PERFORMANCE EVALUATION OF COGNITIVE MULTI-HOP NETWORKS TO ASSIST BUILDING SYSTEM

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ABSTRACT

In recent years, cognitive relay networks (CRNs) have emerged as a fantastic trend in research. It supports the establishment of a new communication network by spectrum-sharing technique. However, most papers focus on studying the performance of the dual-hop scheme. This paper evaluates the proposed multi-hop model by giving the closed-form multi-hop network outage (OP). Simulation verifies our derivation and discovers the impact of several related factors on the secondary outage probability. We also highlight the end-to-end secondary multi-hop network by directly building the map to assist designers and operators on a network.

Keywords: Multi-hop, congnitive relay networks, outage probability.

1. INTRODUCTION

Nowadays, cognitive relay networks (CRNs) are considered by many researchers. Instead of direct transmission from the source to its destination, the relay network has to transfer its data via intermediate relays [1, 2]. In the cognitive regime, some transmitters must adapt their transmit power to limit other receivers' impact in the cognitive relay network. Theoretically, Goldsmith *et al*. [3] first proposed three key cognitive radio network paradigms: underlay, overlay, and interweave. So far, most of the researchers are into the underlay paradigm. The protocol exchanging data are Amplify-and-Forward (AF) [4], Decode-and-Forward (DF), and Randomize-and-Forward (RF) [5], etc. However, network performance significantly decreases when the secondary transmitters have to limit power by many primary users (PUs). In [6], the authors investigate the performance of dual-hop cognitive networks with multiple primary users. Though authors take into account the mutual interference, the work considers the sketchy impact of the primary on the dual-hop secondary network. Moreover, several primary location simulations did not fully know the mutual influence between the two networks. Contrastly, the work [5] concerns with secure communication and compares protocols: DF & RF. The authors also present the foot-print map according to the relay position which gives the best information assisting in network design. Until now, most papers have studied the dual-hop network model.

Some original proposal of the conventional multi-hop scheme was found in [7-9]. Because of the advantage of the low transmit power, low interfering to others, high coverage, and high spectrum efficiency [10], the multi-hop network topology is interested in research in spectrum sharing where the secondary route can be established under the licenced user at a space. In this regime, the multi-hop scheme is better performance than dual-hop one [11, 12].

In particular, Fig. 3 in [11] shows that the outage probability (OP) of the multi-hop cooperative transmission (MCT) is the lowest where the network has 3 or 4 hops depending on the harvesting factor. When it comes to the conventional multi-hop network (CMN), the secrecy outage probability (SOP) in [13] indicates that the best number of hops is 3 and 4. In other words, a triple-hop or quad-hop network is more efficient than dual-hop in these cases. More extensive research, the authors in [14] conclude that the optimal number of hops of MCT is a higher value than CMN. Moreover, the number of both is normally larger than 2 in Table 1. In [15], the authors study the optimal power allocation of every node in which the secrecy rate increase is the main target. Each node is possible of MRC (Maximal Radio Combining) on the frame included multiple time slots. They gave out the algorithm to find the best power vector in terms of LOS (Ligh of Sight) or Non-LOS. However, the multi-hop network occupies its own spectrum. In [16], the authors propose the cognitive network model in which the secondary multi-hop network is constrained power by the multiple antenna primary network. Solved the multi-antenna system by TAS/SC diversity (Transmit Antenna Selection/Selection Combining), the authors calculate the optimal of the OP of primary network that it assists in enhancing the OP on the multi-hop network. Nevertheless, the Rician fading is modeled in the data link. Whereas, the work in [13] use Rayleigh fading for its proposal to derive the SOP with the i.n.i.d primary node distribution. Having said that all aforementioned papers did not show clearly map supports to directly network design.

To the best of our knowledge, hardly papers fully cover the multiple primary users' impact on the outage of the secondary multi-hop network and show the foot-print form to support the design of new cognitive multi-hop networks except [5]. Ignoring the security, this work concentrates on the multi-hop outage performance in CRNs via building the map directly to assist designers and operators on a new network. Furthermore, the hardware imperfection is also concerned in our analysis.

2. SYSTEM ANALYSIS

2.1. Network model

Figure 1 shows the structure of the proposed cognitive networks. The primary network has L PUs, which has more priority in communication. Hence, to avoid suffering from others, PUs define their own interference threshold I_{P}^{i} so that other transmitters have to adjust to satisfy these thresholds. Besides, the secondary multi-hop network has a source ST_0 that transfers data to its destination ST_K with the assistance of $K-1$ relays $\mathrm{ST}_1 \ldots \mathrm{ST}_{K-1}$ via K orthogonal time slots. Source ST_0 transmits the signal to ST_1 in the first slot, exploited Decode-and-Forward (DF) protocol. Next, ST_1 similarly transmits signal to ST_2 in the second time slot. The process is repeated until the data send over K time slots. It is assumed that all channels in the proposed model are subject to slowly varying Rayleigh fading.

