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Outage Probability of Repetition Coding Based Adaptive Decode-and-Forward Protocol for Cooperative Communications

G. D. MENGHWAR, A. KEERIO*, Z. HUSSAIN**, M. MEMON

Information Technology Centre, Sindh Agriculture University, Tandojam, Pakistan

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Abstract: Cooperative communications has been introduced to mitigate the wireless channel effects on the message being received at the destination. Cooperative communication is a mode of transmission where the transmitting users receive message from its surroundings, process it, and repeat some encoded information to the destination to exploit spatial diversity. Considering the fact that the channel between the cooperating users is not always good enough and as a solution some adaptive relaying protocols have been introduced. In this paper, we propose a scheme in which we introduce a dedicated relay to complement the partner user in cooperative communications setup which can not decode the message transmitted from the other user. The analytical as well as simulated results show that the proposed scheme offers higher resistance to the unreliability of the wireless channel as compared to the classical adaptive protocols.

Keywords: Cooperative communication, wireless channel.

1. INTRODUCTION

Twentieth century has revolutionized the field of wireless communications. With the introduction of 4th Generation of mobile communications (3GPP, 2009; Martn-Sacristn *et al.* 2009), one can surely perceive that the future of wireless communications is ever nourishing. Wireless communications where offers us a great benefit of independence of movement also introduce many challenges, due to the varying characteristics of the time varying wireless channel between the transmitter and receiver. The major wireless challenges are the reflection, refraction, scattering and diffraction (Proakis, 2001; Rappaport, 1995). These effects are introduced because of the various obstacles present between the transmitter and receiver. Due to these wireless channel effects, the signal transmitted is dispersed in various directions from where it is, after many reflections or diffraction, reached at the final destination. As a result the transmitted signal not only loses its final shape but the energy content within it is also degraded. To address these issues, the idea of diversity was introduced (Tse, 2005; Goldsmith, 2005). Diversity technique is a novel idea to provide the receiver with multiple replicas of the message, and the receiver makes use of these replicas to better decide about the message transmitted. Cooperative communications is also one of the efforts where it is tried to provide the receiver with more than one copies of the transmitted signal (Cover *et al.* 1979; Sendonaris *et al.*, 2003; Menghwar *et al.*, 2008). In this way of communications, the transmitting users help each other by forwarding, in addition to their own information, each others messages towards the destination.

The relay channel introduced by (Cover *et al.* 1979) forms the basis of cooperative communications. In a relay channel, the information transmitted is first received by a fixed node, called relay, which then forwards some information, based on the received message, to the destination (Cover *et al.* 1979). In cooperative communications, instead of a dedicated relay, the transmitting users themselves act as relays for each other (Sendonaris *et al.*, 2003; Menghwar *et al.*, 2008). The transmitting user, when acting as relays, are called partners and these partners based on their estimates of the messages received send additional information to the destination. These estimates, in turn, are dependent on the channel between the transmitting users themselves However, due to the channel condition, this is not always the case that the transmitted message is received accurately at the partner nodes. Therefore, it is not always good for the partner users to decode the message for forwarding. To address this issue, Laneman *et al.* (Laneman *et al.*, 2002) introduced the idea of adaptive decode and forward protocol, where the channel between the transmitting users is estimated first. If this channel is above a fixed threshold, then the partner node decodes that message and forwards the re-encoded version of it towards the destination; otherwise, the transmitter itself is dictated to repeat the message transmitted. However, in this way, in the case of message not being decoded by the partner user, the idea of diversity is lost.

In this paper, we introduce a fixed node which helps to overcome this issue. In this scheme, in case the partner user is unable to decode, the fixed node tries to decode and forward the message from the transmitter.

++Corresponding author, Email: ayazkeerio@hotmail.com Cell No. +92 3412802830
* Department of IMCS, University of Sindh, Jamshoro, Pakistan
**Quaid-e-Awam Engineering University, Nawabshah, Pakistan

By doing so, the probability that the receiver gets copies of the same message from multiple statistically independent paths is increased and the diversity gain is achieved at the receiver. We derive and simulate outage probability of the scheme being proposed. The analytical as well as the simulated results presented show that with this novel idea, we enhance the reliability of the message received at the destination.

