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Modified Frequency and Frame Synchronization Algorithms for MC-CDMA System

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Abstract: In third generation wireless communication system, high data rate multimedia services are achieved through Wideband Code Division Multiple Access (W-CDMA) systems. Multi carrier CDMA system provides the advantage of frequency diversity in CDMA system and thus reduces the Bit Error Rate (BER). Capacity of CDMA based systems can be increased by decreasing BER, which is possible through interference reduction, interference suppression and proper synchronization. In this study, novel frequency and frame synchronization algorithms are proposed which reduces the frame error rate and BER of MC CDMA system without any transmission overhead. Synchronization schemes proposed also help to incorporate variable frame size for each user so that integration of multimedia service is possible.

Key words: MC CDMA, OFDM, carrier synchronization, frame synchronization

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INTRODUCTION

CDMA is the access scheme standardized for 3G since it supports high data rate multimedia services like voice, audio, image, video and data. It is a multiplexing technique where many users at the same time asynchronously access the same frequency band by spreading their information with pre assigned unique code sequence[1] and hence provides higher capacity over TDMA and FDMA scheme. However, Orthogonal Frequency Division Multiplexing (OFDM) is also a promising choice in the field of radio communication as it can transmit high data rate in a mobile environment. In 1993 three types of new multiple access schemes such as multi carrier CDMA (MC-CDMA), multi carrier DS-CDMA (MC-DS CDMA) and multi tone CDMA (MT CDMA) were proposed based on combination of CDMA and OFDM. MC-CDMA will be the probable access scheme for beyond 3G services. Since FFT is incorporated, it is possible to realize transmitter and receiver without much complexities for the above three schemes. These schemes have high spectral efficiency due to minimally densely sub carrier spacing.

In the case of digital communication, synchronization is the technique that maintains all digital equipments in the communication system to operate in synchronism. Since MC-CDMA system is susceptible to frequency errors high degree of frequency synchronization is required. Network cannot identify the destination of the data unless proper frame synchronization scheme is incorporated. In this study a carrier frequency synchronization system based on the average energy falling across the null carriers (virtual carriers) and a novel, less complex frame synchronization algorithm which does not require any transmission overhead (i.e., no extra bits are used for frame synchronization purpose) for an MC CDMA system is proposed. A prototype network is simulated and the proposed algorithms are utilized for the frequency and frame synchronization purpose and error rate is analysed with and without synchronization schemes.

MC-CDMA TRANSMITTER AND RECEIVER

The MC-CDMA transmitter spreads the original data scheme over different sub carriers using a given spreading code in the frequency domain. Normally orthogonal Walsh code is used in the down link so that attention is not necessary to the auto correlation characteristic of the spreading code. Figure 1 depicts the MC-CDMA transmitter of the jth user, where, G_{mc} denotes the processing gain, N_C the number of sub carriers and $C_j(T) = (C_1^j\, C_2^j \ldots C_{gmc}^j)$ the spreading code of the jth user. The number of sub carrier selection and the guard interval is optimally arrived based on BER minimization and to increase the robustness against frequency selective fading.

A typical MC CDMA receiver is shown in Fig. 2, where after the serial to parallel conversion, the Mth sub

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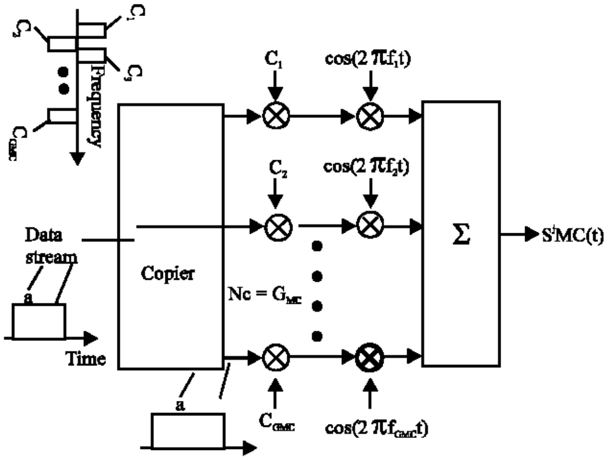

