An Adaptive FH/MC-CDMA to Improve Channel Quality for Multiuser Using Variable Code-Based Carriers

M. Saravanan
Associate Professor, Department of Electronics and Communication Engineering, IFET College of Engineering, Villupuram.

msaravanan@ifet.ac.in

Abstract. The adaptive variable code-based carriers for multiusers in a common channel of communication is a technique of Multi-Carrier Code Division Multiple Access (MC-CDMA). It is an advanced mode of communication, where multiple users are communicating with different code and a different carrier. The proposed adaptive frequency hopping technique in MC-CDMA will give high signal to noise ratio value mitigating multiple access interference. Proposed adaptive technique detects multi-users with the help of matched filters. The simulation of the above system is done with correlated sub-carriers in the presence of realistic fading channels and even imperfect channel state information for recovering at the transmitter. The performance of an improved allocation algorithm for MC-CDMA system with adaptive frequency hopping is investigated. Imperfect channel state information at the base station does not affect the performance of the proposed technique due to the combined allocation algorithm and multi-user detector employment. The above combination mitigates multiple access interference efficiently, and increases the system capacity in a significant way compared to non-adaptive variable code-based carrier system. The results of the simulation confirm the above said performance factors with realistic correlated sub carriers that are faded with practical communication system parameters.

1. Introduction
Adaptive Frequency Hopping in MC-CDMA [1] is used for forward link as well as reverse link. The adaptive transmission using frequency hopping method resolves frequency and multiuser diversity and improves on non-adaptive variable code-based carrier system [2]. In this paper, the work is concentrated on reverse link, where multiple sub-carriers are employed for each user. A water-filling (WF) based sub optimal allocation algorithm is used in the reverse link. There is near-far problem due to short-term fading which gives only limiter recovery (i.e., weak users suffer) by WF algorithm. So, improving MC-CDMA system with adaptive frequency hopping makes a novel allocation algorithm that helps to investigate quasi-synchronous for final implementation. The same is simulated to overcome the drawbacks in WF algorithm. Additionally, the impact of imperfect channel state information and correlated subcarriers is taken for study from simulation. Conventional matched filter receiver has the drawback of multiple access interference when the users are increased, but in this technique, it is avoided by increase in signal to noise ratio and allocation of adaptive technique. Further the allocation algorithms, WF algorithm and the improved algorithm, can be combined with the Lagrangian dual decomposition (LDD) to establish high signal to interference plus noise ratio.

The 2nd generation code division multiple access (CDMA) system is a multiple access digital mobile radio communication technique that can be used to upgrade from 1st generation for voice and medium-speed data communication services will add more users for each cell site. This pays way for more high-value information services. Three types of mobile devices can operate successfully in the above said technique namely IS-95 CDMA system, CDMA
digital alone system and, CDMA digital and AMPS analog system and AMPS analog alone system.

The users need to combine both analog and digital channels with the IS-95 CDMA system made a gradual migration of AMPS analog users to advanced digital services. The figure 1 shows the CDMA system containing both 2nd generation CDMA IS-95 voice radio channels and 1st generation analog radio channels. CDMA system includes voice service, data service and also multimedia service with supporting communication devices.

![CDMA System](image)

The IS-95 CDMA system uses standard 64 coded channels. These 64 channels are used for traffic (user voice and/or data) and for control purposes (paging and the coordination of access to the system). It creates a wide digital radio channel from low-speed digital audio. i.e., each bit the information signal is converted into a long sequence of bits called a spreading code which makes the system as a wideband system. Multiple coded channels co-exist at the same time on the same frequency. The CDMA system uses pseudo-random noise (PN) codes to create 64 uniquely coded channels for each CDMA radio channel for duplex communication. Checking for a match to the channel code, it de-spreads the code into its original information signal. Each CDMA radio channel uses some of the coded channels for a signal timing reference pilot; channel timing synchronization, paging, and access control channels. Each of these channels is received by decoding (de-spreading) the signals using the proper PN sequences. Figure 2 shows differentiating codes for users for individual user identification from a common channel by CDMA system code pattern mask.

