

LETTER

An Advanced Cooperative Scheme in the Broadcasting and Cellular System*

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SUMMARY In this letter, a cooperative scheme is proposed for the broadcasting and cellular communication system. The proposed scheme improves bit error rate (BER) performance and throughput on the edge of a cellular base station (CBS) cooperating with another CBS in the same broadcasting coverage. The proposed scheme for the enhancement of BER performance employs two schemes by a channel quality information (CQI) between a broadcasting base station (BBS) and users. In a physical area, the edge of a CBS is concatenated with the edge of another CBS. When users are on the edge of a CBS, they transmit simultaneously the CQI to CBSs, and then a BBS and CBSs transmit signals by the proposed algorithm. The two schemes apply space-time cyclic delay diversity (CDD) and a combination of space-time block code (STBC) with vertical Bell Laboratories Layered Space-Time (V-BLAST) to a signal from a BBS and CBSs. The resulting performance indicates that the proposed scheme is effective for users on the edges of CBSs.

key words: cooperative communication, OFDM, STBC, V-BLAST, diversity, multiplexing, CDD

1. Introduction

Over the past few decades, the broadcasting system has provided digital TV and radio. It is a typical way of transmission from a base station to receivers by network operators. The way is used primarily in large region. Since the broadcasting system primarily exists in downlink, receivers are not necessary to set the algorithm for connection. Therefore it is an efficient way to transmit data to subscribers. In contrast, the cellular system exists in uplink and downlink between base station and receiver. The coverage of the cellular system is smaller than the broadcasting system. The cellular system requires connections between base station and receiver and must be designed for a specific multiple access technique for uplink and downlink. The multiple access technique is either time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal and non-orthogonal code division multiple access (CDMA) or one of their hybrid combinations [1]. One merit of the cellular system is that receiver communicates with base station through uplink and downlink. Including the efficiency of the broadcasting system and the merit of the cellular system mentioned above, two and more systems are designed into

one system called interworking system. The interworking system maintains the existing system and offers mutual advantages to system operators [2]. Sharing their platforms, the operators are able to reduce initial costs of starting the system [3].

A scheme is proposed in [4] to obtain all merit of the broadcasting system and the cellular system. The cooperative scheme considers channel condition between base station and receiver to transmit. When the channel condition is poor, a base station transmits in the STBC scheme [5] with other base station to decrease error probability. Under good conditions, a base station transmits in V-BLAST scheme [6] to achieve high throughput.

In this letter, a scheme is proposed for the improvement of performance when a user is on the edge of a cellular cell. The scheme employs three base stations and has the better performance than the conventional scheme in [4] when a user is on the edge of CBSs in which the concatenated coverage of cells is formed.

The remaining sections are composed as follows. Section 2 presents a broadcasting and cellular system and channel model and Sect. 3 mentions the conventional scheme. In Sect. 4, the proposed schemes are shown. The performance results are shown in Sect. 5 and the conclusion is in Sect. 6.

2. System and Channel Model

In this letter, a broadcasting cell and cellular cells are considered for the proposed scheme. In the broadcasting and cellular system, the communicating extent of CBSs is concatenated as BBS coverage. In the system, one BBS near the center of a broadcasting cell with one antenna transmits to each user with two antennas shown in the case (1) of Fig. 1. And in need of cooperation, a CBS near the center of a cellular cell with one antenna also transmits to each user in the case (2) of Fig. 1.

The system assumes that the transmitted signals experience Rayleigh fading through the channel and the channel is stable for the transmission of one STBC. The channel is randomly regenerated and independent of the previous channel whenever the code word is transmitted. In addition, the system assumes complex Gaussian random noise added by receiver. The received signal vector \mathbf{Z} is denoted as follows,

$$\mathbf{Z} = \mathbf{H}\mathbf{P}\mathbf{X} + \mathbf{n}, \quad (1)$$

where the received signal \mathbf{Z} is a complex matrix through the channel, \mathbf{X} denotes a matrix of the transmitted complex

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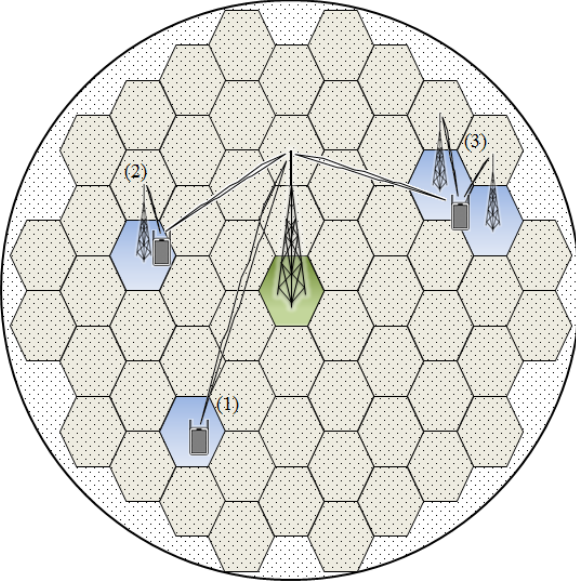


