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A Review of Sub-Carrier Selection Techniques Employed in MC-CDMA System for 4G Networks

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Abstract- The Multi-Carrier Code Division Multiple Access (MC-CDMA) is becoming a very attractive multiple access technique for high-rate data transmission in the future wireless communication systems. This paper is focused on reviewing different sub-carrier selection techniques for MC-CDMA system. It has been seen that appropriate subcarrier selection technique can significantly improve BER performance, Throughput performance, System capacity, Speed and it results in higher spectrum efficiency as well as reduced power consumption at mobile terminal.

Broadly it can be implemented either by selecting the best sub-carrier and transmitting the whole data of the user through that sub-carrier only or varying the number of sub-carriers allotted according to users requirement and transmitting user's data through the selected group of sub-carriers.

Index Terms- SCS, MC-CDMA, UWB, SNR, BER, ACA, APA

I. INTRODUCTION

A. 4G systems

Future generations of broadband wireless systems will aim to support a wide range of services and bit rates in a bandwidth of the order of tens or even hundreds of megahertz. FCC has mandated that the UWB radio transmission lies between 3.1 and 10.6 GHz, with a minimum bandwidth of 500 MHz [1]. The most important objectives in the design of 4G wireless systems are to address the severe inter symbol interference (ISI) resulting from the high data rates, and to utilize the available bandwidth in a spectrally efficient manner. Recently, multicarrier code division multiple access systems (MC-CDMA) have been considered as the potential candidate for 4G wireless communications which handles ISI most effectively [3]. MCCDMA can outperform OFDMA in the case of varying resource loads. The BER performance of MC-CDMA could be better than OFDMA, when traffic load is not very high.

Sub-carrier selecting MC-CDMA system is employed in development of 4G systems to reduce high power consumption of mobile terminals, to increase cell coverage area and to minimize the effect of high Doppler frequency which are otherwise the concerning issues because of the wide bandwidth transmission needed and the expected use of the high frequency microwave band [2].

B. MC-CDMA

Fourth generation wireless communication demands a better multiple access technique for reducing the multiple access interference (MAI) and intersymbol interference (ISI) and to improve the bit error rate performance. It is pointed out by G.K.D. Prasanna venkatesan in [1] that MC-CDMA can prove to be the best candidate satisfies the demands of 4G wireless systems.

The conventional code-division multiple-access (CDMA) technique used in third generation system faces serious limitations by channel dispersion causing inter symbol interference (ISI), and it requires advanced signal processing algorithms to implement it. The MC-CDMA employing multiple stream of data channel can combat channel dispersion, hence ISI, thereby increasing system capability to accommodate a higher number of users and its data rate requirements [4].

In MC-CDMA the transmitter spreads each parallel sub stream of data generated with the aid of serial-to-parallel (S-P) conversion given Np-chip spreading code, {c[0], c[1], …, c[Np – 1]} As seen in Fig. (2) the transmitted MC-CDMA signal using BPSK modulation can be expressed as

$$s_{MC}(t) = \sqrt{\frac{2P}{UN_p}} \sum_{i=-M}^{M} \sum_{u=0}^{U-1} \sum_{j=0}^{N_p-1} b_i[u]c[j]\, PT_s(t - iT_s)\cos\left[2\pi\left(f_c + F_{jU+u}\right)t\right] \quad (1)$$

where P and fc represent the transmitted power and carrier frequency respectively, and the processing gain (spreading factor) of N = Tb/Tc represents the number of chips per bit. Tb and Tc represents the bit duration and chip duration, respectively Furthermore, in Eq. 1 2M + 1 represents the number of bits conveyed by a transmitted data burst, b[i] Є {+1,–1} is the ith transmitted bit, while c[j] Є {+1,–1} is the jth chip of the spreading code, and finally, pτ(t) represents the chip waveform defined over the interval [0,τ). In Eq.1U represents the number of bits that are S-P converted, where each transmitted symbol contains U data bits, 2M + 1 represents the number of U-bit symbols conveyed by a transmitted data burst, and bi[u] Є {+1, –1} represents the uth bit of the ith transmitted symbol [5].

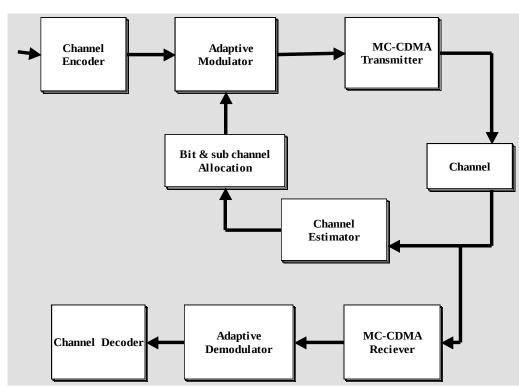

Fig.1: MC-CDMA system [4]

Frequency- domain spreading Data bit: 1(solid)-1(dashed) Subcarrier bandwidth=2/Ts Spreading code: +1+1+1+1-1-1-1-1

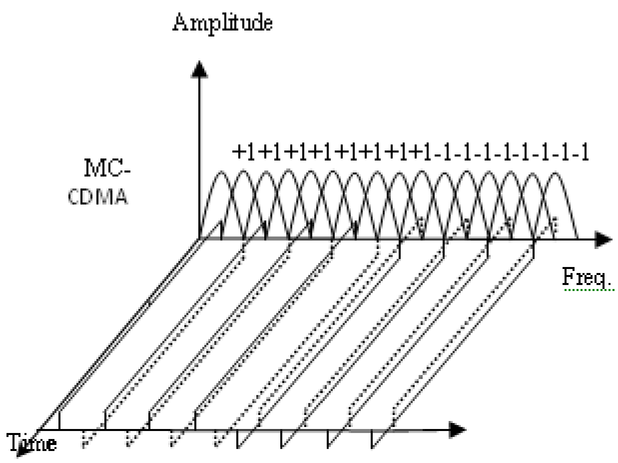

Fig.2 Power Spectra & Time Domain Signal wave forms associated with MC-CDMA using the frequency domain spreading code {+1+1+1+1 -1-1-1-1}and S-P Conversion associated with U=2bits [5].

C. SCS-MC-CDMA

Frequency allocation is a major issue in the performance of wireless networks. In multi user MC-CDMA systems, the channel fading is different at different sub carriers. This feature can be used for allocating the subcarriers to the users according to the instantaneous channel state information. The SCS-MC-CDMA system as seen in Fig.3 assigns to each user a selected number of sub-carriers. The concept of sub-carrier selection is introduced to counter the problem of high power consumption. MC-CDMA systems usually have lots of sub-carriers, by extracting only the assigned sub-carriers from the whole band by using the appropriate sub-carrier selection technique, we can match the power consumption to the user's data rate.

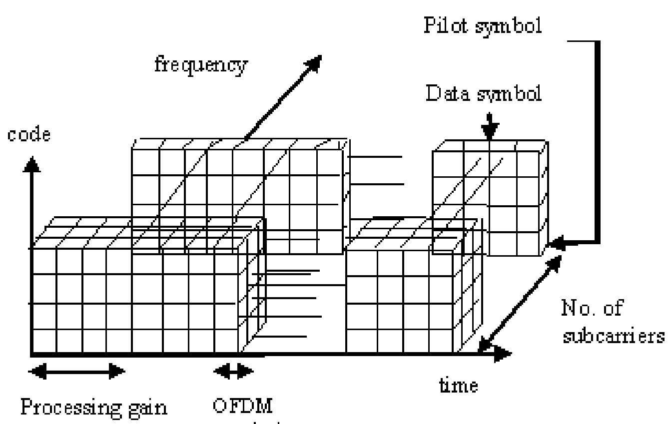

Fig. 3: Frame format of SCS-MC-CDMA system [2]

Sub carriers are allocated depending on user's data or depending on instantaneous Channel State Information (CSI) which include receiving maximum power on particular sub-carrier or finding the sub-carrier with maximum SNR or determining required amount of transmit power on each subcarrier.

Appropriate sub-carrier selection technique results in High Spectrum efficiency, Reduced high power consumption at the mobile terminal, High data throughput in a multicell environment, Improved BER performance due to the high-speed data processing needed, Reduced signal processing load at the mobile terminal.

