

A Method of Constellation Blind Detection for Spectrum Efficiency Enhancement

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Abstract—Modulation classification is a technique to achieve blind estimation of modulation types. Thereby, signaling overhead can be reduced or equivalently spectrum efficiency can be improved. However, the benefit is limited in coded systems, since the code rate information have to be signaled anyway. To fulfill the requirement of higher spectrum efficiency in 5th generation (5G) systems, a method of constellation blind detection is proposed in this paper. By performing rotation and interleaving onto normal constellations, a new shape of constellation is created, and it can be distinguished from the normal constellation by blind detection at the receiver side. The advantage of the proposed method is twofold. Firstly, additional information bits can be carried by blind detection and thus enhancing spectrum efficiency. Secondly, constellation rotation can provide diversity gain. Simulation results have verified the effectiveness of our proposed method.

Keywords—5G, constellation blind detection, modulation classification, NOMA

I. INTRODUCTION

Spectrum efficiency has been improved with the evolution of generations of cellular systems. For the upcoming era of 5th generation (5G), higher spectrum efficiency is required to support potentially emerged services such as high definition video and immersive experience. According to International Mobile Telecommunications 2020 (IMT-2020), 3 ~ 5 times higher spectrum efficiency is a typical 5G target compared with the 4G system of IMT-Advanced [1].

Modulation classification is one of the many candidate techniques which can improve spectrum efficiency. With adaptive modulation used at the transmitter, blind modulation classification is performed by the receiver to detect which modulation type is in use among e.g. quadrature phase shift keying (QPSK), 16 quadrature amplitude modulation (16QAM) and 64QAM [2]. There is no need to use signaling to inform the modulation type, and thus signaling overhead can be reduced or equivalently spectrum efficiency can be enhanced. Modulation classification has been studied in many respects during the last decade. For example, blind detection algorithms are proposed in [3][4] with different criteria used, a low complexity sub-optimal algorithm is introduced in [5], and robustness against channel impairments is dealt with in [6][7]. However, there are limitations to apply modulation classification in systems with channel coding. As the code rate always needs to be signaled in cellular networks, such as Long Term Evolution (LTE) and/or LTE-Advanced, it is

not quite effective on signaling overhead reduction even with modulation classification used.

In this paper, a method of constellation blind detection is proposed to further enhance spectrum efficiency. Different from modulation classification, one of the constellation to be blindly detected is artificially created in our method. More specifically, a new shape of constellation called transformed constellation is obtained by performing rotation and interleaving onto normal constellations. Either transformed or normal constellations are transmitted is controlled by a part of source information bits, and these bits can be recovered by constellation blind detection. Therefore, spectrum efficiency is enhanced by receiving these additionally conveyed bits. Compared with detection among multiple modulation types in modulation classification, it is much easier to detect between only two types of constellations in our method. Also signal space diversity gain from constellation rotation is beneficial for total throughput performance. As non-orthogonal multiple access (NOMA) is an important technique for 5G [8][9], the extension to NOMA is also discussed. Link-level simulations show that our proposed method can achieve throughput gain when signal-to-noise ratio (SNR) exceeds a certain threshold.

The rest of this paper is organized as follows. Section II presents the system model. In Section III, the proposed method of constellation blind detection is introduced. Simulation results are given in Section IV. Finally conclusions are presented in Section V.

II. SYSTEM MODEL

A typical single-input single-output (SISO) model is considered in this paper, which applies to orthogonal frequency division multiplexing (OFDM) and other digital communication systems. The received signal can be written as

$$y = hx + n, \quad (1)$$

where x denotes the transmitted symbol with the normalized power, h represents the small-scale fading channel with $E\{|h|^2\} = 1$, and n is the additive white Gaussian noise (AWGN) with zero mean and σ^2 variance. Therefore, SNR is defined as $\text{SNR} = 1/\sigma^2$. For adaptive modulation, x can be chosen from a constellation of QPSK, 16QAM or 64QAM. For modulation classification, the modulation type is blindly detected based on a group of received y signals.

