Measuring the Spatial Heterogeneity of Outdoor Users in Wireless Cellular Networks Based on Open Urban Maps

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Outline

- HetNets with heterogeneous user distribution ➔ HetHetNets
- Sources of User Spatial Heterogeneity
- Measuring Spatial Heterogeneity
- Open Source Maps – A Great Resource for Wireless Communications Modeling
- Initial Heterogeneity Results in a Dense Urban Area
- Ongoing Related Research

Sources of User Spatial Heterogeneity: 1) Self-Clustering

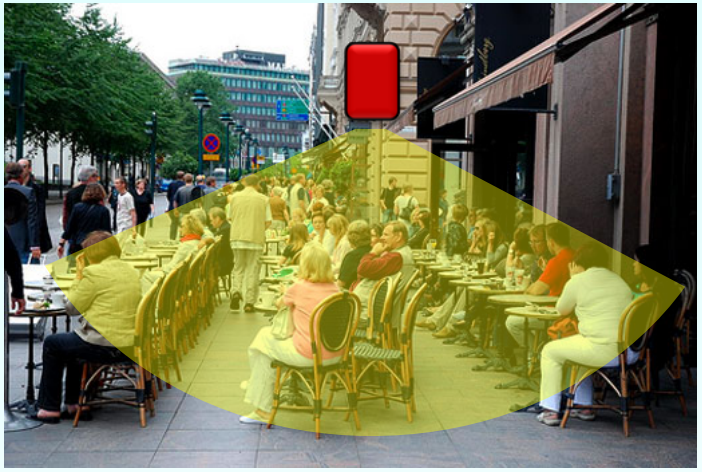
Sources of User Spatial Heterogeneity: 2) Urban Layout

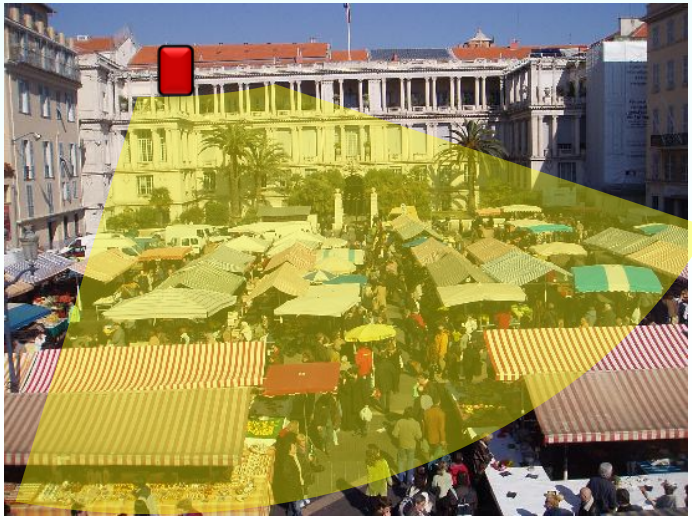
Focus of this paper!

Sources of User Spatial Heterogeneity: 3) Fixed Social Attractors

Small Cell Planning around Social Attractors

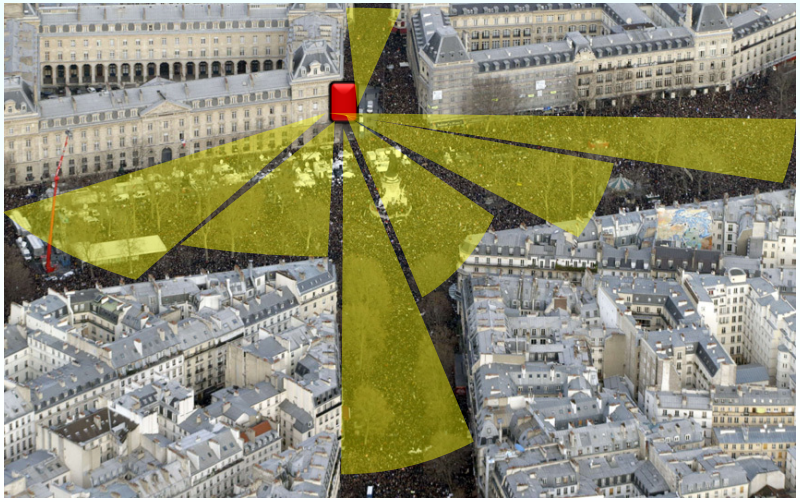
➔ Correlation between user clusters and AP locations

