

An Adaptive Cooperative Protocol for Multi-Hop Relay Selection in Wireless Networks

Smich Butcharoen and Chaeyod Pirak

The Sirindhorn International Thai-German Graduate School of Engineering (TGGS),
King Mongkut's University of Technology North Bangkok, Thailand
smichb@tot.co.th, chaeyod.p.ce@tggs-bangkok.org

Abstract — The multi-hop relay communication system has attracted tremendous attention recently as it is able to improve the service by increasing the distance and reducing the capital expenditure for network expansion. In this paper, an adaptive cooperative decode-and-forward (DF) protocol for the multi-hop relay communication system has been developed to enhance the performance of the system. In particular, the best destination relay selection approach (BDRS) was proposed for realizing the diversity gain available in the multi-hop relay networks. Firstly, the destination node whose channel gain is the maximum is chosen. Then, the relay node will be chosen based on the minimum outage probability approach. The system performance has also been analyzed theoretically by deriving the outage probability. In addition, an optimum power allocation has been investigated. Finally, the theoretical performance analysis has been verified by comparison with the numerical simulation result. The result shows that the theoretical analysis is almost identical to that of the simulation result. Furthermore, the outage probability of the proposed protocol is significantly lower than the conventional and modified multi-hop communication protocols by virtue of the diversity gain. In addition, the outage probability is further minimized when the optimum power allocation is employed.

Keywords—Multi-Hop; Relay selection; Routing strategy; Cooperative communication; Power allocation

I. INTRODUCTION

Multi-hop communications have become more important for future wireless communication systems as they can help to expand the service area, increase system capacity, and also reduce the investment budget for base station expansion. In [1], the authors studied the deployment of an LTE in-band relay and micro base station in a realistic metropolitan scenario. In part IV chapter 22 of [2], an expression (22.15) conducted a relay selection by avoiding bottlenecks in multi-hop routes. The model consists of one source, one destination and many relays in the wireless networks. This model considers the worst channel quality between source-to-relay (SR) and relay-to-destination (RD) channels in order to guarantee a minimum quality of service (QoS) for the system. In [3], the authors designed three routing strategies for multi-hop communications. These are an end-to-end routing strategy, an ad-hoc routing strategy, and an N -hop routing strategy. Each strategy was analyzed by deriving an outage probability.

An ad-hoc routing strategy in [3] selected the best relay, which had the maximum received SNR regardless of the minimum QoS guarantee. In addition, the authors designed a special protocol for the last two hops based on an observation that the worst channel quality would occur between a selected relay and a final destination. This fact could obviously impact the system performance. In order to solve this problem, they selected the relay that had the maximum of a minimum link quality by comparing each pair of the source-to-relay and relay-to-destination channels. Moreover, the authors in [3] proposed the N -hop routing strategy which divided relays into smaller groups of M/N nodes, where M is the hop count of the system and N is the number of sub-hop groups. Then, they determined an optimum number of N as a trade-off between the performance and complexity of the system. By implementing this approach, the conclusion could be drawn that a number N that is greater than four is not necessary if L is sufficiently large (where L is the number of relays in a column). In addition, the system performance is virtually unchanged.

In [4], the multi-hop communications system was studied. The authors analyzed the reliability of the system, and derived the outage probability. They also proposed an algorithm for finding a reliable route by selecting a route that uses the minimum energy consumption. Moreover, they also studied the benefit of the broadcast signal from a source to a selected relay and a destination. These two signals are combined at the destination, which contributes to the diversity of two according to a cooperative protocol principle. Compared with a conventional and modified multi-hop protocol, the performance of this system was found to be superior.

In [5], the authors analyzed the cooperative protocol in the case of multiple relays that help a source to re-transmit the signal to the destination. It was found that the outage probability was not greatly reduced as the number of relays increased. In fact, in some instances, it increased the outage probability. On the one hand, increasing the number of relay nodes increases the possibility that a successful relaying can occur, which increases the mutual information between the source and destination. On the other hand, increasing the number of relay nodes increases the probability of an outage condition at the relay and destination nodes. This trade-off is a result of the time-division channel allocation scheme, which allows proportionally less time for the source to transmit its

signal when the number of relay nodes is increasing, i.e., the source is allowed to transmit only a fraction $1/(m+1)$ of the time. Hence, an optimal number of relay nodes exists, and this could be determined based on the SNR and channel conditions.

