Partial Feedback-Based Opportunistic Scheduling

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Partial Feedback-Based Opportunistic Scheduling
Cross-Layer Design for resource allocation

We consider a network of $N$ independent users communicating with a single access point.

- Resource allocation is done at LINK/MAC layer.
- Goal of cross-layer R.A. is optimal assignment of resource (power, time, frequency, codes) given channel state information and given certain constraints (e.g. QoS, max power).

Two schools of thought:
- Information theory
- Queuing theory
Establishing multiuser capacity regions (for MAC and BC)

Devising R.A. schemes allowing to reach certain points of the CR

For instance, the sum capacity point.

Developing multiuser capacity regions (for MAC and BC)

Sum capacity is achieved by Dirty Paper Coding [Costa].

\[
\sum_{i} \log_{2} \left( \frac{P}{\text{tr}(Q_i) + \text{tr}(H_i^H H_i)} \right) = \text{sum \ capacity}
\]

where \( H_i \) is channel matrix of user \( i \), \( Q_i \) is total TX power, \( P \) is total TX power of user \( i \), \( \text{tr}(\cdot) \) is transmit covariance of user \( i \), is channel matrix of user \( i \), \( P \) is total TX power, and \( Q_i \) is transmit covariance of user \( i \).

Sum capacity of the multiuser MIMO downlink [Caire03][Vishwanath03][Yu03]:

\[
\text{Sum capacity of the multiuser MIMO downlink}\]

Multiuser Information Theory
Consider a network with users, exhibiting independent channels. Establishing the multiple-access stability region. For instance, the optimal throughput under stability point. Devising R.A. schemes allowing to reach certain point within the SR. The set of arrival rates for which there exists a resource allocation policy that keep all queue lengths stable. $\{(\tau)^n\}$ The strong connections between capacity and stability region. For example, the optimal throughput under stability point. Devising R.A. schemes allowing to reach certain point within the SR. For instance, the optimal throughput under stability point. Devising R.A. schemes allowing to reach certain point within the SR. The set of arrival rates for which there exists a resource allocation policy that keep all queue lengths stable. $\{(\tau)^n\}$ The strong connections between capacity and stability region. For example, the optimal throughput under stability point. Devising R.A. schemes allowing to reach certain point within the SR. For instance, the optimal throughput under stability point. Devising R.A. schemes allowing to reach certain point within the SR. The set of arrival rates for which there exists a resource allocation policy that keep all queue lengths stable. $\{(\tau)^n\}$
A few (of the many) critical issues

- Using multiple antennas in the right way (to avoid channel hardening)
- Improving on fairness/performance trade-off
- Multi-user resource allocation heavily relies on good feedback design in MISO/MIMO case
- Information theory advocates NON orthogonal access (unlike TDMA, CDMA)

Channel dependent scheduling
Primary concerns

- Minimizing the load (hard to send full CSI of all users)
- Guaranteeing high quality of feedback (despite delays)
- Defining proper metrics for MIMO case (SNR not sufficient)

On Feedback Design
TDMA is optimal if BTS has one antenna only.

If multiple antennas at BTS, TDMA scheduling capacity is degraded [ISITA04].

Selective multiuser diversity idea can be used (extension to SDMA case).

Blind multi-user beamforming (Hassibi03)

Solutions:

Feedback requirements can be heavy!

Capacity achieving is TD+SDMA like (not TDMA like)?

If multiple antennas at BTS, TDMA scheduling capacity is degraded [ISITA04].

TDMA is optimal if BTS has one antenna only.

The multiple antenna case
With full feedback (antennas at BTS, single antenna at mobiles):

Achieved by superposition coding

\[ N \log \log N \approx W \sum_{i=1}^{N} C \]

With full feedback (N antennas at BTS, single antenna at mobiles):

MISO Broadcast Sum Capacity
A low feedback, low complexity multi-user scheduler is obtained from:

\[ H \]

SR is the rate summed over the users pointed by the scheduling vector.

\[ \max_{\mathcal{U}} \left\{ \left( H, \mathcal{S} \right) \right\} \]

A low feedback, low complexity multi-user scheduler is obtained from:

Opportunistic Unitary Beamforming
Opportunistic multi-user beamforming (1)
Oppportunistic multi-user beamforming (2)
At time slot $t$ the transmitted signal is

(2) \[ (f)_{t}^w s_{t}^w \sum_{i=1}^{w} = (f)s \]