Fig. 1: MC CDMA transmitter

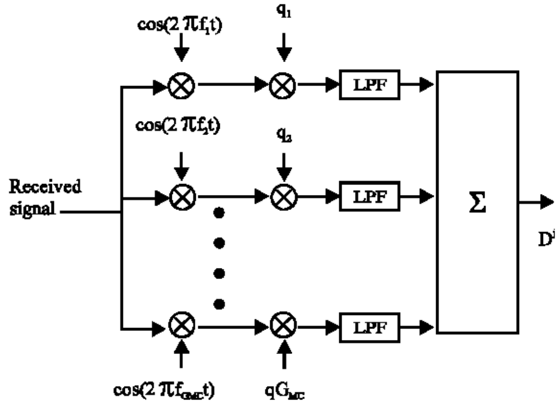

Fig. 2: MC CDMA receiver

carrier is multiplied by the gain qG_{MC} to combine the received signal energy scattered in the frequency domain.

CARRIER FREQUENCY SYNCHRONIZATION IN MC CDMA

Multi carrier CDMA system provides the advantages of frequency diversity in CDMA systems and thus reduces the BER of the communication systems[2]. In order to improve the performance of such a system, the carrier synchronization techniques employed are important. Since MC CDMA is a blend of OFDM and CDMA techniques, a detailed survey regarding the carrier synchronization schemes used for synchronous and asynchronous OFDM system is made[3-6]. In the case of CDMA systems, reception is not possible unless the received spread waveform and receiver generated replica of the spreading waveform are synchronized in both phase and frequency. Generally, this process must be accomplished at very low SNR, as quickly as possible, using the minimum amount of hardware. Hence the algorithms suggested for frequency synchronization in OFDM system does not suit well for MC CDMA system. This study proposes an algorithm for frequency synchronization technique which uses the energy available in the unused sub carriers in a non fully loaded MC CDMA system as a measure of error for frequency correction. An appreciable reduction in BER is achieved due to the incorporation of this algorithm indeed with a less complex hardware.

Proposed frequency synchronization algorithm: The proposed algorithm capitalizes on the basic premise that the system is not fully loaded, i.e., not all available sub carriers are used for transmitting symbols. Sub carriers that are not used for transmitting purpose can be effectively used for frequency synchronization. For this purpose, these unused sub carriers are purposely transmitted with zero, i.e., with null zero energy. If there is no change in received frequency when compared with transmitter frequency, due to Doppler effect or channel disturbances, in the received signal null or virtual sub carriers will be having only zero energy. If non zero average energy is received in virtual sub carrier in the receiver, it indicates that there is a difference in the frequency of transmitter and receiver. Amount of energy present in the virtual sub carrier is an indication of magnitude of deviation between the transmitter and receiver frequencies. An error signal is arrived at based on the magnitude of energy present in the virtual sub carrier and a correction signal is arrived based on the error signal and is used to correct the frequency. Correction is to be carried out iteratively until the energy present in the virtual sub carrier becomes zero, when transmitter and receiver is deemed to be perfectly synchronized but practically, achieving this is quite tougher. Hence iteration is stopped at the time when the synchronization is sufficient to meet the target BER. Since in the proposed scheme no extra bandwidth is required for synchronization and also no extra complex hardware is required proposed algorithm outperforms existing algorithm in terms of BER and complexity.

Simulation results and discussion: MC-CDMA system is simulated with 16/32/64 Processing gain, 16 sub carriers, 2/4 virtual sub carriers and the channel is assumed to be Rayleigh Fading in AWGN environment. Figure 3 shows the comparison of BER plots for the MC-CDMA system with and without synchronization for 16 sub carriers out of which 2 are virtual sub carriers. Simulation is performed for SNR from 0 dB to 8 dB in steps of 0.5 dB with a processing gain of 16 and the result implies that the system performs better with synchronization.

