Energy and Spatial Spectral Efficiency Analysis of Random mimo Cellular Networks

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- Energy and Spatial Spectral Efficiency
- Performance Evaluation and Simulation Results
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INTRODUCTION

- Growth of data traffic demand
  - Re-thinking of the cellular network structure
  - Random BS deployment, such as HetNet
- MIMO over SISO
  - SNR enhancement, Throughput gain, Power saving , etc.
- Power consumption and environmental concerns
  - Energy Efficiency

SYSYEM MODEL

- PVT Random Cellular Net.: Poisson Point Process (PPP)
  - BS's location: Φ_{B} with density λ_B
  - MS's location: Φ_{M} with density λ_M
- M-antenna BS
  - serves K single-antenna MSs $(K \leq M)$
- The received signal in MS_i from the *nearest* BS, BS_j:

$$y_j = \boldsymbol{v}_i \boldsymbol{g}_{ij}^{\mathrm{H}} \boldsymbol{u}_j + \sum_{l \in \Phi_B \setminus \{j\}} \sum_{k=1}^{K} \boldsymbol{v}_i \boldsymbol{g}_{il}^{\mathrm{H}} \boldsymbol{u}_l + n$$

$$\boldsymbol{g}_{ij} = \sqrt{\left(1 + x_{ij}/D\right)^{-\alpha}} \boldsymbol{h}_{ij} \quad , \quad \boldsymbol{h}_{ij} \sim \mathcal{CN}(\mathbf{0}, \mathbf{1})$$

Network Model

- Transition between available and unavailable channels: Modeled by Markov Chain (MC)
- Network state is presented by (m, n)-tuple.
- State Probability:

$$\pi(m,n) = \frac{1}{\chi}\left(\frac{\mu}{\eta}\right)^{m} \frac{1}{m!}\binom{C}{n}\left(\frac{a}{b}\right)^{n}$$

- Channel is unavailable if

$$\epsilon = \mathbb{P}(\mathrm{SINR} < \gamma)$$

  - ϵ: Outage Probability

COVERAGE AND BLOCKING PROBABILITY

- Signal-to-Interference-plus-Noise Ratio (SINR)

$$SINR = \frac{(1+r)^{-\alpha}\left|\boldsymbol{h}_{ij}^{\mathrm{H}}\boldsymbol{w}_{ij}\right|^2}{\sum_{l\in\Phi_B\setminus\{j\}}\sum_{k=1}^{K}\left|\boldsymbol{g}_{il}^{\mathrm{H}}\boldsymbol{w}_{kl}\right|^2 + K\sigma^2/P_T} = \frac{(1+r)^{-\alpha}S}{\boldsymbol{I}(\Phi_B) + K\sigma^2/P_T}$$

- Coverage Probability:

$$\mathbb{P}(\mathrm{SINR} > \gamma) = \int_{r>0} 2\pi\lambda_B r e^{-\pi\lambda_B r^2} . \int_{-\infty}^{+\infty} e^{-2\pi\frac{K\sigma^2}{P_T}js} . \mathcal{L}_{\boldsymbol{I}}(2\pi js) . \frac{\mathcal{L}_S(-2\pi(\gamma(1+r)^{\alpha})^{-1}js) - 1}{2\pi js} ds\, dr$$

COVERAGE AND BLOCKING PROBABILITY

- Lemma 1: The coverage probability in a fully loaded MIMO network, i.e., $M = K$, is

$$\mathbb{P}(\mathrm{SINR} > \gamma) = \int_{r>0} 2\pi\lambda_B r e^{-\pi\lambda_B r^2} . e^{-\gamma(1+r)^\alpha} \frac{K\sigma^2}{P_T}$$

$$. \exp\left\{\pi\lambda_B(1+r).\left(r - 1 - (1+r).\ {}_2F_1\left(K, -\frac{2}{\alpha}; 1 - \frac{2}{\alpha}; -\gamma\right)\right.\right.$$

$$\left.\left. +2\ {}_2F_1\left(K, -\frac{1}{\alpha}; 1 - \frac{1}{\alpha}; -\gamma\right)\right)\right\}$$

COVERAGE AND BLOCKING PROBABILITY

- Blocking Probability:

$$p_b = \sum_{m=n\leq C} \frac{1}{\chi} \left(\frac{\mu}{\eta}\right)^m \frac{1}{m!} \binom{C}{n} \left(\frac{a}{b}\right)^n$$

