Research on Signal Separation Technology for Satellite IoT Signal

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Abstract. Most of transmitted signals of satellite Internet of Things (IoT) terminals have the characteristics of low baud rate, short packet length and burstiness. The collision of massive access of IoT terminals can be solved by a random multiple access technology in company with an efficient and reliable collision separation method in the receiver. However, most existing signal separation technologies are proposed for continuous signals, and the receiving structure is designed based on the phase-locked loop. In this paper, a short burst signal separation method based on adaptive minimum mean square error (MMSE) filtering is proposed for the classical contention resolution diversity slotted Aloha (CRDSA). The proposed method estimates the frequency and phase difference between copies by amplitude and phase estimation (APES) firstly and cancels the collision signal based on a MMSE filter. The theoretical analysis and simulation results verify the feasibility of the proposed method.

Keywords: Adaptive filtering · Signal separation · Random multiple access · Satellite IoT

1 Introduction

As an important infrastructure of national information network, satellite communication system has great strategic significance in maintaining national security, protecting national economy, and promoting economic development for its wide coverage, flexibility and freedom from geographical and climatic factors. It is of great interests worldwide and is a commanding height of economic and technological competition in various countries [1]. As the terrestrial mobile communication system gradually develops from the

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4G to the 5G, the integration of satellite communications and terrestrial 5G networks has get attention. Among them, massive machine type communications (mMTC) is an important application scene for 5G application [2]. Satellite communication system, as an important complement of terrestrial Internet of Things (IoT), can take advantage of wide coverage and strong system survivability to provide access services for IoT terminals in remote areas. The existing satellite IoT systems in the world at present include the Orbcomm satellite communication system in the United States [3] and the ARGOS system [4] jointly established by France and the United States. Chinese satellite IoT system is planning and developing, BeiDou satellite navigation global system (BDS-3) can offer short message communication services [5], which afford lessons of related techniques or features for satellite IoT system.

Random access of massive user terminals is the first problem should to be solved on the transmission and access side for satellite IoT system. Multiple access schemes in satellite communication system can generally be divided into competitive multiple access and non-competitive multiple access. Typical non-competitive multiple access schemes include time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA) [6–8], and demand assignment multiple access (DAMA) [9], etc. Satellite IoT services are not connection oriented with certain suddenness and randomness, also the size of packets is very small. In the face of the burst IoT services with frequent requests and resources are frequently requested by IoT terminals, so that the efficiency of the system will be reduced because of the transmission duty cycle is low. Compared with the non-competitive multiple access scheme, the contention-based multiple access scheme usually refers to random access (RA) [10]. Users can preempt communication resources in a competitive manner without scheduling by using RA scheme. Aloha is the earliest random access protocol used in satellite communication systems [11]. Because there is no resource request and scheduling link, users will encounter data packet collision during resource competition will result in access failure, and its channel utilization is only 18%. Slotted Aloha is based on Aloha by introducing the concept of slot, and the collision probability of packets is reduced. Compared with Aloha, the theoretical channel utilization is improved to 36%. With the development of coding technology and digital signal processing technology, researchers put forward some enhanced version of the scheme, such as diversity slotted Aloha (DSA) [12], contention resolution diversity slotted Aloha (CRDSA) [13], CRDSA+ + [14], and irregular repetition slotted Aloha (IRSA) [15]. These techniques send packets in a data frame through time diversity, and employ successive interference cancelation (SIC) to solve the conflict packets at the receiver, so as to improve the throughput.