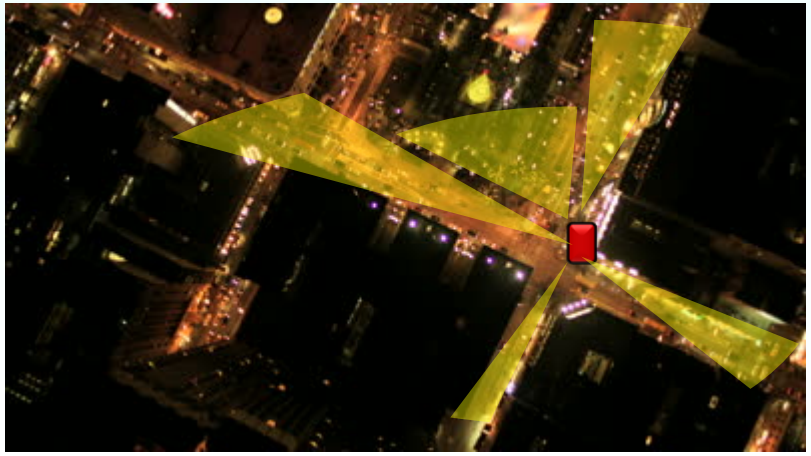




Small Cell Planning around Urban Layout

➔ Correlation between user layout and AP locations



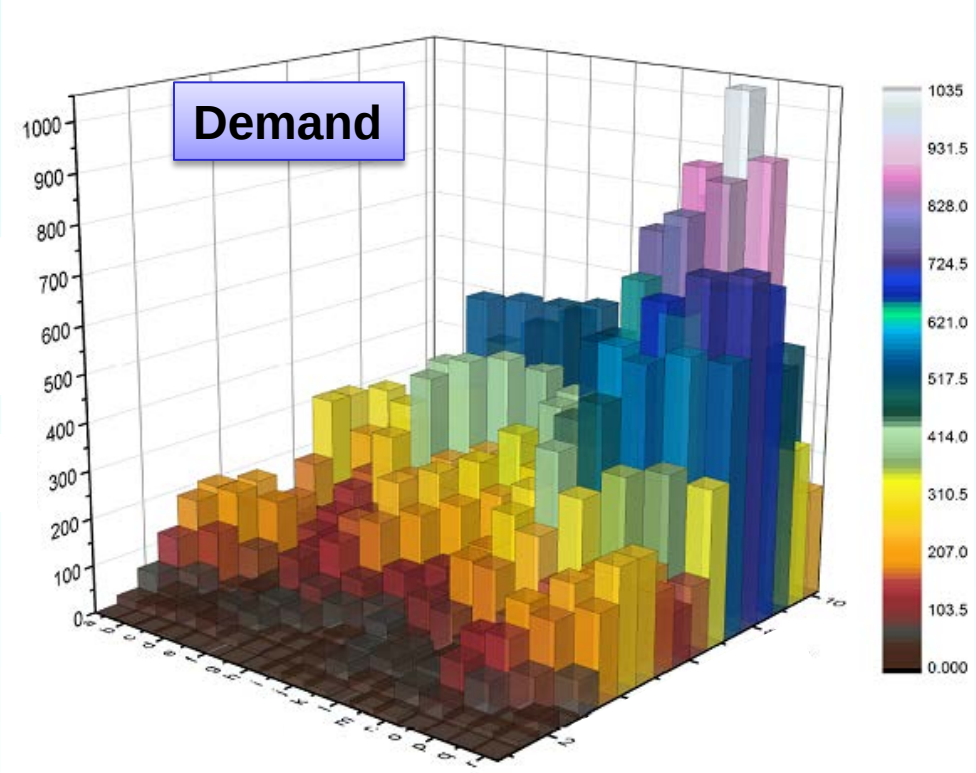


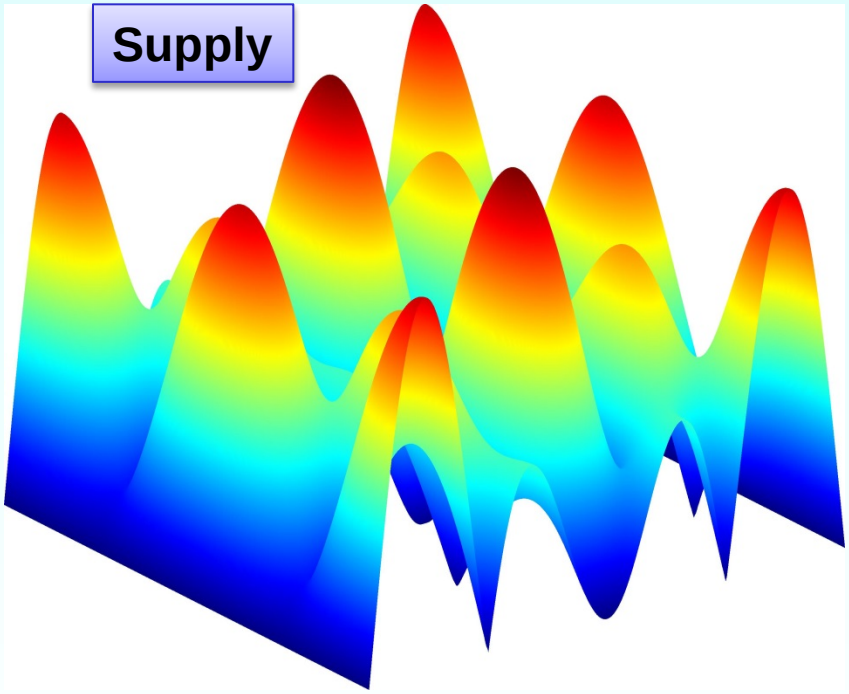
Heterogeneity in Applications

M2M Module	=	3 X
Wearable Device	=	6 X
Smartphone	=	37 X
Tablet	=	94 X
Laptop	=	119 X

* Monthly basic mobile phone data traffic.
Source: Cisco VNI Mobile, 2015

If Supply and Demand Do Not Match in Space and Time…



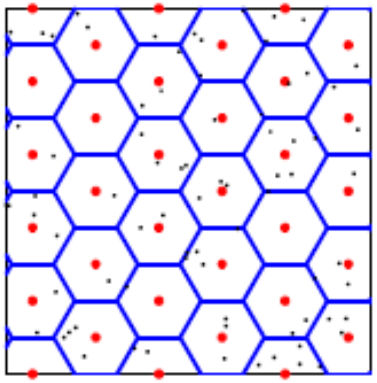


Can we store (in time) and/or transfer (in space) the supply?

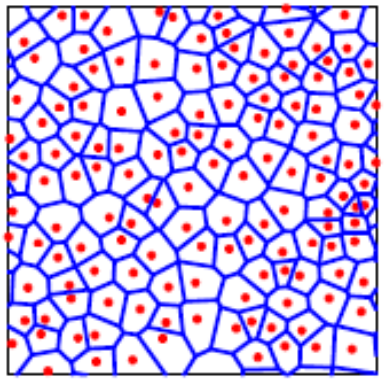
If difficult, then more heterogeneous + more unpredictable → more problems

HetNets: Heterogeneity in Supply (Access Points)

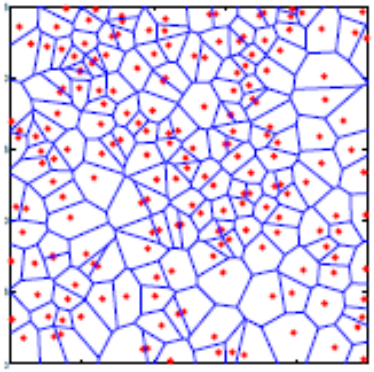
Locations of APs somewhere between a regular grid and total randomness:



Traditional grid model

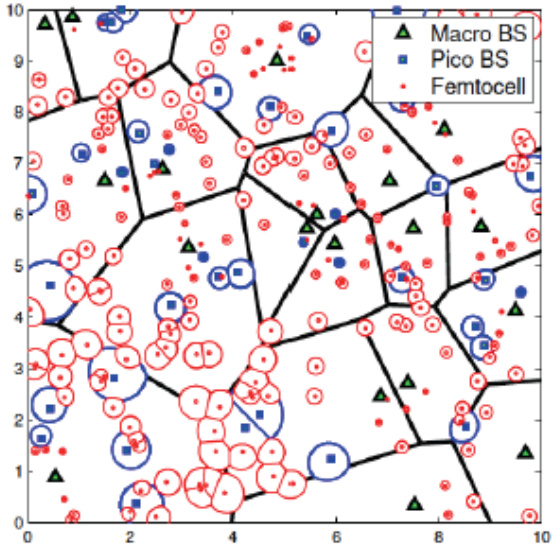


Actual 4G network today



Completely random BSs

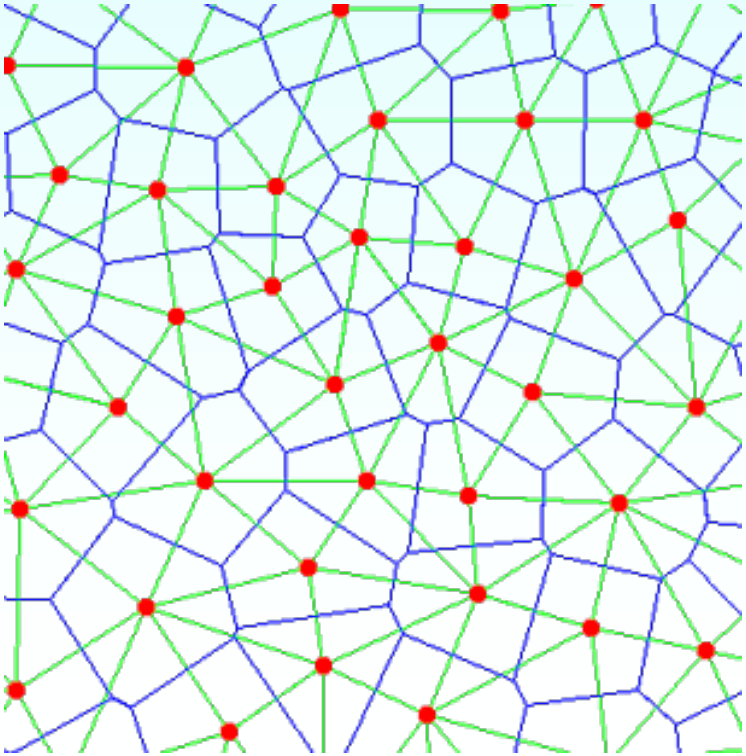
Coexistence of several cells types with very different coverage ranges.



