A Best-Case Performance Comparison of Cellular Data Networks with Cooperating and Non-cooperating Base Stations

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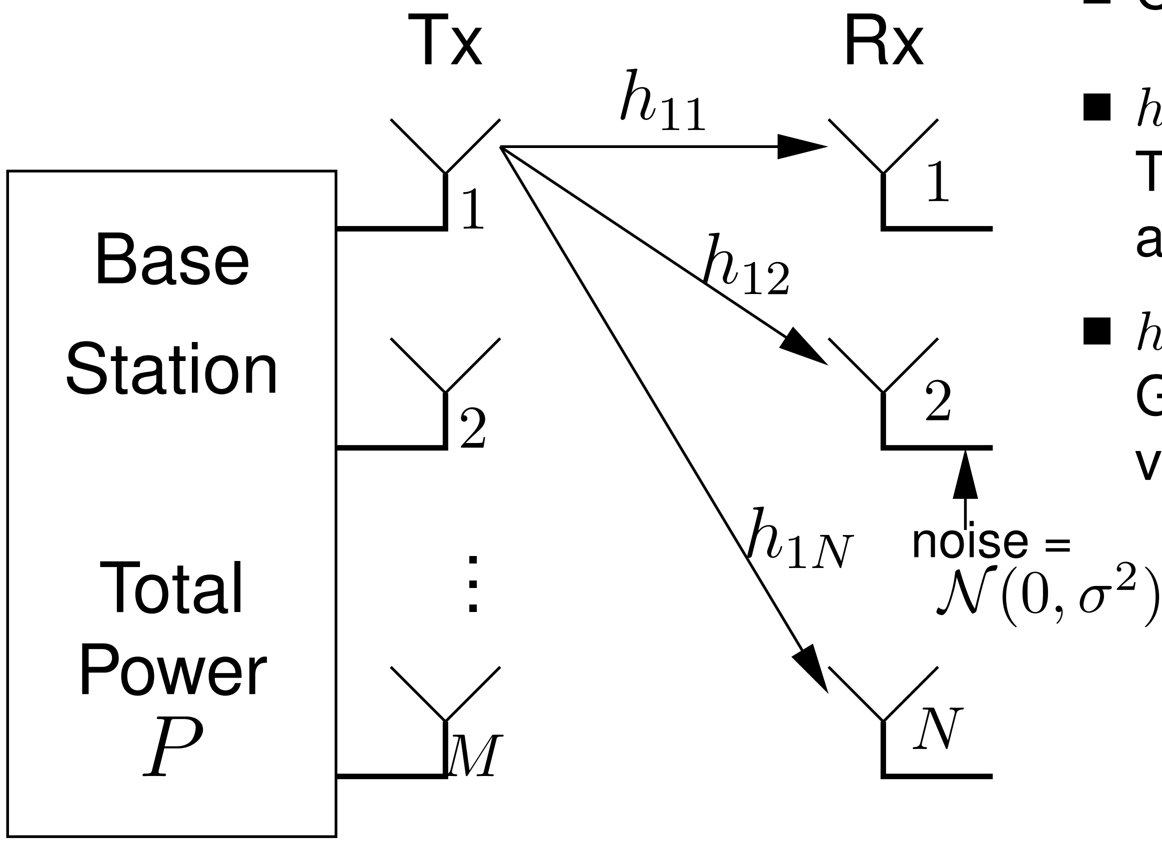
Motivation

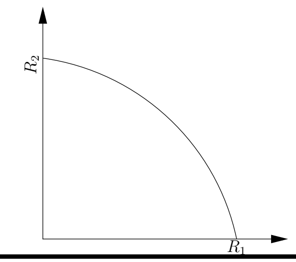
- Consider a cellular system
- Tx antennas interconnected and (may) cooperate with each-other
- Find service disciplines to optimize QoS metrics such as
  - Average delay,
  - Maximum offered load,
  - Probability of outage etc.
- Channel can be modeled as a multi-user MIMO Broadcast Channel (BC)

