The Impact of User Spatial Heterogeneity in Heterogeneous Cellular Networks

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Problem Definition:

- The performance of wireless networks depends highly on their spatial configurations
- Stochastic geometry is increasingly popular in modeling nodes spatial distributions
- The research community mainly focus on locations of base stations; users are assumed to be uniformly (= homogeneously) distributed in the literature
- What is the impact of user spatial heterogeneity on wireless network performance, especially in the context of heterogeneous cellular networks (HCNs)?

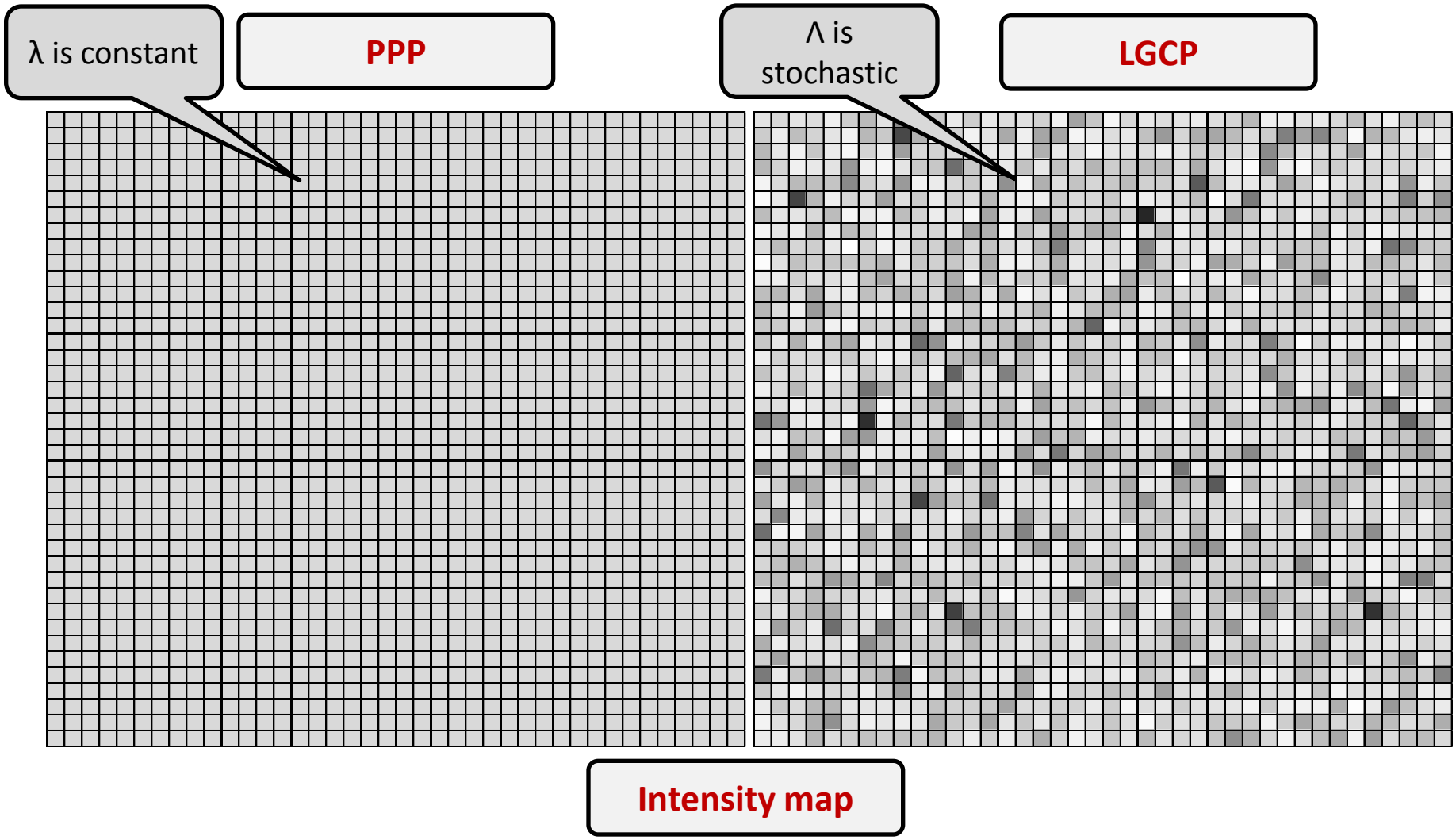
Contributions:

