Combination of Array Processing and Space-Time Coding In MC-CDMA System

Mr. Nguyen Viet Hung* and Dr. W. A. C. Fernando**
*Telecom Faculty 1, Post and Telecommunications Institute of Technology, Hanoi, Vietnam
Tel: +84-4-8549352 Fax: +84-34-511405 E-mail: Ngvihu@yahoo.com
**Telecom Program, School of Advanced Tech, Asian Institute of Technology, Bangkok, Thailand
Tel: +66-2-524573 Fax: +66-2-5245730 E-mail: Fernado@ait.ac.th

Abstract: The transmission capacity of wireless communication systems may become dramatically high by employ multiple transmit and receive antennas with space–time coding techniques appropriate to multiple transmit antennas. For large number of transmit antennas and at high bandwidth efficiencies, the receiver may become too complex whenever correlation across transmit antennas is introduced.

Reducing decoding complexity at receiver by combining array processing and space-time codes (STC) helps a communication system using STC to overcome the big obstacle that prevents it from achieving a desired high transmission rate. Multi-carrier CDMA (MC-CDMA) allows providing good performance in a channel with high inter-symbol interference. Antenna array, STC and MC-CDMA system have a similar characteristic that transmit-receive data streams are divided into sub-streams. Thus, there may be a noticeable reduction of receiver complexity when we combine them together.

In this paper, the combination of array processing and STC in MC-CDMA system over slow selective-fading channel is investigated and compared with corresponding existing MC-CDMA system using STC. A refinement of this basic structure leads to a system design principle in which we have to make a trade off between transmission rate, decoding complexity, and length of spreading code to reach a given desired design goal.

Index Terms: Antenna arrays, Array processing, Space-Time Code, Space-Time Code Modulation, MIMO, Wireless communication channel, MC-CDMA, Space-Time Processing.

1. INTRODUCTION

The application of wireless communication has been growing dramatically in recent years. There is a high demand for multimedia applications such as voice, image, video and data over wireless channel with requirement of high transmission rate as well as high reliability. The design of a wireless communication system must therefore take all of these in to account.

The field of space-time processing (STP) is rapidly becoming one of the most promising areas for the improvement of capacity of wireless communication system [22]. With multiple antennas, received and transmitted signals can be separated not only with temporal processing but also with spatial processing. We call the combination of spatial and temporal processing as STP.

STP in a receiver improves the signal to interference ratio through co channel interference cancellation or beamforming, mitigates fading through improved receive diversity, offers higher signal to noise ratio through array gain and reduces intersymbol interference through spatial equalization. Likewise, STP in the transmitter reduces co channel interference generation, improves transmit diversity and in some cases minimizes intersymbol interference generation. Especially, using STC enlarges transmission capacity of wireless channel that is usually limited by provided frequency bandwidth [14].

Array signal processing is a specialized branch of signal processing that focuses on signal conveyed by propagating. Array processing, always using array of sensors, combines the sensor's output cleverly and then the array's outputs so as [2]: to enhance the signal-to-noise ratio beyond that of a single sensor's output, to characterize the field by determining the number of sources of propagating energy, the locations of these sources, and the waveforms they are emitting, and to track the energy sources as they move in space

By equipping the base station with antenna array, it is possible to more fully exploit the spatial dimension in a wireless communication system. Multiple antennas can provide a processing gain to increase the base station range and improve coverage. In addition to that, by exploiting the spatial selectivity of an antenna array, interference may be reduced which in turn can be traded for increase capacity of the system. A wide range of wireless communication systems may benefit from spatial processing including high mobility cellular systems, low mobility short-range systems, wireless local loop applications, satellite communications and wireless local area network (WLAN) [20].

Space-Time Code Modulation (STCM) is a kind of channel coding, which provides both space and time diversity simultaneously. It is a technique, which is considered to be joint design of the coding, modulation, transmit and receive diversity to provide high efficient performance. In other word, this can be viewed as a combination of coding and modulation for multiple-input (multiple transmit antennas) multiple-output (multiple receive antennas) channel. Recent studies in information theory [4], [27] show that capacity of STC system increases as long as increasing number of both transmit antennas and receive antennas.

Multicarrier modulation (MCM) is the principle of transmitting data by dividing a stream in to several parallel bit streams, each of which has a much lower bit rate, and by using these substreams to modulate several carriers [15]. Orthogonal frequency division multiplexing (OFDM) is a special form of MCM with densely spaced subcarriers and overlapping spectra [16]. Multi-Carrier CDMA (MC-CDMA) is a spread spectrum multiple access communications method first introduced in [28]. This combines multi-user access of CDMA with multi-carrier modulation techniques such as OFDM, which allows providing good performance in channels with serious inter-symbol interference.

Since MC-CDMA is a combination of DS-CDMA and OFDM, it not only inherits all the bad traits from their parents as well as good traits but also shows several new advantages from the combination. In standard single carrier communication systems for high data rate, the effects of multipath propagation increase the equalization costs due to short symbol duration and relative long channel delay times. Where as MC-CDMA has one major advantage that it can lower the symbol rate in each subcarrier so that longer symbol duration makes it easier to quasi-synchronize the transmissions [11]. The combined system has the same capacity as a direct sequence CDMA system, furthermore multi-user detection can be implemented using simple narrowband equalizers. MC-CDMA can handle N simultaneous users with good BER, using standard receiver techniques [6].

