Optimal Access Point deployment in Ultra-dense Networks

Pete Pratt

PhD Student at Bristol University
Joint work with: Carl P Dettmann (Academic Supervisor),
Orestis Georgiou (Industrial Supervisor)and
Woon Hau Chin(Industrial Supervisor)

September 13, 2017

University of BRISTOL

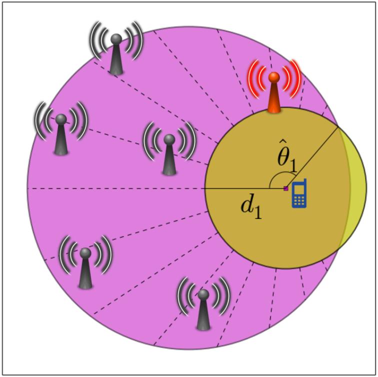
TOSHIBA Leading Innovation

Motivation

Spatial Densification: The heteroginisation of the existing network architecture by deploying smaller base stations, Access Points (APs).

What is the probability that a Mobile User (MU) is in the downlink of its nearest AP?

How should the APs be deployed for a given distribution of mobile users (MU) in order to maximise overall network coverage?



Outline

How should APs be deployed in a finite domain when MUs are distributed non-uniformly.

* Nearest Neighbour distribution for a non-uniform PPP
* A nearest neighbour connection model with interference.
* MU Coverage in an interference limited environment.
* Optimal distribution of APs

Nearest Neighbour Distribution (NND)

Poisson Point Process Φ emits a density,

$$\lambda(t) = \lambda_0 \left(1 - \frac{bR^2}{2} + bt^2\right), \quad \text{where } 2\pi \int_0^R \lambda(t) t \mathrm{d}t = \lambda_0 |\mathcal{V}|$$

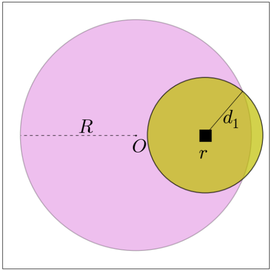
Complementary cdf of d_1, is the probability there are no points within $B_{\boldsymbol{r}}(d_1)$

$$\bar{F} = \mathbb{P}[N(B_{\boldsymbol{r}}(d_1)) = 0] = e^{\left(-\int_{\mathcal{V}\setminus B_{\boldsymbol{r}}(d_1)} \lambda(\boldsymbol{y})\mathrm{d}\boldsymbol{y}\right)}$$

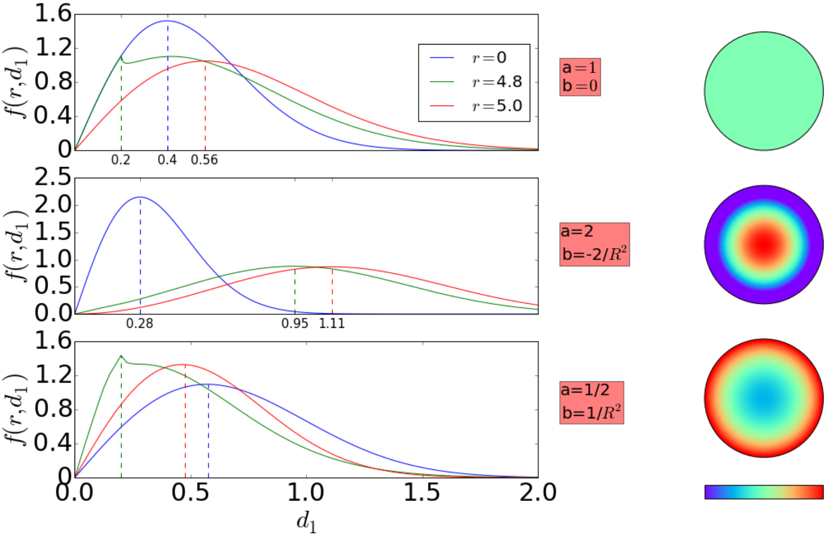
Thus the Nearest neighbour distribution (NND) is defined as,

$$f(r, d_1) = \frac{\mathrm{d}}{\mathrm{d}d_1}(1 - \mathbb{P}[N(B_{\boldsymbol{r}}(d_1)) = 0])$$

$$= -\frac{\mathrm{d}}{\mathrm{d}d_1} \exp\left(-\int_{\mathcal{V}\setminus B_{\boldsymbol{r}}(d_1)} \lambda(\boldsymbol{y})\mathrm{d}\boldsymbol{y}\right)$$



