변조레벨 제어 다중반송파 CDMA 시스템

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Modulation Level-Controlled Multicarrier CDMA System

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요 약

본 논문에서는 전송 채널의 주파수 선택적 특성에 의한 전송 신호의 왜곡현상을 줄이며, 다양한 무선 전송 환경에 대해 일정한 전송 품질을 유지시키는 동시에 최대 데이터 전송률을 제공할 수 있는 다중 반송파 CDMA을 제안한다. 이 시스템은 채널 상태에 따라 작은 지연과 페이딩을 겪는 채널에서는 높은 데이터 전송률로 전송하고, 반면 빠른 페이딩과 긴 지연 성분을 갖는 채널에서는 낮은 전송률로 데이터를 전송한다. 두 경우 모두 다 송신기 구조에서 데이터 직병렬 변환 개수와 데이터 복사 개수를 조절함으로써 가능하다. 여기서, 제안한 시스템은 고정된 수의 부반송파를 갖는다. 따라서 위에서 언급한 직병렬 변화 개수와 데이터 복사 개수의 곱은 항상 일정하게 유지되므로 하드웨어의 변형 없이 구현될 수 있다. 제안한 시스템에서는 직병렬 변환 후 동일 데이터가 여러 다른 부반송파에 복사되어 전송되므로 주파수 다이버시티 이득을 얻을 수 있으며, 레이크(RAKE) 수신구조는 경로 다이버시티 이득도 얻을 수 있게 한다.

ABSTRACT

In this paper, we propose multicarrier CDMA system using the concept of the modulation level-controlled system in order to make the system robust to the frequency selectivity and to provide a maximum data rate maintaining an acceptable transmission quality over various channel environments. This system selects higher data rate when the channel experiences the low delay spread and slow fading. On the other hand, when the fading changes very fast and the delay spread is very long, the system selects lower data rate. In both cases, the system controls the number of serial-to-parallel converted streams and the number of fed streams. This system has the fixed number of sub-carriers. So the product of the number of serial-to-parallel converted streams and the number of fed streams is always kept constant. With the same data fed at different sub-carriers, the frequency diversity is achieved. And a RAKE receiver also is utilized to achieve path (time) diversity.

키워드

multicarrier CDMA, Rake receiver, diversity, modulation level control

Ⅰ. Introduction

There has been a great deal of demand for various multimedia services and also increasing interest in high-bit-rate data transmission to realize such multimedia services like video, audio, speech and data transmission in wireless communication system [1]. In order to achieve high-bit-rate data transmission for satisfactory wireless

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multimedia services, it is indispensable to employ higher modulation level transmission. One of the most promising modulation schemes is quadrature amplitude modulation (QAM). Multilevel QAM has good bandwidth efficiency, so that this technique can increase the system capacity and achieve high-bit-rate transmission using a limited frequency bandwidth [2,4]. Unfortunately, QAM, however, requires higher energy per bit-to-noise spectral density ratio (Eb/No) to achieve the same quality as quaternary phase-shift keying (QPSK)[5] and QAM transmission over Rayleigh fading mobile radio channel are subjected to error bursts due to deep fades ,even when the channel signal-to-noise (SNR) ratio is high[6].

Wireless transmission channel condition dynamically changes according to operating environments. Several papers have proposed modulation level-controlled modulation systems in which the proper modulation levels are selected according to the channel conditions and the traffic or received signal levels, and have shown that the modulation level-controlled modulation is effective in achieving higher bit rate with higher quality. When the receiver is not in a fade the number of constellation points are increased, and as the receiver enters a fade it is decreased down to a value which provides an acceptable bit error rate (BER) but maintaining a constant transmit power throughout. In frequency-selective fading (FSF) channels, however, theses systems cannot adequately improve delay-spread immunity because delay-spread immunity is closely related to the symbol rate, not modulation level.