Fig. 1 System configuration of the broadcasting and cellular system.

orthogonal frequency division multiplexing (OFDM) symbols, \mathbf{H} denotes the complex channel matrix, \mathbf{P} allocates the power of transmission of BBS and CBS and \mathbf{n} is the additive white complex-Gaussian noise vector with zero mean and σ^2 variance.

3. Conventional Cooperative Transmission Scheme

The conventional scheme is formed from one BBS with an antenna, one CBS with an antenna and users with two receiving antennas. It consists of three schemes that the first scheme is the broadcasting transmission for one BBS and users in the case (1) of Fig. 1, the second scheme is diversity transmission for one BBS, one CBS and users in the case (2) of Fig. 1 and the third scheme is multiplexing transmission for one BBS, one CBS and users in the case (2) of Fig. 1. Diversity and multiplexing transmissions are cooperative ways with a CBS transmitting to each user. By CQI, the conventional scheme chooses a transmission way of them in range of an appropriate threshold for the condition between BBS and user [4]. In this scheme, the cooperative transmission promotes the BER performance. The performance for communication is generally required to be under 10^{-3} BER. Therefore, the system chooses a type to obtain the required performance.

4. Proposed Cooperative Transmission Scheme

The conventional transmission scheme can't guarantee the quality of the received signals when users are distant from each CBS. If users are on the edge of a CBS, they will suffer attenuation of the transmitted signal from the BBS and CBS. The signal from the BBS suffers worse attenuation relative to CBS since the distance between the BBS and the user is generally longer than the CBS and the user. It causes degra-

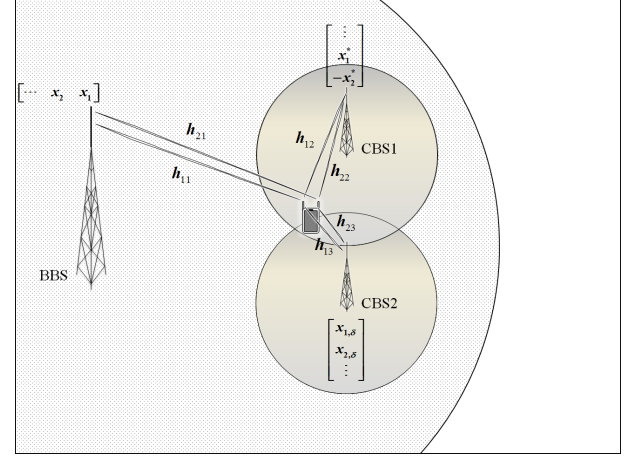


Fig. 2 Transmission scenario for STBC and CDD under poor channel conditions.

Table 1 Transmission sequence for STBC and CDD under poor channel conditions.

Time slot	BBS	CBS1	CBS2
t	\mathbf{x}_1	$-\mathbf{x}_2^*$	$\mathbf{x}_{1,\delta}$
t+T	\mathbf{x}_2	\mathbf{x}_1^*	$\mathbf{x}_{2,\delta}$

ation of BER. In general, propagation models in wireless communications are represented as a function of distance d between a base station and a user [7].

$$L_p(d) \propto \left(\frac{d}{d_{ref}} \right)^n, \quad (2)$$

where $L_p(d)$ is the value of a mean path loss as a function of distance d , d_{ref} is a reference distance corresponding to a point located in the field from a base station, the reference distance is typically 1 km for large cells and n is 2 in free space of a sphere.

With one BBS and two CBSs in the case (3) of Fig. 1, the proposed scheme achieves better than the BER and throughput performances of the conventional scheme when users are on the edge of a CBS since the transmitted signals attenuate by the channel condition and the distance. In this case, one BBS transmits to one user in its coverage and the user locates on the edge of a CBS overlapped with the edge of another CBS. By the attenuation, it is difficult to apply the conventional scheme for transmission in the BBS and CBS. Then, the proposed cooperative scheme of one BBS and two CBSs is able to overcome the decrease of power.

