# Unified and Non-parameterized Statistical Modeling of Temporal and Spatial Traffic Heterogeneity in Wireless Cellular Networks

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# Outline

## Motivation:

- Problem definition, contributed solution and novelty

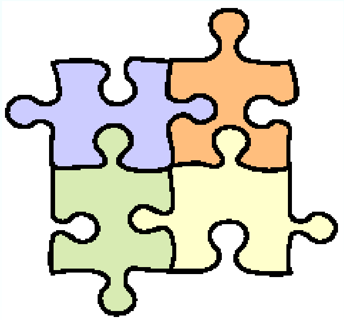
## Contributions and novelties:

- Modeling and fitting procedure; for generator and measurement aspect
- Traffic is adjustable by just one first, second order, and correlation parameter

## Traffic generation process:

- Unified “Traffic Generator Input Parameters” (TGIPs)
- Umbrella for diverse models of point processes (PP)

## Results and Conclusions:



- Experimental results of traffic generation
- Performance results in cellular networks
- Performance improvement by clever placement of small cells
- Future work

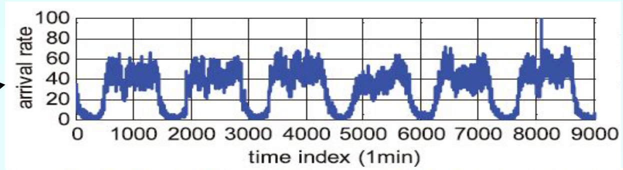
# Novelty

## Problem definition:

- In wireless cellular networks path loss & SINR depend on the spatial distribution of users
- An adjustable and systematic model for a heterogeneous traffic (user) distribution is not available

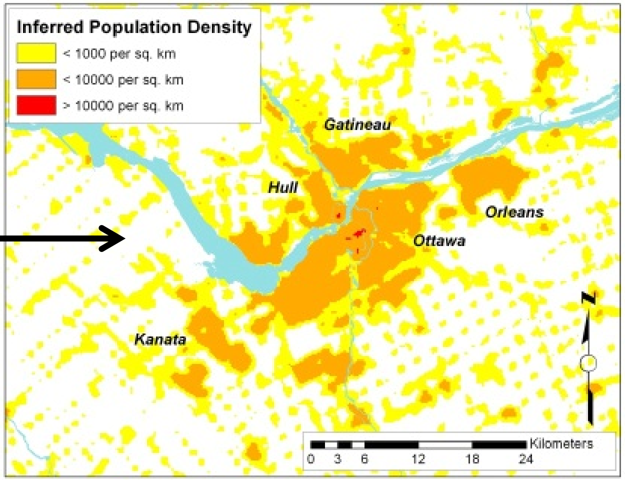
## Relevant literature:

- In time domain traffic modeling has been investigated well
- Stochastic geometry is used for the location of BSs in HetNets




## Solution:

- Use stochastic geometry to model **UT** traffic in space domain
- Include point processes and random tessellations




## Novelty:

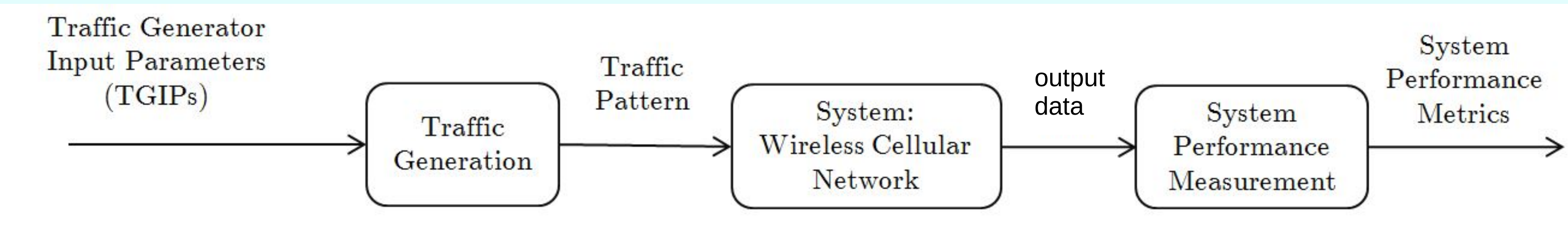
- Comparison and analogy of traffic modeling in the time domain and space domain
- Introduction of unified and accurate metrics for modeling traffic in both domains
- Simply, CoV for adjustable heterogeneity and $\rho$ for cross-correlation of UTs to BSs

# System Model

## and what we want to achieve

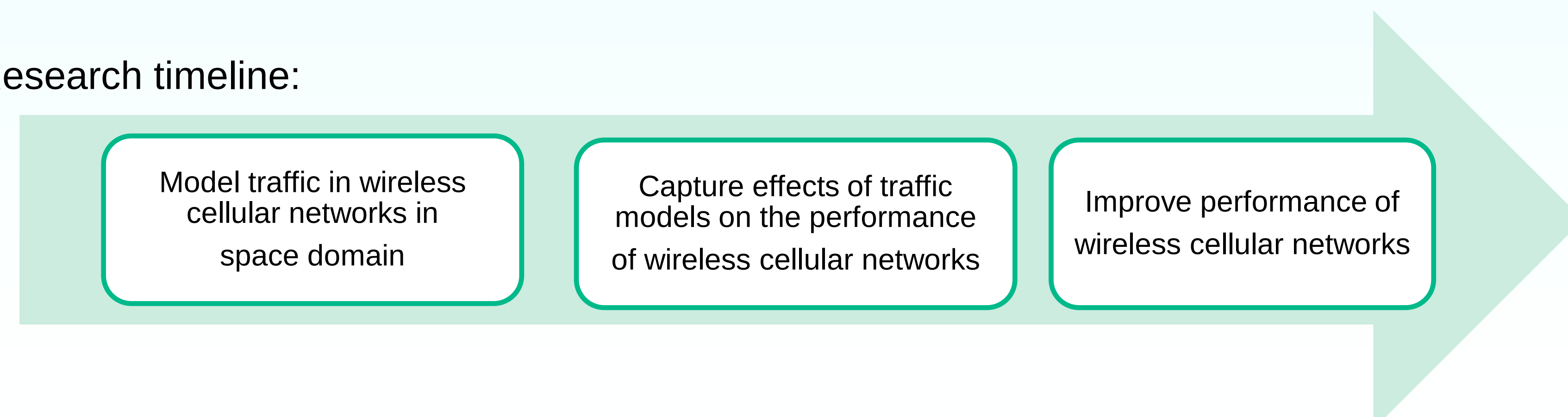
This is the high-level view on what we want to achieve:

- Traffic in
- Performance out



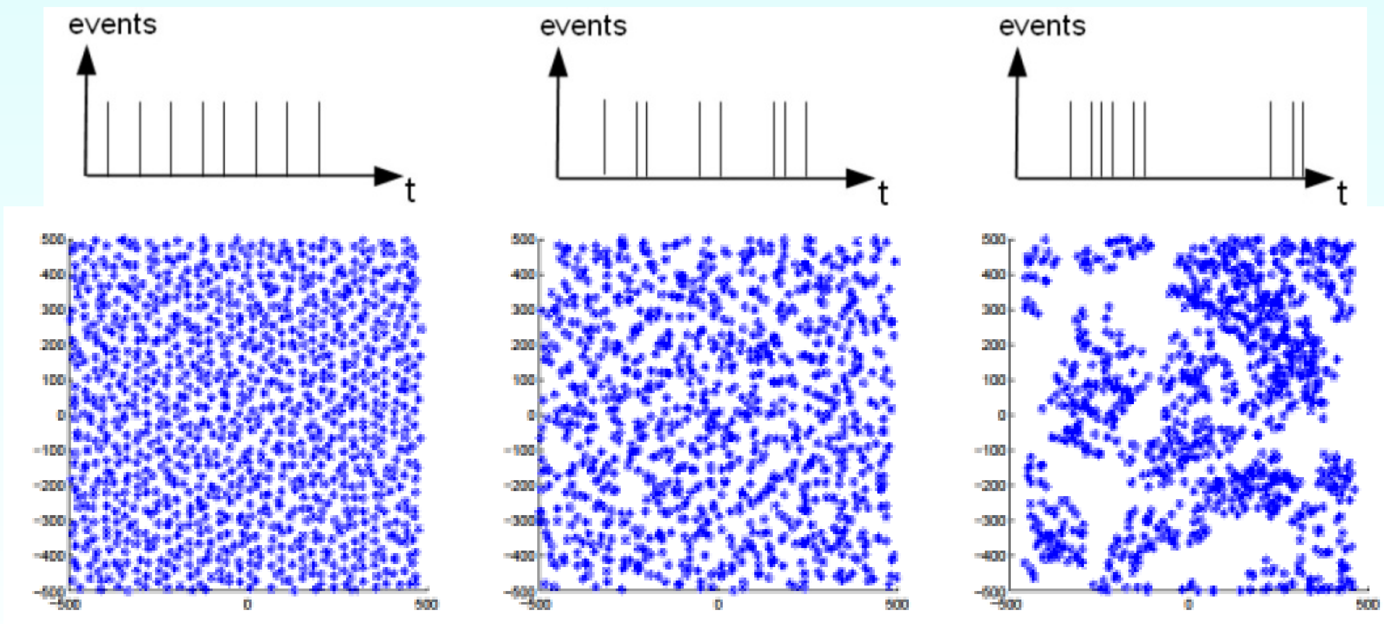

Goal:
Only one simple yet versatile input parameter for heterogeneity

Research timeline:



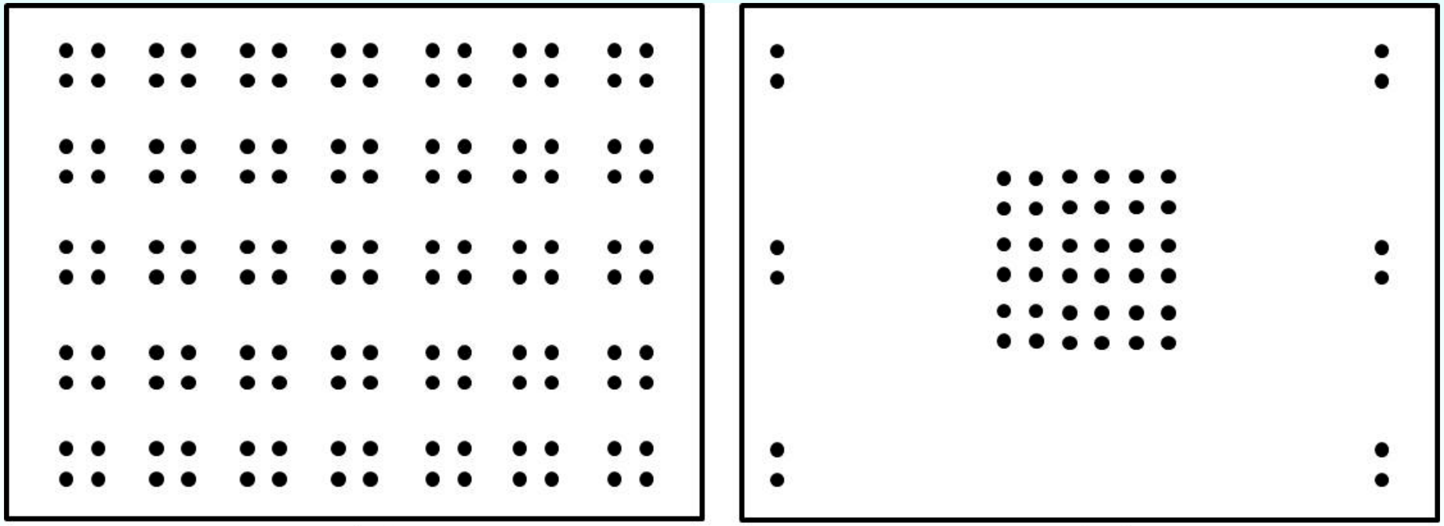
# Analogy between Time and Space

Sub-Poisson | Poisson | Super-Poisson



# Why some metrics are **unsuitable**

Nearest neighbor distance measure can not capture the heterogeneity of point process



(a)

(b)

