Massive MIMO Exposure Analysis using a Stochastic Geometric Approach

Maarouf Al Hajj

Chaire C2M, Télécom Paris,
Paris, France

17-Oct-2019

Why massive MIMO

- To account for the growing need for spectrum 5G and future networks will use mmWave frequencies

- mmWave is different than RF bands by having much higher path loss

- One of the main solutions to maintain an acceptable SNR is to increase the Tx gain using massive MIMO antennas

- Massive MIMO antennas will have varying radiation patterns which makes them hard to model

Why estimate the exposure

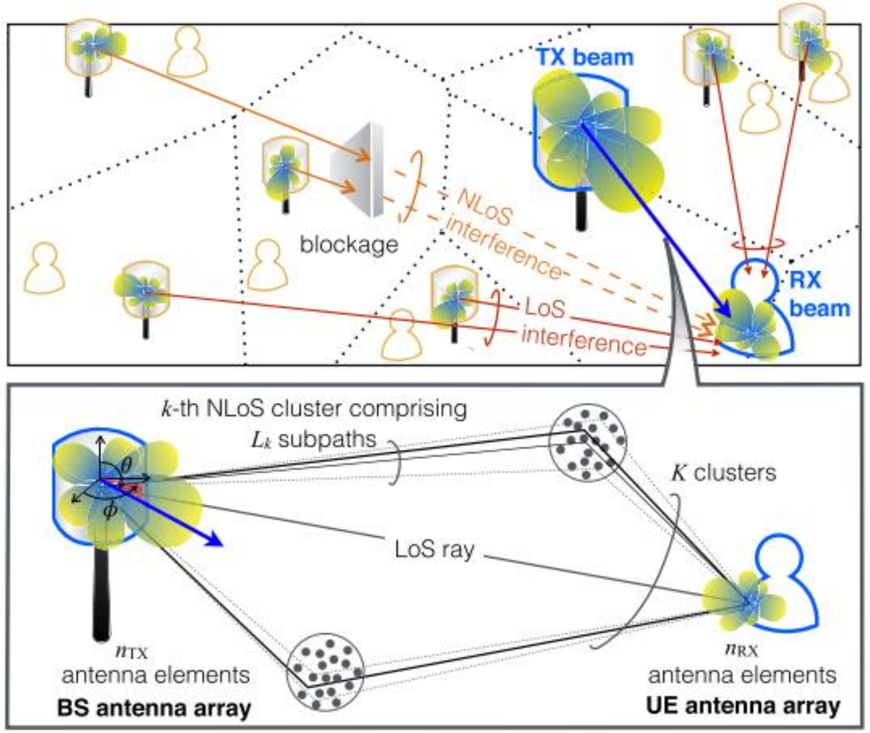
- Exposure assessments are performed by manufacturers and operators to ensure that emitting devices are compliant with safety regulations
- Many methods exist for older systems, but they are not accurate for future systems due to the fundamental differences
- We aim to derive an analytical approach to estimate the downlink exposure in 5G massive MIMO networks

System Model

- We assume a homogenous 5G massive MIMO network
- The BSs and the UEs are independently distributed in a 2D plane
- The BSs transmit independently from each other in full-buffer mode
- We assume no downlink power control exist in the network, which seems the case for 5G networks

System Model

- **We use the NYUSIM channel model which divides the Tx power into clusters and paths**
- **The Rx power is dependent on the transmitted power, the propagation distance, the channel gain and the antenna gain**
- **We use the isotropic antenna radiation model for simplicity**



M. Rebato, J. Park, P. Popovski, E. De Carvalho, and M. Zorzi, “Stochastic geometric coverage analysis in mmWave cellular networks with a realistic channel model,” in Proc. IEEE Global Commun. Conf. Mobile Wireless Netw. (Globecom MWN), Singapore, Dec. 2017, pp. 1

Channel Model

- **We separate the two gains obtained from the channel simulation into channel gain and antenna gain**

- **Channel gain obtained directly from the NYU channel simulation**

- **Antenna gain obtained by determining the antenna radiation pattern for every scanning angle after each channel simulation**

- **Running a large number of simulations, we have empirically fit the distributions of the gain components into statistical models**