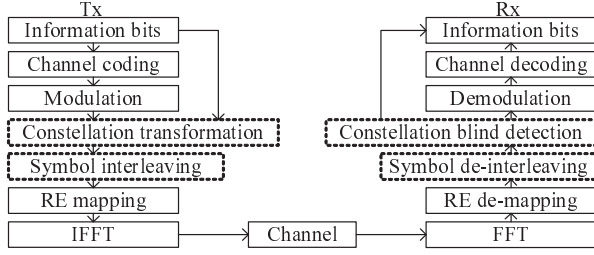


Fig. 1. General processing flow of constellation blind detection.

III. CONSTELLATION BLIND DETECTION

The method of constellation blind detection is introduced in this section. At the transmitter, the transformed constellation is generated under the control of a part of source information bits. At the receiver, if whether the constellation is transformed can be identified by blind detection, this part of bits can be obtained as additional information bits. The whole processing flow is given in Fig. 1 for an OFDM system, where raw information bits are directly used to control constellation transformation.

A. Transmitter processing

Constellation transformation in Fig. 1 is composed of constellation rotation and real/imaginary part interleaving. For simplicity, it will be illustrated by assuming QPSK transmission. Let x_1, x_2 denote two QPSK symbols to be transmitted, and then the signal after constellation rotation is given by

$$u_i = x_i e^{j\theta}, \quad (2)$$

where θ represents the rotation angle and $i \in \{1, 2\}$. The real/imaginary part interleaving is performed by exchanging the imaginary part of u_1 with the real part of u_2 , and the output can be written as

$$v_1 = \Re(u_1) + j\Re(u_2) = \Re(x_1 e^{j\theta}) + j\Re(x_2 e^{j\theta}), \quad (3)$$

$$v_2 = \Im(u_1) + j\Im(u_2) = \Im(x_1 e^{j\theta}) + j\Im(x_2 e^{j\theta}), \quad (4)$$

where $\Re(\cdot)$ and $\Im(\cdot)$ denote taking real and imaginary part respectively. All the possible v_i symbols actually constitute a new constellation with a larger size. One example of transformation from x_i to v_i ($i \in \{1, 2\}$) is given in Fig. 2. It can be seen that x_1 and x_2 are from a 4-point QPSK constellation, however, v_1 and v_2 are from a 16-point transformed constellation. If receiver can blindly detect whether QPSK or transformed constellation is used, 1 bit information can be additionally obtained. Furthermore, since replica information of x_1 is transmitted through both v_1 and v_2 (so is x_2), a type of diversity known as signal space diversity [10][11] can also be exploited. For other modulation types, aforementioned constellation transformation can also be used.

To facilitate blind detection, constellation transformation is performed onto a group of symbols. Whether using transformed constellation is determined by a part of source information bits, while the rest bits are mapped to symbols of different constellations. As an example, in Fig. 3, transmitter

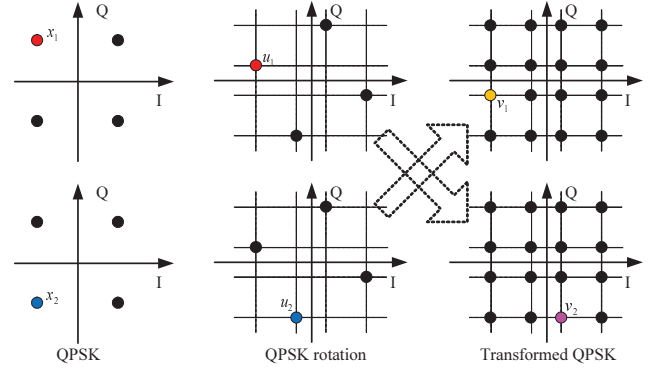


Fig. 2. Constellation rotation and real/imaginary part interleaving.

determines whether to perform constellation transformation every 4 symbols based on a source bit. If the source bit is “1”, constellation transformation is performed on every 2 adjacent symbols. If the source bit is “0”, normal constellation is used instead. If receiver can identify whether transformed or normal constellation is transmitted, 1 bit information can be additionally carried by each group of 4 symbols. There is a tradeoff between detecting more reliably and carrying more bits. With more symbols used in a group, the reliability of blind detection will be improved, while the total number of additionally conveyed bits will decrease.