# Traffic Analysis & Generation with Heterogeneity (second-order)

Complete randomness (CoV=1): Poisson →

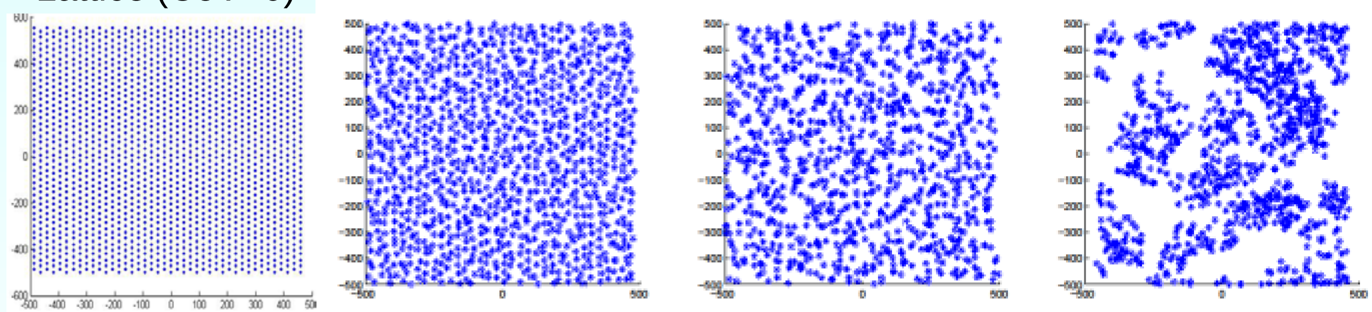
Sub-Poisson (CoV<1): perturbation →

Maximum homogeneity (CoV=0): Lattice ↓

CoV := std/mean = σ/μ)

Sub-Poisson (CoV<1) | Poisson (CoV=1) | Super-Poisson (CoV>1)


Lattice (CoV=0)



Super-Poisson (CoV>1):

- Time domain: Markov-based **hierarchical** processes, e.g. MMPP
- Space domain: Hierarchical, too
  - Clustering perturbation
  - Physics inspired: Gravity (Astronomy: Galaxies)

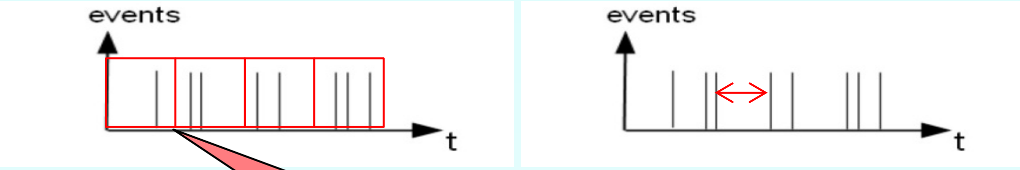
| Point Process | Parent Process (top level hierarchy) | Replication Kernel (number of replicas) | Displacement Kernel (shift in space) |
|---|---|---|---|
| Binomial Point Process | One-Point | Deterministic | Uniform |
| Voronoi-Perturbed Lattices | Lattice | General | General in Voronoi Cell |
| Simple Perturbed Lattice | Lattice | No Replication | Uniform in Voronoi Cell |
| Gaussian Perturbed Lattice | Lattice | No Replication | Gaussian |
| Generalized Shot-noise Cox | General | Poisson | General |
| Poisson-Poisson Cluster PP | Poisson | Poisson | General |
| Matern Point Process | Poisson | Poisson | Uniform in Ball |
| Thomas Point Process | Poisson | Poisson | Gaussian in Ball |
| Neyman-Scott Point Process | Poisson | General | General |
| Cox | General Levy | Poisson | Uniform |
| Log-Gaussian Cox | Log-Gaussian Levy | Poisson | Uniform |

# Measuring Traffic

## Metric:

### Time domain:

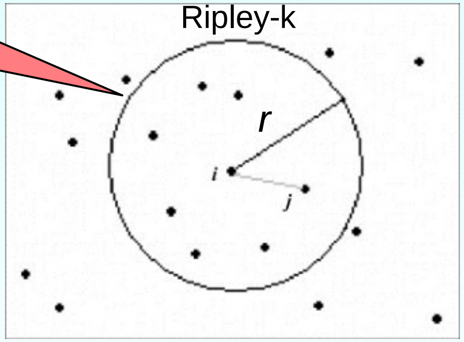
- Density based: Interval counts (rates)
- Distance based: Inter-arrival time




Problem: additional parameter(s)

### Space Domain:

- Density based: Ripley-k, pair correlation, moments, void prob.
- Distance based: nearest-neighbor

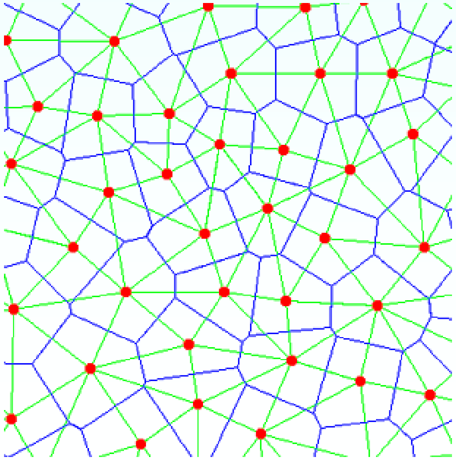



New Approach: Use properties of **Voronoi** & **Delaunay**

Voronoi cell := for each point $p_i$ of the process,

the region consisting of all area closer to $p_i$ than to any other point.

