Simulated Annealing Utilization for Intelligent Reflecting Surfaces

Wen-Bin Li, Thu L. N. Nguyen, and Yoan Shin*
School of Electronic Engineering, Soongsil University
(*Corresponding author)

Abstract

In this paper, we first formulate the path loss model of an intelligent reflecting surface (IRS) in terms of IRS reflection coefficients, then adopt a simulated annealing algorithm to determine a global maximum point of the path loss. Consequently, we can improve the performance of IRS-assisted communication system by avoiding such position deviations in practice. Simulation results show that an optimal solution can be achieved by implementing the proposed algorithm.

I. Introduction

Recently, intelligent reflecting surface (IRS) is a new promising concept that can improve the communication between a source and a destination. As illustrated in Fig. 1, a typical IRS consists of a large array of passive scattering elements called the meta plates, which can controll the reflection of the incident RF signals according to reflection coefficients. When deploying the IRS in the environments, we need to have the path loss model for the IRS-assisted wireless communication. Current studies [1]-[3] showed that the received signal power of an IRS-assisted wireless communication system can be formulated according to the directions of peak radiation of both the transmitting and receiving antennas. In this paper, we present (i) a large space path loss model to express the path loss between the transmitter and the receiver through an IRS element, (ii) adopt simulated annealing (SA) algorithm find a global maximum of the path loss with respect to a certain range of reflection angles.

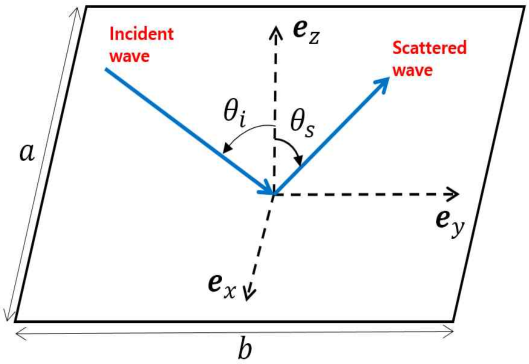

Fig. 1. Illustration of a typical IRS element of size $a \times b$.

II. Main Results

Our work is divided into two parts. First, we construct a relationship between the path loss and the desired reflection angle of an IRS element. Second, we describe how to implement the SA algorithm to find the optimal solution subject to maximizing a path loss threshold. A list of mathematical symbols used in the paper is given in Table I.

1. Path Loss Modeling

Assuming an IRS element of size $a \times b$, the free-space path loss between a transmitter and a receiver through this element can be formulated as [4]

Table 1. List of important symbols

Symbol	Definition
P_t	Transmit power
$P_r(P_t, d_i, r, \theta_s)$	Received signal power for a receiver at a distance r in a direction θ_s
G_t and G_r	Transmitter/receiver antenna gains, respectively
d_i and r	Distances between transmitter-IRS and IRS-receiver, respectively.
λ	RF wavelength
$\theta_i \in \left[0, \frac{\pi}{2}\right]$	Angle of incident
θ_s and θ_r	Observation angle and desired angle, respectively

$$PL(r, d_i, \theta_s) = \frac{P_r(P_t, d_i, r, \theta_s)}{P_t}. \quad (1)$$

Alternatively, a full expression of (1) can be written as

$$PL(r, d_i, \theta_s) = \frac{G_t G_r}{(4\pi)^2}\left(\frac{ab}{d_i r}\right)^2 \cos^2(\theta_i) \times \left[\frac{\sin(\pi b/\lambda)(\sin(\theta_s) - \sin(\theta_r))}{(\pi b/\lambda)(\sin(\theta_s) - \sin(\theta_r))}\right]^2. \quad (2)$$

With a fixed θ_r, $PL(r, d_i, \theta_s)$ can be expressed as a function of θ_s. In the next section, we will explain how to apply the SA algorithm to find a global maximum corresponding to the path loss (2).

2. Simulated Annealing Utilization for Path Loss Prediction

SA is an efficient probabilistic optimization method that finds a global solution in a large search space [4]. In particular, the SA algorithm generates a step-by-step sequence of solutions $\{s_n\}$, then decides whether keeping a solution if it is worse than previous one with a given probability or not. The main steps of the SA algorithm consists of the following components:

- *Initialization*: We select an initial value T_0. This value must be large enough to guarantee a sufficient number of iterations to reach an optimum solution, while limited to avoid computational complexity.
- *Iteration loop*: If s_{n+1} is better than s_n, that is, $PL(s_{n+1}) > PL(s_n)$, we keep s_{n+1} as the current solution of the sequence. Otherwise, we take s_{n+1} as the next current solution with an associated probability as

$$p_n = \exp\left(-\frac{\Delta_n}{T_n}\right), \quad (3)$$

where $\Delta_n = |PL(s_{n+1}) - PL(s_n)|$ and T_n is the decreasing function of the n-th solution. We note that several rules for T_n can be found in [4]. One popular rule is $T_{n+1} = \alpha T_n$ with $\alpha < 1$.

- *Successful search for an acceptable candidate*: If $p_n \geq p_0$, we keep s_{n+1}, where p_0 is the corresponding acceptable probability for T_0.
- *Stopping criterion*: The search process stops when a global maximum is obtained, or a given of number of iterations is reached.

