Transmission Mode Selection in RIS-Assisted Communication Networks

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***Abstract*—Reconfigurable intelligent surface (RIS) has recently emerged as a promising technology to enhance the performance of wireless networks. We present a method for selecting transmission modes in RIS-assisted networks. Leveraging the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), a widely used Multiple-Attribute Decision-Making (MADM) algorithm, we efficiently arrange and rank the available RIS-assisted links based on diverse metrics and service requirements. This approach enables efficient user association, resulting in improved system performance and satisfaction of user needs.**

***Index Terms*—Reconfigurable Intelligent Surface (RIS), 5G and NextG networks, TOPSIS, packet delay.**

I. INTRODUCTION

Reconfigurable intelligent surface (RIS), also known in the literature as Intelligent reflecting surface (IRS) [1], [2] has recently emerged as a technology that enables the control, at least partially, of the wireless channel, thereby offering more favorable propagation characteristics. The concept of controlling the ambient environment involves a shift from regarding reflection and scattering as uncontrollable phenomena with stochastic modeling to treating them as system parameters that can be optimized. This approach has the potential to address numerous challenges in wireless communications and provide additional support for diverse applications.

RIS is a planar surface that consists of a large number of small, low-cost passive reflecting elements. These elements can be flexibly configured to control the amplitudes and phases of incident signals, establishing a controlled wireless channel.

II. MOTIVATION

Large buildings and high-rise structures frequently disrupt wireless links connecting the network infrastructure and users, resulting in degraded Quality of service (QoS) levels. Furthermore, there are specific regions with severe Line of Sight (LoS) obstructions that remain consistently beyond the network's coverage. Extending wireless coverage to these unserved areas presents significant cost challenges and substantially increases operational expenses. In this context, RIS offers a potential solution by intelligently steering wireless signals around obstacles, effectively creating a virtual LoS link between the transmitter and the receiver.

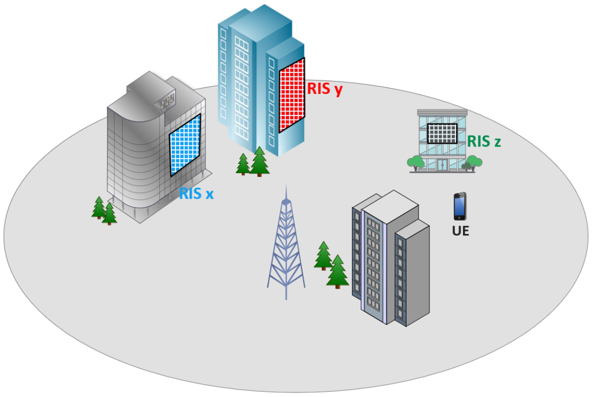

Fig. 1. Transmission mode selection using TOPSIS.

Although there is extensive research on designing and optimizing diverse RIS-aided wireless systems, most studies have primarily focused on improving wireless links through the use of a single RIS. However, this approach may prove inadequate in satisfying the required performance, particularly under challenging propagation conditions. Due to the limited coverage of a single RIS, only the users within its reflection space can be effectively served. Additionally, even when a user falls within the RIS coverage, achieving a consistently unblocked link is not guaranteed in practical situations. Furthermore, the restricted size of a single RIS may only offer limited passive beamforming gains for each user, which may not always meet the user's service requirements, such as desired throughput or minimal data delivery delays [3]. Hence, in cellular networks facing such scenarios, the utilization of multiple RISs with different configurations (single and double RIS links) becomes valuable in establishing additional LoS paths between the base station (BS) and its served users.

This paper introduces a method to determine the most suitable transmission mode for users at particular locations by utilizing certain metrics. To achieve this, we will employ the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) to rank and choose the optimal mode, ensuring alignment with user preferences and requirements.

III. PROPOSED MODEL

Consider a downlink communication system that consists of a transmitting BS, user equipment (UE) as a receiver, and multiple RISs deployed between them as illustrated in Fig.1. We assume that the direct link between the BS and UE is obstructed, then the RISs serve as an intelligent environment to enhance the signal quality while meeting the user's requirements. The user can be connected to the BS through the available RISs, which can operate in either single or double RIS mode. Within each mode, multiple options are available.