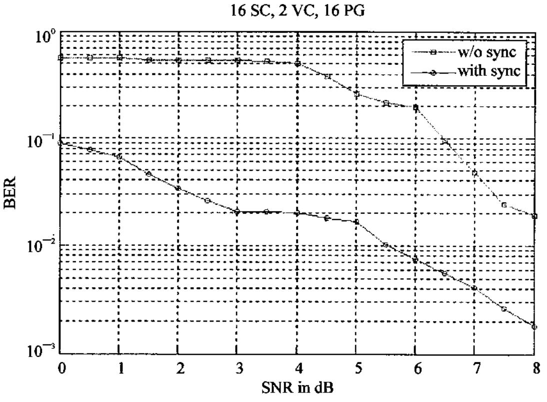

Fig. 3: Performance of the system for 16 PG, 16 SC and 2 VC

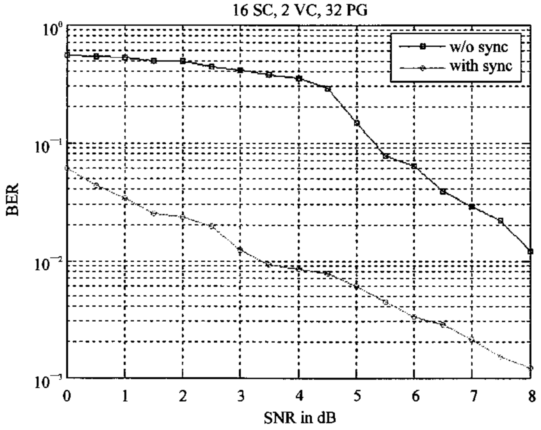

Fig. 4: Performance of the system for 32 PG and 2 virtual Carriers

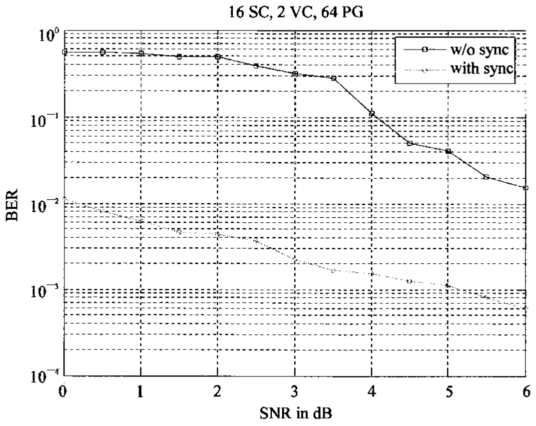

Fig. 5: Performance of the system for 64 PG and 2 virtual carriers

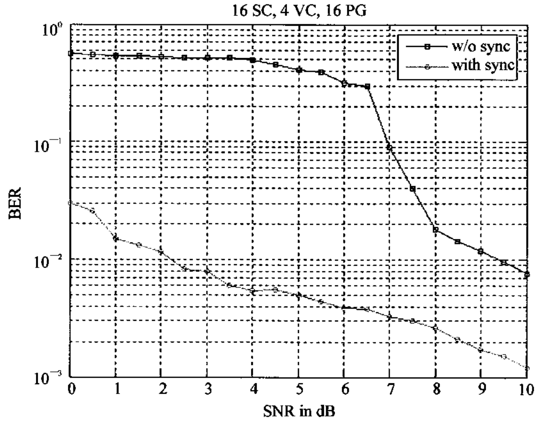

Fig. 6: Performance of the system for 16 PG and 4 VC

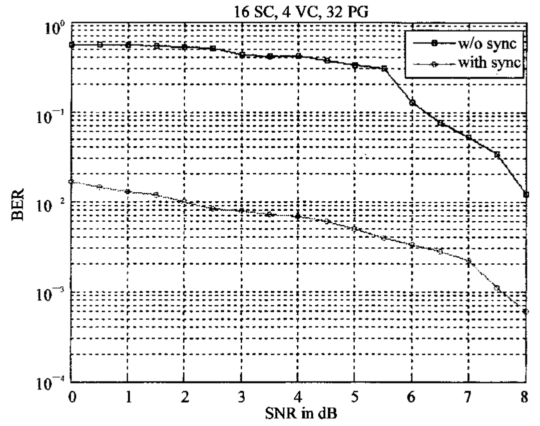

Fig. 7: Performance of the system with 32 PG and 4 VC

Figures 4 and 5 depict the comparison of BER plots for MC-CDMA system for 16 sub carriers and 2 virtual carriers with the processing gain of 32 and 64, respectively. From Figures 3 and 4 it is clearly seen that the BER is decreased with the increase in the processing gain. This is due to the fact; if the processing gain is increased the number of bits lost for synchronization will be less. Figure 5 shows a significant improvement in the performance of the system since the processing gain is 64 and since the oscillator is updated with change in the error for four times (compared with 16 PG) for each and every bit of the data. Figures 6 and 7 show BER comparison plots for 4 virtual carriers out of 16 sub carriers for 16 and 32 processing gain, respectively. The results of Fig. 6 and 7 show that for the same processing gain the performance of the system with 4 virtual carriers is better than the 2 virtual carriers. This is due to the fact that the average error energy from 4 virtual carriers can be used effectively for frequency correction than the average error energy from 2 virtual carriers.

