Digital Modulation Signal Separation Received by Single Antenna using TDL-ICA

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Abstract: Recently, signal source separation technique using independent component analysis (ICA) have been attracting attention in the field of wireless communications. Furthermore, TDL-ICA, which combined a tapped delay line with ICA to increase the number of separable signals with fewer elements, has been proposed. However, the application to the digital modulation has not been considered enough. In this paper, it is shown that the TDL-ICA can separate the overlapped digital modulated signals in the frequency domain by setting the appropriate parameters of the TDL, and the relationship between the number of taps of the TDL and the separation performance is clarified.

Keywords: blind signal source separation, independent component analysis, tapped delay line, digital modulation

Classification: Wireless Communication Technologies

References

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1 Introduction
In recent years, digital modulation systems have been widely used in wireless communications. However, this system has some problems and limitations, such as the strong influence of noise on the transmission line, which makes decoding difficult, and the need for separation operations on the receiving side due to interference with other signals. Therefore, Independent Component Analysis (ICA) [1], a blind source separation technique, which has been studied in the field of wireless communications is effective. However, ICA is an applicable method only under the condition that $M \geq N$ [2] ($M$ is the number of elements, $N$ is the number of independent signals). To solve this problem, Tapped Delay Line-ICA (TDL-ICA) [3], which combined a tapped delay line with ICA to increase the number of separable signals with fewer elements, has been proposed. But the application of this method to digitally modulated signals, which have been widely used in recent years, has not been examined enough.

In this paper, the separation ability of TDL-ICA is confirmed in the case where three digital modulated signals arrive at a single antenna, and they are overlapped in frequency domain by setting the TDL parameters appropriately. This paper is organized as follows. The source separation using TDL-ICA is explained in Section 2. Simulation conditions are explained in Section 3. Separated signals obtained by simulations are shown and the performance is discussed in Sec 4. The conclusion is provided in Section 5.

2 Signal source separation using TDL-ICA

2.1 Concept of TDL-ICA
Concept and transmission model of TDL-ICA and conventional ICA is shown in Fig.1. Conventional ICA (Fig.1(b)) can only separate signal sources that are less than or equal to the number of receiving antenna. Moreover, that can only separate signals which arrive from different direction like multiple access environment. TDL-ICA (Fig.1(a)) has been proposed to increase the number of separable signals by introducing tapped delay lines (TDL). TDL act as a frequency filter by set the weight coefficients appropriately for each delayed signal. On the other hand, TDL-ICA used in this paper, multiple signals with different delays are generated using TDL and input to ICA. Through this process, the signals in the frequency domain are separated. This corresponds to the separation of signals in the angular region by using an array antenna composed of multiple antennas in the spatial region as shown in Fig.1(b). So, in this paper we suppose that different transmission signals with different frequency shifts are multiplexed and transmitted by a single antenna. Then, the signal is received by a signal antenna and separated by TDL-ICA.

2.2 Optimal parameters of TDL
The frequency power spectrum of a digital modulated signal is shown in Fig.1(c). The power spectrum of the digital modulated signal can be divided into the main
lobe with the strongest peak and the side lobes with other smaller peaks. The parameters of the TDL section can be expressed in terms of time and frequency domains as follows:

\[
\tau = \Delta f \\
N = 1 / B * \tau
\]

(1) (2)

Here, \( \tau \) is the delay time of the TDL, \( N \) is the number of taps, \( \Delta f \) is the frequency band to be extracted, and \( B \) is the frequency band that can be processed (Fig.1(d)). This is just like the relationship between aperture length, element spacing and directivity in the directivity control of array antennas.

\[\text{Fig. 1. Concept and Structure of ICA and TDL-ICA}\]

