Using Reflective Intelligent Surfaces for Indoor Scenarios: Channel Modeling and RIS Placement

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***Abstract*—In the recent year, people had to work from home due to the outbreak of the COVID-19 pandemic. When the majority of the family members are working online, the bitrate experienced by the average user may drop, especially if some members have to work in rooms that suffer from weak coverage. Benefiting from the emerging concept of Reflective Intelligent Surfaces (RIS), the network coverage in our houses can be greatly improved. This paper presents a study of an RIS-assisted system for an indoor scenario operating at 2.4GHz. We propose an RIS placement approach that is based on minimizing the pathloss of the channel, to enhance the rate of bad coverage rooms, while taking into consideration their user occupancies. The proposed approach, which we refer to as the Weighted RIS Placement, is modeled and simulated for a single RIS. The problem is then extended to a two-RIS scenario. Our results show that the Weighted RIS placement provides significant rate gains. Also, this is the first work that models the communication channels for the individual rooms, using corresponding Rician K-factor values that reflect the indoor layout.**

***Index Terms*—Reflective Intelligent Surfaces, Wireless Communication, Rician K-factor, Indoor Systems**

I. Introduction and Literature Review

The Corona Virus (COVID-19) pandemic has made working from home a dominant practice around the world, and according to [1], many firms plan to allow their employees to work from home between two and three days a week, for the long term. However, around 49% of Americans, also according to [1] lack the facilities to effectively work from home, such as a private room or a good internet connection.

A potential solution for enhancing the home internet connection is technology of Reflective Intelligent Surfaces (RIS). The main motivation behind RISs is their reflective nature, that can passively reflect the incoming signal by inducing a preconfigured phase-shift so it reaches the receiver through the configured reflected path. This can be seen as having a degree of control over the communication channel [2]. The RIS is formed of several reflecting elements that are configured by a dedicated controller to cause the reflected signals to add constructively at the receiver, without requiring any transmit radio-frequency (RF) chains [3]. In Figure 1, we show an illustration of an RIS deployment in an indoor scenario, where it demonstrates the paths taken by the signal from the Transmitter to the RIS, from the RIS to the receiver, and from the transmitter directly to the receiver, which in some cases might be blocked. Modeling and analysis of RIS aided systems was done for indoor and terrestrial outdoor scenarios for Wi-Fi and mmWaves [4]. A double pathloss is formed due to the cascaded channels that are created, i.e, the Tx-RIS channel and the RIS-Rx channel. This induces the need for different channel models, and different channel estimation techniques [3].

On top of this, the RIS positioning is an important parameter that affects performance. Since the RIS is passive, i.e, it does not regenerate or amplify the signals; it reflects them, a careful placement should be done so as to maximize the performance gain and minimize the performance loss. In this regard, [3] states that placing the RIS near to one of the communicating terminals achieves better achievable rate than placing it in the middle between them. In [3], the authors consider the placement of the RIS in an outdoor scenario, where the channels are assumed to follow the free-space (LoS) model, with neglecting the direct channel between the transmitter and receiver. The work in [5] presents a system model for both indoor and outdoor scenarios, at the mmWave frequencies. The RIS is positioned so that an LoS link is created in the Tx-RIS and the RIS-Rx links. Similarly, [6] shows that the highest benefit of RIS in terms of achievable rate is achieved in LoS Tx-RIS-Rx channels, and by placing the RIS near the Rx. Additionally, the works in [4] and [7] tackled the performance of multi-RIS systems. In [4], they studied the performance of multi-RIS under simultaneous transmission over two independent RISs in an indoor environment, and a double-RIS reflected transmission over a single link in an outdoor environment.In the former case it is assumed that the channels between the Tx and the RIS and between the RIS and the Rx follow a Rician distribution with Rician K-factor of 10dB, to denote a Rayleigh fading distribution. In [8], they assume that the AP-RIS2 and user-RIS1 channels follow an LoS model. Finally in [7], the optimal deployment strategy of the RIS is presented in an indoor scenario for mmWave networks, to minimize the link outage probability, taking into consideration the user mobility in the rooms, for the cases of one and two RISs.

