A Novel MC-CDMA Multilevel Coding Scheme on High Data Rate MIMO-Wireless Communication Systems

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Abstract—**Wireless broadband access system will operate in high mobility and high data rate environment. It is necessary to consider a system that is applied with or without perfect channel information, having more spectrum efficiency, and mitigating selective fading problems. We propose an MC CDMA multilevel coding system model that capable to solve those problems. We consider to this system accommodate various bandwidth usage, QoS or channel response for every user. From the research results, it is concluded that in general the MC CDMA multilevel coding scheme will provide a good performance with high speed user in non coherent channel transmission scheme.**

Index Terms— **wireless, high data rate, MC CDMA multilevel coding scheme**

I. Introduction

In the future, wireless communication systems will not only be used for private access, but also public access with high data rate. The main problem in transmitting high data rate at high speed mobility is how to provide high bandwidth in rapidly changing channel condition [4].

High data rate or wide bandwidth of the information signal is restricted by limited bandwidth of the radio signal. Consequently, it is necessary to implement transmission technique with high spectral efficiency [5]. Furthermore, a wide bandwidth transmission signal is disturbed by selective fading, results in difficulty in recovering these signals [4].

One of the solutions is applying simple transmission scheme that could overcome the selective fading condition. Moreover, in high speed mobility, the channel condition is highly fluctuating. However, it is not easy to estimate the response of the channel. The implementation of non coherent channel transmission scheme is a smart solution [6].

The objective of our study is to develop a transmission technique that can be used to overcome those problems. The proposed scheme is the multicarrier code division multiple access (MC CDMA) multilevel coding scheme in MIMO-wireless systems. This coding scheme combines differential unitary space time frequency (DUSTF) coding scheme and MC CDMA technique [6]. Both schemes are synthesized to become a new coding scheme, without adding more complexity than the two original schemes.

The implementation of MC CDMA scheme could mitigate the influence of rich multipath environment and high speed mobility. Multicarrier scheme will combat the selective fading problems, whereas CDMA technique is a solution to guarantee information signal quality. In addition, parameter adjustment flexibility, independent inter-user transmission also has been considered to accommodate various bandwidth usage, QoS or channel response for every user.

On the other hand, the implementation of DUSTF coding scheme is a proposed solution for non coherent channel transmission scheme and the resulted performance degradation [rien]. Since multilevel DUSTF coding scheme is also applied in multicarrier system, so the synthesis between MC-CDMA and multilevel DUSTF coding can be made in harmony.

The research is accomplished by simulating the proposed scheme. Among those that will be researched are the influence of 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 the implication of the results will be analyzed.

The paper is organized as follows. In Section 2, we study non coherent channel transmission scheme model in the MIMO-wireless system with high data rate transmission scheme. Next, in Section 3 we talk about the transmission technique model. The discussion includes the proposed MC CDMA multilevel coding scheme system, the utilization of MC CDMA technique and multilevel coding scheme. Then, in Section 4 we explore the evaluated performance of MC CDMA multilevel coding scheme. Finally our main conclusions are summarized in Sections 5.

II. The Transmission Scheme Model

Coherent channel transmission scheme is a common practice for fixed or low mobility wireless systems. Learning the coefficients of a MIMO fading channel is very challenging in the narrowband flat fading case. However, mobile broadband access systems are expected to operate at high vehicle speeds. 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. While, 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.

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 apply with or without channel estimation at the transmitter or receiver. This scheme is known as non coherent channel transmission scheme, i.e. by means of differential inner coding scheme. 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. Examples of the schemes are differential space time block code (D-STBC), differential unitary coding, and differential space time frequency transmit diversity [1], [2], [5].

In this paper, we apply the combination of 2 differential schemes, i.e. time differential and frequency differential (Fig. 1). Time differential is acquired from the implantation of differential unitary coding scheme, applied after mapper and before serial to parallel process. On the other hand, frequency differential is obtained by employing differential space frequency coding. This scheme is applied in each MIMO antenna arm.

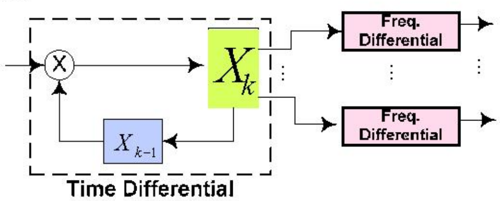

Fig. 1. Non coherent channel transmission scheme

III. MC CDMA Multilevel Coding in MIMO-Wireless System Model

In this section, we suggest a new inner coding scheme, i.e. MC CDMA multilevel coding scheme, which fuses from MC CDMA and Multilevel DUSTF coding scheme. With this approach that the system can apply with or without channel state information, that is known 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.

