Method for the Blind Estimation of Power Coefficients in PD-NOMA Systems

Ya V Kryukov, D A Pokamestov, E V Rogozhnikov, A K Movchan, A S Kvashnina

Email: kryukov.tusur@gmail.com

Department of Telecommunications and Basic Principles of Radio Engineering, Tomsk State University of Control Systems and Radioelectronics, Tomsk, 634045, Russian Federation

Abstract. A method of power domain non-orthogonal multiple access with user channel multiplexing is a promising approach for organizing multichannel communication in modern digital wireless systems. Generation of a non-orthogonal group signal involves the superposition of user signals with different weight power coefficients in a single frequency-time resource segment. Decoding such a signal at the receiver requires the information about the weights used in multiplexing. This information is transmitted in control channels and provides additional load on the data network, which in turn reduces its effectiveness. A blind estimation method of power coefficients is proposed to solve this issue. A simulation model has been developed to study proposed method. Simulation resulted in the dependence of the blind estimation of power coefficients error on the signal-to-noise ratio in the transmission channel and on the signal sample length. The result of the study showed that the blind estimation of power coefficients insignificantly worsens the probability of a bit error when decoding a group non-orthogonal signal. Despite this, the proposed blind estimation method can be considered in an attempt to optimize control channel traffic.

1. Introduction

Modern trends in the development of wireless radio access networks include a manifold increase in the network bandwidth and active devices within a single network. One of the key solutions to achieve this is the use of new multiple access techniques. Power Domain Non-Orthogonal Multiple Access (PD-NOMA) is one of the most promising channel multiplexing methods in next generation wireless networks. The use of PD-NOMA in multichannel wireless communication systems is being actively considered by various development teams. According to PD-NOMA, an additional (power) domain is used to separate user channels. Channel symbols of different users can be allocated in a single time-frequency resource segment if they meet the permissible power ratio between them. The multiplexed channels have mutually controlled co-channel interference that is eliminated at the receiving point. Therefore, PD-NOMA belongs to the group of non-orthogonal compaction methods. There are many studies on the PD-NOMA method today. In particular, the most detailed description of this method is given in [1-3].

The successive interference cancellation (SIC) method is most often used to decode a group PD-NOMA signal at the receiving point. Successful SIC implementation requires the information about the power coefficients of each user signal in group signal. In turn, communicating this information imposes the need to transmit additional traffic in the control channels. This is one of the acute problems of PD-NOMA and leads to a decrease in the usable bandwidth of the radio access network.

Solving this problem may involve methods of blind estimation (BE) of PD-NOMA parameters at the receiving point when decoding. In [4], the authors propose and study their own approach for estimating the received signal parameters, including: the multiplexing method (OMA/NOMA) and the QAM order in each non-orthogonal channel. The paper provides the probability of error classification of parameters depending on the signal-to-noise ratio. However, to a greater extent this paper focuses on the problem of pairwise combining of users for non-orthogonal compaction. At the same time, in [5], the team proposed
a simple and quite accurate algorithm for BE of the QAM order in PD-NOMA systems. The topic of BE of signal parameters is relevant, and in this paper we propose our own simple method for BE of power coefficients in non-orthogonal channels with a known QAM order.

2. PD-NOMA System Model

We use the basic PD-NOMA system model, which the group signal $s$ for $K$ users is generated as follows

$$s = \sum_{k=1}^{K} \sqrt{p_k} x_k,$$  \hspace{1cm} (1)

where $x_k$ is a vector of complex channel symbols and $p_k$ is the power coefficient of the $k$th user. Users are indexed in order of increasing power coefficients according to $p_1 > p_k > p_K$ and $\sum_{k=1}^{K} p_k = 1$. Values $p_1, p_2, ..., p_K$ may be calculated taking into account the states of the propagation channel of all users, using one of the proposed algorithms, for example [7]. Symbols $M_k$-QAM are used as channel symbols, where $M_k$ is the QAM order in the $k$th channel. Therefore, the set of permissible channel characters in vector $x_k$ is determined by the order of the $M_k$-QAM with the alphabet $A_k$. Output signal $E(|s|^2) = 1$ is also normalized.