To present our idea, the remaining paper, section-wise, is organized as follows. Section 2, discuss materials and methods applied along with the model describing the scheme being proposed. In section 3, the mathematical formulation for the analytical analysis of the scheme is discussed. In section 4, results and discussion is given. In section 5, conclusion is drawn.

2. METHODOLOGY

System Model: As illustrated in **(Fig. 1), w**e consider a general wireless network comprising of two transmitting user T_1 and T_2, a fixed relay R, and a single destination d.

The transmitting users are considered to be the partners of each other. We impose half duplex constraint on the transmitting nodes keeping in mind the fact that practical nodes are difficult to devise to have simultaneous transmission as well as reception capability. As shown in **(Fig. 2)**, we assign different time slots to each transmitter to transmit their message and its further detail is given in later section describing operational details of the protocol, i.e., Section III.

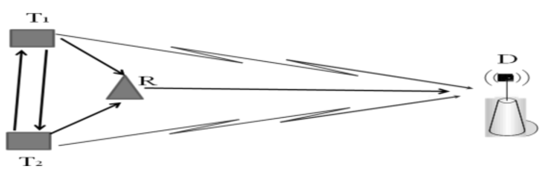

Fig. 1. Cooperative communications using dedicated relay

The transmitting users are considered to be the partners of each other. We follow the notion of partner from (Sendonaris *et al.*, 2003) in the sense that the transmitting user, after receiving and decoding the message from each other, relay each other's information to the destination. We impose half duplex constraint on the transmitting nodes keeping in mind the fact that practical nodes are difficult to devise to have simultaneous transmission as well as reception capability. We assign different time slots to each transmitter to transmit as depicted in **(Fig. 2)**.

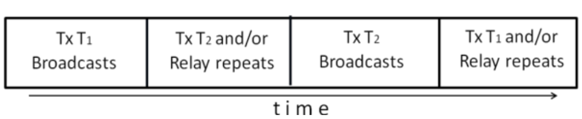

Fig. 2. The channel assignment used by the transmitting users.

h_{sd} is for representing the channel between source and the destination and the channel from partner to destination is denoted as h_{pd}, from source to partner as h_{sp} and finally, the channel from source to the relay is shown as h_{sr}. Each node in the network is imposed a transmit power limitations of *P*. The noise at the receiving nodes is modeled as complex Gaussian random variable. This random variable has having zero mean and unit variance. Moreover, Signal to noise ratio is given as:

here γ is $\frac{P_i}{N}$. $$SNR = \gamma |h_{ij}|^2 \quad (1)$$

Furthermore, slow fading channel model is considered in this paper which implies that the channel is assumed to be constant for some time and is allowed to change state afterwards. The channel is modeled as Rayleigh distribution, where the fading variables h_{ij} are modeled as having zero mean, stationary (complex) Gaussian random variable.

Protocol Description

Our proposed scheme is based on decode-and-forward relaying protocol (Laneman, 2002; Laneman *et al.*, 2004). In decode-and-forward protocol the message transmitted from the transmitting user is received both by the destination and relaying node, as depicted in **(Fig. 3(a))**. Later this relay node decodes and forward some encoded information to the destination and this is shown in **(Fig. 3(b))**. A variation of this fixed protocol is adaptive decode-and-forward protocol (Laneman *et al.*, 2004). Here, the relay forwards re-encoded message to the final destination only if the channel between the transmitting user and the relay node is reliable. The only drawback of this protocol is that if the partner user could not decode the message, then no diversity is achieved.