Unified metric can be: Voronoi cell area, Delaunay edges length …

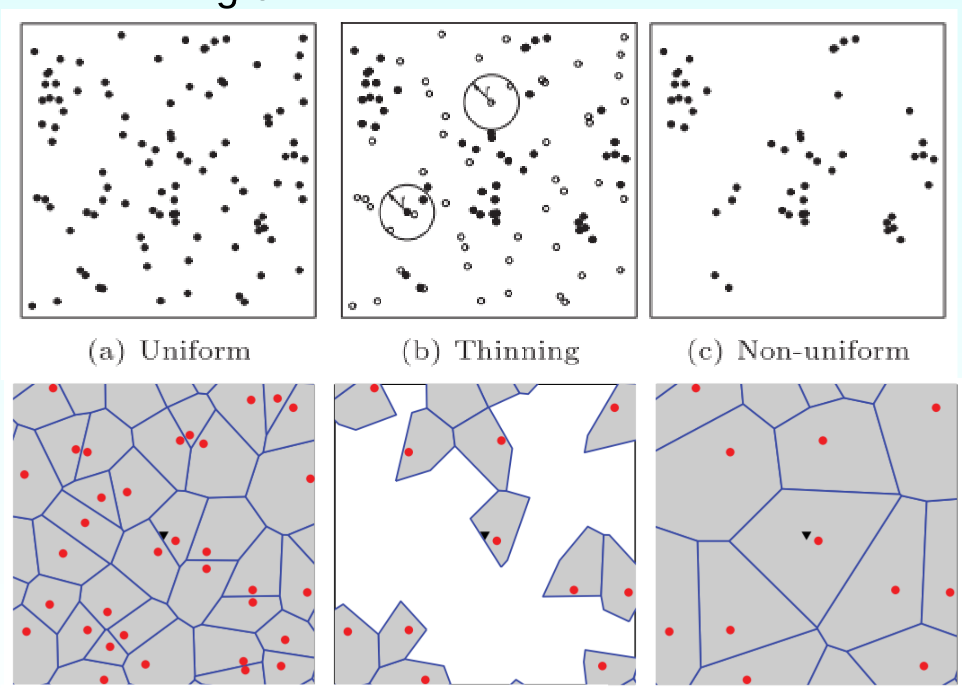


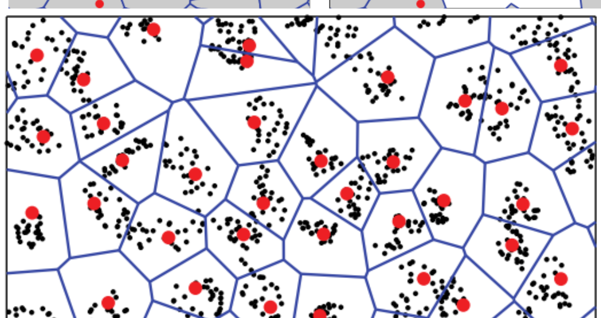
## Statistical property:

CoV := std/mean ($C := \sigma/\mu$)

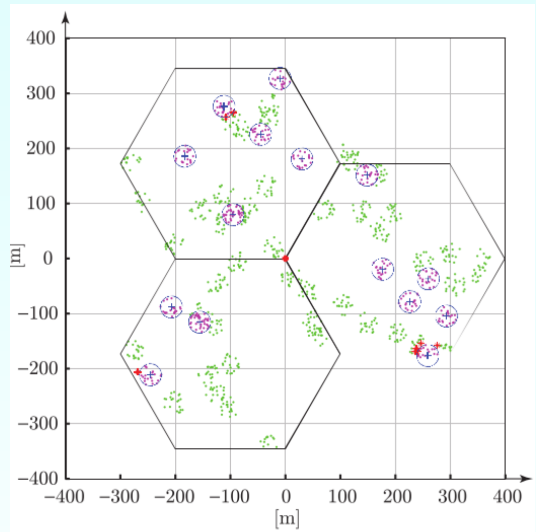
# Users in Literature

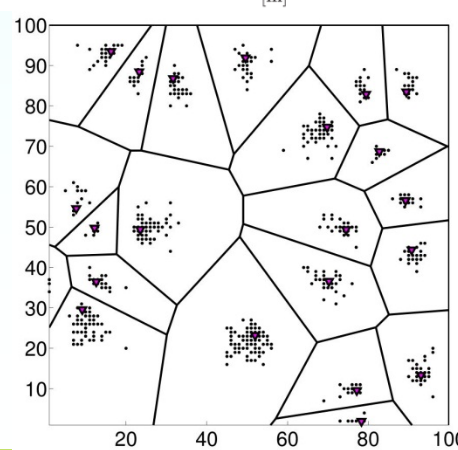
- Mostly homogeneously distributed (PPP) or even fixed number and location in a cell
- Heterogeneous user distribution examples:
  - Thinning on PPP



