Utilization of Reconfigurable Intelligent Surfaces with Context Information – Use Cases

Łukasz Kułacz

Poznan University of Technology, Poznan, Poland

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Abstract — Utilization of reconfigurable intelligent surfaces is a topic that is very interesting in the context of complex radio environments, especially those used in dense urban areas. By relying on simple solutions to control the angle of reflection of the signal from the surface, different effects may be achieved in radio communication systems. Maximization or minimization of the received power at specific locations near the reflecting surface is the most important effect. This phenomenon allows to: receive a signal at a location at which it could not be received previously, detect spectrum occupancy at a place where the sensor could not perform a correct detection, or minimize interference affecting a specific receiver. In this paper, all three concepts are presented and a simple ray tracing simulation is used to show the potential profits attainable in each of the scenarios. Additionally, a scenario was analyzed in which several of the aforementioned situations are combined.

Keywords — context information, reconfigurable intelligent surfaces, spectrum occupancy detection

1. Introduction

The development of wireless communication has been based, recently, on an ever-greater level of intelligence of the networks. Dynamic spectrum access systems may serve as a good example here which often require access to a large amount of contextual information about the environment and network users. This information is necessary to make optimal decisions – based on many parameters (not necessarily directly related to the network itself) and their historical values. Data from the past allows, among other things, to capture trends in the behavior of network users and thus enables to predict upcoming events.

The urban environment has always been highly demanding for designers of wireless systems, where the transmitted signal itself is subjected to many propagation-related phenomena, i.e., reflections or dispersion. The huge number and the great variety of buildings and objects affecting the propagation of the signal collectively create a highly complex radio channel. Additionally, in an urban environment, a large number of users is present in a relatively small area. The combination of those two factors poses a significant challenge for the operation of wireless systems. It is worth noting that, in general, signal reflections are unavoidable. While they hinder the analysis of signal propagation, they generally constitute a beneficial phenomenon, since the signal can reach a receiver which is not located in the transmitter's line of sight. The notion of reconfigurable intelligent surfaces (RIS) [1] is a promising approach that has recently gained much popularity. RIS allows to influence the process of radio wave reflection on the surface involved. This means that it is possible to modify the basic principle where the angle of incidence of the wave is equal to the angle of its reflection. This offers numerous opportunities for creating and controlling the propagation environment. On the one hand, it allows to direct the radio signal to previously unattainable places (due to the geometry of the objects), while on the other it enables to remove radio signal from specific locations (to minimize interference) by directing it in a completely different direction [2].

These two concepts alone seem to offer great potential for use in intelligent networks. They can be relied upon to detect the signal or improve the quality of the received signal by increasing or reducing the received power, in the case of desirable and unwanted signals, respectively. Signals may be detected even if the receiver is not located along the transmitter's line of sight if the power of the reflected signals is sufficient for the operation of signal detection algorithms. However, the solutions described require the development of new algorithms whose task is to control the described RIS [3].

2. Scenario Description

In this work, we consider a simple scenario of an elongated room with a wall between the signal transmitter and three receivers, obscuring direct visibility. At the far end of the room, however, there is a surface that will simulate an RIS. All devices are positioned at the same height, and the effects of the ceiling and floor have been ignored to simplify the scenario that is considered to involve a two-dimensional space only. The layout of the investigated area is presented in Fig. 1. The described room was chosen on purpose to demonstrate the potential of using RIS. This decision is dictated by the desire to highlight the concept of using RIS, and the ideas themselves can be used in more complex analyses where, however, it would be much more challenging to isolate the

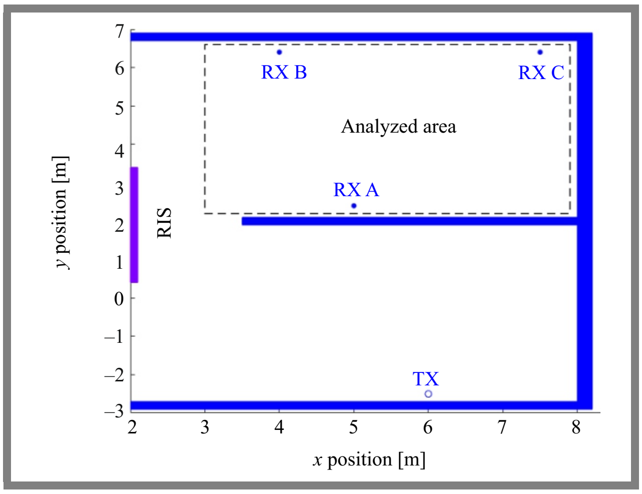

Fig. 1. Area under consideration.

