Low-Complexity Suboptimal ML Detection for OFDM-IM Systems

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Abstract—Orthogonal frequency division multiplexing with index modulation (OFDM-IM) is a novel multicarrier scheme, which uses \( k \) out of \( n \) subcarriers as active subcarriers to transmit data. For detecting the subcarrier activation pattern (SAP) at the receiver, maximum likelihood (ML) detection cannot be used because of its high computational complexity. Instead, the detector selecting the most likely active \( k \) subcarriers is used, which is called a \( k \) largest values (\( klv \)) detector. However, this method degrades the detection performance especially if the ratio of illegal SAPs to SAPs is high. In this letter, the suboptimal ML detector is proposed, which is a simple modification of the \( klv \) detector, but very efficient. The proposed detector has a similar detection performance compared to the ML detection, which is suitable for flexible implementation of OFDM-IM systems.

Index Terms—Index modulation (IM), orthogonal frequency division multiplexing (OFDM), maximum likelihood (ML).

I. INTRODUCTION

Orthogonal frequency division multiplexing with index modulation (OFDM-IM) [1] is an emerging technique which is the application of the spatial modulation (SM) [2] principle to the subcarriers in OFDM systems. In OFDM-IM, the subcarriers are partitioned into subblocks. In each subblock, the subcarriers have two states, active or inactive. Then, OFDM-IM conveys information by not only modulated symbols but also the indices of the active subcarriers. OFDM-IM systems have a better energy efficiency compared to the classical OFDM [1], [3].

For detecting the subcarrier activation pattern (SAP) at the receiver, the optimal method is maximum likelihood (ML) detection, where it detects jointly both the indices of the active subcarriers and the modulated symbols carried on. However, naive implementation of the ML detector requires a huge computational complexity.

In [4], [5], by using the fact that each symbol can be demodulated independently, the equivalent ML detector is proposed, which only needs to search through all possible realizations of SAP and the \( M \) signal space for each symbol, leading to a reduced computational complexity. In spite of the investigation in [4], [5], this ML detector would still become impractical if the number of possible SAPs is large.

To solve this problem, one can practically employ a low-complexity near ML detector which simply picks up \( k \) active indices that have \( k \) largest values of active likelihood metrics, called a \( k \) largest values (\( klv \)) detector in this letter. However, the \( klv \) detector may also decide on an illegal SAP that does not belong to the set of the legal SAPs, resulting in degraded detection performance. The authors in [4] mentioned that the probability of this event is very small and thus the performance loss is negligible. However, as the ratio of illegal SAPs to SAPs increases, the degradation of the detection performance of this \( klv \) detector cannot be ignored.

Meanwhile, in [6], a low complexity detector is proposed by encoding all possible SAPs. Since all possible SAPs are used to convey data, the scheme in [6] neglects the possibility of detecting illegal SAPs and avoid index demodulation errors due to the detection of illegal SAPs. However, this requires the mapping of non-fixed length bits to SAPs, which makes the communication systems more complicated. In [7], a compressive sensing (CS) based detector is investigated for generalized spatial modulation (GSM) systems. However, this CS based detector is only appropriate for multiple receive antennas systems. In [1], log-likelihood ratio (LLR) detector is presented, but its computational complexity is higher than that of efficiently implemented ML detector in [4], [5]. Also, in [8], a power based detector is presented for noncoherent OFDM-IM and it severely degrades detection performance in OFDM-IM.

In this letter, the suboptimal ML detector for OFDM-IM is proposed, where the second best SAP is alternatively tested if the best SAP is illegal, which is a slight modification of the \( klv \) detector. Therefore, the proposed detector has low complexity, but its detection performance is almost the same as the ML detector, as verified thorough the probabilistic analysis and simulation results. Note that the contribution of this letter mainly comes from the probabilistic analysis showing the performance similarity between the optimal ML and the proposed detectors.

II. THE PROPOSED SUBOPTIMAL ML DETECTION

A. OFDM-IM

Let us consider the OFDM-IM system using \( N \) subcarriers and \( m \) information bits to be transmitted. First, these \( m \) bits are divided into \( G \) groups. Each group contains \( p \) bits (\( m = pG \)). Then, the \( p \) bits in each group are mapped to one OFDM-IM subblock with length \( n \) in frequency domain. Different from the classical OFDM system, this mapping procedure is performed by activating \( k \) out of \( n \) subcarriers followed by assigning the \( k \) modulated symbols [1]. The SAP is determined based on the first \( p_1 \) bits of the \( p \) bits in the group. The symbols in the active subcarriers are determined by the remaining \( p_2 = k \log_2 M \) bits of the \( p \) bits with \( M \)-ary signal constellation.
Clearly, \( p = p_1 + p_2 \). The symbols in the inactive subcarriers are set to zero.

