The challenge of the Multiantenna-IC and practical solutions for the MISO case

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Invited talk

INTRODUCTION (1/3)

- The interference channel (IC) models a network of simultaneous communication node pairs
- Interference is not a fundamental limitation:

$$C_k =_{SNR\to\infty} \frac{1}{2}\log\left(1+SNR_k\right)$$

- IA (interference alignment) is cooperative and not selfish. It avoids MUD
- What about intermediate SINR regime in a constant channel? (where the desired signal power is an issue). What about MIMO-IC?

INTRODUCTION (2/3)

- **TWO USER MISO IC is a special case**
  - In the MISO-IC, the achievable rates are: i=1...K

$$R_i = \log\left(1 + \frac{\left|\boldsymbol{h}_{ii}^H \boldsymbol{q}_i\right|^2}{\sigma^2 + \sum_{i \neq j} \left|\boldsymbol{h}_{ij}^H \boldsymbol{q}_j\right|^2}\right)$$

rx tx

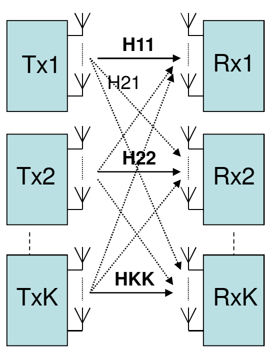
  - The Pareto boundary (i.e. one cannot increase any R_k without decreasing at least one of the other rates) of the achievable rate region is achievable with [Jorswieck08]

$$\boldsymbol{b}_1(\lambda_1) = \frac{\lambda_1 \boldsymbol{b}_1^{MF} + (1-\lambda_1)\boldsymbol{b}_1^{ZF}}{\left\|\lambda_1 \boldsymbol{b}_1^{MF} + (1-\lambda_1)\boldsymbol{b}_1^{ZF}\right\|} \qquad \boldsymbol{b}_2(\lambda_2) = \frac{\lambda_2 \boldsymbol{b}_2^{MF} + (1-\lambda_2)\boldsymbol{b}_2^{ZF}}{\left\|\lambda_2 \boldsymbol{b}_2^{MF} + (1-\lambda_2)\boldsymbol{b}_2^{ZF}\right\|} \qquad 0 \le \lambda_1, \lambda_2 \le 1$$

BUT how to compute the optimal linear combination weights without requiring centralized CSIT?

INTRODUCTION (3/3)

Purpose of this talk is to look at the MISO-IC in detail (PHY layer discuss)



K user interference channel

Transmitter k: $\boldsymbol{x}_k = \sqrt{p_k}\,\boldsymbol{B}_k \boldsymbol{s}_k \qquad \left\|\boldsymbol{B}_k\right\|_F = 1$

Receiver k: $\boldsymbol{y}_k = \sqrt{p_k}\,\boldsymbol{H}_k \boldsymbol{B}_k \boldsymbol{s}_k + \sum_{l \neq k} \sqrt{p_l}\,\boldsymbol{H}_{kl} \boldsymbol{B}_l \boldsymbol{s}_l + \boldsymbol{v}_k$

Rx Tx

The sum rate is an important metric

$$R_{sum} = \sum_{k=1}^{K} \log\left|\boldsymbol{I} + \left(\boldsymbol{R}_k + \sum_{l \neq k} \boldsymbol{H}_{kl} \boldsymbol{B}_l \boldsymbol{B}_l^H \boldsymbol{H}_{kl}^H\right)^{-1} \boldsymbol{H}_{kk} \boldsymbol{B}_k \boldsymbol{B}_k^H \boldsymbol{H}_{kk}^H\right|$$

However it is non-convex with respect to B_l
Iterative design is needed
Note that in the IC:
- individual power constraints→there is no joint processing either at tx. or rx.
- each tx has only local CSI: the channel between itself and all receivers that are within its range

CONTENTS

1- Recent results
- Axiomatic framework
- Relaxation of IA
- Reciprocity

2- Eigenbeamforming
- vs. MMSE

3- Two User MISO IC
- vs. BC

4- Directivity definition in the IC?

5- Applications

6- Conclusions

RECENT RESULTS (1/10)

Axiomatic framework for interference functions [Boche10]

Ex: works with a class of concave resource allocation utilities in interference coupled wireless systems

$$\max_{s} \sum_{k} w_k \, g\left(\varphi(s_k) / I_k\left(\varphi(s)\right)\right)$$

εconcave — Transforms the QoS region into a convex set

Then a sort of iterative algorithms can lead to the optimization [Utschick09]

RECENT RESULTS (2/10)

Relaxation of the IA solutions

In a MIMO-IC, for a Nk-dimensional receive space & Sk stream tx, the idea of IA is to make N interferers appear as N_k-S_k at each rx by having them span a subspace of dimension Nk-Sk . Then the receiver k can resolve its Sk streams interference free.

Ex: K=3 users, S=1

$$\boldsymbol{y}_1 = \boldsymbol{H}_{11}\boldsymbol{b}_1 s_1 + \boldsymbol{H}_{12}\boldsymbol{b}_2 s_2 + \boldsymbol{H}_{13}\boldsymbol{b}_3 s_3 + \boldsymbol{v}_1$$

$$\boldsymbol{H}_{12}\boldsymbol{b}_2 = a_1 \boldsymbol{H}_{13}\boldsymbol{b}_3$$
$$\boldsymbol{H}_{21}\boldsymbol{b}_1 = a_2 \boldsymbol{H}_{23}\boldsymbol{b}_3$$
$$\boldsymbol{H}_{31}\boldsymbol{b}_1 = a_3 \boldsymbol{H}_{32}\boldsymbol{b}_2$$

