ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 4, Issue 10, October 2015

A Convergent Version of Maximum SINR Algorithm for MIMO Interference Channel

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Abstract: The problem of designing linear transmits signaling strategies for the multiple inputs, multiple output (MIMO) interference channel is considered. One of the first algorithms inspired by Interference alignment (IA) is Minimum Leakage Algorithm (Min Leakage Algorithm) for the MIMO Interference Channel. Iterative algorithm, Max SINR, was proposed in [5] that gives better sum rate performance. The Max SINR algorithm starts with arbitrary transmits beam forming vectors and then designs receivers to optimize the signal-to-interference-plus-noise ratio (SINR) at each receiver. Next, the algorithm alternates the direction of communication and repeatedly optimizes the SINR at each receiver. This algorithm outperforms the other algorithms mentioned before, but there is no proof that it actually converges.

Modified Max SINR is the modified version of Max SINR in which the sum rate converges. Modified Max SINR follows the same basic principle as Max SINR with two key differences. First, Modified Max SINR uses the sum stream metric as a convergence criterion. Second, Modified Max SINR changes the powers for each stream when it reverses the direction of communication to achieve SINR duality. Computing Power Allocation to Achieve SINR Duality: In order to achieve SINR duality Algorithm need to compute the appropriate power allocation every time change the direction of communication using a distributed power control algorithm. This algorithm monotonically increases the sum stream and therefore converges.

Keywords: SINR, MIMO Interference Channel, Interference alignment (IA).

INTRODUCTION

High data rate communication is the main focus of wireless network and it can be achieved through interference channel. When MIMO interference channel is used for transmission there is a significant increase in the overall spectral efficiency. Beam forming technology is used to direct the reception and transmission of an array in a chosen angular direction. This signal processing technology can be used in interference alignment. In a convergent version of Max SINR algorithm first, a power control step performed in each iteration insures that the same SINRs can be achieved in both directions of communication. With this observation, a performance metric similar to sum rate converges and the sum rate a monotonically increasing function of the SINRs, and so the sum rate converges. This algorithm monotonically increases sum stream rate.

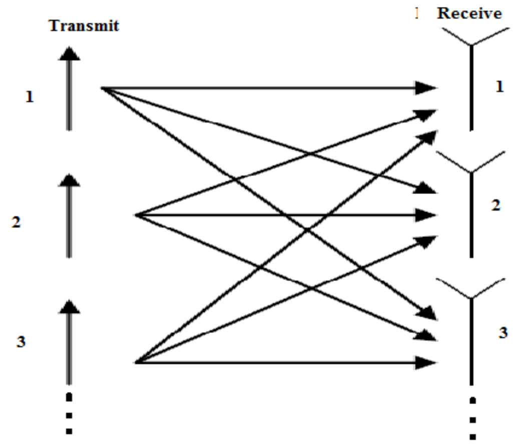
Notations used

Scalars are lower case, vectors are lower case bold, and matrices are upper case bold. Furthermore, **A** (d) is the d^{th} column of the matrix **A**. When we use this notation in general we will refer to a collection of matrices, and therefore in our notation $A_i(d)$ is the d^{th} column of the i^{th} matrix A_i. Also, $x(l)$ is the l th element of the vector **x**, **I** is the identity matrix, $A^{\dagger}$ is the conjugate transpose of **A**, and K= {1, 2. . . K} is the set of all users. $diag(x_1, x_2, ..., x_N)$ is an N × N diagonal matrix with $x_1, x_2, ..., x_N$ on the diagonal. For iterative algorithms presented in this paper, $A_i(n)$ denotes the value of the matrix A_i at iteration n. The proper complex Gaussian vector with mean **μ** and covariance matrix **Σ** is denoted by □□ (**μ**, **Σ**).

