Achievable Degrees-of-Freedom Through Blind Interference Alignment using Staggered Antenna Switching for the $K$-user SISO Interference Channel

Ahmed M. Alaa, Member, IEEE, Mahmoud H. Ismail, Member, IEEE

Abstract

In this letter, we present the first characterization for the achievable Degrees-of-Freedom (DoF) by Blind Interference Alignment (BIA) using staggered antenna switching in the $K$-user Gaussian Interference Channel. In such scheme, each transmitter is equipped with one conventional antenna and each receiver is equipped with one reconfigurable (multi-mode) antenna. Assuming that the channel is known to the receivers only, we show that BIA can achieve $\frac{2K}{K+2}$ DoF, which surpasses the sum DoF achieved by previously known interference alignment schemes with delayed channel state information at transmitters (CSIT). This result implies that the sum DoF is upper bounded by 2, which means that the best we can do with BIA is to double the DoF achieved by orthogonal multiple access schemes. Moreover, we propose an algorithm to generate the transmit beamforming vectors and the reconfigurable antenna switching patterns, and apply this algorithm to the 4-user SISO Interference Channel, showing that $\frac{4}{3}$ sum DoF is achievable.

Index Terms

Blind interference alignment, degrees of freedom, interference channel, reconfigurable antennas.

The authors are with the Department of Electronics and Electrical Communications Engineering, Cairo University, Giza, 12613, Egypt (e-mail: {aalaa}@eece.cu.edu.eg).

Manuscript received XXXX XX, 201X; revised XXXX XX, 201X.
Achievable Degrees-of-Freedom Through Blind Interference Alignment using Staggered Antenna Switching for the $K$-user SISO Interference Channel

I. INTRODUCTION

Interference is one of the most important factors that limit the capacity of wireless networks. Because characterizing the exact capacity region of interference channels is quite complicated, the Degrees-of-Freedom (DoF) has emerged as a convenient metric to quantify the capacity limits of such channels. The DoF correspond to the number of independent interference-free signaling dimensions, and have been characterized for many multiuser network settings.

Recently, interference alignment (IA) has been shown to achieve the DoF of various wireless networks [1]. In [2], Cadambe et al. have shown that IA can achieve the $\frac{K}{2}$ DoF of the $K$-user interference channel. However, the IA schemes presented therein require global CSIT, which is not always possible in practical systems. Stemming from this point, many research efforts have been dedicated to develop “Blind Interference Alignment” (BIA) techniques that can be applied without CSIT. In [3], Jafar has shown that BIA can be applied if the channel temporal correlation structure follows specific patterns. Such patterns were created artificially using reconfigurable antennas in [4] for the broadcast channel (BC). However, the channel temporal correlation structure that achieves the DoF of the $K$-user interference channel cannot arise in nature [3], and cannot be created using reconfigurable antennas [4].

Recently in [5], Wang presented the first characterization for the sum DoF when using BIA over the 3-user interference channel. It was shown that BIA can achieve a sum DoF of $\frac{6}{5}$, which is greater than the unity sum DoF achieved by naive orthogonal schemes. However, this result is specific for the 3-user channel, and the achievable DoF in the generic $K$-user interference channel with BIA remains an open issue. In this work, we extend the analysis in [5], and show that the sum DoF when using BIA with staggered antenna switching over a $K$-user interference channel is $\frac{2K}{K+2}$. A key insight behind this result is that any signal vector can be aligned with interference at most at $K - 2$ unintended receivers. Such result suggests that BIA can at best achieve double the rate achieved by orthogonal schemes, but the sum DoF do not scale linearly with $K$ as in the case when CSIT is available. A major conclusion is that the DoF achieved by BIA is greater than the upper bound on the sum DoF achieved by IA schemes with outdated CSIT in [6], and is identical to the DoF achieved by ergodic IA with delayed CSIT in [7]. Thus, one can dispense with the delayed CSI feedback channel and still achieve the same sum DoF using BIA. This result is novel as it is the first characterization for the DoF of the $K$-user interference channel with BIA. Moreover, we propose a systematic algorithm for generating the transmit beamforming vectors and the receive antennas switching patterns in order to achieve the $\frac{2K}{K+2}$ DoF. Finally, we apply this algorithm to the 4-user SISO interference channel showing that $\frac{4}{3}$ sum DoF are achievable almost surely.
II. System Model