In order to solve this disadvantage and apply the concept of modulation level-controlled modulation system to CDMA system, a modified multicarrier CDMA system is proposed in this paper. A number of MC-CDMA systems have already been proposed [7,8]. These systems solve the ICI problem by transmitting the same data symbol over a large number of narrow band orthogonal carriers, without spectrum spreading per carrier. The proposed system uses the multicarrier modulation scheme and the concept of the modulation level-controlled system in order to make the system robust to the frequency selectivity and to provide a maximum data rate maintaining an acceptable transmission quality over various channel environments. In the proposed multicarrier system, the transmitted data stream is serial to parallel converted to a number of lower rate streams. Each stream feeds some parallel streams with the same rate. The system can controls the number of serial-to-parallel converted streams and the number of fed streams according to the channel conditions. With the same data fed at different sub-carriers, the frequency diversity is achieved. And a RAKE receiver can also be utilized to achieve path (time) diversity. This system can work as an adaptive modulation level-controlled system. It informs the transmitter of the quality of the link which is perceived by the receiver. The transmitter can then respond by changing the number of serial-to-parallel converted data according to the channel condition. This system selects higher symbol rate when the channel condition is not good. On the other hand, when the channel condition is good, lower symbol rate is selected in order to keep a certain transmission quality such as BER. Successful variable rate transmission requires that the fast fading channel changes slowly compared to a number of symbol periods. If this condition is not met, then the frequent transmission of quality control information will significantly increase the bandwidth requirements of the system. CDMA system allows the transmission of more chips before the channel changes significantly through data spreading using a PN code and avoids this problem.

Ⅱ. Modulation level controlled Multi-Carrier CDMA System

In DS-CDMA system, the signals have a wide bandwidth and may be subject to frequency selective multipath fading. In order to solve this problem, the RAKE receiver can be utilized to achieve path diversity. However, the RAKE receiver results in the increase of the complexity of the receiver structure as well as the need of the significant signal processing. And if the channel delay spread exceeds the symbol duration, the conventional DS-CDMA system, in high data-rate application, is subject to severe inter symbol interference (ISI). Besides, even if the data rate is low and ISI is negligible, multipath fading causes severe degradation due to inter chip interference (ICI). A number of multi-carrier (MC) CDMA systems have already been proposed [9] to acquire benefits such as higher rate data transmission, bandwidth efficiency, frequency diversity, and interference reduction. MC-CDMA systems cannot only reduce the effect of ISI but also solve the ICI problem by transmitting the same data symbol over a large number of narrow band orthogonal carriers without spectrum spreading per carrier for high data rate applications. Each carriers is subject to nonselective fading and with the reception of the same data symbol on different carriers frequency diversity also can be achieved. But unless the chip duration is longer than the channel delay spread, this system suffers from severe inter symbol interference. MC-DS-CDMA system is robust to multipath fading and requires lower chip rate since the entire bandwidth of the systems is divided into equi-width frequency bands. But this system cannot achieve frequency diversity since sub-carriers have different data. Other multi-carrier based DS-CDMA scheme, which transmits the same data using several sub-carriers, was proposed in [10].

The proposed MC-CDMA system in this uses the multicarrier modulation scheme and the concept of the modulation level-controlled system in order to make the system robust to the frequency selectivity and to provide a maximum data rate maintaining an acceptable transmission quality over various channel environments. The initial data stream is serial to parallel converted to a number of lower rate streams. Each stream feeds some parallel streams with the same rate. Before this, data bit on each serial-to-parallel converted stream is repeated the number of fed streams times in order to keep bandwidth fixed for any selection of the number of serial-to-parallel converted streams and the number of fed streams. Each stream is spread using a PN code with a 1.2288Mcps chip rate and modulate orthogonal carriers with a successively overlapping bandwidth. BPSK modulation is utilized to simplify the presentation of the new system. But other modulation techniques are equally applicable. This system has the fixed number of sub-carriers. So the product of the number of serial- to-parallel converted streams and the number of fed streams is always kept constant. When the channel experiences the low delay spread and slow fading, the system selects higher data rate. On the other hand, when the fading changes very fast and the delay spread is long, the system selects lower data rate. In both cases, the system controls the number of serial-to-parallel converted streams and the number of fed streams. With the same data fed at different sub-carriers, the frequency diversity is achieved. And a RAKE receiver can also be utilized to achieve path (time) diversity.

