Energy Efficiency of MU-NOMA IRS and Relay Symbiotic Radio Networks

Samuel Kwamena Menanor, Derek Kwaku Pobi Asiedu*, Kyoung-Jae Lee

Hanbat National University, South Korea, IMT-Atlantique, France*

smenanor@edu.hanbat.ac.kr, *kwakupobi@ieee.org, kyoungjae@hanbat.ac.kr

Abstract

This paper compares the performances of two energy efficient multi-user non-orthogonal multiple access (MU-NOMA) systems, a passive intelligent reflective surface (PI-SRN) and an active relay-assisted (AR-SRN) symbiotic radio networks where both assistive devices harvest energy using the multi-stage rectifier circuit. Monte Carlo simulations show the superiority of IRS-aided system to the relay-aided case.

Ⅰ. Introduction

With the direct influence of population size on device density, an exponential growth in population correspondingly causes an increase in the number of wireless devices which poses a threat to energy and spectrum management [1]. Innovative technologies are therefore required to ensure efficient spectrum usage and management. Exploiting the benefits of cognitive radio (CR) networks and ambient backscatter communication (AmBC), a new concept, symbiotic radio network (SRN) has been introduced [2] to improve spectrum and energy efficiency in revolutionizing future mobility in internet of things (IoT) networks. In SRN, aside two networks sharing the same radio spectrum, the secondary network (SN) relies on the primary network's (PN) radio frequency (RF) signal to transmit its own signal while the PN benefits from spatial diversity via the SN's transmission.

Ⅱ. Method

As shown in fig. 1, we consider two SR system models where the PN consisting of N_p multi-antenna base station (BS) employs non-orthogonal multiple access (NOMA) technique to transmit information with the aid of assistive devices to single-antenna primary receivers (PRs) and a secondary receiver (SR).

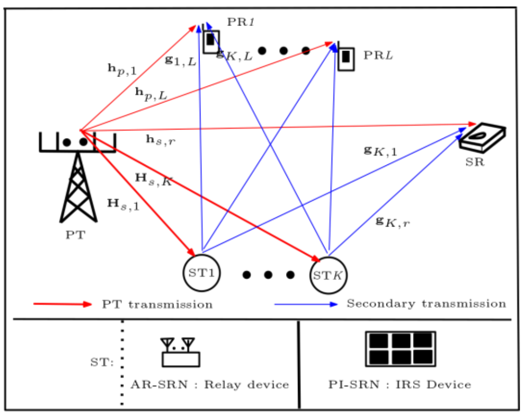

Figure 1. SRN system model

The K assistive devices are either multiple EH semi-passive intelligent reflective surfaces (IRS) devices with N_k reflective elements (using BC)-PI-SRN or multiple multi-antenna energy harvesting (EH) relay devices (using simultaneous wireless information and power transfer (SWIPT) decode and forward (DF) protocol)-AR-SRN. The EH model employed is the non-linear multi-stage rectifier model [3].

In the PI-SRN, the signal transmitted at the BS is

$$\mathbf{x}_p = \sum_{l=1}^{L} \mathbf{w}_{p,l} x_{p,l}$$

where $\mathbf{w}_{p,l}$ and $x_{p,l}$ represent the beamforming vector from BS to PR l and PN information data respectively. For PI-SRN, after BS and IRS devices' BC simultaneous transmissions, the received signals at PR l and SR are expressed as

$$y_{z_1,z_2} = \underbrace{\mathbf{h}^H_{z_1,z_2}\mathbf{x}_p}_{\text{Direct-link signal}} + \underbrace{\sum_{k=1}^{K} \mathbf{g}_{k,z_3}\mathbf{\Theta}_k^{1/2}\mathbf{H}_{s,k}\mathbf{x}_p x_{k,r}}_{\text{Multi-IRS backscattered signals}} + n_{z_3}$$