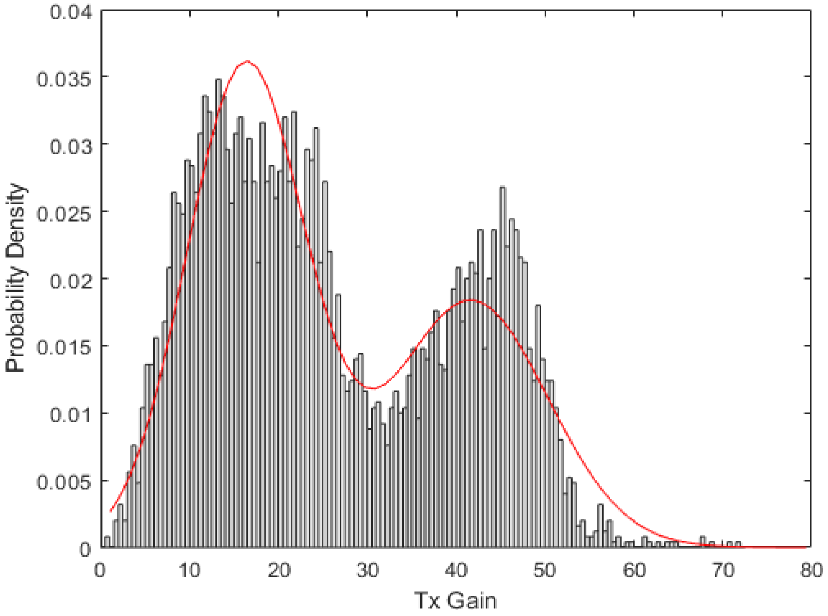
Gain Distribution

The two peaks likely due to side lobes in the antenna pattern

Fitted distribution: Multimodal normal distribution

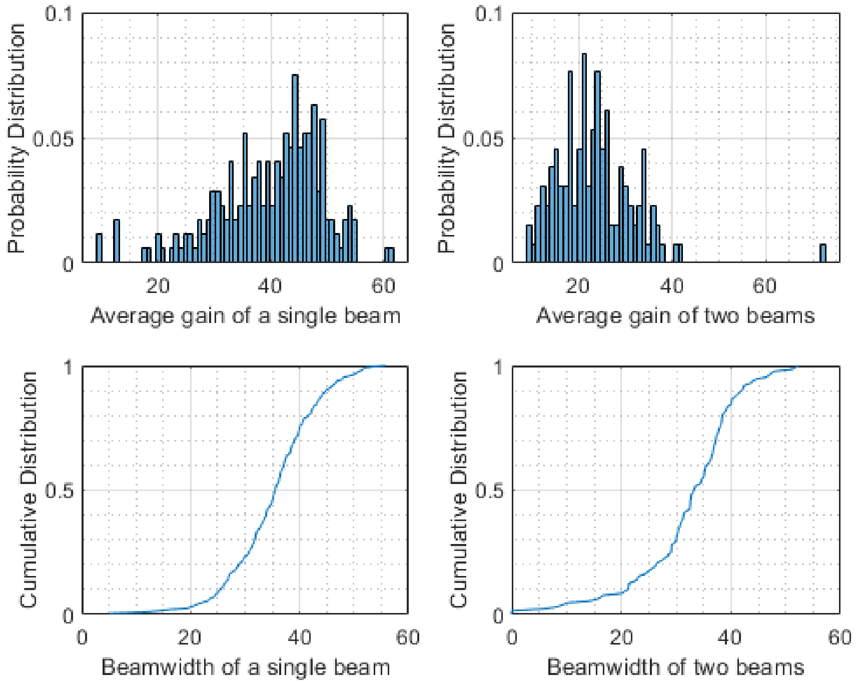
$$\boldsymbol{y = p\frac{1}{\sigma_1\sqrt{2\pi}}e^{-0.5(\frac{x-\mu_1}{\sigma_1})^2} + (1-p)\frac{1}{\sigma_2\sqrt{2\pi}}e^{-0.5(\frac{x-\mu_2}{\sigma_2})^2}}$$