Nearest Neighbour Distribution



Nearest Neighbour Connection Model

$\mathcal{H}_1(d_1, \boldsymbol{r})$: The probability that a receiver at $\boldsymbol{r}$ can successfully decode a signal from its nearest AP separated by a distance d_1.

$$\mathcal{H}_1(\boldsymbol{r}, d_1) = \mathbb{P}\left[\frac{g(d_1)|h_1|^2}{\mathcal{N} + \gamma \sum_{k>1} g(d_k)|h_k|^2} \geq q | \boldsymbol{r}, d_1\right]$$

- $g(d_1) = d_1^{-\eta}$; path loss typically $\eta \in [2, 6]$
- $|h_1|^2 \sim \exp(1)$; channel gain
- $\gamma \in [0, 1]$; captures the orthogonality in the code
- $\mathcal{N}$; Noise
- q; threshold value

Connection Probability

$$\mathcal{H}_1(d_1, \boldsymbol{r}) = \mathbb{P}\left[\frac{|h_1|^2 g(d_1)}{\mathcal{N} + \gamma \sum_{k>1} |h_k|^2 g(d_k)} \geq q \middle| \boldsymbol{r}, d_1\right]$$

$$\mathcal{H}_1(d_1, \boldsymbol{r}) = \mathbb{E}_{\mathcal{I}_1}\left[\mathbb{P}\left[|h_1|^2 \geq \frac{q(\mathcal{N} + \gamma \sum_{k>1} |h_k|^2 g(d_k))}{g(d_1)} \middle| \boldsymbol{r}, d_1, \mathcal{I}_1\right]\right]$$

$$\mathcal{H}_1(d_1, \boldsymbol{r}) = \exp\left[-\frac{q\mathcal{N}}{g(d_1)}\right]\mathcal{L}_{\mathcal{I}}(q\,\gamma\, d_1^{\eta}),$$

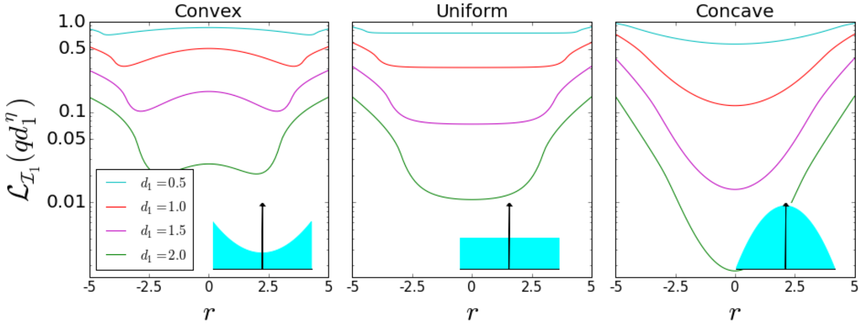
where,

$$\mathcal{L}_{\mathcal{I}_1}(q\,\gamma\, d_1^{\eta}) = \exp\left[-\int_{\mathcal{V}\setminus B_{\boldsymbol{r}}(d_1)} \frac{\lambda(z)}{1 + \frac{d_k^{\eta}}{q\,\gamma d_1^{\eta}}} d_k \mathrm{d}d_k \mathrm{d}\theta\right]$$

$$z = \sqrt{r^2 + d_k^2 - 2rd_k \cos\theta}$$

Interference Continued

The interference component of the connection function.