- Where,

$$\frac{a}{b} = \frac{1-\epsilon}{\epsilon}$$

- And

$$\epsilon = \mathbb{P}(\text{SINR} < \gamma) = 1 - \mathbb{P}(\text{SINR} > \gamma)$$

ENERGY AND SPATIAL SPECTRAL EFFICIENCY

- Refer to the Palm theory, it is sufficient to find SSE and EE for a typical MS and BS, respectively, and then extend the results to the entire PVT random cellular network.
- Cell Throughput

$$T_c = (1 - p_b).W.\mathcal{C}.\sum_{0 \le m \le n \le C} m.\pi(m,n)$$

- Where

$$\mathcal{C} = \mathbb{E}[\log_2(1 + \mathrm{SINR})] = \int_0^{+\infty} \mathbb{P}(\mathrm{SINR} > 2^t - 1)\, dt$$

Energy and Spatial Spectral Efficiency

- Spatial Spectral Efficiency (SSE)

$$\mathrm{SSE} = \lambda_B \,.T_c = (1 - p_b).W$$

$$.\int_0^{+\infty} \mathbb{P}(\mathrm{SINR} > 2^t - 1)\, dt\,.\sum_{0 \le m \le n \le C} m.\pi(m,n)$$

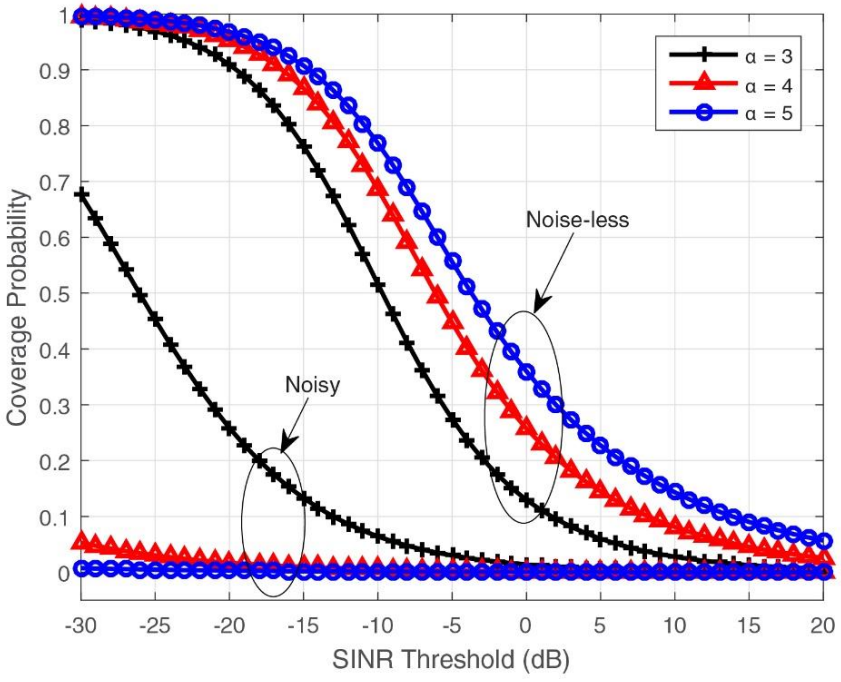
- Energy Efficiency (EE)

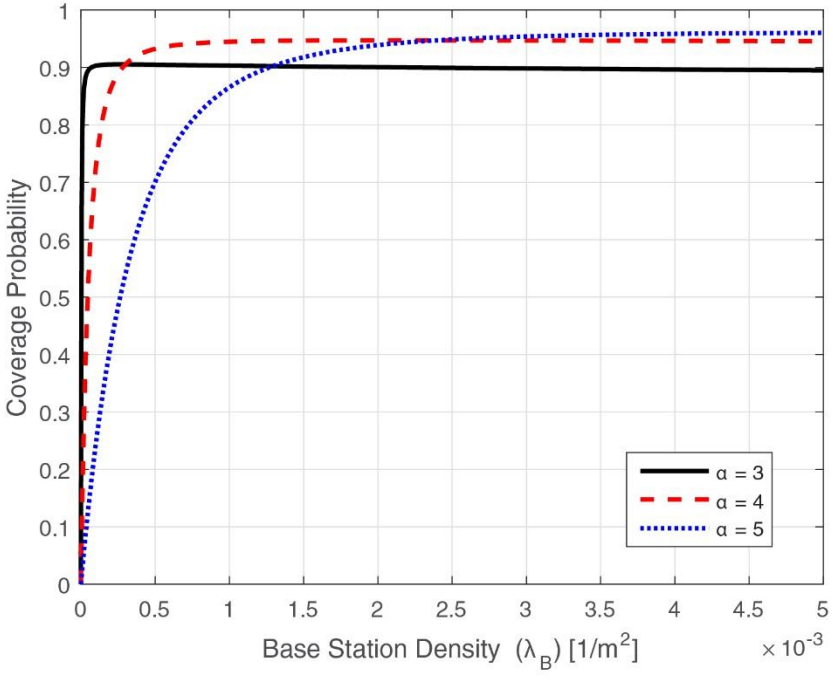
$$EE = \frac{T_c \,.t_{LT}}{E_1 + E_2 + \left(h.P_{tr}\sum_{0 \le m \le n \le C} m.\pi(m,n) + k\right).t_{LT}}$$

