A Phase Tracking Scheme Using Iterative Estimation of Residual Frequency Offset in OFDM Systems

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Abstract OFDM (orthogonal frequency division multiplexing) systems are very sensitive to carrier frequency offset. Although frequency offset is generally compensated for by an automatic frequency control (AFC), residual frequency offset remains after the AFC. Moreover, OFDM signals are also affected by phase noise. Thus, a kind of phase tracking is needed to compensate for these effects. In an OFDM system such as IEEE 802.11a, a phase tracking scheme that uses pilot subcarriers to detect the phase rotation caused by residual frequency offset and phase noise is employed. However, the spectrum of the AFC output signal is shifted by residual frequency offset. That is, the detected phase is the composite phase of the pilot subcarrier and the adjacent subcarrier because of inter-carrier interference (ICI). The compensation based on the composite phase sometimes overcorrects or undercorrects the phase rotation. In this paper, we propose a phase tracking scheme using iterative estimation of residual frequency offset in OFDM systems. The proposed phase tracking scheme estimates residual frequency offset in the frequency domain, and compensates for it in the time domain. The compensation in the time domain mitigates the spectrum shift of the AFC output. Therefore, the proposed scheme can reduce ICI, and track phases more accurately than the conventional phase tracking scheme.

Keywords: OFDM, residual frequency offset, phase noise, phase tracking

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has been adopted as the standards of high-speed wireless local area network (WLAN) systems such as IEEE 802.11a and IEEE 802.11g, and is currently being considered as the most promising transmission technique to support future wireless multimedia communications in frequency selective channels. OFDM is one of multicarrier transmission schemes, in which data are transmitted in parallel using a number of subcarriers. In OFDM, subcarriers are orthogonally placed in the frequency domain and every frequency spacing of adjacent subcarriers is theoretically the narrowest. Therefore, OFDM is very efficient in bandwidth usage.

However, OFDM systems are very sensitive to carrier frequency offset, which occurs when a received signal is downconverted using a local oscillator whose frequency is different from the one used in a transmitter. Since subcarriers are densely placed in the frequency domain, frequency offset causes inter-carrier interference (ICI); this prevents a received signal from being correctly demodulated [1], [2].

Although an automatic frequency control (AFC) is generally employed to compensate for frequency offset, a small error remains after the AFC. This is called residual frequency offset. Residual frequency offset causes a common phase rotation in all subcarriers, and a spectrum shift of the AFC output signal. The spectrum shift causes ICI even if the amount of the shift is small. This degrades the demodulation performance [2], [3]. Therefore, it is required to compensate for residual frequency offset of the AFC output. Moreover, OFDM signal is affected by phase noise, which also causes a common phase rotation in all subcarriers [2], [4]–[6]. Phase noise is fluctuations in the phase of a local oscillator signal, and is also yielded at downconversion. Although the amount of the phase rotation caused by phase noise is smaller than that caused by frequency offset, phase fluctuation results in a relatively large residual frequency offset at the AFC.
Against these problems, WLAN systems employ a phase tracking system in which some subcarriers are used as pilot subcarriers. The phase tracking system compensates for residual frequency offset and phase noise using the amount of the phase rotation detected in the pilot subcarriers [1], [7], [8]. However, since the system compensates for the phase rotation in the frequency domain, it cannot reduce the effect of ICI. This implies that a large residual frequency offset causes a large effect of ICI, and thus, degrades phase information from the pilot subcarriers [3], [9], [10]. Therefore, a scheme which can mitigate the effect of ICI is necessary for a precise compensation for residual frequency offset and phase noise.

In this paper, we propose a new phase tracking scheme which can reduce the effect of ICI caused by residual frequency offset. The proposed phase tracking scheme detects the transition of the phase rotation per symbol duration and estimates the amount of residual frequency offset iteratively over a packet. While the estimated amount of offset is fed back successively and used for the residual frequency offset compensation in the time domain, the phase tracking is carried out in the frequency domain. The compensation in the time domain gradually reduces the effect of ICI, and the degradation of phase information is also gradually mitigated. Therefore, a performance improvement in phase tracking can be expected.

In this paper, we examine two types of the proposed system from the point of the process timings of the residual frequency offset compensation and the phase tracking. First is the case where the phase is tracked successively each time residual frequency offset is estimated. The other is the case where the offset compensation and the phase tracking are collectively performed against the packet stored in a buffer using the finally obtained residual frequency offset after the iterative estimation of residual frequency offset. Since the latter scheme starts the phase tracking after the offset compensation over the whole packet, a uniform accuracy of the phase tracking is obtained throughout the packet.