Fig. 3(a). Relay : 1rst phase of the transmission

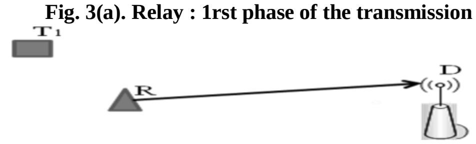

Fig.3(b). Relay: 2nd phase of the transmission

To address this drawback, we develop a novel scheme based on the original adaptive decode-and-forward protocol suggested by Laneman (Laneman, 2002; Laneman *et al.*, 2004). The proposed adaptive protocol works in the following way.

For understanding purpose, we take the same two phase strategy used by (Sendonaris, 2003; . Laneman *et al.*, 2004). The first phase, due to its behavior is named as the broadcast phase, and the second phase is named as the multiple access. In the initial (first) phase, the transmitting nodes broadcast. This information, with different level of certainty, is received by the destination, at the receiving end of each other and at the dedicated relay node *R*. In the later (second) phase of multiple-access of the transmission, either the partners or dedicated relay node repeats this information to the destination.

In our proposed adaptive protocol, it is not compulsory for the partner as well as the dedicated relay to decode the message. They all estimate the channel from the transmitter to their own receiver, and if the channel strength is beyond some certain thresh-hold then they decode the message received and discard, otherwise. The decoded message is then repeated to the destination. The repetition is performed either by the partner or by the relay, and this depends on the channel condition. If the partners as well as relay find the channel strength to be less than the set threshold, they just drop it out and do not repeat anything to the destination. In classical adaptive protocol, if the partner user fails, the transmitting user itself is made to repeat the message; however, in our proposed scheme, the dedicated relay node helps the transmitting users, in case of decoding failure by the partner users. In the light of the above protocol description, the channel assignment strategy shown in **(**Fig. 2) is described as follows.

As seen in (Fig. 2), the first time slot is reserved for transmitter T_1 which broadcasts its information towards the destination. After receiving and decoding, the relay and the partner user repeat, in the 2^{nd} time slot. Following the same way, third time slot is for broadcasting T_2's information and the fourth time slot is for repeating T_2's information with the help of T_1.

In the worst case, when both the partner as well as relay node fail, the transmitting users itself repeats its message to the destination.

Outage Behavior

As mentioned above, this paper considers a slow fading channel model, where the channel does not remain same, but it changes its state frequently. As a result, the rate supported by the channel also varies. In this case, the outage probability is considered to be an appropriate performance measure (Ozarow *et al.* 1994). Outage probability defines the probability of an event when the channel condition causes the mutual information to fall below certain target transmission rate, *R'* given in bits/channel use (Laneman *et al.*, 2004; Ozarow *et al.* 1994). For slow fading channel model, mathematically, the outage probability is written as follows.

$$P^{out}[R'] = P \quad [I < R'] \qquad (2)$$

I denotes the mutual information (Cover *et al.*, 1991) between the cooperating transmitting user, T_i, where i = 1, 2, and the destination, *d*. For repetition coding based decode-and-forward protocol, the mutual information, *I* for different channel conditions between the transmitting source and partner, h_{sp}, between the transmitting source and the fixed relay, h_{sr} and between the transmitting source and the final destination, h_{sd}, can be written as (G. Kramer *et al.* 2005).

$$I = \begin{cases} \frac{1}{2}\log(1+2\gamma|h_{sd}|^2) & (3) \\ \frac{1}{2}\log(1+\gamma|h_{sd}|^2+\gamma|h_{pd}|^2) & (4) \\ \frac{1}{2}\log(1+\gamma|h_{sd}|^2+\gamma|h_{rd}|^2) & (5) \\ \frac{1}{2}\log(1+\gamma|h_{sd}|^2+\gamma|h_{sp}|^2+\gamma|h_{rd}|^2) & (6) \end{cases}$$

Equation (3) is the mutual information when both the relay as well as the partner user can not decode the message transmitted and the transmitter itself repeats this message, in second time slot. In this case, the received SNR is increased by double as in shown in Equation (3).

In second equation, the Equation (4), the source-to-partner channel is considered to be weak, whereas, the channel from the source-to-relay is considered to be strong and, as a result, the relay repeats the message on behalf of the transmitting users. In this case, the destination receives the same message from two statistically independent paths and this is shown by two channel gains in the mutual information expression (4).

