Simple Delay Design of Adjustable-Delay IRS for Spatial Equalization

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1. Introduction

Intelligent reflecting surface (IRS) has attracted attention as a cost-effective solution for enhancing wireless communication performance by manipulating the propagation environment. Recently, adjustable-delay IRS (AD-IRS) was proposed [1], which can control both the delay and the phase shift of reflected signals. We have applied AD-IRS to spatial equalization in single-carrier transmission [2]. However, the delays were designed solely based on the strongest path without considering the contributions of other significant paths. This limited design may restrict the achievable performance. In this paper, we propose a simple delay design method that considers multiple significant paths.

2. System Model and AD-IRS Design

We consider a single-carrier system composed of a transmitter (Tx), a receiver (Rx) with a single antenna, and AD-IRS with M reflecting elements. We assume that the line-of-sight (LOS) path between Tx and Rx is blocked and AD-IRS provides a virtual LOS path. The channels are assumed to be frequency-selective, and inter-symbol interference (ISI) occurs. The role of AD-IRS is spatial equalization to mitigate the ISI by adjusting delays $\{\tau_m\}$ and phase shifts $\{\phi_m\}$.

A signal received via AD-IRS at time i is expressed as $r_i = \sum_{m=1}^{M} e^{j\phi_m} \sum_{l=0}^{L+\tau_{\max}} h_{m,l-\tau_m} s_{i-l} + n_i$, where s_i is the transmitted symbol, $h_{m,l}$, which is 0 for $l \notin [0, L]$, is the impulse response of the composite channel associated with the mth element, L is the composite channel order, $\tau_{\max}$ is the maximum feasible delay, and n_i is channel noise. Assuming discrete delays, their optimization becomes a combinatorial problem. As M increases, its computational complexity grows exponentially. To address the issue, we propose a simple method with limited delay candidates.We focus on strong gain paths in $\{h_{m,l}\}$ for each element and select the delay maximizing SINR. Delay $\{\tau_m\}$ and phase shift $\{\phi_m\}$ are determined as the following steps.

Step1) Initialize all delays and phase shifts using the strongest tap maximization (STA) method [2] and set $m = 1$.
Step2) Find the K strongest gain paths $h_{m,l_m^{(k)}}$, $k = 1, \cdots, K$.

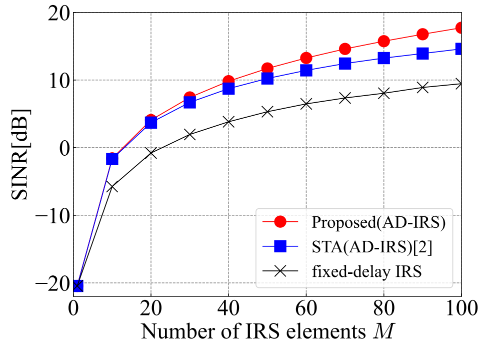

Fig. 1 SINR performance comparison.

Step3) For each path, determine a delay candidate by setting $\tau_m^{(k)} = \delta - l_m^{(k)}$ so that the selected path is aligned at time bin δ, where δ denotes the decision delay.
Step4) For each candidate, phase shift is determined as $\phi_m^{(k)} = -\arg\left(h_{m,l_m^{(k)}}\right)$ and calculate SINR.
Step5) Among all candidates, select the delay and the phase shift that achieves the maximum SINR.
Step6) Repeat Steps 2 − 5 with $m = m + 1$ until $m = M$.

3. Simulation Result

In the simulation, we set transmit power P = 20dBm, noise power $\sigma^2 = -110$dBm, $K = 4$, $L = 10$ and $\tau_{\max} = \delta = L$. In Cartesian coordinates, the positions of the transmitter, AD-IRS, and receiver are (0, 0, 10)m, (100, -20, 10)m, and (120, 0, 0)m, respectively. The results were averaged over 10^5 trials. Fig.1 shows the relation of the number of IRS elements M and the SINR of each method. It can be seen that the proposed method achieves a higher SINR than the conventional STA method corresponding to $K = 1$ [2] and the fixed-delay IRS.

4. Conclusion

We proposed a simple delay design for spatial equalization with AD-IRS and showed its effectiveness.

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References

[1] J. An, et al.,"Adjustable-Delay RIS...," IEEE Trans. Veh. Technol., vol. 73, no. 7, pp. 9927–9942, Jul. 2024.
[2] K. Kurashima et al., "A Study on Spatial Equalization...," IEICE General Conf., Mar. 2025.