In [6], the authors used a model similar to [5], but analyzed the best relay selection using the outage probability. The result yielded a better performance than that of [5]. Even the number of multiple relays in [5] cannot reduce the outage probability significantly, and the best relay selection in [6] is opposite. Specifically, a larger number of relays results in a much deeper outage probability reduction, and the efficiency does not depend on the SNR compared with [5].

In [7], the authors applied an Alamouti code with the best relay selection proposed in [6] to improve the performance of cooperative communications. They also derived the outage probability of the proposed system. After the best relay was selected from two candidate nodes, it would take four time slots for data transmission. In the first and third time slots, a source (S) will broadcast its signal to a relay (R) and a destination (D). In the second and fourth time slots, the system will transmit new data from S directly through D, while the relay decodes and forwards from R to D at the same time. They also used a Quadrature Phase Shift Keying (QPSK) modulation to compensate the timing redundancy used in this protocol. In addition, improved performance could be achieved in comparison with [5].

The purpose of this paper is to improve the system performance of conventional and modified multi-hop relay communication networks by using the cooperative diversity gain. Specifically, the cooperative protocol was applied and studied in order to improve the system performance by using the idealized linear network model as well as an existing protocol widely used in [3], [8] and [9]. In addition, this research also emphasizes the selection of the best destination first, and then considers the best cooperative relay that can minimize the outage probability, whereas the other researches have concentrated on the best cooperative relay selection. This proposed protocol is called the “best destination relay selection approach” (BDRS). Furthermore, we compare our analytical result with a numerical result, and also compare the proposed protocol with an existing multi-hop relay protocol in [3]. Finally, we further improve the system performance by employing an optimum power allocation for S and R.

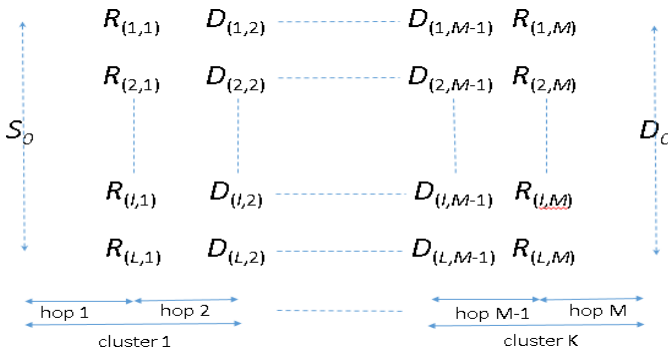


Figure 1. Idealized linear network model for conventional multi-hop communications.

The rest of this paper is organized as follows. In section II, we describe the system, received signal models and the optimum power allocation. In section III, the simulation results are shown, and the implementation issues are considered in section IV. Finally, we conclude this paper in section VI.

II. SYSTEM MODEL

In this section, we describe the system models, including the conventional multi-hop relay selection approach and the proposed best-destination relay selection approach.

A. The conventional multi-hop relay selection approach

Given $l = 1, \dots, L$ being the relay nodes, $m = 1, \dots, M$ being the communication hops, and $k = 1, \dots, K$ being the index of clusters in the communication network. Let S denotes the source node, R_k^* denotes the selected relay node at the k^{th} cluster, D_k^* denotes the selected destination node at the k^{th} cluster, where a hop index $m = 2k$.