As we have already mentioned in previous paragraph that STC system can provide high transmission rate as well as high reliability. However, decoding complexity is an obstacle that prevents STC system from achieving desired transmission rate. The complexity of decoding such a high data rate STC using maximal likelihood (ML) criterion can be prohibitively high even if Min{Number of transmit antennas, Number of receive antennas}is just moderately large [1].

Several approaches solving this problem have been introduced such as combining antenna array and STC in [25] or layering STC in [3] and [1]. However, none of the solutions is evaluated in a specific transmission system such as MC-CDMA system.

In this paper, the combination of array processing and STC in MC-CDMA system is investigated in specific objectives listed as follows

- Study existing systems [3], [1], and [18] using STC as a channel code.
- Evaluate the performance of the proposed simulation model with different transmission rates and different channel conditions.
- Using the simulation results to make the comparisons between existing models and proposed simulation model based on criteria such as complexity, transmission rate and performance.
- Based on comparison results we propose solutions for developing a realizable transmission system providing desired transmission rate with appropriate complexity.

In the framework of this paper we

- Consider the case of single user system.
- Assume ideal channel estimation at receiver.
- Assume the ideal interference cancellation implemented for the case of multipath fading channel.
- Assume ideal beamforming is also implemented at receiver.

2. SPACE-TIME CODE

The physical uncertainties of a channel, usually considered to be random, may cause expensive and unreliable communication in any environment. Specially, it is severe in mobile wireless communications as channel parameters are time-variant. In addition to that, the Doppler effects are big problems. Coding techniques are employed to reduce such uncertainties. Most of the codes can provide high reliability but give a low in data rate. Hence, it is clear that the codes with high data rate and high reliability are desired target in minds of most researchers [18].

STCM is a kind of channel coding, which provide both space and time diversity simultaneously. It is a technique, which is consider to be joint design of the coding, modulation, transmit and receive diversity to provide high efficient performance (both diversity and transmission capacity). This can be viewed as combined coding and modulation for multiple-input (multiple transmit antennas) multiple-output (multiple receive antennas) fading channel. STCs are designed by using Trellis Codes, block codes..., called Space-Time trellis codes, Space-Time block codes..., respectively [24].

Recent studies have explored the ultimate limit of multiple-antenna systems from the information-theoretic point of view [5], [26]. Considering a multiple-antenna system, that has L_t transmitting and L_r receiving antennas. It is shown that, if the narrowband slow fading channel can be modeled as an matrix with i.i.d. complex Gaussian random entries, the average channel capacity of such a system is approximately min(L_t, L_r) times higher than that of a single antenna system for the same overall transmitting power.

2.1. Principle of Space-Time Codes

In STC system, data is encoded by a channel code and the encoded data is split in to L_t streams that are simultaneously transmitted using L_t transmit antennas. The received signal at each receive antenna is a linear superposition of the L_t transmitted signals perturbed by noise using multiple transmit antennas.

A general block diagram for space-time encoding and decoding is shown in Fig.1. In this diagram, the source generates k information symbols from discrete alphabet X, which are encoded by the error control C to produce codewords of length $N = nL_t$ over the symbol alphabet Y. The encoded symbols are parsed among L_t antennas and then mapped by the modulator into constellation points from the discrete complex-valued signaling Ω for transmission across the channel. The modulated streams for all antennas are transmitted simultaneously. At the receiver, there are L_r receive antennas to collect the incoming transmissions. The received baseband signals are subsequently decoded by the space-time decoder [24]. STC is formally defined to consist of an underlying error control code together with the spatial parsing format.

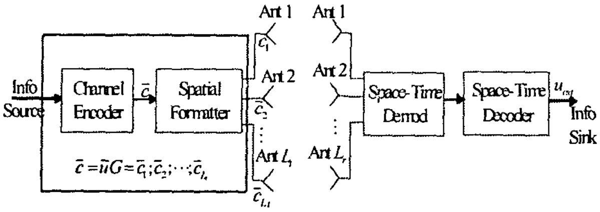

Fig.1. Reference block diagram for space-time encoding and decoding [9].

3. ARRAY PROCESSING

The goal of signal processing is to extract as much information as possible from our environment. Array signal processing is a specialized branch of signal processing that focuses on signal conveyed by propagating.

In mobile wireless cellular networks, the use of multiple antennas and spatial signal processing at base station is sometimes referred to as smart antennas or perhaps more accurately as SPT, since the antenna outputs are processed in space and time to maximize signal reception [14].

STP in general provides three processing leverages, the first one is array gain. Multiple antennas capture more signal energy, which can combine to improve the SNR. Next is spatial diversity to combat space-selective fading. Finally, STP can reduce co-channel and adjacent channel interference. Thus, the use of array signal processing or STP is emerging as a powerful tool for improving cellular wireless network. STP can improve cell coverage, enhance link quality and increase system capacity [21].

