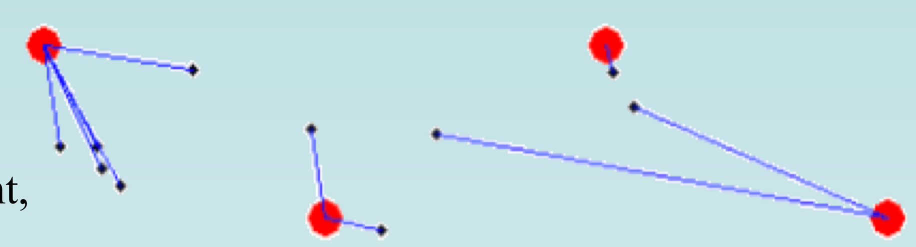
Nash Equilibrium in 5G Cellular Network Selection Games

Zihan Xu(zxu61@hawk.iit.edu A20454244) , ***Yingtong Wang***(ywang502@hawk.iit.edu A20454534)
Yilin Shi(yshi64@hawk.iit.edu A20454146) , ***Wenjin Ji***(wji5@hawk.iit.edu A20455034)
TA ***Mohit Hota***(mhota@hawk.iit.edu)

ILLINOIS INSTITUTE OF TECHNOLOGY

Abstract

We study network selection games in 5G cellular networks and utilize a model which incorporates path loss. A client connects to exactly one Base Station. Each client selects a base station to maximize their own throughput. We formulate a non-cooperative game and study its convergence to a pure Nash equilibrium and calculate the throughput for every client, and present an algorithm to discover pure Nash equilibrium.



Introduction

- In a **Nash Equilibrium** game, regardless of the choice of the other player's strategy, the players will choose a certain strategy which is best for themselves.
- In the model of **Radio Propagation Path Loss Models for 5G Cellular Network**, when directional antennas are pointed in the single best directions at the base station and mobile. The Model is defined as fellow:

- $PL_{SUI}(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_{f_c} + X_{RX} + X_\sigma$
- Where $PL(d_0) = 20\cdot\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$; $n = a - b\cdot h_{TX} + \frac{c}{h_{Tx}}$;

  $X_{f_c} = 6\cdot\log_{10}\left(\frac{f_{MHz}}{2000}\right)$; $X_{RX} = -10.8\cdot\log_{10}\left(\frac{h_{RX}}{2}\right)$.
- λ : carrier wavelength;

  h_{TX}: transmitter antenna heights;

  h_{RX}: receiver antenna heights in meters;

  d_0: a close-in reference distance;

  f_c: carrier frequency.