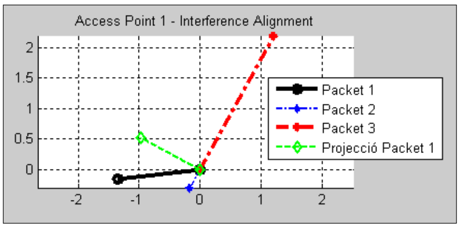
$$\Rightarrow \quad \lim_{SNR\to\infty} \frac{C_{sum}(SNR)}{\log SNR} = \frac{K.M}{2}$$

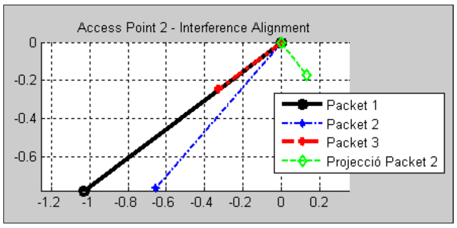
BUTno closed form solutions for K>3

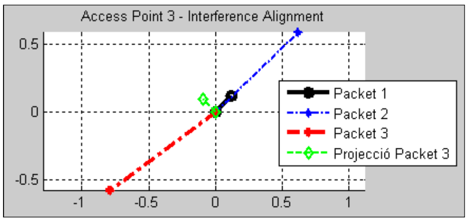
There is no attempt to maximize the desired signal power within the desired signal subspace

RECENT RESULTS (3/10)

IA solutions







HOW TO RELAX IT?

RECENT RESULTS (4/10)

Relaxation of the IA solutions

1.- Minimum leakage:

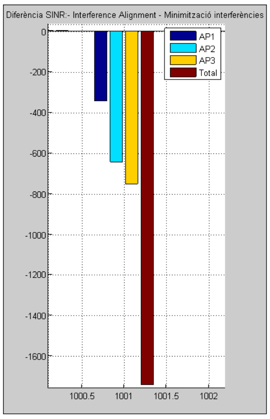
$$\min_{\boldsymbol{b}_j} \sum_{i \neq j} \left| \boldsymbol{h}_{ij}^H \boldsymbol{b}_j \right|^2 \qquad s.t. \quad \left| \boldsymbol{b}_i \right|^2 = 1 \quad \forall i$$

$$\Rightarrow \quad \max_{\boldsymbol{b}_i} \frac{\left| \boldsymbol{b}_i \right|^2}{\sum_{j \neq i} \left| \boldsymbol{h}_{ji}^H \boldsymbol{b}_i \right|^2} \qquad \forall i$$

BUT, why not?

$$\max_{\boldsymbol{b}_i} \frac{\left| \boldsymbol{h}_{ii}^H \boldsymbol{b}_i \right|^2}{\sum_{j \neq i} \left| \boldsymbol{h}_{ji}^H \boldsymbol{b}_i \right|^2} \equiv \max SIR_i^{virtual} \qquad \forall i$$

Ex: 3 MIMO users & ZF rx:
Cumulative differences for 1000 realizations



If both tx and rx are to be designed, by alternate-maximize procedure the convergence is always guaranteed [Heath10].

RECENT RESULTS (5/10)

2- Maximization of virtual Signal-to-Interference-Plus-Noise-Ratio

$$\max_{\boldsymbol{A}_k, \boldsymbol{B}_k} \frac{\sum_k E\left\{ \left| \boldsymbol{A}_k^H \boldsymbol{H}_{kk} \boldsymbol{B}_k s_k \right|_F^2 \right\}}{\sum_k E\left\{ \left| \boldsymbol{A}_k^H \left(\sum_{l \neq k} \boldsymbol{H}_{kl} \boldsymbol{B}_l s_l + \boldsymbol{v}_k \right) \right|_F^2 \right\}}$$

$$s.t. \quad \left| \boldsymbol{b}_{ki} \right|^2 = 1 \qquad \forall i,k$$ i stream, k user

- It can be solved one column at a time [Farrokhi98],[Sayed07]: *signal-to-leakage-noise*
- The solution is the Rayleigh quotient
- If the ZF condition is imposed $H_{lk}.b_k=0$ for all i,k *i* different from *k,* there is a strong condition on the system configuration and no noise filtering.

K user MISO

$$\max_{\boldsymbol{a}_k, \boldsymbol{b}_k} \frac{\left| \boldsymbol{h}_{kk}^H \boldsymbol{b}_k \right|^2}{\sum_{k \neq l} \left| \boldsymbol{h}_{lk}^H \boldsymbol{b}_k \right|^2 + \left| \boldsymbol{b}_k \right|^2} = SINR_k^{virtual}$$

K= 2 users

$$\left(\boldsymbol{h}_{11} \boldsymbol{h}_{11}^H \right) \boldsymbol{b}_1 = \lambda_{\max} \left(\boldsymbol{h}_{21} \boldsymbol{h}_{21}^H + \boldsymbol{I} \right) \boldsymbol{b}_1 \qquad s.t. \quad \left| \boldsymbol{b}_k \right|^2 = 1$$

RECENT RESULTS (6/10)

In [Gesbert09] it was proved that any point on the Pareto boundary may be attained by solving the virtual SINR optimization problem with full power user, for an appropiate choice of α_{ij}, which can be computed distributedly.

$$\max_{b_k} \frac{\left|h_{kk}^H b_k\right|^2}{\sum_{l\neq k}\alpha_{lk}\left|h_{lk}^H b_k\right|^2 + SNR^{-1}} = SINR_k^{virtual}$$

<u>Conclusions</u>

Each of the proposed algorithms outperforms the others in different regimes Since none explicitely maximizes throuput.

Sum rate can be optimized based on iterative procedures that require a lot feedb.

