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Interference Suppression at the base Station Downlink Beamforming using Invariant Transmit Dimensions in MU- MIMO

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Abstract **– A future model in physical mobile layer consists of a Base Station and some Mobile Stations equipped MIMO antennas (MU-MIMO). However, what is information needed to be fed back to the Base Station that uses to form beam patterns and how to not affect on the other mobiles is very important. The paper concentrates on the spatial information (subspaces) of the MIMO channel because it is almost constant (invariant) in fast fading transmission environment. This spatial information helps the Base Station to discover what are the useful radiating directions that track of the considered mobile and prevent radiating to interfere with the other unwanted mobiles. The simulation can prove this spatial feedback can make SNR higher compared to the case of use of beam patterns without the proposed transmit directions combatting the interference.**

Keywords **– Multiuser MIMO, Beamforming, Interference, Multipath.**

I. Introduction

Downlink beamforming for the Multi-User MIMO environment is considerable interest for many researchers. If the transmitter can know the Channel State Information partially, it can form the beam patterns that can improve the channel capacity or the SINR at the mobile. Some papers consider the signal processing [1], [2] for TDD. The paper [1] proposes an inter-user interference suppression method based on a non-linear signal processing for the multi-user in-band full-duplex system. It is afraid of forming null directivity to the direction of the other user causes problem that the transmission capacity deteriorates when the null direction corresponds to the direction of the base station [1]. But in the paper, interference between the uplink and downlink is also not the case for FDD that is considered by this paper. In addition, one paper concentrates on the non-linear processing, the interference signal compressed is sent from the base station, and is subtracted from the received signal at the downlink user [2]. However, that makes the receiver more complicated, especially in large multiuser network. The author gives the signal processing at the transmitter to beam to the true direction of the desired mobile. Although the structure of the transmitter more complex, it is easier to design it compared to the receiver.

To evaluate the performance gain with a proposed precoding with symbol-level link adaptation, another paper considers a beam domain-based hybrid precoding architecture that operates with a small number of radio frequency (RF) chains and limited feedback. The paper states that this particular system would be seriously degraded by multi-beam interference associated inter-beam interference. It demonstrates that the proposed symbol demodulation will get a significant transmission performance gain compared to the existing schemes [3]. However, for a standard transmit smart antenna, which should beam the designed mobile. Therefore, this paper considers how to prevent the interference of the beams of other mobiles on the beam on designed mobile.

One paper has studied reduction of interference of inter-beam in minimeter- wave cellular systems [4], however, it shows the generalised formula for giving the precoder for each BS in cellular system. The solution of the paper is not specific for multipath environment, that is stated in this paper. Another paper consider how to maximise the signal- to- leakage ratio [5]. However, they do not care the realistic transmission environment. The paper demonstrates on the transmission environment, which includes multi physical paths due to the reflection, refraction by the obstacles in line of sight. Furthermore, one paper [6] introduces the multipath diversity that makes null beams to other mobiles by using beamforming, but it does not consider the multipath phenomenon consisting of some important physical paths with high gains, that are demonstrated in this paper.

The main and purpose of this paper is to consider the invariant information of the MIMO channel (subspaces of the channel matrix) that helps to reduce the feedback rate from the receiver to the transmitter while keeping the higher SINR than the conventional method of forming the strongest beam without interference combat at the transmitter ([10] - [15]).

II. Beamforming with the Invariant Dimensions

The paper shall treat a simple model describing the transmission between a BS and single mobile. A snapshot of the received signal consisting of the L physical paths is given by [7], taking account of the fact that the mobile moves:

$$\mathbf{y} = \sum_{l=1}^{L} \mathbf{s}(\varphi_l)\,\vartheta_l e^{j u_l v t} x + \mathbf{n} \tag{1}$$

where x is the transmitted signal; $\mathbf{s}_l = \mathbf{s}(\varphi_l)$ is antenna array response for the l th physical path of the BS with assumption that the mobile is far from the BS; ϑ_l is he channel gain of the l th physical path $\vartheta \sim CN(0, \sigma_l^2)$; $\mathbf{n}$ is the noise of the l th physical path at the mobile $\mathbf{n} \sim CN(0, \sigma^2_{\mathbf{I}_M})$, M is the transmit antenna at the BS; $u_l = (2\pi/\lambda)\cos\theta_l$, v is velocity of receiver and t is time of moving receiver, expressed in second (s), λ is the signal wavelength (m).

