Coordination on the MISO Interference Channel Using the Virtual SINR Framework

Randa Zakhour David Gesbert

Mobile Communications Department
EURECOM

Workshop on Smart Antennas (WSA)
17-18 Feb. 2009

Outline

Motivation

Cooperation in multi-cell/link systems

MISO IC

System Model and Performance Measures

Virtual SINR Framework

Definition

Two link case

Proposed Algorithm

Numerical Results

EURECOM
Sophia Antipolis

Outline

Motivation

- Cooperation in multi-cell/link systems
- MISO IC

System Model and Performance Measures

Virtual SINR Framework

- Definition
- Two link case

Proposed Algorithm

Numerical Results

Outline

Motivation
- Cooperation in multi-cell/link systems
- MISO IC

System Model and Performance Measures

Virtual SINR Framework
- Definition
- Two link case

Proposed Algorithm

Numerical Results

Outline

Motivation
- Cooperation in multi-cell/link systems
- MISO IC

System Model and Performance Measures

Virtual SINR Framework
- Definition
- Two link case

Proposed Algorithm

Numerical Results

Outline

EURECOM

Sophia Antipolis

Outline

Motivation

Cooperation in multi-cell/link systems

MISO IC

System Model and Performance Measures

Virtual SINR Framework

Definition

Two link case

Proposed Algorithm

Numerical Results

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

EURECOM Sophia Antipolis

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

EURECOM
Sophia Antipolis

Why Cooperate?

- In cellular systems, *reuse 1* considered for increased spectral efficiency.
- But cells are not isolated.

$\Rightarrow$ INTERFERENCE!

- Hence, interest in cooperative schemes:
  1. Network MIMO
  2. Interference Avoidance

Outline

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \dots, K$$

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \ldots, K$$

EURECOM

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \ldots, K$$

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \ldots, K$$

EURECOM Sophia Antipolis

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \ldots, K$$

Scenario considered

Cooperation Issues:

- Data sharing
- Channel state information (CSI) sharing

We consider:

- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \dots, K$$

EURECOM Sophia Antipolis

Scenario considered

Cooperation Issues:

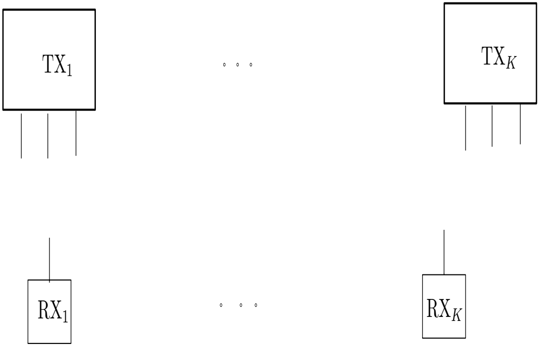
- Data sharing
- Channel state information (CSI) sharing

We consider:

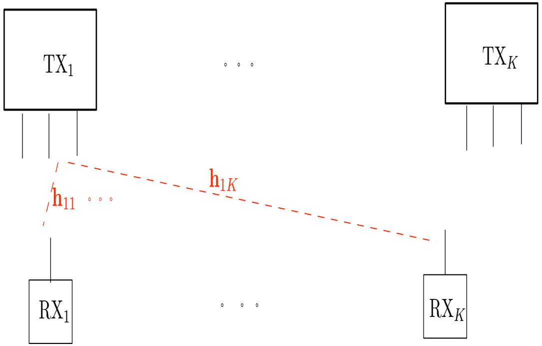
- MISO interference channel (IC)
- local channel information
  - Transmitter k knows:

$$\mathbf{h}_{ki}, i = 1, \ldots, K$$

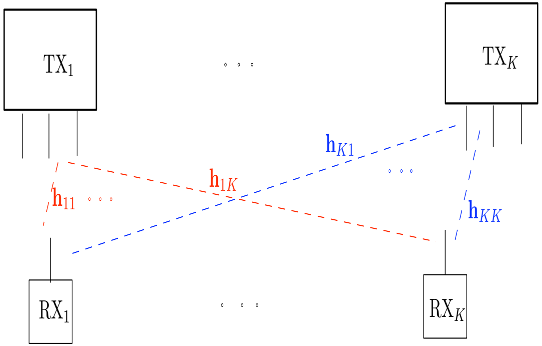
System Model



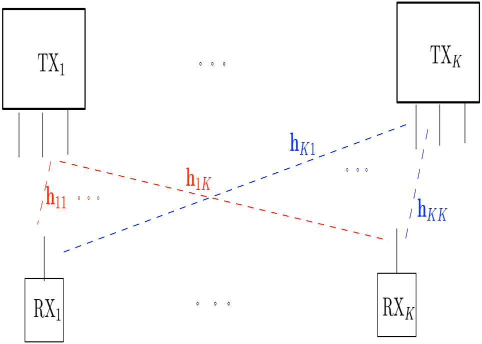
System Model



System Model



System Model



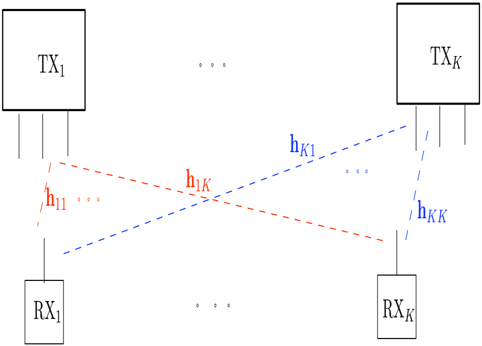
- Linear precoding at each TX:

$$\mathbf{x}_k = \sqrt{p_k}\mathbf{w}_k s_k,$$
$$\text{s.t. } \|\mathbf{w}_k\| = 1, p_k \le P$$

- Single user decoding at each RX:

$$\gamma_k = \frac{p_k|\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j\neq k} p_j|\mathbf{h}_{jk}\mathbf{w}_j|^2}$$

System Model



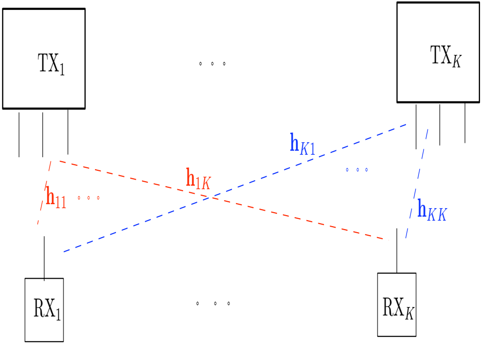
- Linear precoding at each TX:

$$\mathbf{x}_k = \sqrt{p_k}\mathbf{w}_k s_k,$$
$$\text{s.t. } \|\mathbf{w}_k\| = 1, p_k \leq P$$

- Single user decoding at each RX:

$$\gamma_k = \frac{p_k |\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j\neq k} p_j |\mathbf{h}_{jk}\mathbf{w}_j|^2}$$

System Model



How to distributedly design the $\mathbf{w}_k$?

- Linear precoding at each TX:

$$\mathbf{x}_k = \sqrt{p_k}\mathbf{w}_k s_k,$$
$$\text{s.t. } \|\mathbf{w}_k\| = 1, p_k \le P$$

- Single user decoding at each RX:

$$\gamma_k = \frac{p_k|\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j\neq k} p_j|\mathbf{h}_{jk}\mathbf{w}_j|^2}$$

Performance Measures

The rate region $\mathcal{R}$ is defined as the set of rates that may be achieved simultaneously at the different base stations, given the power constraints at each base station. I.e.:

$$\mathcal{R} = \{(R_1, \ldots, R_K) \in \mathbb{R}_+^K \\ | R_k = \log_2(1 + \gamma_k), p_k \leq P \forall k \in \{1, \ldots, K\}\} \quad (1)$$

Its boundary is the set of Pareto optimal rate-tuples: one cannot increase any R_k without decreasing at least one of the other rates.

The higher the sum rate, the better. Being close to the Pareto boundary is also desirable.

Performance Measures

The rate region $\mathcal{R}$ is defined as the set of rates that may be achieved simultaneously at the different base stations, given the power constraints at each base station. I.e.:

$$\mathcal{R} = \{(R_1, \ldots, R_K) \in \mathbb{R}_+^K \\ | R_k = \log_2(1 + \gamma_k), p_k \leq P \forall k \in \{1, \ldots, K\}\} \quad (1)$$

Its boundary is the set of Pareto optimal rate-tuples: one cannot increase any R_k without decreasing at least one of the other rates.