Information signal processing at transmitter side from input data of MIMO wireless communication with MC CDMA multilevel coding scheme will be described here. First, input data is processed at baseband stage, by mean of channel coding, i.e. convolutional code and interleaver, and then the data will be passed to mapper part.

Next step is the MC CDMA multilevel coding part. The implementation of this inner coding scheme is united with MIMO system. The system consists of 2 main parts. The first part is differential unitary encoding subsystem based on [1]. In the inner coding of this subsystem, the first time differential is employed, i.e. differential unitary encoder. The output of this subsystem is adjusted so that the parallel output data is in accordance with the number of antenna at transmitter.

The second part is the merger of MC CDMA and space time frequency scheme. This scheme is applied at every antenna arm of the MIMO wireless system communication. Initially, the inputs data of each antenna arm will undergo serial to parallel conversion process, according to number of transmit antennas that will be formed. After that, space differential frequency will be employed to data symbol in each parallel data. Then direct sequence CDMA scheme is applied, i.e. pseudo noise spreading code in each parallel data. Finally, the symbol data is entered into the IFFT system and ended with cyclic prefix insertion.

Furthermore, the signal is transmitted simultaneously at each antenna of the MIMO wireless system communication. 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 FFT, despreading, and correlation detection. Moreover, signal equalization is applied at differential unitary decoding, by means of suboptimal maximum likelihood.

A. MC CDMA Scheme

The MC-CDMA transmitter spreads the original data stream over different orthogonal sub-carriers using varied scheme of sub-carrier spreading codes based on pseudo noise codes, which has been investigated. In a Rayleigh fading channel environment, the multi-carrier CDMA schemes can be categorized into two groups [6]. First, the multi-carrier CDMA spreads the original data stream using a given spreading code and then modulates a different sub-carrier with each chip. Second, the multi-carrier CDMA spreads the serial to parallel converted data streams using a given spreading code and then modulates a different sub-carrier with each data stream. The first scheme is known as multicarrier CDMA and the second scheme is known as multicarrier direct sequence CDMA.

In this research, multicarrier direct sequence CDMA (MC DS CDMA) is applied, by considering that it will be easier to apply different orthogonal code sequences to each user [7]. In addition, OFDM technique is implemented to create multi-

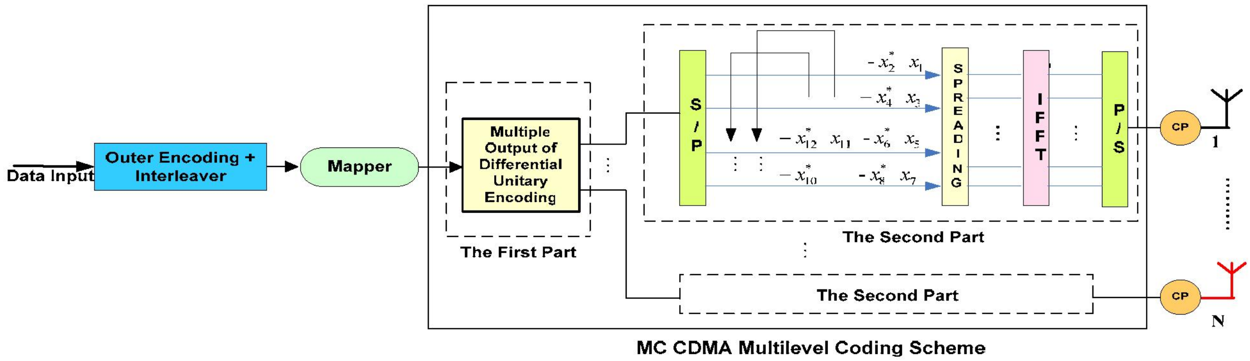

Fig. 2. The MC CDMA multilevel coding scheme

carrier scheme. According to previous researches, signal detection at receiver is no very complex.

In a multi-carrier CDMA transmission system, the available channel bandwidth of individual users, *B,* is divided into multiple sub-channels, *N,* which are spaced *B/N* apart. The data symbol is then modulated by a different sub-carriers can be transmitted in parallel by the OFDM technique. The most of available bandwidth spectra of the adjacent sub-channels are allowed to overlap without inter-channel interference (ICI). All information waveforms of the sub-channels should be orthogonal on some time interval. For high bit rate transmission over non ideal propagation channels, such as multipath frequency selective fading, OFDM parallel transmission offers many advantages.

