Weighted CDF-based Scheduling for an OFDMA Relay Downlink with Partial Feedback

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Outline

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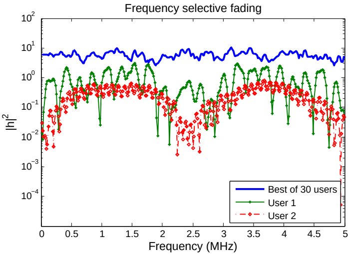
OFDMA system - Multiuser diversity



- Effects of fading on channels of users
  - Multiuser diversity and frequency selectivity
    - Multiuser diversity: channels to different users are different
    - Frequency selectivity: channels on different frequency are different
- Goal: Exploit the diversity to improve system's performance

Performance measures vs. Challenges

- Measures of System's Performance
  - Throughput
  - Fairness: meet users' requirements
  - Feedback constraint
- Challenges
  - A large number of users
  - A large number of resource blocks
  - Diversity in users' characteristics
    - Users' location: different channel gain and channel statistic...
    - Users' requirements: types of service, power, data rate, delay tolerance,...
- At first, we introduce the system model

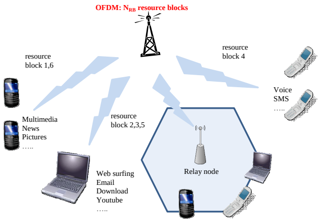
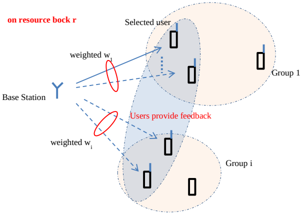


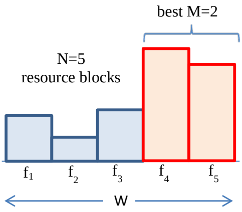
Figure: A multiuser system

Outline

System, Feedback and Scheduling

- System: Groups of users with different priority
  - Groups of macro users
  - Groups of cell edge users, each group is served by a relay
- OFDM with Partial feedback
  - Users feed back the best *M* among channels on *N* resource blocks
  - On resource block *r*, there are subset of users to feed back
- Scheduling
  - Users are selected based on weighted cdf of the SNR.





Weighted CDF scheduling

- How weighted CDF work [5]
  - From SNR Y_{k_i} of user k_i
  - Obtain $u_{k_i} = F_{Y_{k_i}}(x)$,
    - Uniformly distributed in $[0, 1]$
    - Identical for all users
- Compare and prioritize users
  - Select the user with the largest weighted CDF $k^* = \arg\max_k \{F_{Y_{k_i}}(x)\}^{\frac{1}{w_i}}$

Advantage: can control precisely selection probability of all the users

[5] D. Park, H. Seo, H. Kwon, and B. Lee, "Wireless packet scheduling based on the cumulative distribution function of user transmission rates", *IEEE Trans on Communications*, Nov. 2005.

System's performance - average sum rate

- The average system sum rate is

$$R = \frac{1}{N}\sum_{r=1}^{N} E\log(1+X_r) = E\log(1+X_r) \qquad (1)$$

where X_r is SNR to the selected user on resource block r

Performance analysis

- Steps in analyzing system performance [4]

Framework	CQI feedback	
	Random variable	Output
Step 1	$Z_{k,r}$: CQI at a receiver	F_{Z_k}
Step 2	$Y_{k,r}$: SNR seen at a transmitter	F_{Y_k}
Step 3	X_r: SNR of a selected user	$F_{X\|cond}$
Step 4a	$F_X = E_{cond} F_{X\|cond}$	
Step 4b	$E_{cond} E_{X_r}[\log(1 + X_r)\|cond]$	

k: user index, r: block index

[4] Seong-Ho Hur, and Bhaskar Rao, “Sum rate analysis of a reduced feedback OFDMA system employing joint scheduling and diversity", *IEEE Transactions on Signal Processing*, 2011.

Performance analysis

Theorem

In an OFDMA system where all equipments have a single antenna, with L groups of users, each group i has K_i users, if only CQI on M best among N resource blocks is fed back, the CDF of system's throughput is

$$F_R(\zeta(x)) = \sum_{l=1}^{L} \sum_{\substack{n_j=0 \\ j=1,\ldots,L; \bar{\mathbf{n}} \neq \mathbf{0}}}^{K_j} \left(\prod_{j=1}^{L} Pr\{|S_{r,j}| = n_j\} \right)$$
$$\times \begin{cases} \frac{n_l w_l}{\sum_{j=1}^{L} n_j w_j} \sum_{t=1}^{\infty} e_3(\alpha_l, t) \sum_{m=0}^{t(M-1)} e_2(m) F_{Z_k}\left(\frac{x}{\rho}\right)^{Nt-m} & \alpha_l \neq 1 \\ \sum_{m=0}^{M-1} e_1(m) \sum_{k=0}^{N-m} F_{Z_k}\left(\frac{x}{\rho}\right)^{N-m} & \alpha_l = 1 \end{cases}, \quad (2)$$

