Simultaneous Transmitting and Reflecting RIS: Fundamentals and Progress.

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Abstract

In this paper, we explore simultaneously transmitting and reflecting reconfigurable intelligent surfaces (STAR-RIS) and introduce the current technologies and their research direction to achieve wide coverage and quality of service (QoS). Looking at several contributions and state-of-the-art schemes we further analyze its use case and working principles that go hand in hand with the rapidly growing and changing world. Building on various literatures and studies we examined STAR-RIS composition, operating protocols, enabled technologies and their comparison with its conventional scheme RIS. From here we could analyze research directions and significant advancements for future innovative technologies.

I. Introduction

Current technologies demand enhanced communication, wider coverage and high quality of service even in harsh low-coverage areas. The performance of the new generation (NG) sixth generation (6G) wireless communications is being significantly impacted by the recent invention of meta surfaces, which may enable many use cases by altering the propagation environment.

A promising technique that helps in achieving full-space coverage on both sides of the surface is simultaneously transmitting and reflecting reconfigurable intelligent surfaces (STAR-RIS). STAR-RIS, also known as intelligent omni surfaces (IOS) [1], refers to the reconfigurable intelligent surfaces (RISs), capable of simultaneous transmission and reflection (STAR) providing 360° full coverage. This technology works by separating the incident signal into transmitted and reflected signals [2].

The RIS or intelligent reconfigurable surface (IRS) is generally a two-dimensional (2-D) structure composed of numerous low-cost reconfigurable meta surfaces providing 180° reflection of the signal to the desired user. It is feasible to modify the phase and amplitude of these reconfigurable elements practically by integrating a smart controller into the RIS. This allows for reconfiguring incident wireless signal propagation and creating a smart radio environment (SRE).

Table 1: Comparison of STAR-RIS with RIS

STAR-RIS(IOS)	RIS (IRS)
Reflection and transmission of signal	Reflection of signal
360° coverage	180° coverage
Single sided interaction	Dual-sided interaction

Signal manipulation is made possible by the proper configuration of the meta surface, which is a simply passive sub-wavelength scattering of uniformly spaced components with positive intrinsic negative (PIN) diodes.

Each PIN diode's ON/OFF state may be used to achieve these signal alterations by altering the amplitude and phase of the dispersed signals [3], after which the rearranged signals are sent to the proper receiver.

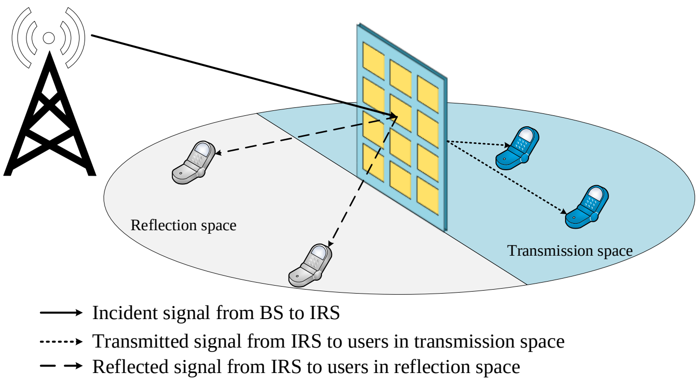

Figure 2: STAR-RIS

II. STAR-RIS protocols

STAR-RIS operating protocols for transmission and reflection consider energy splitting, mode splitting, and time switching. Allowing it to function in 3 different ways as shown in the table below.

Table 2: Comparison of STAR-RIS operating protocols

Energy splitting	Mode splitting	Time switching
Signal energy is split between each element.	Elements separated into protocols	Different protocols at orthogonal time intervals
Transmits and reflects	Transmits or reflects	Transmits or reflects
Design flexibility	On/off protocol	Time domain
Highest gain	Optimizes phase shift	Implementation complexity
$\beta_m \in [0,1]$ $\beta_m^t + \beta_m^r = 1$	$\beta_m \in \{0,1\}$ $\beta_m^t + \beta_m^r = 1$	$\lambda \in [0,1]$ $\lambda^t + \lambda^r = 1$

Each protocol with its advantages and disadvantages affects the system model of STAR-RIS.