MMSE will be commented later. MMSE and max SINR are desirable metrics in most environments. However, they are difficult to implement because:

- non-orthogonal beamforming solution, which complicates feedback
- MMSE requires some optimization to meet the power constraint

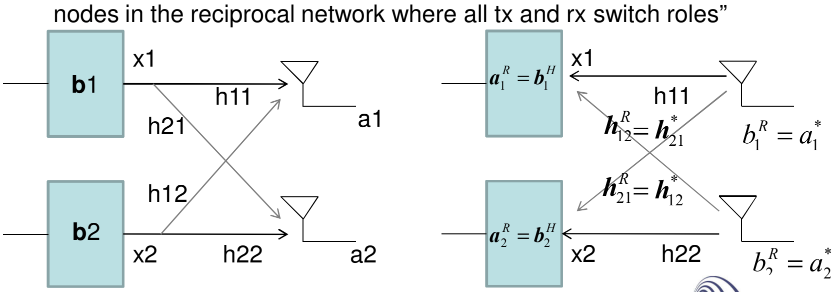
RECENT RESULTS (7/10)

Reciprocity

The transmitter leads the system design whenever the system capacity is known, but this is not the case in IC.

The optimal rx leads the design

"Due to reciprocity, the signalling dimensions along which a receiving node sees the least interference from other users are also the same signalling dimensions along which this node will cause the least interference to other nodes in the reciprocal network where all tx and rx switch roles"



RECENT RESULTS (8/10)

Ex: K=2 MISO

The channel is defined as:

$$y_1 = \boldsymbol{h}_{12}^H \boldsymbol{x}_2 + \boldsymbol{h}_{11}^H \boldsymbol{x}_1 + w_1$$
$$y_2 = \boldsymbol{h}_{21}^H \boldsymbol{x}_1 + \boldsymbol{h}_{22}^H \boldsymbol{x}_2 + w_2$$

Reciprocal channel:

$$\boldsymbol{y}_1^R = \boldsymbol{h}_{12}^R x_2 + \boldsymbol{h}_{11}^R x_1 + \boldsymbol{w}_1^R$$
$$\boldsymbol{y}_2^R = \boldsymbol{h}_{21}^R x_1 + \boldsymbol{h}_{22}^R x_2 + \boldsymbol{w}_2^R$$

Where $\boldsymbol{h}_{12}^R = \boldsymbol{h}_{21}^*$

$\boldsymbol{h}_{21}^R = \boldsymbol{h}_{12}^*$

RECENT RESULTS (9/10)

Algorithm [Jafar08]: we write it explicitely for the MISO case

-In the reciprocal network, compute the receive filters $\boldsymbol{a}_1^R$ such that $SINR_i^R$ is max

$$SNIR_i^R = \frac{\left|\boldsymbol{a}_i^{RH} \boldsymbol{h}_{ii} b_i^R\right|^2}{\boldsymbol{a}_i^{RH}\left(\sum_{j \neq i}\left|\boldsymbol{h}_{ji}^H b_i^R\right|^2 + \sigma^2 \boldsymbol{I}\right)\boldsymbol{a}_i^R} \quad \forall i$$

-Reverse the comm. direction and use the rx combining vectors as precoding vectors

$$\boldsymbol{a}_1^R = \boldsymbol{b}_1^H$$

-Repeat until convergence (although convergence is not guaranteed)

Note that

$$SNIR_i^R = \frac{\left|a_i^* \boldsymbol{h}_{ii}^H \boldsymbol{b}_i\right|^2}{\sum_{j \neq i}\left|a_j^* \boldsymbol{h}_{ji}^H \boldsymbol{b}_i\right|^2 + \sigma^2} \quad \forall i$$

$$p_i \boldsymbol{h}_{ii} \boldsymbol{h}_{ii}^H \boldsymbol{b}_i = \lambda_{\max}\left(\sum_{j \neq i} p_j \boldsymbol{h}_{ji} \boldsymbol{h}_{ji}^H + \sigma^2 I\right)\boldsymbol{b}_i$$

Power or j

RECENT RESULTS (10/10)

$$SNIR_i^R = \frac{\left|a_i^* \boldsymbol{h}_{ii}^H \boldsymbol{b}_i\right|^2}{\sum_{j \neq i} \left|a_j^* \boldsymbol{h}_{ji}^H \boldsymbol{b}_i\right|^2 + \sigma^2}$$

$$p_i \boldsymbol{h}_{ii} \boldsymbol{h}_{ii}^H \boldsymbol{b}_i = \lambda_{\max} \left(\sum_{j \neq i} p_j \boldsymbol{h}_{ji} \boldsymbol{h}_{ji}^H + \sigma^2 I \right) \boldsymbol{b}_i$$

Non self-contained
(but useful if Tx j does not tx)

$$SNIR_i^{virtual} = \frac{p_i \left|\boldsymbol{h}_{ii}^H \boldsymbol{b}_i\right|^2}{\sum_{j \neq i} p_i \left|\boldsymbol{h}_{ji}^H \boldsymbol{b}_i\right|^2 + \sigma^2}$$

$$\left|\boldsymbol{b}_i\right| = 1$$

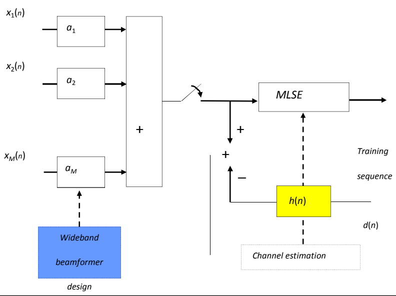
$$p_i \boldsymbol{h}_{ii} \boldsymbol{h}_{ii}^H \boldsymbol{b}_i = \lambda_{\max} \left(p_i \sum_{j \neq i} \boldsymbol{h}_{ji} \boldsymbol{h}_{ji}^H + \sigma^2 I \right) \boldsymbol{b}_i$$

Self-contained

Eigenbeamforming

EIGENBEAMFORMING (1/5)