- Use log Gaussian Cox process to model heterogeneous user spatial distribution
- Get network performance with respect to user spatial heterogeneity
- Apply clustering analysis on user points to find locations for small cell

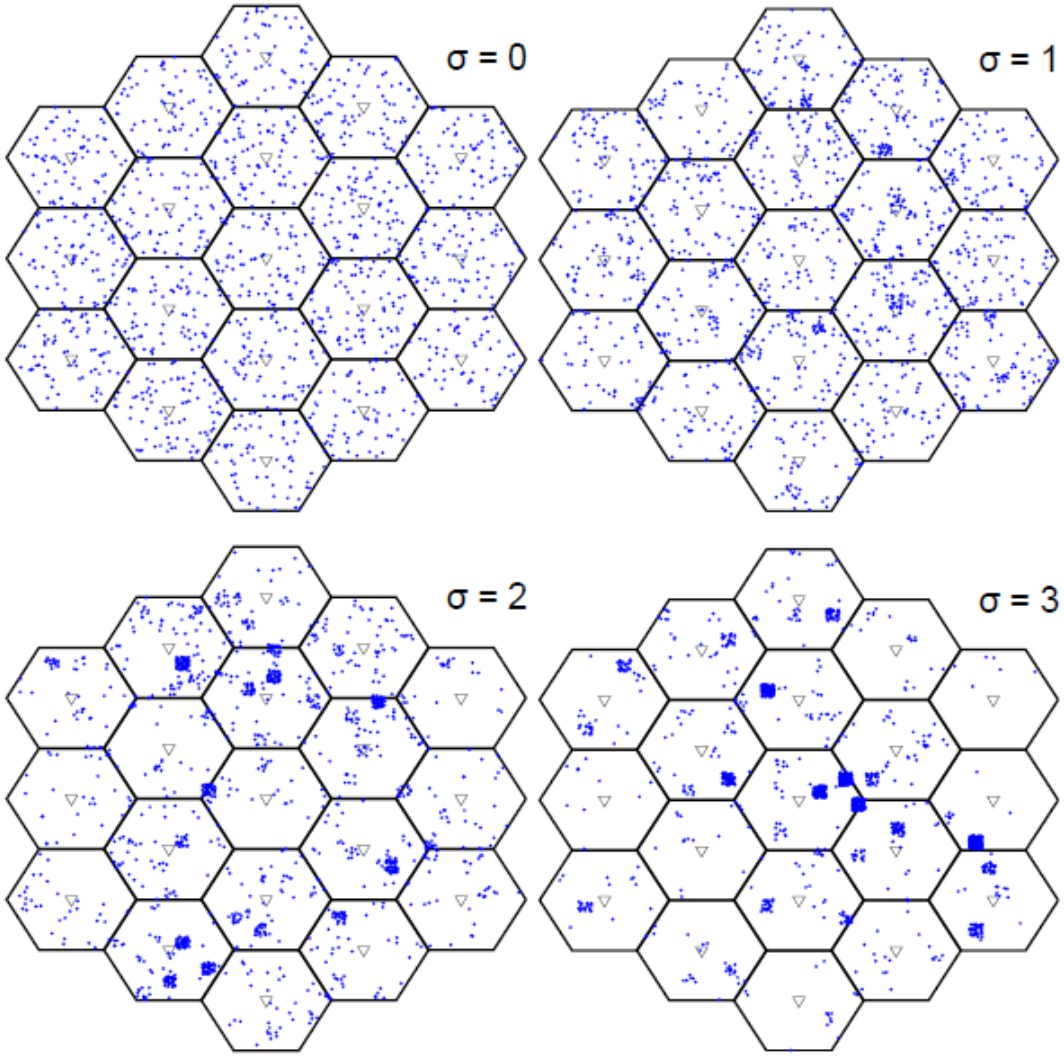
Log Gaussian Cox Process (LGCP)

- Cox process is a generalization of the PPP, also known as Doubly Stochastic Poisson Process.
- The intensity in Cox Λ is itself a stochastic process.
- In a PPP, for any bounded area B, the number of points in B is a Poisson number with mean $\lambda \cdot A_B$
- In a Cox process, the number of points in B is a Poisson number with mean $\int_B \Lambda(s)ds$.
- A Cox process is a LGCP if $\Lambda(s) = \exp(Y(s))$, where $Y = \{Y(s): s \in R^2\}$ is a real valued Gaussian process.
- By changing the σ in Y, the LGCP generates a wide range of heterogeneities.