Initialization: $S = S_0$

Recursion:

For $m = 1: M - 1$

$$R_k^* = \arg \max_{R_{l,2k-1}} (\gamma_{S_0, R_{l,2k-1}}), \quad l = 1, 2, \dots, L$$

- Decode and remodulate at R_k^*

- Send from R_k^* to D_k^*

$$D_k^* = \arg \max_{D_{l,2k}} (\gamma_{R_k^*, D_{l,2k}}), \quad l = 1, 2, \dots, L$$

- Decode and remodulate at D_k^*

$$S = D_k^*$$

End

$$D_K^* = D_0$$

Output the optimal path $\{S_0, (R_k^*, D_k^*), D_0\}$ where $k = 1, \dots, K$

The received signal at the selected relay R_k^* can be calculated as

$$\gamma_{S, R_k^*}^{\text{hop}} = \sqrt{P_s} h_{S, R_k^*} x + n_{R_k^*} \quad (1)$$

where P_s is the power send from S to R_k^* , x is transmit symbol, h_{S, R_k^*} is the channel impulse response between S and R_k^* , and $n_{R_k^*}$ is Additive White Gaussian Noise (AWGN) at R_k^* .

In phase 2, R_k^* will decode and encode data then forward to the selected destination (D_k^*), where D_k^* is a node $D_{l,2k}$ who has maximum received SNR from $D_k^* = \arg \max_{D_{l,2k}} (\gamma_{R_k^*, D_{l,2k}})$,

where $\gamma_{R_k^*, D_{l,2k}} = P_R \left| h_{R_k^*, D_{l,2k}} \right|^2 / N_0$ represents the received SNR of a selected R_k^* to $D_{l,2k}$ at the hop $2k^{\text{th}}$ where $l = 1, 2, \dots, L$ is a number of cluster k^{th} . R_k^* will be decoded and remodulated data $\tilde{x}$ before forward to D_k^* in a cluster k^{th} . The received signal at the selected destination relay ($\gamma_{R_k^*, D_k^*}^{\text{hop}}$) for multi-hop can be calculated from

$$\gamma_{R_k^*, D_k^*}^{\text{hop}} = \sqrt{P_{R_k^*}} h_{R_k^*, D_k^*} \tilde{x} + n_{D_k^*} \quad (2)$$

where $P_{R_k^*}$ is the power send from R_k^* to D_k^* , $\tilde{x}$ is decoded symbol, $h_{R_k^*, D_k^*}$ is the channel impulse response between R_k^* and D_k^* , $n_{D_k^*}$ is AWGN at a selected D in cluster k^{th} .

B. The proposed best-destination relay selection approach

We can calculate received signal by using an expression

$$\gamma_{S, D_k^*}^{\text{coop}} = \sqrt{P_S} h_{S, D_k^*} x + n_{D_k^*} \quad (3)$$

where P_S represents transmit power from S to D , x represents the modulated transmit symbol, h_{S, D_k^*} represents the channel impulse response of S - D , $n_{D_k^*}$ represent AWGN at the destination receiver.

The selected relay received a broadcast signal from a source then detect a signal by Maximum-Likelihood (ML) receiver. The detected symbol from a selected relay represent by $\tilde{x}$. After that $\tilde{x}$ is modulated and sent to D in the second phase. The received signal in the second phase can express in (3)

In phase 2, a selected relay R_k^* (is selected from a relay who achieve minimum outage probability (P_{out}), where $R_k^* = \arg \min_{R_{l,2k-1}} (P_{\text{out}})$. R_k^* received a broadcast signal from a source then detect a signal by Maximum-Likelihood (ML) receiver, decoded and re-encoded before transmit to the selected destination node D_k^* . The optimal path output is $\mathbf{R} = \{S_0, (R_k^*, D_k^*), (R_K^*, D_0^*)\}$, where $k = 1, \dots, K$. The received signal from R_k^* to D_k^* can be calculate by an expression

$$\gamma_{R_k^*, D_k^*}^{\text{coop}} = \sqrt{P_{R_k^*}} h_{R_k^*, D_k^*} \tilde{x} + n_{D_k^*} \quad (4)$$

where $P_{R_k^*}$ represents transmit power from a selected relay (R_k^*) to D_k^* , $\tilde{x}$ represents the decoded transmit symbol, $h_{R_k^*, D_k^*}$ represents the channel impulse response of R - D in cluster k^{th} , $n_{D_k^*}$ represent AWGN at the destination receiver.