- **The receiver leads the design and by reciprocity the transmitter is obtained**
- Sequence detectors (Viterbi decoder):
  - Become quite complex when using spatial diversity at the receiver: vector sequence detectors
  - Degrade performance if there is co-channel interference
  - Degrade performance due to late arrivals above their length



MDIR receiver

The **beamformer** removes or properly attenuates co-channel interference and late arrivals

h(n) is the **DIR** (Direct Impulse Response) and emulates the channel from transmitter to beamformer output

EIGENBEAMFORMING (2/5)

Signal model: $\boldsymbol{x}_n = \boldsymbol{G}d_n + \boldsymbol{i}_n + \boldsymbol{w}_n$

ML detection: No MMSE

$$\Lambda = (\boldsymbol{x}_n - \boldsymbol{G}d_n)^H \boldsymbol{R}^{-1} (\boldsymbol{x}_n - \boldsymbol{G}d_n) = \left|\boldsymbol{R}^{-1/2}\boldsymbol{x}_n - \boldsymbol{R}^{-1/2}\boldsymbol{G}d_n\right|^2$$
$$= \left|\boldsymbol{A}^H \boldsymbol{x}_n - \boldsymbol{B}d_n\right|^2$$

$\boldsymbol{A}: receiver \quad \boldsymbol{B}: DIR$

A) No dispersive channel (LOS): $\boldsymbol{G}d_n = \boldsymbol{s}_d d_n \qquad \boldsymbol{R}_D = p_d \boldsymbol{s}_d \boldsymbol{s}_d^H$

$$\Lambda = \left|\boldsymbol{a}^H \boldsymbol{x}_n - g(0)d_n\right|^2$$
$$= \left|\boldsymbol{a}^H (\boldsymbol{x}_n - \boldsymbol{s}_d d_n)\right|^2$$

$\min_a \boldsymbol{a}^H (\boldsymbol{R}_I + \sigma^2 \boldsymbol{I})\boldsymbol{a}$

$s.t. \quad const. --->$

- AGCr: $\boldsymbol{a}^H \boldsymbol{R}_D \boldsymbol{a} = \phi$
- AGCc: $\boldsymbol{a}^H (\boldsymbol{R}_D + \sigma^2 \boldsymbol{I})\boldsymbol{a} = \phi$

The constraint is imposed on the Automatic Gain Control

EIGENBEAMFORMING (3/5)

EIGr:

$$\boldsymbol{R}_D \boldsymbol{a} = \lambda_{max} (\boldsymbol{R}_I + \sigma^2 \boldsymbol{I})\boldsymbol{a}$$

EIGc:

$$(\boldsymbol{R}_D + \sigma^2 \boldsymbol{I})\boldsymbol{a} = \lambda_{max} (\boldsymbol{R}_I + \sigma^2 \boldsymbol{I})\boldsymbol{a}$$

EIGr or max SNIR solution.

If $\boldsymbol{R}_D = p_d \boldsymbol{s}_d \boldsymbol{s}_d^H$ it is also the MMSE solution **?** $\boldsymbol{a} = \alpha \boldsymbol{R}_x^{-1} \mathrm{E}\{\boldsymbol{x}_n d_n^*\}$

It depends on the channel

EIGENBEAMFORMING (3/5)

EIGr or maxSNIR:

$$R_D a = \lambda_{max}\left(R_I + \sigma^2 I\right) a$$

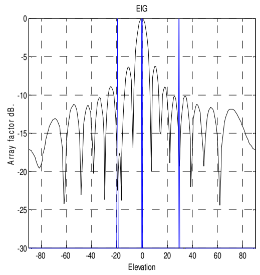
B) Dispersive channel:

DIR: practical receivers use to underestimate the channel length due to complexity of the sequence detector and instability of late multipath (L=5)

For example, in a channel with one echo (i.e. coh. Int.)

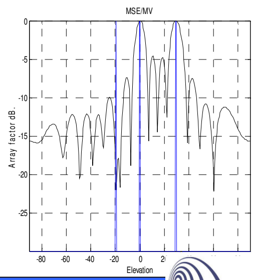
$$x_n = s_{d,n} d_n + s_{d,n-1} d_{n-1} + i_n + w_n$$

{desired in broadside with 10dB, coh.echo at 30º,Interference at -20º and with 0dB}



$$a = \beta\left(R_I + \sigma^2 I\right)^{-1} s_{d,n}$$

$$a = \alpha R_x^{-1}\left(s_{d,n} + s_{d,n-1}\right)$$



DIR length = 1

EIGENBEAMFORMING (4/5)

General NLOS case:

$$G = [G_D \quad G_I]$$

$$G_D = E\{x_n d_n^H\} \qquad R_x = E\{x_n x_n^H\} = G_D . G_D^H + R_I + \sigma^2 I$$

$$R_D = G_D . G_D^H$$

$$R_I = E\{i_n i_n^H\} + G_I . G_I^H$$

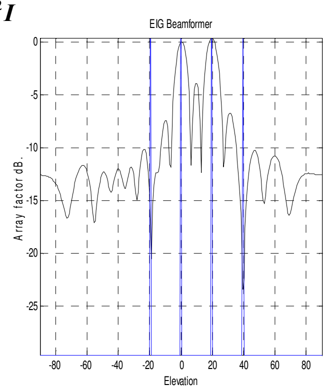
EIGc

$$\min_{a,b} E\left\{\left|a^H x_n - b^H d_n\right|^2\right\}$$

$$s.t. \quad a^H\left(G_D G_D^H + \sigma^2 I\right) a = \phi_o$$

$$b = G_D^H a \quad (DIR)$$

$$\left(G_D G_D^H + \sigma^2 I\right) a = \lambda_{max}\left(R_I + \sigma^2 I\right) a$$



The desired (QPSK modulated) d(n) (10dB.,0º), d(n-1) (10dB,20º) and d(n-2) (10dB.,40º). **DIR of the receiver set with length equal to 2 taps**. Un-coherent interference at -19º and 10 dB.

