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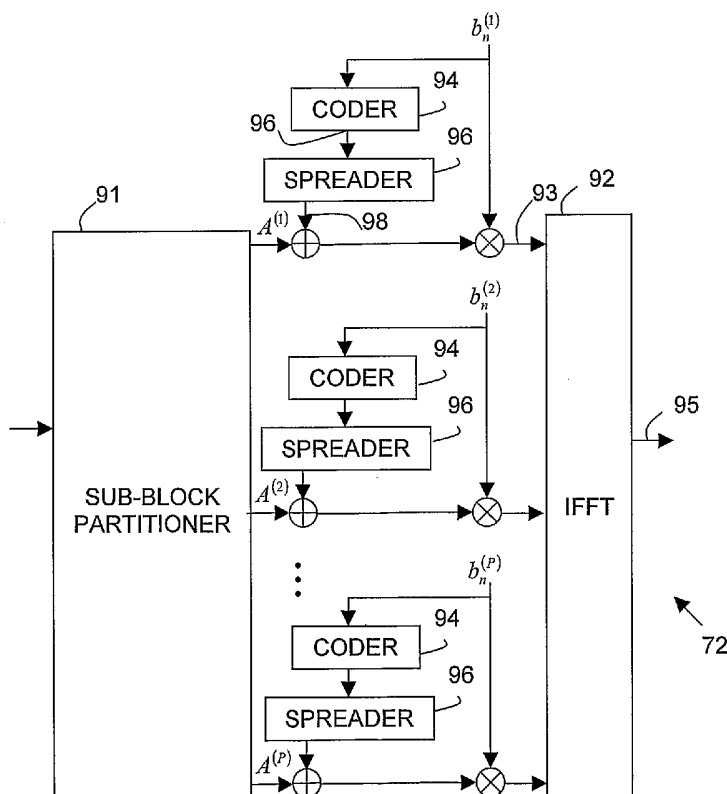
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(54) Title: A METHOD AND APPARATUS FOR A MULTICARRIER CODE DIVISION MULTIPLE ACCESS SYSTEM



(57) Abstract: A method (140) and apparatus (70,72) for partial transmit sequence (PTS) approach for peak to average power ratio (PAPR) reduction in a multi-carrier code division multiple access (MC-CDMA) applications for transmitting an optimised transmit sequence (85), the phase information is transmitted as spread data. The apparatus having a modulator (72) for the spread data and providing a transmit sequence having phase sequence and transmit sequence together in single sequence (85) for transmission.



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A METHOD AND APPARATUS FOR A MULTICARRIER CODE DIVISION MULTIPLE ACCESS SYSTEM

FIELD OF INVENTION

The invention generally relates to multi-carrier code division multiple access (MC-CDMA) applications, and more particularly, to partial transmit sequence (PTS) approach for peak to average power ratio (PAPR) reduction in MC-CDMA applications.

BACKGROUND

Multicarrier transmission schemes have been proposed as an effective way to improve channel capacity utilization under multipath interference and frequency selective fading reception. By dividing total bandwidth into many narrow sub-channels that are transmitted in parallel, the effect of multipath delay spread can be minimised. Orthogonal frequency division multiplexing (OFDM) is an effective multicarrier modulation scheme to combat the frequency selectivity of the channel using a simple one-tap equalizer. OFDM prevents inter-symbol interference (ISI) and inter-carrier interference (ICI) by inserting a cyclic prefix (CP) between adjacent OFDM symbols. Moreover, the signal can be transmitted and received using fast Fourier transform (FFT) devices without increasing the transmitter and receiver complexities. This technology has been proposed or adopted for digital audio broadcasting, digital terrestrial television broadcasting, wireless LANs and high-speed cellular data.

Uncoded OFDM transmission technique applied in a multipath environment has a bit error rate (BER) comparable to that of a narrow band radio channel because the fading of each subcarrier is frequency non-selective. To overcome this behaviour and to reduce the BER, a combination of OFDM and

code division multiple access (CDMA), called multicarrier CDMA (MC-CDMA), has been proposed recently. In MC-CDMA system, the energy of each information symbol is spread over several subcarriers, which leads to a diversity gain in a broadband-fading channel. However, same as any multicarrier modulation schemes, one disadvantage of using MC-CDMA for wireless applications is the potentially large peak to average power ratio (PAPR) characteristic of multicarrier signals. When passed through a non-linear device, such as transmit power amplifier, the signal may suffer significant spectral spreading and in-band distortion. Hence, in order to prevent spectral growth of the multicarrier signal intermodulation among subcarriers and out-of-band radiation the transmit amplifier must operate in its linear region, where the conversion from direct current to radio frequency power is highly inefficient. Moreover, the required large linear range directly translates into significantly more expensive devices, limiting widespread industrial applications.

For wireless applications, efficient power amplification is required to provide adequate area coverage and minimum battery consumption. Conventionally, PAPR problems are solved using either a linear amplifier or back off the operating point of a non-linear amplifier. But both approaches result in significant power efficient penalty. Some other methods have been suggested to solve PAPR problems. The simplest is to clip the signal before amplification as discussed in R. O'Neill et al., "Envelope variations and spectral splatter in clipped multicarrier signals", Proceedings of PIMRC'95, pp. 71-75, which gives a good PAPR but at the expense of some performance degradation. Non-linear block coding is another method as discussed in A. E. Jones et al., "Block coding scheme for reduction of peak to mean envelope power ratio o multicarrier transmission scheme", Electronic

Letters, vol. 30, No. 25, Dec. 1994, 2098-2099, in which the desired data sequence is embedded in a larger sequence and only a subset of all possible sequences with low peak powers are used for transmission. Even though, a 3dB PAP can be achieved using this method, it requires large look-up tables at transmitter and receiver. Some other coding schemes with error correction abilities have also been proposed for the reduction of PAP as discussed in R. D. J. van Nee, "OFDM Codes for Peak-to-Average power reduction and error correction, "Proceedings of the Globecom '96, pp. 740-744

For MC-CDMA, a dynamic spread code selection method is proposed to lower PAPR as discussed in H. Ochiai et al., "OFDM-CDMA with Peak Power Reduction Based On the Spread of Sequences", Proceedings of the IEEE International Conference on Communications, June 1998, vol. 3, pp. 1299-1303. In this method, initially each user is assigned a low and a high PAPR spreading code, which allows selecting one when the system is operating. The spread code for each user is dynamically selected so that the total PAPR level of the whole user group present in the system is minimised. The actual PAPR reduction based on this method depends on the system capacity needed. The maximum number of users is limited by half of the spreading code.

One of the recent methods for reducing PAPR is partial-transmit sequence (PTS) approach as discussed in S. H. Muller et al., "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences", Electronic Letters, vol. 33, No. 5, Feb 1997, pp. 368-369. This introduces additional complexity but improves PAPR statistics for multicarrier modulation with little cost of efficiency. In this scheme, subband signals are partitioned into multiple disjoint

sub-blocks. Several sub-block partition schemes are available in literature (e.g. S.G. Kang et al., "A novel subblock partitioning scheme for partial transmit sequence OFDM", IEEE Transactions on Broadcasting, vol. 45, no. 3, September 1999, pp. 333-338). Phase of each sub-block is modified by a set of rotation factors to achieve PAPR to be as low as possible. The receiver readjusts this phase shifts and recovered the data. To do that both transmitter and receiver share the same information on phase rotations that make the system design very complicated.

