Effective Interference Reduction Transmission Scheme for Cooperative PB/MC-CDMA System

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Abstract

Recently, the cooperative communication has been proposed and studied to improve the system performance in wireless communication environments. In this paper, we propose the STBC (Space Time Block Coding) cooperative communication system with interference cancellation scheme. The multiple cooperated relay nodes that help the source signal forward are considered to be the multiple transmit antennas. The STBC scheme is applied to achieve higher diversity gain without the transmitter knowing the CSI (Channel State Information) and to decrease the complexity of the transceiver. However, if errors occur at relay nodes because of the frequency selective fading channel, error propagation would lead to degradation of the system performance when the decoded signal is retransmitted to the destination. To solve this problem, interference canceller is employed at the relay nodes when we decoded the source signals in the proposed system. Simulation result shows that better performance is achievable when interference canceller and STBC schemes are used in the PB/MC-CDMA (Partial Block Multi-Carrier CDMA) system.

Keywords: *Cooperative, interference, cancellation, STBC, PB/MC-CDMA*

1. Introduction

Cooperative relaying cellular networks are new advanced technologies for future generation of cellular systems, where relays have to forward cooperatively the received data from source to destination. The cooperative techniques utilize the broadcast nature of wireless signals by observing that a source signal intended for a particular destination can be “overheard” at neighboring nodes. These nodes, called relays, process the signals they overhear and transmit towards the destination, thus, higher transmission rates and robustness against channel variations due to fading can be obtained [1].

The relay nodes work together to form a virtual antenna array, so it is possible to exploit the spatial diversity with the traditional MIMO concept while the source and destination node need not to have multiple antennas [2]. Without destination node having multiple receive antennas, this cooperative relaying technique efficiently provides transmission diversity through distributed wireless relay nodes over fading channels. Some prior researches [3] have done about the cooperative relay network, they propose a way of beam forming, with the assumption of acknowledgement of the forward channel, source and a cooperative relay adjust the phase of their transmissions so that the two copies can add coherently at the destination at the receiver side. Beam forming requires considerable modifications to existing RF (Radio Frequency) front ends that increase system complexity and cost. Some other papers consider the case of orthogonal transmission between source and relays, and assume the simultaneously transmission of the source and relays [2], with synchronization and orthogonal constrains, considerable improvement in performance can be achieved. However, the improvement for these previous works is obtained at the expense of the increment of system complexity and terminal equipment cost. So, in our proposed system, the multiple relay nodes distributed in space are considered as the multiple input antennas, in order to avoid complexity of the front ends with beam forming, which needs acknowledgement of CSI (Channel State Information), we employ STBC for the retransmitted signals from different relay nodes. And we can obtain the diversity gain not only provided by STBC but also the extra time diversity gain by the proposed scheme.

In general, relaying systems can be classified as either *decode-and-forward* (DF) or *amplify-and-forward* (AF) systems. In decode-and-forward schemes, where relays are also referred to as digital repeaters, bridges, or routers, the relay nodes regenerate the signal by fully decoding and re-encoding the signals prior to retransmission. By contrast, in amplify-and-forward systems the relays essentially act as analog repeaters, thereby increasing the systems noise level [3]. Generally, we consider decode-and-forward systems as the majority of proposed concepts, and they are considered to be more viable with respect to implementation. In the case of DF scheme, when error occurs at the decoding process, the error is propagated during the retransmission process. So error detecting method is proposed in the paper [4]. In this paper, CRC (Cyclic Redundancy Check) coding and DF scheme are jointly used to avoid error propagation while an extra layer of CRC coding is required to enable the relay to perform error detection. However, this CRC scheme is time consuming while incorrect decoding is detected, thus result in the loss of transmission rate. So, in our proposed system, we introduce interference canceller to decrease error propagation probability when data was decoded at the relay station. In addition, we propose to integrate interference canceller and STBC technique to PB/MC-CDMA [5] cooperative system, in order to exploit all the advantages of the mentioned scheme. The proposed network is expected to provide high speed broadband service that guarantees QoS on date, voice and video traffic.