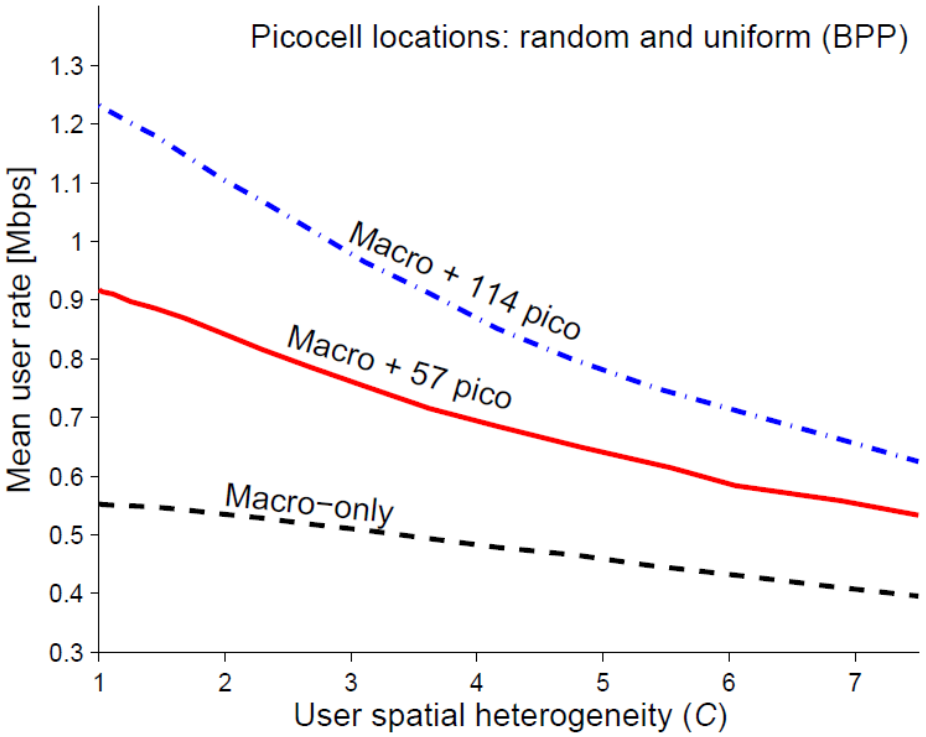
Realization of LGCP

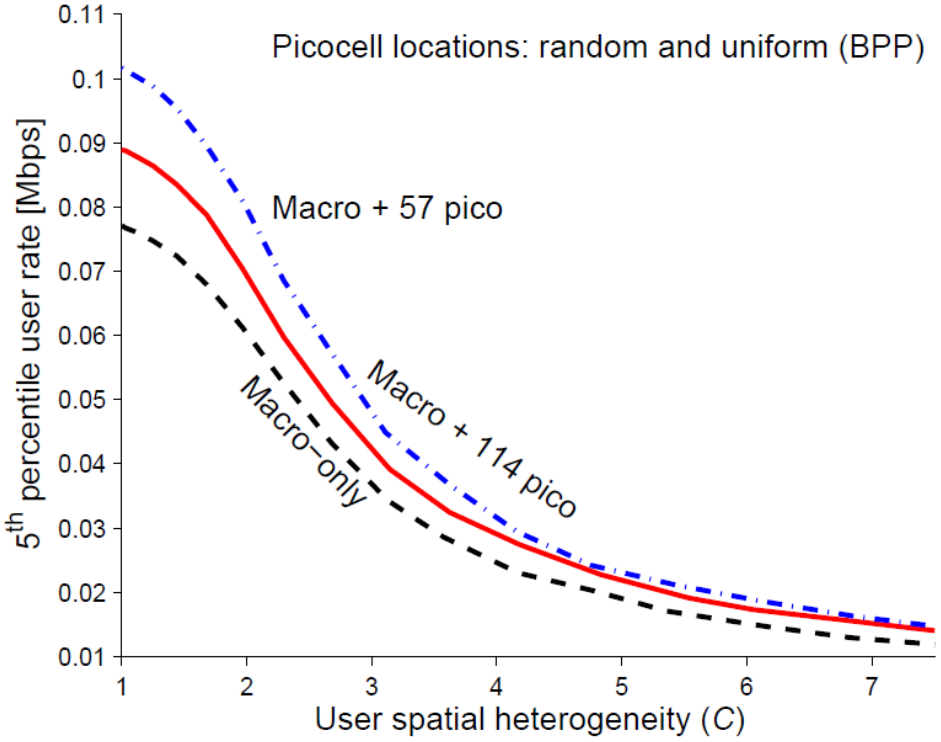


Realizations of LGCP with Different σ



The Impact of User Spatial Heterogeneity





- **The locations of macrocell sites are fixed in the centers of hexagons**
- **Picocells are deployed randomly and uniformly.**