Most of the transmitted signals of satellite IoT terminals have the characteristics of low baud rate, short packet time and burstiness. The problem of massive access of IoT user terminals can be solved by random multiple access technology in company with an efficient and reliable collision separation method. At present, most existing signal separation technologies are proposed for continuous signals, and the receiving structure is designed based on the phase-locked loop. The separation method for short burst signals is lack of researching in the open literature. A robust physical layer receiving technology still needs to be studied for uplink multiple access of the short burst IoT signals. In most cases, the satellite channel varies slowly and the IoT signals have the characteristics of low baud rate and narrow bandwidth. In CRDSA scheme, the Doppler shift of the copies sent by the same user terminal is small, and the difference exists in complex coefficients introduced by satellite channel. The correlation between the waveforms of copies are still strong if the frequency offset and phase offset of copies can be compensated. Based on the above-mentioned analyses, a short burst signal separation method is proposed in this paper. The proposed short burst signal separation method employs adaptive minimum mean square error (MMSE) filtering combined with amplitude and phase estimation (APES) [16] in the receiver for the CRDSA scheme.

Following this Introduction, Sect. 2 describes the shortcoming of existing multiple access scheme of satellite IoT briefly and the CRDSA scheme. Section 3 describes the received signal model. Section 4 describes the signal separation method and key performance results are provided in Sect. 5. Finally, the conclusions are drawn in Sect. 6.

2 Satellite IoT Access Scenario

Multiple access is designed to divide and allocate system resources from different dimensions. It plays a vital role in improving system resource utilization, reducing terminal access delay, and saving terminal power consumption. In traditional terrestrial mobile communication systems, the multiple access scheme has gradually evolved from TDMA / FDMA of the 2G, CDMA of the 3G, and OFDMA of the 4G to non-orthogonal multiple access. However, multiple access schemes need to be redesigned for satellite IoT system according to its system architecture, service characteristics, etc. The multiple access scenario of satellite IoT is shown in Fig. 1.

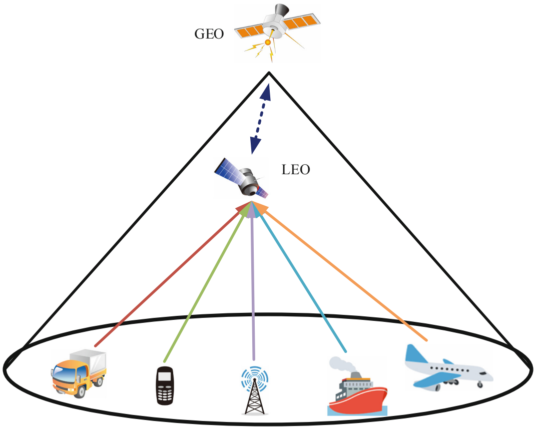

Fig. 1. Satellite IoT multiple access scenarios

User signal collision becomes an inevitable problem in the massive access process of IoT terminals because of large coverage of satellite beams for satellite IoT system. This paper studies the problem of short burst signal collision in the uplink access. The following contents introduces the receiving process of the CRDSA scheme and signal collision scenarios.

The random multiple access has attracted people's favor since it was proposed because of high flexibility and the overhead of signaling is low. An enhanced version of the DSA scheme, which is contention resolution diversity slotted Aloha (CRDSA) has been proposed by Casini et al. [13], in order to solve the problem of low access efficiency of the conventional Aloha schemes. The CRDSA scheme exploits SIC at packet level to recover conflicting packets based on the DSA scheme, which can further improve system throughput and reduce packet loss ratios. The CRDSA access process is shown in Fig. 2.