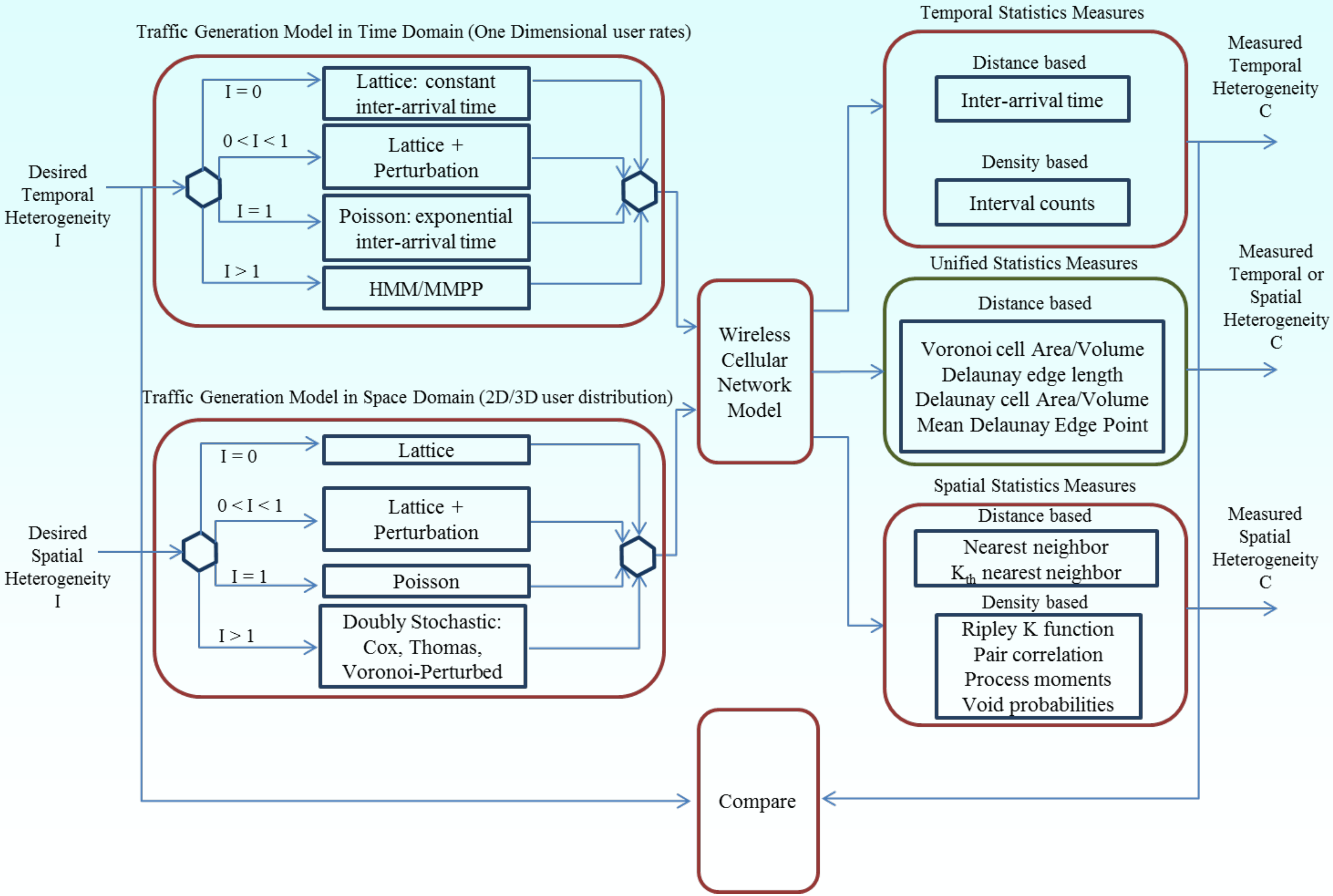



  - Poisson Cluster Process



# Detailed Model



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# Different PPP Metrics and their properties, 2D versus 3D

| Distance based metrics | Analogue in the time domain | Statistics | 1D | 2D | 3D |
|---|---|---|---|---|---|
| Nearest-neighbor distance (G) | $\min\{I_i, I_{i+1}\}$ | Mean (μ) | $0.5\ \lambda^{-1}$ | $0.5\Lambda^{-0.5}$ | $0.5539\Lambda^{-0.33}$ |
| | | Variance ($\sigma^2$) | $0.25\ \lambda^{-2}$ | $0.0683\Lambda^{-1}$ | $0.04049\Lambda^{-0.66}$ |
| | | CoV (C) | 1 | 0.6535 | 0.364 |
| Voronoi cell area/volume (V) | $\frac{I_i + I_{i+1}}{2}$ | Mean (μ) | $\lambda^{-1}$ | $\Lambda^{-1}$ | $\Lambda^{-1}$ |
| | | Variance ($\sigma^2$) | $\lambda^{-2}$ | $0.28\Lambda^{-2}$ | $0.18\Lambda^{-2}$ |
| | | CoV (C) | 1 | 0.529 | 0.424 |
| Delaunay cell area/volume (T) | $I_i$ | Mean (μ) | $\lambda^{-1}$ | $0.5\Lambda^{-1}$ | $0.147\Lambda^{-0.5}$ |
| | | Variance ($\sigma^2$) | $\lambda^{-2}$ | $0.443\Lambda^{-2}$ | $0.015\Lambda^{-1}$ |
| | | CoV (C) | 1 | 0.879 | 0.833 |
| Delaunay cell edge length (E) | $I_i$ | Mean (μ) | $\lambda^{-1}$ | $1.131\Lambda^{-0.5}$ | $1.237\Lambda^{-0.33}$ |
| | | Variance ($\sigma^2$) | $\lambda^{-2}$ | $0.31\Lambda^{-1}$ | $0.185\Lambda^{-0.66}$ |
| | | CoV (C) | 1 | 0.492 | 0.347 |

$\Lambda$: is the mean density of the point process [e.g., points/$m^2$, points/$m^3$]
$C_x$: is the CoV of that random process assuming a volume filled with PPP of density $\Lambda$.

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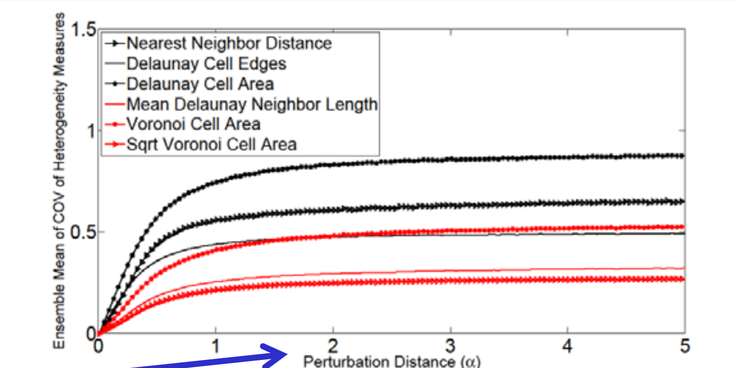
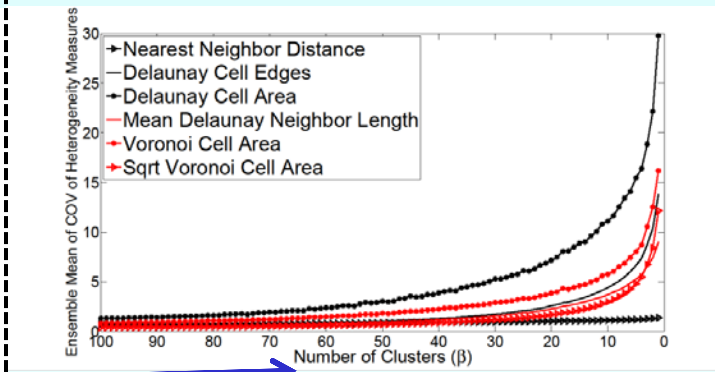
# Assessment Results
(in space domain)

