Performance Analysis of Element Splitting in Self Sustained IRS assisted Networks

Selome Tesfaye Deribe, Danish Mehmood Mughal, Hyosang Ju, Min Young Chung, Sang-Hyo Kim*

Sungkyunkwan University

selome@g.skku.edu, *iamshkim@skku.edu

Abstract

The demand for future technologies that guarantee wide coverage, self-efficiency, and high signal quality is growing at a rapid rate. 6G or technologies of the future lacking these prospects are not considered for deployment. Due to this demand, intelligent reflecting surfaces (IRS) technologies studies must catch up in the aspect of harvesting its own energy. IRS must use the energy harvested to power itself and reflect signals to the users or the area needed which we call the Harvest and Reflect method. In this paper. we studied how harvesting and reflecting are achieved through element splitting of a self-sustained IRS-assisted networks in a downlink scenario in which the of IRS elements are fixed for harvesting then we analyze the result of the simulation in terms of its outage performance and throughput.

Ⅰ. Introduction

Passive metasurfaces, known as intelligent reflecting surfaces (IRS), function similarly to relay systems in that they simply reflect signals to user equipment or targeted regions without amplifying the signals. It is one of the upcoming technologies that is highly studied. Research on IRS has reached the point where studies have evolved to using it in programmable wireless environments (PWEs) [1]. By allocating elements from the IRS for energy harvesting and reflecting signals to users in various groups, we can maximize the optimal use of the IRS components.

Motivated by multi-channel IRS-assisted IoT network deployed in a cellular environment. We aim to propose a network architecture that doesn't require more spectrum resources to function within the current cellular network [2]. The IRS will sustain itself to reflect the signals immediately after it has accumulated and conserved enough energy to function.

In this case, we examine a downlink two-UE self-sustained IRS-assisted multi-user networks in which we assume the reflection connections travel across a Rician fading channel.

Ⅱ. System Model

This Fig. 1. depicts the basic architecture of our self-sustaining IRS-assisted network, whereby NIRS-antenna element IRS is split into three parts: one for energy harvesting antennas N_{EH}, where it is considered to absorb the BS signals and harvest energy. And the rest of the IRS elements antennas is divided to consist of N_{U1} and N_{U2} number of antennas to serve user 1 (U_1) and user 2 (U_2), respectively.

We are considering all the IRS elements for N_{EH} are fixed while the reflecting splits of IRS antenna elements N_{U1} and N_{U2} are allocated through the split factor (α). The user equipment farther away from the IRS is allocated more elements while the user equipment closer to the IRS is allocated fewer elements [3].

Considering the Rician fading channel, from the base station to IRS and from IRS to the UEs. The signal received at the IRS EH Antenna is given as

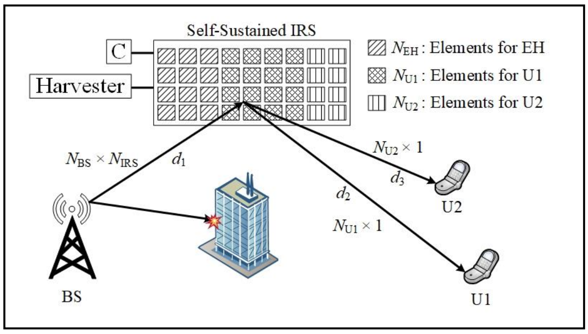

Fig. 1. Self-sustained IRS-assisted networks with two users in element splitting

$$y_{BS\_IRS_j} = \frac{\boldsymbol{g}_j \phi \boldsymbol{g}_j^H}{\sqrt{d_1^\beta}} + n,$$

where y is the received signal from base station to the jth antenna IRS, $\boldsymbol{g}_j$ is the Rician channel vector, ϕ is the phase shift, d_1 is the distance from the base station to IRS where β is the path loss exponent and n is the noise experienced at IRS.

We hereby consider that full channel state information (CSI) is available at the IRS, and it optimally adjusts the phases of antenna elements thus the phases induced by the fading channels are not considered [4]. Moreover, $\boldsymbol{g}_j$ the Rician fading channel vector between the BS and IRS, is given as

$$\boldsymbol{g}_j = \sqrt{\frac{\kappa}{\kappa+1}} \tilde{\boldsymbol{g}}_j^{LOS} + \sqrt{\frac{1}{\kappa+1}} \tilde{\boldsymbol{g}}_j^{NLOS},$$

where κ is the Rician factor and, $\tilde{\boldsymbol{g}}_j^{LOS}$ is line of sight (LOS) component, whereas $\tilde{\boldsymbol{g}}_j^{NLOS}$ is the non-line of sight (NLOS) component modeled via Rayleigh Fading channel.

The harvested energy at the IRS can be given by

$$EH = \sum_{i=1}^{N_{BS}} \sum_{j=1}^{N_{EH,}} \frac{P_{BS_i} |g|^2}{d^\beta},$$

where N_{BS} is the number of antennas at BS and P_{BS_i} is the transmit power of i^{th} BS antenna. Moreover, the transmit power of BS antennas is constrained by $\sum_{i=1}^{M} P_{BS_i} \leq P_{BS}$,where P_{BS} is the power of the BS.

Similarly, SNR received at U_1can be given as

$$\gamma_1 = \frac{P_{BS} \, \|\mathbf{G}_1\|^2 \boldsymbol{\phi} |\boldsymbol{h}_1|^2}{\sigma^2 d_1^\beta d_2^\beta}$$

Furthermore, the SNR for U2 is given below.

$$\gamma_2 = \frac{P_{BS} \, \|\mathbf{G}_1\|^2 \boldsymbol{\phi} |\boldsymbol{h}_2|^2}{\sigma^2 d_1^\beta d_3^\beta}$$

where σ^2 is the variance. Assuming the CSI is available at the IRS the impact of $\boldsymbol{\phi}$ is not considered.

