Application of Simulated Annealing in 5G Cellular Network Selection Problems

Yilin Shi   Wenjin Ji   Zihan Xu   Yingtong Wang

TA Mohit Hota

ILLINOIS INSTITUTE OF TECHNOLOGY

Introduction

The wireless network selection game has P clients connect to K base stations. We assume one client can only connect to one base station. The objective is to schedule clients on base stations to minimize interference and optimize throughput. Path loss is a major component in the analysis of the throughput of a telecommunication system. In our research, we use SUI path loss model [1] to calculate path loss. We introduce two different ways to measure the optimum schedule of clients. One is to maximize the sum of each client's throughput, called max-sum measure. Another is to maximize the minimum throughput among all clients, called max-min measure.

For problems where finding an approximate global optimum is more important than finding a precise local optimum in a fixed amount of time, simulated annealing [2] may be preferable to other alternatives. Therefore, we use simulated annealing algorithm to find the optimum schedule of clients.

In the situation of selfish selection, each client selects base station only to maximize her own throughput, regardless of the others.

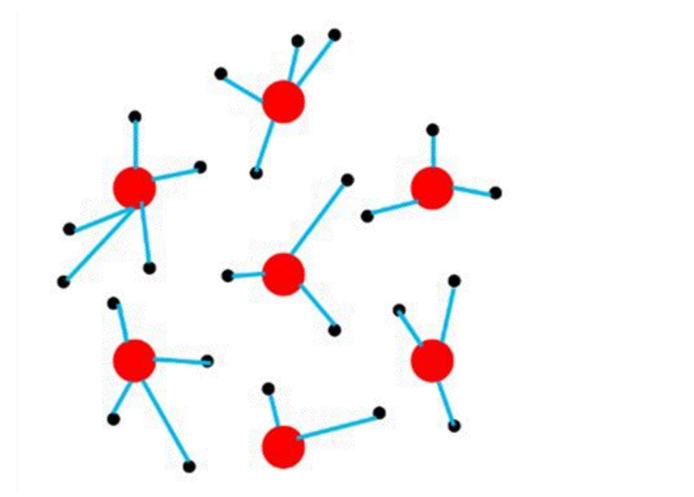

Figure1.a clients(black)-base stations(red) connection(blue) model for Selfish Selection

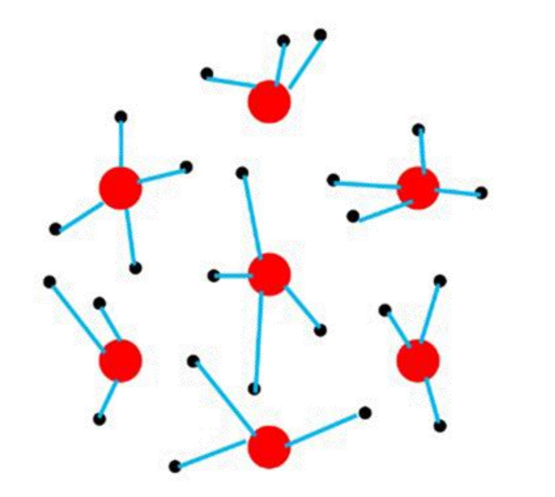

Figure1.b clients(black)-base stations(red) connection(blue) model for Optimum Solution

SUI Path Loss Model

$$PL_{SUI}(d) = PL(d_0) + 10n\log_{10}(\frac{d}{d_0}) + X_{f_c} + X_{RX}$$

where

$$PL(d_0) = 20 \cdot \log_{10}(\frac{4\pi d_0}{\lambda})$$

$$n = a - b \cdot h_{TX} + \frac{c}{h_{TX}}$$

$$X_{f_c} = 6 \cdot \log_{10}\left(\frac{f_{MHz}}{2000}\right), f_c > 2GHz$$

$$X_{RX} = -10.8 \cdot \log_{10}\left(\frac{h_{RX}}{2}\right)$$

PL(d0) denotes the free space path loss in dB; d0 is the close-in reference distance; λ is the carrier wavelength in meters. The parameters a, b, and c are constants used to model the terrain types encountered in the service area (we consider the model suited for hilly and dense vegetation, with parameters given as a = 4.6, b = 0.0075, and c = 12.6). X(fc) and X(RX) denote the correction factors for frequency and receiver heights, respectively; f(MHz) is the carrier frequency in MHz; h(TX) and h(RX) are the transmitter (TX) and receiver (RX) antenna heights in meters, respectively.

