A Self-Optimization Method for Coverage-Capacity Optimization in OFDMA networks with MIMO

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Outline

Background and motivation

- Wireless networks feature channel-aware schedulers, and there is a need to know the complete channel statistics for the evaluation of their performance
- Multiple antennas techniques (MIMO) allow to boost the network capacity dramatically
- Self-organisation and Self-optimization (SON) have become important research topics
- Example of application of SON: automatic outage detection and compensation

Related work

- Concept of α-fairness ([1])
- Capacity of MIMO systems ([2])
- Asymptotic distribution of the capacity of MIMO systems ([3])

[1] J. Mo and J. Walrand. "Fair End-to-End Window Based Congestion Control". In: *IEEE transactions networking* 8 (2000), pp. 556–566.

[2] Emre Telatar. "Capacity of Multi-antenna Gaussian Channels". In: *European Transactions on Telecommunications* 10 (1999), pp. 585–595.

[3] M. A. Kamath and B. L. Hughes. "The asymptotic capacity of multiple-antenna Rayleigh-fading channels". In: *IEEE Transactions on Information Theory* 51.12 (2005), pp. 4325–4333.

Alpha-fair scheduling: notations

- We consider a cell with N users
- The total available bandwidth W is divided in K Resource Blocks (RBs)
- Time is slotted, with a set of scheduling instants $(t_m)_{m\in\mathbb{N}}$
- $r_{i,t_m}^{(k)}$ denotes the instantaneous data rate of user i at time t_m on RB k
- The mean data rate is calculated by a low-pass filter , with $\epsilon > 0$:

$$\overline{r}_{i,t_{m+1}}^{(k)} = (1-\epsilon)\overline{r}_{i,t_m}^{(k)} + \epsilon\delta_{m+1,i,k} r_{i,t_{m+1}}^{(k)} \quad (1)$$

$$\overline{r}_{i,t_m} = \sum_{k=1}^{K} \overline{r}_{i,t_m}^{(k)} \quad (2)$$

with $\delta_{m,i,k} = 1$ if user i was allowed to transmit on RB k at t_m and 0 otherwise.

Alpha-fair scheduling: definition

Definition

Given $d > 0$, the α-fair scheduler is the scheduling strategy which maximizes:

$$U = \begin{cases} \sum_{i=1}^{N} \log(d + \bar{r}_i) & , \quad \alpha = 1 \\ \sum_{i=1}^{N} \frac{(\bar{r}_i + d)^{1-\alpha} - 1}{1 - \alpha} & , \quad \alpha \neq 1 \end{cases} \tag{3}$$

Alpha-fair scheduling: scheduling rule

Theorem

When $\epsilon \to 0^+$ the allocation rule of the α-fair scheduler is:

$$\arg\max_{1 \le i \le N} \frac{r^{(k)}_{i,t_{m+1}}}{(\bar{r}_{i,t_m} + d)^{\alpha}} \tag{4}$$

Sketch of proof:

- Applying stochastic approximation results, the behaviour of the system as $\epsilon \to 0^+$ reduces to the ODE $\dot{\theta}(t) = h(\theta(t)) - \theta(t)$
- The ODE has a solution using the Picard theorem, and we can use the Kamke condition to prove its convergence to an unique θ^*
- We show that θ^* is a local maximum of U, and we conclude using the convexity of U

MIMO channel: asymptotic capacity

- We assume n_t transmit antennas and n_r receive antennas
- I_{n_r} - the $n_r \times n_r$ identity matrix , H - the $n_r \times n_t$ channel matrix, Rayleigh fading, no antenna correlation
- Given H, the instantaneous capacity on RB k is:

$$C_i^{(k)} = \log_2 \left[\det \left(I_{n_r} + \frac{S_i^{(k)}}{n_t} H H^* \right) \right] \tag{5}$$

- Kamath and Hughes have shown that as $n_{min} = \min(n_t, n_r) \to +\infty$, $C_i^{(k)}$ converges in distribution to a normally distributed random variable with known mean and variance.
- The approximation is very accurate even for small values of n_{min}