In conclusion, in the OFDM-IM, the information is conveyed by both of the \( M \)-ary modulated symbols and the indices of the active subcarriers [1]. Since the number of possible SAPs is \( \binom{k}{l} \), there has to be \( \binom{k}{l} - 2p_1 \) redundancy or illegal SAPs. We denote the set of the \( \binom{k}{l} \) possible SAPs as \( \mathcal{I} \). Also we denote the set of the \( 2p_1 \) legal SAPs as \( \mathcal{I}_l \) and denote the set of the \( \binom{k}{l} - 2p_1 \) illegal SAPs as \( \mathcal{I}_i \). Clearly, \( \mathcal{I} = \mathcal{I}_l \cup \mathcal{I}_i \).

Denote the set of the indices of the \( k \) active subcarriers in the transmitted \( g \)-th OFDM-IM subblock, \( g = 1, 2, \ldots, G \), as

\[
\mathcal{I}_g = \{ i_{g,1}, i_{g,2}, \ldots, i_{g,k} \}
\]

with \( i_{g,m} \in \{ 1, 2, \ldots, n \} \) for \( m = 1, 2, \ldots, k \). Clearly, \( \mathcal{I}_g \in \mathcal{I}_l \). Also, the set of \( k \) modulated symbols is denoted by

\[
\mathcal{S}_g = \{ S_{g,1} S_{g,2} \ldots S_{g,k} \}
\]

where \( S_{g,m} \in \mathcal{S} \) and \( \mathcal{S} \) is the used \( M \)-ary signal constellation. Then the \( g \)-th OFDM-IM subblock can be constructed as

\[
\mathbf{X}_g = [X_{g,1} X_{g,2} \ldots X_{g,n}]^T,
\]

where the \( i \)-th OFDM-IM symbol \( X_{g,i} \) is in \( \mathcal{S} \) only if \( i \in \mathcal{I}_g \) and otherwise \( X_{g,i} = 0 \).

After creating \( \mathbf{X}_g \) for all \( g \), these \( G \) subblocks of length \( n \) are concatenated for generating the \( N \times 1 \) OFDM-IM symbol sequence. To achieve the frequency diversity gain as much as possible, concatenation in an interleaved manner is preferred [9]. Then, like the classical OFDM, the OFDM-IM signal in time domain is generated by processing the OFDM-IM symbol sequence into inverse discrete Fourier transform (IDFT).

### B. Detection for OFDM-IM

Let us consider the detection of the \( g \)-th subblock. We omit the subblock index \( g \) for simplicity. By considering a joint detection for the indices of the active subcarriers and the modulated symbols carried on, the ML detector for OFDM-IM is given by

\[
\hat{\mathcal{I}}_{\text{ML}}(\hat{S}) = \arg \min_{\mathcal{I} \in \mathcal{I}_l, \hat{S}} \sum_{i=1}^{n} |Y_i - H_i X_i|^2
\]

\[
= \arg \min_{\mathcal{I} \in \mathcal{I}_l, \hat{S}} \sum_{i=1}^{n} |H_i|^2 |R_i - X_i|^2,
\]

(1)

where \( \hat{S} \) is a possible set of \( k \) modulated symbols, \( Y_i = H_i X_i + Z_i \) is the \( i \)-th received OFDM-IM symbol, \( H_i \) is the \( i \)-th channel frequency response (CFR), \( Z_i \) is the Gaussian noise with \( \mathcal{CN}(0, 2\sigma^2) \), and \( R_i = H_i^{-1} Y_i \) for \( i = 1, \ldots, n \).