All of the works considered above have either assumed a Line of Sight (LoS) channel, or a Rayleigh channel. However, in practical scenarios this is not the case, especially in indoor

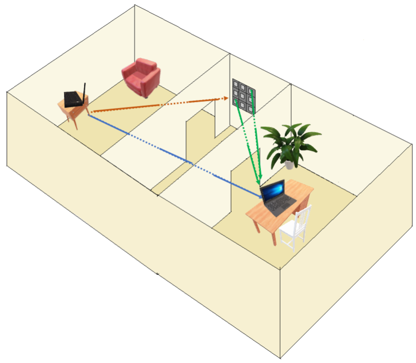

Fig. 1. Illustration of RIS deployment in an indoor scenario

environments, the channels are controlled by the nature of the walls, the furniture, and the architecture of the house. Hence, there is a need to create a realistic channel model that takes into consideration the aforementioned factors. The contributions of this paper can be summarized as follows:

- Applying to the channels of the indoor system a realistic model, based on the Rician K-factor and pathlosses for the individual rooms.
- Proposing an RIS positioning approach that maximizes the achievable rate in the rooms.
- Extending the proposed approach to multiple RISs.

In the rest of this paper, Section II presents the system and channel models. Section III presents the proposed approach for the single RIS case. Section IV discuses the proposed approaches for multiple RISs. Then the simulation results are provided in section V before the conclusion in Section VI.

II. System and Channel Models

We consider an initial system formed of a transmitter with a single antenna ($M_t = 1$) which is denoted by the Access Point (AP), a receiver (Rx) with a single antenna ($M_r = 1$), and a passive RIS with N reflecting elements, and continuous phase shifts. We define the vector θ as $\theta = [\theta_1, ...\theta_N]$ and let $\Theta = diag(\beta_1 \exp j\theta_1, ..., \beta_N \exp j\theta_N)$ denote the reflection coefficients matrix of the RIS, where $\theta_n \in [0, 2\pi]$ and $\beta_n \in [0, 1]$ represent the phase shift and the amplitude reflection coefficient of the n^{th} element of the RIS, respectively. We also let the channel between the AP and the RIS be denoted by $H \in N \times M_t$, the channel between the the RIS and the l^{th} user be denoted by $h_l \in M_r \times N$ where $l \in 1...L$, and the direct channel between the AP and the Rx be denoted by $h_d \in M_r \times M_t$. For this work, perfect channel knowledge is assumed. In what follows, the optimal phase angle configuration of the RIS, the pathloss, and the Rician channel model in the RIS system are presented, then the received signal to noise ratio is calculated based on the received signal model.

A. Phase Angle Configuration

With the perfect channel knowledge assumption, the RIS phase angles are configured so that the reflected paths are aligned with the direct path. For maximal received SNR, the configuration of the phase angles of the RIS(s) is calculated as in [9]:

$$\theta_n^* = arg(h_d^H) - arg(h_l^H) - arg(H) \tag{1}$$

B. Path loss in the Indoor Channel Model

As in [4], it is assumed a reflect-array type RIS in which the RIS elements are separated with half-wavelength under the far-field case. Accordingly, the path loss of the cascaded channel (AP-RIS-Rx) in this paper is calculated as:

$$P_L^C = ((\frac{\lambda}{4\pi})^4 \frac{{G_e}^i {G_e}^r}{d_{SR}^2 d_{RD}^2} \epsilon_p) \tag{2}$$

where λ is the wavelength, ${G_e}^i$, and ${G_e}^r$ are the gain of the RIS in the direction of the incoming wave and in the direction of the received wave, respectively, and ϵ_p is the efficiency of the RIS where it is assumed here that $\epsilon_p = 1$.

Also, the pathloss of the direct channel is given as:

$$P_L^D = ((\frac{\lambda}{4\pi})^2 \frac{{G_e}^i}{d_{SD}^2}) \tag{3}$$

where the distances between any two nodes are calculated by the Euclidean distance formula.

C. Rician Indoor Channel Model

As mentioned in the above section, the other works in the literature consider an LoS between the AP and the RIS, and/or between the RIS and the Rx. In this work, we consider the K-factor of each room which in turn takes into consideration the nature and number of obstacles that affects the path of the signal. The Rician K-factor is defined to be the ratio of energy delivered along the direct paths, to the energy delivered along the scattered paths [10].