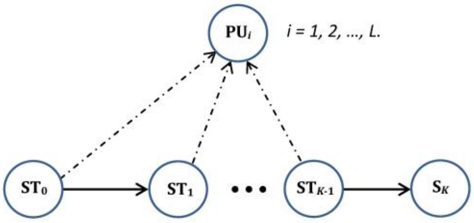

Figure 1. Network model

2.2. Performance evaluation

2.2.1. Limitation of the secondary transmit power due to the multiple interference constraints

To avoid the inteference between the PUs and secondary transmitter ST_{k-1}, all the secondary nodes has to adjust their power as long as the PUs can decode their signals. According to the formula 13.26 [17], the transmit power of the ST_{k-1} relates to

$$g_{k,1}Q_{k-1} \le I_{\mathrm{P}}^{i}, \tag{1}$$

where Q_{k-1} is the real transmit power of $\mathrm{ST}_{k\text{-}1}$, and $I_{\mathrm{P}}^{1},...,I_{\mathrm{P}}^{L}$ are the maximum interference levels at the respective $\mathrm{PU}_1,...,\mathrm{PU}_L$. For the sake of simplicity, we assume that every interference threshold $I_{\mathrm{P}}^{1},...,I_{\mathrm{P}}^{L}$ is equal to I_{P}. Hence, the domain that is satisfied all inequalities in (1) can be writen to

$$\max_{i=1\div L} \, g_{k-1,i} \;\; Q_{k-1} \le I_{\mathrm{P}}, \tag{2}$$

$$Q_{k-1} \le \frac{I_{\mathrm{P}}}{\max\limits_{i=1\div L} \, g_{k-1,i}}. \tag{3}$$

It is also assumed that we have L PUs, which located in the form of a cluster, and takes account into path-loss, we have the maximum allowable normalized power following

$$P_{k-1} = \frac{Q_{k-1}}{N_0} = \frac{\alpha_k I_{\mathrm{P}}}{N_0 \max\limits_{i=1\div L} \, \varpi_{k-1,i}}, \tag{4}$$

where $\alpha_k = d_{k-1,\mathrm{PU}}^{\eta}$. More clearly, the $d_{k-1,\mathrm{PU}}$ is the distance between the $\mathrm{ST}_{k\text{-}1}$ and PUs. η is the path loss exponent. Similarily, we have $\beta_k = d_{k-1,k}^{\eta}$ is of the k-th hop.

2.2.2. Performance evaluation of the secondary multi-hop network

Because of cluster form in the primary network, we denote $V_k^{\max} = \max\limits_{i=1\div L} \, \varpi_{k-1,i}$, where $\varpi_{k-1,i}$ is the channel gain from $\mathrm{ST}_{k\text{-}1}$ to PU_i. When it comes to the secondary network, the instantaneous signal-to-noise ratio (SNR) at a secondary receiver expresses by

$$\Psi_k = \frac{P_{k-1}\beta_k^{-1}\omega_k}{\tau P_{k-1}\beta_k^{-1}\omega_k + 1} = \frac{AB_k.\omega_k \,/\, V_k^{\max}}{\tau AB_k.\omega_k \,/\, V_k^{\max} + 1}, \tag{5}$$

where P_{k-1} is in (4), and ω_k is the normalized channel coefficient of $\mathrm{ST}_{k\text{-}1}$ to ST_k link. The τ is respective harware impairment level, as defined in [18, 19]. Also, we symbolize $A = I_{\mathrm{P}}/N_0$, $B_k = \alpha_k/\beta_k$. Thus, the outage of the k-th hop is given to

$$\mathrm{OP}_k = \Pr \;\; \Psi_k < \gamma_{\mathrm{th}} \;\; = \Pr\left(\frac{AB_k.\omega_k \,/\, V_k^{\max}}{\tau AB_k.\omega_k \,/\, V_k^{\max} + 1} < \gamma_{\mathrm{th}}\right), \tag{6}$$

where γ_{th} is the target rate.

