Performance of Partial Parallel Interference Cancellation With MC-CDMA Transmission Techniques for Power Line Communication Systems

[1]Yung-Fa Huang, [2] Tan-Hsu Tan, [3]Chia-Hsin Cheng and [4]Neng-Chung Wang
[1]Department of Information and Communication Engineering
Chaoyang University of Technology, Taiwan
E-mail: yfahuang@cyut.edu.tw
[2] Department of Electrical Engineering, National Taipei University of Technology, Taiwan
E-mail:thtan@ntut.edu.tw
[3]Department of Information and Communication Engineering
Chaoyang University of Technology, Taiwan
E-mail: chcheng@cyut.edu.tw
[4]Department of Computer Science and Information Engineering
National United University, Taiwan
Email:ncwang@nuu.edu.tw

Abstract: - In this paper, we describe and evaluate multistage partial parallel interference cancellation (PPIC) multiuser detectors to improve the performance of multi-carrier direct-sequence code-division multiple-access (MC-CDMA) power line communication (PLC) systems over frequency selective fading channels with non-perfect power control. To improve the effectiveness of PPIC, we examined the adequate partial cancellation weights (PCWs) for the PPIC. Thus, the performance improvement in MC-CDMA based PLC systems using PPIC multiuser detectors is investigated. The high data rate demanded in the multimedia PLC systems can be offered by the MC-CDMA systems. However, the multiple access interferences (MAIs) exist in the frequency selective fading channels for the down link even though using an orthogonal pseudo-random noise (PN) code and occur for the up link due to the non-orthogonal spreading codes. In the high system load, the MAIs become the dominant factor degrading the performance. Therefore, the performance of a multistage PPIC is further investigated for the MC-CDMA PLC systems. Simulation results show that with adequate cancellation weights, the PPIC scheme can obtain a superior performance than the conventional PIC scheme, especially at heavy system load. Furthermore, with the bit-error rate (BER) requirements of 0.001, the five-stage PPIC with PCWs, 0.7, 0.8, 0.9 and 1 for stage 2, 3, 4 and 5, respectively, increases the capacity from 15 of CPIC to 19 users with the processing gain 32 over the power line channels.

Key-Words: - MC-CDMA, PLC, Multiuser detection, Multiple access interference, Partial parallel interference cancellation, Partial cancellation weight

1 Introduction

The orthogonal frequency division multiplexing (OFDM) supports high rate data transmission. The conventional direct-sequence code-division multiple-access (DS-CDMA) can give a high potential capacity for the multiple access communication systems [1]. Therefore, the combined technique of OFDM and CDMA, multi-carrier code-division multiple-access (MC-CDMA) communication technique, which exploits the spreading feature of CDMA but without the adverse effect of increasing frequency selectivity in the channel, has received much attention among researcher and been adored as a favorite candidate for 4th generation cellular communication systems [2-5].

Powerline Communication (PLC), a communication technique that uses the existing power wiring (120 Volts, 240, etc…) to carry information, has attracted much attention and has become a mature subject of research in last few years due to its low cost and high availability. Powerline communication could offer ideal solutions, mainly because the power supply infrastructure is denser than any other communication network [6-8]. The full infrastructure from the provider to the home wall plug is there, ready for use without any additional installation cost. Although the powerline network has not been designed for transferring data and is thus characterized by unfavorable transmission properties, frequency ranges of some MHz are at the disposal for telecommunication purposes. To achieve high data rates of some Mbit/s required for multimedia applications, sophisticated and well-designed digital transmission systems are necessary in order to exploit the available frequency bands [8].

Therefore, by using multi-carrier modulation, CDMA signal is spread over several carriers by which frequency diversity over the power lines is achieved similar to path diversity in RAKE receivers. The multiple narrowband channels in each subcarrier undergo nearly frequency flat fading. A suitable guard time can be inserted to eliminate the effect of delay spread. Then, with a sufficient cyclic extension, the PN codes spreading in each subcarrier can keep synchronously. Therefore, the MC-CDMA communication systems perform the multiple accesses and overcome the multipath frequency selective fading over the power lines.

When the perfect power control scheme is exerted for subcarriers, the frequency selectivity in each subcarrier is vanished, thus the orthogonal PN codes perform with multiple access interference (MAI) free. However, perfect power control is hard to reach. Therefore, the MAI due to the frequency selectivity in fading channels degrades the performance of MC-CDMA communication systems. Then, the performance of an MC-CDMA PLC system is primarily limited by MAIs. Code orthogonality among users in MC-CDMA PLC systems is highly distorted by the instantaneous frequency response of the powerlines channels. Thus multiuser detection (MUD) becomes very important for separating user's signals, even in the absence of the near/far effect [9].

