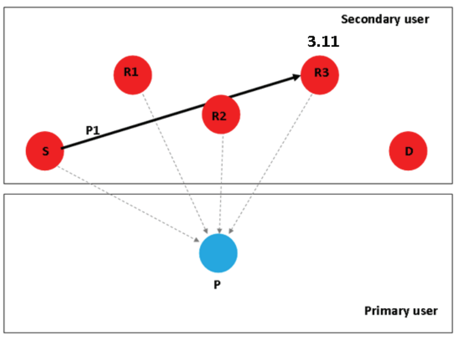

Figure 5: First Step Choosing the Best Path.

Step2: In this stage, R1 has been detected as the best relay node as shown in Figure 6 and table 2.

Step3: The last step showed the system choosing the direct path between R1 and (D) to as the best path as shown in figure 7 and table 3.

Table 2: Step two for the path cases at (0.9,0.2) (0.75,0.1) (0.82,0).

Path	γ	Case
R3-R1	10.46	ON
R3-R2	8.3	OFF
R1-D	3.8	OFF

The TDMA slots division for the previous case in Figure 8, where the first time slot will be used by the source and the second will go to R3 and the third will go to R1.

As had been mentioned before, we used the TDMA channel access with the half duplex transmission technique. One of the disadvantages that have been faced in our work is the delay, because of our need to a single time slot for each transmission process in the system, where we used one time slot for the transmission of the secondary source and one time slot for the transmission of each relay node included in the calculations of choosing the best path selection.

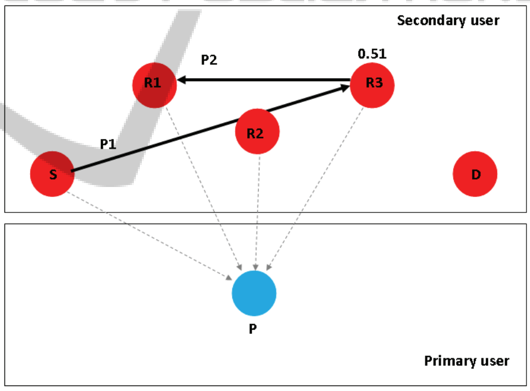

Figure 6: Second Step Choosing the Best Path.

Table 3: Step three for the path cases at (0.9, 0.2) (0.75,0.1) (0.82,0).

Path	γ	Case
R1-R2	0	OFF
R1-D	77.6	ON

To overcome this point, we can determine the number of time slots to be used in the transmission system, for example, if we depend on a system that consists of multi relay nodes like a three relay node system, we need four time slots when using the three nodes as a relay node. For this, we minimized the number of relay nodes that have been used in the transmission system to reduce the delay of the system, and this process was implemented by controlling the number of time slots that was used for each transmission system.

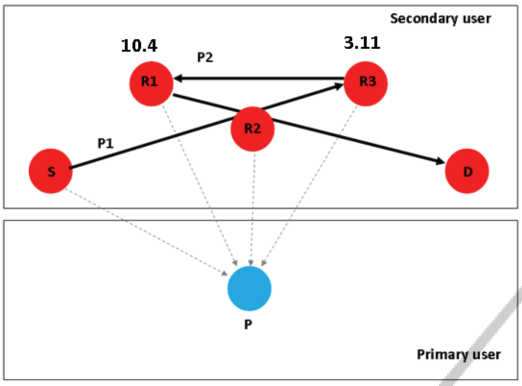

Figure 7: Third Step Choosing the Best Path.

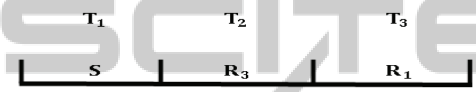

Figure 8: Time Slots Distribution.

For example, we took the case of the time slot constraint with (P) position at (0.5, 0.5) and applied the values of γ_{th}=0.3 and Q=15dB and relay nodes positions R1 at (0.7,-0.1), R2 at (0.85,-0.1) and R3 at (0.9,0) and the process of creating the best path in this form:

Step 1: R1 is the best relay node selection here, as explained in figure 9 and table 4.