Simulated Annealing Algorithm

Algorithm 1 The model is denoted by G = (P, K, E)

Start with random assignment of n clients to m base stations

Calculate the signal strength $\sigma_{i,j}$ each client i obtains on each base station j

$$\sigma(i,j) = P \times 10^{\frac{-PL}{10}}$$

Connect clients to base stations where they get maximum signal strength

Set T = 3000

while T > 1 **do**

  Select $\frac{n}{10}$ clients with minimum SIR, and randomly connect them to new stations

$$SIR_i = \frac{\sigma(i,j)}{\sum_{i)} \sigma(i,j)}$$

  if the change improves the objective function **then**

    Accept the change

  else

    Accept the change in probability P, where $P = \exp(\frac{\Delta O}{k_0 T})$

    T = T×(1-β)

  end if

end while

In order to find out what value we should set for k_0 and cooling rate(β) in the simulated annealing algorithm, we run a small example with 8 clients and 4 stations, and enumerate all possibilities. Through calculating the goodness of fit, we get the most appropriate value for k_0 and cooling rate.

$$\text{Goodness of fit} = \frac{\text{optimum result get from simulated annealing}}{\text{optimum result get from enumeration}}$$

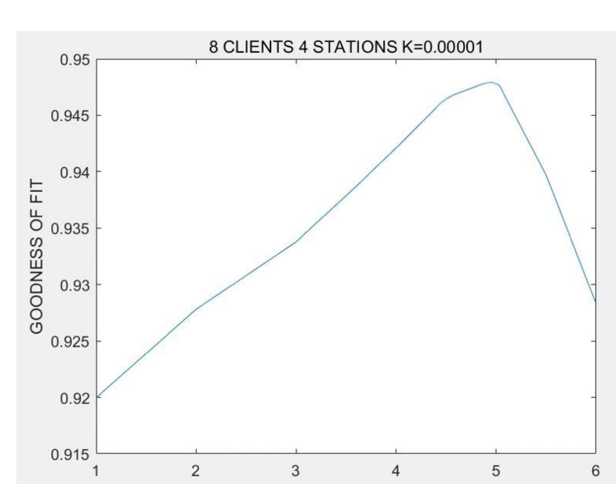

Figure2.a The most appropriate cooling rate(β) = 0.005.

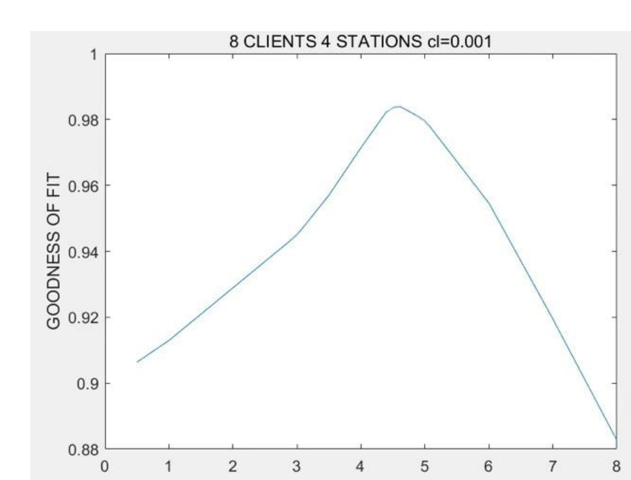

Figure2.b The most appropriate k0 = 0.000045.

Wireless Network Interference Model

$$\sigma(i,j) = P \times 10^{\frac{-PL}{10}}$$

$$SIR_i = \frac{\sigma(i,j)}{\sum_i \sigma(i,j)}$$

$$w(i,j) = log(1 + SIR_i)$$

σ (i,j) denotes the signal strength that client i obtains on base station j, P is the power of station j (we assume all stations have same power, which is equal to 1); PL is the path loss in dB. SIR denotes the signal-to-interference ratio. w (i,j) denotes the throughput client i obtains on base station j.