The destination relay (D_k^*) will combine received signal from S and R_k^* by C-MRC technique (5). Notice that, at high $\gamma_{SR_k^*}$, the detector places full confidence to the arriving signals from the relay. At low $\gamma_{SR_k^*}$ the confidence is weighted according to the ratio of both hops, those are SR_k^* and $R_k^*D_k^*$ links, respectively. We detect a received symbol by using a maximum likelihood (ML) receiver. Then, the destination relay (D_k^*) will be a source ($S_{l,2k-2}$) for a next connected cluster. The received signal is detected and re-encode before transmit to the relay in the new cluster.

At the last cluster, we select a cooperative relay (R_K^*) who achieve minimum outage probability from $R_k^* = \arg \min_{R_{l,2K-1}} (P_{\text{out}})$. In this paper, we assume five relays in each hop ($L = 5$).

$$\gamma_{C-MRC}^{\text{coop}} = \frac{\sqrt{P_S} h_{S, D_k^*}^* y_{S, D_k^*}}{n_{D_k^*}} + \frac{\min(\gamma_{S, R_k^*}, \gamma_{R_k^*, D_k^*})}{\gamma_{R_k^*, D_k^*}} \left(\frac{\sqrt{P_R} h_{R_k^*, D_k^*}^* y_{R_k^*, D_k^*}}{n_{D_k^*}} \right) \quad (5)$$

Given $l = 1, \dots, L$ being the relay nodes, $m = 1, \dots, M$ being the communication hops, and $k = 1, \dots, K$ being the index of clusters in the communication network. Let S denotes the source node, R_k^* denotes the selected relay node at the k^{th} cluster, D_k^* denotes the selected destination node at the k^{th} cluster, where a hop index $m = 2k$. The details of a proposed protocol are summarized below.

Initialization: $S = S_0$

Recursion:

For $k = 1 : K - 1$

$D_k^* = \arg \max_{D_{l,2k}} (\gamma_{S, D_{l,2k}})$, $l = 1, 2, \dots, L$

$R_k^* = \arg \max_{R_{l,2k-1}} (P_{\text{out}})$

where P_{out} is outage probability

- Decode at R_k^* and remodulate
- Send from R_k^* to D_k^*
- C-MRC for cooperative communication protocol according to (5)
- Decode at R_k^* and remodulate at D_k^*

$S = D_k^*$

End

$D_K^* = D_0$

$R_K^* = \arg \max_{R_{l,M-1}} (P_{\text{out}})$

where P_{out} is expressed in (20)

Output the optimal path $\{S_0, (R_k^*, D_k^*), (R_{M-1}^*, D_0^*)\}$, where $k = 1, \dots, K$.

Next, we studied the effect of the channel qualities between source to relay and relay to destination for the optimum power allocation strategy. The MRC expressions in (4 and 5) cannot guarantee the maximum of total SNR at the destination. Hence, the power allocation objective is to minimize the approximated P_{out} with respect to user power, subject to a fixed total power constraint. The concept of power allocation is that the quality of the decoded symbols and $\tilde{x}$ greatly depends on the channel variances of both phase I and phase II. If we define the transmit power P_S for the source and P_R is the transmit power for the relays, for a fixed total transmission power of $P_S + P_R = P_T$, where P_T is the total transmit power, then we can write the power allocation condition as

$$P_T = (1-\lambda)P_S + \lambda P_R \quad \text{at } 0 < \lambda < 1 \quad (6)$$

where λ is a power allocation factor between P_S and P_R .

According to the outage probability expression in (20), we are able to heuristically search for optimum power allocation by replacing P_R with λP_S and P_S with $(1-\lambda)P_S$. In our study, we use computer simulations to validate the optimum power allocation concept. Fig.4 show the P_{out} simulation results of the proposed the best destination relay selection protocol with changing power range of 0 to 1.