Amplitude limiting and coding schemes are not very successful for reducing PAPR because of bandwidth expansion and high complexity, respectively. The dynamic allocation of spread codes and/or restricting the number of spread codes for the reduction of PAPR is obviously not an optimal choice. This method will significantly reduce the system capacity in terms of number of spread codes available for transmission. The overall PAPR obtained by this method is not the absolute minimum since the size of user group can be less than total number of users in the system. Also, the complexity of transmitter and receiver units will significantly increase by using this method.

Partial-transmit sequence with phase rotation is a better alternative for PAPR reduction. But the practical implementation of this approach faces several challenges. It is obvious that the receiver must have knowledge about the generation process of the transmitted symbol in each FFT period. Thus the set consists of all optimum phase rotation factors that have to be transmitted to the receiver so that the subcarriers can be phase adjusted appropriately. When the phase changes continuously, a huge number of bits will be required as side information. Moreover, the detection error in this phase information will severely degrade the BER performance.

Therefore, there is a need to solve the problem to translate into the optimisation of phase information into a finite number of predetermined levels, and designing a suitable method to convey the phase information to the receiver of a MC-CDMA system without increasing the complexity of the receiver.

SUMMARY

Embodiments of the invention provide an apparatus for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the apparatus comprising a spreader for spreading an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal, a modulator for the spread data corresponding to the input signal to generate an output sequence having a phase sequence and a transmit sequence together in a single output sequence; and a transmission subsystem for transmitting the transmit sequence.

An embodiment may further comprise at least two modulators, each modulator having different phase sequences corresponding to a phase value selected for each modulator, and a selector for comparing each output sequence of each modulator and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence. Additionally, the modulator may further comprise a coder for coding the selected phase value of the modulator into a coded sequence of the phase value of the modulator, a spreader for spreading the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value, a partitioner for partitioning the spread data into at least two sub-blocks of partial data, an adder for adding each sub-block of partial data together with the spread data corresponding to the coded sequence of the

phase value of the partial data providing a sum, and a multiplier for multiplying the sum with the phase value for a sub-block sequence of the sub-block, and an inverse fast fourier transformer (IFFT) for transforming the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

In another aspect of the invention is a method for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the method comprising spreading with a spreader an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal, generating an output sequence having a phase sequence and a transmit sequence together in a single output sequence with a modulator for the spread data corresponding to the input signal, and transmitting with a transmission subsystem the transmit sequence.

The generating of the output sequence may be generated with at least two modulators, each modulator having different phase sequences corresponding to a phase value selected for each modulator; and comparing with a selector each output sequence of each modulator and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence.

The generating of the output sequence may further comprise coding with a coder the selected phase value of the modulator into a coded sequence of the phase value of the modulator, spreading with a spreader the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value, partitioning with a partitioner the spread data into at least two sub-blocks of partial data, adding with an adder each

sub-block of partial data together with the spread data corresponding to the coded sequence of the phase value of the partial data providing a sum; and multiplying with a multiplier for the sum with the phase value for a sub-block sequence of the sub-block, and transforming with an inverse fast fourier transformer (IFFT) the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

In yet another aspect of the invention a computer program product for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the computer usable medium having computer readable program code means embodied in the medium for causing the calculation of the output transmit signal, the computer program product comprising a computer readable program code for spreading an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal, a computer readable program code for generating an output sequence having a phase sequence and a transmit sequence together in a single output sequence, for the spread data corresponding to the input signal; and a computer readable program code for transmitting with a transmission subsystem the transmit sequence.

The computer readable program code for generating of the output sequence may be generated with at least two modulators routines, each modulator routines having different phase sequences corresponding to a phase value selected for each modulator routine; and comparing with a selector each output sequence of each modulator routine and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence.

The computer readable program code for generating of the output sequence may further comprise coding the selected phase value into a coded sequence of the phase value of the modulator routine, spreading the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value, partitioning the spread data into at least two sub-blocks of partial data, adding each sub-block of partial data together with the spread data corresponding to the coded sequence of the phase value of the partial data providing a sum; and multiplying for the sum with the phase value for a sub-block sequence of the sub-block, and transforming with an inverse fast fourier transformer (IFFT) the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, objects and advantages of embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, in conjunction with drawings, in which:

FIG. 1 shows a schematic block diagram of a multi-carrier code division multiple access (MC-CDMA) transmitter structure;

FIG. 2 shows a schematic block of diagram of peak to average power ratio (PAPR) reduction using a partial-transmit sequence (PTS);

FIG. 3 shows a schematic block diagram of a peak-to-average power reduction scheme in accordance with an embodiment of the invention;

FIG. 4 shows a detailed schematic block for a modulator of FIG. 3 in accordance with an embodiment of the invention;

FIG. 5 shows a graph comparison a peak-to-average power reduction scheme between a conventional MC-CDMA system and MC-CDMA systems of embodiments of the invention;

FIG. 6 shows a graph comparison of change in peak to average power ratio for different number of users using an embodiment of the invention;

FIG. 7 shows a graph of receiver performance of a single user system for a transmitter using an embodiment of the invention;

FIG. 8 shows a graph of receiver performance of a multi-user system for a transmitter using an embodiment of the invention;

FIG. 9 shows a flowchart of a method of a PAPR scheme in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

The transmitter structure 20 of MC-CDMA system for downlink transmission is given in FIG. 1. The input information sequence corresponding to k^{th} user $S^{(k)}$ is first converted by serial-parallel (S/P) converter 18,19 into M parallel data sequences $(S_1^k, S_2^k \dots S_M^k)$ and then each serial/parallel (S/P) converter output is spread by spreader 28,29 with the spreading code $c^{(k)}$ of length G to get spread sequence $(D_1^k, D_2^k \dots D_N^k)$, corresponding to user k where $N = M \times G$. The spread sequence of all active users (K) are correspondingly added $\left(\mathbf{A} = [A_1, A_2, \dots, A_N], \text{ where } A_n = \sum_{k=1}^K D_n^{(k)} \right)$ and input to inverse fast Fourier transform (IFFT) device 40 of size N . The IFFT vector output is converted back into serial data from parallel to serial by parallel/serial (P/S) converter 42 and a cyclic prefix of length p is inserted by inserter 44 between symbols to avoid the

intersymbol interference caused by multipath fading. The signal is finally transmitted after radio frequency up-conversion. Without loss of generality, the baseband transmitted signal for one OFDM block of symbol length T_s can be represented as follows:

$$a(t) = \sum_{n=0}^{N-1} \sum_{k=1}^K S_n^{(k)} c_l^{(k)} e^{j2\pi \frac{nt}{T_s}} = \sum_{n=0}^{N-1} A_n e^{j2\pi \frac{nt}{T_s}} \quad 1$$

The PAPR is defined as

$$\lambda = \max_{0 \leq t < T_s} |a(t)|^2 / \frac{1}{T_s} \int_0^{T_s} |a(t)|^2 dt \quad 2$$