1. MIMO COMMUNICATION SYSTEM

In a multiple access system with multiple antennas at the base station allows several users to simultaneously communicate with the base station. Spatial separation of signal from the different users is achieved by using multiple antennas. Point to point channel with multiple transmit and receive antennas give the similar effect. It has been observed that under suitable channel fading condition multiple transmit and receive antennas provide an additional spatial dimension for communication and degree of freedom gain. This additional degree of freedom gives an increase in capacity with spatial multiplexing. The capacity of such MIMO channel with 'n' transmit and receive antennas are proportional to 'n'. It has been seen that multiple antennas provide power gain and increase the reliability of wireless link with channel knowledge at the transmitter. Multiple transmit antenna can provide a power gain via transmit beam forming.

Multiple antennas may be used to perform smart antenna functions such as spreading the total transmit power over the antennas to achieve an array gain that incrementally improves the spectral efficiency or achieving a diversity gain that improves the link reliability (reduces fading,) or both. However, today the term "MIMO" usually refers to a method for multiplying the capacity of a radio link by exploiting multipath propagation.



MIMO Communication system

In a communication system, where N signals are transmitted from N transmitters simultaneously. For example, in a wireless communication system, at each time slot t, signals $C_{t,n}, n = 1, 2, \ldots N$ are transmitted simultaneously from N transmit antennas. The signals are the inputs of a MIMO channel with M outputs. Each transmitted signal goes through the wireless channel to arrive at each of the M receivers. In a wireless communication system with M receive antennas, each output of the channel is a linear superposition of the faded versions of the inputs perturbed by noise. Each pair of transmit and receive antennas provides a signal path from the transmitter to the receiver. The coefficient $\alpha_{n,m}$ is the path gain from transmit antenna n to receive antenna m. Figure 2.3 given below shows the MIMO channel. Based on this model, the signal, which is received at time t at antenna m, is given by

$$r_{t,m} = \sum_{n=1}^{N} \alpha_{n,m} C_{t,n} + \eta_{t,m}$$

Where $\eta_{t,m}$ is the noise sample of the receive antenna m at time t . The replica of the transmitted signal from each transmit antenna is added to the signal of each receive antenna. Although the faded versions of different signals are mixed at each receive antenna, the existence of the M copies of the transmitted signals at the receiver creates an opportunity to provide diversity gain.If the channel is not flat, the received signal at time tdepends on the transmittedsignals at times before t as well. The result is an extension to the case of one transmit andone receive antenna. Important factor in the behavior of the channel is the correlation between different path gains at different time slots. There are two general assumptions those correspondto two practical scenarios. First, assume a quasi-static channel, where the path gains areconstant over a frame of length T 'and change from frame to frame. Generally assumethat the path gains vary independently from one frame to another. Another assumption is to consider a correlation between the fades in adjacent time samples. The value of T ' dictates the slow or fast nature of the fading.

If a block of data is transmitted over a time frame T that is smaller than T ', the fading is slow. In this case, the fades do not change during the transmission of one block of data and the values of path gains are constant for every frame. On the other hand, in a fast fading model, the path gains may change during the transmission of one frame of data, T >>T '.To form a more compact input-output relationship, collect the signals that are transmitted from N transmit antennas during T time slots in a $T \times M$ matrix, **C**, as follows:

$$N = \begin{bmatrix} \eta_{1,1} & \eta_{1,2} & \cdots & \eta_{N,1} \\ \eta_{2,1} & \eta_{2,2} & \cdots & \eta_{N,2} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{r,1} & \eta_{r,1} & \cdots & \eta_{r,M} \end{bmatrix}$$

Similarly, we construct aN □M received matrix **r** that includes all received signals during
T time slots:

$$r = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,N} \\ r_{2,1} & r_{2,2} & \cdots & r_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ r_{T,1} & r_{T,2} & \cdots & r_{T,N} \end{bmatrix}$$

Then, assuming T □T ' , gathering the path gains in an N □M channel matrix H.