  - t_{LT}: Lifetime of the BS
  - E_1 : Consumed energy in factories during the manufacturing phase
  - E_2 : Required energy for maintenance

Performance Evaluation and Simulation Results

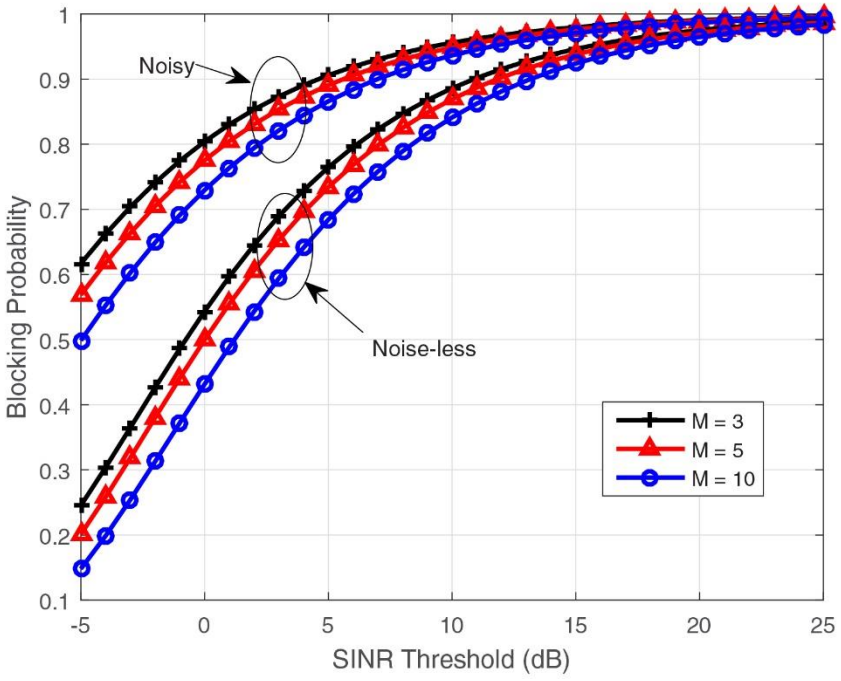
- Coverage Probability

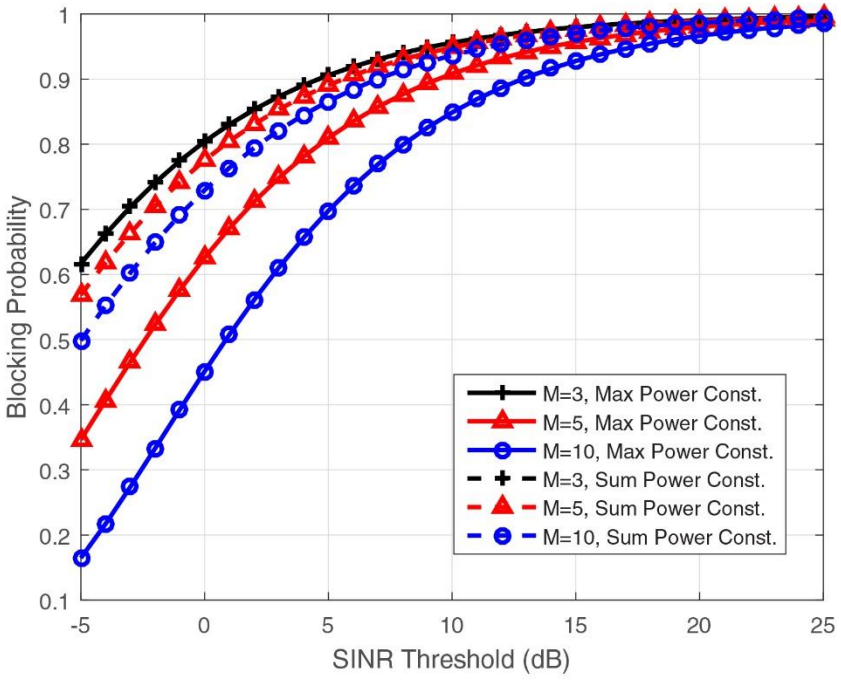