The Proposed Feedback System Includes the 3 Steps:

- Step 1: Using the SVD (Singular Value Decomposition) to find out the subspaces of channel matrix at each user:

Recalling that the invariant dimensions are extracted from the covariance matrix and the subspace for finding these invariant dimensions can be rewritten in single user model as [8], [9], that beam on the slow moving physical paths in multipath environment:

$$\mathbf{S} = [\mathbf{s}_1 \quad \mathbf{s}_2 \quad \dots \quad \mathbf{s}_L] \tag{2}$$

where

$$\mathbf{s}_l = \begin{bmatrix} 1 \\ e^{-j\kappa \sin\varphi_l s_T} \\ \dots \\ e^{-j\kappa \sin\varphi_l s_T (M-1)} \end{bmatrix}, l = 1 \rightarrow L$$

φ_l, s_T is the transmit angle, the spacing between transmit elements, $\kappa = 2\pi/\lambda$ where λ is the wavelength.

Generalised method of forming beams at the Base Station is based on the subspaces information from all users MS_1 to MS_Z. The subspaces include $\mathbf{S}^{(i)} = \left[\mathbf{s}_1^{(i)} \quad \mathbf{s}_2^{(i)} \quad \ldots \quad \mathbf{s}_{L_i}^{(i)}\right]$, $i = 1 \to Z$ as the subspace of the i th mobile, $L_1 \to L_Z$ are number of paths for the mobile stations MS_1 to MS_Z.

- Step 2: Uplink feedback channel in which the subspaces of channel matrix $\mathbf{S}^{(i)}$, $i = 1 \to Z$ are fed back to the BS.

- Step 3: Downlink beamforming from the BS to multiple users:

Optimum beam-forming algorithm using the invariant dimensions to the multi-user environment, exploits the method for determining invariant dimensions of the single-user. The analysis considers one MS as the desired mobile and other mobiles as interferers. The information of invariant dimensions achievable with this scenario is presented in Fig. 1.

For simplicity in this section, it is assumed that $\mathbf{s}_i = \mathbf{s}_i / norm(\mathbf{s}_i), i = 1 \to L$ so that given the subspace, the productive beam matrix at transmitter can be expressed as:

$$\mathbf{W} = \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \cdots \\ \mathbf{w}_L \end{bmatrix} = \begin{bmatrix} \mathbf{s}_1^H \\ \mathbf{s}_2^H \\ \cdots \\ \mathbf{s}_L^H \end{bmatrix} \tag{3}$$

where $\mathbf{w}_i \mathbf{s}_i = 1$.

In the situation where the multi-user system includes Z mobiles, i.e., when the desired mobile is denoted by the i th mobile with the subspace $\mathbf{S}^{(i)} = [\mathbf{s}_1^{(i)} \quad \mathbf{s}_2^{(i)} \quad \ldots \quad \mathbf{s}_{L_i}^{(i)}]$. The information of $\mathbf{W}^{(i)} = \left[\mathbf{w}_1^{(i)} \quad \mathbf{w}_2^{(i)} \quad \ldots \quad \mathbf{w}_{L_i}^{(i)}\right]^T$ for the i th mobile satisfying $\mathbf{w}_m^{(i)} \mathbf{s}_m^{(i)} = 1$, with $m = (1, L_i)$, it is optimum for suppressing the interference when $\mathbf{w}_m^{(i)} \mathbf{s}_n^{(j)} = 0$, where $j = 1 \to Z, j \neq i, n = (1, L_j)$.

