A Real-Time Implementation of Interference Neutralization for Multi-Source Multi-Hop Wireless Networks

Wonjae Shin¹, Jong Bu Lim¹, Wonjong Noh¹, KyungHun Jang¹
Sangseok Yun¹⁷, Jinho Baek¹⁷, and Jeongseok Ha¹⁷

¹Signal and Systems Lab., Samsung Advanced Institute of Technology (SAIT), Samsung Electronics Co., Ltd., South Korea
¹⁷Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), South Korea

Abstract—Interference neutralization (IN) is a promising multi-hop cooperative transmission technique for future wireless networks, which cancels co-channel interference caused by multiple sources with the help of multiple relay nodes. This paper presents the first real-time implementation of IN using software defined-radio testbed based on MATLAB/Simulink and Universal Software Radio Peripheral (USRP) platform. The testbed is used to demonstrate the feasibility of IN and to compare its network's sum-rates with conventional multi-hop transmission strategies. Measured results show that we are able to successfully achieve over-the-air IN in real-world settings. We believe that IN technology can be well applied to consumer mobile communication devices, such as smart phones, tablets, etc., in infra-structure assisted ad-hoc or future cellular networks.

I. INTRODUCTION

Using wireless relays for the next generation networks has received significant interest from both academic and industrial communities for several reasons: coverage extension, and capacity enhancement etc [1]. Recently, it has been shown that the relay nodes can also play a role of mitigating inter-user interference in multi-source multi-hop networks as well as boosting the signal power through a cooperative diversity in single-source multi-hop networks. Specifically, a novel idea of interference neutralization (IN) based on amplify-and-forward (AF) relaying mode was introduced by Rankov and Wittneben in [2]. The authors presented a technique of canceling multi-hop interference signals by a careful selection of forwarding strategies when the signal travels through relay nodes before reaching the destination. This is especially remarkable because interference-free transmission is possible with the help of multiple relays in multi-source multi-hop wireless networks, corresponding to infra-structure assisted ad-hoc or future cellular networks [3].

In this paper, we present the first implementation of interference neutralization demonstrating its feasibility in multi-source multi-hop networks. Other implementations in the literature are either done multi-source single-hop wireless networks or single-source multi-hop wireless networks [4]. On the other hand, we have built a prototype of IN in MATLAB/Simulink platform and evaluated it using a testbed of 7 USRP hardware nodes to build up multi-source multi-hop wireless networks. Our measured results show that the interference neutralization over-the-air is achievable in our experimental setup, and outperforms other exiting multi-hop transmission scheme in terms of the network's sum rate, which is coherent with theoretical analysis.

II. INTERFERENCE NEUTRALIZATION BACKGROUND

The multi-hop interference network used in this paper is illustrated in Figure 1. This paper assumes a two-hop relay network, comprising 2 source and destination nodes, each of which has 1 antennas, and 3 relay nodes, each of which has 1 antennas. In addition, we assume that the relay nodes are operated in the half-duplex mode where they do not transmit and receive simultaneously. In other words, two time slots are required to send message from the source to the destination.

We define some parameters and notations as follows:

- \( h_{ij} \): the channel coefficient from source \( j \) to relay \( i \) (backward channel), which is independent and identically distributed (i.i.d) with \( CN(0,1) \)
- \( g_{ij} \): the channel coefficient from relay \( j \) to destination \( i \) (forward channel), which is i.i.d with \( CN(0,1) \)
- \( x_i \): symbol transmitted from source \( i \) to destination \( i \) with an average power constraint, \( P \)
- \( w_i \): the scaling factor of relay \( i \) for AF mode

