

Analysis of Passive Jamming on MIMO Communications via Intelligent Reflecting Surfaces

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Abstract—We investigate the feasibility of using an Intelligent Reflecting Surface (IRS) to manipulate multi-input multi-output (MIMO) wireless channels with the goal of disrupting communication. To ensure a realistic representation of IRS systems in practical deployment scenarios, we incorporate the radiation patterns of both antennas and IRS unit cells into the system model. Through numerical simulations, we analyze the signal-to-noise ratio (SNR) under varying IRS phase shift designs, demonstrating the potential of IRS-based jamming attacks by strategically altering the wireless channels.

I. INTRODUCTION

In recent years, intelligent reflecting surfaces (IRSs) have emerged as a promising technology for a multitude of applications in wireless communications [1]–[4]. For instance, [1], [2] explore the use of an IRS to enable covert communication, concealing the presence of transmissions by a legitimate transmitter from a potential adversary. By optimizing the IRS reflection matrix, the system enhances covertness while maximizing the achievable rate at the receiver. In another line of research, [3] investigates the deployment of an adversarial IRS to launch jamming attacks on multi-user MISO systems.

While these studies highlight the diverse applications of IRSs, they often overlook important factors that impact their performance. Specifically, the effects of directional antennas, IRS unit cells, and their associated radiation patterns—especially crucial for high-frequency applications where directional antennas are required to mitigate significant propagation losses—have not been adequately addressed. These factors are essential for accurately modeling realistic systems and understanding their performance under practical scenarios. In [4], free-space path loss models for IRS-reflected signals are introduced, excluding the direct path component, while incorporating the radiation pattern effects of both the antennas and the IRS unit cells. Extending this framework, we demonstrate how IRSs can be utilized to manipulate wireless MIMO channels to degrade communication performance. Our analysis considers both the direct path and IRS-reflected channels, offering insights into potential jamming attacks through numerical simulations.

II. SYSTEM MODEL

We consider a scenario where an IRS is deployed by a potential adversary to degrade MIMO wireless channels, as illustrated in Fig. 1. Here, the transmitter (receiver) is equipped with K (J) antennas. The IRS is composed of a 2-D array of $N \times M$ unit cells, each with dimensions $d_{ux} \times d_{uy}$, where N and M represent the number of rows and columns, respectively. The center of the unit cell in the n^{th} row and the m^{th} column,

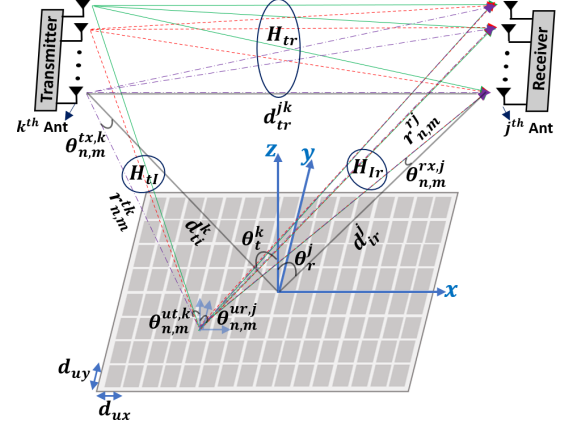


Fig. 1. System model for MIMO channel manipulation via IRS.

denoted as $U_{n,m}$, is located at $((m - \frac{1}{2})d_{ux}, (n - \frac{1}{2})d_{uy}, 0)$, where $m \in [1 - \frac{M}{2}, \frac{M}{2}]$ and $n \in [1 - \frac{N}{2}, \frac{N}{2}]$ (M and N are even numbers). The distances from the k^{th} transmit (T_X) and j^{th} receive (R_X) antennas to the center of $U_{n,m}$ are denoted as $r_{n,m}^{tk}$ and $r_{n,m}^{rj}$, respectively. Their orientations relative to $U_{n,m}$ are characterized by elevation angles $\theta_{n,m}^{ut,k}$, $\theta_{n,m}^{ur,j}$, and azimuth angles $\phi_{n,m}^{ut,k}$, $\phi_{n,m}^{ur,j}$. Similarly, the k^{th} T_X and j^{th} R_X antennas are positioned at distances d_{ti}^k and d_{ir}^j from the IRS center, with orientations specified by elevation angles θ_t^k , θ_r^j , and azimuth angles ϕ_t^k , ϕ_r^j . The wireless channels are represented as $H_{tr} \in \mathbb{C}^{J \times K}$ for the transmitter-to-receiver link, $H_{tl} \in \mathbb{C}^{(N \times M) \times K}$ for the transmitter-to-IRS link, and $H_{lr} \in \mathbb{C}^{J \times (N \times M)}$ for the IRS-to-receiver link.