A user broadcasts a CQI of the channel between one BBS and itself to a CBS in which the user locates. A CQI from user is decided by the signal to noise ratio (SNR) measured at user. In Fig. 2, when the condition of the channel between BBS and users is poor, the BBS and the CBS1 transmit to a user on the edge of the CBSs in STBC scheme, and the CBS2 transmits CDD signals for BBS signal to the user in the shared area of the CBSs [8], [9]. The transmission sequence is indicated in Table 1 and the transmission scenario is in Fig. 2.

In the two time slots in Table 1, the BBS and the CBS1

Table 2 Transmission sequence for STBC and V-BLAST under good channel conditions.

Time slot	BBS	CBS1	CBS2
t	\mathbf{x}_1	$-\mathbf{x}_2^*$	\mathbf{y}_1
t+T	\mathbf{x}_2	\mathbf{x}_1^*	\mathbf{y}_2

transmit the symbols in STBC scheme and CBS2 transmits CDD symbols of BBS symbols in the same time slot. Since the channel condition from a BBS to users decreases the BER performance of received signals, the CBS2 obtains the better BER performance for BBS signals using the CDD scheme. The received signals are composed in polynomial form as follows,

$$\begin{aligned} z_{1,1} &= x_1 h_{1,1} - x_2^* h_{1,2} + x_{1,\delta} h_{1,3}, \\ z_{2,1}^* &= x_2^* h_{1,1}^* + x_1 h_{1,2}^* + x_{2,\delta}^* h_{1,3}^*, \\ z_{1,2} &= x_1 h_{2,1} - x_2^* h_{2,2} + x_{1,\delta} h_{2,3}, \\ z_{2,2}^* &= x_2^* h_{2,1}^* + x_1 h_{2,2}^* + x_{2,\delta}^* h_{2,3}^*. \end{aligned} \quad (3)$$

At the second time slot in Table 1, the received signals are transformed into complex-conjugated equations for orthogonality of the received signals. The equation of the received signals is arranged in Eq. (4).

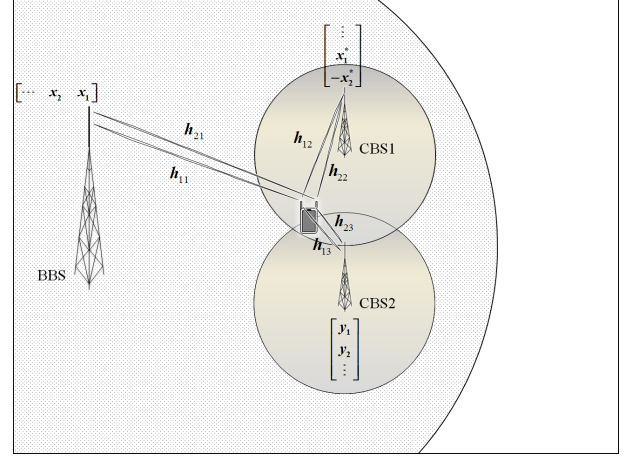
$$\begin{bmatrix} z_{1,1} \\ z_{2,1}^* \\ z_{1,2} \\ z_{2,2}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} + e^{j\theta} h_{1,3} & -h_{1,2} \\ h_{1,2}^* & h_{1,1}^* + e^{-j\theta} h_{1,3}^* \\ h_{2,1} + e^{j\theta} h_{2,3} & -h_{2,2} \\ h_{2,2}^* & h_{2,1}^* + e^{-j\theta} h_{2,3}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2^* \end{bmatrix}, \quad (4)$$

where the symbol x_i is transmitted from the BBS for the i th symbol and $x_{i,\delta}$ from the CBS2 is applied in CDD method. $z_{i,j}$ is the signals received for the j th antenna of a user at the i th time slot and $h_{i,j}$ is the channel from the j th base station to the i th antenna of a user, i.e., $h_{i,1}$ represents the channel between the BBS and the i th antenna of a user, $h_{i,2}$ represents the channel between the CBS1 and the i th antenna of a user and $h_{i,3}$ represents the channel between CBS2 and the i th antenna of a user.

