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

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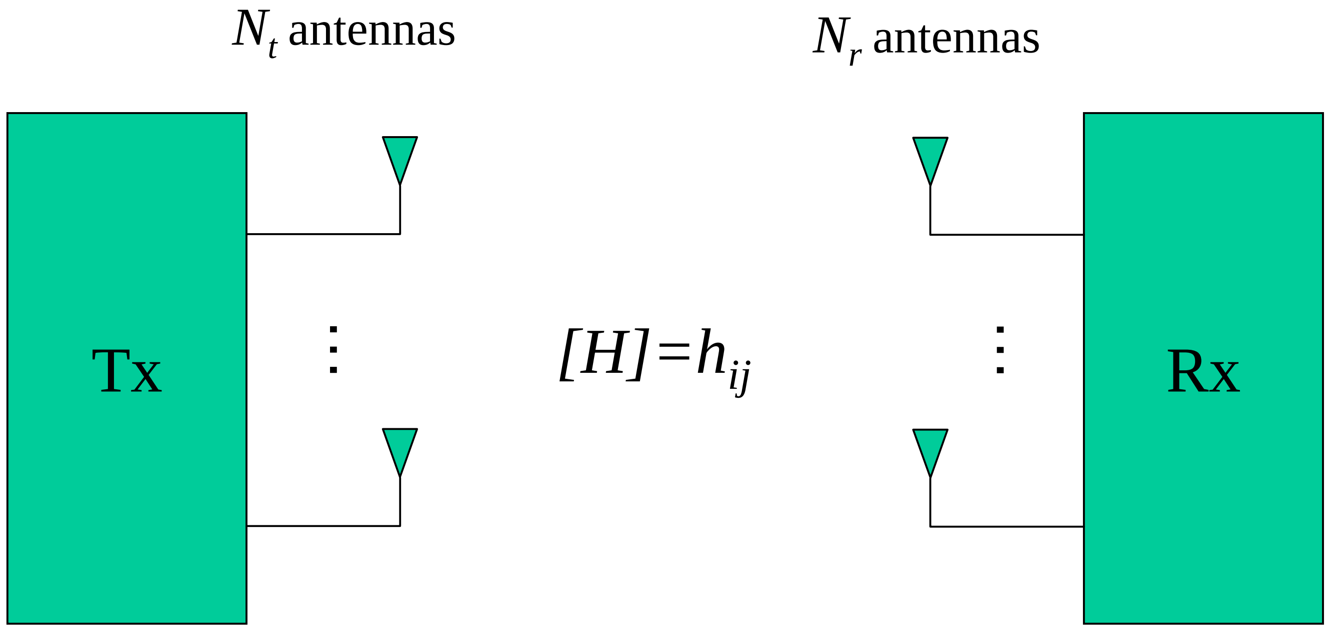
Outline

- 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 = $Nt\ Nr$)
- deliver multiplexing gain, (max order = min(Nt, Nr))

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

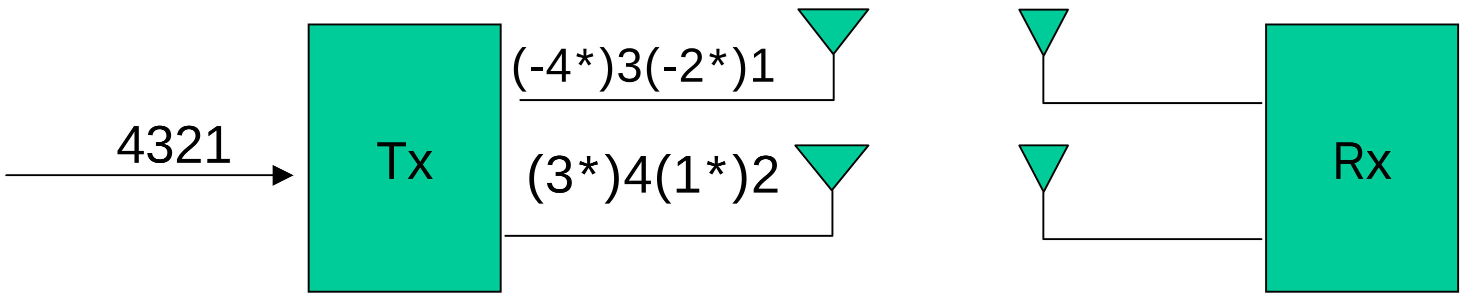
$$C_k = \mathrm{E}\left[\log\det\left(I + \frac{\rho_k}{n}\mathbf{H}_k\mathbf{H}_k^\dagger\right)\right]$$

