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Retrospective Interference Alignment Scheme for 4 User Interference Channel

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Abstract:

The degree of freedom (DoF) is investigated for 4 user interference channel when only delayed channel state information is available at the transmitter (delayed CSIT). Retrospective interference alignment scheme exploits only delayed CSIT. This work presents that with this scheme whole work is divided into parts: interfering symbols and desired symbols, retrospective interference alignment scheme is utilized in desired symbol part. Keeping the interference aligned in 10 dimensions and remaining 4 dimensions to recover the desired messages. Therefore, the delayed CSIT scenario with 4 user interference channel can achieve 8/7 degree of freedom almost.

Keywords: DoF (Degree of Freedom), Interference Alignment, CSIT.

Introduction

Area of interest lies in the exploration of interference alignment scheme potential in wireless network in the absence of CSIT by calculating DoF [1] [2] [3] [4].Retrospective interference alignment was introduced by [5]. It refers to interference alignment scheme that exploits only delayed CSIT. Delayed CSIT, which is independent of the current channel state, can increase the available degree of freedom. For retrospective interference alignment the channels can be identically and independently distributed isotropic. In the absence of delayed CSIT, identically and independently distributed isotropic fading channels would lose all signal multiplexing benefits and have only one degree of freedom [5].

Three delayed feedback models are illustrated for understanding of readers; considering a simple channel scenario with '*Y*' as receiver output in response to '*X*' channel transmitted input through rayleigh channel '*H*' considering external noise '*N*' i.e.

$$Y = HX + N \tag{1}$$

Delayed feedback implies that the information is accessible at the transmitters via feedback channel based on the previous observations at the receivers being independent of the current channel state.

- Delayed CSIT feedback: Transmitter is able to access only the information of previous channel states i.e. H with the help of feedback channel but no channel output i.e. Y is available at the transmitter.
- Delayed Output Feedback: Transmitter is able to access only the information of previous channel output i.e. Y with the help of feedback channel but not the past channel states i.e. H.
- Delayed Shannon Feedback Model: Transmitter is able to access the previous channel output i.e. Y along with the previous channel state information i.e. H [6].

Considering a delayed CSIT feedback model for 4 user interference channel i.e. current channel state is not known to the transmitters but they are accessible to all the previous channel states and receivers are considered to have the perfect knowledge about all the channel states.

Taking in view the channel with 14 symbol extension where every user is believed to forward 4 symbols of information over the extension of the channel. Every receiver will receive 12 interfering symbols in addition to 4 required symbols. But the total number of channels is 14 only, which implies that out of 12 interfering symbols 2 symbols have to align in the vector space available for rest of the 10 symbols so that 4 interference free channels are available for desired signals. The following section is subdivided into two parts to clearly explain the interfering and desired symbols mathematics.

Part I: Interfering Symbols

In order to align 12 interfering symbols in 10 dimensions, as 10 dimensions are available so, 10 random combinations of symbols can be send from each transmitter via 10 channel uses without violating the channels available to the interfering symbols.

Receiver 1 receives:

$$Y^{[1]} = H^{[11]}\left[V_1^{[1]} \quad V_2^{[1]} \quad V_3^{[1]} \quad V_4^{[1]}\right]\begin{bmatrix} u_1^{[1]} \\ u_2^{[1]} \\ u_3^{[1]} \\ u_4^{[1]} \end{bmatrix} + H^{[12]}\left[V_1^{[2]} \quad V_2^{[2]} \quad V_3^{[2]} \quad V_4^{[2]}\right]\begin{bmatrix} u_1^{[2]} \\ u_2^{[2]} \\ u_3^{[2]} \\ u_4^{[2]} \end{bmatrix} + H^{[13]}\left[V_1^{[3]} \quad V_2^{[3]} \quad V_3^{[3]} \quad V_4^{[3]}\right]\begin{bmatrix} u_1^{[3]} \\ u_2^{[3]} \\ u_3^{[3]} \\ u_4^{[3]} \end{bmatrix} + H^{[14]}\left[V_1^{[4]} \quad V_2^{[4]} \quad V_3^{[4]} \quad V_4^{[4]}\right]\begin{bmatrix} u_1^{[4]} \\ u_2^{[4]} \\ u_3^{[4]} \\ u_4^{[4]} \end{bmatrix} \tag{2}$$

