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A Novel Successive Interference Cancellation Arithmetic Based on NOMA System

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Abstract. As one of the key candidate technologies for 5G, the NOMA (Non-orthogonal Multiple Access Technology) employs the way of power domain reuse, which has improved the system throughput and frequency utilization effectively. Among the existing discussions about the NOMA system, it is mostly acknowledged that the folding signal is completely synchronous. However, in the actual using, the folding signal is not completely synchronous. Aiming at the time delay problem of the folding signal during different users' transmitting, this paper puts forward a new successive interference cancellation algorithm. Firstly, the constructional output data is gotten through the way of asynchronous sampling. Then, the symbol is reconstructed by the manner of the new successive interference cancellation in the receiving terminal. The results show that the new method has obtained the cleaner exceptional properties of the interference signal cancellation. Meanwhile, the channel status information is estimated through Kalman filter dynamic analysis, thus improving the error code property of the whole channel.

Key words: Non-orthogonal Multiple Access Technology; Asynchronous Symbol; Scalar Kalman Filter; Successive Interference Cancellation.

INTRODUCTION

The OFDM (Orthogonal Frequency Division Multiplexing) technology is adopted in the 4G system. Realized OFDM multi-carrier transmission with MIMO (Multiple-Input Multiple-Output) multiple antenna configuration, thus maximizing the transmission rate. In order to eliminate the interference between the subcarrier and the signal greatly, the system introduces the CP (Cyclic Prefix) that accounts for 20% of the total bandwidth, which is a great waste of the essentially scarce spectrum resource. So many scholars start to consider the manner of non-orthogonal transmission. One of the current study issues about the non-orthogonal transmission is NOMA.

The literatures [2]-[5] have mainly studied the basic principle of NOMA, a new multi-access technology in 5G. NOMA system brings the interference information in by using SC (Superimpose Coding) at the transmitting terminal, and then sends the users' information. The receiving terminal gets the correct demodulation of the receiving signal through the SIC (Successive Interference Cancellation) receiver or other valid receivers. The basic idea of the algorithm is to get the signals numbered in descending order according to SNR (Signal Noise Ratio), and to reconstruct and reduce the users' interference who has the maximum SNR step by step. This operation will be repeated in turn, till all the users' signals have been gotten. Most of the current researches about NOMA default that the folding signal is completely synchronous. While, in the actual using of the NOMA, depending on the location and the movement state of the different users, there will be some delay when the signal arrives the base station, which cannot be fully synchronized. Therefore, it is of great importance to study the asynchronous NOMA and optimize the processing of asynchronous interference.

The literature [6] and [7] introduced the detecting techniques of SIC based on NOMA synchronously. Literature [8] introduced a sampling method for asynchronous signals in the MIMO channel. This paper puts forward a new successive interference cancellation algorithm based on the asynchronous NOMA. In the transmitting terminal, the algorithm makes use of the time delay relationship among different users and makes superposition users possesses temporal correlation which obtained from the receivers' sampling output. Then, the new successive interference cancellation proceeded in the receiving terminal. Compared with the synchronous NOMA, the manner in this paper is closer to the situation of the actual condition. Furthermore, it can cancel the interference signal preferably. Because the reductive accuracy of each symbol and the channel state of each time slot will all directly influence on the subsequent signal detecting. So, this paper also simulates the channel which is linear time-varying [9] and proposes a scalar Kalman filter algorithm [10]-[12] to estimate the channel in the direction of time. Restored every users' signal through the successive interference cancellation technology with the exact state of channel at every time slot and the structural signals after sampling. Furthermore, we compared the algorithm in this paper with the ZF (Zero Forcing), MMSE (Minimum Mean Square Error) in literature [15] which is combined with the SIC during the situation of the mutative channel. The outstanding property of the Kalman filtering algorithm can exactly estimate the state of different time, thus improving the total detecting property.

SYSTEM MODEL

NOMA Model.

NOMA is a new multi-access technology based on the power domain allocation. To achieve the transferring of the resources in the same time domain, frequency domain and airspace domain, it conducts the simple linear superposition of multiple users' signals in power domain.