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

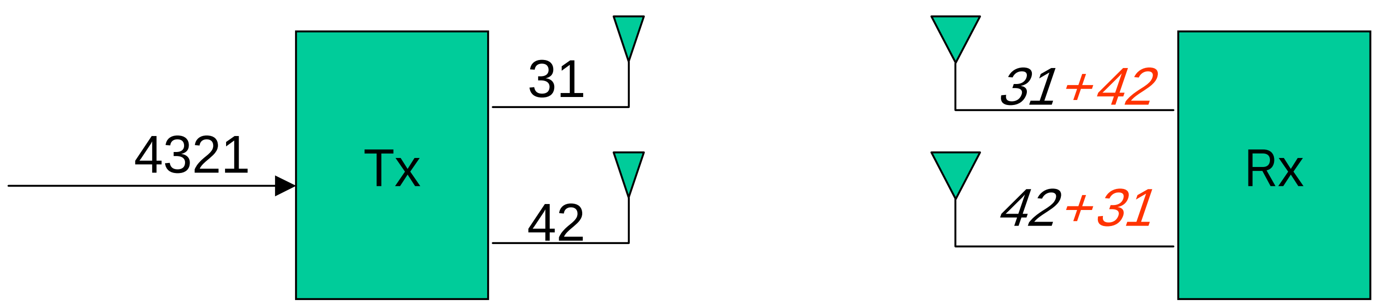
- Close-loop
  - Full channel knowledge at Tx -> water-filling policy
  - Partial channel knowledge at Tx

Multiplexing vs Diversity in MIMO system

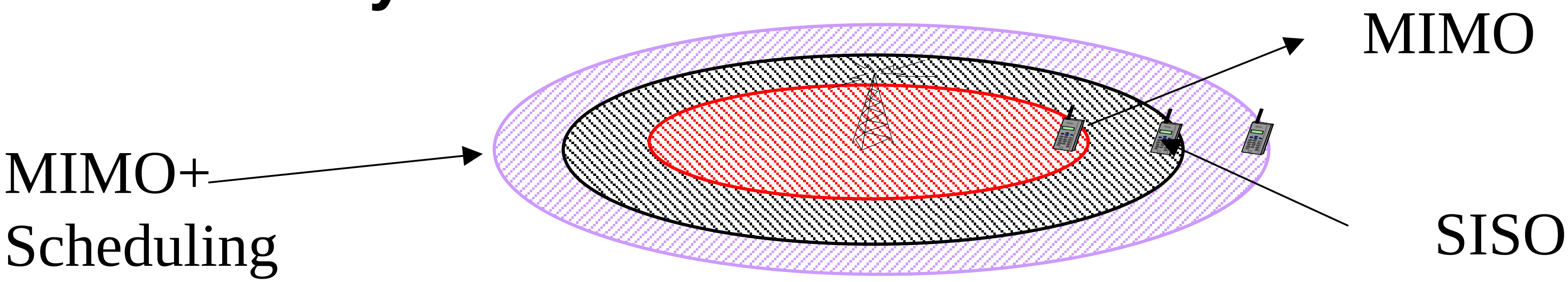
- Diversity



- Multiplexing



Tradeoff between Coverage and Capacity for MIMO Systems



Antenna number	Capacity gain	Coverage Area to maintain ***n*** times capacity
n=1	1	1
MIMO (2x2)	1.94	0.71
MIMO (3x3)	2.89	0.58