III. Simulation Results

In order to verify the effectiveness of our proposed scheme, we perform several simulations with Python. The simulation parameters are given as follows. $G_t = G_r = 5$ [dB], $a = b = 10$ [m], $\theta_r = \pi/3$ [rad], $\theta_i = \pi/6$[rad], $d_i = 100$ [m] and $r = 25$ [m]. Figure 1 shows the path loss of the reflected path versus observation angle θ_s.

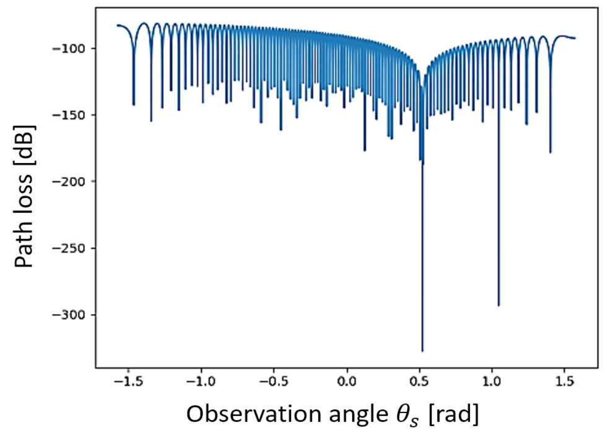

Fig. 2. Path loss versus observation angle θ_s.

Figure 3 plots the average path loss versus the number of iterations obtained by the SA algorithm. We observe that path loss curve has large fluctuations which may be caused by the random factor (3) in the SA configuration in the iteration loop. After the annealing schedule, a good solution can be achieved such as red point in the figure.

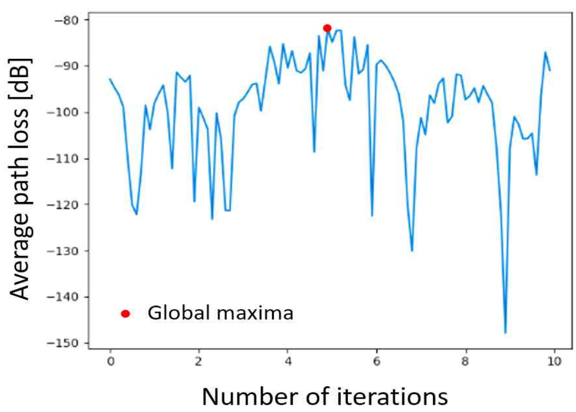

Fig. 3. Average path loss versus number of iterations via the SA algorithm.

In Fig. 4, we analyze the required number of iterations for obtaining an optimal solution as in Fig. 3. We observe that the convergence of the SA algorithm to a global maximum is reasonably fast. In particular, a neighborhood of the red point in Fig. 3 can be obtained within few iterations.

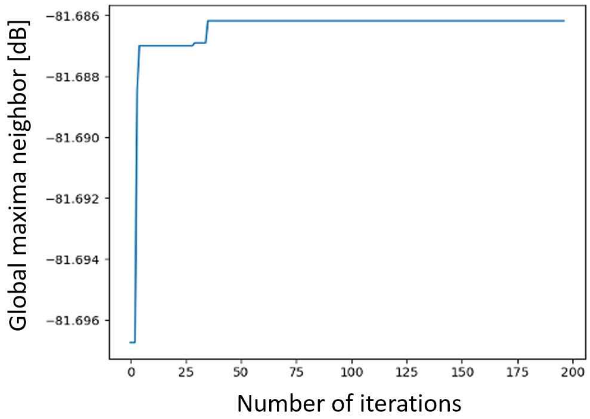

Fig. 4. Number of iterations required for the SA algorithm.

III. Conclusion

Under a large-scale path loss model, we employ in this paper the SA algorithm as an optimization strategy to find a global maximum point of the path loss. Thus, the IRS can select a good observation angle to avoid the maximal loss. Simulation results show that our scheme is effective under certain conditions of a typical IRS-assisted communication settings.

Acknowledgment

This work was supported by IITP grant funded by the Korea government (MSIT) (No. 2017-0-00724, Development of Beyond 5G Mobile Communication Technologies (Ultra-Reliable, Low-Latency, and Massive Connectivity) and Combined Access Technologies for Cellular-based Industrial Automation Systems).

References

[1] O. Özdogan and E. Björnson, "Intelligent reflecting surface: Physics, propagation, and pathloss modeling" *IEEE Wireless Commun. Lett.*, vol. 9, no. 5, pp. 581-585, May 2020.

[2] S. Gong, X. Lu, D. T. Hoang. D. Niyato, L. Shu, D. I. Kim, and Y.-C. Liang, "Toward smart wireless communications via intelligent reflecting surfaces: A contemporary survey," *IEEE Commun. Surveys & Tutorials*, vol. 22, no. 4, pp. 2283-2314, June 2020.

[3] W. Tang, M. Z. Chen, X. Chen, J. Y. Dai, Y. Han, M. D. Renzo, Y. Zeng, S. Jin, Q. Cheng, and T. J. Cui, "Wireless communications with reconfigurable intelligent surface: Path loss modeling and experimental measurement," *IEEE Trans Wireless Commun.*, vol. 20, no. 1, pp. 421-439, Jan. 2021.

[4] M. J. Atellah and M. Blanton (Eds.), *Algorithms and Theory of Computation Handbook: General Concepts and Techniques*, Ch. 3, Chapman & Hall, 2010.