Comparative Study of MIMO-OFDM Uplink Scheduling Criteria

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Introduction: Multiple Input Multiple Output (MIMO) Channels

- A MIMO channel is a wireless link between $M_T$ transmit and $M_R$ receive antennas.
- MIMO channels boost the information capacity of wireless systems by order of magnitude [Telater95][Foschini98].
MIMO Capacity

(a) Complementary CDF at SNR=10dB; Fading Channels Comparisons

(b) Complementary CDF at SNR=10dB for MIMO Channels

(c) Complementary CDF at SNR=10dB; MISO Channels

(d) Complementary CDF at SNR=10dB; SIMO Channels

Doubling number of antennas, doubles the information capacity

Diminishing returns

Good gains but not comparable to MIMO
MIMO Outage Probability

Outage Probability vs SNR for 4 bps/Hz

SNR in dB

Outage Probability

4x4 MIMO
4x1 MISO
1x4 SIMO
1x1 SISO

1x1
4x1
1x4
4x4

6dB
10dB
Introduction: Open Loop MIMO Communication Systems

Open Loop MIMO Communication Systems

Transmit Diversity

- Differential Block Coding [Tar00]
- Block Coding [Ala98][Tar99a]
- Trellis Coding [Tar98]

Spatial Multiplexing

- D-BLAST [Fos96]
- V-BLAST [Wal99]

Diagram:
- STBC $G_f$
- STBC Combiner and Detector
- MIMO Fading Channel
- V-BLAST Detector
- MIMO Fading Channel
Vertical Bell Labs LAYered Space Time (VBLAST) architecture

![Diagram of VBLAST architecture]

- **Null out interfering layers using Zero forcing or MMSE**
- **Detect**
- **Cancel Detected Layers**

**MIMO Fading Channel**

**V-BLAST Detector**

**MIMO Channel Estimation**

**Cancel 0:k-1 Detected symbols**

**Null Out transmitted signals k+1:N_M**

**Detect Signal k**

**Sink**

**Increment k (Detect Next Signal)**
Uplink Scheduling for Multiuser Systems with Spatial Multiplexing

• In a multiuser environment, each user has different channel statistics.

• Scheduling transmission to the user with the best channel condition at each time leads to a form of selection diversity known as multiuser diversity.

• In SISO, MaxSNR scheduling maximizes the capacity of the uplink [Kno95] and downlink [Tse97].
Our focus is on

- Scheduling for uplink MIMO-OFDM system.
- Scheduling and STBC aren’t a good match [Gozali03].
- We focus on scheduling for spatial multiplexing systems selecting a single user at a time and we focus on practical detection algorithms, specifically V-BLAST.
System Model

the received signal for user $k$ and at the $i^{th}$ subcarrier is:

$$y_{k,i} = H_{k,i} x_{k,i} + \eta_{k,i}$$
Scheduling Algorithms

• **Optimal MIMO capacity maximizing scheduler**

\[
\max_{k=1, \ldots, K} \left\{ \min_{i=1, \ldots, N_c} \left\{ \log_2 \left( \det \left( I_{M_R} + \frac{SNR}{M_T} H_{k,i} H_{k,i}^H \right) \right) \right\} \right\}
\]

• **MaxSNR scheduler** selects the user with maximum MIMO channel power

\[
\max_{k=1, \ldots, K} \left\{ \min_{i=1, \ldots, N_c} \left\{ \text{trace} \left( H_{k,i} H_{k,i}^H \right) \right\} \right\}
\]

• **Round robin** scheduling allows each user to transmit in a time-division fashion regardless of their channel condition.
Scheduling Algorithms

• **V-BLAST capacity** maximizing scheduler

V-BLAST capacity is dominated by the weakest layer [Pap02]

\[
C_{VBLAST}^{ZF} = M_T \cdot \min_{i=1,2,K,M_T} \left\{ \log_2 \left( 1 + \frac{\text{SNR}}{M_T \left\| W_{ZF,i} \right\|^2} \right) \right\}
\]

Thus, the scheduler selects the user with

\[
\max_{k=1,\ldots,K} \left\{ \min_{i=1,\ldots,N_c} \left\{ C_{VBLAST}^{ZF} \left( H_{k,i} \right) \right\} \right\}
\]
Scheduling Algorithms

• **MinMaxES**: Minimum Eigenspread

\[
\min_{k=1, \ldots, K} \left\{ \max_{i=1, \ldots, N_c} \left\{ s \left( H_{k,i} H_{k,i}^H \right) \right\} \right\} \text{ where } s \left( H_{k,i} H_{k,i}^H \right) = \lambda_{\text{max}} / \lambda_{\text{min}}
\]

\( \lambda_{\text{max}} \) and \( \lambda_{\text{min}} \) are the largest and smallest eigenvalues of \( H_k H_k^H \)

• **MaxMinSV**: Maximum Minimum Singularvalue

\[
\max_{k=1, \ldots, K} \left\{ \min_{i=1, \ldots, N_c} \left\{ \rho_{\text{min}} \left( H_{k,i} \right) \right\} \right\} \text{ where } \rho_{\text{min}} = \frac{\rho_{\text{max}}}{\sqrt{s}}
\]

\( \rho_{\text{min}} \) is the smallest singularvalue of \( H_{k,i} \)
Advantage of V-BLAST compared to SISO and SIMO systems

10% Outage at 15dB

MaxCapc Scheduling comparison at K=10 Users and at 8bps/Hz
Aggregate OFDM SER of $4 \times 4$ QPSK MIMO-OFDM uplink scheduling at 64 subcarriers and over FSC of length four
Effect of Suboptimal Detection

2x2 MIMO Channels at 15dB

4x4 MIMO Channels at 15dB

Within 1 bps/Hz

Within 2.5 bps/Hz
Scheduling and Fairness Issue

• The greedy algorithm selects the best user irrespective of other users.
• Fairness is considered in this work.
  – Opportunistic Round Robin
  – Proportional Fair

\[ PF(\Psi) = \frac{\Psi}{T_k} \]
Comparison: Greedy vs. ORR and PF

10% outage capacity comparison of Greedy and ORR schedulers over 4x4 MIMO channels and at SNR=15dB

Greedy, PF and ORR at 10 users and over 4x4 MIMO Channels using MaxVBLASTCapc scheduler

Greedy, ORR, and PF comparison at 10 Users, 4x4 QPSK V-BLAST 8bps/Hz
Conclusions

• We presented and compare scheduling algorithms for MIMO-OFDM users based on V-BLAST scheme.
• We showed that scheduling based on maximum MIMO capacity doesn’t work well for V-BLAST systems neither based on Maximum SNR.
• We compared several scheduling algorithms and found that MaxMinSV scheduling performs close to MaxVBLAST capacity scheduler.