To estimate the channel state information (CSI), the transmitter sends pilot signals, denoted as S_{tp} , to the receiver. The received signal can be expressed as $S_{rp} = (H_{tr} + H_{lr}\Phi H_{tl})S_{tp} + n_r$, where $\Phi \in \mathbb{C}^{(N \times M) \times (N \times M)}$ represents the effects of the IRS, and $n_r \sim \mathcal{CN}(0, \sigma_p^2)$ is the complex additive Gaussian noise at the receiver. Using S_{rp} , the receiver estimates the composite CSI, denoted as H_{est} , which encompasses both the direct path channel H_{tr} and the IRS-reflected path channels H_{lr} and H_{tl} . However, the receiver does not have access to the individual channel components separately. For optimal transmission performance, the receiver designs the weighting vector using maximum ratio transmission (MRT) based on H_{est} , which is given by $W_t = H_{est}^H = [w_t^1, w_t^2, \dots, w_t^K]^H$.

The transmitter sends a data symbol $s_t \sim \mathcal{CN}(0, 1)$ weighted by W_t , to the receiver. Introducing random phase shifts of the IRS within the channel coherence time, the

received signal, weighted by the receive beamforming vector $W_r = (H_{est}W_t)^H \in \mathbb{C}^{1 \times J}$ based on maximum ratio combining (MRC), is expressed as $s_r = W_r(H_{tr} + H_{Ir}\Phi^H H_{tI})W_t s_t + W_r n_r$, where Φ^H represents the updated effects of the IRS compared to Φ . As a result, the W_t and W_r , derived from H_{est} , may no longer align effectively with the updated channel conditions.

The direct path channel H_{tr} is modeled as Rayleigh fading, scaled by the log-distance path loss model $PL_{DP}^{jk}(d_{tr}^{jk}) = PL(d_0)(\frac{d_{tr}^{jk}}{d_0})^\gamma$, where PL_{DP}^{jk} is the path loss at distance d_{tr}^{jk} , d_0 is the reference distance, and γ is the path-loss exponent. The IRS-reflected path channel also follows Rayleigh fading but is scaled by the free-space path loss model:

$$PL_{RP}^{jk} = \frac{16\pi^2}{G_t G_r d_{ux}^2 d_{uy}^2} \times \frac{1}{|\Psi^{jk}|^2}, \quad (1)$$

where

$$\Psi^{jk} = \sum_{m=1-\frac{M}{2}}^{\frac{M}{2}} \sum_{n=1-\frac{N}{2}}^{\frac{N}{2}} \frac{\sqrt{F_{n,m}^{jk}|\Gamma|}}{r_{n,m}^{tk} r_{n,m}^{rj}} e^{\frac{-j(2\pi(r_{n,m}^{tk} + r_{n,m}^{rj}) - \lambda\phi_{n,m})}{\lambda}}. \quad (2)$$

Here, $F_{n,m}^{jk} = F_{tx}^{k}(\theta_{n,m}^{tx,k}, \phi_{n,m}^{tx,k})F_u(\theta_{n,m}^{ut,k}, \phi_{n,m}^{ut,k})F_u(\theta_{n,m}^{ur,j}, \phi_{n,m}^{ur,j})F_{rx}^j(\theta_{n,m}^{rx,j}, \phi_{n,m}^{rx,j})$ accounts for the normalized power radiation patterns for the k^{th} T_X antenna and j^{th} R_X antenna pair. Additionally, G_t and G_r represent the T_X and R_X antenna gains, respectively, while $\Gamma_{n,m} = |\Gamma|e^{j\phi_{n,m}}$ is the reflection coefficient of the $(n,m)^{th}$ IRS unit cell.