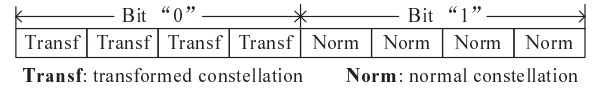


Fig. 3. Distribution of transformed constellation and source bit.

If the group of symbols in Fig. 3 experiences continuous deep fading, reliable constellation blind detection will be hard to achieve. Therefore, symbol-level interleaving is performed onto the output of constellation transformation in Fig. 1. This is to make successive symbols experience independent channel fading and thus enhancing blind detection performance.

In principle, the method can be extended to NOMA where constellations with different power are superposed [8][9]. With constellation transformation on high power constellation, additional bits can be detected by treating low power constellation as noise. With constellation transformation on low power constellation, additional bits can be recovered by first cancelling high power constellation. Details are still for further study. Hereafter only normal constellation is used for illustration.

B. Receiver processing

At the receiver, symbol-level de-interleaving is performed, and then blind detection is done on a per group basis. Let m_1, m_2 index normal and transformed constellation respectively, denote M_1, M_2 as the size of normal and transformed constellation respectively, and define a_j^i as the j th symbol from constellation m_i ($i \in \{1, 2\}$). Then x_i in (2) is from a symbol set $\{a_1^1, a_2^1, \dots, a_{M_1}^1\}$, and v_i in (3), (4) is from $\{a_1^2, a_2^2, \dots, a_{M_2}^2\}$.

After symbol-level de-interleaving, the group of symbols to be detected can be denoted as $\mathbf{Y} = [y_1, y_2, \dots, y_L]$, and the corresponding channels are given as $[h_1, h_2, \dots, h_L]$. Then the probability of using constellation m_i can be written as

$$P(\mathbf{Y}|m_i) = \prod_{n=1}^L \left(\frac{1}{\pi \sigma^2 M_i} \sum_{j=1}^{M_i} \exp \left(-\frac{|y_n - h_n a_j^i|^2}{\sigma^2} \right) \right). \quad (5)$$

The most possibly used constellation is m_i which has a bigger $P(\mathbf{Y}|m_i)$. Therefore the result of blind detection is given as

$$\hat{m}_i = \arg \max_{m_i} P(\mathbf{Y}|m_i) \quad (6)$$

where $i \in \{1, 2\}$. If the detection result is normal constellation, conventional demodulation and decoding proceed. If the detection result is transformed constellation, detailed demodulation process is given as follows. Given transmitted symbols as (3) and (4), the signals y_1, y_2 can be written as

$$y_1 = h_1 v_1 + n_1 = h_1 (\Re(x_1 e^{j\theta}) + j\Re(x_2 e^{j\theta})) + n_1, \quad (7)$$

$$y_2 = h_2 v_2 + n_2 = h_2 (\Im(x_1 e^{j\theta}) + j\Im(x_2 e^{j\theta})) + n_2, \quad (8)$$

where n_1, n_2 denote noise. Then zero forcing is used to obtain

$$z_1 = (\Re(x_1 e^{j\theta}) + \Re(\eta_1)) + j(\Re(x_2 e^{j\theta}) + \Re(\eta_1)), \quad (9)$$

$$z_2 = (\Im(x_1 e^{j\theta}) + \Re(\eta_2)) + j(\Im(x_2 e^{j\theta}) + \Im(\eta_2)), \quad (10)$$

where $\eta_i = n_i/h_i$ with $i \in \{1, 2\}$. After that, real and imaginary part de-interleaving is performed, and we have

$$\begin{aligned} l_1 &= (\Re(x_1 e^{j\theta}) + \Re(\eta_1)) + j(\Im(x_1 e^{j\theta}) + \Re(\eta_2)) \\ &= x_1 e^{j\theta} + (\Re(\eta_1) + j\Re(\eta_2)), \end{aligned} \quad (11)$$

$$\begin{aligned} l_2 &= (\Re(x_2 e^{j\theta}) + \Im(\eta_1)) + j(\Im(x_2 e^{j\theta}) + \Im(\eta_2)) \\ &= x_2 e^{j\theta} + (\Im(\eta_1) + j\Im(\eta_2)), \end{aligned} \quad (12)$$

