A Blind Detection Algorithm for Modulation Order in NOMA Systems

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Abstract. The blind detection algorithm for modulation order (MOD) of interference user in power-domain non-orthogonal multiple access (NO-MA) is studied by academics. Maximum likelihood method is the optimal approach, but with huge computational complexity. A sub-optimal approach based on max-log approximation is deduced which can reduce computational complexity, but with performance degradation. This paper investigates an improved blind detection algorithm for modulation order based on max-log likelihood approach in NOMA systems. Unlike the other two algorithms, the proposed algorithm takes the statistical characteristics of the received signal into consideration. The complexity analysis and link-level simulation results are provided to verify that the proposed method outperforms the max-log likelihood method with a little additional computational complexity, and it is a good trade-off between complexity and performance.

Keywords: NOMA · Blind detection · Modulation order

1 Introduction

With the rapid development of wireless communications, the number of users and the volume of services have exploded, putting higher demand on the system capacity of wireless networks. Subsequently, mobile communication technology is presently facing a new challenge, giving birth to the emergence of fifth-generation (5G) wireless communication. Since the exponential development of mobile Internet and the Internet of Things (IoT), one of the critical points that 5G needs to solve is high data-rate and capacity in applications.

Non-orthogonal multiple access (NOMA), as one of the candidate standards for next generation cell communication technology, has a series of advantages, such as higher spectral efficiency (SE) [8], higher sum channel capacity [7], smaller feedback requirement and lower transmission latency [5]. More importantly, with guaranteed user fairness assumption, the system throughput of NOMA can be significantly larger than orthogonal multiple access (OMA) [4].

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Generally, different NOMA solutions can be classified into two categories, power-domain NOMA and code-domain NOMA. This paper focuses on power-domain NOMA. According to the concept of NOMA, signals for multiple users are superposed in power domain and transmitted in the same time-frequency resources at transmitter. Multiuser detection (MUD) algorithms, such as successive interference cancellation (SIC) are utilized to detect desired signals at receiver.

Reference [1] shows that a significant performance gain can be achieved under the assumption that receiver has ideal interference parameters associated with undesired signals at the receiver end. The most common and easiest way to get interference parameters is broadcast signaling (higher layer signaling or dynamic signaling). Another method to obtain those dynamic interference parameters is blind detection (BD) [2]. Reference [2] shows the assistance information that is required for receivers to cancel superposition interference. Obviously, if dynamic interference parameters are transmitted through signaling, a large amount of signaling resources will be consumed and the number of UEs that BS can serve simultaneously will be reduced. Assume that N bits is needed to signal those parameters for one UE, when M UEs are superposed, the total consumed bits would be $M(M-1)N/2$ bits. This is exactly opposite to the idea of designing the NOMA system. Therefore, blind detection or hybrid method would be the feasible solution in practice implementation.

Heunchul Lee et al. proposed blind detection algorithms based on max-log approximation for estimating the dynamic interference parameters TPR, RI, PMI, and MOD [6]. Alexei Davydov et al. proposed a blind maximum likelihood (ML) interference suppression receiver relying on direct estimation of the interfering signal parameters, such as transmission scheme, precoding vector, power boosting and modulation [3]. Maximum likelihood blind detection algorithm is the optimal solution but with high complexity, which can not be achieved in practice. To reduce complexity, max-log likelihood algorithm based on max-log approximation is deduced. However, This is done at the expense of performance for the reduction in complexity. And how to find the trade-off between performance and complexity has not been addressed so far. This paper focuses on blind detection algorithm for modulation order in power-domain NOMA.

The remainder of this paper is organized as follows: Sect. 2 presents system model, including multiuser superposition coding scheme. Section 3 proposes an improved blind detection algorithm for modulation order based on max-log likelihood algorithm and provides complexity analysis among different algorithms. In Sect. 4, we provide link-level simulation results to compare the performance of blind detection correct rate and link-level throughput between conventional algorithm and proposed algorithm. Finally, conclusions are made in Sect. 5.