We commence with a brief discussion of different sub-carrier selection techniques one by one.

II. OVERVIEW OF SUB-CARRIER SELECTION TECHNIQUES EMPLOYING SINGLE SUB-CARRIER SELECTION

In this category out of the available sub-carriers at the base station the best sub-carrier is selected for transmission and the whole data of the user is transmitted through that sub-carrier only. Part A and part B discusses a basic technique for sub-carrier selection depending on the SNR of the sub-carrier. In part C a sub-carrier selection technique depending on receiving power of the sub-carrier is discussed.

A.Water-filling algorithm

Water-filling algorithm has been employed in many research studies for selecting the best sub-carrier amongst all. The design of this algorithm is given by Qingxin Chen, Elvino S. Sousa and Subbarayan Pasupathy [10] and it was motivated by the water-filling (WF) principle in information theory. This principle states that given parallel channels with Gaussian noise, information should be first fed into channels with lower noise levels to achieve the maximum channel capacity. This algorithm aims at maximizing the average SINR of the system.

A simple recursive algorithm has been given [10] as follows

Following notations are used in the Algorithm,

K – Total number of users,

$k = 1,2 \ldots, K,$

M – Total number of subchannels.

$m = 1,2, \ldots, M.$

Algorithm from the paper [10] is simplified as,

Step 0) Define and initialize matrix S , elements of S are given as below by $s_{i,j}$:

$$s_{i,j} = \frac{N_0}{v_{i,j}}, \qquad i = 1,2 \ldots, K, \quad j = 1,2, \ldots, M. \qquad (2)$$

where

$v_{i,j}$ -- Received energy per bit for the (i,j) sub channel given as,

$$v_{i,j} = \frac{1}{2} Y_{i,j}^2 \mathbf{T} \qquad (3)$$

where

$$Y_{i,j} = \alpha_{i,j}\sqrt{2P}$$

Where $\alpha_{i,j}$ -- Fading amplitude which measures the channel quality .

Sub channels with $\alpha_{k,m} > 1$ - Enhances the signal levels and

Sub channels with $\alpha_{k,m} < 1$ - Weaken the signal.

P – Transmitted Power per data stream.

N -- Gaussian distribution with variable variance

Step 1) Define a set **Q** = {1,2,...,K}.

Step 2) Find the (k,rn) subchannel such that:

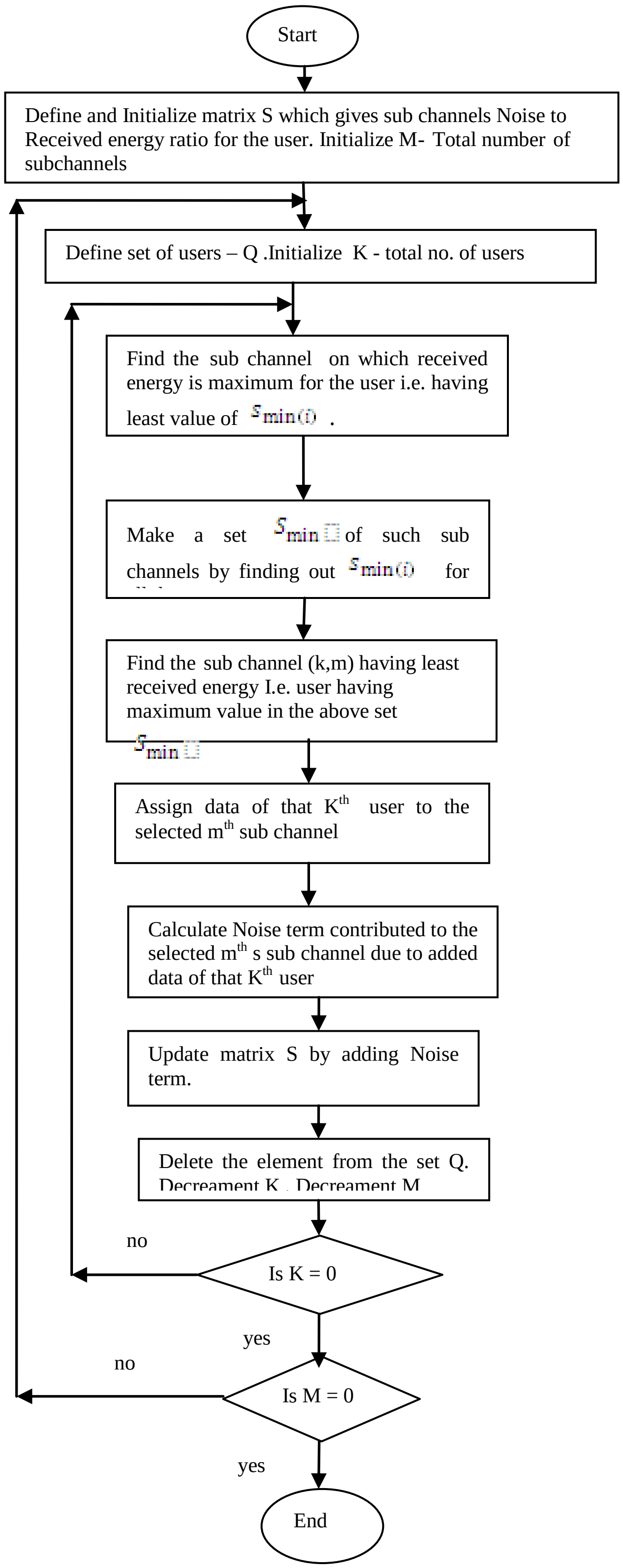

Fig 4 : Flowchart of water filling algorithm

$$s_{k,m} = max(S_{min}) \quad (4)$$

Where

$$S_{min} = \{ s_{min(i)}, \quad i \in Q \}$$

And

$$s_{min(i)} = min(s_{i,1}, s_{i,2}, \dots, s_{i,M})$$

Step 3) Assign data from the kth user to the (k , m) sub channel and update S as follows:

$$s_{i,m} = s_{i,m} + \delta_{i,\frac{m}{k}} \quad (5)$$

$$i = 1,2, \dots, K$$

where

$\delta_{i,\frac{m}{k}}$ - NIT(Normalised interference term) contributed to sub channel (i, m) by adding one data to sub channel (k , m)

$$\delta_{i,\frac{m}{k}} = \frac{v_{k,m} T^2}{v_{i,m} N} \quad (6)$$

Where

$$T = \frac{T_d}{T_c}$$

Where

T_d - Channel delay spread.

T_c – Chip duration.

Step 4) Delete the element F from the set Q.
Step 5) If Q # 0, go to Step 2.
Step 6) Repeat Steps 1 - 5, M times

Flowchart for the above algorithm is constructed as shown in Fig 4 using it one can easily understand the basic principle,

The WF algorithm is simple to implement and it will converge after K x M iterations. Where K is the total no. of users and M is the total no.of subchannels.

In the next section it is going to consider that how a WF algorithm is used as a subcarrier selection technique for adaptive modulation based MC-CDMA System.

B. Dynamic Sub-Carrier Allocation Technique for Adaptive Modulation based MC-CDMA System

In MC-CDMA the performance of the system is improved by adaptively loading sub-carriers in accordance with the varying channel conditions [3]. This technique is focused on selecting the best sub-carrier and transmitting the data through that sub carrier by adaptive bit loading algorithm. In this technique water filling algorithm is used to select the best sub-carrier, over the existing subcarriers. Differently from conventional MC-CDMA system, in this scheme, a best conditioned sub-carrier is first chosen for each user, and a narrowband direct sequence waveform is transmitted through the chosen sub-carrier instead of all the sub carriers.

From the paper considering given MC-CDMA system with K users, the transmitted signal is given by,

$$s(t) = \sqrt{2ME_c} \sum_{k=1}^{K} \sum_{l=-\infty}^{\infty} d_l^{(k)} c^{(k)} (t - lT) . cosw_{j_k} t$$

Where

$$c^{(k)}(t) = \sum_{n=0}^{N-1} c_n^k \, p(t - nT_c) \tag{7}$$

In Eq. (7), $d_l^{(k)}$ is the binary symbol bit of the *k* th user, c_n^k is the signature sequence of the *k* th user, $T = NMT_c$ is the symbol duration with $M\,T_c$ the chip duration for MC system, and *Ec* is the energy per chip. M is the number of sub- carriers, j_k *indicates* the best transmission sub-carrier, and

$p(t - nT_c)$ is a rectangular pulse with duration $M\,T_c$.

