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Evaluation of Multi-Rate Transmission Schemes based on Contiguous and Non-Contiguous Subcarrier Allocation

Mr. G. Kamba Rajan
P. G. Student, ECE Department
MepcoSchlenk Engineering College, Sivakasi, TamilNadu, India
Email: kambarajan@gmail.com

Mrs. G. Indumathi
Professor, ECE Department
MepcoSchlenk Engineering College, Sivakasi, TamilNadu, India

Abstract – In this paper, **two multirate transmission schemes have been proposed for carrier interferometry multicarrier code division multiple access (CI/MC-CDMA) system. System models for wide range of data rates are discussed based on orthogonal property of CI codes of any length. Non-contiguous CI codes have been introduced for multirate CI/MC-CDMA. Advantage of frequency diversity in non-contiguous allocation improves the performance of variable rate system over frequency selective channel. It is shown that non-contiguous allocation allows more number of very high data rate users compared to contiguous allocation with some increased complexity at iterative receiver.**

Keywords **– CI/MC-CDMA, HDR, LDR, Multicarrier, Multirate, VHDR.**

I. INTRODUCTION

Future wireless communication should provide fair capacity sharing among high data rate users and low data rate users. To support time varying quality of service(QOS) with multicarrier code division multiple access(MC-CDMA),different techniques have been developed earlier [1],[2].In fixed spreading gain, low data rate users suffer from more multiple access interference(MAI) then high data rate users because high data rate users transmit larger amount of time. In variable spreading gain(VSG), inter symbol interference(ISI) is one of the drawbacks for high data rate users due to short spreading gain over multipath channel. It has been reported in [1], [2], that multicode MC-CDMA(MC MC-CDMA) approach is more promising than VSG MC-CDMA. In MC-CDMA, if k_m denotes the number of total virtual user ($\sum_{m=1}^{M} mk_m$) is fixed. So number of active users ($m \times R_0$, where R_0 is basic data rate) increases [2].

In multicode CDMA, well known orthogonal Walsh-Hadamard (WH) codes are used to assign multiple codes. But WH codes exist for certain code length (2^{p}, p £I+). So, in cognitive radio and/or dynamic spectrum access, WH code sets need to deactivate more number of subcarrier. Recently [4] proposed a novel spreading code called orthogonal binary code (based on WH code) of any code length to increase diversity gain. Carrier interferometry (CI) codes(complex orthogonal spreading codes) [5] have unique features which allow MC-CDMA to: 1) have orthogonal spreading sequence of any length *N*, (*N* £I+), 2) support additional(*N* − 1) pulse shape (with *π/N* phase shifted) to accommodate extra users or information using pseudo-orthogonal CI (POCI) codes [5] with no expansion in bandwidth. Also noncontiguousCI (NCI) codes have been constructed to [6] operate over multiple non-adjacent carriers without any multirate capability. The purpose of this project is to propose variable rate CI/MC-CDMA which supports wide range of data rate based on contiguous and non-contiguous subcarriers. Soft decision based subcarrier parallel interference cancellation receiver (SDSub-PIC) [7] has been used to alleviate MAI created by active multirate users over frequency selective channel.

Wireless multimedia communications are playing increasingly important roles in the emerging communication generations to serve various applications, which require not only effective transmission technique but also resource allocation to provide different quality-of-services (QoS) for users of various demands. MC-CDMA that combines Orthogonal-Frequency-Division-Multiplexing (OFDM) and CDMA was shown its advantages in transmitting broadband signals over frequency-selective fading channels and providing high capacity [9], [10]. It is regarded as a promising candidate to replace single-carrier DS-CDMA for advanced multimedia applications in systems beyond 3G. In addition to effective receiver design, system optimization by efficient resource allocation is then a critical topic for wireless multimedia communications.