In CDMA system, STP is traditionally referred to receiver beamforming (space processing) and multipath combining (time processing) [21].

3.1. Beamforming

Beamforming is the name given to a wide variety of array processing algorithms that, by some means, focus the array's signal-capturing abilities in a particular direction. Based on the analogy of a flashlight, the main lobe of an array's directivity pattern is called beam. Just as one might point a telescope or a radar dish, a beam forming algorithm "points" the array spatial filter to ward desired directions but algorithmically rather than physically [2].

In DS-CDMA system, beamforming and adaptive antenna array are very efficient capacity enhancement techniques. They have been proposed to reduce multipath fading of desired signal and suppress the co-channel interference.

Beamforming algorithms generally perform the same operations on the antenna element outputs regardless of the number of sources or the character of the noise present in the wavefield.

4. MC-CDMA SYSTEM

MCM is the principle of transmitting data by dividing the stream in to several parallel bit streams, each of which has a much lower bit rate, and by using these sub streams to modulate several carriers [15]. OFDM is a special form of MCM with densely spaced subcarriers and overlapping spectra [16]. The narrowband subcarriers are generated so that they are orthogonal to each other. At the receiver, the component at each subcarrier may be filtered out by modulating the received signal with the frequency corresponding to the particular subcarrier of interest and integrating over a symbol duration. This kind of modulation partitions the channel in to a large number of small bandwidth subchannels so that a subchannel is narrow enough and the frequency response of the channel is approximately complex constant. Then there is no ISI in this subchannel [16].

Multi-Carrier CDMA (MC-CDMA) combines multi-user access of CDMA with multi-carrier modulation techniques such as OFDM which allow good performance in channels with bad inter-symbol interference. The MC-CDMA system has the same capacity as a direct sequence CDMA system, but multi-user detection can be implemented using simple narrowband equalizers. It not only inherits all the bad traits from their parents as well as good traits but also shows several new advantages from the combination. In standard single carrier communication systems for high data rates, the effects of multipath propagation increase the equalization costs due to short symbol duration and relative long channel delay times. Where as MC-CDMA has one major advantage that it can lower the symbol rate in each subcarrier so that longer symbol duration makes it easier to quasi-synchronize the transmissions [11]. In a dispersive multipath channel, DS-CDMA with a spread factor N can accommodate N simultaneous users only if highly complex interference cancellation techniques are used. In practice, this is difficult to implement. MC-CDMA can handle N simultaneous users with good BER, using standard receiver techniques [6]. When there is a deep frequency selective fading, OFDM loses the corresponding data on corrupted subcarriers. As MC-CDMA spreads an information bit over many subcarriers, it can make use of information contained in sound subcarriers to recover the original symbol. Various frequency domain equalizers for MC-CDMA have been proposed for this purpose and they were reported to outperform DS-CDMA with Rake receivers with much lower complexity. A diversity gain is obtained even without channel coding and the effect that deep fades significantly degrade the system performance is eliminated [13].

MC-CDMA is different from the OFDM in how the subcarriers are actually used in data transmission. In OFDM, different users don't use the same set of subcarriers. Multiple accesses in OFDM may be implemented by having different users transmit on different sets of subcarriers (frequency division multiplexing).

The MC-CDMA schemes are categorized mainly into two groups. One spreads the original data stream using a given spreading code and then modulates a different subcarrier with each chip (spreading operation in the frequency domain). The other spreads the serial-to-parallel converted data streams using a given spreading code, and then modulates a different subcarrier with each of the data stream (the spreading operation in the time domain), similar to a normal DS-CDMA scheme [7].

In this paper, we utilize the system that spreads in frequency domain, the principle of theoretical transmitter and utilized transmitter of a such system are illustrated in [8], and fig.2, respectively.