It is remarkable that the symbol detection can be independently performed for each subcarrier [4], [5]. Then, the symbol detection is separately performed as

\[
\hat{s}_i = \arg \min_{s \in \mathcal{S}} |R_i - s|^2
\]

for \( i = 1, \ldots, n \). Then, (1) becomes

\[
\hat{I}_{\text{ML}} = \arg \min_{\mathcal{I} \in \mathcal{I}_l} \left\{ \sum_{i \in \mathcal{I}} |H_i|^2 |R_i - \hat{s}_i|^2 + \sum_{j \notin \mathcal{I}} |H_j|^2 |R_j|^2 \right\},
\]

(2)

Since \( \sum_{i=1}^{n} |H_i|^2 |R_i|^2 \) is not related to the realizations of \( \hat{I} \), we subtract it from (2). Then we have

\[
\hat{I}_{\text{ML}} = \arg \min_{\mathcal{I} \in \mathcal{I}_l} \sum_{i \in \mathcal{I}} |H_i|^2 (|R_i - \hat{s}_i|^2 - |R_i|^2)
\]

\[
= \arg \max_{\mathcal{I} \in \mathcal{I}_l} \sum_{i \in \mathcal{I}} |H_i|^2 (|R_i - \hat{s}_i|^2 - |R_i|^2) / A_i
\]

\[
= \arg \max_{\mathcal{I} \in \mathcal{I}_l} \sum_{i \in \mathcal{I}} A_i,
\]

(3)

where \( A_i \) is an active likelihood metric for the \( i \)-th subcarrier.

Since the ML detector calculates \( 2p_1 \) combinations of \( A_i \) in (3), the ML detector would become impractical for a larger \( p_1 \) as \( p_1 \) grows exponentially with it. Therefore, the \( k \)-lv detector that chooses the indices with the \( k \) largest values of \( A_i \) may be preferred in practical systems. That is, the \( k \)-lv detector is

\[
\hat{I}_{\text{klv}} = \arg \max_{\mathcal{I} \in \mathcal{I}_l} \sum_{i \in \mathcal{I}} A_i.
\]

(4)

This \( k \)-lv detector may also decide on illegal SAPs that do not belong to \( \mathcal{I}_l \), resulting in degraded detection performance. Although the probability of this error event is small unless the ratio of illegal SAPs to SAPs is large [4], this constraint prevents the flexible implementation of OFDM-IM systems with various parameters \( n \) and \( k \).

### C. Active Likelihood Metric \( A_i \)

First, we investigate the diversity order of the index demodulation error event through the characteristics of \( A_i \). For example, if we employ quadrature phase shift keying (QPSK) for modulating symbols, \( A_i \) in (3) becomes

\[
A_i = 2|H_i|^2 (|\text{Re}\{R_i\}| + |\text{Im}\{R_i\}| - 1).
\]

For a given \( H_i \), \( A_i \) is a Gaussian distribution with \( \mathcal{N}(|H_i|^2, 2|H_i|^4\sigma^2) \) if the \( i \)-th subcarrier is active. Otherwise, \( A_i \) becomes a distribution of \( \mathcal{N}(-|H_i|^2, 2|H_i|^4\sigma^2) \). Assume that the \( i \)-th subcarrier is active and the \( j \)-th subcarrier is inactive. Since the means of \( A_i \) and \( A_j \) are opposite to each other, confused detection of the \( i \)-th and \( j \)-th subcarriers occurs when both \( A_i \) and \( A_j \) are close to zero. It means that bad channel qualities (or small magnitudes of \( H_i \) and \( H_j \) at the same time are necessary for confused detection of the \( i \)-th and \( j \)-th subcarriers. For other modulations, a similar tendency can be shown. This phenomenon can also be mentioned in [1], where it is shown that the index demodulation error event has a diversity order of two.

For future use, we denote the indices of \( A_i \) as \( \hat{i}_1, \ldots, \hat{i}_n \) when \( A_i \) are sorted in descending order. That is,

\[
A_{\hat{i}_1} > A_{\hat{i}_2} > \cdots > A_{\hat{i}_n}.
\]

(5)

Then, the set constructed by the indices of the \( k \) largest values of \( A_i \) becomes the best SAP for the \( k \)-lv detector in (4) as

\[
\hat{I}_{\text{klv}} = \hat{I}_1 = \{ \hat{i}_1, \hat{i}_2, \ldots, \hat{i}_k \}.
\]
We may also denote \( \hat{I}_v \)'s for \( v = 2, \ldots, \binom{n}{k} \), which means the \( v \)-th best SAP based on the metrics in (5). Clearly, the second best SAP \( \hat{I}_2 \) is
\[
\hat{I}_2 = \{\hat{i}_1, \hat{i}_2, \ldots, \hat{i}_{k-1}, \hat{i}_{k+1}\}. \tag{6}
\]
Note that the other \( v \)-th best SAPs (\( v \geq 3 \)) are not fixed and can be varied according to the specific values of \( A_i \)'s. For example, the third best SAP \( \hat{I}_3 \) can be either \( \{\hat{i}_1, \hat{i}_2, \ldots, \hat{i}_{k-1}, \hat{i}_{k+1}\} \) or \( \{\hat{i}_1, \hat{i}_2, \ldots, \hat{i}_{k-2}, \hat{i}_k, \hat{i}_{k+1}\} \) according to the values of \( A_i \).

