Decode-and-Forward Cooperative Protocol for Multiuser Communication Systems

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Abstract

Cooperative diversity is a promising solution for diversity gain, multiplexing gain and energy saving. This technique involves multiple users sharing resources in order to build a virtual antenna array in a distributed manner. In this paper, we propose multi-user cooperation strategy that allows multiple users to transmit their data simultaneously in decode-and-forward relaying systems. We consider non-orthogonal transmission scenario where users interfere each other. The proposed protocol is well-configured to cope with the interfering scenario. We introduce 3-user cooperation strategy and extend the protocol to arbitrary N-user cooperation strategy. Analytical results show that proposed scheme achieves diversity order of 2 without any loss of multiplexing gain while conventional schemes experience half-loss of multiplexing gain or have several drawbacks. We confirm through computer simulations that the proposed protocols provide higher data rate with more reliability than the conventional schemes.

I. Introduction

In recent few years, many cooperative communication protocols have been studied to acquire diversity gain in wireless fading channel environment. One representative work is Sendonaris’ [1] and Laneman’s [2,3]. Since those several cooperative communication protocols have been introduced, many researches have been performed to improve its performance [4,5] and extended to channel coding [7], multi antenna environment [9], and multi-user environment [5,6,8].

In this paper, we propose multiuser cooperation diversity protocol, especially cooperative multiple access channel which multiple users share their data to send to common destination (e.g. Base station). Even though there have been many prior works on multiuser case like Laneman [2,3], Azarian [5] and Ding [8], those works had several inevitable drawbacks which came from halfduplex assumption. For example, selection decode-and-forward(SDF) protocol [3] requires extra orthogonal channels for relaying so it results in loss of multiplexing gain and the remaining two protocols require extra operation like superposition modulation or creating artificial ISI which is used to recover multiplexing gain while achieving diversity gain.

Therefore, this paper focuses on non-orthogonal transmission which does not need any additional resource and proposes efficiently configured protocol by exploiting multiuser situation to recover multiplexing gain loss while achieving diversity gain. In detail, proposing protocol provides inter-user interference cancellation process so that cooperating users can easily share their data.

And we adopted decode-and-forward(DF) relaying because we regarded it as practical scenario as we can see at IEEE 802.16j adopting DF system even though DF protocol requires additional decoding process at relaying nodes.

We also analyze the proposed protocol in terms of diversity order and compared with direct transmission and protocols in [3],[5].

The rest of this paper is organized as follows: In section II, system model is described and our protocol is described in section III. In section IV, we analyze the diversity order and diversity-multiplexing tradeoff of the protocol. Simulation results for our protocol are shown in Section V. Conclusion is given in section VI.

II. System Model

We consider multiple access channel with several users which cooperate to transmit their own symbols to one common destination as shown Fig 1. This paper also assumes that channels between nodes are experiencing Rayleigh fading and all users are equipped with one antenna, have equal power constraint and CSIR (CSI at Receiver side).

We assumed time-slotted and half-duplex system which consists of frames and each frames are consists of N timeslots. N denotes number of users which participate in cooperative transmission. Channel coefficient $h_{ij}$ denotes the Rayleigh flat fading channel from node $i$ to node $j$ where $i \in \{U_1,U_2,U_3,...,U_N\}$, $j \in \{U_1,U_2,U_3,...,U_N,D\}$, and pathloss is considered in $h_{ij}$. $U_i$ denotes $i$th user and $D$ denotes common destination node. $x_j$ denotes data symbol transmitted at timeslot $i$ of $j$th frame. We denoted all indices in italic font.

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A. 3-user cooperation case

A simple example of the proposed cooperation protocol is shown in Fig. 2. Fig. 2 shows the 3-user cooperation case (N=3) which can be the most appropriate example. At first, In timeslot 1 of first frame, \( U_1 \) transmits \( x_{1,1} \), \( U_2 \) transmits \( x_{2,1} \) at timeslot 2 of first frame and \( U_3 \) relays \( x_{2,1} \) simultaneously if \( x_{2,1} \) is decoded correctly by \( U_1 \) in the previous timeslot. In timeslot 1 of first frame, \( U_1 \) transmits \( x_{1,1} \) and \( U_3 \) relays \( x_{3,1} \) if \( x_{3,1} \) is decoded correctly by \( U_1 \) in the previous timeslot. Note that in timeslot 2 at first frame, \( U_1 \) receives \( x_{1,1} \) relayed by \( U_3 \) as well as \( x_{2,1} \). In order to relay \( x_{2,1} \), user 1 have to cancel \( x_{2,1} \) relayed by \( U_3 \) which is the interference when decoding \( x_{2,1} \). However, \( U_1 \) already knows what \( x_{2,1} \) is, because \( x_{2,1} \) is transmitted by itself in first timeslot. In next timeslots, participating users change their role in turn. For example, following equations show received data by destination and user 2 at timeslot 2 of \( k \) th frame,

\[
y_{2,k} = h_{2,k} x_{2,k} + h_{3,k} x_{3,k} + n_{2,k} \quad (1)
\]

\[
u_{2,k} = h_{2,k} u_{2,k} + h_{3,k} u_{3,k} + n_{2,k} \quad (2)
\]

As we can see at (2), user 1 receives its own symbol estimated by user 3 so that user 1 can decode \( x_{2,k} \) without interference and thus user 1 can relay \( x_{2,k} \) at next timeslot (3rd timeslot) in 1st frame.

