Examination of signal separation / demodulation method of multi-value modulation sensor terminal signal using STFT in storage batch signal processing

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Abstract: In this paper, in order to establish the storage batch signal processing technology on the network, the method of separating the IoT / M2M terminal signal that collided or interfered and the method of demodulating the data after signal separation, which cannot be realized by the conventional receivers. We proposed a method of signal separation by feature quantity extraction using short-time Fourier transform and the method of using the obtained feature quantity for demodulation. In addition, the effectiveness of the proposed method for multi-valued modulated signals will be evaluated by computer simulation.

Keywords: Stored batch signal processing, IoT, M2M, Short-time Fourier transform, Signal separation

Classification: Wireless communication technologies

References

[1] Takayuki Yamada, Doohwan Lee, Hiroyuki Shiba, Yo Yamaguchi, Kazunori Akabane, and Kazuhiro Uehara, “Signal separation and Reconstruction method for simultaneously received multi-system signals in Flexible Wireless System,” IEICE Transactions on Communications, vol. E95-B, no. 4, pp. 1085-1092, April 2012.

[2] Toru Nishiyama, Ryuku Miyachi, Humiya Ohno, Shigeru Tomisato, Satoshi Denno, Kazuhiro Uehara, “A study of signal separation / demodulation method by accumulated batch signal processing” The 2019 IEICE Conference, no. B17-12, Sep. 2019.

[3] Toru Nishiyama, Takuyuki Hirakawa, Syo Nakaie, Shigeru Tomisato, Satoshi Denno, Kazuhiro Uehara, “A study on window function and window width of STFT in collision signal separation and demodulation method using stored batch signal processing” ICETC 2020, no. C4-1, Dec. 2020.
1 Introduction

The IoT era is approaching, and there are problems that many low-function terminals communicate randomly and cannot receive due to collision or interference within limited frequency resources, and sometimes threaten safe and secure for people. Therefore, in order to establish a stored batch signal processing technology on the network, we aim to separate and demodulate collided signals and interfered signals, which cannot be realized with conventional receivers.

To achieve this purpose, we propose a signal separation method using feature extraction by short-time Fourier transform (STFT) as a signal separation method used for stored batch signal processing [1], and a feature demodulation method as a demodulation method [2]. Of these, regarding the data demodulation method, it is known that when the BPSK and QPSK modulation method signals are separated, the same performance as when using the conventional synchronous detection method can be obtained. In this paper, we compare the conventional method and the proposed method by computer simulation using 16QAM modulation method signals as a more multi-value modulation method, and evaluate the effectiveness of the feature demodulation method, which is the proposed method.

2 Signal separation method using feature extraction by STFT

For signal separation, the power component and phase component on the center frequency of the desired signal are extracted as features from the temporally continuous frequency characteristics of the superimposed received signal by STFT.

After that, the desired signal is restored by multiplying the power component and the phase component of the reference signal, which is an unmodulated signal having the same frequency as the center frequency of the desired signal. When STFT is performed using the window function \( w(t) \) with the desired signal as \( y(t) \) and the noise as \( n(t) \), the desired signal complex spectrum \( Y(\omega, \tau) \) at time \( \tau \) represented by Eq. (1) is obtained. From the spectrum \( Y(\omega_c, \tau) \) on the center frequency \( f_c \) and the complex spectrum \( G(\omega_c, \tau) \) on the center frequency obtained by short-time Fourier transform of the unmodulated signal represented by Eq. (2), the feature quantity can be extracted as Eq. (3).

\[
Y(\omega, \tau) = \int_{-\infty}^{\infty} w(t-\tau) y(t) e^{-j\omega t} dt + \int_{-\infty}^{\infty} w(t-\tau) n(t) e^{-j\omega t} dt \quad (1)
\]

\[
G(\omega_c, \tau) = \int_{-\infty}^{\infty} w(t-\tau) e^{j(\omega_c - \omega) t} dt \quad (2)
\]

\[
\sqrt{p} e^{j\phi}(\omega_c, \tau) = \frac{Y(\omega_c, \tau)}{G(\omega_c, \tau)} \quad (3)
\]

3 Feature demodulation method

The feature demodulation method is used as the demodulation method after signal separation. The feature quantity demodulation method is a method of demodulating by discriminating this coordinate information because the power component and phase component of the extracted feature quantity represent the signal point arrangement of the modulated signal on the IQ plane. As shown in Eq. (4), this feature quantity can be said to be the modulated signal \( s(t) \) at the center
frequency $\omega_c$, so demodulation can be performed without problems. The modulated signal $s(t)$ is the desired signal $y(t)$ plus noise $n(t)$ as shown in Eq. (1), but in feature demodulation, $s(t) = y(t) + n(t) \approx y(t)$. Because the influence of noise is only on the center frequency under the AWGN environment.