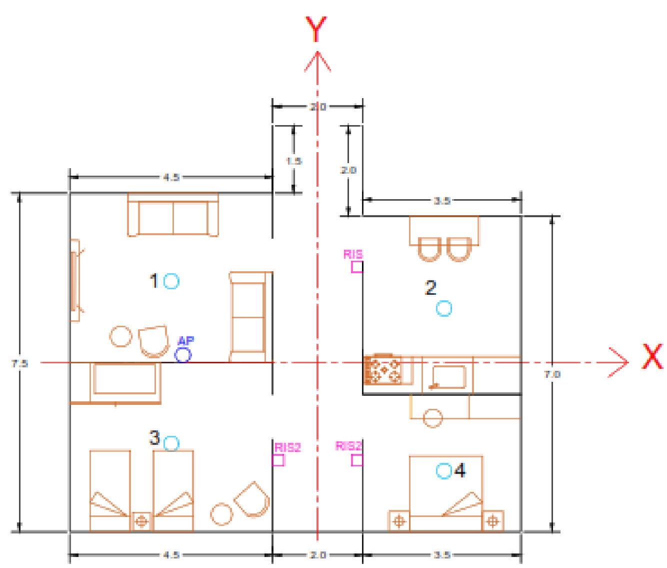

Fig. 2. Indoor Test Scenario

For each room r, the channel between the AP and the RIS, the RIS and the receiver, and between the AP and the receiver can be expressed as in [4]:

$$H_r = \sqrt{\frac{K_1}{1+K_1}} H_{LOS} + \sqrt{\frac{1}{1+K_1}} H_{NLOS} \quad (4)$$

$$h_{l,r} = \sqrt{\frac{K_2}{1+K_2}} h_{l,LOS} + \sqrt{\frac{1}{1+K_2}} h_{l,NLOS} \quad (5)$$

$$h_{d,r} = \sqrt{\frac{K_3}{1+K_3}} h_{d,LOS} + \sqrt{\frac{1}{1+K_3}} h_{d,NLOS} \quad (6)$$

where K_1, K_2, K_3 denote the Rician factors of these links respectively, H_{LOS}, $h_{l,LOS}$, $h_{d,LOS}$ stand for the LoS components, and H_{NLOS}, $h_{l,NLOS}$, $h_{d,NLOS}$ stand for the NLoS components, and follow complex normal distribution denoted by *CN(0,1)*. The values of the Rician K-factors are based on the indoor measurements obtained at 2.4GHz for a similar indoor model, done in [11]. Under the condition of slow and flat fading channels, the baseband received signal at the l^{th} user by the cascaded RIS path and the direct path can therefore be expressed as:

$$y_l = \sqrt{P_T}[\sqrt{P_L^C} h_{l,r} \Theta H_r + \sqrt{P_L^D} h_{d,r}]x + n \quad (7)$$

where P_T is the transmit power, and x is the data symbol selected from an M-ary Quadrature Amplitude Modulation (QAM) constellation with $M = 16$, and unit power. Finally, $n \sim CN(0, N_0)$ represents the additive white Gaussian noise (AWGN), where N_0 is the total noise power.

The received Signal-to-Noise Ratio (SNR) and the achievable bit rate, are respectively given by

$$SNR = \frac{P_T|\sqrt{P_L^C} h_{l,r} \Theta H_r + \sqrt{P_L^D} h_{d,r}|^2}{\sigma^2} \quad (8)$$

$$rate = \log_2(1 + SNR) \quad (9)$$

III. Proposed Approach for Single RIS

In this section, a home model is selected to serve as the test environment, but we should note that the proposed approach can be applied to a generic indoor environment after setting the corresponding K-factors. We consider a 3D Cartesian coordinate system for the top view of a simple home shown in Figure 2. The rooms are labeled as shown in the figure from Room1 to Room4, and the AP is placed in Room1. The rooms are occupied with furniture and the walls are made of concrete with all the doors being open. The shown dimensions are in meters. In this section, we have one RIS for which we are working to determine its optimal position, given that it is to be placed on the right side of the hallway.

