논문 04-29-12A-8

한국통신학회논문지 '04-12 Vol 29 No 12A

# OFDM 시스템에서 부분 데이터 추가정보를 이용한 데이터 공간 감소를 갖는 최대 전력 대 평균 전력 비 최소화 시퀀스 사상 기법

준회원 김 기 우*, 준회원 류 관 웅*, 정회원 박 용 완*

# PAPR-minimized Sequence Mapping with Data Space Reduction by Partial Data Side Information in OFDM System

Jiyu Jin*, Kwan-Woongn Ryu* ***Associated Members,*** Yong-wan Park* ***Regular Member***

## 요 약

본 논문에서는 OFDM 시스템에서 최대전력 대 평균전력(Peak-to -average Power Ratio . PAPR) 및 계산량(computation)을 최소화하는 PAPR-최소화하는 시퀀스 매핑 기법을 제안한다 PAPR을 줄이기 위해, 낮은 신호 전력의 블락 지수(block index)와 심벌 패턴들에 관한 정보를 이용하여 사상 표(mapping table)을 작성한다 입력 데이터 시퀀스는 목(quotient)과 나머지(remainder)을 찾기위해 블락 지수로 나눈다 낮은 신호 전력의 심벌 패턴은 사상 표에서 몫에 따른 블락 지수의 항으로 찾게되고, 수신기에서 최초의 데이터 시퀀스를 구별하고 복원하기 위한 추가정보처럼 나머지와 함께 전송된다 본 논문에서는 두가지 방식의 사상(mapping) 기법을 제안한다. 하나는 OFDM 신호를 복원하기위해 송신기와 수신기 양쪽 다 사상 표를 갖는 기법이고, 다른 하나는 이동국(mobile) 시스템에서 부하와 복잡성을 줄이기 위해 단지 송신기만 사상 표를 사용하는 기법이다. 이들 알고리즘은 다중 캐리어 시스템에서 PAPR 경감, 단순 처리, 그리고 적은 계산량을 확인할 수 있었다

Key Words OFDM, PAPR, Peak power, Mapping sequence

## ABSTRACT

In this paper, we propose a PAPR-minimized sequence mapping scheme that achieves the minimum Peak-to-Average Power Ratio (PAPR) and the minimum amount of computations for the OFDM system To reduce the PAPR, the mapping table is created with information about block index and symbol patterns of the lower signal power When the input data sequence comes, it performed division by the block length to find the quotient and remainder. The symbol pattern of the lower signal power can be found in terms of the block index as the quotient in the mapping table and transmitted with remainder as the side information to distinguish and recover the original data sequence in the receiver The two methods with the proposed mapping scheme are proposed in this paper One is with mapping table to recover the OFDM signal in both transmitter and receiver. The other is with mapping table only in transmitter to reduce the load and the complexity in the mobile system. We show that this algorithm provides the PAPR reduction, the simple processing and less computational complexity to be implemented for the multi-carrier system

---

* 영남대학교 정보통신공학과 이동통신 연구실 (ywpark@yu ac kr)

논문번호 #KICS2004-09-185, 접수일자 2004년 9월 6일

※This research was supported by University IT Research Center Project

※이 논문은 2004년도 두뇌 한국 21사업에 의하여 지원되었음

## Ⅰ. INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) is a method of digital modulation that a high-rate data stream is split into a number of lower rate data streams that are transmitted simultaneously over a number of subcarriers Due to robustness the inter symbol interference (ISI) and multipath fading, OFDM has found wide applications in digital communication systems However, one of the major drawbacks in OFDM system is the high Peak-to-Average Power Ratio (PAPR). An OFDM signal consists of a number of independently modulated subcarriers, which can give a large peak-to-average power when added up coherently: N signals are added with the same phase This results in a peak power that is N times the average power. Most radio systems employ high power amplifiers (HPA's) which cause the major expenses in the RF system. For the purpose of achieving the maximum output power efficiency, the HPA is usually operated at or near the saturation region, and this introduces memoryless nonlinear distortion into communication channels. Unfortunately, the variation of OFDM signal amplitudes is very wide with a large PAPR A large amplitude input into the transmitter power amplifier may cause nonlinear amplification of the input signal This can cause serious degradation in transmission performance Hence, it is highly desirable to reduce the PAPR.