2. Background work

The channel allocation to numerous users can be carried by either fixed or dynamic basis. Also, there is a hybrid that allows fixed and dynamic channel allocation for users. The methodology by which this allocation is done varies [4] and can be compared by simulation analyses to go for best fit. Such a system of best fit is discussed below. The block diagram of the methodology is shown in figure 3. It is a modification of system diagram [3] of adaptive frequency hopping in multi carrier code division multiple access. For example, of N users, where needed channels can accommodate a total bandwidth of B, divided into different code carriers C with same bandwidth Δh = B/C. The user information after analog to digital conversion is multiplexed over S sub-streams and these sub-streams are spread by code carriers in time domain.
This spreaded signal as per law of modulation is passed through impulse modulator and wave shaping filter. The signal output of this process is a low pass equivalent with respect to time ‘i’ for the $s^{th}$ sub-stream of the $n^{th}$ user can be given as

$$a_{n,s}(i) = (2E_b)^{1/2} \sum_{k=-\infty}^{\infty} \sum_{l=0}^{PG-1} b_{n,s}(k)r_{n,s}(l)h(i - kl_B - ll_f)$$

where, $b_{n,s}(k)\in\{-1, +1\}$ … binary phase shift keying modulated information symbols, 
$r_{n,s}(l)$ … random spreading sequences [5] and
$h(i)$ … normalized impulse response of the wave-shaping filter.

The spreading function assigns the sub-stream $jn$ to $s^{th}$ sub-carrier where $jn,s\in\{1, S\}$. The allocation of sub-carriers is controlled by base station control unit with channel state information from mobiles. This channel allocation instruction signal $\{jn,s\}$ is sent to each mobile through the channel forward link control. The allocation algorithm uses more than one sub-stream of the same user for hopping onto the same subcarrier. The time frame of all users is aligned by synchronization within small window and the sub-streams of the same user undergo orthogonality maintenance so that intra-user interference is eliminated.

The usual normalized random spreading codes make the code word of each sub-stream as a product of individual user random spreading code and one of the Walsh codes. The low pass equivalent of the above transmitted signal for the $n$th user is given by

$$L_n(i) = \sum_{s=1}^{S} a_{n,s}(i)e^{-j2\pi f_{jn,s}i}$$

where $f_{jn}$ is the subcarrier frequency offset from carrier frequency $f_c$ for the $jn$, $s^{th}$ subcarrier.

3. Improved Allocation Algorithm
The total number of sub-streams assigned to the $s^{th}$ sub-carrier is denoted by $R_s$. Now for our improved allocation algorithm let $Q_s$ of size of $R_s$ as the index set denoting all sub-streams allocated to the $s^{th}$ sub-carrier. The parameters initialize as $R_s$ and $Q_s=\emptyset$; for all $s \in [1... S]$, for $k = 1$ to $K$ and for $n = 1$ to $N$.

**Step 1:** Augment $Q'_s = \{ Q_s, (n, s) \}$ for $s \in [1... S]$. Let $y(s, r)$ be the Signal to interference and noise ratio of the $r^{th}$ sub-stream ($r \in 1..,R_m+1$).

**Step 2:** Find $s_0$ for the below condition

$$s_0 = \arg \max_{s \in [1... R]} \left\{ \min_{r \in [1... R_s]} y(s, r) \right\}$$

Where $y(s, r)$ is the Signal to interference and noise ratio.

**Step 3:** Based on the above finding assign sub-stream $(n, s)$ to the $s_0^{th}$ sub-carrier. i.e., set $j(n, s) = s_0$. Now update $R_{so}=R_{so}+1$ and $Q_{so}=Q'_{so}$.

When optimal channel state information is available in the base station, the Signal to interference and noise ratio in step 1 in the proposed allocation methodology is calculated based on information gained from detector at the receiver.