Data stream in MC-CDMA is spread by a given spreading code and each code chip modulates a different sub-carrier, which is the so-called frequency-domain spread spectrum [9]–[11] and all sub-carriers are mutually orthogonal. Power, subcarrier, and spreading codes are available radio resources in MC-CDMA. Conventionally, power is uniformly distributed to all sub-carriers without optimization and it is obviously inefficient according to the information theory. Providing channel state information to the transmitters, a method ever proposed to turn off deep-faded sub-carriers and uniformly distribute power to the remaining sub-carriers to improve the performance of maximum-ratio-combining (MRC) receiver [12]. However, it is not proven an optimal method in any sense.

Most previous research about resource allocation in CDMA systems only considered conventional matched-filterbased single-user-detection (SUD) receivers [13]–[14], where simplified signal-to-interference-ratio (SINR)-based formulations were used to treat the interference as merely an accumulated power sum of all users, but it is well- known that multiuser detection (MUD) can significantly improve the performance and capacity of CDMA systems [15] and especially recommended in MC-CDMA uplink applications due to the serious distortion of code orthogonality in frequency selective fading channels [16]. Hence, radio resource allocation with MUD receivers is essential to practical MC-CDMA applications. For multi-rate transmissions, Multi-Code (MC) and Variable-Spreading-Length (VSL) are two widely adopted multi-rate schemes in CDMA systems [17], and their applications in MC-CDMA were studied [18] with LMMSE MUD effectively to mitigate multiple access interference and orthogonality distortions. we consider all users in a MC-CDMA system have individual QoS demands ondata rate and bit-error-rate (BER), and we allocate transmission rate, sub-carriers, and sub-carrier power to minimize total transmitted power.

For easily dealing with the nature of MC/VSL access, the optimization is processed over the domain where users are decomposed as unit-rate virtual users such that these two kinds of multi-rate MC-CDMA systems exhibits structural regularity. We derive the user capacity under their QoS constraints is derived and proposed a simple but practical user (or data stream) admission criterion. To allocate power of each admitted user, an iterative allocation algorithm is proposed to adjust sub-carrier power and phase, in which sub-carrier selection is jointly achieved. In future wireless networks such as wireless LANs, third generation cellular mobile systems (3G), and PCS[19] variety of services is expected. Different rate and quality of service (QOS)requirements must be accommodated. A mobile terminal may set up and modify sessions for voice, data, image, as well asvideo through wireless connections to the base station. To provide such services, the network must be able to statistically multiplex users with different rates and or QOS requirements while maximizing the spectral efficiency.

II. PROPOSED METHODOLOGY

A. Transmitter Model

Synchronous CI/MC-CDMA system with Kuser is considered. Multirate users are classified into Mgroups with different rates. The number of users and the data rate of a user in m_{th} group are denoted by

K_m and R_m respectively. The multirate users are categorized into three groups; high data rate user (HDR) group, low data rate user (LDR) group and very high data rate user (VHDR) group. They differinterms of their data rate which is shown in Table 1.

Table 1: Data Rates of Different Users

Data Rate	Abbreviation	Lower Rate	Upper Rate
Low Data Rate	LDR	30kbit/sec	300kbit/sec
High Data Rate	HDR	3mbit/sec	30mbit/sec
Very High Data Rate	VHDR	30mbit/sec	300mbit/sec

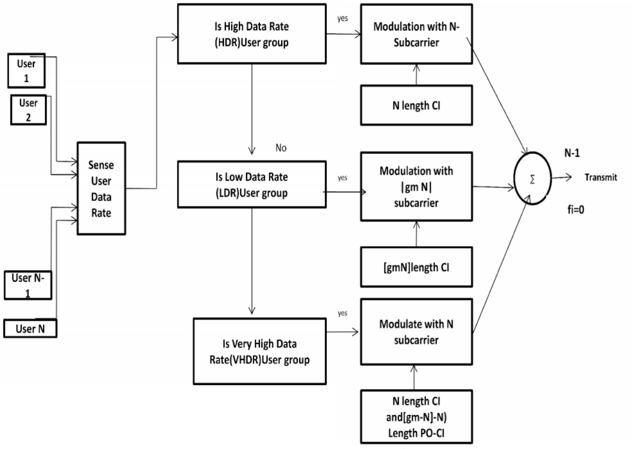

Fig.1. Transmitter Block diagram for CI/MC-CDMA system transmitter

Normally the system is assumed to transmit data at high rate. Let us define a factor gm such that $g_{m\ \min} < g_m < 2$ and $g_m \in Q+$. Here,