Measured Output Metrics:

| | Sub-Poisson (CoV<1) | Super-Poisson (CoV>1) |
|---|---|---|

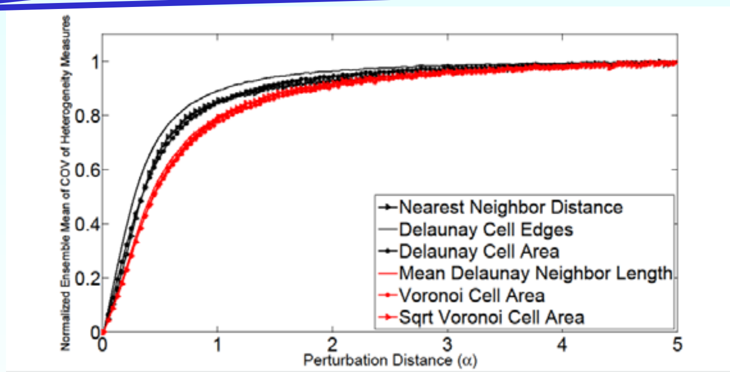
Ensemble Mean of CoV

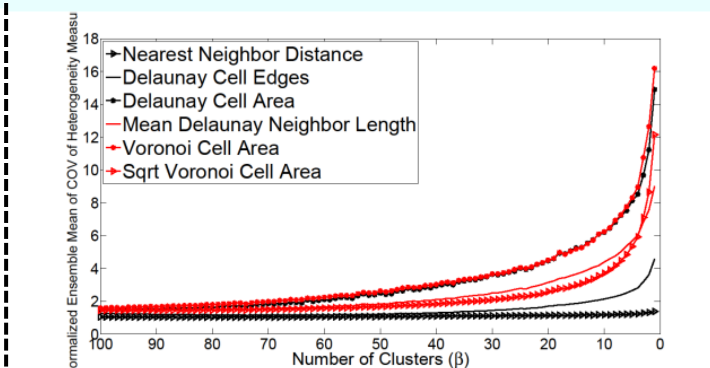


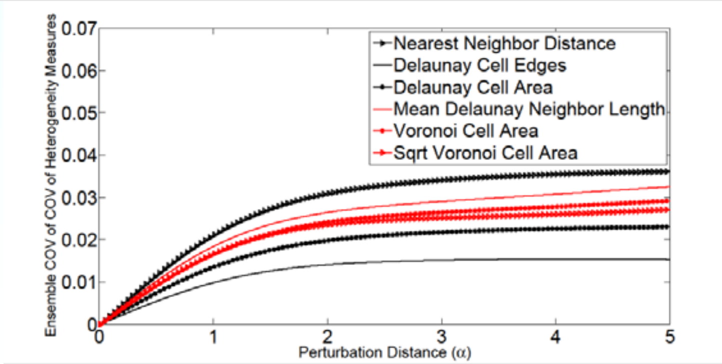

*Internal parameters: (TGIPs)*

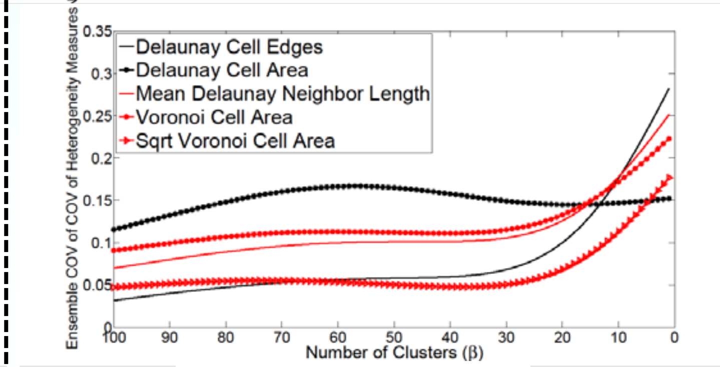
Normalized Mean of CoV
(interval [0..1])




Ensemble CoV of CoV
(means:
quality, accuracy)