where, $V_i^{[j]}$: 10×1 precoding vectors
$Y^{[j]}$: 10×1 signal recieved
$H^{[jk]}$: 10×10 channel matrix from Transmitter k to Receiver j

Interfering vectors are aligned over first 10 channel uses. As 12 vectors is only in a 10 dimensional space, a 12×1 null vector

$$\alpha^{\rightarrow[1]} = \left[\alpha_1^{[1]}, \alpha_2^{[1]}, \ldots, \alpha_{12}^{[1]}\right]$$

is recognized for receiver 1 so that

$$\begin{bmatrix} H^{[12]} V_1^{[2]} & H^{[12]} V_2^{[2]} & H^{[12]} V_3^{[2]} & H^{[12]} V_4^{[2]} & H^{[13]} V_1^{[3]} & H^{[13]} V_2^{[3]} \\ H^{[13]} V_3^{[3]} & H^{[13]} V_4^{[3]} & H^{[14]} V_1^{[4]} & H^{[14]} V_2^{[4]} & H^{[14]} V_3^{[4]} & H^{[14]} V_4^{[4]} \end{bmatrix} \alpha^{\rightarrow[1]} = 0_{10\times1} \tag{3}$$

Similarly, $\alpha^{\rightarrow[2]}$ $\alpha^{\rightarrow[3]}$ and $\alpha^{\rightarrow[4]}$ are null vectors defined for receiver 2, 3 and 4 respectively so that

$$\begin{bmatrix} H^{[21]} V_1^{[1]} & H^{[21]} V_2^{[1]} & H^{[21]} V_3^{[1]} & H^{[21]} V_4^{[1]} & H^{[23]} V_1^{[3]} & H^{[23]} V_2^{[3]} \\ H^{[23]} V_3^{[3]} & H^{[23]} V_4^{[3]} & H^{[24]} V_1^{[4]} & H^{[24]} V_2^{[4]} & H^{[24]} V_3^{[4]} & H^{[24]} V_4^{[4]} \end{bmatrix} \alpha^{\rightarrow[2]} = 0_{10\times1} \tag{4}$$

$$\begin{bmatrix} H^{[31]} V_1^{[1]} & H^{[31]} V_2^{[1]} & H^{[31]} V_3^{[1]} & H^{[31]} V_4^{[1]} & H^{[32]} V_1^{[2]} & H^{[32]} V_2^{[2]} \\ H^{[32]} V_3^{[2]} & H^{[32]} V_4^{[2]} & H^{[34]} V_1^{[4]} & H^{[34]} V_2^{[4]} & H^{[34]} V_3^{[4]} & H^{[34]} V_4^{[4]} \end{bmatrix} \alpha^{\rightarrow[3]} = 0_{10\times1} \tag{5}$$

$$\begin{bmatrix} H^{[41]} V_1^{[1]} & H^{[41]} V_2^{[1]} & H^{[41]} V_3^{[1]} & H^{[41]} V_4^{[1]} & H^{[42]} V_1^{[2]} & H^{[42]} V_2^{[2]} \\ H^{[42]} V_3^{[2]} & H^{[42]} V_4^{[2]} & H^{[43]} V_1^{[3]} & H^{[43]} V_2^{[3]} & H^{[43]} V_3^{[3]} & H^{[43]} V_4^{[3]} \end{bmatrix} \alpha^{\rightarrow[4]} = 0_{10\times1} \tag{6}$$