A. *Multilevel DUSTF Coding Scheme*

In this paper, we suggest a new differential modulation for multiple transmit and multiple receive antennas based on group codes with parallel processing. The selection of this inner coding scheme is in accordance with the utilized multicarrier technique application. We propose using a multicarrier space time coding that is synthesized from differential unitary coding and differential space time frequency coding. The invention of the new inner coding scheme is based on previous researches.

Some reviews from inner coding modeling extracted from previous research are as follows. Modeling in [2] employs the following assumptions: DSTF scheme is applied in system with 2 TX antennas and 1 RX antenna. This scheme is a combination between D-STBC scheme and STF encoding. In our previous research result [5], improvement factor of this scheme is less significant than those of other simple differential encoding schemes, i.e. D-STBC and D-unitary encoding. It does not worth with its complexity. Another scheme with similar complexity yet significantly improves performance at low SNR and high mobility that we propose, DUSTF scheme proposed, is a combination between D-unitary scheme and STF scheme [6].

Based on those results, in order to overcome bandwidth restriction and channel condition in high mobility and high data rate, we suggest a new and general approach to differential modulation for multiple transmit and multiple receive antennas based on group codes with parallel processing. We propose the use of multilevel space time encoding, i.e. the synthesis of differential unitary coding and differential space time frequency coding. The differential unitary encoding guarantees information signal performance, particularly at low SNR [5]. On the other hand, the differential space time frequency encoding could combat the problems of bandwidth restriction and selective coding condition.

The application of parallel processing functions as spatial multiplexing will theoretically reduce signal performance, although it could give another advantage of system capacity. Nevertheless, in the proposed scheme, that poor influence is compensated by means of D-unitary encoding and multiple antennas, particularly at receiver side. Eventually, better diversity gain is observed.

Multilevel DUSTF encoding can be applied with arbitrary number of antennas at the transmitter or at the receiver, and any signal constellation. These schemes can be demodulated with or without channel estimates. However, large number of antennas (at transmitter or at receiver) has to be restricted by multiple of digit 2, otherwise 2^x with $x = 1,2,3,\ldots$. On the other hand, the fewer number of antennas (at transmitter or at receiver) could be in arbitrary number of antennas. For any *m* > *n,* we consider that the structure of differentially encoded group codes. In that case, to send $G_k \in \mathcal{G}$ in block k, the transmitter sends messages with differentially encoded with $G_k \in \mathcal{G}$ to be an m x *m* matrix. Conversely, for any *m* < *n,* to send $G_k \in \mathcal{G}$ in block k, the transmitter sends messages with differentially encoded with $G_k \in \mathcal{G}$ to be an *n x n* matrix.

In transmission scheme without CSI, ML detection system usually applies forms of quadratic receiver. This scheme is used to detect the sequence of transmit data from multilevel DUSTF encoder. In this research, a simple suboptimal receiver is utilized for differentially encoded unitary group codes with.

The data entries of the DUSTF decoder are:

$$[Y_1 \quad Y_2 \quad Y_3 \quad Y_4 \quad Y_5 \quad Y_6] \tag{1}$$

$$Y_0 = C_D \tag{2}$$

$$\hat{G} = \arg\max \operatorname{Re} Tr\{G.Y_k^H Y_{k-1}\} \tag{3}$$

$$\operatorname{Re} Tr\{G.Y_1^H .Y_0\} = \operatorname{Re} Tr\{G.Y_1^H .C_D\} \tag{4}$$

Given the example of BPSK with constellation C_{con}, due to the set of possible messages with BPSK modulation with constellation C_{con_BPSK}, there are four possibilities of the results:

1. $\mathrm{Re}\,Tr\{G_1.Y_1^H C_D\}$ or $\mathrm{Re}\,Tr\{-G_1.Y_1^H C_D\}$ (5)
2. $\mathrm{Re}\,Tr\{G_2.Y_1^H C_D\}$ or $\mathrm{Re}\,Tr\{-G_2.Y_1^H C_D\}$ (6)

If the first condition is maximal, then the output of ML is 1. On the other hand, if the 2nd condition is maximal, then the output of ML is -1.

IV. PERFORMANCE EVALUATION AND DISCUSSION

In this paper, the research is focused on the downlink transmission, i.e. signal transmission from Base Station to mobile user (Fig. 3). 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 MC CDMA multilevel coding scheme in each information data of each user independently (Fig.2). 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.