For max-sum measure, the objective function is $\sum_i w(i,j)$

For max-min measure, the objective function is $min_i w(i,j)$

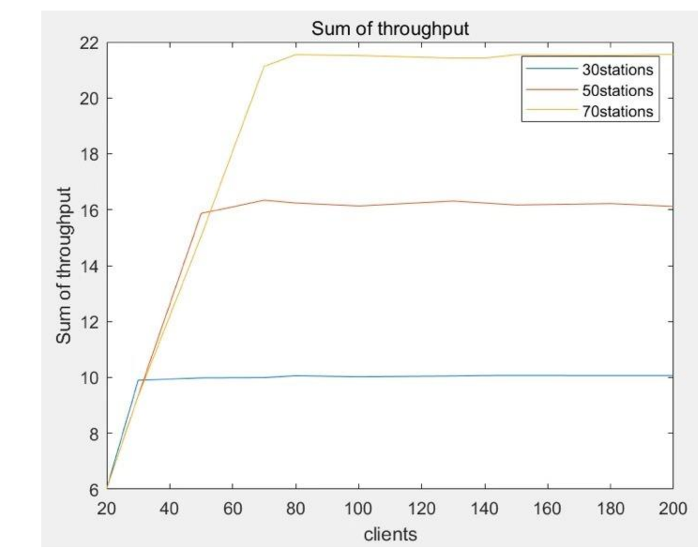

Figure3.a Relationship between sum of throughput and the number of clients. Objective function is ∑log(1+SIR).

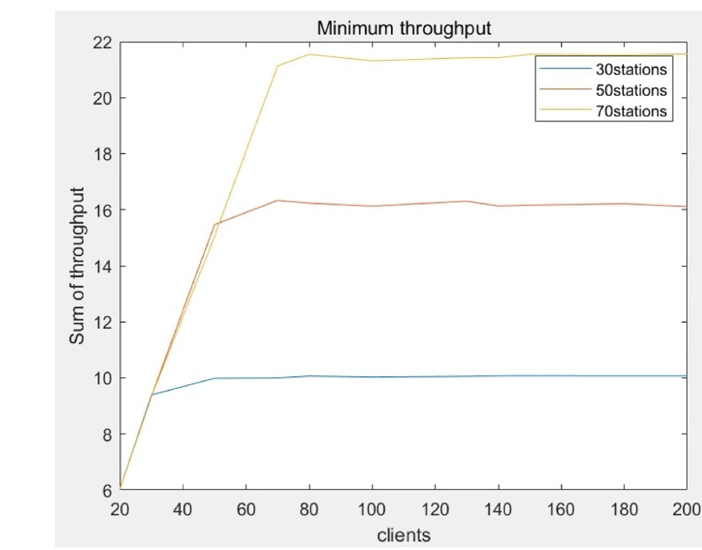

Figure3.b Relationship between sum of throughput and the number of clients. Objective function is min_log(1+SIR).

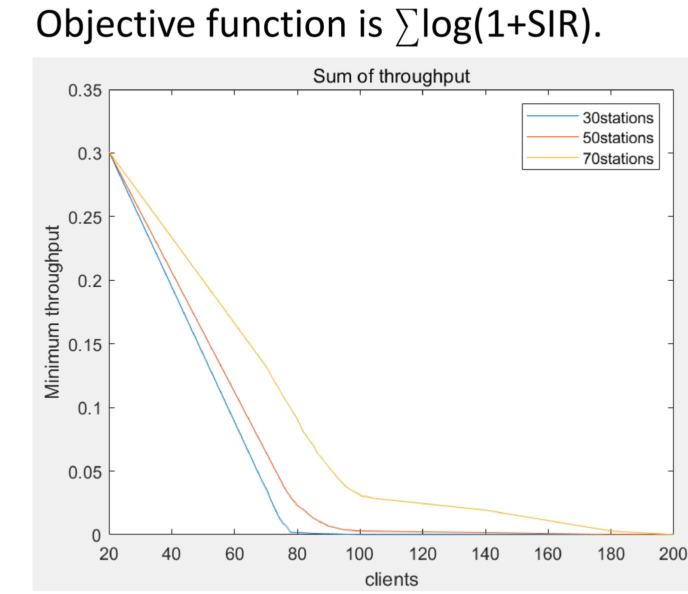

Figure4.a Relationship between minimum throughput and the number of clients. Objective function is ∑log(1+SIR).