System Model

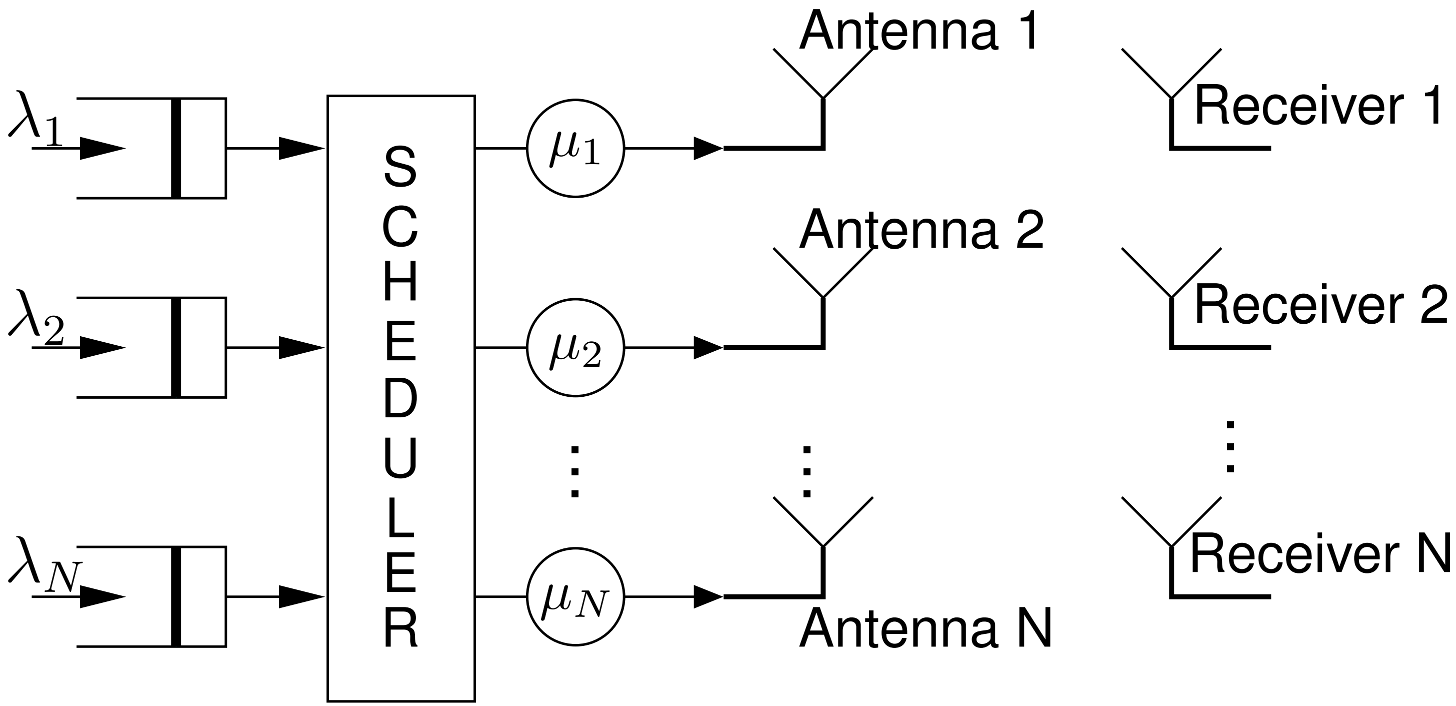


- Channel $\underline{\underline{H}} = [h_{ij}]$
- h_{ij} - channel coefficient from Transmit antenna i to Receive antenna j
- h_{ij} assumed to be complex Gaussian zero mean unit variance and identical

- Dirty-paper coding can be applied to find capacity region
- Capacity region depends upon $\underline{\underline{H}}$ and P.
- SNR $\triangleq \frac{P}{\sigma^2}$.