EIGENBEAMFORMING (5/5)

IMPORTANCE OF THE CONSTRAINT: relationship to IA

In the general multistream (S streams) case and no delay spread

$$\min_A E\left\{\left|A^H\left(x_n - H_d d_n\right)\right|^2\right\} \quad s.t. \quad A^H A = I \quad \Rightarrow \quad A = eig^S_{\min}\left(R_I + \sigma^2 I\right)$$

-This solution effectively tries to align the coordinated interference with the dominant directions of the noise (or uncoordinated interference).

-In particular, if the noise is highly spatially correlated with $R_n = \sigma^2 s_n^H s_n$
This algorithm will attempt to align the interference to $\mathbf{s}_n$ if possible

-In contrast to MMSE the receiver **A** does not counteract the channel distortion

MMSE (1/2)

So far we have seen that EIGr is equivalent to max SNIR
&
The MMSE solution is the max SNIR solution for MISO (non-dispersive), in rx not otherwise:

$$\min_A E\left\{\left|A^H x_n - d_n\right|^2\right\} \quad \Rightarrow \quad A = R_x^{-1}.E\left\{x_n.d_n^H\right\}$$

The problem is that if we incorporate the transmitter constraint

$$s.t. \quad Tr\left(A^H A\right) = 1 \quad \Rightarrow \quad A = \left(\mu I + R_I\right)^{-1} E\left\{x_n.d_n^H\right\}$$

Where μ is the Lagrange multiplier chosen to meet the power constraint

In BC: MMSE IS THE BEST OPTION but maybe is not the most suitable in IC

MMSE has been applied for the IC by [Heath08] using the alternate-maximize procedure

MMSE (2/2)

Other possibility that we propose is to depart from [Palomar 1]: to obtain close form solutions.

For each receiver k: $\boldsymbol{x}_k = \boldsymbol{H}_k \boldsymbol{s}_k + \boldsymbol{n}_k \qquad \boldsymbol{s}_k = \boldsymbol{B}_k \boldsymbol{v}_k$

1.- Receiver design:

$$\boldsymbol{A}_k = \left(\boldsymbol{H}_k \boldsymbol{B}_k \boldsymbol{B}_k^H \boldsymbol{H}_k^H + \boldsymbol{R}_k\right)^{-1} \boldsymbol{H}_k \boldsymbol{B}_k \qquad with \qquad \boldsymbol{R}_k = \sum_{l \neq k} \boldsymbol{H}_l \boldsymbol{B}_l \boldsymbol{B}_l^H \boldsymbol{H}_l^H$$

Associated error:

$$\boldsymbol{E}_k = \left(\boldsymbol{B}_k \boldsymbol{R}_{Hk} \boldsymbol{B}_k^H + \boldsymbol{I}\right)^{-1} \boldsymbol{H}_k \boldsymbol{B}_k \qquad with \qquad \boldsymbol{R}_{Hk} = \boldsymbol{H}_k \boldsymbol{R}_{nk}^{-1} \boldsymbol{H}_k^H$$

2.- Transmitter design based on different strategies:

$$\min_{\boldsymbol{B}_k} f_o\left(\left\{\left(\boldsymbol{B}_k \boldsymbol{R}_{Hk} \boldsymbol{B}_k^H + \boldsymbol{I}\right)^{-1}\right\}_{ii}\right)$$

$$s.t. \quad Tr\left(\boldsymbol{B}_k \boldsymbol{B}_k^H\right) \leq P_k \qquad \forall k$$

$f_o(.)$: Schur-concave function (arithmetic SINR mean, geometric SNIR mean, mutual info,…) or
Schur-convex (harmonic SNIR mean, max SINR, arithm. BER mean…)

In [Palomar 2] game theory is used to maximize sum rate with ZF constraints

CONCLUSIONS

CRITERIA

- SNIR
  - Reciprocity: non self-contained
  - Virtual: self-contained

Which is better?

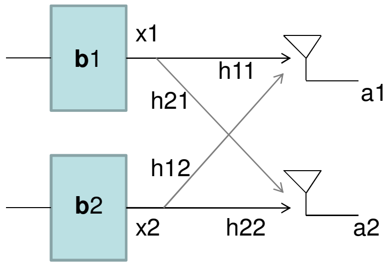
- MMSE
  - Equivalent design to maxSNIR only in MISO (LOS) and rx
  - Similar performance to maxSNIR in MIMO
- **EIG**
  - CAGr: equivalent design to maxSNIR
  - **CAGc**: NEW design (self-contained or not), from MDIR&reciprocity

TWO USER MISO IC (1/5)

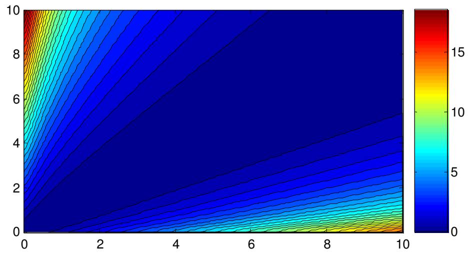
By applying reciprocity to the EIGc

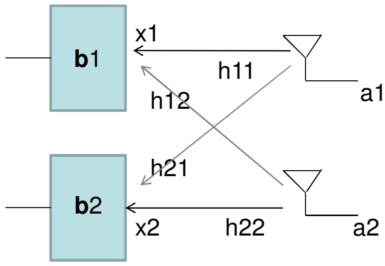
$$\left(p_1 \boldsymbol{h}_{11}\boldsymbol{h}_{11}^H + \boldsymbol{I}\right)\boldsymbol{b}_1 = \lambda_{\max}\left(p_2 \boldsymbol{h}_{21}\boldsymbol{h}_{21}^H + \boldsymbol{I}\right)\boldsymbol{b}_1 \qquad \boldsymbol{q}_1 = \frac{\boldsymbol{b}_1}{|\boldsymbol{b}_1|}$$

$$\left(p_2 \boldsymbol{h}_{22}\boldsymbol{h}_{22}^H + \boldsymbol{I}\right)\boldsymbol{b}_2 = \lambda_{\max}\left(p_1 \boldsymbol{h}_{12}\boldsymbol{h}_{12}^H + \boldsymbol{I}\right)\boldsymbol{b}_2 \qquad \boldsymbol{q}_2 = \frac{\boldsymbol{b}_2}{|\boldsymbol{b}_2|}$$



