Generalization of channel estimation weights for multiple differential detection based on per-survivor processing

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Abstract: This paper proposes novel channel estimation weights for multiple differential detection based on per-survivor processing (PSP-MDD). Channel estimation weights for PSP-MDD can control a trade-off between performance in the required signal-to-noise power ratio (SNR) and tracking capability. There have been proposed the two channel estimation weights: weights of simple first-order channel prediction and weights of higher-order channel prediction based on the binomial theorem. In order to control this trade-off widely and precisely, this paper proposes channel estimation weights generalizing the two conventional weights. Finally, computer simulation results confirm that the proposed weights can control the trade-off widely and precisely.

Keywords: differential encoding, multiple differential detection, per-survivor processing, channel prediction, fast time-varying channels

Classification: Transmission Systems and Transmission Equipment for Communications

References


1 Introduction

Fast time-varying fading channels are serious issues for underwater acoustic communications (UWAC) and wide-area point-to-multi point (P-MP) communications [1, 2]. Multiple differential detection based on per-survivor processing (PSP-MDD) employing channel prediction is one of good approaches for fast-time varying channels [3]. PSP-MDD can control a trade-off between performance in the required signal-to-noise power ratio (SNR) and tracking capability according to its channel estimation weights. In the absence of channel state information (CSI), channel estimation weights are derived according to parameters of a maximum order of channel prediction \( L \) and an observation symbol number of the received signals \( N \). The following two channel estimation weights have been proposed in [3]:

1) channel estimation weights of simple first-order channel prediction for an arbitrary \( N \);
2) channel estimation weights of higher order channel prediction employing the binominal theorem for an arbitrary \( L \) and a fixed \( N (N = L + 1) \).

Thus, the channel estimation weights have the following constraints:
- an arbitrary \( N \) but \( L = 1 \);
- an arbitrary \( L \) but \( N = L + 1 \).

Thus, these channel estimation weights cannot be derived for an arbitrary \( L \) and an arbitrary \( N \).

This paper proposes generalized channel estimation weights for an arbitrary \( L \) and an arbitrary \( N \) expanding the simple first-order channel prediction. Computer simulation results confirm that the proposed weights can widely and precisely control the trade-off between performance in the required SNR and tracking capability.

2 Communication system model

Fig. 1 shows a single-input multiple-output (SIMO) communication system model with \( N_R \) receive antennas. In Fig. 1, the SIMO channel has the channel impulse responses (CIRs) at symbol time \( k \) received at the \( q \)th \((q = 1, 2, \ldots, N_R)\) receive antenna in the absence of intersymbol interference (ISI), \( h_k[q] \). The transmitted information signal \( b_k \) \((b_k \in \{0, 1, \ldots, 2^m - 1\})\), i.e., \( m \) bps/Hz) is converted to the following modulated information signal \( u_k \):

\[
 u_k = \exp\left( \frac{2\pi}{M} b_k \right),
\]

where the modulated information signal \( u_k \) is assumed \( M \)-ary phase shift keying (PSK) signals \((M = 2^m)\). The transmitted modulation signal \( x_k \) is:

\[
 x_k = u_k x_{k-1},
\]

where \( x_0 = 1 \). The transmitted modulation signal \( x_k \) is corrupted by additive white Gaussian noise (AWGN) at symbol time \( k \) received at the \( q \)th receive antenna, \( w_k[q] \), resulting in the following received signal at symbol time \( k \) received at the \( q \)th receive antenna, \( r_k[q] \):

\[
 r_k[q] = h_k[q] x_k + w_k[q].
\]
A demodulator estimates the information signal, i.e., decisions $\hat{b}_k$, according to the received signals $r_k[q]$. 

3 Conventional channel estimation weights for PSP-MDD

3.1 Branch metric of PSP-MDD

PSP-MDD estimates information sequence based on the Viterbi algorithm (VA) [3]. This paper denotes a candidate of the transmitted information sequence as $\{\tilde{b}_k\}$. In this paper, $\tilde{a}_k$ denotes a candidate of signal $a_k$ corresponding to $\{\tilde{b}_k\}$. The path metric $H$ and the branch metric $\Gamma_k$ of the VA are defined as follows:

$$H = \sum_k \Gamma_k,$$

$$\Gamma_k = -\sum_{q=1}^{N} |r_k[q] - \tilde{r}_k[q]|^2.$$ (4) (5)

PSP-MDD calculates the path metric $H$ for each $\{\tilde{b}_k\}$ and selects $\tilde{b}_k$ with the maximum $H$ as the estimated information sequence $\{\tilde{b}_k\}$. An estimate of the received signal $\tilde{r}_k[q]$ in Eq. (5) denotes a candidate of the received signal $r_k[q]$. In the absence of ISI, $\tilde{r}_k[q]$ can be denoted as follows:

$$\tilde{r}_k[q] = \tilde{h}_k[q]\tilde{x}_k,$$ (6)

where $\tilde{h}_k[q]$ is a candidate of the estimated CIR and $\tilde{x}_k$ is a candidate of the transmitted modulation signal. $\tilde{h}_k[q]$ is written as the following equation:

$$\tilde{h}_k[q] = \sum_{n=1}^{N} v_n \tilde{G}_{k-n}[q],$$ (7)

$$\tilde{G}_{k}[q] = r_k x_k^*,$$ (8)

where $a^*$ denotes the complex conjugate of $a$, $\tilde{G}_{k-n}[q] (n = 1, 2, \cdots, N)$ is a reverse-modulated value, $N$ is an observation symbol number of the received signals, and $v_n$ is channel estimation weights for the reverse-modulated value $\tilde{G}_{k-n}[q]$. PSP-MDD predicts the CIR at time $k$ by the channel estimation weights $v_n$ and the reverse-modulated value $\tilde{G}_{k-n}[q]$ at time $(k - n)$ for the CIR estimation. For channel prediction, the reverse-modulated value from time $(k - N)$ to time $(k - 1)$ are approximated to $L$-th order function.
3.2 Channel estimation weights of simple first-order channel prediction