$$H = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \cdots & \alpha_{N,1} \\ \alpha_{2,1} & \alpha_{2,2} & \cdots & \alpha_{N,2} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{N,1} & \alpha_{N,1} & \cdots & \alpha_{N,M} \end{bmatrix}$$

which results:
r=**C**□**H**+ N
Where N is the T □M noise matrix defined by

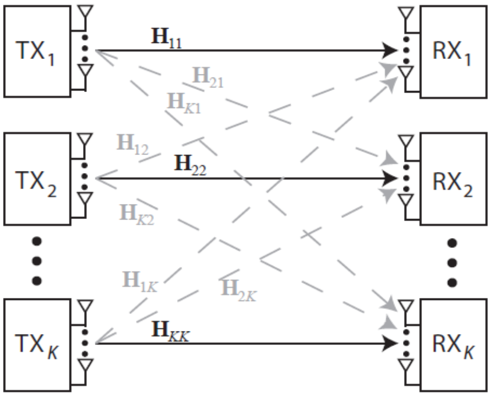
$$N = \begin{bmatrix} \eta_{1,1} & \eta_{1,2} & \cdots & \eta_{N,1} \\ \eta_{2,1} & \eta_{2,2} & \cdots & \eta_{N,2} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{r,1} & \eta_{r,1} & \cdots & \eta_{r,M} \end{bmatrix}$$

Where again is the received SNR.

2. INTERFERENCE CHANNEL

DOI 10.17148/IJARCCE.2015.41074

The natural setting considered to manage interference is interference channel. The unwanted signal in the presence of desired signal is considered as interference. Interference network consist of multiple transmit receive antenna pairs. In which each transmitter communicate with paired receiver in presence of interference from other pairs. The interference channel foraK user MIMO system is given below.



MIMO interference channel

The K-user MIMO interference channel has K transmitters and K receivers, with transmitter i having M_i antennas and receiver i having N_i antennas. For i = 1, . . . , K, receiver i wishes to obtain a message from the corresponding transmitter i . The remaining signals from transmitters $j \neq i$ are undesired interference. The channel is assumed to be constant over time, and at each time-step the input-output relationship is given by

$$Y_i = H_{ii} x_i + \sum_{\substack{i \leq j < K \\ j \neq i}} H_{ij} x_j + Z_i, 1 \leq i < K$$

Here for each user i have $x_i \in C^{M_i}$ and $Y_i, Z_i \in C^{N_i \times M_j}$,withth x_i transmitted signal, Y_i the received signal, and Z_i □ CN$(0, I_{N_i}$)is additive isotropic white Gaussian noise. The channel matrices are given by $H_{ij} \in C^{N_i \times M_j}$ for 1 ≤i, j ≤K

3. INTERFERENCE MANAGEMENT APPROACHES

In [2] Interference management approaches are used to develop an efficient communication scheme. Some of interference management approaches used in practice is given below

3.1. Decoding Of Signal

This approach is used in the case of strong interference. The interfering signal is decoded along with the desired signal; there occurs a tradeoff between interference and decodability. Decoding interference may improve the rates of desired signal but it limits other user rates. Decoding approach is less commonly used in practice. This approach is supported in the case of very strong, strong interference in context of two user interference channel.

3.2. Signals Treated As Noise

If interference is weak the interfering signal can be treated as noise. This approach allows same degree of freedom to all communication links. It is suitable for single user encoding decoding suffices. But in some cases the signal which actually carries information is considered as interference.

3.3. OrthogonalisationOf Signals

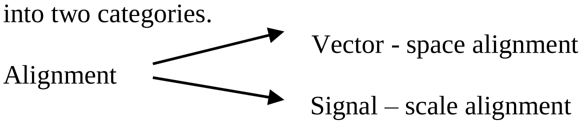
This approach is used in the case of strong interference as that of desired signal. Interference can be avoided by making orthogonal communication link in time or frequency. This approach causes loss of degrees of freedom.

3.4. Beam forming

It is a signal processing technology. Interference alignment can be achieved by directing array in a particular direction.

3.5. Interference Alignment

In [3] the basic idea of interference alignment is to align or overlap multiple interfering signals at each receiver so it reduces effective interference. This approach has higher performance. Mainly interference alignment is divided into two categories.



