Analysis of IRS-Assisted NOMA for 6G Wireless Communications

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1. Introduction

For fifth-generation (5G) and beyond wireless communications include indoor localization [1-20], terahertz strategies [21-33], and antenna architecture [34-50] and more expectations on energy usage, spectrum efficiency, and huge connectivity have been put [51]-[53]. IRS technology [54], [55] has recently received a lot of interest. IRS is a metasurface typically made up of numerous passive reflecting elements that allow dynamic modification of signal characteristics. Its capacity to manage signal reflection and change the propagation circumstances can result in a performance boost at reduced power consumption.

The IRS is envisaged as a game-changing technology for 6G wireless networks. IRS, as opposed to standard wireless relaying technology [56], merely reflects signals and operates in a full-duplex configuration with reduced energy usage. The reflected signal transmission may be jointly adjusted by modifying the phases of the reflecting elements of IRS. This improves throughput, coverage, and energy efficiency.

NOMA [57] has recently gained a lot of interest because of its enormous potential to facilitate vast connections and improve spectrum efficiency. Fig. 1 shows a typical IRS-assisted NOMA communication scenario.
NOMA, as opposed to traditional orthogonal multiple access (OMA) [58], is indeed one of the important innovations in prospective wireless communication networks because of its greater connectivity support, spectral efficiency accomplishment, user fairness guarantee, etc. The fundamental concept of NOMA is to accommodate numerous users over the same resource block (i.e., frequency, time, and code), using superposition coding and successive interference cancellation at the transmitter and receiver end, respectively [59]. Users with superior channel quality are capable of reducing intra-channel interference from users having poor channel conditions.

This article investigated the possible performance enhance-
ment brought about by efficiently combining IRS with NOMA techniques inspired by the aforementioned features of the IRS and NOMA [60].

The work explored an IRS-assisted NOMA downlink system with two users across fading channels i.e. evaluates the performance of the reference model (based on the conventional distance-dependant path loss model) and modified the model by incorporating an IRS-specific frequency-distance-dependent path loss model. Furthermore, this work figure out an improvement scope in the reference model and enhanced the model however the enhancement of the reference model is still unparallel to the modified model.

2. Related Literature

The section of the paper briefed several prior works and literature relative to the downlink IRS-assisted NOMA communication.

Wang et al. [61] examined the effectiveness of the deployment of IRS-assisted NOMA in terms of transmit power consumption. In this context, the downlink transmission power minimization problem is analyzed considering the constraint of the user’s minimum level of SINR. Cheng et al. [62] studied a downlink NOMA system, in which an IRS is deployed to im-
prove the network coverage by supporting cell-edge devices. Fu et al. [63] considered the downlink transmit power optimization problem for an IRS-assisted NOMA system by optimizing the transmit beamforming and the phase-shift matrix. Zhu et al. [64] proposed and analyzed a downlink multi-input single-output (MISO) NOMA scheme assisted by an IRS. Sena et al. [65] exploited dual-polarized IRS to improve the performance of massive multi-input multi-output (MIMO) NOMA in the case of imperfect successive interference cancellation (SIC). Zuo et al. [66] investigated the downlink IRS-aided NOMA to maximize the network throughput in terms of resource allocation namely the channel assignment, power allocation, and reflection coefficients. Liu et al. [67] proposed and analyzed a millimeter-wave (mmWave) downlink IRS-assisted massive MIMO NOMA system incorporating a lens antenna array under transmission power constraints.
3. System Model

The research considered an IRS-empowered downlink NOMA system in which the base station and paired user equipment both are performing communication with a single antenna. In which a near and a far user (an outer circle user having separation distance twice of the near user from the IRS) denoted by $u_1$ and $u_2$ respectively are assigned to be operated in a pair to share the common frequency-time resource block.

The base station transmits the superimposed signal of the users $x = \sqrt{\wp}(a_1 s_1 + a_2 s_2)$, where $\wp$ is the transmission power of the base station, $s_1$ and $s_2$ are the complex message of the near and far user $u_1$ and $u_2$ respectively. During the transmission, the SIC technique is utilized at the receiver end, therefore superposition coding (SC) is applied at the base station, and a higher power coefficient is assigned to a far user due to the weaker channel characteristics (i.e. highly faded channel), namely $a_2 > a_1$ and $a_1^2 + a_2^2 = 1$. According to the principle of NOMA, the far user $u_2$ have to decode its message or signal $s_2$ considering the message of the near user $u_1$ as interference.

