Investigating The data rate of Intelligent Reflecting Surface Under Different Deployments

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***Abstract*—intelligent reflecting surface (IRS) is capable to control the scattering, reflection, and refraction characteristics of the electromagnetic signals. The IRS is usually deployed near the distributed users for the purpose of enhancement the local coverage which is completely different from that for the active relay, almost placed in the middle of the transmitter and receiver for balancing the signal to noise ratio (SNRs) of the two-hop links, that process and amplify the source signal before forwarding it to the receiver. We have studied the deployment of IRS for different locations in SISO wideband system with single antenna at the AP and each user. We used the communication setup considered in the IEEE signal processing Cup 2021 to investigate the user data rate enhancement under different IRS deployments. Simulation results have shown that the data rate improved when the IRS is placed either near the users or the AP. However, the data rate has been reduced when placing the IRS in the middle between the AP and the users.**

I. INTRODUCTION

Recently, a new technology was emerged into the wireless communication research: reconfigurable intelligent surfaces (RISs) or (IRSs). The RISs are intelligent surfaces which are manufactured from electromagnetic materials (EM). The materials are controlled by microelectronic circuits that have the features of wireless communications and hence managing the wireless propagations scenarios in a way that was not discovered in the prior research [1-3]. It is worth mentioning that IRS might be deployed much more widely across the network, due to its cheap price, to effectively modify signal propagation. However, this creates a considerably larger-scale deployment optimization challenge that is difficult to address in addition to the fact that because IRS is passive equipment, the strength of their reflected signals decays fast with distance.

In this research, we investigate the IRS deployment for IRS-assisted wireless communication systems. We look at a simple multi-user wideband communication system with transmission enhanced by orthogonal frequency division multiplexing (OFDM) and concentrate on determining users' maximum possible rates by optimizing their IRS deployment. We assume that both the AP and the user have a single antenna, therefore the achievable rate is exclusively governed by the received SNR at the user. The simulation findings show that situating the IRS near the users or the AP results in a higher achievable rate but positioning it in the centre between the users and the AP results in a low data rate.

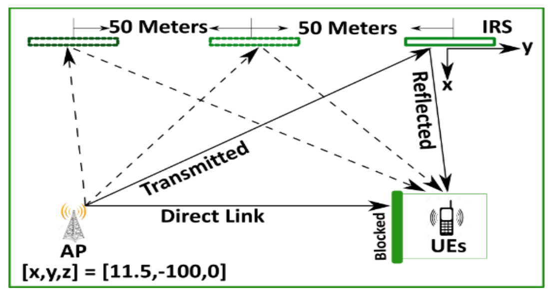

Figure 1. Simulation Setup for different IRS Deployments

II. SYSTEM MODEL

We discuss communication from a single antenna source (AP) to many users' equipment's (UEs) using an IRS with N reconfigurable controllable elements as per Fig.1. We assume the transmission is carried out using OFDM with a unit energy sinc-function as the pulse shape filter as in the model derived in [3]. The received discrete time signal sequence $z[k]$ is given by:

$$z[k] = \sum_{l=0}^{M-1} h_\theta[l]x[k-l] + w[k] \quad (1)$$

Where $\{h_\theta[l]: l = 0, \ldots\ldots, M-1\}$ is the finite impulse response (FIR) filter that describe the wideband channel in the time domain with the IRS configuration θ and $\{w[k]\}$ is the receiver noise. $h_\theta[l]$ is given by:

$$h_\theta[l] = h_d[l] + v_l^T w_\theta \quad (2)$$

Where $h_d[l]$ is the uncontrollable channel, $v_l \in \mathbb{C}^N$ is the cascaded channels via each of the N elements and $w_\theta \in \mathbb{C}^N$ contains the actual reflection coefficients of the IRS that determine the amplitude losses and phase shifts. The sum rate over the subcarriers is given as [3] for a given configuration, equal power allocation, and perfect channel estimate at the receiver:

$$R = \frac{B}{K+M-1}\sum_{v=0}^{K-1} log_2\left(1+\frac{P\left|\overline{h_\theta[v]}\right|^2}{BN_o}\right)\ \frac{bit}{s} \quad (3)$$

Where B is the channel bandwidth, P is the transmit power and N_o is the noise power spectral density $\left(i.e\ \overline{w}[k]\sim N_c(0,N_o)\right)$. The rate can be maximized with respect to θ. We will investigate the rate performance in the same setup in [4] but for different IRS Deployments. There is LOS link between the AP and IRS and NLOS propagation between the AP and users. The channel parameters values are generated by adopting the 3GPP model [5] where the number of subcarriers $K = 500$ and the channel Taps $M = 20\ Taps$ and the number of users (UE's) are 50 users, 14 of them are NLOS users while the others are LOS users. The number of elements in the IRS, $N = 4096$. The AP is situated at $[11.5, -100, 0]^T$(in meters) and the users are in a room 13 meters X 14 meters in the azimuth plane centered around $[11.5,0,0]^T$.