Part II: Desired Symbols

In this part, the remaining 4 channel used are explained utilizing retrospective interference alignment scheme, based on the information of the channel states from the previous part. This part does not utilize delayed CSIT i.e. no knowledge of the channel states. Considering the m[th] transmission transmitter sends the linear combination as illustrated below:

$$\text{Transmitter 1: } V_1^{[1]}(m)u_1^{[1]} + V_2^{[1]}(m)u_2^{[1]} + V_3^{[1]}(m)u_3^{[1]} + V_4^{[1]}(m)u_4^{[1]} \quad (7)$$

$$\text{Transmitter 2: } V_1^{[2]}(m)u_1^{[2]} + V_2^{[2]}(m)u_2^{[2]} + V_3^{[2]}(m)u_3^{[2]} + V_4^{[2]}(m)u_4^{[2]} \quad (8)$$

$$\text{Transmiter 3: } V_1^{[3]}(m)u_1^{[3]} + V_2^{[3]}(m)u_2^{[3]} + V_3^{[3]}(m)u_3^{[3]} + V_4^{[3]}(m)u_4^{[3]} \quad (9)$$

$$\text{Transmiter 4: } V_1^{[4]}(m)u_1^{[4]} + V_2^{[4]}(m)u_2^{[4]} + V_3^{[4]}(m)u_3^{[4]} + V_4^{[4]}(m)u_4^{[4]} \quad (10)$$

where, m is the time slot and its value is 11,12,13 and 14 and $V_i^{[j]}$(m) are linear precoding coefficients, $u_i^{[j]}$is symbol at transmitter j defined from part I on the information of the channel coefficients i.e. delayed CSIT.

For the sake of interference to be comprised in a 10 dimensional space at every receiver, the precoding coefficients of part II should have the similar relationship as recognized in part I. Therefore at receiver 1, mathematically:

$$\begin{bmatrix} H^{[12]}(m)V_1^{[2]}(m) & H^{[12]}(m)V_2^{[2]}(m) & H^{[12]}(m)V_3^{[2]}(m) & H^{[12]}(m)V_4^{[2]}(m) & H^{[13]}(m)V_1^{[3]}(m) & H^{[13]}(m)V_2^{[3]}(m) \\ H^{[13]}(m)V_3^{[3]}(m) & H^{[13]}(m)V_4^{[3]}(m) & H^{[14]}(m)V_1^{[4]}(m) & H^{[14]}(m)V_2^{[4]}(m) & H^{[14]}(m)V_3^{[4]}(m) & H^{[14]}(m)V_4^{[4]}(m) \end{bmatrix} \alpha^{\to[1]} = 0 \quad (11)$$

$$\begin{bmatrix} H^{[21]}(m)V_1^{[1]}(m) & H^{[21]}(m)V_2^{[1]}(m) & H^{[21]}(m)V_3^{[1]}(m) & H^{[21]}(m)V_4^{[1]}(m) & H^{[23]}(m)V_1^{[3]}(m) & H^{[23]}(m)V_2^{[3]}(m) \\ H^{[23]}(m)V_3^{[3]}(m) & H^{[23]}(m)V_4^{[3]}(m) & H^{[24]}(m)V_1^{[4]}(m) & H^{[24]}(m)V_2^{[4]}(m) & H^{[24]}(m)V_3^{[4]}(m) & H^{[24]}(m)V_4^{[4]}(m) \end{bmatrix} \alpha^{\to[2]} = 0 \quad (12)$$

$$\begin{bmatrix} H^{[31]}(m)V_1^{[1]}(m) & H^{[31]}(m)V_2^{[1]}(m) & H^{[31]}(m)V_3^{[1]}(m) & H^{[31]}(m)V_4^{[1]}(m) & H^{[32]}(m)V_1^{[2]}(m) & H^{[32]}(m)V_2^{[2]}(m) \\ H^{[32]}(m)V_3^{[2]}(m) & H^{[32]}(m)V_4^{[2]}(m) & H^{[34]}(m)V_1^{[4]}(m) & H^{[34]}(m)V_2^{[4]}(m) & H^{[34]}(m)V_3^{[4]}(m) & H^{[34]}(m)V_4^{[4]}(m) \end{bmatrix} \alpha^{\to[3]} = 0 \quad (13)$$