$$R_m = g_m \times R_b \tag{1}$$

where, R_b is data rate of HDR user.

For VHDR user ($g_m > 1$), N length CI and ($[g_m N] - N$) length PO-CI codes are used to support higher data rate than normal data rate users. For LDR users, less sub carriers are sufficient to maintain acceptable bit error rate (BER) in receiver without increasing subcarrier overload. The unused spectrum or bandwidth can be used for other wireless applications and/or to support VHDR users. $[g_m N]$ length CI codes are used for LDR users ($g_m < 1$). Fig.1 illustrates variable rate CI/MC-CDMA transmission. It is important to note that orthogonal CI codes can be designed for any length.

This enables wide range of data rates compared to other conventional codes like WH codes. In contiguous allocation scheme, $[g_m N]$ contiguous subcarrier with contiguous CI codes and ($[g_m N] - N$) contiguous subcarrier with PO-CI codes are used for LDR users and VHDR users respectively. A more flexible method to exploit the frequency diversity of the channel is achieved by non-contiguous subcarrier with NCI codes over frequency selective fading channel. This frequency diversity gain improves the performance of LDR users compared to fixed spreading gain . In contiguous allocation scheme, transmitted signal of LDR user is

$$s_{k_m}(t) = \sum_{i=0}^{N-1} c_{i,m} a_k[n] \exp\left(j2\pi f_i t + \frac{ji2\pi k}{[g_m N]}\right).p(t - nT_b) \tag{2}$$

$$f_i = f_c + i\Delta f \tag{3}$$

$$\Delta f = 1/Tb \tag{4}$$

Where,

$a_k\,[n]$ = n^{th} input data symbol of k^{th} user,

f_i = frequency of i^{th} narrow band subcarrier,

f_c = center frequency

T_b = is bit duration of Nyquist pulse shape $p(t)$

which is modelled as a sequence of independent and identically distributed (i.i.d.) random variables taking values from ±1 with equal probability. $\Delta f$is selected such that orthogonality between carrier frequencies can be maintained. The subcarrier bandwidth is assumed to be less than coherence bandwidth of the channel so that each subcarrier is frequency non-selective.

Total $[g_m\ N]$ non-contiguous active subcarriers are used for LDR users with NCI codes. So total occurrence of $c_{i,m}$= 1 will be $[g_m\ N]$. For VHDR users, N contiguous subcarrier with CI and $([g_m\ N] - N)$ non-adjacent subcarriers with $([mN]-N)$ non-contiguous PO-CI codes (NPO-CI) are used. Transmitted signal of VHDR user corresponds to

$$s_{k_m} = a_k[n][\sum_{i=1}^{N-1} \exp(j2\pi f_i + \frac{ji2\pi k}{N}) + \sum_{i=1}^{N-1} \rho_{i,m} \exp(j2\pi f_i t + ji(\frac{2\pi k}{N} + \frac{\pi}{N}))].p(t - nT_b) \qquad (5)$$

