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Cooperative Transmission with Broadcasting and Communication

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***Abstract*—In this paper, we propose a novel cooperative transmission strategy with broadcasting and cellular communication in a hybrid network system. With the help of cellular base station (CBS), two cooperative schemes are analyzed to improve broadcast performance. We define two thresholds in this paper. For users whose channel quality information (CQI) is less than the low threshold, e.g., the users near the edge of the broadcast cell, we deploy cooperative diversity transmission. Meanwhile, cooperative multiplexing transmission is exploited for users whose CQI is greater than the high threshold, such as those near the broadcasting base station (BBS). Our simulation results validate the effectiveness of our proposed cooperative schemes.**

***Index Terms*—cooperative transmission; diversity; multiplexing; broadcast communication;**

I. Introduction

Recently, with the rapid growth of information industry, more and more user services require high transmission rate. In this regard, only traditional broadcast network or traditional cellular network cannot achieve satisfactory performance. In the traditional broadcast network, larger region can be covered than cellular network. Since it has high efficiency of one-way transmission, it is good for pushing some public service content, such as digital TV and popular radio. However, without uplink feedback channel, it is not conductive to transmit personalized content. The comparison of the traditional cellular network and broadcast network shows that cellular network has smaller coverage, more efficient two-ways communication, better performance of personalized content delivery but lower broadcasting and pushing efficiency than the broadcast network. To overcome the aforementioned problems, broadcast and cellular cooperative transmission are put forward, which can take full advantage of the broadcast networks and cellular networks carrying different business, and distribute the network resource. By using such cooperative transmission strategy, we can improve the system performance.

The exiting broadcast network usually works with the base station which can coverage a large region and transmit signals at high power. But the quality of the received signal may be poor due to the shadow fading caused by block, frequency selective fading caused by multipath, and Rayleigh fading and Doppler shift caused by the relative motion between the transmitter and the receiver, especially for the users near the edge of the coverage areas. [1] proposes that broadcasters need cooperate with telecommunication operators to support interactivity. New technologies, methods, services and particularly system level solutions for a combined interactive broadcasting, navigation and mobile communication environment are proposed in [2]. [3] analyzes the different spectrum requirements when broadcast data is transmitted by using cellular transmitter. But they don't mention the solution to the aforementioned problems. [4] proposes that we could built a dedicated broadcast relay station in the edge of the network. The broadcast signal is transmitted to the relay station by the fiber, and then the relay transmits the received signal to the destination, or uses CBS which is adjacent to the blind point as the relay to transmit the received signal. However, this cannot effectively improve the signal quality in the edge and the spectrum efficiency.

In this paper, we will introduce a new transmission model in the broadcasting and communication hybrid network by using both BBS and CBS. The channel quality is bad for the users in the edge of the broadcasting network due to various fading and Doppler spread, thus we deploy cooperative diversity transmission to improve the received signal quality. Meanwhile, the users near BBS own line-of-sight (LOS) transmission and have a high K-factor, so the channel quality is good. Then cooperative multiplexing transmission is exploited between BBS and CBS to increase the throughput. Considering the different power level of broadcast and communication, we will analyze the scenarios with unequal transmit power in BBS and CBS in these two cooperative schemes. In addition, with methods of [6], we can use different modulation techniques while using cooperative multiplexing transmission. The simulation results show our proposed schemes can improve the signal quality for the users whose channel quality is bad and the spectrum efficiency of the hybrid network.

The rest of this paper is outlined as follows. System model is presented in Section II. Then in Section III and IV, we introduce the cooperative diversity transmission and cooperative multiplexing transmission, respectively. In Section V, we present the simulation results of the proposed scheme compared with the conventional methods. Finally, a conclusion is drawn in section VI.

