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RECONFIGURABLE INTELLIGENT SURFACES FOR WIRELESS COMMUNICATIONS: BEYOND 5G

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Abstract— The advancement in the technology has led to the tremendous variance in the 5G domain. Development in some of the physical layer technologies would help think beyond 5G. One such technology is Intelligent Reflecting Surfaces (IRS). IRS caters to focusing the reception of the signal, only to the intended receiver, without loss of power. This otherwise termed as beamforming. In this a new and vast dimension, the wireless environment, in which signal propagates, to be tuned, for reliable transmission.

The paper deals about what are Intelligent Reflecting Surfaces, features, false ideas, and critical analysis of how IRS can be a part of future beyond 5G.

Keywords—Intelligent Reflecting Surfaces (IRS), Reconfigurable Intelligent Surfaces (RIS), metasurfaces,

I. INTRODUCTION

The information carrying signals in wireless environment, communicate with objects and surfaces all along the channel. As there are many signals transmitted, there is a possibility of fading and interference. And each propagation path can have unique and constant behavior for every transmission, but not guaranteed. Still a solution to overcome variation is reconfigurability. The Reconfigurable Intelligent Surfaces (RIS) also called as Intelligent Reflecting Surfaces are the materials, that tweak the wireless environment to facilitate the smooth, errorless signal propagation in the upcoming high band width applications.

Basically, RIS are the software-controlled metasurfaces. Metasurfaces have the ability to vary the magnitude and phase of the real signals using the software approach. Recent studies have shown that programmable metasurfaces can enhance the wireless channel environment for optimal reception and also transmission. By controlling the reflection coefficient of the metasurface based transmitter electrically, the phase modulation can be achieved.

A reconfigurable intelligent surface (RIS) is observed to be a 2D surface of engineered material, an array of discrete elements whose properties are reconfigurable rather than static. This even exhibit the negative refraction which is an

assumptive approach that can be controlled individually or on a group level. What makes RIS unique apart from the general antenna array is that, antenna array is a part of transmitter and receiver, whereas this is a part of wireless environment. RIS aids and influences the signals to propagate, rather than it adding the extra signals. Combining the physical-layer signaling with wireless signal conditions results in executing the idea of RIS.

Designing an antenna towards the wireless environment can be understood as RIS or IRS.

Looking at the Fig.1, it is a wireless environment where the transmitted signal meets the RIS. RIS as observed is an array of discrete scatterers, and are nearly passive in the sense that the incoming signals are reradiated after “passive” analog filtering that cannot increase the power. Each array element filters the signal by potentially reducing the amplitude, incurring time delays, and/or changing the polarization. Each element is controlled by a switch. On controlling the impedance of the material, the amplitude and phase that makes the reflection coefficient is varied to suit the environment.

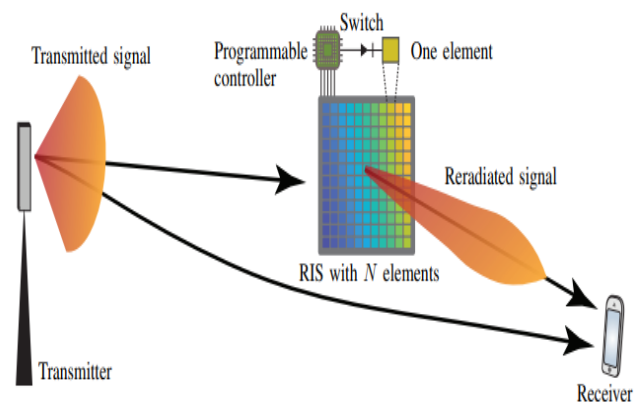


Figure 1: Wireless environment with RIS

RIS is deployed to capture signal energy proportional to its area and re-radiate it in the shape of a beam towards the receiver. And as the surface is reconfigurable, it makes sure to focus the beam towards the intended user device. This saves up the loss and contributes in improving the SNR of the



channel. If the SNR is good then the channel capacity also increases, paving the way for vast applications to come into use.

The analysis of phase variations in the form of phase shifts, add up constructively to establish the same concept of beamforming. In this case we can tune the beamforming as the surface is reconfigurable.

How is the propagation of signals analyzed in RIS? It is essentially done by (i) Obtain Green's function of the signal source, (ii) calculate the impinging field at each RIS element in the array, (iii) find the current density by integration, (iv) compute the radiated field from each element, and (v) finally apply the superposition principle to find the field at the receiver.