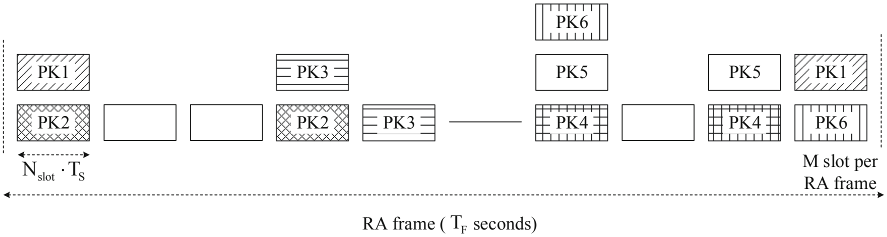

Fig. 2. CRDSA access process

The core idea of the CRDSA scheme is that the same user terminal randomly selects two different time slots to send twins of packet in the same frame, and each packet contains information on the position of all time slots where its copy is located in the same frame. On the access side, the receiver employs SIC based on the copies without collision to successively decompose the packets with collision. In the example presented in Fig. 2, packet 2 cannot be initially recovered as both twins have suffered a collision in slot 1 and slot 4 of the frame. However, one copy of packet 3 (in slot 5) has been successfully recovered and its information can be used to cancel the interference caused by packet 3 in slot 4. Then packet 2 can be recovered in slot 4, after removing the interference generated by packet 3. Removing packet 2 in slot 1 allows to recover packet 1 so that also packet 6 can be decoded in slot M.

The CRDSA scheme exploits SIC to recover more packets that have suffered a collision originally, and the premise of the scheme is that there must be a clean copy of packet in time slot. In the following sections we use this as an entry point, describe the received signal model and a short burst collision signal separation method for the CRDSA scheme, and assess the performance of the proposed signal separation method.

3 Received Signal Model

In this section, the received signal model is described based on the CRDSA scheme. In the following derivations, it is assumed that two user terminals of IoT have sent packets to the satellite, where the packet 1 sent by user terminal in slot m is $s_{0k_1}(t)$, and the copy of packet 1 in slot j is $s'_{0k_1}(t)$. The other user terminal sent packet 2 as $s_{0k_2}(t)$ in slot m, and the copy of packet 2 as $s'_{0k_2}(t)$ in slot $j+i$, where $i \neq 0$ and $j+i \neq m$. Therefore, the packet 1 and packet 2 sent by different user terminals have suffered a collision in slot m, and the received collision signal in slot m at the receiver is

$$\begin{aligned} r_m(t) &= s_{k_1 m}(t) + s_{k_2 m}(t) + v(t) \\ &= h_1\sqrt{p_1}s_{0k_1 m}(t) + h_2\sqrt{p_2}s_{0k_2 m}(t) + v(t) \\ &= h_1\sqrt{p_1}A_1\cos(\omega_1 t + \varphi(t) + \varphi_1) + h_2\sqrt{p_2}A_2\cos(\omega_2 t + \varphi(t) + \varphi_2) + v(t) \end{aligned} \tag{1}$$

where h_1, h_2 are channel gains, there just multiply a complex coefficient before signal because of the slowly varying satellite channel and the narrow bandwidth of IoT signals as mentioned in Sect. 1. p_1, p_2 are transmitted signal powers, A_1, A_2 are transmitted signal amplitudes, ω_1, ω_2 are frequencies of the received signal, and φ_1, φ_2 are initial phases of the received signal, $v(t)$is additive white Gaussian noise.

Since the other copy of packet 1 and the other copy of packet 2 are not sent in the same slot, assuming that a detection result without error of a clean copy of packet 1 is obtained and restored to a waveform without noise after a normal single user detection as

$$\begin{aligned} x(t) = s_{k_1 j}(t) &= h_1\sqrt{p_1}s'_{0k_1}(t) \\ &= h'_1\sqrt{p_1}A_1\cos\left(\omega' t + \varphi(t) + \varphi'_1\right) \end{aligned} \tag{2}$$

where h'_1 is channel gain, which is approximately equal to h_1 in the received signal, p_1 is transmitted signal power, A_1 is the amplitude of the clean copy of packet 1, and ω', φ'_1 represent, respectively, the carrier frequency and phase of the clean copy.

The special characteristic of satellite IoT system is significantly different transmission channel compared with terrestrial IoT system, that is, exploiting communication satellites as relays to achieve the transmission of IoT information. The transmission channel of satellite IoT system is the line-of-sight (LOS) channel or the block fading channel, which has a short term stationary. Combining the characteristics of satellite channel and the rate of IoT signals is very low, the twins sent by the same user terminal are stable in one slot and non-stationary in different slots in CRDSA scheme [17].