II. System Model

Consider a broadcast cell with one BBS. There are N cellular cells in this broadcast cell, as shown in Fig. 1. In this paper,

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we assume all users can receive both broadcast and cellular signals. The BBS broadcasts signal flow $[x_1, x_2, x_3, x_4 \cdots]$, where each symbol duration is T and x_n denotes the symbol transmitted at time nT, or at time slot n. The users' channel quality varies greatly in different positions. Here we define two thresholds $th1$ and $th2$ where $th1 < th2$. Some users' CQI is less than $th1$, especially those near the edge. To improve the quality of their received signals, CBS can cooperate with BBS to transmit the broadcast data. Note that the signal flow of CBS is orthogonal with that of BBS. This cooperative scheme is *cooperative diversity transmission* shown in Fig. 1(a).

While for users whose CQI is greater than $th2$, *cooperative multiplexing transmission* is exploited to improve network throughput, as shown in Fig. 1(b). Note that CBS can transmit different signals in this cooperative scheme. When users' CQI is less than $th2$ and greater than $th1$, traditional transmission without cooperation is used.

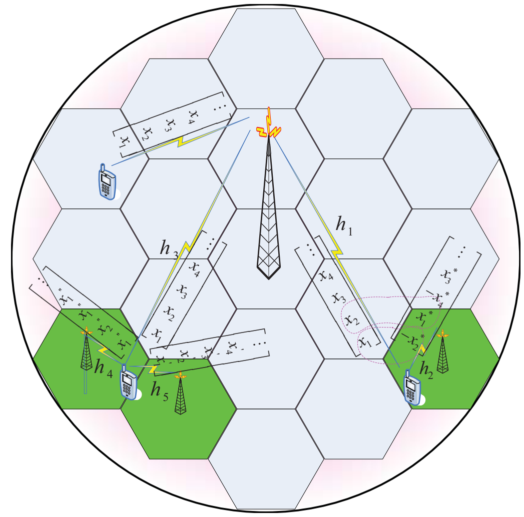
III. Cooperative Diversity Transmission

In practical broadcast systems, the received signal quality may be poor for the users whose CQI is less than $th1$ due to the shadow fading caused by block, frequency selective fading caused by multipath, Rayleigh fading and Doppler spread caused by the relative motion between the transmitter and the receiver. To overcome this problem and improve the signal quality of these users, we can use BBS and CBS cooperatively space-time or space-frequency code, i.e., *cooperative diversity transmission*.

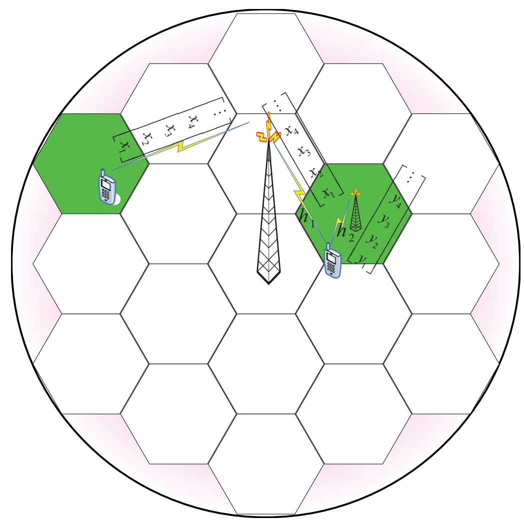
Fig. 2 depicts the process of cooperative diversity transmission. The process can be described as follows.

- *Step 1*: BBS broadcasts the signal, and both users and CBS will receive the signal. Note that BBS can transmit the signal to CBS by wire or wireless, even by the fiber.
- *Step 2*: Then, the users will feedback CQI to the CBS belonging to the same cellular cell.
- *Step 3*: The CBS receives CQI. If the CQI is less than $th1$, CBS will choose the best diversity pattern, i.e., space-time block coding (STBC) or space-frequency block coding (SFBC) based on the number of users in the cellular, the motion speed of the user, and the position of the user, etc, and then sends the cooperative request consisting of the diversity pattern to BBS.
- *Step 4*: The BBS receives the request and then makes an ACK to CBS. To guarantee the quality of retransmitted signal, BBS pushes the data to CBS by wire or fiber.
- *Step 5*: Finally, BBS sends the original information, i.e., $[x_1, x_2, x_3, x_4 \cdots]$, and CBS sends the information with the orthogonal coding simultaneously.