where $\mathbf{\Theta}_k$ represents the reflection coefficient matrix of IRS device k, $\{z_1, z_2, z_3\} \in \{(p,l),(s,r),(l,r)\}$ and $x_{k,r}$ is the signal transmitted by IRS device k. The additive white Gaussian noise (AWGN) at PR l and SR are defined as $n_{z_2} \sim \mathcal{CN}(0, \sigma^2_{z_3})$. Assuming perfect channel state information (CSI) and using successive interference cancellation (SIC), the signal-to-interference-noise ratio (SINR) for PR l and IRS device k after data decoding are expressed as

$$\gamma_l = \frac{A_l}{B_l + C_l + \sigma_l^2} \text{ and } \gamma_{k,r} = \frac{A_{k,r}}{B_{k,r} + C_{k,r} + \sigma_r^2}$$

where $A_l = |\mathbf{h}^H_{p,l}\mathbf{w}_{p,l}|^2 + \sum_{k=1}^{K} |\mathbf{g}^H_{k,l}\mathbf{\Theta}_k^{1/2}\mathbf{H}_{s,k}\mathbf{w}_{p,l}|^2$,

$B_l = \sum_{j \neq l}^{L} (|\mathbf{h}^H_{p,l}\mathbf{w}_{p,j}|^2 + \sum_{k=1}^{K} |\mathbf{g}^H_{k,l}\mathbf{\Theta}_k^{1/2}\mathbf{H}_{s,k}\mathbf{w}_{p,j}|^2)$,

$B_{k,r} = \sum_{l=1}^{L} (|\mathbf{h}^H_{s,r}\mathbf{w}_{p,l}|^2 + \sum_{j=1}^{K} |\mathbf{g}^H_{j,r}\mathbf{\Theta}_j^{1/2}\mathbf{H}_{s,j}\mathbf{w}_{p,l}|^2)$,

$C_l = \sum_{j=1}^{L}\sum_{k=1}^{K} |\mathbf{g}^H_{k,l}\mathbf{\Theta}_k^{1/2}\mathbf{H}_{s,k}\mathbf{w}_{p,j}|^2$, $A_{k,r} = \sum_{l=1}^{L} |\mathbf{g}^H_{k,r}\mathbf{\Theta}_k^{1/2}\mathbf{H}_{s,k}\mathbf{w}_{p,l}|^2$

$C_{k,r} = \sum_{j \neq k}^{K}\sum_{l=1}^{L} |\mathbf{g}^H_{j,r}\mathbf{\Theta}_j^{1/2}\mathbf{H}_{s,j}\mathbf{w}_{p,l}|^2$. Here, A_l and $A_{k,r}$ are the desired decoded signals at PR l and SR respectively, while B_l, $B_{k,r}$, $C_{k,r}$ and C_l are interference signals encountered at PR l and the SR during data decoding. In AR-SRN, during the first timeslot, τ, the transmitted signal from the BS is deduced as

$$\mathbf{x}_p = \sum_{l=1}^{L}\sum_{k=1}^{K} \mathbf{w}_{s,k} x_{p,l}$$

where $\mathbf{w}_{s,k}$ is the beamformer from the BS to relay k. The relays use the power splitting ratio (PSR) SWIPT scheme to harvest energy and decode the PT transmitted signal, $\mathbf{x}_p$. In the second timeslot $(1-\tau)$, relay k forwards its own signal, $\mathbf{x}_{k,r}$ with the decoded BS signal, defined as $\mathbf{x}_{s,k} = \mathbf{w}_{k,r} x_{k,r} + \sum_{l=1}^{L} \mathbf{w}_{k,l} x_{p,l}$ to PRs and the SR using the beamformers $\mathbf{w}_{k,l} \in \mathbb{C}^{N_k \times 1}$ and $\mathbf{w}_{k,r} \in \mathbb{C}^{N_k \times 1}$. Simultaneously, the PT transmits data $\mathbf{x}_p$ to the PRs. Hence, the received signal at PR l and the SR from relay k are respectively given as

$$y_{k,z_1} = \sum_{k=1}^{K} \mathbf{g}_{k,z_1}^{H} \left(\mathbf{w}_{k,r} x_{k,r} + \sum_{l=1}^{L} \mathbf{w}_{k,l} x_{p,l} \right) + \sum_{l=1}^{L} \mathbf{h}_{z_2} \mathbf{x}_p + n_{z_1}$$