In discrete time representation, it can be rewritten as

$$\lambda = \max_{0 \leq t < N} \frac{\left| \sum_{n=0}^{N-1} \sum_{k=1}^K S_n^{(k)} c_l^{(k)} e^{j2\pi \frac{tn}{N}} \right|^2}{\sigma_a^2} \quad 3$$

where $\sigma_a^2 \cong \varepsilon \left\{ \left| \sum_{k=1}^K S_n^{(k)} c_l^{(k)} \right|^2 \right\}$, $\varepsilon\{\}$ denotes the expectation

operation. Following the exposition in [8 – 9], the probability that PAPR λ of a randomly generated multicarrier symbol exceeds the PAPR threshold, say, $\lambda_0 = a_0^2 / \sigma_a^2$ can be approximated as follows:

$$\text{prob}\{\lambda > \lambda_0\} = 1 - (1 - e^{-\lambda_0})^N \quad 4$$

For PTS approach, the input data vector A is partitioned into disjoint sub-blocks, as $\{A^{(p)} | p=1, 2, \dots, P\}$ and are combined to minimise PAPR. Assume the simplest sub-block partitioning scheme for $A^{(p)}$, consist of a contiguous set of subcarriers and are of equal size. Consider $a_n^{(p)} (= [a_1^{(p)}, a_2^{(p)}, \dots, a_N^{(p)}]^T)$, the zero padded IFFT of $A^{(p)}$. The signal samples at the output of PTS combiner can be written as

$$\mathbf{a} = \begin{bmatrix} a_1^{(1)} & a_1^{(2)} & \dots & a_1^{(P)} \\ a_2^{(1)} & a_2^{(2)} & \dots & a_2^{(P)} \\ \dots & \dots & \dots & \dots \\ a_N^{(1)} & a_N^{(2)} & \dots & a_N^{(P)} \end{bmatrix} \begin{bmatrix} e^{j\phi^{(1)}} \\ e^{j\phi^{(2)}} \\ \vdots \\ e^{j\phi^{(P)}} \end{bmatrix} \quad (5)$$

where the phase vector $\{\phi^{(p)} | p=1, 2, \dots, P\}$ are the phase rotation factors chosen to minimise the PAPR of transmitted symbol $\mathbf{a}$. Thus, the problem of PAPR reduction is translated as follows: Minimise $\max_{0 \leq t < N} |\mathbf{a}(\Phi)|$ subject to $0 \leq \phi^{(p)} < 2\pi, \quad p=1, \dots, P$ (6)

FIG. 2 shows the block diagram for a conventional partial-transmit sequence (PTS) approach for PAPR reduction system 50. For PTS approach the data sequence $\mathbf{A} (= [A_1, A_2, \dots, A_N])$ (with reference to FIG. 1) to be partitioned into P sub-blocks by partitioner 52. Each sub-block $\mathbf{A}^{(p)}$ is input to an IFFT 54, 56, 58 where $\mathbf{a}_n^{(m)} = \text{IFFT}(\mathbf{A}^{(m)})$. The IFFT output of each sub-block is phase rotated by the phase rotation factor. The phase shifted sub-blocks are then added together by adder 62 to produce alternate transmit signals containing the same transmit information, and the optimum phase-rotation vector peak-value is determined by optimization device 60. This process is repeated for all different possible phase rotation factors, and the multicarrier symbol with lowest PAPR is transmitted. The information on transmit signal phase rotation 64 has to be sent as a side information for the correct decoding of data at the receiver.

By restricting the finite set of values for phase factors, the problem of PAPR reduction given in equation (6) can be modified as follows:

$$\text{Minimise } \max_{0 \leq t < N} |\mathbf{a}(\Phi)| \text{ subject to } \phi^{(p)} \in \left\{ \frac{2\pi l}{W} \mid l=0, \dots, W-1 \right\} \quad (7)$$

The number of choices available for phase rotation is determined by the rotation factor W . If W is sufficiently large, equations (6) and (7) gives identical result. By fixing the phase information of the first sequence $(\phi^{(1)})$ constant, the system has $(P-1)$ free variables for phase information and correspondingly $W^{(P-1)}$ distinct phase vectors need to be tested. In most of the studies, it has been shown that optimal performance can be obtained by selecting $W=2$, which in turn converts the phase rotation vector as an optimal binary phase sequence (OBPS) as discussed in Muller et al. For OBPS, the phase factors are restricted to 0 and π and hence an exhaustive search can be carried out over all combinations of permissible phase factors. Hence the complexity of OBPS search increases linearly with the number of sub-blocks.

The implementation of this embodiment of PAPR reduction in MC-CDMA assumes $W=2$. Of course it will be appreciated W can be any discrete number. The corresponding values are +1 and -1. Instead of sending this information as separate side information, an embodiment of the invention of a system considers the side information as a user data. The information will be spread using a predefined spread code and added with all other user channels. The sub-blocks corresponding to partial transmitted sequences are then multiplied with respective phase values. By this arrangement extra overhead required for transmission of phase vectors is almost negligible. But to decide OBPS, an exhaustive search with all possible combinations of ± 1 for all sub-blocks is required. The total number of possible choices is 2^P where P is the number of sub-blocks. If the phase factor of the first sub-block is fixed, the number of choices are reduced to $2^{(P-1)}$. The number of parallel transmitters required for deciding the transmitted symbol with lowest PAPR is equal to this value. Obviously transmitter requires more and/or faster

hardware, while the receiver is nearly unaffected, when compared to the original MC-CDMA. Since this scheme is designed for downlink transmission, the more complexity at the transmitter is not a serious issue and keeping the same simplicity for the receiver is an added advantage.

FIG. 3 shows the block diagram for an apparatus 70 generating optimised transmit sequence in accordance with an embodiment of the invention, and FIG. 9 shows a flowchart of a method of PAPR scheme 140. As mentioned, in order to find out OBPS, an exhaustive search with all possible combinations of binary phase sequences is required. Although it is shown in FIG. 9 assignment and calculation of each binary phase sequence is conducted sequentially, it will be appreciated that it may be configured in parallel, as shown in FIG. 4. Since the number of partitions employed in a practical system is not very large, this search process can be paralleled in the transmitter. The parallel arrangement is shown in FIG. 3. Each modulator 72,74,76,78 represents a possible combination of binary phase sequence, where the modulator with the lowest PAPR is selected by selector 80.

FIG. 4 shows the details of the modulator 72,74,76,78 corresponding to the binary phase sequence b_n . After spread of input signal 142 and partitioning 144 into different disjoint sub-blocks with sub-block partitioner 91 binary phase information is assigned 146 to each sub-block, each partial data is added 146 with the spread data 142 corresponding to binary phase value of the partition (for example $b_n^{(p)}$ for p^{th} partition). Specifically, the phase value is coded by coder 94 to a coded sequence 97 of the phase value, and then spread by spreader 96 to a spread data 98 corresponding to the coded sequence of the phase value. The resultant sum is multiplied 152 with the respective binary phase

value to provide an output sequence 93 of the sub-block before IFFT conversion 154 at IFFT converter 92. This process is repeated 156 as shown in FIG. 9, or conducted simultaneously in parallel as shown in FIG. 4, for all binary phase sequences.