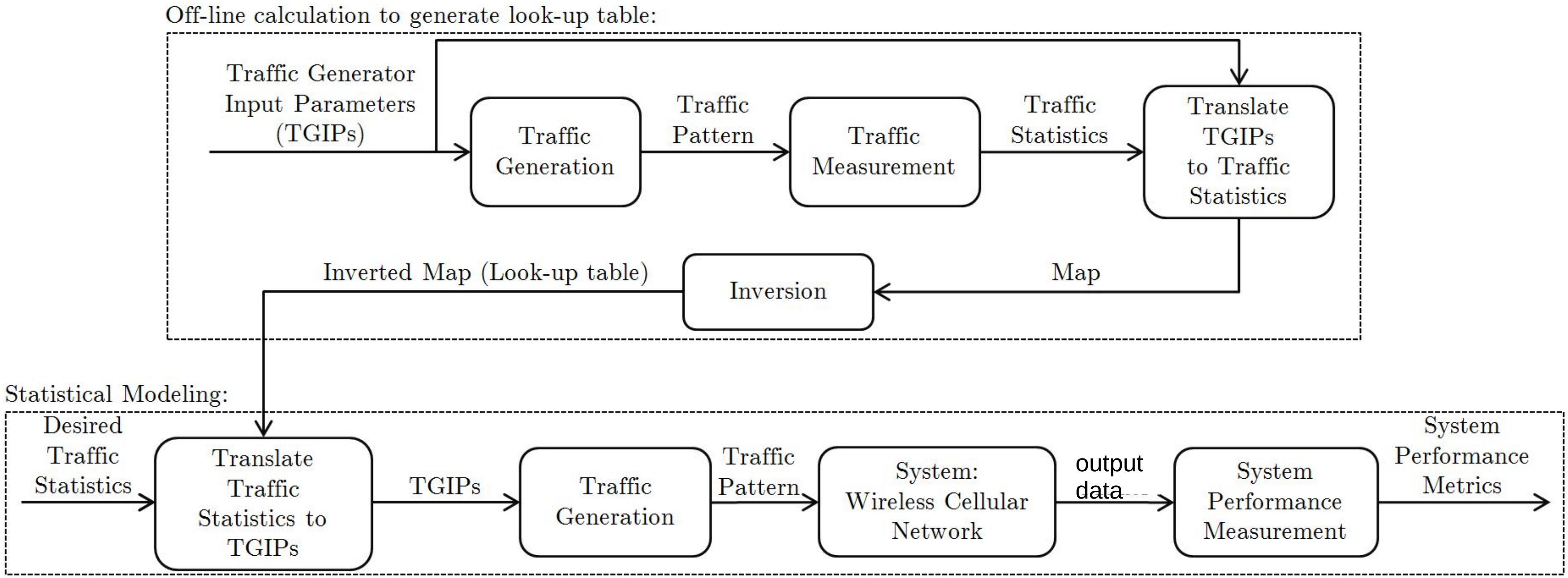




Perturbation distance

Number of clusters

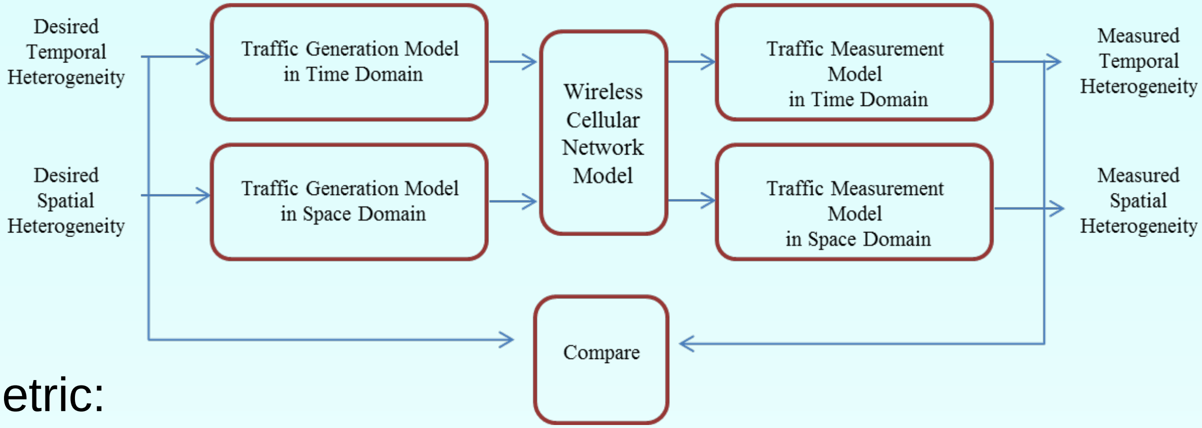
(internal parameters; TGIPs)

# Modeling and Fitting Procedure



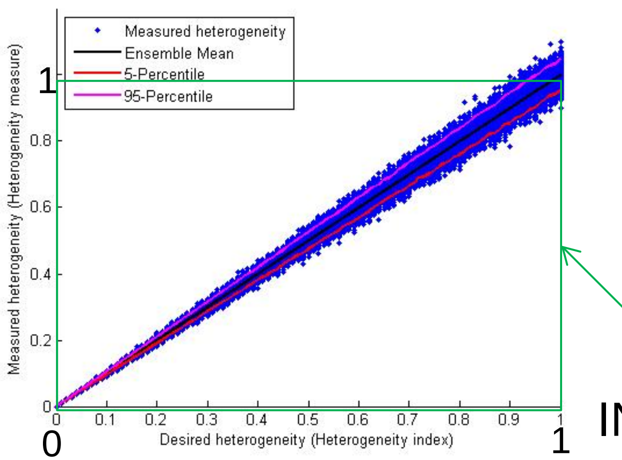

This is the generic procedure (for time and space domain)

# Simulation Results
## (in space domain)




Using Voronoi cell area as metric:

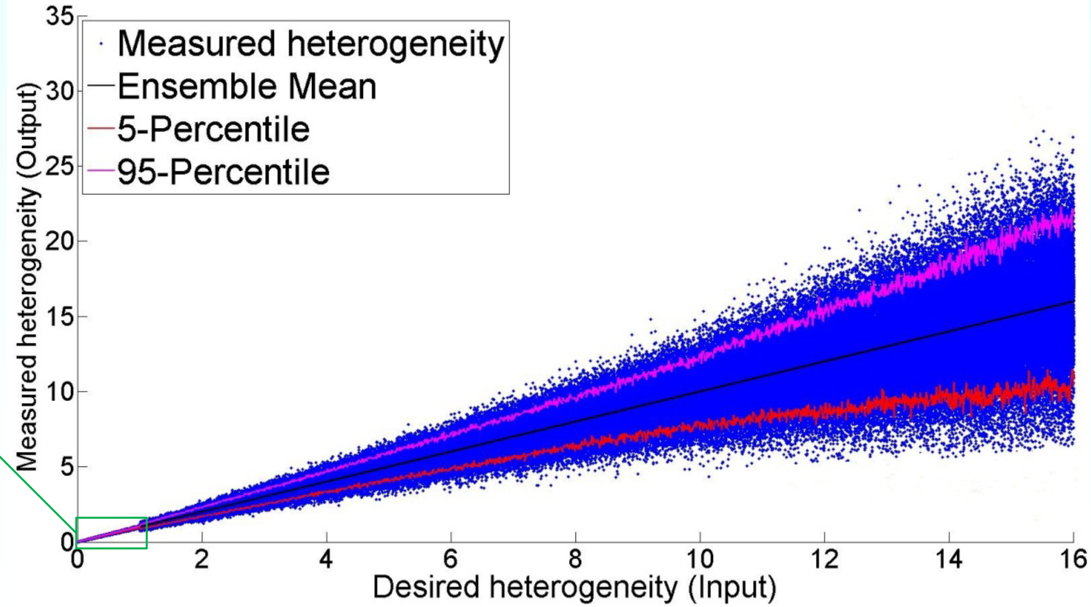
OUT (CoV for sub-Poissonian case)




IN

CoV

OUT (CoV for super-Poissonian case)




IN

CoV

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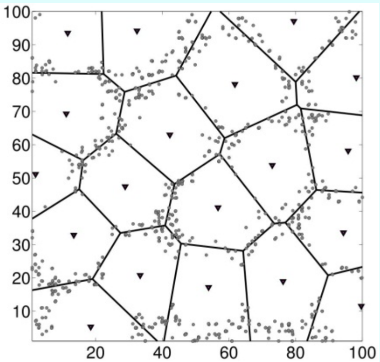
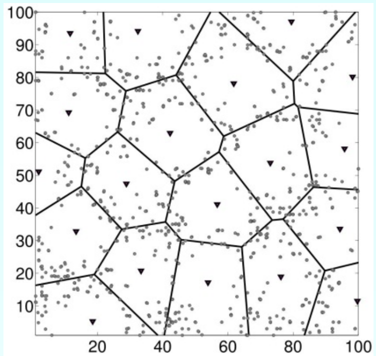
# Outlook: CoV + BS-X-correlation

