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Smart EM Surfaces for Future Wireless Communication Systems

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Abstract

Smart surfaces represent a promising technology that allow to make the wireless environment a smart reconfigurable space playing an active role in the information transfer process. In this work, a reflectarray-based smart surface is investigated for next-generations communications, Device-to-Device systems and Internet of Things. The preliminary design of a smart surface is presented which is able to focus and redirect the impinging electromagnetic wave along a desired direction. The designed smart surface is extensively analyzed, under different environment conditions.

1 Introduction

Wireless communications have now become an integral part of our daily lives. Consumer demand for wireless services and applications has increased exponentially over the past decade, leading to explosive growth of networks and devices. In order to empowering users' experiences, significant technological innovations have been introduced, in the last years, to realize the fifth generation of wireless communications (5G). To this end, the international telecommunication scientific community has focused on the development of several enabling technologies for 5G communication systems, offering higher data rates (i.e. 1-10 Gbps), lower network latencies, and better energy efficiency [1].
Currently, researchers have already started research beyond 5G, or even 6th generation (6G), to offer a more and more intelligent and ubiquitous connectivity [1].
New communication paradigms will be necessary, especially at the physical level, to face next challenges of wireless communications. The wireless environment, i.e. the physical objects located near the wireless communication devices, will play an active role in the development of next-generations communication systems.

In current wireless networks, the environment is out of control of the telecommunication operators; it is a passive observer in the data exchange process. Furthermore, the environment usually has negative effects, such as: reflections/refractions from large objects are sources of interferences, signal attenuation reduces the connectivity and multipath propagation causes fading phenomena.

In future wireless communications, the propagation environment will be 'smart'; it will become a smart reconfigurable space that plays an active role in transferring and processing data. In this contest, the attention of the wireless research community has focused on the reconfigurable intelligent surfaces (RISs) concept [1]. RISs, or smart skin/surface, are artificial surfaces having the abilities to control the electromagnetic signal impinging upon them [2]. Smart skins can be integrated with active elements and materials, such as pin-diodes or varactor diodes, to offer a variety of reconfiguration capabilities.
Current implementations include reflectarrays, meta-materials and liquid crystal surfaces [3]-[7].
RISs allow to control wireless environments, by way of their specific functionalities, such as wave absorption, anomalous reflection, wave focusing, etc. For examples, a RIS can be fruitfully exploited to provide additional transmission paths, when the line-of-sight (LOS) communication link is blocked. RIS concept is applicable to a number of innovative applications, such as 5G and 6G, Device-to-Device systems and Internet of Things (IoT), both in indoor as well as in outdoor settings (e.g. a RIS can cover the walls of a room or the facade of a building).

This work introduces a preliminary investigation on a reflectarray-based smart surface, covering a (4.2×4.2) m^2 wall, which is able to focus and redirect the impinging wave along a desired direction. The performances offered by the designed smart surface are evaluated under different environment conditions. This preliminary analysis allowed us to establish how the surface performance is deteriorated by the presence of a window in the wall.
As future development, the surface will be integrated with one or more active components, to realize its smart functionalities. Furthermore, a synthesis strategy preventing pattern degradation, due to the presence of any surface discontinuities (e.g. a window in the wall) will be developed.

2 Numerical analysis

A reflectarray-based smart surface is designed in this work to focus the impinging plane wave along a given direction. As it is well known, when a wireless signal reaches the boundary between two isotropic mediums, the Snell's law (see red lines in Fig. 1) governs the relationship between the angle of incidence and the angle of reflection. However, by exploiting reflectarrays and/or metasurface concept, it is possible to change the impedance of the surface and introduce a phase shift in the field scattered from each reflectarray element, giving a total reflection along any desired direction (see green line in Fig. 1).

A (4.2×4.2) m^2 surface example is designed at the frequency of 3.6 GHz. The surface is composed of N×M= 101×101 square patches of variable sizes, printed on a Diclad880 grounded substrate (thickness h=1.524mm). The surface size is 50λ×50λ with respect to the operating frequency.

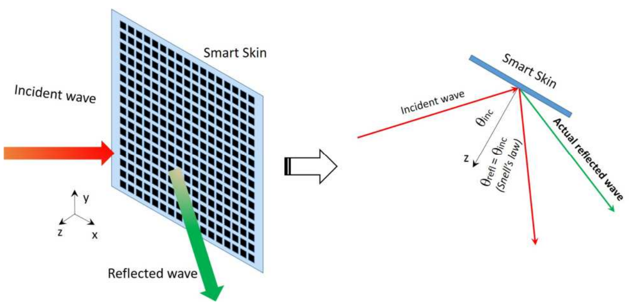

Figure 1. Sketch of a smart surface.