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

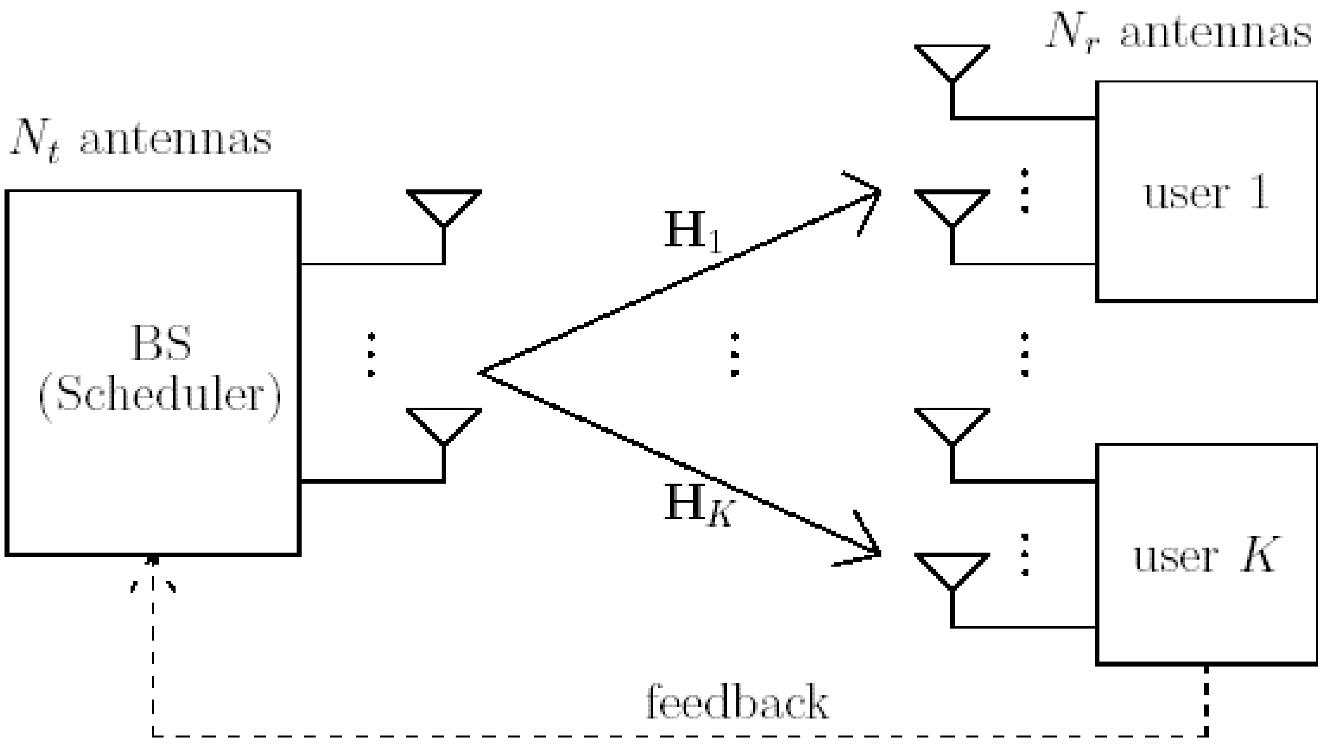
Link-based wireless scheduling algorithms

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

$$j = \arg\{\max_i \frac{\gamma_i(k)}{\bar{\gamma}_i(k)}\}$$

- Exponential rule scheduler
- Queue length based exponential rule scheduler

Joint MIMO and Scheduling Systems



Scheduling and MIMO Diversity Systems

Channel Model

Nakagami Fading

$$f(\gamma) = \left(\frac{m}{\Omega}\right)^m \frac{\gamma^{m-1}}{\Gamma(m)} \exp\left(-\frac{m\gamma}{\Omega}\right), \;\; \gamma > 0$$

