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

Sources of User Spatial Heterogeneity: 2) Urban Layout

Focus of this paper!
Spatial Heterogeneity of Outdoor Users in Wireless Cellular Networks Based on Open Urban Maps

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

<table>
<thead>
<tr>
<th>Device</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2M Module</td>
<td>3 X</td>
</tr>
<tr>
<td>Wearable Device</td>
<td>6 X</td>
</tr>
<tr>
<td>Smartphone</td>
<td>37 X</td>
</tr>
<tr>
<td>Tablet</td>
<td>94 X</td>
</tr>
<tr>
<td>Laptop</td>
<td>119 X</td>
</tr>
</tbody>
</table>

* 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 $\rightarrow$ more problems
HetNets: Heterogeneity in Supply (Access Points)

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

Coexistence of several cells types with very different coverage ranges.
Measuring Spatial Heterogeneity: Step 1: Voronoi Tessellation

- 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:**
  
  \[ CoV\{x\} = \frac{\text{std.dev.}\{x\}}{(\text{mean}\{x\} \times K)} \]  
  - \( K \) 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

User clustering around APs: increases with alpha

CoV=1.53
CoV=2.38
CoV=3.46
CoV=4.03
CoV=4.88
CoV=5.51
Comparison with Propagation Modeling

- A topic in wave sciences (physics)

- But simple models for mobile radio exists:
  \[ \text{Path-loss} = A + 10^n \log(d) + X(\sigma) \]

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

- \( n \) and \( \sigma \): 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)
Spatial Heterogeneity of Outdoor Users in Wireless Cellular Networks Based on Open Urban Maps

Users Placed Randomly in Outdoor Areas

Heterogeneity becomes more prominent with increased user density
Users Placed Randomly in Outdoor Areas

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Measuring Heterogeneity of Outdoor Urban Users

CoV > 1: Point Process exhibits clustering-like behaviour

CoV (C)

Traffic Density (\( \lambda \))

Outdoor users/km²

Based on 83 1km² maps with high building density
Measuring Heterogeneity of Outdoor Urban Users

Based on 83 1km² maps with high building density
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 the users’ locations.
- Other interesting uses of OpenStreetMaps data in wireless communications…