The rest part of this paper is organized as follows. Section 2 introduces the system model and Section 3 explains the proposed cooperative STBC-PB/MC-CDMA system with interference canceller. The next part evaluates the proposed scheme by computer simulation. The final part gives some conclusion for this paper.

2. System Description

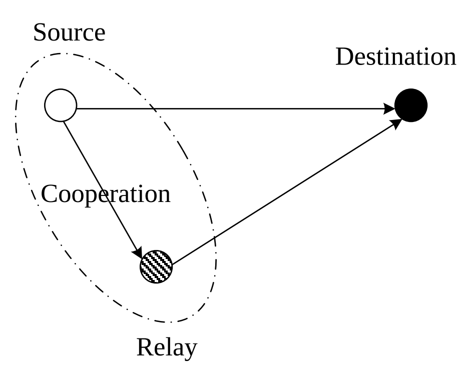

Figure 1. Cooperation Model by the Source Node and Relay Node

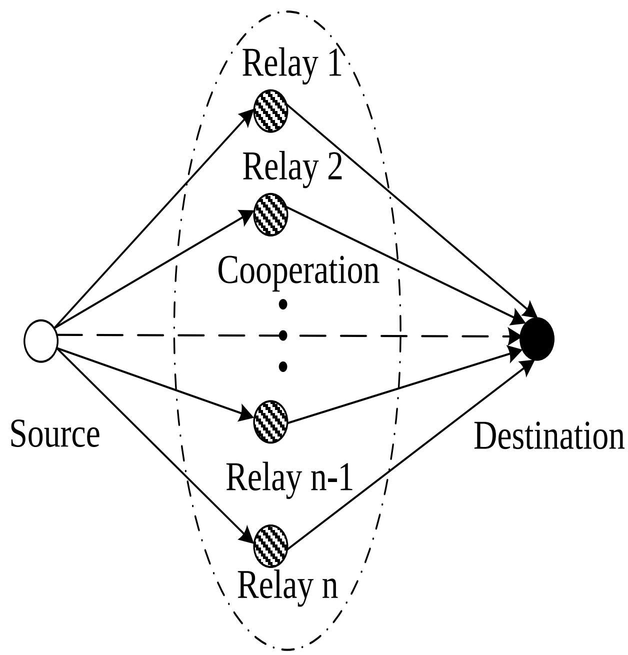

Figure 2. Cooperation Model by the Multi Relay Nodes

Consider cooperative communication in a dual-hop wireless network where information is transmitted from source node to destination node with the aid of the relay node as shown in Figure 1, which is the simplest model that source node, cooperates with relay node. To be general, Figure 2 shows the model that the cooperative nodes are multiple relay nodes. Here we suppose each node, including source node, relay node and destination node, has only one transmit or receive antenna.

For the wireless cooperative system shown in Figure 1, only one relay station is available, the destination node can get space diversity by coherently combining the direct transmitted signal and the relayed signal. However, if the direct path experiences long transmit distance or severe propagation environment, we can’t gain any benefit with the combination of the directly transmitted signal. For Figure 2, we ignore the direct path and find some other relay nodes to assist the source signal forward, so more space diversity can be obtained when combining at destination node. But the drawback for relay scheme is that error propagates when signals are retransmitted to the destination.

The proposed cooperative communication system which considering error propagation of DF scheme at the cooperated relays, IC (Interference Canceller) is employed when we decoded the source signals at the first hop, so as to enhance the system performance. For second hop transmission STBC is introduced for the retransmitted signal from the multiple relays, where the multiple relay nodes are considered as virtual antenna arrays which are the same as multiple input antennas in MIMO concept, so STBC can be applied without knowing the CSI (Channel State Information) for the multiple transmit antennas. In this case, the system can get transmit diversity gain with source and destination having only one antenna. This will describe in the part 3 in detail.