To reduce the PAPR, several methods which can be divided into three categories have been proposed First, there are signal distortion techniques such as clipping [1], [2], which reduce thepeak amplitudes by nonlinearly distorting the OFDM signal at or around the peaks Clipping is the simplest and an effective PAPR reduction method However, it causes a serious in-band and out-ofband clipping noise This makes BER performance degradation in an adjacent channel interference (ACI). The second category is coding techniques which use a special code set that excludes OFDM symbol with a large PAPR. One type of coding techniques is called block coding [3]-[7], which is attractive because it does not create any out-of-band radiation, but there is no proper coding solution that can maintain a reasonable coding rate for an arbitrary large number of subcarriers. The third technique is based on scrambling each OFDM symbol with different scrambling sequences and selecting the sequence that gives the lower PAPR [8], [9]. Other similar schemes can be found in [10]~[13]. The Selected Mapping (SLM) algorithm [9], one method of scrambling, is to select and transmit the sequence with the lowest PAPR after making the M different phase changes on the identical input data sequence M different sequences are generated by multiplying the input data sequence by the phase control sequences of length N. The phase of first cluster (branch) is generally not changed, while the phase of M-1 branches are changed differently Then, the sequence with the lowest PAPR among the M branches is selected This method is known to be effective and flexible since it is spectrally efficient and no signal deformation is made, unlike the block coding and clipping method, etc. However, this method has a high computational and hardware complexity because of many IFFT stages and iterative calculations Thus, this technique requires so many IFFT stages equivalent to complex structures in the OFDM transmitter, so that it is very difficult to realize in practice.

In this paper, we propose a PAPR-minimized sequence mapping scheme to reduce the PAPR with the simple processing and less computational complexity We create a mapping table with information about block index and symbol patterns of thelower signal power. When the input data sequence comes, it performed division by the block length to find the quotient and remainder The symbol pattern of the lower signal power can be found in terms of the block index as the quotient in the mapping table and transmittedwith remainder as the side information(SI) to distinguish and recover the original data sequence in the receiver. Compared with SLM, the computational complexity of this scheme can be greatly reduced at the cost of memory. The two methodswith PAPR-minimized sequence mapping scheme are proposed in this paper. One is with mapping table to recover the OFDM signal in both transmitter and receiver. The other is with mapping table only in transmitter to reduce the load and the hardware complexity in the mobile system. We compared the PAPR performance with SLM and discussed about the characteristics of the proposed algorithm.

The paper is organized as follows: In Section 2 the PAPR of the OFDM signal is explained. The proposed scheme to reduce the PAPR of an OFDM system is presented in Section 3. Simulation results are given in Section 4, and finally, Section 5 concludes the paper.

## Ⅱ. PAPR ANALYSIS IN OFDM SYSTE

The complex baseband OFDM signal may be represented as

$$s(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} d_n e^{j(2\pi\Delta f t)} \qquad (0 \le t < T)\ , \tag{1}$$

where N is the number of subcarriers, dn is the data applied to the nth subcarrier, the frequency separation between any two adjacent subcarriers is $\Delta f = 1/T$ and T is the OFDM symbol duration. The envelope power of the multi-carrier signal, p(t), is given by (2)

$$p(t)=s(t)\cdot s(t)^* \ , \tag{2}$$

where $(\cdot)^*$ denotes complex conjugate. If the power in the individual carriers is normalized to 1W then the maximum peak envelope power (PEP) and the average power of $s(t)$ can be written as :

$$P_{peak}=\max\{|s(t)|^2\}_{t\in[0,T)}=N^2(\mathrm{W}), \tag{3}$$

and

$$P_{avg}=E\left[|s(t)|^2\right]=N. \tag{4}$$

where $E[\cdot]$ denotes the average. With (3) and (4), the PAPR can be defined as:

$$PAPR=10\log_{10}\left\{P_{peak}/P_{avg}\right\}=10\log_{10}N \ \ (\mathrm{dB}). \tag{5}$$

In order to decrease the PAPR, the maximum of the instantaneous signal power should be decreased. From the (1),(3) and (5), it is clear that the PAPR is entirely determined by dn .

## Ⅲ. THE PROPOSED SCHEME

In an OFDM system, the envelope power of signal as a function of time, for all possible N bits data sequences, can be expressed as the decimal number increasing sequentially from 0 to 2N. Figure 1 shows the PEP when N=16 bits, i.e. number of subcarriers is 16. It is clear that there is a large probability that the code word will have a rather low PEP, and only a small fraction of all possible OFDM symbols has a bad peak-to-average power ratio.

