Double decision-feedback multiple differential detection for double differential encoding

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Abstract: This paper proposes double decision-feedback multiple differential detection (DDFMDD) of double differential encoding (DDE) for fast time-varying Rayleigh fading. DDE can improve tracking capability at a large modulation alphabet size. In order to improve performance in the required signal to noise power ratio (SNR) and tracking capability aiming at higher frequency efficiency, the proposed DDFMDD employs decision-feedback multiple differential detection (DFMDD) with channel averaging and DFMDD with channel prediction. Finally, computer simulation results confirm that the proposed DDFMDD has excellent bit error rate (BER) performance for fast time-varying Rayleigh fading at a larger modulation alphabet size.

Keywords: Double Differential Encoding, Underwater Acoustic Communication, Decision-Feedback Differential Detection, Fast Time-Varying Channels, Channel Prediction

Classification: Wireless Communication Technologies

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1 Introduction
For acoustic communications, it is important to combat severe doubly-selective channels. Especially doubly-selective channels are a serious issue for underwater acoustic communications (UWAC) [1]. To cope with severe doubly-selective channels, there exist the following two important items:

1) to improve tracking capability for time-selective channels, e.g., larger maximum Doppler frequency normalized by symbol rate, $f_D T$;

2) to mitigate performance degradation due to frequency-selective channels, e.g., larger maximum delay interval normalized by symbol duration, $\tau_D / T$,

where $T$ is symbol duration. In order to cope with doubly-selectivity, this paper focuses on the item 1), i.e., performance improvement for larger $f_D T$. In order to improve tracking capability, differential encoding (DE) and differential detection (DD) are one of good approaches. However, DE/DD suffers from serious performance degradation on extremely fast time-varying channels.

In order to cope with frequency offset, double differential encoding (DDE) has been studied by several researchers [2], [3]. In addition, DDE and double differential detection (DDD), i.e., DDE/DDD, have better tracking capability compared with DE/DD at a higher modulation alphabet size. However, there are not many studies of DDE for fast time-varying Rayleigh fading. DE/DD have been employed for mobile radio communications. For further performance improvement, it has been proposed decision-feedback multiple differential detection (DFMDD) with channel averaging [4] and DFMDD with channel prediction [5]. These DFMDDs can realize a good performance in the required signal to noise power ratio (SNR) and tracking capability on fast time-varying channels, respectively. Since DDE needs two DE demodulators, DDE can be demodulated by combination of these DFMDDs.

This paper proposes double DFMDD (DDFMDD) employing two DFMDDs, aiming at a larger modulation alphabet size for fast time-varying Rayleigh fading. In order to improve both performance in the required SNR and tracking capability at a higher modulation alphabet size, the proposed DDFMDD employs DFMDD with channel averaging and DFMDD with channel prediction. Computer simulation results confirm that the proposed DDFMDD has excellent bit error rate (BER) performance. For example, assuming two receive antennas, the proposed scheme can achieve a frequency efficiency of 4bits/symbol and can track $f_D T$ of 6%.

2 Communication System Models
2.1 Communication Systems
This paper assumes a communication system model with $N_R$ receive antennas. $a_k[q]$ denotes a signal $a$ at symbol time $k$ received at the $q$th ($q = 1, 2, \cdots, N_R$) receive antennas. This paper assumes that single-input multiple-output (SIMO) channels have the channel impulse responses (CIRs) of $h_k[q]$
in the absence of intersymbol interference (ISI). A modulator generates the modulated information signal \( u_k \) according to the information transmitted signal \( (b_k \in \{1, 2, \ldots, 2^m-1\} \), i.e., mbit/symbol) as follows:

\[
 u_k \in \{\exp(j2\pi i/M) \mid i = 1, 2, \ldots, 2^m-1\},
\]

where \( M(=2^m) \) is the modulation alphabet size and \( u_k \) is \( M \)-ary phase shift keying (PSK). The transmitted double differential phase shift keying (DDPSK) modulated signal \( y_k \) is given by:

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

\[
 y_k = x_k y_{k-1},
\]

where \( x_0 = 1 \) and \( y_0 = 1 \). The transmitted modulation signal \( y_k \) is transmitted through the SIMO channel with the CIRs of \( h_k[q] \) and suffers from additive white Gaussian noise (AWGN) \( w_k[q] \), resulting in the received signal \( r_k[q] \):

\[
 r_k[q] = h_k[q] y_k + w_k[q].
\]

A DDE demodulator estimates the information signal, i.e., decision \( \hat{b}_k \), according to the received signal \( r_k[q] \).

