Interference cancellation in RIS-assisted FD relay transmission

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***Abstract*—Reconfigurable intelligent surface (RIS) is one of the promising technology for the next-generation wireless networks. The RIS reflects the received signal with phase shift introduced by reflecting elements without analog to digital conversion. In relay transmission scenario, RIS could be exploited to enhance the network coverage and improve transmission performance. In this paper, we consider RIS-assisted full-duplex (FD) relay transmission scenario. In the considered scenario, RIS and FD relay node performs relay transmission. Although the beamformed signal could be generated by phase shift of RIS, the interference from RIS to FD relay node may degrade the throughput performance. The proposed method cancels both of interference from RIS and self-interference at the FD relay node by estimating interference channels in the preparation phase before data transmission.**

I. Introduction

In wireless networks, relay transmission is widely used to enhance the network coverage. In areas with densely deployed obstacles, line-of-sight is hard to be achieved, and thus, data transmission through direct link from the source node to the destination node is likely to be failed with low signal-to-interference-plus-noise (SINR) ratio. Instead of one-hop transmission from the source node to the destination node, relay node could be deployed for successful data transmissions. To decrease the forwarding delay and increase spectral efficiency, a relay node capable of intra-band full-duplex could be deployed. FD relay transmission has been studied in various wireless system. Sohaib and Uppal studied FD compress-and-forward (CF) relay transmissions under residual self-interference [1]. The authors derived the achievable rate in which largely depends on the transmission power of the FD node, and compared the performance of FD relay transmission with half-duplex relay transmission. Choi *et al.* studied pipelined relay transmission using FD relay nodes in multi-hop scenario [2]. The authors proposed the pipelined MAC protocol that cancels self-interference and intra-flow interference originated from more than two-hop away nodes. Through various simulations and experiments, the authors show that cancelling the intra-flow interference is important in multi-hop transmissions. For relay transmissions, utilizing nodes capable of FD has been extensively studied.

Besides the nodes capable of FD for relay transmissions, reconfigurable intelligent surface (RIS) has attracted a lot of attention in wireless networks. RIS is a radio environment that controls propagation of radio signals without highly extensive signal processing including analog-to-digital conversion or vice versa. The reflecting elements of RIS performs phase shift of received signals, and the signals could be beamformed to a specific direction under the appropriate phase shift values. Because of low signal processing complexity of RIS, RIS could be utilized in various wireless networks. Phan *et al.* investigated the cooperative communication with multiple RISs in the network over Nakagam-m fading channels [3]. As the number of deployed RIS increases, the number of relay paths through RIS increases, and the authors derived the symbol error probability with regard to the number of RISs over Nakagami-m fading channels. Nguyen *et al.* studied bidirectional full-duplex system with multiple RISs [4]. In the considered scenario, the authors assume that two nodes capable of FD performs data transmissions with each other with a help of multiple RISs for relaying. Chen *et al.* studied the RIS assisted FD relay system [5]. The proposed method tries to maximize the transmission rates by jointly adjusting phase shift of RIS, transmission power of base station, and transmission power of relay node.

In this paper, we focus on the interference cancellation in RIS-assisted FD relay transmission. In the preparation phase for relaying, interference channels regarding self-interference and interference from RIS is estimated. With the estimated channel information, interference could be canceled in the data transmission phase.

II. System Model

We consider a wireless relay network scenario where a source node transmits data to a destination node through relay nodes. In the considered relay transmission, we assume that relay node capable of FD and RIS are deployed to support relay transmissions as show in in Fig. 1. The relay node capable of FD simultaneously receives signals from the source node and transmits signals to the destination node. Because the same channel could be utilized for both of data reception and transmission, time resources are reduced compared to the half-duplex relay system. The RIS reflects the received signal to the specific direction by shifting the phase of signals. With the help of FD relay node and RIS deployed in the network, the destination node could receive data from the source node even

