The Performance of The Modified MC-CDMA Inner Coding Scheme on High Mobility MIMO Wireless Systems

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ABSTRACT
In the future, wireless broadband communication systems will not only be used for private access, but also public access with high data rate. The problems in transmitting high data rate at high speed mobility are how to provide wide bandwidth in rapidly changing channel condition, to mitigate selective fading problems, to estimate response of the channel, and to solve degradation of signal performance. We propose a comprehensive solution for those problems, i.e. modified MC-CDMA inner coding system model in MIMO wireless systems. We also consider that this system can accommodate multi user with multi services, various bandwidth usage, QoS or channel response for every user. The simulation result shows that the MIMO wireless system with the proposed inner coding in non coherent channel transmission scheme provides a good system performance. The proposed scheme can outperform other previously published inner coding schemes for high mobility, high E_b/N_0 and multi user conditions.

General Terms
Performance, Design.

Keywords
Inner coding, Modified MC-CDMA, MIMO-Wireless.

1. INTRODUCTION
In wireless broadband communication system, high data rate or wide bandwidth of the information signal is disturbed by selective fading, results in difficulties in recovering these signals [9], so that it can cause the system performance degradation. A wide band transmitted signal is also restricted by limited bandwidth of the radio signal. Furthermore, in high speed mobility, the channel condition is fluctuating rapidly. However, it is not easy to estimate the response of the channel under this channel condition.

One of the solutions is applying a simple transmission scheme that has high spectrum efficiency and could overcome the selective fading condition. For instance, we can utilize a multiple antenna techniques due to its spectrum efficiency and a simple multicarrier transmission scheme capable to overcome the selective fading condition. In addition, to overcome high speed mobility problems, the implementation of non coherent channel transmission scheme is also a good solution [3]. Furthermore, to improve the system performance degraded by the fading channel, the wireless broadband communication system could utilize a combination of an outer coding as channel encoding and an inner coding as successive coding scheme, to enhance the performance of multiple transmit antennas system.

The objective of our study is to develop a transmission technique that can be used as a comprehensive solution for high data rate and high mobility problems, considering multi user with multi services or multi quality. The proposed scheme is the modified multicarrier code division multiple access (MC CDMA) inner coding scheme in MIMO-wireless systems. This coding scheme unites multiple output of differential unitary space time frequency (DUSTF) coding scheme [3] and MC CDMA technique. Both schemes are synthesized to become a new coding scheme, without adding complexity more than the two original schemes [2].

The research in this paper is achieved by simulating the proposed scheme. Simulation is focused on the utilization of proposed inner coding scheme in MIMO wireless communication systems in non coherent channel transmission scheme. Among those that will be researched are the influence of high user velocity in selective channel condition, the influence of various numbers of antennas at transmitter and receiver, as well as the influence of single and multiuser to system performance. Then, as comparison, the bit error rate (BER) system performance of other inner coding schemes with high mobility of users is also presented. Finally, the implication of the results will be analyzed, especially with non coherent channel transmission scheme.

The rest of the paper is organized as follows. In Section 2, we talk about the transmission scheme model in MIMO-wireless systems with non coherent channel transmission scheme. Next, in Section 3 we investigate about the system performance of the modified MC CDMA inner coding scheme in MIMO-wireless systems**.** Then, Section 4 presents the discussion of the simulation results of the modified MC CDMA inner coding scheme. The discussion includes the proposed modified MC CDMA inner coding system, the utilization of space time block coding (STBC) and the multiple output DUSTF coding [3] in MIMO-wireless systems. Particularly, the focus of discussion is to acquire better gain the proposed inner coding than the other scheme to overcome the channel transmission problems. Additionally, the inner coding scheme is resilient to delay or asynchronous code at the receiver. Finally our main conclusions are summarized in Sections 5.

2. THE TRANSMISSION SCHEME MODEL IN MIMO –WIRELESS SYSTEMS

In general, the implementation of transmission scheme model in MIMO wireless communication system can have two specific conditions, which are coherent and non coherent channel transmission scheme. In the sense that the channel state information is known or unknown, coherent channel transmission scheme is a common practice for fixed or low mobility wireless systems. In order to support transmission scheme, several channel estimation methods have been developed that are employed in MIMO wireless system. Previous researches are focused on the investigation of multipath channel influence on system performance. In fact, it is difficult to acquire an ideal coherent channel.