- **Users are modeled with LGCPs independently with the locations of BSs.**
- **The user spatial heterogeneity is measured by a positive real number *C*, which is equal to 1 for PPP, greater than 1 for super-Poisson processes.**

Cluster Analysis - K-means Algorithm

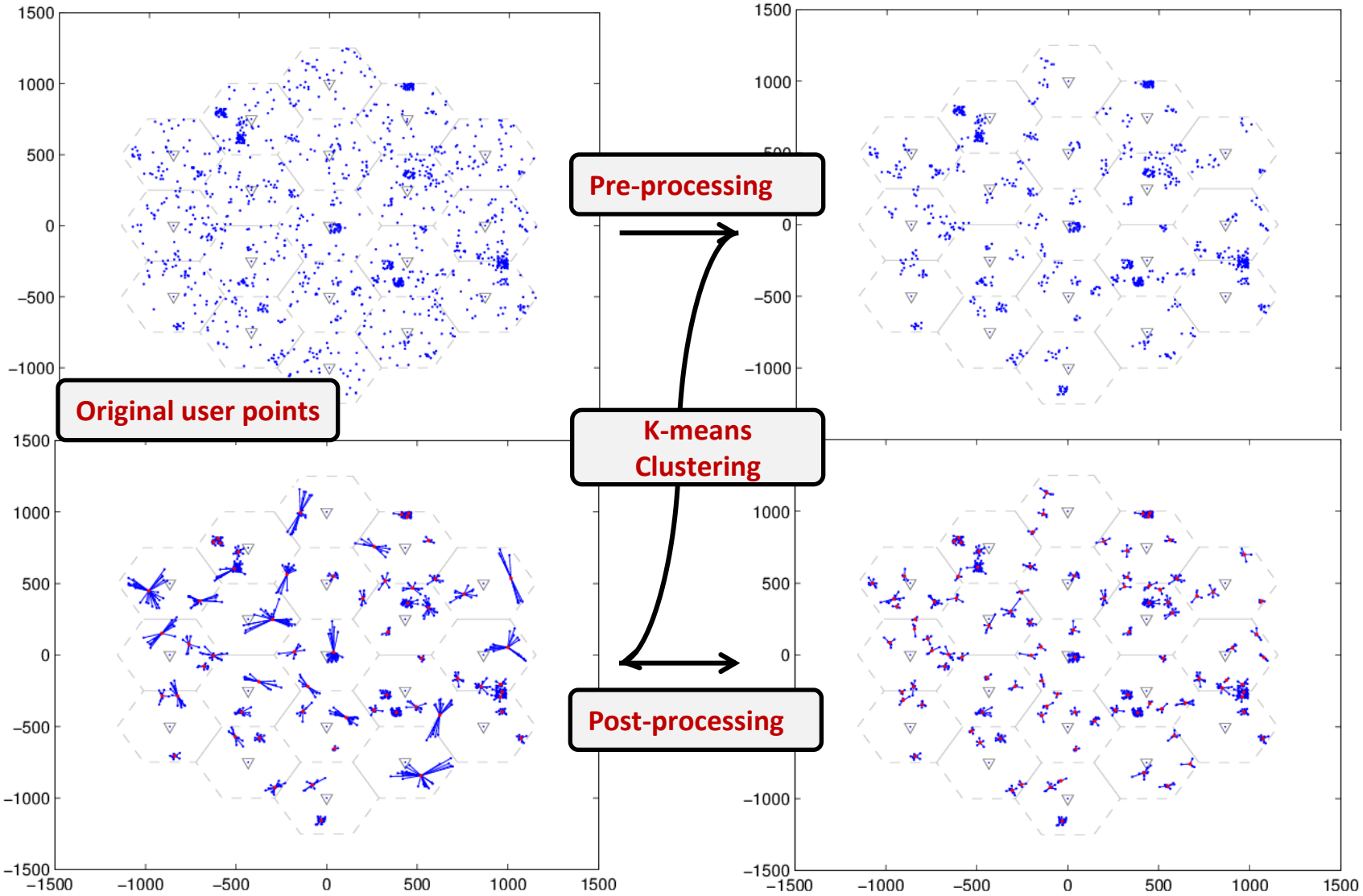
K-means algorithm is one of the most popular clustering algorithms

