A Unified View on the Interplay of Scheduling and MIMO Technologies in Wireless Systems

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Outline

• MIMO antenna systems
  – Deliver diversity gain
  – Deliver multiplexing gain
• Multiuser scheduling systems
  – Deliver multiuser diversity gain
• Interaction of scheduling and MIMO technologies
  – Scheduling + MIMO diversity systems
  – Scheduling + MIMO multiplexing systems
• Some numerical results
• Conclusion
MIMO Antenna Systems

- deliver diversity gain, (max order = \( N_t N_r \))
- deliver multiplexing gain, (max order = \( \min(N_t, N_r) \))
MIMO Diversity Systems

• Rx –
  - SC (Selective Combining), EGC (Equal Gain Combining), MRC (Maximum Ratio Combining), ...
• Tx –
  - ST (Selective Transmission), EGT (Equal Gain Transmission), MRT (Maximum Ratio Transmission), ...
• MIMO
  - ST/SC, MRT/MRC, ST/MRC,
  - STBC (Space Time Block Codes)
MIMO Multiplexing Systems

- **Open-loop**
  - No channel knowledge at Tx

  \[
  C_k = \mathbb{E} \left[ \log \det \left( I + \frac{\rho_k}{n} H_k H_k^\dagger \right) \right] 
  \]

  \[
  = \sum_{i=1}^{n} \mathbb{E} \left[ \log \left( 1 + \frac{\rho_k}{n} \lambda_{k,i} \right) \right] 
  \]

- **Close-loop**
  - Full channel knowledge at Tx -> water-filling policy
  - Partial channel knowledge at Tx
Multiplexing vs Diversity in MIMO system

- Diversity

- Multiplexing
Tradeoff between Coverage and Capacity for MIMO Systems

<table>
<thead>
<tr>
<th>Antenna number</th>
<th>Capacity gain</th>
<th>Coverage Area to maintain n times capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MIMO (2x2 )</td>
<td>1.94</td>
<td>0.71</td>
</tr>
<tr>
<td>MIMO (3x3 )</td>
<td>2.89</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Catreus_Greenstein_Erceg(JSAC03)
Scheduling and Multi-user Diversity

- Scheduling technique can deliver multi-user diversity gain
  - One user at a time will maximize throughput in multi-user communication system [Knopp, 1995][D. Tse, 2002]
  - Take advantage of delay-tolerant traffic.
  - Channels are independent among users
  - Multi-user diversity inherently exists in a multi-user system
Link-based wireless scheduling algorithms

- Maximum C/I scheduler
- Fair time scheduler
- Proportional fair scheduler

\[ j = \arg \left\{ \max_i \frac{\gamma_i(k)}{\overline{\gamma}_i(k)} \right\} \]

- Exponential rule scheduler
- Queue length based exponential rule scheduler
Joint MIMO and Scheduling Systems
Scheduling and MIMO Diversity Systems
Channel Model

Nakagami Fading

\[ f(\gamma) = \left( \frac{m}{\Omega} \right)^m \frac{\gamma^{m-1}}{\Gamma(m)} \exp\left( -\frac{m\gamma}{\Omega} \right), \quad \gamma > 0 \]
Scheduling and MIMO Diversity Systems

- Four practical schemes considered:
  - ST/SC
  - ST/MRC
  - MRT/MRC
  - STBC

- Assume Nakagami-m fading channel

- A unified capacity formula connecting three domain contributions: (Chen_Wang_icc’04)

\[
C(\alpha, \beta, K) \simeq \frac{K \log_2(e)}{\Gamma(\alpha)} \sum_{i=1}^{N_p} w_i \ln \left( 1 + \frac{z_i}{\beta} \right) \left[ \tilde{\Gamma}(\alpha, z_i) \right]^{K-1} z_i^{\alpha-1}
\]

\[
\alpha = m, \quad \beta = \frac{m}{\Omega} \quad \text{(SISO)}
\]
Effect of MIMO on Signal Characteristics

Amount of fading

Array Gain

MIMO

SISO

user 1

$r_1$

$\lambda_1$
Change of Coordination Parameters

- Define array gain as
  \[ a = \frac{\mathbb{E}[\gamma_k]}{\Omega} = \frac{\alpha}{\beta} \]

- Define amount of fading gain \( f \)
  \[ f = \frac{AF[\gamma_k]}{1/m} \]
  \[ AF[\gamma_k] = \frac{\text{Var}[\gamma_k]}{\mathbb{E}[\gamma_k]^2} \]

- Define selection order \( S = g(K, N_t, N_r) \)

\[ C(a, f, S) \approx \log_2 \left( 1 + a\Omega \left[ 1 + \sqrt{\frac{Sf}{2m}} \right] \right) \]
## MIMO System Capacity with Scheduling