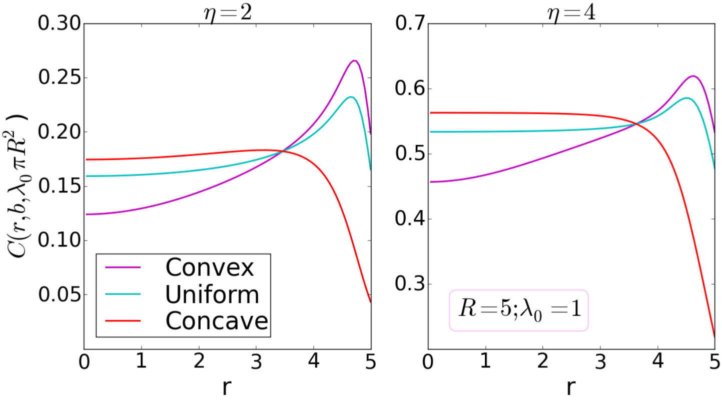
Parameters: $R = 5$; $\eta = 6$; $q = 1$; $\gamma = 1$

Conditioning on a larger d_1, $\mathbb{E}\left[\frac{d_1}{d_k}\right] \to 1$

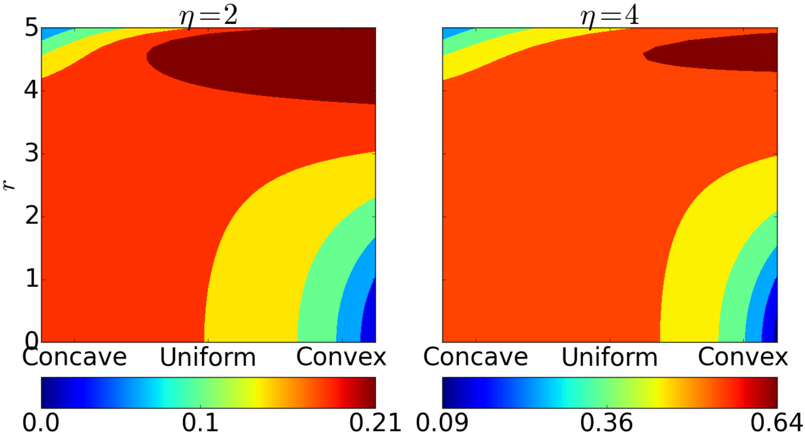
Network Coverage

The probability that a mobile user receiver located at $\boldsymbol{r}$ can decode a message from its nearest transmitter.

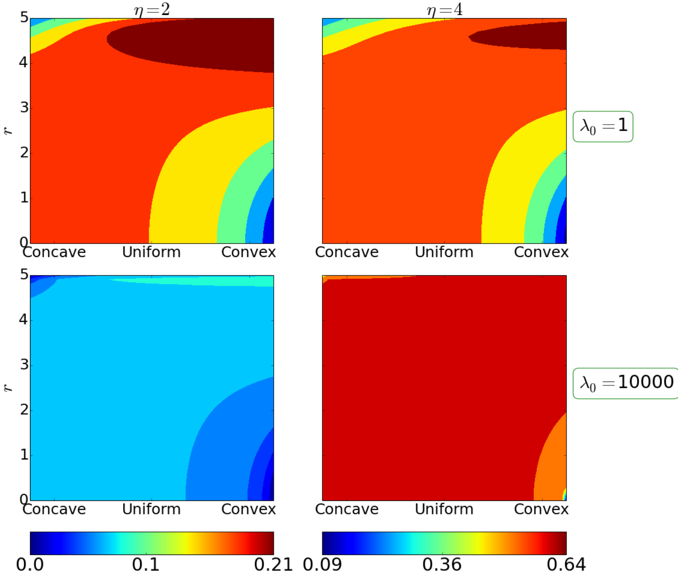
$$C(\boldsymbol{r}, b, \lambda_0 \pi R^2) = \int_0^{d_{max}} f(\boldsymbol{r}, d_1, b, \lambda_0 \pi R^2) \mathcal{H}_1(d_1, \boldsymbol{r}) \, \mathrm{d}d_1$$



Network Coverage

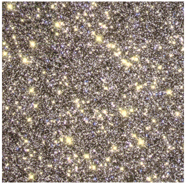


High Densities - Coverage



Olbers' Paradox

Olbers' paradox summary: *"The paradox is that a static, infinitely old universe with an infinite number of stars distributed in an infinitely large space would be bright rather than dark."*



Comparison: The paradox is that for an infinite density of devices, a user located anywhere would expect to be able to connect to its nearest neighbour regardless of the interference. For $\eta = 2$ the aggregate interference causes an *"interference storm"*.
Namely, $\eta =$ dim. of the network is the transition point between local and global behaviour.