Algorithm

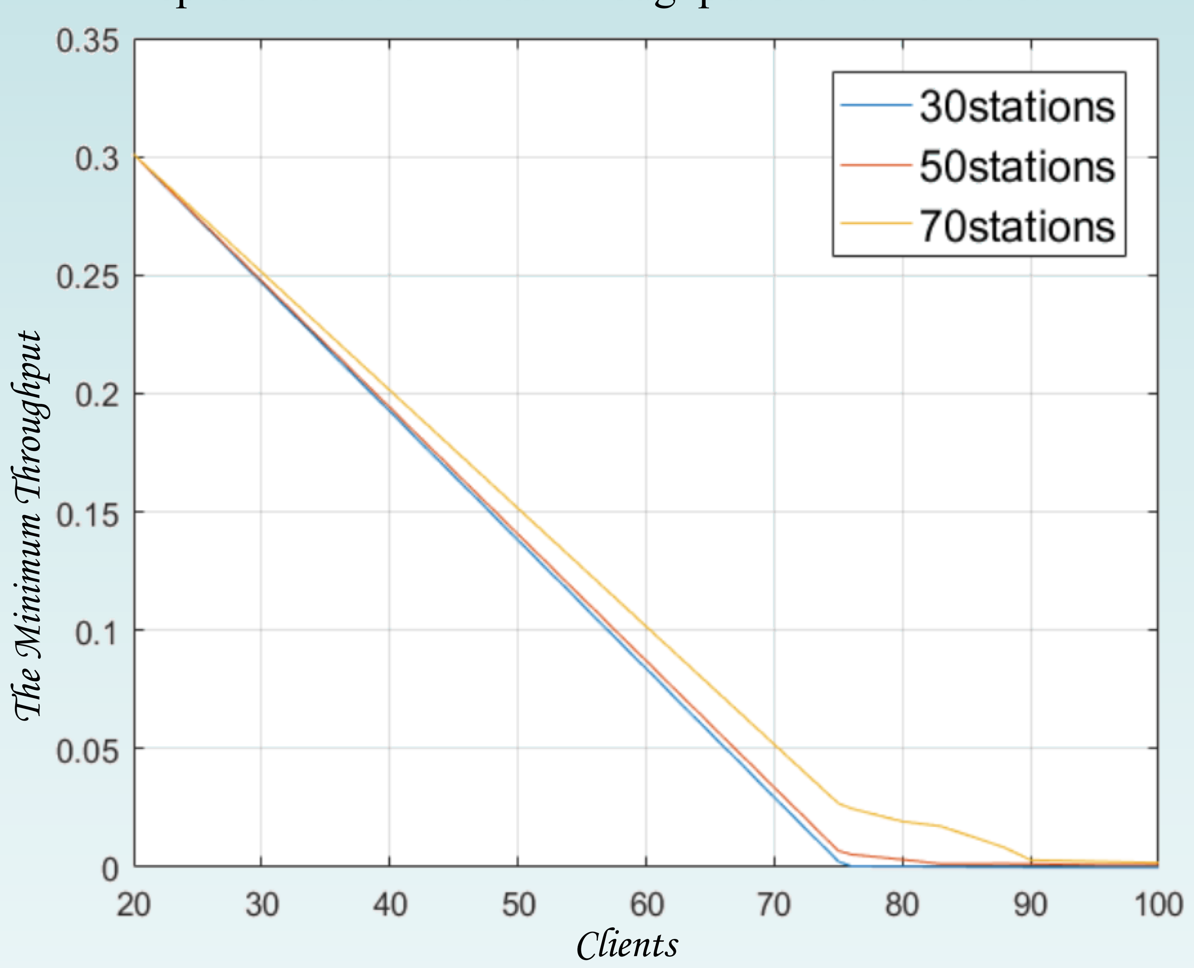
- Start with random assignment of users
- Throughput $\omega_i(s(k))$ that client i obtains on base station k is defined as follows

- $SIR_i = \frac{\sigma(i,j)}{\sum_{i\in s(j)}\sigma(i,j)}$; $\omega_i(s(k)) = log(1 + SIR_i)$
  - SIR_i**:** signal to interference ratio
  - σ**:** signal strength
  - $\omega_i(s(k))$***:*** *throughput*
- **While** ∃ clients who can improve throughput by a factor of $(1+\epsilon)$ by switching to another base station **do**
  - Select and move client i from $k \rightarrow k'$

