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다상 필터 기반 OFDM 전송 시스템을 위한 파일럿 채널 추정 기법

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Pilot-symbol-aided channel estimation for the polyphae filter-based OFDM trnasmission system

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Abstract - The polyphase filter-based orthogonal frequency division multiplexing (PF-OFDM) is proposed in [1]. It provides more efficient data transmission mechanism than the classical OFDM method. However, the channel estimation mechanism in the classical OFDM system such as the cyclic prefix can not be applied straightforwardly, since the received signal contains unpredictable terms. Therefore, the PF-OFDM system requires a complicated channel estimation scheme when it works on the multipath fading communication channel. In this paper, we proposed a pilot-symbol aided channel estimation algorithm suitable for the PF-OFDM system which efficiently deals with the unpredictable terms and verified its performance through a series of computer simulations.

1. Introduction

The OFDM system is well known for its robustness against the multipath, thme-varying communication channels [2]. Its performance comes from the insertion of the guard interval, which is purely redundant in the sense of data transmission and hence decreases the spectral efficiency (up to 25% loss). The PF-OFDM system is known to provide the identical performance while eliminating the requirement for the guard interval through a careful construction of prototype filter and polyphase structure. However, the PF-OFDM system requires a complicated channel estimation scheme because of the unpredictable terms contained on received signals. Those unpredictable terms comes from the real/imaginary part selection operations within the PF-OFDM receiver structure.
Accordingly, we proposed an algorithm which can remove the effect of those unpredictable terms. The proposed approach relies on a simple but important observation that we can get the ratio of the real and imaginary parts of the channel impulse response through a linear combination of received pilot data. This ratio is then inserted to the received pilot sequence in order to eliminate the effect of the unpredictable terms.

2. PF-OFDM transmission system

The PF-OFDM system has a similar structure as that of the MDFT (modified DFT) transmultiplexer. Therefore, it inherits the properties of the MDFT system, especially the robustness against the ICI and ISI. Moreover, it can also provide a backward compatibility to the classical OFDM system. Fig. 1 shows the receiver part of the PF-OFDM system. For the detailed structure of the PF-OFDM structure, a reader may refer to [1]. The PF-OFDM and OFDM systems share the same structural components such as IDFT, polyphase filters, and down-/up-samplers. The main difference between them is the prototype filter. The PF-ODFM system has a freedom to choose a prototype filter which is properly localized both time and frequency domain so as to efficiently combat against the ICI and ISI. Above all, the PF-OFDM system can transmit data without the guard interval over multipath fading channel, and thus enhance the spectral efficiency.

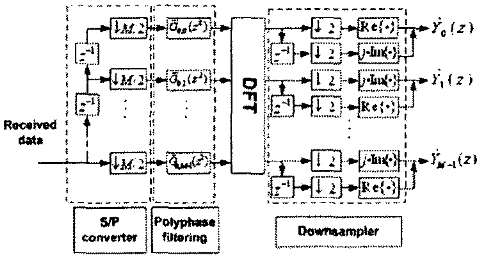

Fig. 1 PF-OFDM receiver

The detailed the PF-OFDM structure is presented in [1]. The structural difference between the PF-OFDM and the conventional OFDM is that the additional polyphase filtering blocks are added and downsampling and upsampling operations are performed. The introduction of polyphase filtering in the muti-carrier modulation systems leaded to performance improvement in the time and frequency domains. The PF-OFDM technique can transmit data without the guard interval. Although the PF-OFDM has better spectral efficiency, the unpredictable terms that occurred by polyphase filtering block and I/DFT block interfere pilot channel estimation. In section 3, we theorically explain this phenomenon and propose a reliable method to remove it.

3. Proposed channel estimation algorithm

In this section, we first explain the difficulty in the channel estimation of the PF-OFDM system, Here, we suppose that we place the pilot data as in the pilot-symbol aided OFDM system [5]. Then, the PF-OFDM system would have unpredictable real or imaginary terms in front of the real and imaginary operation blocks. Fig. 2 shows one part of the receiver. For known complex pilot data $c_k(n)$, the real and imaginary parts, $c_{k,R}(n)$ and $c_{k,I}(n)$, are fed into the input separately. The assignment of real and imaginary parts to pilot data with and without a phase offset varies from channel to channel [1]. In other words, it can be represented as

$$c_k(n) = \begin{cases} c_{k,R}(m) + j c_{k,I}(m-1), & k \text{ even} \\ c_{k,R}(m-1) + j c_{k,I}(m), & k \text{ odd} \end{cases} \tag{1}$$

where n and m are the sampling times in OFDM and PF-OFDM, respectively ($n=2m$).