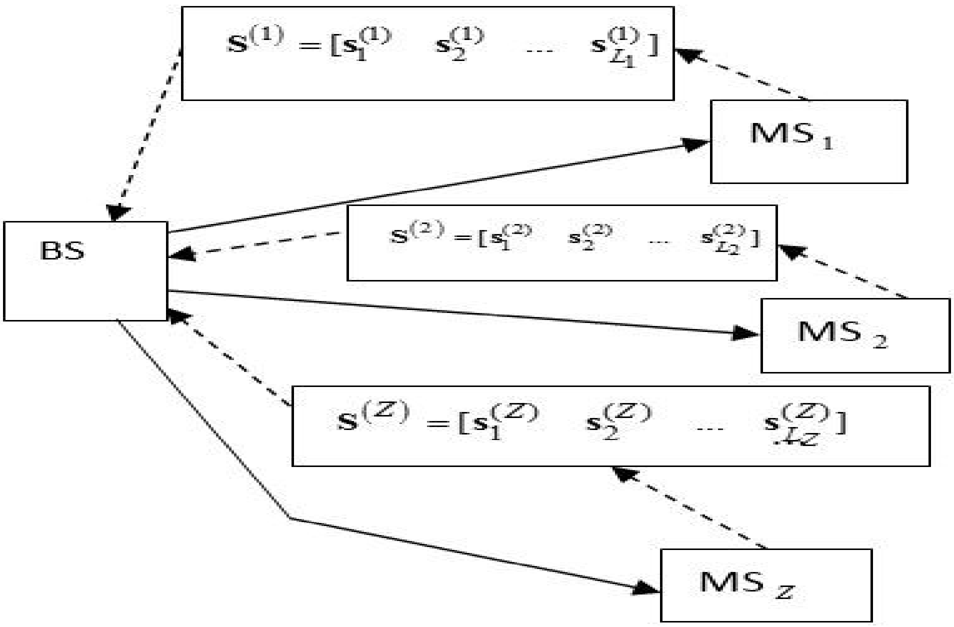

Fig. 1. Illustration of the feedback information of invariant dimensions of all mobiles in multi-user environment.

$\mathbf{S}^{(i)} = [\mathbf{s}_1^{(i)} \ \ \mathbf{s}_2^{(i)} \ \ \ldots \ \ \mathbf{s}_{L_i}^{(i)}], i = 1 \to Z$ is the subspace of the i th mobile, $L_1 \to L_Z$ are number of paths for the mobile stations MS$_1$ to MS$_Z$, respectively.

Ideally, $\mathbf{w}_m^{(i)}\mathbf{s}_m^{(i)} = 1$ and $\mathbf{w}_m^{(i)}\mathbf{s}_n^{(j)} = 0$. An optimum solution is obtained by maximising the following for the m th beam pattern for the i th mobile, that is defined as:

$$\frac{\mathbf{w}_m^{(i)}\mathbf{s}_m^{(i)}}{\sum_{\substack{j=1\\ j\neq i}}^{Z}\sum_{n=1}^{L_j}\mathbf{w}_m^{(i)}\mathbf{s}_n^{(j)}} \tag{4}$$

where

$$\mathbf{w}_m^{(i)} = 1/\sqrt{M}\left[1 \quad e^{j\kappa\sin\varphi_m^{(i)}s_T} \quad \ldots \quad e^{j\kappa\sin\varphi_m^{(i)}s_T(M-1)}\right]$$

$$\mathbf{s}_m^{(i)} = 1/\sqrt{M}\left[1 \quad e^{-j\kappa\sin\varphi_m^{(i)}s_T} \quad \ldots \quad e^{-j\kappa\sin\varphi_m^{(i)}s_T(M-1)}\right]^T$$

$$\mathbf{s}_n^{(j)} = 1/\sqrt{M}\left[1 \quad e^{-j\kappa\sin\varphi_n^{(j)}s_T} \quad \ldots \quad e^{-j\kappa\sin\varphi_n^{(j)}s_T(M-1)}\right]^T$$

For simplicity in this section, it is assumed that $\mathbf{S}_n^{(j)} = \mathbf{s}_n^{(j)}\left(\mathbf{s}_n^{(j)}\right)^H$ and $\mathbf{S}_m^{(i)} = \mathbf{s}_m^{(i)}\left(\mathbf{s}_m^{(i)}\right)^H$ so that the ratio in (4) is equivalent to:

$$\frac{\mathbf{w}_m^{(i)}\mathbf{S}_m^{(i)}\left(\mathbf{w}_m^{(i)}\right)^H}{\mathbf{w}_m^{(i)}\left(\sum_{j=1,\neq i}^{Z}\sum_{n=1}^{L_j}\mathbf{S}_n^{(j)}\right)\left(\mathbf{w}_m^{(i)}\right)^H} \tag{5}$$

In order to keep the ratio (5) simple, the new term $\mathbf{S}^{(j)}$ (representing total interfering other user subspaces) is denoted as:

$$\mathbf{S}^{(j)} = \sum_{\substack{j=1\\ j\neq i}}^{Z}\sum_{n=1}^{L_j}\mathbf{S}_n^{(j)} \tag{6}$$

Hence, the ratio can be rewritten as:

$$\frac{\mathbf{w}_m^{(i)}\mathbf{S}_m^{(i)}\left(\mathbf{w}_m^{(i)}\right)^H}{\mathbf{w}_m^{(i)}\mathbf{S}^{(j)}\left(\mathbf{w}_m^{(i)}\right)^H} \tag{7}$$

When considering the optimum weight vector $\mathbf{w}_m^{(i)}$ offered by (7), $\mathbf{w}_m^{(i)}$ is presented (if $\mathbf{S}^{(j)}$ is invertible) as:

$$\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)}\right)^{-1}\mathbf{s}_m^{(i)}\right)^H \tag{8}$$

III. The Comparison with the Use of the Strongest Dimension

The ability to suppress the interference achievable with such an equation is presented in Figure 2 when comparing with $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)}\right)^H$ where the parameters for this figure can be listed in Table 1.

