Journal of Theoretical and Applied Information Technology
10th April 2015. Vol.74 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

PERFORMANCE OF TWO-PATH SUCCESSIVE RELAYING IN THE PRESENCE OF INTER-RELAY INTERFERENCE

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ABSTRACT

Half-duplex constraint refers to the inability of a radio to transmit and receive signals simultaneously due to the hardware limitation. In cooperative communication, half duplex constraint requires orthogonal time or frequency channel use between source transmission phase and relay transmission phase. This limits the spectral efficiency of conventional relaying to half of the performance of direct transmission without relay. Two-path successive relaying has been proposed to relax this half-duplex constraint by allowing non-orthogonal transmission, where the source transmits new message continuously in every time slot. In two-path successive relaying, two relays are scheduled to assist the transmission alternately. However, the inter-relay interference degrades the performance significantly since the two relays are not operating in orthogonal channel. Majority of the existing literature neglects the inter-relay interference and over estimates the performance of two-path successive relaying. The main objective of this paper is to investigate the actual interference limited performance of two-path successive relaying compared to conventional half-duplex relaying in terms of ergodic capacity. We consider several channel and system conditions to identify the optimal scheme in respective conditions. The results show that the two-path successive relaying is not always optimal if compared to the conventional half-duplex relaying in interference limited scenario.

Keywords: *Wireless Communication, Cooperative Communication, Two-Path Successive Relaying, Decode and Forward, Inter-Relay Interference*

1. INTRODUCTION

Wireless communication is one of the most active topics in the telecommunication field today. Since each transmitter-receiver pair communicates over the air, therefore channel fading and interference are the two main challenges in wireless communication. Channel fading between the transmitter and receiver is due to the small-scale effect of multipath fading and also large-scale effects such as path loss and shadowing. Interference happens when more than one transceiver pair access the same channel at the same time.

Cooperative communication is introduced to improve the wireless communication using spatial diversity to overcome highly shadowed or deeply faded links [1-2]. In cooperative communication, additional relay node assists in the transmission to offer alternative and independent transmission paths. However, a conventional half-duplex relay is subject to half-duplex constraint (HDC), i.e. it cannot transmit and receive signal simultaneously

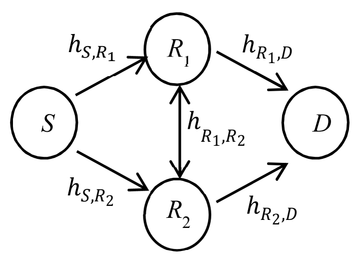

Figure 1: Two-Path Successive Relaying (SR)

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1: The Transmission Protocol of Two-Path Successive Relaying

Time Slots	1	2	3	4	5
S	Tx	Tx	Tx	Tx	Tx
R_1	Rx	Tx	Rx	Tx	Rx
R_2		Rx	Tx	Rx	Tx
D		Rx	Rx	Rx	Rx

in the same frequency channel, due to the hardware limitation [3, 4]. The conventional half-duplex relay is unable to isolate the received signal and the transmitted signal, since the power of self-transmitted signal is much higher than received signal from a remote transmitter. Therefore, the source transmitter has to keep silent and stop transmission of new message during the relay transmission phase. As a result, the conventional half-duplex relay needs double amount of channel resources (requires orthogonal channel use) and the maximum multiplexing gain is only half of the direct transmission without relay.

A full-duplex relay receives and transmits at the same time on the same channel utilises the spectrum resources more efficiency [5-7]. However, the full-duplex relay is subject to loop interference (LI) due to signal leakage from the relay's transmission to its own reception. The latest literature shows that the LI can be mitigated sufficiently and the residual interference may be regarded as mere additional noise [6, 7]. However, these advanced signal isolation techniques require sophisticated hardware and/or advanced signal processing which significantly increases the cost and complexity of relay nodes.