In the following sections we derive the signal separation method based on the received signal model combined with the transmission characteristics of satellite IoT channel, and assess the performance of the proposed signal separation method.

4 Signal Separation Method

The separation problem based on reference signals is essentially a parameter estimation and fitting problem. In the following, we assume that the clean copy of packet as reference signal, and make use of the correlation between reference signal and collision signal to study efficient and reliable signal separation methods for the CRDSA scheme. The signal separation principle framework is shown in Fig. 3.

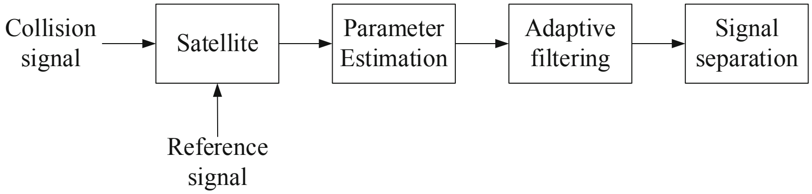

Fig. 3. Signal separation principle framework

The correlation is severely reduced because of the large frequency offset between the clean copy of packet 1 and the packet 1 in collision signal, so that a parameter estimation step needs to be added to achieve short burst signal separation. The received collision signal $r_m(t)$ in (1) is multiplied by the detection result without error $x(t)$ of the clean copy of packet 1 obtained by single user detection in (2) (see Sect. 3). As a result, the channel gain h and transmitted signal power p do not participate in the derivation calculation, and the obtained demodulated signal is

$$\begin{aligned} r'_m(t) &= \left(s_{k_1 m}(t) + s_{k_2 m}(t) + v(t)\right) \cdot x(t) \\ &= \left(A_1 \cos(\omega_1 t + \varphi(t) + \varphi_1) + A_2 \cos(\omega_2 t + \varphi(t) + \varphi_2) + v(t)\right) \cdot A_1 \cos\left(\omega' t + \varphi(t) + \varphi'_1\right) \\ &= \frac{A_1^2}{2}\left[\cos\left((\omega_1 + \omega')t + 2\varphi(t) + \varphi_1 + \varphi'_1\right) + \cos\left((\omega_1 - \omega')t + \varphi_1 - \varphi'_1\right)\right] \\ &+ \frac{A_1 A_2}{2}\left[\cos\left((\omega_2 + \omega')t + 2\varphi(t) + \varphi_2 + \varphi'_1\right) + \cos\left((\omega_2 - \omega')t + \varphi_2 - \varphi'_1\right)\right] + v(t) \end{aligned} \tag{3}$$

Let $\triangle\ \varphi = \varphi_1 - \varphi'_1$, the signal $r''_m(t)$ after filtering the high frequency components by low pass filtering is

$$\begin{aligned} r''_m(t) &= \frac{A_1^2}{2}\left[\cos\left((\omega_1 - \omega')t + \triangle\ \varphi\right)\right] \\ &+ \frac{A_1 A_2}{2}\left[\cos\left((\omega_2 - \omega')t + \varphi_2 - \varphi_1 + \triangle\ \varphi\right)\right] + v(t) \end{aligned} \tag{4}$$

It can be seen from (4) that the signal after low pass filtering does not contain the modulation term, but there is frequency offset and phase offset. In order to use the correlation between the clean copy and the collision signal to separate the collision signals, the frequency and phase must be estimated first and the frequency offset and phase offset are then compensated into the clean copy signal.

Considering that APES algorithm can be employed to estimate frequency offset and phase offset of short burst signal. The amplitude and phase estimation (APES) is a new filter design method proposed by Li et al. [16]. The APES algorithm breaks through the limitations of the traditional fast Fourier transform (FFT) algorithm, and still has a high frequency resolution for short term signals. It can not only accurately estimate the frequency of the signal, but also calculate its amplitude and initial phase angle.

