IRS-based Wireless Jamming Attacks:
When Jammers can Attack without Power

Bin Lyu, Dinh Thai Hoang, Shimin Gong, Dusit Niyato and Dong In Kim

Abstract

This paper introduces a new type of wireless jamming attack, called IRS jamming attack, which enables a jammer to attack a legitimate communication without using any internal energy to generate jamming signals. In particular, for such kind of attacks, the jammer uses an Intelligent Reflection Surface (IRS) which can control reflected signals to diminish the Signal-to-Interference-plus-Noise Ratio (SINR) at the legitimate receiver. To be more specific, once receiving signals from the legitimate transmitter, the IRS jammer will adjust its phase shifts to minimize the received signals at the legitimate receiver. In other words, the jammer can launch jamming attacks just by leveraging signals from the legitimate transmitter. Through simulation results, we show that by using the IRS-based jammer, we can reduce the signal power received at the legitimate receiver by up to 98%. Interestingly, the performance of the proposed IRS jammer is even better than that of the conventional active jamming attacks, although the IRS jammer does not need to use any energy to launch jamming attacks.

Index Terms

Jamming attack, IRS, intelligent backscatter, IoT, low-power sensor networks.

I. INTRODUCTION

Recently, Intelligent Reflecting Surface (IRS) has been emerging to be a breakthrough technology which enables significantly improving spectrum and energy efficiency for future wireless communication systems [1], [2]. Unlike the conventional backscattering communication techniques which uncontrollably scatter reflected Radio Frequency (RF) signals [3], the IRS provides a smart radio environment in which

B. Lyu is with Nanjing University of Posts and Telecommunications, China (e-mail: blyu@njupt.edu.cn).
D. T. Hoang is with University of Technology Sydney, Australia (email: hoang.dinh@uts.edu.au).
S. Gong is with Sun Yat-sen University, China (email: gongshm5@mail.sysu.edu.cn).
D. Niyato is with Nanyang Technological University, Singapore (email: dniyato@ntu.edu.sg)
D. I. Kim is with Sungkyunkwan University, South Korea (e-mail: dikim@skku.ac.kr)
the reflected signals will be controlled in order to remarkably enhance the network performance. In particular, IRS is a reconfigurable metasurface composed of multiple low-cost passive reflecting elements. Each element can reflect the incident signal independently with an adjustable phase shift controlled by an IRS micro-controller (as illustrated in Fig. 1). In this way, by simultaneously adjusting the phase shifts of all elements, the IRS can fully control the strength and direction of the reflected electromagnetic waves, thereby the signal power received at the target devices can be significantly improved. As a result, IRS has a huge potential to fundamentally change how wireless networks are designed and pave the wave for future wireless communication systems.

In the literature, most of current research works now focus on developing IRS applications with the aims of improving system performance, e.g., improving network throughput [4], [5] and achieving high secrecy rate [6], [7]. For example, in [4], [5], the authors propose to use IRSs as intelligent relay nodes to improve the received signal power at the receivers. In [6], [7], the authors propose the idea of using IRS to maximize the achievable secrecy rate to protect the system from eavesdropping attacks. Unlike the aforementioned works and others in the literature, in this paper we introduce an adverse application of IRS in wireless networks where an IRS will be used as a **green jammer** to sabotage the communication between two legitimate devices. Different from conventional active jamming attacks which use their own internal energy to transmit strong noise signals to the victim system, our proposed IRS-based jammer can use right the signals of victim communication system to degrade the Signal-to-Interference-plus-Noise Ratio (SINR) at the legitimate receiver (LR). Consequently, the IRS-based jamming attacks can disturb the system without leaving any energy footprint, and thus it is very difficult to detect and prevent such kind of attacks.

In particular, in the system under considerations, once receiving signals transmitted from the legitimate transmitter (LT), the IRS jammer will optimize the phase shifts of reflecting elements to minimize the total received signal power at the LR. In other words, the jammer will use right the LT’s signals to attack the legitimate system. To address the non-convex problem in determining the optimal phase shifts for the jammer, we first adopt the semidefinite relaxation (SDR) technique [8] to relax the rank-one constraint and then use the CVX tool [9] to solve the convex semidefinite program (SDP). However, in this way, the obtained solution may not satisfy the rank-one constraint. Thus, we develop a Gaussian randomization method to obtain a sub-optimal solution. Through simulation results, we show that our proposed IRS jammer can degrade the received signal power at the LR by up to 98%. More interestingly, we show that
in some cases, the performance obtained by our proposed IRS jammer can be even better than that of conventional active jamming attacks.