3. Proposed Cooperative Strategy and IC for Relay Node in PB/MC CDMA System

3.1. Proposed Transmitter

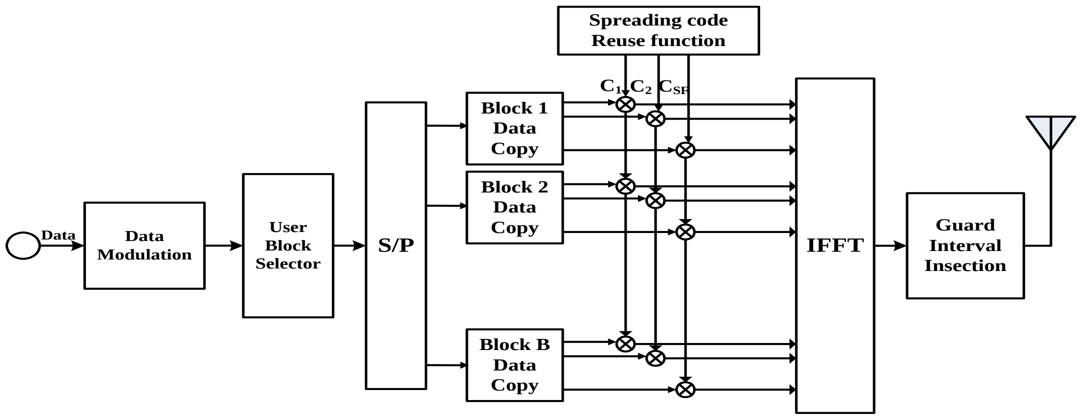

Figure 3. Block Diagram of the Transmitter for a Cooperative STBC-PB/MC-CDMA System

Figure 3 shows the transmitter structure for our PB/MC-CDMA system. In the diagram, the total bandwidth is divided into B sub-blocks, and each block has K sub-carriers, with the number of total subcarriers N_c being equal to KB. In this paper, we assume that one user employs only one specific block. If the number of users is less than the number of blocks or if a higher data rate is needed, the user's data rate is easily adjusted by using more blocks [5]. In Figure 3, $\{C_{\phi(u,B)}(k), k = 0 \sim SF-1\}$ is the orthogonal Walsh-Hadamard spreading code $\Phi(u,B)$ is the code reuse function stated as $\Phi(u,B) = \lceil u/B \rceil$, then the k^{th} subcarrier component can be expressed in an equivalent low pass representation, as follows:

$$S(k) = \sqrt{\frac{2E_c}{SF \cdot T_c}} \sum_{u=0}^{U-1} d_u^s c_{\phi(u,B)}(k \bmod SF) \tag{1}$$

where E_c is the transmit signal power per user, SF is the spreading factor which is reused in different blocks, T_c is the sample duration, U is the number of active users in the same block, and d_u^s is the transmitted complex QPSK data of user u. After an inverse fast Fourier transform (IFFT), the time domain PB/MC-CDMA signal is generated as

$$s(t) = \sum_{k=0}^{N_c-1} S(k) \exp\left(j2\pi \frac{t}{N_c} k \right) \tag{2}$$

After the insertion of $N_g{}^{th}$ sample cyclic prefix (CP) into the guard interval (GI), the PB/MC-CDMA signal is transmitted from the antenna.

Assuming that the channel has L independent propagation paths with chip-spaced distinct time delays, the impulse response $h(t)$ of the channel can be expressed as [3, 5]

$$h(t)=\sum_{l=0}^{L-1} h_l \delta(t-\tau_l) \tag{3}$$

where h_l and τ_l are the l^{th} path gain and time delay, respectively, and $\sum_{l=0}^{L-1} E[|h_l|^2]=1$, where, $E[\cdot]$ is the ensemble average operation and $\delta(\cdot)$ is the delta function.