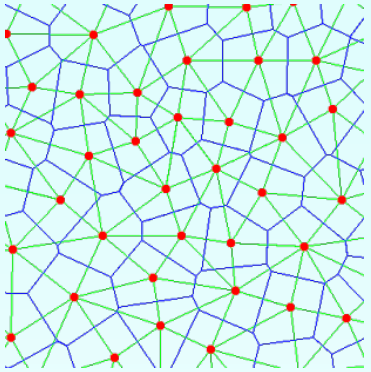
[U of Texas, Austin]

Measuring Spatial Heterogeneity: Step 1: Voronoi Tesselation

- For a set of Points, Find the Voronoi Partition: areas that are closer to their own point than any other point.
- Two points are “natural neighbours” if their Voronoi cells touch.
- Natural neighbours are connected by straight edges to form the Delaunay triangulation.



Measuring Spatial Heterogeneity: Step 2: Coefficient of Variation



- Statistic: Coefficient of Variation:

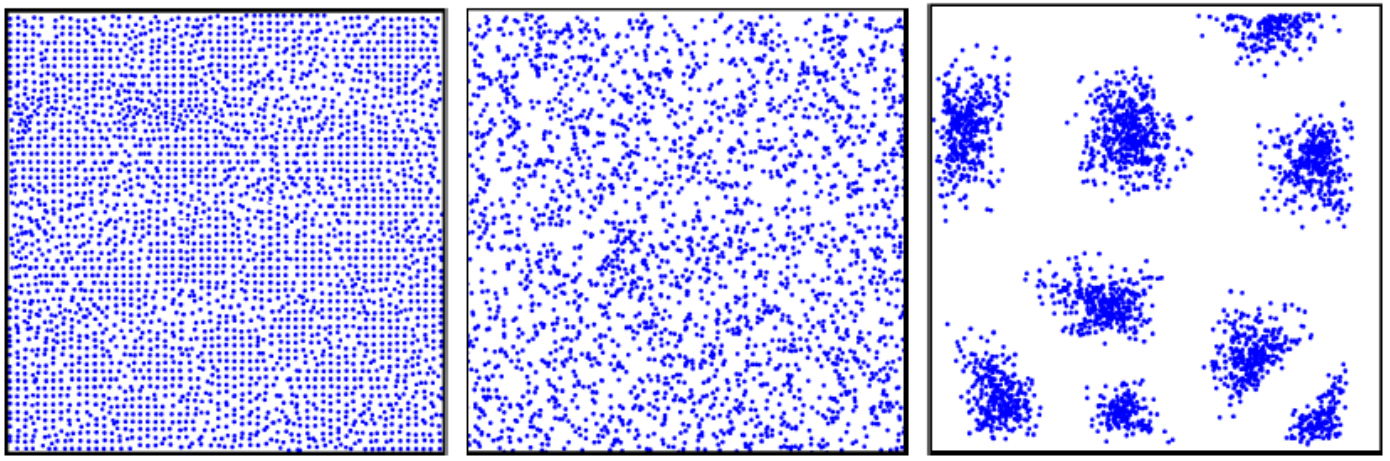
  CoV{x} = std.dev.{x}/(mean{x} * K) - K a constant

- We study two metrics (two “flavours”):
  - CoV of Voronoi Cell Areas (K=0.529)
  - CoV of Delaunay Cell Edge Lenghts (K= 0.492)
- CoV (either flavour) captures heterogeneity(dispersion/clustering) of any point process in one positive scalar value:

sub-Poissonian (e.g., repulsive): 0<CoV<1

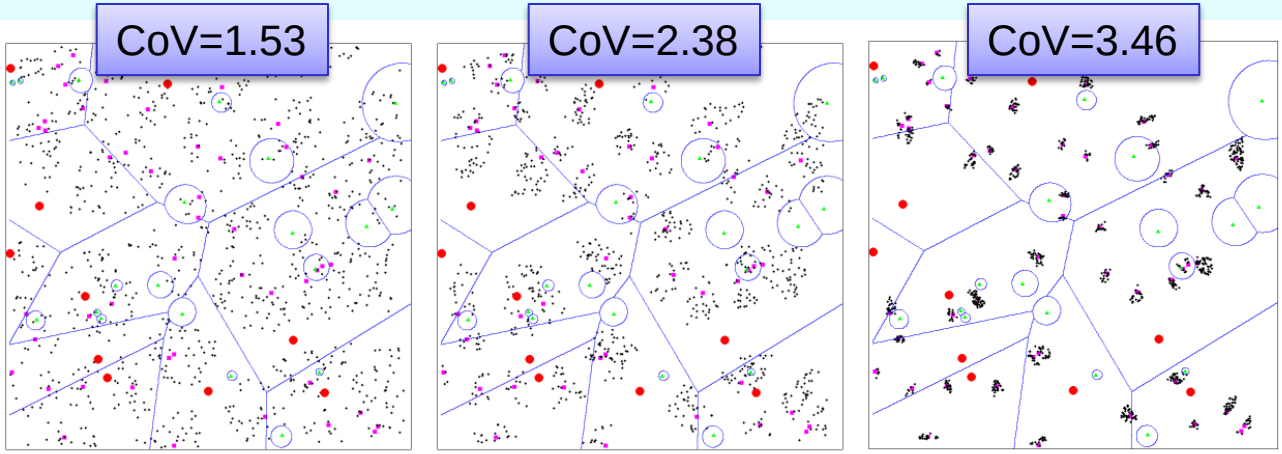
Poisson Point Process: CoV=1

super-Poissonian (e.g. clustered): CoV>1



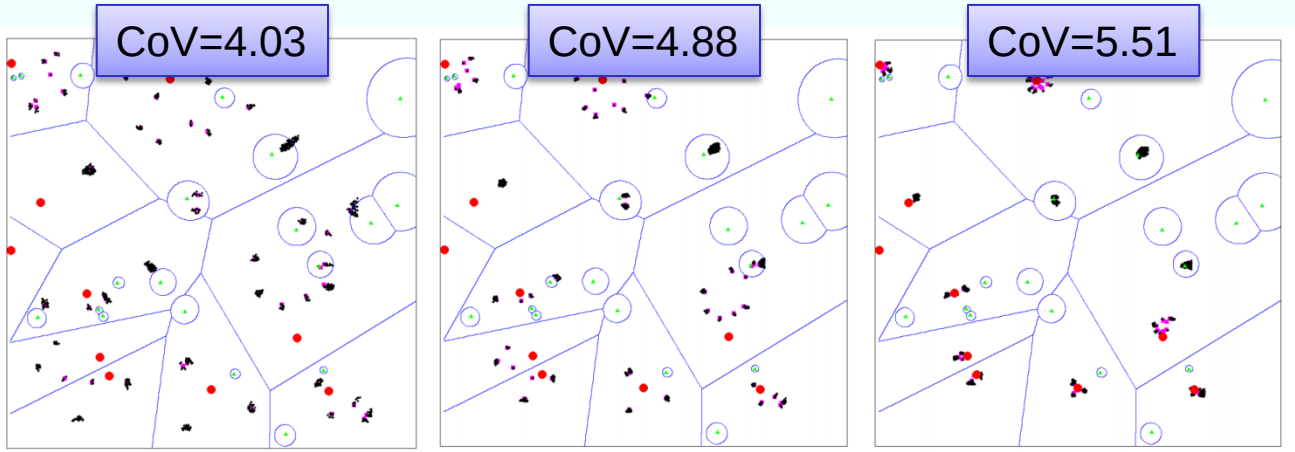
HetHetNets = HetNets + Heterogeneity in Demand (User Locations)

Users (black) self-clustering: clustering increases with beta



(b) $\alpha = 0$ and $\beta = 0.3$ (c) $\alpha = 0$ and $\beta = 0.6$ (d) $\alpha = 0$ and $\beta = 0.9$

User clustering around APs: increases with alpha



(h) $\alpha = 0.3$ and $\beta = 0.9$ (l) $\alpha = 0.6$ and $\beta = 0.9$ (p) $\alpha = 0.9$ and $\beta = 0.9$

[JSAC Oct 2015]

Comparison with Propagation Modeling

- A topic in wave sciences (physics)

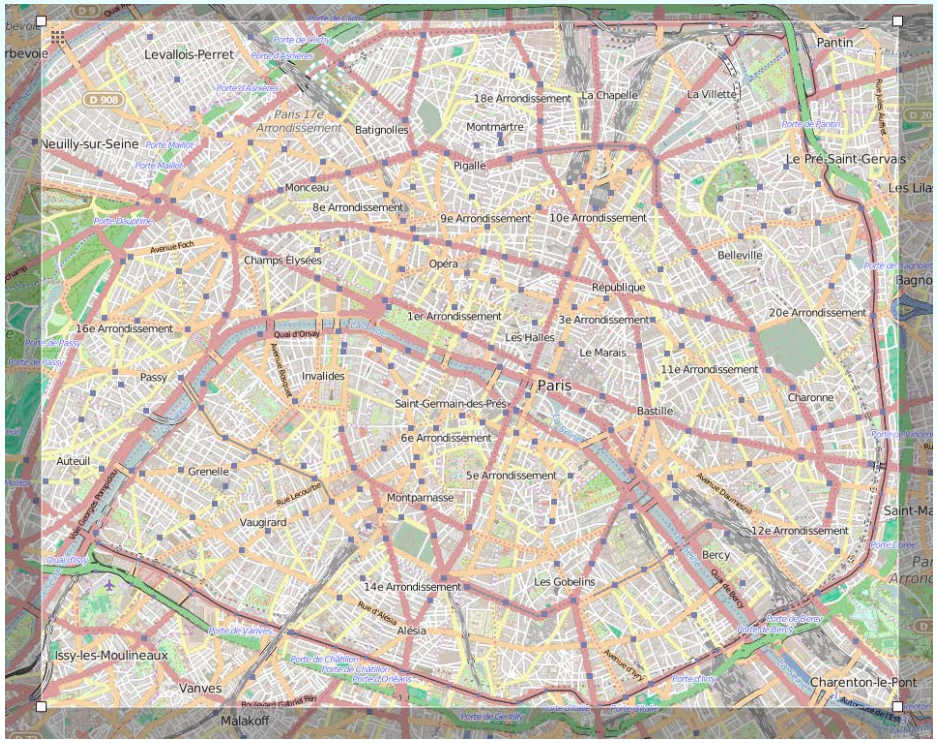
- But simple models for mobile radio exists:
  Path-loss = $A + 10n \log(d) + X(\sigma)$

- Path-loss model: from 2 parameters to very many parameters
- COST, WINNER, 3GPP, …

- n and σ: Describe a scenario (urban microcell, rural macrocell, etc.)

OpenSourceMaps.org: Open Maps of the Entire World

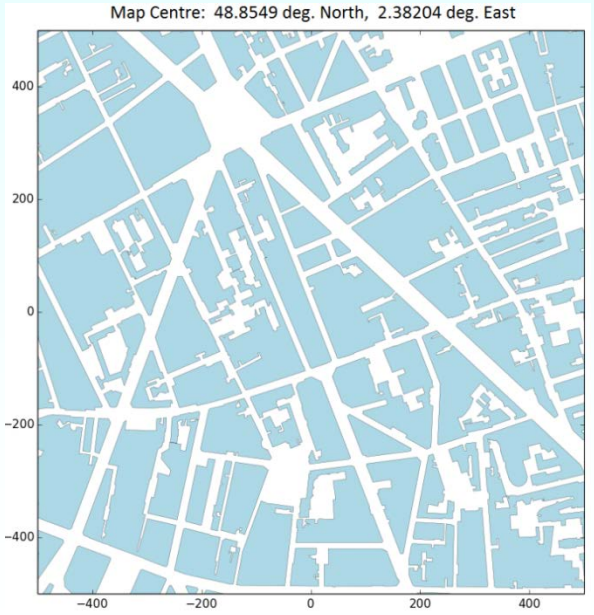
- Free open vector maps made by volunteers from around the world.
- Some cities, notably central Paris, France, have very complete building footprint information.
- Every building is encoded as a closed polygon with known coordinates.
- We use data from central Paris: 10km x 8km, divided into overlapping 1km x 1km tiles.