Author G.K.D. Prasanna assume the channel is frequency selective Rayleigh fading, but the sub-carriers are frequency nonselective and independent of each other this can be achieved by selecting M properly. Then the complex low pass impulse response of the sub-carriers has been modeled as,

$$h_{k,m}(t) = \alpha_{k,m} e^{j\varphi_{k,m}} \delta(t) \tag{8}$$

where $\alpha_{k,m}$ is the fading amplitude, $\varphi_{k,m}$ is the random phase of the sub-carrier. The amplitude { $\alpha_{k,m}$, m = 1,2,…….M } , are independent and identically distributed (i.i.d.)

Rayleigh fading random variables and { $\varphi_{k,m}$, m = 1,2,…….M } , are uniform i.i.d. random variables over $[0,2\pi)$.

The received signal at the k th mobile is given by

$$r(t) = \sqrt{2ME_c} \sum_{k=1}^{K} \sum_{l=-\infty}^{\infty} d_l^{(k)} c^{(k)}(t - lT) \, \alpha_{k,j_k} \cos\left(w_{j_k} t + \varphi_{k,j_k}\right) + n_w(t) + n_j(t) \tag{9}$$

where $n_W(t)$ is the additive white Gaussian noise with a double side spectral density of No /2 , and $n_J(t)$ is partial band interference with spectral density of $Sn_J(f)$. The pdf of the partial band interference, $Sn_J(f)$ is defined as

$$S_{n_j}(f) = \begin{cases} \frac{N_j}{2}, & f_j - \frac{W_j}{2} \le |f| \le f_j + \frac{W_j}{2} \\ 0, & \text{elsewhere} \end{cases} \tag{10}$$

Thus, the adaptive technique will have a higher data throughput when the channel conditions are favorable and will reduce the throughput as the channel worsens. In other words,from the given technique the principle of adaptive modulation consists of allocating many bits to carriers with a high SNR, whereas on carriers with low SNR, only a few or no bits at all are transmitted

C. Adaptive Sub-carrier and Power Allocation

A dynamic sub channel and power allocation algorithm for MC-CDMA system. is proposed in [12]. In this scheme, data is transmitted over the user's best subcarrier and power control is applied for the selected subcarrier, rather than transmitted over all the subcarriers. This scheme outperforms the conventional MC-CDMA in BER performance. In this scheme first $\alpha_{k,m}$,the magnitude of the channel gain (assuming the coherent reception) of the m^{th} subcarrier is denoted as seen by the k^{th} user, which can be obtained by pilot signal.

Furthermore, P_k the pilot symbol power is denoted and the received power of m^{th} subcarrier for the k^{th} user is equal

$$P'_{k,m,re} = P'_k \alpha_{k,m}^2 \tag{11}$$

From the paper it can be concluded that the subcarrier that has the maximum receiving power will be the best subcarrier for that user.

Next section throws light on different techniques which are used for selecting no. of subcarriers instead of selecting only one subcarrier for data transmission of one user.

III. OVERVIEW OF SUB-CARRIER SELECTION TECHNIQUES EMPLOYING NUMBER OF SUB-CARRIER SELECTION

In this category out of the available sub-carriers first the numbers of sub-carriers required for one user are selected and then user's data is transmitted through that selected group of sub-carriers.

In A subcarriers are allocated by computing SNR. In the next technique B subcarrier selection filters are used. In C a different subcarrier selection technique called as Grouped MC-CDMA is used which subdivides system subcarriers into a set of non overlapping subcarrier groups. In D an algorithm is used where the subcarriers are allocated to the user according to the instantaneous Channel State Information (CSI).

A. Dynamic subcarrier allocation and adaptive slot management

By dynamically allocating subcarriers and adaptive slot management the system can meet the large dynamic resource requirements of a real-time multimedia application in Internet [4]. In this scheme the selection of subcarriers is carried out based on it's current SNR to support a minimum BER. In this technique, the effect of asymmetric slot management strategy employing adaptive resource allocation in a MC-CDMA system is studied, in which each cell has its own slot allocation policy according to the level of traffic load. The algorithm manages the subcarrier and slots to meet the quality of service requirement of an application. The slot management algorithm (Fig. 3) decides whether an outgoing slot is to declared as uplink/downlink based on the existing capacity of the present slot.

System model for MC-CDMA in multi-cell environment has been built by generalizing the two cell model. Paper considers two cell approaches,in which four cases arise: i. cell1 uplink cell2 uplink, ii. Cell1 uplink cell2 downlink, iii. Cell1 downlink cell2 uplink, and iv. Cell1 downlink cell2 downlink. Here cell1 represents a home cell for tagged mobile, and cell2 a cell in first tier interfering cells. First the SNR is calculated using the formulae that falls under any one of the four cases considered. SNR computation from the paper is given as below,

SNR computation for Cell1 UL Cell2 DL:

Assuming at a particular time, slot in Cell1 is for uplink and in cell2 it is for downlink. In the SNR computation, considering noise because of presence of other user, assuming that all MS are perfectly synchronized with uplink and downlink slots in a TDD frame. Further it is assumed that a perfect power control mechanism is implemented, so that BS receives equal power from all MS in its cell. The background thermal noise N_o, can be ignored as it is very small compare to the I_{int} and I_{ext}. Let the equal power received by BS from every MS in cell1 is Prms1. The internal noise, I_{int} can be related to the number of channels in cell1 and the number of cross slot as,

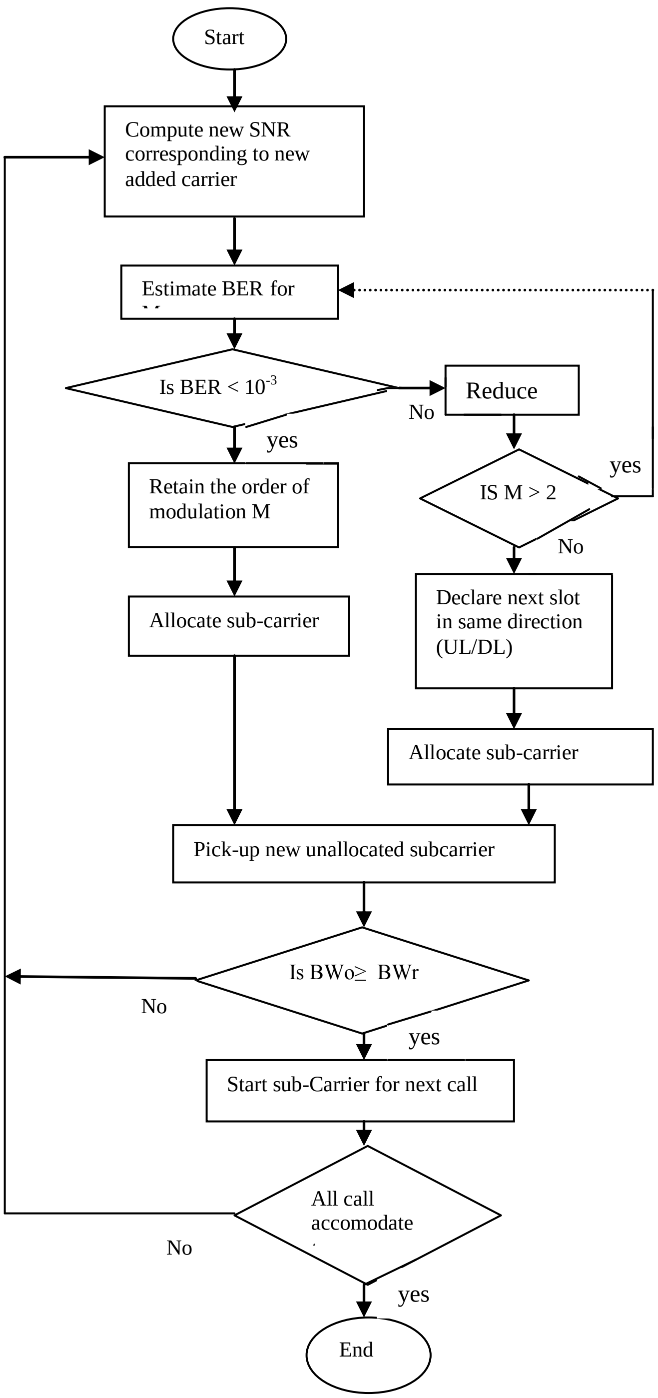

Fig.5 : Flow chart of algorithm [4]