Table 1. The parameters for the fig. 1.

Wavelength	$\lambda = 1$ m
The spacing between the transmit elements	$s_T = 0.5$ m
The transmit angle for the vector $\mathbf{w}_m^{(i)}$	$\varphi_m^{(i)} = 30^o$
The number of elements at the transmitter	$M = 4$
Number of interferers	$Z = 2$
The number of paths of each interferer	2 paths
The transmit angles of path $n = 1,2$ of the interferer $j = 1,2$	$\varphi_{n=1}^{(j=1)} = 45^o; \varphi_2^{(1)} = 135^o$ $\varphi_{n=1}^{(j=2)} = 225^o; \varphi_2^{(2)} = 315^o$

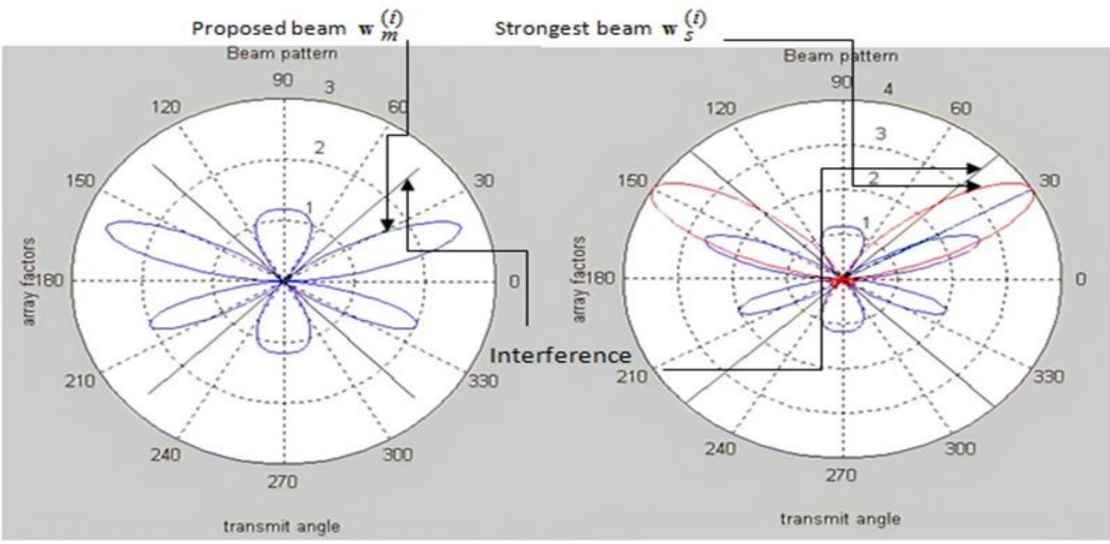

Fig. 2. Representation of the new optimum method for multi-user environment $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)}\right)^{-1}\mathbf{s}_m^{(i)}\right)^H$ and strongest beam method without interference combat using $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)}\right)^H$ for forming the mth path's transmit beam for the ith mobile.

Fig. 2 illustrates the performance of the new algorithm. This method uses the advantage of considering other interferers since it is shown that this method can suppress the interferers better than the method using only information of the desire mobile. This can be identified that two directions of interferers are affecting the beam using $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)}\right)^H$ ([10] - [15]) while they do not effect the beam using $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)}\right)^{-1}\mathbf{s}_m^{(i)}\right)^H$.

Analysis has been performed over all the transmit angles demonstrates the performance of the new method when employing $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)}\right)^{-1}\mathbf{s}_m^{(i)}\right)^H$. Note that in Fig. 3, two graphs present the $SINR$ versus the transmit angle variable $\varphi_m^{(i)} = 0^0 \rightarrow 360^0$ where other parameters are described in Table. 1, except: $\varphi_m^{(i)} = 0^0 \rightarrow 360^0, \varphi_{n=1}^{(j=1)} = 15^0, \varphi_2^{(1)} = 45^0$ and $\varphi_1^{(2)} = 75^0, \varphi_2^{(2)} = 90^0$. Therefore two graphs can be compared.

When considering the $SINR$ employing two methods, the results of these methods are different. Using the information of other mobiles $\mathbf{S}^{(j)}, j = 1 \to Z, j \neq i$, the new method provides a better result in terms of the $SINR$. This emphasizes that using the new method using $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)} \right)^{-1} \mathbf{s}_m^{(i)} \right)^H$ permits the use of more interference suppression than the case where $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)} \right)^H$ for one beam is employed.