B. Multipath Channels

Two parameters often used to characterize multipath channels are delay spread and coherence bandwidth. The delay spread, T_d, is a measure of the length of the impulse response of the channel. A large delay spread would lead to intersymbol interference (ISI), thus degrading the performance of the system. The RMS delay spread for each subcarrier is assumed to be comparatively small and hence the ISI is minimal. For channels that have a large delay spread the ISI can be checked by using a guard interval that is longer than the maximum delay spread. Coherence bandwidth is the approximate maximum bandwidth or frequency interval such that any two frequencies lying within this interval are likely to experience correlated fading. If the average multipath delay spread is Td, then the coherence bandwidth, Wc, is given as

$$W_c = \frac{1}{2\pi T_d} \qquad (6)$$

Doppler spread is defined as a measure of the spectral broadening caused by the temporal rate of change of the mobile channel. A small Doppler spread implies a large coherence time or a slowly changing channel. We considered a slowly changing wireless channel in which the Doppler shifts are relatively small and the channel can be assumed to be constant over the bit duration, T_b.

Multipath channels are commonly characterized by Rayleigh or Rician distributions. These distributions describe the random amplitudes resulting from the multipath channels. In the absence of a line-of-sight component of the received signal, such as when the direct path is obstructed by the environment or buildings and the received signal consists of only scattered components, the channel can be modeled as a Rayleigh faded channel. In this case, the signal amplitude resulting from the vector addition of all components is mutually uncorrelated Rayleigh distributed with the probability density function (pdf)

$$f_\rho(x) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2} \quad x \geq 0, \qquad (7)$$

where σ^2 is the variance of the in-phase and quadrature components of the received signal and the phases are mutually independent random variables uniformly distributed over the interval $[0, 2\pi)$. The n^{th} moment of the Rayleigh random variable is given by

$$E[(\rho)^n = (2\sigma^2)^{n/2} \Gamma(1 + \frac{n}{2})] \qquad (8)$$

where, $\Gamma(p) = (p-1)!,\ p \in I,\ p > 0$

Then, the mean and the variance is given by

$$E[\rho] = \sqrt{\frac{\pi\sigma}{2}} \qquad (3.17)$$

$$E[\rho] = 2\sigma^2(1 + \frac{\pi}{4}) \qquad (9)$$

In certain environments, like the indoor radio channel, there may be a direct LOS component present. Here, the signal consists of the LOS component as well as the less dominant scattered components corresponding to the reflected paths. In such a case, the received signal amplitude can be characterized by a Rician distribution given by

$$f_\rho(x) = \frac{x}{\sigma^2} e^{-\frac{x^2+s^2}{2\sigma^2}} I_0(\frac{xs}{\sigma^2}) \quad x \geq 0 \qquad (10)$$

where s^2 is the amplitude of the LOS component, $I_0(x)$ is the zeroth order modified Bessel function and s^2 is the variance of the in-phase and quadrature components of the received signal. The envelope distribution is often characterized in terms of the Rice factor $K = s^2 = (2\sigma^2)$ which is defined to the be ratio of the power of the LOS component to the power of the scattered component.

The signals of the different users are transmitted synchronously from the transmitter at the base station to the receiver of the mobile unit. This is typically characteristic of the downlink channel and increasingly, there are communication systems proposed with quasi-synchronous uplink channels. The channel is assumed to be a frequency selective channel with the subcarrier bandwidth much less than the coherence bandwidth, 1=Tb <<Wc. This implies that the subcarrier does not experience significant dispersion and overlapping between adjacent bits, i.e., the intersymbol interference (ISI) is minimal. ISI can be minimized even further by the insertion of an appropriate guard interval that is longer than the maximum delay of the impulse response of the channel. The Doppler

shift due to the motion of the mobile unit or the environment is assumed to be negligible.