Under good channel conditions, the BBS and the CBS2 transmit respectively signals in V-BLAST to a user on the edge of the CBS1 and the CBS2, and the CBS1 simultaneously transmits STBC signals with the BBS signals. The transmission sequence is in Table 2 and the transmission scenario is in Fig. 3. It obtains the both advantages of diversity and multiplexing gain with the CBS1 and the CBS2. The received signals are as follows,

$$\begin{aligned} z_{1,1} &= x_1 h_{1,1} - x_2^* h_{1,2} + y_1 h_{1,3}, \\ z_{2,1}^* &= x_2^* h_{1,1}^* + x_1 h_{1,2}^* + y_2^* h_{1,3}^*, \\ z_{1,2} &= x_1 h_{2,1} - x_2^* h_{2,2} + y_1 h_{2,3}, \\ z_{2,2}^* &= x_2^* h_{2,1}^* + x_1 h_{2,2}^* + y_2^* h_{2,3}^*. \end{aligned} \quad (5)$$

At the second time slot in Table 2, the received signals are transformed into complex-conjugated equations for orthogonality of the received signals. The equation of the received signals is arranged in Eq. (6),

**Fig. 3** Transmission scenario for STBC and V-BLAST under good channel conditions.

$$\begin{bmatrix} z_{1,1} \\ z_{2,1}^* \\ z_{1,2} \\ z_{2,2}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & -h_{1,2} & h_{1,3} & 0 \\ h_{1,2}^* & h_{1,1}^* & 0 & h_{1,3}^* \\ h_{2,1} & -h_{2,2} & h_{2,3} & 0 \\ h_{2,2}^* & h_{2,1}^* & 0 & h_{2,3}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2^* \\ y_1 \\ y_2^* \end{bmatrix}. \quad (6)$$

For the detection of the received signals, minimum mean square error (MMSE) is utilized for pseudo inverse matrix. The MMSE matrix \mathbf{G}_{mmse} is expressed as

$$\mathbf{G}_{\text{mmse}} = \text{inv}(\mathbf{H}^H \mathbf{H} + \sigma^2 \mathbf{I}) \mathbf{H}^H, \quad (7)$$

where $\text{inv}(\cdot)$ transforms into an inverse matrix, σ^2 represents noise variance, \mathbf{I} is a unit matrix and $(\cdot)^H$ denotes conjugate transpose operation.

5. Simulation Results

This section presents the performance of the proposed scheme in terms of SNR, BER and throughput. The transmitted signals are coded in a convolutional code with the code rate 1/2 and modulated in 16QAM. It assumes that the path length of Rayleigh channel is 7 and the transmission power allocation is uniform. The value of the cyclic delay is half of the number of subcarriers. The results of simulation are based on OFDM.

For comparing the results in the fair conditions among users on the same distance from the BBS, the standard of the distance from the BBS is set to three ranges in decibels; 0 dB, -3 dB and -6 dB indicating measurement relative to original signals. The 0 dB means that the user is near the BBS, -3 dB the user is on the approximately half power point of the original signals, and -6 dB the user is on the approximately quarter power point. In Fig. 4, the BER performances of the nine schemes are described when the channel condition between a BBS and a user is poor. Figure 4 indicates that the cooperative transmissions achieve much better BER performance than the non-cooperative broadcasting transmission. And the proposed scheme 0 dB using space-time CDD obtains more about 1.5 dB than the conventional scheme 0 dB in the BER of 10^{-3} , the proposed

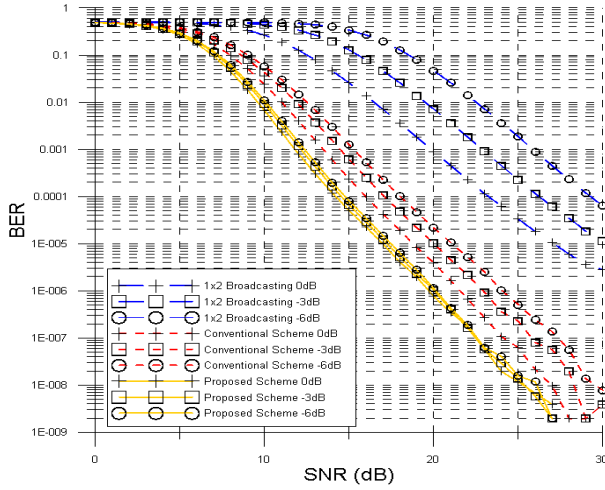


Fig. 4 BER performance under poor channel conditions.

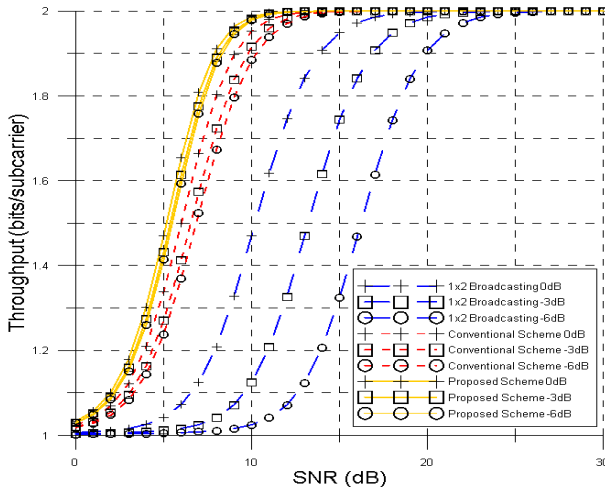


Fig. 5 Throughput under poor channel conditions.