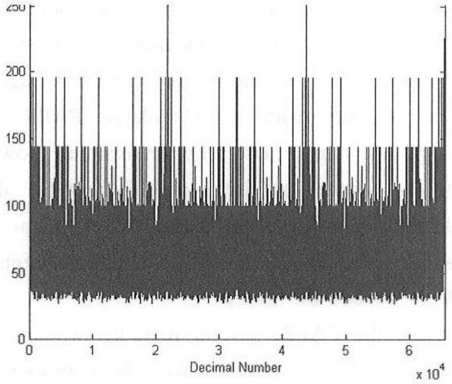

Figure 1. PEP for all possible code words ( N=16 )

Suppose we divide the conventional signal space that contains 2N symbol patterns into the high PAPR subspace and the low PAPR subspace. According to the low PAPR subspace, after pre-calculate all possible N subcarriers OFDM symbols, we create a mapping table with information about block index and symbol patterns of the low signal power as the mapping of the signal. If the mapping table contains k symbol patterns by the chosen number of blocks, we can reduce the conventional signal space with 2N into the k blocks of the lower PAPR signal subspace. The number of blocks and length of block (symbols/block) are related to (6),

$$l \cdot k = 2^N, \tag{6}$$

where l denote length of the block. Note that the larger number of blocks means the smaller length of the block The N bits input sequence U, is divided by the length of the block l, as given in (7);

$$U=q\,l+p \quad (0 \le U < 2^N,\ 0 \le q < k,\ 0 \le p < 2^N/k) \tag{7}$$

where p and q are the quotient and remainder, respectively.

### 1. Algorithm I

In this algorithm, we consider the simple PAPR reduction processing with a mapping table in both transmitter and receiver to recover the original signal After pre-calculation, we create the mapping table with information about the block index as the quotient, q,and k symbol patterns with the lowest PAPR that are selected from 2N symbol patterns as shown in Table 1.

Table 1 Mapping table for Algorithm I

| Block index (q) | Selected PAPR symbol patterns |
|---|---|
| 0 | $s_0$ |
| 1 | $s_1$ |
| 2 | $s_2$ |
| ⋮ | ⋮ |
| k-1 | $s_{k-1}$ |

In the transmitter, the input data sequence is divided by block length l(symbols/block) As defined, the quotient is the same as the block index number According to this quotient, we can find the corresponding symbol pattern in the mapping table By doing this, we can represent l different data sequences using the same symbol pattern To distinguish and recover these different data sequences, we should transmit the remainder p as side information that represents the difference between original input code word and the first code word in the same block. The flow chart of the proposed scheme is given in Figure 2.

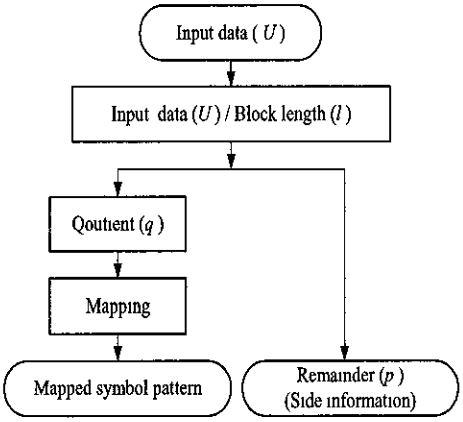

Figure 2 Flow chart of the transmitter

In the receiver, the received sequences are mapped in the provided mapping table which is same as the transmitter's to find the block number index, q. Because both the transmitter and the receiver know the length of the block, we can recover the original data sequence by (7) with the side information p. Figure 3 shows the flow chart of the receiver For N=8, k=32, the example of transmitter and receiver is shown in Figure 4.