Optimised transmit sequence 85 is generated after comparing the outputs of all possible modulators, and selecting 158 the sequence with the lowest PAPR for transmission 159 in a transmission subsystem such as discussed above with reference to FIG. 1 and 2. It will be appreciated that other arrangements may be envisaged, for example there may be multiple or a plurality of IFFTs where each IFFT outputs partial transmit sequences that are added up by adder instead of a single IFFT 92, 154 for possible transmission 159.

As mentioned, phase information is transmitted as spread data. The data being spread is an indication of phase sequence. Since $W=2$, the possible phase values are ± 1 . Due to the inverse multiplication of -1 , these values cannot be used directly for spreading. As shown in FIG. 4, the resulting sum of user data and spread data corresponding to phase values are multiplied with the respective phase value, which might negate the overall result if the phase vector is -1 . This affects the detection accuracy of OBPS, and hence the BER performance. In order to solve this problem, a two-bit representation scheme for phase value is used. Since the possible choices are ± 1 , "+1" may be represented using same bits (-1-1 or 1 1) and the "-1" with a transition of bits (-1 1 or 1 - 1).

The receiver despreads the phase vector using the assigned spread code, and decides the phase values based on the presence of transition. The system represents +1 with identical bits and -1 with a transition of bits. Since this approach does not require any additional computation, the receiver complexity

remains the same with the added feature of OBPS. The multiplication with phase values in the transmitter can be simplified as a simple sign change in case of -1 and remain same for $+1$. The complexity mainly lies in OBPS selection at transmitter, which can be paralleled. Of course, it will be appreciated that greater than two-bit representation schemes may be implemented, for example three, four, etc., multi-bit representation schemes. For multi-bit cases when the number of bits is a power of two, the coded sequences resemble that of a Walsh-Hadamard sequence. If the number of bits is not a power of two, the coded sequences have different bit transition patterns. An example with different phase rotation factors is shown in Table 1:

<u>Phase Rotation Factor</u>	<u>Phase Values</u>	<u>Coded Sequence</u>
2	(+1	1 1
	(	
	(-1	1 - 1
4	(+1	1 1 1 1
	(	
	(+j	1 - 1 1 - 1
	(	
	(-1	1 1 - 1 - 1
	(-j	1 - 1 - 1 1

TABLE 1

The simulation results of the methods of FIG. 3 and 4 in MC-CDMA systems are shown FIG. 5 and FIG. 6, where in this embodiment a MC-CDMA system with 256 subcarriers is assumed. Each multicarrier symbol consists of 16 data symbols and the processing gain is 16. The spread codes are selected from orthogonal Walsh-Hadamard transform. Additional details of simulation parameters are shown in the Table 2:

Bandwidth		80 MHz
Number of Subcarriers		256
Subcarrier Separation		312.50 KHz
Spreading code	Scrambling	Random Sequences
	Channelization	Walsh Sequence
Spreading Factor		16
Modulation		QPSK
Packet length		64 OFCDM Symbols (Data: 60, Pilot:4)
Number of partitions		1/ 2/ 4/ 8
Channel Model		Multipath Rayleigh fading channel (L=24)
Normalized Doppler frequency ($f_d T$)		0.01
Power control		Nil
Antenna Diversity		None

TABLE 2: Simulation Parameters

FIG. 5 shows the improvement in PAPR at transmitter with the increase in the number of PTS in a MC-CDMA system. The probability of PAPR crossing a threshold value ($PAPR_o$) is plotted. The number of active users for the system under test is selected as 16, which includes the spread data corresponding to PTS. The MC-CDMA system with 2, 4 and 8 partial transmit sequences 102, 104, 108 respectively, are compared against a system without PTS optimisation 100. As expected, the PAPR reduces considerably when the number of PTS increases. But the computational complexity at the transmitter also increases with the number of PTS. For example, if a system uses 8 PTS, then it requires 2^8 parallel modulators to decide the optimal binary phase sequence (OBPS). The number of parallel modulators can

be minimised to 2^7 if the phase vector corresponding to the first partition is fixed.

FIG. 6 shows PAPR where the probability of exceeding certain peak power, $\text{prob}(\text{PAPR} > \text{PAPR}_0)$, is 10^{-3} , with respect to the number of users. As the number of users increases, the PAPR improves considerably. The MC-CDMA system with 2, 4 and 8 partial transmit sequences 112, 114, 118 respectively, are compared against a system without PTS optimisation 110. It is because, for large number of users, the superimposed sequences tend to cancel out the elements of several subcarriers, resulting in the reduction of effective number of subcarriers, and if the actual number of subcarriers is reduced without changing the average power, eventual PAPR becomes lower. This feature is true for all MC-CDMA systems, but the absolute value of PAPR will change according to the number of partial transmit sequences used.

FIG. 7 and 8 show graphs of receiver performance of the MC-CDMA system after the incorporation of partial transmit sequence of the simulation parameters of Table 1. The graph of FIG. 7 represents a single user system, while the graph of FIG. 8 represents a multi-user system of 8 users. The single user MC-CDMA system of FIG. 7 has 2, 4 and 8 partial transmit sequences 122, 124, 128 respectively, are compared against a system without PTS optimisation 120. The multi-user MC-CDMA system of FIG. 8 has 2, 4 and 8 partial transmit sequences 132, 134, 138 respectively, are compared against a system without PTS optimisation 130. Since the whole sequence is multiplied with partial transmit sequence, any decision error on the sequence affects the overall performance of the system. It is reflected in the slight degradation of performance in low signal to noise (SNR) regions.

The embodiments depicted herein may generally be implemented in and/or on computer architecture that is well known in the art. The functionality of the embodiments of the invention may generally be implemented in hardware or software, or a combination of both. An embodiment may be implemented in hardware, where a component is a functional hardware unit designed for use with other components, such that a component may be implemented with discrete electrical components, or may form a portion of an entire electronic circuit such as an application specific integrated circuit (ASIC). An embodiment may be implemented in software, where the system may be a program, process or portion thereof that usually performs a particular function or related functions. Computer architectures to run such programs or processes are well known in the field. There are numerous other possibilities that exist, those skilled in the art would appreciate that such a program or process may also be implemented as a combination of hardware and software components.

In the foregoing manner an apparatus and method for a multicarrier code division multiple access (MC-CDMA) system is disclosed. Only several embodiments are described. However, it will be apparent to one skilled in the art in view of this disclosure that numerous changes and/or modifications may be made without departing from the scope of the invention.

CLAIMS:

1. An apparatus for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the apparatus comprising:
 - a spreader for spreading an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal;
 - a modulator for the spread data corresponding to the input signal to generate an output sequence having a phase sequence and a transmit sequence together in a single output sequence; and
 - a transmission subsystem for transmitting the transmit sequence.
2. An apparatus as claimed in claim 1 further comprising:
 - at least two modulators, each modulator having different phase sequences corresponding to a phase value selected for each modulator; and
 - a selector for comparing each output sequence of each modulator and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence.
3. An apparatus as claimed in claim 2, wherein a modulator further comprising:
 - a coder for coding the selected phase value of the modulator into a coded sequence of the phase value of the modulator,

a spreader for spreading the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value,

a partitioner for partitioning the spread data into at least two sub-blocks of partial data;

an adder for adding each sub-block of partial data together with the spread data corresponding to the coded sequence of the phase value of the partial data providing a sum; and

a multiplier for multiplying the sum with the phase value for a sub-block sequence of the sub-block; and

an inverse fast fourier transformer (IFFT) for transforming the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

4. An apparatus as claimed in claim 2 or 3 wherein the phase value is a binary phase value and the phase sequence is calculated by fixing the value of rotation factor and restricting the a set of values for phase factors.
5. An apparatus as claimed in claims 3 or 4 wherein the coded sequence of the phase value of a modulator is a multi-bit value, each coded sequence having a different bit transition pattern.
6. An apparatus as claimed in any of claims 3-5 wherein the multi-bit value is a two-bit value, one sequence of the coded sequence has transition and the other sequence is without transition.