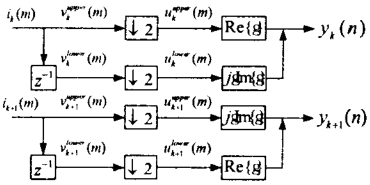

Fig. 2 Downsapler part of reciever

If pilot data pass through an ideal channel, the received pilot data in each branch of Fig. 2 can be expressed as

$$\begin{aligned} i_k(m) &= c_{k,R}(m) + j a_{k,I}(m) \\ i_k(m-1) &= a_{k,R}(m-1) + j c_{k,I}(m-1), \ k \text{ even} \end{aligned} \tag{2}$$

where $a_{k,R}$ and $a_{k,I}$ represent the unpredictable terms.

$$\begin{aligned} v_k^{upper}(m) &= c_{k,R}(m) + j a_{k,I}(m) \\ v_k^{upper}(m+1) &= a_{k,R}(m+1) + j c_{k,I}(m+1) \\ v_k^{lower}(m) &= a_{k,R}(m-1) + j c_{k,I}(m-1) \\ v_k^{lower}(m+1) &= c_{k,R}(m) + j a_{k,I}(m) \end{aligned} \tag{3}$$

$$\begin{aligned} u_k^{upper}(m) &= c_{k,R}(m) + j a_{k,I}(m) \\ u_k^{lower}(m) &= a_{k,R}(m-1) + j c_{k,I}(m-1) \end{aligned} \tag{4}$$

$$\begin{aligned} y_k(n) &= \hat{c}_k(n) \\ &= \mathrm{Re}\{\hat{c}_{k,R}(m) + j a_{k,I}(m)\} \\ &\quad + j\mathrm{Im}\{a_{k,R}(m-1) + j\hat{c}_{k,I}(m-1)\} \\ &= c_{k,R}(m) + j c_{k,I}(m-1) \end{aligned} \tag{5}$$

If the pilot data are contaminated by the multipath fading channel, the received pilot data can be expressed as

$$\begin{aligned} i_k(m) &= (c_{k,R}(m) + j a_{k,I}(m))(g_{k,R}(m) + j g_{k,I}(m)) \\ i_k(m-1) &= (a_{k,R}(m-1) + j c_{k,I}(m-1)) \\ &\quad \cdot (g_{k,R}(m-1) + j g_{k,I}(m-1)) \end{aligned} \tag{6}$$

where $g_k(n)$ represents a complex gain of the multipath fading,

$$g_k(n) = g_{k,I}(n) + j g_{k,Q}(n) \tag{7}$$

$$\begin{aligned} v_k^{upper}(m) &= (c_{k,R}(m) + j a_{k,I}(m)) \\ &\quad \cdot (g_{k,R}(m) + j g_{k,I}(m)) \\ v_k^{upper}(m+1) &= (a_{k,R}(m+1) + j c_{k,I}(m+1)) \\ &\quad \cdot (g_{k,R}(m+1) + j g_{k,I}(m+1)) \\ v_k^{lower}(m) &= (a_{k,R}(m-1) + j c_{k,I}(m-1)) \\ &\quad \cdot (g_{k,R}(m-1) + j g_{k,I}(m-1)) \\ v_k^{lower}(m+1) &= (c_{k,R}(m) + j a_{k,I}(m)) \\ &\quad \cdot (g_{k,R}(m) + j g_{k,I}(m)) \end{aligned} \tag{8}$$

$$\begin{aligned} u_k^{upper}(m) &= (c_{k,R}(m) + j a_{k,I}(m)) \\ &\quad \cdot (g_{k,R}(m) + j g_{k,I}(m)) \\ u_k^{lower}(m) &= (a_{k,R}(m-1) + j c_{k,I}(m-1)) \\ &\quad \cdot (g_{k,R}(m-1) + j g_{k,I}(m-1)) \end{aligned} \tag{9}$$

$$\begin{aligned} y_k(n) &= \hat{c}_k(n) \\ &= c_{k,R}(m) g_{k,R}(m) - a_{k,I}(m) g_{k,I}(m) \\ &\quad + j\begin{pmatrix} c_{k,I}(m-1) g_{k,R}(m-1) \\ + a_{k,R}(m-1) g_{k,I}(m-1) \end{pmatrix} \end{aligned} \tag{10}$$

$$\begin{aligned} \hat{c}_{k,R}(n) &= c_{k,R}(m) g_{k,R}(m) - a_{k,I}(m) g_{k,I}(m) \\ \hat{c}_{k,I}(n) &= c_{k,I}(m-1) g_{k,R}(m-1) \\ &\quad + a_{k,R}(m-1) g_{k,I}(m-1) \end{aligned} \tag{11}$$