In Equation No. (5), source-to-partner channel is considered to be weak and message is repeated by the dedicated relay node.

Finally in the last equation, i.e., in the Equation No. (4), both source-to-partner as well as source-to-relay channel is considered to be satisfactory for decoding. Hence, the mutual information expression includes the terms for all the channels involved, i.e, the channel between source and partner, h_{sp}, from transmitting source to relay, h_{sr} and finally, from source to the destination, h_{sd}. However, in this condition only one node, either the partner or the dedicated relay node is allowed to repeat.

$$I = \begin{cases} \frac{1}{2}\log(1+2\gamma|h_{sd}|^2) & (7) \\ \frac{1}{2}\log(1+\gamma|h_{sd}|^2+\gamma|h_{rd}|^2) & (8) \end{cases}$$

In this scheme, the first equation shows that the channel between the transmitter and the partner is weak and the transmitter repeats the information. In the second equation, the partner user can decode and repeats the message. As a result, the destination receives two copies, from two statistically independent paths, of the same message transmitted.

3. RESULTS AND DISCUSSION

This section is devoted to discuss the simulated probability of outage results for our proposed scheme. Simulation is performed in Matlab. We use two transmitters, T_1, T_2, a dedicated relay node R, and a single destination *d*. The transmitting users are using binary phase shift keying (BPSK) and the channel between various nodes is modeled as Rayleigh fading. The noise has been taken to be zero mean and circularly symmetric (complex) random variable following Gaussian distribution.

The partner as well as the dedicated relay node employ decode and forward relaying and the repetition coding is used to forward the information received. In addition, we also present the outage probability for classical direct transmission, where the transmitting users are not assisted by any partner or relay node and the results for fixed decode-and-forward protocol are also shown. As seen in **(Fig. 4)**.

outage.

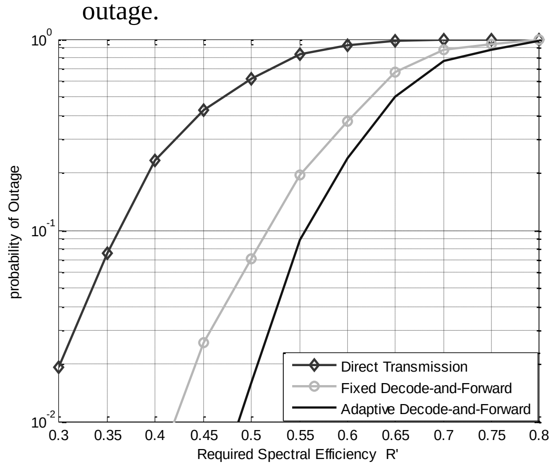

Fig. 4. Outage behaviour of adaptive decode-and-Forward protocols.
All the three curves show that as the requirement on *R* increases, the system faces more outage. However, the curves representing outage probability for adaptive protocols shows that they offer better performance as they have less probability of being in outage for the same rate requirement. For instance, in Figure 4, if we fix the required R' at 0.5 bits/channel use, we can see that the vertical axis showing outage probability has higher rating for direct transmission and then next higher rating is for classical adaptive protocol and the least outage probability rating is for our proposed adaptive protocol. Specifically, at 0.5 bits/channel use, the transmitting users have $10^{-0.5}$ less probability of outage with the proposed scheme as compared to direct or no-cooperative communications.

This shows that our proposed scheme offers better performance than fixed or classical adaptive decode-and-forward protocol. With the presented results we show that by exploiting the availability of a fixed relay terminal in the network, improve the reliability of the link by reducing its probability of outage.

4. CONCLUSION

In this paper, a novel scheme is proposed where we introduce a dedicated relay to aid the cooperating user based on adaptive decode and forward protocol. This dedicated relay tries to overcome the problem occurred with the cooperating user that can not decode the message received. The analytical as well as simulations results shows that we get better outage probability results than the fixed as well as adaptive decode- and-forward protocol proposed so far.

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