Particularly, it might be difficult or costly to estimate the channel accurately in high-mobility situations. Channel estimation over fast fading environment requires more training symbols and complex computing power. Meanwhile, the perfect estimates of channel conditions assumption is acceptable if the channel changes slowly compared with the symbol rate, because the transmitters can send training symbols which allow the receiver to estimate the channel accurately[9],[3].

Furthermore, in the frequency selective case, estimating the MIMO channels becomes significantly more difficult due to the presence of multiple paths, which results in an increased number of channel coefficients. If multiple antennas are used, the path gains between each pair of transmit and receive antennas must be estimated too.

Based on those reasons, in high mobility case, it is practical to develop modulation techniques that can be applied with or without channel estimation at the transmitter or receiver. This scheme is known as non coherent channel transmission scheme. The implementation of the scheme with differential modulation scheme is also a good solution to overcome difficulties in estimating the response of the channel condition. These schemes could be applied regardless of the knowledge of the channel state. In a single transmit antenna, for example differential phase shift keying (DPSK) can be demodulated without the use of channel estimation or training symbols. It is usual to consider extensions of these schemes to multiple transmit antennas. General approaches to differential modulation for multiple transmit antennas are based on group codes, as shown in Figure 1. For differential unitary coding, unitary space time signals resulted from each antenna are orthonormal in time. It has been shown to be reliable in a Rayleigh fading channel where neither the transmitter nor the receiver knows the fading coefficients [7.], [6].

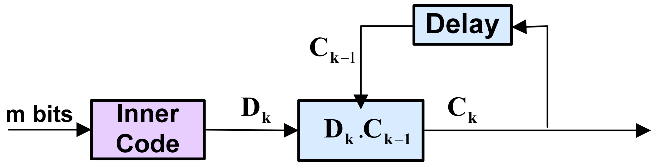

Figure 1. Differential modulation technique, based on block code or group code in MIMO-wireless communication system

3. THE MODIFIED MC CDMA INNER CODING SCHEME IN MIMO-WIRELESS SYSTEMS

We propose a multicarrier differential inner coding scheme, i.e. the modified MC CDMA inner coding to solve high data rate and high mobility problems. The proposed inner coding scheme is taking into account the wireless system that could be applied regardless knowledge of the channel state with non coherent channel transmission scheme. In addition, this scheme will be considered to accommodate the selective fading problems, various bandwidth usage, QoS or channel response for every user. Therefore, it is a proposed comprehensive solution for those problems. Figure 2 illustrates the modified MC CDMA inner coding in MIMO-wireless system.

General idea of information signal processing at transmitter side from input data of MIMO wireless communication system with the modified MC CDMA inner coding in MIMO-wireless system will be described. First, input data is processed at baseband stage, by means of channel coding as outer coding, i.e. convolutional code and interleaver, and then the data is fed to the mapper for signal constellation, i.e. *m*-BPSK. Next step is the modified MC CDMA inner coding part. The implementation of this inner coding scheme is unified with MIMO system, which can be applied with arbitrary $N_R \times M_T$ antennas system. The modified MC CDMA inner coding system consists of 2 main parts.

The first part of the inner coding employs a differential space time encoding expanded from [7]. That is multiple output of differential unitary encoding subsystem [3]. The parallel output of this subsystem is adjusted so that the parallel output data conforms to the number of antenna at transmitter. The application of parallel processing functions as spatial multiplexing will reduce the system performance theoretically, although it could give another advantage of system capacity. Nevertheless, in the proposed scheme, that poor performance is compensated by means of multiple output of differential unitary coding and multiple antennas, particularly at transmitter and receiver side.

