Optimizing Propagation Channels using Static Scatterers: Modeling and Ray-tracing Simulations

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***Abstract*—In this paper, we consider the possibility of improving the propagation of radio signals in complex environments using a set of simple purely passive resonant dipole scatterers. We use the Matlab ray tracer, amended with a model of dipolar scatterers based on their bistatic scattering cross-section, to analyze the influence of the scatterers on the received power at the user position. The analytical and simulation results show that placing additional scattering elements has no significant impact when a direct link exists. However, in non-line-of-sight scenarios, the proposed technique can significantly contribute to the delivered power. This simple and low-cost method can be an alternative or additional method of channel optimization, complementing the use of reconfigurable intelligent surfaces.**

I. Introduction

In wireless communication systems, propagation channels need to be optimized to avoid any blind spots where the signal is too low for serving users. One of the methods is to deploy more base stations or add active relays between the base stations and the users. However, adding active antennas is expensive and complicated. The other option is to use passive antenna structures such as Reconfigurable Intelligent Surfaces (RIS), but they are also complex and expensive devices.

In addition to these methods, we have identified an alternative of deploying a number of static scatterers in the form of resonant dipoles. These additional scatterers enhance the propagation environment by re-radiating signal waves in all directions. This method is very cheap and convenient since it does not require any signal processing or optimization, yet, it can offer significant improvements in coverage. In this work, we first introduce a necessary modification of the path loss model used for the scatterers in the Matlab ray tracer. Next, we run ray-tracing simulations in two indoor scenarios, one scenario with a strong direct link and the other one without a direct link, to investigate how much improvement the user can receive from these scatterers.

II. Path-loss model

If a link between a transmitter (Tx) and a receiver (Rx) is established via scattering by an object with the bistatic cross-section σ, the received power P_r is given by the radar range equation [1]:

$$P_r = \frac{P_t G_t G_r \sigma \lambda^2}{64\pi^3 (R_1 R_2)^2}, \qquad (1)$$

where P_t is the transmitted power, and G_t and G_r are the gains of the Tx and the Rx antennas, respectively. R_1 and R_2 denote the distances between the Tx and the scatterer, and between the scatterer and the Rx, respectively. However, this path-loss model assumes a free-space scenario. Therefore, we use the Matlab ray tracer to obtain a more accurate path-loss model that takes reflections from the environment into account.

For simplicity, we consider electric dipoles as scatterers, since the radiation pattern of a dipole is omnidirectional in the azimuthal plane and does not particularly focus on one specific direction. We place dipoles randomly at different locations in the environment, as the Rx position is not known and can vary. When a dipole is at resonance and absorption in its body and the load can be neglected, its scattering is maximized, e.g. [2]. In this case, the scattering cross-section of the dipole is $\sigma_{\text{max}} = \frac{9}{4\pi}\lambda^2$ [2], which can be expressed also in terms of the effective area A_e and gain G as $\sigma_{\text{max}} = 4A_eG$ [3], since for lossless dipoles $G = 3/2$ and $A_e = \frac{3}{8\pi}\lambda^2$, e.g. [2].

The Matlab ray tracer calculates the received power at the Rx from each propagation path not in terms of the bistatic cross-section, but as

$$P_r = P_t \frac{G_t G_{\text{rx}} \lambda^2}{(4\pi R_1)^2} \frac{G_{\text{tx}} G_r \lambda^2}{(4\pi R_2)^2} = \frac{P_t G_t G_r G_{\text{tx}} G_{\text{rx}} \lambda^4}{(4\pi)^4 (R_1 R_2)^2}, \qquad (2)$$

with G_{tx} and G_{rx} being the gains of the scatterer when it is in the transmitting and receiving modes, respectively. For reciprocal scatterers, $G_{\text{tx}} = G_{\text{rx}} = G$. Equation (2) is based on the Friis formula, and it holds the assumption that the load of the scattering antenna is conjugate-matched. In this case, the scattering cross section is $\sigma_{\text{match}} = A_eG$ [3]. Since the difference of σ for lossless resonant dipole and the conjugate-matched dipole is the factor of four, the Matlab ray-tracing model for links via lossless resonant dipole scatterers should be corrected as

$$P_r = \frac{4 P_t G_t G_r G_{\text{tx}} G_{\text{rx}} \lambda^4}{(4\pi)^4 (R_1 R_2)^2}. \qquad (3)$$

We stress that Eq. (3) is valid only for resonant lossless dipoles, while Eq. (1) can be used for arbitrary scatterers.