A. Transmitter Structure

In the transmitter structure, the bit stream with bit duration T_b is serial to parallel converted into M parallel streams. The new symbol duration on each stream is $T=MT_b$. Each stream feeds S parallel streams such that the same data stream exists on S branches (subcarriers), and thus the frequency diversity can be acquired. Before each stream feed S parallel streams, the symbol repetition must be needed in order to keep the bandwidth fixed for any selection of the number of serial-to-parallel converted streams, M, and the number of fed streams, S. So, the symbol duration on each stream becomes $T'=MST_b$ and always constant. These all MS parallel streams are spread by the same PN sequence, C_k , which is the k^{th} user's specific sequence with length N and chip duration T_c. And then all the spread symbols are transmitted using different subcarriers. This transmitter modulates all the subcarriers using BPSK modulation. In order to achieve frequency bandwidth efficiency, it would be desirable to space the subcarriers as closely together as possible. The closest possible spacing between subcarriers is $1/T_c$. With this particular spacing, the modulation structure of the system is exactly the same that of orthogonal frequency division multiplexing (OFDM). The k^{th} user's transmitter structure of the proposed system in this is shown in figure 1.

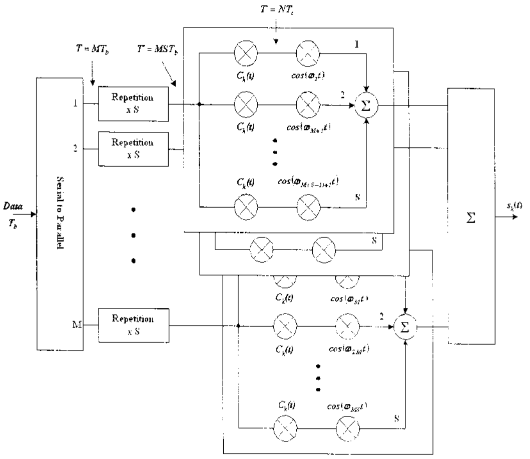

그림 1. 제안된 다중반송파 CDMA송신기
Fig. 1. Transmitter for the proposed multi-carrier CDMA

In figure 1, the channel coding and the interleaving process are omitted for simplicity. But they are very essential processes in the system. Especially, even if we assume that each subcarrier is subject to nonselective fading, when there exists fading over each subcarrier, and thus these subchannel fading parameters vary differently due to frequency selectivity of the entire transmission channel, a role of the interleaving process becomes crucial to combat a long burst of errors over each subcarrier. And the channel coding is also needed in order to enhance the system performance.

Assuming K users, all employing the proposed multi-carrier CDMA system with equal selection of M and S and the same power for all carriers, the k^{th} user's transmitted signal is given by

$$s_k(t) = \sum_{m=1}^{MS} \sqrt{2P} \cdot b_{k,p}(t) C_k(t) \cos(\omega_m t + \phi_{k,m}) \tag{1}$$

where p is the branch number of the serial to parallel converter and p=1+[(m-1) mod M] such that $b_{k,p}$(t) is the bit stream on the identical-bit branches fed from the p_{th} branch, p=1, 2, ⋯ , M, of the serial to parallel converter as shown in figure 1.The transmitted data bit $b_{k,p}$(t) takes the values of ±1 with equal probability. In (1), P is the transmitted power per each subcarrier. The bit and chip waveforms are rectangular. And the orthogonal frequencies, ω_m , is related as follows.

$$\omega_m = \omega_1 + (m-1)\frac{2\pi}{T_c} \tag{2}$$

where m=1,2,⋯,MS and $\omega_1 = 2\pi f_c$

The subcarriers are spaced apart from their neighboring subcarriers by $1/T_c$. In other words, the frequency spectrum of successive carriers is allowed to overlap as shown in figure 2. the MS frequencies are assigned to the MS streams such as, given the number of serial-to-parallel conversion, M, the frequency separation between any two successive carriers with the same data bit stream is maximized.