Performance analysis

where

- $\zeta(x) = \log(1+x)$
- $F_{Z_k}\left(\frac{x}{\rho}\right)$ is CDF of SNR from the BS to user k
- $Pr\{|S_{r,l}| = n_l\} = \binom{K_l}{n_l}\left(\frac{M}{N}\right)^{n_l}\left(1-\frac{M}{N}\right)^{K_l-n_l}$
- $\alpha_l = \frac{\sum_{j=1}^{L} w_j n_j}{n_l w_l}$;
- $e_1(m) = \sum_{i=m}^{M-1} \frac{M-i}{M}\binom{N}{i}\binom{i}{m}(-1)^{i-m}$
- $e_2(0) = e_1(0)^t$; $e_2(m) = \frac{1}{me_1(0)}\sum_{k=1}^{\min(M-1,m)}(kt-m+k)e_1(k)e_2(m-k)$;
- $e_3(\alpha_l, t) = \sum_{i=t}^{\infty}\binom{\alpha_l}{i}\binom{i}{t}(-1)^{i-t}$.

Weights for groups of users

The probability of selection of user k_l is

$$Pr\{k_r^* = k_l\} = \sum_{\pi(\bar{\mathbf{n}})} \frac{w_l}{\sum_{j=1}^{L} n_j w_j} \frac{n_l}{K_l} \binom{K_1}{n_1} \binom{K_L}{n_L} \left(\frac{M}{N}\right)^{\sum_{j=1}^{L} n_j} \left(1 - \frac{M}{N}\right)^{\sum_{j=1}^{L}(K_j - n_j)} . \quad (3)$$

- Initialize $\mathbf{w}(0) = [\frac{P_{alloc,1}}{K_l}, \ldots, \frac{P_{alloc,L}}{K_L}]$ which is the weights for the full feedback case.
- Solving $\delta\mathbf{w}(t)\phi(\mathbf{w}(t)) = -\nabla\phi(\mathbf{w}(t))$.
- Update $\mathbf{w}(t+1) = \mathbf{w}(t) + \delta\mathbf{w}(t)$. Normalize $\mathbf{w}$ so that $\|\mathbf{w}\|_2 = 1$ which does not change $\phi(\mathbf{w})$.
- End $\|\phi(\mathbf{w})\|_2 < \epsilon$.

- Set $\epsilon = 10^{-10}$
- Target $P_{alloc} = [0.2, 0.8]$
- Found weight $\mathbf{w} = [0.318,\ 0.682]$ after 4 iterations

Iteration	Norm $\|\phi(\mathbf{w})\|_2$
0	2.4691512e-001
1	6.2304622e-002
2	3.0325582e-003
3	7.4881615e-006
4	4.5758897e-011

Table: Convergence behavior

Experimental results

We consider an OFDMA system with $N = 10$ resource blocks and groups of users with different priority

- Group 1
  - $K_1 = 10$ users, weight $w_1 = 0.4$, located at $d_1 = 414$m
- Group 2 - cell edge
  - $K_2 = 5$ users, weight $w_2 = 0.6$, located at $d_2 = 834$m

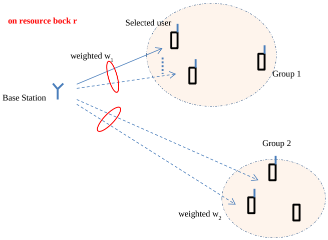


Figure: A partial feedback OFDMA system

System's performance with partial feedback

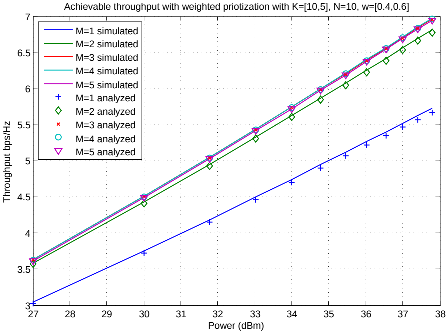


Figure: Analyzed and simulated performance of a partial feedback OFDMA system with $N = 10$, $K = [10, 5]$, $w = [0.4, 0.6]$

System's performance with different number of users

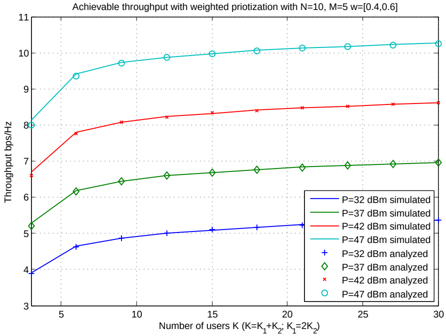


Figure: Analyzed system throughput of a partial feedback OFDMA system with $N = 10$, $M = 5$, $w = [0.4, 0.6]$, $K_1 = 2K_2$