It is better than a self-contained design





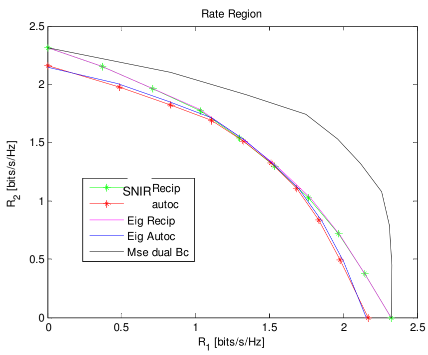
$(SNR1+SNR2)_{EIGc}$-$(SNR1+SNR2)_{EIGc\_SC}$

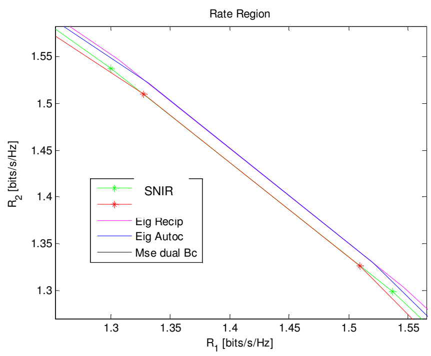
2 users, MISO with varying power. 500 Monte Carlo runs of the Rayleigh channel

25

TWO USER MISO IC (2/5)

2 users

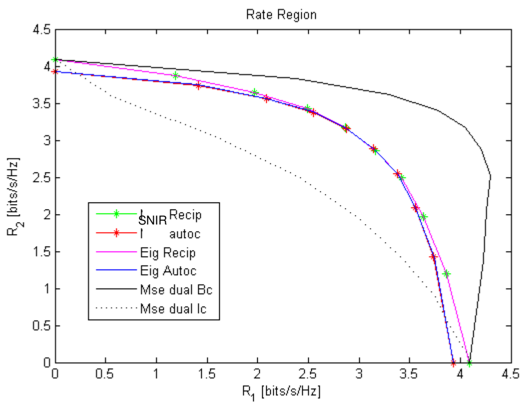




Total energy equal to 0 dB, 4 antenna. 10000 Monte Carlo Runs

Results:
- the reciprocity opens the rate region
- EIGc: improves with respect to EIGr or masSNIR
- If energy in increased, the same results keep
- the more antennas: the less the difference

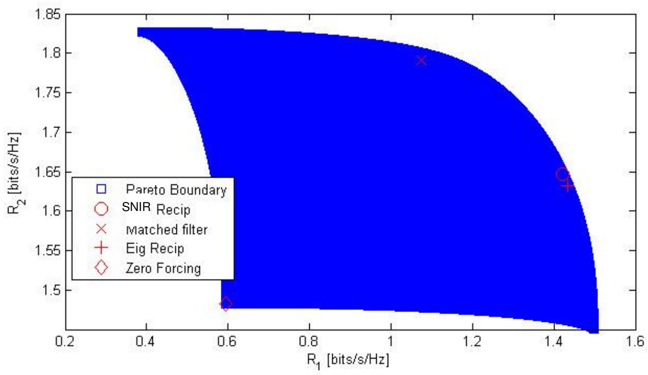
TWO USER MISO IC (3/5)



Total energy equal to 5 dB. 10000 Monte Carlo Runs

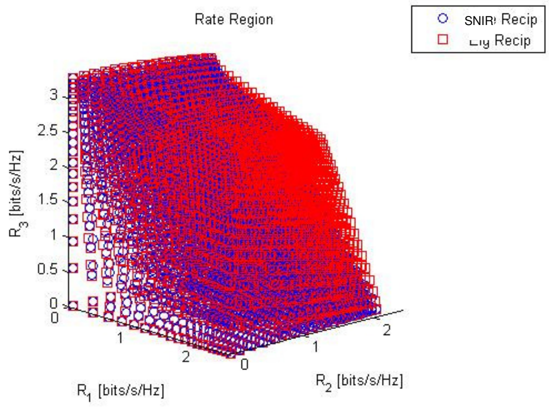
TWO USER MISO IC (4/5)

SNR = 0db, 1 Rayleigh channel realization.
2 antenna, p1 = 0dB y p2 = 0dB.



TWO USER MISO IC (5/5)

3 users



Total energy equal to 6 dB: p1, p2 y p3 en [0, pt/3]. , 1 realization

TWO USER MISO BC (1/3)

$$\boldsymbol{HB} = \begin{bmatrix} \boldsymbol{h}_1^H \\ \boldsymbol{h}_2^H \end{bmatrix} \begin{bmatrix} \boldsymbol{q}_1 & \boldsymbol{q}_2 \end{bmatrix} = \begin{bmatrix} r11 & r12 \\ r21 & r22 \end{bmatrix}$$

$$snr1 = \frac{r11}{1+r12} = \frac{\left|\boldsymbol{q}_1^H \boldsymbol{h}_1\right|^2 E_1}{1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_1\right|^2 E_2}$$