FRAME SYNCHRONIZATION

Many systems used in digital communication send data in synchronous back-to-back frames. When a receiver tunes to such a data stream, it has no knowledge of the frame boundaries. Frame synchronization is required to ensure that the receiver reliably interprets the received bit stream on correct boundaries. Frame synchronization is usually accomplished with the aid of some special signalling procedure from the transmitter. The non-data aided technique and the data aided technique are the two types of frame synchronization. In non-data aided technique some non information bits are stuffed at regular intervals for frame synchronization purpose. The major drawback here is that the frame marker size may be very large in order to avoid false detection and the expected time required to acquire synchronization would be long and due to transmission overhead, channel capacity and bandwidth efficiency is reduced. To overcome this problem, data aided technique is being practiced, wherein the information bit itself is used for frame synchronization. The advantage of this technique is that it does not require any transmission overhead hence channel capacity and bandwidth efficiency is increased. The proposed frame synchronization algorithm uses the data-aided technique and also supports variable frame size for all users.

Existing data aided frame synchronization algorithm: The basic idea behind the existing data aided frame synchronization method for a single user multi carrier system is the deletion of a sub channel to indicate the start of the frame. The sub channel to be deleted is determined by the encoding block and the information of the deleted sub channel is also retrieved by the algorithm used[7]. Let x be N random data symbol vector, i.e., $X= \{x_1 x_2 . . . x_n\}^T$ and $D = \{1, 2... U\}$, Where, ^{T} denotes the transpose and D is the data alphabet of size U. Each data symbol is mapped to a signalling symbol, y_n, using the MAP operation and the mapping is such that each possible data symbol is associated with one particular value of a set of U distinct values $y = [y_1\ y_2 . . . . . y_N]^T$, $y_n= A(x_n)$, $A = \{A(1), A(2),...,A(U)\}$, $y_n \in A$ where, $n \in [1,N]$, A is the signalling alphabet with size U. Each y_n is allocated a sub channel. The vector y is encoded by the frame encoding block only if it is the first symbol of a frame; otherwise, Z = y. Then, Z is modulated to produce a symbol vector S. The Rayleigh fading channel is described by a diagonal matrix $C(\alpha)$, with the fading coefficients on the main diagonal , additive white Gaussian noise (AWGN), W, is combined with the signal and thus the received signal is $r = C(\alpha) \times S + W$.

The receiver consists of a demodulation block, DEMOD, followed by frame detection and decoding block, FDDE, a signalling symbol decision block, SSD and a signalling symbol demapper, DMAP[8]. In the receiver, perfect OFDM symbol and carrier recovery and perfect channel estimation are assumed and a linear equalizer is used to offset the effect of fading in the demodulator. The frame encoder only encodes the first symbol of every frame. The total number of sub channels, N, in vector y is divided into q groups of U sub channels for frame encoding $y=[y(1)\ y(2)\ y(3)........y(q)\ y_r]^T$ Where, y(n) is a 1 x U vector and y_r is a vector of size (N-qU) containing the remaining signalling symbols. Here, q is defined as the maximum group available for frame encoding and is given by the integer part of the division of N by U. Note that N = U is required here. The vector y_R is not involved in the frame encoding process. Each vector y(n) in y is encoded as follows: $Z_1 \leftarrow y_{x1}, Z_{x1} \leftarrow 0, Z_n \leftarrow y_n$ where, $n \in [2,U]$, $n \neq x_1$. The x_1 and Z1 correspond to the first data symbol and the signalling symbol in the first sub channel in each vector y(n), respectively. The first data symbol, x_1, specifies the ith sub channel which will replace the first sub channel, Z_1. The flow chart describing this is given in Fig. 8.