The receive station of the first hop is a relay station; therefore, after removing the GI, the received signal $r_1(t)$ at one relay node (RN) can be expressed as,

$$r_i^r(t)=\sum_{l=0}^{L-1} h_{l_i} s(t-\tau_{l_i})+\eta(t) \tag{4}$$

where $\eta(t)$ represents the zero-mean noise process with a variance of $2N_0/T_c$, where N_0 represents the single-sided power spectrum density of the additive white Gaussian noise (AWGN). This paper considers two RNs, $r_1^r(t)$ and $r_2^r(t)$, as the received signals in separate locations. Then, the RN's received signals decompose into an N_c-point FFT. The k^{th} sub-carrier component of the received signal can be expressed as

$$R_i^r(k)=\frac{1}{\sqrt{N}}\sum_{t=0}^{N_c-1} r_i^r(t)\exp\left(-j2\pi k\frac{t}{N_c}\right)=H_i(k)S(k)+\Pi_i(k) \tag{5}$$

where $H_i(k)$ and $\Pi_i(k)$ are the Fourier transforms of the channel impulse response and the noise, respectively, and the subscript $i=1,2$, which represent the number of RNs, are given as follows:

$$\begin{cases} H_i(k)=\sum_{l=0}^{L-1} h_{l_i}\exp\left(-j2\pi\frac{k}{N_c}\tau_{l_i}\right) \\ S(k)=\frac{1}{\sqrt{N_c}}\sum_{t=0}^{N_c-1} s(t)\exp\left(-j2\pi\frac{k}{N_c}t\right) \\ \Pi_i(k)=\frac{1}{\sqrt{N_c}}\sum_{t=0}^{N_c-1} n_i(t)\exp\left(-j2\pi\frac{k}{N_c}t\right) \end{cases} \tag{6}$$

However, if errors occur at relay nodes due to the frequency selective fading channel, then error propagation would lead to the degradation of system performance when the decoded signal is retransmitted to the destination. In order to solve this problem, the interference canceller is employed at the relay nodes.

3.2. Interference Cancellation at Relay Station

When the signals are transmitted from the source, the channels are highly frequency-selective, as the number of user increase, the performance is severely degraded due to orthogonality distortion caused by spreading codes in different users, causing multi-user interference (MUI) within the same block-unit. To avoid error propagation, interference canceller is used at the first hop when multiple relays receive the source information.

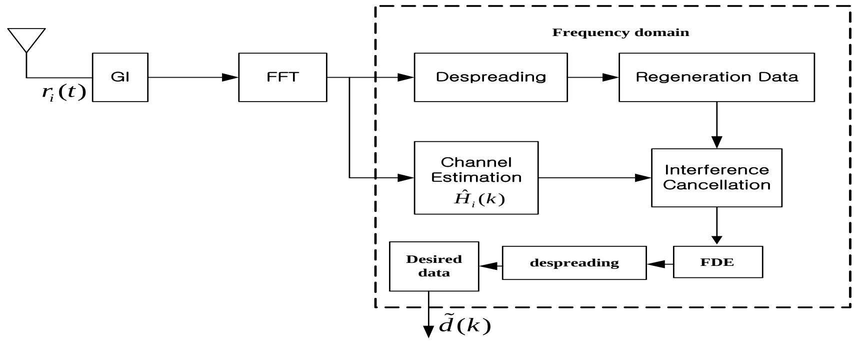

Figure 4. The Flowchart of the Proposed Relay Node Canceller

To transfer the RN receive signal to frequency domain in Figure 4, the regenerated data are re-spread and multiplied channel estimation $\hat{H}_i(k)$ to generate the interference in frequency domain, the interference cancellation is performed on $\tilde{R}_i(k)$ as

$$\tilde{R}_i^r(k) = R_i^r(k) - \hat{H}_i(k) \sum_{\substack{u=0 \\ u \neq u_d}}^{N_u - 1} \hat{S}_u(k) C_\Phi(k) \tag{7}$$

where $\tilde{R}_i^r(k)$ is the received frequency signal on the frequency domain after interference cancellation. $\hat{H}_i(k)$ is the channel estimation on the k^{th} subcarrier and $\hat{S}_u(k)$ is the regenerated transmit data for the u^{th} user.