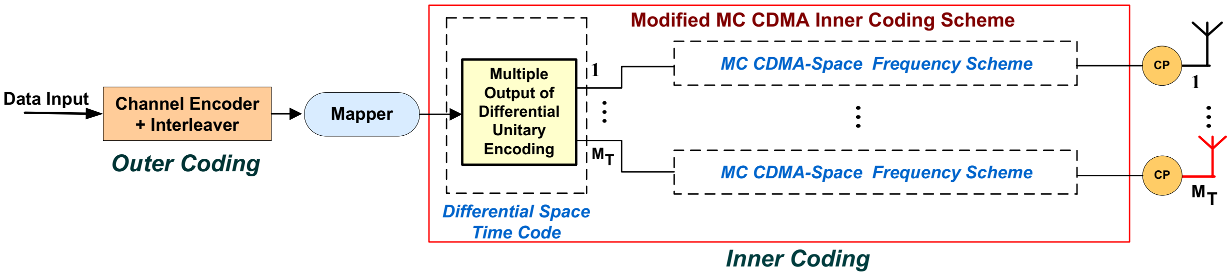

Figure 2. The modified MC CDMA inner coding scheme in MIMO-wireless system

The differential unitary encoding guarantees the system performance, particularly at low signal to noise ratio (SNR) [8].

The second part is the multicarrier space frequency scheme to combat the selective fading problems, whereas the unitary coding technique is a solution to guarantee information signal quality. Moreover, the merger of between multiple antennas and the MC CDMA-space frequency scheme can be capable to combat in harmony the problems of bandwidth restriction, selective coding condition and degradation of signal performance at high speed mobility. This scheme is employed to data symbol in each parallel data at every antenna arm of the MIMO wireless communication system. First, space differential frequency will be employed to data symbol in each parallel data. Then multicarrier CDMA or multicarrier direct sequence is applied, i.e. Hadammard code or Golay code as spreading code in each parallel data. Then, the symbol data is entered into the IFFT system and ended with cyclic prefix insertion. The MC CDMA-space frequency scheme in this new inner coding is similar to the modeling in [2]. Furthermore, the signal is transmitted simultaneously at each antenna of the MIMO wireless communication system. The rich environment condition will result in Rayleigh fading channel.

Receiver side will conduct the reverse process of that in transmitter. In each arm of receiver antenna, cyclic prefix is removed, followed by serial to parallel conversion, FFT, despreading, correlation detection, and removing the round robin scheme. Moreover, signal equalization is applied at multiple output of differential unitary decoding, by means of suboptimal maximum likelihood function, then followed by de-mapper, de-interleaving and viterbi decoding.

3.1 Multiple-output DUSTF Coding System Model

Figure 3 explains the particular model of multiple output of differential unitary encoding subsystem. The *k*th symbol data, $\mathbf{D}_k$ from the mapper is processed at generator of the unitary group code stage, so that $\mathbf{G}_k \in \mathcal{G}$ is obtained. $\mathcal{G}$ is considered as the set of possible messages. The group structure code, $\mathcal{G}$ can be constructed for any number of transmit antennas and any constellation $\mathbf{C}_{con}$, where $\mathcal{G}$ is any group of $n_s \times n_s$ unitary matrices, so that $\mathbf{G}^H\mathbf{G} = \mathbf{G}\mathbf{G}^H = \mathbf{I}$ for all $\mathbf{G} \in \mathcal{G}$.

First, we assume that the system has a consideration: $M_{Tx} = N_{Rx} = n_s$ with encoding process such as follows. An arbitrary C_u is a unitary code, whose characteristic is:

$$C_u C_u^H = n_s I \qquad \text{for all } u = 1,\cdots,U \tag{1}$$

Where $(\ )^H$ is the conjugate transpose and n_s is number of symbols.

When perfect channel state information is available at the receiver, we can use the differential encoder, as below:

$$\mathbf{S}_k = \mathbf{C}_D\mathbf{G}_k \qquad k = 1,\cdots,K \tag{2}$$

In that case $\mathbf{C}_D\mathbf{G}_k$ is basically a space time block code with perfect channel estimation, which is available at the receiver. The collection of matrices of a group code of length n_s over constellation $\mathbf{C}_{con}$ can be expressed as:

$$\mathbf{C}_D\mathcal{G} \stackrel{\Delta}{=} \{\mathbf{C}_D\mathbf{G}_k : \mathbf{G}_k \in \mathcal{G}\} \tag{3}$$