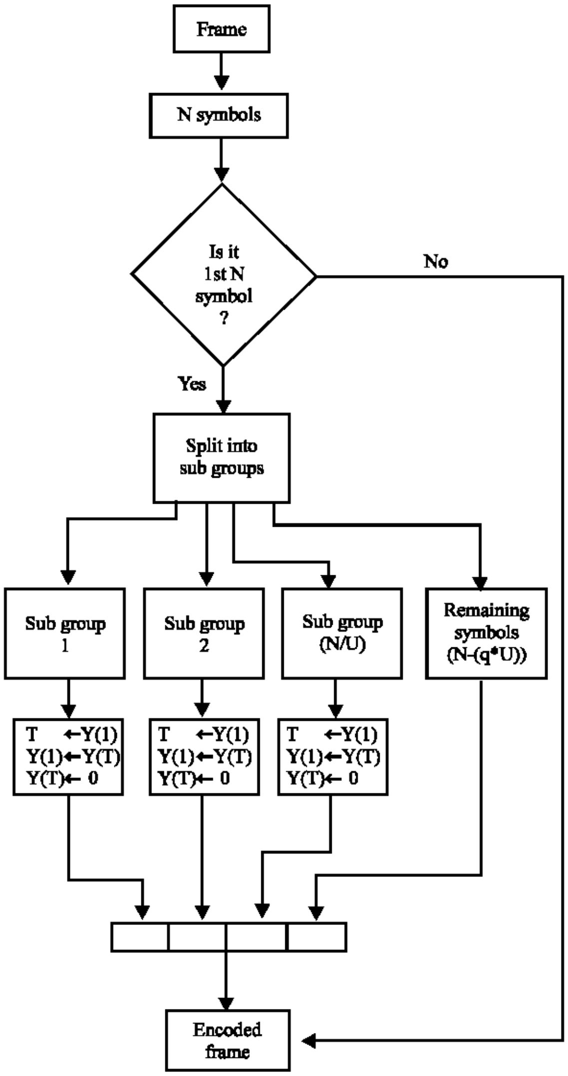

Fig. 8: Frame encoding block

Then, the i^{th} sub channel is deleted and no signal energy will be transmitted in i^{th} sub channel. It should be noted that no information is lost in this process because the information in i^{th} sub channel is conveyed via the first sub channel and the information in the first sub channel is specified by the position of the deleted sub channel. The frame detection and decoding block must first detect the start of the frame before it can recover the data from a frame encoded symbol. Like the frame encoder, the received symbol is divided into q groups of U sub channels: $V= [\ v(1)\ v(2)\ v(3)\ldots\ldots v(q)\ v_r\ ]^T$ where, v(n) is 1x U vector of the received signalling symbols, v(n) and v(r) is a vector of size (N-qU) containing the remaining received signalling symbols. Again, the vector v(r) is not involved in the frame detection or frame decoding processes. In each v(n)vector, a sub channel that has the minimum absolute magnitude among the sub channels within the group is selected. Then, the selected minimum absolute magnitude sub channels from all the groups are summed, i.e., $E = \frac{1}{q}\sum_{1}^{q}\min\big(\mathrm{abs}\big(u(n)\big)\big)$ where, min(.) is the minimum of a group of number n and $n \in [1,q]$ and abs(.) is the absolute value of the argument. E is then compared with a predefined threshold. This threshold can be chosen according to the required false alarm and miss detection rates and considering the prevailing channel conditions: $E > T_{F,}\ H_A$ and $E < T_{F,}\ H_F$ where, T_F is the threshold for frame detection , H_F and H_A are the hypotheses indicating the frame is present or absent, respectively. If all the elements in signalling alphabet set A have similar energy and the consequences of a false alarm and a miss detection are the same, then the threshold should be chosen as half the maximum absolute magnitude. After the frame is detected, the sub channels in the frame encoded symbol have to be rearranged to recover the actual symbol. This is simply the reverse of the frame encoding procedure. For each v(n) vector, the position of the minimum absolute magnitude sub channel among the sub channels within the group is determined by i = pos (min (abs(v(n)))) where, $n \in [1,q]$ and pos(.) is the position of the argument in a vector. Then the signalling symbol in i^{th} sub channel is replaced by the signalling symbol in the first sub channel and the signalling symbol for the first sub channel is the i^{th} element in signalling alphabet set, $Z_i \leftarrow V_{1,} Z_1 \leftarrow A(i), Z_n \leftarrow V_n$ where, $n \in [2,U]$, $n \neq I$. This frame decoding procedure is implemented only when a frame is detected, otherwise, Z=V. The existing method shows that the frame information can be embedded in the normal data stream without the need for a special preamble sequence. Consequently, frame synchronization can be achieved without transmission overheads. Furthermore, the method has low complexity and is simple to implement.