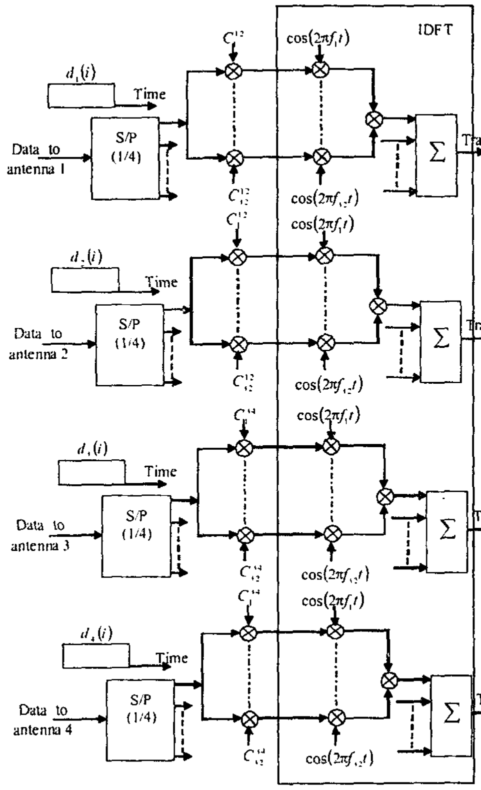

Fig.2. MC-CDMA Transmitter

5. REDUCING THE COMPLEXITY OF SPACE-TIME CODE SYSTEM

As we have known that multiple-antenna systems provide very high capacity compared to single antenna systems in a Rayleigh fading environment. Recent studies in [5], [26] exploring the ultimate limit of multiple antenna systems from the information-theoretic point of view shows that. In a multiple-antenna system with L_t transmit and L_r receive antennas, if the narrowband slow fading channel can be modeled as an matrix with i.i.d. complex Gaussian random entries, the average channel capacity of such a system is approximately $\min(L_t, L_r)$-times higher than that of a single antenna system for the same overall transmitting power. Thus, by increasing $\min(L_t, L_r)$ we may achieve a communication system with arbitrary high data transmission rate.

Aside from the consideration of combating channel uncertainty, another practical consideration for space-time codes is the decoding complexity. The complexity of decoding such a high data-rate channel code using the ML criterion can be prohibitively high even if $\min(L_t, L_r)$ is just moderately large [1], it is a big obstacle that prevent STC system from achieving a desired data transmission rate; thus, STCs that admit high performance, low complexity suboptimal decoding algorithms are desirable.

For Space Time Block Codes (ST-Block Codes), the layered space-time architecture introduced in [3] and refined in [1] is applied to reduce the complexity of receiver.

For Space Time Trellis Codes (ST-TCM), when number of transmit antennas is fixed, decoding complexity measured by the number of trellis states increases exponentially with transmission rate [25]. Thus, reducing number of trellis states of ST-TCM is one intuitive approach for solving the decoding complexity problem. These solutions following this approach are known as "Multistage decoding" introduced in [24], and "Combined array processing and Space-Time Coding" introduced in [25].

5.1 The Layered Space-Time Codes (LST)

A multilevel method for constructing codes is described in [10] where transmitted symbol are obtained by combining codeword symbols from component codes. The STC designed with multilevel structure and multistage decoding can be useful in some practical communication systems, particularly when number of transmit antennas is high. This has the significant advantage of reducing decoding complexity [24].

Depending on assignment rule of each constituent encoder outputs to transmit antenna, LST codes are divided into Horizontal LST codes and Diagonal LST codes, originally proposed by Foschini in [3]. These principles are described in detail in [1]

5.2. Combine Array Processing and Space-Time Code

Combining array processing and STC is another approach that dramatically reduces encoding and decoding complexity by partitioning antennas at the transmitter into small groups, and using an individual STC, called the component codes, to transmit information from each group of antennas. At the receiver, an individual STC is decoded by a novel linear processing technique that suppresses signals transmitted by other groups of antennas by treating them as interference. This combination of array processing at the receiver and coding techniques for multiple transmit antennas can provide reliable and very high data rate communication system that operates close to the limits given by outstage capacity over narrowband wireless channels [25].

In order to illustrate more detail about the principle of combining array processing and STC introduced in [25] and described in Fig.3, we model a wireless communication system with L_t antennas at the transmitter and L_r antennas at the receiver. Channel encoder so called space-time product encoder is used to encode input data. The input data of the encoder consisting of B bits in each time slot t is divided in to q strings of length $B_1, B_1, \ldots, B_q$ with $B_1 + B_2 + \cdots B_q = B$. L_t transmit antennas are partitioned into q groups $G_1, G_2, \cdots, G_q$, respectively, comprising $L_{t1}, L_{t2}, \ldots, L_{tq}$ antennas with $L_{t1} + L_{t2} + \ldots + L_{tq} = L_t$. Then each block $B_j, 1 \le j \le q$ is encoded by a space–time component encoder C_j. The output of C_j provides L_{tj} sequences of constellation symbols for $1 \le j \le q$ which are simultaneously transmitted from the antennas of the group G_j. The q space-time component encoders give a total of L_t sequences of constellation symbols that are transmitted simultaneously from antennas $1, 2 \cdots, L_t$. We can consider a space–time product encoder as a set of q space–time encoders denoted by $C_1 \times C_2 \cdots \times C_q$.

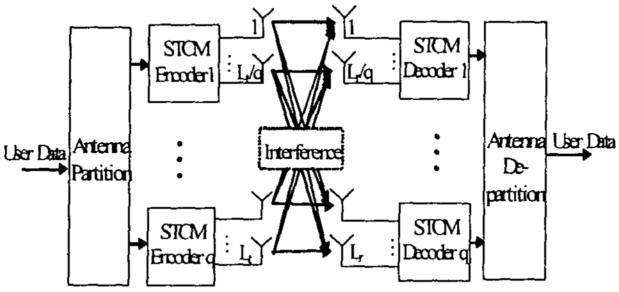

Fig.3. Principle of Combining Array Processing and STC.

At the receiver, group interference suppression method is applied. Codewords from each component encoder C_j are separately decoded while suppressing signal from the other component encoders. It is clear that this method has much lower complexity but achieve a lower diversity order than full diversity order $L_t \times L_r$.