$$\begin{bmatrix} H^{[41]}(m)V_1^{[1]}(m) & H^{[41]}(m)V_2^{[1]}(m) & H^{[41]}(m)V_3^{[1]}(m) & H^{[41]}(m)V_4^{[1]}(m) & H^{[42]}(m)V_1^{[2]}(m) & H^{[42]}(m)V_2^{[2]}(m) \\ H^{[42]}(m)V_3^{[2]}(m) & H^{[42]}(m)V_4^{[2]}(m) & H^{[43]}(m)V_1^{[3]}(m) & H^{[43]}(m)V_2^{[3]}(m) & H^{[43]}(m)V_3^{[3]}(m) & H^{[43]}(m)V_4^{[3]}(m) \end{bmatrix} \alpha^{\to[4]} = 0 \quad (14)$$

As we know that transmitters have no knowledge about the current channel states H[**](n), so to prove the authenticity of above equations for the realization for all current channel states is by selecting precoding vector $V_i^{[j]}$ in such a manner that :

$$V_1^{[1]}(m)\alpha_1^{[2]} + V_2^{[1]}(m)\alpha_2^{[2]} + V_3^{[1]}(m)\alpha_3^{[2]} + V_4^{[1]}(m)\alpha_4^{[2]} = 0 \quad (15)$$

$$V_1^{[1]}(m)\alpha_1^{[3]} + V_2^{[1]}(m)\alpha_2^{[3]} + V_3^{[1]}(m)\alpha_3^{[3]} + V_4^{[1]}(m)\alpha_4^{[3]} = 0 \quad (16)$$

$$V_1^{[1]}(m)\alpha_1^{[4]} + V_2^{[1]}(m)\alpha_2^{[4]} + V_3^{[1]}(m)\alpha_3^{[4]} + V_4^{[1]}(m)\alpha_4^{[4]} = 0 \quad (17)$$

$$V_1^{[2]}(m)\alpha_1^{[1]} + V_2^{[2]}(m)\alpha_2^{[1]} + V_3^{[2]}(m)\alpha_3^{[1]} + V_4^{[2]}(m)\alpha_4^{[1]} = 0 \quad (18)$$

$$V_1^{[2]}(m)\alpha_5^{[3]} + V_2^{[2]}(m)\alpha_6^{[3]} + V_3^{[2]}(m)\alpha_7^{[3]} + V_4^{[2]}(m)\alpha_8^{[3]} = 0 \quad (19)$$

$$V_1^{[2]}(m)\alpha_5^{[4]} + V_2^{[2]}(m)\alpha_6^{[4]} + V_3^{[2]}(m)\alpha_7^{[4]} + V_4^{[2]}(m)\alpha_8^{[4]} = 0 \quad (20)$$

$$V_1^{[3]}(m)\alpha_5^{[1]} + V_2^{[3]}(m)\alpha_6^{[1]} + V_3^{[3]}(m)\alpha_7^{[1]} + V_4^{[3]}(m)\alpha_8^{[1]} = 0 \quad (21)$$

$$V_1^{[3]}(m)\alpha_5^{[2]} + V_2^{[3]}(m)\alpha_6^{[2]} + V_3^{[3]}(m)\alpha_7^{[2]} + V_4^{[3]}(m)\alpha_8^{[2]} = 0 \quad (22)$$

$$V_1^{[3]}(m)\alpha_9^{[4]} + V_2^{[3]}(m)\alpha_{10}^{[4]} + V_3^{[3]}(m)\alpha_{11}^{[4]} + V_4^{[3]}(m)\alpha_{12}^{[4]} = 0 \quad (23)$$