Table 4: Step one for the path cases at (0.7,-0.1) (0.85,-0.1) (0.9,0).

Path	γ	Case
S-R1	10.57	ON
S-R2	7.02	OFF
S-R3	0	OFF
S-D	5.62	OFF

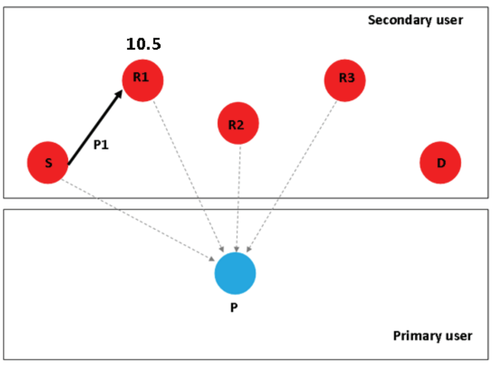

Figure 9: First Step Choosing the Best Path.

Step2: In this step, R1 had been chosen by the system as the best path, as figure 10 and table 5 shows.

Table 5: Step two for the path cases at (0.7,-0.1) (0.85,-0.1) (0.9,0).

Path	γ	Case
R1-R2	5.63	ON
R1-R3	0	OFF
R1-D	2.18	OFF

Step 3: The system chose the direct link, because were bounding with two time slots as seen in figure 10 and table 6.

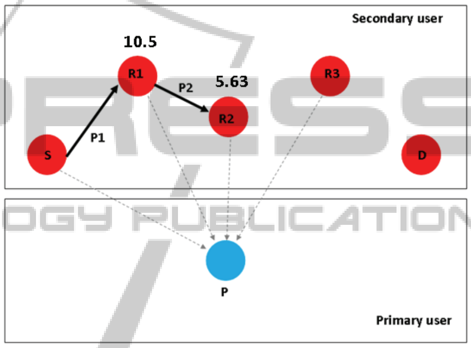

Figure 10: Second Step Choosing the Best Path.

Table 6: Step three for the path cases at (0.7,-0.1) (0.85,-0.1) (0.9,0).

Path	Case
R2-D	ON

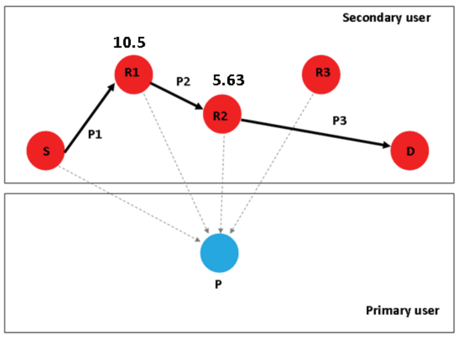

Figure 11: Third Step Choosing the Best Path (Obligatory Step).

According to the time constraint, the time slots division is described in figure 11.

This time slot constraint obligates the system to work with two relay nodes even if the three nodes have the ability to work as relay nodes to avoid the delay in the system.

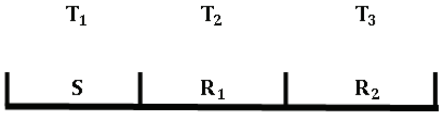

Figure 12: Time Slots Distribution.

In this part from the simulation results, we calculated the outage performance of our proposed protocol, where we proved that the best path system performance is a huge breakthrough in improving the performance of the system during the process between the transmitter, the secondary source (S) and the secondary destination (D).

Where we studied the outage probability of this system in different relay nodes distribution with different values of γ_{th}.

We supposed that the secondary source (S) at the (0, 0) position and the secondary destination (D) at the (1,0) position, while the primary user location is at (0.5,0.5).

For this protocol, we observed from the results that the system performance behaves almost randomly depending on the relationship between the relay nodes, the primary user and the destination positions. Overall, this protocol provides a great performance on the path between the (S) and the (D).