3.5.1. Interference alignment in signal scale

This scheme was introduced for many interference channels and for fully connected interference network. This scheme depends on code word with lattice structure.

3.5.2 Interference alignment in signal vector space

It is an iterative scheme based on overlapping interference spaces. The basic idea of interference alignment is to force all interfering signal at receiver and the interfering signal to be aligned in a small subspace which is achieved by designing precoding matrices at the transmitter over multiple of these dimensions.

4. COMMUNICATION IN INTERFERENCE CHANNEL

4.1 Specific Channel Model

In [1] Considering both forward and reverse channel, the interference channel system model is given.Here the MIMO interferencechannel model can arise from the use of multiple antennas at transmitters and receivers. Consider K –user MIMO interference channel with the kthuser's channel having M_k inputs and N_k outputs. The system model from the perspective ofreceiver kis given by:

$$\tilde{y}_k = \sum_{j=1}^{K} H_{kj} \tilde{x}_j + \tilde{z}_k$$

where $\tilde{y}_k$ is the $N_k \times 1$ receive vector, $\tilde{z}_k$ is the $N_k \times 1$ AWGN vector normalized tohave unit covariance so that

DOI 10.17148/IJARCCE.2015.41074

$\tilde{z}_k \sim$ CN(0, I_{N_k}), H_{kj} is the $N_k \times M_j$ matrix of channel coefficients between transmitter jand receiver k, and $\tilde{x}_j$ is the $M_j \times 1$transmitted signal vectorfrom user j. Assume that user k sends a total of d_k complex symbols for each of use of the MIMO channel. Transmitted symbol d_k chosen is given below. The vector of d_k symbols ofuser k is denoted by x_k. Let the quantity ρ_{kl} be the power allocated to symbol l of user k, $x_k(l)$ is complex Gaussian signaling, i.e., $x_k \sim \square\square(0, diag(\rho_{k1}, ..., \rho_{kd_k}))$ with ρ_{kl} chosen to satisfy a power constraint P_k, i.e.,

$$\sum_{l=1}^{d_k} \rho_{kl} \le P_k$$

The vector of all stream powers $\sum_{j=1}^{K} d_j \times 1$is

$$\rho = \left[\rho_{11}, ..., \rho_{1d_1}, ..., \rho_{k1}, ..., \rho_{kd_k}\right]$$

Precoding at Transmitter

Let beV_k a $M_k \times d_k$ matrix whose columns are the orthonormal basis of the transmittedsignal space of user k. The symbols x_k are then linearly transformed to form the channel input $\tilde{x}_k$ mathematically, the transmitted signal vector of user k is given by, $\tilde{x}_k = V_k x_k$ where the matrix V_k is a matrix of unit norm transmit beamforming vectors of size $M_k \times d_k$.

Let U_k be an $N_k \times d_k$ matrix whose columns are the orthonormal basis of the interference-free desired signal subspace at receiver. Thereceiver filters its received signal to obtain

$$y_k = U_k^{\dagger} \tilde{y}_k$$

The effective system model is given

$$y_k = \sum_{j=1}^{K} U_k^{\dagger} H_{kj} V_j x_j + z_k$$

In this equation, $z_k \sim \square\square(0, U_k^{\dagger} U_k)$.

4.2. Reciprocal Channel

In the reciprocal channel the transmitters become the receivers andthe receivers become the transmitters. The roles of V_k andU_k are reversed and d_k is kept the same as in the originalchannel. Anarrow above a quantity will indicatethe direction of communication. The channel model for the reciprocal channel is given by

$$\overleftarrow{y}_k = \sum_{j=1}^{K} \overleftarrow{U}_k^{\dagger} \overleftarrow{H}_{kj} \overleftarrow{V}_j \overleftarrow{x}_j + \overleftarrow{z}_k$$

Where $\overleftarrow{H}_{kj} = \overrightarrow{H}^{\dagger}_{jk}$ The original channel will also be referredto as the forward channel and the reciprocal channel as the reverse channel when appropriate.