For simplicity, an impinging plane wave is considered, travelling along a direction equal to $(\theta_{inc}, \phi_{inc}) = (-20°, 0°)$. A synthesis algorithm, based on the iterative projection method [5], is applied in order to choose the array elements, giving the correct phase distributions to focus the signal along the following directions θ_{refl}= 0°; 10°; 20°, 30°, 40° (in the H-plane i.e. ϕ_{refl}= 0°). As depicted in Fig. 2, the surface satisfy the design constraints, so resulting in the so-called reconfigurable intelligent surface.

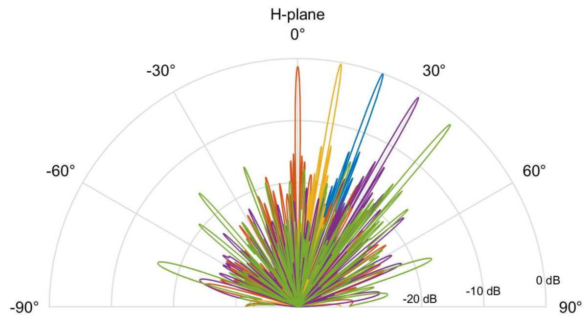

Figure 2. Pattern of the synthesized reflected signals for $(\theta_{inc}, \phi_{inc}) = (-20°, 0°)$.

In this preliminary analysis, the performances offered by the designed smart surface are evaluated in different environment conditions, namely by considering an opening upon it (i.e. a window in the wall) having different size, ranging from (0.83×0.83)m^2 up to (1.5×1.5)m^2.
In order to simulate the above conditions, an absorbing window is considered in the center of the smart surface (see Figs. 3 and 4).
The analysis allow us to establish how the surface performance is deteriorated by the presence of a discontinuity in the wall, like a window.
Both Figs. 3 and 4, shows that the smart surface correctly focuses the signal along the desired directions (i.e. $(\theta_{refl},\phi_{refl})$=(0°,0°) and $(\theta_{refl},\phi_{refl})$=(40°,0°)).
However, while in the case of the (0.83×0.83)m^2-window the radiation patterns show quite low side lobes (≅-12 dB with respect to main lobe level – Fig. 3), when the window size increase up to (1.5×1.5)m^2, the difference between main lobe and side lobes level is equal to about 9.6 dB, for θ_{refl}=0°, and 9.3 dB, for θ_{refl}=40° (Fig. 4). Furthermore, a 1.27 dB drop can be observed along the main lobe direction.
In conclusion, the designed smart surface works quite well, also in the presence of a window; anyway, by progressively increasing the window size, the reflected signal starts to degrade when the window surface is about 13% of the smart surface area.

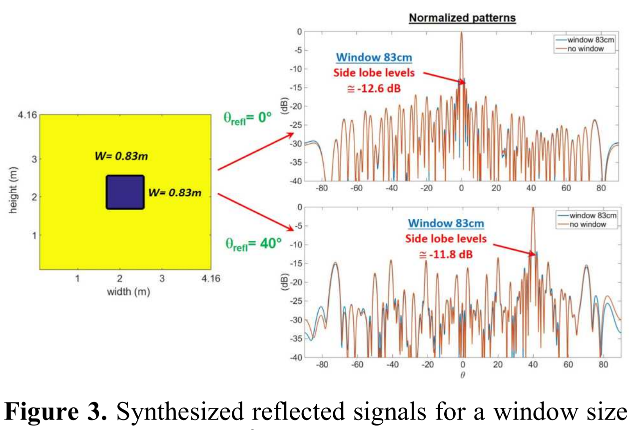

Figure 3. Synthesized reflected signals for a window size equal to (0.83×0.83) m^2.

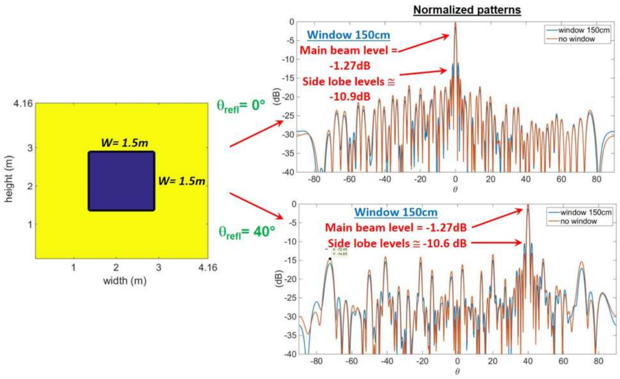

Figure 4. Synthesized reflected signals for a window size equal to (1.5×1.5) m^2.

3 Conclusions

A preliminary design of a smart surface has been presented, which is able to focus the impinging electromagnetic wave along a desired direction. The performance of the designed smart surface have been evaluated in terms of the reflected pattern for different environment conditions, namely by considering an opening upon it (i.e. a window). As future developments, the integration of active components will be considered, in order to fully exploit the smart functionalities of the proposed surface. Furthermore, a synthesis strategy will be developed, taking into account any surface discontinuities (e.g. a window in the wall).

4 References

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