D. Correct Detection Probabilities of \( \hat{I}_{k_{lv}} \) and \( \hat{I}_{ML} \)

Consider a sample space in probability theory of one received OFDM-IM subblock, which denotes the set of all possible realizations. The sample space can be separated into three sets according to which the best SAP \( \hat{I}_1 \) is, as in Fig. 1.

Specifically, the sets are separated by the following criteria:
- \( \Omega(c) \): The best SAP is correct. (\( \hat{I}_1 = I \))
- \( \Omega(l) \): The best SAP is incorrect and legal. (\( \hat{I}_1 \neq I \) and \( \hat{I}_1 \in I_l \))
- \( \Omega(i) \): The best SAP is incorrect and illegal. (\( \hat{I}_1 \in I_i \))

Moreover, according to the second best SAP \( \hat{I}_2 \), \( \Omega(i) \) can be separated into three subsets as
- \( \Omega(i, c) \): \( \hat{I}_2 \in I_l \) and the second best SAP \( \hat{I}_2 \) is correct.
- \( \Omega(i, l) \): \( \hat{I}_2 \in I_l \) and the second best SAP \( \hat{I}_2 \) is incorrect and legal.
- \( \Omega(i, i) \): \( \hat{I}_2 \in I_i \) and the second best SAP \( \hat{I}_2 \) is incorrect and illegal.

Likewise, \( \Omega(i, i) \) can be further separated into three subsets \( \Omega(i, i, c), \Omega(i, i, l) \), and \( \Omega(i, i, i) \) according to the third best SAP \( \hat{I}_3 \). For example, \( \Omega(i, i, c) \) means \( \hat{I}_3 \in I_l, \hat{I}_2 \in I_l, \) and \( \hat{I}_3 = I \). In the same manner, this separation can be performed until we have \( \Omega(i, i, i, \ldots, i, c) \).

Clearly, the correct detection probability of the klv detector is
\[
P_{klv} = P(\Omega(c)). \tag{7}
\]

The ML detector in (3) finds the SAP having the largest sum of \( A_i \) in the set of legal SAPs \( I_l \) as in (3). Therefore, if we use the ML detector, then not only the case in \( \Omega(c) \) but also the cases in \( \Omega(i, c) + \cdots + \Omega(i, i, i, \ldots, i, c) \) can be correctly detected by the ML detector. That is, the correct detection probability of the ML detector is
\[
P_{ML} = P(\Omega(c)) + P(\Omega(i, c)) + \cdots + P(\Omega(i, i, i, \ldots, i, c)). \tag{8}
\]

Therefore, the ML detection is superior to the klv detector. Also, from (7) and (8), the probability gap becomes
\[
P_{ML} - P_{klv} = P(\Omega(i)) + \cdots + P(\Omega(i, i, i, \ldots, i, c)) \left( \begin{array}{c} n \\text{\text{-}2}p^1 \end{array} \right)
\leq P(\Omega(i))
= \left( \begin{array}{c} n \\text{\text{-}2}p^1 \end{array} \right)
- 1
= r \cdot (1 - P(\Omega(c))), \tag{9}
\]

where \( r \) is the ratio of the illegal SAPs to all incorrect SAPs as
\[
r = \frac{\binom{n}{k} - 2p^1}{\binom{n}{k}}.
\]

Without loss of generality, we consider the transmitted SAP \( I = \{1, 2, \ldots, k\} \). Then,
\[
P(\Omega(c)) = P(\min(A_1, \ldots, A_k) > \max(A_{k+1}, \ldots, A_n)),
\]
where the probability \( P(\Omega(c)) \) is regardless of \( r \). Therefore, the gap \( P_{ML} - P_{klv} \) in (9) becomes larger as \( r \) increases.