We evaluate the phase tracking performance of the proposed scheme using computer simulation. Simulation results show the proposed phase tracking scheme can compensate for residual frequency offset and can track phases more accurately than the conventional scheme even when phase noise exists. We also show the proposed scheme is effective when the amount of residual frequency offset varies slowly.

2. System Model

In this section, we describe a conventional phase tracking scheme which is generally employed in WLAN systems. A simplified block diagram of the conventional phase tracking system is shown in Fig. 2 to illustrate the phase tracking process. In each OFDM symbol in an IEEE 802.11a system, some subcarriers are dedicated to pilot signals [1], [7]. The conventional phase tracking scheme extracts the channel-equalized pilot subcarriers, and detects the amount of phase rotation by comparing the received pilot phases with the known pilot phases.

Here, the phase rotation in each pilot subcarrier does not yield only by residual frequency offset and phase noise but also by AWGN, ICI, and residuals of the channel equalization. The rotation due to residual frequency offset is constant within a symbol [12]–[14]. Furthermore, the rotation due to residuals of the channel equalization is also constant when we assume the channel fading is slow enough and does not cause

802.11a, is used as a phase noise model [3], [11]. RMS phase noise is agreed to be a white Gaussian process filtered with a single-pole low-pass filter. RMS phase noise $\phi(k)$ is given by following equations:

$$\phi(k) = \varphi_{RMS} x(k)$$  \hspace{1cm} (1)

$$x(k + 1) = x(k) + \alpha(\beta\psi(k) - x(k))$$  \hspace{1cm} (2)

$$\alpha = 2\pi F_c T_s$$  \hspace{1cm} (3)

$$\beta^2 = (2/\alpha) - 1$$  \hspace{1cm} (4)

where the RMS phase noise power is defined as the phase noise to signal power ratio $\varphi_{RMS}^2$ [3]. $F_c$ is the 3-dB bandwidth of phase noise, $T_s$ is the sampling duration, $k$ is a time slot number of the sampling duration, and $\psi(k)$ is a zero mean random variable with variance of one [3], [11].

The AFC output $z(k)$ which is affected by residual frequency offset and phase noise is given by

$$z(k) = y(k) \exp\{j(2\pi\Delta f k + \phi(k))\} + n(k)$$ \hspace{1cm} (5)

where $y(k)$ is a received baseband OFDM symbol, $\Delta f$ is residual frequency offset normalized by the subcarrier spacing, and $n(k)$ is an additive white Gaussian noise (AWGN). Each data symbol on each subcarrier is channel-equalized and phase-tracked.

Fig. 1 shows a low-pass equivalent block diagram of the receiver after downconversion. The received baseband OFDM signal $y(k)$ is affected by phase noise $\phi(k)$ when it is downconverted using a local oscillator in the receiver. Next, the resultant signal is processed by an AFC, and residual frequency offset $\Delta f$ remains in the signal. Finally, the resultant signal is split into each subcarrier signal using FFT, and demodulated after the channel equalization and phase tracking.

3. Conventional Phase Tracking Scheme

In this section, we describe a conventional phase tracking scheme which is generally employed in WLAN systems. A simplified block diagram of the conventional phase tracking system is shown in Fig. 2 to illustrate the phase tracking process. In each OFDM symbol in an IEEE 802.11a system, some subcarriers are dedicated to pilot signals [1], [7]. The conventional phase tracking scheme extracts the channel-equalized pilot subcarriers, and detects the amount of phase rotation by comparing the received pilot phases with the known pilot phases.
phase fluctuation over a packet [11]. Then, to detect the phase rotation which is common to all subcarriers, the system averages the detected phase rotations of all the pilot subcarriers.

Here, we illustrate the detection process of the phase rotation in the $m$th OFDM symbol ($m$ is a positive integer, $m \geq 1$). The averaged phase rotation $\hat{\theta}_m$ of the $m$th OFDM symbol is given by

$$\hat{\theta}_m = \frac{1}{L} \sum_{l=1}^{L} \hat{\theta}_{l,m}$$  (6)

where $L$ is the number of subcarriers in one OFDM symbol, $\hat{\theta}_{l,m}$ is the phase rotation detected in the $l$th subcarrier of the $m$th OFDM symbol. The resultant phase rotation $\hat{\theta}_m$ is common to all subcarriers and used in compensation for residual frequency offset and phase noise. At the compensation part in Fig. 2, the detected $\hat{\theta}_m$ is used for phase tracking of the $m$th OFDM symbol.