We consider a fully connected $K$-user SISO interference channel where each transmitter is equipped with one conventional antenna, and each receiver is equipped with a reconfigurable (multi-mode) antenna that can switch among 2 distinct modes. The received signal at the $k^{th}$ receiver over $m$ channel uses is given by

$$y_k = \sum_{i=1}^{K} H_{ki} x_i + n_k, \quad k, i \in \{1, 2, \ldots, K\}$$

where $y_k \in \mathbb{C}^{m \times 1}$ represents the received signal over $m$ channel uses (time or frequency slots), $x_i \in \mathbb{C}^{m \times 1}$ is the transmitted signal vector by the $i^{th}$ user, $n_k \in \mathbb{C}^{m \times 1}$ is an additive noise vector where the noise sample at the $j^{th}$ channel use is $n_k(j) \sim \mathcal{CN}(0, 1)$, and $H_{ki} \in \mathbb{C}^{m \times m}$ is the channel matrix between the $i^{th}$ transmitter and the $k^{th}$ receiver. The channel matrix can be written as

$$H_{ki} = \text{diag}([h_{ki}(p_k(1)) \ h_{ki}(p_k(2)) \ldots h_{ki}(p_k(m))]),$$

where $p_k$ is the reconfigurable antenna switching pattern at the $k^{th}$ receiver. We assume an antenna with two possible modes, thus $p_k(j) \in \{1, 2\}$ is the selected antenna mode at the $j^{th}$ channel use. Each mode corresponds to a distinct channel realization, which means that at the $j^{th}$ channel use, the channel between the $i^{th}$ transmitter and the $k^{th}$ receiver is either $h_{ki}(1)$ or $h_{ki}(2)$, depending on the switching pattern $p_k$. We assume that all channel coefficients are drawn i.i.d. and are constant for $m$ channel uses. The transmitted signal vector $x_i$ is given by

$$x_i = \sum_{d=1}^{d_i} s_d^{[i]} u_d^{[i]},$$

where $d_i$ is the number of symbols transmitted by the $i^{th}$ user over $m$ channel uses, $s_d^{[i]}$ is the $d^{th}$ transmitted symbol, and $u_d^{[i]}$ is an $m \times 1$ transmit beamforming vector for the $d^{th}$ symbol, where $u_d^{[i]} = [u_d^{[i]}(1) \ u_d^{[i]}(2) \ldots u_d^{[i]}(m)]^T$, and $u_d^{[i]}(j) \in \{0, 1\}$, i.e., we either activate or deactivate a certain symbol at a certain channel use based on its beamforming vector.

III. BIA using Staggered Antenna Switching

In this section, we derive the achievable DoF using BIA with staggered antenna switching at the receivers, along with an algorithm to construct the scheme achieving these DoF.

A. Achievable DoF

Theorem 1: For the $K$-user SISO interference channel, BIA using staggered antenna switching can achieve $\frac{2K}{K+2}$ DoF.

Proof Assume that user $i$ sends $d_i$ symbols over $m$ channel uses. That is, $x_i = \sum_{d=1}^{d_i} s_d^{[i]} u_d^{[i]}$. Let $v_d^{[i]} = s_d^{[i]} u_d^{[i]}$ be the $d^{th}$ dimension transmitted by user $i$, and $V^{[i]} = [v_1^{[i]} \ v_2^{[i]} \ldots v_d^{[i]}]$ be an $m \times d_i$ matrix containing all dimensions transmitted by user $i$. Now assume that $v_d^{[i]}$ aligns with $l - 1$ dimensions from a set of $l - 1$ distinct transmitters,
e.g., \{1, 2, ..., i - 1, i + 1, ..., l\} at the remaining \((K - l)\) receivers. In this case, the following condition is satisfied

\[
\forall j \in \{l + 1, l + 2, ..., K - 1, K\}, \quad \text{and } \forall k \in \{1, 2, ..., i - 1, i + 1, ..., l - 1, l\}. \quad \text{Given that all channel matrices } H_{ji}, \forall i, \text{ have the same changing pattern dictated by the predefined antenna mode switching pattern at receiver } j, \text{ we directly apply Lemma 2 in [5] to (4) and (5) to obtain}
\]

\[
v_d^{[i]} \in \text{span}(V^{[k]}),
\]

\[
\forall k \in \{1, 2, ..., i - 1, i + 1, ..., l - 1, l\}. \quad \text{Now, consider receiver } l + 1. \quad \text{From (4) we have } H_{l+1,i}v_d^{[i]} \in \text{span}(H_{l+1,k}V^{[k]}), \text{ which can be written as}
\]

\[
H_{l+1,i}v_d^{[i]} \in \text{span}(H_{l+1,1+1}^{-1}H_{l+1,1+1}H_{l+1,k}V^{[k]}).
\]