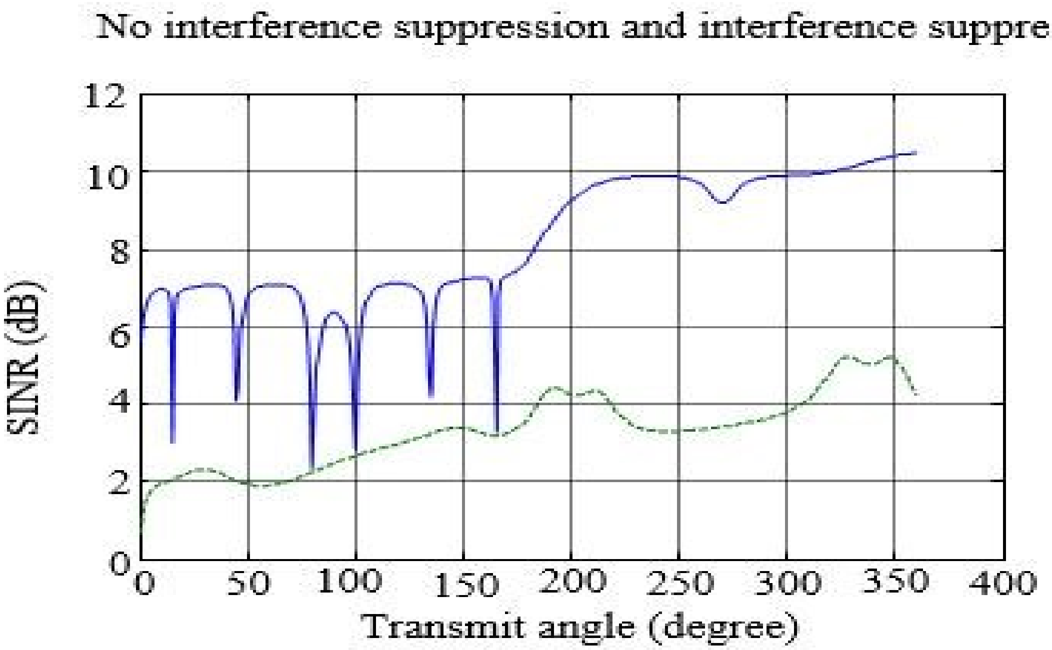

Fig. 3. The SINR versus the transmit angle in the new method using $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)} \right)^{-1} \mathbf{s}_m^{(i)} \right)^H$ (solid line) and the method without interference combat employing $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)} \right)^H$ for forming the mth path's transmit beam for the ith mobile (dotted line) as presented with parameters as reported as above.

Therefore, in the context of the use of the strongest dimension $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)} \right)^H$ ([10] - [15]), the $SINR$ which is computed with $\mathbf{w}_m^{(i)} = \left(\left(\mathbf{S}^{(j)} \right)^{-1} \mathbf{s}_m^{(i)} \right)^H$, $m = 1 \to L_i$ for L beams is higher than the case of the use of the strongest dimension $\mathbf{w}_m^{(i)} = \left(\mathbf{s}_m^{(i)} \right)^H$ as illustrated in Fig. 3. This means if the transmitter utilises the beam with the proposed interference suppression, the channel capacity is higher the case using the strongest beam.

We can extend the above simulation to the L paths instead of 1 path with AoD of $\varphi_m^{(i)} = 30^o$. The transmitter can use the L beams, corresponding to the L paths, each of which has the proposed noise suppression method as explained the same as 1 path. That case can make value of the $SINR$ increased to L times its value for the case of 1 path, which is even better than the conventional method using the strongest beam (without the interference suppression). On the other way, the transmitter utilises the L proposed beams can help the $SINR$ larger L times than its value in the case of using the strongest beam ([10] - [[15]). However, the transmitter structure using the L proposed beams is more complex than the case for forming the strongest beam, that leads to more size and cost for building the proposed transmitter.

IV. Conclusion

The paper has applied the proposed interference -from-other- mobiles combat in a model of the Base Station and some Mobiles where the desired transmit beam does not include the beaming directions for other mobiles. Moreover, compared to other papers [1] – [6], this paper considers the realistic transmission environment where the multipath phenomenon is very important. This method bases on the invariant spatial characteristics of MIMO model to give the better SINR to the considered mobile than the strongest beam ([10]- [15]). The paper states through the simulation that the proposed interference combat can improve the SINR at the wanted mobile.

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