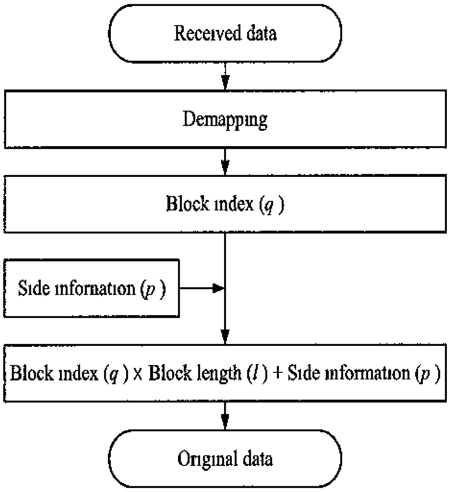

Figure 3 Flow chart of the receiver (Algorithm I)

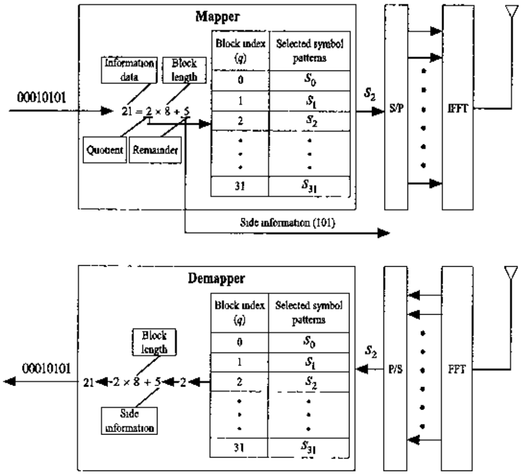

Figure 4 Mapping and Demapping processing of Algorithm I

As mentioned above, the relation of the number of side information bits m, the length of the block l, and the number of blocks k is as follows;

$$l = 2^{m} \quad (0 \le m < N) \tag{8}$$

and

$$k = 2^{N-m} \quad (0 \le m < N) \tag{9}$$

As denoted in [9], in an OFDM system, the side information can be introduced as a function of the PAPR

$$PAPR = 10\log 10(-\ln(1-2^{-m/N})). \tag{10}$$

The side information needed to restore the original data sequence in the receiver must be transmitted appropriately. In particular a powerful error correcting code has to be applied, as this information is crucial for the transmission error performance In this paper, we assume the side information can be received perfectly.

### 2 Algorithm II

We noted that both the transmitter and the receiver are needed the mapping table in Algorithm I However, in most communication systems, the hardware of the receiver is more complex than the transmitter To reduce the hardware complexity and load of the receiver, we suggest another method based on the Algorithm I with a differentmapping table only in transmitter. We create a mapping table with the desired kblock indexes in the transmitter, the same as Algorithm I However, the mapping table is composed of with different method compared with Algorithm I When any number U is divided by thenumber of blocks, k, the range of remainder, p', and the quotient, q as the block index are both from 0 to k-1 Thus, we can represent the block index number as the remainder p' in the mapping table. And we know that there are l data sequences with the same remainder, p' in the 2N signal space From these l data sequences, we select the symbol pattern with the lowest PAPR and put it into the p' th block index in the mapping table

In the transmitter, the data sequence is then divided by block length, l The quotient is then used for mapping it to the mapping table. Note that the quotient of the input data sequence divided by block length l, is the same range from 0 to k-1 as the remainder of the mapped symbol pattern divided by number of blocks, k The mapped symbol pattern with the lowest PAPR of ldata sequences is then converted into parallel streams by a serial to parallel converter (S/P) After IFFT, the OFDM symbol and side information are transmitted

In the receiver, the block index can be found as the remainder by the converted received data sequence modular the number of blocks, k. Then we easily find the original data from (7) with the received side information Figure 5shows the flow chart of the receiver By doing this, we can design the PAPR reduction scheme without the mapping table in the receiver For N=8, k=32, the example of mapping and recover processing is shown in Figure 6

As known in the Algorithm I and II, the block size controls the PAPR reduction level, i e , the number of the lowest PAPR symbol patterns If we increase/decrease the block size, the smaller/larger PAPR reduction can be obtained. However, the side information also decreases/increases dependent on

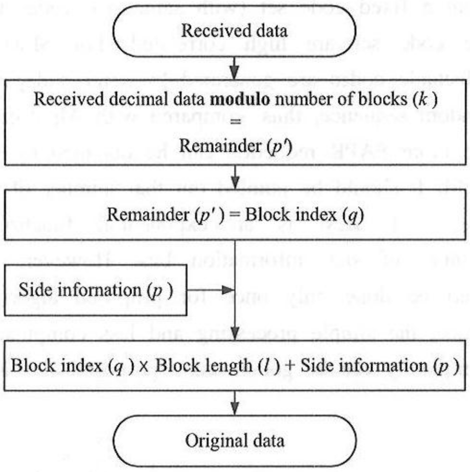

Figure 5. Flow chart of the receiver (Algorithm II)