$I_{int} = \{(m_1 / N_o) - 1\} P_{rms1}$ (12)

The external noise Iext in cell1 is the downlink signal originating from BS in cell2, and can be given by,

$$I_{ext} = \lambda(2D)^{-4}\left(\frac{m_2}{N_o}\right)P_{tbs2} \qquad (13)$$

Where 2D is the distance (i.e. cell radius of D) between two BS, P_{tbs2} is the transmit power at BS2. If W is the total spreading bandwidth, the spreading factor, (also called processing gain) for uplink, SF_u is given by,

$$SF_u = \frac{W}{R_u} \qquad (14)$$

Now the SNR for the uplink slot in cell1 is given by

$$SNR = \frac{r^{-4}P_{tms1}SF_u}{\left(\frac{m_1}{N_o} - 1\right)P_{rms1} + (2D)^{-4}P_{tbs2}\,{}^{m_2}/_{N_o}} \qquad (15)$$

BER Calculation

The BER for the Ith Sub-Carrier corresponding to M-QAM is given by [16]

$$\mathbf{BER_I} = \frac{1}{5} \times \exp\left[\frac{-1.5 \times \mathbf{SNR_i}}{\mathbf{M} - 1}\right] \qquad (16)$$

Where SNRi is the signal to noise ratio for Ith subcarrier, and M is the constellation points in M-QAM

The SNR is recomputed every time based on the new call arrival rate, and hence the addition of a new subcarrier in a slot. The new call includes handoff user too. The BER is computed using (16) based on the SNR and a high modulation order (M=8). If BER > 10^{-3}, then order of modulation M is reduced and BER is computed again, and this process is repeated till BER falls below $10^{-3}$and the corresponding M value is retained to be used for order of modulation in M-QAM. If BER does not falls below10^{-3} and M = 2, then the next slot is declared as same status (e.g. uplink if the current slot is uplink) and new calls are accommodated in new slots. Based on the existing SNR and application's bandwidth requirement, the no. of subcarriers are allocated to these new calls. If the accumulated bandwidth (BWc) i.e. no of subcarrier is just enough to meet the requirement (BWr), the resource allocation completes for a user and the algorithm takes next call to be processed.

In the next technique Butterworth filter is used for subcarrier selection.

B. Sub-Carrier Selecting MC-CDMA System for 4G Systems

Teruya Fujii, Noboru Izuka, Hiroyoshi Masui, and Atsushi Nagate [2] has introduced the concept of sub-carrier selection to counter the problem of high power consumption. For high speed data processing high power consumption at the mobile terminals is needed. In this scheme each user has assigned only as many subcarriers as are needed to support the user's data rate. To reduce the implementation complexity here in the paper,use of only one or two sub-carrier selection filters is considered.

The SCS-MC-CDMA system assigns to each user a selected number of sub-carriers as shown in Figure below,

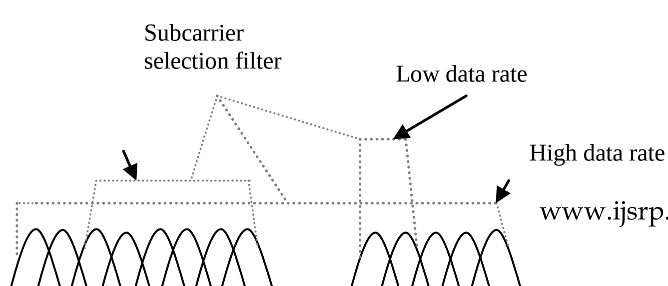

Fig. 6 : Sub carrier selection [2].

For example, 32, 128, or 1024 sub-carriers out of a total of 1024 sub-carriers can be assigned for each low, middle, or high data rate communications, respectively. Therefore, a mobile terminal needs only one or two sub-carrier selection filters. The users who are assigned the same sub-carriers use different spreading codes, so that orthogonality among users is maintained. As for the base station, it just needs to map the data of each user onto the particular sub-carriers. This mapping is the only difference between the base station of the given system and that of the original MC-CDMA systems. Figure shows the block diagram of the receiver.

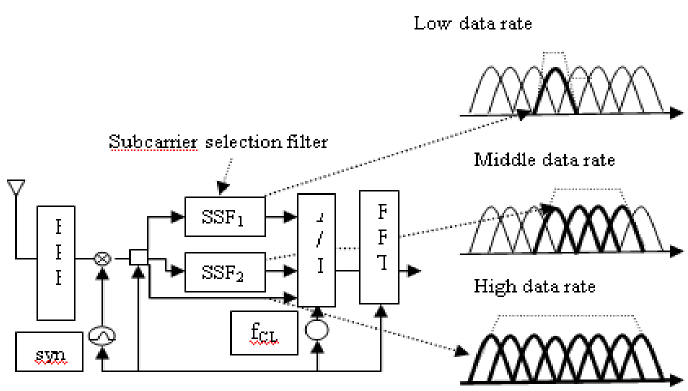

Fig. 7 : Receiver block diagram [2]

The key to the scheme considered is the sub-carrier selection filter (SSF), each of which has a different bandwidth. In the transmitter, the number of assigned sub-carriers is changed as the user's data rate changes. In the receiver, corresponding to the number of sub-carriers assigned, the controller selects the appropriate sub-carrier selection filter; it also adjusts the sampling frequency of the A/D converter and the number of FFT points. The controller adjusts the frequency of the synthesizer according to the center frequency of the signal at the band-pass filter output.

Because the receiver selects the sub-carrier selection filter with appropriate bandwidth and demodulates only the assigned sub-carriers, the received signal bandwidth is narrower than that with the conventional approach. Therefore, this technique can lower the sampling rate of the A/D converter as well as the signal processing power required for FFT as part of demodulation. As a result, the power consumption of a mobile terminal, which is running a low data rate service such as voice or control, can be significantly reduced. Without sub-carrier selection technique, the signal processing power required for demodulation is proportional to Nc^2 regardless of the data rate at the receiver, where Nc is the total number of sub-carriers. With the use of sub carrier selection filter on the other hand, the signal processing power at the receiver is proportional to Nd^2, where Nd is the number of assigned sub-carriers. Moreover, mobile terminals, which do not need high rate communications, such as voice terminals can be downsized easily.

C. Subcarrier Group Assignment for MC-CDMA Wireless Networks

Grouped MC-CDMA systems have the potential of enhancing prospective system capacity. Grouped MC-CDMA subdivides system subcarriers into a set of nonoverlapping subcarrier groups [6] . This opens a platform for isolating the received target signal from sources of intolerably high interference and potentially resulting in capacity improvements.

Two interference-based subcarrier group assignment strategies in dynamic resource allocation are considered in [6] for MC-CDMA wire-less systems to achieve high throughput in a multicell environmen**t**. Least interfered group assignment (LIGA) selects for each session the subcarrier group on which the user receives the minimum interference, while best channel ratio group assignment (BCRGA) chooses the subcarrier group with the largest channel response-to-interference ratio**.** In particular, under low loading conditions, LIGA renders the best performance. However, as the load increases BCRGA tends to offer superior performance.

Consider MC-CDMA cellular network where the system bandwidth, W, is subdivided into N_c subcarriers. Bandwidth of subcarriers is selected such that they each ap- roximately exhibit flat fading channel characteristics (i.e., $W/ N_c \le B_c$ where B_c is the coherence bandwidth). Assume for grouped MC-CDMA that each G subcarriers con- stitute a group over which individual streams will be spread. As a result of subcarrier grouping, system bandwidth could be described in terms of a set of subcarrier groups,

$C = \{C^{(1)}, C^{(2)}, \dots, C^{(j)}, \dots, C^{(N_G)}\}$,where

$N_G = N_C/G$ is the number of subcarrier groups. Subcarriers belonging to the same group are selected such that they are G subcarriers, $C^{(j)}$ is used to signify the jth subcarrier group. A multicell network constituted of $B = \{1, 2, \dots, N_B\}$ base stations is considered. Subcarrier grouping defined by the set C is presumed to be the same across all base stations. Each base station, $b \in B$,is effectively simultaneously supporting K active data users. Each base station b operates under the constraint that it has at its disposal a maximum amount of power P_{MAX} to share among active sessions. It is assumed for the analysis presented that each user may be assigned to only one group. Power dedicated for each user assigned to a certain group is assumed to be uniformly distributed over subcarriers of such group. In other words, for a user k of interest allocated with $P^{(b, j)}$ by base station b over $C^{(j)}$, the power share per subcarrier of $C^{(j)}$ will be evenly distributed as $P_k^{(b, j)}/ G$.