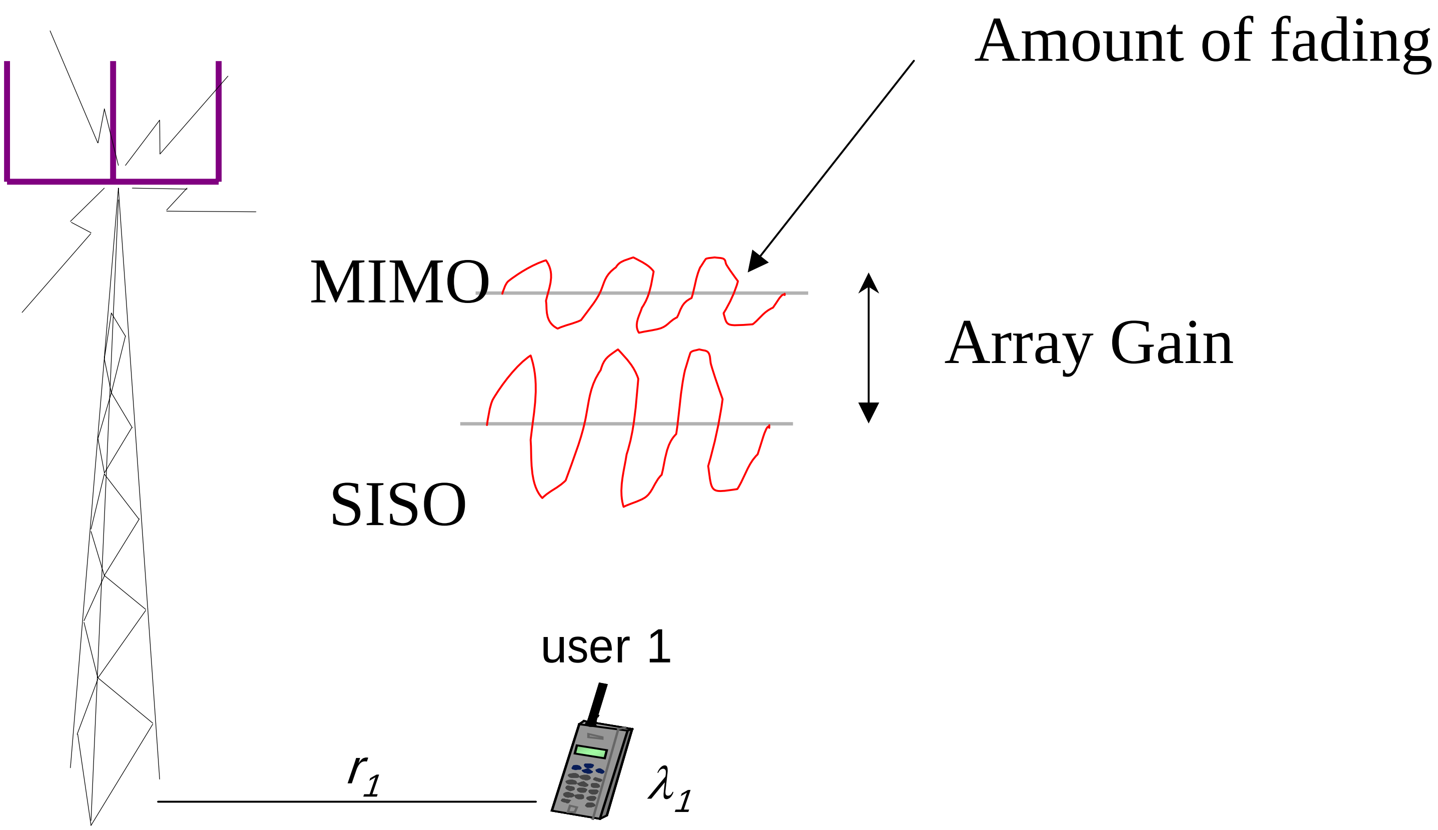
Scheduling and MIMO Diversity Systems

- 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)

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

$$\alpha = m\,, \quad \beta = \frac{m}{\Omega} \qquad \text{(SISO)}$$

Effect of MIMO on Signal Characteristics



Change of Coordination Parameters

- Define *array gain* as

$$a = \frac{\mathrm{E}[\gamma_k]}{\Omega} = \frac{\alpha/\beta}{\Omega}$$

- Define *amount of fading gain f*

$$f = \frac{AF[\gamma_k]}{1/m}$$

$$AF[\gamma_k] = \frac{\mathrm{Var}[\gamma_k]}{\mathrm{E}[\gamma_k]^2}$$

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

$$C(a, f, S) \simeq \log_2\left(1 + a\Omega\left[1 + \sqrt{\frac{Sf}{2m}}\right]\right)$$