The target of demodulation is to find out which a_j^1 within constellation m_1 is transmitted. For soft decoding, the symbol-level likelihood value with regard to each candidate symbol a_j^1 needs to be calculated. For a particular $l_i (i \in \{1, 2\})$ given by (11) or (12), the symbol-level likelihood value is given as

$$\begin{aligned} \mathcal{V}(l_i|a_j^1) &= \\ \exp \left(-\frac{g_1 |\Re(l_i) - \Re(a_j^1 e^{j\theta})|^2 + g_2 |\Im(l_i) - \Im(a_j^1 e^{j\theta})|^2}{\sigma^2} \right), \end{aligned} \quad (13)$$

where $g_i = |h_i|^2$ with $i \in \{1, 2\}$. The bit-level likelihood ratio (LLR) for the b th bit of l_i is calculated as

$$LLR(b) = \ln \frac{\sum_{a_j^1 \in \mathcal{A}_b^{(0)}} \mathcal{V}(l_i|a_j^1)}{\sum_{a_j^1 \in \mathcal{A}_b^{(1)}} \mathcal{V}(l_i|a_j^1)}, \quad (14)$$

where $\mathcal{A}_b^{(0)}$ and $\mathcal{A}_b^{(1)}$ represent the sets of a_j^1 of which the b th bit is "0" and "1" respectively. Channel decoding proceeds with all these LLRs as input. The total recovered bits are composed of decoded bits and bits carried by blind detection.

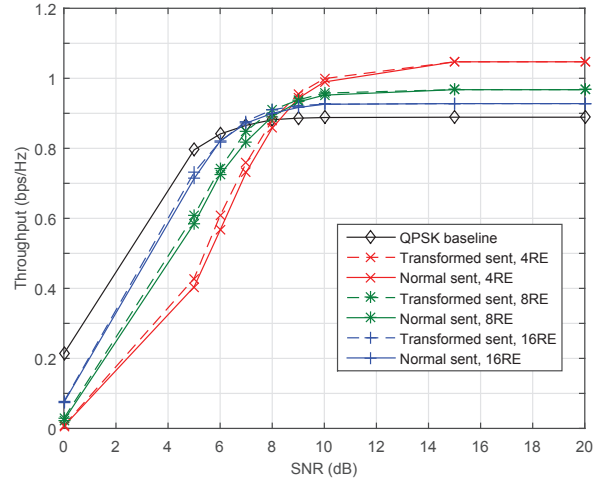


Fig. 4. Throughput for different blind detection granularities, ETU 120km/h, QPSK, $I_{MCS} = 9$.

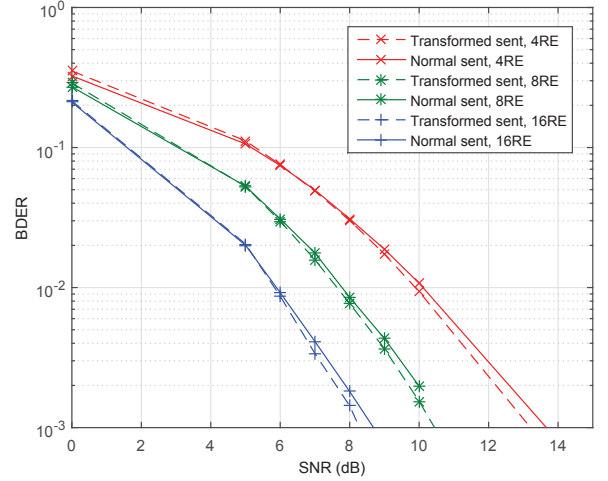


Fig. 5. Blind detection error for different blind detection granularities, ETU 120km/h, QPSK, $I_{MCS} = 9$.