Following the approach as described above, we can reduce code design for a multiple antenna communication system with L_t transmit antennas and L_r receive antennas to that designing codes for communication system with L_{ti} transmit antennas and $L_{ti} + L_t - L_r, i = 1, 2 \ldots, q$ receive antenna where $\sum_{i=1}^{q} L_{ti} = L_t$ and $L_{ti} \ge L_t - L_r + 1$, based on the theorem introduced in [25].

6. COMBINATION OF ARRAY PROCESSING AND SPACE TIME CODING IN MC-CDMA SYSTEM

The MC-CDMA system using STC promises to provide a transmission system with "arbitrary" high transmission capacity as well as high reliability. In order to realize such a transmission system, we must consider the trade off among several aspects such as complexity, performance and capacity. In such scenery, we propose an example of MC-CDMA transmission system presented in Fig.4 that uses the combination of space-time coding and array processing. In next paragraphs, model configurations are described in detail.

6.1 Simulation Configuration

In this system, we consider the general synchronous transmission link. The data bits are generated by random data generator and passed to serial to parallel converter that plays a role as the antenna partitioning. Next, data bits are encoded by Space-Time encoders and then interleaved. At the MC-CDMA transmitter, encoded data symbols are serial to parallel converted; spread in frequency domain; interleaved to minimize the subcarrier correlation and multicarrier modulated using IFFT. The resulting signals are transmitted by four transmit antennas over independent multipath relatively slow fading channels. The channel is modeled as a 4-Tapped Delay Line model and channel state information is supposed available at the receiver. AWGN is added at the receiver front end of antenna array. The received signals at two receive antennas are combined with equal weights and passed to MC-CDMA receiver where the received signal is processed inversely; multicarrier demodulated using FFT; de-interleaved and de-spread in frequency domain. Herein, we suppose that ideal interference cancellation (IC) is implemented. The signal at the output of MC-CDMA receiver is de-interleaved before being decoded by Space-Time decoders.

Due to the previous work of STCM [18], [24] and [25] proposed for high data rate applications have been done with frame error rate (FER) performance with 256 in each frame. Hence, in our simulation, FER performance is used for comparison. At the receiver, if a frame has at least one error bit it will be considered as error.

We use 2-STCM (4 states) in [24]. This code utilizes 4-PSK modulation with designing transmission rate of 2 bits/s/Hz. Maximum likelihood decoder using Viterbi algorithm is employed with the received soft-output information from Rx MC-CDMA.

We use Tx MC-CDMA with 128 subcarriers, Walsh Hadamard Codes spreading code with the processing gain of 32,

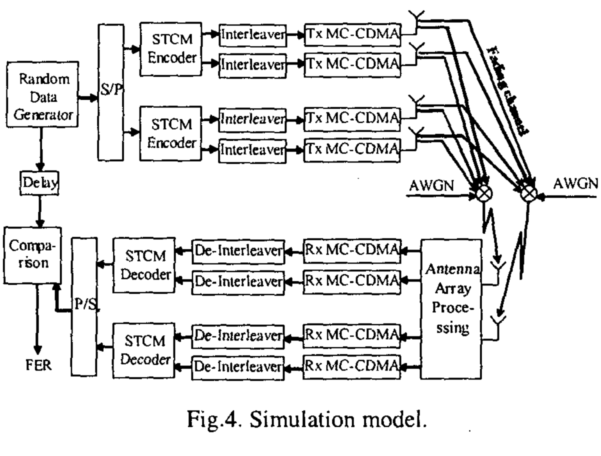

Fig.4. Simulation model.

The rectangular-array symbol interleaver consisting of 8 rows and 8 columns is used in this simulation model. In the framework of this example, we only consider the case of single user with 4 transmit antennas and 2 receive antennas. Thus, we use a simple case of beamforming algorithm in which the received signals at each receive antenna are combined with equal gain (equal weight) and zero delay between each antenna elements.

In next sections, some simulation results of the proposed system in comparison with MC-CDMA system using 4-STCM (64 states) over slowly frequency-selective fading channels as well as AWGN channel are presented. The comparisons are made based on different data transmission rates as well as different channel conditions.

In this simulation model, parameters are chosen similarly to those in [18] in order to make the comparisons.

6.2. Comparison over AWGN Channel

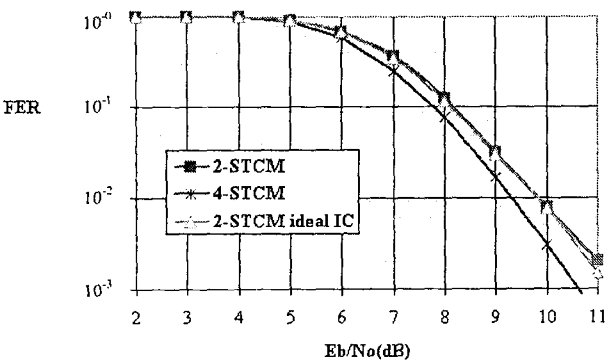

Fig.5. Comparison of combining array processing and STC scheme (using 2-STCM) and 4-STCM scheme over AWGN channel for the case of single user.