NOMA follows the principle that high power is allocated to the channel with poor quality. Assuming that uer1 and user2 are in the same time/frequency/empty resource, the two signals are superimposed on the power domain, user1 is the center user of the community, and user2 is the marginal user of the community. Both of the two are superimposed on the power domain, where user 1 is allocated with lower power, and user 2 is allocated with higher power. The superposition signal that has been sent can be expressed as follows:

$$x=\sqrt{\beta_1}x_{UE1}+\sqrt{\beta_2}x_{UE2} \tag{1}$$

where x_{UE1} and x_{UE2} respectively represents the sending signal of user1 and user2, β_1 and β_2 represents the power distribution factor of user1 and user2, also, for the convenience of discussion, assuming that the total emission power is 1.The sending signal of user k can be expressed as follows:

$$x_{UEk}=\sum_{n=1}^{N}b_k\left(n\right)s\left(t-nT\right) \tag{2}$$

In this article, k = 1, 2. N denotes the number of symbols sent by each user, $b_k\left(n\right)$ denotes the symbol (n = 1, 2,..., N) that user k sends at the slot time of n; T is the period of sending signals; $s\left(t\right)$ is the rectangular filter with the T period, which should meet the conditions: $s\left(t\right)=0,t\notin\left[0,T\right]$, $\int_0^T\left\|s\left(t\right)\right\|^2dt$.

As shown in FIG.1, SIC technology is used to detect receiving signals at the receiving terminal by NOMA, and the capability of SIC will directly affects the performance of the receiver. The basic idea of SIC technology is to eliminate the folding signals interference of multiple users. First, the signals will be sequenced according to the size of the SNR, then, refactor the signal of the user who had the biggest SNR, and eliminate the signal as a disturbance from the receiving signals. Next, refactor the signal of the user which had the second largest SNR. Perform again and again according to the above operations till all the users' signals get detected.

The Successive Interference Cancellation Technology

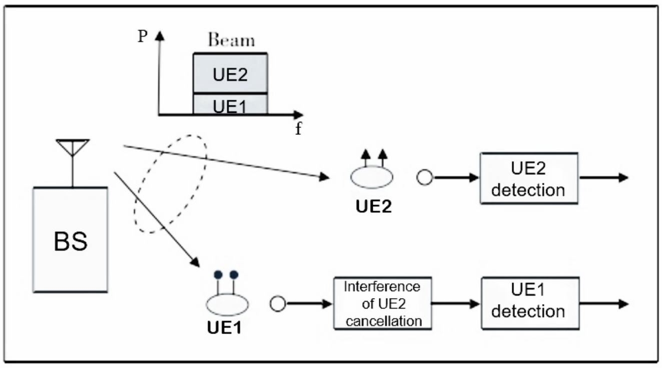

FIG. 1. Receiver for NOMA with SIC

THE INTERFERENCE ELIMINATION ALGORITHM BASED ON ASYNCHRONOUS SAMPLING

Asynchronous NOMA Signal.

Considering the delay problem caused by different users' statements and the distance from users to the base station, the superimposed signal users received is expressed as follows:

$$y(t) = h_1\sqrt{\beta_1}x_{UE1}(t - \tau_1) + h_2\sqrt{\beta_2}x_{UE2}(t - \tau_2) + n(t) \tag{3}$$

Among them, $h_k, k = 1,2$ is the user channel gain; τ_k is the time delay that user k gets to the base station. Without loss of generality, assuming the time delay of the first user is $\tau_1 = 0$, symbol period T = 1, and $\tau_1 < \tau_2 < T$; $n(t)$ is the white gaussian noise with constant of 0 and variance of σ^2.

NOMA Signal Sampling.