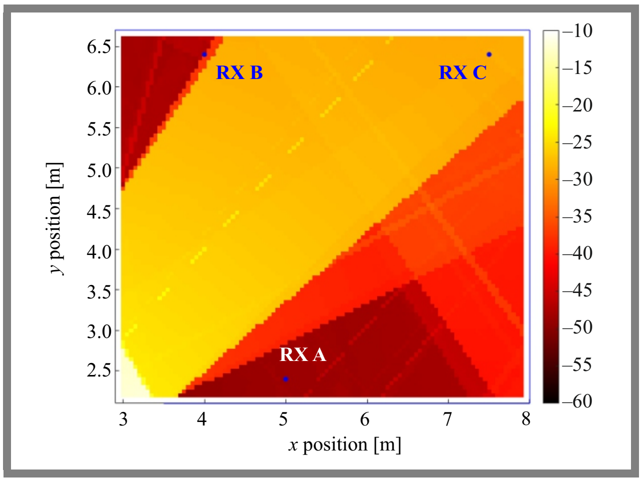

Fig. 2. Received power without influence of RIS.

impact of RIS. The work described in this paper compares three simulation scenarios:

– Scenario 1 assumes no use of RIS that has been replaced by a fragment of a regular wall – this is a benchmark for the remaining scenarios.

– Scenario 2 assumes that a simplified RIS is used that operates independently of external factors, i.e., periodically and alternately changes the angle of the reflected signal, simulating the use of a mirror rotated from left to right and back. This scenario has been proposed to demonstrate the potential profits from using even such a simple control mechanism.

– In Scenario 3, network users have access to information about the current RIS setting and indirectly influence those settings. In this example, context information (the current RIS setting) is used to achieve the current goal, i.e. to minimize interference.

Three use cases based on those three scenarios are analyzed in the paper: improved spectrum occupancy detection by the sensor, improvement in the received signal level for two receivers, and reduction of interference at the receiver. During the simulation, the operation of RIS was simulated as a rotational change in the position of the selected surface, with its angle varied from –20° to 20°, with a step of 5°.

3. Simulation Results

Figure 2 presents the spatial distribution of the received power in the analyzed area for the given transmitting parameters and uses a propagation model based on ray tracing. Preliminary analysis of the indicated distribution shows that a certain part of the area under consideration is characterized by lower signal attenuation (warmer colors, receiver C). In comparison, the remaining part of the area has greater signal attenuation – darker colors, receivers A and B – remaining "in the shadow" of the signal. The received power in this situation results directly from the perpendicular arrangement of the wall marked as "RIS" in Fig. 1 which, however, acts as a regular wall here. It can be seen that receivers A and B would have a problem with receiving and detecting the analyzed signal. However, they would be deprived of excessive interference. The situation is exactly the opposite for receiver C. Nevertheless, it should be remembered that in the opposite situation, when receivers A and B consider the analyzed signal undesirable and receiver C deems it a desirable signal, it would not be beneficial to influence the current propagation. Figure 3 shows the received power of all three analyzed receivers, depending on all RIS settings under consideration. It shows all received power values for all receivers and will be used depending on the current role of a particular receiver.

3.1. Case 1 - Spectrum Occupancy Detection

For the first use case, i.e. the one in which the spectrum occupancy detection processes performed by receiver B are to be improved, preliminary simulations showed that in the first scenario, correct detection is challenging. In the second scenario, correct detection is possible for 31.25% of the time, and in the third scenario, for 79.17% of time there is a possibility of correct detection. The received power in the second scenario (depending on the RIS angle) is presented in Fig. 3 – see RX A. The last scenario depends, to a large

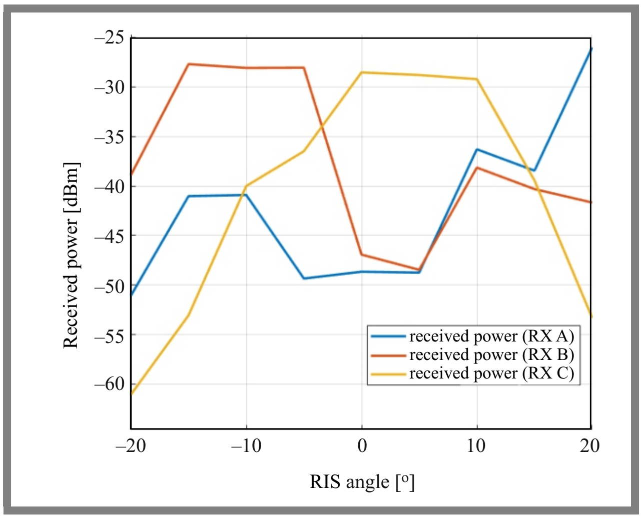

Fig. 3. Received power in receivers versus RIS setting.