The time invariance of the channel over one bit interval implies that the channel coefficients, which are assumed to be estimated perfectly, remain constant over the bit interval, T_b. This is equivalent to assuming that the channel is slowly fading, as is typical of the wideband channels for MC-CDMA systems. The channel is frequency selective over the entire bandwidth and since OFDM transforms a frequency-selective fading channel into a number of parallel flat-fading channels, the individual subcarriers are assumed to experience flat-fading (frequency non-selective fading). Therefore, each subcarrier appeared to arrive at the receiver via a single, frequency non-selective fading path. Also the different subcarriers are assumed to experience independent Rayleigh fading and hence the complex fading channel coefficients are considered independent for each subcarrier. Further, the orthogonality of the carriers ensures the absence of intercarrier interference (ICI).With these assumptions, the frequency selective channel can be modelled as a number of complex flat-fading channels. The fading for the nth subcarrier when the k^{th} user is transmitting the j^{th} bit can be described by,

$$\mathrm{H}_{j,n}{}^{k} = \rho_{j,n}{}^{k} \exp(i\phi_{j,n}{}^{k}) \qquad (11)$$

where, $\mathrm{H}_{j,n}{}^{k}$ is Rayleigh distributed and $\phi_{j,n}{}^{k}$ is uniformly distributed on$[0,2\pi)$ Independentfading between users implies that the fading amplitude $\rho_{j,n}{}^{k}$ $:k=1,\ldots N_u;n=1,..N_c)$ are a set of mutually independent Rayleigh random variables and phases $(\phi_{j,n}{}^{k}:k=1,\ldots N_u;n=1,..N_c)$ are a set of mutually independent uniform random variables on $[0,2\pi)$ From the previous section, the mean and variance are given by

$$m_{\rho_{j,n}{}^{k}} = E[(\rho_{j,n})]^2 = \sqrt{\pi\sigma/2} \qquad (12)$$

$$\sigma^2{}_{\rho_{j,n}{}^{k}} = E[(\rho_{j,n})^2] - E[(\rho_{j,n})]^2 = 2\sigma^2(1-\frac{\pi}{4}) \qquad (13)$$

C. Receiver Model

The block diagram of CI/MC-CDMA receiver is shown in Fig.2.

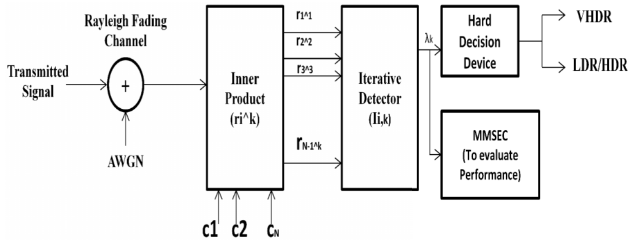

Fig.2. Receiver Block diagram for CI/MC-CDMA system

The channel is modeled as a slowly varying frequency selective Rayleigh fading channel. It is assumed that every user experiences an independent propagation. The frequency selectivity over the entire bandwidth results correlated subcarrier[5], [8]. The complex channel gain of i^{th} subcarrier for k^{th} user can be defined as $\alpha_{i,k}$. Received signal for all users corresponds to

$$R(t) = \sum_{m=1}^{M} \sum_{k=1}^{k_m} a_k[n] \sum_{i=0}^{N-1} \alpha_{i,k} (c_{i,m} \exp(j2\pi f_i t) + \frac{ji2\pi k}{[\psi g_m N]}) + \rho_{i,m} \exp(j2\pi f_i t + ji(\frac{2\pi k}{N} + \frac{\pi}{N}))). p(t-nT_b) + \eta(t) \qquad (14)$$

$\eta(t)$ represents additive white Gaussian noise (AWGN) at receiver with zero mean and variance of **N**0/2. The received signal is projected onto N orthogonal subcarriers, outputting