$$r1 = \log 2(1+snr1)$$

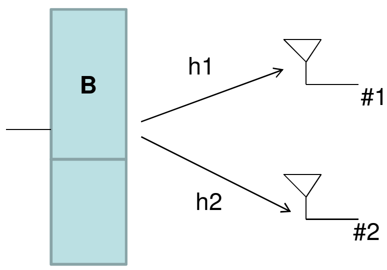
$$snr2 = r22 = \left|\boldsymbol{q}_2^H \boldsymbol{h}_2\right|^2 E_2$$

$$r2 = \log 2(1+snr2)$$

$$(1+snr1)(1+snr2) = \left(1+\frac{r11}{1+r12}\right)(1+r22) =$$

$$= \left(1+\frac{\left|\boldsymbol{q}_1^H \boldsymbol{h}_1\right|^2 p_1}{1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_1\right|^2 p_2}\right)\left(1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_2\right|^2 p_2\right) =$$

$$= \left(1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_1\right|^2 p_2 + \left|\boldsymbol{q}_1^H \boldsymbol{h}_1\right|^2 p_1\right)\left(\frac{1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_2\right|^2 p_2}{1+\left|\boldsymbol{q}_2^H \boldsymbol{h}_1\right|^2 p_2}\right)$$



$MSE \quad BC \quad (optimal \quad by \quad duality)$

$$\boldsymbol{q}_1 = \frac{\boldsymbol{h}_1}{\left|\boldsymbol{h}_1\right|}\left(1+\left|\boldsymbol{h}_1^H \boldsymbol{q}_2\right|^2\right)^{1/2}\sqrt{p_1}$$

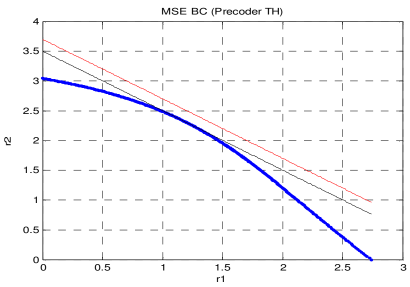
$$\boldsymbol{q}_2 = \left(I+\boldsymbol{h}_1\boldsymbol{h}_1^H p_1\right)^{-1}\boldsymbol{h}_2\left(\frac{\sqrt{p_2}}{\left|\left(I+\boldsymbol{h}_1\boldsymbol{h}_1^H p_1\right)\boldsymbol{h}_2\right|}\right)$$

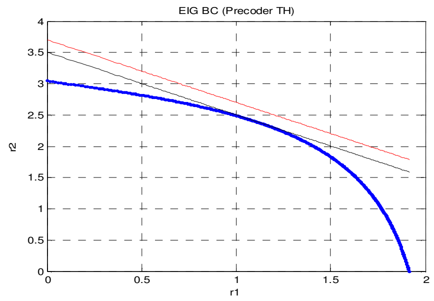
EIG_BC Power loading?

$$\boldsymbol{q}_1 = \frac{\boldsymbol{h}_1}{\left|\boldsymbol{h}_1\right|}$$

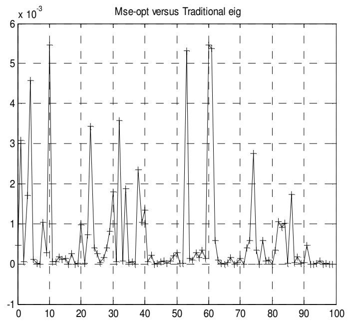
$$\left(I+p_2\boldsymbol{h}_2\boldsymbol{h}_2^H\right)\boldsymbol{q}_2 = \lambda_{\max}\left(I+p_2\boldsymbol{h}_1\boldsymbol{h}_1^H\right)\boldsymbol{q}_2 \qquad \boldsymbol{q}_{2EIG} = \frac{\boldsymbol{q}_2}{\left|\boldsymbol{q}_2\right|}$$

TWO USER MISO BC (2/3)



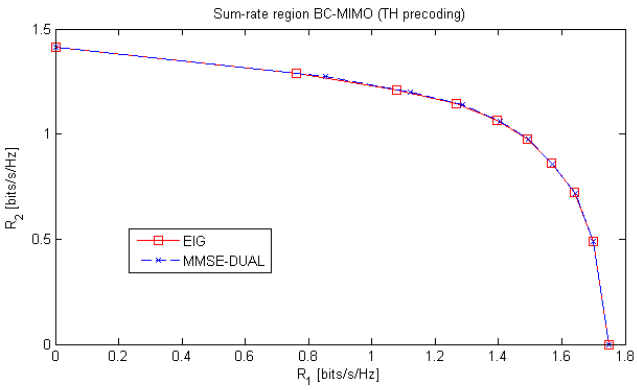


1 Rayleigh realization



100 Rayleigh MR

TWO USER MISO BC (3/3)



10000 Rayleigh realization

DISCUSSION ON DIRECTIVITY(1/3)

Directivity

Effective area

$$D(s_d) = \frac{q^H (s_d s_d^H) q}{|q|^2} (4\pi r^2)$$

The transmitter design can be conceived as a problem of directivity maximization

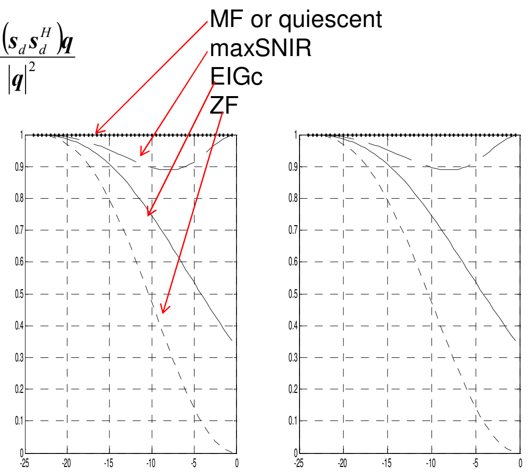
To extend it to incorporate: NLOS channel and behaviour in front ot interference

$$A_e(R_D) = \alpha_1 \frac{trace(R_D) + \sigma^2 |q|^2}{trace(R_Y) + \sigma_Y^2 |q|^2} \Rightarrow A_e(R_D) = \alpha_2 \frac{trace(R_D) + |q|^2}{trace(R_Y) + |q|^2}$$

$$\left(H_{TD}^H H_{TD} + \sigma^2 I\right) q = \lambda_{MAX} \left(H_{TY}^H H_{TY} + \sigma_Y^2 . I\right) q$$