Second, we assume that $\mathbf{C}_D\mathcal{G}$ is unitary group structure code, that is if and only if $\mathbf{C}_D\mathbf{C}_D^H = n_s\mathbf{I}$. Initial matrix coding, $\mathbf{C}_D$ can be chosen to be a $M_{Tx} \times n_s$ matrix in $\mathbf{C}_{con}$. For example, for $m = n_s = 2$ we can choose $\mathbf{C}_D$ to be any matrix that satisfies $\mathbf{C}_D\mathbf{C}_D^H = 2\mathbf{I}$. In this paper, $\mathbf{S}_0 = \mathbf{C}_D$ is a $m \times n_s$ Hadamard matrix such that $\mathbf{C}_D\mathbf{G} \in \mathbf{C}_{con}^{m \times n_s}$ for all $\mathbf{G}_k \in \mathcal{G}$, that is constrained by $|\mathcal{G}| = 2^p$. So the larger number of antennas (at transmitter or at receiver) is restricted to multiple powers of 2. The fewer number of antennas (at transmitter or at receiver) may possibly have arbitrary number of antennas.

When no channel states information or no channel estimation scheme, with motivation from traditional differential modulation, PSK we can use the differential encoder as follows (see Figure 3):

$$\mathbf{S}_k = \mathbf{S}_{k-1}\mathbf{G}_k \qquad k = 1,\cdots,K \tag{4}$$

with initial code $\mathbf{S}_0 = \mathbf{C}_D$. The group structure code ensures that:

$$\mathbf{S}_k \in \mathbf{C}_D \mathcal{G} \quad \text{whenever} \quad \mathbf{S}_{k-1} \in \mathbf{C}_D \mathcal{G} \tag{5}$$

Next step is the multiple output of differential modulation part. The parallel output of this subsystem is adjusted so that the parallel output data conforms to the number of antenna at transmitter.

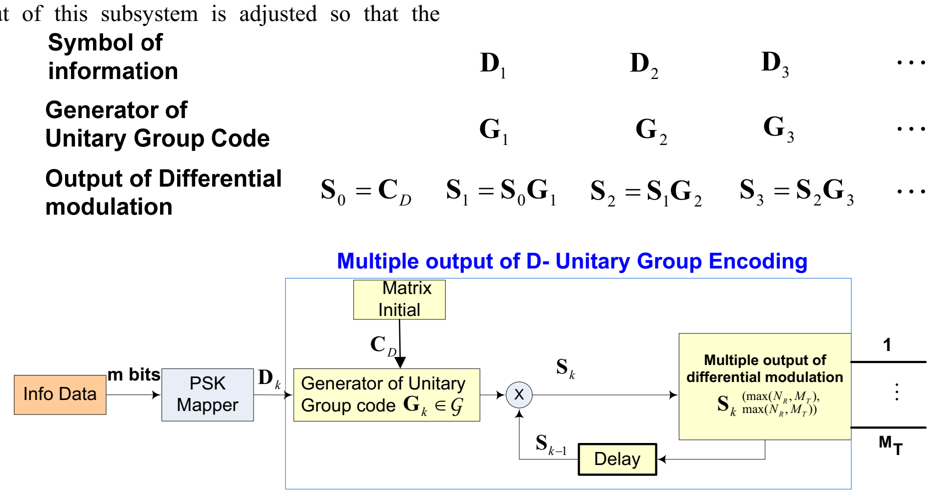

Figure 3. Multiple output of differential unitary group encoding subsystem

3.2 MC CDMA-space frequency subsystem model

In broadband wireless communication systems, the channel presents frequency selectivity because of delay spread, resulting in ISI (inter symbol inference) or inter code inference, that can cause performance degradation. There are various ISI mitigating approaches, multicarrier modulation is one of the most helpful techniques as it eliminates the ISI, which also offers high spectral efficiency. MIMO-modified MC CDMA inner coding systems, has been proposed, where two dimensional coding is applied to allocate symbols across space and frequency. Allocating symbols across space is done by utilizing multiple transmit antennas with multiple output of differential unitary encoding. Whereas, allocating symbols across frequency is by MC CDMA-space frequency tones. MC CDMA-space frequency coding can achieve the maximum diversity available in frequency selective MIMO fading channels and high improvement factor in high mobility conditions. In addition, this scheme could accommodate various bandwidth usage, QoS or channel response for every user.