However, after the frequency domain canceller, the interference term has still existed although having slight effect, which we called residual interference. Here the residual interference also limits the achievable performance improvement. So we considered the frequency domain equalization (FDE) weight $w(k)$ to restrain the residual interference. Then the signal can be written as

$$\hat{R}_i^r(k) = w(k) \cdot \tilde{R}_i^r(k) \tag{8}$$

Afterward, it is de-spread and de-modulated the signal, then the i^{th} relay node received data can achieve by

$$\tilde{d}_u^{\,i} = \frac{1}{SF} \sum_{k = Na \cdot SF}^{Na \cdot SF + SF} \hat{R}_i^r(k) c_u^*(k) \tag{9}$$

Here, $Na = (user\%B)$ and $B = \dfrac{N_c}{SF}$. Thus, finally the desired data was acquired.

For assumption, we have considered two relay stations. In addition, the desired data at different RNs can be expressed as $\tilde{d}_u^1$ and $\hat{d}_u^2$. Due to use of the interference canceller, $\tilde{d}_u^1 \approx \hat{d}_u^2 \approx d_u^s$, indicating that the desired data at different relay stations are nearly equal to the original data. In order to get the spatial diversity gain at the destination, the STBC will be used at the relay nodes which will be introduced in next part.

3.3. STBC System

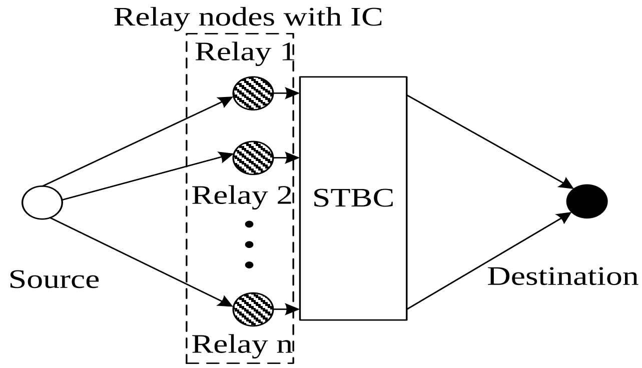

Figure 5. Proposed Cooperative Communication System with STBC

The STBC system has been actively studied as a highly reliable, promising multi-antenna transmission scheme. Here, we consider the relay nodes to be virtual antenna arrays. As shown in Figure 5, after the interference canceller at the relay stations, reliably retransmitted data is produced. In order to achieve further system performance improvements, STBC was applied at the relay nodes before signal retransmission.

Here, the retransmitted signals $\hat{d}_u^1$ and $\tilde{d}_u^2$ from the two cooperated relay nodes of the same user are modulated again, and after the user block selection procedure, different users are mapped to different blocks, as in the source station process. Next, the signal is coded using STBC and can be expressed via the following matrix:

Table 1. STBC Matrix

	$t = t_j$	$t = t_{j+1}$
RN1	$\tilde{d}_j$	$-\hat{d}_{j+1}^*$
RN2	$\hat{d}_{j+1}$	$\tilde{d}_j^*$

Here, $\tilde{d}_j$ and $\hat{d}_j$ are the j^{th} symbols of relay node 1 and relay node 2, respectively, and the next symbols are $\tilde{d}_{j+1}$ and $\hat{d}_{j+1}$, where $j = 2n$ and n are integers. Here, we must emphasize again that the two retransmitted relay node signals are nearly the same as the original source signals. Encoding can be performed using two adjacent symbols, as shown in Table 1, where t is the symbol time, t_j is the j^{th} symbol time and * represents the complex conjugate.