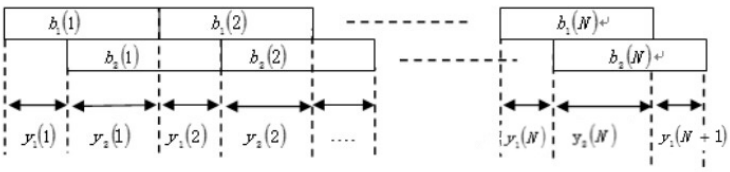

FIG. 2. Samping for symbol asynchronous superimposed NOMA signal

Assuming that the user's transmission delay τ_k has accurately detected by receiver through the synchronization module, among receivers, the superposition signal received is matched with filtering, and sampled wtith the channel transmission delay intervals as interval sampling respectively. In contrast to the synchronous NOMA signal, all symbols of signal are checked and reconstructed entirely without sampling. In this paper, when the new detection algorithm is used to reconstruct the asynchronous NOMA signal, it reconstructs symbol one by one. Therefore, NOMA signal will be sampled firstly.

As shown in FIG.2, take the case of two users' signal superposed as an example. Making $\Delta = \tau_2 - \tau_1$, and for convenient analysis, we assumed the power P = 1. The receiver constructs 2N + 1 sampling value through sampling from $y(t)$:

$$\begin{aligned} y_1(n) &= \frac{1}{\Delta}\int_{n-1}^{(n-1)+\Delta} y(t)dt \\ &= \frac{1}{\Delta}\int_{n-1}^{(n-1)+\Delta}\left(h_1[n]b_1[n] + h_2[n]b_2[n-1] + w(t)\right)dt \\ &= h_1[n]b_1[n] + h_2[n]b_2[n-1] + w_1[n] \end{aligned} \tag{4}$$

$$\begin{aligned} y_2(n) &= \frac{1}{(1-\Delta)}\int_{(n-1)+\Delta}^{n} y(t)dt \\ &= \frac{1}{(1-\Delta)}\int_{(n-1)+\Delta}^{n}\left(h_1[n]b_1[n] + h_2[n]b_2[n] + w(t)\right)dt \\ &= h_1[n]b_1[n] + h_2[n]b_2[n] + w_2[n] \end{aligned} \tag{5}$$

Among them, n = 1,2,…, N + 1; $b_2[0]=0$, $b_1[N+1]=0$, $y_1[N+1]=0$. $w_1[n]$ and $w_2[n]$ respectively represents the white gaussian noise with the constant of 0, variance of $\frac{\sigma^2}{\Delta}$ and $\frac{\sigma^2}{(1-\Delta)}$.

A New Successive Interference Cancellation Algorithm Base on the Signal Sampling.

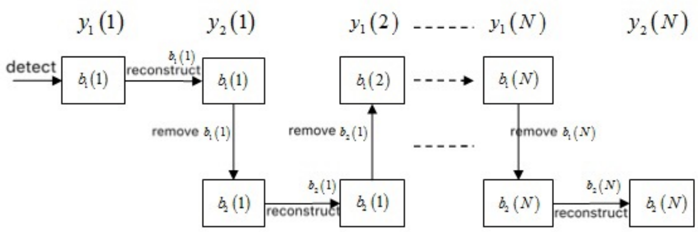

FIG. 3. Successive interference cancellation for Samping single

After sampling the superposed NOMA signal, the fore-aft sampling symbols possess great structures. It can be seen from picture 2 that only $b_1[1]$ in $y_1(1)$, but there are both $b_1[1]$ and $b_2[1]$ are sampled from $y_2(1)$.With the relationship of the time delay differential, we can conduct the intersected successive interference cancellation as FIG.3:

A new SIC algorithm for two users signals sampling

Input: sampling output signal $y_1(n)$, $y_2(n)$, symbol number N;

Algorithm step:

Initializing order i = 1, first detect and restore $b_1[i]$ from $y_1(i)$;

Eliminate the interference signal $b_1[i]$ from $y_2(i)$ and reconstruct $b_2[i]$, if i < N, turn to (3), so when i =N, the cycling is over;

Eliminate $b_2[i]$ in $y_1(i+1)$ and reconstruct $b_1[i+1]$;

i = i +1, if i ≤ N, return to (2), repeated again till detecting all the symbols.

Output: Users send symbol string $b_1[n]$, $b_2[n]$.

