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# 높은 지연 페이딩 채널에서 반송파 간섭신호를 이용한 개선된 OFDM 시스템

정회원 정 연 호

# Improved OFDM System with Carrier Interferometry Codes in Highly Dispersive Fading Channels

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## 요 약

OFDM 기술은 전송 대역을 다수의 협대역으로 분할한 뒤 다수의 부반송파를 이용하여 고속의 데이터를 전송한다. 여기서 부반송파 대역은 협대역으로서 코히런스 대역보다 작아야 한다. 본 논문은 주파수 다이버시티 효과를 증대시켜 성능을 개선시키는 새로운 기술인 반송파 간섭신호를 OFDM 시스템에 적용한 반송파 간섭신호 OFDM 을 제안한다. 본 반송파 간섭신호를 적용한 OFDM 시스템의 성능 검증을 위해 다중레벨 변조를 적용하였으며 높은 지연확산을 가지는 페이딩 채널 환경에서 성능을 조사하였다. 본 OFDM 시스템의 성능 조사는 친사용자 환경의 시뮬레이션 플랫포옴인 SPW를 사용하여 구현한 시뮬레이터를 이용하였다. 시뮬레이션 결과에서 반송파 간섭신호를 적용한 OFDM 시스템은 주파수 선택적 페이딩 채널에 대해 강한 특성과 개선된 성능을 제공함을 알 수 있었는데 특히 보호구간 800ns 에 비해 높은 지연 확산 현상을 나타내는 151ns 채널 모델에서 적절한 전송 전력이 제공될 경우 $10^{-3}$ 혹은 더 양호한 비트오율을 얻을 수 있었다.

**Key Words** : Carrier interferometry; OFDM; Performance; Dispersive fading.

## ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) transmits high-speed data by splitting the transmission bandwidth into a number of subcarriers. The bandwidth of each subcarrier is ensured to be smaller than the coherence bandwidth. This paper presents an OFDM system incorporated with the Carrier Interferometry (CI) codes to improve the performance by enhancing frequency diversity effect. The performances of CI-OFDM with multilevel modulations are investigated in highly dispersive fading channels. For the investigation of performance improvement of CI-OFDM, a simulator has been developed using a well-known SPW simulation platform. The simulation results show that the CI-OFDM provides both performance improvement and robustness against dispersive fading channel behavior. The performance of CI-OFDM with multilevel modulations demonstrates that CI-OFDM outperforms a traditional OFDM system, particularly in highly dispersive channels. With a relatively large delay spread of 151ns compared to the guard interval of 800ns, CI-OFDM provides a BER of $10^{-3}$ if sufficient signal power is present.

## Ⅰ. Introduction

Growing demand for high speed wireless networks have led to the development of more sophisticated broadband transmission technologies. The provision of high performance and high

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capacity in broadband wireless networks becomes essential for the successful deployment. Unfortunately, the characteristics of mobile radio propagation channel state that the higher the data rate is, the more vulnerable the transmitted data will be to intersymbol interference (ISI) due to delay spread. This phenomenon is also referred to as frequency selective fading in the frequency domain. One efficient method of overcoming this adverse effect is to employ a multicarrier transmission, where a number of subcarriers occupying narrowband transmission bandwidth are employed. By doing so, each subcarrier will experience flat fading rather than frequency selective fading. An example of the multicarrier transmission schemes is Orthogonal Frequency Division Multiplexing (OFDM), which is a high-speed, bandwidth efficient modulation scheme[1,2].

OFDM is widely adopted as a standard for high-speed wireless LAN access services. In Europe, for instance, the HIPERLAN/2 specifications for broadband radio access networks have been developed by the European Telecommunication Standard Institute (ETSI)[3]. Indeed, OFDM is a high-speed transmission system with an effective counteraction against delay spread using a number of narrowband subcarriers. However, OFDM does not fully utilize frequency diversity effect inherent in multi-carrier transmission schemes. This is because OFDM only transmits a symbol on a single subcarrier. Recently, a Carrier Interferometry (CI) code has been proposed to enhance performance of multicarrier transmission systems, TDMA and CDMA systems[4,5]. Unlike a traditional OFDM, OFDM combined with this code utilizes all available subcarriers in the symbol transmission. That is, each symbol is transmitted on all subcarriers rather than on a single subcarrier and thus frequency diversity effect is enhanced. It is important to note that the CI code ensures orthogonality between the symbols using a symbol specific phase offset. This paper considers an OFDM incorporated with the CI codes (CI-OFDM) and investigates a performance improvement in various channel scenarios and also with multi-level modulation schemes applied. For efficient simulations of CI-OFDM in various channel scenarios, the system has been developed on a well-known simulation platform of SPW[6], on which various channel scenarios can easily be created by simply changing relevant parameters.

