Jamming Power Optimization for Data Freshness in Covert Relay Networks

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***Abstract*—In this paper, we analyze covert amplify-and-forward (AF) relay networks with a metric for measuring the data freshness, i.e, age of information (AoI), with aid of the cooperative jammer that generates artificial noise (AN) to protect from Warden Willie's surveillance. We first derive lower boundary of covertness, average AoI and formulate an average AoI minimization problem by optimizing the jamming power of the cooperative jammer. Our analysis shows that the optimal jamming power is the minimum value that satisfies the lower boundary of covertness, which varies depending on the prior probability.**

***Index Terms*—Covert communication, age of information, detection error proability, AF, relaying network**

I. Introduction

As data usage increases with the development of fifth generation (5G) wireless networks, the importance of security is strengthened. As a result, a new field called covert communication has emerged. To guarantee the strong security, the covert communication aims to communicate while hiding the existence of the wireless communication [1]. In [2], the authors introduced non-orthogonal multiple access (NOMA) user as an artificial noise in a NOMA network to increase uncertainty of warden. The authors in [3] proposed the unmanned aerial vehicles (UAV) relaying covert network, UAV can be utilized to enhance the communication confidentiality because of the deployment flexibility.

There have been many works considering the covert communication in various environment, but most works only focused on the covertness throughput while overlooking data freshness in communications. However, data freshness is of fundamental importance in many application scenarios requiring covert communication, e.g., telehealth monitoring, or military actions, etc and even if covertness is guaranteed, the data with slow rate cannot be utilized properly [4].

Therefore, this paper considers the amplify-and-forward (AF) relay networks that requires data transmission maintaining covertness and data freshness. In this system, cooperative jammer generating artificial noise (AN) is introduced to increase the warden's uncertainty. We first derive bound of covertness and average age of information (AoI) at Bob and formulate an optimization problem for jamming power to ensure data freshness. Then, we optimize the jamming power to solve the average AoI minimization problem.

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II. System Model

In this section, we introduce a network scenario and analyzes the detection error probability at Willie.

A. Network Scenario

This paper considers an AF relay covert network consisting of Alice, Relay, Bob, warden Willie and cooperative jammer. A transmitter Alice want to transmit information to a receiver Bob covertly with help of Relay under the detection of a passive warden Willie. We assumed that every node has a single antenna and the transmission between Alice and Bob has two phase. In the first phase, Alice attempts to transmit a message to Relay with prior probability ρ under the Willie's detection. Meanwhile, cooperative jammer also transmits jamming signal to Willie to hide the Alice's signal. In the second phase, Relay amplifies the received signal from Alice and forward it to Bob.

In this system, P_j denotes the transmit power of transmitter j, where $j \in \{A, R, J\}$, and A, R, J denotes Alice, Relay and Jammer. The path-loss and channel between a and b can be expressed as $d_{ab}^{-\alpha}$ and h_{ab}, where $ab \in \{AR, RB, AW, RW\}$ and B denotes Bob. α is path-loss exponent and channel h_{ab} is subject to experience the block quasi-static Rayleigh fading with mean value $\lambda_{ab} = E(|h_{ab}|^2) = 1$. We consider the worst case scenario, so we assumed that Willie knows complete knowledges on h_{AW} and h_{RW}.

According to the above assumption, in the first phase, the signals received at Relay can be given by

$$y_R[i]=\sqrt{P_A}h_{AR}d_{AR}^{-\frac{\alpha}{2}}x_A[i]+\sqrt{P_J}h_{JR}d_{JR}^{-\frac{\alpha}{2}}x_J[i]+n_R[i], \quad (1)$$

where $x_A[i]\sim CN(0,1)$ and $x_J[i]\sim CN(0,1)$ denotes the Alice's signal and Jammer's signal and $i = 1, ..., .., n$ is index of the channel use. $n_R[i]\sim CN(0,\sigma_R^2)$ denotes the additive white gaussian noise (AWGN) at Relay. In the second phase, the signals received at Bob can be given by

$$y_B[i]= G\sqrt{P_R}h_{RB}d_{RB}^{-\frac{\alpha}{2}}y_R[i] + n_B[i], \quad (2)$$

where $n_B[i]{\sim}CN(0,\sigma_B^2)$ denotes the AWGN at Bob. The Aplification factor G can be expressed as

$$G=\sqrt{\frac{1}{\sqrt{P_A}h_{AR}d_{AR}^{-\frac{\alpha}{2}}x_A[i]+\sqrt{P_J}h_{JR}d_{JR}^{-\frac{\alpha}{2}}x_J[i]+n_R[i]}}. \quad (3)$$

Therefore, the total signal-to-noise ratio (SNR) at Bob is given by [5]

$$SNR_{AB}=\frac{SNR_{AR}SNR_{RB}}{SNR_{AR}+SNR_{RB}+1}, \quad (4)$$

where $SNR_{AR}=\frac{P_A|h_{AR}|^2d_{AR}^{-\alpha}}{P_J|h_{JR}|^2d_{JR}^{-\alpha}+\sigma_R^2}$ denotes SNR from Alice to Relay and $SNR_{RB}=\frac{P_R|h_{RB}|^2d_{RB}^{-\alpha}}{\sigma_B^2}$ denotes SNR from Relay to Bob.