Successive relaying protocols are introduced to recover the loss of spectral efficiency without incurring the LI [8-10]. Two-path successive relaying (SR) is one of the popular successive relaying protocols [10]. The SR schedules a pair of half-duplex relays to assist the transmission between source and destination pair alternately. In the SR, a message is transmitted in two time slots. In the first time slot, the source, S transmits the message to relay R_1 or R_2. In the second time slot, the message is forwarded to the destination, D, as shown in Figure 1 and Table 1. The SR recovers the loss of spectral efficiency due to the HDC by allowing the source continues transmitting new messages. This is also known as non-orthogonal transmission.

In the early literature, the relays in SR are assumed to be orthogonal to each other [11]. However, in practice the relays in SR do not necessary operate in orthogonal channels. When they operate in co-channel, the concurrent transmission of the source and relay (interferer) transmitters causes the co-channel interference to another relay receiver (victim). This co-channel interference is known as the inter-relay interference and degrades the performance of the SR significantly.

Successive interference cancellation (IC) technique is proposed to mitigate the inter-relay interference in [10, 12]. The IC is performed at the relay when the inter-relay interference is stronger than the channel gain of the source-to-relay. The relay decodes the inter-relay interference first and treats the desired message from the source as noise. After that, the relay subtracts the decoded inter-relay interference from the received signal and proceeds to decode the desired message from the interference-free signal. To further improve the performance of SR, relay selection has been proposed in [13]. This opportunistic two-path successive relaying (OSR) considers the instantaneous signal to interference plus noise ratio (SINR) of source-to-relay channels and the instantaneous signal to noise ratio (SNR) of relay-to-destination channels respectively during the relay selection to optimise the capacity performance of SR [13]. Successive interference cancellation is performed in [13] when the instantaneous rate of the inter-relay channel is greater than the target rate to mitigate the inter-relay interference. However, the interference cancellation technique is only 3effective when the inter-relay interference is strong. In fact, the ergodic capacity of OSR performs worse than the conventional opportunistic half-duplex relaying (OHR) under some channel and system conditions [14].

In order to justify the actual performance of the OSR, the capacity performance of OSR in several channel and system conditions are investigated in this paper. The channel and system conditions that we study in this paper are the signal-to-noise ratio (SNR) and strength of inter-relay interference and number of potential relays. We also compare the performance of the OSR with OHR in this paper to gain a better understanding on the actual performance of the SR. The ergodic capacity performance is simulated in the MATLAB software by using the Monte Carlo technique.

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. SYSTEM MODEL

In this paper, we assume all nodes are equipped with single antenna and subject to half-duplex constraint. The half-duplex constraint is realised using time division duplexing and the individual transmit power of the source and relays are subject to unit power constraint. We consider the channels are independent and identically distributed (i.i.d.) with quasi-static Rayleigh fading distribution and reciprocal unless stated otherwise. We assume each node can obtain perfect channel state information (CSI) for local channels and each receiver is corrupted by complex circularly symmetric additive white Gaussian noise with distribution $\mathcal{CN}\sim$ (0, σ^2). The signal-to-noise ratio (SNR) is defined as P/σ^2 where P=1. The target rate of the transmission, T_R is fixed to 1 bits/s/Hz.

In this paper, a scenario of one source, S, and one destination, D with N potential decode-and-forward half-duplex relays is considered. It is assumed that the direct channel between S and D does not exist due to severe shadowing or extreme path loss.

3. TWO-PATH SUCCESSIVE RELAYING (SR)

In this paper, we consider the two-path successive relaying without relays selection (SR) [10], opportunistic two-path successive relay with interference cancellation (OSR-IC) [13] and opportunistic two-path successive relay without interference cancellation (OSR).

The achievable sum-rate of relay R_1 and R_2 for the SR can be expressed as follows [10],

$$C_{SR} = \min\left(c\left(\frac{P|h_{S,R_p}|^2}{\sigma^2+P|h_{R_1,R_2}|^2}\right), c\left(\frac{P|h_{R_p,D}|^2}{\sigma^2}\right)\right), \quad (1)$$

where $c(x) = \log(1+x)$ and $p \in \{1, 2\}$.