Optimal Distribution of APs

Aim: Find the optimal distribution of APs so that we can maximise the number of MUs we can serve.
Define the distribution of MUs as

$$\rho(r,\beta) = \rho_0\left(1 - \frac{\beta R^2}{2} + \beta r^2\right)$$

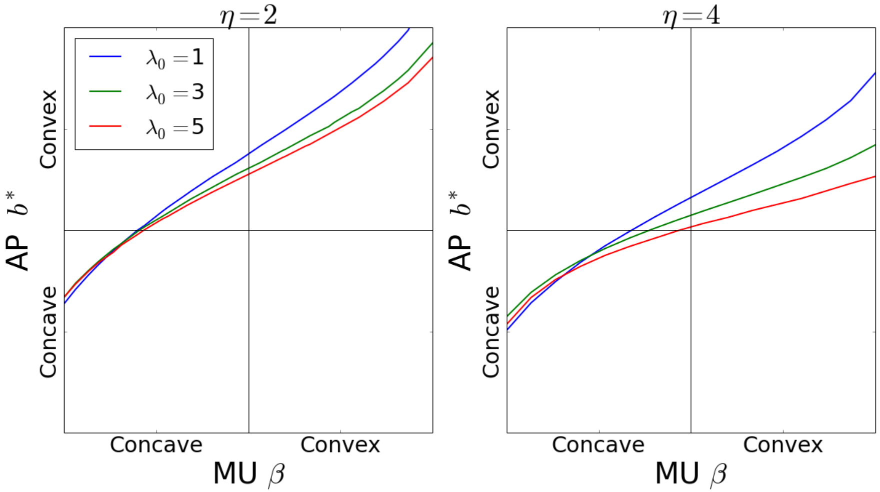
The average coverage is,

$$\bar{C}(b,\beta,\lambda_0\pi R^2) = \frac{2}{R^2}\int_0^R \rho(r,\beta)C(r,b,\lambda_0\pi R^2)r\mathrm{d}r$$

Find b^* such that $\bar{C}$ is maximised,

$$b^*(\eta,\lambda_0\pi R^2) = \arg\max_b \bar{C}$$

Optimal Distribution of APs



Conclusions and Applications

- Trade-off between border effects and distribution of APs.
- User coverage depends on location, distribution of APs, border affects and the pathloss model in interference limited environments.
- Pathloss exponent captures the global or local behaviour of the network.
- Adaptive transmission schemes could be used to provide optimal MU Coverage.

References

J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. Soong, and J. C. Zhang (20140
What will 5G be?
IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 10651082

Guoqiang Mao and Brian DO Anderson (2013)
Connectivity of large wireless networks under a general connection model
IEEE Transactions on Information Theory vol. 59 no.3 pp, 1761-1772.

E. Hyytia, P.Lassila, J. Virtamo (2006)
Spatial node distribution of the random waypoint mobility model with applications
Mobile Computing, IEEE Transactions on vol. 5, no. 6, pp680–694.

C. Bettstetter, C. Wagner, et al (2002)
The spatial node distribution of the random waypoint mobility model
WMAN vol. 11, pp41-58.

Paolo Santi(2005)
The critical transmitting range for connectivity in mobile ad hoc networks.
IEEE transactions on mobile computing vol. 4 no.3 pp, 310-317.

M. Haneggi (2012)
Stochastic geometry for wireless networks
Cambridge University Press 2012

S. A. Banani, A. W. Eckford, R.S. Adve (2015)
Analysing the impact of access point density on the performance of finite-area networks
Communications, IEEE Transactions on vol.63, no. 12, pp 5143-5161

Carl P. Dettmann and Orestis Georgiou (2016)
Random geometric graphs with general connection functions
Physical Review E vol.93 (2016)