B. Detection Performance at Warden Willie

In the first phase, the signal received at Willie can be expressed as

$$y_W[i]=\begin{cases}\sqrt{P_J}h_{JW}d_{JW}^{-\frac{\alpha}{2}}x_J[i]+n_W[i], & H_0,\\ \sqrt{P_J}h_{JW}d_{JW}^{-\frac{\alpha}{2}}x_J[i]+\sqrt{P_A}h_{AW}d_{AW}^{-\frac{\alpha}{2}}x_A[i]+n_W[i], & H_1,\end{cases} \quad (5)$$

where H_0 is the null hypothesis meaning Alice does not transmit, H_1 is the alternative hypothesis indicating Alice transmits. The signal $n_W[i]{\sim}CN(0,\sigma_W^2)$ denotes the AWGN at Bob. Accordingly, the total detection error probability detection error probability (DEP) is given by $p_{we}=(1-\rho)p_{FA}+\rho p_{MD}$ where p_{FA} denotes the false alarm probability that Willie determines H_1 while H_0 is true, p_{MD} denotes the Miss detection probability that Willie determines H_0 while H_1 is true. To acheive the covertness, the detection error probability of Willie should satisfy [6]

$$p_{we}=(1-\rho)p_{FA}+\rho p_{MD}\geq 1-\epsilon, \quad (6)$$

where ϵ is a certain level of covertness which is an arbitrarily small positive value. According to [7], the lower boundary of the detection error probability is expressed as

$$p_{we}=(1-\rho)p_{FA}+\rho p_{MD}\geq max(1-\rho,\rho)\sqrt{\frac{1}{2}D(\mathbb{P}_0|\mathbb{P}_1)}, \quad (7)$$

where $\mathbb{P}_0$ and $\mathbb{P}_1$ denote likelihood functions under H_0 and H_1 respectively, and $D(\mathbb{P}_0|\mathbb{P}_1)$ denotes the relative entropy (Kullback-Leibler divergence) from H_0 to H_1. Considering (6) and (7), the lower boundary of the detection error probability can be re-expressed by [6]

$$max(1-\rho,\rho)\sqrt{\frac{1}{2}D(\mathbb{P}_0|\mathbb{P}_1)}\leq\epsilon. \quad (8)$$

$D(\mathbb{P}_0|\mathbb{P}_1)$ can be expressed as [8]

$$D(\mathbb{P}_0|\mathbb{P}_1)=n\left[\ln\left(1+\frac{P_A|h_{AW}|^2d_{AW}^{-\alpha}}{P_R|h_{RW}|^2d_{RW}^{-\alpha}+\sigma_W^2}\right)-\frac{P_A|h_{AW}|^2d_{AW}^{-\alpha}}{P_A|h_{AW}|^2d_{AW}^{-\alpha}+P_R|h_{RW}|^2d_{RW}^{-\alpha}+\sigma_W^2}\right], \quad (9)$$

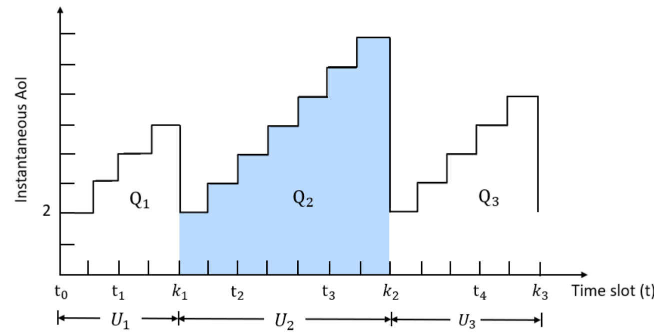

Fig. 1. The instantaneous AoI of Bob.

$\mathbb{E}(D(\mathbb{P}_0|\mathbb{P}_1))=\overline{D(\mathbb{P}_0|\mathbb{P}_1)}$ can be derived as

$$\overline{D(\mathbb{P}_0|\mathbb{P}_1)}=\int_0^\infty\int_0^\infty\frac{n}{2}D(\mathbb{P}_0|\mathbb{P}_1)f_{|h_{AW}|^2}(x)f_{|h_{JW}|^2}(y)dxdy. \quad (10)$$

Then, the covertness constraint is rewritten as

$$\frac{n}{2}\overline{D(\mathbb{P}_0|\mathbb{P}_1)}\leq\left(\frac{\epsilon}{max(1-\rho,\rho)}\right)^2. \quad (11)$$

III. Analysis of The Age of Information

In this section, we derived the average AoI at Bob and formulate the average AoI minimization problem.