2 System Model

This section presents system model. This paper considers a downlink single-cell scenario where consists one base station (BS) and N user equipments (UEs). The UEs are denoted as U_i, $i = 1 \cdots N$. The channel condition from BS to each

UE is denoted as h_i, $i = 1 \cdots N$. Assume that the channel conditions for every UE are sorted as

$$0 < |h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_N|^2, \tag{1}$$

which means that the N-th user U_N holds the strongest channel condition and the first user U_1 holds the worst channel condition.

Based on the concept of NOMA, BS can serve more than one UEs on the same time-frequency resource simultaneously. And those UEs hold distinct channel conditions. Reference [4] has proved that NOMA with fixed power allocation (F-NOMA) can offer a larger sum rate than orthogonal multiple access (MA), and the performance gain of F-NOMA over conventional MA can be further enlarged by selecting users whose channel conditions are more distinctive. The NOMA scheme implements superposition coding (SC) in power domain at transmitter and decodes UE's signal with the help of SIC techniques at receiver. At transmitter, the UE with better channel condition would be assigned with a lower power ratio, and the UE with worse channel condition would be assigned with a higher power ratio. The portion of total power assigned to U_i is denoted as α_i, which satisfies $\sum_{i=1}^{s} \alpha_i = 1$, where s indicates the number of superposed signals on the same time-frequency resource. At receiver end, each UE needs to decode the signals of weaker UEs before decoding its own signal, i.e., U_i needs to decode signals of U_m, where $m < i$. The signals of weaker UEs would be reconstructed and subtracted from the received signal. U_i treats signals of U_n with $n > i$ as interference.

Without loss of generality, we choose a simple NOMA scenario with one BS and two UEs. The two UEs are marked as "Target UE" and "Interference UE", with channel condition h_2 and h_1, respectively. The channel conditions h_1 and h_2 satisfy $|h_2|^2 > |h_1|^2$, which indicates that "Target UE" has better channel condition than "Interference UE". Therefore, α, the portion of total power $\mathscr{P}$ allocated to target UE, is less than 0.5, which can be written as $\alpha < 0.5$.

Let us denote the K-dimensional complex signal vector transmitted from BS to user U_i as

$$\boldsymbol{x}^{(i)} = [x_1^{(i)}, x_2^{(i)}, \cdots, x_K^{(i)}]^T, \tag{2}$$

where $i = 1, 2$, $x_k^{(i)}$ denotes the k-th symbol for user U_i, K indicates the number of symbols for user U_i, and $(\cdot)^T$ denotes the transpose of a vector. Symbol $x_k^{(i)}$ is chosen from constellation set $\mathbb{C}^{(i)}$, whose cardinality is denoted by $|\mathbb{C}^{(i)}|$. Thus, the superposed signal to be transmitted to U_1 and U_2 can be written as

$$\boldsymbol{t} = \sqrt{\alpha \mathscr{P}} \boldsymbol{x}^{(2)} \oplus \sqrt{(1-\alpha)\mathscr{P}} \boldsymbol{x}^{(1)}, \tag{3}$$

where $\boldsymbol{t}$ denotes the superposed signal to be transmitted, α represents the fraction of total power assigned to near user U_2, $\mathscr{P}$ denotes the total power used for transmission at transmitter, and the rules for $\oplus$ operation is shown in Fig. 5.1.2–2 in [2].

Let us define $\boldsymbol{r}^{(i)}$ as the received signal vector at the user U_i. Then, $\boldsymbol{r}^{(i)}$ can be written as

$$\boldsymbol{r}^{(i)} = \boldsymbol{H}^{(i)} \boldsymbol{t} + \boldsymbol{n}^{(i)}, \quad \text{for} \quad i = 1, 2, \tag{4}$$

where $\boldsymbol{H}^{(i)}$ denotes the channel matrix from BS to user U_i, $\boldsymbol{n}^{(i)}$ is the additive noise vector, whose elements are independent and identically-distributed (i.i.d.) complex Gaussian, $\mathbb{E}[|\boldsymbol{n}^{(i)}|^2] = \sigma_i^2$, where $\mathbb{E}[\cdot]$ denotes the expectation operator, and $|\cdot|$ represents the absolute value of a complex number.