Fig. 5 shows that performance of 2-STCM with none interference cancellation is a little bit inferior than 4-STCM (about 0.7 dB at FER of 0.001). Using IC in this case does not give considerable improvement in performance of 2-STCM.

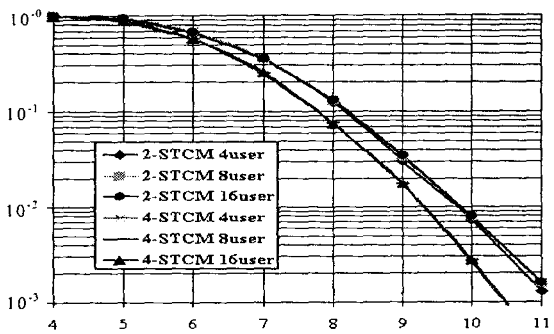

Fig.6. Comparison of combining array processing and STC scheme (using 2-STCM) and 4-STCM scheme over AWGN channel for the case of multiuser.

In Fig. 6, when the number of users increases 4-STCM performance remains the same while 2-STCM scheme's degrades a little bit with negligible level of degradation (0.0013 FER at 11 dB, 0.0015 FER at 11 dB and 0.0016 at 11 dB for number of users of 4, 8 and 16 respectively).

6.3. Comparison over Slowly Frequency Selective Fading Channel

In this part, simulation result is carried out up to a FER of 0.01 giving satisfactory quality of service in data transmission [18]. We only consider the case of single user system. We will compare combining array processing and STC scheme using 2-STCM and 4-STCM scheme in two channel conditions, namely coherent time of 20 frame duration and coherent time of 20 symbols duration.

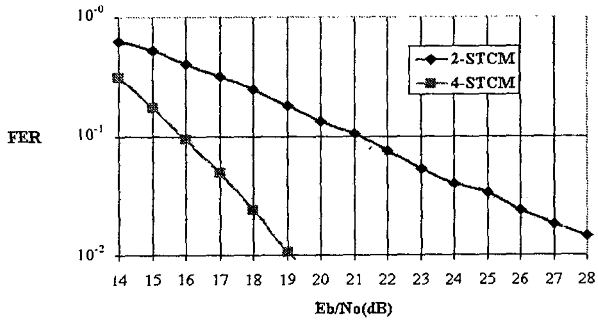

Fig.7. Comparison of combining array processing and STC scheme (using 2-STCM) and 4-STCM scheme over slowly frequency selective fading channel with the same data rate and coherent time of 20 frames duration.

In addition to that, combining array processing and STC scheme using 2-STCM component codes can provide data transmission rate of 2 times as high as 4-STCM's with the same given channel bandwidth. Thus, we will make the comparison in four cases as follows:

- **Case 1**: The same data transmission rate and coherent time value of 20 frame duration.
- **Case 2**: The same data transmission rate and coherent time value of 20 symbol duration.
- **Case 3**: Double data transmission rate and coherent time value of 20 frame duration.
- **Case 4**: Double data transmission rate and coherent time value of 20 symbol duration.

In Fig.7 and Fig.8, it is clear that performance of combining array processing and STC scheme using 2-STCM is degraded quite much comparing with 4-STCM scheme (about 10dB at FER of 0.01).

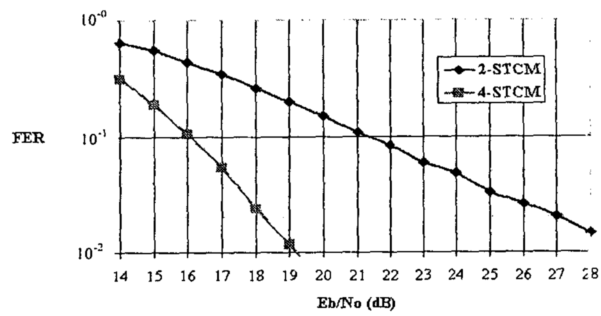

Fig.8. Comparison of combining array processing and STC scheme (using 2-STCM) and 4-STCM scheme over slowly frequency selective fading channel with the same data rate and coherent time of 20 symbols duration.

With the same data transmission rate, performance of 2-STCM scheme with coherent time value of 20 frame duration is similar to that of 20 symbol duration (0.0145 FER at 28dB and 0.0147 at 28dB for the coherent time of 20 frame duration and coherent time of 20 symbol duration, respectively)

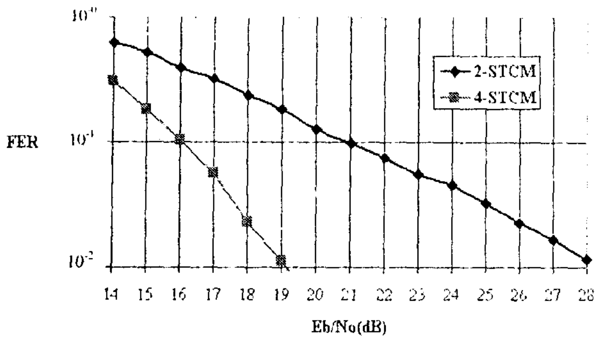

Fig.9. Comparison of combining array processing and STC scheme (using 2-STCM) and 4-STCM scheme over slowly frequency selective fading channel with double data rate and coherent time of 20 frame duration.