The multiuser detector, an upcoming main-stream research for CDMA receivers, which attempts to eliminate MAIs and the near-far problem simultaneously, has become an approved capacity improving technique and received much significant attention recently [9-11]. The computational complexity of the optimal maximum likelihood (ML) detector proposed by Verdú [9] grows exponentially with the number of users and the length of the bit sequence, so that it is unsuitable for implementation. Therefore, several suboptimal multiuser detection schemes have been proposed [10-13, 19] in DS-CDMA systems and ultra-wide band (UWB) communication systems [20-21].

Among the suboptimal multiuser detectors, the parallel interference cancellation (PIC) scheme simultaneously subtracts the interference from each user's received signal and finishes the procedure at most a few bit times. Therefore, the PIC scheme is preferable for practical and real-time implementation. However, at high system load, the multistage conventional PIC approach, which attempts to completely cancel the interference caused by all other users, suffers performance degradation due to a poor cancellation, which is brought about by the relatively high error rate of bit decisions in the preceding stage. Thus, the partial cancellation contrarily is a better policy than the complete cancellation. Consequently, in this paper, a multistage partial PIC (PPIC) is chosen for countering MAI and then improves the performance over a quasi-synchronous uplink channel in a non-perfect power control environment over the power lines.

The rest of this paper is organized as follows. In Section 2, the system model of MC-CDMA PLC systems and the power lines channel models are described. Section 3 describes the multistage PPIC multiuser detectors. Simulation results of the multistage PPIC multiuser detectors are presented in Section 4. Finally, conclusions are given in Section 5.

2 System Model of MC-CDMA Based PLC Systems

In this section, we describe the system model of MC-CDMA PLC systems.

2.1 Transmitter Model

In this paper, we consider an MC-CDMA-based PLC system in which K users are communicating simultaneously at the same rate over power lines each with a binary phase-shift keying (BPSK) data modulation and its own PN code. Fig. 1 shows the block diagram for MC-CDMA based power line communication systems.

The description of MC-CDMA based PLC system in this paper here focuses on the uplink system. A quasi-synchronous uplink system is assumed for simplicity of the system model. A K-user MC-CDMA system with BPSK modulation is considered. The block diagram of the transmission scheme is shown in Fig. 2. After serial to parallel (S/P) conversion, the kth user transmits P parallel data symbols with the binary data signal $d_k(t)=\sum_{i=-\infty}^{\infty}\sum_{p=0}^{P-1} b_{k,p}(i)p_{T_b}(t-iT_b)$, where $b_{k,p}(i)\in\{-1,+1\}$ is the pth symbol of the kth user during the ith data duration and $p_{T_b}(t)$ is a rectangular pulse with amplitude 1 and duration T_b. On the $(Pn+p)$th sub-carrier, the kth user's signal is spread by the spreading codes, $a_{k,n}$ = {-1,+1}, the nth chip of the kth user. Then, the signal $c_k(t)$ transmitted by the kth user is given by

$$c_k(t) = \sum_{i=-\infty}^{\infty} \sum_{p=0}^{P-1} \sqrt{\frac{2P_{k,i}}{N}} b_{k,p}(i) \cdot \sum_{n=1}^{N} a_{k,n} \cos(\omega_m t + \theta_k) \cdot p_{T_b}(t - iT_b), \quad (1)$$

where $P_{k,i}$ and θ_k are the signal power and the phase of the kth user respectively, and $\omega_m = \omega_c + 2\pi(Pn+p)\Delta f$ is the nth subcarrier frequency of the pth symbol where ω_c is the common carrier frequency and $\Delta f = 1/T_b$ is the minimum carrier separation between subcarriers.

To increase the frequency diversity and to ensure that each sub-carrier undergoes frequency non-selective fading [5], the number of sub-carriers is chosen to be a multiple, P, so that P symbols will be transmitted during one OFDM symbol of duration, Tb, comprising of $N_c = NP$ subcarriers. The transmission signal vector corresponding to the pth symbol, p = 0,1,…,P-1. The N_c components of the kth user are scrambled by applying frequency interleaving in order to eliminate the correlation among fading between adjacent subcarriers. Then, the summation of N_c components is followed by inserting a guard interval, which is greater than the multipath delay spread, T_m of the radio channel.