Next consider the mobile user k of interest served by base station b that offers the best path-loss for such user. If it is assumed that the user has been assigned to C(j) , then the total signal power measured in the downlink direction at the receiver input of user k excluding thermal noise is

$$\rho_k^{(b,j)} = A \sum_{c=1}^{G} \left[\left(P_k^{(b,j)} \Big/ G \right) H_{kb'}^{(b,j)} S_{kb'}^{(b,j,c)} \right] \quad (17)$$

where A is the average antenna gain for the transmitted signal relative to all interferers; $H_{xy}^{(z,j)}$ signifies the large-scale path-loss between the mobile user x and base station y given that user x is being served by base station z and assigned to C(j) ; $S_{xy}^{(z,j,c)}$ depicts the small-scale fading power for the cth sub- carrier belonging to C(j) defined between the mobile user x and base station y given that user x is being served by base station z; $I_k^{(b,j)}$ is the total interference measured by user k served by base station b over C(j) . , expressed as

$$I_k^{(b,j)} = E_k^{(b,j)} + \sum_{b' \neq b,, b'=1}^{N_B} \sum_{c=1}^{G} \left[\left(P^{(b',j)}/_G \right) H_{kb'}^{(b,j)} S_{kb'}^{(b,j,c)} \right] \quad (18)$$

where $E_k^{(b,j)}$ depicts the intracell interference from users assigned within base station b to the same group as user k; $P^{(y,j)}$ is the total power transmitted by base station y over C(j). In a multicell environment, it is commonly assumed for intracell interfer- ence to be negligible when compared to intercell interference [14]. Furthermore, for a large number of interferers, small- scale fading variations over interfering paths are presumed to inflictminimal effects on SINR performance. Under such circumstances, the average large-scale interference is employed to represent the interference component in the SINR equation Therefore, the equation for interference affecting user k of interest reduces to

$$I_k^{(b,j)} = \sum_{\substack{b'=1 \\ b' \neq b,}}^{N_B} P^{(b',j)} H_{kb'}^{(b,j)} \quad (19)$$

Consequently, given that G (number of subcarriers per group) depicts the equivalent expected processing gain of MC-CDMA signals, then the SINR $\Gamma_k^{(b,j)}$ experienced by a given user k served by base station b over $C^{(j)}$ could be ex- pressed as

$$\Gamma_k^{(b,j)} = \frac{GA}{I_k^{(b,j)}} \sum_{c=1}^{G} \left[\left(P_k^{(b,j)}/_G \right) H_{kb}^{(b,j)} S_{kb}^{(b,j,c)} \right]$$

$$= P_k^{(b,j)} \Omega_k^{(b,j)} \quad (20)$$

Where

$$\Omega_k^{(b,j)} = GAH_{kb}^{(b,j)} S_{kb}^{(b,j)} \Big/ I_k^{(b,j)} \quad (21)$$

is the normalized signal to- interference ratio (SIR) corresponding to a unit of power allocated to user *k* and

$$S_{kb}^{(b,j)} = \left(1/_G\right) \sum_{c=1}^{G} S_{kb}^{(b,j,c)} \quad (22)$$

ROUP ASSIGNMENT STRATEGIES:

Group assignment without interference consideration

RGA

In RGA, active user k is assigned to subcarrier group $C^{(j)}$ in a random manner, that is,

j = rand (1: N_G), where "rand" is a random generator of integers from one to the number of groups (N_G) of the system.

BSGA

In BSGA, user *k* is assigned to subcarrier group $C^{(j)}$ if it offers the best small-scale fading channel response, that is,

$$C^{(j)} = \max_{c^{(l)}} S_{kb}^{(b,l)} \quad (23)$$

Note that in RGA and BSGA, the selection of $C^{(j)}$ for user *k* is independent of assignments across the network as well as within the same cell.

Interference-based group assignment

LIGA

In a multicell environment, intercell interference inflicts significant contribution on attained throughput performance. Subcarriers with the best small-scale fading channels no longer have the potential to support the highest transmission rates since they might coincide with intolerable interference power generated from other cells of the network. Consequently, it is provisioned in this paper that LIGA has the potential to outperform BSGA that has been popular for single cell scenarios. In LIGA, active user *k* is assigned to subcarrier group $C^{(j)}$ such that

$$C^{(j)} = \min_{c^{(l)}} I_k^{(b,l)} \quad (24)$$

BCRGA

BCRGA is considered as a composite group assignment scheme that is based on LIGA and BSGA. The notion "channel ratio" in BCRGA indicates that the metric used for group selection is based on the ratio of small-scale fading channel to- interference ratio received on a particular group. Accordingly, *C*(*j*) in BCRGA is selected such that it supports the best channel ratio, that is,

$$C^{(j)} = \max_{c^{(l)}} \left(S_{kb}^{(b,l)} \Big/ I_k^{(b,l)} \right)$$

$$= \min_{c^{(l)}} \left(I_k^{(b,l)} \Big/ S_{kb}^{(b,l)} \right) \quad (25)$$

D. Adaptive sub-carrier and power allocation

In multi-user MC-CDMA systems, the channel fading is different at different sub-carriers . This feature is utilized by some researchers to investigate an Adaptive Channel Allocation (ACA) where the channels are allocated to the user according to the instantaneous Channel State Information (CSI) [11]. This technique [11] is focused on the joint channel and power allocation in the downlink transmission of multi-user MC-CDMA systems and considers the throughput maximization problem as a mixed integer optimization problem. , under the constraints that the total transmit power should not exceed the maximum transmit power and each channel's SINR should be not be less than a pre-defined value.

In the proposed scheme first the subcarriers are allocated to the different users by calculating required power on each channel and then power is allocated to all the subcarriers..

Throughput maximization problem has been considered as a following optimization problem as,

$$\max \sum_{k=1}^{K} \sum_{m=1}^{M} n_m^k \qquad (26)$$

Where

n_m^k - number of the **k**th user's channels on the **m**th group.
K – Total number of users
M - Total number of groups of subcarriers.
Above problem in equation (26) Subject to

$$\max \sum_{k=1}^{K} \varphi(n_m^k) \leq 1, \forall m \qquad (26.a)$$

Above equation (26.a) imposes the restriction that at most one user can be allocated to each group simultaneously.
Where $\Phi(n_m{}^k)$ is a function defined as

$$\varphi(n_m^k) = \begin{cases} 1 & n_m^k > 0 \\ 0 & n_m^k = 0 \end{cases}$$

Problem in equation (26) is also Subject to

$$\sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{l=1}^{L} n_m^k P_{m,l}^k \leq P_T^{max} \qquad (26.b)$$