II. SYSTEM FEATURES

A. Spatial filtering

Spatial filtering is also termed as beamforming. Beamforming functions by shaping the beam in the direction of the receiver. A number of antennas broadcast exactly the same signal; however, each one is specifically distorted in the phase. This gives rise to constructive interference at spatial locations where the copies are received synchronously and destructive interference elsewhere.

RIS or IRS, has the ability to perform passive beamforming. The signal power received from the transmitter is proportional to its surface area, which is proportional to the number of elements, N . When the RIS re-radiates the signal, with time-delays selected to beamform at the receiver, an array gain of N is obtained just as with conventional beamforming. The combination of these two leads to an SNR at the receiver proportional to N^2 called the square law [1].

If in case RIS is replaced with a transmitter array having the same size then the RIS setup will achieve an SNR that grows as N^2 , while the SNR in the RIS as transmitter only grows as N . It has been claimed that these are asymptotic scaling laws [1], which means that the SNR with the RIS grows unboundedly with N at the order of N^2 and eventually becomes larger than with the transmitter array. This is incorrect.

But what is believed hypothetically is that, a better asymptotic array gain is achieved in this RIS passive beamforming than with conventional beamforming.

The above statement fails if the surface area is more compared to the propagation distances. Since the surface area grows with N , the far-field approximation eventually breaks down as N increases.

SNR grows quadratically with the number of elements for the surfaces which are used practically [2]. Hence, it might seem possible that a better SNR can be achieved in the RIS setup when considering large, equal-sized arrays.

The second failure with the statement is the theory that the quadratic power scaling is helpful. The pathloss from the transmitter to each RIS element is huge in the far-field.

In Fig. 2 because of RIS suffers from the power loss inherent in the square law, DF relay outperforms. Since we use logarithmic scales, the quadratic array gain is observed from the steeper slope of the RIS curve. However, this curve begins at a much smaller value and when it approaches the DF relay

curve, the steeper slope has tapered off. Both curves will eventually converge to a finite number [2]. The reason that the RIS became preferable for very high SEs in Fig. 2 is that the SNR gap eventually becomes so small that the half-duplex operation of the DF relay becomes the bottleneck. Due to the faster-than-linear SNR scaling, physically large surfaces are highly preferable.

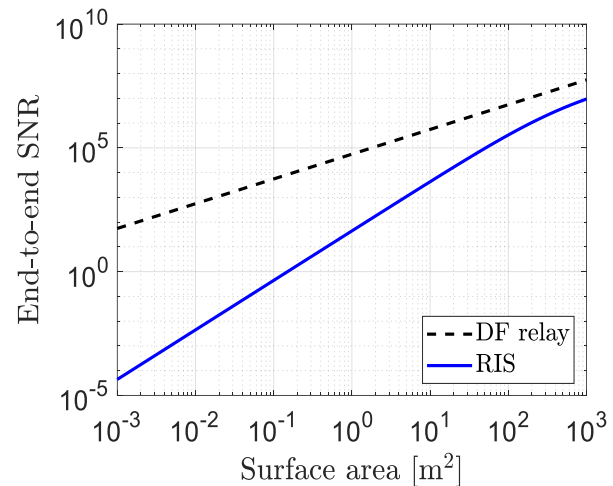


Figure 2: End to end user SNR performance

B. Reconfigurable wireless environment

The saliency of RIS is the ability to adopt to the wireless signals propagation in the channel. The wireless environment is controllable/smart/programmable using the channel state information.

There has been a notion that [3], [1], [4] current network technology cannot control the environment in between, but can manipulate the transmitter and receiver. The wireless repeater and advanced relaying technology, capable of adaptively improving the channel between the transmitter and receiver, has been supported by cellular standards since 3G [5]. Hence, the statement above is a myth.

Controllable radio environments mean the channel entities are co-optimized with the transmitter and receiver. We can divide relaying into transparent relaying and regenerative relaying. In transparent relaying each relay acts as an entity that receives a signal from the transmitter and processes before re-radiating towards the receiver. One of the main protocols used for this is Amplify-and-forward. Whereas in case of regenerative relaying, before retransmitting each relay is decoding the received signal and processes. The familiar one used is Decode-and forward (DF). The RIS technology here is full duplex, it affects the real time propagation. The RIS outperforms from the other is because large surfaces are implemented with reduced energy consumption and cost. Fig. 3 shows that RIS is possibly replaced by a multi-antenna half-duplex repetition-coded DF relay.