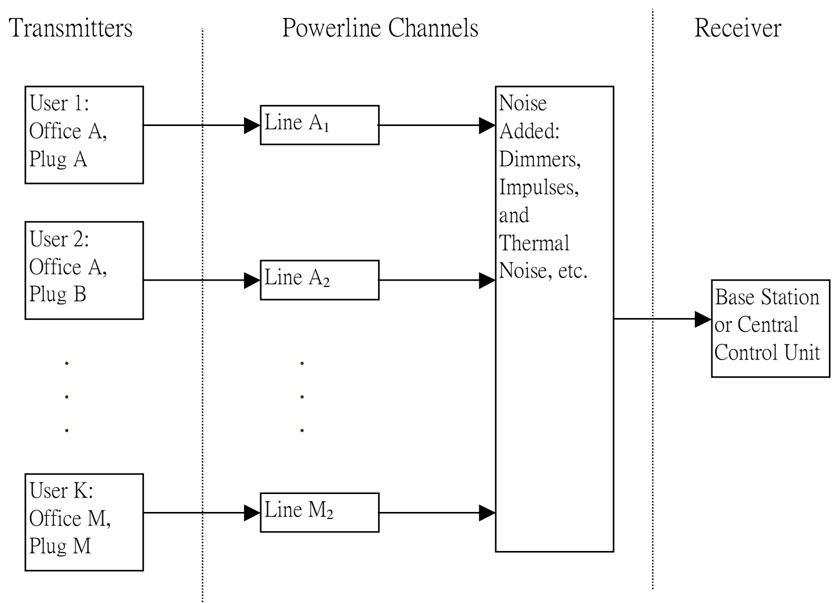

Fig. 1 Block diagram for MC-CDMA based power line communication systems.

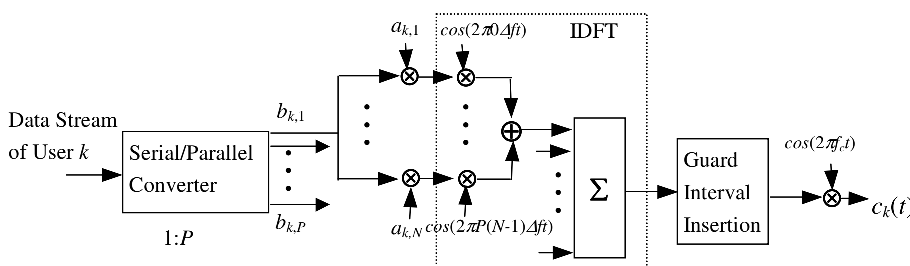

Fig. 2. Block diagram of transmitter for MC-CDMA PLC communication systems.

2.2 Channel Model

Since the typical power line networks have a lot of impedance discontinuities, a transmitted signal will be received as a number of distinctively delayed and attenuated signals at the receiver side corresponding to reflections from those discontinuities. Hence, a multipath signal propagation model seems to be suitable to describe the channel transfer characteristics [14-16]. Therefore, we model the transfer function of the power lines channel as a random process $h(t)$. Thus, the channel is characterized by the equivalent complex baseband representation of the channel impulse response of the kth user's link, $h_k(t)$, $k = 1, \ldots, K$,

$$h_k(t) = \sum_{\lambda=1}^{L_k} g_{k,\lambda}(t)\delta(t - \tau_{k,\lambda}), \quad (2)$$

where $g_{k,\lambda}(t)$ is the λth gain which is a mutually independent complex Gaussian random process with zero mean and variance and $\tau_{k,\lambda}$ is the propagation delay of the λth path of kth user. Besides, L_k denotes the maximum number of paths of the kth user and k is the user index, and δ (•) is the Dirac delta function.

2.3 Receiver Model

The received signal at the base station can be expressed as

$$r(t) = \sum_{i=-\infty}^{\infty}\sum_{k=1}^{K}\sum_{p=0}^{P-1} b_{k,p}(i) \sum_{n=0}^{N-1} G_{k,Pn+p}(i) a_{k,n} \cos[\omega_m (t - \tau_{k,Pn+p}) + \phi_{k,Pn+p}(i)] \times p_{T_b}(t - iT_b) + n(t), \quad (3)$$

where $G_{k,Pn+p}(i)$ and $\phi_{k,Pn+p}(i)$ are the received signal amplitude and phase at the $(Pn+p)$th subcarrier in the ith data bit for the pth symbol of kth user, respectively, $n(t)$ is an AWGN process with zero mean and two-sided power spectral density (PSD) $N_o/2$, $\tau_{k,Pn+p}$ is the propagation delay at the $(Pn+p)$th subcarrier of the kth user, and $\phi_{k,Pn+p}(i)$ is a random variable with uniform distribution on $(0, 2\pi)$.

After the discrete Fourier transform (DFT) operation, the received signal for the $(Pn+p)$th subcarrier during the ith data interval at the base station can be expressed as

$$\mathsf{r}_{Pn+p}(i) = \sum_{k=1}^{K} \mathsf{G}_{k,Pn+p}(i) b_{k,p}(i) a_{k,n} + \mathsf{n}(i), \quad (4)$$

where $\mathsf{G}_{k,Pn+p}(i)$ is the complex gain of the received signal at the $(Pn+p)$th subcarrier in the ith data bit for the pth symbol of kth user, and $\mathsf{n}(t) = n_I(t) + j\, n_Q(t)$ is a complex-valued AWGN with independent real and imaginary components and the two-sided *PSD* equals to $N_o/2$.