MIMO System Capacity with Scheduling

MIMO antenna schemes	System capacity	Array gain (a)	AF gain (f)	Selection order (S)
C_{siso}, $(1,1)$	$C\left(m, \frac{m}{\Omega}, K\right)$	1	1	K
C_{sc}, $(1,N_r)$	$C\left(m, \frac{m}{\Omega}, KN_r\right)$	1	1	KN_r
C_{mrc}, $(1,N_r)$	$C\left(mN_r, \frac{m}{\Omega}, K\right)$	N_r	$1/N_r$	K
C_{st}, $(N_t,1)$	$C\left(m, \frac{m}{\Omega}, KN_t\right)$	1	1	KN_t
C_{mrt}, $(N_t,1)$	$C\left(mN_t, \frac{m}{\Omega}, K\right)$	N_t	$1/N_t$	K
$C_{\text{st-sc}}$, (N_t,N_r)	$C\left(m, \frac{m}{\Omega}, KN_tN_r\right)$	1	1	KN_tN_r
$C_{\text{st-mrc}}$, (N_t,N_r)	$C\left(mN_r, \frac{m}{\Omega}, KN_t\right)$	N_r	$1/N_r$	KN_t
$C^{\text{ub}}_{\text{mrt-mrc}}$, (N_t,N_r)	$C\left(mN_tN_r, \frac{m}{\Omega}, K\right)$	N_tN_r	$1/N_tN_r$	K
$C^{\text{lb}}_{\text{mrt-mrc}}$, (N_t,N_r)	$C\left(mN_tN_r, \frac{mN}{\Omega}, K\right)$	N_tN_r/N	$1/N_tN_r$	K
C_{stbc}, (N_t,N_r)	$C\left(mN_tN_r, \frac{mN_t}{\Omega}, K\right)$	N_r	$1/N_tN_r$	K