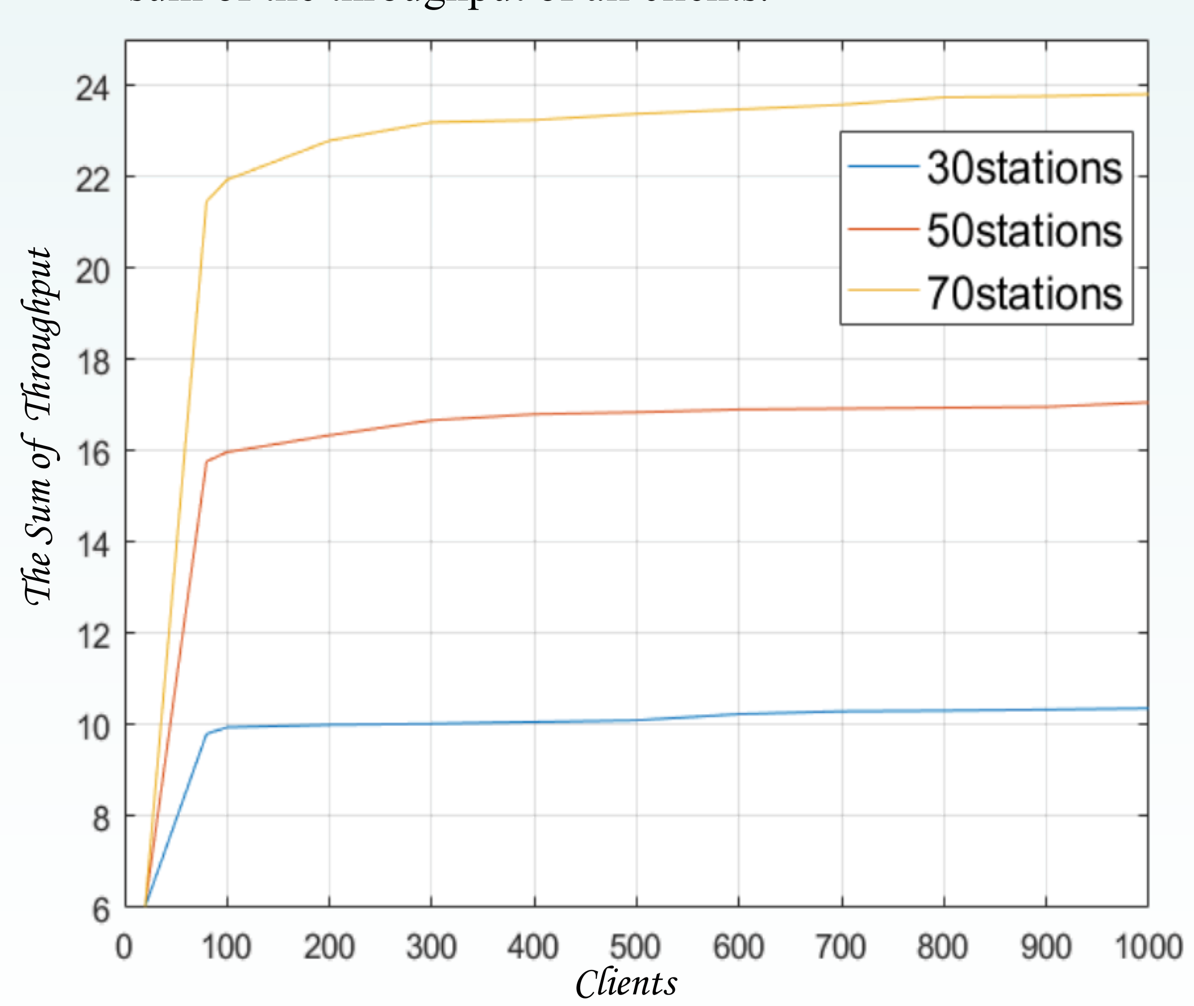
Simulation

The Minimum and Sum of Throughput in Nash Equilibrium Based on Different Clients and Base Stations' Number

- Minimum Throughput = $\min_i\ (\log(1 + \mathrm{SIR}_i))$ represents the smallest throughput over all clients.