After passing through the fading channel, the signals arrive at the receiver and are combined with differing path losses and fading fluctuations. The channel information can be expressed using h_0 and h_1, the received signals at times t_j and t_{j+1} are shown as follows:

$$\begin{cases} r_j^d = h_1\tilde{d}_j + h_2\hat{d}_{j+1} + n_j(t = t_j) \\ r_{j+1}^d = -h_1\hat{d}_{j+1}^* + h_2\tilde{d}_j^* + n_{j+1}(t = t_{j+1}) \end{cases} \tag{10}$$

where n_j represents the AWGN.

The STBC decoding is performed to attain the final desired signal:

$$\begin{cases} d_j^d = (h_1^2 + h_2^2)\tilde{d}_j + h_1^* n_j + h_2 n_{j+1}^* \\ d_{j+1}^d = (h_1^2 + h_2^2)\hat{d}_{j+1} + h_2^* n_j - h_1 n_{j+1}^* \end{cases} \tag{11}$$

Using the equalization $\tilde{d}_u^1 \approx \hat{d}_u^2 \approx d_u^s$, then

$$\begin{cases} d_j^d = (h_1^2 + h_2^2) d_j^s + h_1^* n_j + h_2 n_{j+1}^* \\ d_{j+1}^d = (h_1^2 + h_2^2) d_{j+1}^s + h_2^* n_j - h_1 n_{j+1}^* \end{cases} \tag{12}$$

After STBC decoding, the signal of the u^{th} user is assigned to the b^{th} block, and it is de-spread according to the orthogonal spreading code in order to extract the desired signal, as shown in Figure 6. Finally, the system can attain the transmit diversity gain using a source and destination with only one antenna.

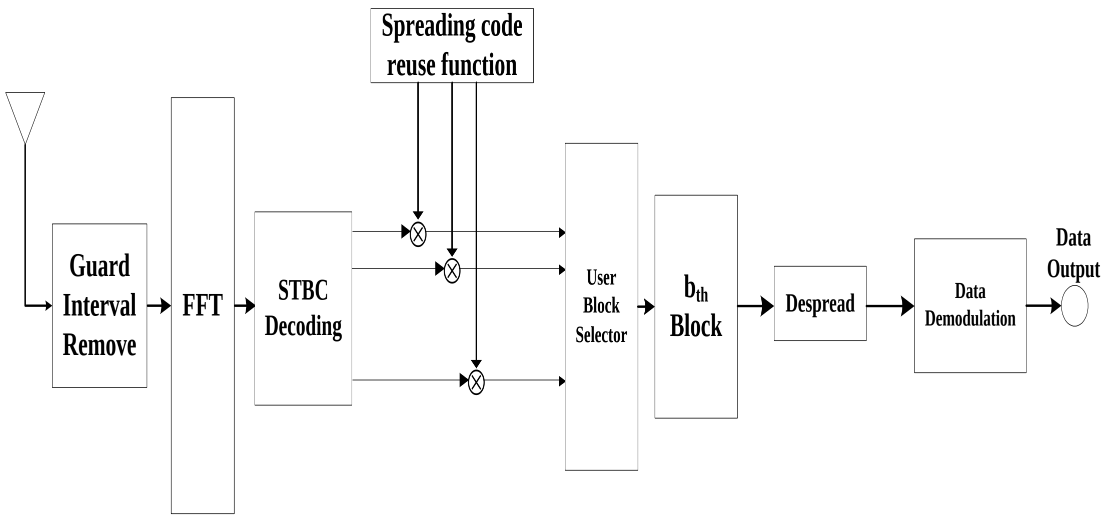

Figure 6. Block Diagram of the Receiver in the Proposed System

4. Simulation Parameter and Results

Table 2. Simulation Parameter

Modulation	QPSK
Number of subcarriers, FFT size	128, 128
Spreading factor (K), User	32 , 32
Length of guard interval	25% of a symbol length
Combining method	EGC
Channel model	18-path Exponential Rayleigh

Simulations were performed in order to evaluate the effectiveness of the proposed system using the simulation conditions in Table 2.