The basic idea of non-orthogonal multiple access technology is to introduce interference information at the transmitter and simultaneously transmit the information of multiple users on the same time-frequency resource by superposition coding. Reference [2] describes candidate multiuser superposition transmission schemes, which can be categorized into three categories — Category 1, Category 2 and Category 3.

Because of the loss of power ratio in category 3 and the loss of gray mapping in category 1, this paper chooses category 2 as superposition coding scheme. An example of composite constellation of Category 2 is shown in [2]. With joint modulation mapping for target and interference UEs, gray mapping is kept for the label bits of the composite constellation. Moreover, receiver uses SIC technique to achieve the correct demodulation of the received signal.

3 Proposed Blind Detection Algorithm for Modulation Order and Complexity Analysis

This section investigates blind detection problem for estimating MOD interference parameter in NOMA systems. Note that by transmitting the downlink control information (DCI) through physical downlink control channel (PDCCH), the MOD parameter of target UE can be found explicitly. One way to get MOD parameter of interference UE is broadcast signaling. However, this method consumes too much unnecessary signaling. Another way to get MOD parameter of interference UE is blind detection, which will be presented in this section. Furthermore, complexity analysis will be presented in this section.

3.1 Proposed Algorithm for Blind Detection

It is well known that blind detection based on maximum likelihood (ML) estimation minimizes the error probability. Let $p(r_k^{(i)}|t_k)$ denote the conditional probability density function for $r_k^{(i)}$, given t_k, which is represented by

$$p(r_k^{(i)}|t_k) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp(-\frac{||r_k^{(i)} - H_k^{(i,\mathrm{e})} * t_k||^2}{2\sigma_i^2}), \tag{5}$$

where $H_k^{(i,\mathrm{e})}$ is the k-th element in the effective channel matrix $\boldsymbol{H}^{(i,\mathrm{e})}$ and the superscript “e” is the abbreviation of “effective”.

Assume that candidate modulation order set for interference user is a P-by-1 vector $\boldsymbol{M}^{\mathrm{itf}}$ and the modulation order for target user is m^{tar}. P is the number of candidate modulation orders. Thus, the candidate composite modulation order for superposition coding is

$$\boldsymbol{M} = \boldsymbol{M}^{\mathrm{itf}} + m^{\mathrm{tar}}. \tag{6}$$

And p is one of elements in $\boldsymbol{M}$. In case of a certain modulation order p, the maximum likelihood blind detection algorithm for interference modulation order is [6]

$$M_p = \frac{1}{K}\sum_{k=1}^{K}\frac{1}{|\mathbb{C}_p|}\sum_{t_k\in\mathbb{C}_p}\exp(-\frac{||r_k^{(i)} - H_k^{(i,\mathrm{e})} * t_k||^2}{\sigma_i^2}). \tag{7}$$

Constants in (5) is omitted in (7). Then, the ML detector performs an exhaustive search among all the possible constellation points corresponding to all the candidate composite modulation order p, and makes the best decision of p^{opt} which maximizes the metric

$$p^{\mathrm{opt}} = \arg\max_{p} M_p. \tag{8}$$

Although ML detector is optimal, it is not practical, since it leads to prohibitive computational complexity. Thus, a suboptimal approach with reduced computational complexity to solve the optimal metric in (7), termed max-log likelihood, is derived. Max-log likelihood blind detection algorithm for interference modulation order can be described as [6]

$$\begin{aligned} M_p &= \frac{1}{K}\sum_{k=1}^{K}\log\frac{1}{|\mathbb{C}_p|}\sum_{t_k\in\mathbb{C}_p}\exp(-\varpi_k^2/\sigma_i^2) \\ &= \frac{1}{K}\sum_{k=1}^{K} -(\varpi_{k,\min}^2/\sigma_i^2 + \log|\mathbb{C}_p|) \\ &+ \frac{1}{K}\sum_{k=1}^{K}\log(1+\frac{\sum\limits_{\substack{t_k\in\mathbb{C}_p\\ t_k\neq t_{\min}}}\exp(-\varpi_k^2/\sigma_i^2)}{\exp(-\varpi_{k,\min}^2/\sigma_i^2)}) \end{aligned} \tag{9}$$