The case of three user signals is analogized, sampling 3N+2 data: $y_1(n)$, $y_2(n)$, $y_3(n)$, then process the sampling data that the receiver terminal has received with the new successive cancellation algorithm.

NOMA Signal Detection Based on Scalar Kalman Filter.

When the new successive interference cancellation technology used in detecting terminal, the accuracy of the first detected signal the estimation of channel state directly influences on the subsequent signal detecting accuracy. Furthermore, the accuracy rate of the channel estimating at any time affect the symbols reconstructing directly. So, in this paper, we adopted Kalman filtering to optimize the slow time-varying channel of asynchronous NOMA and compare the signal detection error performance when the channel is assumed to be unchanged.

The Kalman filter includes two main processes: pre-estimation and correction. The pre-estimation process uses the time updating equation to establish a priori estimation of the current channel state. The current state variables and covariance estimates are estimated from the channel state at the previous moment in time, furthermore, construct a priori estimation for the next time state; The process called positive feedback, that is, using a priori estimate obtained from the pre-estimation process in combination with the current measured variable to make a posterior estimation about the current state.

First, the LS (Least Square) algorithm is used to estimate the channel states s at the first pilot signal on the subcarriers, then the sinusoidal Kalman filter is used to estimate the initial value h [-1], and the observing data y[n] samples at the pilot frequency, perform scalar observation Kalman estimation on the status of channel on the subcarrier at each moment. The channel state can be viewed as a first order gaussian process:

$$h_k[n] = h_k[n-1] + u_k[n], 0 \le n \le N, k = 1,2 \tag{6}$$

Among them, $u_k[n], k = 1,2$ are both gaussian white noise with a mean value of 0 and variance of $\sigma_k^2 = 1$, the sample is independent and mutual independence with $w_i[n](i = 1,2)$. Based on the above assumptions, the pre-estimation and correction process of the Kalman channel estimation algorithm is:

Pre-estimate:

$$h_k[n \mid n-1] = \alpha_k h_k[n-1 \mid n-1] \tag{7}$$

Minimum mean error estimation:

$$M_k[n \mid n-1] = \alpha_k^{\,2} M_k[n-1 \mid n-1] + \sigma_k^2 \tag{8}$$

Kalman gain:

$$K_k[n] = \frac{M_k[n \mid n-1]}{M_k[n \mid n-1] + \sigma_k^2} \tag{9}$$

Correction process:

$$\begin{cases} h_1[n|n] = h_1[n|n-1] + K_1[n]\big(y_1[n] - h_1[n|n-1]b_1[n] - h_2[n|n-1]b_2[n-1]\big) \\ h_2[n|n] = h_2[n|n-1] + K_2[n]\big(y_2[n] - h_1[n|n-1]b_1[n] - h_2[n|n-1]b_2[n]\big) \end{cases} \tag{10}$$

Minimum mean square error:

$$M_k[n|n] = (1 - K_k[n]) M_k[n|n-1] \quad (11)$$

Among them, $h_k[n|n], k = 1,2$ denotes the k-user's channel state at time n, $h_k[n|n-1]$ represents the pre-estimated value of the channel state at time n obtained from the state at time n-1 of k-user, and α_k stands for the state transition factor, which derived from the established system mathematical model. It is assumed as a constant here.

In the time direction, by performing Kalman estimation on the state of channel on each subcarrier at each moment, a more accurate estimate can be obtained. From which the first user's signal $b_1[n]$ can be more accurately restored from $y_1[n]$,then eliminate $b_1[n]$ from $y_2[n]$ and restore $b_2[n]$, and so on. Interference signals are eliminated circularly until all user's information is detected. More accurate channel status and elimination of the first user interference greatly improves the accuracy of post-detection weak signals.