Figure 7 shows the performances of several systems under the same conditions. This paper uses an ideal transmission in which the transmitted signals of the source and relay nodes are the same. This means that the signal of the relay node does not include errors. Direct transmission means that the DF scheme is used to forward the signal to the relay node with no applied cooperation. This system performs worse than do the other schemes due to the error propagation problem. The cooperative system without IC shows very little improvement because cooperating with the received signal directly transmitted from the source to destination results in diversity gain in the final received signal. However, for the proposed cooperative system with IC, we can attain a highly improved BER performance, which, with the increase in SNR, approaches that of the ideal case. When the IC technique is adopted at the relay node, the probability of error propagation is greatly minimized. As a result, the retransmitted signal is approximately close to that of the ideal case and, in addition to the cooperative gain, the proposed system can obtain significant improvement.

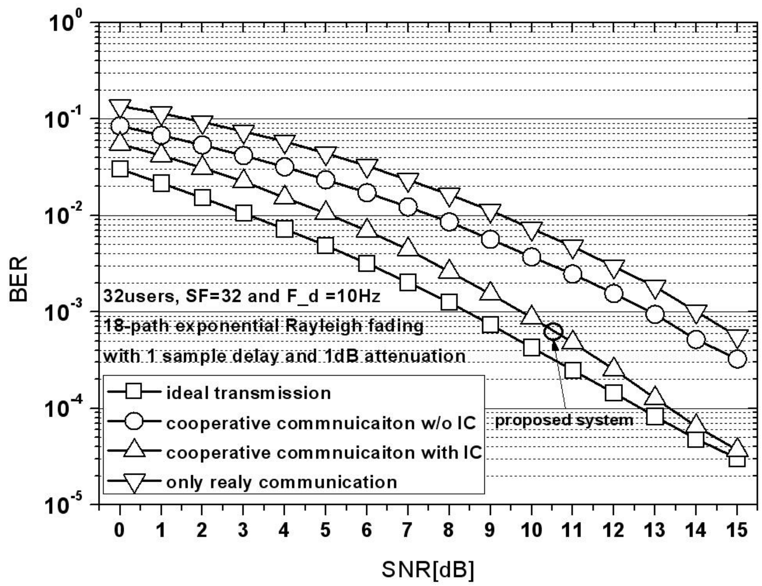

Figure 7. The BER Performance of several Systems under the same Conditions

5. Conclusions

This paper discusses cooperative coding with the use of an interference cancellation technique. The BER performances of several systems were presented, including a cooperative system with and without IC and direct transmission in the PB/MC-CDMA system. The proposed scheme was able to achieve improved frequency diversity gain while reducing interference compared to those of the other schemes. Simulations verified the effectiveness and practicality of the proposed scheme for use in frequency selective fading channels. The proposed algorithm can provide the high quality service required in wireless communication channels.

References

[1] P. Li and Z. Tao, “Cooperative wireless communications: A cross-Layer Approach”, IEEE Wireless communications, vol. 13, no. 4, **(2006)**, pp. 84-92.

[2] J. N. Laneman and G. W. Wornell, “Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks, IEEE Trans. Inf. Theory, vol. 49, no. 10, **(2003)**, pp. 2415-2525.

[3] S. Ait Fares and F. Adachi, "A novel cooperative relaying network scheme with inter-relay data exchange", IEICE Trans. Commun., vol. E92-B, no. 5, **(2009)**.
[4] A. Murugan, K. Azarian and H EI Gamal. Cooperative lattice coding and decoding in half-duplex channels, IEEE J. Sel. Areas Commun., vol. 25, no.2, pp. 268-279, **(2007)**.
[5] K. Lee and K. Lee, "Adaptive Resource Allocation for the PB/MC-CDMA System in Frequency Selective Fading Channels", IEICE Trans. Commun., vol. E91-B, no. 12, pp. 4042-4045, **(2008)**.

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