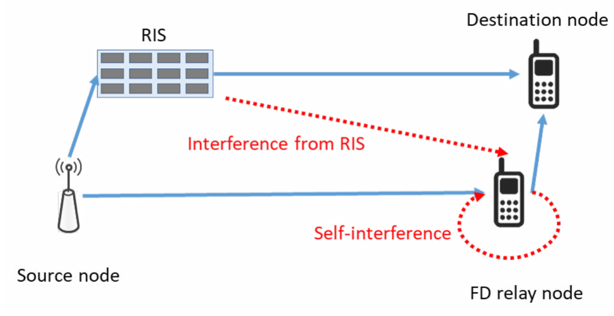

Fig. 1. RIS-assisted FD relay transmission.

when the direct wireless channel between the source node and the destination node is vulnerable. We denote the source node, destination node, FD relay node, and RIS as n_s, n_d, n_f, and n_r, respectively.

Let the RIS n_r consist of L reflecting elements, i.e, $\mathcal{K} = k_1, k_2, \cdots, k_L$. The reflecting element $k_l \in \mathcal{K}$ is represented as $k_l = |k_l|e^{j\varphi_l}$ where $|k_l| \in [0, 1)$ is an amplitude and φ_l is a phase shift. Note that the amplitude of reflecting element k_l is less than 1 because passive RIS without amplifiers are considered in the scenario. Then, the feature of RIS can be expressed via diagonal matrix as follows [6], [7]:

$$\Theta = \text{diag}(|k_1|e^{j\varphi_1}, |k_2|e^{j\varphi_2}, \cdots, |k_L|e^{j\varphi_L}). \quad (1)$$

Depends on the phase shift status denoted as Θ, the strength of reflected signal is decided. When the phase shift of RIS is adjusted to strengthen the signal to a specific direction, i.e., beamforming, the destination node is likely to successfully receive data.

III. RIS-Assisted FD Relay Transmission

Deploying the RIS with appropriately adjusted phases of reflecting elements would improve throughput performance in the relay system. However, the reflected signal from the RIS could affect the FD relay node as an interference in the considered relay scenario. As the FD relay node located closer to the destination node, the FD relay node would affected by the signal from RIS. In this section, we investigated the impact of RIS in the considered relay scenario, and propose an interference cancellation at the FD relay node. Fig. 1 shows a considered RIS-assisted FD relay transmission scenario. We assume that signals strength from two-hop away node is negligible owing to the channel vulnerability. For example, direct data transmission from the source node n_s to the destination node n_d is hard to be achieved. Instead of data transmission with direct link from n_s to n_d, relay transmission could be performed using RIS n_r and FD relay node n_f.

One relay path consists of n_s, n_r, and n_d. Let $K^{\Theta}_{n_r,n_d}$ be the RIS gain toward the destination node n_d. The signal from the source node n_s is reflected at the RIS depending on the Θ, and multiple reflecting elements could be adjusted to increase RIS gain $K^{\Theta}_{n_r,n_d}$ so that SINR at the destination node increases. The received signal at the RIS before phase shift at time t is expressed as follows:

$$Y_{n_s,n_r}(t) = G_{n_s,n_r} X_{n_s}(t) + Z_{n_r} \quad (2)$$

where G_{n_s,n_r} is channel gain from n_s to n_r, $X_{n_s}(t)$ is the transmitted signal at time t, and Z_{n_r} is the white Gaussian noise at n_r. At the next time slot, the destination node n_d receives the reflected signal $Y_{n_s,n_r}(t)$. In terms of time slot t, the received signal at n_d is expressed as follows:

$$\begin{aligned} Y_{n_s,n_r,n_d}(t) &= G_{n_r,n_d} K^{\Theta}_{n_r,n_d} X_{n_r}(t) + Z_{n_d} \\ &= G_{n_r,n_d} K^{\Theta}_{n_r,n_d} Y_{n_s,n_r}(t-1) + Z_{n_d} \\ &= G_{n_r,n_d} K^{\Theta}_{n_r,n_d} G_{n_s,n_r} X_{n_s}(t-1) + Z_{n_d}. \end{aligned} \quad (3)$$

The appropriately adjusted phase shift increases the transmission success probability.