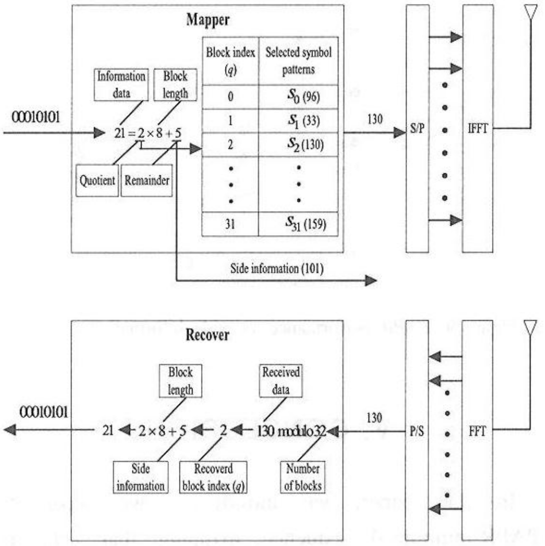

Figure 6. Mapping and Recover processing of Algorithm II

the increase/decrease of the block size. Since the Algorithm I transmits the lowest PAPR symbol pattern, the lowest PAPR by simple processing can be guaranteed with the well trade-off of the cost, i.e., the size of side information bits and the mapping table in transmitter and receiver. In the Algorithms II, PAPR of the transmitted symbol pattern is the lowest in $l$ sequences with same remainder, therefore PAPR of some symbol patterns might be higher than PAPR of the symbol pattern set in the Algorithm I. Thus the smaller PAPR reduction can be obtained compared to the Algorithm I. However note that the Algorithm II does not need the mapping table in the receiver.

## IV. SIMULATION RESULTS

In this section, we show the simulation results for the proposed two algorithms. Themapping table is created by pre-calculating all possible OFDM symbols. Because pre-calculation can be done offline, therefore none computational complexity can be introduced into thesystem. For large number of subcarriers and high-levelmodulation, a huge amount pre-calculation is need, so we consider 16 subcarriers and BPSK in our simulations.

In Figure 7, the PAPR reduction of the proposed algorithms is shown for a different numberof blocks with the subcarriers N=8, 12, 16, respectively. As expected, the Algorithm I provides better PAPR reduction than the Algorithm II due to the different mapping table scheme. However, we can reduce hardware complexity of the receiver of the Algorithm II. When the number of blocks is equal to the number of subcarriers,both Algorithm I and Algorithm II are same as the normal OFDM, and we can not gain the PAPR reduction, here, because the number of block indexes of the mapping table is equal to the conventional signal space's. Because the PAPR increased with number of subcarriers, therefore the more number of subcarriers, the more PAPR reduction can be obtained.

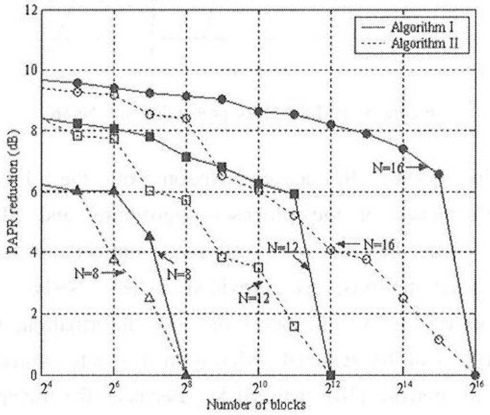

Figure 7. PAPR reduction for the proposed system

Also the excess probability of the PAPR of the both proposed algorithms with 2 and 4 side information bits is shown in Figure 8. For the Algorithm I, 2 side information bits provides 214 mapped symbol patterns with the lowest PAPR, and 4 side information bits provides 212 mapped symbol patterns with the lowest PAPR. Because the symbol patterns arranged in ascending order of the PAPR in the mapping table of the Algorithm I, so the less number of side information bits means the more PAPR. Since Algorithm I can reduce PAPR greatly, for 2 and 4 bits side information, no symbol patterns can be generated when PAPR0excess 3.8dB and 4.6dB, respectively. For the Algorithm II, 2 side information bits for every transmitted symbol pattern can provide only 4 selectable symbols, and for 4 side information bits, there are 16 selectablesymbol patterns can be provided for every transmitted symbol pattern. Obviously, the performance of 4 side information bits is better.