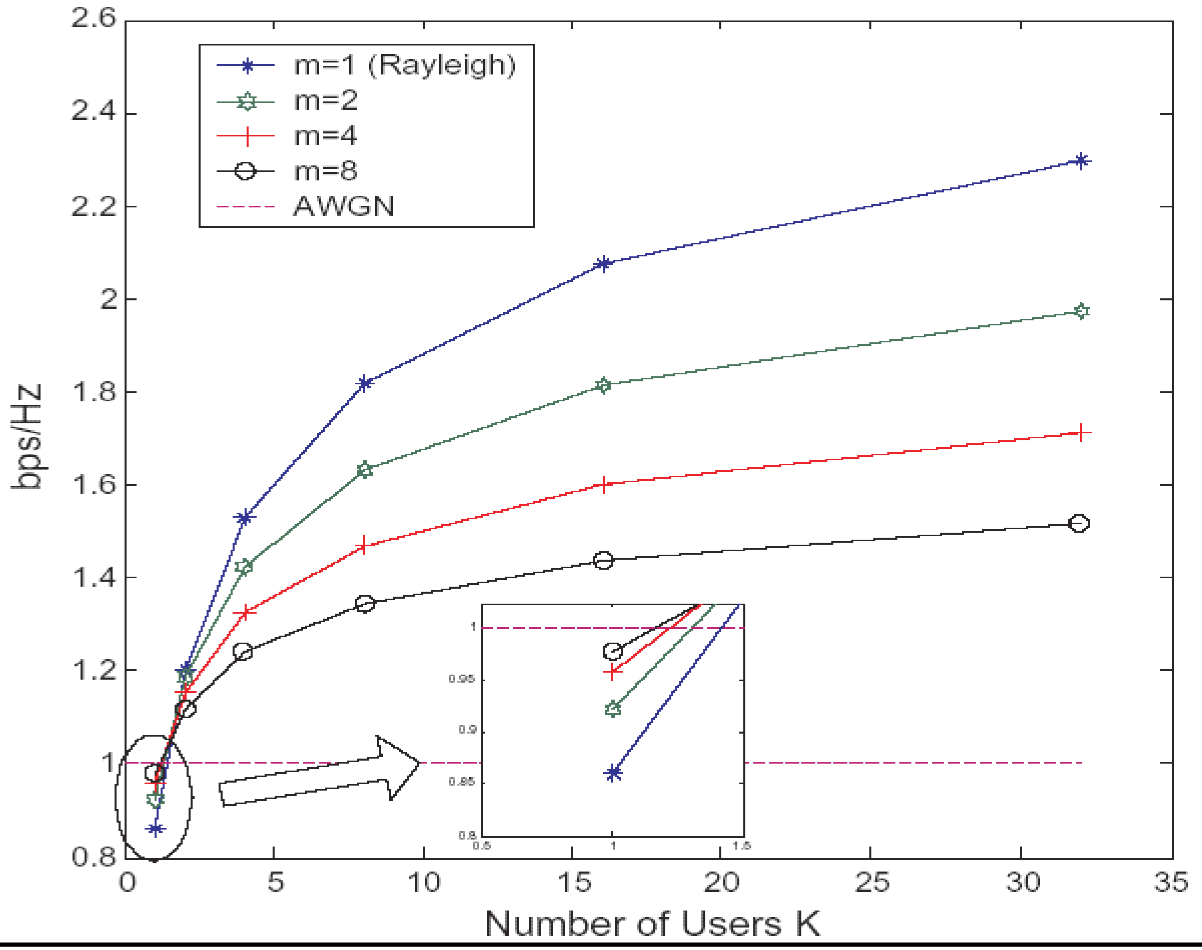
$N = \min(N_t, N_r)$

Some Observations

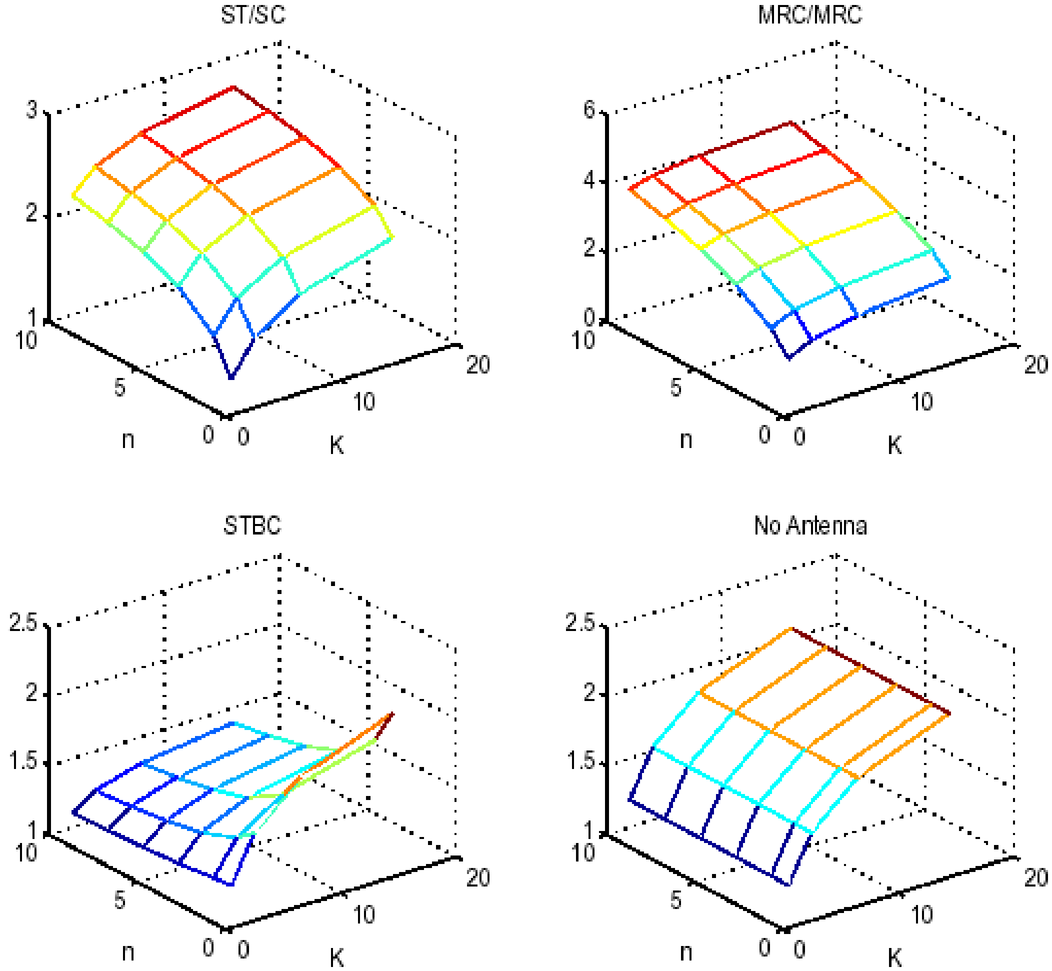
- The fading parameter *m* is inversely proportional to capacity
- SC/ST can improve capacity in the form of amplifying multiuser diversity
- MRT/MRC can improve capacity as a consequence of increased array gain and reduced amount of fading
- Employing STBC with N_t transmit antennas could damp channel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