However, residual frequency offset and phase noise shift the received signal spectrum [2]. The spectrum shift introduces ICI on each subcarrier. As a result, the detected phase is the composite phase of the pilot subcarrier and the adjacent subcarrier. Since the effect of the adjacent subcarrier differs among different pilot subcarriers, there is a performance boundary in the phase tracking based on the composite phase when a large residual frequency offset remains. Therefore, to improve the phase tracking performance, the reduction of ICI is required. In this paper, we propose a scheme that can reduce the effect of ICI and can have an improved performance.

Fig. 1 Simplified OFDM receiver model with residual frequency offset and phase noise

Fig. 2 Block diagram of a conventional phase tracking scheme

4. Proposed Phase Tracking Scheme

In this section, we depict the proposed phase tracking scheme which employs iterative estimation of residual frequency offset. Fig. 3 shows the block diagram of the proposed phase tracking system. The proposed phase tracking scheme extracts the pilot subcarriers and detects $\hat{\theta}_m$ in the same way as the conventional scheme. The proposed scheme further estimates the amount of residual frequency offset using $\hat{\theta}_m$, and carries out compensation in the time domain.

Since the amount of the phase rotation due to residual frequency offset accumulates from symbol to symbol at a fixed rate, the phase transition per symbol can be detected using the difference between $\hat{\theta}_m$ and $\hat{\theta}_{m-1}$. The residual frequency offset $\Delta f$ can be estimated by dividing the difference by $2\pi T_s$ [15], where $T_s$ is the duration of an OFDM symbol including the guard interval. The proposed scheme compensates for residual frequency offset by feeding the estimated amount of offset back to the time domain signal $z(k)$. By compensating for residual frequency offset in the time domain, the effects of residual frequency offset and the adjacent subcarriers on the phase rotation can be gradually reduced. Therefore, the accuracy of the residual frequency offset estimation is improved toward the end of the packet.

Incidentally, there are two possible combinations of timings of the residual frequency offset estimation and the phase tracking. First is the case where the system tracks phases successively while compensating for residual frequency offset in the time domain (The successive processing). The other is the case where the phase tracking are performed when the feedback
estimation of residual frequency offset has been finished and the offset compensation against the packet stored in a buffer using the finally obtained residual frequency offset has been finished (The block processing). In the former case, since the accuracy of the residual frequency offset compensation is gradually improved toward the end of the packet, the phase tracking performance is not uniform over the packet. On the other hand, the system waits until the residual frequency offset estimation and the compensation over the packet are finished to start the phase tracking in the latter case. Therefore, a uniform phase tracking performance can be attained though this requires additional processing time. In this paper, we investigate both the schemes and begin with the successive processing.

4.1 The successive processing

When the system compensates for residual frequency offset and tracks phases successively, the feedback timing of the estimated residual frequency offset is related to the phase tracking performance. For example, the averaged phase transition obtained from three or more successive symbols provides a better estimate of residual frequency offset than the phase transition obtained from only two successive symbols because phase noise varies from symbol to symbol. Now the system detects \((M-1)\) phase transitions from \(M\) symbols and take the average of them, where \(M\) is an integer \((M \geq 2)\) and denotes the estimation period of \(\Delta f\). This averaging operation reduces the effect of phase noise, which varies from symbol to symbol, and improves the phase tracking performance. Fig. 4 illustrates the timings of the residual frequency offset estimation.

The first \(M\) data symbols within the packet corresponds to the estimation period of \(\Delta f_1\). Since the residual frequency offset compensation in the time domain does not carried out within this period, the phase tracking performance is the same as that of the conventional scheme within this period. Next, the proposed scheme compensates for residual frequency offset using \(\Delta f_1\) from the \((M+1)\)th data symbol to the \(2M\)th data symbol in the time domain while the proposed scheme estimates residual frequency offset \(\Delta f_2\) from the \((M+1)\)th data symbol to the \(2M\)th data symbol in the frequency domain and the phase tracking of these symbols is carried out. Hence, the compensation using \(\Delta f_2\) in the time domain is carried out against the next \(M\) symbols. By repeating this feedback process, the phase tracking performance and the accuracy of the offset estimation is improved toward the end of the packet.