A. Conventional Model

The received signal at the user-end ($u_i$) is given by (Eq. 1)
where \( \Theta = \text{diag}(e^{j\theta_1}, e^{j\theta_2}, ..., e^{j\theta_N}) \in \mathbb{C}^{N \times N} \) is the diagonal phase shift matrix of the IRS. \( g_i \in \mathbb{C}^{M \times 1} \) defines the channel fading between the user \( (u_i) \) and the IRS. \( g_0 \in \mathbb{C}^{M \times 1} \) indicates the fading between the base station and the IRS. \( \mathcal{L}(d)[dB] = 35.1 + 36.7\log_{10}(d) - G_t - G_r \) [18] is the formula for measuring the path loss of the communication channels, \( G_t = 10 \) dB and \( G_r = 10 \) dB [68] are the transmitter and receiver gains, respectively, and \( d \) denotes the separation distance for either base and IRS or IRS and user. \( w \) is the Gaussian noise (-94 dBm).

Therefore, the received SINR for the user \( u_2 \) can be formulated by (Eq. 2),

\[
\mathcal{S}_2 = \frac{|g_2^T \Theta g_0|^2 \nu a_2^2}{\mathcal{L}(d)_{BS-IRS} \mathcal{L}(d)_{IRS-u_2}} + w
\] (2)

After decoding the received SINR of \( u_2 \) the received SNR for the user \( u_1 \) can be measured by (Eq. 3),

\[
\mathcal{S}_1 = \frac{|g_1^T \Theta g_0|^2 \nu a_1^2}{\mathcal{L}(d)_{BS-IRS} \mathcal{L}(d)_{IRS-u_1}}
\] (3)
B. Modified Model

The research modified the [69] reference model by incorporating a dedicated frequency-distance-dependent path loss model for IRS-assisted communication instead of a typical or conventional distance-dependant path loss model.

The received signal at the user-end is formulated by (Eq. 4) incorporating (Eq. 5),

\[ y_i = \frac{g_i^T \Theta g_0}{\sqrt{\mathcal{L}_{IRS(u)}}} x + w \]  

where

\[ \mathcal{L}_{IRS} = \frac{64\pi^3(d_1d_2)^2}{M^2N^2\lambda^2A^2GG_tG_r \int \int \cos(\theta_t)\cos(\theta_r)} \]  

where

\[ d_1 = \sqrt{(x_{BS} - x_{IRS})^2 + (y_{BS} - y_{IRS})^2 + (z_{BS} - z_{IRS})^2} \]

is the separation between the base station and the IRS positioned at \((x_{BS}, y_{BS}, z_{BS})\) and \((x_{IRS}, y_{IRS}, z_{IRS})\) respectively.

\[ d_2 = \sqrt{(x_{IRS} - x_U)^2 + (y_{IRS} - y_U)^2 + (z_{IRS} - z_U)^2} \]

indicates the separation distance between the user located at \((x_U, y_U, z_U)\) and the IRS. The transmitter and receiver gains are \(G_t\) and \(G_r\). The scattering gain is determined by \(G = \frac{4\pi d_t d_u}{\lambda^2}\). The numbers of transmitting and receiving elements are denoted
by $M$ and $N$, respectively. $d_x$ is the length and $d_y$ is the width of the elements of IRS. The carrier wavelength is $\lambda$. $\theta_t$ and $\theta_r$ are the transmitting and receiving angles. The reflection coefficient of the IRS is $A$.

The received SINR at $u_2$ is given by (Eq. 6),

$$S_2 = \frac{|g^T_2 \Theta g_0|^2 \rho a^2}{L_{\text{IRS}(u_2)}} + w$$

The received SNR at $u_1$ is measured by (Eq. 7),

$$S_1 = \frac{|g^T_1 \Theta g_0|^2 \rho a^2}{L_{\text{IRS}(u_1)}}$$

4. Numerical Results and Discussions

The section of the paper includes the measurement results and corresponding discussions on the derived results. Table I includes the measurement parameters and values.