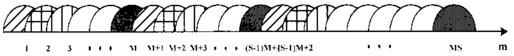

그림 2. 전송신호의 스펙트럼
Fig. 2. Frequency spectrum of the transmitted signal (the same data bit stream is expressed with the same pattern)

The proposed transmitter system consists of MS oscillator banks, that is, one oscillator bank for each subcarrier. In the above system it should, however, be noted that the multi-carrier CDMA signal shares the same signal structure as OFDM. The analysis of OFDM has shown that the discrete-time version of the OFDM transmitter is simply a Discrete Fourier Transform (DFT). Thus, the transmitter model for multi-carrier CDMA in figure 1 may simply be replaced by Fast Fourier Transform (FFT) operation which is the minimum frequency spacing between adjacent subcarriers.

B. Receiver Structure

The k^{th} user's receiver structure of the proposed system is shown in figure 3. The receiver employs MS RAKE receivers and the detector of each subcarrier employs a RAKE receiver. The RAKE receiver structure at each subcarrier is shown in figure 4. In figure 4,

$\varphi'_{k,m,l} = (\phi_{k,m} + \gamma_{k,m,l} - \omega_m \tau_k) \bmod 2\pi$.

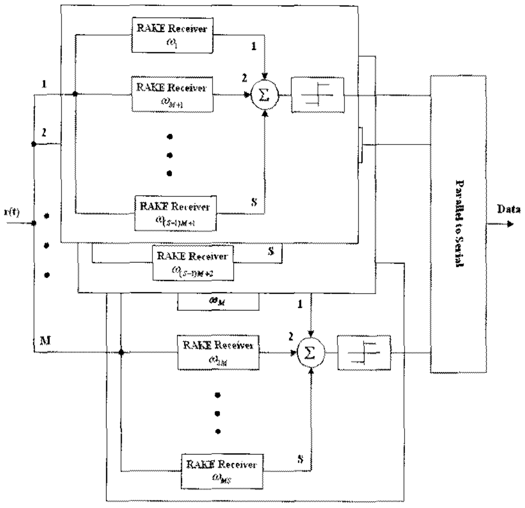

그림 3. 제안된 다중반송파 CDMA의 수신기구조
Fig. 3 Receiver structure for the proposed multi-carrier CDMA

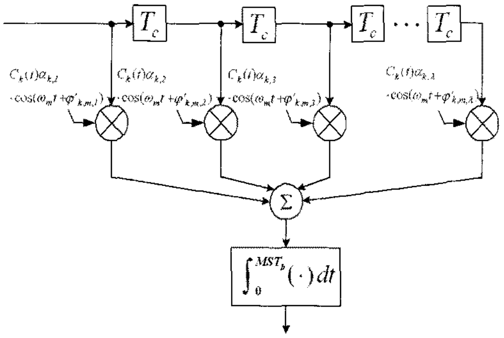

그림 4. 제안된 다중반송파CDMA의 레이크수신기
Fig. 4 RAKE Receiver structure for the proposed multi-carrier CDMA

In multipath fading channel, time or path diversity gain is achieved with RAKE receiver. The RAKE receiver output signals of the identical-bit carriers, which are frequencies carrying the same data bit stream, are combined and then the decision statistic is formed through the threshold device. This process is called post-detection equal gain combining. In addition to path diversity gain, frequency diversity gain can also be achieved by the combining of the signals modulated by S identical-bit carriers. After decision, the M signals, $Z_{k,1}, Z_{k,2}, \cdots, Z_{k,M}$ are parallel to serial converted to get the desired signal sequence.

In the receiver scheme, equal gain combining (EGC) technique is used to reduce the effect of the fading and the interference while not enhancing the effect of the noise on the decision of what data symbol was transmitted. EGC technique does not attempt to equalize the effect of the channel distortion in any way.

In the proposed system, the number of serial-to- parallel conversion, M, and the number of fed data, S, is the most important design parameters to determine the BER performance and the frequency diversity gain. Therefore, it is crucial to optimize the proposed system and to choose the optimized system parameters in accordance with the given channel.