Here, we define \(\Delta f_p\) as the residual frequency offset obtained in the \(p\)th estimation period, where \(p\) is a positive integer. Then, the system detects the difference between residual frequency offset \(\Delta f\) of \(z(k)\) and the \((p-1)\)th estimate in the \(p\)th estimation period. Therefore, the amount of residual frequency offset \(\Delta f_p\), which is used for the \((p+1)\)th offset compensation in the time domain, is given by

\[
\Delta f_p = \Delta f_{p-1} + \frac{1}{M-1} \sum_{j=1}^{M-1} \Delta \theta_{j+1+(p-1)M} - \Delta \theta_{j+(p-1)M} \cdot \frac{2\pi}{T_0} \tag{7}
\]

where \(\Delta f_0 = 0\) and \(m = j + (p-1)M\). In the proposed scheme, since residual frequency offset accumulates phase rotation through the packet, the initial phase value for the compensation is required to be adjusted to the accumulated phase rotation of the \((pM+1)\)th OFDM symbol in the time domain. The proposed scheme uses \(\theta_{pM}\) as the initial phase for the compensation. Thus, the \((p+1)\)th offset compensation in the time domain is carried out by multiplying \(z(k)\) by \(\exp(-j(2\pi \Delta f_p k + \theta_{pM}))\).

When the value of \(M\) is small, the system reduces the effect of ICI with a short cycle; thus the phase tracking performance is improved quickly. On the other hand, when the value of \(M\) is large, the number of symbols for averaging is increased. Therefore,
the effects of AWGN and phase noise on $\Delta f$ can be reduced, and a reliable phase tracking performance can be obtained. In either case, if the offset compensation is precisely carried out, the resultant phase rotation is caused only by phase noise and AWGN; thus the conventional scheme can track phases accurately.

4.2 The block processing

Next, we consider the case where the phase tracking is performed after the offset compensation over the whole packet. The residual frequency offset is also estimated every $M$ symbol in the block processing; this is the same as the process in the successive processing. However, the offset compensation is carried out from the first symbol to the last symbol against the packet stored in a buffer using the finally obtained estimate $\Delta f$. Similar techniques are widely used in various systems; these are sometimes called block demodulation. In [16], a similar technique is used in the frequency offset estimation. The use of block processing sometimes can be expected to reduce the effect of noise because of averaging over the observation period. In the proposed scheme, however, a uniform precision of the residual frequency offset compensation is the major benefit.

When the phase tracking is successively processed, the phase tracking performance is not uniform over the packet because the cycle of ICI reduction varies according to the length of the estimation period. The phenomenon appears conspicuously when the packet size is small. On the other hand, the block processing can provide a uniform phase tracking performance within the packet because the offset compensation is carried out with a constant precision.

In tracking loops which has a feedback structure, the loop response speed is a trade-off for the loop stability [17]. When we improve the response speed of the loop, the tracking speed is improved but the system is more susceptible to the effect of disturbance. Therefore, the proposed scheme with a shorter feedback cycle sometimes results in an erroneous final es-

\begin{table}
\centering
\caption{Common simulation parameters}
\begin{tabular}{|l|c|}
\hline
Number of subcarriers & 128 \\
Number of pilot subcarriers & 4 \\
Guard interval length & 25\% of a symbol length \\
$F_c$ & 50 kHz \\
$T_s$ & 0.1 $\mu$s \\
Multipath model & Exponentially decaying Rayleigh fading channel \\
\hline
\end{tabular}
\end{table}

timate when there is a disturbance near the end of the packet. Therefore, a longer estimation period $M$ can be advantageous for a precise compensation in the block processing.

5. Simulation Results

To confirm the validity of the proposed phase tracking scheme, we have carried out the performance evaluation using computer simulation. Table 1 shows the common simulation parameters. Phase noise is generated based on [11], and Gray-coded 64QAM with square constellation is used for data modulation [2], [7]. In an OFDM symbol, there are four pilot subcarriers. 11-path Rayleigh fading channel is used, and the delay spread of the channel is shorter than the guard interval length [11]. Packet structure is illustrated in Fig. 5. Four pilot symbols are added at the beginning of each packet, and sixty data symbols follow. Channel equalization is carried out by averaging the estimated channel information obtained from all the pilot symbols and by applying it to the whole packet.