[www.openstreetmap.org]

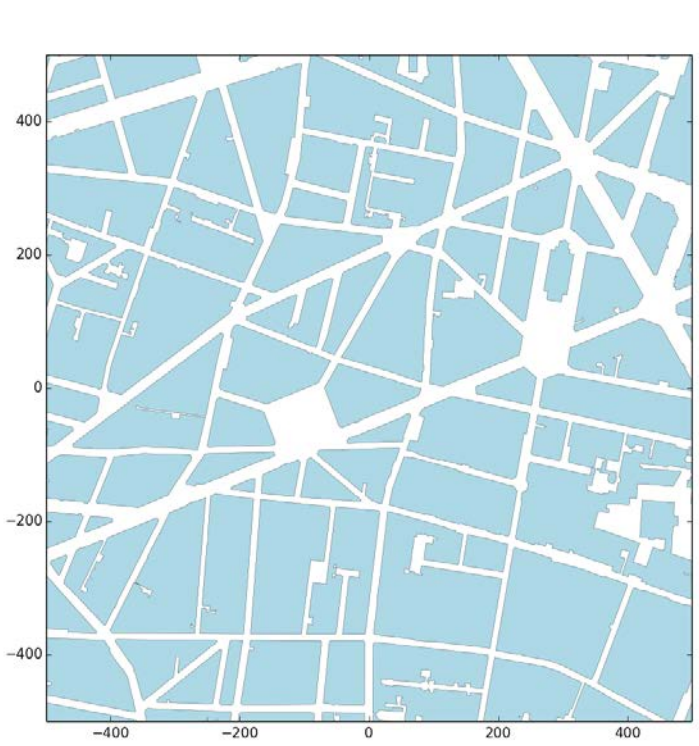
Tile Processing

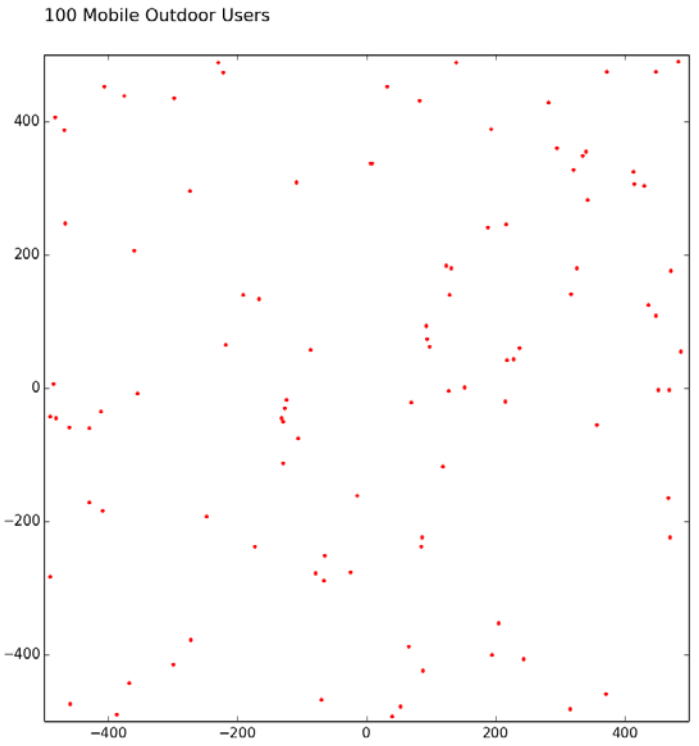
- Cut tiles (1km x 1km) from a large (whole city) master file.
- Find all buildings.
- Convert building coordinates from spherical (lat/lon) to local 2D approximation (error < 4cm).
- Merge building into blocks and remove inner courtyards.
- Final Result: City blocks (light blue) and open areas (white)



Users Placed Randomly in Outdoor Areas

Heterogeneity becomes more prominent with increased user density





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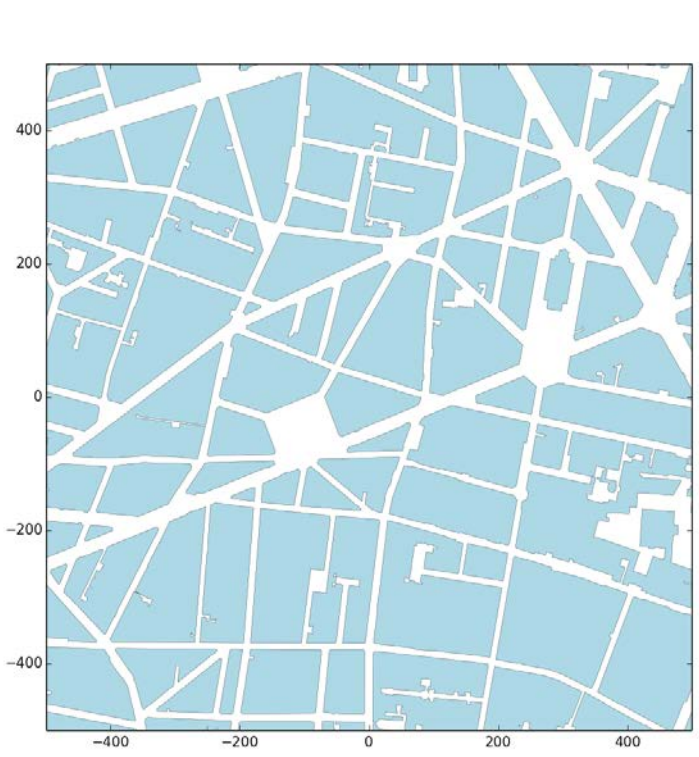

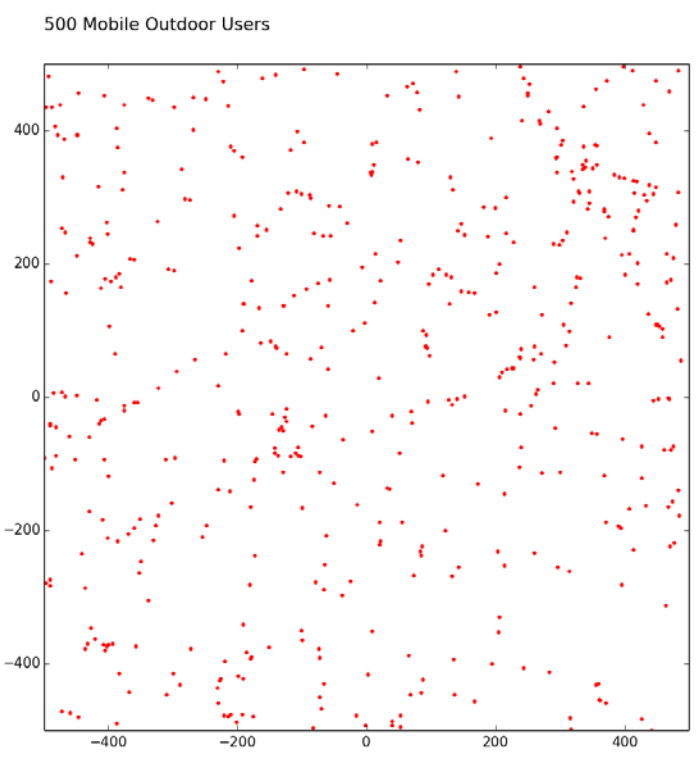

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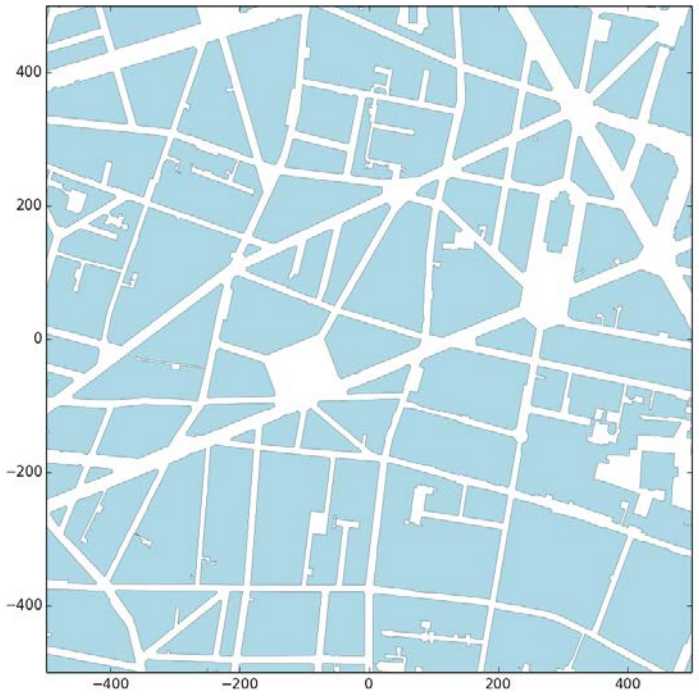