Algorithm Basic k-means Algorithm

1: Select k points as initial centroids.
2: **repeat**
3: Form k clusters by assigning each point to its closest centroid.
4: Recompute the centroid of each cluster.
5: **until** Centroids do not change.

- **Cluster analysis groups data into clusters such that objects in the same cluster are more similar to each other than to those in a different cluster.**
- **It is a main task of data mining and has played an important role in a wide variety of fields.**

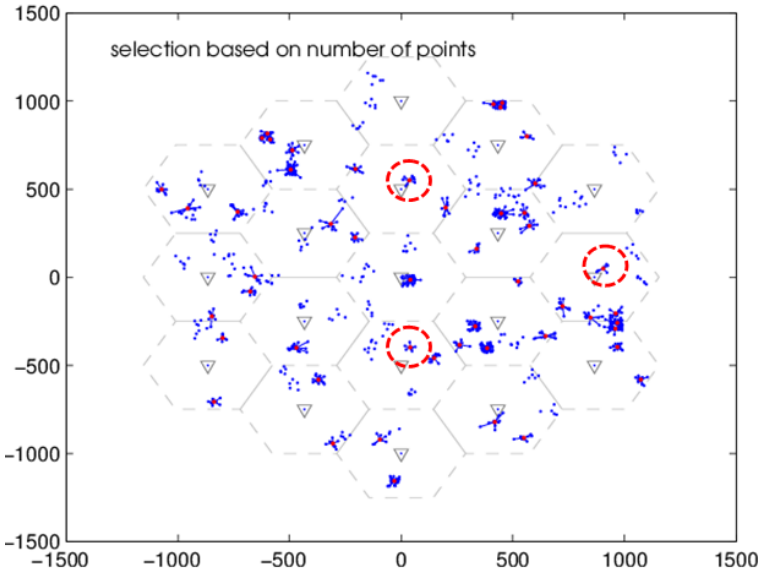
Pre-processing and Post-processing

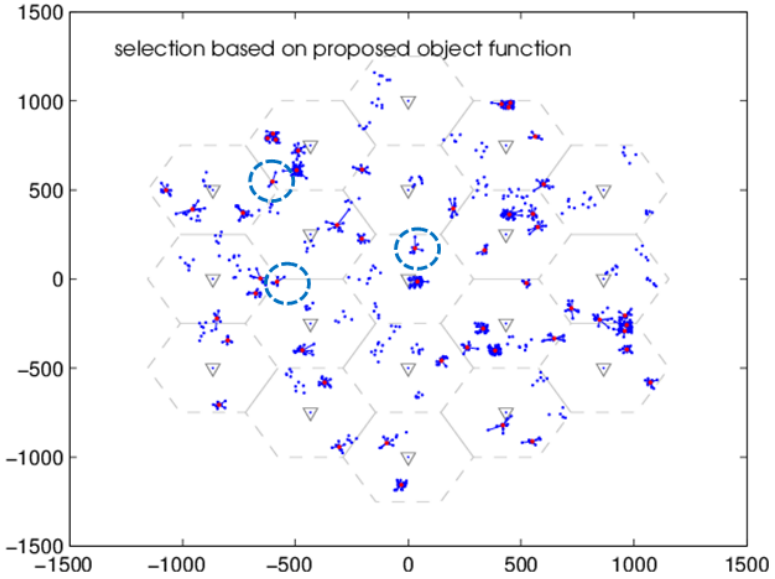


Cluster Selection

- Set *K* equals the number of planned small cells, after splitting (post-processing), we got more than *K* clusters. How to select *K* clusters out of them?
- The straight forward way is to select *K* clusters that have the most points inside. Yet a better way is to take the distance between users and macrocells into consideration. We propose the objective function as