In the evaluation of the phase tracking performance, the estimation performance of the preceding AFC is closely related. When the AFC is precise enough, it is natural that the state of the art phase tracking is unnecessary, or the performance difference between the conventional phase tracking scheme and the proposed one is quite small even when the system
Fig. 5  Packet structure

requires phase tracking. In general, it is known that the effect of frequency offset can be negligible when the frequency offset is less than one percent of the subcarrier spacing in OFDM systems [2]. Therefore, AFCs are generally designed to have the average estimation error being less than one percent [1], [18]–[20].

However, even if the normalized estimation error is less than one percent on the average, still it sometimes exceeds one percent when the variance of the estimation error is large [21]. In [21], it is reported that the estimation error exceeds one percent with probability of more than forty percent, and exceeds two percent with probability of more than thirty percent under 2-path Rayleigh fading channel with $E_b/N_0 = 20$ dB.

Moreover, it is also reported that phase noise affects the AFC performance, and tends to cause a large residual frequency offset [3]. Since the phase tracking at issue is the final bastion for accurate data demodulation, it is important that the tracking system can handle a relatively large residual frequency offset. Therefore, we evaluate the phase tracking performance when the normalized residual frequency offset is two percent, which is slightly larger than the usual AFC target of one percent.

Figure 6 shows the bit error rate (BER) performances of the proposed system and the conventional system when 2-percent residual frequency offset exists and phase noise does not exist. The proposed scheme employs $M = 2$, $M = 3$, or $M = 4$ for the estimation period. In the figure, the square plot represents the conventional scheme, the dashed lines are the successive processing (denoted by ‘A’), and the solid lines are the block processing (denoted by ‘B’).

In Fig. 6, the performances of A’s are superior to that of the conventional scheme by 5 dB at BER = $10^{-3}$. Among the dashed lines, A with $M = 2$ shows the best performance. This is because a short feedback cycle of $M = 2$ quickly improves the phase tracking performance. When the estimation period becomes short, the proposed scheme can quickly reduce ICI. Therefore, it is found that the phase tracking scheme with a shorter feedback cycle is more effective for A. Furthermore, the BER performances of B’s are better than those of A’s. There is no performance difference among the solid lines regardless of the value of $M$. When phase noise does not exist, the accuracy of the residual frequency offset estimation does not change according to the value of $M$ in B.

Next, we show the effectiveness of the proposed scheme in the presence of phase noise. Figure 7 shows the BER performances when residual frequency offset is two percent and the phase noise power is $\varphi_{RMS}^2 = -30$ dB. In Fig. 7, the performances of A’s and B’s are superior to that of the conventional scheme by about 9 dB at BER = $10^{-3}$. Compared with the performances in Fig. 6, all the schemes are degraded because of phase noise. Since A with $M = 3$ and $M = 4$ well average the phase fluctuation of phase noise in the frequency domain, the performance difference among A’s becomes small. On the other hand, the performances of B with $M = 3$ and $M = 4$ are almost the same, and the performance of B with $M = 2$ is slightly degraded. As stated in the previous section, the final estimate is sometimes influenced by disturbance when the feedback cycle is short. Therefore, $M$ above 3 is preferable for B when the phase noise power is $\varphi_{RMS}^2 = -30$ dB.

To confirm these statements, Figs. 8 and 9 show the mean square error and the variance of the residual frequency offset estimation at each symbol position in the packet, respectively, when $E_b/N_0$ is 32 dB. The horizontal axis is the OFDM symbol number from the beginning of the packet, and the vertical axis is the normalized mean square error or the variance of the residual frequency offset estimation. Here, the performances of A’s are only shown; the performance of B is the same as that of the last symbol of A and is constant over the packet.

In Fig. 8, A with $M = 2$ is small from the beginning of the packet, and A with $M = 4$ takes 36 symbols to converge. However, the variance is almost constant in Fig. 9. Therefore, A with $M = 4$ is at a disadvantage because of a slow convergence speed of the mean square error. Meanwhile, $M = 4$ is suitable for B because
Fig. 7  BER performance when residual frequency offset is 2% and $\varphi_{RMS}^2 = -30$ dB (A: successive processing, B: block processing)

Fig. 8 Transition of the mean square error of the residual frequency offset estimation when $\varphi_{RMS}^2 = -30$ dB and $E_b/N_0 = 32$ dB

Fig. 9  Transition of the variance of the residual frequency offset estimation when $\varphi_{RMS}^2 = -30$ dB and $E_b/N_0 = 32$ dB

Fig. 10  Mean square error of the residual frequency offset estimation versus the amount of residual frequency offset when $\varphi_{RMS}^2 = -30$ dB and $E_b/N_0 = 32$ dB

the final variance has the smallest value. Therefore, $M = 2$ is suitable for the successive processing, and $M = 4$ is suitable for the block processing though the performance difference is small.