**TABLE 1: Parameters and their representation**

| Parameter | Representation |
|-----------|----------------|
| $N$       | Number of users |
| $E_b$     | Energy per Bit |
| $n, s(i)$ | $S^{th}$ substream of the $N^{th}$ user over time $i$ |
| $b_n, (k)$ | Binary phase shift keying modulated information symbol |
| $r_n, (l)$ | Random spreading sequences |
| $h(i)$    | Normalized impulse response of the wave-shaping filter |

The table 1 represents the above parameters and their meanings. For reverse link in a multiuser communication, the channel gets allocated effectively with different code carrier by adaptive frequency hopping in the direct sequence code division multiple access technique at the base station by the above principle. The updated channel allocation assignments $j(n, s)$ are communicated back to
mobiles for sub carrier employment. From the above process it can be well understood, the entire computations are carried at the base station without much mobile intervention. The feedback load also is very less due to minimum number of bits exchange. The drawback of WF algorithm is overcome by this methodology. The improved allocation algorithm is an improvement of WF algorithm and also it takes into account of signal to interference and noise ratio in step 1. The efficiency will be more based on the type of detector employed at the receiver, as channel state information is collected at base station from detector. Adaptive frequency hopping hops the carrier frequency among many frequency channels using the pseudorandom sequence that is likely known to both transmitter and receiver. The channels are well classified as good or bad in an adaptive frequency hopping technique for adaptive selection of good by the algorithm.

4. Multi-carrier CDMA system
Multiple user’s data is transferred through same channel by using several sub-carriers in multicarrier modulation technique. This technique was first implemented using a bank of analogue Nyquist filters that provide a set of orthogonal continuous time basis functions [6], [12]. In today’s modern world multicarrier modulation is implemented using digital signal processors for very fast and low-cost terms, for generating set of orthogonal subcarriers by discrete Fourier transform. The said functionality makes it optionally first priority. Multiple sub-carriers make the system adaptable to high capacity due to more users communicate in the same channel.

![Multi-Carrier spread-spectrum transreceiver](image)

Also, this kind of system makes the spectral efficiency [7] high and being robust to frequency selective fading. The complete system is so compact that makes cellular system to use this concept to increase its capacity per base station and optimize spectral efficiency. The system in simple can be seen as a modulation – demodulation by invers discrete Fourier transform – discrete Fourier transform technique. The major design issue is filter that carries this technique to maximum gain within design bandwidth. Optimization methods [8] for multi-carrier systems is to use one of perfect reconstruction quadrature mirror filter types which are called discrete wavelet multi tone.

Transmitter uses S different subcarriers for transmitting each bit. The spreading code sets offset for each sub-carrier that is concerned with that particular carrier. This is shown with simple model above, called as multicarrier spread spectrum transmitter. i.e., one in which the user signal is multiplied by a fast code sequence [9], [10]. The codes can be different but for using Discrete Fourier Transform of a binary, say, Walsh Hadamard code sequence is used. This is shown in Figure 4. The same in reverse process yields user data shown in simple model in the above figure.

5. Simulated results
The below results represent the output of simulated experiment. The figure 5 shows the experiment considering the presence of primary first and fourth user out of five users as a graph denoting power vs
frequency. Figure 6 shows adding secondary user into the system and that is shown as second user because primary second user is absent, in the same power vs frequency graph. Next figure 7 shows addition of noise at snr=15dB. The various levels of output are shown below in figure 8.

Fig. 5 Power vs. Frequency with only primary users

Fig. 6 Power vs. Frequency with primary and secondary users

Fig. 7 Number of users with noise
The above figures show increase in user detection with high power as a result of improved allocation algorithm used for adaptive frequency hopping. For simulation purpose manual selection of parameters is made and it confines better understanding to view the results.