B. General N-user cooperation

This strategy also can be extended to general N-user system with additional decoding process in each user node. (Or we next consider a system with N users and one destination). Each \( k \) th frame consists of N timeslots. During timeslot \( n \) of \( k \) frame, user \( n \) transmits \( x_{n,k} \) and user \( n+1 \) relays \( x_{n+1,k} \) if user \( n+1 \) decodes correctly \( x_{n+1,k} \) which is transmitted in the previous timeslot by user \( n \) while the destination receives \( y_{n,k} \) and user \( n+2 \) receives \( u_{n+2,k} \) where \( y_{n,k} \) denotes the symbol which is received by the destination in time slot \( i \) at \( j \) th time frame, and \( u_{n,j} \) denotes the symbol which is received by user \( i \) in time slot \( j \) at \( k \) th time frame.

\[
y_{n,k} = h_{n,k} x_{n,k} + h_{n+1,k} x_{n+1,k} + n_{n,k} \quad \text{(3)}
\]

\[
u_{n+2,k} = h_{n+2,k} u_{n+2,k} + h_{n+1,k} u_{n+1,k} x_{n+1,k} + n_{n+2,k} \quad \text{(4)}
\]

where

\[
x_{n,k} = \begin{cases} x_{n,k} & \text{if } |h_{n+1,k}| > g(\rho) \\ 0 & \text{if } |h_{n+1,k}| \leq g(\rho) \end{cases}
\]

the threshold is \( g(\rho) = \left(\frac{2^\rho - 1}{\rho}\right) \), \( \rho \) denotes SNR, and \( n_{n,k} \) is the additive complex Gaussian noise at the destination in time slot \( i \) at \( j \) th time frame and \( n_{n,k} \) is the additive complex Gaussian noise at user \( i \) in time slot \( j \) at \( k \) th time frame. From (4) in order to cancel the interference \( x_{n+1,k} \) and decode the information \( x_{n,k} \), the proposed protocol can achieves diversity order 2 in multiuser scenario without any additional resource or extra operation while requiring roughly similar or less decoding complexity in each nodes and destination.

III. Proposed Protocol

A. 3-user cooperation case

As we can see at (2), user 1 receives its own symbol estimated by user 3 so that user 1 can decode \( x_{2,k} \) without interference and thus user 1 can relay \( x_{2,k} \) at next timeslot (3rd timeslot) in 1st frame. In the case of \( N=3 \), user \( n+2 \) uses the information about \( x_{n+1,k} \) which transmitted by itself in two time slot before, as explained in Fig. 2.

During \( n+1 \) time slot, user \( n+2 \) relays \( x_{2,k} \) decoded successfully in the previous time slot, and user \( n+1 \) transmits \( x_{n+1,k} \) while destination receives \( y_{n+1,k} \) and user \( n+3 \) receives \( u_{n+3,k} \).

\[
y_{n+1,k} = h_{n+1,k} x_{n+1,k} + h_{n+2,k} x_{n+2,k} + n_{n+1,k} \quad \text{(5)}
\]

\[
u_{n+3,k} = h_{n+3,k} u_{n+3,k} + h_{n+1,k} u_{n+1,k} x_{n+1,k} + n_{n+3,k} \quad \text{(6)}
\]

From (1), (3) the signal model of the proposed protocol is written as

\[
Y_{n,k} = HX_{n,k} + N_{n,k}
\]

where

\[
Y_{n,k} = \begin{bmatrix} y_{n,1}^T \\ x_{n,1}^T \end{bmatrix}, \quad X_{n,k} = \begin{bmatrix} x_{n,k,1}^T \\ x_{n,k,2}^T \end{bmatrix}, \quad N_{n,k} = \begin{bmatrix} n_{n,k,1}^T \\ n_{n,k,2}^T \end{bmatrix}
\]

\[
H = \begin{bmatrix} h_{n,1,k} w_{11} & h_{n,1,k} w_{12} & 0 \\ 0 & h_{n,1,k} w_{22} & h_{n,1,k} w_{23} \end{bmatrix}
\]

\[
w_{11} = \begin{cases} 1 & \text{if } |h_{n+1,k}| > g(\rho) \\ 0 & \text{if } |h_{n+1,k}| \leq g(\rho) \end{cases}
\]

\[
w_{22} = \begin{cases} 1 & \text{if } |h_{n+1,k}| > g(\rho) \\ 0 & \text{if } |h_{n+1,k}| \leq g(\rho) \end{cases}
\]

In this paper, for the simplicity, we assumed that all participating users are well-grouped so that links between each user are not in deep fading state which means \( w_{11} = w_{22} = 1 \). Comparing with previous work in [2][5][8], the proposed protocol can achieves diversity order 2 in multiuser scenario without any additional resource or extra operation while requiring roughly similar or less decoding complexity in each nodes and destination.
IV. Performance Analysis

In this section, we analyze the proposed protocol in terms of the diversity-multiplexing trade-off [11]. The diversity gain is defined as

\[
d = \lim_{\rho \to \infty} -\log P_{\text{out}} \log \rho
\]

and the multiplexing gain is defined as

\[
r = \lim_{\rho \to \infty} R(\rho) \log \rho
\]

where \(\rho\) denotes SNR, \(P_{\text{out}}\) denotes outage probability, and \(R(\rho)\) denotes bits per channel use.