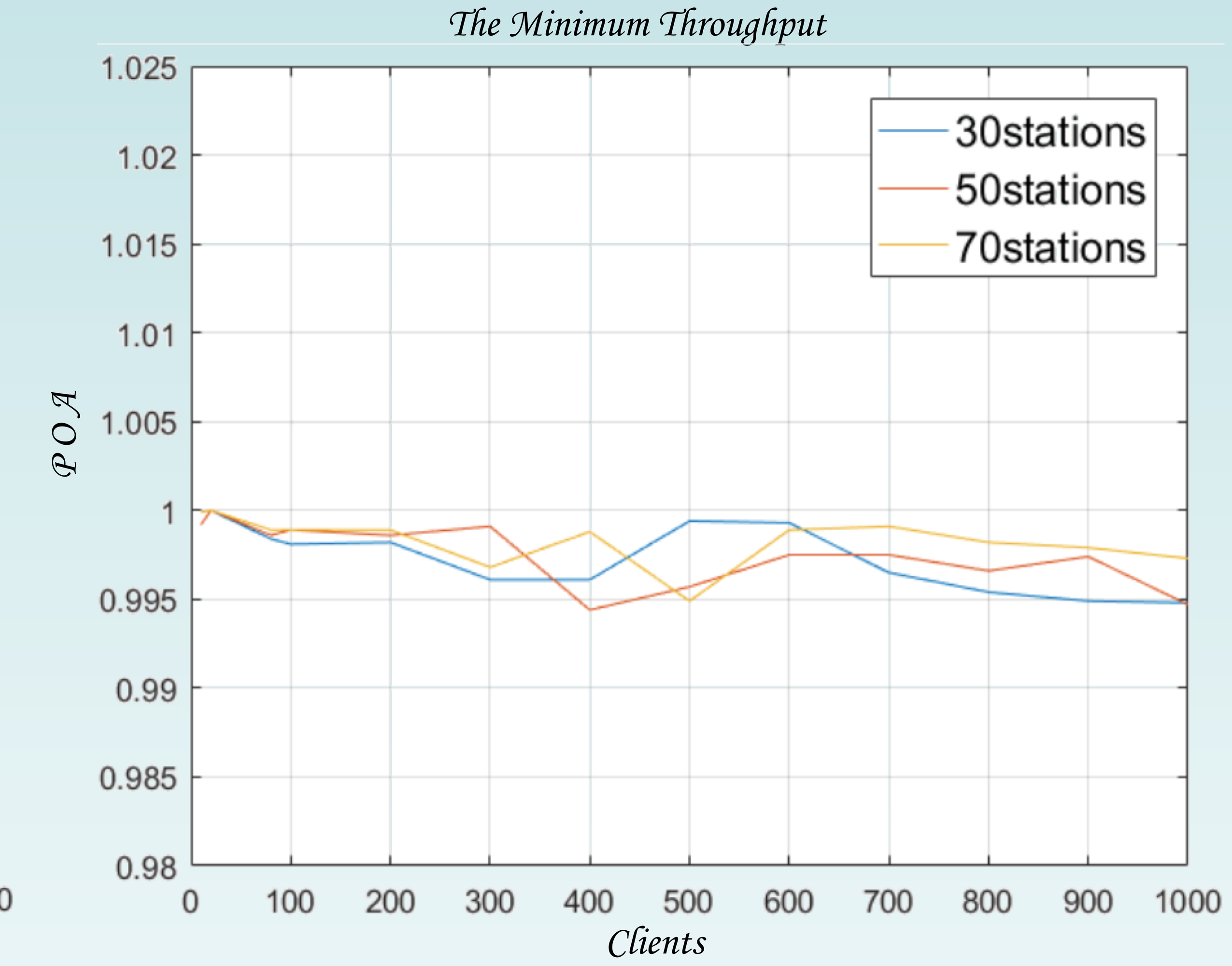
- Sum of throughput = $\sum_i \log(1 + SIR_i)$ represents the sum of the throughput of all clients.