Thus, we have \(v_d^{[i]} \in \text{span}(H_{l+1,1+1}^{-1}H_{l+1,k}V^{[k]}), \forall k \in \{1, 2, ..., i - 1, i + 1, ..., l - 1, l\} \). From (6), we know that \(v_d^{[i]} \in \text{span}(V^{[l+1]})\). Therefore, \(\text{span}(V^{[l+1]})\) and \(\text{span}(H_{l+1,1+1}^{-1}H_{l+1,k}V^{[k]})\) have at least one-dimensional common subspace, and \(\text{dim}(V^{[l+1]} \cap H_{l+1,1+1}^{-1}H_{l+1,k}V^{[k]}) > 0\), which implies that \(H_{l+1,1+1}V^{[l+1]}\) and \(H_{l+1,k}V^{[k]}\) have a non-zero intersection \(\forall k \in \{1, 2, ..., i - 1, i + 1, ..., l - 1, l\}\). Because \(H_{l+1,1+1}V^{[l+1]}\) is the desired signal, then receiver \(l + 1\) will have its signal polluted with interference if \(v_d^{[i]}\) is aligned with distinct dimensions from the set of transmitters \(\{1, 2, ..., i - 1, i + 1, ..., l - 1, l\}\) simultaneously. Therefore, we reach the following conclusion. If any dimension from one transmitter aligns with interference from \(l - 1\) distinct transmitters at the remaining \(K - l\) unintended receivers, then it cannot be aligned with any other set of transmitters at another set of unintended receiver.

Let \(d_{i_1, i_2, ..., i_l}\) denote the number of dimensions of the common subspace projected from the \(l\) transmitters \(\{i_1, i_2, ..., i_l\} \subset \{1, 2, ..., K\}\) at the remaining \(K - l\) receivers. Then we can generalize conditions (21) and (22) in [5] as

\[
d_{j_1, j_2, ..., j_l} = d_{u_1, u_2, ..., u_l},
\]

\(^1\text{Note that a set of } l\text{ dimensions from } l\text{ transmitters can be aligned at most at } (K - l)\text{ receivers. Otherwise, some receivers will have their desired signals aligned with interference. Besides, we cannot align multiple dimensions from the same transmitter at any unintended receiver, because if we did so, those dimensions will align at their desired receiver and will not be decodable.}\)
∀j₁ ≠ j₂ ≠ ... ≠ jᵢ, u₁ ≠ u₂ ≠ ... ≠ uᵢ, and j₁, j₂, ..., jᵢ, u₁, u₂, ..., uᵢ ∈ \{i₁, i₂, ..., iₖ\}, and
\[ \sum_{k₁=1}^{K} \sum_{k₂=1}^{K} \ldots \sum_{kᵢ=1}^{K} dᵢ₁, ..., dᵢᵢ ≤ dᵢ, \]
where \( i ∈ \{1, 2, ..., K\} \). Now, consider receiver \( k \). Because the desired signal vectors must be linearly independent from each other and from interference, they occupy \( d_K \) dimensions. In addition, the interference signals from every set of \( l \) interfering transmitters \( \{i₁, i₂, ..., iₙ\} \subset \{1, 2, ..., K - 1, K + 1, ...K\} \) overlap in \( d₁, d₂, ..., dᵢ \) dimensions. Because the total number of dimensions is equal to the number of channel uses \( m \), we have
\[ \sum_{i=1}^{K} dᵢ - (K - l) \sum_{k₁=1}^{K} \sum_{k₂=1}^{K} \ldots \sum_{kᵢ=1}^{K} dᵢ₁, ..., dᵢᵢ ≤ Km, \]
where the factor \( (K - l) \) arises from the fact that each dimension \( dᵢ₁, ..., dᵢᵢ \) aligns at \( (K - l) \) receivers. Next, we sum (9) over \( i \) to get
\[ \sum_{i=1}^{K} dᵢ - (K - l) \sum_{k₁=1}^{K} \sum_{k₂=1}^{K} \ldots \sum_{kᵢ=1}^{K} dᵢ₁, ..., dᵢᵢ ≤ Km, \]
By summing the inequality in (10) over \( k \), we have
\[ K \sum_{i=1}^{K} dᵢ - (K - l) \sum_{k₁=1}^{K} \sum_{k₂=1}^{K} \ldots \sum_{kᵢ=1}^{K} dᵢ₁, ..., dᵢᵢ ≤ Km, \]
where \( \sum_{i=1}^{K} dᵢ \) is a design parameter, so we are interested in selecting \( l \) that maximizes the sum DoF \( \frac{1}{m} \sum_{i=1}^{K} dᵢ \). We can rearrange (12) as
\[ \frac{1}{m} \sum_{i=1}^{K} dᵢ ≤ \sup_{l ≥ 2} \frac{Kl!}{l! - K + 1} = \frac{2K}{K + 2}, \]
which completes the proof. ■