As previously mentioned, the received pilot data are contaminated by the multipath fading channel. Moreover, the contaminated unpredictable real or imaginary terms are added in (11). Because of this phenomenon, it is difficult to estimate the complex gain of the multipath fading. Accordingly, we propose a solution to this problem. First of all, the real and imaginary parts of the pilot data are identically transmitted as follows;

$$c_{k,U}(m) = c_{k,R}(m) = c_{k,I}(m-1) \tag{12}$$

Then, we suppose that the complex gain of the multipath fading is constant during two-symbol duration of the PF-OFDM which is equal to one-symbol duration of the OFDM.

$$\begin{aligned} g_{k,R}(m) &\simeq g_{k,R}(m-1) \\ g_{k,I}(m) &\simeq g_{k,I}(m-1) \end{aligned} \tag{13}$$

The Real and imaginary parts of $u_k^{upper}(m)$ and $u_k^{lower}(m)$ are defined by

$$c_{k,U}(m) g_{k,R}(m) - a_{k,I}(m) g_{k,I}(m) = \alpha \tag{14}$$

$$c_{k,U}(m) g_{k,I}(m) + a_{k,I}(m) g_{k,R}(m) = \beta \tag{15}$$

$$a_{k,R}(m-1) g_{k,R}(m) - c_{k,U}(m) g_{k,I}(m) = \gamma \tag{16}$$

$$c_{k,U}(m) g_{k,R}(m) + a_{k,R}(m-1) g_{k,I}(m) = \delta \tag{17}$$

Adding (15) and (16), we obtain

$$g_{k,R}(m)\{a_{k,R}(m-1) + a_{k,I}(m)\} = \beta + \gamma \tag{18}$$

Subtracting (14) from (17), we get

$$g_{k,I}(m)\{a_{k,R}(m-1) + a_{k,I}(m)\} = \delta - \alpha \tag{19}$$

Dividing (18) by (19), we get the ratio of the real to imaginary part of the complex gain of the multipath fading:

$$g_{k,R}(m)/g_{k,I}(m) = \beta + \gamma/\delta - \alpha = \lambda \tag{20}$$

where λ is a constant real value.

Dividing $u_k^{upper}(m)$ and $u_k^{lower}(m)$ by $\lambda + j$, we can remove the effect of the unpredictable terms.

$$
\begin{aligned}
u_k^{upper}(m) &= (c_{k,R}(m) + ja_{k,I}(m)) \cdot \\
&\quad ((g_{k,R}(m) + jg_{k,I}(m)) / (c_{k,R}(m)(\lambda + j)) \\
&= (1 + ja_{k,I}(m)/c_{k,R}(m))(g_{k,R}(m)\lambda \\
&\quad + g_{k,I}(m) + jg_{k,I}(m)\lambda - jg_{k,R}(m)) \\
&= (1 + ja_{k,I}(m)/c_{k,R}(m)) \cdot \\
&\quad \left(\frac{g_{k,R}(m)\lambda + g_{k,I}(m)}{\lambda^2 + 1} \right)
\end{aligned} \tag{21}
$$

$$
\begin{aligned}
u_k^{lower}(m) &= (a_{k,R}(m-1) + jc_{k,I}(m-1)) \cdot \\
&\quad \left(\begin{matrix} (a_{k,R}(m-1) + jg_{k,I}(m-1)) \\ /(c_{k,I}(m-1)(\lambda + j)) \end{matrix} \right) \\
&= (a_{k,R}(m-1)/c_{k,I}(m-1) + j) \cdot \\
&\quad \left(\frac{g_{k,R}(m) + g_{k,I}(m)}{\lambda^2 + 1} \right)
\end{aligned} \tag{22}
$$

$$
\begin{aligned}
y_k(n) &= \left(\frac{g_{k,R}(m)\lambda + g_{k,I}(m)}{\lambda^2 + 1} \right) \\
&\quad + j\left(\frac{g_{k,R}(m)\lambda + g_{k,I}(m)}{\lambda^2 + 1} \right)
\end{aligned} \tag{23}
$$