CSI is assumed perfectly and each element scatters all the incoming signal energy with a controlled phase perfectly. We observe that the DF relay can have a much smaller form factor than the RIS, except if very high SE is required. The reason is that the DF relay achieves a much higher SNR but it also



needs a higher SNR to achieve the same SE since it operates in half-duplex, whereas the RIS operates in full-duplex.

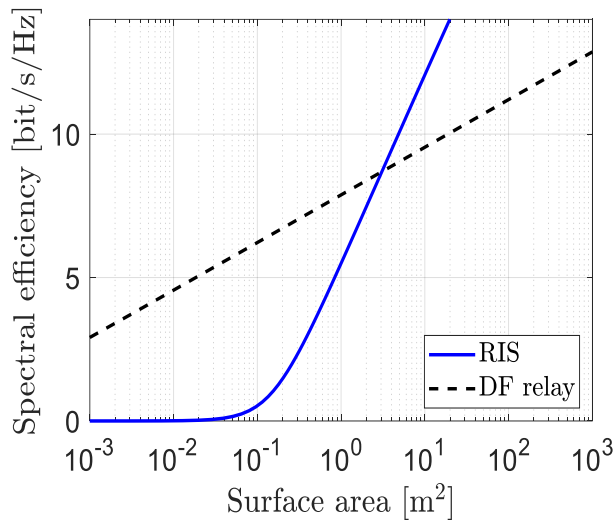


Figure 3: Spectral Efficiency of the user

RIS technology control the propagation environment between the transmitter and receiver, just as earlier relaying technologies. Thus, this RIS reduces the hardware complexity as a tradeoff with larger surface area.

C. Forming a Different Surface Shape electronically

Creation of a superposition of multiple beams or a diffuse scatterer is possible by RIS. A mirror acts as a surface that reflects an outgoing plane wave. A conventional mirror always satisfies the 2 law of reflection: the angles of the incident and the reflected waves to the surface normal are the same but are opposite in direction. A normal mirror reflects incident plane waves as outgoing plane waves with a different angle to the surface normal [6]. A property of mirrors is that the receiver observes the transmitting source as being behind the mirror.

The wave propagation can be analyzed as the transmitter is moving to the location of the mirror image. RIS acts as mirror if the length and width of the surface is larger man times compared to the wavelengths. Addition of distance between RIS and receiver and RIS and transmitter formulates the pathloss.

The false assumptions are stated below.

The loss in the paths is equal to the loss seen in the normal mirrors.

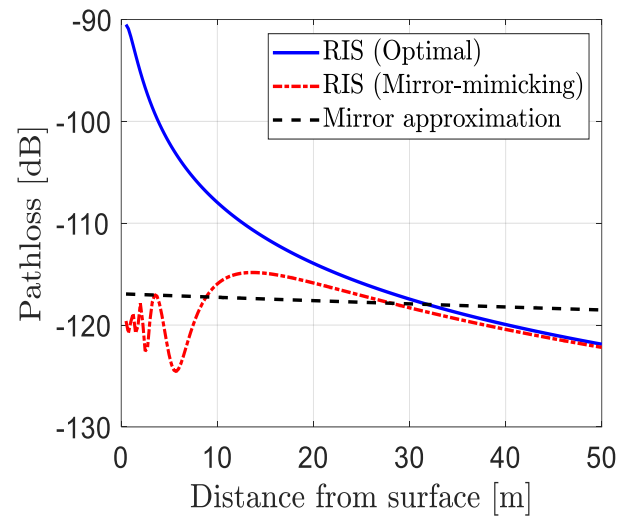


Figure 4: Pathloss of the signals

A perfect mirror reflects a transmitted signal with beamwidth being zero. When wave is incident on a RIS that is being configured for the focusing the signal towards a receiver located in the far field, though the wave is not a plane wave, the radiated electromagnetic field will be strongest in the angular direction of the receiver. The half-power beamwidth of the reflected signal is inversely proportional to the size of the RIS. Radio spectrum are a part of wireless communications. We know that the wavelength is nearly 100000 times more in radio spectrum than in visible light, the given surface must be 100000 times larger to equally reflect signals. Viewing RIS from far enough away, the radiated field shows beamwidth and size are inversely proportional to each other.