Remarkably, the interference channels suffer from slow Rayleigh fading and have the same distances, we have

$$F_{V_k^{\max}} \;\; x \;\; = \Pr \;\; \max_{i=1\div L} \, \varpi_{k-1,i} \;\; < x \;\; = \;\; 1 - e^{-\lambda_k x} \;\; {}^{L}, \tag{7}$$

and
$$f_{V_k^{\max}}(x)=\sum_{i=0}^{L-1}C_{L-1}^{i}.(-1)^{i}L.e^{-(i+1)x}. \tag{8}$$

Back to (6), the outage rewrites to

$$\mathrm{OP}_k(\gamma_{\mathrm{th}})=\Pr(\Psi_k<\gamma_{\mathrm{th}})=\Pr\left((1-\tau\gamma_{\mathrm{th}})AB_k.\omega_k/V_k^{\max}<\gamma_{\mathrm{th}}\right). \tag{9}$$

With the $\tau>1$, the probability is absolutely right. Hence, we only consider the otherwise. In that case, the (9) changes to

$$\begin{aligned}\mathrm{OP}_k(\gamma_{\mathrm{th}})&=\Pr\left(\omega_k<\frac{\gamma_{\mathrm{th}}}{(1-\tau\gamma_{\mathrm{th}})AB_k}V_k^{\max}\right)\\&=\int_0^{+\infty}F_{\omega_k}\left(\frac{\gamma_{\mathrm{th}}}{(1-\tau\gamma_{\mathrm{th}})AB_k}y\right)f_{V_k^{\max}}(y)\,dy.\end{aligned} \tag{10}$$

After some algebra manipulations, we have the outage of the k-th hop as follows

$$\mathrm{OP}_k(\gamma_{\mathrm{th}})=1-\sum_{i=0}^{L-1}(-1)^{i}C_{L-1}^{i}L.\frac{(1-\tau\gamma_{\mathrm{th}})AB_k}{\gamma_{\mathrm{th}}+(i+1)(1-\tau\gamma_{\mathrm{th}})AB_k}. \tag{11}$$

By exploiting the DF protocol to transfer data from the source to destination, we finally obtain the closed form of the end-to-end outage probability of the secondary multi-hop network under multiple interference constraints and present to following

$$\mathrm{OP}(\gamma_{\mathrm{th}})=1-\prod_{k=1}^{K}\sum_{i=0}^{L-1}(-1)^{i}C_{L-1}^{i}L\frac{(1-\tau\gamma_{\mathrm{th}})AB_k}{\gamma_{\mathrm{th}}+(i+1)(1-\tau\gamma_{\mathrm{th}})AB_k}. \tag{12}$$

3. SIMULATION RESULTS AND DISCUSSION

3.1. Verification of the theoretical derivation

On the XY plane, we set the source at $(0,0)$ and the destination at $(1,0)$. All the relays are located at the source and destination gap so that its communication distance is the same as others. For example, when $K=2$, $\mathrm{ST}_1(0,0.5)$, and when $K=3$, $\mathrm{ST}_1(0,0.33)$, $\mathrm{ST}_2(0,0.67)$. The PUs were installed at $(x_{\mathrm{P}},y_{\mathrm{P}})$.

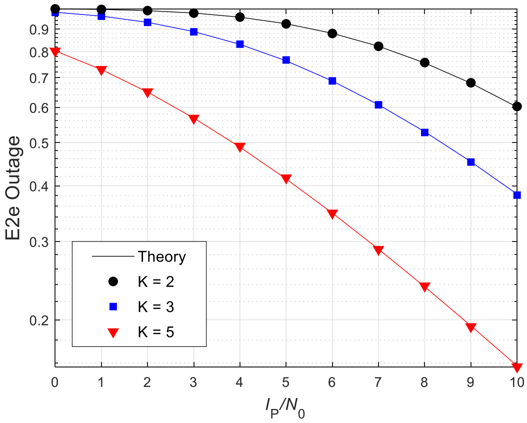

Figure 2. OP as a function of *A* when $L=5,\ \tau=0,\ \gamma_{\mathrm{th}}=1,\ x_{\mathrm{P}}=y_{\mathrm{P}}=0.3.$

As seen in Figure 2, the end-to-end OP goes down when the I_P/N_0 rises. It is because the I_P/N_0 looser, the multi-hop transmitters can transmit with higher power at that time. It leads to OP reduction. When it comes to the number of secondary hops, we observe that the OP is a lower value where the number of hops increases. It relates to the shorten distance on each hop.

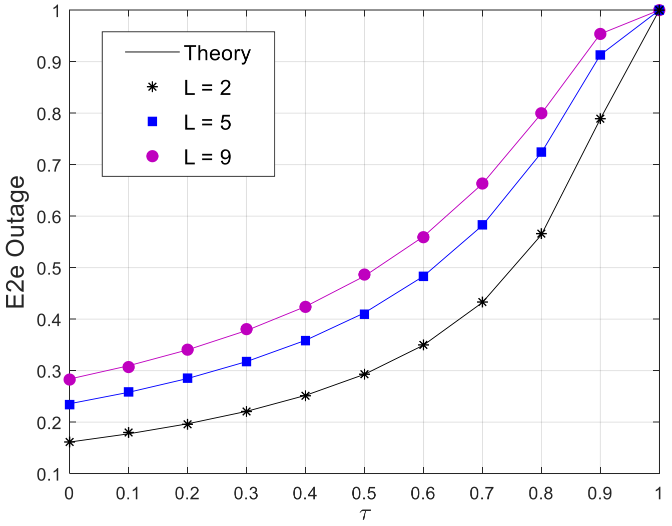

Figure 3. OP as a function of τ when $K=4$, $A=10\,(\mathrm{dB})$, $\gamma_{\mathrm{th}}=1$, $x_P=y_P=0.3$.