SIMULATION AND ANALYSIS

Based on the above model and algorithm, the downlink signal detection of the asynchronous NOMA system is simulated under the Rayleigh fading channel. The channel coefficients are independent and obey the Rayleigh distribution with mean of 0, and variance of 1. The noise has mean of 0 and variance of $\sigma^2 = 10^{\frac{-SNR}{10}}$. The bit error rate is expressed as:

$$BER = \frac{The\ number\ of\ error\ code\ in\ transmission}{The\ number\ of\ total\ code} \times 100\% \quad (12)$$

The method of modulation is BPSK. The difference value between two users' time delay is $\Delta = \tau_2 - \tau_1$, and $e = \frac{\Delta}{T}$ after normalization processing. The other simulation data is shown in TAB. 1:

TAB.1. Simulation Parameters

Parameter	Parameter values
The number of antennas in BS M	1
The number of users K	2
Channel bandwidth	10MHz
SNR	0~20dB
The number of codes N	100000
Total transmitted power P	1

As shown in FIG.4, we assumed that e = 0.5, and be similar to the synchronization situation, the larger the difference in the power distribution coefficients of the asynchronous NOMA signals is, the better the error performance is. Therefore, in the subsequent simulation comparison, the power allocation factors of the superposition signals are all taken as (0.1, 0.9).

As shown in FIG.5, The difference value between two users' time delay is respectively taken as e = 0, 0.25, 0.5, 0.75, and the detection mode of the receiver terminal is asynchronous ZF-SIC. The simulation diagram shows that the detection error performance of the signal is the best when e = 0.5, so the difference value Δ between the asynchronous signals set as 0.5T in the subsequent simulation comparison.

Assuming that the NMSE (Normalized Mean Square Error) of channel estimation is:

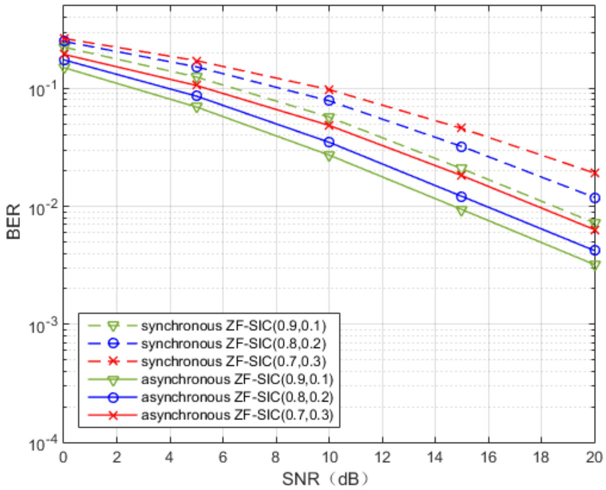

FIG. 4. Comparison of BER between different power allocation coefficient with ZF-SIC

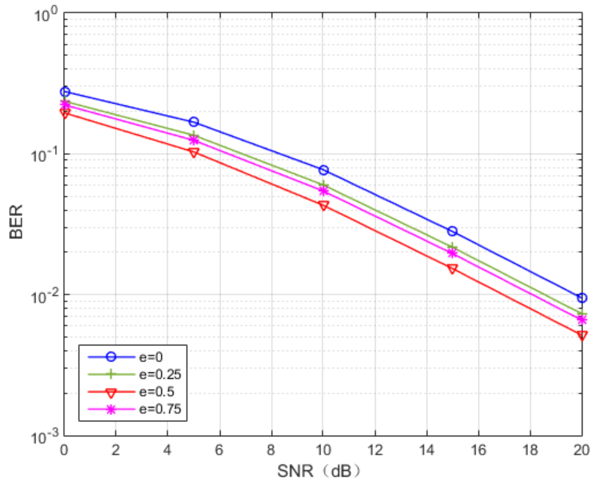

FIG. 5. Comparison of BER between different delay relationship with ZF-SIC

$$NMSE = \frac{E\left(\hat{h}-h\right)^2}{E\left(h\right)^2} \tag{13}$$

Where $\hat{h}$ is the channel estimated and h is the true value of channel. In Figure. 6, simulating the BER performances of the synchronous NOMA and the asynchronous NOMA when the channel is completely known, the NMSE = 0.01 and the NMSE = 0.04.