7. An apparatus as claimed in any preceding claim wherein the phase sequence is calculated by the equation:

$$\text{Minimise } \max_{0 \leq l < N} |a(\Phi)| \text{ subject to } \phi^{(p)} \in \left\{ \frac{2\pi l}{W} \mid l = 0, \dots, W-1 \right\}$$

wherein, W is a rotation factor.

8. An apparatus as claimed in claim 7 wherein the values of rotation factor is 2.
9. An apparatus of any of claims 3, 5 or 6, or as claimed in claims 4 or 7-8 as depending from claim 3, wherein the number of sub-blocks determines and is equal to the number of choices of phase sequences.
10. A method for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the method comprising:
- spreading with a spreader an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal;
 - generating an output sequence having a phase sequence and a transmit sequence together in a single output sequence with a modulator for the spread data corresponding to the input signal; and
 - transmitting with a transmission subsystem the transmit sequence.
11. A method as claimed in claim 10 wherein the generating of the output sequence is generated with at least two modulators, each modulator having different phase

sequences corresponding to a phase value selected for each modulator; and comparing with a selector each output sequence of each modulator and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence.

12. A method as claimed in claim 11 wherein the generating of the output sequence further comprising:

coding with a coder the selected phase value of the modulator into a coded sequence of the phase value of the modulator;

spreading with a spreader the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value,

partitioning with a partitioner the spread data into at least two sub-blocks of partial data;

adding with an adder each sub-block of partial data together with the spread data corresponding to the coded sequence of the phase value of the partial data providing a sum; and

multiplying with a multiplier for the sum with the phase value for a sub-block sequence of the sub-block; and

transforming with an inverse fast fourier transformer (IFFT) the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

13. A method of claim 11 or 12 wherein the phase value is wherein the phase value is a binary phase value and the phase sequence is calculated by fixing the value of rotation factor and restricting the a set of values for phase factors.

14. A method of claim 13 or 14 wherein the coded sequence of the phase value of a modulator is a multi-bit value, each sequence having a different bit transition pattern.
15. A method as claimed in claim 12-14 wherein the multi-bit value is a two-bit value, one sequence of the coded sequence has transition and the other sequence is without transition.
16. A method as claimed in any of claims 10-15 wherein the phase information of the data sequence is calculated by the equation:

$$\text{Minimise } \max_{0 \leq t \leq N} |a(\Phi)| \text{ subject to } \phi^{(p)} \in \left\{ \frac{2\pi l}{W} \mid l = 0, \dots, W-1 \right\}$$

wherein, W is a rotation factor.

17. A method as claimed in claim 16 wherein the values of rotation factor is 2.
18. A method of any of claims 12, 14 or 15, or as claimed in claims 13 or 16-17 as depending from claim 12, wherein the number of sub-blocks determines and is equal to the number of choices of phase sequences.
19. A computer program product for transmitting an output transmit signal in multicarrier code division multiple access (MC-CDMA) applications, the computer usable medium having computer readable program code means embodied in the medium for causing the calculation of the output transmit signal, the computer program product comprising :

a computer readable program code for spreading an input signal in accordance to a predefined spread code for providing spread data corresponding to the input signal;

a computer readable program code for generating an output sequence having a phase sequence and a transmit sequence together in a single output sequence, for the spread data corresponding to the input signal; and

a computer readable program code for transmitting with a transmission subsystem the transmit sequence.

20. A computer program product as claimed in claim 19 wherein the computer readable program code for generating of the output sequence is generated with at least two modulators routines, each modulator routines having different phase sequences corresponding to a phase value selected for each modulator routine; and comparing with a selector each output sequence of each modulator routine and selecting the output sequence with the lowest peak to power ratio (PAPR) selected as the transmit sequence.

21. A computer program product as claimed in claim 20 wherein the computer readable program code for generating of the output sequence further comprising:

coding the selected phase value into a coded sequence of the phase value of the modulator routine;

spreading the coded sequence of the phase value into spread data corresponding to the coded sequence of the phase value,

partitioning the spread data into at least two sub-blocks of partial data;

adding each sub-block of partial data together with the spread data corresponding to the coded sequence of the phase value of the partial data providing a sum; and
multiplying for the sum with the phase value for a sub-block sequence of the sub-block; and
transforming with an inverse fast fourier transformer (IFFT) the output sequence of each sub-block to provide the output sequence of the modulator having phase sequence and transmit sequence together in a single sequence.

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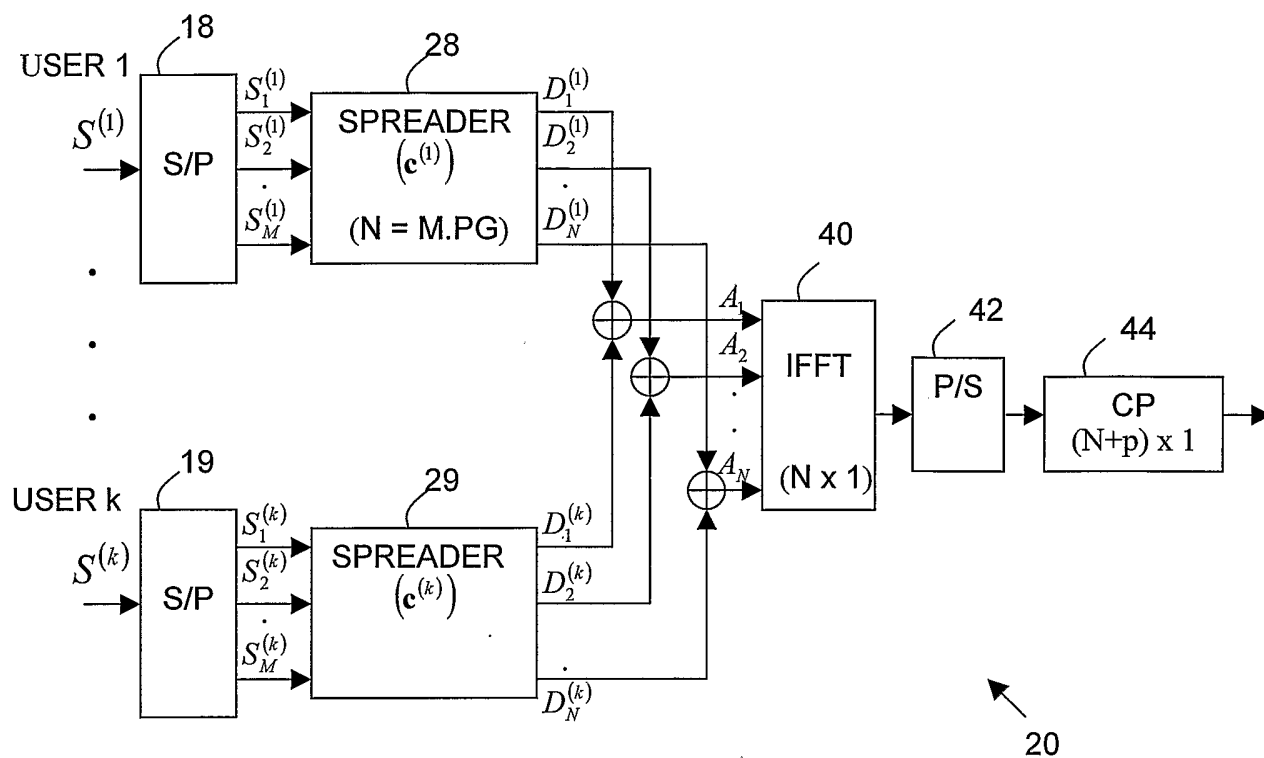