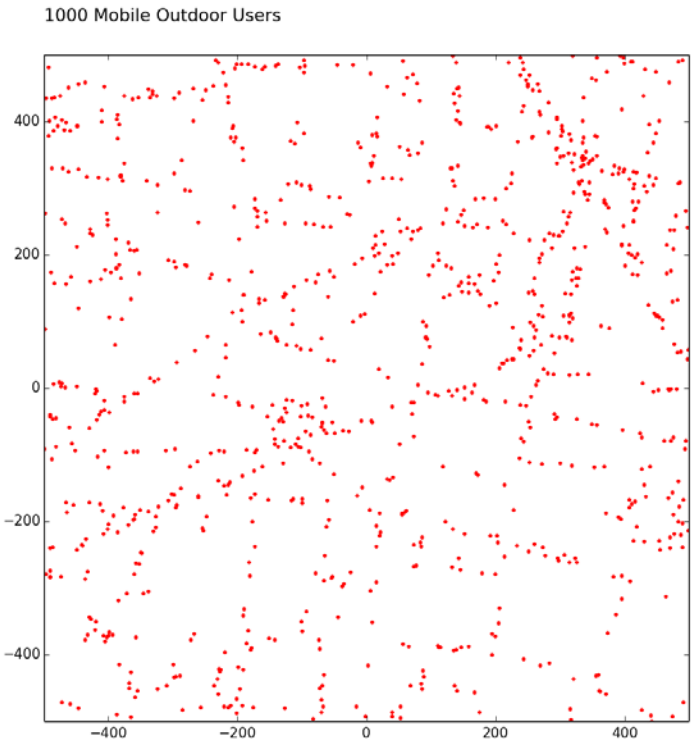

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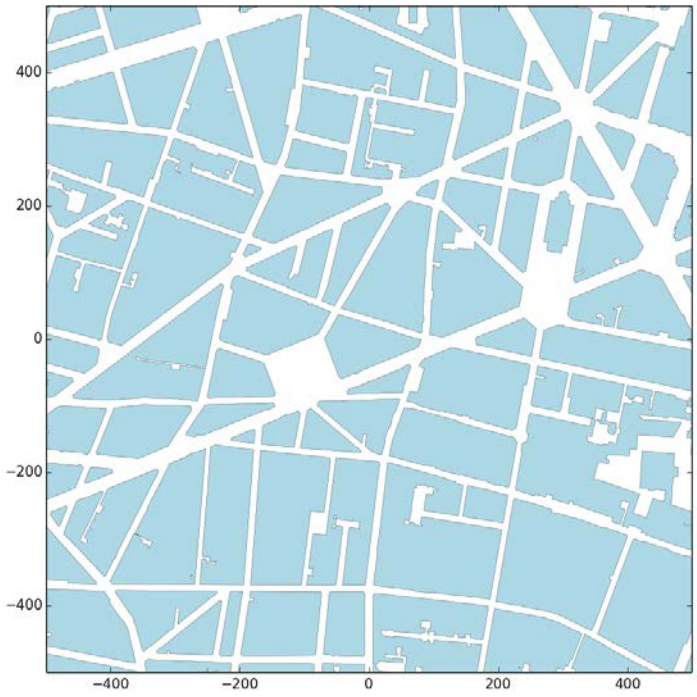