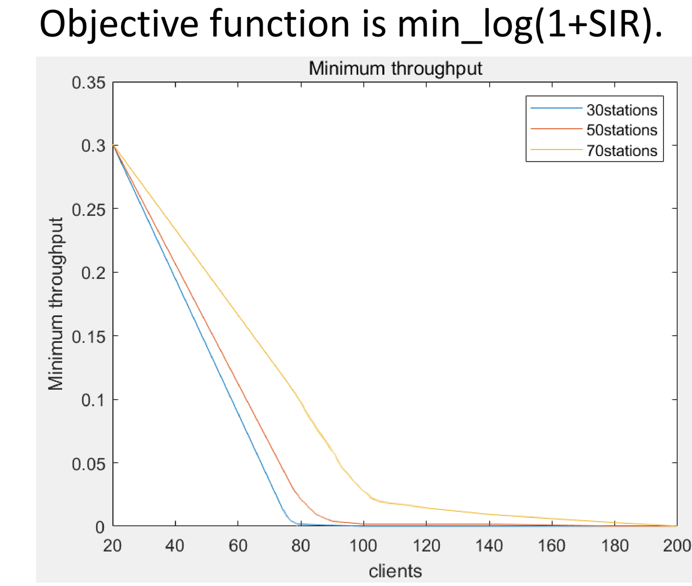

Figure4.b Relationship between minimum throughput and the number of clients. Objective function is min_log(1+SIR).

$$\text{Unfairness} = \frac{\text{maximum throughput}}{\text{minimum throughput}}$$

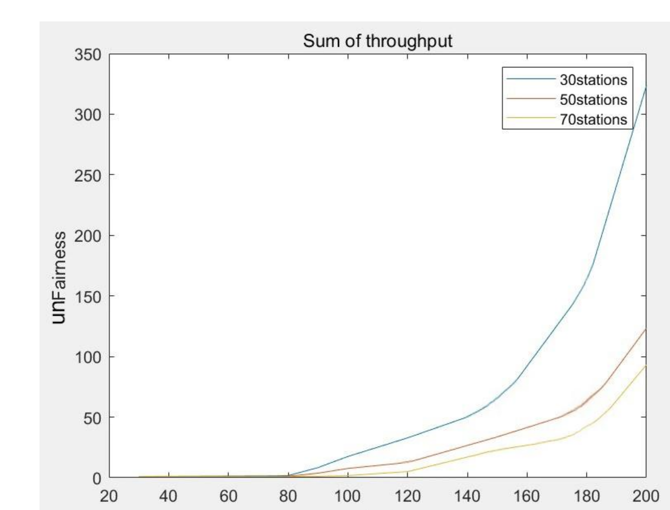

Figure5.a Unfairness when the objective function is ∑log(1+SIR).

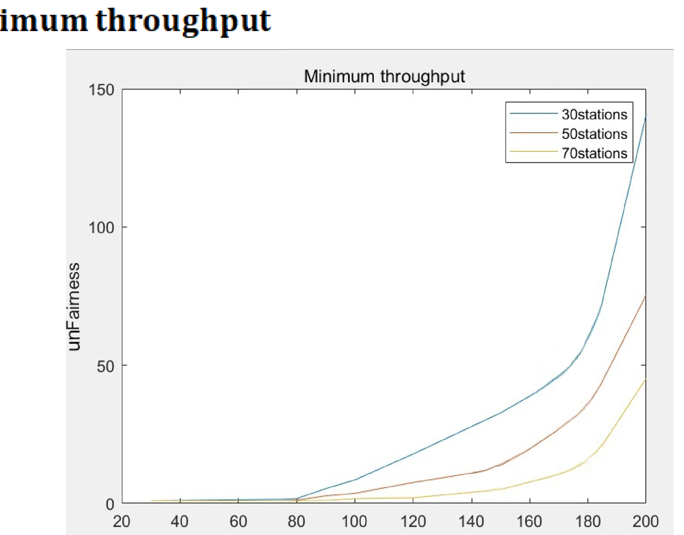

Figure5.b Unfairness when the objective function is min_log(1+SIR).

Conclusions

- For both objective functions, price of anarchy is close to 1, which implies the objective of selfish selection and optimum solution are similar.
- For social fairness, selfish selection is much worse than the optimum solution.
- To ensure fairness in throughputs, optimizing using the max-min metric is clearly better than optimizing the sum of all throughputs.

References

[1] A. I. Sulyman, A. T. Nassar, M. K. Samimi, G. R. Maccartney, T. S. Rappaport and A. Alsanie, "Radio propagation path loss models for 5G cellular networks in the 28 GHZ and 38 GHZ millimeter-wave bands," in IEEE Communications Magazine, vol. 52, no. 9, pp. 78-86, September 2014.

[2] S. Kirkpatrick, C. D. Gelatt, Jr., and M. P. Vecchi, Science 220:671–680 (1983).