Sampling after low pass filtering signal $r''_m(t)$ of (4) as the input signal of filter, and it is assumed that the frequency of transmitted signals of the two user terminals is the same, that is $\omega_1 = \omega_2 = \omega$. We consider designing M tapped FIR filter so that the signal with the desired angular frequency offset $\triangle\ \omega = \omega - \omega'$ passes through the filter without distortion, while suppressing other frequency components of signal $\boldsymbol{r''}_m(n)$and noise as much as possible.

Define the filter weight vector as $\boldsymbol{w}$. To make the signal with angular frequency offset $\triangle\ \omega$ pass through the filter without distortion, there should be

$$\boldsymbol{w}^T\boldsymbol{a}(\omega) = 1 \tag{5}$$

where $\boldsymbol{a}(\omega)$ is the signal frequency vector.

The above problem can be transformed into the following constraint optimization problem through calculation:

$$\min_{\boldsymbol{w},\alpha}\left\{J(\boldsymbol{w},\alpha) = \frac{1}{L}\sum_{n=M-1}^{N-1}\left|\boldsymbol{w}^H\boldsymbol{r''}_m(n) - \alpha e^{j\omega n}\right|^2\right\},\quad s.t.\quad \boldsymbol{w}^H\boldsymbol{a}(\omega) = 1 \tag{6}$$

where $L = N - M + 1$, ω represents any given frequency, and α is the complex amplitude of the signal which frequency is ω.

Expanding the objective function defined in (6), we get

$$J(\boldsymbol{w},\alpha) = \left|\alpha - \boldsymbol{w}^H\boldsymbol{g}(\omega)\right|^2 + \boldsymbol{w}^H\boldsymbol{R}\boldsymbol{w} - \boldsymbol{w}^H\boldsymbol{g}(\omega)\boldsymbol{g}^H(\omega)\boldsymbol{w} \tag{7}$$

where

$$\begin{aligned} \boldsymbol{g}(\omega) &= \frac{1}{L}\sum_{n=M-1}^{N-1}\boldsymbol{r''}_m(n)e^{-j\omega n} \\ \boldsymbol{R} &= \frac{1}{L}\sum_{n=M-1}^{N-1}\boldsymbol{r''}_m(n)\boldsymbol{r''}_m(n)^H \end{aligned} \tag{8}$$

We can find that α which minimizes the objective function from (7) is

$$\alpha(\omega) = \boldsymbol{w}^H\boldsymbol{g}(\omega) \tag{9}$$

Substituting (9) into (7), and letting

$$\boldsymbol{Q}(\omega) = \boldsymbol{R} - \boldsymbol{g}(\omega)\boldsymbol{g}^H(\omega) \tag{10}$$

Then the constraint optimization problem (6) can be transformed into

$$\min_{\boldsymbol{w}}\ \boldsymbol{w}^H\boldsymbol{Q}\boldsymbol{w},\quad s.t.\quad \boldsymbol{w}^H\boldsymbol{a}(\omega) = 1 \tag{11}$$

The optimal weight vector of the APES algorithm can be obtained by solving the above optimization problem as

$$\boldsymbol{w}_{\text{APES}} = \frac{\boldsymbol{Q}^{-1}(\omega)\boldsymbol{a}(\omega)}{\boldsymbol{a}^H(\omega)\boldsymbol{Q}^{-1}(\omega)\boldsymbol{a}(\omega)} \tag{12}$$

Substituting $\boldsymbol{w}_{\mathrm{APES}}$ into (9), the estimation of the complex amplitude α of the signal can be obtained as

$$\alpha(\omega) = \frac{\boldsymbol{a}^H(\omega)\boldsymbol{Q}^{-1}(\omega)\boldsymbol{g}(\omega)}{\boldsymbol{a}^H(\omega)\boldsymbol{Q}^{-1}(\omega)\boldsymbol{a}(\omega)} \tag{13}$$