Received signal is

(3) \[ N' \cdots I = \gamma \sum_{i} + w s_{w}^y H \sum_{i=1}^{w} = \gamma f \]

SINR calculation:

(4) \[ \frac{I_{dB}^y H \sum_{i=1}^{w} + y d/I}{I_{dB}^y H} = w \gamma H N I S \]

Sum rate performance:

$$\left\{ \frac{w y H N I S}{\log_{2}(1+\gamma I_{dB}^y H \sum_{i=1}^{w})} \left( \sum_{i=1}^{N' \cdots} \right) \right\} E \approx S N R$$
For very large number of users:

\[ A \frac{F}{B} \]

The sum rate converges to \( A \frac{F}{B} \) with \( n \) users.

For sparse networks (low number of users):

Blind beamformer does not reach \( A \frac{F}{B} \) nor \( \sum_n \).

Severe degradation

The scaling laws of \( A \frac{F}{B} \) and \( \sum_n \) are identical.

WHAT TO DO?

- Blind beamformer does not reach \( A \frac{F}{B} \) nor \( \sum_n \).
- Severe degradation

For sparse networks (low number of users):

- The scaling laws of \( A \frac{F}{B} \) and \( \sum_n \) are identical.
- F the sum rate converges to \( A \frac{F}{B} \) for very large number of users.

Memory less opportunistic BF performance
Opportunistic beamforming with beam power control (BPC) [SPAWC 2005]

Exploiting channel memory [ISIT 2005]

Robust opportunistic beamforming for Sparse Networks
Random BF might not reach 100% target in a sparse network.

Major source of complexity/feedback is multiuser BF over entire user set.

Refinement can take form of recalculation of optimal BF, or power control over existing BF.

Modest complexity/feedback.

Once user set is decided with $\phi$, MU BF can be refined at the cost of gains.

$\phi$ is good at helping detect linearly separable users, with good channel gains.

Key Ideas:

Opportunistic beamformer with beam power control
We assume the transmitter knows all the SIRs and noise level.

We propose an iterative solution for $N \geq 2$ antennas.

\[
D = \frac{1}{2} \sum_{\ell=1}^{N-1} \sum_{m \neq \ell} D^\ell_m + \sum_{\ell \in I} \log_2 \left( \max_{d} \left| H_{\ell,m}^d \right| \right)
\]

where $H_{\ell,m}^d$ is the SIR of $\ell$th antenna from the $m$th interferer with power control.
Step 1 Calculate $\gamma^b_i$ for $i \in I^b$.

Repeat $n = 1, 2, \ldots$.

Beam power control based on iterative waterfilling.
Here we only use the knowledge of SIR-R based beam power control.

The Beam-on Beam-off (BOBO) algorithm is proposed:

For $N = 2$, we compute $\theta$. If $\theta < \text{threshold}$, then worse beam is turned off (with same total power), otherwise is kept on.
Simulated performance
Simultaneous performance
Simultaneous performance

Number of users

Sum rate (bps/Hz)

- Greedy power allocation
- BOBO scheme f = 0.4
- Random unitary beamforming
Define set of ‘preferred’ unitary beamformers. At each time slot $t$

\[
\begin{bmatrix}
\mathcal{D}^1 & \mathcal{D}^2 & \cdots & \mathcal{D}^S
\end{bmatrix} = \mathcal{O}_{\text{pre}}
\]

with minimum sum rate. Where $\mathcal{O}$ is matrix $\mathcal{O}_{\text{pre}}$, replace $\mathcal{O}$ by $\mathcal{O}_{\text{new}}$.  

Second phase (update of the set)

Select from the set of ‘preferred’ matrices $\mathcal{O}_{\text{pre}}$ such that $\mathcal{O}_{\text{new}}$.  

Generate a new random $\mathcal{O}_{\text{new}}$ with sum rate $\mathcal{O}_{\text{pre}}$.  

memory based opportunistic beamformer
Channel Memory: $[\text{ISIT 05}]$

Asymptotic performance
Simultaneous performance
Simultaneous performance
Simultaneous performance with multiuser PFS

Number of Antennas

Sum Rate

- MOB-PFS
- RBF-PFS
- MOB block fading
- MOB static channel
- MOB- PFS
- RBF
Simulated performance with multiuser PFS
We showed low-feedback techniques for improving robustness based on power control (from fine to coarse depending on feedback).

We treated MISO case. Techniques may be extended and analyzed in multi-user MIMO case.

- Memory

Conclusions