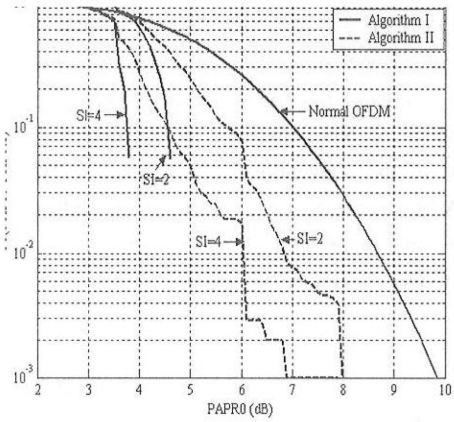

Figure 8. PAPR-excess probability for N=16

In Figure 9, a comparison of the PAPR performance of the proposed algorithms and SLM [9] with BPSK, with different number of side information bits, is provided when N=16. As expected, as we increased the side information, the PAPR can be reduced. Algorithm I much approach to theoretical (10) than SLM. Because the mapped symbol patternswith lowest PAPR, in fact, Algorithm I is an ideal case for PAPR reduction. For Algorithm II, the transmitted signal is selected from a fixed code set (with same p'), codes thatin the code set are high correlated. For SLM, the selectable codes are generated by some independent random sequence, thus, compared with Algorithm II, the more PAPR reduction can be obtained by using SLM. It should be pointed out that number of IFFT stages of SLM is an exponential function of number of side information bits. However, IFFT need be done only once for proposed algorithms, hence, the simple processing and less computational complexity can be gotten using proposed algorithms.

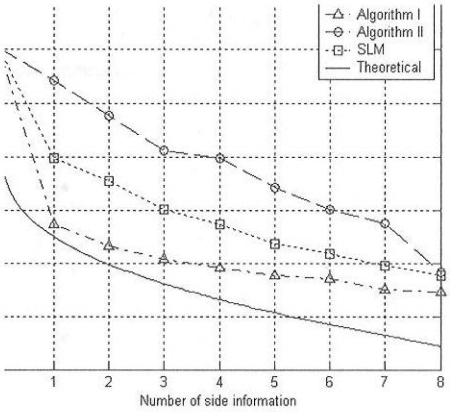

Figure 9. PAPR performance vs. side information (N=16)

## V. CONCLUSION

In this paper, we introduced two types of PAPR-minimized sequence mapping that achieves the minimum Peak-to-Average Power Ratio andthe minimum amount of computations for theOFDM system. To reduce the PAPR, the mapping table is created with information about block index and symbol patterns of the lower signal power. In the Algorithm I, we consider the simple PAPR reduction processing with a mapping table in both transmitter and receiver to recover the original signal. We create it with information about the block index as the quotient, q, and k symbol patterns with the lowest PAPR that are selected from 2Nsymbol patterns. To reduce the hardware complexity and load of the receiver, we suggest another method in Algorithm II based on the

Algorithm I with a different mapping table in only transmitter We create a mapping table with the desired k block indexes in the transmitter, the same as Algorithm I However, the mapping table is composed of different method compared with Algorithm I We choose the block size based on the remainder and the PAPR symbol pattern based on the lowest PAPR from block length 1.

As known in the Algorithm I and II, the block size controls the PAPR reduction level, i.e., the number of the lowest PAPR symbol pattern If we increase/decrease the block size, the smaller/larger PAPR reduction can be obtained However, the side information also decreases/increases dependent on the increase/decrease of the block size In this simulation, we show that by increasing the number of the side information bits, the PAPR performance is increased and the size of mapping table is decreased at the cost of spectrum efficiency We can adjust this trade-off problem accordingto requirement in practice by considering the PAPR reduction, block size of the mapping table and the size of the side information bits. Compared to SLM, the Algorithm I provides more advantageous because of its PAPR performance, the lower IFFT stages and the lower amount of computations. However, using the Algorithm II, we can decrease the hardware complexity of the receiver, which is very important in a practical OFDM system and other multi-carrier system applications

## REFERENCES

[1] Li X.,and L J Cimini, "Effects of Clipping and Filtering on the Performance of OFDM," IEEE VTC'97, 1997,pp 1634-1638

[2] Xiaodong Li and Cimini, L J, Jr, "Effects of Clipping and Filtering on the Performance of OFDM", IEEE Commun. Lett., vol. 2 No. 5, May 1998, pp. 131 133