The higher the sum rate, the better. Being close to the Pareto boundary is also desirable.

EURECOM
Sophia Antipolis

Performance Measures

The rate region $\mathcal{R}$ is defined as the set of rates that may be achieved simultaneously at the different base stations, given the power constraints at each base station. I.e.:

$$\mathcal{R} = \{(R_1, \ldots, R_K) \in \mathbb{R}_+^K \\ |R_k = \log_2(1 + \gamma_k), p_k \leq P \forall k \in \{1, \ldots, K\}\} \quad (1)$$

Its boundary is the set of Pareto optimal rate-tuples: one cannot increase any R_k without decreasing at least one of the other rates.

The higher the sum rate, the better. Being close to the Pareto boundary is also desirable.

Outline

Virtual SINR

Definition

- General form:

$$\gamma_k^{virtual} = \frac{p_k |\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j \neq k} \alpha_{kj} p_k |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (2)$$

  where $\alpha_{kj} \in \mathbb{R}_+, j, k = 1, \ldots, K$ are a given set of weights.
- Ratio of useful power generated to sum of noise plus weighted sum of interference caused.
- Specialization to full-power use:

$$\gamma_k^{virtual} = \frac{|\mathbf{h}_{kk}\mathbf{w}_k|^2}{\frac{1}{\rho} + \sum_{j \neq k} \alpha_{kj} |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (3)$$

  where $\rho = \frac{P}{\sigma^2}$.

Virtual SINR

Definition

- General form:

$$\gamma_k^{virtual} = \frac{p_k |\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j\neq k} \alpha_{kj} p_k |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (2)$$

  where $\alpha_{kj} \in \mathbb{R}_+, j, k = 1, \ldots, K$ are a given set of weights.
- Ratio of useful power generated to sum of noise plus weighted sum of interference caused.
- Specialization to full-power use:

$$\gamma_k^{virtual} = \frac{|\mathbf{h}_{kk}\mathbf{w}_k|^2}{\frac{1}{\rho} + \sum_{j\neq k} \alpha_{kj} |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (3)$$

  where $\rho = \frac{P}{\sigma^2}$.

Virtual SINR

Definition

- General form:

$$\gamma_k^{virtual} = \frac{p_k |\mathbf{h}_{kk}\mathbf{w}_k|^2}{\sigma^2 + \sum_{j \neq k} \alpha_{kj} p_k |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (2)$$

  where $\alpha_{kj} \in \mathbb{R}_+, j, k = 1, \ldots, K$ are a given set of weights.
- Ratio of useful power generated to sum of noise plus weighted sum of interference caused.
- Specialization to full-power use:

$$\gamma_k^{virtual} = \frac{|\mathbf{h}_{kk}\mathbf{w}_k|^2}{\frac{1}{\rho} + \sum_{j \neq k} \alpha_{kj} |\mathbf{h}_{kj}\mathbf{w}_k|^2}, \quad (3)$$

  where $\rho = \frac{P}{\sigma^2}$.

Outline

Motivation

- Cooperation in multi-cell/link systems
- MISO IC

System Model and Performance Measures

Virtual SINR Framework

- Definition
- Two link case

Proposed Algorithm

Numerical Results

Results from the Two-link case

Theorems

Theorem

Any point on the Pareto boundary may be attained by solving the virtual SINR optimization problem with full power use, for an appropriate choice of $\alpha_{12}, \alpha_{21} \in \mathbb{R}_+$.

Theorem

The rate pair obtained by using virtual SINR maximizing beamformers with $\alpha_{12} = \alpha_{21} = 1$ *lies on the Pareto boundary of the two-link rate region.*

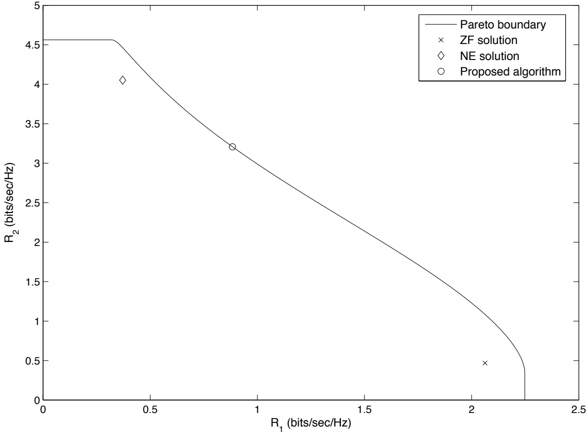
Theorem

Any point on the Pareto boundary may be attained by solving the virtual SINR optimization problem with full power use, for an appropriate choice of $\alpha_{12}, \alpha_{21} \in \mathbb{R}_+$.