where

$$t_{\min} = \arg\min_{t_k\in\mathbb{C}_p} ||r_k^{(i)} - H_k^{(i,\mathrm{e})} * t_k||^2, \tag{10}$$

$$\varpi_k = ||r_k^{(i)} - H_k^{(i,\mathrm{e})} * t_k||, \tag{11}$$

$$\varpi_{k,\min} = ||r_k^{(i)} - H_k^{(i,\mathrm{e})} * t_{\min}||, \tag{12}$$

and the last term in (9) is omitted to reduce complexity [6]. Thus, max-log likelihood algorithm can be written as

$$\begin{aligned} M_p &= \frac{1}{K}\sum_{k=1}^{K}\log\frac{1}{|\mathbb{C}_p|}\sum_{t_k\in\mathbb{C}_p}\exp(-\varpi_k^2/\sigma_i^2) \\ &\approx \frac{1}{K}\sum_{k=1}^{K} -(\varpi_{k,\min}^2/\sigma_i^2 + \log|\mathbb{C}_p|). \end{aligned} \tag{13}$$

Based on the above discussion, ML algorithm is optimal, but consumes too much time to get final result. Max-log likelihood algorithm consumes less time, but loses performance. And it demonstrates an interesting phenomenon that, in (7)–(13), the term $1/|\mathbb{C}_p|$ is a constant when p is given, which does not take the statistical characteristics of the received signal into consideration. Because of limited number of symbols and bandwidth constraints in a transmission process, the number of symbols can not be achieved statistically large. In another word, the joint modulated symbols at transmitter are non-uniform distribution. This results in the number of symbols, corresponding to each constellation point, is not exactly equal, but with slight deviations. Thus, the constant term $1/|\mathbb{C}_p|$ can not reflect actual characteristics of the signal, and the performance of blind detection degrades. The proposed method will take the features of signal into account, and can be written as

$$\begin{aligned} M_p &= \frac{1}{K}\sum_{k=1}^{K} \log \xi_j \sum_{t_k \in \mathbb{C}_p} \exp(-\varpi_k^2/\sigma_i^2) \\ &\approx \frac{1}{K}\sum_{k=1}^{K} -(\varpi_{k,\min}^2/\sigma_i^2 - \log \xi_j), \end{aligned} \tag{14}$$

where

$$\xi_j = \frac{|\mathbb{S}_j|}{K}, \tag{15}$$

where $\mathbb{S}_j$ is the set of received symbols which have the minimum Euclidean norm to the j-th composite constellation point, and its cardinality is denoted by $|\mathbb{S}_j|$. j is the index of composite constellation symbol, which is in range $[1, \cdots, 2^p]$, where p denotes composite modulation order. K denotes the number of received symbols. The proposed method is termed as K-max-log likelihood algorithm.

3.2 Complexity Analysis

To further analyze the efficiency of the proposed K-max-log likelihood algorithm, we study the computational complexity of the proposed method. As described in Sect. 3.1, the proposed method is constructed using the max-log likelihood approach. Thus, as shown in Table 1, the computational complexity of maximum likelihood, max-log likelihood and K-max-log likelihood are compared associated with addition, subtraction, multiplication, division, exponent, logarithm and comparison. In Table 1, P denotes the number of modulation order candidates for interference user, K denotes the number of received symbols, and $|\mathbb{C}_p|$ denotes the number of constellation symbols in a certain composite modulation order p.

It is well known that multiplication, division, exponent and logarithm mathematical operations are more time-consuming. Both max-log likelihood and K-max-log likelihood reduce the number of such mathematical calculations, which can reduce computational complexity significantly. The term $\sum_{p=1}^{P} \mathbb{C}_p$ in K-max-log likelihood, compared to K, is pretty small. Therefore, with a little additional calculation, K-max-log likelihood algorithm almost has the same computational complexity as the max-log likelihood algorithm. And the proposed method has a much lower complexity than the maximum likelihood blind detection algorithm which requires exhaustive search and is impractical for real systems.