IV. SIMULATION RESULTS

In this section, link-level simulations are performed to evaluate our proposed method. A LTE OFDM system with single transmit and single receive antenna is assumed. 6 consecutive physical resource block (PRB) pairs are scheduled for physical downlink shared channel (PDSCH), where LTE Turbo coding and ideal channel estimation are assumed. 1 cell-specific reference signal (CRS) port and 2 demodulation reference signal (DMRS) ports are configured, and physical downlink control channel (PDCCH) occupies 3 OFDM symbols. Normal QPSK transmission is used as the baseline, where the modulation and coding scheme (MCS) index is $I_{MCS} = 9$. For constellation rotation, the rotation angle is set as $\theta = 45^\circ$. With assumed resources, the total number

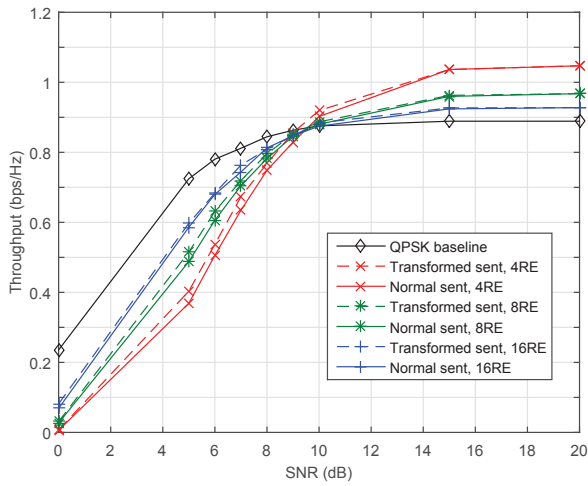


Fig. 6. Throughput for different blind detection granularities, EPA 3km/h, QPSK, $I_{MCS} = 9$.

of resource elements (REs) available for PDSCH is 684. Let n REs (symbols) constitute a group which is the smallest unit for blind detection. Since every n REs can potentially carry 1 bit via constellation blind detection, the total number of bits which can be additionally conveyed amounts to $684/n$.

Throughput and blind detection error rate (BDER) are evaluated for ETU and EPA channels from Fig. 4 to Fig. 7. Evaluations are performed for different blind detection granularities, i.e., every 4/8/16 REs carry 1 additional bit. For the proposed method, with blind detection working at the receiver, the solid curve is obtained by always transmitting symbols from QPSK constellation, and the dotted curve is obtained by always transmitting symbols from transformed constellation. Actually these are two extreme conditions, and the real-life performance curve which is obtained by transmitting symbols randomly will lie between the solid and dotted curves. For all the observed results, two curves are quite close to each other.

Throughput under ETU 120km/h channel is shown in Fig. 4. Throughput gain can be observed when SNR is higher than a certain value. This is due to the successfully conveyed bits via constellation blind detection. When SNR is low, blind detection performance is degraded and wrong detection may cause throughput loss. It can be seen that throughput gain is obtained when the normal QPSK curve just achieves the stable state. Therefore, there is a possibility to exploit throughput gain before the MCS changes to a higher level. With more REs used for conveying 1 bit, the required SNR threshold becomes lower due to improved detection performance, while the asymptotic throughput decreases. The ratio of the number of correct detections and the total number of blind detections is defined as blind detection error rate, and it is shown in Fig. 5 for ETU 120km/h channel. With more REs used for blind detection, the detection performance gets improved since more samples can be collected.

The simulation results under EPA 3km/h channel are given in Fig. 6 and Fig. 7, and generally the observations are similar.