Theorem

The rate pair obtained by using virtual SINR maximizing beamformers with $\alpha_{12} = \alpha_{21} = 1$ *lies on the Pareto boundary of the two-link rate region.*

Results from the Two-link case
Illustration



EURECOM
Sophia Antipolis

Proposed Algorithm

- Always use full power (this is also optimal for the multi-link case provided $N_t \geq K$): $p_k = P, \forall k = 1, \ldots, K$.
- Design beamforming vectors as the solutions to the following virtual SINR maximization problem:

$$\mathbf{w}_k = \arg \max_{\|\mathbf{w}\|^2=1} \frac{|\mathbf{h}_{kk}\mathbf{w}|^2}{\frac{1}{\rho} + \sum_{j \neq k} |\mathbf{h}_{kj}\mathbf{w}|^2}. \quad (4)$$

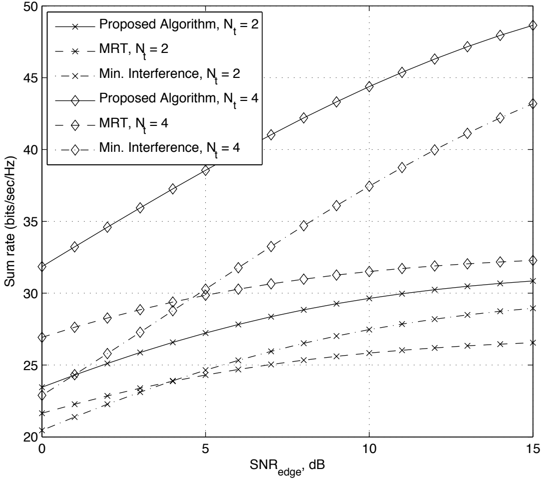
Proposed Algorithm

- Always use full power (this is also optimal for the multi-link case provided $N_t \geq K$): $p_k = P, \forall k = 1, \ldots, K$.
- Design beamforming vectors as the solutions to the following virtual SINR maximization problem:

$$\mathbf{w}_k = \arg \max_{\|\mathbf{w}\|^2=1} \frac{|\mathbf{h}_{kk}\mathbf{w}|^2}{\frac{1}{\rho} + \sum_{j \neq k} |\mathbf{h}_{kj}\mathbf{w}|^2}. \quad (4)$$

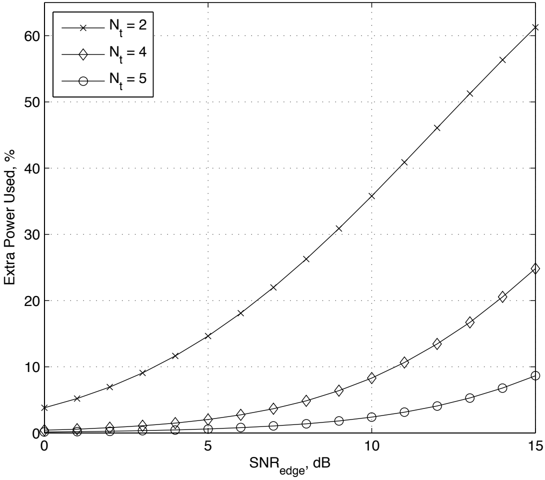
Numerical Results
Sum rate

For 7 cells and a channel model including path loss, lognormal slow fading and Rayleigh fast fading:



EURECOM Sophia Antipolis

Numerical Results For 7 cells and a channel model including path loss, lognormal slow fading and Rayleigh fast fading:



Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Conclusion

- A distributed algorithm for beamforming on the MISO IC was proposed.
- Its optimality was illustrated for the two-link case, in terms of achieving rates on the Pareto boundary.
- Simulation results illustrate that gains are achieved in the more general case as well.

- Outlook
  - Different models of local CSI could be considered.
  - A more general model of cooperation could be looked at under different CSI conditions.

Thank You! Questions?