III. Ray-tracing simulations

A. Indoor scenario with a strong direct link

First of all, we set up an indoor room scenario as shown in Fig. 1 in the Matlab ray tracer. A wooden-wall room with the size of $6 \times 4 \times 5$ m^3 corresponding to the length $\times$ width $\times$ height includes two high shelves. The Tx and Rx antennas are blocked by the shelves. However, the transmitted signals from the Tx antenna can still reach the Rx antenna through wall reflections even though there is no line-of-sight (LoS) path between the Tx and Rx antennas. Between them are multiple randomly placed dipoles. Each dipole has LoS connections with both the Tx and Rx antennas. The dipoles and the Tx

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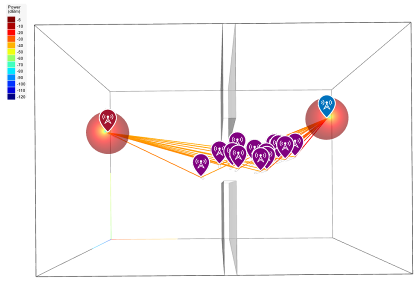

Fig. 1. An indoor room scenario with a strong direct link. The red, blue, and purple markers represent the Tx, Rx, and dipoles, respectively.

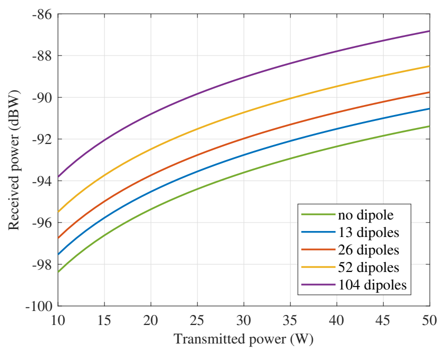

Fig. 2. Received power with different numbers of dipoles in an indoor scenario with a strong direct link.

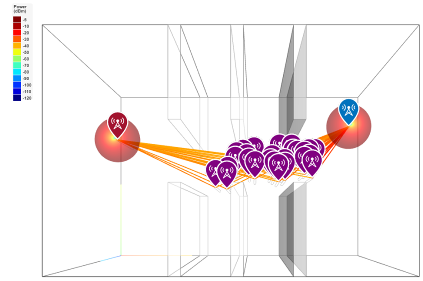

Fig. 3. A library scenario with the direct link being totally blocked. The red, blue, and purple markers represent the Tx, Rx, and dipoles, respectively.

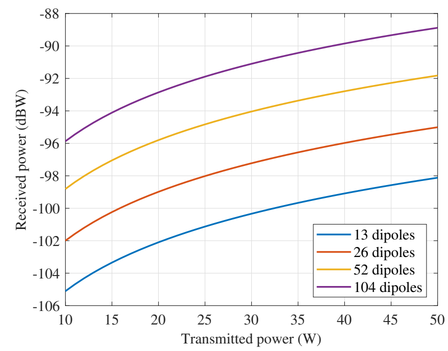

Fig. 4. Received power with different numbers of dipoles in an indoor scenario without a direct link.

and Rx antennas are all in the far-field of each other. The heights of the Tx, Rx, and the dipoles are all 1.5 m.

The simulation results with different numbers of dipoles are displayed in Fig. 2. We observe that the direct link from the Tx to the Rx antennas is quite strong. When placing 13, 26, 52, and 104 dipoles in the scenario, the received power improves by 0.84, 1.63, 2.88, and 4.56 dB, respectively. Therefore, placing dipoles in such a scenario when the direct link exists is not very beneficial.

B. Indoor scenario without a direct link

Next, we simulate a library scenario, shown in Fig. 3. It is the same as that in Sec. III-A except that there are six high shelves instead of two, which totally block the direct link. The results for the received power in this scenario are displayed in Fig. 4, showing that the received power difference between the cases of 26 and 13 dipoles is 3.11 dB. The difference between 52 and 26 is 3.19 dB, and between 104 and 52 is 2.94 dB. This approximately 3 dB improvement with doubling the number of scatterers agrees with the result of [4] for a random RIS that is not tuned to serve any desired user. This agreement with [4] is due to the assumption of negligible coupling between RIS elements made in [4]. While this assumption usually does not hold for RIS with densely packed elements, it holds for the considered here scenario with several resonant dipoles placed at various positions in the room. The presented results show that delivered power can be significantly improved by placing a set of static resonant scatterers at some random places. We believe that this is a useful alternative possibility for eliminating blind spots since passive dipoles are very cheap and easy to install.

IV. Conclusion

In this contribution, we set up multiple resonant dipoles in complex environments to improve wave propagation. We modify the Matlab ray-tracing model using the consistent model of a bistatic scattering cross-section of passive scatterers. The simulation results show that in scenarios with a strong direct link, placing resonant dipoles does not offer significant improvements. However, in totally blocked cases, the received power can be significantly improved. For a small number of dipoles, the received power increases roughly by 3 dB when doubling the number of dipoles. These results open up a simple and cheap alternative for channel optimizations.

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