III. SIMULATION RESULTS

In this section, based on computer simulations by MATLAB software, performance evaluations of the proposed the best-destination relay selection protocols are examined. For the sake of comparison, the conventional multi-hop DF protocol for five relay and destination nodes in each cluster between the source and the destination. The BPSK modulation with a total transmitted power has average energy 1, a variance of a noise is N_0 and bandwidth efficiency is 1 bit/s/Hz. In addition, Jake's model [12] is employed with a normalize doppler shift of 5,000 Hz for simulating Rayleigh fading channels, and we also assume all channel link variances in the system are depend on the distance between nodes in linear system model.

Figure 2 is simulation results of the proposed best-destination relay selection in the first cluster. We found that when fixed the number of cooperative relay and vary the number of destination. For example, one relay one destination (1R1D), one relay two destinations (1R2D), and one relay three destinations (1R3D). The system achieved more diversity gain. On the other hand, when we fixed the number of destination and vary the number of relay. For example, one relay two destinations (1R2D) and two relays two destinations (2R2D). The system achieved a little bit more coding gain.

Figure 3 shows that P_{out} performance of the proposed the best-destination relay selection protocol by simulation, the source is moving when 10,000 bits are transmitted, and the destination for three clusters. The results show that the proposed protocol is better than the conventional multi-hop communication. The SNR difference in comparison with the

proposed protocol for three relays and three destinations (3R3D), specifically, 13 dB and 14 dB at P_{out} of 10^{-2} . In addition, the proposed protocol will achieve more coding gain when the number of candidate relays are increasing. However, less coding gain when the number of candidate relays more than three.

We can summarize the strategy of power allocation to the proposed the best-destination relay selection as follows. In this system, we should put more power at the destination nodes and less power at the relay node. For a high SNR case, we can observe the effect of the channel qualities on the power allocation strategy, as in Figure 4, by plotting the P_{out} as a function of λ at SNR = 10dB, 20dB, and 30dB.

IV. IMPLEMENTATION ISSUES

In practical, the receiver can not detect data completely at phase I. To solve this problem, at phase II, we can recover data by using cyclic redundancy check (CRC) technique, or by define the received SNR threshold. When the source moving after transmit data every 10,000 bits, we can estimate the channel impulse response by short-term statistics technique in [13]. The source will know channel variances, create a cluster, and select the cooperative relay by the proposed protocol. Each cluster may implemented in distributed way. In [14], a distributed relay selection algorithm is proposed where each relay sets a timer based on its measured channel gain. The larger the channel gain, the shorter the timer should be. In this way, the timer of the relay with the best channel will expire first. That relay then sends a flag signal. As soon as all the other potential relays hear the flag signal, they back off. To deal with the possible collision problem resulting from the hidden-node problem, each of these relays can randomly avoid transmission and wait to see if other relays are re-transmitting. Using the local-timer concept proposed in [14], that present a decentralized implementation for the per-hop relay selection can be applied to our proposed protocol. Even though, the decentralized implementation scheme is assuming each node has obtained knowledge about the mean channel state information (CSI) at the current cluster, in practice, the distribution for the mean CSI between any two adjacent relay clusters might be another implementation issue worthy of concern. Two possible approaches could be used to deal with this issue. One is to combine this information distribution into the process of forming and maintaining relay clusters. As an example, it could be done using destination initiated flooding, in which nodes periodically flood updates of the mean CSI in a large time scale. The other is to utilize the Request to Send/Clear to Send (RTS/CTS) and Code Division Multiple Access (CDMA), which has been suggested in [15]. In [15], the instantaneous CSI at the current hop and downstream need to be exchanged for each transmission; however, in our proposed cooperative protocol, only the mean CSI at the current cluster is required. The resulting overhead could be acceptable in practice. In addition, it seem the proposed BDSR limited for the system that has even hops. In case of the system has odd hops, we can select the cooperative relay from

neighbor nodes in same column of the source, to help the source transmit the signal to the destination.