Because of the frequency selective channels over the powerlines, the received amplitudes exhibit characteristics of multipath fading [16]. Therefore, we can model the received power of users by a random variable of lognormal distribution as

$$p_i = 10^{\frac{x_i}{10}}, \quad (5)$$

where x_i is a normal random variable with zero mean and standard deviation σ_x. The standard deviation represents the effect of attenuation in the PLC systems.

To acquire the advantage of frequency diversity, the combining technique of RAKE receiver is used for frequency selective fading channels [17]. In RAKE receivers, the maximal ratio combining (MRC) can maximize the instantaneous signal to interference and noise ratio (SINR). Therefore, with MRC, we can get more benefits of frequency diversity than EGC [17]. The decision statistic for the pth symbol of the ith data duration of the kth user for conventional MRC receivers is thus obtained as

$$Z_{k,p}(i) = \Re\left[\sum_{n=0}^{N-1} \mathsf{r}_{Pn+p}(i) a_{k,n} \mathsf{G}^{*}_{k,Pn+p}(i)\right], \quad (6)$$

where [ ]* is the conjugate operation. Here, the real and imaginay parts of a complex number are denoted by $\mathsf{a} = \Re\{\mathsf{a}\} + j\Im\{\mathsf{a}\}$. Then, the pth data symbol can be estimated by hard decision as obtained by

$$\hat{b}_{k,p}(i) = Z_{k,p}(i) / \left|Z_{k,p}(i)\right|. \quad (7)$$

The block diagram of MRC receiver for MC-CDMA communication systems thus is shown in Fig. 3.

3 Multistage Partial Parallel Interference Cancellations

3.1 Multistage Parallel Interference Cancellation

The multistage PIC scheme is one of the effective and efficient ways to remove the MAIs. The PIC detector estimates and subtracts out all of the MAIs for each user in parallel as shown in Fig. 4. The tentative decision of the first stage of multistage PIC detector is a hard-decision approach that is used in a conventional receiver with MRC. After the DFT operation, the signal obtained from the $(Pn+p)$th subcarrier, for the pth symbol in the ith bit at the first stage (i.e., before any interference cancellation) is obtained as (4). The decision statistic for the pth symbol of the kth user at the ith data duration is obtained by despreading and combining as (6). Then, the ith data bit can be estimated by hard decision as obtained by $\hat{b}^{(1)}_{k,p}(i) = Z^{(1)}_{k,p}(i) / \left|Z^{(1)}_{k,p}(i)\right|$.

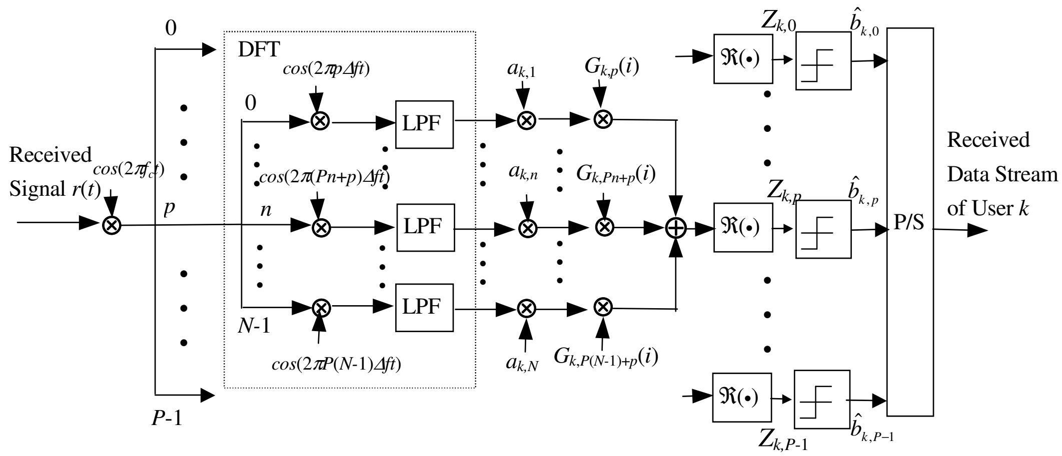

Fig. 3. Block diagram of MRC receiver for MC-CDMA communication systems.