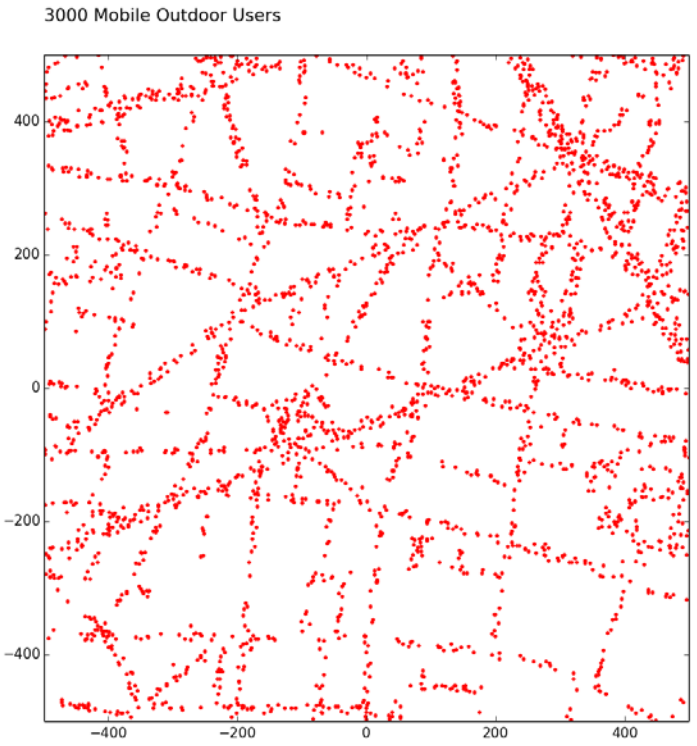

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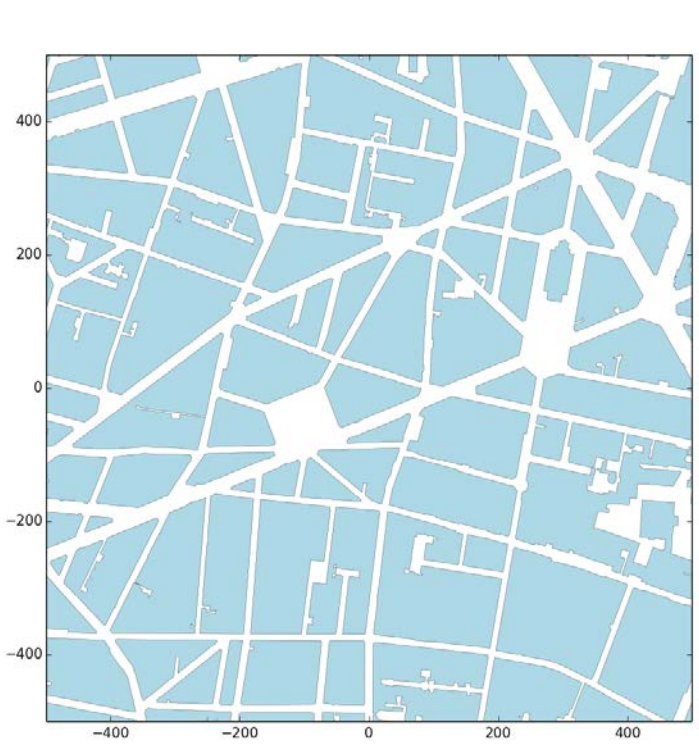
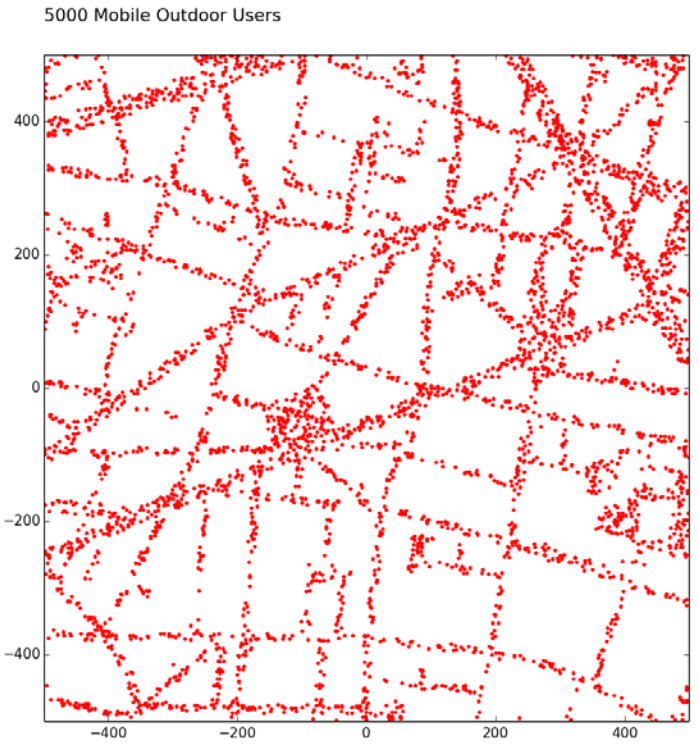
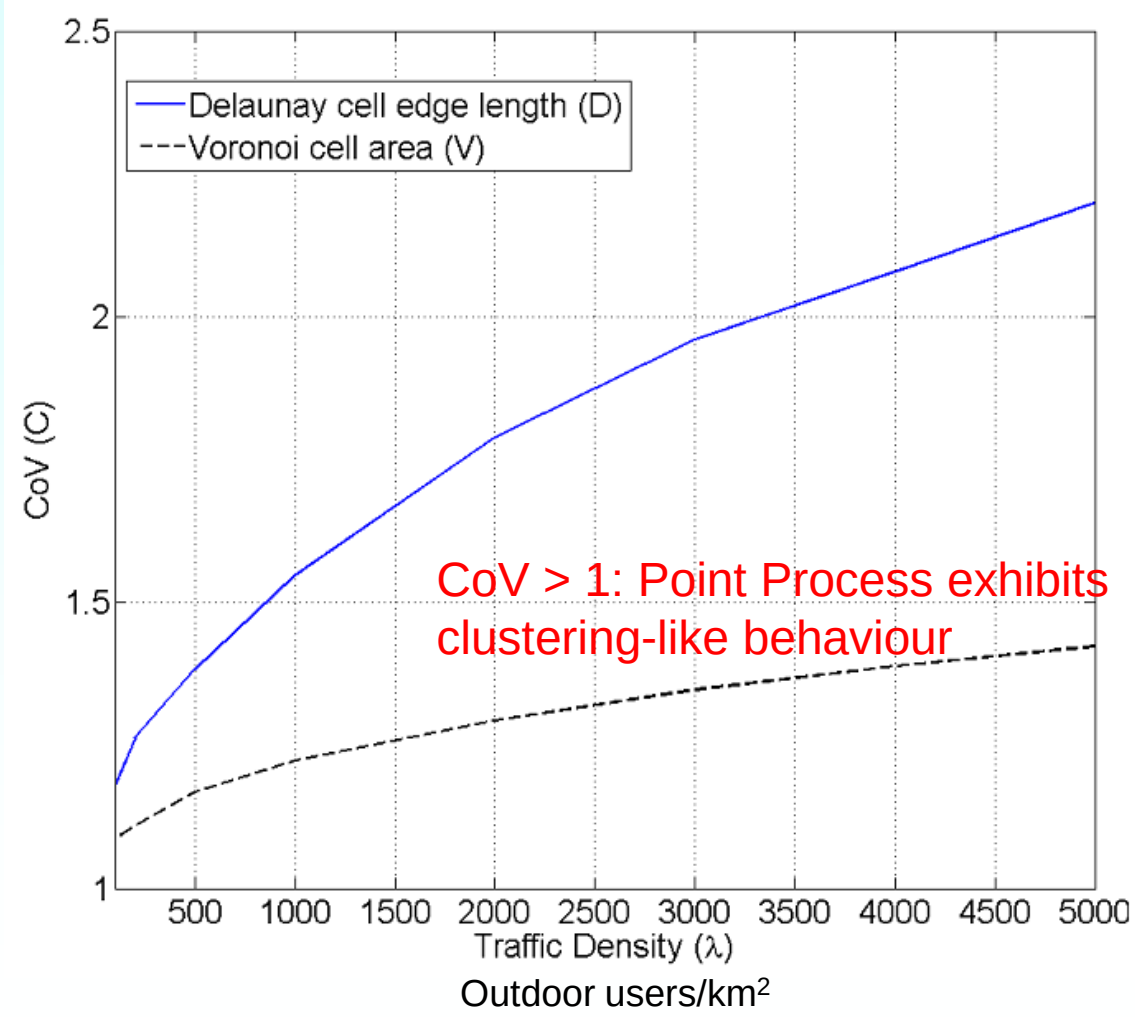
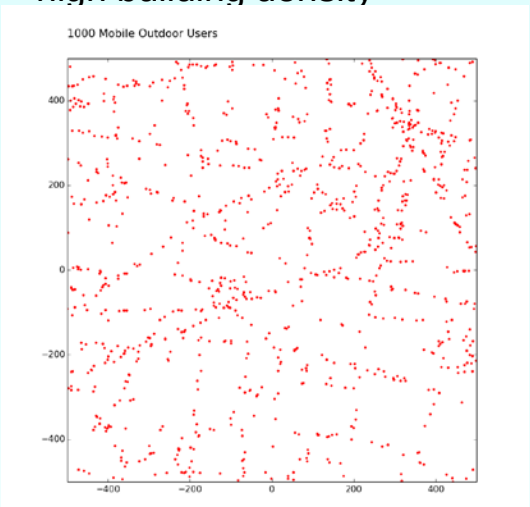