Figure 3 shows the OP as a function of various hardware imperfections. In fact, when the imperfect level increases to one, the transmission is unsuccessful because of OP = 1 regardless of other factors. Compared to the model [14] which exists power beacons and primary users, the hardware impairment tolerance is higher where OP = 1 due to the fact that its transmit power is not constrained in this case. Besides, more PUs results in higher OP value.

3.2. Building footprints of the desired network

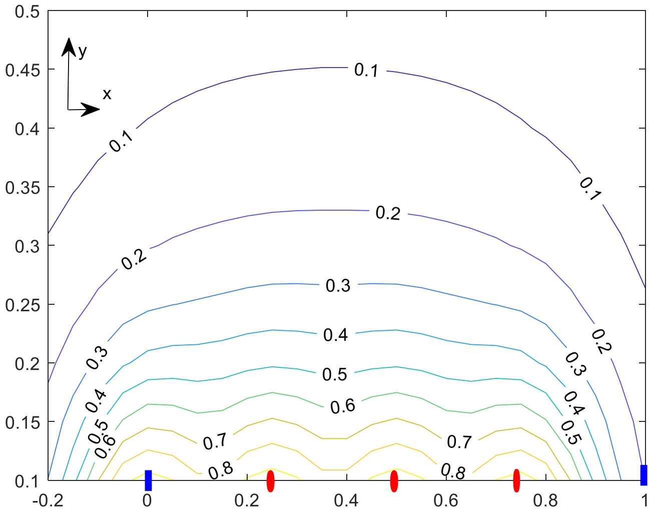

Figure 4. OP on the PU’s location map when $K=4$, $L=5$, $\tau=0{,}01$, $\gamma_{\mathrm{th}}=1$, $A=10(\mathrm{dB})$

We determine the end-to-end multi-hop outage with the verified derivation above in terms of fixed $K=4$, $L=5$ on half of the vicinity in Figure 4. As seen, OP is the highest when the PU is nearest the transmitter or receiver. Compared to [10], [20, 21], and [22] with simply sliding the Eavesdropper, the Relay, and the Power Beacon respectively in one direction (1D), the Figure above indicates that the multi-hop network is not only severely affected performance by PU's location on the horizontal direction but also significantly changed on the vertical PU's moving. Back to [5] with a 2D optimal relay map, Figure 4 clearly shows the map which indicates the effect of PUs on the performance of the secondary multi-hop network. Based on this map, it is recommended that setting a new network install the multi-hop transceiver positions in the condition that the PUs are placed farther the multi-hop network.

4. CONCLUSION

In this paper, we evaluate the performance of the secondary multi-hop network in the underlay CRNs paradigm. Our research shows that the multi-hop topology has better performance when compared to dual-hop in the same condition. Many more PUs results in low multi-hop QoS. The hardware imperfection can influent the end-to-end OP, but it is significant if the level is 1. Based on the PU's location map, we suggest that the multi-hop transceiver needs farther away from the PUs if it's possible.

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TÓM TẮT

ĐÁNH GIÁ HIỆU NĂNG MẠNG ĐA CHẶNG NHẬN THỨC NHẰM HỖ TRỢ XÂY DỰNG HỆ THỐNG MẠNG

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Trong những năm gần đây, mạng chuyển tiếp nhận thức (CRNs) đã được quan tâm như một xu hướng nghiên cứu mới. Đặc tính của mạng nhận thức có thể hỗ trợ thiết lập một mạng truyền thông mới bằng kỹ thuật chia sẻ phổ tần. Tuy nhiên, hầu hết các bài báo trước đây chỉ dừng lại ở việc nghiên cứu hiệu năng của mạng thứ cấp với sơ đồ hai chặng (dual-hop). Bài báo này đánh giá hiệu năng của mô hình mạng đa chặng bằng cách đưa ra công thức xác suất dừng từ đầu cuối đến đầu cuối. Từ đó, mô phỏng kiểm chứng tính chính xác của các kết quả đưa ra. Ngoài ra, kết quả mô phỏng cho thấy những ảnh hưởng của một số yếu tố liên quan khác đến xác suất dừng của mạng đa chặng thứ cấp. Chúng tôi đặc biệt đưa ra được biểu đồ xác xuất dừng hệ thống trong mối tương quan ở dạng footprint nhằm hỗ trợ trực tiếp các nhà thiết kế và vận hành mạng.

Từ khoá: Mạng chuyển tiếp đa chặng, mạng nhận thức, xác suất dừng.