Note that the aim of this work is not to propose an adversary wireless application. Our main goal is to raise a concern about a new type of attack, i.e., IRS jamming, which can cause serious harmful interferences to critical wireless systems and is very difficult to detect and defend because it does not leave any energy footprint. More importantly, as IRS jammers do not actively generate signals, they have not yet been considered to be illegal as those of conventional jamming attacks. Thus, without proper management solutions, IRS jammers will be a big concern for future wireless communication systems.

II. System Model

In this paper, we consider a conventional legitimate communication system including an LT and an LR as illustrated in Fig. 1. The LT is equipped with $M$ antennas, while the LR has a single antenna. There is an IRS jammer located between the LT and LR with the aim to disturb the legitimate communication. The IRS is equipped with $N$ passive reflecting elements, each of which is equipped with an adjustable phase shift to reflect the incident signals independently. The IRS uses a micro-controller to perform necessary calculation and control functions, such as channel estimation or controlling the switching circuit in passive elements to change the phase of the reflected signal. The channels between the LT-LR link, IRS-LR link, and LT-IRS link are denoted by $C_d^H \in \mathbb{C}^{1 \times M}$, $C_r^H \in \mathbb{C}^{1 \times N}$, and $G \in \mathbb{C}^{N \times M}$, respectively, where the
superscript $H$ represents the conjugate transpose operation and $\mathbb{C}$ denotes the space of $a \times b$ complex-valued matrices.

Let denote $\theta = [\theta_1, \ldots, \theta_N]$ as the phase shifts of all IRS’s elements. We have $\theta_n \in [0, 2\pi], \forall n = \{1, \ldots, N\}$. Then, denote $\Theta = \text{diag}(\beta e^{j\theta_1}, \ldots, \beta e^{j\theta_N})$ as the IRS’s diagonal phase-shift matrix. Here, $j$ is the imaginary unit, $\text{diag}(A)$ is the diagonal matrix with each diagonal element being the corresponding element in $A$, and $\beta \in [0, 1]$ is the amplitude reflection coefficient on the combined incident signal. In this paper, we consider a linear beamforming at the LT with $\Omega \in \mathbb{C}^{M \times 1}$ denoting the transmit beamforming vector and satisfying $\|\Omega\|^2 = P_T$, where $P_T$ is the total transmit power at the LT. Then, the total signal received at the LR can be expressed as:

$$y = (C^H_t \Theta G + C^H_d) \Omega s + z,$$

where $s$ the information-carrying signal with unit power, and $z$ denotes the additive white Gaussian noise (AWGN) at the LR with zero mean and variance $\sigma^2$. Accordingly, the signal power received at the LR is given by:

$$\gamma = \|C^H_t \Theta G + C^H_d\|\Omega|^2.$$  

### III. Problem Formulation

In this paper, we focus on minimizing the received signal power in (2) by optimizing the phase shift $\theta$. The corresponding optimization problem can be formulated as follows:

$$\min_\theta |(C^H_t \Theta G + C^H_d)\Omega|^2,$$

$$0 \leq \theta_n \leq 2\pi, \forall n = \{1, \ldots, N\}. \quad (P1)$$

$P1$ is a non-convex optimization problem and is thus difficult to obtain its optimal solution. To solve it efficiently, we first introduce some auxiliaries for substitutions. Let $v_n = e^{j\theta_n}$ and $v = [v_1, \ldots, v_N]^H$, where $|v_n| = 1, \forall n$. Denote $\alpha = \text{diag}(C^H_t) G \Omega$ and $\psi = C^H_d \Omega$. Then, the objective function of $P1$ can be reformulated as $|\beta^2 v^H \alpha + \psi|^2 = \beta^2 v^H \alpha \alpha^H v + \beta v^H \alpha \psi^H + \beta \psi \alpha^H v + |\psi|^2$. $P1$ is thus equivalent to the following optimization problem:

$$\min_v \beta^2 v^H \alpha \alpha^H v + \beta v^H \alpha \psi^H + \beta \psi \alpha^H v + |\psi|^2,$$

$$|v_n| = 1, \ n = 1, \ldots, N. \quad (P2)$$
Note that \( P2 \) is still non-convex. To address this issue, an auxiliary matrix \( R \) and an auxiliary vector \( \mu \) are further introduced for substitutions, which are expressed as follows:

\[
R = \begin{bmatrix}
\beta^2 \alpha \alpha^H & \beta \alpha \psi^H \\
\beta \alpha^H \psi & 0
\end{bmatrix}, \quad \mu = \begin{bmatrix} v \\ 1 \end{bmatrix}.
\]

With \( R \) and \( \mu \), the objective function of \( P2 \) can be recast by: \( \text{Tr}(R\mu\mu^H) + |\psi|^2 \). Let \( V = \mu\mu^H \), where \( V \geq 0 \) and \( \text{rank}(V) = 1 \). Then, \( \text{Tr}(R\mu\mu^H) + |\psi|^2 \) is equivalent to \( \text{Tr}(RV) + |\psi|^2 \). In addition, we have a new constraint that \( V_{n,n} = 1 \) due to that \( |v_n| = 1 \), \( \forall n \), where \( V_{n,n} \) denotes the \( n \)-th diagonal element of \( V \). Hence, \( P2 \) can be reformulated as

\[
\min_V \quad \text{Tr}(RV) + |\psi|^2,
\]

\[V_{n,n} = 1, \quad \forall n,
\]

\[V \succeq 0,
\]

\[\text{rank}(V) = 1.
\]

\( P3 \) is still a non-convex optimization problem due to the rank-one constraint. However, we can apply the semidefinite relaxation (SDR) technique [8] to relax the rank-one constraint. After that, \( P3 \) is recast as:

\[
\min_V \quad \text{Tr}(RV) + |\psi|^2,
\]

\[V_{n,n} = 1, \quad \forall n,
\]

\[V \succeq 0.
\]

\( P4 \) is a convex SDP [10] and can be thus solved by the CVX tool [9]. However, the solution obtained from \( P4 \) solved by the CVX is generally not a rank-one solution and leads to an upper bound performance of the IRS jamming attack. In other words, the solution for \( P4 \) is not an exact solution for \( P3 \). Thus, we propose to utilize the Gaussian randomization method to construct an approximate solution for \( P3 \) based on the solution from \( P4 \). Denote the solution for \( P4 \) as \( \hat{V} \), the singular value decomposition is given by:

\[
\hat{V} = U \Sigma U^H,
\]

where \( U \in \mathbb{C}^{(N+1) \times (N+1)} \) and \( \Sigma \in \mathbb{C}^{(N+1) \times (N+1)} \) are the unitary matrix and the diagonal matrix of \( \hat{V} \), respectively. Based on the Gaussian randomization method, a rank-one solution for \( P3 \) can be constructed.
by $\bar{V} = \bar{\mu}\bar{\mu}^H$, where

$$\bar{\mu} = U\sqrt{\Sigma}r,$$

(4)

and the random vector $r \in \mathbb{C}^{(N+1)\times 1}$ is independently generated according to $\mathcal{CN}(0, I_{N+1})$. With $\bar{\mu}$, an approximate solution for $P_2$, denoted by $\bar{v}$, is recovered by

$$\bar{v} = e^{j \arg \left( \left[ \bar{\mu}/\bar{\mu}_{(N+1)} \right]_{(1:N)} \right)},$$

(5)

where $[w]_{(1:N)}$ indicates the first $N$ elements selected from the vector $w$, $\arg(w)$ denotes the phase of each element in the vector $w$, and $\bar{\mu}(N+1)$ is the $(N+1)$-th element of $\bar{\mu}$.

Through generating $r$ for a sufficiently large number, we can find the best $\bar{v}$ among all $r$’s that minimizes the received signal power at the LR, which is considered as the sub-optimal solution for $P_2$. It was confirmed that the SDR technique followed by the Gaussian randomization method with sufficiently large number of randomization can guarantee at least an $\frac{\pi}{4}$ approximation of the minimum received signal power at the LR achieved by solving $P_2$ [11]. The algorithm for solving $P_2$ is summarized in Algorithm 1.