For the OSR-IC that has been proposed in [13], the first relay, R_1 is chosen from the N potential relays according to the following criterion:

$$\max\min\{SNR_{S,R_k},\ SNR_{R_k,D}\}, \quad (2)$$

where $k \in \{1, \ldots, N\}$. The second relay, R_2 is chosen from the rest $N-1$ potential relays according to the following criterion:

$$\max\min\{SINR_{S,R_k},\ SNR_{R_k,D}\}, \quad (3)$$

where $R_1 \neq R_2$. In this case, the rate constraint of the inter-relay channel is greater than the target rate, T_R as follows,

$$\log_2\left(1+\frac{P|h_{R_1,R_k}|^2}{P|h_{S,R_k}|^2+\sigma^2}\right) > T_R, \quad (4)$$

the successive interference cancellation (IC) is performed. Therefore, the achievable sum-rate of relay R_1 and R_2 for the OSR-IC can be expressed as follows [13],

If (4) is satisfied and the IC is performed at the relay R_1 and R_2:

$$C_{OSR-IC} = \min\left(c\left(\frac{P|h_{R_1,R_2}|^2}{\sigma^2+P|h_{S,R_p}|^2}\right), c\left(\frac{P|h_{R_1,R_2}|^2}{\sigma^2}\right), c\left(\frac{P|h_{R_p,D}|^2}{\sigma^2}\right)\right), \quad (5)$$

Else if (4) is not satisfied:

$$C_{OSR} = \min\left(c\left(\frac{P|h_{S,R_p}|^2}{\sigma^2+P|h_{R_1,R_2}|^2}\right), c\left(\frac{P|h_{R_p,D}|^2}{\sigma^2}\right)\right). \quad (6)$$

In order to justify the effectiveness of the IC in optimising the performance of the SR, we compare the OSR-IC [13] to the OSR which does not performing the IC and the achievable sum-rate of relay R_1 and R_2 for the OSR is as stated as (6).

4. CONVENTIONAL HALF-DUPLEX RELAYING (HR)

The conventional half-duplex relaying (HR) [1] and opportunistic half-duplex relaying (OHR) [15] are served as the comparison schemes in this paper.

The achievable of the HR can be expressed as follows [1],

$$C_{HR} = \frac{1}{2}\min\left(c\left(\frac{P|h_{S,R}|^2}{\sigma^2}\right), c\left(\frac{P|h_{R,D}|^2}{\sigma^2}\right)\right). \quad (7)$$

For the OHR, the relay, R_B is chosen from the N potential relays according to the following criterion [15]:

$$\max\min\{SNR_{S,R_k},\ SNR_{R_k,D}\}, \quad (8)$$

where $k \in \{1, \ldots, N\}$. Therefore, the achievable rate of OHR can be expressed as follows [15],

$$C_{OHR} = \frac{1}{2}\min\left(c\left(\frac{P|h_{S,R_B}|^2}{\sigma^2}\right), c\left(\frac{P|h_{R_B,D}|^2}{\sigma^2}\right)\right). \quad (9)$$

5. ERGODIC CAPACITY VERSUS SNR

Journal of Theoretical and Applied Information Technology
10th April 2015. Vol.74 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This section shows the ergodic capacity of the SR varies with the signal-to-noise ratio (SNR) which is defined as P/σ^2 and P=1.

Figure 2 shows the ergodic capacity of various schemes versus SNR. We observe that the SR-IC outperforms the SR and same goes to the OSR-IC and OSR. This shows that the successive interference cancellation (IC) is able to improve the ergodic capacity of the SR in the presence of inter-relay interference. However, the SR and SR-IC still perform worse than the HR and same goes to the OSR and OSR-IC toward the OHR when SNR ≥ 20dB. This is because the inter-relay interference, i.e. $|h_{R_1,R_2}|^2$, limits the performance of the SR at high SNR regime, i.e. $\sigma^2 \to 0$.