Where
L – Total number of subcarriers in mth group.
Above equation (26.b) is the total transmit power constraint.
where
$P_T{}^{max}$ - The maximum transmit power.
$P_{m,l}^k$ – The signal power of one channel on the lth subcarrier of the desired group.
Problem in equation (26) is also Subject to

$$\Gamma_m^{(k,i)} \geq \gamma, \forall k, m, i \qquad (26.c)$$

Above equation (26.c) is the SINR constraint.
Where
$\Gamma_m^{(k,i)}$ - Signal power to interference-plus-noise power ratio (SINR) of the signal on the ith channel of the **m**th group.
γ - Target threshold of BER.
Problem in equation (26) is also Subject to

$$P_{m,l}^k \geq 0, \forall k, m, l \qquad (26.d)$$

$$n_m^k \in \{0,1,\ldots\ldots,L\}, \qquad \forall k, m \qquad (26.e)$$

Equations (26.d) and (26.e) ensure the correct values for the transmit power and the channel number respectively.
Before giving the actual scheme, the two sub-problems are discussed, respectively by the author,.
Adaptive Power Allocation (APA): In this paper, the criteria used for power allocation is to minimize the transmit power on each channel while satisfying the SINR and given transmit power constraints. If the transmit power consumption
of each allocated channel can be reduced, more channels can be allocated to improve the throughput.
Assuming that the mth group is assigned to the kth user, then the optimal power allocation can be obtained by solving the following optimization problem:

$$\min \sum_{l=1}^{L} P_{m,l}^k \qquad (27)$$

Subject to

$$\Gamma_m^{(k,i)} \geq \gamma, \qquad \forall i \qquad (27.a)$$

$$P_{m,l}^k \geq 0, \qquad \forall l \qquad (27.b)$$

Therefore, one channel's minimum transmit power on the ithsub-carrier of the mth group can be obtained as ,

$$P_{m,l}^k = \frac{\gamma N_o \sum_{l=1}^{L} |\omega_{m,l}^k|^2}{L^2 |\omega_{m,l}^k h_{m,l}^k|^2} \qquad (27.c)$$

Moreover, for one channel on the mth group, the required transmit power is expressed as

$$S_m^k = \sum_{l=1}^{L} P_{m,l}^k = \gamma N_o L^{-2} \sum_{l=1}^{L} |\omega_{m,l}^k|^2 \sum_{l=1}^{L} |\omega_{m,l}^k h_{m,l}^k|^{-2} \qquad (28)$$

Adaptive Channel Allocation (ACA) : In this paper the criteria used for channel allocation can be defined by two approaches. First each group is assigned to the user who requires the minimum transmit power for one channel on that group and second is if the total power is not sufficient then select the groups and allocate channels to the users according to the increasing order of the associated transmit power.
If the required amount of transmit power of each channel has been determined for all users before the channel allocation, then the constraints (26.b), (26.c) and (26.d) in the optimization problem (26) can be substituted by one constraint as following:

$$\sum_{k=1}^{K} \sum_{m=1}^{M} n_m^k S_m^k \leq P_T^{max} \qquad (29)$$

The optimization problem (26) has been further simplified into a channel allocation problem as ,

$$\max \sum_{k=1}^{K} \sum_{m=1}^{M} n_m^k \qquad (30)$$

subject to

$$\sum_{k=1}^{K} \mathrm{sgn}(n_m^k) \leq 1, \forall k, m \quad (30.a)$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} n_m^k S_m^k \leq P_T^{max} \quad (30.b)$$

$$n_m^k \in \{0, 1, \ldots, L\}, \quad \forall k, m \quad (30.c)$$

Denoting µm as the user whose transmit power for one channel on the mth group is minimum among all users, i.e.

$$\mu_m = \arg \min_{1 \leq k \leq K} \{S_m^k\} \quad (31)$$

Thus following Proposition 1 is given in the paper,.

Proposition 1. There exists one optimal solution to the optimization problem (24) satisfying that each group is assigned to the user who requires the minimum transmit power for one channel on that group, i.e., for m = 1, . . . , M, the m^{th} group is allocated to the $\mu_m{}^{th}$ user.

The size of solution space of the optimization problem (30) is $K^M(L+1)^M$, an efficient search method given in proposition 1 can reduce the size of solution space to $(L+1)^M$.

According to Proposition 1, each group is associated with a transmit power, i.e., for m = 1, . . . , M, the associated transmit power of the m^{th} group is $S_m^{\mu m}$. If these associated transmit power for all groups is sorted according to the increasing order, one can obtain an order $\{v(i)\}_{i=1,\ldots,M}$, where v(i) is the group whose associated transmit power is the i^{th} minimum among the associated transmit power of all groups..The associated transmit power according to the increasing order is

$$S_{v(1)}^{\mu_{v(1)}} < S_{v(2)}^{\mu_{v(2)}} < \cdots < S_{v(M)}^{\mu_{v(M)}} \quad (32)$$

Then, the following Proposition 2. is given in the paper,.

Proposition 2. Under the constraints of any given maximum transmit power P_T^{max} and the maximum channel number on every group L, if the transmit power is not enough to be allocated to all channels of all groups simultaneously, that is

$$\sum_{i=1}^{M} L S_{v(i)}^{\mu_{v(i)}} > P_T^{max} \quad (33)$$

then the throughput is maximized by selecting the groups and allocating channels according to the increasing order of the associated transmit power, i.e., one optimal channel allocation for the optimization problem (30) owns the following form

$$\tilde{N} \triangleq \left(\tilde{n}_{v(i)}^{\mu_{v(i)}}\right)_{i=1,\ldots M} = (\underbrace{L, \ldots L}_{\alpha}, l, \underbrace{0, \ldots 0}_{\beta})$$

where $l \in \{0, 1, \ldots, L\}, \alpha, \beta \in \{0, 1, \ldots, M-1\}$ and

$$\alpha + \beta + 1 = M \quad (34)$$

In this method, the channel with lower transmit power requirement owns higher priority to be selected for transmission. According to Propositions 1 and 2, author has proposed ACA algorithm as follows:

Initialization

$P_R = P_T^{max}, C = \{1, 2, \ldots, M\}, n_m^k = 0$ **for**
$k = 1, \ldots, K$ **and** $m = 1, \ldots, M.$

For each group
$m = 1, \ldots, M$, **do % group assignment.**
$\mu_m = \arg\min\{S_m^k\}$

End For

while $C \neq \emptyset$ **% channel allocation**
$t = \arg \min_{\forall m \in c} \{S_m^{\mu_m}\}$; **% select the group with lowest power requirement**

$n_t^{\mu_t} = \min\left(\left\lfloor \frac{P_R}{S_t^{\mu_t}} \right\rfloor, L\right)$; **% calculate the available channel number**

$P_R = P_R - n_t^{\mu_t} S_t^{\mu_t}$; **% calculate the residual transmit power**
$C = C \setminus \{\mu_t\}$;
If $n_t^{\mu_t} = 0$ **% since the residual transmit power is not enough ,terminate channel allocation.**
Break the loop;
End If
End While

It has been stated that the allocation result of the ACA algorithm discussed above is optimal for the optimization problem (30).