Note that the complex amplitude estimate $\alpha(\omega)$ is a function of the frequency ω, and the amplitude spectrum of the signal can be obtained from (13), that is:

$$|\alpha(\omega)| = \left|\frac{\boldsymbol{a}^H(\omega)\boldsymbol{Q}^{-1}(\omega)\boldsymbol{g}(\omega)}{\boldsymbol{a}^H(\omega)\boldsymbol{Q}^{-1}(\omega)\boldsymbol{a}(\omega)}\right|, \qquad \omega \in [-\pi, \pi] \tag{14}$$

The frequency offset and phase offset of the clean copy relative to the packet 1 in collision signal can be accurately estimated exploiting APES spectrum estimation, based on the power difference between the clean copy and the packet 1 in collision signal. $|\alpha(\omega)|$ will show a peak at frequency offset $\omega = \triangle\omega$, while $|\alpha(\omega)|$ will be flat at other frequencies. The results of frequency estimation can be substituted into (13) to obtain the amplitude and phase of the signal at the frequency offset $\omega = \triangle\omega$.

The frequency offset and phase offset between the clean copy and the packet 1 in collision signal are compensated into the clean copy after APES spectrum estimation to improve correlation between twins sent by the same user terminal. In the following, we can make use of the correlation to separate the collision signal based on the MMSE criterion.

Let the clean copy of packet 1 after compensating the frequency offset and phase offset as the input signal $\boldsymbol{x}'(n)$of the MMSE filter, and define the estimation error of the collision signal separation as

$$e(n) = r_m(n) - y(n) = r_m(n) - \boldsymbol{w}^H\boldsymbol{x}'(n) = r_m(n) - \boldsymbol{x}'^H(n)\boldsymbol{w}^* \tag{15}$$

where $r_m(n)$ is the received collision signal, the filter output $y(n)$ is an estimate of the packet 1 in the collision signal, and $y(n) = \boldsymbol{w}^H\boldsymbol{x}'(n) = \boldsymbol{x}'^H(n)\boldsymbol{w}^*$.

Define the average power of the estimation error $e(n)$ as

$$\xi(\boldsymbol{w}) = E\Big[|e(n)|^2\Big] = E\big[e(n)e^*(n)\big] \tag{16}$$

where $E[\cdot]$ represents mathematical expectation. It is often called $\xi(\boldsymbol{w})$s as the estimated mean square error (MSE) or cost function. Substituting (15) into (16), we have

$$\begin{aligned} \xi(\boldsymbol{w}) = E\Big\{\Big[r_m(n) - \boldsymbol{w}^H\boldsymbol{x}'(n)\Big]\Big[r_m(n) - \boldsymbol{x}'^H(n)\boldsymbol{w}^*\Big]^*\Big\} \\ = E\Big\{|r_m(n)|^2\Big\} - E\Big\{r_m(n)\boldsymbol{x}'^H(n)\Big\}\boldsymbol{w} \\ -\boldsymbol{w}^T E\big\{\boldsymbol{x}'(n)r_m^*(n)\big\} + \boldsymbol{w}^H E\Big\{\boldsymbol{x}'(n)\boldsymbol{x}'^H(n)\Big\}\boldsymbol{w} \end{aligned} \tag{17}$$

Defining the filter weight vector as $\boldsymbol{w}$ is a certain quantity, and it is assumed that the mean value of the expected response $r_m(n)$ is 0, the average power of the first expected response in (17) is also the variance, let $\sigma_r^2 = E\big\{|r_m(n)|^2\big\}$.

The twins sent by the same terminal have a strong correlation because of the frequency offset and phase offset between the twins have been compensated by APES algorithm. We can make use of the clean copy and the collision signal to calculate the covariance matrix $\boldsymbol{R}$ and the cross correlation vector $\boldsymbol{p}$. Where $\boldsymbol{R}$ and $\boldsymbol{p}$ represent, respectively, the covariance matrix of the clean copy, that is, $\boldsymbol{R} = E\left[\boldsymbol{x}'(n)\boldsymbol{x}'^{H}(n)\right]$, and the cross correlation vector of the clean copy and the collision signal, that is, $\boldsymbol{p} = E\left[\boldsymbol{x}'(n)r_m^*(n)\right]$. The mean square error Eq. (17) can be expressed by using σ_r^2, $\boldsymbol{R}$, and $\boldsymbol{p}$ as

$$\xi(\boldsymbol{w}) = \sigma_r^2 - \boldsymbol{p}^H\boldsymbol{w} - \boldsymbol{w}^H\boldsymbol{p} + \boldsymbol{w}^H\boldsymbol{R}\boldsymbol{w} \tag{18}$$