Thus, the sum DoF of BIA in the \( K \)-user interference channel is bounded by \( 2 \). This means that the best we can do when the CSIT is not available is to offer double the DoF achievable by orthogonal multiple access schemes. For \( K > 3 \), the upper bound presented herein is greater than the \( 4/(6 \ln(2) - 1) ≈ 1.266 \) upper bound achieved by IA schemes with outdated CSI in \[6\]. Besides, BIA achieves the same DoF of the ergodic IA scheme with delayed CSIT presented in [7]. Thus, one can use BIA and dispense with the delayed CSIT without any loss in the sum DoF.
B. BIA Algorithm

In order to achieve the DoF presented in Theorem 1, we need to satisfy the bounds in (9) and (12). It is obvious that the bound in (9) is achieved if every dimension transmitted by user \(i\) aligns with some other dimension from another user. Thus, each user needs to send \(K - 1\) symbols per \(m\) channel uses. Moreover, the bound in (12) is satisfied if we use the minimal number of channel uses that keeps the desired signals and the interference linearly independent. This is simply satisfied by setting 
\[
m = \frac{1}{2} (K + 2) (K - 1),
\]
which is the division of the total number of symbols \(K(K - 1)\) by the maximum sum DoF. The following algorithm can be used to generate the transmit beamforming vectors and the antenna switching patterns for all users.

1: \textbf{procedure} BIA\((a, b)\)
2: \hspace{1em} Generate a matrix \(P = [p_1, p_2, \ldots, p_K] \in \mathbb{M}^{\frac{1}{2} (K + 2) (K - 1) \times K}\), where \(\mathbb{M} = \{1, 2\}\), such that \(P\) has full row and column ranks.
3: \hspace{1em} Construct \(\tilde{p}_1, \tilde{p}_2, \ldots, \tilde{p}_K = P - 1_{\frac{1}{2} (K + 2) (K - 1) \times K}\), where \(1_{n \times m}\) is an \(n \times m\) matrix with all elements = 1.
4: \hspace{1em} \(x \leftarrow 1\).
5: \hspace{1em} \textbf{while} \(x \leq \frac{K}{K - 2}\) \textbf{do}
6: \hspace{2em} Pick a new pair of distinct users \(i\) and \(j\), and a new pair of dimensions \(k_i\) and \(k_j\).
7: \hspace{2em} Set \(u_{k_i}^{[i]} = u_{k_j}^{[j]} = \tilde{p}_1 \circ \tilde{p}_2 \circ \cdots \circ \tilde{p}_{i-1} \circ \tilde{p}_{i+1} \circ \cdots \circ \tilde{p}_{j-1} \circ \tilde{p}_{j+1} \circ \cdots \circ \tilde{p}_K\), where \(\circ\) is the Hadamard product (element-wise product).
8: \hspace{2em} \(x \leftarrow x + 1\).
9: \hspace{1em} \textbf{end while}
10: \hspace{1em} \textbf{return} \(P\) and \(u_1^{[1]}, \ldots, u_{K-1}^{[1]}, u_1^{[2]}, \ldots, u_{K-1}^{[2]}, \ldots\).
11: \hspace{1em} \(u_1^{[K]}, \ldots, u_{K-1}^{[K]}\).
12: \textbf{end procedure}

The algorithm returns \(P\), whose column vectors represent the antenna switching patterns for all users, and \(u_k^{[i]}\), which is the beamforming vector for the \(k^{th}\) dimension (symbol) sent by the \(i^{th}\) user. In the next section, we apply this algorithm to the 4-user Interference Channel.

