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Enhancement of WPT Performance Using Intelligent Reflecting Surfaces

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Summary

The work studies intelligent reflecting surfaces (IRS) for wireless power transfer (WPT) performance enhancement via simulation based on the ray-tracing method combined with Floquet-Bloch theory-based method. It is shown that this approach can enhance the efficiency of wireless power transfer in complex indoor environments where the line-of-sight channel is absent.

1. Introduction

The growing interest in far field wireless power transfer (WPT) is supported by the possibility of avoiding the necessity of regularly changing batteries of the sensor nodes (SNs) employed in the Internet of Things (IoT) and Wireless Sensor Networks (WSNs). The development trends in WPT aim to incorporate and combine new technologies to increase WPT's performance, with the main focus currently on intelligent surface-aided beamforming [1].

One aspect that severely limits WPT's performance is the propagation environment (RF-RF coupling). The power-carrying signal can be better adapted to the propagation environment by applying beamforming. This technique increases the received power of the receiver, increasing the received DC power and extending the WPT system's range. Thus, beamforming becomes essential not only for a single power transfer but also for a multi-hop WPT scenario.

Intelligent Reflecting Surface (IRS) comprises unit cells that reflect the RF signals. The cells are built from passive components and can be controlled to set the required amplitude and phase of the signal, thus performing the passive beamforming. The use of IRS was demonstrated in wireless communication systems [2] and IoT applications, which is crucial in enhancing ambient backscatter communications [3]. Applying this established technology to wireless power transfer is receiving increased attention [4], [5].

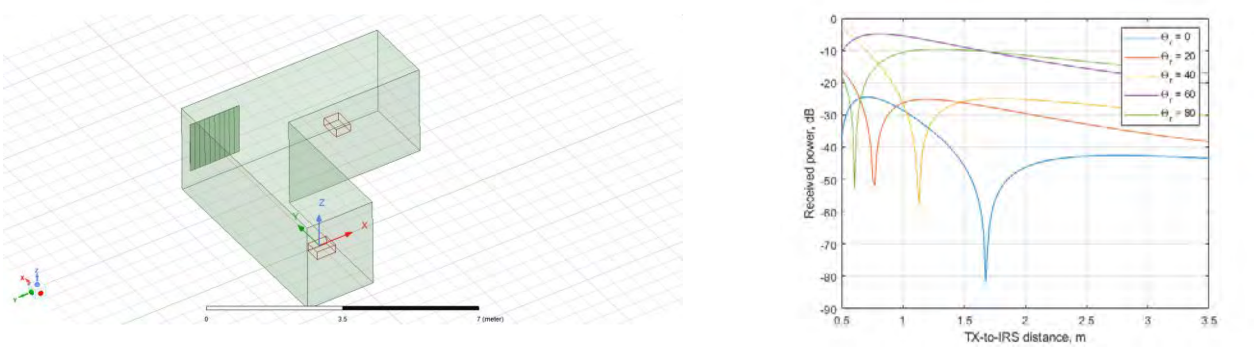
The study aims at demonstrating that under No-Line-of-Sight conditions in indoor environments the wireless power transfer efficiency of a two-antenna wire-less power transfer system can be appreciably enhanced via the use of IRS.

2. Passive Beamforming Concept

Intelligent reflecting surfaces (IRSs) [6] are a class of passive planar devices capable of controlling the direction (reflection angle) of an incoming wave by locally changing the phase of the reflection coefficient. This property of the IRS enables one to redirect the power of a wave impinging on such a surface to a desired direction, e.g., toward the intended receiver, in case there is no Line-of-Sight channel between the power transmitter and the receiver. There are several approaches to achieve a total reflection from the surface so that the reflected wave is a plane wave (locally plane wave) propagating away from the surface in the desired direction. The way the IRS interacts with an incoming electromagnetic wave is typically described using the surface impedance concept [7]. However, alternative methods also employ the surface susceptibility model [8]. The latter method is employed in the present study because it is more flexible and versatile than its surface impedance counterpart. Specifically, it provides a set of angle-independent parameters characterizing the behavior of metasurfaces, which allows for finding the circuit's response to a wave with an arbitrary wavefront shape or equivalently to any plane wave regardless of its polarization and the incidence angle.

3. Simulation Results

The present study chooses a long narrow corridor with a right-angle turn-in as the test object. The multi-path propagation, in this case, is the only way for some fraction of the transmitted power to reach the receiving antenna located around the corner, resulting in low received power. To mitigate this issue, one can mount an IRS on the corridor wall so that the wave radiated by the transmitting antenna impinges normally to the IRS. The perspective view of the constructed 3D model of the corridor with the IRS panel is presented in Fig 1(a). The numerical analysis is performed using the ray-tracing method in conjunction with the Floquet-Bloch theory-based surface field approximation similar to that described in [9]. The transmitting and the receiving antenna are assumed to be identical printed 7-element Uda-Yagi antennas with a maximum gain of 13 dBi. The corridor's width and height are 2 m and 2.65 m, respectively. The vertical and horizontal dimensions of the employed IRS panel are 1.5 m and 1.5 m, respectively. Both antennas are located at the same height of 1 m. The corridor's walls, ceiling, and floor are assumed to be made of concrete with a relative dielectric permittivity of 5.31 and an electrical conductivity of 0.19 S/m. The distance between the inner corner of the corridor turn and the transmitting antenna is fixed and set equal to 2 m. The maximum number of reflections each ray may undergo considered in the field approximation is 4. Fig 1(b) shows the received power as a function of the distance between the transmitting antenna and the IRS panel. The case Θr = 0 is equivalent to a conventional reflector.



(a) (b)

Figure 1. The 3D model of the corridor with a right-angle turn (a) and the received power as a function of the distance between the TX antenna and the IRS panel at different IRS reflection angles, Θ_r.

4. Discussion

An indoor power transfer environment involving a long narrow corridor with a right-angle turn in it has been studied to ascertain whether the use of the IRS-based passive beamforming in indoor environments in the case of the absence of the Line-of-Sight condition can enhance the power transfer efficiency of a two-antenna wire-less power transfer system. The numerical results show that employing a single IRS makes it possible to increase the received power by more than an order of magnitude. This proves that IRS-based passive beamforming has great potential in wireless power transfer.

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