E. The Proposed Suboptimal ML Detector

We focus on the fact that in (8) the first and second terms are dominant and these terms can be obtained when we also test the second best SAP in addition to the first best SAP. Fortunately, the second best SAP is fixed as in (6). Using these, we propose the suboptimal ML detector in Algorithm 1. Note that the differences between the klv detector and the proposed detector are marked in Algorithm 1. Although the proposed suboptimal ML detector is a simple modification of the klv detector in (4), the proposed detector is very efficient as will be analyzed and verified in simulations. Note that this simplicity of the proposed ML detector may be the biggest advantage in practical systems.

Let us investigate the computational complexities of the three detectors. The three detectors have common procedures: calculating the values of \( A_i \) for \( i = 1, \ldots, n \) and searching a look-up table of size \( 2^{p^1} \) followed by conversion of the detected SAP to \( p_1 \) bits. Therefore, we compare the rest procedures of the three detectors. First, the ML detector in (3)
calculates $2^{|I_1|}$ combinations of $A_1$'s. Second, the $k lv$ detector makes $I_1$ by choosing $k$ largest values from $A_1$'s. Third, the proposed detector makes $I_1$ and $I_2$ by choosing $k + 1$ largest values from $A_1$'s. Also, there is the additional searching of $I_2 \in I_1$, as in the fifth line in Algorithm 1. However, this additional searching rarely occurs and its complexity can be neglected. This is because it occurs only if the first searching $I_1 \in I_2$ fails. Its probability is $1 - P_{k lv}$ and small except when the signal-to-noise ratio (SNR) is very low. We summarize the computational complexities of the three detectors in Table I. When we use $n = 10$ and $k = 5$, the number of additions of ML, $k lv$, and the proposed detectors are 512, 35, and 39, respectively.

Now, we investigate the detection performance of the proposed detector compared to the optimal ML detector. If we use the proposed suboptimal ML detector, then the received OFDM-IM subblock in $\Omega(c)$ and $\Omega(i, c)$ in Fig. 1 can be correctly detected. Then its correct detection probability is

$$P_{\text{subML}} = P(\Omega(c)) + P(\Omega(i, c)). \quad (10)$$

The difference between (10) and (8) is

$$P_{\text{ML}} - P_{\text{subML}} = P(\Omega(i, c) + \cdots + \Omega(i, i, \ldots, i)) \leq P(\Omega(i, i)) = \left(\begin{array}{c} n \\ k \end{array}\right) - 2^{|I_1|} - 1 \cdot (P(\Omega(i)) - P(\Omega(i, i))). \quad (11)$$

Now we consider $P(\Omega(i))$ and $P(\Omega(i, c))$ in (11). Without loss of generality, we assume that the transmitted SAP is $I = \{1, 2, \ldots, k\}$. First, $P(\Omega(i))$ becomes

$$P(\Omega(i)) = P(I_1 \in I) = P(I_1 \in I_2 \cap |I_1 - I| = 2) + P(I_1 \in I_2 \cap |I_1 - I| = 4) + \cdots \approx P(I_1 \in I_2 \cap |I_1 - I| = 2) = r \cdot k(n - k) \cdot P(I_1 = \{1, \ldots, k - 1, k + 1\}) = r \cdot k(n - k) \cdot P(\min(A_1, \ldots, A_{k-1}, A_{k+1}) > A_{k+1} > A_k > \max(A_{k+2}, \ldots, A_n)). \quad (12)$$

where the similarity in the third line is reasonable because the event $|I_1 - I| = 2$ frequently occurs compared to the other events, $k(n - k)$ in the fifth line is the number of $I_1$ satisfying $|I_1 - I| = 2$, and $I_1 = \{1, \ldots, k - 1, k + 1\}$ in the fifth line is one example of the possible realizations of $I_1$ satisfying $|I_1 - I| = 2$.