A. IRS Configuration for Different Deployments

The practical phase shift model for the nth reflecting element is a parallel resonant circuit is given as per [6] where the reflection coefficient is described as:

$$v_n = \frac{Z_n(C_n,R_n)-Z_o}{Z_n(C_n,R_n)+Z_o} \quad (4)$$

The reflected (EM) waves may be controlled and programmed by altering the values of $C_n, R_n\ and\ w$. Values of C_n, which range from 0.15pF to 1.5pF, $R_n = 1\ ohm$, $z_o = 377\Omega$ is the free space impedance, and f=4 GHZ, respectively. If a sinusoidal signal with frequency f impinging the IRS element, it will be scattered with an amplitude change of $|v_n|$ and phase shift of $\arg(v_n)$. The IRS is controlled by different numbers of PIN diodes. Each PIN Diode can take two different values of ON and OFF capacitances.

The maximization of (3) with respect to the RIS configuration θ entails selecting the most optimal vector w_θ which is affecting all the subcarriers because the transmissions are simultaneous. Consequently, channel estimation is required, the least square (LS) estimate can be calculated as follows [3]:

$$\left[\hat{h}_d, \hat{V}_{row}^T\right] = \sqrt{\frac{B}{P}}\ F^\dagger Z \begin{bmatrix}1, \dots\dots, 1\\ A^T\hat{\Omega}\end{bmatrix}^\dagger \quad (5)$$

Where $A = (1_{N_V} \otimes I_{N_H}) \in \mathbb{C}^{NXN_H}$is the reduced matrix, $Z = [\bar{z}1, \dots\dots, \bar{z}c] \in \mathbb{C}^{NXC}$ contains all the received signals and $\dagger$ denotes Moore-Penrose inverse. The maximization of $\hat{h}_d\ and\ \hat{V}_{row}^T$ with respect to the RIS configuration needs selecting the most preferred vector $\hat{\Omega} = [w_{\theta_1}, \dots\dots, w_{\theta_c}]$. We will utilize the identical approach in [4] to make sure it works for both LOS and NLOS channels. The power method algorithm is utilized to find the maximum dominant eigen vector of the matrix to be the optimal solution. The received signal power can be represented in a quadratic form where the number of iterations must be completed until convergence. To achieve the least pathloss exponent that leads to the minimal pathloss under a given connection distance, it is practicable to put IRS under LoS conditions with AP and users. Despite a single IRSs of order $\mathcal{O}(N^2)$ passive beamforming gain, the received signal strength at the user suffers from a twofold path-loss proportionate to the product of the user-IRS and IRS-AP connections' distances.

B. Simulation Results

The simulation Results are obtained for different IRS positions. The first scenario when the IRS is place near the users (above the users) while in the second deployment, we place it in the middle between the users and AP and finally, it is located near the AP. It is clear from Fig.2 the superior data rate for all users when placing the IRS either near the users or AP nevertheless, the rate is degraded when it is located in the middle. The reason behind that is when placing the IRS near the user or AP it yields the largest SNR while placing it around the middle between the user and AP leads to the smallest SNR.

III. CONCLUSION

IRS deployment should be taken into consideration when designing the wireless communication networks. Placing the IRS near the AP and USERs gives the maximum data rates.

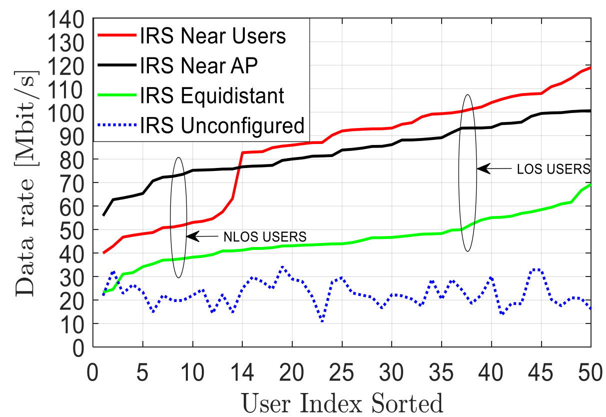

Figure 2. Achievable Data rate for different IRS Deployments

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