Fig.4 shows the Pathloss in different scenarios. As the surface area increases the optimal and mirror mimicking both shows a similar performance.

On changing different criteria, the pathloss value of equal-sized RIS is widely different. RIS has the effect on both the direction and shape of the reflected signal. Because of this, the SNR of RIS is proportional to N^2 and inversely proportional to the product of the squared distances given in the meta surfaces.

III. CRITICAL CASES OF IRS

A. In other technologies

To build a concept from theory to practice, it needs a lot of resources and time. Massive MIMO and mm Wave communications have achieved great success in the 5G development. mm Wave increase the data rate per user and Massive MIMO increase the number of users by many times. Because the gains are limited, many technologies failed here. What is the convincing solution case for RIS, is the main concern?

To look into it, RIS is a kind of technology looking to cater a service. We exactly do not know where this RIS/IRS is extended to. As known, every RIS element must be configured identically over the entire frequency band, the RIS technology has a further competitive disadvantage over wideband channels. Efficient spatial multiplexing and interference



mitigation is another potential use case, but then it needs to beat Cell-free Massive MIMO for combined antenna performances. RIS is more advantageous for the sparse channels and coherent transceivers. There is still no hardware implementation made for this RIS technology.

B. Controlling the environment and channel estimation

The proposed RIS use models rely significantly on a suitable CSI-driven element setup. The acquisition of channels is especially difficult for RIS for two reasons. First, a RIS is not naturally equipped with transceiver chains, unlike traditional transceiver designs. Sensor capacities are lacking yet the impinging signals merely "reflect." Conventional techniques for estimating channels cannot thus be used. Secondly, the inclusion of a RIS in the current setup increases in relation to the number of components the channel coefficients, N . For RIS to be competitive, as demonstrated previously, the overall estimate may be enormous. One important issue is: can a RIS be changed in real time for user mobility management? Initial attempts to the issue are included in the literature. One method is to repeatedly broadcast a pilot sequence and to measure the signal received by utilizing various RIS setups.

For example, elements may be switched on/off depending on the pattern or the geometry of the array can be utilized to switch the primary angle of reflection. In order to stimulate all channel dimensions, N reconfigurations need to be tried in various timeslots. The estimate is complicated only by the combination of the channels to/from the RIS and by the reciprocal coupling of the RIS components. Fig. 6 shows this method and needs a wireless control loop with a capacity proportionate to N between the receiver and the RIS controller. Even when CSI is obtained, selecting suitable time lags in wideband channels is computationally difficult. [7].

In order to minimize complexity, neighboring RIS components may be joined together at a performance penalty to get the same configuration. The passive character of the RIS is further altered by a number of components with receiver chains, allowing sensing and channel estimates directly to the RIS. The possibility for extend a few of measures to estimate the full broadband channel calls for space-saving channels with a defined parametrization. In mm Wave and terahertz bands this may be feasible but more work is needed on channel modelling and technology. Smaller channels may also flat out across quite broad bandwidths. While RIS has the capability to sensitize, a control circuit is required to choose the RIS design and the transmitter/receiver beamforming together. Algorithms for estimation may use unique channel features to minimize the overhead substantially. The channels in between BS and the RIS, for example, are semi-static and usual across all users, which correlate between all end-to-end channels. The BS-to-RIS channel may include numerous coefficients if the BS has several antennas; however, because this channel is quasi, it can be estimated less often than the RIS-to-user channel. RIS can be utilized for permanent connections, however mobile operation has to be estimated and reconfigured in real time channel, even in indoor situations. Within mm Wave bands, a few of millimeters of motion will alter the channel. It has to be shown if any protocol can allow real-time reconfiguration and under what circumstances of mobility. For reconfigurability via wireless channels, the RIS needs a power supply. The

control interface is expected to use most power at the RIS, thus the overall power consumption cannot be predicted until the channel estimates and reconfigurability have really been resolved and confirmed.

IV. CONCLUSION

RIS is a complete transparent, duplex relay that synthesizes arbitrarily formed object's scattering behavior. As RIS does not enhance the signal, the area of a given SNR is greater than traditional relays and multi-antenna transceivers. RIS-assisted communication is a developing area of study in which compelling use cases and the development of realistic reconfigurability protocols are the major challenges.

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