In the similar way, we also have

$$P(\Omega(i, c)) = P(I_1 \in I_2 \cap I_2 = I) \approx P(I_1 \in I_2 \cap I_2 = I \cap |I_1 - I| = 2) = r \cdot k(n - k) \cdot P(I_1 = \{1, \ldots, k - 1, k + 1\} \cap I_2 = \{1, \ldots, k\}) = r \cdot k(n - k) \cdot P(\min(A_1, \ldots, A_{k-1}) > A_{k+1} > A_k > \max(A_{k+2}, \ldots, A_n)). \quad (13)$$

From (12) and (13), $P(\Omega(i)) - P(\Omega(i, c))$ becomes

$$P(\Omega(i)) - P(\Omega(i, c)) \approx r \cdot k(n - k) \cdot (P(\min(U, A_{k+1}) > \max(A_k, V)) - P(U > A_{k+1} > A_k > V)) = r \cdot k(n - k) \cdot (P(A_{k+1} > U > A_k > V) + P(U > A_{k+1} > V > A_k) + P(A_{k+1} > U > V > A_k)), \quad (14)$$

where

$$U = \min(A_1, \ldots, A_{k-1}) \quad V = \max(A_{k+2}, \ldots, A_n).$$

Let us consider the three probabilities in (14). Note that the bad channel qualities are necessary condition for confusion of active subcarriers, as explained in Section II-C. Then the event $A_{k+1} > U > A_k > V$ in (14) occurs rarely because this event requires that the $k$-th, $k + 1$-th, and $z$-th ($1 \leq z \leq k - 1$) CFRs are bad at the same time. That is, this event has a frequency diversity order of three. Likewise, the other two events $U > A_{k+1} > V > A_k$ and $A_{k+1} > U > V > A_k$ require three and four bad CFRs, respectively. Therefore, $P(\Omega(i) - \Omega(i, c))$ in (14) is small and thus, from (11), we expect that the detection performance gap between the ML detector and the proposed suboptimal ML detector is also small especially in high SNR region.

### III. Simulation Results and Conclusion

To verify the performance of the proposed suboptimal ML detector, we simulate several OFDM-IM systems with variable parameters. For modulating the symbols in the active subcarriers, QPSK is commonly used because OFDM-IM gives better bit error rate (BER) performance in the low to medium data rate region than the conventional OFDM [1]. Also, we consider a Rayleigh fading channel with length eight having an exponential power-delay profile. The CFR is assumed known at the receiver. Since an interleaved concatenation is employed, in frequency domain, the elements within an OFDM-IM subblock experience nearly independent CFRs.

Fig. 2 shows the BER performance of the three detectors, where we use $N = 128$, $n = 8$, and $k = 4$. Here, SNR means energy per information bit over noise power $2\sigma^2$. In this case, the illegal SAPs ratio is only $r = 0.086$ and thus there is only a small gap between the ML detector and the $k lv$ detector, described in (9). Also, the proposed suboptimal ML detector shows a similar BER performance compared to the ML detector, explained in (14).

Fig. 3 shows the BER performance of the three detectors, where we use $N = 100$, $n = 10$, and $k = 5$. In this case, the redundancy SAPs ratio is $r = 0.49$ and thus there is a visible gap between the ML detector and the $k lv$ detector. Also, this

| TABLE I | THE NUMBER OF REAL ADDITIONS REQUIRED FOR THREE DETECTORS |
| --- | --- |
| ML | $2^{|I_1|}$ |
| $k lv$ | $(n - 1) + \cdots + (n - k)$ |
| Proposed | $(n - 1) + \cdots + (n - k)$ |
performan gap becomes smaller in high SNR region. This is because the index demodulation error event (choosing a wrong SAP) has a diversity order of two and it rarely occurs in high SNR region. Meanwhile, the proposed suboptimal ML detector shows almost the same BER performance compared to the ML detector. As explained in (14), the performance gap between the ML detector and the proposed detector becomes negligible as SNR increases.

Fig. 4 shows the BER performance of the three detectors, where we use $N = 500$, $n = 10$, and $k = 5$. The $(171, 133)$ convolutional code with code rate $1/2$ is used. To boost the channel coding efficiency, random interleaving of coded bits is performed before OFDM-IM modulation. It prevents error of consecutive coded bits if index demodulation error event occurs in an OFDM-IM subblock.

In this case, the performance gap between the ML detector and the $klv$ detector becomes larger compared to the uncoded case in Fig. 3. This phenomenon is because the $klv$ detector may also decide on illegal SAPs and this catastrophic event results in more bit errors than the number can be corrected by the channel code. In other words, channel coding is not efficient for $klv$ detector, compared to the ML detector. Since the proposed detector has a similar performance to the ML detector, it is shown that the proposed detector has a better performance about 1 dB compared to the $klv$ detector.

By using the proposed suboptimal ML detector with low complexity, we obtain almost the same detection performance compared to the optimal ML detector. This leads to the flexible and unconstrained implementation of OFDM-IM systems.

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