Table 1. Complexity comparison

	Max likelihood	Max-log likelihood	K-Max-log likelihood
Addition	$\sum_{p=1}^{P}(2K\lvert\mathbb{C}_p\rvert)+K$	KP	KP
Subtraction	$\sum_{p=1}^{P}2K\lvert\mathbb{C}_p\rvert$	$\sum_{p=1}^{P}(K\lvert\mathbb{C}_p\rvert+2K)$	$\sum_{p=1}^{P}(K\lvert\mathbb{C}_p\rvert+2K)$
Multiplication	$\sum_{p=1}^{P}3K\lvert\mathbb{C}_p\rvert$	$\sum_{p=1}^{P}(K+2K\lvert\mathbb{C}_p\rvert)$	$\sum_{p=1}^{P}(K+2K\lvert\mathbb{C}_p\rvert)$
Division	$\sum_{p=1}^{P}(K\lvert\mathbb{C}_p\rvert+K+1)$	$P(K+1)$	$P(K+1)$
Exponent	$\sum_{p=1}^{P}K\lvert\mathbb{C}_p\rvert$	0	0
Logarithm	0	0	$\sum_{p=1}^{P}\lvert\mathbb{C}_p\rvert$
Comparison	P	$P+\sum_{p=1}^{P}K\lvert\mathbb{C}_p\rvert$	$P+\sum_{p=1}^{P}K\lvert\mathbb{C}_p\rvert$

4 Performance Evaluation

In this section, we provide a series of link-level simulation results to verify the efficacy and accuracy of the proposed detection algorithm for estimating the MOD parameter of interference user. The candidate interference modulation set includes four kinds of modulation types, namely NONE, QPSK, 16QAM and 64QAM, where NONE means there is no interference user in current transmission process. Other simulation parameters are listed in Table 2. We use blind detection rate and link-level throughput, especially 70% throughput, as the measurements of the pros and cons of the proposed algorithm.

Table 2. Simulation parameters

Parameter	Value	Parameter	Value
Channel bandwidth	10 MHz	Carrier frequency	2 GHz
Sampling rates	15.36 MHz	TTI size/duration	14 OFDM Symbols/ms
CFI	2	Channel estimation	MMSE
Cyclic Prefix type	Normal	HARQ	Disabled
Number of FFT size	1024	CSI reporting mode	PUCCH 2-0
Fast fading	Rayleigh	No. of PRBs of PDSCH	50
Propagation channel	EPA	Receiver type	CWIC

First, we clarify the performance of blind detection rate of different algorithms. Figure 1 shows the blind detection correct rate of MOD parameter of interference user in NOMA transmission for 1-by-2 SIMO. The figure shows that K-max-log likelihood can always outperform max-log likelihood. On the other hand, the required SNR of K-max-log likelihood for achieving the correct rate of 100% is about 1.6–1.8 dB less than that of max-log likelihood algorithm. One thing should to be pointed out is that the number of simulation curves in Fig. 1 is less than the total number of simulation curves in Fig. 2a–d. The first reason is that there are no detection rate curves for “ideal” cases. The second reason is that the blind detection rate is affected by modulation order rather than transport block size.

Second, we clarify the performance of link-level throughput of max-log likelihood and K-max-log likelihood algorithm. Figure 2a illustrates the link-level throughput results of ideal, max-log likelihood and K-max-log likelihood method under certain conditions, where target user and interference user both use QPSK, but with different modulation coding schemes (MCSs). The “ideal” means that the MOD parameter of interference user is perfectly known through network signaling at the receiver. Figure 2b–d show the comparison of system throughput with those three methods under different conditions, which have already been shown in the corresponding captions and legends.