The other path consists of n_s, n_f, and n_d. Unlike the RIS that simply reflects the received signals, the FD relay node performs self-interference cancellation to simultaneously transmit and receive signals using same channel. The received signal at the FD relay node n_f without interference cancellation is expressed as follows:

$$\begin{aligned} Y_{n_s,n_f}(t) =& G_{n_s,n_f} X_{n_s}(t) + G_{n_f,n_f} X_{n_s}(t-1) \\ &+ G_{n_r,n_f} K^{\Theta}_{n_r,n_f} X_{n_s}(t-1) + Z_{n_f}. \end{aligned} \quad (4)$$

Note that G_{n_f,n_f} is a self-interference channel. The signal transmitted from n_f at the previous time slot becomes the self-interference at the current time slot. Likewise, the reflected signal from RIS at the previous time slot also affects the current signal reception at the FD relay node. Both the self-interference signal and the interference from RIS may significantly degrade the SINR performance at the FD relay node. To cancel the interference terms, i.e., $G_{n_f,n_f} X_{n_s}(t-1)$ and $G_{n_r,n_f} K^{\Theta}_{n_r,n_f} X_{n_s}(t-1)$, the FD node may generate the cancellation signal to improve SINR. The channel gain G_{n_f,n_f} and $G_{n_r,n_f} K^{\Theta}_{n_r,n_f}$ could be measured during preparation phases for relay system. Let $\hat{G}_{n_f,n_f}$ and $\hat{G}_{n_r,n_f} \hat{K}^{\Theta}_{n_r,n_f}$ be the measured channel gain from n_f to n_f and from n_r to n_f, respectively. Then, the received signal added with cancellation signal is expressed as follows:

$$Y_{n_s,n_f}(t) = G_{n_s,n_f} X_{n_s}(t) + R_{SI}(t) + R_{IR}(t) + Z_{n_f} \quad (5)$$

where $R_{SI}(t)$ and $R_{IR}(t)$ are residual self-interference and residual interference from RIS, respectively. Note that $R_{SI}(t) = G_{n_f,n_f} X_{n_s}(t-1) - \hat{G}_{n_f,n_f} X_{n_s}(t-1)$ and $R_{IR}(t) = G_{n_r,n_f} K^{\Theta}_{n_r,n_f} X_{n_s}(t-1) + \hat{G}_{n_r,n_f} \hat{K}^{\Theta}_{n_r,n_f} X_{n_s}(t-1)$. The FD relay node transmits $Y_{n_s,n_f}(t)$ to the destination node n_f at the next time slot. Hence, in terms of time slot t, the received signal at the time slot t through the FD relay is expressed as follows:

$$\begin{aligned} Y_{n_s,n_f,n_d}(t) &= G_{n_f,n_d} X_{n_f}(t) + Z_{n_d} \\ &= G_{n_f,n_d} Y_{n_s,n_f}(t-1) + Z_{n_d} \\ &= G_{n_f,n_d} \big(G_{n_s,n_f} X_{n_s}(t-1) \\ &\quad + R_{SI}(t-1) + R_{IR}(t-1) \big) + Z_{n_d}. \end{aligned} \quad (6)$$

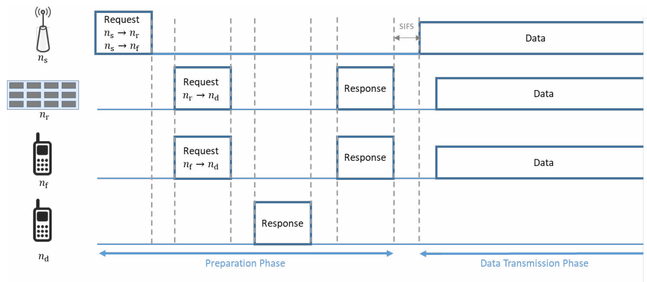

Fig. 2. Interference cancellation for relay transmission

Note that the residual interference $R_{SI}(t-1)$ and $R_{IR}(t-1)$ affects the received signal $Y_{n_s,n_f,n_d}(t)$.