6. INTER-RELAY INTERFERENCE

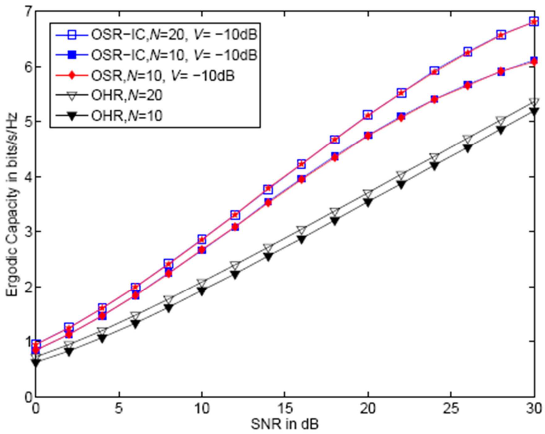

Figure 4: Ergodic Capacity Versus SNR Of Various Schemes With Weak Inter-Relay Interference.

This section discusses the effect of inter-relay interference toward the performance of the SR when the channels gains are not identically distributed. The V is the ratio of the fading variance of inter-relay channel to the fading variance of source-to-relay channel, i.e. $V = v_{R,R}/v_{S,R}$, where $v_{S,R} = v_{R,D} = 1$.

Figure 3 shows the ergodic capacity of various schemes with strong inter-relay interference, i.e. $V = 10dB$, and when the number of potential relays, $N = 10, 20$. We observe that the OSR-IC outperforms the OHR when the strength of the inter-relay interference is strong. This is because the advantage of the IC in strong inter-relay interference. On the other hand, without IC the SR performs worse than the OHR.

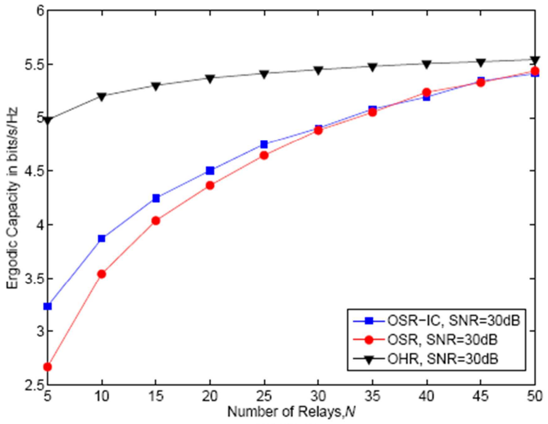

Figure 5: Ergodic Capacity Versus Number Of Potential Relays, N When SNR=30db.

Figure 4 show the ergodic capacity of various schemes with weak inter-relay interference, i.e. $V = -10dB$ and when the number of potential relays, $N = 10, 20$. We observe that the OSR and OSR-IC achieved similar ergodic capacity when the inter-relay interference is weak. Due to the weak inter-relay interference, the OSR and OSR-IC outperform the OHR significantly in terms of ergodic capacity. This is because the higher multiplexing gain due to pre-log factor in the SR compared to the HR.

7. NUMBER OF POTENTIAL RELAYS

This section shows the effect of the number of potential relays, N towards the ergodic capacity of various schemes at high SNR and low SNR.

Figure 5 shows the ergodic capacity of various

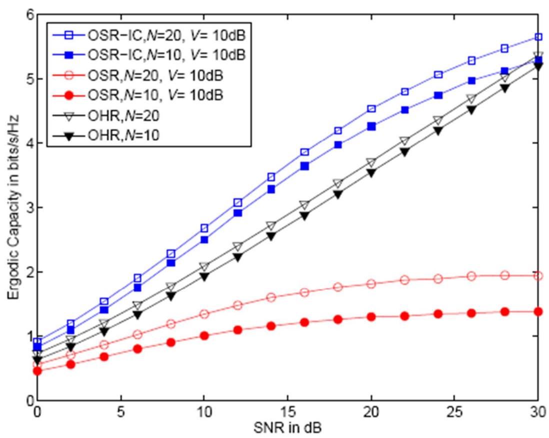

Figure 5: Ergodic Capacity Versus SNR Of Various Schemes With Strong Inter-Relay Interference.