Therefore, we can construct an estimated signal of the ($Pn+p$)th subcarrier in the ith bit of the kth user at stage s as

$$\hat{\mathsf{s}}_{k,Pn+p}^{(s)}(i) = \hat{b}_{k,p}^{(s)}(i) a_{k,n} \mathsf{G}_{k,Pn+p} . \qquad (8)$$

The signal amplitude can be estimated by transmitting a training sequence in the pilot-tone channel. The multistage PIC is performed by regenerating and simultaneously subtracting the estimated signals of the interfering users from the received subcarrier's signal $r_{Pn+p}(i)$ to form a new received subcarrier's signal $\mathsf{r}_{k,Pn+p}^{(s)}(i)$ in the ith bit interval for the kth user after stage s, given by

$$\mathsf{r}_{k,Pn+p}^{(s)}(i) = \mathsf{r}_{Pn+p}(i) - \sum_{\kappa=1,\kappa\neq k}^{K} \hat{\mathsf{s}}_{\kappa,Pn+p}^{(s)}(i) . \qquad (9)$$

The decision statistic of the ith bit at stage s, $Z_{k,p}^{(s)}(i)$, is obtained by despreading and combining the new received (after interference cancellation) subcarrier's signal $\mathsf{r}_{Pn+p}^{(s)}(i)$ with the kth user's signature signal

$$Z_{k,p}^{(s)}(i) = \Re\left\{ \sum_{n=0}^{N-1} \mathsf{r}_{k,Pn+p}^{(s)}(i) \cdot a_{k,n} \mathsf{G}_{k,Pn+p}^{*} \right\} . \qquad (10)$$

Using this procedure, an arbitrary number of stages of the PIC may be performed to obtain the data bits transmitted by each user.

3.2 Partial Parallel Interference Cancellation

Since the estimates of MAIs may not be completely correct, thus, adding a partial cancellation weight (PCW) on the path of the interference cancellation, which is called PPIC, would improve the performance of interference cancellation. With this modification, the new received signal $\mathsf{r}_{k,Pn+p}^{(s)}(i)$ for the kth user after stage s is given by

$$\mathsf{r}_{k,Pn+p}^{(s)}(i) = \mathsf{r}_{Pn+p}(i) - \sum_{\kappa=1,\kappa\neq k}^{K} w_{\kappa}^{(s)}(i) \hat{\mathsf{s}}_{\kappa,Pn+p}^{(s)}(i) , \qquad (11)$$

where $w_{\kappa}^{(s)}(i)$ is the PCWs for the κth user at stage s and $0 \le w_{\kappa}^{(s)}(i) \le 1$. For simplicity, the PCW used for each sub-carrier in one stage is identical, then we call it constant weight PPIC (CW-PPIC) in which the new received signal $\mathsf{r}_{k,Pn+p}^{(s)}(i)$ for the kth user after stage s is given by

$$\mathsf{r}_{k,Pn+p}^{(s)}(i) = \mathsf{r}_{Pn+p}(i) - \sum_{\kappa=1,\kappa\neq k}^{K} w^{(s)}(i) \hat{\mathsf{s}}_{\kappa,Pn+p}^{(s)}(i) , \qquad (12)$$

where $w^{(s)}(i)$ is the constant PCW for all subcarriers at stage s. Obviously, the optimal PCWs of the latter stages should be larger than those of the front stages. Thus, we can construct a multistage PPIC multiuser detector for MC-CDMA systems.

4 Simulation Results

In this section, we describe the simulation results that had been carried out to evaluate the performance of multistage PIC schemes discussed in Section 3. In all simulations, the quasi-synchronous MC-CDMA PLC system model described in Section 2 is adopted. To examine the characteristics of MAI incurred by the corruption of orthogonality, both the orthogonal Walsh Hadamard codes and the non-orthogonal Gold codes [18] are generated for each user with the processing gain 32.

The combination of OFDM signaling and CDMA scheme has one major advantage that it can lower the symbol rate in each subcarrier so that a longer symbol duration makes it easier to quasi-synchronize the transmissions [5]. Therefore, in this paper, we assume a quasi-synchronous uplink channel, and then we discuss the BER performance of MC-CDMA systems with Walsh codes and Gold codes in the non-perfect power control environments. In order to focus much attention on the BER variations on the different partial cancellations, we assume perfect subcarrier synchronization with no frequency offset and no nonlinear distortion and perfect subcarrier amplitude/phase estimation for MC-CDMA systems. The terms CPIC (conventional PIC) and PPIC are used to represent the PIC schemes mentioned in Section 3. The CPIC is a simply full PIC, however, the PPIC is a partial cancellation.