$\mathbf{r}_i{}^{k}=(r_0{}^{k}, r_1{}^{k}, \ldots r_{N-1}{}^{k})$, where

$$r_i{}^{k} = \alpha_{i,k} \alpha_{i,k}{}^{*} \sqrt{\frac{2E_s}{N_0}}.x_k[n] + I_{i,k} + \eta_{i,k} \qquad (15)$$

where* denotes complex conjugate and $\eta_{i,k}$ is Gaussian random variable with zero mean and variance of N0/2 . E_s is the transmitted symbol energy. Perfect estimates of channel response at the receiver are assumed. $I_{i,k}$ is actual MAI experienced by k^{th}user due to $(K-1)$ users in i^{th} subcarrier

$$I_{i,k} = \sum_{m=1}^{M} \sum_{q=1,q\neq k} c_{i,m} \alpha_{i,q} \alpha^{*}{}_{i,q} \sqrt{\frac{2E_s}{N_0}}.x_q[n] \exp(ji(\frac{2\pi q}{[\psi g_m{}^{q}]}) + \frac{\lambda_q \pi}{N} - \frac{2\pi k}{\psi g_m{}^{k} N})) + \sum_{q=1,q\neq k}^{K_{m,\forall:g_m>1}} c_{i,m} \rho_{i,m} \alpha_{i,q} \alpha^{*}{}_{i,q} \sqrt{\frac{2E_s}{N_0}} x_q[n] \exp(ji(\frac{2\pi q}{[\psi g_m{}^{q} N]} + \frac{\lambda_q \pi}{N} - \frac{2\pi k}{N} - \frac{\lambda_k \pi}{N}))) \qquad (16)$$

In conventional PIC scheme, estimated interference due to $(K-1)$ users is directly subtracted from $R(t)$. In subcarrier PIC (Sub-PIC), received signal is projected onto N orthogonal subcarriers and estimated interference $(\hat{I}_{i,k}{}^{iter},)$ due to other users is subtracted at subcarrier level. $\hat{Iter}_{i,k}$ is the estimated MAI experienced by k^{th}user due to $(K-1)$ users t $iter^{th}$iteration. After subtraction of $\hat{I}_{i,k}{}^{iter}$, reconstructed signal component corresponds to$r_i{}^{k} = r_i{}^{k} - \hat{I}_{i,k}{}^{iter}$,. For synchronoustransmission, uncertainty lies only in $\hat{I}_{i,k}{}^{iter}$, assuming spreading code availability at receiver. In SDSub-PIC ,estimation of $a_k[n]$ is performed by soft decision of $\hat{z}_k{}^{iter}$, i.e., $\hat{a}_k[n] = \varphi\{\hat{z}_k{}^{iter}\}$, where $\hat{z}_k{}^{iter}$is decision combiner output (here, minimum mean square error combiner (MMSEC) is used to obtain best performance in MC-CDMA). Piecewise linear approximation of Hyperbolic Tangent is used for nonlinear function φ{.}. In last stage of iteration, decision is made by hard detector.

III. SIMULATION RESULTS

The assigned data rate of Low Data Rate (LDR) user is range from 30 to 300kbit/sec, observed over 1ms. The assigned datarate of High Data Rate (HDR) user is range from 3 to 30mbit/sec observed over 1ms. The assigned data rate of Very High Data Rate (VHDR) user is range from 30 to 300mbit/sec observed over 1ms. These data rates are generated randomly.

M-ary QAM modulation is considered for Simulation. Rectangular QAM constellations are, in general, sub-optimal in the sense that they do not maximally space the constellation points for a given energy. However, they have the considerable advantage that they may be easily transmitted as two (PAM) signals on quadrature carriers, and can be easily demodulated. The non-square constellations, achieve marginally better bit-error rate (BER) but are harder to modulate and demodulate. The first rectangular QAM constellation usually encountered is 16-QAM.Here the constraint is removed, and the in-phase and Quadrature components are thereby permitted to be independent, so we get a QAM. In this modulation scheme, the carrier experiences amplitude as well as phase modulation.

The modulated signals of different users are then passed through an OFDM modulator. Then these signals are transmitted through Rayleigh fading channel where AWGN noise alone is assumed. For simulation AWGN is artificially added to the transmitted signal at various SNR levels. When the transmitted signal is real, AWGN is added as real Gaussian noise and produces a real output signal. When the transmitted signal is complex, then AWGN complex Gaussian noise is added and produces a complex output signal. Additive white Gaussian noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density(expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude. This model does not Account for fading, frequency selectivity, interference, nonlinearity or dispersion.

