BS-side Estimation for Reduced Feedback Best-M Scheme in OFDM Systems

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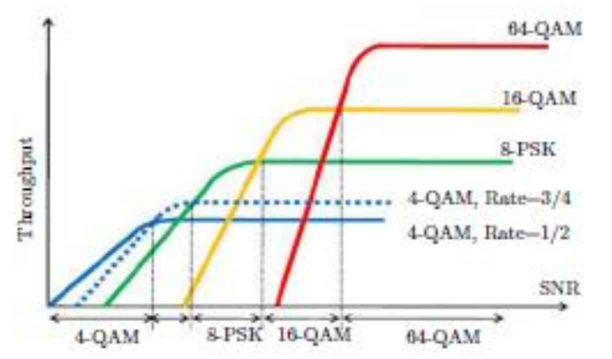
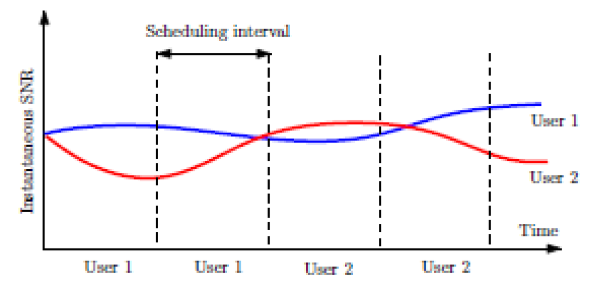
Introduction

- Channel adaptive signalling is used in current cellular systems
  - Scheduling: selecting the user for downlink transmission
  - Rate adaptation: choosing the rate of transmission



Rate adaptation

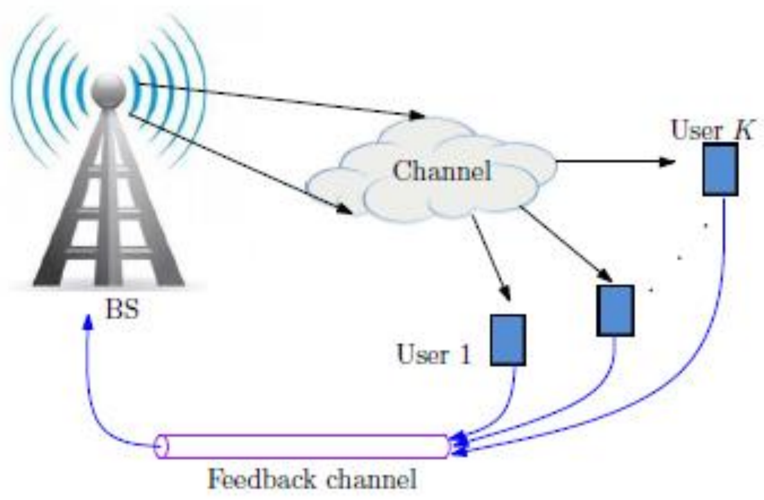


User scheduling

- Improves spectral efficiency and avoids worst-case designs
- Challenge: channel knowledge is needed at the BS

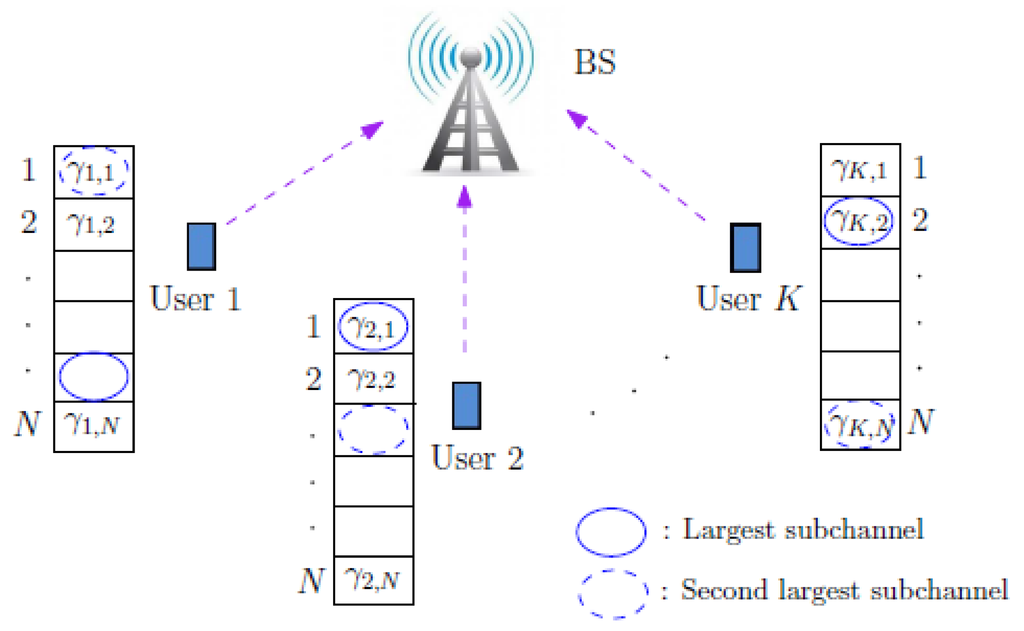
Feedback in the Uplink

- Channel information must be fed back to the BS in the uplink
  - expends uplink radio resources
  - overhead increases as the number of users and subchannels increase
- Complete feedback is impractical and reduced feedback schemes are needed
- They reduce uplink feedback overhead without degrading system throughput
- Several schemes have been proposed:
  1. threshold-based scheme
  2. one-bit scheme
  3. subchannel clustering
  4. best-M scheme
  5. hybrid schemes etc.