- Outage probability calculations for $\gamma_{th} = 0.5$: We applied 0.5 for the receiver γ_{th} and from Figure 12 we observe that the best distribution for the relay nodes is when all the relay nodes exist after the half the distance between the secondary source and the secondary destination, similar to the best relay protocol case.

- Outage probability calculations for $\gamma_{th} = 1$: γ_{th} in this case was chosen to be 1. Figure 13 explains the outage probability of the system with different relay nodes distribution sets.

In the final stage from the simulation results, the paper presents a comparison between the outage probability for the direct path system model, one relay system model in (Tran, 2013) and the best path system model.

We applied Monte Carlo simulation with 10^6 trails for different values of Q, ranging from 1 to 20 in each scenario, and we adopted $\beta = 3$. For the one relay node system the authors in (Tran, 2013) depended on the following positions for the secondary source, the secondary destination and the primary user (0,0), (1,0) and (0.5,0.5) respectively. Also they adopted 0.5 as the value for the receiver γ_{th}, and the relay node at the position (0.5,0).

Here we used the same values that have been mentioned above in the one relay node protocol for the secondary source, the secondary destination and the primary user positions. Additionally, we fixed the value of γ_{th} to 0.5. The relay nodes positions in the two proposed protocol are $R_1(0.2,-0.2)$,$R_2(0.6,-0.1)$ and $R_3(0.9,-0.3)$.

Figure 14 presents the outage probability compression results for the three system models as a function of Q.

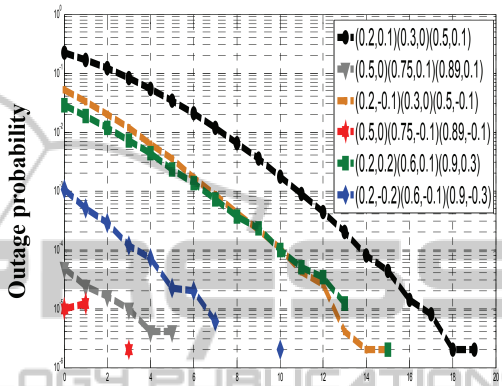

Figure 13: Outage Probability in Different Relay Nodes Distributions.

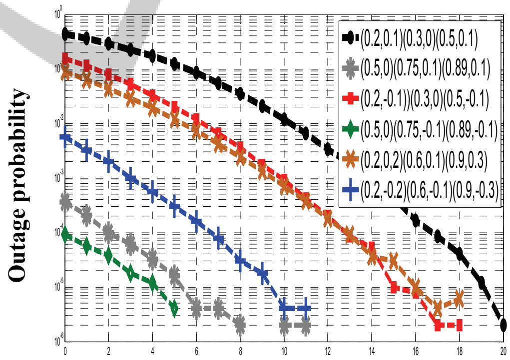

Figure 14: Outage Probability in Different Relay Nodes Distribution.

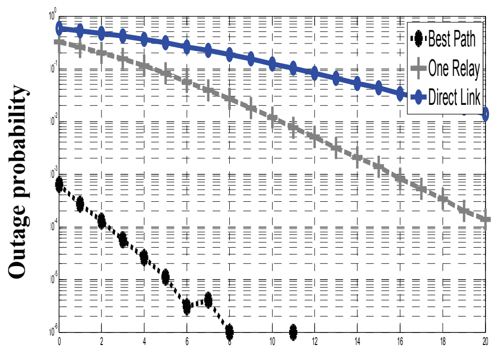

Figure 15: The Outage Probability Comparison.

5 CONCLUSIONS

In this paper, we proposed a best path selection system. The procedure is based on choosing the best path between the secondary source and the secondary destination by a cooperation process between the relay nodes. Time delay is taken into consideration in the case of best path protocol. A solution is presented by using time constraint protocol to overcome time delay. Numerical results show a significant reduction in outage probability when comparing with single relay node system, for instance, a reduction from 10^{-1} to 10^{-5} is shown at signal to noise ratio of 4.

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