**Algorithm 1** The Algorithm for solving $P_2$.

1: Initialize $D$, which is a sufficiently large number of generating random vectors.
2: Solve $P_4$ and obtain $\bar{V}$.
3: Compute the singular value decomposition of $\bar{V}$, and obtain $U$ and $\Sigma$.
4: Initialize $\Gamma = \emptyset$.
5: for $d = 1, \ldots, D$ do
6: Generate $r$ according to $\mathcal{CN}(0, I_{N+1})$.
7: Construct $\bar{\mu}$ by (4), and obtain $\bar{v}$ by (5).
8: Compute the objective function value of $P_2$ with $\bar{v}$, which is denoted by $\gamma_d$.
9: $\Gamma = \Gamma \cup \gamma_d$.
10: end for
11: Obtain the sub-optimal solution for $P_2$ by $v^* = \arg \min_{\bar{v}} \Gamma$.

IV. PERFORMANCE EVALUATION

The simulated network topology is a 2D coordinate system, where the coordinates of the LT, the LR, and the IRS are given as $(x_t, 0)$, $(x_r, 0)$, $(x_i, y_i)$, respectively. The large-scale path-loss is modeled as $10^{-3}d^{-\alpha}$, where $d$ is the distance between two nodes, $\alpha$ is the path-loss exponent and set to be 2. The small-scale fading is assumed to follow the Rayleigh distribution. Unless otherwise stated, other parameters are given as follows: $\beta = 1$, $M = 5$, $N = 80$, $x_t = 0$, $x_r = 5$ m, $x_i = 2.5$ m, and $y_i = 2$ m. The traditional active
jamming scheme with transmit power $P_a$ is used as a benchmark, where the active jammer is deployed at the location of the IRS. In addition, the scheme without jamming is also used as a benchmark to evaluate the impact of the IRS jamming attack.

In order to evaluate the performance of the proposed IRS jammer with the conventional active jamming attack, we first vary the LT’s transmit power and the number of reflecting elements and compare their performance in terms of SINR. The SINR is determined by:

$$\text{SINR} = \frac{P_{\text{signal}}}{P_{\text{noise}} + P_{\text{interference}}}.$$  \hfill (6)
In the case of the conventional active jamming attack, $P_{\text{interference}}$ is the power of received jamming signals transmitted by the active jammer, while $P_{\text{interference}}$ is set to be zero in the case of IRS jamming attack. The noise power $P_{\text{noise}}$ in both cases is set at $\sigma^2 = -30$ dBm.

In Fig. 2, we vary the LT’s transmit power and show the SINR at the LR under different attacks. It can be observed that our proposed scheme can degrade the SINR at the LR by about 10 dB compared to the scheme without jamming. Also, it can be observed that when we increase the transmit power of the conventional active jammer, the SINR at the LR will be reduced. Here, it is obvious that the active jamming scheme with high jamming power (e.g., $P_a = 35$ dBm) can achieve the lowest SINR, i.e., the best attack performance. However, interestingly, if the active jamming power is not high, i.e., $P_a = 20$ dBm, our proposed IRS jammer can even achieve better attack performance even without using any internal energy to launch jamming attacks. The reason is that in our proposed scheme, the phase shifts of all passive reflecting elements can be carefully designed such that the total received signals at the LR from the direct link and reflecting links can be added destructively, which can significantly reduce the received power and thus diminish the SINR at the LR.

In Fig. 3, we plot the SINR at the LR versus the number of reflecting elements. It can be observed that as the number of reflecting elements increases, the SINR at the LR under the IRS jamming attacks will be significantly reduced due to very low signal powers received at the LR. Interesting, if the number of reflecting elements is sufficiently large, e.g., 120, our proposed IRS jammer can achieve almost the same attack performance as that of the active jamming scheme with $P_a = 35$ dBm. In addition, we can conclude that the performance of our proposed scheme can be further enhanced with the increase of reflecting elements and can be even better than that of the active jamming scheme.