$$V_1^{[4]}(m)\alpha_9^{[1]} + V_2^{[4]}(m)\alpha_{10}^{[1]} + V_3^{[4]}(m)\alpha_{11}^{[1]} + V_4^{[4]}(m)\alpha_{12}^{[1]} = 0 \quad (24)$$

$$V_1^{[4]}(m)\alpha_9^{[2]} + V_2^{[4]}(m)\alpha_{10}^{[2]} + V_3^{[4]}(m)\alpha_{11}^{[2]} + V_4^{[4]}(m)\alpha_{12}^{[2]} = 0 \quad (25)$$

$$V_1^{[4]}(m)\alpha_9^{[3]} + V_2^{[4]}(m)\alpha_{10}^{[3]} + V_3^{[4]}(m)\alpha_{11}^{[3]} + V_4^{[4]}(m)\alpha_{12}^{[3]} = 0 \quad (26)$$

Transmitter 1 sends the precoding coefficients$V_j^{[k]}(m)$ *where* $i = 1,2,3,4$, on the basis of (15), (16),(17); $V_2^{[1]}, V_3^{[1]}$ *and* $V_4^{[1]}$ can be expressed as linear combination of $V_1^{[1]}$. Therefore transmitter 1 is required to send:

$$X^{[1]}(m) = \mathrm{V}_1^{[1]}(\mathrm{m})\mathrm{u}_1^{[1]} + \mathrm{V}_2^{[1]}(\mathrm{m})\mathrm{u}_2^{[1]} + \mathrm{V}_3^{[1]}(\mathrm{m})\mathrm{u}_3^{[1]} + \mathrm{V}_4^{[1]}(\mathrm{m})\mathrm{u}_4^{[1]} \quad (27)$$

$$= \mathrm{c}\,[\mathrm{u}_1^{[1]}(\mathrm{ec}-\mathrm{bf}) + \mathrm{u}_2^{[1]}(\mathrm{af}-\mathrm{dc}) + \mathrm{u}_3^{[1]}(\mathrm{bd}-\mathrm{ae}) + \mathrm{u}_4^{[1]}\,\mathrm{z}] \quad (28)$$

where;

a = $(\alpha_1^{[2]}\alpha_4^{[3]} - \alpha_1^{[3]}\alpha_4^{[2]})$, b= $\left(\alpha_2^{[2]}\alpha_4^{[3]} - \alpha_2^{[3]}\alpha_4^{[2]}\right), c = (\alpha_3^{[2]}\alpha_4^{[3]} - \alpha_3^{[3]}\alpha_4^{[2]}), d = \left(\alpha_1^{[3]}\alpha_4^{[4]} - \alpha_1^{[4]}\alpha_4^{[3]}\right)$,

$e = (\alpha_2^{[3]}\alpha_4^{[4]} - \alpha_2^{[4]}\alpha_4^{[3]}), f = (\alpha_3^{[3]}\alpha_4^{[4]} - \alpha_3^{[4]}\alpha_4^{[3]})$,

z =$\alpha_1^{[2]}\alpha_2^{[3]}\alpha_3^{[4]}\alpha_4^{[4]} - \alpha_1^{[2]}\alpha_3^{[3]}\alpha_2^{[4]}\alpha_4^{[3]} + \alpha_2^{[2]}\alpha_3^{[3]}\alpha_1^{[4]}\alpha_4^{[3]} - \alpha_2^{[2]}\alpha_1^{[3]}\alpha_3^{[4]}\alpha_4^{[3]} + \alpha_3^{[2]}\alpha_1^{[3]}\alpha_2^{[4]}\alpha_4^{[3]} - \alpha_3^{[2]}\alpha_2^{[3]}\alpha_1^{[4]}\alpha_4^{[3]}$

c = any constant which can be set to unity.