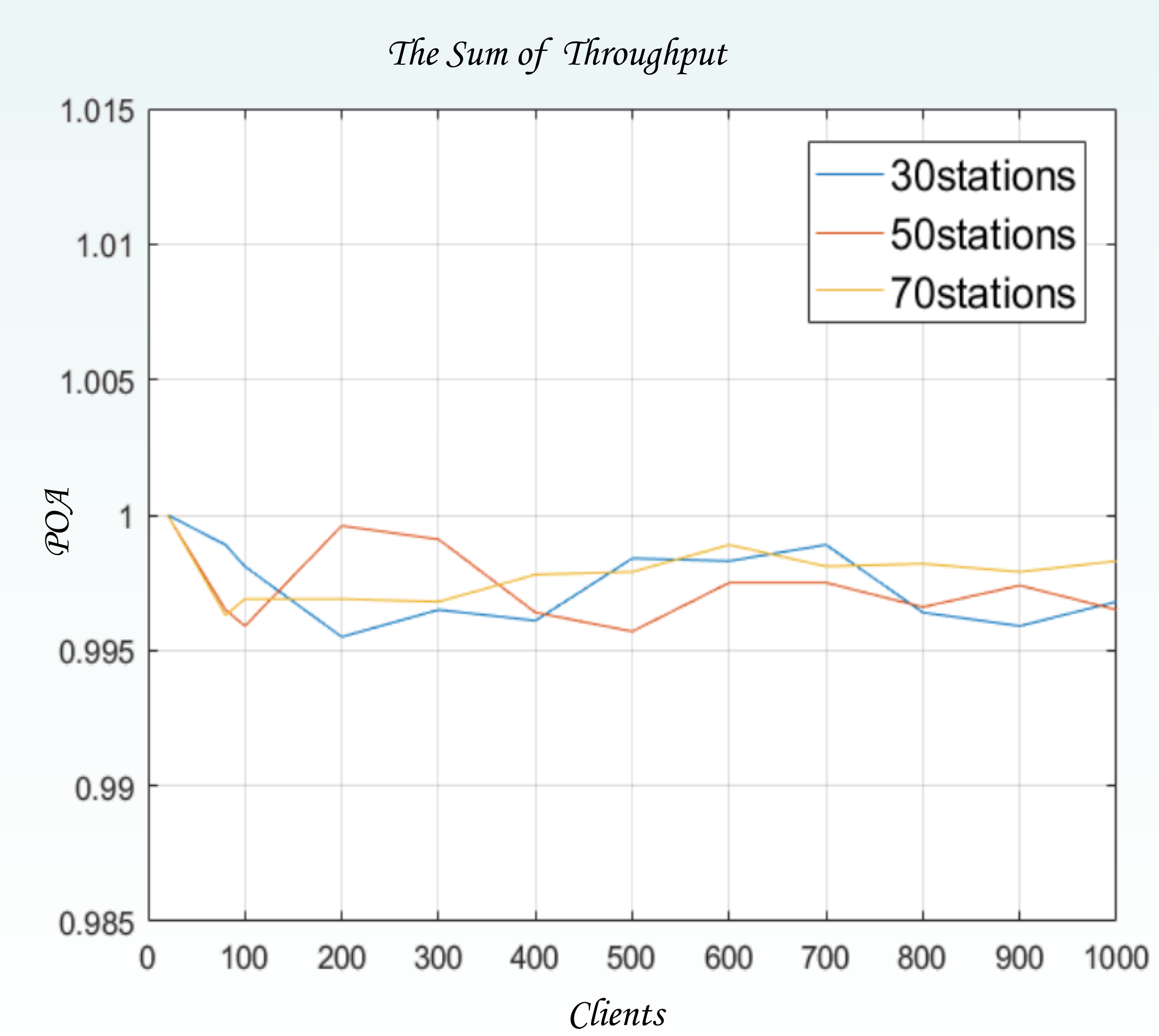


- More base stations means more resources are provided to the same number of clients, and more clients means more people share the same amount of resources.

The POA Comparison Between Nash Equilibrium and Simulated Annealing Based on Different Clients and Base Stations' Number

$$\mathrm{POA} = \frac{Nash\ Equilibrium\ Social\ Welfare}{Optimum\ Social\ Welfare}$$