where $z_1 \in \{l, r\}$ and $z_2 \in \{(p,l),(s,r)\}$. Employing SIC, the SINR for PR l and relay k after data decoding are expressed as

$$\gamma_l = \frac{N_l}{A_l + B_l + \sigma_l^2} \text{ and } \gamma_{k,r} = \frac{N_{k,r}}{A_{k,r} + B_{k,r} + \sigma_r^2}$$

where $N_{k,r} = |\mathbf{g}_{k,r}^{H} \mathbf{w}_{k,r}|^2$, $N_l = |\mathbf{h}_{p,l}^{H} \mathbf{w}_{p,l}|^2 + \sum_{k=1}^{K} |\mathbf{g}_{k,l}^{H} \mathbf{w}_{k,l}|^2$,

$$B_l = \sum_{k=1}^{K}\sum_{j=1}^{L} |\mathbf{g}_{k,l}^{H} \mathbf{w}_{k,j}|^2, \quad A_{k,r} = \sum_{j \neq k}^{K} |\mathbf{g}_{k,r}^{H} \mathbf{w}_{j,r}|^2,$$

$$A_l = \sum_{k=1}^{K}\sum_{j \neq l}^{L} |\mathbf{g}_{k,l}^{H} \mathbf{w}_{k,j}|^2 + \sum_{j \neq l}^{L} |\mathbf{h}_{p,l}^{H} \mathbf{w}_{p,j}|^2,$$

$$B_{k,r} = \sum_{i=1}^{K}\sum_{j=1}^{L} |\mathbf{g}_{i,r}^{H} \mathbf{w}_{i,j}|^2 + \sum_{j=1}^{L} |\mathbf{h}_{s,r}^{H} \mathbf{w}_{p,j}|^2.$$

Also, N_l and $N_{k,r}$ are the desired decoded signals at PR l and SR respectively, while A_l $A_{k,r}$ B_l, and $B_{k,r}$ are interference signals encountered at PR l and the SR during data decoding.

Considering that the assistive devices are powered by renewable energy, we focus on the energy efficiency of the source node. The energy efficiency (EE) of both systems is given as the ratio of the total throughput to the total power used. Fig. 2 compares the Monte Carlo simulation using the average EE against N_p. In both PI-SRN and AR-SRN scenarios, EE increases with N_p. The PI-SRN outperformed the AR-SRN which is attributed to the higher spatial diversity benefits using IRS devices compared to relays.

In fig. 3, we considered the influence of the number of PRs on the average EE. With a constant power of 30dBm at the BS, increasing PRs results in higher sum-rate implying a better use of the available power at the BS. When the BS power is efficiently used to serve a larger number of users, a better EE is observed.

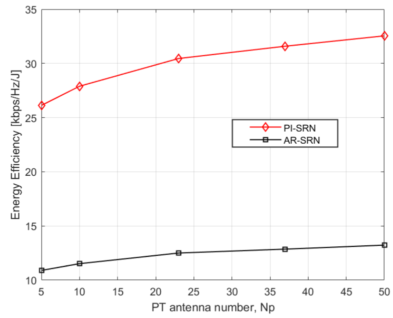

Figure 2. Average EE vs. Np

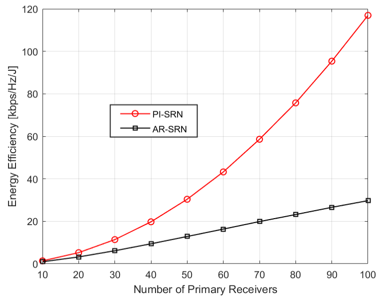

Figure 3. Influence of PR number

Ⅲ. Conclusion

The EE performance of an IRS-aided system was compared to its relay-assisted counterpart. Results show that the PI-SRN is superior to that of the AR-SRN. Since better EE performances were observed for increasing BS antenna number, massive MIMO can be deployed in SRN.

IV. Acknowledgement

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