Self-Optimizing Strategies for Interference Coordination in OFDMA Networks

R. Combes[1] Z. Altman[1] M. Haddad[2] E. Altman[2]

[1]Orange Labs

[2]INRIA Sophia-Antipolis

IEEE ICC 2011, Workshop on Planning and Optimization of Wireless Communication Networks

Outline

Background and motivation

- Self-Organizing Networks (SON): embedding of autonomic features into networks, actively discussed by standardisation bodies:
    - self-configuration
    - self-optimization
    - self-healing
- Inter-Cell Interference Coordination (ICIC) is one of the major SON use cases
- A SON mechanism should be:
    - distributed
    - computationally light
    - delay-tolerant
- In this work we study various light-weight distributed ICIC mechanisms, including complexity/performance trade-off and engineering guidelines

Related work

The major SON use cases currently discussed by researchers and standardisation bodies are:

- ICIC ([1],[2])
- Cell outage management[3]
- Coverage-capacity optimization[4]
- Energy savings and green networks[5]

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[1] A.L. Stolyar and H. Viswanathan. “Self-Organizing Dynamic Fractional Frequency Reuse for Best-Effort Traffic through Distributed Inter-Cell Coordination”. In: *INFOCOM*. 2009.

[2] G. Wunder et al. “Self-organizing distributed inter-cell beam coordination in cellular networks with best effort traffic”. In: *WiOpt*. 2010.

[3] M. Amirijoo et al. “Cell outage management in LTE networks”. In: *ISWCS*. 2009.

[4] R. Combes, Z. Altman, and E. Altman. “Scheduling gain for Frequency-selective Rayleigh-Fading channels with application to Self-Organizing packet scheduling”. In: *Performance Evaluation* (2011).

[5] 3GPP. *Telecommunication management; Study on Energy Savings Management (ESM)*. TR 32.826. 3GPP, Apr. 2010.

The model

- We consider an OFDMA-based network under full reuse, in the downlink scenario
- Available bandwidth is divided into N_p RB (resource blocks), and RBs are grouped into N_b sub-bands
- Each base-station adjusts it's transmit power on each sub-band, and can exchange information with its neighbours using an interface (X2 interface in LTE)

The model:ICIC strategies

- Three ICIC schemes are considered:
  - Power control: $N_b = 1$ sub-band, continuous power levels
  - Fractional load: $N_b > 1$, discrete power levels $\{P_{min}, P_{max}\}$
  - Fractional frequency reuse: $N_b > 1$, continuous power levels

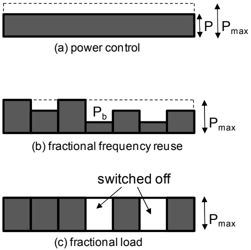

Figure: ICIC schemes

The model:SINR and data rates calculation

- The mean SINR on a RB is calculated by summing the interference from neighbouring base stations:

$$S_{s,i}^{(b)} = \frac{h_{s \to i} P_s^{(b)}}{N_0^2 + \sum_{s' \in \mathcal{N}_s} h_{s' \to i} P_{s'}^{(b)}} \qquad (1)$$

- The corresponding user peak data rate on a RB is obtained by integration over the fast-fading distribution (ignoring fading in the interfering signals)

$$\Psi(S_{s,i}^{(b)}) = N_{PRB} \int_0^{+\infty} \Phi(x S_{s,i}^{(b)}) e^{-x} dx \qquad (2)$$

- Ψ allows to calculate the data rate of a user for both round-robin and proportional fair (opportunistic) scheduler

$$r_i = \frac{1}{N_u(s)} \sum_{b=1}^{N_b} \Psi\left(S_{s,i}^{(b)}\right) \qquad (3)$$

The model: traffic model and ICIC

- Users arrive in the network at random locations and instants, to receive a file of given size.
- Users leave the network upon service completion
- We want to design an ICIC mechanism to maximize metrics such as: capacity region, blocking rate or file transfer time
- Given dynamical arrivals and departures, the problem is a large-dimensional MDP, which is too complex for a large number of base stations
- We use a greedy approach: for each configuration of users (state) we maximize a well-chosen function of the user data rates

The model: utility function

- We define the utility of a base station using α-fairness:

$$U_s = \begin{cases} \sum_{i=1}^{N_u(s)} \log(d + r_i) & , \quad \alpha = 1 \\ \sum_{i=1}^{N_u(s)} \frac{(d + r_i)^{1-\alpha}}{1-\alpha} & , \quad \alpha \neq 1 \end{cases} \tag{5}$$

- Utility of the network is the sum of the base station utilities: $U = \sum_s U_s$
- We will show that there exists an optimal α