To generalize the model, we let the total number of users be N_u, the total number of rooms be N_r, and define the set $P = \{p_1, ...p_r\}$ as the rooms' user occupancy, where $pi = \frac{N_{ui}}{N_u}$, $i = 1, ...N_r$ and N_{ui} is the number of users occupying Room$i$, on average. We assume equal distribution of the home network's bandwidth consumption among the users, and consider a set of four User Occupancy (UO) scenarios: a normal ("Weekday") scenario and three stress-testing scenarios: { ("UsersRoom2", "UsersRoom3", "UsersRoom4")}. We assume that the users are fixed in their positions. For illustration, in this study, we set $N_u = 5$ and $N_r = 4$. Hence, we have:

- Weekday: $\{p_1 = \frac{3}{5}, p_2 = \frac{0}{5}, p_3 = \frac{1}{5}, p_4 = \frac{1}{5}\}$
- UsersRoom2: $\{p_1 = \frac{0}{5}, p_2 = \frac{5}{5}, p_3 = \frac{0}{5}, p_4 = \frac{0}{5}\}$
- UsersRoom3: $\{p_1 = \frac{0}{5}, p_2 = \frac{0}{5}, p_3 = \frac{5}{5}, p_4 = \frac{0}{5}\}$
- UsersRoom4: $\{p_1 = \frac{0}{5}, p_2 = \frac{0}{5}, p_3 = \frac{0}{5}, p_4 = \frac{5}{5}\}$

In this work, the achievable bitrate for every room is calculated at its center. We refer to the proposed approach as the Weighted RIS Placement. Related to this, the coordinates of the terminals are given as: $AP(x_{AP}, y_{AP}, z_{AP})$, $RIS(x_{RIS}, y_{RIS}, z_{RIS})$, and $Rx(x_{Rx}, y_{Rx}, z_{Rx})$.

We now present the steps of the Weighted RIS Placement:

1) Denote by B the total channel of the system. Thus, $B = (\sqrt{P_L^C} h_{l,r} \Theta H_r + \sqrt{P_L^D} h_{d,r})$.
2) Express the pathloss of the cascaded channel P_L^C as a function of the variable y_{RIS}, i.e, $P_L^C = f(y_{RIS})$. The expressions of H, h_l, h_d and P_D^L, show that they are independent of the position of the RIS.
3) Substitute the coordinates of every Room$i$, denoted by (a_i, b_i, c_i), in the expression of the previous step:

$$P_L^C = [f(y_{RIS})]_{Roomi} \quad (10)$$

4) Solving $\frac{dP_L^C}{dy_{RIS}} = 0$ simplifies to finding the root of a third order polynomial as a function of y_{RIS}:

$$P_{RIS}(y_{RIS}) = \alpha y_{RIS}^3 + \beta y_{RIS}^2 + \gamma y_{RIS} + \eta \quad (11)$$

5) We set $y_{RIS,opt}$, to be the solution of the polynomial $P_{RIS}(y_{RIS}) = 0$, which is of size N_r (i.e., one for each room).
6) Set the values of p_i, corresponding to a user-occupancy scenario.
7) The y coordinate of the RIS for the proposed Weighted RIS placement, is (i.e., one for each room) calculated as follows:

$$y_{RIS,weighted} = \frac{\sum_{i=1}^{N_r} R_i^{-1} \times y_{i,RIS,opt} \times p_i}{N_r} \quad (12)$$

In Eq.12, R_i^{-1} is the inverse of the bitrate per Room$i$, so that rooms with higher rates receive lower weights and vice versa. Thus, the objective of our proposed approach is to enhance the achievable rate for the rooms with low SNR, and at the same time, take into consideration the average user occupancy per room. For illustration, the expression of P_L^C, and for the AP and RIS coordinates $AP(-2, 0, 1)$, $RIS1(1, y_{RIS1}, 1.5)$, becomes:

$$P_L^C(y_{RIS}) = \frac{1}{\left(x^2 + \frac{37}{4}\right)\left((x - b_i)^2 + \left(\frac{3}{2} - c_i\right)^2 + (1 - a_i)^2\right)} \quad (13)$$

IV. Extensions for Multi-RIS

In this section, the positioning of two RISs that transmit simultaneously is studied, although this can be extended to scenarios of larger numbers of RISs. The received signal model with two RISs is given by following the lead of the work done in [4]:

$$y_{mRIS,l} = \sqrt{P_T}[\sqrt{P_{L1}^C} h_{l,r,1}\Theta 1 H_{r1} + \sqrt{P_{L2}^C} h_{l,r,2}\Theta 2 H_{r2} + \sqrt{P_L^D} h_{d,r}]x + n \quad (14)$$

where $r \in \{1...m\}, m = 2$, is the number of RISs, and $l \in \{1...N_r\}$ is the room index. The incremental benefit of adding an additional RIS to the first one is studied, where three approaches are presented.