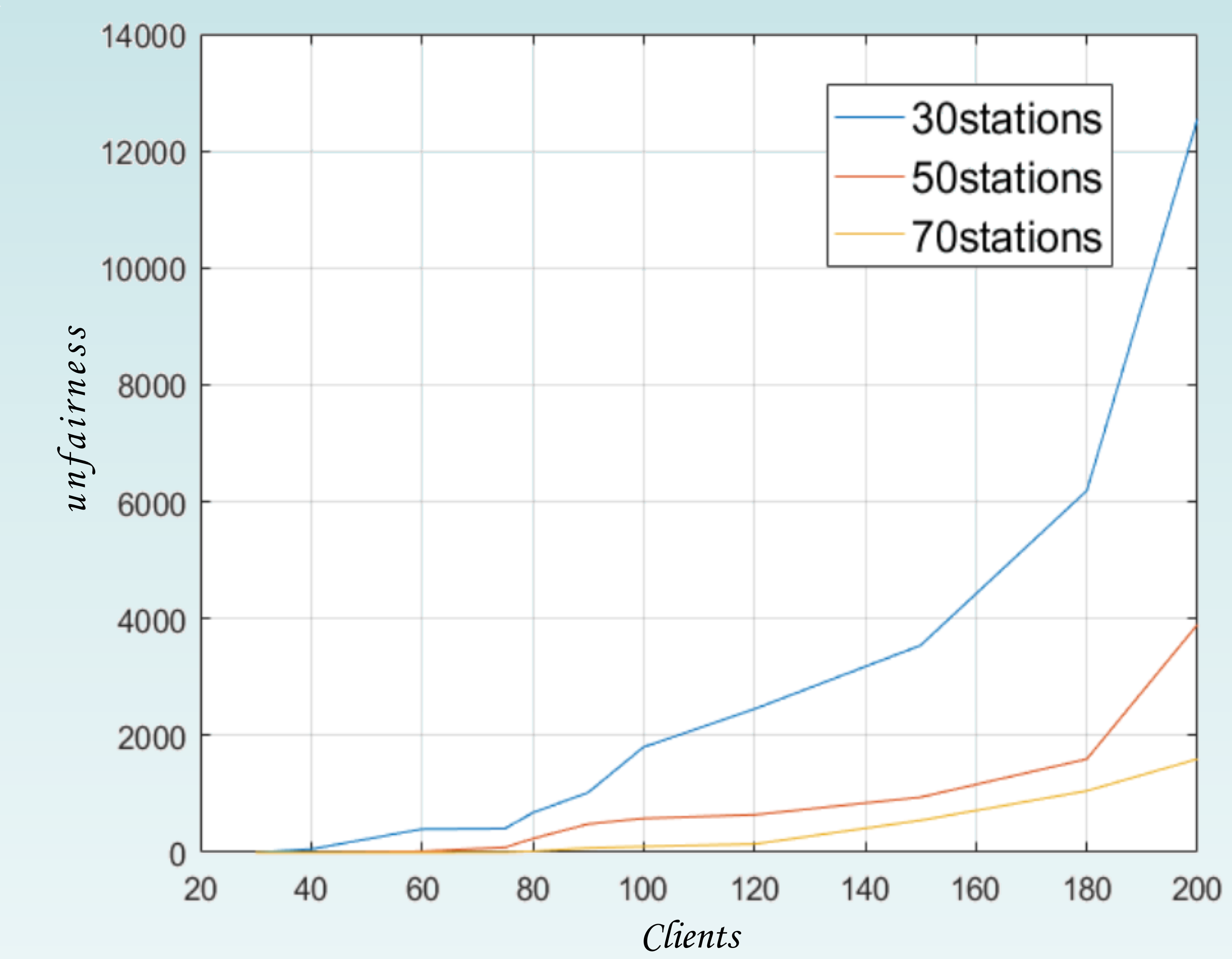




- The Nash Equilibrium algorithm performs well in comparison to the optimum even when the number of clients approaches 1000.

The Fairness Comparison in Nash Equilibrium Based on Different Clients and Base Stations' Number

$$UNFAIRNESS = \frac{Max\ Throughput}{Min\ Throughput}$$



Conclusion

- Through the calculation of the algorithm of the program, we observe that the Nash Equilibrium exists in most cases. But in rare cases (probability seems to be less than about one in a hundred million), Nash Equilibrium does not exist.
- Through the POA comparison between Nash Equilibrium and Optimum, we conclude that the POA is very close to 1 in the case of a small number of clients and base stations, indicating that both the Nash Equilibrium algorithm and the optimum are close to each other w.r.t. throughput.
- Even when the number of clients and base stations becomes large, the POA is still close to 1.
- While POA is close to 1, with an increase in the number of clients, we observe that Nash Equilibrium yields a strong disparity in fairness. Multiple clients appear to starve.