4.3. Interference Suppression at Receiver

Let d_k, denote the degrees of freedom for user's message. There are mainly two possible approaches for choosing d_k this will refer to as the number of (symbol) streamsfor user k. One possible approach is based on the idea of interference alignment, in which the goal is to find matrices V_k and U_k for each k to completely eliminate the interference at all the receivers at high signal to noise ratio (SNR), i.e.,

If interference is aligned into the null space ofU_k then the following condition must be satisfied:

$$rank\left(U_k^{\dagger} H_{kk} V_k\right) = d_k \forall k$$

$$U_k^{\dagger} H_{kj} V_j = 0, \forall j \ne k$$

The interference alignment conditions are equivalent to the condition that the desired signals are linearlyindependent of the interference. In other words the desired signals are received through $d_k \times d_k$ a full rank channel matrix

$$\tilde{H}_{kk} \square U_k^{\dagger} H_{kk} V_k$$

While the interference is completely eliminated. The effectivechannel for user is then given by

$$\tilde{y}_k = H_{kk} \tilde{x}_j + \tilde{z}_k$$

Where $\tilde{y}_k$ is the $N_k \times 1$ receive vector, $\tilde{z}_k$ is the $N_k \times 1$ additive white Gaussian noise AWGN vector normalized tohave unit covariance so that $\tilde{z}_k \sim \square\square$ $(0, I_{N_k})$.Another approach from algebraic geometry, a necessary condition foralignment given by

$$\sum_{k=1}^{K} d_k (M_k + N_k - 2d_k) \ge \sum_{j \ne k} d_j d_k$$

4.4 Channel Knowledge

The channel knowledge is assuming global channel knowledge. This means that the channelcoefficients are fixed and known at all transmitters' andreceivers. For example, receiver k could estimate the channels H_{kj} for all j, feed the estimated channels back to transmitterk, and exchange the estimated channels with all other transmitters.

5. PROPERTIES OF INTERFERENCE ALIGNMENT

In [4] properties of interference alignment are given

5.1 Feasibility of Alignment

The linear interference alignment solution is similar to design transmit precoding matrices $V_k$and receive interference suppression matricesU_k. Given the channel

DOI 10.17148/IJARCCE.2015.41074

matrices $H_{kj}, k, j \in K$, the degrees of freedom allocation $(d_1, d_2, ...d_k)$ is feasible if there exist transmit precoding matrices V_k and receive interference suppression matrices U_k

$$V_k : M_k \times d_k, {V_k}^{\dagger} V_k = I_{d_k}$$

$$U_k : N_k \times d_k, {U_k}^{\dagger} U_k = I_{d_k}$$

The feasibility condition is given by

$$rank\left({U_k}^{\dagger} H_{kk} V_k\right) = d_k \forall k$$

$${U_k}^{\dagger} H_{kj} V_j = 0, \forall j \neq k$$

Given a set of randomly generated channel matrices and a degree-of-freedom allocation, $(d_1, d_2, ...d_k)$ it is not known if one can almost surelyfind transmit and receive filters that will satisfy the feasibilityconditions. The minimum leakage algorithm will be useful in obtaining numericalinsights into this open problem.

5.2. Reciprocity Of Alignment

Reciprocity of alignment is a key property used for distributedinterference alignment algorithms. Duality relationship between interference alignmenton a given interference channel and its reciprocal channelobtained by switching the direction of communication. Specifically,let $\overleftarrow{V}_k, \overleftarrow{U}_k$ denote the transmit precoding filters andthe receive interference suppression filters on the reciprocalchannel.

$$\overleftarrow{V}_k : N_k \times d_k, {\overleftarrow{U}_k}^{\dagger} \overleftarrow{U}_k = I_{d_k}$$

$$\overleftarrow{U}_k : M_k \times d_k, {\overleftarrow{V}_k}^{\dagger} \overleftarrow{V}_k = I_{d_k}$$