Signal $s_0^*$ at the input of the receiver, having transmitted via the propagation channel with additive white Gaussian noise (AWGN), can be described as

$$s_0^* = \alpha \cdot s \cdot w,$$  \hspace{1cm} (2)

where $\alpha$ is a complex propagation channel coefficient and $w \sim CN(0, \sigma^2)$ is a vector of complex AWGN samples. The signal-to-noise ratio $H$ [dB] at the decoder input can be calculated using

$$H = 10 \cdot \log_{10}\left(\frac{|a|^2}{\sigma^2}\right).$$

SIC is used to decode a group signal. According to it, user signals are decoded one by one in descending order of their power coefficient [8]. Thus, the user signal with power coefficient $p_1$ is always decoded first. Each signal is decoded according to the principle of finding the smallest Euclidean distance between the reference points of the constellation from alphabet $A_1$ and samples from $s_0^*$. The decoding process can be described as follows

$$x_1 = \arg\min_{x_1 \in A_1} |s_0^* - \sqrt{p_1} x_1|^2,$$

The decoded signal of the first subscriber $x_1$ is cancelled from $s_0^*$ with weight coefficient $\sqrt{p_1}$ according to $s_1^* = s_0^* - \sqrt{p_1} x_1$. During the next iteration, SIC will be decoded $x_2$ with a weight of $p_2$ from $s_1^*$ and so on down the chain for the rest of the user channels. In general, decoding a signal on the $k$th non-orthogonal layer can be described using the following expression

$$x_k = \arg\min_{x_k \in A_k} |s_{k-1}^* - \sqrt{p_k} x_k|^2,$$  \hspace{1cm} (3)

where $s_{k-1}^*$ is a group signal compensated at $k-1$ step of the SIC iteration which can be obtained as

$$s_k^* = s_{k-1}^* - \sqrt{p_k} x_k$$  \hspace{1cm} (4)

3. Proposed Blind Power Estimation

According to the PD-NOMA system model, power coefficients $p_1, p_2, ..., p_K$ must be known at the receiver side for SIC decoding. It is performed sequentially and the decoding of $k$th layer requires information about $p_1, p_2, ..., p_{k-1}$ and we propose a simple BE method for it. It consists in estimation of
power coefficient of the decoded layer and calculating of the power for remaining layers. Thus, we are decoding \( k \)th layer and getting \( p_k \), and total power of the remaining \( k+1, k+2, \ldots, K \) layers is 

\[
1 - \sum_{m=1}^{k} p_m.
\]

According to the system model, group PD-NOMA signal \( s \) obtained by (1) is transmitted via the propagation channel and we get \( s_0^* \) by (2) at the receiver side. We normalize the received signal so that 

\[
E[|s^*_0|^2] = 1.
\]

Based on SIC, signal \( x_k \) transmitted in the \( k \)-th non-orthogonal layer with power coefficient \( p_k \) is decoded from \( s_0^* \) using (3, 4). Simultaneously with it, we group symbols from received signal \( s_k^* \) in vector \( Z_k = \{Z_{k,1}, Z_{k,2}, \ldots, Z_{k,M_k}\} \) according to decoded signal \( x_k \). Here \( Z_{k,n}^* \) is a vector carrying samples from \( s_k^* \) with the minimum Euclidean distance with \( x_k^* \) symbol given by alphabet \( A_k \) \((n=1,2,\ldots,M_k)\) and \( B_{k,n}^0 \) - is a length of \( Z_{k,n}^\ast \). Then the BE of \( p_k \) may be obtained by

\[
P_k = \frac{1}{M_k} \sum_{n=1}^{M_k} \left( \frac{\sum_{i=1}^{b_{n}^{0}} Z_{k,n}^i(i)}{B_{k,n}^0} \right)^2.
\]  

(5)

As an example, consider a BE procedure for a simple PD-NOMA configuration. We perform PD-NOMA multiplexing of two \( (K=2) \) 4-QAM user signals \( (M_1,M_2=4) \) with their power-weight constellations are shown in Fig. 1a-b. PD-NOMA signal constellation \( s \) after multiplexing is shown in Fig. 1c. The constellation of the group signal that has transmitted via propagation channel \( s_0 \) is shown in Fig. 1d.

![Constellation Diagrams](image-url)

**Figure 1.** Constellation diagram: (a) – first layer; (b) – second layer; (c) – group signal; (d) – received signal

Let’s take a look at the SIC decoding of the first layer \( (k=1) \). According to the proposed approach, those samples from vector \( s_0^* \) that were decoded as \( x_1^* \in A_1 \) are written to \( Z_{1,n}^* \) for \( n=1..4 \). Thus, vector \( Z_1 = \{Z_{1,1}, Z_{1,2}, Z_{1,3}, Z_{1,4}\} \) is formed as shown in Fig. 1d. Then, we are using (5) for obtaining \( p_1 \) by

\[
P_1 = \left( \frac{1}{4} \sum_{n=1}^{4} \left( \frac{\sum_{i=1}^{b_{n}^{0}} Z_{1,n}^i(i)}{B_{1,n}^0} \right)^2 \right)^{\frac{1}{2}}
\]