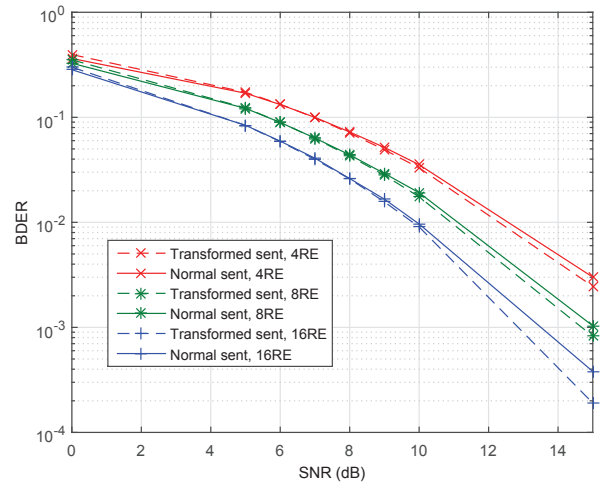


Fig. 7. Blind detection error for different blind detection granularities, EPA 3km/h, QPSK, $I_{MCS} = 9$.

Since EPA 3km/h channel is flat in frequency domain and slow varying in time domain, there is not much diversity to be exploited. The diversity includes frequency/time selective diversity from channel variation and signal space diversity from constellation rotation. Therefore, the required SNR to achieve throughput gain in Fig. 6 is a little higher than that of ETU 120km/h channel in Fig. 4. Diversity from channel variation also benefits constellation blind detection. Due to diversity loss in EPA 3km/h channel, blind detection performance in Fig. 7 is worse than that of Fig. 5. Note that symbol-level interleaving is just to gain diversity.

V. CONCLUSION

As symbols transmitted in real systems are from finite constellations but not Gaussian signals, there is still room for further enhancing spectrum efficiency. To this end, a method of constellation blind detection is proposed in this paper. By constellation rotation and real/imaginary part interleaving, a transformed constellation is generated which has a different shape from normal constellation. Source information bits are used for switching between two types of constellations, e.g., bit "0" and "1" indicate normal and transformed constellations are transmitted respectively. These bits can be recovered by constellation blind detection, and thus throughput can be enhanced with these additionally conveyed bits. Also signal space diversity can be exploited with the transformed constellation. Simulation results have verified the effectiveness of our proposed method. Extension to NOMA, joint coding for control and information bits, and advanced blind detection algorithm are potential directions for future study.

REFERENCES

- [1] ITU, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," June 2015.

- [2] O. A. Dobre, A. Abdi, Y. Bar-Ness, and W. Su, "Survey of automatic modulation classification techniques: classical approaches and new trends," *IET Communications*, vol. 1, no. 2, pp. 137-156, April 2007.
- [3] A. D. Pambudi, S. Tjondronegoro, and H. Wijanto, "Statistical properties proposed for blind classification OFDM modulation scheme," *IEEE ICARES 2014*, Nov. 2014.
- [4] S. B. Reddy, T. Yucek, and H. Arslan, "An efficient blind modulation detection for adaptive OFDM systems," *IEEE VTC fall 2003*, Oct. 2003.
- [5] T. Yucek and H. Arslan, "A novel sub-optimum maximum-likelihood modulation classification algorithm for adaptive OFDM systems," *IEEE WCNC 2004*, March 2004.
- [6] M. Marey and O. A. Dobre, "Blind modulation classification for Alamouti STBC system with transmission impairments," *IEEE Wireless Communications Letters*, vol. 4, no. 5, pp. 521-524, June 2015.
- [7] W. C. Headley, V. G. Chavali, and C. R. C. M. da Silva, "Maximum-likelihood modulation classification with incomplete channel information," *IEEE ITA 2013*, Feb. 2013.
- [8] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, "Non-orthogonal multiple access (NOMA) for future radio access," *IEEE VTC spring 2013*, June 2013.
- [9] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "System-level performance of downlink non-orthogonal multiple access (NOMA) under various environments," *IEEE VTC spring 2015*, May 2015.
- [10] J. Boutros and E. Viterbo, "Signal space diversity: a power-and bandwidth-efficient diversity technique for the Rayleigh fading channel," *IEEE Trans. Inform. Theory*, vol. 44, no. 4, pp. 1453-1467, July 1998.
- [11] J. Boutros, E. Viterbo, C. Rastello, and J. C. Belfiore, "Good lattice constellations for both Rayleigh fading and Gaussian channels," *IEEE Trans. Inform. Theory*, vol. 42, no. 2, pp. 502-518, March 1996.



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