Fig. 4 shows the received SINR versus the variation of the LT’s horizontal coordinate, i.e., $x_t$. From Fig. 4, we can observe that our proposed scheme can always degrade the received SINR at the LR compared to the scheme without jamming. As $x_t$ varies from -5 m to 4 m, the received SINR increases due to the decrease of distance between the LT and the LR. If $x_t$ varies from -5 m to 2 m, the attack performance of the proposed scheme is better than that of the active jamming scheme with $P_a = 20$ dBm. However, if $x_t$ is larger than the threshold, i.e., 2 m, our proposed scheme achieves a worse performance compared to the active jamming scheme. The reason is that when $x_t$ varies from 3 m to 4 m, the distance between the IRS and the LT increases but the distance between the LT and the LR reduces, which thus declines the effect of IRS jamming attack.
Fig. 4. SINR versus horizontal coordinate of LT.

Fig. 5. SINR versus horizontal coordinate of LR.

Fig. 5 investigates the received SINR versus the variation of the LR’s horizontal coordinate, i.e., $x_r$. As $x_r$ varies from 1 m to 8 m, the received SINRs at the LR achieved by all schemes reduce. It can be observed that compared to the active jamming schemes, the attack performance of the proposed IRS jammer is not sensitive to the location of the LR. For example, when $x_r$ varies from 4 m and 8 m, the SINR achieved by the active jamming scheme almost remains stable. However, our proposed scheme can still further reduce the received SINR at the LR. The reason is that as $x_r$ increases, the distance between the LT and the IRS is unchanged, and only the distance between the LR and the IRS increases. Hence, the reduction rate of all received signal power from reflecting links at the LR is much limited compared
to that from the direct link, which thus degrades the total received signal power at the LR due to the destructive addition.

V. CONCLUSIONS

In this paper, we introduce a new type of jamming attack, called IRS jamming. Different from all other wireless jamming attacks in the literature which have to use their own energy to generate jamming signals, our proposed IRS jammer can leverage right the LT’s signals to reduce the SINR at the LR. This is due to the fact that the IRS jammer can control its phase shifts to reflect signals which can significantly reduce the received signal power at the LR. Through simulation results, we show that our proposed IRS jammer can not only remarkably reduce the LR’s SINR, but also achieve better performance than that of conventional active jamming attack.

REFERENCES

[1] M. D. Renzo, et. al., “Smart radio environments empowered by AI reconfigurable meta-surfaces: An idea whose time has come,” Available Online: [https://arxiv.org/abs/1903.08925](https://arxiv.org/abs/1903.08925), Mar. 2019.
[2] S. Gong, et. al., “Towards smart radio environment for wireless communications via intelligent reflecting surfaces: A comprehensive survey”, Available Online: [https://arxiv.org/pdf/1912.07794.pdf](https://arxiv.org/pdf/1912.07794.pdf), Dec. 2019.
[3] N. V. Huynh, et. al., “Ambient backscatter communications: A contemporary Survey,” vol. 20, no. 4, pp. 2889-2922, May 2018.
[4] Q. Wu and R. Zhang, “Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming, IEEE Transactions on Wireless Communications, vol. 18, no. 11, pp. 5594-5409, Aug. 2019.
[5] C. Huang, et. al., “Reconfigurable intelligent surfaces for energy efficiency in wireless communication,” IEEE Transactions on Wireless Communications, vol. 18, no. 8, pp. 4157-4170, Jun. 2019.
[6] X. Yu, D. Xu, and R. Schober, “Enabling secure wireless communications via intelligent reflecting surfaces,” Available Online: [https://arxiv.org/abs/1904.09573](https://arxiv.org/abs/1904.09573), Apr. 2019.
[7] M. Cui, G. Zhang, and R. Zhang, “Secure wireless communication via intelligent reflecting surface,” IEEE Wireless Communications Letters, vol. 8, no. 5, pp. 1410-1414, Oct. 2019.
[8] Z. Q. Luo, et. al., “Semidefinite relaxation of quadratic optimization problems,” IEEE Signal Processing Magazine, vol. 27, no. 3, pp. 20-34, May 2010.
[9] M. Grant and S. Boyd, “CVX: Matlab software for disciplined convex programming,” version 2.0 beta. [http://cvxr.com/cvx](http://cvxr.com/cvx), Sept. 2013.
[10] S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge University Press, 2004.
[11] A. M.-C. So, J. Zhang, and Y. Ye, “On approximating complex quadratic optimization problems via semidefinite programming relaxations,” Mathematical Programming, vol. 110, pp. 93110, Jun. 2007.