Even though the transmitter has four information messages to be sent, it is allowed to send only the scaled versions of the scalar $[\mathrm{u}_1^{[1]}(\mathrm{ec}-\mathrm{bf}) + \mathrm{u}_2^{[1]}(\mathrm{af}-\mathrm{dc}) + \mathrm{u}_3^{[1]}(\mathrm{bd}-\mathrm{ae}) + \mathrm{u}_4^{[1]}\,\mathrm{z}]$ so that interference is contained within 10 dimensions at every receiver. Similarly scalars can be defined to be send by transmitters 2,3 and 4. There are only 4 messages and 4 channel uses, therefore it can be analyzed that each transmitter is resending its own information messages, so that each receiver has different linear combination of the 4 messages every time. In this way at the end every receiver is capable to decode all the four scalar symbols. The transmitted message from transmitter 1 is shown in (29).Thus, resulting precoding vectors have been determined sent over 14 messages, keeping the interference aligned in 10 dimensions and remaining 4 dimensions to recover the desired messages. Therefore, the delayed CSIT scenario with 4 user interference channel can achieve 8/7 degree of freedom almost.

Conclusion:

An alignment scheme is proposed for 4 user interference channel with delayed CSIT. Presented scheme operates in two parts: interfering symbols and desired symbols. It proves the achievability of 8/7 degrees of freedom. Though the given scheme shows that interference is limited within 10 dimensions, it is also important to show that the desired signal vectors are not aligned within the interference or aligned among themselves, which is proved by showing that the determinant of the matrix of transmitted symbol i.e. polynomial in part1 is not a zero polynomial.

$$\begin{bmatrix} X^{[1]}(1) \\ X^{[1]}(2) \\ X^{[1]}(3) \\ X^{[1]}(4) \\ X^{[1]}(5) \\ X^{[1]}(6) \\ X^{[1]}(7) \\ X^{[1]}(8) \\ X^{[1]}(9) \\ X^{[1]}(10) \\ X^{[1]}(11) \\ X^{[1]}(12) \\ X^{[1]}(13) \\ X^{[1]}(14) \end{bmatrix} = \begin{bmatrix} V_1^{[1]}(1) & V_2^{[1]}(1) & V_3^{[1]}(1) & V_4^{[1]}(1) \\ V_1^{[1]}(2) & V_2^{[1]}(2) & V_3^{[1]}(2) & V_4^{[1]}(2) \\ V_1^{[1]}(3) & V_2^{[1]}(3) & V_3^{[1]}(3) & V_4^{[1]}(3) \\ V_1^{[1]}(4) & V_2^{[1]}(4) & V_3^{[1]}(4) & V_4^{[1]}(4) \\ V_1^{[1]}(5) & V_2^{[1]}(5) & V_3^{[1]}(5) & V_4^{[1]}(5) \\ V_1^{[1]}(6) & V_2^{[1]}(6) & V_3^{[1]}(6) & V_4^{[1]}(6) \\ V_1^{[1]}(7) & V_2^{[1]}(7) & V_3^{[1]}(7) & V_4^{[1]}(7) \\ V_1^{[1]}(8) & V_2^{[1]}(8) & V_3^{[1]}(8) & V_4^{[1]}(8) \\ V_1^{[1]}(9) & V_2^{[1]}(9) & V_3^{[1]}(9) & V_4^{[1]}(9) \\ V_1^{[1]}(10) & V_2^{[1]}(10) & V_3^{[1]}(10) & V_4^{[1]}(10) \\ (ec-bf) & (af-dc) & (bd-ae) & (z) \\ (ec-bf) & (af-dc) & (bd-ae) & (z) \\ (ec-bf) & (af-dc) & (bd-ae) & (z) \\ (ec-bf) & (af-dc) & (bd-ae) & (z) \end{bmatrix} \begin{bmatrix} u_1^{[1]} \\ u_2^{[1]} \\ u_3^{[1]} \\ u_4^{[1]} \end{bmatrix} \quad (29)$$

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