Best-M Scheme

- Each user feeds back M largest subchannel SNRs and their subchannel indices



Subchannels

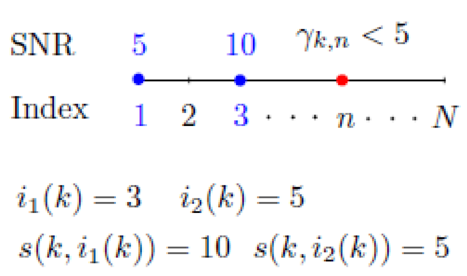
	1	2	3	4
User 1	$\gamma_{1,1}$	–	–	–
User 2	–	–	$\gamma_{2,3}$	–
User 3	–	–	$\gamma_{3,3}$	–

Best-M feedback for $M=1$

- Degradation in throughput occurs due to:
  - instances of no user reporting a subchannel
  - loss in multi-user diversity
- Use subchannel correlation information to improve the throughput

System Model

- Single antenna OFDM cellular network with K users and N subchannels
- Rayleigh fading:
  - $H_{k,n} \sim \mathcal{CN}(0,\Omega_k)$
  - $\gamma_{k,n} = |H_{k,n}|^2 \sim \text{Exp}(\Omega_k)$



- Best-M feedback
  - Reported indices: $\mathbf{x}_{k,M}=[i_1(k),\ldots,i_M(k)]$
  - Reported SNRs: $\mathbf{s}_{k,M}=[s(k,i_1(k)),\ldots,s(k,i_M(k))]$
- Discrete rate adaptation with rates $0=R_1<R_2<\cdots<R_L$

MMSE Approach

- MMSE estimate of the SNR of an unreported subchannel is generated at the BS
- Given the best-M feedback $(\mathbf{s}_{k,M},\mathbf{x}_{k,M})$, the MMSE estimate is the conditional mean:

$$\begin{aligned}\hat{\gamma}_{k,n} &= \mathbf{E}\left[\gamma_{k,n}|\mathbf{s}_{k,M},\mathbf{x}_{k,M}\right]\\ &= \mathbf{E}\left[\gamma_{k,n}|\gamma_{k,u}=s(k,u),\forall u\in\mathbf{x}_{k,M};\gamma_{k,v}<s(k,i_M(k)),\forall v\in\mathbf{x}^c_{k,M}\right]\end{aligned}$$

- Incorporates both subchannel correlation and best-M feedback

For uncorrelated subchannels, the MMSE estimate $\hat{\gamma}_{k,n}$ is given by

$$\hat{\gamma}_{k,n}=\Omega_k-\frac{s(k,i_M(k))}{\exp\left(\frac{s(k,i_M(k))}{\Omega_k}\right)-1}$$

- Can be extended to general subchannel correlation models

Subchannels

	1	2	3	4
User 1	$\gamma_{1,1}$	–	–	–
User 2	–	–	$\gamma_{2,3}$	–
User 3	–	–	$\gamma_{3,3}$	–

Best-M feedback for $M=1$

→

Subchannels

	1	2	3	4
User 1	$\gamma_{1,1}$	$\hat{\gamma}_{1,2}$	$\hat{\gamma}_{1,3}$	$\hat{\gamma}_{1,4}$
User 2	$\hat{\gamma}_{2,1}$	$\hat{\gamma}_{2,2}$	$\gamma_{2,3}$	$\hat{\gamma}_{2,4}$
User 3	$\hat{\gamma}_{3,1}$	$\hat{\gamma}_{3,2}$	$\gamma_{3,3}$	$\hat{\gamma}_{3,4}$

After estimation

Throughput-Optimal Approach

- Maximizes the throughput instead of minimizing the MSE
- Define feedback-conditioned goodput: $G_n(k,l)=R_l\mathbf{P}\left(\gamma_{k,n}\geq T_l|\mathbf{s}_{k,M},\mathbf{x}_{k,M}\right)$
- It is the average number of successfully transmitted bits with rate R_l given the best-M feedback

The optimal user ω_n^* and the MCS π_n^* for transmission on subchannel *n* are:

$$\omega_n^*=\arg\max_{1\leq k\leq K}\{G_n(k,m_n(k))\},$$

$$\pi_n^*=m_n(\omega_n^*),$$

where $m_n(k)=\text{argmax}_{1\leq l\leq L}\{G_n(k,l)\}$.