A. Average Age of Information at Bob

To analyze the impact of jamming power on Bob's data freshness, the average AoI of Bob is expressed as [4]

$$\bar{\Delta}_B=\frac{\mathbb{E}[Q_k]}{\mathbb{E}[U_k]}=\frac{\mathbb{E}[U_k^2]}{2\mathbb{E}[U_k]}+\frac{3}{2}=\frac{1}{\rho q}+1, \quad (12)$$

where Q_k denotes the area over time between the $k-1$ th and k th successful transmissions of Bob, U_k denotes the time interval between the $k-1$ th and k th successful transmissions. $q=1-p_{o,B}$ is the successful decoding probability of Bob and $p_{o,B}$ is outage probability at Bob, which can be expressed as [9]

$$p_{o,B}=Q\left(\frac{c_{AB}-R}{\log_2(e\sqrt{(1-2^{(-2c_{AB})})/n})}\right), \quad (13)$$

where $Q(x)=\int_x^\infty\frac{1}{\sqrt{2\pi}}\exp(-\frac{u^2}{2})du$ denotes Q-function, $c_{AB}=\log_2(1+SNR_{AB})$ denotes channel capacity of Bob, R denotes target transmission rate at Bob.

B. Problem Formulation

From the perspective of the average AoI in covert communication between Alice and Bob, we formulate the average AoI minimization problem under the covertness constraint by

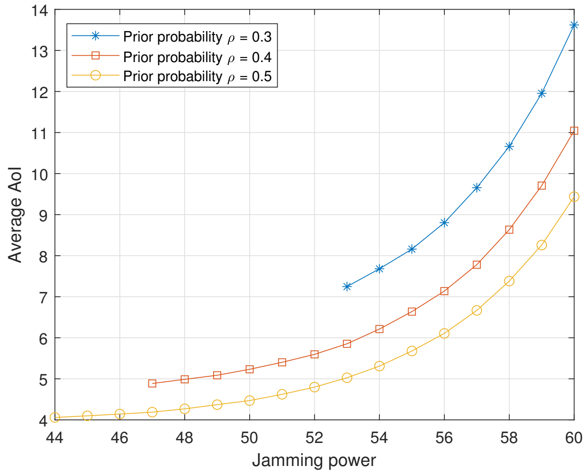

Fig. 2. The average AoI at Bob within the feasible range of covertness constraint

optimizing the jamming power at the jammer. Therefore, the optimization problem is given by

$$\min_{P_J} \quad \bar{\Delta}_B \tag{14}$$

$$\text{s.t.} \quad \frac{n}{2}\overline{D(\mathbb{P}_0|\mathbb{P}_1)} \leq \left(\frac{\epsilon}{max(1-\rho,\rho)}\right)^2, \tag{15}$$

$$0 \leq \rho \leq 1. \tag{16}$$

$\bar{\Delta}_B$ is increasing function of jamming power P_J and the covertness constraint (15) is decreasing function of jamming power P_J because the jamming power decreases the Bob's successful decoding probability while helping to hide the presence of Alice's signal from detection of Willie. Therefore, optimal jamming power P_J is the value that satisfies $\frac{n}{2}\overline{D(\mathbb{P}_0|\mathbb{P}_1)} = \left(\frac{\epsilon}{max(1-\rho,\rho)}\right)^2$.

IV. Simulation Results

In this section, we present the performance of the considered system. In our simulations, we set the predetermined target rate from Alice to Bob as $R = 0.2$ bpcu, the level of covertness as $\epsilon = 0.1$, the number of channel uses as $n = 250$. The transmit power of Alice P_A is set to 35 dBm and the transmit power of Relay P_R is set to 60 dBm. The mean values of all channel fading are set to 1, noise power of Bob and Relay, σ_B and σ_R are set to 0 dBm and the noise power of Willie σ_W is set to 5 dBm. The distance between Alice and Relay, Relay and Bob d_{AR}, d_{RB} are set to 50 m, the distance between Jammer and Relay d_{JR} is set to 250 m and the distance between Alice and Willie, Jammer and Willie d_{AW}, d_{JW} are set to 150 m, 250 m.

Fig. 2 presents the average AoI at Bob within the feasible range of covertness constraint according to the jamming power for different prior probability. In this figure, we can first observe that the average AoI at Bob increases with the jamming power because the jamming signal is also forwarded to the Bob at second phase and it is considered as the AN when Bob receives signal from the relay. We can also observe that as the jamming power increases, the covertness constraint can be easily satisfied because jamming signal disturbs the detection of Willie. Lastly, as the prior probability increases, the feasible range of covertness constraint becomes more alleviated because higher prior probability helps to reduce the average AoI at Bob by sending more communications.

V. Conclusion

In this paper, we considered covert AF relay networks with data freshness. We first derived the lower boundary of covertness and the average AoI and formulated the average AoI minimization problem under the covertness constraint by optimizing the jamming power at the jammer. Then, we show that the optimal jamming power is the minimum value that satisfies the lower boundary of covertness constraint. Our results show that the average AoI at Bob increases with the jamming power and as the jamming power increases, the covertness can be easily satisfied.

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