$$C(a, f, S) \simeq \log_2\left(1 + a\Omega\left[1 + \sqrt{\frac{Sf}{2m}}\right]\right)$$

Impact of Nakagami Fading Parameter *m*



Joint Antenna and Multiuser Diversity



Scheduling and MIMO Multiplexing Systems

The SWNSF Scheduling

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

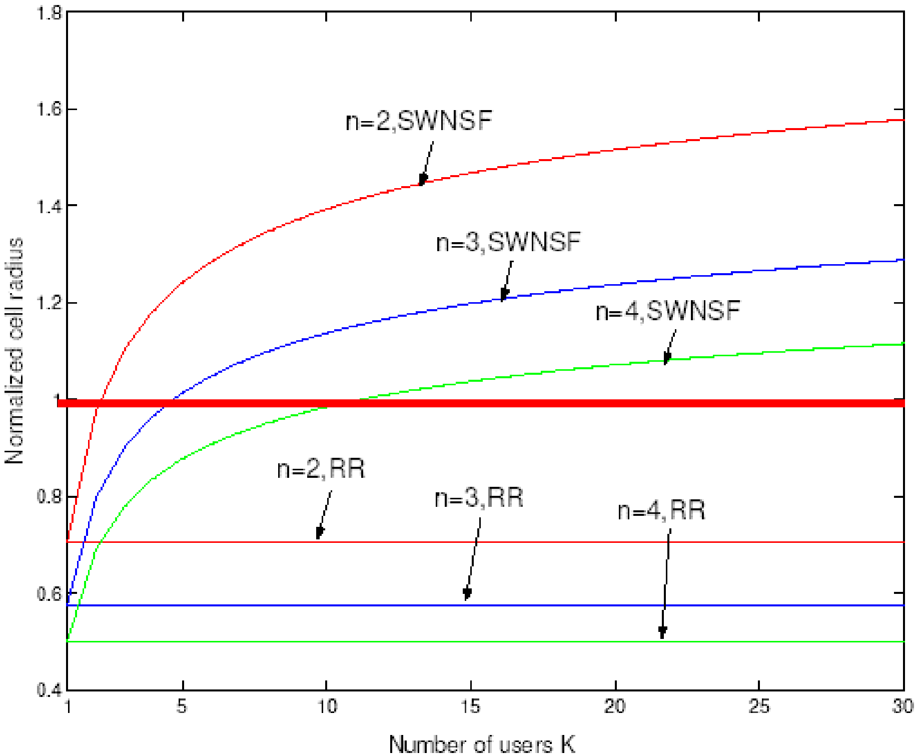
$$
\begin{aligned}
k^* &= \arg\max_k \frac{\lambda_{\min}\left(\mathbf{G}_k \mathbf{G}_k^\dagger\right)}{g_k} \\
&= \arg\max_k \lambda_{\min}\left(\mathbf{H}_k \mathbf{H}_k^\dagger\right) \\
&= \arg\max_k \lambda_{k,n} \quad .
\end{aligned}
$$