Note that the interference from source \( k \) to destination \( j \) is neutralized if we choose the relay scaling factor \( w_i \) such that

\[
\sum_{k=1}^{n} g_{j,k} w_k h_{k,j} = 0, \quad k, j \in \{1,2\}, k \neq j
\]

is satisfied. We note that this is a linear equation with respect to the relay scaling factor \( w_i \), and it leads to two linear constraints of the above form. There are three variables, \( w_i \), \( i \in \{1,2,3\} \) in the above interference neutralization conditions. Hence, we can find nonzero relay scaling coefficient \( w_i \) to neutralize all interference over-the-air [2], so that

\[
\begin{bmatrix}
  y_1 \\
  y_2
\end{bmatrix} =
\begin{bmatrix}
  g_{1,1} & g_{1,2} & g_{1,3} \\
  g_{2,1} & g_{2,2} & g_{2,3}
\end{bmatrix}
\begin{bmatrix}
  w_1 & 0 & 0 \\
  0 & w_2 & 0 \\
  0 & 0 & w_3
\end{bmatrix}
\begin{bmatrix}
  h_{1,1} & h_{1,2} & x_1 \\
  h_{2,1} & h_{2,2} & x_2 \\
  0 & 0 & n_i
\end{bmatrix} +
\begin{bmatrix}
  n_1 \\
  n_2
\end{bmatrix}
\]

where \( y_i \) and \( n_i \) are the received signal and overall noise at the destination \( i \), respectively.
III. ENABLING REAL-TIME INTERFERENCE NEUTRALIZATION

In this section, we explore the first real-time implementation of this promising theoretical idea using software defined-radio (SDR) testbed based on MATLAB/Simulink and USRP platform. Simulink includes hardware drivers for the USRPs and has several communication toolkits to aid in the development of SDR system.

A. Testbed Setup

Interference neutralization is applied to our testbed with 2 Tx/Rx pairs and 3 relays, referred to as 2x3x2 networks. Figure 2 is a block diagram of the testbed and pictures of the experimental hardware. The three computers are connected to the same network, and we take advantage of UDP protocol to share the feedback channel state information required for interference neutralization technique. Transmitter, relay, and destination USRP nodes are controlled using a gigabit Ethernet connection. A function generator provides 10MHz clock and PPS signal to all of the USRP nodes in order to synchronize their frequency and time, respectively. It should be noted that MATLAB/Simulink does not provide any function blocks for elaborately control their timing to transmit or receive not like LabVIEW or GNU Radio platform. Thus, an algorithm based time synchronization function block has been implemented in our testbed. To be more specific, each transmission packet contains a training data for signal detection and channel estimation with a repeated length 79 Zadoff-Chu sequences. Based on the sequence, we can estimate the timing error among multiple nodes and try to fix it by post-processing. To avoid the self-interference problem in relay nodes, we employ half-duplex AF relaying mode, so different frequency bands (1 GHz and 1.5 GHz) for backward and forward channels are utilized.

B. Measured Results

The SNR is calculated using the measured signal and noise energy during the each link, and we make SNRs for every links in backward and forward channels almost same by adjusting the relative positions of USRPs. To demonstrate IN’s effectiveness, the network’s sum-rate, $R_{\text{sum, IN}}$ is calculated as $R_{\text{sum, IN}} = \sum_{k=1}^{2} \log_2 (1 + \text{SINR}_k)$. The network’s sum-rates are plotted in Figure 3 versus SNR for measured results. Results show that IN implementation outperforms the conventional multi-hop interference avoidance method, TDM scheme. From the experiments, we can confirm that IN enables interference-free communication with the aid of multiple relays as mentioned in the introduction.

Fig. 2: Interference neutralization 2x3x2 testbed setup using PCs and USRPs.

Fig. 3: The network sum-rates versus SNR.

IV. CONCLUSION

In this paper, we have built a testbed based on USRP and MATLAB/Simulink platform. Multi-source multi-hop wireless network has been implemented in the testbed, and we were able to successfully achieve over-the-air 2x3x2 IN. Measured results from the testbed demonstrate the achievable performance gains of IN in real-world settings. Future works involve distributed time and frequency synchronization, and over-the-air channel state information feedback, enabling us to verify the feasibility of IN in fully distributed ad-hoc wireless networks without any help of infra-structure as well.

REFERENCE