6. Conclusion

In this paper, the performance of adaptive variable code-based carriers for multiusers in a common channel of communication is investigated. The imperfect channel state information at the base station usually does not help in successful communication, but the combined adaptive allocation algorithm and multi user detection methodology makes a successful communication. Adaptive frequency hopping increases the capacity with additional parameters as discussed in results section. The proposed methodology is efficient in mitigating multi access interference, resulting in a much larger system capacity. The results of the simulation confirm the above said performance factors with realistic correlated sub carriers that are faded with practical communication system parameters. The future may extend these techniques to upcoming environment that may introduce new wireless local area networks (WLAN), wide area networks (WAN) and mobile broadcast networks. 3G cellular technologies utilize code division multiple access as the core radio access technology. Many performance parameters like higher capacities, throughputs, and efficiencies support the growing usage of increasingly bandwidth-intensive data services.

References

[1]. M. Saravanan and S. Ravi, “Software Radio Technology in FH/MC DS-CDMA Communication System”, in International Engineering and Technology Journal of Communication Technologies, IETECH Publications, Bangalore-560076, India, Vol.2, No. 3, pp. 117-121, 2008.

[2]. S. T. Tseng and J. S. Lehnert, "LMSE-based parameter acquisition for multicarrier CDMA systems," in IEEE Transactions on Communications, vol. 57, no. 10, pp. 3113-3122, October 2009.
[3]. T. Jia and A. Duel-Hallen, "Improved channel allocation for multicarrier CDMA with adaptive frequency hopping and multiuser detection," in IEEE Transactions on Communications, vol. 57, no. 11, pp. 3389-3396, Nov. 2009.

[4]. D. F. Cardoso, F. D. Backx and R. Sampaio-Neto, "Performance of multicarrier CDMA systems with improved pilot-aided channel estimation," 2009 Sixth International Conference on Wireless On-Demand Network Systems and Services, Snowbird, UT, 2009, pp. 78-82.

[5]. K. Yuan, W. Liu and L. L. Yang, "Reliability-Aided Multiuser Detection in Time-Frequency-Domain Spread Multicarrier DS-CDMA Systems," VTC Spring 2009 - IEEE 69th Vehicular Technology Conference, Barcelona, 2009, pp. 1-5.

[6]. Peng Pan, L. L. Yang and Youguang Zhang, "Near-optimum iterative multiuser detection in time-frequency-domain spread multicarrier DS-CDMA systems," 2010 5th International ICST Conference on Communications and Networking in China, Beijing, 2010, pp. 1-6.

[7]. M. Saravanan and S. Ravi, “Performance Analysis of Different Spreading Codes in CDMA System Environment for Multi-user Adaptive SDR Environment”, in International Journal of Computer Science and Network Security, pages 28-37, Vol.11, Number 7, July 2011.

[8]. J. He, M. O. Ahmad and M. N. S. Swamy, "Joint Space-Time Parameter Estimation for Multicarrier CDMA Systems," in IEEE Transactions on Vehicular Technology, vol. 61, no.7, pp. 3306-3311, Sept. 2012.

[9]. X. Ju, Y. Zhang and L. L. Yang, "Decision-Feedback Multiuser Detection in Multicell Multicarrier DS-CDMA Systems with/without BS Cooperation," 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), Dresden, 2013, pp. 1-5.

[10]. J. Shi and L. L. Yang, "Subcarrier-allocation in downlink multicarrier DS-CDMA systems," 2013 IEEE/CIC International Conference on Communications in China (ICCC), Xi'an, 2013, pp. 502-508.

[11]. H. Tsuda and K. Umeno, "New expression of SNR formula for CDMA system," 2016 International Conference on Smart Green Technology in Electrical and Information Systems (ICSGTEIS), Bali, 2016, pp. 64-68.

[12]. Suresh Koneri Chandrasekaran, Prakash Savarimuthu, Priya Andi Elumalai, and Kathirvel Ayyaswamy, “Primary Path Reservation Using Enhanced Slot Assignment in TDMA for Session Admission,” The Scientific World Journal, vol. 2015, Article ID 405974, 11 pages, 2015.