1) Fixing the position of RIS1, which is calculated from the approach in the earlier section, and checking the incremental benefit of adding RIS2 on the same wall.
2) Placing RIS1 and RIS2 on the opposing walls of the hallway, where the position of each one is also calculated using the approach in the previous section.
3) Moving RIS1 and RIS2 simultaneously and mutually on the opposite walls starting from the ends of the hallway and going toward the middle, to determine the positions that maximize the average rate in the rooms.

A. Approach 1: Incremental Placement of RIS2 - Same Wall

The position of RIS1 is determined in Eq.12. If we denote by $Rate_1$ the one obtained after placing RIS1, then the position of RIS2 is such that the achievable rate $Rate_2$ is based on enhancing $Rate_1$. Thus, for the same user occupancy values, y_{RIS2} is given by:

$$y_{RIS2,weighted} = \frac{\sum_{i=1}^{N_r} Rate_{1,i}^{-1} \times y_{i,RIS,opt} \times p_i}{N_r} \quad (15)$$

Note that $y_{i,RIS,opt}$, the obtained solution from solving $\frac{dP_L^C}{dy_{RIS1}} = 0$, is the same for RIS1 and RIS2, for this case. We note that Eq. 15 can be recursively extended into mRIS's.

B. Approach 2: Simultaneous Placement - Opposite Walls

Placing the RIS's on opposite walls of the hallway is expected to increase the number of reflected paths, which in turn shall increase the achievable rate. We differentiate between placing the RIS on the right side (x_{RIS}=1m), or on the left side of the hallway (x_{RIS}=-1m). For the considered scenario, Room1 and Room3 observe a better LoS condition for the channels H and h_l when the RIS is placed facing them i.e, on the right side of the hallway. Also, this is true for Rooms2 and Room4 when the RIS is placed on the left side of the hallway. Both y_{RIS1} and y_{RIS2} are calculated according to Eq.12 by following the steps in section III. The pathloss in this case is minimized with respect to y_{RIS1} and y_{RIS2}, i.e, $\frac{dP_L^C}{dy_{RIS1}} = 0$ and $\frac{dP_L^C}{dy_{RIS2}} = 0$. This yields eight third order polynomials, for which the solutions give the optimal positions for the two RISs. The results are presented below in Section V.

C. Approach 3: Experimental Placement - Opposite Walls

This is an experimental approach where RIS1 and RIS2 are moved along the opposite sides of the hallway, in opposite directions of y, in order to figure out the placement of the RISs that maximizes the average throughput in all rooms.

V. Simulation Results

In this section, the obtained simulation results for the proposed approaches are presented. The selected K-factor values corresponding to the placement of RIS on the right side of the hallway (x_{RIS}=1m), and the left side of the hallway (x_{RIS}=-1m), are given in table I. The first column represents the AP-RIS channel H, the second column represents RIS-Rx channel h_l, and the third column represents the direct channel between the AP and the receiver h_d. The values of K[dB] are based on the obtained measurements for a similar indoor scenario in [11], where obstructed paths with a dominant LoS component takes a value of K between 7 and 8. Paths that contain more obstructions due to walls and moving people, yields a value of K=5.95. Complete LoS takes a value of K=10, and finally channels with no dominant LoS component and relatively larger Tx-Rx separation distances take a value of K=4.

TABLE I
K-factor values for each room in dB

RIS Position	Room	H	h_l	h_d
x_{RIS}= +1	1	8	6	10
	2	7	5	6
	3	8	6	7
	4	7	5	4
RIS Position	Room	H	h_l	h_d
x_{RIS}= -1	1	7	5	10
	2	8	6	6
	3	7	5	7
	4	8	6	4

The coordinates of each of the terminals with respect to the chosen center of the coordinate system (see Fig. 2), are as follows: $AP(-2,0,1)$, $RIS1(1, y_{RIS1}, 1.5)$, $RIS2(\pm 1, y_{RIS2}, 1.5)$. The centers of the rooms are $R_1(-3.25, 1.8, 0)$, $R_2(2.8, 1.2, 0)$, $R_3(-3.25, -1.8, 0)$ and $R_4(2.8, -2.4, 0)$, and the length of the hallway is 9m. The polynomial coefficients according to Eq.11, for RIS1 and RIS2 are given respectively as

$$P_{RIS_1} = \begin{bmatrix} 800 & -2160 & 13121 & -6660 \\ 100 & -180 & 809 & -555 \\ 800 & 2160 & 13121 & 6660 \\ 20 & 72 & 205 & 222 \end{bmatrix}$$

$$P_{RIS_2} = \begin{bmatrix} 1200 & -2880 & 4921 & -1800 \\ 75 & -120 & 497 & -75 \\ 1200 & 2880 & 4921 & 1800 \\ 15 & 48 & 121 & 30 \end{bmatrix}$$

where each row represents the polynomial coefficients that correspond to each of the four rooms under study. The gains G_e^i and G_e^r are 5dB, $\sigma^2 = 0.1$ and $N = 16$.