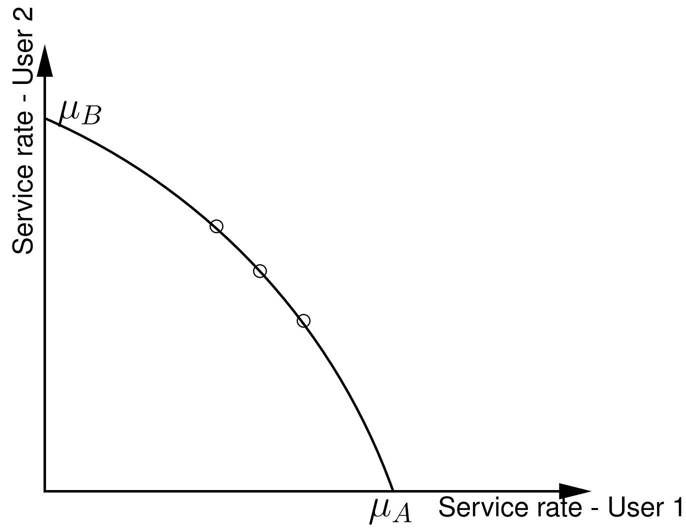
Queueing Model



$$\boldsymbol{\lambda} = \lambda_1[k_1, k_2, \cdots, k_N]$$

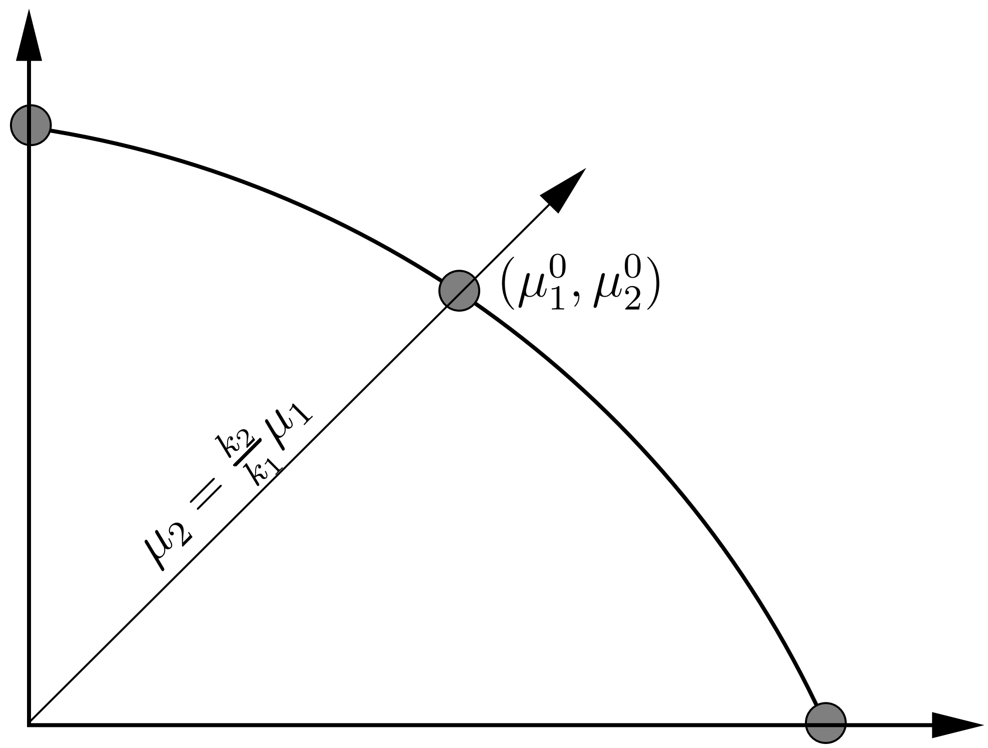
- Poisson arrivals
- Exponentially distributed message lengths

Queue Service Scheduling



- Operate at $(R_1, R_2) = (\mu_A, 0)$ if queue 2 is empty.
- Operate at $(R_1, R_2) = (0, \mu_B)$ if queue 1 is empty.
- Operate at the point on the capacity region surface if queue 1 and queue 2 are both non-empty.
- Optimum point may depend on lengths of queue 1 and queue 2.
- Generalize for N-user case
- An objective is to find the operating points that optimize some metric.

Metric 1: Maximize Saturation Throughput



- For 2-users, it can be shown that 3-point operation maximizes throughput.
- The third point corresponds to $(R_1, R_2) = (\mu_1^0, \mu_2^0)$ where $\frac{\mu_1^0}{\mu_2^0} = \frac{k_1}{k_2}$.
- This third point is used whenever both queues are non-empty.
- The above generalizes to $2^N - 1$ operating points for N users.