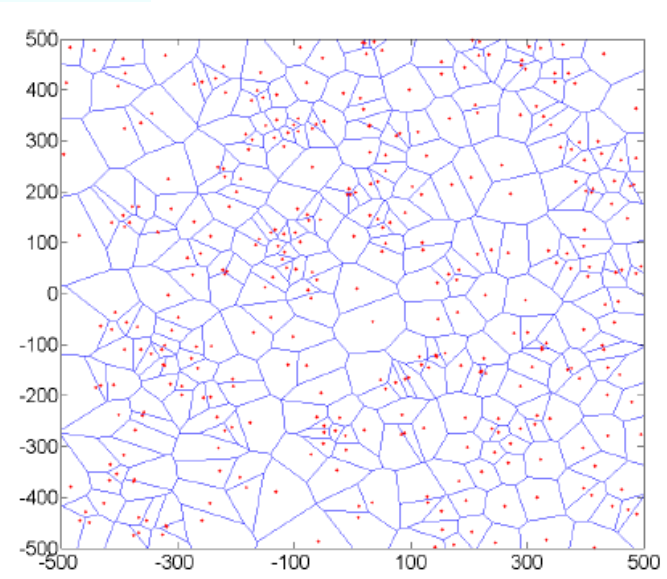


Measuring Heterogeneity of Outdoor Urban Users

Based on 83 1km^2 maps with high building density







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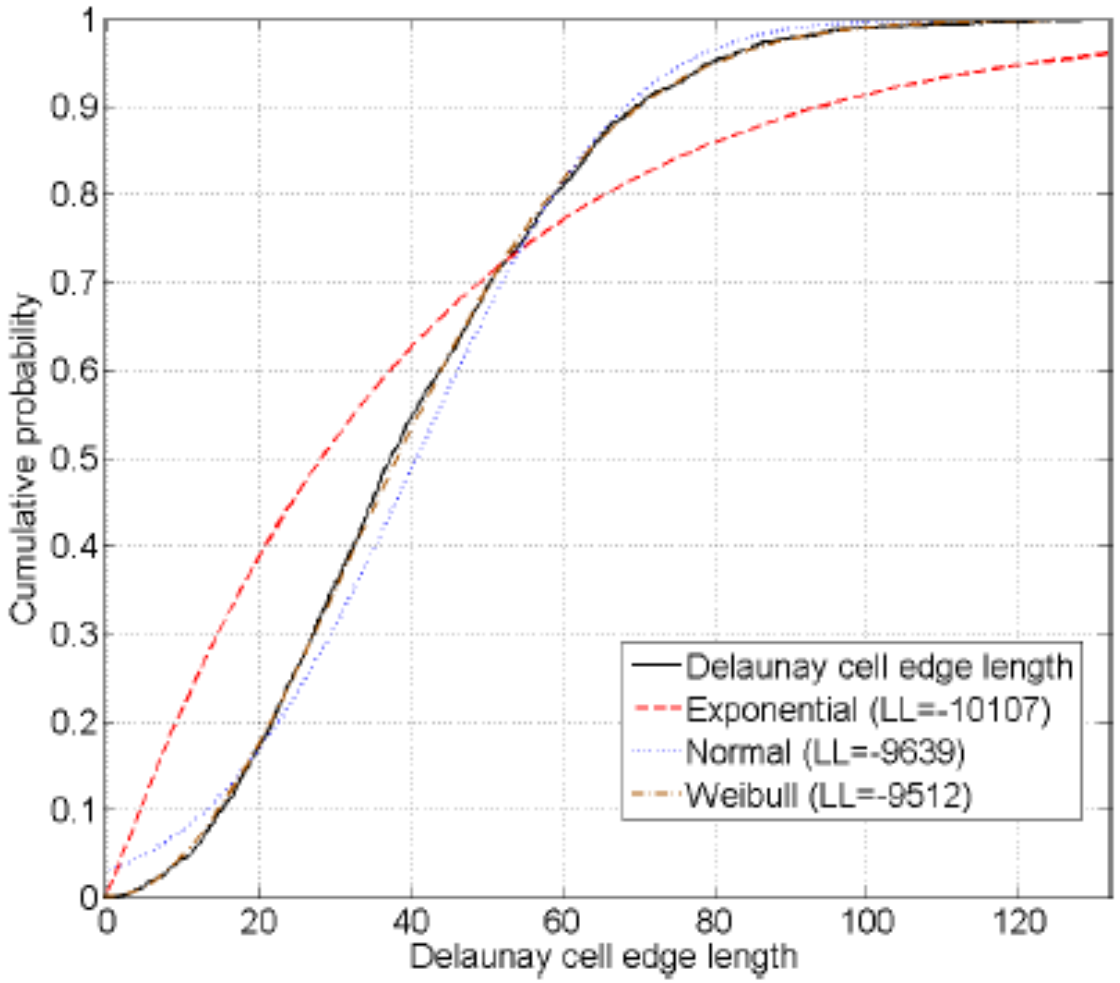

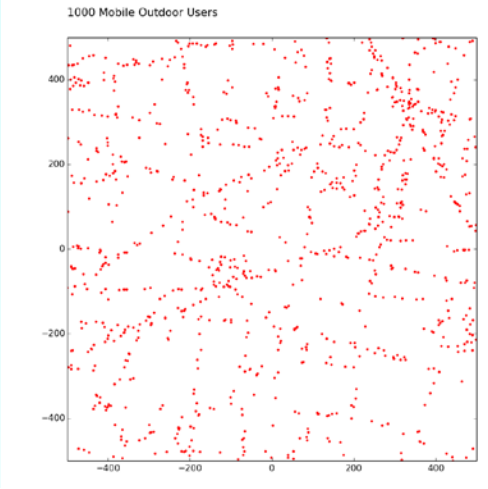

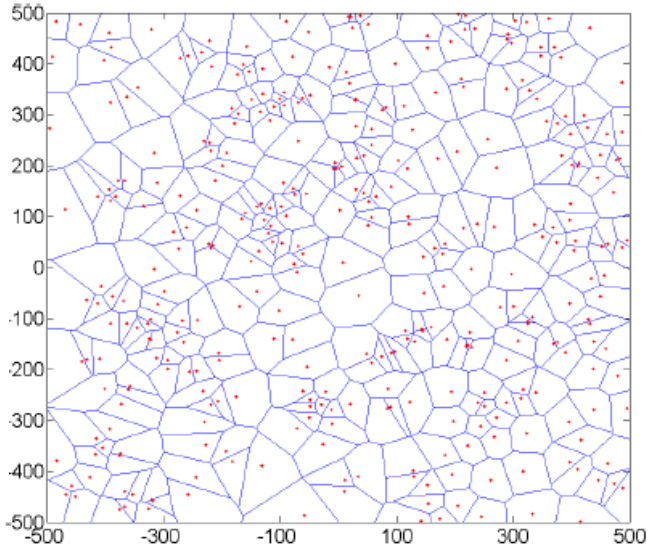

Ongoing Related Research

- Comparison between different types of cities (European vs US, urban vs suburban)
- Are there more appropriate metrics for characterizing the outdoor urban users' distribution.
- Combine urban information with social attractors model for even more heterogeneity.
- Finding a simple-enough point process that has similar properties to the urban users location, with tunable parameters that can account for different types of urban areas.
- Use urban data to characterize the spatial distribution of small cell AP locations, their coverage, and their correlation with he users' locations.
- Other interesting uses of OpenStreetMaps data in wireless communications…