A. Weighted RIS Placement: Single RIS

Figure 3 shows the individual rate per room as the RIS slides along the right side of the hallway. The dashed vertical lines correspond to the optimal solutions $y_{RIS,opt}$ (Step 5 of the Weighted RIS Placement). It can be seen that the analytical solutions are consistent with the simulated achievable rates, where the the graphs intersect with the lines at their maxima. As explained earlier, the Weighted RIS placement takes into consideration both the initial achievable rate without the RIS and the user occupancy of each room. Table II shows the effect of these factors on the calculated position of the RIS and the resulting achievable rate.

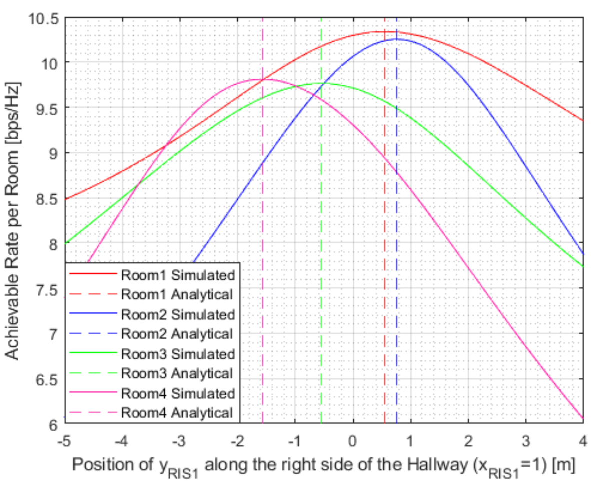

Fig. 3. Individual Achievable rate at optimal RIS positions

TABLE II
EFFECT OF THE USER OCCUPANCY ON THE WEIGHTED RIS PLACEMENT

User Occupancy	Room1	Room2	Room3	Room4	y_{RIS}
No IRS	5.34	1.79	3.95	1.14	–
Weekday	10.84	9.93	10.69	9.23	-0.0601
All users at Room2	10.92	10.01	10.60	9.13	0.1058
All users at Room3	10.85	9.94	10.68	9.22	-0.0346
All users at Room4	10.68	9.77	10.83	9.38	-0.3424

The weight of the initial rate can be seen by observing Room4, i.e, the room with the lowest initial rate, where it gets the highest rate gain, regardless of the user occupancy (1.14 to 9 bps/Hz). On the other hand, the effect of user occupancies on the RIS position, can be seen by comparing for each Room$i$, the rates achieved for each occupancy scenario. For example, Room2 observes the highest achievable rate when all the users are there (10.01bps/Hz), compared to the other occupancy scenarios observed by this room. Consequently, y_{RIS} in this case is calculated to be 0.1058m, which is in the direction towards Room2 (Recall that $y = 0$ lies at the center of the hallway, and $y_{Room2} = 1.2$). It should be noted that y_{RIS} will still lie around the middle, since $y_{RIS,weighted}$, depends both on the rates and occupancies. Also, when all users are in Room4, $y_{RIS} = -0.3424$, which is in the direction of Room4. For the normal weekday scenario, $y_{RIS} = -0.0601$ which is approximately around the center of the home. This is because for this scenario, the users are distributed among all of the Rooms. For proof of concept, we have chosen the normal weekday user occupancy scenario, which is defined in section III, for the rest of simulations to demonstrate the effectiveness of the RISs boosting the average bitrate when family members are working from home (online). The achievable rates for the Weighted RIS placement, are shown in Figure 4. The average rate across the four rooms is 10.1408bps/Hz, and the gain attained relative to not having an RIS is 7.081 bps/Hz. The results also show that the rate has tripled. Also, it is observed that Room1 and Room3 observe a higher rate increase, due to placing the RIS in favor of their direction,i.e, by facing them.