## Ⅱ. Carrier Interferometry OFDM

The CI codes are defined as a superposition of N carriers separated by Δf[4]:

$$p(t) = \sum_{n=0}^{N-1} \cos(2\pi n \Delta f t) \tag{1}$$

Δf is typically set to be 1/Ts, where Ts is the symbol duration. The CI code has one mainlobe, which occurs at the time of 1/Δf, and a number of sidelobes. The correlation function of p(t) is found to be

$$\begin{aligned} R(\tau) &= \frac{1}{\Delta f} \sum_{n=0}^{N-1} \cos(2\pi n \Delta f \tau) \\ &= \frac{1}{\Delta f} \frac{\sin\left(N\pi\Delta f\tau\right)}{\sin\left(\pi\Delta f\tau\right)} \cos\left(\pi(N-1)\Delta f\tau\right) \end{aligned} \tag{2}$$

From (2), it is readily found that there are a large number of zeros. That is, zero correlation occurs at the following values; $\tau = n/N\Delta f$ and $2n-1/2(N-1)\Delta f$ (n = 0,1,...., N-1). Thus, we have, in total, 2N-1 zeros when N is odd, and 2N-3 zeros when N is even. This large number of zeros in the correlation function is exploited in ensuring orthogonality between the symbols transmitted on all available subcarriers.

The input data stream is first modulated (e.g. BPSK) and then serial-to-parallel converted. The kth symbol, $S_k(t)$, in the OFDM block is submitted to the CI modulation process as shown in Figure 1. That is,

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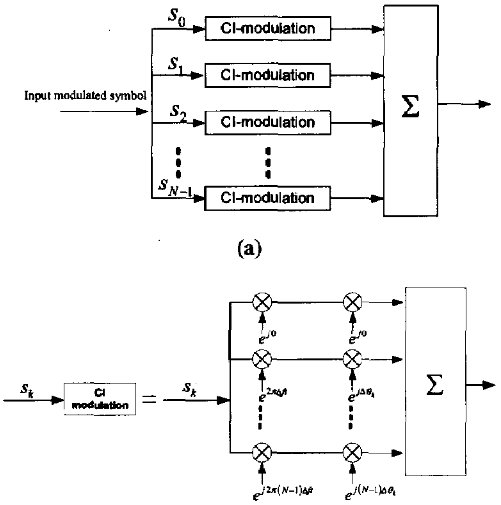

(a)

(b)

Figure 1. Transmitter of CI-OFDM

$$S_k(t)=d_k\sum_{n=0}^{N-1}\cos\left(2\pi n\Delta f\left(t-\frac{k}{N\Delta f}\right)\right) \tag{3}$$

where $d_k$ is a modulated symbol (+1 or -1 in case of BPSK). Therefore, the transmitted signal is given by

$$s(t)=\sum_{k=0}^{N-1}d_k\sum_{n=0}^{N-1}\cos\left(2\pi n\Delta ft-\frac{2\pi nk}{N}\right) \tag{4}$$

During the signal transmission over the mobile radio propagation channel, the transmitted signal undergoes multipath fading, which results in signal attenuation and signal delay. In addition, the additive white Gaussian noise is added. Thus, the received signal is expressed as,

$$\begin{aligned} r(t)=&\sum_{k=0}^{N-1}d_k\sum_{n=0}^{N-1}\alpha_n \\ &\times\cos\left(2\pi n\Delta f(t-\tau_n)-2\pi nk/N+\phi_n\right)+n(t) \end{aligned} \tag{5}$$

where $\alpha_n$ is the channel fade of the nth subcarrier, $\phi_n$ is the channel phase of the nth subcarrier and n(t) is the additive white Gaussian noise. It suould be noted that each symbol within an OFDM symbol block is transmitted on all subcarriers and for orthogonality a symbol specific phase offset is introduced to each symbol.

The CI demodulator basically performs the reverse operation. It first separates the complex baseband signal, r(t), into its N orthogonal carriers through a Fast Fourier Transform (FFT) and compensates for the channel phase effect. Then, it removes the phase offset of the kth symbol from each carrier. Therefore, assuming perfect phase synchronization for simplicity, the decision vector for the kth symbol is given

$$r_k=\left(r_k^0,r_k^1,\ldots,r_k^{N-1}\right) \tag{6}$$

where

$$\begin{aligned} r_k^n=&\alpha_n d_k+\sum_{j=0,j\neq k}^{N-1}\alpha_n d_j \\ &\times\cos\left(2\pi nk/N+\Delta\theta_k-2\pi nj/N-\Delta\theta_j\right) \\ &+n_n \end{aligned} \tag{7}$$