FIG. 1

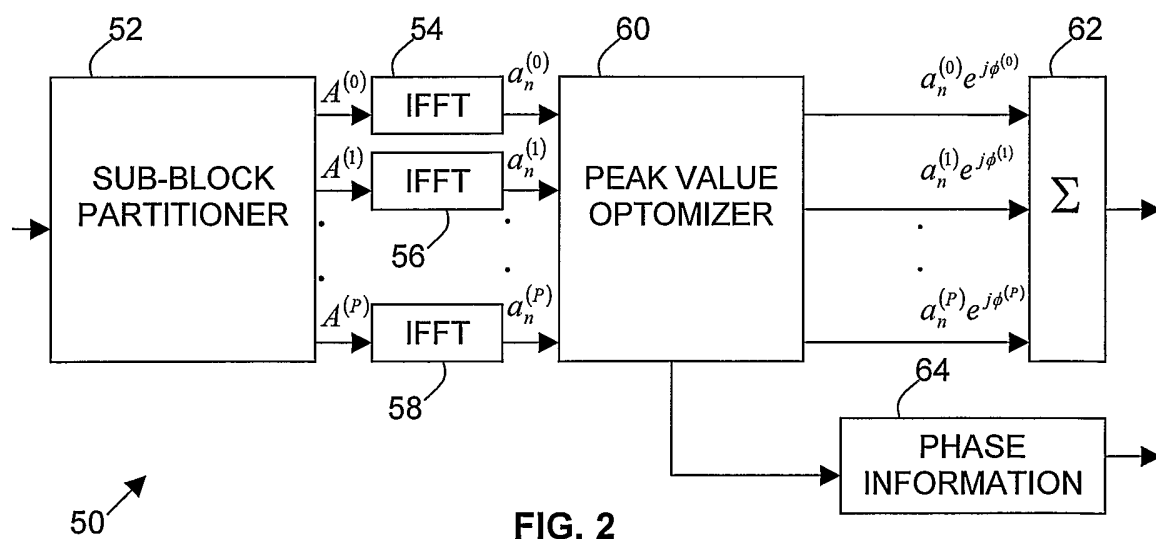


FIG. 2

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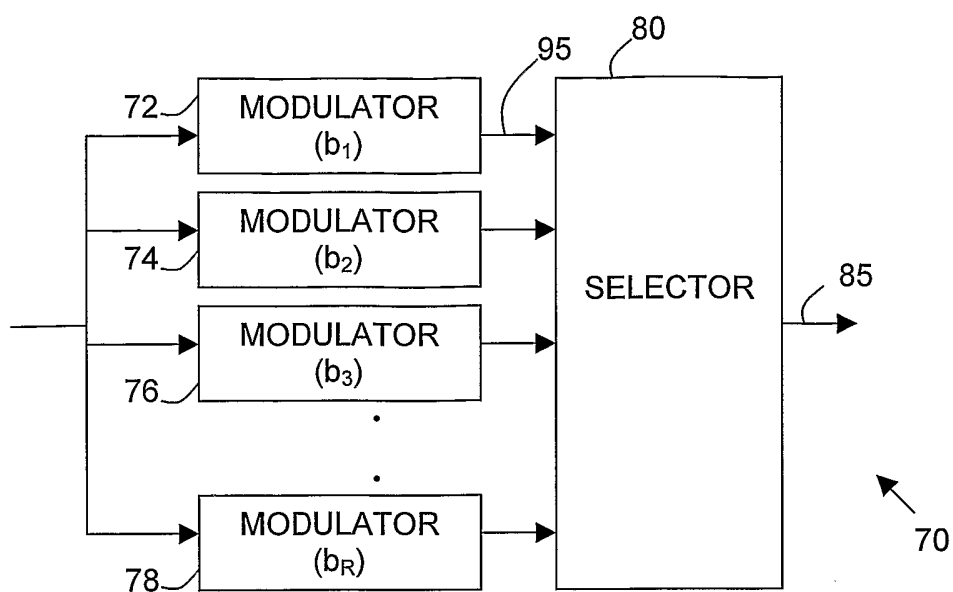