Performance Evaluation and Simulation Results

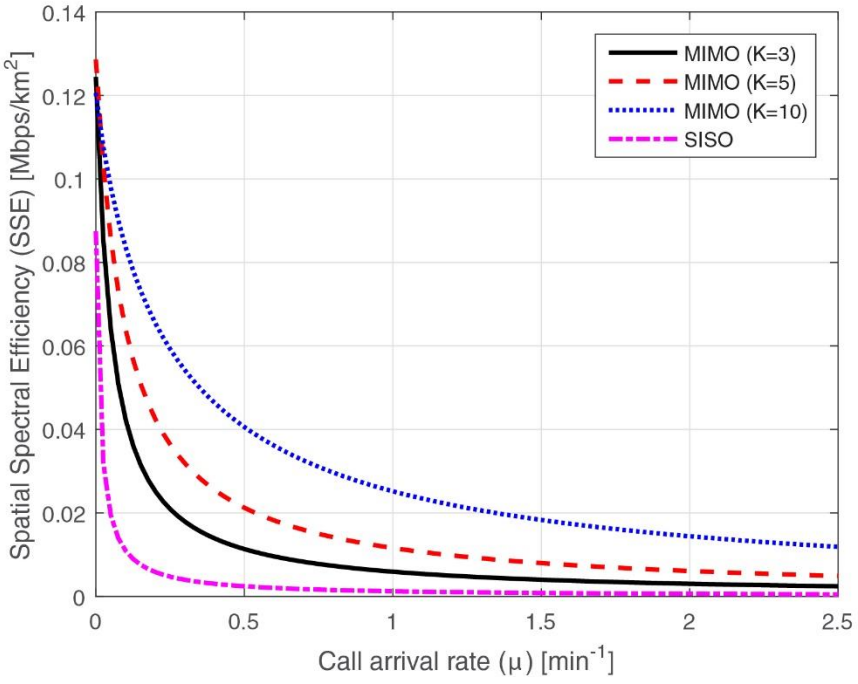
- Blocking Probability

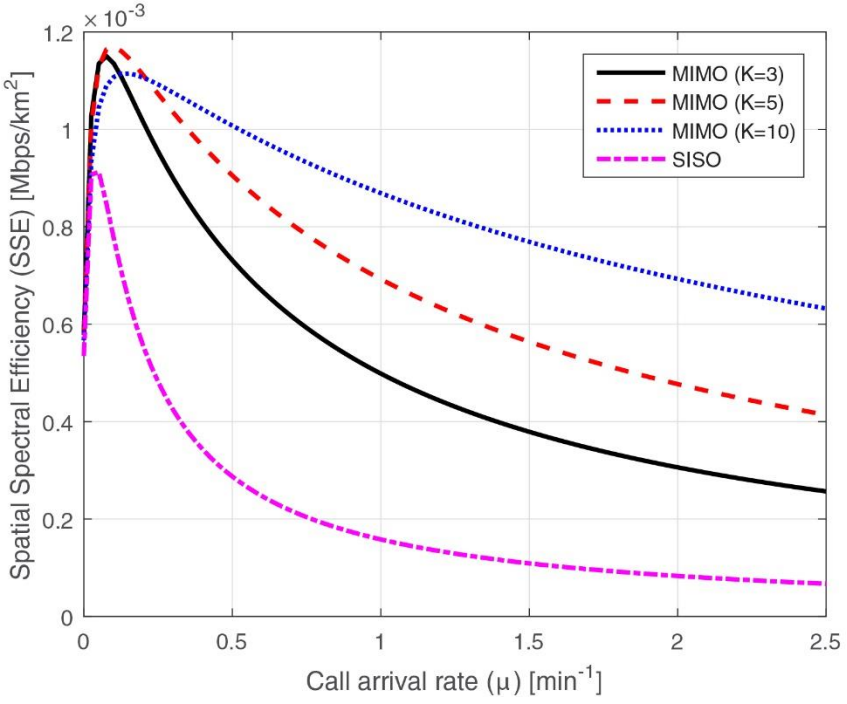




Performance Evaluation and Simulation Results

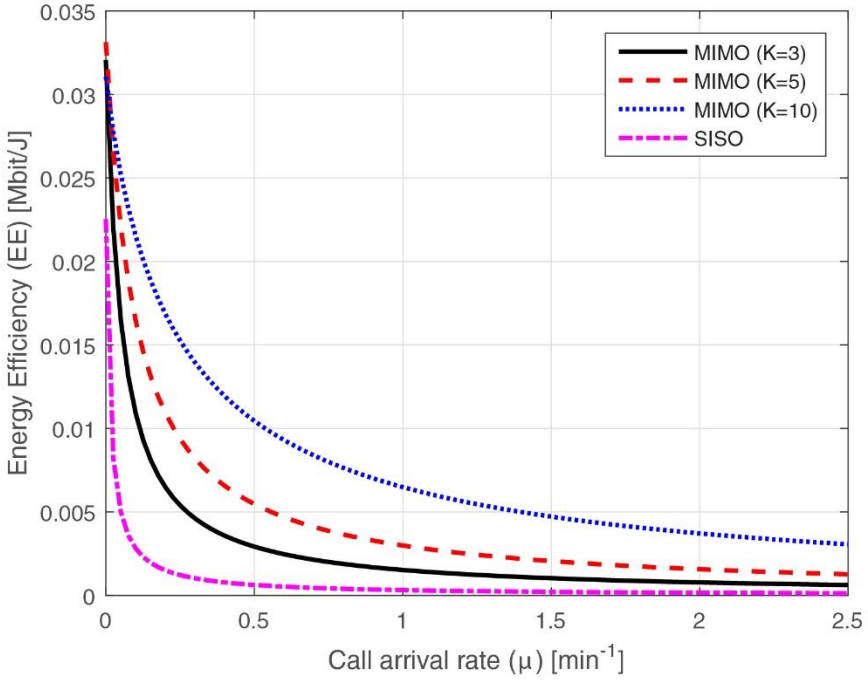
- Spatial Spectral Efficiency (SSE)