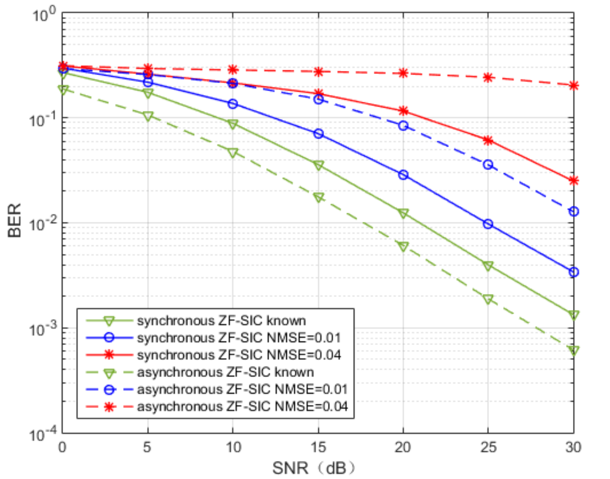

FIG. 6. Comparison of BER between different channel estimation errors with ZF-SIC

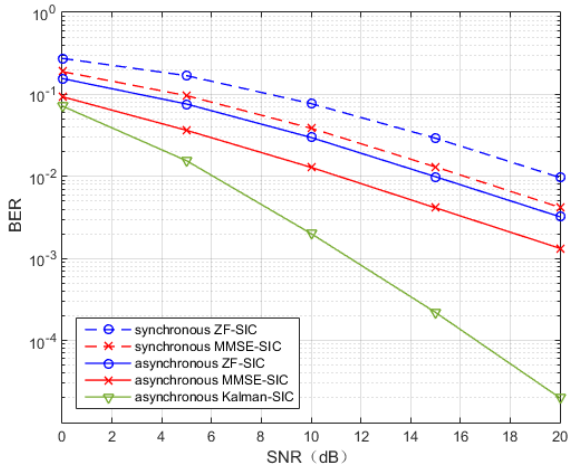

FIG.7. Comparison of BER of slowly time-varying NOMA channel

As shown in FIG.6, the error performance of asynchronously sampled NOMA signal detection is better than synchronization signal when the channel is completely known. However, when the channel estimation is biased, the larger the estimation error is, the worse performance of the successive interference cancellation is, which means the error performance of estimation about the channel of asynchronous signal is affected more than the synchronization signal. Therefore, the new successive interference cancellation method in this paper will have the effect of error expansion when error estimation occurs somewhere. Therefore, the accuracy of the algorithm for channel estimation will be higher.

As shown in FIG.7, assuming that the channel is slowly time-varying, the slow time-varying channel is defined as follows [9]:

$$h_k(n) = h_k\left(\frac{N}{2}-1\right) + \left(n - \left(\frac{N}{2}-1\right)\right)\xi T \tag{14}$$

Among them, instead of the channel gain average $h_k(n)_{avrage}$, the channel gain value $h_k\left(\frac{N}{2}-1\right)$ at the middle point of the symbol data, ξT represents the slope of the channel gain variation, assuming ξ as a sufficiently small constant that the channel changes slowly over time. After the Kalman estimation, the signal was detected with the ZF-SIC algorithm.

The result shows that the error performance of asynchronous single is better than synchronous one because of the great structure after sampling. And the performance of MMSE-SIC is better than ZF-SIC. What's more, its error performance will be greatly affected when the channel is time-varying even on the slowly time-varying channel. But it can be improved after the pre-estimation and correction processes of scalar Kalman filter in the time direction.

SUMMARY

In this paper, a new successive interference cancellation detection method based on NOMA channel is proposed. By using the delay relationship between superimposed signals, the signal is sampled so that the output sequence can have a good structure and be better to eliminate interference signals. However, this structural will make the error expansion problem, which affects the detection and reconstruction of all subsequent signals. Therefore, the requirement for the accuracy of each signal estimation and the channel estimation is more stringent. So, the scalar kalman filter estimation algorithm is also adopted in this paper. The estimation of the channel state in the time direction can be more accurate which results in the great improvement of error detection performance of the entire signal detection. Breaking through the traditional research on synchronous NOMA signals, the algorithm discussed in this paper is more applicable to the actual signal estimation.

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