Our simulation is accentuated in a research to explore the response of MIMO wireless communication system to the proposed inner coding scheme. The objectives are to answer high data rate problems, selective fading problems, and difficulty to estimate response of the channel in high speed mobility. Besides, it is compared with MIMO wireless system that is merely applying MC-CDMA or merely multilevel DUSTF coding scheme. Then the influence of multiuser in this system is also observed. In addition the influence of this system, especially at high speed mobility, is investigated as well.

By considering to those problems above, in this section we present simulation results supporting those considerations. Accordingly, in our simulation the proposed inner coding scheme is applied in MIMO wireless communication systems with non coherent channel transmission scheme. In all simulation scenarios, we use frequency of 5 GHz, convolutional code rate ½, and 512 bits per block data with 16 subcarriers.

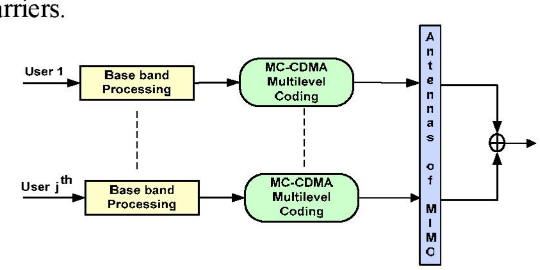

Fig. 3. Multiuser transmission scheme of MIMO wireless system in Base Station with the MC CDMA multilevel coding scheme

Mapper system could be any scheme, M-PSK or M-QAM. But in our simulation, BPSK and QPSK are implemented, with power efficiency consideration.

Firstly, the influence of the application of this scheme to the MIMO wireless system in fading channel condition is shown for various user speeds. The effect of this scheme with BPSK and QPSK mapper is observed at low and high user speeds. As comparison, the system performance with BPSK mapper in AWGN condition is also presented.

Fig. 4 shows that the system performance with BPSK mapper in low mobility is generally distinguished nearly the same as that of AWGN. While in very high mobility, the performance is significantly reduced. Then, the simulation result of system with m-array, such as QPSK, looks like performance as BPSK.

Secondly, the advantages of MC CDMA multilevel coding scheme in MIMO wireless systems is investigated and then compared with MIMO wireless system that is merely applying multilevel DUSTF coding scheme or merely MC CDMA, particularly for user with high speed.

In the simulation, the three types of MIMO wireless are utilizing radio and channel parameters. Yet some differences are assumed for channel state information. Because of the implementation of differential encoding, the MIMO wireless system with two first schemes, MC CDMA multilevel coding scheme and multilevel DUSTF coding scheme, are investigated with non coherent channel transmission scheme. On the other hand, the MIMO wireless system with MC CDMA is explored with coherent channel transmission scheme, i.e. channel state information.

Fig. 5 shows that MIMO wireless system with the proposed scheme in fading channel has signal performance that outperforms much better than that of MIMO wireless system with merely applying MC-CDMA or merely multilevel DUSTF coding scheme. Furthermore, it is apparent that the application of multilevel DUSTF coding scheme in MIMO wireless system is more prominent than multilevel DUSTF coding scheme in MIMO wireless system with MC-CDMA.

At the third research, the focus is how system performance with high mobility user could be operated in multiuser condition. In addition, the observation is also conducted on the performance if the numbers of antennas are increased.

Fig. 6 shows that the greater number of users, the significant system performance deteriorates. It could be understood that this condition occurs due to other users' interference. Besides, simulation results show that raising the number of BTS antenna could extend the performance significantly. Hence, it can be chosen as an alternative to overcome performance degradation due to multiuser operation.

V. CONCLUSION

From the research results, it is concluded that in general the proposed inner coding scheme will provide a good performance. For high mobility user, compared to application of other coding schemes, the performance of the proposed scheme shows better performance, although MC CDMA scheme in the MIMO wireless system is investigated in coherent channel transmission scheme. The proposed scheme in MIMO wireless system presents superior performance than the system with multilevel DUSTF coding scheme in accommodating various bandwidth usage, QoS or channel response for every user. In multiuser transmission scheme, the utilization of greater number of antenna at BTS could compensate performance deterioration.

This proposed scheme does not increase system complexity compared to the other schemes, i.e. MC CDMA and multilevel DUSTF coding scheme. When MIMO wireless system will be applied to serve high speed mobility then the application of the proposed coding scheme will provide a good performance, because of its capability to compensate the fading channel effect, high speed mobility and could be operated with or without channel state information. 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.