The destination node receives data from the two paths, and the SINR of the received signal based on (3) and (6) is calculated as follows:

$$\gamma_{n_d}(t) = \frac{|(G_{n_r,n_d} K^{\Theta}_{n_r,n_d} G_{n_s,n_r} + G_{n_f,n_d} G_{n_s,n_f}) X_{n_s}(t-1)|^2}{|G_{n_f,n_d}(R_{SI}(t-1) + R_{IR}(t-1))|^2}. \tag{7}$$

When the amount of interference from RIS n_r to the FD relay node n_f is significant owing to the geographical or channel related reasons, the SINR could be degraded.

Figure 2 shows the preparation phase and the data transmission phase for relay transmissions. In the preparation phase, the source node transmits requests messages to the destination node through RIS and FD relay node. Note that RIS simply reflects the signals while FD relay node performs analog and digital signal processing. When the RIS reflects the signals of request messages and FD relay transmits request message to the destination node, FD node can estimate interference channel. With the estimated channel information, FD relay node cancel the interference during data transmission phase.

IV. Performance Evaluation

We evaluate the performance of the RIS-assisted FD relay transmission through simulations. The residual interferences at the previous time slot $t-1$, i.e., $R_{SI}(t-1)$ and $R_{IR}(t-1)$, degrade the SINR at time t as shown in (7). We constructed the IEEE 802.11n-based relay network using the function of WLAN system toolbox. The distance between two nodes in the relay path is assumed to be 50 meters. Data transmission is performed with 20MHz bandwidth and 64QM modulation. Fig. shows the packet error rate with respect to the RIS interference suppression level which denotes the difference between the actual interference $G_{n_r,n_f} K^{\Theta}_{n_r,n_f} X_{n_s}(t-1)$ and the estimated interference $\hat{G}_{n_r,n_f} \hat{K}^{\Theta}_{n_r,n_f} X_{n_s}(t-1)$. As shown in the figure, regardless of the self-interference suppression level compared to the ideal case, interference cancellation from RIS is still important in the environment where FD relay node receives a large amount of interference from RIS.

V. Conclusion

In this study, we investigated the impact of interference cancellation in RIS-assisted FD relay transmission. The phase

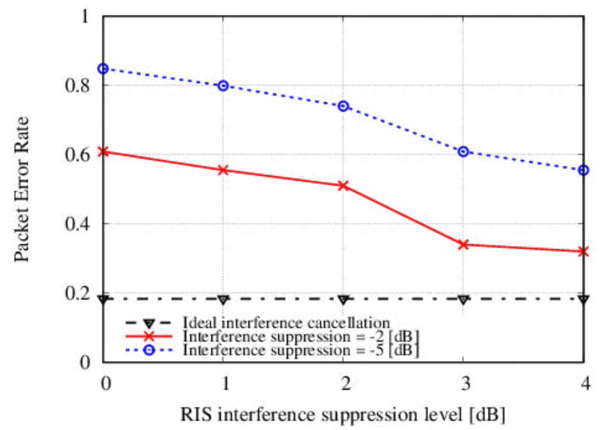

Fig. 3. Packet error rate with regard to the interference suppression.

shift of RIS is performed to increase SINR at the desired direction. However, FD relay node may experience significant interference from the RIS, and thus, data reception from the source node could be failed. Eventually, total throughput performance at the destination node is degraded. To enhance the throughput performance in the relay system, both the interference from RIS and self-interference are measured and cancelled. As a future work, multi-hop pipelined relay transmissions is to be studied with RISs and FD relay nodes.

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