Next we introduce the orthogonal coding method in cooperative diversity transmission. We assume that there is only one antenna in both BBS and CBS. When there is one CBS cooperatively transmit the signal as depicted at the bottom right corner of Fig. 1, we can use complex orthogonal design proposed by Alamouti for two transmit antennas [5]. Alamouti



(a) Cooperative diversity transmission.



(b) Cooperative multiplexing transmission.

Fig. 1. System model in broadcast system with cellular cells.

2×2 design is:

$$\mathbf{G_2} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}, \tag{1}$$

where x^* is the complex conjugate of x, and the first row represents the signal transmitted from BBS, the first column represents the signal transmitted from both BBS and CBS in the first slot.

Sometimes there may exist two or more CBS who can cooperatively transmit the signal. [7] introduces a rate one QO-STBC coding scheme with three transmit antennas. [8] introduces a complex orthogonal design of rate $R = 3/4$. But they cannot be used in our proposed scheme, since BBS can only transmits the original signal without any changing. In our future work, we will try to find a new quasi-orthogonal design with rate one as depicted at the bottom left corner of the Fig.

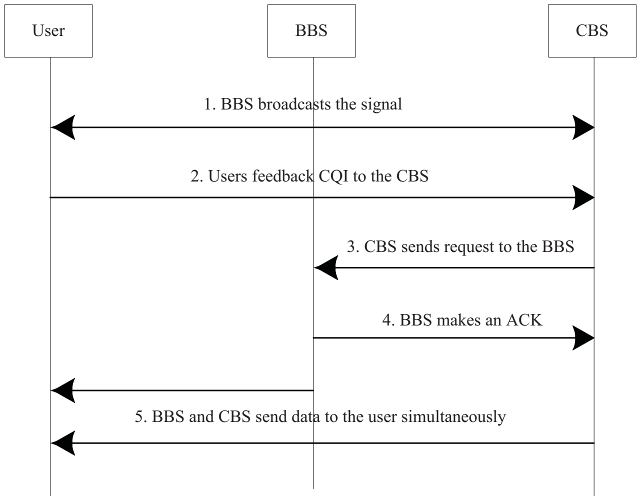


Fig. 2. The process of cooperative transmission.

1.

In practice, the transmit power in BBS and CBS is unequal, and we model a factor matrix to describe this unequal power ratio, i.e.,

$$\mathbf{D} = \begin{bmatrix} \sqrt{\alpha} & 0 \\ 0 & \sqrt{1-\alpha}. \end{bmatrix}. \tag{2}$$

We can change α to deploy any possible power ratio. Then, assuming there are two antennas in the user side, the received signal is,

$$\mathbf{R} = \mathbf{H}\mathbf{D}\mathbf{G_2}{+}\mathbf{N}, \tag{3}$$

where

$$\mathbf{R} = \begin{bmatrix} r_{t,1} & r_{t+T,1} \\ r_{t,2} & r_{t+T,2} \end{bmatrix}, \mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}, \quad \mathbf{N} = \begin{bmatrix} n_{t,1} & n_{t+T,1} \\ n_{t,2} & n_{t+T,2} \end{bmatrix}, \tag{4}$$

with $r_{t,n}$ is the received signal at the nth receive antenna at time t, $h_{i,j}$ is the channel gain from the jth transmit antenna to the ith receive antenna, and $n_{t,n}$ is the complex Gaussian noise with zero means and variance σ^2 added to the received signal at the nth receive antenna at time t. Assume that fading is constant across two consecutive symbols.

In this paper, we use minimum mean square error (MMSE) equalization at the receiver in frequency domain. The MMSE matrix is:

$$\mathbf{W} = (\mathbf{H^H}\mathbf{H}{+}\frac{\boldsymbol{\sigma^2}}{\mathbf{E_s}}\mathbf{I})^{-\mathbf{1}}\mathbf{H^H}, \tag{5}$$

where the superscript $\mathbf{H}$ denotes Hermitian transposition and $\mathbf{E_s}$ is the signal energy. Then we can use MMSE equalization to recover the transmitted signal [11].