Flowchart for the above ACA algorithm is constructed as below,

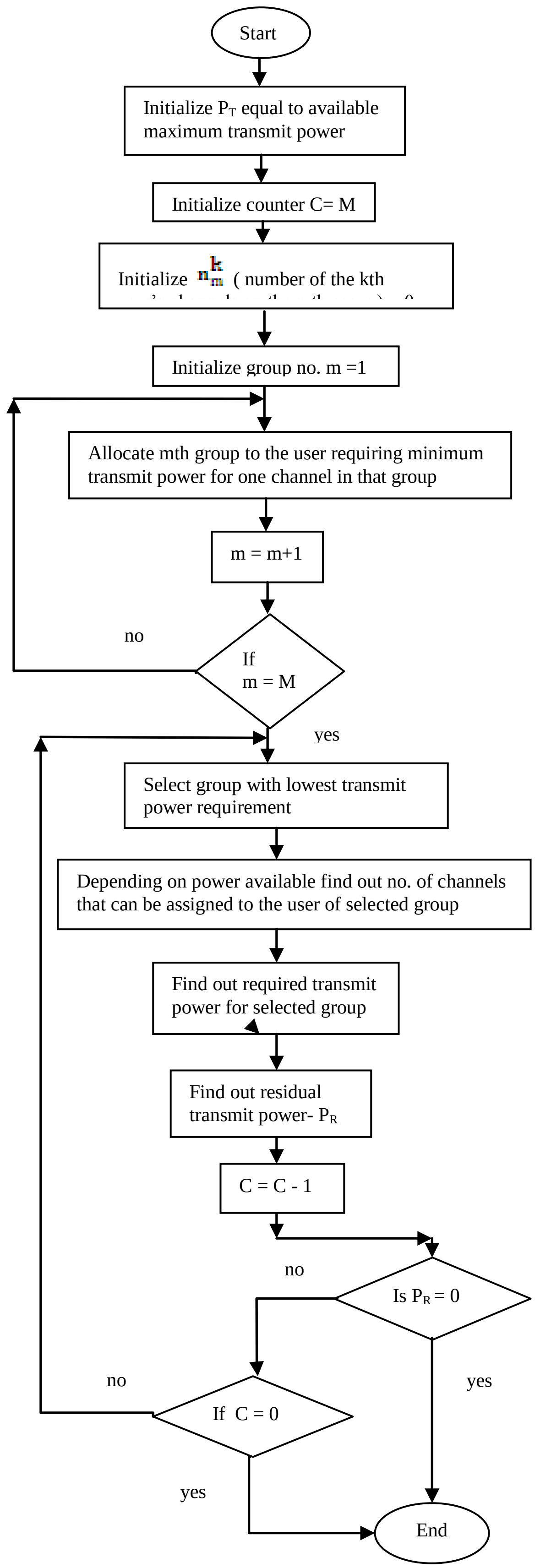

Fig. 8 flowchart for ACAalgorithm

Combined final scheme: By combining the proposed APA and ACA algorithms, an adaptive channel and power allocation scheme has been proposed for the optimization problem given by first equation in (19). This scheme consists of three steps and is described as follows:
Step 1: According to the obtained CSI, for all users, the required amount of transmit power to be allocated to one channel of every group S_m^k is determined by (22).
Step 2: Based on the results obtained in Step 1, the channels are allocated to different users by using the ACA algorithm
Step 3: The transmit power is allocated to all sub-carriers of all allocated channels using (21).
Author has carried out simulations of the above scheme and compared it with the conventional systems in terms of throughput.

IV. OTHER TECHNIQUES

There are some other subcarrier selection techniques which are briefly summarized here.
In MC-CDMA the most power-efficient allocation is to distribute the power of each user over several sub-carriers of better quality and even concentrate on the best one, if it is exclusive[18].In this paper an iterative power allocation algorithm is proposed after deciding all supportable transmission rates to allocate the sub-carrier power of each user and jointly solve the sub-carrier allocation problem.

Santi P. Maity, Mithun Mukherjee divides the available sub-carriers as even sub carriers and odd sub-carriers [9]. This paper proposes a high capacity carrier interferometry/ multicarrier code division multiple access (CI/MCCDMA) system through the simultaneous support of high and low data rate transmission. This paper attempts to make a good compromise among BER, capacity and computation cost through the development of a new CI/MC-CDMA system where users transmit their data at different rates. This is achieved by allocating all sub-carriers to the users who transmit high data rate. The users of low data rate share alternate odd and even subcarriers. The effect of MAI (multiple access interference), arising out from the cross-correlation among the code patterns, is reduced through the phase shift of even (odd) CI code using even (odd) sub-carriers by an amount $\pi/2$ and odd (even) CI code using even(odd) subcarriers by $-\pi/2$, all measured with respect to the orthogonal CI codes assigned to support high data rate transmission.
In another technique [19] the problem of subcarrier grouping is studied in the downlink of multi-carrier code division multiple access (MC-CDMA) systems with linear minimum mean square error (MMSE) receiver. The problem is treated as
combinatorial optimization problem.An optimal subcarrier grouping scheme is presented. The given scheme is efficient in computational time. According to the instantaneous channel conditions, the given optimal scheme can be applied adaptively subcarrier grouping to maximize the system capacity. The simulation results show that the proposed scheme outperforms the conventional static schemes. and is efficient in improving the system performance.

A deep insight can be made in the above techniques which are equally important as the other techniques mentioned in this paper.

Table I. Different approaches studied in the paper

Sr.No.	Class	Sub-Carrier Selection strategy	Supporting Technique	Improvement In performance
1	I	Water- filling algorithm	-	Speed, Avarage SINR of the system
2	I	Dynamic Sub-Carrier Allocation Technique for Adaptive Modulation based MC-CDMA System	Adaptive Modulation	BER performance,Throug-hput can be increased
3	I	Adaptive Sub-carrier and Power Allocation	Adaptive Power Allocation	BER performance
4	II	Dynamic subcarrier allocation and adaptive slot management	Adaptive time slot management	BER performance
5	II	Sub-Carrier Selecting MC-CDMA System for 4G Systems	-	Reduces power consumption of mobile terminal
6	II	Subcarrier Group Assignment for MC-CDMA Wireless Networks	Grouping of sub-carriers	High Throughput
7	II	Adaptive sub-carrier and power allocation	Adaptive power allocation	High Throughput

V. PERFORMANCE COMPARISON

Simulation results of different techniques are discussed below with respect to BER performance or throughput performance.

In most of the cases Water Filling Algorithm is used for allocating power to the selected sub carriers but in this paper we discussed its application for selecting sub carriers. Fig, 6 shows the BEP's (averaged among all users) obtained with the GA algorithm and the WF algorithm [10]. The important feature of Water Filling Algorithm is that it requires very less time as compared to GA Algorithm. The performance obtained in Fig, 6 with the WF algorithm is slightly inferior. However, even with K = 5, where K is the number of users, the time taken by the GA algorithm to reach the solution is almost a thousand times longer than that of the WF algorithm [10].Hence, the WF algorithm can be consider to be a very strong candidate for sub carrier selection, it has been used in next technique [3] recently. K is set to 64 for the rest of the results in the paper.

In Dynamic Sub-Carrier Allocation Technique for Adaptive Modulation based MC-CDMA System [3] during simulation, the total available bandwidth is the same for both the systems shown in Fig. 7 and NM=512. Then the processing gain for each sub carrier signal is N=256 when the number of sub carriers is M=2 and 128 and when M= 4, respectively. The number of users is, K=50.The BER performance for different number of sub carriers and different narrowband interference power to signal power ratio is considered [3]. From the fig. 7 it can be seen that the BER performance is reasonably improved by the proposed method [3] as compared to conventional MC-CDMA. By using higher order modulation on selected sub carriers that means allocating more number of bits to these subcarriers throughput can be increased reasonably.

In the other method of adaptive subcarrier and power allocation [12] while carrying out simulation the total available bandwidth is kept same for the systems and spreading gain equal to256, symbol duration Tw = 1/4.8 x1O^3, chip duration T_c = 1/1.2288 x 10^6, signal-to- interference-ratio (SIR) 5dB, the power control sampling period 1.25ms, and the power control command BER has been set to 0.01. From the fig.8, it can be seen that the proposed multicarrier system outperforms the conventional MC CDMA system in BER performance for its exploiting frequency diversity positively. As the mobile velocity increases, the BER performance decreases.

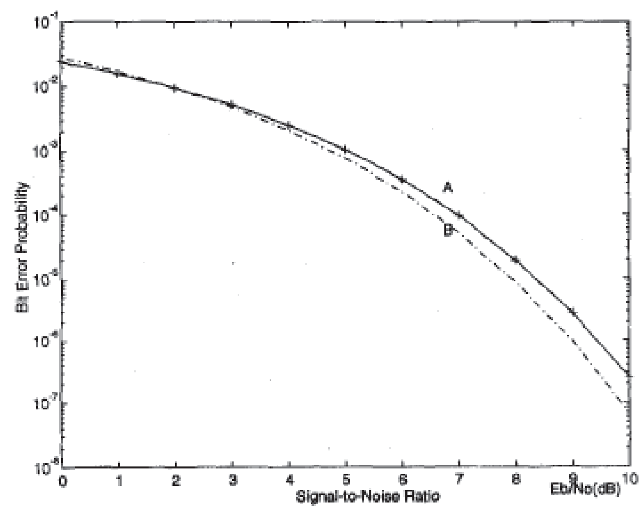

Fig. 9 Avarage system BEP's obtained with the GA algorithm and with the WF algorithm. L, = 3, T,! = G jts, K = 5, M = 8, and N = 156. A-WF algorithm and B - GA algorithm [10]

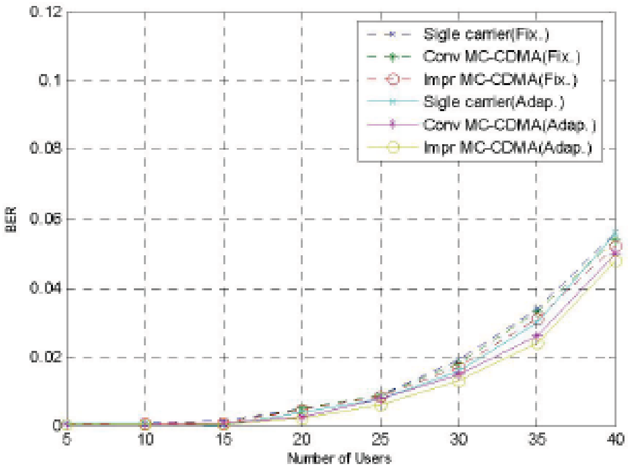

Fig.11 BER performance comparison of different CDMA systems in Rayleigh channel (mobile velocity 5 km/h) [12]