If the proposed system is for an asynchronous CDMA system with K users and the power control is applied such that without fading, all user signals would arrive at the intended receiver with equal power, the received signal takes the form

$$r(t)=\sqrt{2P}\sum_{k=1}^{K}\sum_{m=1}^{MS}\sum_{l=1}^{L}\beta_{k,m,l}b_{k,p}(t-t_{k,l}-\tau_k)C_k(t-t_{k,l}-\tau_k)\cos(\omega_m t+\varphi_{k,m,l})+\eta(t) \quad (3)$$

where $\eta(t)$ is AWGN with zero mean and two-sided power spectral density $N_0/2$, $\varphi_{k,m,l} = (\phi_{k,m} + \gamma_{k,m,l} - \omega_m t_{k,l} - \omega_m \tau_k) \bmod 2\pi$. The k_{th} user's propagation delay is τ_k and The set $\{\tau_k\}$ and $\{\varphi_{k,m,l}\}$ are i.i.d. uniformly distributed random variables with the values in $[0, T']$. Even if $\{\gamma_{k,m,l}\}$ are correlated for the same k and l and different m, $\{\varphi_{k,m,l}\}$ is assumed to be i.i.d. $\phi_{k,m}$ for all k, m, l. Without loss of generality we assume that user one ($k=1$) is the intended receiver and let $\tau_1 = 0$ and when a sufficiently large amount of the frequency separation with respect to the coherence bandwidth of the channel, the amount of correlation may be ignored. The RAKE receiver output of user one $k=1$, carrier $m=q$ and path $l=n$ is given by

$$Z_{q,n} = \int_{t_{1,n}}^{t_{1,n}+MST_b} r(t)C_1(t-t_{1,n})\cos(\omega_q t + \varphi_{1,q,n})dt \qquad (4)$$

The receiver of user one consists of M groups, one per bit of the parallel transmitted bits. Each group consists of S RAKE receivers, on for each of the S identical-bit carriers. Each RAKE receiver consists of λ Matched Filters (MFs) that lock to the first λ paths, $1 \le \lambda \le L$. For a bit transmitted on group p, p=1,2,⋯,M, the decision statistics of the Sλ MFs are added to form the final decision statistic

$$Z \mid p = \sum_{v=1}^{S} \sum_{n=1}^{\lambda} Z_{q,n} = \eta + D + I \qquad (5)$$

where v represents the relative carrier number within group p, and q is the corresponding absolute carrier number, so the following equation is acquired.

$$q = p + M(v-1) \qquad (6)$$

where v=1,2,⋯,S. D is the desired output signal by setting $k=1$, $l=n$, and $q=m$. η is a Gaussian random variables with zero mean and the variance of $S\lambda N0T'/4$. And λ is the number of Rake branches. I is the interference component. We can employ the Gaussian approximation known to provide good results for large numbers of users and long codes. So all the interference components can be assumed to be Gaussian random variables with a zero mean and a variance. It contains four types of interference and the details are introduced in[10].

Ⅲ. Simulation and Results

The channel model for evaluation of the proposed system refers to the Recommendation ITU-R M.1225. This recommendation provides guidelines for both the procedure and the criteria to be used in evaluating candidate Radio Transmission Technologies (RTTs) for a number of test environments which, defined herein, are chosen to simulate closely the more stringent radio operating environments. A central factor of mobile radio propagation environments is multi-path propagation causing fading and channel time dispersion. The fading characteristics vary with the propagation environment and its impact on the communication quality (i.e. bit error patterns) is highly dependent on the speed of the mobile station relative to the serving base station. These environments are described in Recommendation ITU-R M.1034. The following sections provide a brief description of the conditions that might be expected in the identified environments. We consider three types of channel model such as indoor office, pedestrian and vehicular channel.

Channel model includes the parameters such as relative delay and average power for indoor office, outdoor to indoor (or pedestrian), and vehicular test environment. To accurately evaluate the relative performance, it is desirable to model the variability of delay spread as well as the worst case locations where delay spread is relatively large. In order to evaluate the proposed system, it is assumed that the offset frequency between the subcarriers and the local oscillator is negligible, and the coarse frame timing and frequency synchronization is perfectly taken. The proposed system has two- fingers RAKE receiver in order to get the path diversity gain. As for the spreading code to detect multi users, the PN sequence is used. This sequence is taken from the 6th order code generator function. The product of the number of serial- to-parallel converted data, S, and the number of fed data, M, is 32, and always kept constant. As many subcarriers are needed. The chip duration, T_c, is also constant. this means that the number and the bandwidth of subcarriers is always fixed regardless of the change of S and M. For computer simulation, we consider the case that the number of serial-to-parallel converted data, M, is 1, 2, 4, 8, 16, 32. Alternatively, the number of the fed data, S, is 32, 16, 8, 4, 2, 1 respectively. In case of M=64 (S=1), the system can be considered as the conventional MC-DS-CDMA. No channel coding and no interleaving are considered.