IV. Cooperative Multiplexing Transmission

For users whose CQI is greater than $th2$, we exploit *cooperative multiplexing transmission* to improve network throughput, as shown in Fig. 1(b). The process is also depicted in Fig. 2, which is similar to the cooperative diversity transmission.

- *Step 1*: BBS broadcasts the signal to the users and CBS.
- *Step 2*: Then, the users feedback CQI to CBS belonging to the same cellular cell.
- *Step 3*: CBS receives the CQI and decides whether send the cooperative multiplexing transmission request to BBS. If the CQI is larger than $th2$, CBS will send the request to BBS.
- *Step 4*: BBS receives the request and then makes an ACK.
- *Step 5*: Finally, BBS sends the signal $[x_1, x_2, x_3, x_4 \cdots]$, while CBS sends the signal $[y_1, y_2, y_3, y_4 \cdots]$ which can be the former frame sent by BBS as the supplement to the user's push, or the cellular data used to increase the throughput.

We also assume there are two antennas in the user side. Then, the received signal is:

$$\mathbf{R} = \mathbf{HDS} + \mathbf{N}, \tag{6}$$

where

$$\mathbf{R} = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix}, \mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}, \mathbf{S} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix}, \quad \mathbf{N} = \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}, \tag{7}$$

with r_i represents the received signal at the ith received antenna, and n_i is the complex Gaussian noise with zero means and variance σ^2 added to the received signal at the ith received antenna.

The same as described in section III, we can change α in matrix $\mathbf{D}$ to deploy different power ratio. [6] introduces an unequal transmit power Spatial Multiplexing (SM) scheme, where different antennas can use different modulation type by adjusting the coefficient α. Considering low-order modulation is often used in broadcast network to achieve large coverage while modulation type can be adaptive changed in cellular network, the method in [6] can also be applied in our proposed scheme.

V. Simulation Results

We evaluate the bit error rate (BER) and the throughput performance of the proposed schemes over uncorrelated Rayleigh fading channel. In order to assess the performance enhancement of the proposed schemes compared with the traditional transmission strategy, we apply a simple simulation model. Assume that the signals are coded by Turbo coding and modulated using the QPSK scheme. We use the ideal channel estimate with the channel type is pedestrian B (PB).

Fig. 3 shows the BER performance of our proposed scheme and traditional transmission strategy with $\alpha = 1/2$ and N_r denoting the number of users' receive antennas. We can see that the BER decreases largely compared with traditional

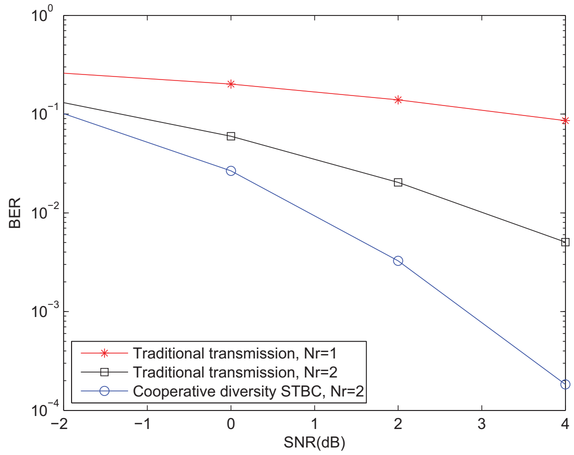


Fig. 3. BER of cooperative diversity transmission v.s. traditional transmission strategy, $\alpha = 1/2$.