$p, \sigma_1, \sigma_2, \mu_1, \mu_2$ **have the respective values [0.6, 16.35, 41.67, 6.68, 8.63]**



Gain Distribution

- **We fit separate distributions for each case of single or multi-user usage**
- **We deduce the half-power beamwidth and the gain as the average value for the ISO antenna pattern.**
- **In the figure, The gain and HPBW distributions for single user MIMO and 2-beam configuration**



Analytical Formulation

Exposure characteristic function:

$$\phi(t) = E\left\{\exp\left(jt \sum_{r_i \in \phi_{BS}} P_{tx} G_{tx} r^{-\alpha}\right)\right\}$$

$$= \exp\left(-2\pi\lambda\, BW\ G\ P_G\ \frac{jtP_{tx}G\bar{\gamma}m^{2-\alpha}}{\alpha - 1}\ {}_2F_1\left(1, \frac{\alpha - 2}{\alpha}, 2 - \frac{2}{\alpha}, \qquad jtP_{Tx}G\ BW\ P_G\ \bar{\gamma}m^{-\alpha}\right)\right)$$

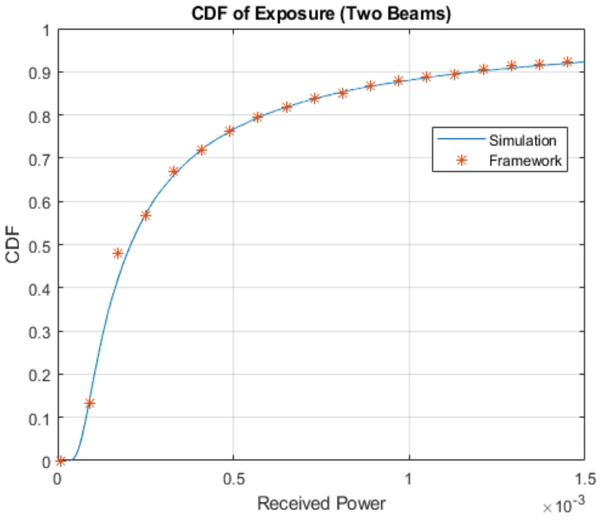
Where, α is the path loss exponent, BW is the beamwidth, λ is the PPP intensity, G is the average gain, P_{tx} the transmit power, and m the minimum separation distance between the BS and the user to avoid infinite values at distance 0.

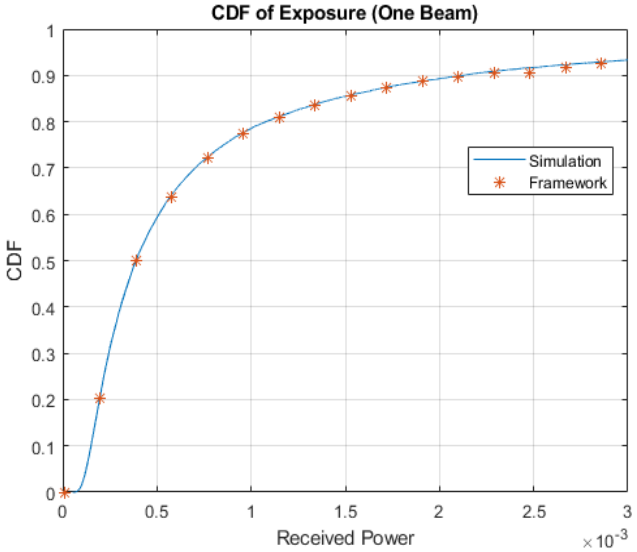
Results

- **The CDF of the exposure can be determined using the Gil-Peleaz theorem:**

$$F(x) = \frac{1}{2} - \frac{1}{\pi}\int_0^{\infty} \frac{Im\left[e^{-jtx}\varphi(t)\right]}{t}\,dt$$

- **We compare the analytical results with monte-carlo simulations in the figures below**





Conclusion

- In this paper, we have presented an accurate framework to analytically estimate the exposure in a massive MIMO network
- We have also made the comparison between two simple implementation cases of a massive MIMO antenna which can have significant effect on the exposure
- Future work will focus on producing more accurate and representative model and study the effect of change in the network characteristics