IV. Application to the 4-User SISO Interference Channel

Consider a fully connected 4-user SISO interference channel. It follows from the discussion in the previous section that each user can send 3 symbols over 9 channel uses. One possible choice for the matrix \(P\) is given as

\[
P^T = \begin{bmatrix}
1 & 2 & 1 & 2 & 1 & 2 & 2 & 2 & 1 \\
2 & 1 & 1 & 2 & 2 & 1 & 2 & 2 & 2 \\
2 & 2 & 2 & 2 & 1 & 1 & 1 & 1 & 2 \\
2 & 2 & 2 & 2 & 1 & 1 & 1 & 1 & 1 \\
\end{bmatrix},
\]

(14)
\[ H_{1k} = \text{diag}([h_{1k}(1)\ h_{1k}(2)\ h_{1k}(1)\ h_{1k}(2)\ h_{1k}(1)\ h_{1k}(2)\ h_{1k}(2)\ h_{1k}(1)]). \] (20)

\[
\begin{bmatrix}
  h_{11}(1) & h_{11}(1) & h_{11}(1) \\
  0 & 0 & h_{11}(2) \\
  0 & 0 & h_{11}(1) \\
  0 & h_{11}(2) & 0 \\
  0 & h_{11}(1) & 0 \\
  0 & 0 & 0 \\
  0 & 0 & 0 \\
  h_{11}(2) & 0 & 0 \\
  h_{11}(1) & 0 & 0
\end{bmatrix}
\]
Rank = 3

\[
\begin{bmatrix}
  0 & 0 & h_{12}(1) & 0 & 0 & h_{13}(1) & 0 & 0 & h_{14}(1) \\
  h_{12}(2) & h_{12}(2) & h_{12}(2) & 0 & h_{13}(2) & 0 & 0 & h_{14}(2) & 0 \\
  0 & 0 & h_{12}(1) & 0 & 0 & 0 & 0 & 0 & 0 \\
  0 & h_{12}(2) & 0 & 0 & h_{13}(2) & 0 & 0 & 0 & 0 \\
  0 & 0 & 0 & h_{13}(2) & 0 & 0 & h_{14}(2) & 0 & 0 \\
  0 & 0 & 0 & 0 & h_{14}(2) & 0 & 0 & h_{14}(1) & 0 \\
  0 & 0 & 0 & 0 & 0 & h_{14}(1) & 0 & 0 & 0 \\
  h_{12}(2) & 0 & 0 & h_{13}(2) & 0 & 0 & h_{14}(2) & h_{14}(2) & h_{14}(2) \\
  0 & 0 & 0 & 0 & 0 & 0 & h_{14}(1) & 0 & 0 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
  s_1^{[1]} \\
  s_1^{[2]} \\
  s_2^{[1]} \\
  s_2^{[2]} \\
  s_3^{[1]} \\
  s_3^{[2]} \\
  s_3^{[3]} \\
  s_3^{[4]}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  s_1^{[1]} \\
  s_1^{[2]} \\
  s_2^{[1]} \\
  s_2^{[2]} \\
  s_3^{[1]} \\
  s_3^{[2]} \\
  s_3^{[3]} \\
  s_3^{[4]}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  s_1^{[1]} \\
  s_1^{[2]} \\
  s_2^{[1]} \\
  s_2^{[2]} \\
  s_3^{[1]} \\
  s_3^{[2]} \\
  s_3^{[3]} \\
  s_3^{[4]}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  s_1^{[1]} \\
  s_1^{[2]} \\
  s_2^{[1]} \\
  s_2^{[2]} \\
  s_3^{[1]} \\
  s_3^{[2]} \\
  s_3^{[3]} \\
  s_3^{[4]}
\end{bmatrix}
\]