Journal of Theoretical and Applied Information Technology
10th April 2015. Vol.74 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

schemes vary with the number of potential relays, N at high SNR, i.e. SNR = 30dB. We observe that the OSR and OSR-IC underperform the OHR significantly at high SNR when N is small. However, the ergodic capacity increases and the gap between the OHR towards the OSR and OSR-IC decreases when N increases. This thanks to the advantage of relay selection in the OSR and OSR-IC. As the N increasing, the probability of choosing relay pair with weak inter-relay interference and/or strong inter-relay interference is increasing as well. We also observe that the ergodic capacity of the OSR and OSR-IC converge when N is large. This is because when the SNR is high, i.e. $\sigma^2 \rightarrow 0$, the inter-relay interference limits the performance of the SR even when the N is large.

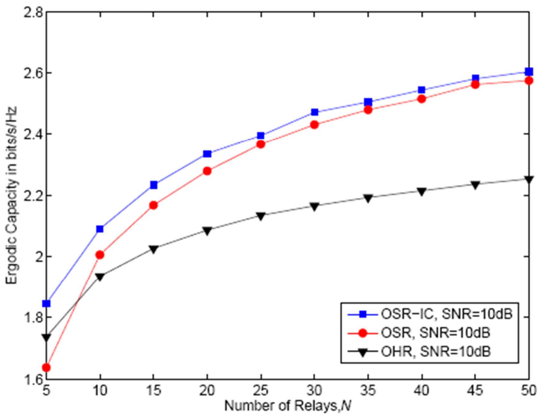

Figure 6: Ergodic capacity versus number of potential relays, N when SNR=10dB.

Figure 6 shows the ergodic capacity of various schemes vary with the number of potential relays, N at low SNR, i.e. SNR = 10dB. The figure shows that the OSR-IC and OSR outperform the OHR significantly when the N increases. This is because of the pre-log factor gain of the SR compared to the HR. We also observe that the OSR-IC performs better than the OSR. This is because the adaptive gain of the OSR-IC that performing the IC when the rate constraint of the inter-relay channel is greater than the target rate, T_R.

8. SUMMARY

Table 2: Performance Comparison of Various Schemes in Different Channel and System Conditions.

Channel or system conditions	OHR	OSR	OSR-IC
Low SNR	Worst	Good	Optimal
High SNR	Optimal	Worst	Good
Weak inter-relay interference	Worst	Good	Optimal
Strong inter-relay interference	Good	Worst	Optimal
Small N	Optimal	Worst	Good
Large N	Worst	Good	Optimal

Table 2 shows the performance comparison of OHR, OSR and OSR-IC in different channel and system conditions based on the discussions in the earlier section. From Table 1, we observe that the performance of the OHR, OSR and OSR-IC varies with the channel and system conditions. The results also reveal that the performance of OSR-IC is not always better than the OHR.

9. CONCLUSION

This paper compares the interference limited performance of the two-path successive relaying and half-duplex relaying in terms of ergodic capacity in several channel and system conditions. From fair comparison and detailed investigation, the optimal schemes in respective channel or system conditions are identified. The results also reveal that the two-path successive relaying is not always performing better than the conventional half-duplex relaying in the presence of inter-relay interference.

ACKNOWLEDGEMENT:

This research is supported by the Ministry of Science, Technology and Innovation Malaysia (MOSTI), the Ministry of Education Malaysia (MOE) and University Teknologi Malaysia under Project Vote No. 4S079, 4F261 and 05H39.

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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