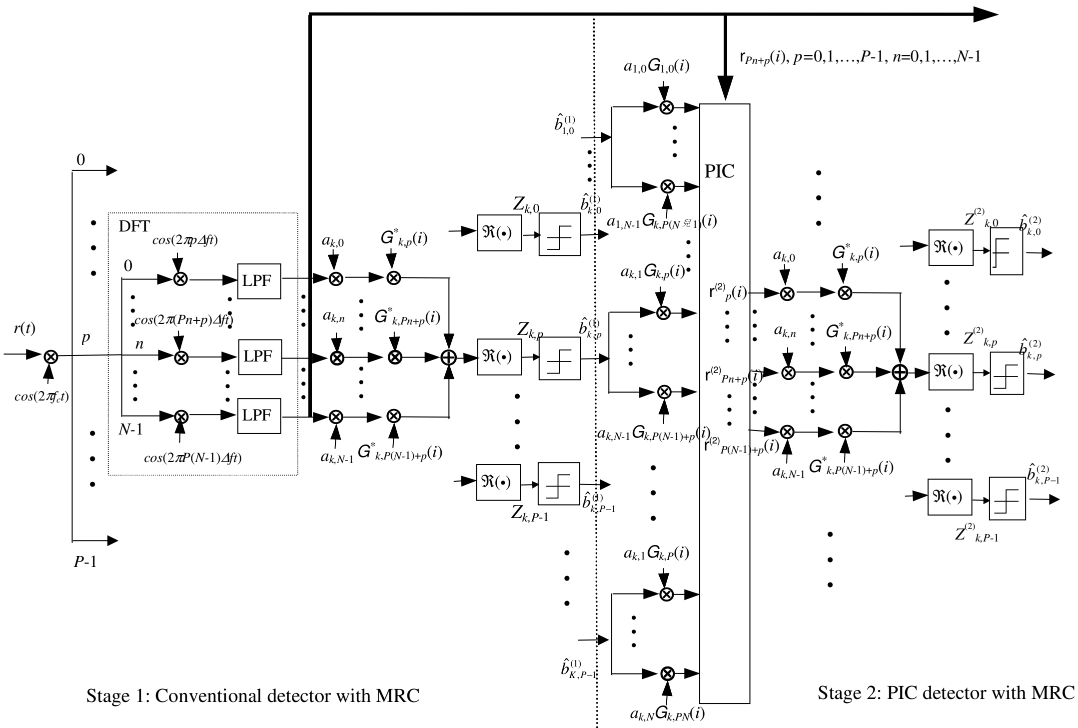

Fig. 4. Multistage parallel interference cancellation detection scheme with MRC for MC-CDMA PLC systems.

Fig. 5 depicts the benefits of frequency diversity for MRC receiver. From Fig. 5, we can observe that the benefits of frequency diversity performed by MRC for non-perfect power control and frequency selective fading channels without power control is almost the same for Walsh Hadamard codes or Gold codes.

From Fig. 6, it is observed that the partial cancellation can improve the performance of the conventional MRC receiver when the PCW is greater than 0.35. Moreover, the PPIC with adequate PCWs can outperform the CPIC, a PPIC with *PCW* = 1.

Figs. 7 and 8 depict performance for stage 2 of CPIC and PPIC with PCW = 0.4, 0.6, 0.7, 0.8, in frequency selective power line channels without power control. From Figs. 7 and 8, it is seen that the performance of PPIC with PCW=0.7 performs more robustly than the CPIC and other PPICs. Therefore, we select 0.7, 0.8, 0.9 and 1, as the PCWs for stage 2, 3, 4 and 5 in a five-stage CW-PPIC, respectively, to perform robust interference cancellations. Then, the comparisons on the performance of multistage CW-PPIC and CPIC are shown in Figs. 9 and 10. The results in Fig. 9 show that the performance of CW-PPIC is superior to the CPIC at stage 2, 3 and 4, respectively.

Besides, the BER vs. number of users of the stage 2, 3, 4 and 5 of CPIC and CW-PPIC is shown in Fig. 10. From Fig. 10, it is shown that the CW-PPIC outperforms the CPIC at heavier system load is due to the higher MAI in a frequency selective fading channel without power control. Besides, the CW-PPIC outperforms the CPIC especially at high system load.

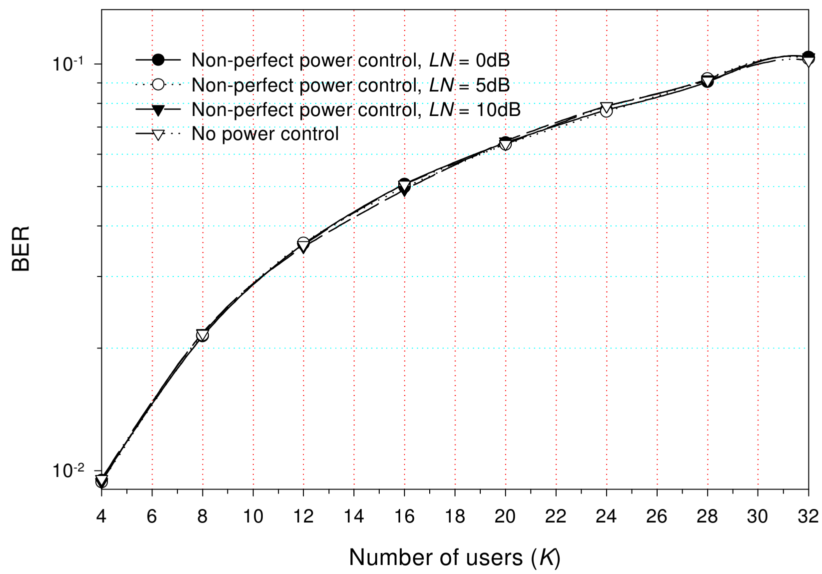

Fig. 5. Performance of MRC receivers with Gold codes for non-perfect power control over power line channels.