[3] A Wilkinson, A.E Jones, "Minimization of the Peak to Mean Envelope Power Ratio of Multicarrier Transmission Schemes by Block Coding", IEEE VTC'95,vol 2, 1995, pp 825-829

[4] Yunjun Zhang; Yongacoglu, A., Chouinard, J -Y, "Reducing Multicarrier Transmission Peak Power with a Modified Simple Block Code", Commun. Techno Proc, WCC - ICCT 2000. International Conference, vol 1, 2000, pp 578 -580,

[5] Tae-Han Kim; Kwan-Woong Ryu; Yong-Wan Park, "A Study on the PAR Reduction using ABC (Adaptive Block Coding) in OFDM System", CIC, vol.II, 2002, pp.98-102

[6] Mizhou Tan, Cheng, J, Bar-Ness, Y, "OFDM Peak Power Reduction by a Novel Coding Scheme with Threshold Control", VTC'2001 Fall, vol.2, 2001, pp 669 672

[7] Jones, A.E., Wilkinson, T.A., "Combined Coding for Error Control and Increased Robustness to System Nonlinearities in OFDM", VTC'96, vol. 2, 1996, pp.904 908

[8] Van Eetvelt, P; Wade, G; Tomlinson, M., "Peak to Average Power Reduction for OFDM Schemes by Selective Scrambling", Electron Lett , vol 32 Issue· 21 , Oct. 1996, pp. 1963 1964

[9] Muller, S. H., R. W. Baumal, R. F. H. Fischer, and J B. Huber, "OFDM with Reduced Peak-to-Average Power Ratio by Multiple Signal Representation", Annals of Telecommunications, vol 52, no 1-2, February 1997, pp.58-67

[10] Sumasu, A.; Ue, T.; Uesugi, M.; Kato, O; Homma, K. "A Method to Reduce the Peak Power with Signal Space Expansion (ESPAR) for OFDM System", IEEE VTC 2000-Spring Tokyo vol.1, 2000, pp. 405-409

[11] P.A. Pushkarev, Kwan-Woong Ryu, Kook-Yeol Yoo and Yong-Wan Park, "A study on the PAR reduction by hybrid algorithm based on the PTS and SLM techniques," IEEE VTC 2003-Spring, vol. 2 , pp. 1263 - 1267, April 2003.

[12] Myeong-Hwan Cho, Seong-Jae Lee, JiYu Jin, Yong-Wan Park, "A study on the PAPR using Variable Code Sets (VCS) in multi-user MC-CDMA system", IEEE VTC2004-Fall, 2004. 9.

[13] Ji-Yu Jin, Kwan-Woong Ryu, Kook-Yeol Yoo, "A Decimal Mapping Algorithm to Reduce Peak-to-Average Power Ratio in an OFDM System", JCCI 2003, pp II-C-5.1~4, 5. 2004

### Jiyu Jin

Associated Member

2003.8 : M.S degree in Infor-mation and Communication Engineering from Yeungnam University

2003.9~present : Ph.D candidate in Information and Communication Engineering from Yeungnam University

Research interests : MIMO, OFDM

### Kwan-Woong Ryu

Associated Member

1999.2 : M.S degree in Infor-mation and Communi-cation Engineering from Yeungnam University

2002.3~present : Ph.D candidate in Information and Communication Engineering from Yeungnam University

2004. 2~present : Internship from NTT DoCoMo, Inc. in YRP(Yokosuka Research Park), Japan

Research interests : Multicarrier CDMA, MIMO-OFCDM, Binary CDMA

### Yong-wan Park

Regular Member

He received the B.E. and M.E. degree in Electrical Engineering from Kyungpook University, Daegu Korea, in 1982 and 1984, respectively, and his M.S. and Ph.D. degree in Electrical Engineering from State University of New York (Buffalo), U.S.A, in 1989 and 1992, respectively. He joined the California Institute of Technology as research fellow from 1992 to 1993. From 1994 to 1996, he has served as a chief researcher for developing IMT-2000 system at SK Telecom, Korea. Since September 1996, he has been a Professor of Information and Communication Engineering at Yeungnam University, Korea. From Jan. 2000 to Feb. 2000, he was a invited Professor at NTT Mobile Communications Network Inc. (NTT DoCoMo) Wireless Lab, Japan. He was also a visiting Professor at UC Irvine, U.S.A, in 2003. His current research areas of interest include Beyond 3G/4G system, OFDM system, PAR reduction, interference cancelation and resource management in wireless communication etc..