Fixed Point Approximation (FPA)

- In general, coupled queueing system as described above cannot be solved in closed-form.
- Fixed point approximations are considered.
- Used to study the behavior of parallel queues w/ dependent service rates [Kel89]
- Replaces the parallel queues by independent $M/M/1$ queues with dependent but constant service rates.
- Our system:
  Parallel queues with varying and dependent service rates
- We expect good approximations in high-load and no-load regions
  because queues are almost always independent and Markovian in those regions.

Sample Results for SNR = 10 dB

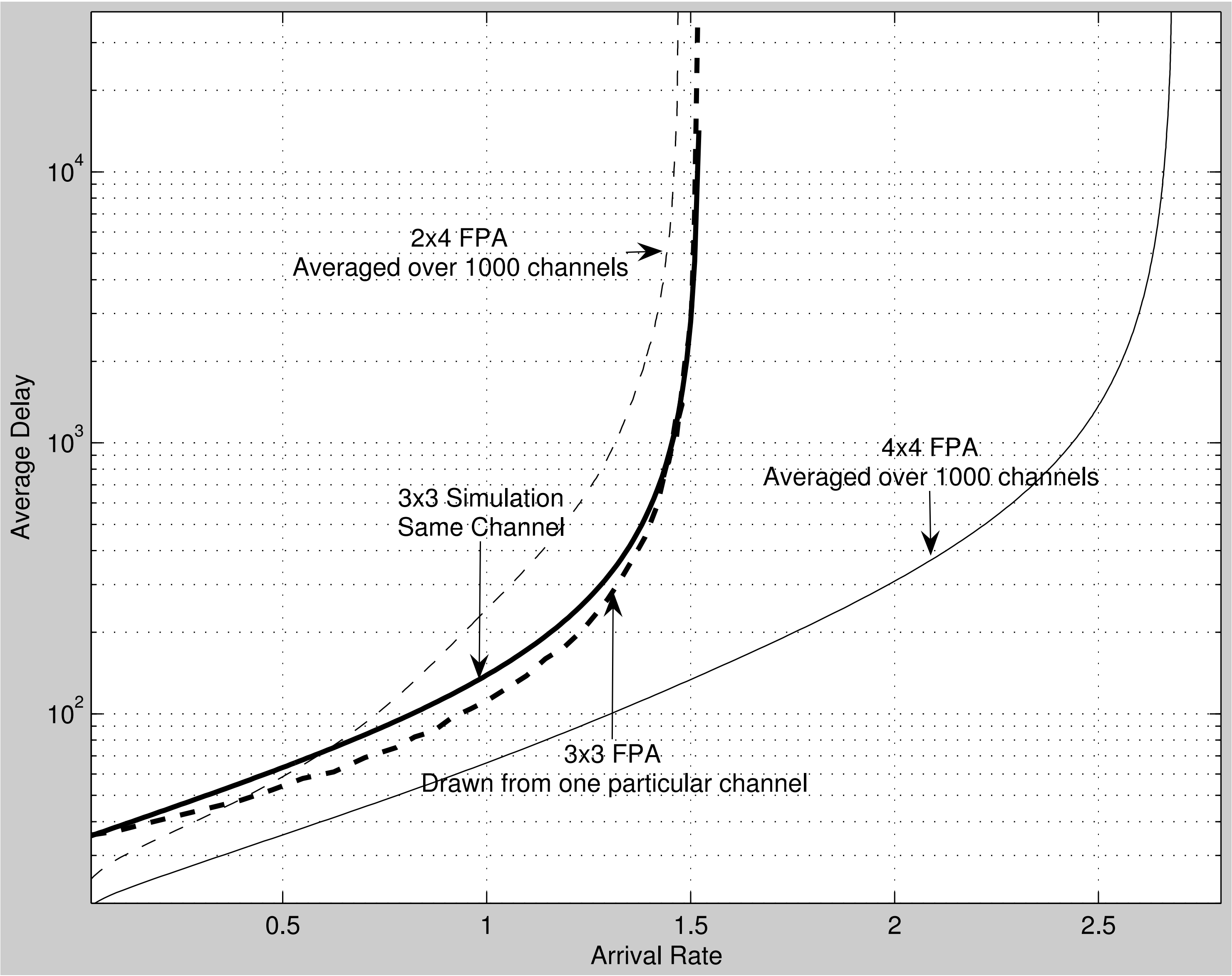
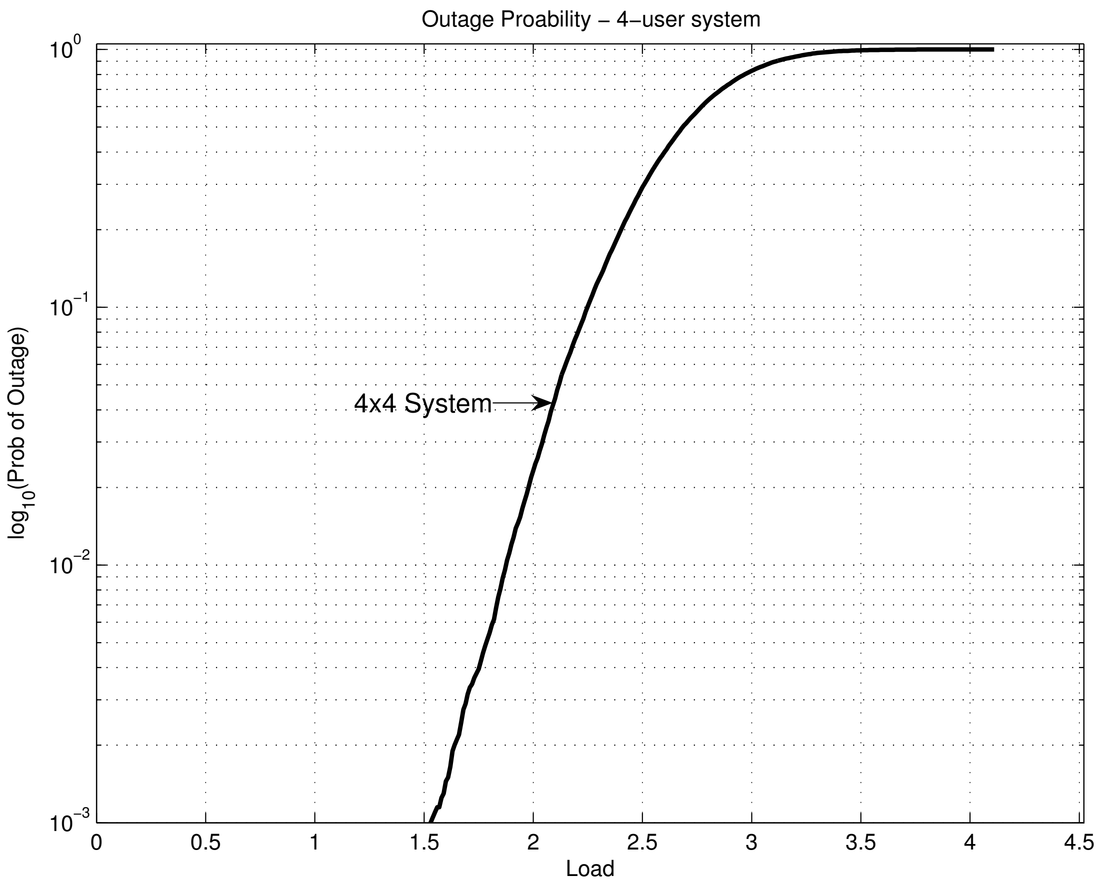


Figure 1: Comparison of FPA with simulation for 3- and 4-user systems

Sample Outage Results for SNR = 10 dB

- Outage occurs whenever the offered load cannot be supported.
- Results obtained by computing the saturation throughput for 20000 randomly drawn channels.



Conclusions

- FPA gives results comparable to the simulation results for high-load and no-load conditions.
- For mid-value of loads, it appears that the difference diminishes as the number of users increases.
- For a given channel model, we can find outage probability for a given offered load.

References

[Kel89] F. P. Kelly. Fixed point models of loss networks. Journal of Australian Mathematical Society Series B, 31:204–218, 1989.

[VJG03] Sriram Vishwanath, Nihar Jindal, and Andrea Goldsmith. Duality, achievable rates, and sum-rate capacity of gaussian mimo broadcast channels. IEEE Trans. Inform. Theory, 49(10):2658–2668, October 2003.

[WSS04] H. Weingarten, Y. Steinberg, and S. Shamai (Shitz). The capacity region of the gaussian mimo broadcast channel. In Proc. of the 2004 IEEE International Symposium on Information Theory, July 2004.