To minimize the mean square error equation, find the partial derivative of $\boldsymbol{w}$ in (19). Note that the differential operation of the scalar function on the vector can be expressed by the gradient of the scalar function on the vector. We can get the gradient of (18) as

$$\begin{aligned} \nabla_{\boldsymbol{w}}\xi(\boldsymbol{w}) &= 2\frac{\partial}{\partial \boldsymbol{w}^*}[\xi(\boldsymbol{w})] = 2\frac{\partial}{\partial \boldsymbol{w}^*}\left[\sigma_r^2 - \boldsymbol{p}^H\boldsymbol{w} - \boldsymbol{w}^H\boldsymbol{p} + \boldsymbol{w}^H\boldsymbol{R}\boldsymbol{w}\right] \\ &= 2\frac{\partial \sigma_r^2}{\partial \boldsymbol{w}^*} - 2\frac{\partial}{\partial \boldsymbol{w}^*}\left(\boldsymbol{p}^H\boldsymbol{w}\right) - 2\frac{\partial}{\partial \boldsymbol{w}^*}\left(\boldsymbol{w}^H\boldsymbol{p}\right) + 2\frac{\partial}{\partial \boldsymbol{w}^*}\left(\boldsymbol{w}^H\boldsymbol{R}\boldsymbol{w}\right) \\ &= \boldsymbol{0} - 2\frac{\partial \boldsymbol{w}^T}{\partial \boldsymbol{w}^*}\boldsymbol{p}^* - 2\frac{\partial \boldsymbol{w}^H}{\partial \boldsymbol{w}^*}\boldsymbol{p} + 2\boldsymbol{R}\boldsymbol{w} \\ &= \boldsymbol{0} - 2\mathbf{O}\boldsymbol{p}^* - 2\mathbf{I}\boldsymbol{p} + 2\boldsymbol{R}\boldsymbol{w} \\ &= -2\boldsymbol{p} + 2\boldsymbol{R}\boldsymbol{w} \end{aligned} \tag{19}$$

where **O** and **I** represents the zero matrix and the identity matrix respectively.

The necessary condition for the mean square error $\xi(\boldsymbol{w})$ to obtain an extreme value at $\boldsymbol{w}$ is $\frac{\partial \xi(\boldsymbol{w})}{\partial w_i^*} = 0, i = 1, 2, \cdots, M$. Let $\nabla_{\boldsymbol{w}}\xi(\boldsymbol{w}) = \boldsymbol{0}$, have

$$\boldsymbol{R}\boldsymbol{w} = \boldsymbol{p} \tag{20}$$

Using $\boldsymbol{R}^{-1}$ to multiply both sides of (20) to get collision signal separation weight

$$\boldsymbol{w}_{\mathrm{MMSE}} = \boldsymbol{R}^{-1}\boldsymbol{p} \tag{21}$$

Obviously, the closer the filter output estimated by the separation weight $\boldsymbol{w}_{\mathrm{MMSE}}$ is to the packet 1 in collision signal, the closer the separated packet 2 is to the packet 2 sent by user terminal 2.

Finally, the collision signal and the filter output signal are destructively processed to achieve the separation of collision signal. The proposed short burst collision signal separation method can be achieved based on adaptive MMSE filtering through detailed derivation.

5 Simulation Results and Analysis

In this section, the performance results of proposed short burst signal separation method have been provided through an analytical model and Monte Carlo simulations.