DISCUSSION ON DIRECTIVITY(2/3)

$$A_{ef}(s_d) = \frac{q^H (s_d s_d^H) q}{|q|^2}$$

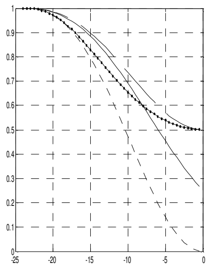


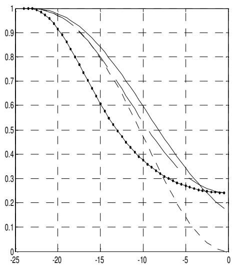
P P'

5 antenna, desired rx at broadside, interferred from -25º(orth.) on…

DISCUSSION ON DIRECTIVITY(3/3)

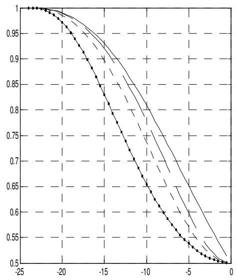
$$A_{ef}(s_d)=\frac{q^H\left(s_d s_d^H\right)q}{q^H R_{YT} q+|q|^2}$$

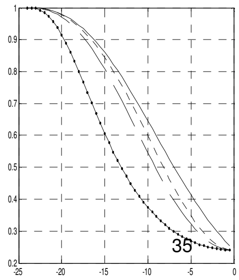




$$A_{ef}(s_d)=\frac{1}{1+P_T}\,\frac{P_T\left|q^H s_d\right|+|q|^2}{P_T\left|q^H s_T\right|+|q|^2}$$

5 antenna





35

CONCLUSIONS (I)

- EIGc is a practical design able to manage full coherent arrivals to an aperture both in order to remove selective fading at the beamformer output, as well as to properly match the expectation of a sequence detector in terms of accepting early arrivals and properly remove late arrivals which produce residual ISI degrading the performance of the sequence detector.

The performance of the EIG beamforming is shown in a BC multiuser scenario with implementation advantages over optimum MSE

-The extension of the versatility and performance of the new beamformer to broadcast scenarios BC as well as to the so-called interference channel IC

-By applying reciprocity heterogenous terminals can be dealt with

-Other focus?

- **Are iterative solutions ever useful?**

DISCUSSION ON APPLICATIONS

That may raise specific issues to answer

MULTICELL NETWORKS
Inter-cell interference:
whenever the goal is to increase system rate: frequency is reused among cell sectors or even cells, spatial dimension is used to diminish Interference. Competing BS rather than Cooperative ones: attempt to serve a separate user each despite the interference generated by the others
Feedback channel is an issue: low CSIT available

COGNITIVE RADIO
Diminish interference towards primary user and increase sum rate [Palomar10]

SECURE PHY
Note that: $C = \log\left|1 + \boldsymbol{q}^H \boldsymbol{R}_D \boldsymbol{q}\right| - \log\left|1 + \boldsymbol{q}^H \boldsymbol{R}_E \boldsymbol{q}\right|$

is solved by the EIGc (self-contained)

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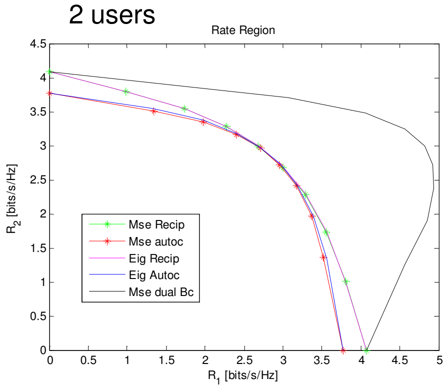
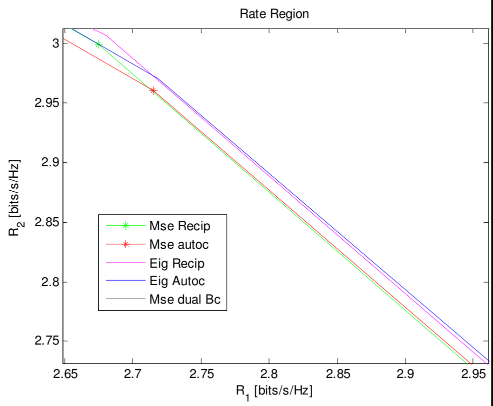
Thank you !

Questions?

TWO USER MISO IC (3/6)

2 users

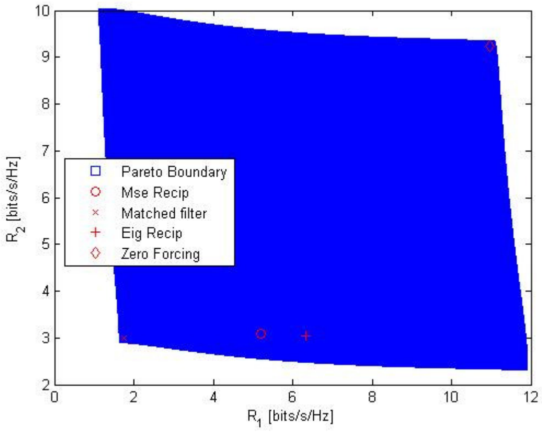




Total energy equal to 5 dB. 10000 Monte Carlo Runs

TWO USER MISO IC (6/7)

SNR = 30db, 1 Rayleigh channel realization. 2 antenna, p1,p2=[0,15] dB



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