The upper bound of outage probability \(P_0\) is [6]

\[
P_0 \leq P_0 = P_1 + P_2 + P_3 + P_4
\]

where

\[
P_1 = \Pr[I(x_{n,1}, Y_1 | x_{n-1,1}, x_{n+1,1}) < R]
\]

\[
P_2 = \Pr[I(x_{n,1}, x_{n,1}; Y_1 | x_{n-1,1}) < 2R]
\]

\[
P_3 = \Pr[I(x_{n,1}, x_{n,1}; Y_1 | x_{n+1,1}) < 2R]
\]

\[
P_4 = \Pr[I(x_{n-1,1}, x_{n+1,1}; Y_1 | x_{n,1}) < 3R]
\]

Since the diversity order follows the slowest decaying rate of outage probability [6], and from inequality (11), we can infer \(D_0\) is the minimum diversity order where \(D_i\) denotes the diversity order of \(P_i\) and \(D_u\) denotes the diversity of union probability \(P_u\), thus, the diversity order of proposed protocol \(D_o\) is lower bounded by \(D_1\).

\[
D_0 \geq D_1
\]

The signal model for the outage probability \(P_1\) is

\[
Y_{n,1} = H_{n,1} X_{n,1} + N_{n,1}
\]

where

\[
H_{n,1} = \begin{bmatrix} 0 & h_{n,1,0} & 0 \\ 0 & 0 & h_{n,1,0} \end{bmatrix}
\]

and \(R\) denotes target rate. Using (15), we can show that

\[
P_1 = P_{\text{out}}(\log(1 + H_{n,1}^T H_{n,1}) < R)
\]

\[
= \Pr\left[\left|h_{n,i,\nu,\nu}^T + h_{n,\nu,\nu}^T\right|^2 < 2^R - 1\right]
\]

where \(|h_{n,i,\nu,\nu}|^2\), \(|h_{n,\nu,\nu}|^2\) are i.i.d. exponentially distributed random variable.

From (9), (15), the diversity order of the proposed protocol can be calculated as

\[
D_o \geq D_1 = 2
\]

Using (9), (10), (15) the diversity-multiplexing tradeoff [11] can be shown to be easily

\[
d(r) = 2(1-r)
\]

From above results, it is shown that the proposed protocol has diversity gain and multiplexing gain is recovered.

V. Simulation Results

In Fig 3 and Fig 4, we show the outage probability of the proposed protocol compared with SDF protocol in [3] which utilize 2 users and achieves diversity order of 2, and CMA-NAF protocol in [5] which utilize 3 users and achieves diversity order of 3. Distance between users is the same as the distance from user to destination and pathloss exponent is 4. In Fig 3, target rate \(R\) is 2 bps/Hz and \(N=3\). Proposed protocol outperforms SDF protocol in all SNR region. However, CMA-NAF protocol outperforms proposed protocol in high SNR region, since diversity order for CMA-NAF protocol is 3 while proposed protocol’s diversity order is 2. In Fig 4, target rate \(R\) is 4 bps/Hz. The proposed protocol outperforms both protocols at all practical SNR region. We can expect that the difference between the proposed protocol and CMA-NAF protocol is larger as target rate increases.

Comparing with CMA-NAF, the proposed scheme performs similarly when target rate is 2 bps/Hz, but performs better as target rate increases. In detail, the SNR region in which proposed protocol outperforms CMA-NAF protocol is widened as target rate increases. This is due to AF (amplify-and-forward) nature of CMA-NAF protocol, that is, when number of user increases, even if CMA-NAF can achieve higher diversity order, SNR loss is also occurred inevitably due to amplifying noise within received signal over again.

VI. Conclusion

In this paper, we propose a simple spectral efficient cooperative protocol in multiuser environment. We introduce 3-user cooperation protocol which is the most pertinent example primarily and extend to general \(N\)-user cooperation protocol.

As shown in section IV, we derive that the proposed protocol achieves diversity order 2 without loss of multiplexing gain. Simulation results show that the proposed protocol outperforms SDF protocol by 2–3dB at practical SNR region while achieving the same diversity order. Furthermore, the proposed protocol also outperforms CMA-NAF protocol. For future work, decoding and demodulation issues will be dealt with.
Fig. 4 Outage probability vs SNR, target rate R=4 (bps/Hz)

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주 최  (사)한국통신학회
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한국통신학회
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