Fig. 2 shows the measurement of received power for both the models in the context of user 1.

Fig. 3 illustrates the measurement of received power for both of the models in the context of user 2.

Fig. 4 represents the SINR measurement in the case of user.
Table 1: Parameter and Values

| Parameters                          | Values                                      |
|-------------------------------------|---------------------------------------------|
| Cell area                           | 200x200m                                    |
| Transmit power                      | 6W                                          |
| Transmitter and receiver gain       | 5 dB (This work), 10 dB [18], 20 dB (Enhanced [20] for [18]) |
| Number of IRS transmit-receive elements | 64                                          |
| Length and width of the IRS elements | 0.0038m                                    |
| Transmit and receive angle          | 45°                                         |
| Reflection coefficient              | 0.9                                         |
| Carrier frequency                   | 90 GHz                                      |
Figure 2: Received power at user 1.
Figure 3: Received power at user 2.
1 for both of the models.

Fig. 4 visualizes the SINR measurement in the case of user 2 for both of the models.

Fig. 5 shows the measurement of received power in the context of user 1 increasing the transmitter-receiver gain considered in the research of Ding et al. [68] through the utilization of an mmWave horn antenna [70].

Fig. 7 illustrates the received power for user 2 increasing the transmitter-receiver gain [70] considered in the research of Ding et al. [68].
Figure 5: SINR at user 2.
Figure 6: Received power at user 1 (utilizing horn antenna at Ding et al. model).
Figure 7: Received power at user 2 (utilizing horn antenna at Ding et al. model).
Fig. 8 represents the measurement of SINR of user 1 for both the models increasing the transmitter-receiver gain through the utilization of an mmWave horn antenna [70] in the Ding et al. [68] model.

![SINR Measurement; User 1](image)

**Figure 8:** SINR at user 1 (utilizing horn antenna at Ding et al. model).

Fig. 9 shows the measurement of SINR of user 2 increasing the transmitter-receiver gain through the utilization of an mmWave horn antenna in the Ding et al. [68] model.

According to the observation of Figs. 2-5 it is evident that the modified model incorporating a dedicated path loss model
Figure 9: SINR at user 2 (utilizing horn antenna at Ding et al. model).
for IRS ensures better measurements of received power and SINR compared to the conventional path loss equation-based model presented in the work of Ding et al. [68].

Further, the work tried to enhance the performance of the model presented in the work of Ding et al. [68]. In this circumstance, the work considers the gain of a horn antenna in the conventional path loss model included in the work of Ding et al. [68]. The consideration of the enhanced gain achievable by mmWave horn antenna [70] enhances the performance of the model of Ding et al. [68] but is still unparalleled to the modified model presented by this work even with a lower level of transmitter-receiver gain (as per the observation of Figs. 6-9).

The work modified the [68] reference model incorporating a dedicated frequency-distance-dependent path loss model for IRS-assisted communication instead of a typical or conventional distance-dependant path loss model. From the point of view of this research, since the reference work is on the IRS-assisted NOMA system an IRS-specific path loss model should be preferable to figure out a more convenient measurement result. As per the observation of this work the conventional path loss model is unable to provide the realistic measurement result as an IRS-specific model.
5. Conclusion

The research targeted the investigation of the IRS-enhanced NOMA scheme for downlink. Relative literature and works are reviewed to obtain an insight into recent developments and figure out further enhancement scopes. According to the observation, it seemed that it will be more convenient to adopt an IRS-specific path loss model instead of a conventional path loss model. This work, therefore, modified the reference model by adopting an IRS-specific path loss model instead of a typical or conventional path loss model. The research derived that the incorporation of an IRS-specific model provides a more convenient measurement compared to the conventional model. Moreover, the work figures out an enhancement scope in the reference model by considering the gain of the horn antenna. The approach enhances the performance of the reference model but still, it’s unparalleled to the model modified by this work. The research will be supportive to the researchers and enthusiasts for performing extended research on the relative research issue.

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