- Fair scheduling algorithm
- Require limited amount of feedback

Coverage Extension with Scheduling

- Can show that

$$r_{\text{SWNSF}}^{\text{MIMO}} \simeq \left[\frac{1}{n^2}\left(\frac{1}{P_{\text{out}}} - \frac{1}{2}\right)\log\left(\frac{1}{1 - \sqrt[K]{P_{\text{out}}}}\right)\right]^{1/\mu} r^{\text{SISO}}$$

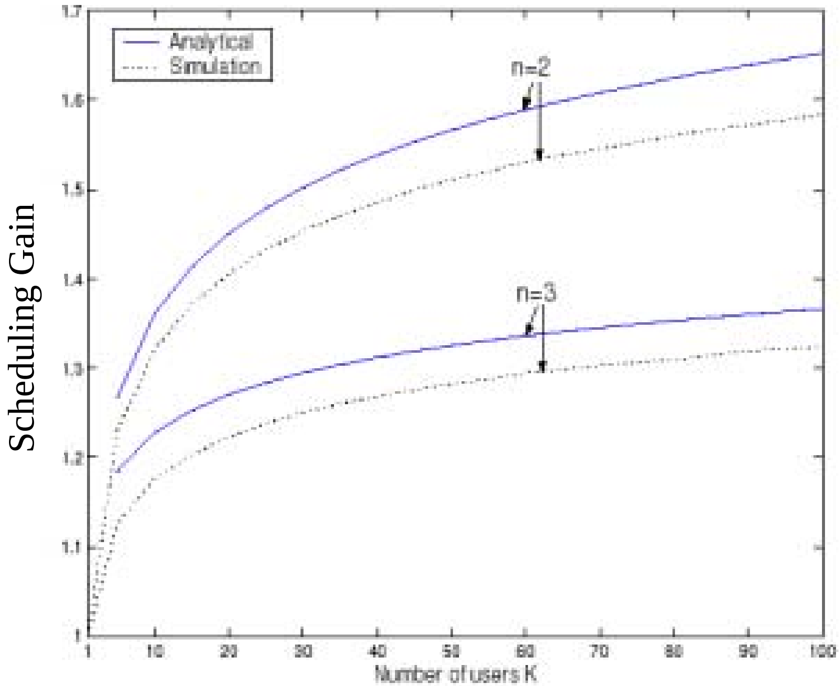


Capacity Enhancement with Scheduling

- Can show that

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

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



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, "An Analytical Framework for Capacity and Fairness Evaluation in High Speed Wireless Data Networks," IEEE Globecom, 2003 and submitted to IEEE Trans. on Wireless Communications.
- Chiung-Jang Chen and Li-Chun Wang, "A Unified Capacity Analysis for Wireless Systems with Joint Antenna and Multiuser Diversity in Nakagami Fading Channels," accepted for IEEE ICC, 2004 and submitted to IEEE Trans. on Communications.
- 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.
- Chiung-Jang Chen and Li-Chun Wang, ``Interference Suppression in TDD/CDMA Cellular Systems with Asymmetric Traffic Using MVDR Beamforming," IEEE VTC Fall, 2002 and submitted to IEEE Trans. on Vehicular Technology.

Thank You!

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Reference

- Chiung-Jang Chen and Li-Chun Wang, `` A Feasibility Study of Beamforming Techniques for Suppressing Interference in TDD/CDMA Systems with Asymmetric Traffic," IEEE ISWC, 2002.
- Chiung-Jang Chen and Li-Chun Wang, `` A Hierarchical TDD Microcell/FDD Macrocell CDMA System Using Antenna Arrays and Power Ratio Adjustments," IEEE Globecom, 2002.