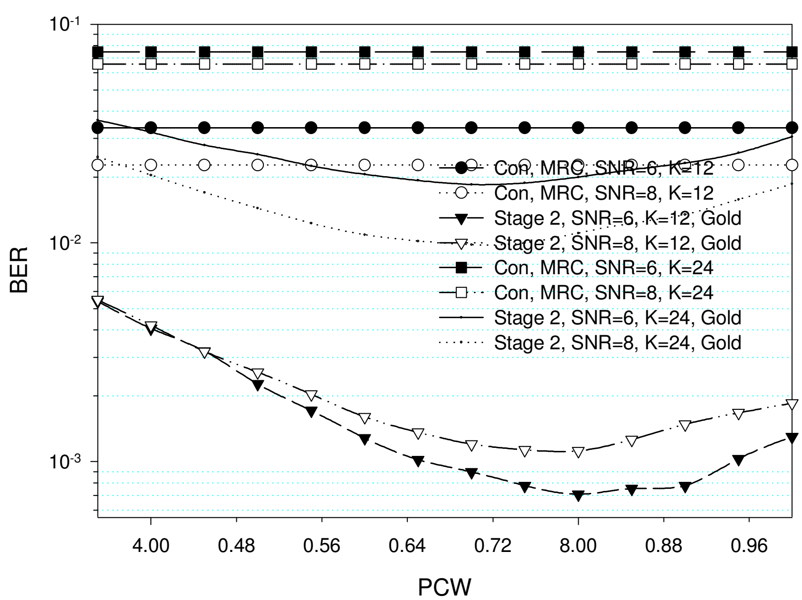

Fig. 6. Comparisons of BER vs. PCW for two-stage PPIC detector over power line channels without power control.

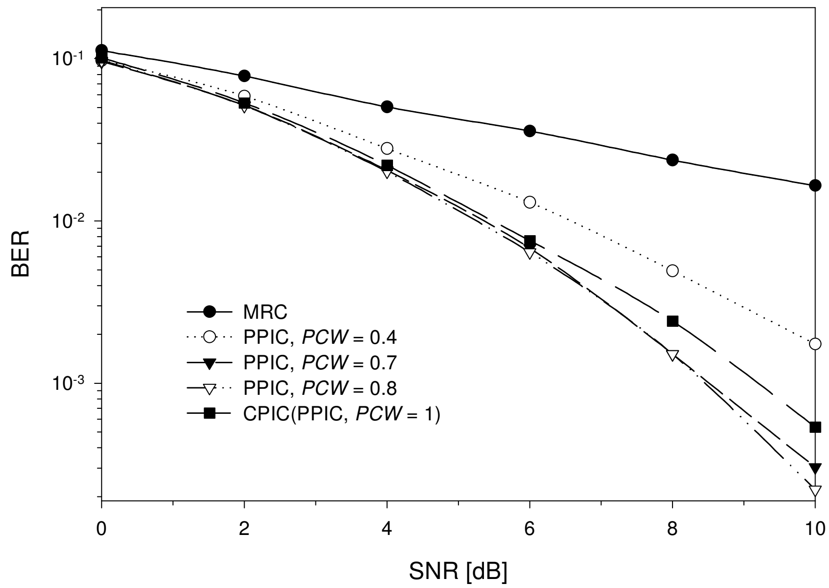

Fig. 7. The BER vs. SNR for two-stage PPIC detector with Gold codes, K = 12.

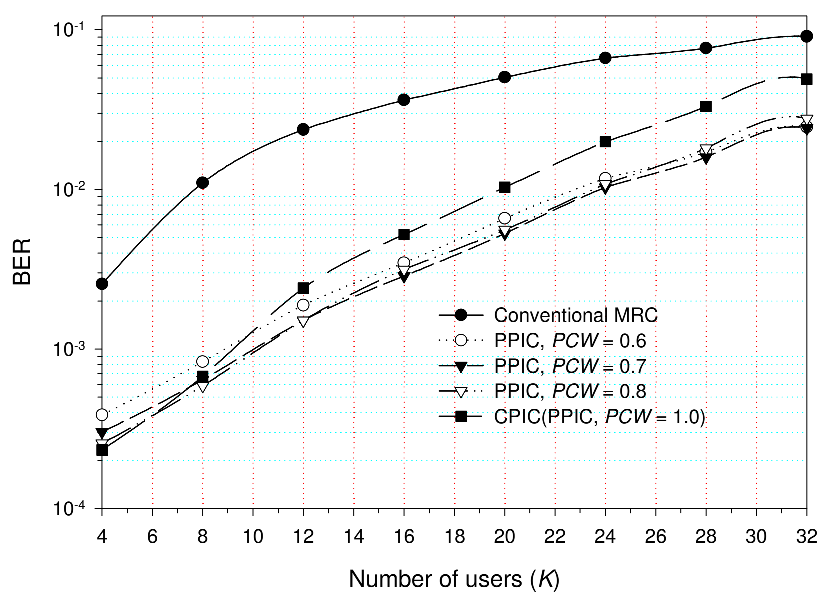

Fig. 8. The BER vs. number of users for two-stage PPIC detector with non-perfect power control power line channels, SNR = 6dB.