III. NUMERICAL SIMULATION RESULTS

Numerical analysis based on the system model was performed. The setup consists of a single-stream MIMO link, where the k^{th} T_X antenna is positioned at $d_{ti}^k = 10\text{ m}$ with $\theta_k^t = \pi/4, \forall k$. The T_X antennas are uniformly distributed along the azimuth angle with a separation of one wavelength. Similarly, the R_X antennas follow the same uniform distribution. However, the j^{th} R_X antenna moves along d_{ir}^j and varies from 20 m to 60 m , while covering all combinations of θ_r^j and ϕ_r^j angles at each d_{ir}^j . The system parameters were configured as follows: $PL(d_0) = 37\text{ dB}$, $\gamma = 3.9$, $N = 20$, $M = 28$, $J = K = 8$, $G_t = G_r = 7.8\text{ dBi}$, and $|\Gamma| = 1.0$.

Fig. 2 depicts the simulated SNR as a function of θ_r^j at $d_{ir}^j = 60\text{ m}, \forall j$, with the azimuth angle of the receiver centered at 0. The results are presented for two cases: (1) IRS phase shifts set to 0, and (2) IRS phase shifts randomly assigned within $[0, 2\pi)$ during each iteration of the simulation. In both cases, the antennas are oriented toward the IRS center to maximize signal reflection at the specular angle ($\theta_r^j = \pi/4, \forall j$) when zero phase shifts are applied. This setup highlights the impact of the IRS on the SNR by contrasting zero and random phase shift assignment. Notable SNR degradation is observed in the random phase shift case, attributable to channel manipulation introduced by the IRS. Fig. 3 illustrates the simulated SNR as a function of the distance between the transmitter and receiver. Similarly, the results include the SNR with randomly assigned IRS phase shifts and the SNR with



Fig. 2. SNR versus the angular position of the receiver.

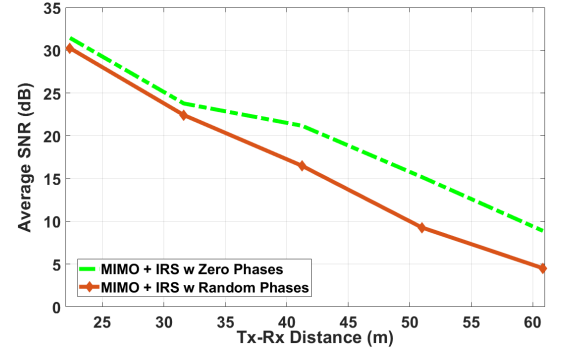


Fig. 3. SNR versus the distance between the transmitter and receiver.

zero IRS phase shifts for comparison. The introduction of random IRS phase shifts degrades the SNR by altering the channel, resulting in imperfect CSI and thus disrupting optimal signal alignments. The extent of SNR degradation depends on the level of interference caused by the signals reflected from the IRS path.

IV. CONCLUSION

We demonstrate the potential of using IRSs for passive jamming of MIMO links. Leveraging realistic system models, our numerical simulations reveal significant SNR degradation as a function of the angular position of the receiver. The SNR control is achieved through channel manipulation by designing IRS reflection coefficients with random phase shifts, without requiring prior channel knowledge.

REFERENCES

- [1] J. Kong, F. T. Dagefu, J. Choi, and P. Spasojevic, "Intelligent reflecting surface assisted covert communication with transmission probability optimization," *IEEE Wirel. Commun. Lett.*, vol. 10, no. 8, Aug. 2021.
- [2] J. Kong, F. T. Dagefu, J. Choi, R. Aggarwal, and P. Spasojevic, "Covert communication in intelligent reflecting surface assisted networks with a friendly jammer," *IEEE Trans. Veh. Technol.*, vol. 73, no. 1, Jan. 2024.
- [3] H. Huang *et al.*, "Disco intelligent reflecting surfaces: Active channel aging for fully-passive jamming attack," *IEEE Trans. Wirel. Commun.*, vol. 23, no. 1, Jan. 2024.
- [4] W. Tang *et al.*, "Wireless communications with reconfigurable intelligent surface: Path loss modeling and experimental measurement," *IEEE Trans. Wirel. Commun.*, vol. 20, no. 1, Jan. 2021.