Fig.9 and Fig.10 clearly show that the performance degradation level of 2-STCM scheme comparing with 4-STCM scheme is similar to the case of equal transmission rate (approximately 10 dB at FER of 0.01). In this case, performance of 2-STCM scheme corresponding to coherent time value of 20 frame duration is 1 dB better than the case of coherent time value of 20 symbol duration at FER of 0.01.

In our simulation for multipath fading channel, we assume that ideal IC is implemented. This assumption is not considered to increase complexity of the system. Because IC also has to be used to gain acceptable performance in 4-STCM simulation model over multipath fading channel in [18] when multiuser is considered.

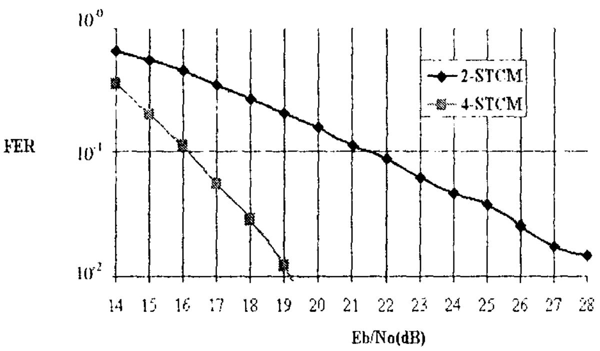

Fig.10. Comparison of combining array processing and STC scheme (using 2- STCM) and 4-STCM scheme over slowly frequency selective fading channel with double duration.

One of the reasons that make performance of combining array processing and STC scheme using 2-STCM degrades quite much comparing with 4-STCM scheme is error correction ability of 2-STCM (4 states) in multipath fading environment. This reason is partly proved in [12]. In Jung's simulation model, a quite complex equalizer is used before a decoder block to achieve acceptable performance in multipath fading channels. However, in our simulation model, it is impossible to apply such an equalizer, although channel state information is available at the receiver. There is one intuitive way to increase performance of 2-STCM scheme that is utilizing more complex 2-STCM component codes such as 2-STCM (8 states), 2-STCM (16 states) and 2-STCM (32 states).

Other reason caused serious performance degradation of 2-STCM scheme may be power of Walsh-Hadamard spreading codes in multipath fading channel. Walsh-Hadamard sequences are exactly orthogonal for zero time shift. This makes performance of combining array processing and STC scheme using 2-STCM is similar to that of 4-STCM in AWGN channel as well as flat fading channel for both the case of single user and the case of multiuser. However, Walsh-Hadamard sequences have relatively poor autocorrelation and cross correlation properties for none zero time shift, which degrades performance, when they are used in multipath propagation environment, where delays spread exceeds the chip interval. There is an intuitive approach to improve performance of 2-STCM scheme, we can change spreading code to achieve better autocorrelation and cross correlation properties in multipath fading environment. Furthermore, we can make a trade off between performance and data transmission rate by exploiting longer spreading code (higher spreading gain) to achieve better performance.

7. CONCLUSIONS AND FUTURE WORK

STC scheme used in this simulation model can provide higher data rate (2 times) while reducing decoding complexity (16 times) comparing with 4-STCM scheme in [18]. However, there is penalty to be paid for simplified decoding, especially in multipath fading channel. That is serious performance degradation (about 10 dB at FER of 0.01) at both the same data transmission rate and double data transmission rate comparing with 4-STCM scheme in [18].

Performance of two coding scheme in MC-CDMA system is not varied much when coherent time of the channel is changed.

Following structure of this simple simulation model we can design a system with transmission rate, decoding complexity, length of spreading code ...etc. that is most suitable to apply for WLAN system where antenna array can be easily employed. In order to reach a such desired goal, several problems should be solved such as: searching for suitable spreading codes with appropriate length, designing a channel code using combined array processing and STC principle with given performance and data transmission rate, finding out a simple interference cancellation scheme to cancel interferences from the other group of antennas in the case of single user as well as interferences from other user in the case of multiuser.

References

[1] Da-shan Shiu, Joseph and M. Kahn, "Layered Space-Time Codes for Wireless Communications Using Multiple Transmit Antennas," *ICC 99*, Vancouver, Canada, June, pp. 155-159, 1999.

[2] D. H. Johnson and Dan E. Dudgeon, Array Signal Processing: Concept and Techniques, Prentice Hall, Englewood Cliffs, NJ 07632, 1993.

[3] G. J. Foschini, "Layered Space-Time Architecture For Wireless Communication in a Fading Environment When Using Multi-Element Antennas," Bell Labs Technical Journal, pp. 41-59, Autumn, 1996.

[4] G. J . Foschini, Jr. Gans, "On Limits of Wireless Communication in a Fading Environment when using Multiple Antennas," Wireless Personal Commun., Vol. 6, No. 3, pp. 311–335, March, 1998.

[5] G. J. .Foschini, and R. A.Valenzuela, "Initial Estimation of Communication Efficiency of Indoor Wireless Channel," Wireless Networks, Vol. 3, pp. 141- 154, 1997.