Throughput is computed in terms of Shannon capacity as

$$T = (1 - p_{out}) \cdot \log_2(1 + \gamma)$$

where p_{out} is outage probability at each user, defined as the probability that the signal strength at the receiving user is less than the pre-defined threshold ($\gamma < \gamma_{th}$).

Ⅲ. Simulation Results

Following Fig. 1, we consider a downlink network whereby BS, IRS, U_1, and U_2 are located at (0,0), (3,3), (6,2), and (6,0), respectively. We consider that BS has 10 antennas, and the total transmit power of BS is constrained by the P_{BS}=10W and 20W. Moreover, we regard that IRS has 200 antenna elements, whereby 40 antenna elements are dedicated for EH, while the rest are divided for information transmission among U_1 and. U_2. We consider $\gamma_{TH} = 30$dB while κ is 10dB. We consider that 40 antenna elements for EH are enough to harvest enough energy to activate IRS elements and thus not plotted.

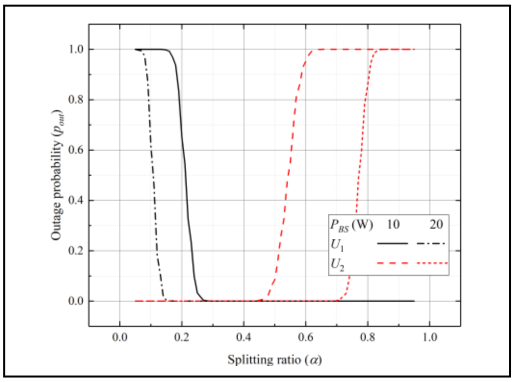

Fig. 2. Outage probability (p_{out}) of U1 and U2 vs different values of a for Pbs =10W and 20W

From the figure above in Fig. 2, we can see that the outage probability of U_1 starts at a high value in contrast U_2 which has an outage probability of close to zero with low splitting factor because most of the IRS elements is being allocated to U_2. As the splitting factor increases and more IRS elements are being allocated to U_1 we can see that the outage probability of U_2 increases significantly. This is because U_2 is far away from the IRS. The further U_2 is from the IRS the more IRS elements should be allocated to U_2.

We can even see that when a higher power is used for transmission the faster U_2 outage probability increases as compared to the less power transmission as it is far from IRS and in contrast, we can see U_1 outage probability decreases faster as it is

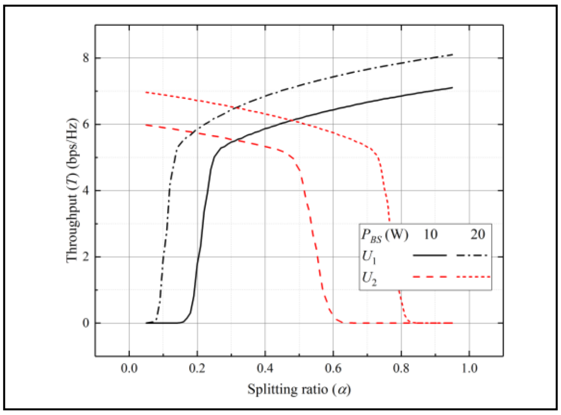

Fig. 3. Throughput (T) of U1 and U2 vs different values of a for Pbs =10W and 20W

closer to the IRS and getting more antenna elements. We can also further see in the throughput, Fig. 3, the effect the number of elements allotted has on the user equipment and the proximity it has with the IRS. The closer the user equipment has a far higher throughput compared to the user that is farther away. Furthermore, when throughput is zero, we can tell that it is when the outage probability is very high. Meaning with higher throughput the less outage probability we have.

Ⅳ. Conclusions

With the growing demand for self-efficient and self-sustained technology studies of the IRS have taken a turn where it harvests its energy to reflect signals. Considering a self-sustained IRS-assisted NOMA network our simulation results show that when a user is further away from the IRS more IRS antenna elements must be allocated for less outage. The closer the user is to the IRS the fewer elements it needs as compared to the user farther away.

ACKNOWLEDGEMENT

This work was partly supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No.2024-00397216, Development of the Upper-mid Band Extreme massive MIMO(E-MIMO) and by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2022R1A4A1033830).

References

[1] D.Tyrovolas et al., "Zero-Energy Reconfigurable Intelligent Surfaces (zeRIS)," in IEEE Transactions on Wireless Communications, pp. 1-1, Dec. 2023, doi:10.1109/TWC.2023.3336956.

[2] D. M. Mughal, D. Munir and M. Y. Chung, "Outage Analysis of IRS-Assisted RF Powered Networks for Energy-Constrained IoT Devices," in IEEE Transactions on Wireless Communications, vol. 22, no. 11, pp. 7805-7818, Nov. 2023, doi: 10.1109/TWC.2023.3255860.

[3] B. Tahir, S. Schwarz, and M. Rupp, "Outage Analysis of Uplink IRS-Assisted NOMA under Elements Splitting," 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), pp. 1-5, Helsinki, Finland, 2021, doi: 10.1109/VTC2021-Spring51267.2021.9449027.

[4] V. S. Asadchy, M. Albooyeh, S. N. Tcvetkova, A. Díaz- Rubio, Y. Ra'di, and S. A. Tretyakov, "Perfect control of reflection and refraction using spatially dispersive metasurfaces," Phys. Rev. B, Condens. Matter, vol. 94, no. 7, 2016, Art. no. 075142.