Next, the signal component \( \sqrt{p_1} x_1 \) cancels from \( s_0^* \) by (3), and \( x_2 \) can be obtained by SIC-decoding of \( s_1^* \). So we can calculate \( p_2 \) by \( 1 - p_1 \) or by using the proposed method obtaining \( Z_2 \) and using (5) according to
The advantage of the proposed method is its simplicity. As with any blind signal estimation algorithm, the estimation accuracy can be improved by expanding the signal sample involved in the analysis. The disadvantage of the proposed method is the accumulation of the error in power coefficient estimation which leaks from the previous non-orthogonal layer to the next one. The calculation error (5) inevitably leads to the error of cancelling the $k$th non-orthogonal layer using (4). In turn, this leads to an increase in the error in decoding each next non-orthogonal layer.

4. Simulation

The simulation purpose is to measure power estimation error depending on the signal-to-noise ratio in the propagation channel and on the signal sample length. In the first part of the section, we demonstrate the behavior of the BE of power coefficients in AWGN propagation channel. In the second part we demonstrate the effect on the bit error rate (BER) of user channels. We have developed a simulation model that allows the generation and SIC-decoding of the PD-NOMA signal which has been transmitted via AWGN channel.

In the simulation, we multiplex in power domain of three user channels ($K = 3$) which are using $M_1$, $M_2$, $M_3$ orders of square $M$-QAM with $p_1$, $p_2$, $p_3$ power coefficients ($p_1 > p_2 > p_3$ and $\sum_{k=1}^{3} p_k = 1$). The user signal lengths are equal to each other and controlled by $N$ value. The multiplexing configuration is given in Table 1.

| Layer (k) | Power coefficient ($p$), W | Order of QAM ($M$) |
|-----------|--------------------------|------------------|
| Layer 1 (k = 1) | 0.85 | 4 |
| Layer 2 (k = 2) | 0.13 | 4 |
| Layer 3 (k = 3) | 0.02 | 4 |

The first part of the simulation results in a comparison of the calculated estimation of the power coefficient with its real value depending on the signal-to-noise ratio. It presented in Figure 2 that shows the behavior of $p_1$, $p_2$, $p_3$ values estimated based on $N = 200$ signal length. Analyzing the simulation result, it can be seen that the power estimation values approach their true values with an increase in $H$. This means that with a sufficient value of signal-to-noise ratio at the SIC decoder input, the proposed method may result in the estimation of power coefficients with a sufficiently high accuracy.

Next, we are measuring estimation error and in figure 3 the mean square error (MSE) for $p_1$, $p_2$, $p_3$ vs $H$ for $N = 200$ is shown. It is seen that the behavior of the dependence $\text{MSE}(p)$ vs $H$ is of an asymptotic nature. After a certain value of $H$, the estimation error stops decreasing which means that we will never get the perfectly exact $p$ value at the BE using the proposed method. This will adversely affect the decoding result and lead to a degradation of the BER characteristic.
Any BE of signal parameters has a strong dependence on the length of the signal sample involved in the calculations. In Figure 4, we show MSE($p_k$) vs signal length $N$ for fixed $H = 20$ dB. It can be seen from the simulation result that an increase in the length of signal sample $N$ leads to a decrease in MSE due to more accurate averaging in (5).

In the second part of this section, we show the effect of the BE of power coefficients on BER characteristic in non-orthogonal layer decoding. In Figure 5, marker dots show the BER values resulting from decoding a signal with BE of $p_k$ value for signal duration $N = 200$. Dashed lines show the BER values when decoding with the perfect estimation. From Fig. 5, it can be seen that the BE slightly worsens the BER characteristics. This is due to the previously described effect of the accumulation of the error in estimating the power coefficient.

5. Conclusion
The paper proposes a method for the blind estimation of power coefficients of non-orthogonal user channels multiplexed by PD-NOMA method. This eliminates the need to transmit a significant portion of the PD-NOMA multiplex configuration information and reduces the load on service channels. The proposed approach consists in sequential SIC decoding of a group signal and estimation of the power coefficient of non-orthogonal layer with the highest power coefficient, followed by its elimination from the group signal. It then becomes possible to calculate total power of the remaining non-orthogonal layers and to initialize the next SIC link.

The advantage of our method lies in the simplicity of its practical implementation, and the disadvantage is the accumulation of the estimation error during sequential SIC decoding. The result of simulation modeling showed that the estimation error can be reduced by increasing the signal sample. The paper shows that the proposed method for the BE of power coefficients leads to an insignificant increase in the bit error probability when decoding PD-NOMA channels. Despite this, the BE can be considered when trying to reduce service traffic on PD-NOMA systems.
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