In order to transmit high rate data with sufficient processing gain, the chip rate of the MC CDMA-space frequency system should be significantly high. So, the parallel transmissions of transmitter structure of a MC CDMA-space frequency signals is using the modified OFDM structure. The input symbol sequence is first converted to parallel data using a de-multiplexer and adjusted according to round robin scheme to produce blocks of low bit rates data, where each blocks contains two bits sequence (case in this paper). Then, each parallel block data streams, $s_k(i)$ is spread by the user's spreading sequence in the time domain with length C_{MC_SF}. Hence, the resulting spectrum of each subcarrier can satisfy the orthogonality condition with the minimum frequency separation $\Delta f'$. All the data $D = C_{MC\_SF} x N_{SC}$ (corresponding to the total number of sub-carriers, N_{SC}) are modulated in baseband by the inverse fast Fourier transform (IFFT) and converted back into serial data. The cyclic prefix is applied to avoid inter symbol interference (ISI) caused by multipath fading. Finally the signal is transmitted after RF up conversion. The data bit sequence with the source bit rate of R_b is first reduced to R_b / N_{SC} and then the system produces the rate $R_b G_{MC\_SF} / N_{SC}$ by means of spreading. If N_{SC} is equal to the length of the spreading code, G_{MC_SF}, the MC CDMA-space frequency spectrum has the same shape, as that of an MC DS CDMA system [5]. The transmitted signal of the user is written as:

$$S_{MC\_FS}(t) = \sum_{i=-\infty}^{+\infty} \sum_{k=0}^{N_{SC}-1} \sum_{m=0}^{G_{MC\_SF}-1} s_k(i) c_m p_c\left(t - mT_c - iT_S'\right) \times \cos\left\{2\pi\left(f_0 + k\Delta f'\right)t\right\} \tag{6}$$

Where :

$s_k(i)$ is the *i*th message symbol of the user

c_m represents the *m*th chip of the spreading sequence of *j*th user, with $m = 1, \cdots, G_{MC\_DS}$

T_S denotes the symbol duration

T_S' denotes the symbol duration at subcarrier level $T_S' = N_C . T_S$

T_C denotes the chip duration $T_C = \dfrac{T_S'}{G_{MC\_DS}}$

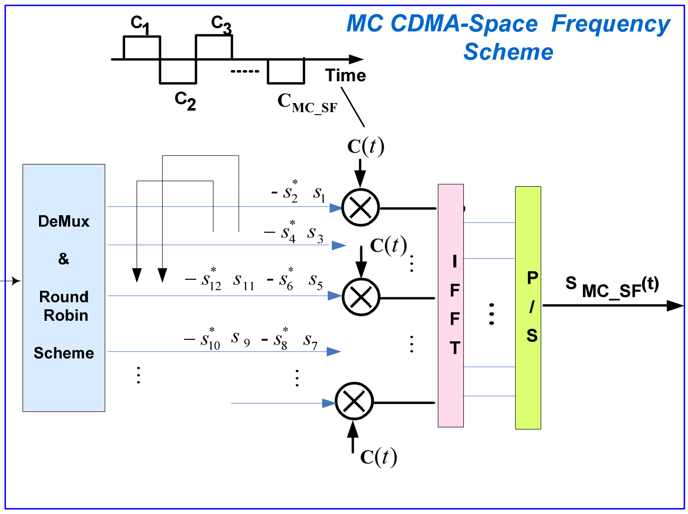

Figure 4. MC CDMA-space frequency subsystem model at every antenna arm of MIMO wireless communication system

4. DISCUSSION OF THE SIMULATION RESULTS

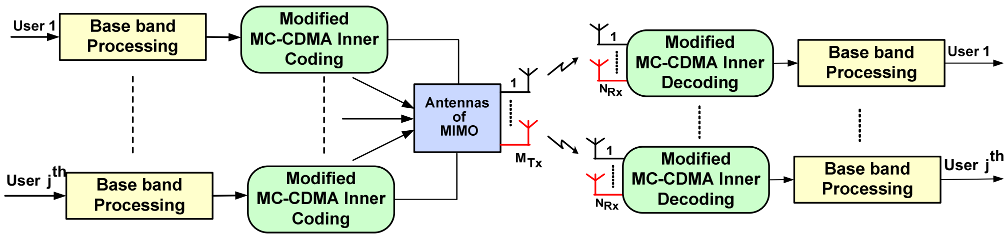

Figure 5. Multiuser transmission scheme of MIMO-modified MC CDMA inner coding wireless system on the downlink transmission