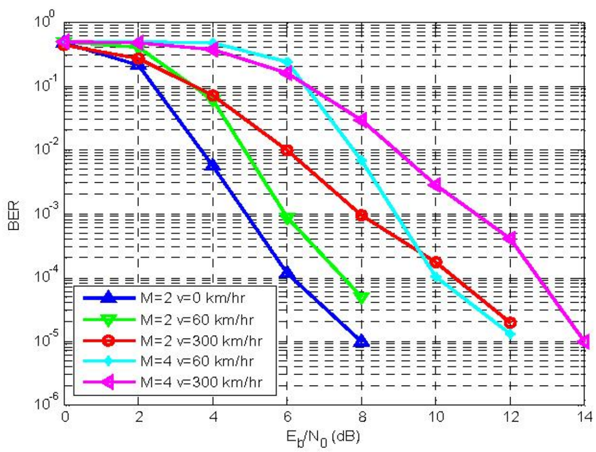

Fig. 4. The system performance with BPSK and QPSK mapper in low and high mobility of users

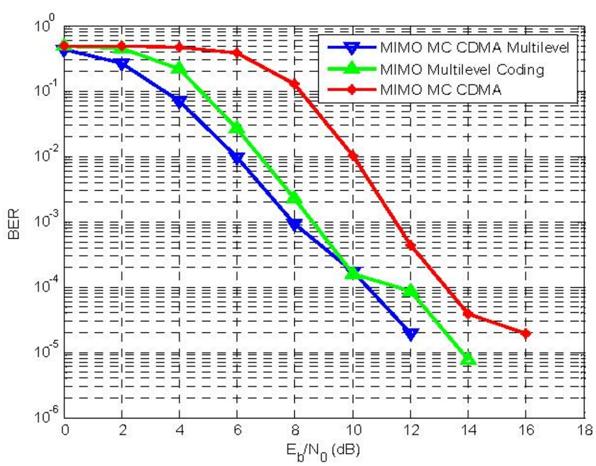

Fig. 5. The BER performance comparisons of MIMO wireless system with MC CDMA multilevel coding scheme, MC-CDMA coding scheme and multilevel DUSTF coding scheme high mobility of users

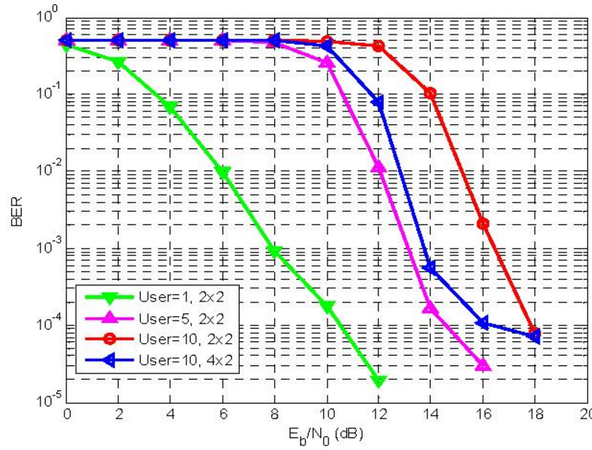

Fig. 6. The BER performance of MC CDMA multilevel coding scheme in high speed mobility for several of users

REFERENCES

[1] B.L. Hughes, "Differential Space Time Modulation", *IEEE Transactions on Information Theory*, Vol. 46, no.7, pp. 2567-2578, 2000.

[2] G. Bauch, "Differential Space Time Frequency Transmit Diversity in OFDM", *Proc. Of International Symposium on Wireless Personal Multimedia Communications*, October 2003.

[3] H. Jafarkhani, *Space Time Coding, Theory and Practice*, New York, U.S., Cambridge University Press, 2005

[4] M Patzold, *Mobile fading Channels,* John Wiley & Sons, England, 2002

[5] R. P. Astuti, A.B. Suksmono , Sugihartono, A. Kurniawan, "The Performance of Non-Coherent Space Time Coding in MIMO-wireless Systems," in *Proc. of TSSA 2006 & WSSA 2006, International Joint Conf, pp. 278-284,* Des. 2006

[6] R. P. Astuti, A.B. Suksmono , Sugihartono, A. Kurniawan,"The Simulated Performance of Multilevel DUSTF Encoding for MIMO Wireless Communications" in press.

[7] S. Hara and R. Prasad, *Multicarrier Techniques for 4G Mobile Communications,* Boston, London, Artech House, 2003

[8] Tarokh, Vahid, and H. Jafarkhani, "A Differential Detection Scheme for Transmit Diversity", *IEEE Journal on Selected Areas inCommunications,* vol.18, no.7, pp. 1169-1174, July 2000