TOPSIS ranks the available transmission modes by their scores, the highest being the best. The modes that represent the alternatives of the problem are denoted by $\grave{M} = \{M_i,\ i = 1, 2, .., q\}$, the set of attributes, or criteria that characterize the mode is denoted by $\grave{A} = \{A_j,\ j = 1, 2, ..., d\}$, and each has a value X_{ij}. These attributes have a weight vector $W = \{W_1, W_2, ..., W_d\}$, that is satisfying $\sum_{l=1}^{d} W_l = 1$, as shown in Table I.

TABLE I
TOPSIS MATRIX

	$\boldsymbol{A_1}$ (W_1)	$\boldsymbol{A_2}$ (W_2)	... ...	$\boldsymbol{A_d}$ (W_d)
$\boldsymbol{M_1}$	X_{11}	X_{12}	...	X_{1d}
$\boldsymbol{M_2}$	X_{21}	X_{22}	...	X_{2d}
$\vdots$				
$\boldsymbol{M_q}$	X_{q1}	X_{q2}	...	X_{qd}

The TOPSIS algorithm is applied for the transmission mode selection as follows:

1) The value of each attribute is normalized by,

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{q} X_{ij}^2}} \tag{1}$$

2) The matrix is updated with the normalized values of each attribute.
3) Using the weight for each attribute, to consider the UE's requirements, construct the weighted normalized matrix as $v_{ij} = W_j * r_{ij}$.
4) Identify the best and the worst value for each attribute, i.e., V_j^+ and V_j^- respectively. If the attribute is desirable then the highest value is the best (e.g., throughput), and if the attribute is undesirable (e.g., delay) then the lowest value is the best.
5) Measure the distances of each attribute within each available mode from the best and worst cases, i.e.,

$$D_i^+ = \sqrt{\sum_{j=1}^{d} (v_{ij} - V_j^+)^2}, \qquad D_i^- = \sqrt{\sum_{j=1}^{d} (v_{ij} - V_j^-)^2} \tag{2}$$

6) Calculate the coefficient C for each available transmission mode, $C = \frac{D_i^-}{D_i^- + D_i^+}$.
7) Select the transmission mode with the highest C value.

In our model, we will use three attributes: outage probability, average packet delay, and packet loss to describe each available mode.

The attributes are derived by examining the cascaded channel between the BS and the UE, assisted by RIS technology in both single and double RIS scenarios. By analyzing the distribution of the overall cascaded channel and the corresponding signal-to-noise ratio (SNR) distribution, we can explore the metrics that assess RIS-assisted networks through closed-form expressions. The outage probability over the RIS-assisted link is defined as the probability that the acquired data rate by the UE is less than a certain target rate ζ, i.e. $P_o = Pr(R_\varsigma < \zeta)$, where ς can be s or d for the single and double RIS-assisted link, respectively. This probability can be calculated using the cumulative distribution function (CDF) of the cascaded channel. Similarly, the average packet delay can be determined by utilizing the SNR distribution and its CDF for each scenario. We assume a time-slotted scheme and the transmission succeeds if the received SNR is larger than a threshold value δ. Otherwise, the transmission is failed, and a retransmission is required. Therefore, the average packet delay over the RIS-assisted link can be expressed as follows

$$T_p = t_s * \omega * \frac{1}{P_s} \tag{3}$$

where t_s denotes the time slot length, ω is the required number of time slots to transmit a packet, and P_s is the transmission success probability that can be calculated by $P_s = Pr(SNR > \delta) = 1 - CDF(\delta)$. Subsequently, we can utilize our analysis of the cascaded channel and packet delay to derive additional metrics, such as packet loss for each link.

Consider a scenario, where a user is located at a specific location in the network and the direct link with the BS is blocked, as shown in Fig. 1. The user can be connected to the BS through available RISs in single or double RIS mode. For the single mode, we have three available RISs to choose from, RIS x, RIS y, and RIS z, while for the double RIS mode, we have two available cascaded links, RIS x - RIS z and RIS y - RIS z paths. Therefore, the alternatives will be the transmission modes through the single and double RIS-assisted links embedded with the RIS association within each mode. Then, based on the service requirements of the user that are determined by the weight vector, the best mode and best association will be selected to satisfy the user's requirements. For example, if the weight vector for the user is $W = \{0.3, 0.5, 0.2\}$, then the largest weight is given to the delay metric, 0.5, while 0.3 and 0.2 are given to the outage probability and packet loss, respectively.

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