FIG. 3

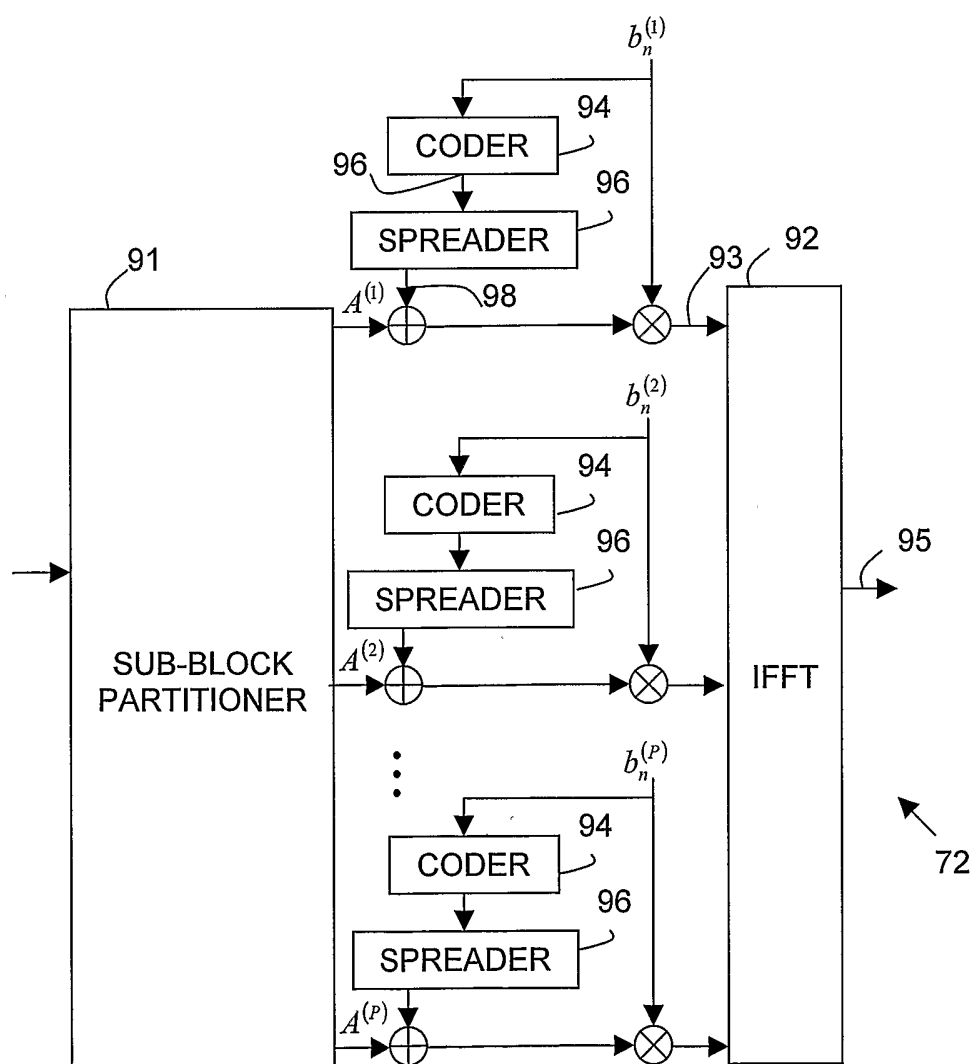


FIG. 4

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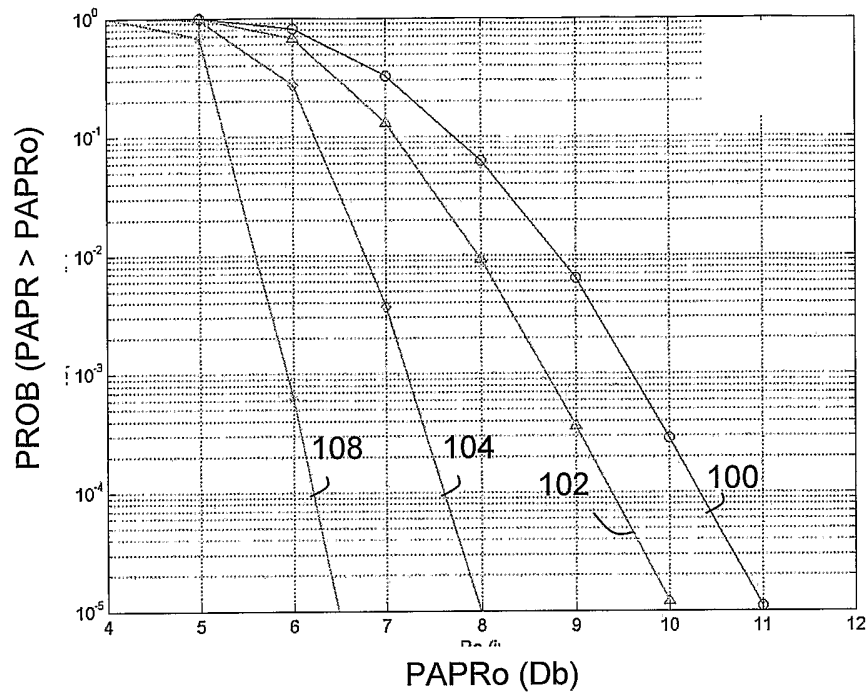