The simulation parameters are as follows: the signal-to-noise ratio (SNR) difference between the received signals is 3 dB; the carrier frequency of received signal is 1100 Hz, and initial phase is π; the carrier frequency of the clean copy at the receiver is 1000 Hz, and initial phase is 0; the sampling frequency is 10 kHz, and the remaining parameters described in Table 1 have been used for the simulations.

Table 1. Simulation parameters

Parameter	Value
Packet size	100 bit
Packet rate	1000 bit/s
Modulation	BPSK
Channel type	AWGN
Filter length	1
E_b/N_0	0~10 dB

It is assumed that the packet 2 in the collision signal separated by the proposed signal separation method, and the performance results are obtained after the packet 2 is demodulated. Simulation performance results are shown in Figs. 4 and 5 for APES algorithm and signal separation method, respectively.

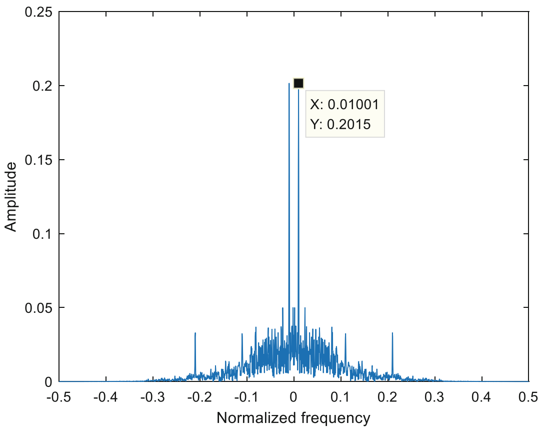

Fig. 4. Spectrum of collision signal estimated by APES

Figure 4 demonstrates the collision signal spectrum after APES algorithm. As it can be seen that the frequency offset between packet 1 in the received collision signal and the clean copy of packet 1 is about 100.1 Hz (the sampling frequency is 10 kHz), which corresponds to a theoretical value. The peak of multiplying the clean copy and the packet 1 after the low pass filter is much higher than the peak of multiplying the clean copy and the packet 2 after the low pass filter at the frequency offset position. The frequency offset and phase offset of the received collision signal can be well estimated by APES algorithm.

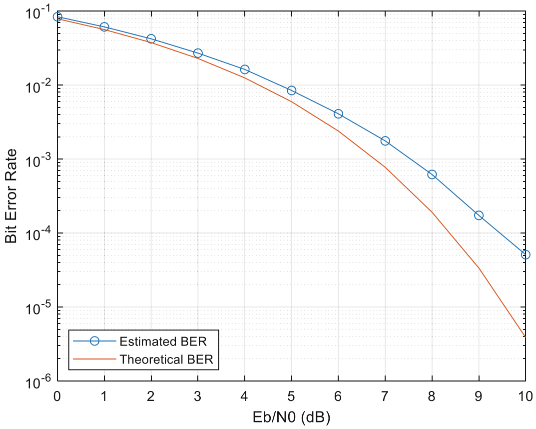

Fig. 5. Collision signal separation performance curve

The collision signal separation performance curve has been derived in Fig. 5 for various E_b / N_0. As shown in Fig. 5, the bit error rate gradually decreases in company with the E_b / N_0 increases. The estimated bit error rate curve and the theoretical bit error rate curve basically coincide with each other at low E_b / N_0, and there is a certain degree of deviation at high E_b / N_0. It can be concluded from the performance result that the proposed short burst collision signal separation can be achieved.

6 Conclusions

In this paper, a short burst collision signal separation method employs adaptive MMSE filtering combined with APES spectrum estimation at the receiver side, based on the correlation between collision signal and clean copy for the CRDSA scheme has been proposed and shown to solve the problem of user signal collision because of massive access process of satellite IoT terminals, and its performance assessed through detailed simulations, which verifies the feasibility of proposed method. Different simulation parameters can be set to further analyze the performance of proposed short burst collision signal separation method in the next work.

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