The feasibility conditions on the reciprocal channel are

$${\overleftarrow{U}_j}^{\dagger} \overleftarrow{H}_{kj} \overleftarrow{V}_j = 0, \forall j \neq k$$

$$rank\left({\overleftarrow{U}_k}^{\dagger} \overleftarrow{H}_{kk} \overleftarrow{V}_k\right) = d_k \forall k \in K$$

Suppose $\overleftarrow{V}_k = U_k, \overleftarrow{U}_k = V_k$. Then the feasibility conditions on the reciprocal channel become identical tothe original feasibility conditions. The feasibility conditions are identical; if the degrees of freedom allocation $(d_1, d_2, ...d_k)$ is feasible on the original interference network then it is also feasible on the reciprocal network (and vice versa). Interference alignment on the reciprocal interference network is simply achieved by choosing the transmit filters and the receive filters on the reciprocal channel as the receive filters and the transmit filters of the original channel.

For an efficient interference alignment solution there are two conditions must be satisfied one is existence of a separately desired subspace with number of symbol transmitted dimension. Second one is that desired signal does not interfere from other users.

6. MINIMUM LEAKAGE ALGORITHM

Minimum leakage is a distributed iterative algorithm. This algorithm starts with arbitrary transmit and receive filters and the value of filter is updated on each iteration in order to achieve interference alignment. The leaked interference power in each receiver measures the quality of interference alignment. The leaked interference power is the interference power remaining in the received signal after receive interference suppression filter is applied.

Minimum leakage algorithm minimizes the leaked interference power, at each receiver. If the leaked interference power equals zero, feasibility condition is satisfied, and this algorithm yieldsan IA solution as desired. This algorithm works by repeatedlyreversing the direction of communication and designing receivevectors to minimize the leaked interference power in eachdirection.

It is desired that interference alignment is achieved by progressively reducing the leakage interference. Interference alignment solution becomes feasible after the number of iterations and power goes to a desired minimum value. It can be seen that the convergence of leakage power reduction is not monotone. The algorithm stops when the leakage value becomes converged or the number of iterations reaches a limit defined earlier.

7. MAXIMUM SINR ALGORITHM

In [5] Maximum SINR algorithm achieves good sumrate by copying the basic structure of the minimum leakage algorithm but with a different metric than interference leakage. The interference leakage is replaced with SINR of each stream. In maximum SINR algorithm the goal is to design receive vectors for each stream to maximize SINR of each stream. It is known through simulations that maximum SINR algorithm produces good sumrate in all SINR but the convergence is not guaranteed.

8. A CONVERGENT VERSION OF MAXIMUM SINR ALGORITHM

It is an algorithm similar to maximum SINR with good sum rate performance. This algorithm uses sum stream metric as convergence criteria. The convergence is guaranteed by adding a power control step in each direction of communication. It uses different metric than sum rate called sum stream rate. It is given by

$$R_{sum-stream} = \sum_{k=1}^{K} \sum_{l=1}^{d_k} \log(1 + SINR_{kl})$$

Where $R_{sum-stream}$ the sum of the rates achieved by decoding each stream treating all other stream as noise.

8.1 Sum power constraint

In convergent version of maximum SINR algorithm a power control step is required which impose a power constraint across all the users.

$$\sum_{k=1}^{K} \sum_{l=1}^{d_k} \rho_{kl} \leq KP$$

Sum power constraint is used for managing interference. More intelligent interference managing is by using linear transmitting and receives strategies.

8.2 SINR duality

In [7] the problem of power efficient multiuser beamforming transmission for both uplink and down link is considered. Uplink and down link beamforming are very closely related. The beam formers are optimizers of downlink. This relation between links is referred to as duality. From [8] SINR duality ensures that same set of SINR's can be achieved in the forward and reciprocal network with same total transmit power.

8.2.1 Computing power required for duality

The power required to achieve equal SINR in both forward and reciprocal direction is given in the algorithm

8.2.2 Distributed Power Control Algorithm

1: Choose an initial power vector $\rho^{(1)}$ such that $1^{\perp}\rho^{(1)} \le KP$.