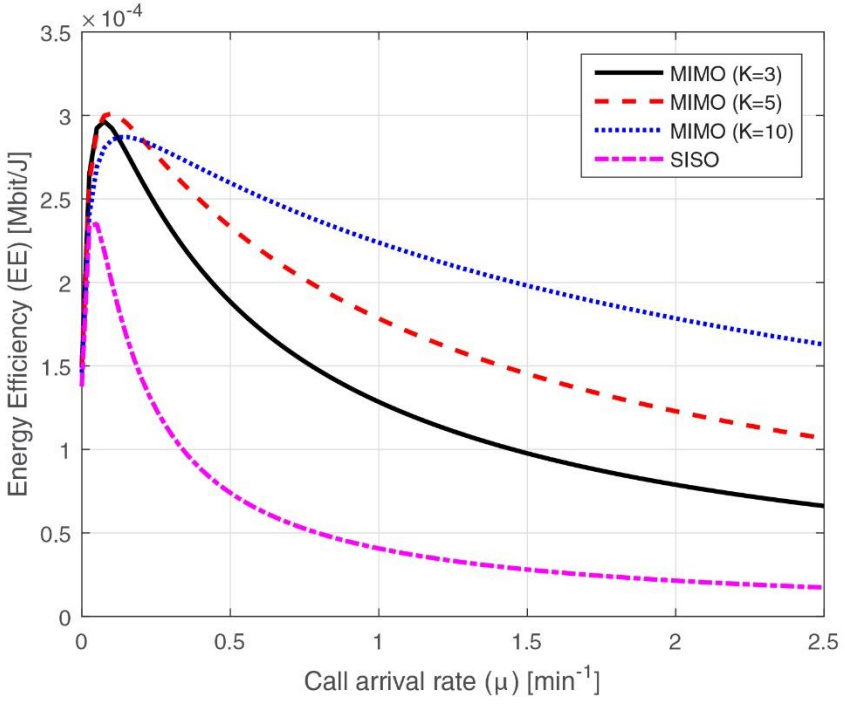




Performance Evaluation and Simulation Results

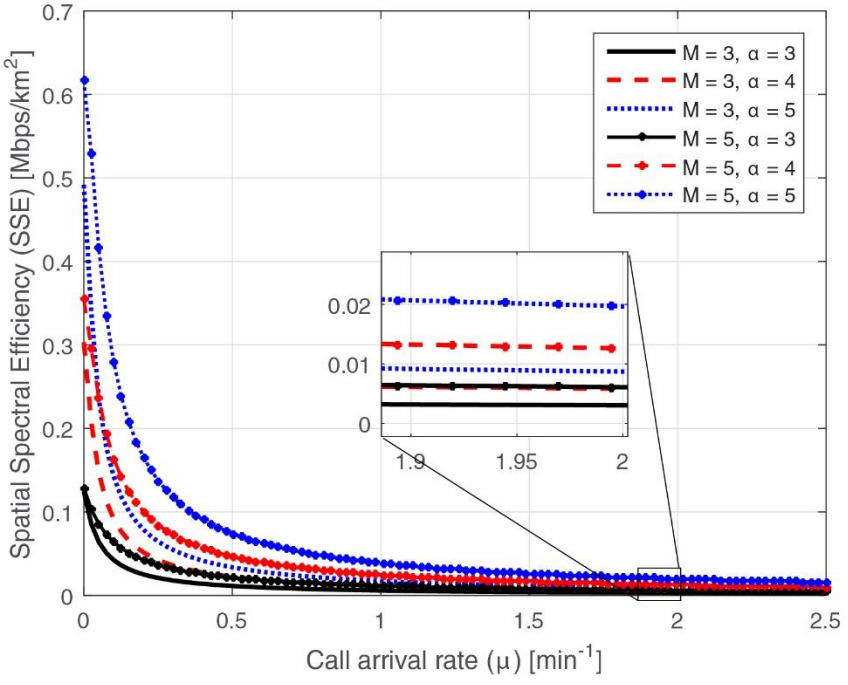
- Energy Efficiency (EE)

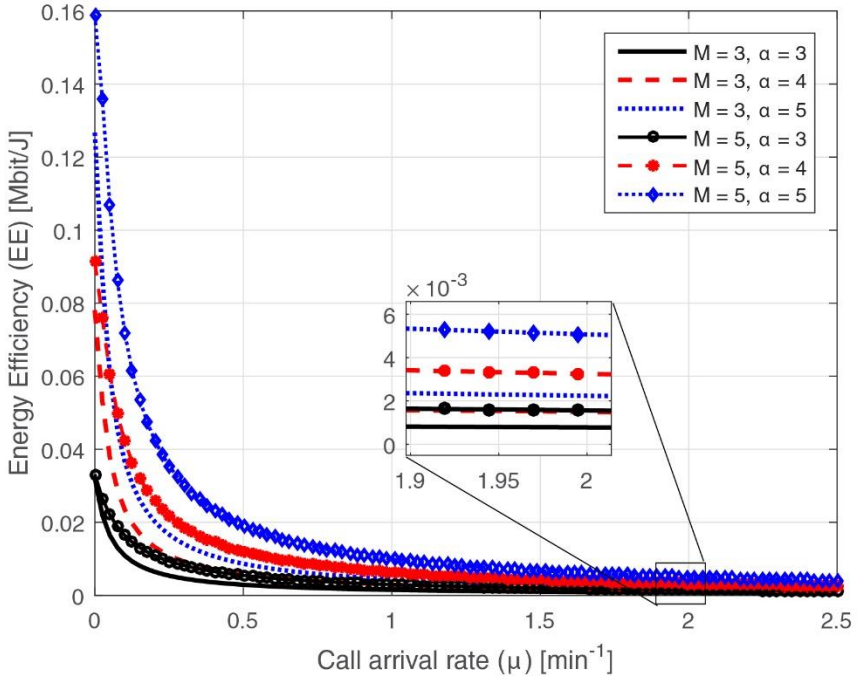




Performance Evaluation and Simulation Results

- SSE and EE for different path-loss exponent





CONCLUSION

- Performance evaluation of a MIMO system in a PVT random cellular network
  - Coverage Probability and Ergodic Capacity
- a MC transition model for the network
  - Blocking probability, Energy Efficiency and Spatial Spectral Efficiency
- PVT random cellular network with multiple antennas is more sensitive to interference than to noise.
- Higher path-loss exponent has positive impact on the coverage and blocking probabilities as well as SSE and EE.

Thanks for your attention!

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