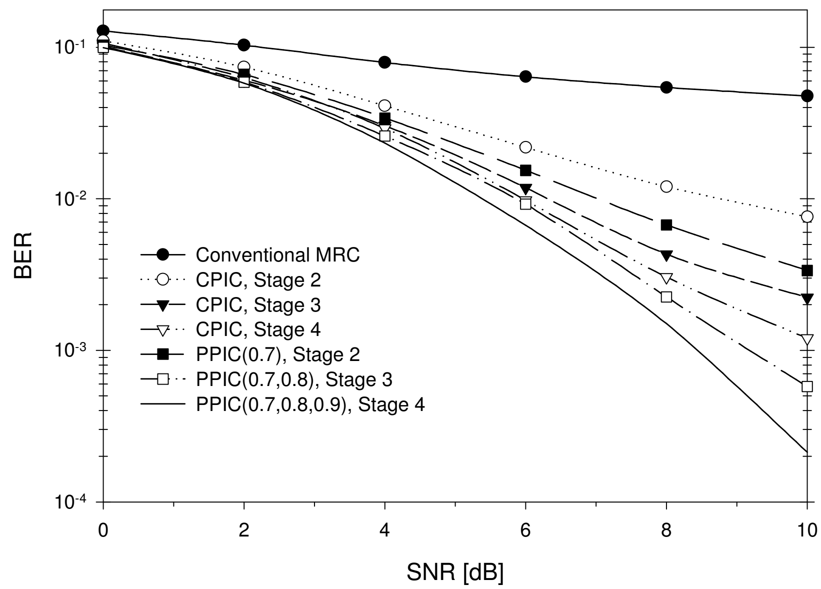

Fig. 9. Performance of BER vs. SNR for four-stage PPIC detectors, K = 20.

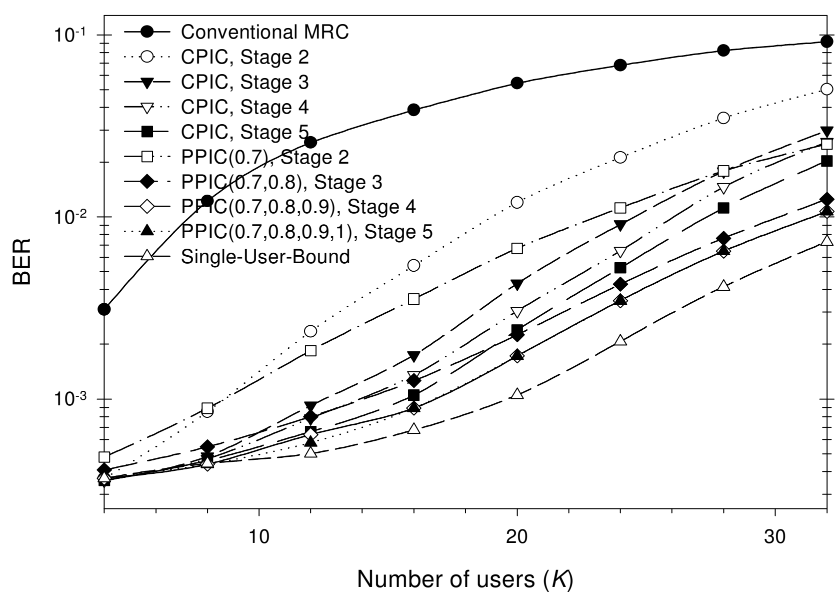

Fig. 10. Performance of BER vs. number of users for five-stage PPIC detectors, SNR = 8 dB.

5 Conclusion

In this paper, we describe and evaluate multistage PPIC multiuser detectors to improve the performance of MC-CDMA PLC systems over frequency selective fading channels with non-perfect power control. To improve the effectiveness of PPIC, we examined the adequate PCWs for the PPIC. Simulation results show that with adequate PCWs the CW-PPIC can then outperform the CPIC over power line channels, especially at heavy load for both non-orthogonal Gold codes and orthogonal Walsh codes. Furthermore, with requirements of BER = 0.001, the five-stage PPIC with PCWs, 0.7, 0.8, 0.9 and 1 for stage 2, 3, 4 and 5, respectively, increases the capacity from 15 users of CPIC to 19 users.

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