Next, we evaluate the performance of the residual frequency offset estimation versus the amount of residual frequency offset. Figures 10 and 11 show the mean square error and the variance of the residual frequency offset estimation versus the amount of residual frequency offset when $E_b/N_0 = 32$ dB, respectively. From Fig. 10, the mean square error becomes small when the amount of residual frequency offset is close to zero. When the residual frequency offset becomes large, the mean square errors of $M = 3$ and $M = 4$ become also large. This agrees with the discussion of Fig. 8; it takes longer time for the offset estimation to converge. Furthermore, we can find from Fig. 11 that the variance does not vary according to the amount of residual frequency offset, nor diverge even when the residual frequency offset is small.

Next, we show the BER performances of the proposed phase tracking schemes when residual frequency offset is two percent and the phase noise power is $\varphi_{RMS}^2 = -20$ dB in Fig. 12. In Fig. 12, the performance improvement over the conventional scheme is about 2 dB at BER = $10^{-2}$ though the performance
Fig. 11 Variance of the residual frequency offset estimation versus the amount of residual frequency offset when $\varphi_{rms}^2 = -30$ dB and $E_b/N_0 = 32$ dB

Fig. 12 BER performance when residual frequency offset is 2% and $\varphi_{rms}^2 = -20$ dB (A: successive processing, B: block processing)

Fig. 13 Transition of the mean square error of the residual frequency offset estimation when $\varphi_{rms}^2 = -20$ dB and $E_b/N_0 = 32$ dB

Fig. 14 Transition of the variance of the residual frequency offset estimation when $\varphi_{rms}^2 = -20$ dB and $E_b/N_0 = 32$ dB

difference in the proposed systems is small because of a large phase noise. Among the proposed schemes, B with $M = 4$ show the best performance, and B with $M = 2$ is inferior to A with $M = 3$.

Figures 13 and 14 show the mean square error and the variance of the residual frequency offset estimation at each symbol position in the packet when $E_b/N_0$ is 32 dB. Although the curves in Fig. 13 show the same tendency as those in Fig. 8, the variance of $M = 2$ is five times larger than that of $M = 4$ in Fig. 14. Therefore, $M = 4$ is suitable for both A and B.

Figures 15 and 16 also show the mean square error and the variance of the residual frequency offset estimation versus the amount of residual frequency offset in the presence of phase noise of $\varphi_{rms}^2 = -20$ dB, respectively. From Fig. 15, the mean square error curves do not differ from those in the case when the phase noise power is $\varphi_{rms}^2 = -30$ dB, but the variance of $M = 2$ becomes large in Fig. 16. Therefore, $M = 4$, which provides a good convergence, is more suitable considering the variance.

The evaluation above is carried out under the channel model which was used for evaluation of IEEE 802.11a systems [11]. The channel is static over the packet. Therefore, we finally evaluate the case of the flat fading channel. In the case, the proposed scheme
compensates for a common phase rotation caused by both flat fading and residual frequency offset. Figure 17 shows the BER performance under the flat fading channel with $f_dT = 0.001$ when residual frequency offset is two percent and the phase noise power is $\varphi_{RMS}^2 = -30$ dB.

From Fig. 17, both A and B provide better performances than the conventional scheme under the flat fading channel. Here, flat fading causes phase rotation which is common to all subcarriers within one OFDM symbol. The amount of rotation varies from symbol to symbol because fading is slowly changing. The same is true for the case when residual frequency offset changes slowly. Therefore, the proposed scheme can handle the case.

6. Conclusion

In this paper, we have proposed a phase tracking scheme using iterative estimation of residual frequency offset in OFDM systems. The proposed phase tracking scheme estimates residual frequency offset in the frequency domain, and compensates for it in the time domain. By repeating the estimation and compensation, residual frequency offset is gradually reduced. As a result, the uncertainty in phase information of the pilot subcarriers is reduced, and the phase tracking performance is improved. In this paper, we consider two implementation methods of the proposed scheme: the successive processing and the block processing.

Simulation results show both the proposed systems attain better performances than the conventional scheme even when phase noise exists. When the phase noise power is small, the block processing, in which the offset compensation is carried out when the estimation is finished, provides a better performance. On the other hand, when the phase noise power is large, the performance difference in the proposed systems is small.

References


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