Proposed algorithm: continuous power levels

- Finding the global optimum of U for a general user configuration is generally computationally hard, so we settle for local optima and heuristics
- Using previous calculations, $\vec{\nabla} U$ can be calculated in closed form
- For continuous power levels, we use a projected gradient descent, which can be implemented in a distributed way

$$\pi_s(0) \in \mathcal{P}_s \ , \ \pi_s(t+1) = \Big[\pi_s(t) + \mu \vec{\nabla}_s U(\pi_s(t))\Big]^+ \qquad (6)$$

Proposed algorithm: discrete power levels

- For discrete power levels we introduce a greedy heuristic to choose a sub-band to “turn off” and another to “turn on”, given a constraint on the number of “off” bands.

$$b_{off} = \underset{b,(\pi_s(t))_b = P_{max}}{\arg\min} \; (\vec{\nabla}_s U(\pi_s(t)))_b$$

$$b_{on} = \underset{b,(\pi_s(t))_b = P_{min}}{\arg\max} \; (\vec{\nabla}_s U(\pi_s(t)))_b$$

Turn on b_{on} and turn off b_{off} if it is admissible
and $(\vec{\nabla}_s U(\pi_s(t)))_{b_{on}} > 0$ and $(\vec{\nabla}_s U(\pi_s(t)))_{b_{off}} < 0$
Else turn on b_{on} if it is admissible and $(\vec{\nabla}_s U(\pi_s(t)))_{b_{on}} > 0$
Else turn off b_{off} if it is admissible and $(\vec{\nabla}_s U(\pi_s(t)))_{b_{off}} < 0$
Else keep the same power allocation

Table: fractional load algorithm

Complexity, signalling load and delay

- All power updates are done using closed-form formulas so the computational effort is very small
- For each power update, a base station has to exchange the corresponding derivatives of U with it's neighbours through an interface (X2 interface in LTE)
- The signalling load is proportional to the number of bands N_b times the number of neighbours, in practice less than 1 kbps
- Power updates occur every $1s$, and the interface delay is expected to be below $50ms$, hence delay is not critical either

Simulation

The efficiency of the proposed mechanism is assessed using a network simulator:

- Users arrive according to a Poisson process
- Channel fast-fading and opportunistic scheduling are taken into account (proportional fair)
- Distance-dependant path-loss and shadowing are taken into account
- Performance/complexity of the ICIC mechanisms trade-off is assessed
- The optimal value of α is found numerically

Simulation results

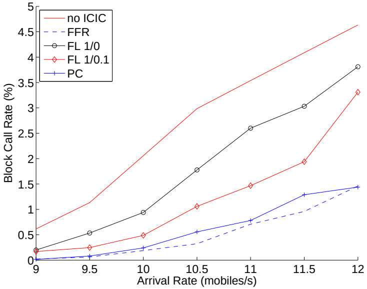

Figure: Comparison of blocking rates for different ICIC strategies

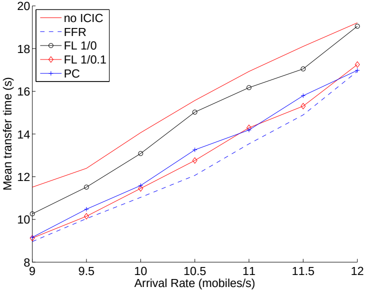

Figure: Comparison of mean file transfer time for different ICIC strategies

Simulation results(cont'd)

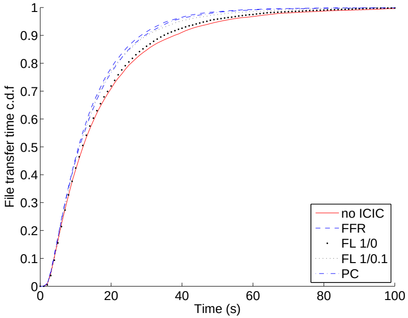

Figure: c.d.f of file transfer time

Simulation results(cont'd)

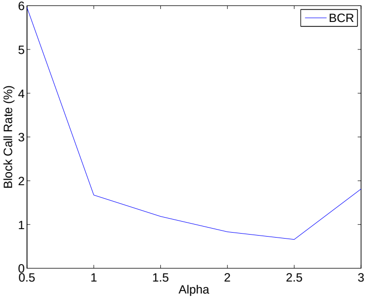

Figure: Blocking rate for different values of α

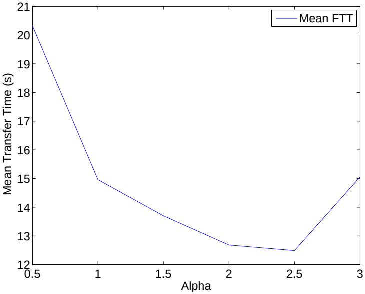

Figure: Mean file transfer time for different values of α

Conclusion

- Trade-off between performance and complexity of light-weight ICIC schemes have been assessed at the flow-level
- ICIC schemes effectively reduce congestion and bring noticeable improvement of QoS metrics such as blocking rate and file transfer time
- It has been shown that minimizing the potential delay (setting α = 2) gives the best performance