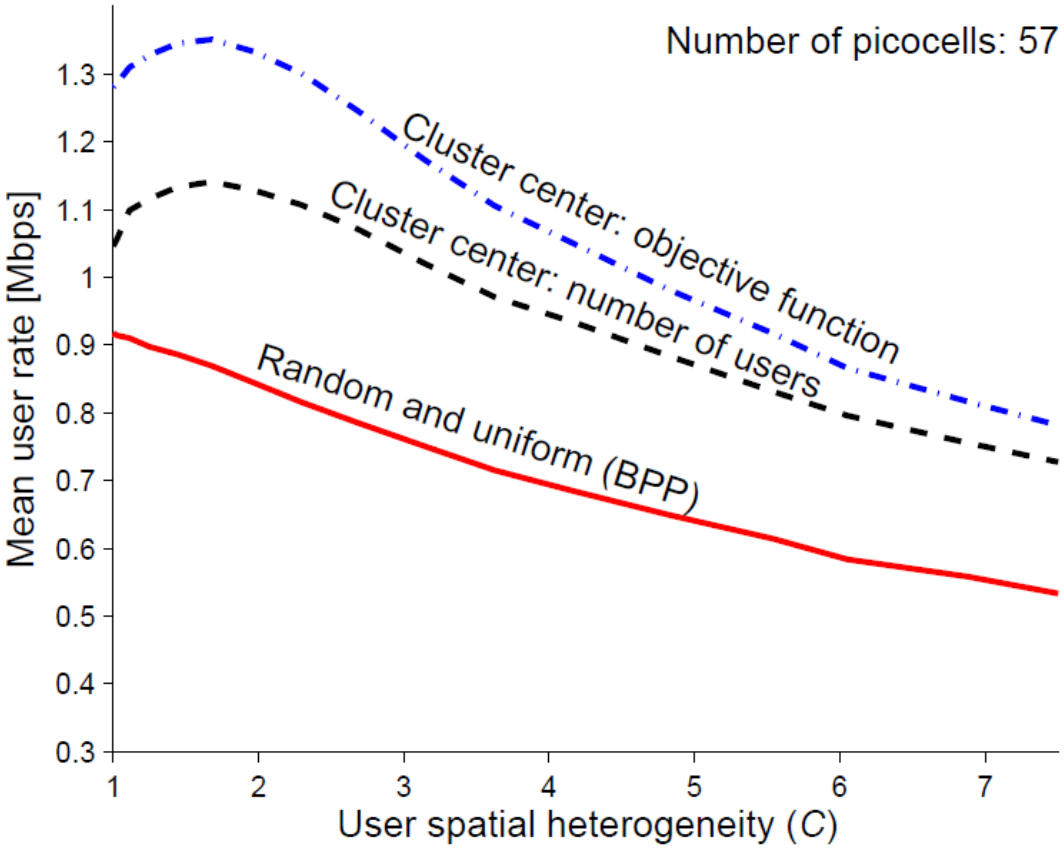
$$U_i = \frac{1}{n_i}\sum_{j=1}^{n_i} \log\left(\frac{d_j^{(m)}}{d_j^{(s)}}\right)$$





Performance Evaluation

- **Performance is improved significantly when picocells are deployed in the centers of user clusters.**
- **HetNet can benefit from user spatial heterogeneity in a certain degree.**
- **Cluster selection considering relative distance between users to macrocells and users to potential small-cells performs the best**



Conclusion

❑ Contributions:

- We generate heterogeneous user spatial heterogeneity by log Gaussian Cox process, and investigate the impact of user spatial heterogeneity on HCNs.
- The simulation results show that network performance deteriorates when users are more heterogeneously distributed.
- By deploying small cells in the center of users hot-zone found by clustering analysis, we provide insight that HCNs can benefit from a certain degree of user spatial heterogeneity if the locations of small cells are strongly correlated to the centre of user clusters.

❑ Outlook:

- Use user-in-the-loop technique to reduce user spatial heterogeneity so as to improve network performance.
- Instead of same user rate demand, investigate different rate demand with different properties, e.g., real-time and non-real-time, and their influences on user-in-the-loop.

Thank you!