where it can be seen that \( P \) has full row and column ranks. The algorithm starts by picking any distinct pair of users, e.g., users 3 and 4, and take any of their symbols, say the first symbol of each. These symbols can be aligned at receivers 1 and 2. We let the beamforming vectors \( u_1^{[3]} \) and \( u_1^{[4]} \) for both symbols be equal and set their values to \( \tilde{p}_1 \circ \tilde{p}_2 \). From (14), we have \( \tilde{p}_1 = [0 \ 1 \ 0 \ 1 \ 0 \ 1 \ 1 \ 1 \ 0]^T \), and \( \tilde{p}_2 = [1 \ 0 \ 0 \ 1 \ 1 \ 0 \ 1 \ 1 \ 1]^T \). Thus, we have \( u_1^{[3]} = u_1^{[4]} = [0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 1 \ 1 \ 0]^T \). Similarly, we can align every pair of 2 symbols from 2 distinct users at the \( K-2 \) receivers of the remaining users as follows:

\[
\begin{align*}
  u_1^{[2]} &= u_2^{[4]} = \tilde{p}_1 \circ \tilde{p}_3 = [0 \ 1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 0]^T, \quad (15) \\
  u_2^{[2]} &= u_2^{[3]} = \tilde{p}_1 \circ \tilde{p}_4 = [0 \ 1 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0 \ 0]^T, \quad (16) \\
  u_1^{[1]} &= u_3^{[4]} = \tilde{p}_2 \circ \tilde{p}_3 = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 1]^T, \quad (17) \\
  u_2^{[1]} &= u_3^{[3]} = \tilde{p}_2 \circ \tilde{p}_4 = [1 \ 0 \ 0 \ 1 \ 1 \ 0 \ 0 \ 0 \ 0]^T, \quad (18) \\
  u_3^{[1]} &= u_3^{[2]} = \tilde{p}_3 \circ \tilde{p}_4 = [1 \ 1 \ 1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]^T. \quad (19)
\end{align*}
\]

Now, we focus on receiver 1. The antenna switching pattern of receiver 1 is \( p_1 = [1 \ 2 \ 1 \ 2 \ 1 \ 2 \ 2 \ 2 \ 1]^T \). Thus, the equivalent channel between transmitter \( k \) and receiver 1 is given by (20), and the received signal at receiver 1 is given by (21), where we drop the additive noise term for convenience. From (21), we see that the desired
symbols $s_{1}^{[1]}$, $s_{2}^{[1]}$, and $s_{3}^{[1]}$ occupy a 3-dimensional space. For the interfering symbols, we observe that $s_{1}^{[2]}$ and $s_{2}^{[4]}$ align along the vector $[0\ 1\ 0\ 0\ 0\ 0\ 1\ 0]^{T}$, $s_{2}^{[2]}$ and $s_{3}^{[2]}$ align along the vector $[0\ 1\ 0\ 1\ 0\ 0\ 0\ 0]^{T}$, while $s_{1}^{[3]}$ and $s_{1}^{[4]}$ align along the vector $[0\ 0\ 0\ 1\ 0\ 0\ 1\ 1\ 0]^{T}$. This is due to the fact that every pair of these symbols have a non-zero entry in their beamforming vectors only when the receiver selects mode 2, which is guaranteed by step 7 in the BIA algorithm. Thus, the interfering signal occupies a 6-dimensional space. To make sure that all desired symbols are decodable, we need to prove that all vectors carrying the desired symbols are linearly independent and the 3-dimensional subspace carrying the desired symbols does not intersect with the 6-dimensional interference subspace. This can be easily proved by showing that the $9 \times 9$ matrix $R$ defined in (22), which contains all the received desired and interference vectors, is full rank, which follows from the fact that all rows and columns in $R$ are linearly independent almost surely. Thus, receiver 1 achieves $\frac{1}{3}$ DoF almost surely. The same analysis can be applied to receivers 2, 3, and 4. At every receiver, the interference will occupy a 6-dimensional space while the desired signal occupies a 3-dimensional space. Hence, the achieved sum DoF is $\frac{4}{3}$.

V. CONCLUSION

In this letter, we have shown that $\frac{2K}{K+2}$ sum DoF are achievable by linear Blind Interference Alignment (BIA) using staggered antenna mode switching, which surpasses the sum DoF of many IA schemes with delayed CSIT. A key insight is that each signal dimension from one user can be aligned with a single set of distinct users at the receivers of the remaining users. This result suggests that the best we can do with BIA is to double the unity DoF of orthogonal multiple access schemes. Moreover, we proposed an algorithm to generate the transmit beamforming vectors and antenna switching patterns utilized in BIA. By applying this algorithm to the 4-user Interference Channel, it was shown that a sum DoF of $\frac{4}{3}$ is achievable.

REFERENCES