In the synchronous detection method of the conventional method, if the inflection point of the symbol is included when the modulated wave is cut out by the window function in STFT, the signal is distorted when the signal is restored, which causes an error. If the inflection point of the symbol is included in the waveform cut out by STFT, the value obtained by mixing the features before and after the inflection point will be extracted when extracting the features. If the waveform is restored from there, the phase, frequency, and amplitude will shift. Then, from the fact that it'll be gone a detection in a state in which the synchronization is not achieved, it is considered that it was not possible to accurately demodulate the data. In the feature demodulation method, the signal is restored from the coordinate information instead of the waveform, so demodulation can be performed more accurately.

$$\sqrt{p e^{\text{np}}} (\omega_c, \tau) = \frac{Y(\omega_c, \tau)}{G(\omega_c, \tau)} \left( \int_{-\tau}^{\tau} s(t) \cos \omega_c t dt \right)$$

$$= s(t) \left[ e^{j(\omega_c - \omega)t} - e^{-j(\omega_c + \omega)t} \right] \left[ e^{j(\omega_c - \omega)t} - e^{-j(\omega_c + \omega)t} \right]$$

$$= s(t) \left[ \frac{1}{2} \omega_c - \omega e^{j(\omega_c + \omega)t} \right]$$

$$= \frac{s(t)}{2} (\because \omega = \omega_c)$$

4 Simulation result

4.1 Simulation parameters

Table 1 shows the simulation parameters. In the simulation performed in this paper, BPSK, QPSK and 16QAM are used as the modulation method, and we are studying under the condition of single carrier transmission. In addition, the modulation method and power of the undesired signal are the same as the desired signal.

$E_b/\text{SNR}$ in Table 1 is the value whose BER is less than $10^{-3}$ for each modulation method when the signal is restored by the proposed method without adding an interference signal.
Table 1 Simulation parameters

| Modulation system | BPSK | QPSK | 16QAM |
|-------------------|------|------|-------|
| Center frequency of the desired signal | 1000 Hz | | |
| Occupied bandwidth | 926 Hz | 1200 Hz | |
| Symbol rate | 64 symbol/s | | |
| Sampling rate | 8192 Hz | | |
| Window width | 32 sample lengths | | |
| Propagation environment | AWGN | | |
| $E_b/N_0$ | 7 dB | 10dB | |

In the evaluation of signal separation performance in this paper, the scale defined as the ratio of the occupied bandwidth of the desired signal and the undesired signal to the occupied bandwidth of the desired signal (Overlapped Bandwidth Ratio [%]: OBR) (Fig. 1) is used. We are evaluating the BER characteristics when the OBR is small, that is, when the center frequencies of the two signals are separated.

4.2 Evaluation of signal separation performance

Fig. 2 shows the signal separation performance when the conventional method of synchronous detection and the proposed method of feature demodulation are used for the demodulation method after signal separation. If BER = $10^{-3}$ is a signal separable value, from Fig2(a), in the case of the BPSK signals, it was confirmed that both the conventional method and the proposed method can be separated at OBR = 97.5%. From Fig. 2(b), in the case of the QPSK signals, it was confirmed that the conventional method can be separated at OBR = 84.9% and the proposed method at OBR = 83.8%. From Fig. 2(c), in the case of the 16QAM signals, separation was not possible with the conventional method, but with the proposed method, separation was possible with OBR = 63.5%.

From this result, the superiority of the proposed method in the 16QAM signal was clarified. In the case of BPSK and QPSK signals, there is no difference in signal separation performance between the conventional method and the proposed method. Therefore, when amplitude magnitude is used for modulation such as 16QAM modulation, it is considered that synchronous detection degrades signal separation performance.
In this study, the window function used in STFT, the window width, and the way the windows overlap were simulated under certain conditions. However, since the frequency resolution and time resolution change by changing these, it is expected that the signal separation performance will be further improved by setting the optimum conditions for each [3].

5 Conclusion
We proposed a feature demodulation method that directly demodulates using the amplitude and phase components of the feature quantity, and evaluated its effectiveness by computer simulation. From the results, it was clarified that in the case of 16QAM signal, signal separation is possible even under conditions that cannot be separated by the conventional synchronous detection.

For future studies, we are considering performance evaluation using the feature demodulation method when the modulation method is more multi-valued or when the modulation method differs between the desired signal and the undesired signal.

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