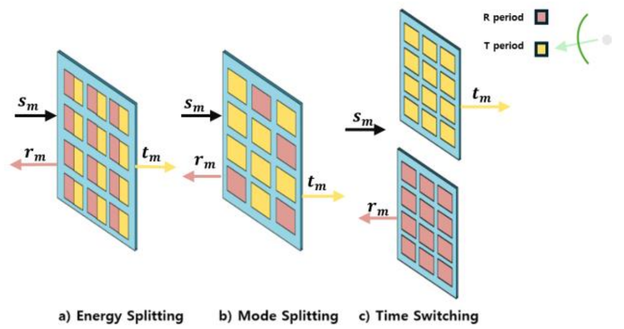

Figure 3: STAR-RIS operating protocols

To characterize the basic signal model of STAR-RIS let s_m be a signal incident. M number of STAR-RIS element and the signals transmitted be $t_m = \sqrt{\beta_m^t} e^{j\theta_m^t}$ and reflected $r_m = \sqrt{\beta_m^r} e^{j\theta_m^r}$ where the amplitude and phase shift response are given as $\beta \in [0,1]$ and $\theta_m^t = [0,2\pi)$ According to the law of conversation power allocation is affected where the amplitude adjustments are coupled to adhere. This means the sum of energy for transmission and reflection must equal to the incident signal $|t_m|^2 + |r_m|^2 = |s_m|^2$ and time allocation is given by $\lambda^t + \lambda^r = 1$ where $\lambda \in [0,1]$ [4].

III. STAR-RIS-enabled technologies

STAR-RIS is consulted and implemented with different innovations to enhance the functionality of other 6G technologies. Technologies like non-orthogonal multiplexing access (NOMA), integrated sensing and communication (ISAC) and terahertz (THz) communications are few mentioned. We elaborate on the first few approaches with STAR-RIS as follows.

1. Non-orthogonal multiple access

NOMA is a wireless communication system that enhances spectral efficiency by dividing users depending on power levels and allowing them to use the same frequency, time, and coding resources.

To enable NOMA, users at the transmission and reflection sides can be grouped. In which high-performance gain and asymmetric channel conditions between transmitted and reflected users can be achieved. Cluster beamforming design is proposed to jointly optimize user assignment and beamforming. Suitable mitigation of inter and intra-cluster interference is an ongoing study that is yet to be solved.

Recent research has further expanded to Hybrid NOMA a concept that multiple NOMA-pairs served via time division multiple access (TDMA). [5]

2. Integrated sensing and communications

ISAC is a wireless communication paradigm that combines communication and radar sensing capabilities onto a single time-frequency power-hardware resource.

STAR-RIS leverages this property of ISAC and allows radar communication coexistence where the spectrum is shared and dual functional radar communication in which the hardware platform is common. STAR-RIS is used to combat interference between radar and BS where a reasonable trade-off is seen between each and achieve the QoS [2].

We can further analyze recent made where STAR-RIS is analyzed and studied with both NOMA and ISAC systems all at once as mentioned in [6].

IV. Future directions

Looking at the vast opportunity of studies and use cases that can be made with STAR-RIS one can realize this field has yet to be explored. Studies from its channel models and resource allocation have yet to be studied deeply. Further studies can be made on caching at STAR-RIS with ISAC to improve network efficiency and diversity; reproducible channel models also channel models for different scales of networks; fading distribution for system design and its application scenarios have yet to be investigated extensively [7].

V. Conclusion

In this survey, we investigated STAR-RIS simultaneous and reflective and their operating modes. We further mention some important technologies STAR-RIS is integrated into and studied with in addition to the wide area of experiments that STAR-RIS has yet to embark on. As a technology for the future STAR-RIS is envisioned to provide a solution to radio-frequency impairment and signal propagation alongside its counterpart RIS.

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