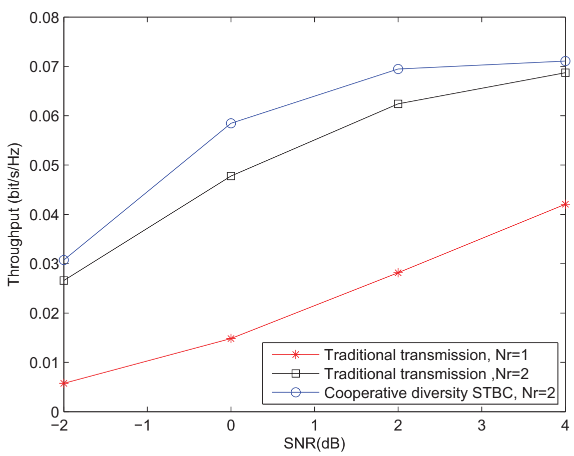


Fig. 4. THR of cooperative diversity transmission v.s. traditional transmission strategy, $\alpha = 1/2$.

transmission at the same SNR by using cooperative diversity transmission, which indicates that the signal quality for the user is improved. Fig. 4 shows the throughput when cooperative diversity transmission is applied. From the figure, we can see that the throughput increases little compared with traditional transmission. Fig. 5 shows the BER performance when α is 2/3. It can be seen that the system performance is better than others when unequal transmit power is used. As shown in Fig. 6, the throughput increases greatly by using the cooperative multiplexing transmission compared with traditional transmission strategy. From the simulation results, we can see that the system performance has improved greatly by using our proposed schemes.

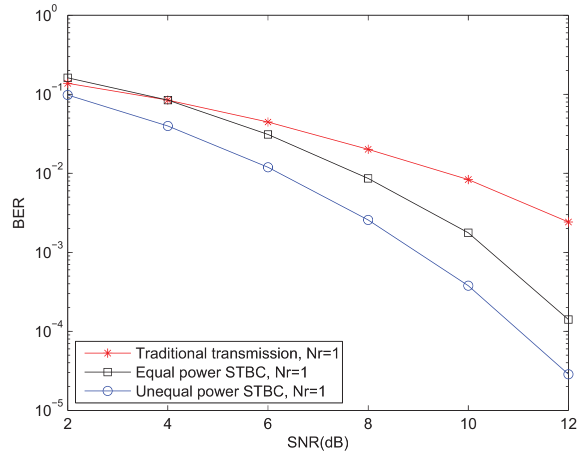


Fig. 5. BER of cooperative diversity transmission when transmit power is unequal, $\alpha = 2/3$.

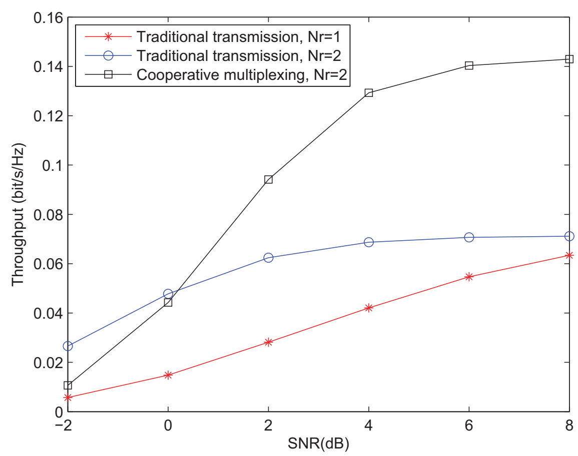


Fig. 6. THR of cooperative multiplexing transmission v.s. traditional transmission strategy, $\alpha = 1/2$.

VI. Conclusion

In this paper, we propose a new cooperative transmission strategy with broadcasting and communication in a hybrid network system. With the help of CBS, two cooperative schemes are analyzed. We define two thresholds $th1$ and $th2$ where $th1 < th2$. First, we propose cooperative diversity transmission to improve the quality of received signal for the users whose CQI is less than $th1$. In such transmission scheme, we apply Alamouti coding to improve performance. Next, cooperative multiplexing transmission is analyzed for those users whose CQI is larger than $th2$. From the simulation results, we can see cooperative diversity transmission can improve BER performance while cooperative multiplexing transmission can improve throughput performance. Therefore, it is believed that it will have a bright application prospect.

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