2: To compute the next power allocation compute $\rho^{(2)} = I(\rho^{(1)})$.

3: Repeat step 2 until convergence.

Modified Maximum SINR algorithm

Modified Maximum SINR algorithm uses sum stream metric as convergence criterion and changes power for each stream when it reverses the direction of communication to achieve SINR duality.

8.3 Modified Maximum SINR Algorithm

1. Choose $\left\{\vec{V}_k^{(1)}\right\}$ and $\vec{\rho}^{(1)}$ that satisfy the power constraint.

2. Next, the steps to compute the new transmit and receive vectors. Choose the receive vectors. Compute MMSE RX vectors $\vec{U}_k^{(1)}\ \forall k \in K$ and then $\vec{R}_{sum-stream}^{(1)}$.

3. Reverse the direction of communication. Calculate power allocation $\overleftarrow{\rho}^{(1)}$ to achieve SINR duality. Set

$$\overleftarrow{V}_k^{(1)}(l) = \frac{\vec{U}_k^{(1)}(l)}{\left\|\vec{U}_k^{(1)}(l)\right\|}$$

$$\overleftarrow{U}_k^{(1)}(l) = \vec{V}_k^{(1)}(l)$$

$\forall k \in K, l \in (1,2,....d_k)$. Now calculate the sum stream rate of reciprocal network denoted by $\overleftarrow{R}_{sum-stream-switch}^{(1)}$.

4. Compute MMSE RX vectors $\overleftarrow{U}_k^{(1)}\ \forall k \in K$ and then sum stream of reciprocal network denoted by $\overleftarrow{R}_{sum-stream}^{(1)}$.

5. Reverse the direction of communication. Calculate power allocation $\overleftarrow{\rho}^{(1)}$ to achieve SINR duality. Set

$$\vec{V}_k^{(2)}(l) = \frac{\overleftarrow{U}_k^{(1)}(l)}{\left\|\overleftarrow{U}_k^{(1)}(l)\right\|}$$

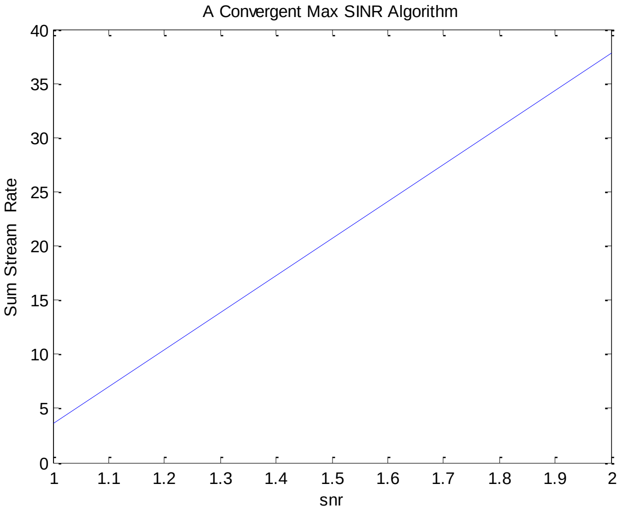
$$\vec{U}_k^{(2)}(l) = \overleftarrow{V}_k^{(1)}(l)$$

$\forall k \in K, l \in (1,2,....d_k)$. Now calculate the sum stream rate of reciprocal network denoted by $\vec{R}_{sum-stream-switch}^{(1)}$.

6. Repeat steps 2 through 5 until convergence of $\vec{R}_{sum-stream}^{(n)}$ or the number of iterations reaches a limit as defined earlier.

8.4 Conclusion

The modified Maximum SINR Algorithm may converge faster or slower depending on the channel parameter and channel coefficients. The key idea to make Maximum SINR converge is to choose the power allocation appropriately. The algorithm stops when the sum stream ratebecome converged or the number of iterations reaches a limit defined earlier. The convergence of convergent version of maximum SINR algorithm is given in the figure Convergence behavior of convergent version of maximum SINR algorithm



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