<table>
<thead>
<tr>
<th>MIMO antenna schemes</th>
<th>System capacity</th>
<th>Array gain ($a$)</th>
<th>AF gain ($f$)</th>
<th>Selection order ($S$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{\text{siso}}, (1, 1)$</td>
<td>$C \left( m, \frac{m}{\Omega}, K \right)$</td>
<td>1</td>
<td>1</td>
<td>$K$</td>
</tr>
<tr>
<td>$C_{\text{sc}}, (1, N_r)$</td>
<td>$C \left( m, \frac{m}{\Omega}, KN_r \right)$</td>
<td>1</td>
<td>1</td>
<td>$KN_r$</td>
</tr>
<tr>
<td>$C_{\text{mrc}}, (1, N_r)$</td>
<td>$C \left( mN_r, \frac{m}{\Omega}, K \right)$</td>
<td>$N_r$</td>
<td>$1/N_r$</td>
<td>$K$</td>
</tr>
<tr>
<td>$C_{\text{st}}, (N_t, 1)$</td>
<td>$C \left( m, \frac{m}{\Omega}, KN_t \right)$</td>
<td>1</td>
<td>1</td>
<td>$KN_t$</td>
</tr>
<tr>
<td>$C_{\text{mrt}}, (N_t, 1)$</td>
<td>$C \left( mN_t, \frac{m}{\Omega}, K \right)$</td>
<td>$N_t$</td>
<td>$1/N_t$</td>
<td>$K$</td>
</tr>
<tr>
<td>$C_{\text{st-sc}}, (N_t, N_r)$</td>
<td>$C \left( m, \frac{m}{\Omega}, KN_tN_r \right)$</td>
<td>1</td>
<td>1</td>
<td>$KN_tN_r$</td>
</tr>
<tr>
<td>$C_{\text{st-mrc}}, (N_t, N_r)$</td>
<td>$C \left( mN_r, \frac{m}{\Omega}, KN_t \right)$</td>
<td>$N_r$</td>
<td>$1/N_r$</td>
<td>$KN_t$</td>
</tr>
<tr>
<td>$C_{\text{ub-mrt-mrc}}, (N_t, N_r)$</td>
<td>$C \left( mN_tN_r, \frac{m}{\Omega}, K \right)$</td>
<td>$N_tN_r$</td>
<td>$1/N_tN_r$</td>
<td>$K$</td>
</tr>
<tr>
<td>$C_{\text{lb-mrt-mrc}}, (N_t, N_r)$</td>
<td>$C \left( mN_tN_r, \frac{m}{\Omega}, KN_tN_r \right)$</td>
<td>$N_tN_r/N$</td>
<td>$1/N_tN_r$</td>
<td>$K$</td>
</tr>
<tr>
<td>$C_{\text{st-be}}, (N_t, N_r)$</td>
<td>$C \left( mN_tN_r, \frac{mN_t}{\Omega}, K \right)$</td>
<td>$N_r$</td>
<td>$1/N_tN_r$</td>
<td>$K$</td>
</tr>
</tbody>
</table>

$$N = \min(N_t, N_r)$$
Some Observations

- The fading parameter $m$ is inversely proportional to capacity.
- SC/ST can improve capacity in the form of amplifying multiuser diversity.
- MRT/MRC can improve capacity as a consequence of increased array gain and reduced amount of fading.
- Employing STBC with $N_t$ transmit antennas could damp channel variations, thus reducing capacity.

\[
C(a, f, S) \approx \log_2 \left( 1 + a\Omega \left[ 1 + \sqrt{Sf \over 2m} \right] \right)
\]
Impact of Nakagami Fading Parameter $m$
Joint Antenna and Multiuser Diversity

![Graphs showing performance of different antenna and multiuser diversity techniques.]
Scheduling and MIMO Multiplexing Systems
The SWNSF Scheduling

• The strongest-weakest-normalized-subchannel-first (SWNSF) scheduling:

\[ k^* = \arg \max_k \lambda_{\min} \left( G_k G_k^\dagger \right) \]
\[ = \arg \max_k g_k \lambda_{\min} \left( G_k G_k^\dagger \right) \]
\[ = \arg \max_k \lambda_{k,n} \].

• Fair scheduling algorithm
• Require limited amount of feedback
Coverage Extension with Scheduling

- Can show that

\[ r_{\text{MIMO SWNSF}} \approx \left[ \frac{1}{n^2} \left( \frac{1}{P_{\text{out}}} - \frac{1}{2} \right) \log \left( \frac{1}{1 - \frac{k}{\sqrt{P_{\text{out}}}}} \right) \right]^{1/\mu} r_{\text{SISO}} \]
Capacity Enhancement with Scheduling

- Can show that

\[
\tilde{C}_k \simeq \rho_k \left[ n + \frac{1}{n} \left( \log K + \beta - 1 \right) \right], \quad \text{for small } \rho_k
\]

\[
\tilde{C}_k \leq n \log \left( \frac{\rho_k}{n} \right) + n \log \left[ n + \frac{1}{n} \left( \log K + \beta - 1 \right) \right], \quad \text{for large } \rho_k
\]
Conclusion

- We have established a unified view on the interplay of scheduling and MIMO diversity and MIMO multiplexing systems.
- Selecting an appropriate scheduling technique in MIMO diversity systems is critical.
- A novel SWNSF scheduling is proposed to extend coverage and enhance capacity in the multiuser MIMO multiplexing systems.
- Scheduling can be used as a virtual antenna for improving the coverage of MIMO multiplexing systems.
Publications


• Chiung-Jang Chen and Li-Chun Wang, "Coverage and Capacity Enhancements of Multiuser MIMO Systems with Scheduling", submitted to IEEE Globecom, 2004 and IEEE Tran. on Comm.

Thank You!

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