In this paper, the study is focused on the downlink transmission, i.e. signal transmission from base station to mobile user. The objectives are to solve high data rate problems, selective fading problems, degradation of signal performance, and difficulties in estimating response of the channel in high speed mobility. By considering those problems, in this section we present simulation results supporting those considerations. Our simulation is accentuated in a research to explore the response of MIMO wireless communication system to the proposed inner coding scheme in non coherent channel transmission condition. Besides, it is compared with MIMO wireless system that is merely applying STBC or merely multiple output DUSTF coding scheme in perfect estimation channel condition. In all simulation scenarios, we use frequency of 5 GHz, convolutional code rate ½, Viterbi decoder at receiver and 256 bits per data block. Modulation system could be any scheme, MPSK or MQAM, but in our simulation, BPSK is implemented, with power efficiency consideration. It is assumed that the simulations of all coding schemes are observed in fading channel condition (urban) by applying suboptimal ML detection at receiver.

In order to accommodate various bandwidth usage, QoS or channel response for every user is investigated, by considering parameters adjustment flexibility and independent inter-user transmission. Hence, multi user transmission scheme is applied by employing modified MC CDMA inner coding scheme in each information data of each user independently (Fig.5). Then the influence of multiuser in this system is observed, especially at high speed mobility. Accordingly, the data could accommodate various service demands in the future public access wireless communication system. The proposed scheme is expected to overcome the existing wireless system limitation, i.e. to transmit high data rate or wide bandwidth in high speed mobility.

Firstly, we explore the modified MC CDMA inner coding with single user, 64 sub-carriers, 2x2 antennas system, using Hadamard code as user spreading code and orthogonal code in multiple output of differential unitary encoding subsystem, and non coherent channel transmission scheme in the selective fading channel condition. As comparison, the BER system performance of the other schemes is also presented, i.e. MIMO-STBC with coherent channel transmission scheme and MIMO-multiple output

DUSTF coding with coherent channel transmission scheme, which had been observed in [3]. It is assumed that the simulation results of all inner coding schemes are observed in the same transmission parameters, and the same fading channel condition.

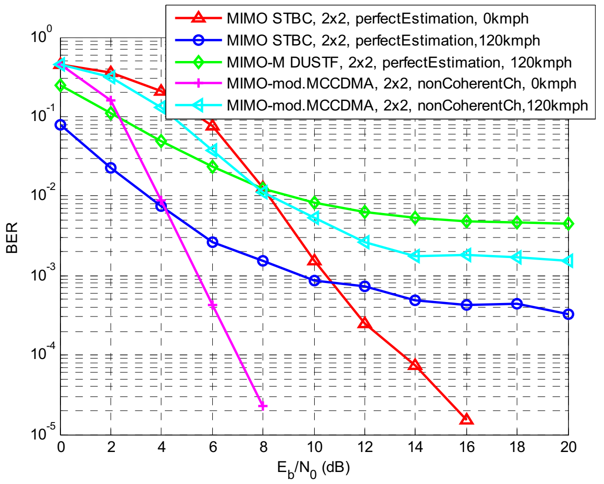

Figure 6. BER performance comparisons of MIMO wireless system with the modified MC CDMA inner coding, STBC scheme and multiple output of DUSTF coding scheme

Fig. 6 shows that theoretical condition MIMO-STBC, which is applied with perfect estimation acknowledgement by the receiver side for non mobility of user, has better performance than the other system. Yet, in high mobility condition, this perfect estimation is difficult to obtain. In contrast for high mobility of user, the modified MC CDMA inner coding with single user has a leader system performance than the other inner coding scheme, especially at high E_b/N_0.

Secondly, we investigate the effect of various combinations of differential code's type (Hadamard code) and user spreading code's type (Hadamard code and Golay code) to the channel response in the modified MC CDMA-MIMO wireless system with non coherent channel transmission scheme. The influence of the proposed inner coding scheme is shown for both non mobility and high mobility of users, and various numbers of users. It is assumed that the simulation results of all schemes above are observed in the same transmission parameters, i.e. 64 sub-carriers, 2x2 antennas system, and in the same fading channel condition.

Fig. 7 shows that generally the selection of differential code's type and user spreading code's type does not improve the system performance significantly, as a result of utilization of combination between orthogonal scheme with multicarrier scheme and code orthogonal with differential unitary code. It could be a good solution for difficult synchronization problems in the relative motion of the transmitter and the receiver.