- For uncorrelated subchannels,

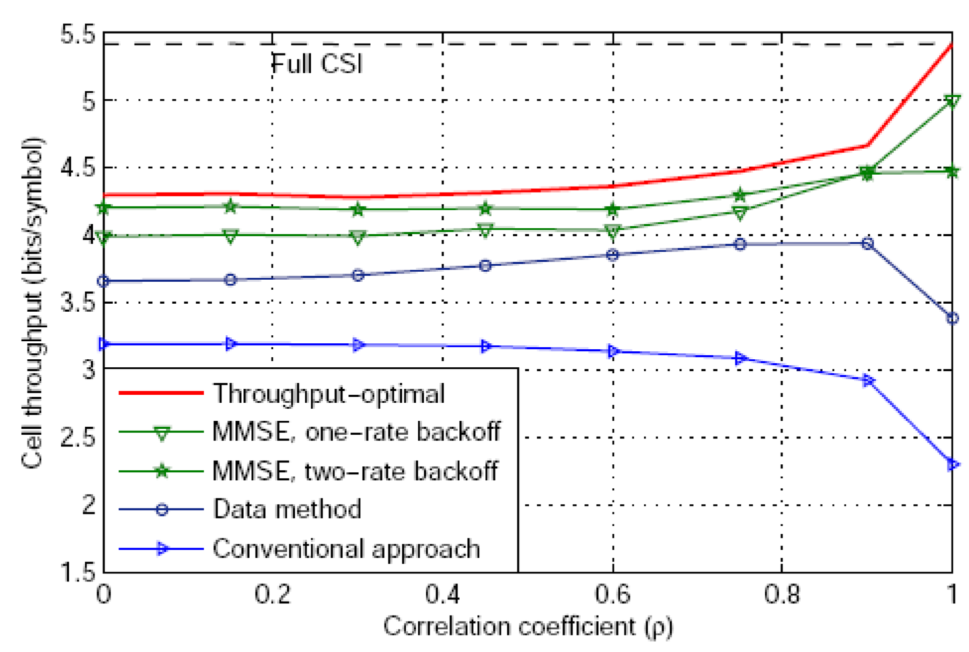
$$G_n(k,l)=\frac{\exp\left(-\min\left\{\frac{T_l}{\Omega_k},\frac{s(k,i_M(k))}{\Omega_k}\right\}\right)-\exp\left(-\frac{s(k,i_M(k))}{\Omega_k}\right)}{1-\exp\left(-\frac{s(k,i_M(k))}{\Omega_k}\right)}R_l$$

- Can be extended to general correlation models

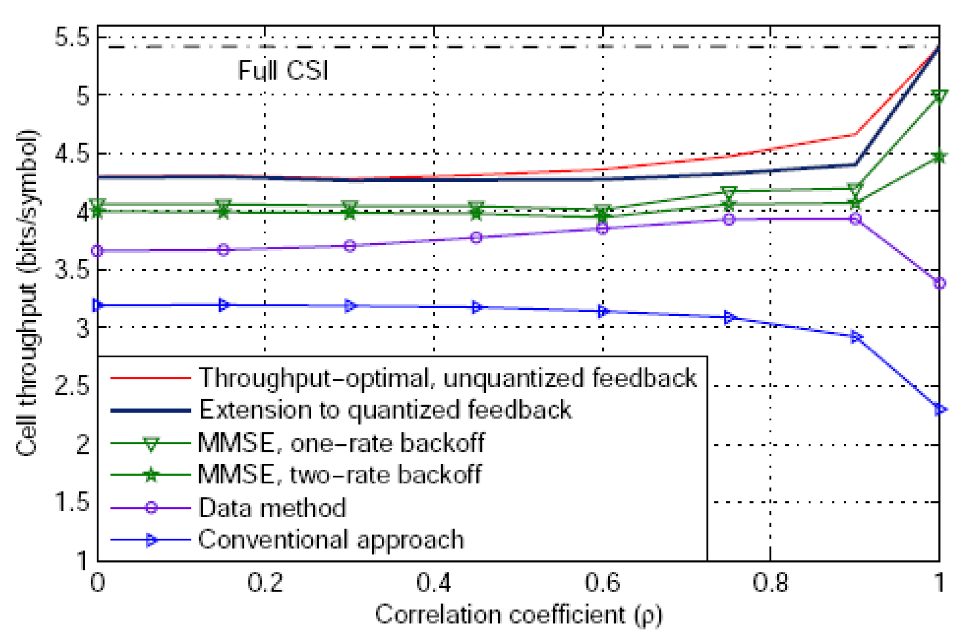
Numerical Results

- Simulation parameters: $K=N=10$, $\Omega_k=\Omega\alpha^{k-1}$, $\Omega=9$ dB, $\alpha=1.4$, $\mathbf{E}[H_{k,n}H^*_{k,m}]=\Omega_k\rho^{|n-m|}$

Throughput benchmarking for M=1



Quantized feedback and M=1



- MMSE approach with an appropriate rate backoff is near-optimal
- Loss with quantized feedback is negligible for $\rho\leq 0.45$

Conclusions

- Proposed approaches outperformed benchmark approaches without any additional feedback
- Throughput-optimal approach gives a fundamental limit on the achievable throughput
- MMSE approach is near-optimal with an appropriate rate backoff