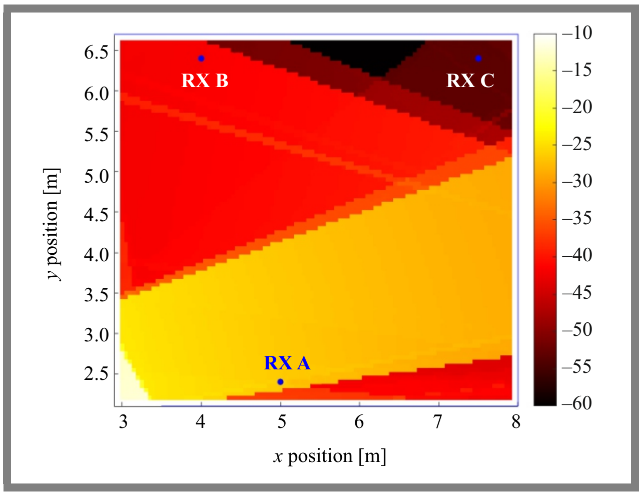

Fig. 4. Received power map for a specific RIS setting (angle 20°).

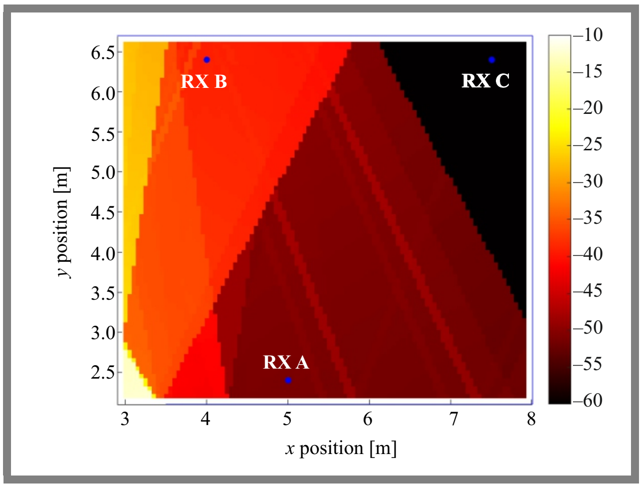

Fig. 5. Received power map for a specific RIS setting (angle –15°).

extent, on the algorithm used and its purpose. But even if only information about the current RIS setting is available, this allows the sensor to assume that the occupancy decision is updated only at a particular time.

This approach is not ideal, and its effectiveness depends very much on the transmission characteristics (frequency, length of transmission, etc.). The solution, which assumes the ability to control the RIS even in a very simple scenario, enables, for example, periodic "combing" of all available settings and then maintaining one setting (or several alternating settings) for a certain period of time. In the considered system with one sensor, it is possible to correctly set the RIS for the entire observation period after a short time, achieving almost 100% of the detection time available. Figure 4 presents the received power map with the best RIS setting for receiver A which is considered to be a spectrum detection sensor in this particular use case.

3.2. Case 2 - Received Signal Level Improvement

For the second use case, i.e., improving the received signal level for receivers B and C, the preliminary results of the simulation show that in the first scenario, receiver B cannot receive the signal correctly, while receiver C can receive the signal all the time. In the second scenario, for 35.29% of the time, receiver B receives a signal with a sufficient power level, while receiver C receives it for 41.18% of the time. In this case, we notice the advantage stemming from the ability to service the receiver that was in the "shadow" of the signal and could not receive the signal without changing its position. In the third scenario, however, it was assumed that for an initial period of time, RIS checks all available settings and then, based on reports from the receivers, alternately uses the best-reported settings. As a result, receiver B could receive the signal for 45.1% of the time and receiver C for 47.06% of the time.

At this point, it is worth mentioning traffic steering algorithms used to adjust the duration of settings for individual receivers. For example, in Fig. 5, a received power map with the best RIS setting for receiver B is shown.

3.3. Case 3 - Interference Reduction

For the third use case, i.e., interference reduction in receiver C, preliminary simulation results show that in the first scenario, the receiver encounters significant interference for 100% of the time. In the second scenario, the interference exceeds the threshold 35.29% of the time. It is worth mentioning that the average observed interference level decreases by approx. 3.715 dB, the median by approx. 7.972 dB, and the 10th percentile by approx. 24.762 dB. The 90th percentile remains the same. The knowledge of the RIS setting could at least provide information about the occurrence of potential interference - which can, for example, be used in the transmission planning process. In the third scenario, we once again assume a specified period of checking all RIS settings and then, based on the report from receiver C, set up a configuration that causes minimum interference. Thanks to such an approach, it was possible to reduce the time with interference above the threshold value from 100% to approx. 19.61%.