Proposed Frame synchronization algorithm: In the modified algorithm, the main objective is to reduce the frame error rate and is accomplished by incorporating the barker sequence in the existing algorithm. The existing algorithm encodes only the first N symbols and transmits the remaining data bits of a particular frame which is of fixed size as such wherein here the data bits are frame encoded as in the existing algorithm to indicate the start of the frame with a modification as indicated here. A 5 bit barker sequence, say 11101 is used as a marker. For a bit value of 1, the algorithm is applied for N symbols and for a bit value of 0; the N symbols are transmitted as such. The frame error rate for the proposed algorithm is seen to be less when compared to the existing one.

As the existing algorithm provides only a fixed frame size for a particular user, it is not possible to support integrated services. The modified algorithm support integrated service which is dealt in detail here. In the existing frame synchronization, if the frame synchronization technique is applied to all q groups of U sub-channels, then the frame size is constrained to be any multiple of N symbols. However, if it is applied to the upper half of the q groups and to the lower half of the q groups independently, then the frame size can be any multiple of 0.5 N. If the upper half and lower half are further split into 2 subgroups, the frame size can be any multiple of 0.25 N. Nevertheless, this can be done only if the division of N by the number of subgroups, n_S, yields an integer. It should be noted that, as n_S increases, the number of sub-channels that can be used for frame detection in each subgroup, N/n_S, decreases. Hence, the flexibility in frame size is inversely dependent on the robustness of the frame synchronization. The minimum possible frame size, U, is achieved when $n_S = q$, where, U is the signalling symbol alphabet size. Thus the algorithm ensures different frame size for different user. But if each user is assigned a fixed frame size, one cannot implement integrated service facility. By varying the size of the frame for each user, integrated services can be incorporated. If the frame size is made variable in the existing algorithm the probability of miss (p_m) and false alarm (p_f) is large resulting in increased frame error rate. But in the proposed algorithm with the help of the marker sequence the data bits are frame encoded as in the existing algorithm to indicate the start as well as the end of the frame. This algorithm is implemented at the start and end of the frame and the intermediate symbols are transmitted as such. At the receiver side, the probability of a 0 in the marker sequence becoming a 1 is very less. This property of the algorithm decreases probability of false detection and probability of miss and facilitates variable frame sizes at reduced Frame Error Rate (FER).

Simulation results and discussion: With the MC-CDMA system setup, the frame synchronization block is included to implement the non-data aided technique. The source alphabets D are randomly generated which takes a value up to U, say U = 7. Here 2000 symbols are generated. The generated symbols are converted to bits and the frame marker is inserted at the start of each frame. The marker sequence is a 15 bit code, Marker = [1 1 1 1 0 1 0 1 1 0 0 1 0 0 0]. The resultant bits are spread using direct sequence spreading and is modulated using BPSK. The modulated signal is transmitted through the Rayleigh fading channel and performance of the system is analyzed. At the receiver side, coherent detection is carried out and the bits are retrieved. For various Signal to Noise Ratios (SNR), the Bit Error Rate (BER) is calculated. Figure 9 shows the simulation plot between BER and SNR in Rayleigh channel for a MC-CDMA system incorporating non data aided algorithm.

In data aided technique, the source alphabets x are generated randomly which takes a value from D. $x = [x_1, x_2, x_3 \ldots x_n]$ and $D = [1, 2, 3, ..U]$ where, $x_i \in D$. Here U = 7 and n = 2000. The generated symbols are mapped using a matrix, MAP = [7 6 5 4 3 2 1], that is in the reverse order. The frame size (F) is fixed to be of a particular value (say 100 symbols). A number N (say 25) which is a factor of F is chosen and the first N symbols in each frame are considered for the frame encoding and the remaining symbols are transmitted as such. The N symbols are divided into q groups each having U symbols, where, q is mod (N/U). The first symbol in each group is taken and demapped and the position of the symbol to be encoded is given by this value. The symbol at that position is moved to the first position of the group and the symbol at that position indicated by demapped value is deleted (made as zero). Hence the position of the deleted symbol gives the actual first symbol in the group and the first symbol present in the group gives the actual symbol at the deleted position. Hence no data is lost in frame encoding and no additional bits are required for frame synchronization. This is followed for every frame and it is transmitted through MC-CDMA transmitter similar to the non-data aided technique as explained above. The Fig. 10 shows the simulation plot between BER and SNR in Rayleigh Fading channel for a MC-CDMA system incorporating data aided algorithm.