Outline

Fast fading BS-RS links

We consider an OFDMA system with $N = 10$ resource blocks and groups of users with different priority

- Group 1
  - $K_1 = 10$ users, weight $w_1 = 0.4$, located at $d_1 = 414$m
- Group 2 - cell edge
  - $K_2 = 5$ users, weight $w_2 = 0.6$, located at $d_2 = 834$m
- A relay located at $d_r = 815m$

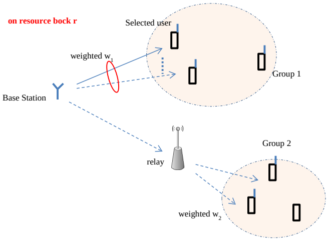


Figure: A partial feedback OFDMA system

System's performance with relays

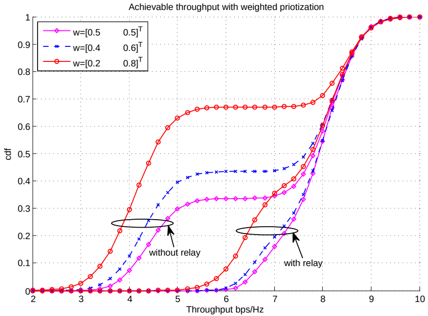


Figure: Performance tradeoff due to the biased treatment with users; OFDMA system with $N = 10$, $K = [10, 5]$, $P = 37$dBm, the distance BS-macro MS is $d_1 = 414$m and the distance BS-MS group 2 is $d_2 = 834$m which are aided by a relay with power 30dBm located 815m from the BS, full feedback is provided

Slow fading BS-RS links

- Group 1
  - Macro users, located at $d_1 = 414$m
- 5 groups (2,...,6) - at the cell edge
  - Users, each group served by a relays
  - Located at $d_2 = 834$m
- A relay located at $d_r = 815m$
- Parameters
  - Number of users $K = [2\ 2\ 2\ 3\ 3\ 3]$
  - Weights $w = [0.05\ 0.1\ 0.15\ 0.2\ 0.2\ 0.3]$
  - Log-normal shadowing fading 8dB
  - ...

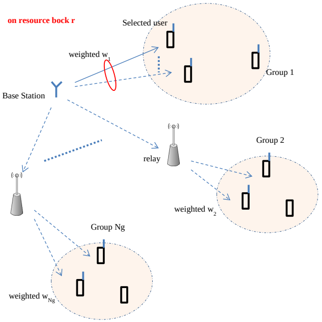


Figure: A partial feedback OFDMA system

Slow fading BS-RS links

- Allocation of users does not meet requirements
- Groups in resource starvation
  - Out of service if the coherence time is large
- Short term adjustment can not maintain fairness among users

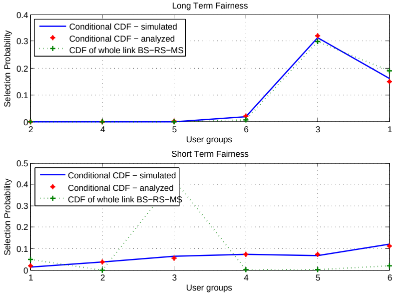


Figure: Selection probability of users in an OFDMA system

Slow fading BS-RS links

The proposed solutions

- Interpolate CDF to create an artificial CDF
  - Continuous
  - Uniformly distributed [0, 1]
- Can, again precisely control allocation probability for users

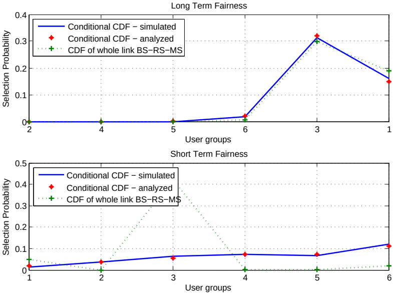


Figure: Selection probability of users in an OFDMA system

Slow fading BS-RS links

- Tradeoff in system's performance
- Goal: propose a modified technique
  - Similar allocation management
  - Better tradeoff in performance

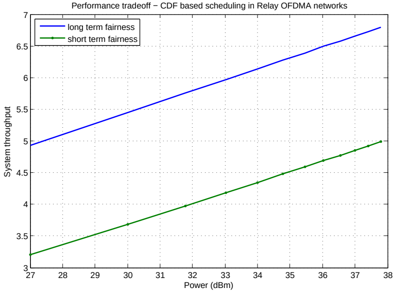


Figure: Tradeoff in system's throughput

Outline

Conclusion

- Consider a Weighted CDF-based scheduling OFDMA system with partial feedback
  - Ensures fairness
  - Supports user priority
  - Exploits multiuser diversity users
- Developed an analytical expression for system throughput
- The simulations verify the performance of the scheduling method on OFDMA systems

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Thank you!