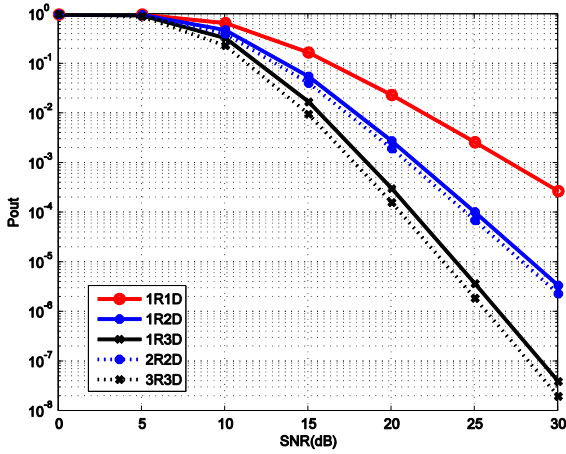


Figure 2. Simulation result between the proposed best-destination relay selection in the first cluster, various number of relays and destinations when the source is fixed.

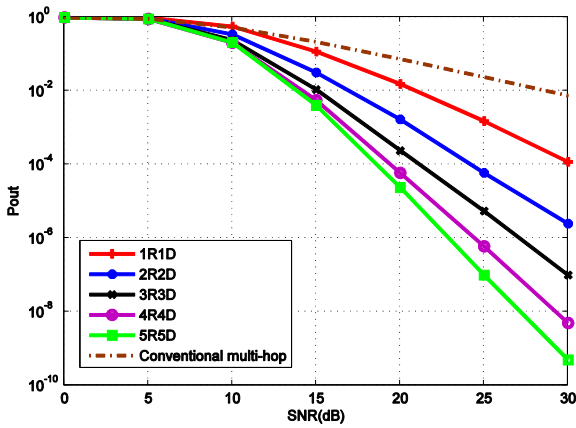


Figure 3. Comparison between the proposed best destination relay selection and conventional multi-hop, when the source is moving for three clusters.

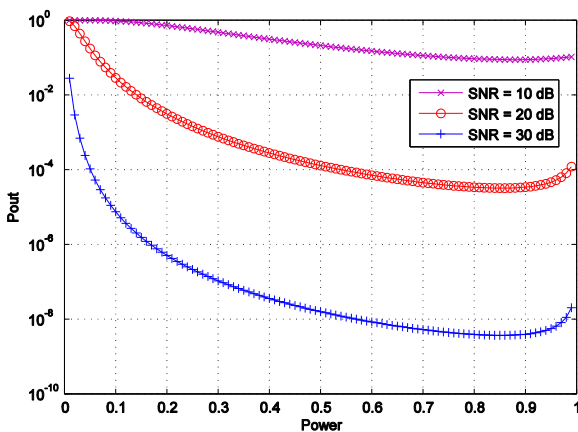


Figure 4. P_{out} of the proposed cooperative protocol (1R3D) with various transmit power at SNR = 10, 20, and 30 dB.

V. CONCLUSIONS

In this paper, we propose adaptive protocol for cooperative multi-hop wireless networks. An analysis focusing on the first cluster. Then, investigate the results when a number of cluster is increasing. The simulation results indicate that a proposed protocol significantly outperforms the conventional multi-hop protocol. The main reason is the influence of diversity gain from many direct transmissions that improving SNR 5 dB at the outage probability lower than 10^{-6} . Moreover, we performed an optimum power allocation to achieve better system performance. Future more, we conducted a proof to confirm that the outage probability analysis that nobody has been not derive by comparison with a Monte carlo simulation. The curve of analysis and simulation are very similar.

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Smich Butcharoen received his Bachelor degree in telecommunication engineering from Suranaree University of Technology, Nakhonratchasima, Thailand in 1997. Master degree in information technology from King Mongkut's University of Technology North Bangkok, Thailand in 2004. Currently, he is a Ph.D. candidate in wireless communication engineering of The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, Thailand.



Chaiyod Pirak received his Bachelor degree in telecommunication engineering from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 2001 and Ph.D. degree from University of Maryland, College Park, MD, USA in 2005. He is holding a lecturer position at communication engineering department of TGGS. His research interests include the area of wireless communication.