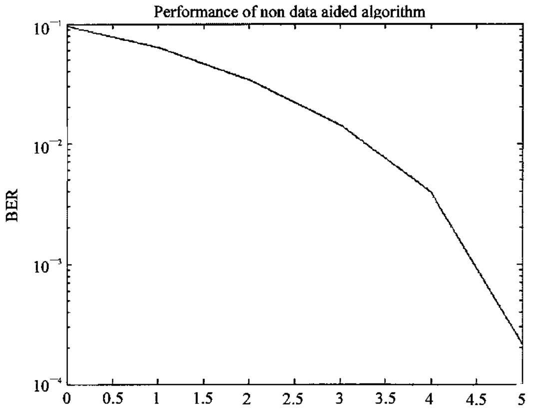

Fig. 9: Performance of non-data aided algorithm

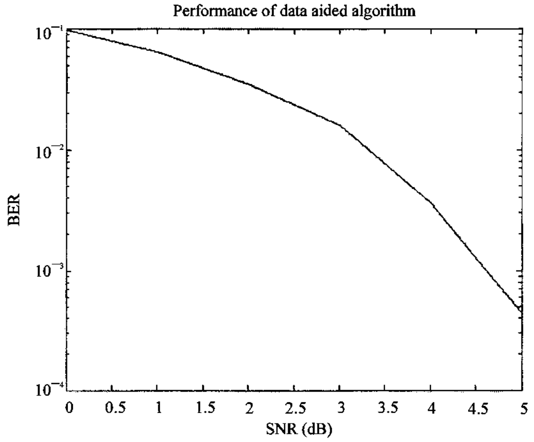

Fig. 10: Performance of data aided algorithm

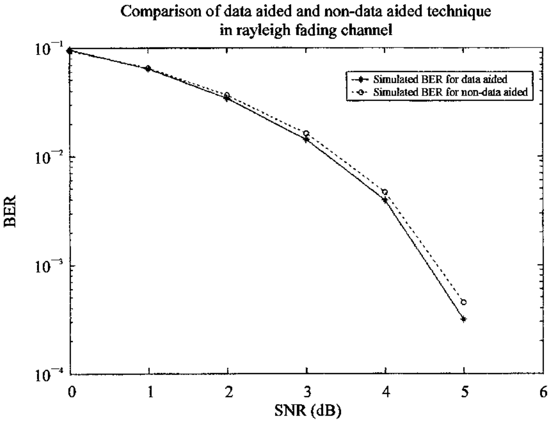

Fig. 11: Comparison of data aided and non data aided schemes

At the frame detection block, the frames are scanned for the N symbols that are frame encoded. If it identifies that N symbols, then it is indicated as the start of the frame and a stream of N symbols are added to it, to have a complete frame (here 100-25 = 75 symbols). Again the receiver scans for the next starting point of the frame. If the frame start is not identified the frames are left as such. Figure 11 shows the BER comparison for data aided and non-data aided techniques in Rayleigh fading channel in a MC-CDMA system. From Fig. 11 it is clear that there is not much difference in bit error rate for data aided and

Table 1: Comparison of existing and modified algorithm for fixed frame size

Frame No.	Frame size	Existing algorithm	Modified algorithm
1	100	Identified	Identified
2	100	Not identified	Identified
3	100	Identified	Identified
4	100	Identified	Identified
5	100	Not Identified	Identified

Table 2: Comparison of the existing and modified algorithm for variable frame size

Frame No.	Frame size	Existing algorithm	Modified algorithm
1	350	Not Identified	Identified
2	400	Not Identified	Identified
3	450	Identified	Identified
4	550	Not Identified	Identified
5	400	Not Identified	Identified