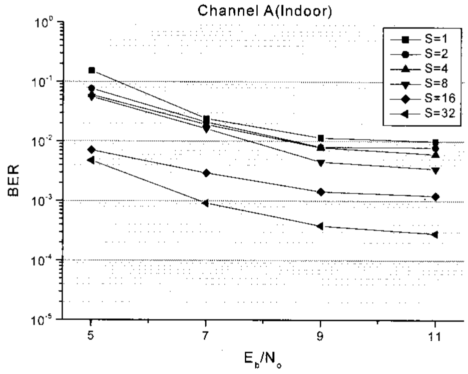

그림 5. 실내환경에서 E_b/N_0 에 따른 BER성능
Fig. 5 BER performance according to E_b/N_0, in indoor office

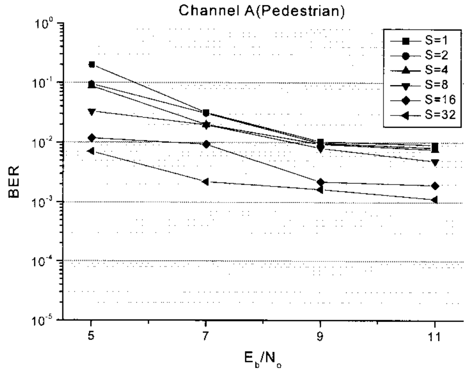

그림 6. 보행자환경에서 E_b/N_0 에 따른 BER성능
Fig. 6 BER performance according to E_b/N_0, in pedestrian

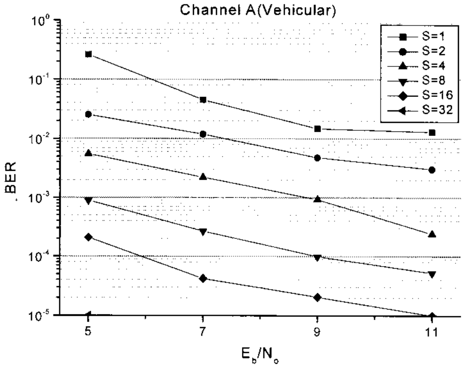

그림 7. 이동환경에서 E_b/N_0 에 따른 BER성능
Fig. 7 BER performance according to E_b/N_0, in vehicular

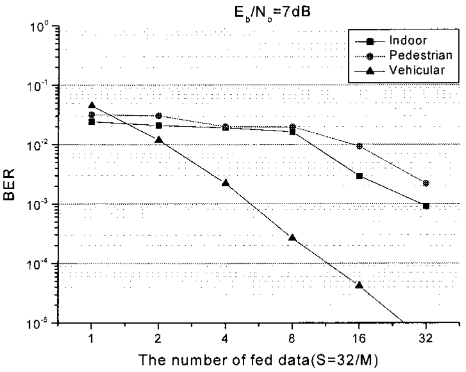

그림 8. 송신데이터 S에 따른 BER성능
Fig. 8 BER comparison according to the number of fed data, S.

Ⅳ. Conclusions

The proposed MC-CDMA system in this paper uses the multicarrier modulation scheme and the concept of the modulation level-controlled system in order to make the system robust to the frequency selectivity and to provide a maximum data rate maintaining an acceptable transmission quality over various channel environments. This system selects higher data rate when the channel experiences the low delay spread and slow fading. On the other hand, when the fading changes very fast and the delay spread is very long, the system selects lower data rate. In both cases, the system controls the number of serial-to-parallel converted streams and the number of fed streams. With the same data fed at different sub-carriers, the frequency diversity is achieved. And a RAKE receiver also is utilized to achieve path (time) diversity. This system can work as an adaptive modulation level-controlled system. It informs the transmitter of the quality of the link which is perceived by the receiver. The transmitter can then respond by changing the number of serial-to-parallel converted data according to the channel condition.

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