Using $\lambda + j$ and (23), we can compensate for multipath fading channel.

$$
\begin{aligned}
& u_k^{upper}(l) \\
&= (x_{k,R}(l) + ja_{k,I}(l)) \\
&\quad ((g_{k,R}(l) + jg_{k,I}(l)) / (\lambda + j)) \cdot \\
&\quad \left(\frac{\lambda^2 + 1}{g_{k,R}(m)\lambda + g_{k,I}(m)} \right) \\
&= (x_{k,R}(l) + ja_{k,I}(l)) \left(\frac{g_{k,R}(l)\lambda + g_{k,I}(l)}{\lambda^2 + 1} \right) \\
&\quad \cdot \left(\frac{\lambda^2 + 1}{g_{k,R}(m)\lambda + g_{k,I}(m)} \right)
\end{aligned} \tag{24}
$$

where we suppose that the channel is slowly fading for one frame block. So we can write as follows.

$$
\frac{g_{k,R}(l)\lambda + g_{k,I}(l)}{\lambda^2 + 1} \simeq \frac{g_{k,R}(m)\lambda + g_{k,I}(m)}{\lambda^2 + 1}, \quad \text{for } |l - m| < \text{one frame} \tag{25}
$$

Substituting (25) into (24) yields

$$
u_k^{upper}(l) \simeq x_{k,R}(l) + ja_{k,I}(l) \tag{26}
$$

In the same way, $u_k^{lower}(l)$ can be obtained as

$$
u_k^{upper}(l) \simeq x_{k,I}(l+1) + ja_{k,I}(l+1) \tag{27}
$$

Consequently, the information data are compensted over the multipath fading channel.

$$
\begin{aligned}
y_k(n) &= \text{Re}\{u_k^{upper}(l)\} + j\text{Im}\{u_k^{upper}(l)\} \\
&= x_{k,R}(l) + jx_{k,I}(l+1)
\end{aligned} \tag{28}
$$

4. Simulation

In this section, we demonstrate the performance of the proposed algorithm for the PF-OFDM system. First, we briefly describe the simulated PF-OFDM system.

A. System parameters

In our simulation, the uncoded BER performance of the proposed pilot-symbol-aided PF-OFDM system is compared with the ideal channel estimation scheme and the conventional pilot-symbol-aided OFDM system with guard interval(OFDM/GI). In the simulation, 64-subcarrier, QPSK-modulated OFDM symbol are transmitted over the two-path Rayleigh fading channels. The delayed path has a 0.11 μs delay spacing and a relative power of -10dB. The useful OFDM symbol duration and guard interval duration are set to 3.2 μs and 0.8 μs, respectively. The maximum Doppler frequency is 150 Hz at 5 GHz.

B. Simulation results

Fig. 3 shows the performance of the uncoded BER. The performance of the proposed algorithm is shown to be equivalent to that of the pilot-symbol-aided OFDM/GI. One can observe a slight performance degradation over $E_b/N_o = 25$ dB compared to pilot-symbol-aided OFDM/GI, which we suspect that the choice of the prototype filter caused it.

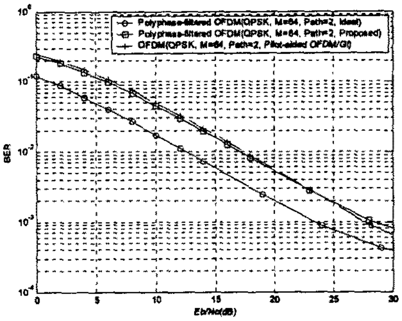

Fig. 2 Performance of the BER

5. Conclusion

In this paper, we have studied a pilot-symbol channel estimation algorithm for the PF-OFDM system. We observed that the unpredictable terms of the PF-OFDM make channel estimation difficult. To remove the effect of these unpredictable terms, we proposed an algorithm suitble for the PF-OFDM. The characteristic of the proposed algorithm is that the ratio of real to imaginary part of the complex gain of multipath fading can be obtained through a linear combination of received pilot data and used for removing the effect of unpredictable terms. In simulation, the performance of proposed algorithm in the presence of multipath rays was evaluated . The placement of pilot-symbol used for the proposed algorithm is based on basic placement of pilot-symbol-aided OFDM systems. The proposed algorithm can be applied to structures that have another pilot symbol placement such as scattered pilot symbol.

[Reference]

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