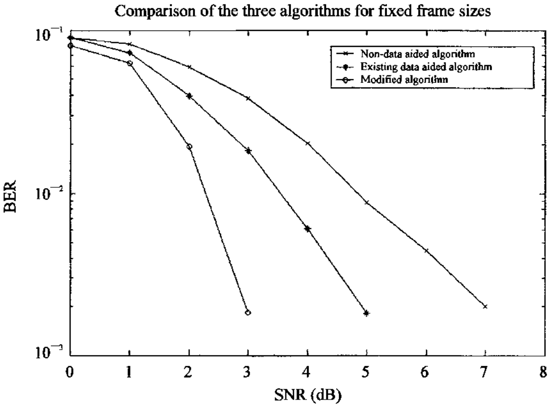

Fig. 12: FER comparison of algorithms for fixed frame size

non-data aided techniques, this is due to the fact that whatever be the frame synchronization algorithm used the bit error rate depends only on the channel and the type of modulation used. Also the BER depends on the multiple access technique used and here the system provides a minimum BER due to the multi carrier code division multiple access technique used. Hence the difference is produced only in the frame error rate of the systems.

To analyse the performance of modified algorithm, a barker sequence of length 'm' is chosen, which satisfies the correlation property. The first m x N symbols in the frame are taken for frame encoding, where m is the length of the barker sequence. The barker sequence is assumed as 11101 and m = 5 and N = 25. Hence first 125 symbols are taken and are frame encoded with respect to the barker sequence. The digit '1' in the barker sequence indicates that the N symbols are frame encoded as explained above. The digit '0' indicates that the N symbols have to be transmitted without frame encoding. Thus the first 125 symbols are frame encoded based on barker sequence. Table 1 and Fig. 12 show the comparison of FER in Rayleigh fading channel for modified algorithm, the existing data aided technique and the non-data aided technique.

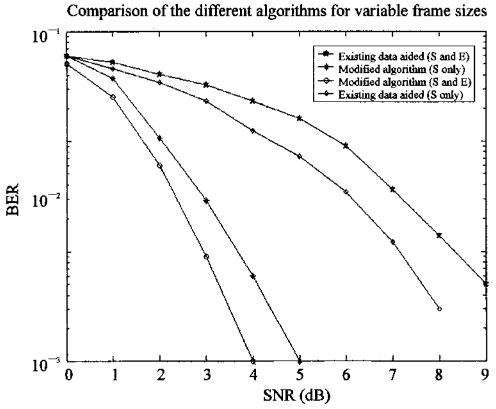

Fig. 13: FER comparison of algorithms (variable frame size)

The FER of the modified algorithm is very less when compared to the existing technique for a fixed frame size. This is due to the correlation property of the barker sequence which provides a reduced probability of false alarm and probability of miss. In order to make the frame size variable and to reduce the frame error rate further, the frame marker is included both at the start and end of the frame. i.e., the last 125 symbols are frame encoded with the same barker sequence as explained earlier. The comparison of the frame error rate for the different algorithms for variable frame size is shown in Table 2 and Fig. 13 (S-start only encoded, S and E start and end encoded) and it reveals that the modified frame synchronization algorithm with the frame marker at the start and end of the frame provides a better FER than any other scheme.

CONCLUSIONS

In future wireless communication system, the main aim is to integrate multimedia services (voice, data and video services) in a single unit. Hence systems which incorporate high data rate services are to be provided to the users and also the channel capacity of the system should be improved in order to accommodate more number of users. This study proposes a "Carrier Synchronization Algorithm for MC-CDMA System ", which forms a very important issue in MC-CDMA transmission in Rayleigh and Rician channels. The simulation results of BER without and with carrier frequency synchronization are being compared and it is proved that the BER reduces when the proposed synchronization algorithm is incorporated. Since BER is reduced, more number of users can be accommodated. The proposed frame synchronization algorithm exploiting the advantage of the Barker sequence reduces FER to a greater extent. This algorithm provides an added advantage to the Barker sequence by the property that the probability of the bit 0 of the frame marker becoming a 1 is very less. This is because at least one of the symbols in all the q groups should be deleted in order to make a 0 as 1. Thus the probability of losing a frame is highly reduced in this case. This algorithm also provides variable frame size for a particular user. In this case, to reduce the FER further, both the start and end are indicated for each frame carrying out the same modified algorithm at both ends of the frame. As capacity of CDMA system is interference limited, for a fixed FER and BER more number of users can be accommodated if this modified synchronization algorithms are used. Thus the modified frequency and frame synchronization algorithm employed provides a better performance than the existing algorithm for MC-CDMA systems and also ensures efficient bandwidth utilization.

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