FIG. 5

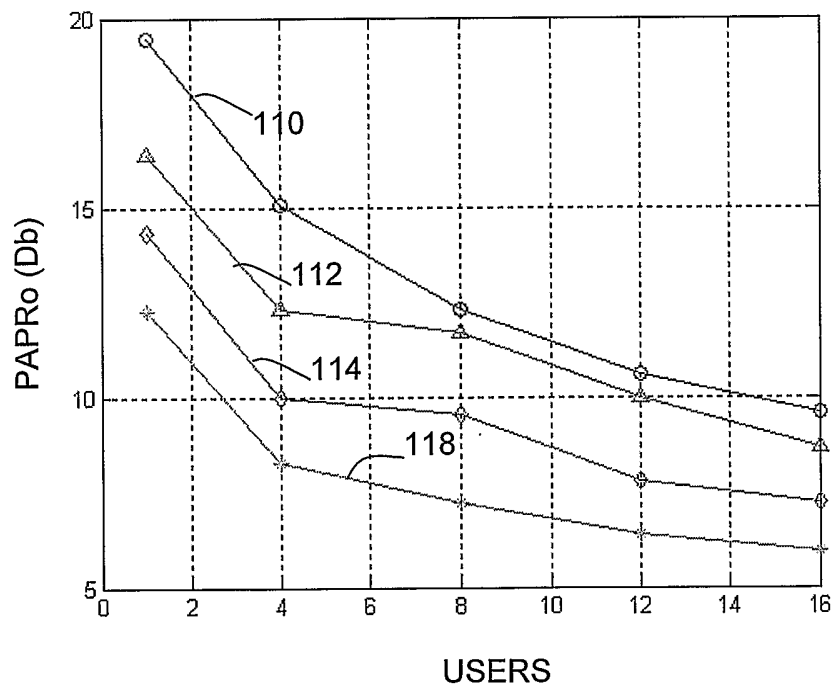


FIG. 6

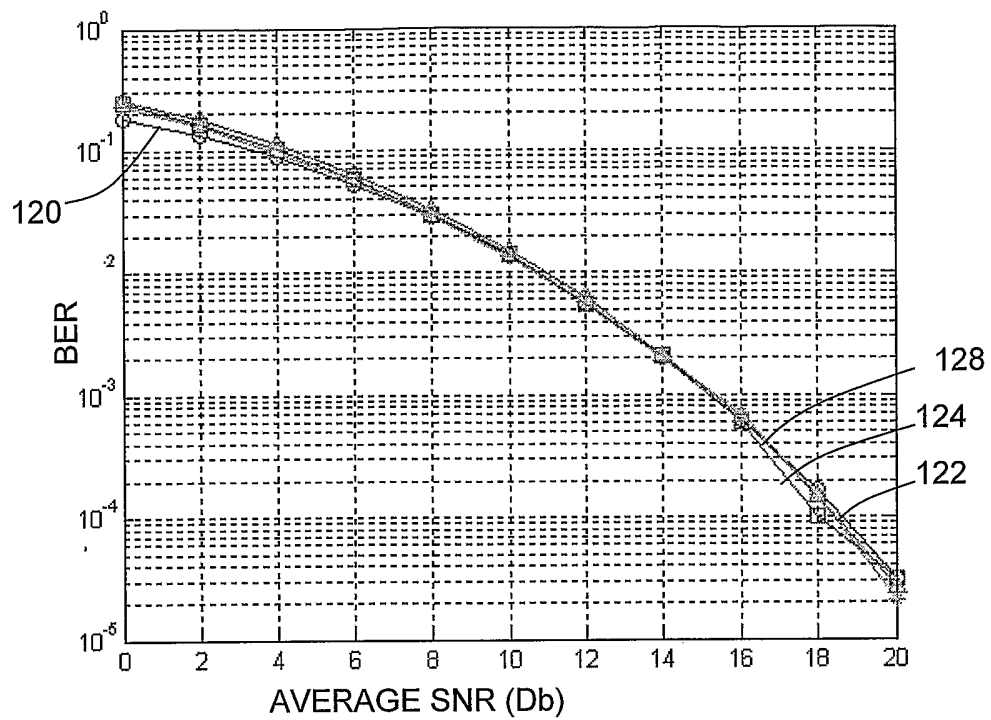


FIG. 7

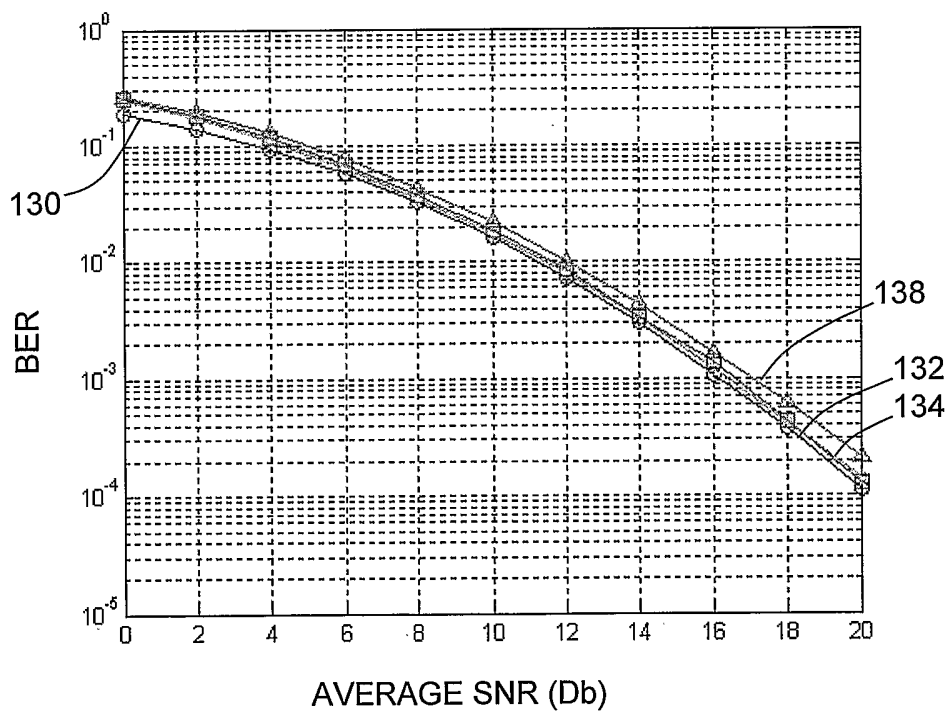


FIG. 8

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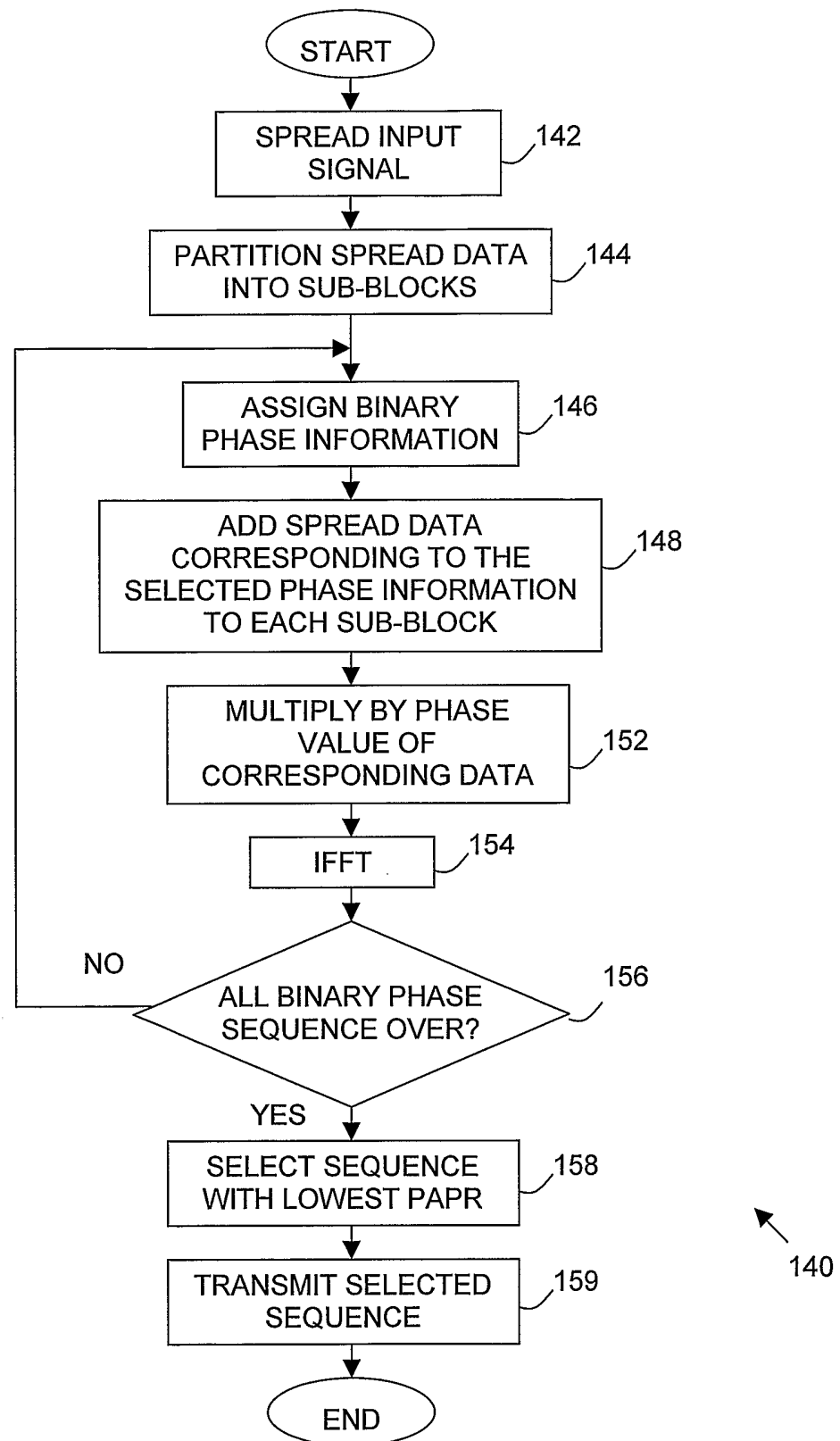


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG03/00138

A. CLASSIFICATION OF SUBJECT MATTERInt. Cl. ⁷: H04B 7/216

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT, USPTO: MULTI CARRIER, CDMA, SPREAD, PHASE, MODULATE AND SIMILAR TERMS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1128592 A2 (NTT DoCoMo, Inc.) 29 August 2001 whole document	1-21
A	WO 99/59265 A1 (SAMSUNG ELECTRONICS CO., LTD) 18 November 1999 whole document	1-21
A	EP 0929161 A2 (LUCENT TECHNOLOGIES INC.) 14 July 1999 whole document	1-21



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
29 July 2003

Date of mailing of the international search report

- 5 AUG 2003

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG03/00138

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
EP	1128592	AU	21217/01	AU	754268
		CN	1324159	JP	2001237803
WO	99/59265	AU	37351/99	AU	729775
		EP	997011		
EP	0929161	CN	1232353	JP	11261462
		EP	829982	JP	10107692
		CA	2212265	EP	837565
				CA	2335225
				US	2001028637
				BR	9906499
				CA	2212439
				US	5805567
				US	5956345
END OF ANNEX					