Ref. [3] has proposed the following channel estimation weights $v_n$:

$$v_n = \begin{cases} 
  N/(N - 1) & n = 1 \\
  -1/(N - 1) & n = N \\
  0 & \text{otherwise}
\end{cases}$$  \hspace{1cm} (9)

Let us denote that the conventional channel estimation weights of Eq. (9) are channel estimation weights of simple first-order channel prediction (SFP). For SFP, the order of channel prediction $L$ is 1. SFP can improve performance in the required SNR for a larger $N$. However, the larger $N$ causes degradation of tracking capability on fast time-varying channels.

3.3 Channel estimation weights of higher order channel prediction employing the binominal theorem

Ref. [3] has also proposed the following channel estimation weights $v_n$:

$$v_n = (-1)^{n-1} \binom{N}{n} \quad (n = 1, 2, \cdots, N).$$  \hspace{1cm} (10)

Let us denote that the conventional channel estimation weights of Eq. (10) are channel estimation weights of higher order channel prediction employing the binominal theorem (HBT). For HBT, the order of channel prediction $L$ is equal to $(N - 1)$. HBT can improve tracking capability for a larger $L$. However, the larger $L$ causes degradation of performance in the required SNR.

4 Generalized channel estimation weights for PSP-MDD

This section proposes generalized channel estimation weights for PSP-MDD. The generalized channel estimation weights are derived for an arbitrary $L$ and an arbitrary $N$. In this section, $[q]$ is omitted for its simplicity.

The conventional SFP estimates a value of first-order channel variation by calculating a difference of the reverse-modulated values at time $(k - N)$ and that at time $(k - 1)$. Expanding the concept of SFP, this section proposes channel estimation weights which estimate a value of higher-order channel variation. Similar to SFP in Eq. (9), an first-order average channel variation $\Delta G_k$ for unit time interval is calculated as the follows:

$$\Delta G_k = \frac{1}{N-L} (G_{k-1} - G_{k-N+L-1}).$$  \hspace{1cm} (11)

An estimated value of $l$-th order channel variation $\Delta G^{(l)}_k$ can be recursively derived as follows:

$$\Delta G^{(l)}_k = \Delta G^{(l-1)}_k - \Delta G^{(l-1)}_{k-1} \quad (l = 2, 3, \cdots, L),$$  \hspace{1cm} (12)

where an estimated value of first order channel variation for unit time interval, $\Delta G^{(1)}_k$, is:

$$\Delta G^{(1)}_k = \Delta G_k.$$  \hspace{1cm} (13)
The estimated CIR at time $k$, $\hat{h}_k$, is calculated by summation of $G_{k-1}$ and overall $\Delta G_k^{(l)}$’s as follows:

$$\hat{h}_k = G_{k-1} + \sum_{l=1}^{L} \Delta G_k^{(l)}.$$  \hspace{1cm} (14)

Although it is difficult to provide exact formulation of $v_n$ for Eq. (14), these $v_n$ can be obtained by the following relationship:

$$\sum_{n=1}^{N} v_n G_{k-n} = G_{k-1} + \sum_{l=1}^{L} \Delta G_k^{(l)}.$$  \hspace{1cm} (15)

Let us denotes that the proposed channel estimation weights $v_n$ for Eq. (14) are generalized channel estimation weights. For $L = 1$, the channel estimation weights $v_n$ of Eq. (9) is equivalent to that for Eq. (14). For $L = N - 1$, the channel estimation weights $v_n$ of Eq. (10) is equivalent to that for Eq. (14). Therefore, the proposed weights can generalize the conventional SFP and HBT.

5 Computer simulation results

This section evaluates the BER performances of PSP-MDD employing the proposed generalized channel estimation weights. This paper assumes that a modulation scheme is BPSK, $N_R$ is 1, and channels suffers from independent Rayleigh fading in the absence of ISI, where the maximum Doppler frequency normalized by symbol rate, $f_D T$, of 0% corresponds to quasi-static fading channels. Fig. 2 shows BER performances of PSP-MDD with the proposed weights as a function of average $E_b/N_0$ on quasi-static fading channels, where BER of differential detection (DD) is also plotted for reference. On the other hand, Fig. 3 shows BER performances in the absence of noises as a function of $f_D T$, where BER of DD is also plotted for reference.

From Figs. 2 and 3, we can obtain the following results:

- A larger $L$ improves tracking capability, and a smaller $L$ improves performance in the required SNR;
A smaller $N$ improves tracking capability, and a larger $N$ improves performance in the required SNR. Thus, the proposed weights can control the trade-off between performance in the required SNR and tracking capability more widely and more precisely than the conventional SFP and HBT.

6 Conclusion

This paper has proposed the channel estimation weights for PSP-MDD which generalize the two conventional channel estimation weights. The proposed weights are derived for an arbitrary order of channel prediction $L$ and an arbitrary observation symbol number of the received signals $N$. Computer simulation results have confirmed the proposed weights can control the trade-off between performance in the required SNR and tracking capability widely and precisely.

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