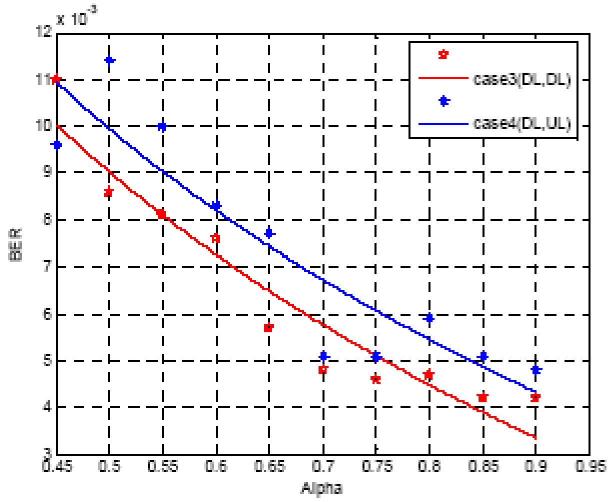

Fig 12 (b). BER with respect to orthogonality factor in internal interference. [4]

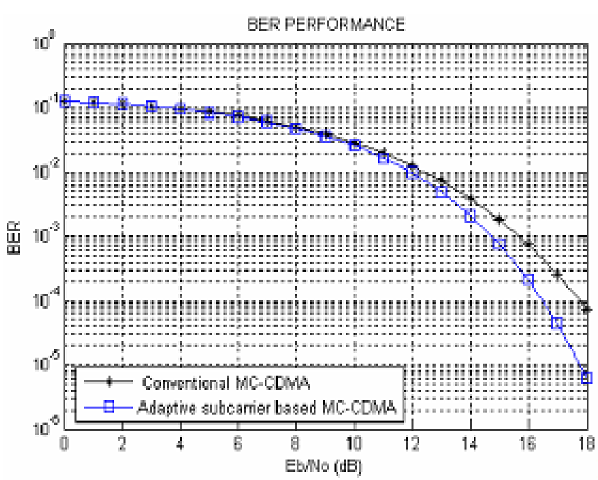

Fig.10 BER Performance of proposed MC-CDMA scheme [3]

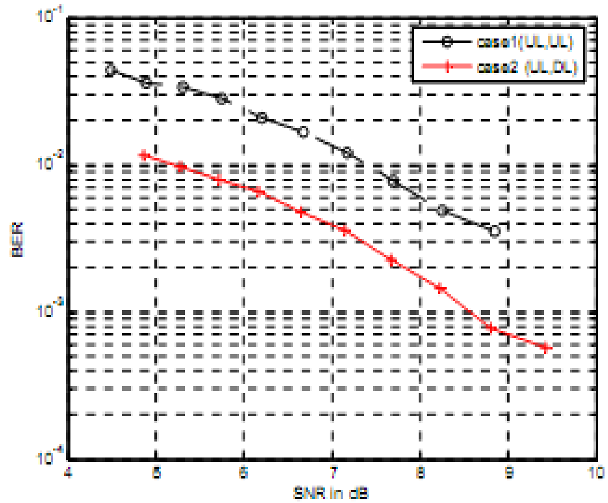

Fig. 12 (a) BER performance in case1 and case2 [4]

Under the second class of sub carrier selection we are considering four different techniques of which simulation results are discussed below,

In the first technique [4] simulations were carried out for the four cases of uplink and downlink scenario of MC-CDMA system. First simulation of the BER performance of proposed algorithm [4] in presence of AWGN and Rayleigh channel was carried out. Different Walsh codes were used for spreading user data on each subcarrier. The major channel parameters considered in simulation are listed in table II,

Table II. [4]

Bandwidth	10 MHz
Spreading Factor	128
FFT Length	1024
Modulation(M-QAM)	2- 8
Rayleigh Channel	Ts =0.01 s , Δf = 10 Hz
Number of users	15 – 30
Length of Walsh Code	8

Table III [4] Simulation scenario

Case	Cell 1	Cell 2
Case 1	Uplink (UL)	Uplink (UL)
Case 2	Uplink (UL)	Downlink (DL)
Case 3	Downlink (DL)	Downlink (DL)
Case 4	Downlink (DL)	Uplink (UL)

In table III each case represents a traffic direction and interference pattern changes accordingly. The BER in case1 shown in Fig.12(a) below follows a higher path as in uplink base station suffers intra cell and inter cell interference from a large no. of users. In downlink the intra cell interference is caused by orthogonality factor. Fig.12(b) shows the BER performance with respect to variation in orthogonality factor. In case of cross slot, i.e. case4, there could be heavy interference, as interfering mobile in neighboring cell may be near to the tagged mobile.

In the next technique [2] The simulations assume a Butterworth filter for sub-carrier selection. The following equation shows the transfer function of the Butterworth band-pass filter with delay equalization,

$$A(f) = \frac{1}{\sqrt{1 + \left\{{(2\pi f - 2\pi f_o)}/{\pi B}\right\}^{2n}}}$$

Because the equalization removes the delay distortion of the filter, the transfer function is a real value. B and f_0 are the 3dB-bandwidth and center frequency of the filter, respectively
Simulation parameters used are,

Table IV. [2]

Subcarrier Spacing	40 KHz
Number of subcarriers	1024
Guard Interval	¼ OFDM symbol length
Processing Gain	16
Number of Users	15
FEC	Convolutional Coding with Viterbi Decoding(R=1/2 ,K=7)
Modulation	QPSK

Next the simulation results for throughput for two schemes is given.
Fig.13 shows the throughput versus the number of users, when the spreading factor is 8, the BER requirement is 1O-3 and the MaxSNR is 8 dB. When the number of users is one, no multi-user diversity can be exploited. So, no matter which combining scheme is applied, the two channel allocation schemes have almost the same throughput. However, with the increase of the number of users, the throughput of the proposed channel and power allocation scheme increases as well, while the throughput for the SCA algorithm with APA algorithm remains constant. The differences between the proposed scheme and the SCA algorithm with APA algorithm result from the effects of multi-user diversity. When the number of users exceeds 16 and the EGC or ZFC is applied, all channels have been allocated for transmission and the system throughput becomes a constant.

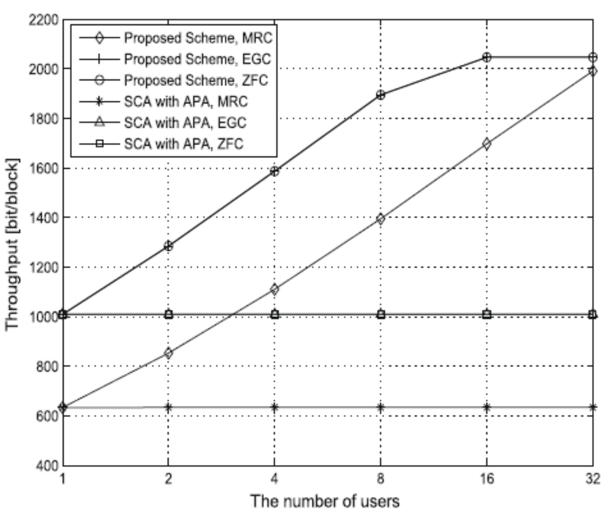

Fig.13 Throughput versus the number of users [11]

VI. CONCLUSION

This paper studies various subcarrier selection techniques combined with adaptive power allocation, adaptive modulation, adaptive slot allocation and other schemes.
The sub carrier selection work can be extended for performance improvement in Ultra wide band MC-CDMA, to improve the overall system performance. The BER and system capacity alone were analyzed in some systems and other system parameters like delay and throughput need to be analyzed. Future work can be carried out for reducing computational complexity by reducing no. of iterations while searching for best subcarrier. With the given power constraint and BER the work can be extended giving dynamic priority to the users.

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