(2.3) Signal process in TDL-ICA

In this paper, the complex FastICA[4] is used as the separation algorithm in TDL-ICA. The procedure of the FastICA algorithm in TDL-ICA for a single antenna is described below. At first, \( x(t) \) is obtained as the received signal. Then,
time delays are applied by TDL, so the input signal vector of ICA is expressed as
\[ x^T = \begin{bmatrix} x(t), x(t + \tau), x(t + 2\tau) \ldots x(t + (n-1)\tau) \end{bmatrix}^T \]  
(3)
where \( n \) is the number of taps, and superscript \( T \) represents transpose. Then, complex FastICA is applied to the input signal as same as conventional ICA to obtain separated signals. The separated signal can be expressed as follows:
\[ y = W^H x \]
\[
\begin{bmatrix} w_{11}x(t) + w_{12}x(t + \tau) + \ldots + w_{1n}x(t + (n-1)\tau) \\ w_{21}x(t) + w_{22}x(t + \tau) + \ldots + w_{2n}x(t + (n-1)\tau) \\ \vdots \\ w_{n1}x(t) + w_{n2}x(t + \tau) + \ldots + w_{nn}x(t + (n-1)\tau) \end{bmatrix} \]  
(4)
where \( W \) is separation matrix determined by complex FastICA and superscript \( H \) represents Hermitian transpose. Then, the output signal is expressed as the sum of the delayed signals weighted by the coefficients. FastICA in TDL-ICA can separate the independent frequency components from the received signal without prior information.

### 3 Simulation condition

The performance of the TDL-ICA is confirmed through numerical simulation. The transmission model is shown in Fig.1(a), where the three signals(s1-s3) are overlapped in the frequency domain at the transmitter side, and only the direct wave arrives at the receiving antenna. The number of source signals are three, modulation scheme is QPSK. Here, total number of symbols is 1024, and they are transmitted at the same level. Fig.2(a), Fig.2(b) and Fig.2(c) shows the constellation of each source signal, respectively. Fig.2(d) shows the power spectrum of the three signals. As shown in Fig.2(d), each signal is overlapped in the frequency domain half of main lobe width. The constellation of the signal received by the single antenna is shown in Fig.2(e), and the power spectrum is shown in Fig.2(f). From the spectrum of each signal, the frequency band to be extracted, \( \Delta f = 10\text{kHz} \), and the frequency band that can be processed, \( B = 30\text{kHz} \) or more. Therefore, we simulated \( B=30\text{kHz}, 40\text{kHz}, 50\text{kHz}, \) and 60kHz. In this case, \( \tau = 0.33, 0.25, 0.20 \) and 0.17ms and \( N = 3, 4, 5 \) and 6. The received signal is input to the TDL-ICA. SNR of received signal is set to 10dB. Here, SNR is defined as a power ratio of received signal to thermal noise. The signal separation performance is evaluated by the BER.
Fig. 2. Input signals in Simulation

4 Simulation results and discussion

Fig.3 shows the separation results of TDL-ICA. Fig.3(a)-(c) show the output power spectrum of TDL-ICA when $\tau = 3$. Fig.3(d) shows the average BER for each number of taps. From Fig.3(a)-(c), it can be confirmed that the TDL-ICA is able to separate each input signal component because each power spectrum has a frequency component of the transmitted signals. From Fig.3(d), we found that as the number of taps increases, the average of BER becomes smaller. This is because when the number of outputs exceeds the number of signals, the thermal noise component is separated into outputs other than the output in which the desired signal appears. In addition, the reason why BER deteriorates when the number of taps is 4 than when the number of taps is 3 is as follows. When the number of taps is 3, the thermal noise component is evenly distributed to three outputs. On the other hand, when the number of taps is 4, the number of outputs is not large enough, and there are outputs that contain a lot of thermal noise components. When the number of taps is 5 or more, it is considered that the thermal noise component is
discharged from the output that does not include the desired signal.

(a) Power spectrum of 1st output  
(b) Power spectrum of 2nd output  
(c) Power spectrum of 3rd output

(d) Average BER for the number of taps  
Fig.3 Output of TDL-ICA

5 Conclusion
It was confirmed that the signal separation by TDL-ICA was possible when three waves of digital modulated signals arrive at a single antenna by setting the appropriate parameters of the TDL. It was also shown that the separation performance is improved by increasing the number of taps.