As shown in Fig. 2a–d, we can observe that the performance of proposed method always overcomes max-log likelihood’s. In addition, the simulation results also show that target user throughput is significantly improved around 70% throughput point. Another noticeable feature is that the performance of the proposed method is very close to the ideal receiver around 70% throughput point in some simulation cases. Furthermore, the higher modulation order and the larger transport block size of the target user and the interference user is, the more performance degrades due to the failure of blind detection.

From the simulation results presented in this section, we can conclude that the proposed method can significantly improve blind detection rate and link-level throughput in NOMA systems, especially at 70% throughput point.

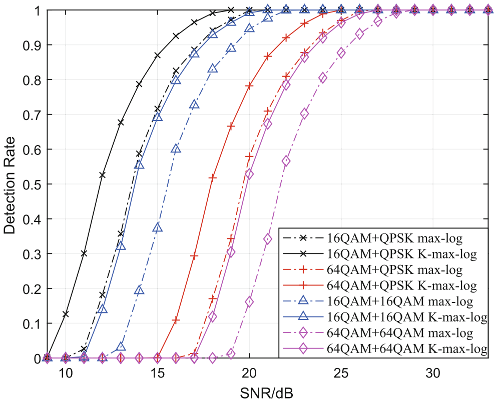
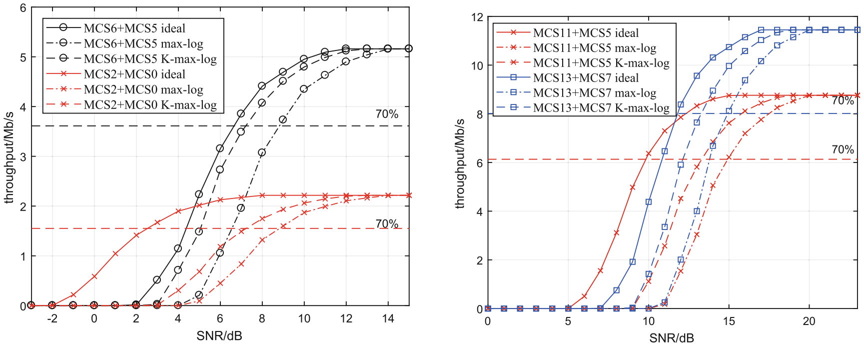
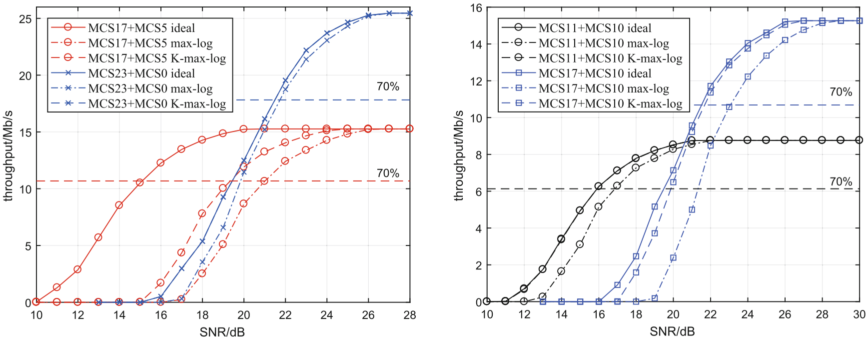


Fig. 1. The comparison of blind detection correct rate



(a) QPSK+QPSK (b) 16QAM+QPSK



(c) 64QAM+QPSK (d) 16QAM+16QAM and 64QAM+16QAM

Fig. 2. Simulation results on different algorithms: link-level throughput

5 Conclusion

In this paper, we have investigated the blind detection problem of the MOD parameter for interference user in NOMA systems, and proposed an improved max-log-likelihood-based method for blind detection. The proposed method takes the statistical characteristics of received signal into consideration, which is not considered in max-log algorithm. Link-level simulation results have proved that the performance of proposed method outperforms that of max-log likelihood method with a little additional computational complexity. In conclusion, we have shown that the SIC receiver based on K-max-log likelihood blind detection algorithm can be a promising candidate for future high performance and low complexity UE devices in the next generation communication.

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