[6] L. Freiberg, A. Annamalai, W.K. Bhargawa, "Crest Factor Reduction Using Orthogonal Spreading Codes in Multi-carrier CDMA Systems," Conference Proceeding of PIMRC, Helsinki, Finland, pp. 120-124, 1997.

[7] S. Hara, and R. Prasad, "Overview of Multicarrier CDMA," in Fourth IEEE International Symposium on Spread Spectrum Techniques and Applications (ISSSTA'96), 22-25 Sept., Mainz, Germany, pp. 126-133, 1996.

[8] S. Hara and R. Prasad, "Design and Performance of Multicarrier CDMA System in Frequency-Selective Rayleigh Fading Channels", IEEE Transactions of Vehicular Technology, Vol.48, No.5, September, pp. 1548- 1595, 1999.

[9] A.R. Jr. Hammons and Hesham, El. Gamal, "On theory of Space –Time Codes for PSK Modulation," IEEE Tran. Inform. Theory, Vol. 46, No.2, pp. 524-542, March, 2000.

[10] A. Imai and Hirakawa, "A New Multilevel Coding Method using Error Control Codes," IEEE Trans. Inform. Theory, Vol. IT-24, pp. 264-268, 1978.

[11] I. Jeong and M. Nakagawa, "Multi-carrier CDMA System Using Multi-antenna for Indoor Wireless Communication," Sao Paulo, Brazil, ITS'98, 1998.

[12]Jung Chang Chia, "Performance of Space-Time Coded Modulation over Frequency-Selective Rayleigh Fading Channels" Master's Research Study, TC-99-3, Asian Institute of Technology (AIT), Bangkok, 1999.

[13] S. Kaiser and P. Hoeher, "Performance of Multi-Carrier CDMA Systems with Channel Estimation in Two Dimensions," Conference Proceedings of PIMRC, Helsinki, Finland, pp. 115-119, 1997.

[14] E. Lindskog, "Space-Time Processing and Equalization for Wireless Communications," PhD Dissertation in Signal Processing, Uppsala University, 1999.

[15] J. P. Linnartz, "Special issue on Multi-carrier Modulation" Wireless Personal Communication, Kluwer, No. 1-2, 1996.

[16] M. Lorlak, S. Kim, J. Kang, , G. Xu, and H. Li, "Performance of MC-CDMA System Using Antenna Arrays" IEEE Conference Record of The Thirty-Third Salome Conference on Signals, Systems, and Computers Vol. 1, pp. 179-182, 1999.

[17] R. Lupas and S. Verd'u, "Linear Multiuser Detectors for Synchronous Code- Division Multiple-Access Channels," IEEE Trans. Inform. Theory, Vol.35, pp. 123-136, January, 1989.

[18] Maitree Sanguanchaiyakit, "Performance Investigation of MC-CDMA Using Space-Time Codes Over Slow Frequency-Selective Fading Channels" Master's Thesis, TC-00-2, Asian Institute of Technology (AIT), Bangkok, 2000.

[19] K. Makelainen, Cellular Mobile System, Lecture Notes, Asian Institute of Technology (AIT), Telecommunications Program, Bangkok, January, 2001.

[20] B. Ottersten , "Array Processing for Wireless Communications," Proceedings of the IEEE Signal Processing Workshop on Statistical Signal and Array Processing, Corfu, Greece, pp 466-473, March, 1996.

[21] A.J. Paulraj and C.B. Papadias, "Space-Time Processing for Wireless Communication," IEEE Signal processing, Mag., pp. 49-83, November, 1997.

[22] R.V Pieter, L. Michiel, and D.V. Wyk, Space-Time Processing for CDMA Mobile Communication, Kluver Academic Publishers, Boston Hardbound, ISBN 0-7923-7759-1, 2000.

[23] T.S. Rappaport, Wireless Communications Principle and Practice. Prentice Hall, Upper Saddle River, New Jersey, NJ 07458, 1996.

[24] V. Tarokh, N. Seshadri, and A.R. Calderbank, "Space-Time Codes for High Data Rate Wireless Communication: Performance Criterion and Code Construction," IEEE Trans. Inform. Theory., Vol. 44, No. 2, pp. 744-765, March, 1998.

[25] V. Tarokh, A. Naguib, N. Seshadri, and R. Calderbank, "Combined Array Processing and Space–Time Coding", IEEE Trans. Inform. Theory, Vol. 45, No. 4, pp. 1121-1128, May, 1999.

[26] E. Telatar, "Capacity of Multi-antenna Gaussian Channels," Europe. Trans. Telecommun., Vol.10, No.6, pp. 585-595, November,1999.

[27] J. Winter, J. Salz, and R.D. Gitlin, "The Impact of Antenna Diversity on Capacity of Wireless Communication Systems", IEEE Tran., Commun., Vol.42, pp.1740-1751, February/March/April, 1994.

[28] N. Yee and J.P. Linnartz, "Multi-Carrier CDMA in an Indoor Wireless Radio Channel," Proc. of IEEE PIMRC'93, pp. 109-113,Yokohama,Japan, September, 1993.