Thirdly, we consider that the effect of receive antenna diversity or transmit antenna diversity to the BER performance of the proposed inner coding scheme for single and multi users. This coding scheme is studied in the MIMO wireless system with non coherent channel transmission scheme, i.e. observing the influence of 2 transmit antenna and *n* receive antennas, and also *m* transmit antennas and 2 receive antennas. It is assumed that the simulation results of the proposed inner coding schemes are observed in the same transmission parameters and fading channel condition.

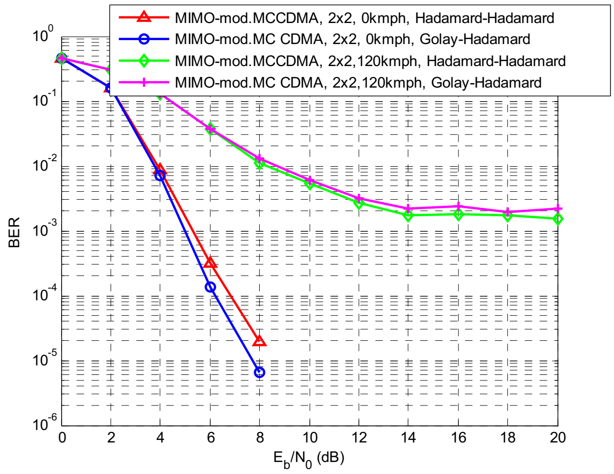

Figure 7. Influences of various combination of differential code's type and spreading code's type to the BER performance of the modified MC CDMA-MIMO wireless system for high mobility of user

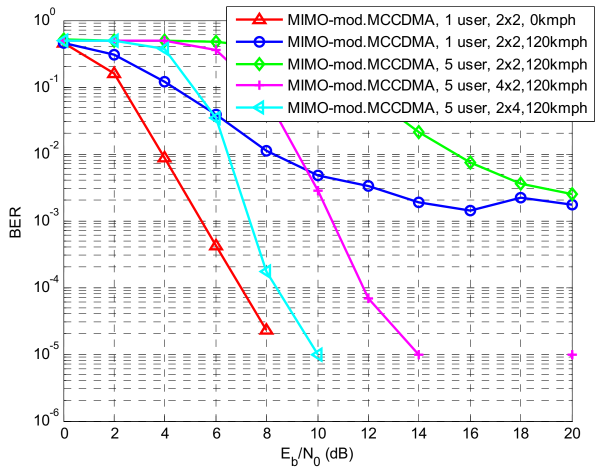

Figure 8. The influences of n receive antennas diversity or m transmit antennas diversity to the performance of MIMO-modified MC CDMA inner coding wireless system

Fig. 8 shows that generally increasing the number of receive antennas provides better performance than increasing the number of transmit antennas, although it gives another advantage, i.e. system capacity improvement. Applying greater number of transmit or receive antennas at BTS could be a good solution for compensation of the performance deterioration in multi user and high mobility conditions.

5. CONCLUSION

From the research results, it is concluded that in general the proposed inner coding scheme can guarantee information signal quality, which is capable to overcome frequency selective fading and high speed mobility problems. For high mobility user, compared to other coding schemes, the performance of the proposed scheme shows better performance, although the modified MC CDMA inner coding scheme in the MIMO wireless system is investigated in non-coherent channel transmission scheme. Particularly, applying greater number of transmit or receive antennas in multi user and high mobility conditions can improve the system performance significantly.

Because of parameter adjustment flexibility and independent inter-user transmission, the modified MC CDMA inner coding scheme in MIMO wireless system presents superior performance than the other system in accommodating various bandwidth usage, QoS or channel response for every user. So, the proposed scheme is good option as a total solution for high data rate-high mobility for multi user with multi services or multi quality condition. In multiuser transmission scheme, the utilization of greater number of antenna at BTS could compensate performance deterioration.

The new inner coding scheme with non-coherent channel transmission scheme with has a limitation, which has slightly lower signal performance than the system with perfect coherent channel transmission scheme, particularly in low speed mobility. There are also trade-offs among the system performances, channel capacity and system complexity. Accordingly, the future research is to investigate the increase of system complexity compared to more simple system, i.e. MIMO OFDM wireless system. The influence of the proposed coding scheme to system capacity is also a research subject in the future.

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