### 2.2 Algorithm of DFMDD

DFMDD has been studied as a demodulation scheme for DE. DFMDD inputs signals \( s_k[q] \) and detects the following soft decision \( \tilde{g}_k \) according to the sum of DD values, \( s_k[q]s_{k-n}^* \), weighted by the tap coefficient \( v_n \) as follows:

\[
 \tilde{g}_k = \sum_{q=1}^{N_R} \sum_{n=1}^{N} v_n \hat{G}_k^{(n)} s_k[q]s_{k-n}^*[q],
\]

\[
 \hat{G}_k^{(n)} = \hat{g}_{k-1} \hat{g}_{k-2} \cdots \hat{g}_{k-n+1},
\]

where \( \hat{G}_k^{(1)} \) is 1, \( a^* \) denotes the complex conjugate of \( a \), and \( N \) is the observation range of the input signals. We can obtain the hard decision \( \hat{g}_k \) by performing the hard decision for the soft decision \( \tilde{g}_k \). Performance of DFMDD is highly dependent on the tap coefficient \( v_n \). In order to improve performance in the required SNR, the tap coefficient of channel averaging \( v_n \) can be given by:

\[
 v_n = \frac{1}{N}.
\]

A related work [5] has described DFMDD with channel prediction in order to improve tracking capability on fast time-varying channels. The tap coefficient of channel prediction \( v_n \) can be given by:

\[
 v_n = \begin{cases} 
 \frac{N}{N-1} & n = 1 \\
 \frac{N-1}{N-1} & n = N \\
 0 & \text{otherwise} 
\end{cases}
\]

\( N \) can control a trade-off between performance in the required SNR and tracking capability. A larger \( N \) improves performance in the required SNR, and vice versa. From (7) and (8), DFMDD can switch between channel averaging and channel prediction by the tap coefficient.
3 Double Decision-Feedback Multiple Differential Detection

DE/DD aiming at a higher modulation alphabet size suffers from serious performance degradation on fast time-varying fading channels. In addition, there exists a trade-off relationship between performance in the required SNR and tracking capability. This paper proposes DDFMDD that has a good trade-off between performance in the required SNR and tracking capability. In order to improve this trade-off, the proposed scheme employs DFMDD with channel averaging and DFMDD with channel prediction.

Fig. 1 shows a block-diagram of the proposed DDFMDD. The proposed DDFMDD consists of 1st-loop DFMDD and 2nd-loop DFMDD, where Table corresponds to function of $\hat{G}(n)$ of Eq. (6). First, 1st-loop DFMDD generates the soft decision signal $\hat{x}_k$ according to the received signals $r_k[q]$. Next, 2nd-loop DFMDD estimates the information signal $\hat{u}_k$ according to the soft decision signal $\hat{x}_k$. Each DFMDD can switch between channel averaging and channel prediction by the tap coefficient $v_n$. Thus, the proposed DDFMDD can manage both performance in the required SNR and tracking capability according to set appropriate value of the tap coefficient $v_n$.

4 Computer Simulation

This section compares BER performances of the proposed DDFMDD by computer simulations. In following figures of simulations, $\text{ave}$ and $\text{pre}$ mean the channel averaging and channel prediction, respectively. For a transmit side, the number of transmitted information bits per symbol, $m$, is 4, and one slot has 960-symbol data. For a receiver side, the received signal is sampled at the Nyquist timing, and the number of received antennas, $N_R$, is 2. Channels are assumed independent Rayleigh fading channels without ISI. $f_{DT}$ of 0% corresponds to quasi-static fading channels, where channel variation due to Rayleigh fading is negligible during a unit data slot.

Fig. 2 shows BER performance as a function of average $E_b/N_0$ on quasi-static fading channels. Fig. 3 shows BER floor performance as a function of $f_{DT}$, where average $E_b/N_0$ is $\infty$. In the simulations, the observation range $N$’s of DFMDD with channel averaging and channel prediction are 4 and 5, respectively. This is because $1/4$ and $1/(5-1)$ can be implemented not by multiplication but by bit-shift operation. From these figures, we can obtain...
Fig. 2. BER performance as a function of average $E_b/N_0$ on quasi-static fading channels ($f DT = 0\%$).

Fig. 3. BER floor performance as a function of $f DT$.

the following results:

- from the viewpoint of performance in the required SNR for DDE, BER
performance of the proposed DDFMDD employing DFMDD with channel averaging is better than DFMDD with channel prediction;

- from the viewpoint of tracking capability, BER performance of the proposed DDFMDD employing 1st-loop DFMDD with channel prediction has better tracking capability, however the proposed DDFMDD employing 2nd-loop DFMDD with channel prediction suffers from tracking capability degradation.

In addition, DE/DD has the best performance in the required SNR, because DE does not suffer from noise enhancement due to double differential detection. However, DE/DD suffers from tracking performance degradation at large $f_D T$. Thus, DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DFMDD with channel averaging has excellent tracking capability, keeping relatively good performance in the required SNR. Although DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DD has slightly better tracking performance than DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DFMDD with channel averaging. However, DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DD suffers from approximately 2dB degradation in the required SNR compared with DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DFMDD with channel averaging. Thus, DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DFMDD with channel averaging can improve tracking capability and performance in the required SNR at a frequency efficiency of 4bits/symbol.

5 Conclusion

This paper has proposed DDE/DDFMD for fast time-varying Raleigh fading, where DFMDDs operate based on channel averaging and channel prediction. Computer simulation results have confirmed that the proposed DDFMDD has a good trade-off between performance in the required SNR and tracking capability. In addition, the proposed DDFMDD employing 1st-loop DFMDD with channel prediction and 2nd-loop DFMDD with channel averaging can track $f_D T$ of 6% at a frequency efficiency of 4bits/symbol.

This paper does not discuss frequency selectivity due to ISI and does not evaluate performance of multi-carrier modulation schemes employing DDE/DDD on doubly-selective channels. This topic is under consideration by the authors.

Acknowledgments

This work was partly supported by JSPS Grants-in-Aid for Scientific Research (KAKENHI) Grant Number 16K06374.