This time, the outcomes are of course hugely dependent on a given configuration and the presence of other devices. Figure 6 presents the received power map with the best RIS setting for receiver C treating the analyzed signal as interference. It should be remembered that the simulations assumed a constant transmission throughout the entire experiment. Temporary signal transmissions for all three use cases would be an additional challenge for the algorithm that controls the operation of the RIS.

3.4. All Use Cases Combined

An additional experiment was carried out combining all three use cases analyzed, i.e. receiver A as a spectrum occupancy detection sensor, receiver B as a receiver of the analyzed signal (desired signal), and receiver C as not a receiver of the analyzed signal (unwanted signal). It needs to be borne in mind that in the benchmark scenario, the objectives of none of the receivers are met. Then, RIS operating according to the following scheme was used: initially, all possible RIS configurations are checked, and then all the best settings reported by the receivers are used alternately.

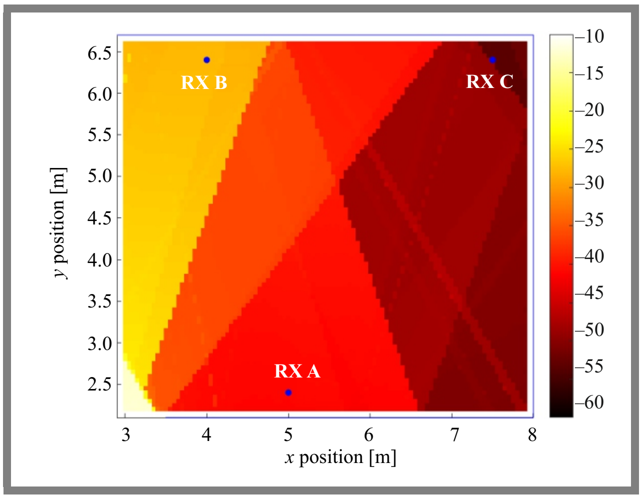

Fig. 6. Received power map for a specific RIS setting (angle –20°).

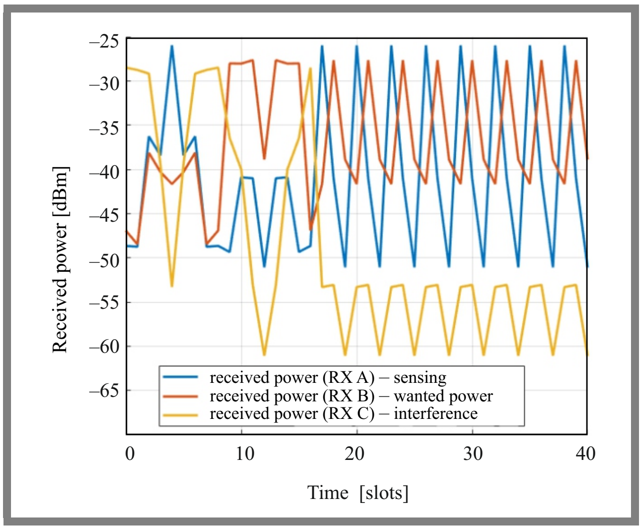

Fig. 7. Received power for all receivers in the time domain.

As a result of preliminary simulations, receiver A can successfully detect the signal for approx. 43.4% of the time; receiver B can successfully receive the desired signal for approx. 45.28% of the time, and receiver C is free of significant interference for approx. 79.25% of the time. In addition, the average interference power observed at receiver C decreases by approx. 8.58 dB. The received power in the time domain for each receiver is shown in Fig. 7.

4. Conclusions

The simulations presented in the paper show that using RIS, even with the most straightforward control mechanism, can benefit each of the analyzed use cases. However, much better results can be obtained by adding a simple algorithm to the RIS control mechanism and providing the interested receivers with information about the current RIS setting. Such an approach offers a very flexible solution that should be carefully considered. In particular, the nature of the environment, the nature of the signal source or sources, potential signal receivers, their positions, and the intended use should be taken into account. On the one hand, the presented concepts allow to direct the signal to previously inaccessible locations. However, this situation may bring about both positive and negative outcomes, because there is a risk of introducing interference at a location where it has not been occurring so far. This problem is exacerbated in the case of devices that are unaware of the existence and presence of RIS. Nevertheless, the ideas presented in this paper seem promising in terms of potential gains for specific applications.

Acknowledgments

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Łukasz Kułacz, Ph.D.
Institute of Radiocommunications, Faculty of Computing and Telecommunications
https://orcid.org/0000-0002-3434-1917
E-mail: lukasz.kulacz@put.poznan.pl
Poznan University of Technology, Poznan, Poland
https://cat.put.poznan.pl