B. Multi RIS

The achievable rate obtained after placing RIS1 and RIS2, with respect to the three proposed scenarios in section IV, is studied. It can be seen from Figure 4 that adding the second RIS after fixing the position of the first one, i.e, calculating y_{RIS2} according to Approach-1 in the multi-RIS case, indeed increases the achievable rate per room, thus increasing the average achievable rate to 12.223bps/Hz, resulting in an achievable rate gain of 2.089bps/Hz more than the Single RIS case.

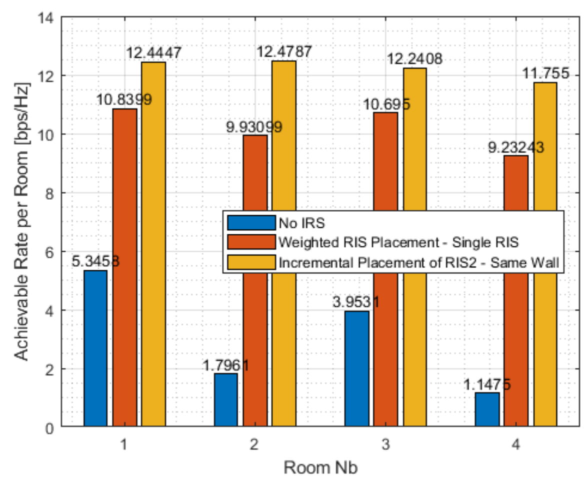

Fig. 4. Incremental benefit of adding RIS2 along with RIS1

The effect of placing RIS2 on the opposing wall ($x_{RIS2} = -1$), and calculating y_{RIS2} according to Approach-2 is shown in Figure 5. The average achievable rate across the four rooms have increased into 13.412bps/Hz. Thus resulting in a rate gain of 1.189 bpz/Hz over placing RIS2 on the same wall (Approach-1). Placing the RIS according to Approach-3 (Experimental Placement), gives an average achievable rate of 13.379bps/Hz. In comparing opposing-walls to the Experimental RIS placement, shows a similarity in their performance. This is expected since they both share the same channel conditions of having the RIS placed at the left side of the hallway.

The resulting coordinates of the RISs according to the simultaneous placement are $RIS1(1, 0, 1.5)$ and $RIS2(-1, 0, 1.5)$, stating that for this approach the RISs are to be placed exactly facing each other. Finally, it can be inferred that placing the RISs on opposing walls allows for a higher rate gain at the level of individual room rates.

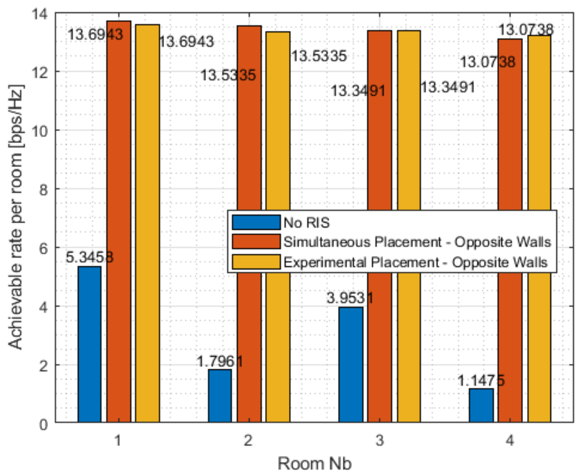

Fig. 5. Multi RIS Second and Third Approaches

VI. Conclusion

This paper has presented a study on how RIS positioning can contribute to the rate enhancement for indoor environments. This problem is of high importance as the work from home trend seems to be continuing after the pandemic, where most of homes are not equipped with work space conditions (coverage and separate rooms). The indoor channel model was presented using corresponding values of the Rician K-factor, thus taking into consideration the nature of the obstacles that usually exist, such as furniture, walls, and so on. Then, using the established channel model, an RIS positioning approach (The Weighted RIS Placement), was proposed to calculate the position of the RIS that maximizes the achievable rates of all the rooms. This approach was then extended to the case of two RISs, where three positioning scenarios were proposed and analyzed. The proposed approaches provide high gains in the achievable rate (doubling the rate). Even-though the results obtained correspond to the presented house scenario, the approach we proposed should work equally well for other house scenarios, after setting the appropriate K-factors.

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