The decision vector is now subject to a combining technology, through which orthogonality between symbols is to be restored. Unlike an AWGN or flat fading channel, popular combining technologies, such as equal gain combining or maximal ratio combining, are not optimal for frequency selective fading channel[4]. In this paper, we employ a suboptimal combining technique called a Minimum Mean Square Error Combining (MMSEC) scheme. This strategy was identical to the one utilized in[4]. Thus, the decision variable for the kth symbol can be expressed as:

$$C_k=\sum_{n=0}^{N-1}r_k^n\frac{\alpha_n}{N\alpha_n^2+N_o/2} \tag{8}$$

where $r_i$ is the output of ith subcarrier correlation, N is the number of subcarriers, No is one-sided noise power spectral density and $\alpha_i$ is the fade of ith subcarrier. Figure 2 shows the receiver of CI-OFDM.

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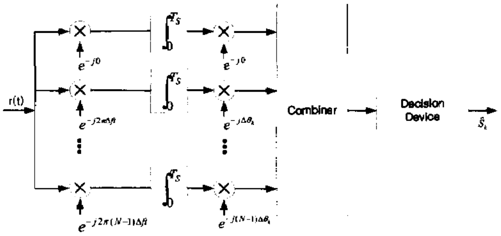

Figure 2. Receiver of CI-OFDM

## III. Carrier Interferometry OFDM Simulator

For the investigation of the CI-OFDM performance, a simulator has been developed using SPW simulation platform. This simulator has been designed to run under various channel scenarios in a user-friendly manner. It consists of a number of functional blocks developed and linked in a hierarchical manner. A large number of essential and basic blocks for the simulation are provided by SPW standard library, while core blocks in the simulator are custom coded. The top-level block diagram of the simulator is comprised of 5 main blocks as shown in Figure 3. The first block is a data source block, where it generates a necessary number of binary data and the modulator block performs a digital modulation scheme. Each modulated symbol is then passed into the CI modulator block. After cyclic prefix is inserted into the OFDM block, the block is transmitted over the mobile radio channel. The block diagram of the mobile radio channel is shown in Figure 4. It is represented using a tapped delay line model. In this study, the number of paths is limited to 6, due to a computational load. In addition to fading, the additive white Gaussian noise is added. The receiver basically performs reverse operation. As mentioned previously, it combines the CI demodulated signal using the MMSE combining technique. In the simulation, we assume the channel fade required for the combining process is completely known at the receiver.

## IV. Simulations and Discussions

By making use of the SPW simulator, the simulations were performed with the following modulation schemes applied: BPSK, QPSK, 8QAM, 16QAM, 32QAM and 64QAM. The simulation parameters for the evaluation are identical to those of HIPERLAN/2. That is, the useful symbol part duration is 3.2 μs with guard time of 800ns, the number of subcarriers is 64 and the data rate with BPSK is 20Mbps.

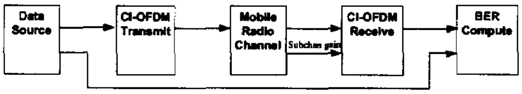

Figure 3. Top-level block diagram of the CI-OFDM simulator

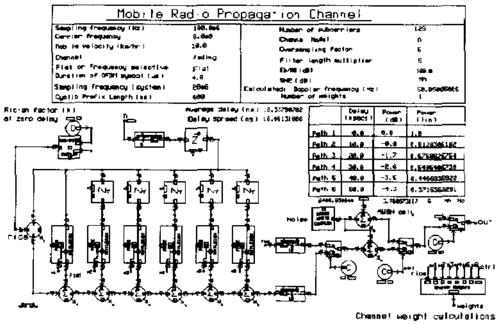

Figure 4. Dispersive fading channel block

For the simulation of highly dispersive fading channel, we generated two channel models (CH1, CH2) represented as power delay profile. In generating the two channel models, it is taken into account that BER performance often varies according to the power distribution of a power delay profile[8]. Figures 5 and 6 show these power delay profiles, respectively. The delay spreads of the power delay profiles are found to be approximately 76ns (CH1) and 151ns (CH2), respectively.

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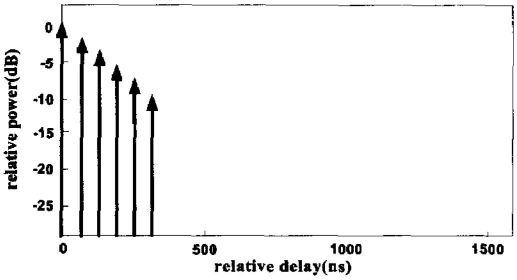