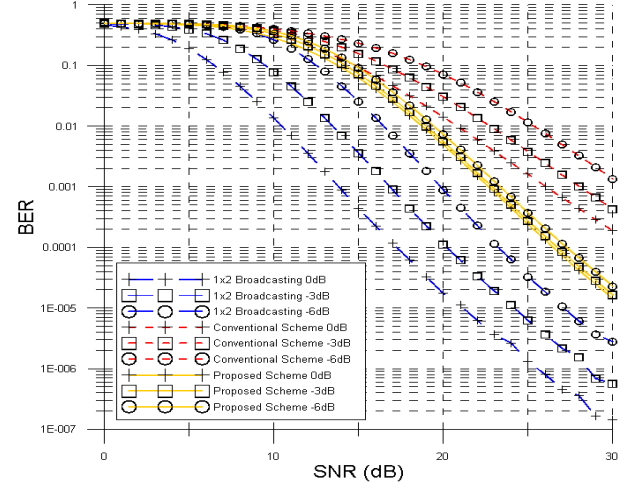


Fig. 6 BER performance under good channel conditions.

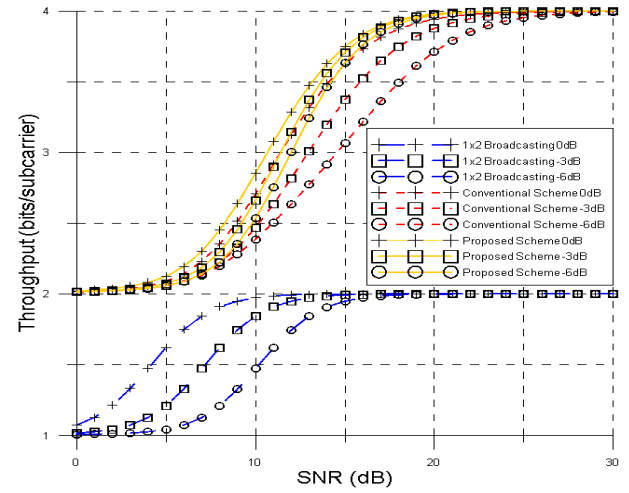


Fig. 7 Throughput under good channel conditions.

scheme -3 dB obtains more about 2 dB than the conventional scheme -3 dB in the BER of 10^{-3} , and the proposed scheme -6 dB obtains more about 3 dB than conventional scheme -6 dB in the BER of 10^{-3} . Figure 5 represents throughput of the nine schemes under poor channel conditions. The proposed scheme achieves better throughput performance in the cooperative scheme with another CBS than the broadcasting and the conventional schemes when users are on the edge of a CBS. Throughput is calculated as

$$\frac{N_I \times (1 - P(e))}{N_s \times N_{FFT}} \quad (\text{bits/subcarrier}), \quad (8)$$

where N_I is the number of total transmitted information bits, $P(e)$ is a BER, N_s is the number of the received symbols and N_{FFT} is the number of subcarriers. In Fig. 6, the BER performances of the nine schemes are described when the condition between a BBS and a user is good. And Fig. 7 represents the throughput of the nine schemes under good channel conditions. Although the BER performances of the proposed schemes in Fig. 6 are lower than

the broadcasting schemes, the throughput of the proposed schemes are greater than the throughput of the broadcasting transmissions in Fig. 7. And the proposed schemes are compared with the conventional schemes in Fig. 6. It appears that the proposed scheme 0 dB of cooperation with the CBS1 and the CBS2 achieves more about 3 dB than the conventional scheme 0 dB in the BER of 10^{-3} , the proposed scheme -3 dB achieves more about 5 dB than the conventional scheme -3 dB in the BER of 10^{-3} , and the proposed scheme -6 dB achieves more about 7 dB than the conventional scheme -6 dB in the BER of 10^{-3} .

6. Conclusion

In this letter, a possible solution is proposed for users on the edges of CBSs in a cooperative scheme. When users are on the edges of CBSs, the proposed scheme obtains higher diversity and multiplexing gains according to the channel condition.

In practice, since the size of the cellular coverage in the

system is small, e.g. picocell and femtocell in cellular wireless networks such as Global System for Mobile Communications (GSM), CDMA2000, Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE), the probability that users are on the edges is more frequent. Therefore, the proposed scheme is necessary for the concatenated cellular environment.

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