However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behavior of a system before other phenomena are considered. At the receiver side, LMS equalization algorithm is considered to remove noise from the received signal. LMS algorithm uses the estimates of the gradient vector from the available data. LMS incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error. Compared to other algorithms LMS algorithm is relatively simple; it does not require correlation function calculation nor does it require matrix inversions.

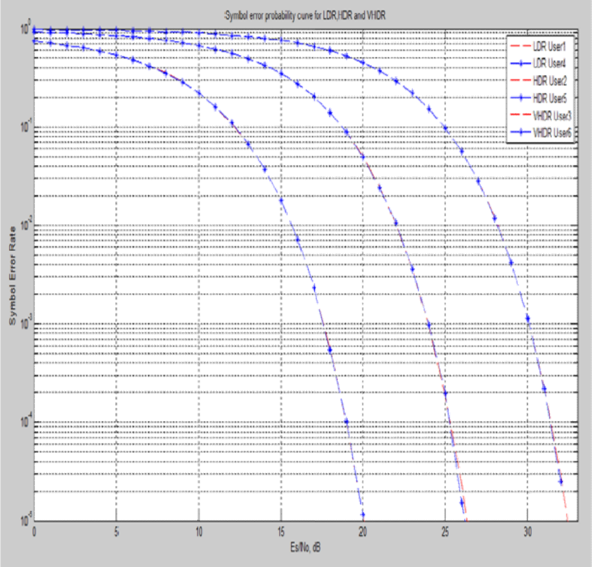

Fig.3. Performance of variable rate contiguous system for LDR, HDR and VHDR

From the Fig.3 it is observed that, Bit Error Rate performance, at a given SNR, is best for Low Data Rate (LDR) user, and better for High Data Rate user. It also shows that to achieve the BER performance of LDR user, the SNR level of HDR user &VHDR user has to be increased.(For example, 25db for HDR & 34db for VHDR).

IV. CONCLUSION

In this project, a variable rate CI/MC-CDMA transmission scheme is proposed to support wide range of data rate based on contiguous and Non-contiguous subcarriers. Synchronous CI/MC-CDMA with K=6 users are considered. The channel is considered as a slowly varying frequency selective fading channel corrupted by AWGN noise. In this work, contiguous subcarrier allocation scheme for CI/MC-CDMA has been investigated and its performance was evaluated in terms of BER with different data rate users. From the performance comparison, it has been observed that even at low SNR, low bit error rate can be achieved for very high data rate users. The SNR has to be increased to achieve the required bit error rate for other users. Also, the incremental SNR leads to increment in power. To avoid this kind of problem, a non-contiguous subcarrier allocation scheme will be considered as a future work.

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AUTHOR’S PROFILE

Mr. G. Kamba Rajan

received the B.E. degree in Electronics and Communication Engineering from Odaiyappa College of Engineering and Technology, Theni, India, in 2010. He is currently pursuing his M.E. degree in Communication Systems from Mepco Schlenk Engineering College, Sivakasi, India. His area of interest is Wireless Communications.

Mrs. G. Indumathi

obtained Bachelor’s degree in Electronics and Communication Engineering and Master’s Degree in Communication Systems both from Madurai Kamaraj University, Madurai, India in 1990 and 1997 respectively. She earned doctoral degree from Anna University, Chennai for her research work in the field of wireless Technology in the year 2012.Her current research interests are in the areas of Wireless and Mobile communications and Digital signal Processing. She is a Life member in Indian Society for Technical Education (LM25836) and Fellow in Institution of Electronics and Telecommunications Engineers. She has published many research papers in International and National Journals. Her area of interest includes Cross-layer design, resource allocation in wireless networks.