Figure 5. Channel model #1 (CH1) with a delay spread of 76ns

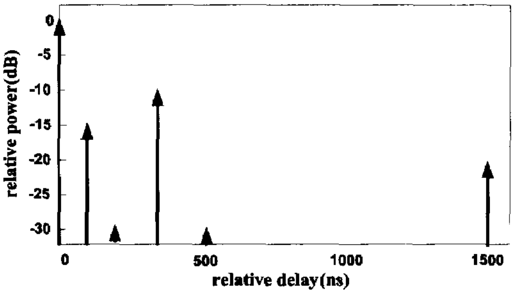

Figure 6. Channel model #2 (CH2) with a delay spread of 151ns

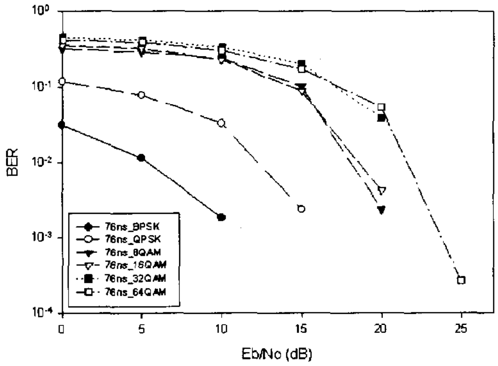

Figure 7. BER performance of CI-OFDM for CH1

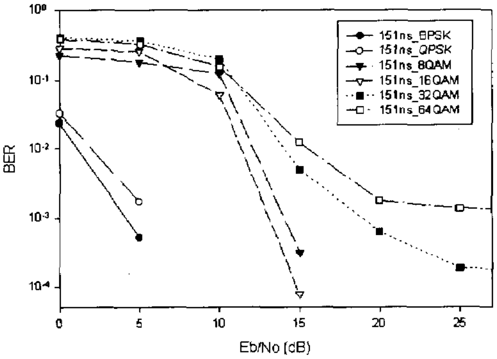

Figure 8. BER performance of CI-OFDM for CH2

The simulator has been run for a different level of modulation scheme under the channel conditions concerned. For reasonable performance evaluation, 100,000 binary data are submitted to the simulator for each modulation level. The simulation results of CI-OFDM are shown in Figures 7 and 8 for CH1 and CH2, respectively. It can be seen that the BER performance of $10^{-3}$ can easily be achieved for the both channel models if sufficient signal power is provided. Even in the case of CH2 where a relatively large delay spread of 151ns is present, CI-OFDM offers a BER performance of $10^{-3}$ or better.

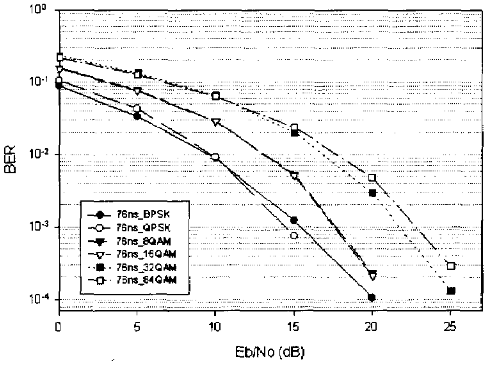

Figure 9. BER performance of Traditional OFDM for CH1

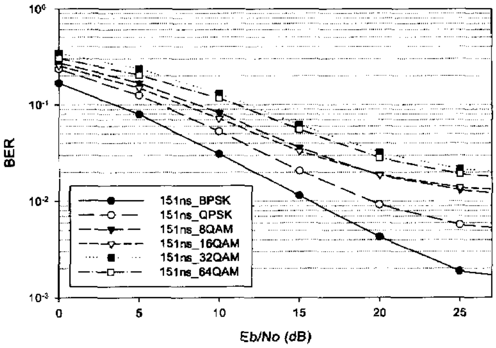

Figure 10. BER performance of Traditional OFDM for CH2

In order to verify the capabilities of CI-OFDM, the performances of CI-OFDM are compared with those of the traditional OFDM system for the identical channel models and the same simulation parameters as those used for CI-OFDM. Figures 9 and 10 show the performances of the traditional

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OFDM for CH1 and CH2, respectively. It can be clearly seen that CI-OFDM outperforms the traditional OFDM in all simulation scenarios with the channel model of CH2, while the performance of CI-OFDM for CH1 is either comparable or improved. This observation leads to the conclusion that the frequency diversity gain through the CI techniques makes a significant contribution to the performance improvement of OFDM and this gain is more discernible with a highly dispersive channel.

## V. Conclusions

The investigation of OFDM performance based on the CI codes has been conducted in highly dispersive fading channels. The performance of an OFDM system is improved with the CI codes via enhanced frequency diversity effect. High performance of CI-OFDM is observed, particularly in highly dispersive fading channels. The performances of the OFDM system with multilevel modulation schemes indicate that an adaptive modulation scheme can also be useful, in order to further improve performance and efficiency. This work is presently underway.

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