Scheduling Gain

- Using the Gaussian approximation, the scheduling gain can be calculated for $\alpha \in \{0, 1, +\infty\}$
- $\alpha = 0$, Max Throughput

$$\bar{r}_i = \frac{K}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} (z\sigma_i + \mu_i) \left[\prod_{j \neq i} F\left(\frac{\mu_i - \mu_j + z\sigma_i}{\sigma_j} \right) \right] e^{-\frac{z^2}{2}} dz \tag{6}$$

- $\alpha = 1$, Proportional Fair

$$\bar{r}_i = \frac{K}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} (z\sigma_i + \mu_i) \left[\prod_{j \neq i} F\left(z \frac{\mu_i \sigma_j}{\mu_j \sigma_i} \right) \right] e^{-\frac{z^2}{2}} dz \tag{7}$$

- $\alpha = +\infty$, Max-min fair

$$\bar{r}_i = \frac{K}{\sum_{i=1}^{N} \frac{1}{\mu_i}} \tag{8}$$

Coverage capacity self-optimization

- We consider a service with minimal data rate R_{min}, and we want to adjust α dynamically to serve the maximal number of users
- Previous formulas allow to calculate which users can be served, providing that α is large enough
- Every 1s or so, the base station increases α if some users are below R_{min}, and decreases α otherwise.

Simulation

- We consider a multi-cell network where users arrive according to a Poisson process to receive a service with minimal data rate (e.g streaming) and leave upon completion
- α is adjusted according to the mechanism described above
- Users are dropped if they do not receive the minimal data rate for a certain period of time
- We show that the mechanism decreases the dropping rate appreciably

Simulation results

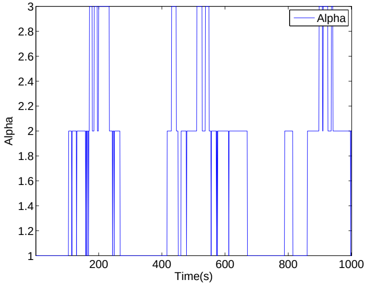

Figure: Evolution of α as a function of time for a base station.

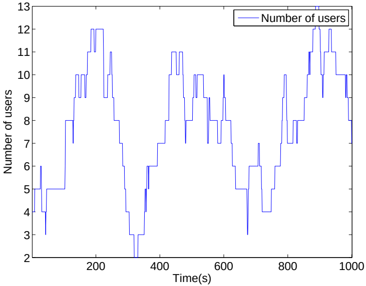

Figure: Number of users in a base station as a function of time.

Simulation results(cont'd)

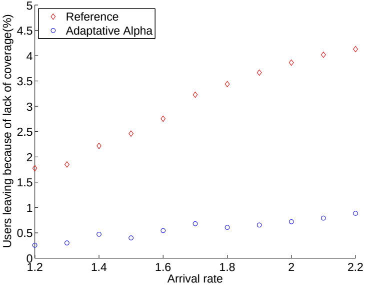

Figure: Number of users leaving because of lack of coverage as a function of arrival rate.

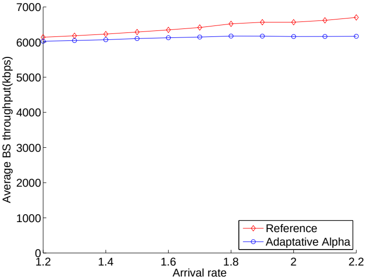

Figure: Average base station throughput as a function of arrival rate.

Conclusion

- The α-fair scheduler in the context of OFDMA with MIMO has been analysed
- Scheduling gain for $\alpha \in \{0, 1, +\infty\}$ has been derived using the asymptotic distribution of the MIMO channel capacity
- A mechanism based on α-fair schedulers has been introduced and it's performance has been evaluated using a network simulator
- The mechanism brings a considerable increase in user perceived quality of service