(outcome of our algorithm)

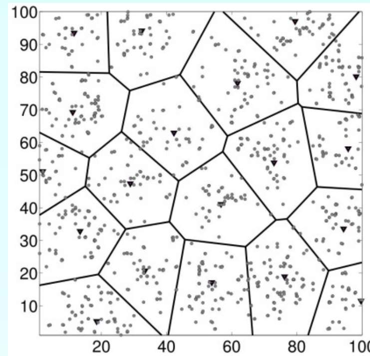
K=1, b=-0.9



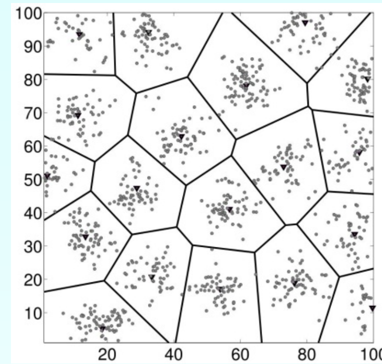

K=1, b=-0.5



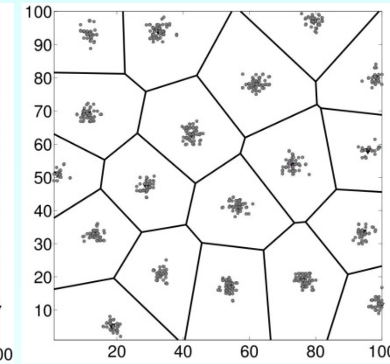

K=1, b=0



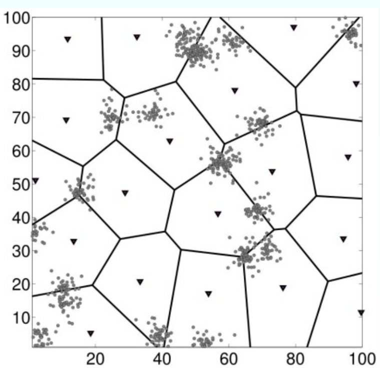

K=1, b=0.5



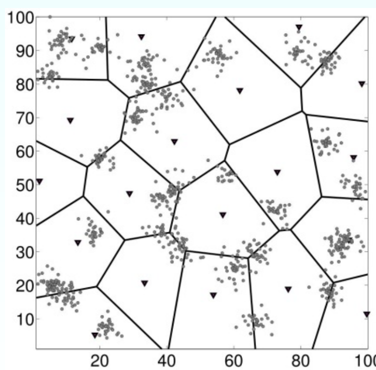

K=1, b=0.9



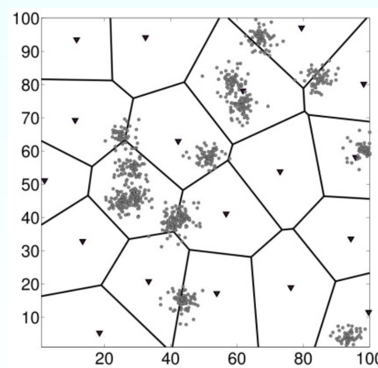

K=50, b=-0.9



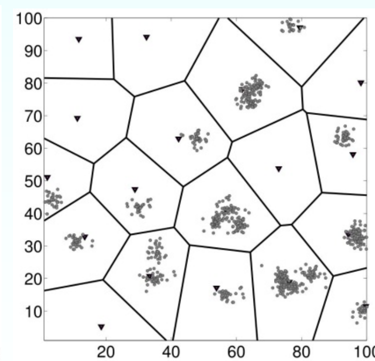

K=50, b=-0.5



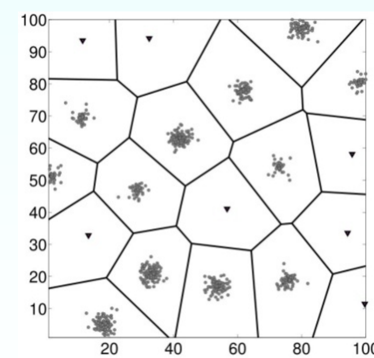

K=50, b=0




K=50, b=0.5




K=50, b=0.9




$K = N_u / N_c$

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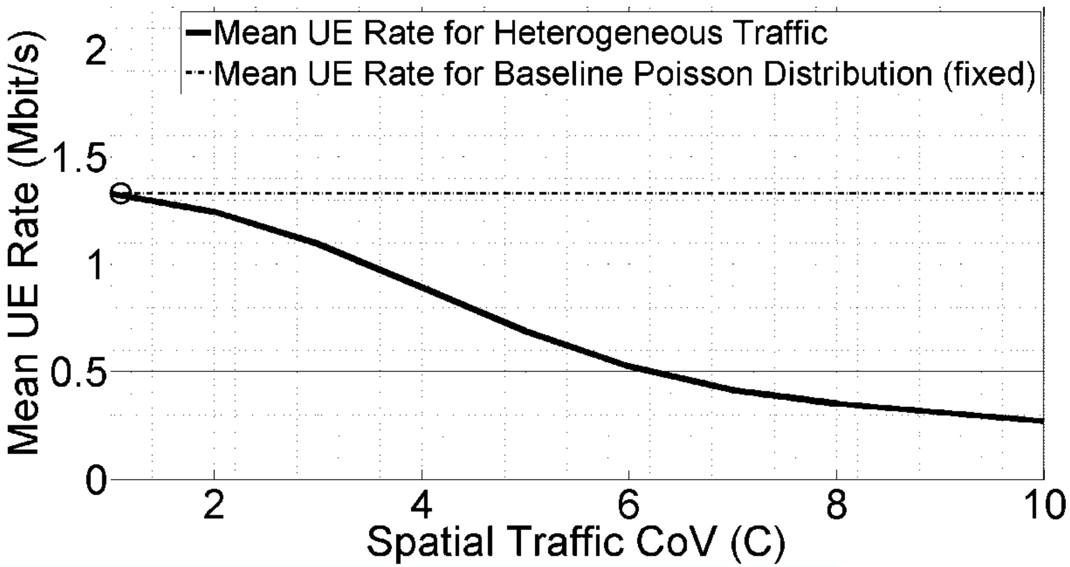
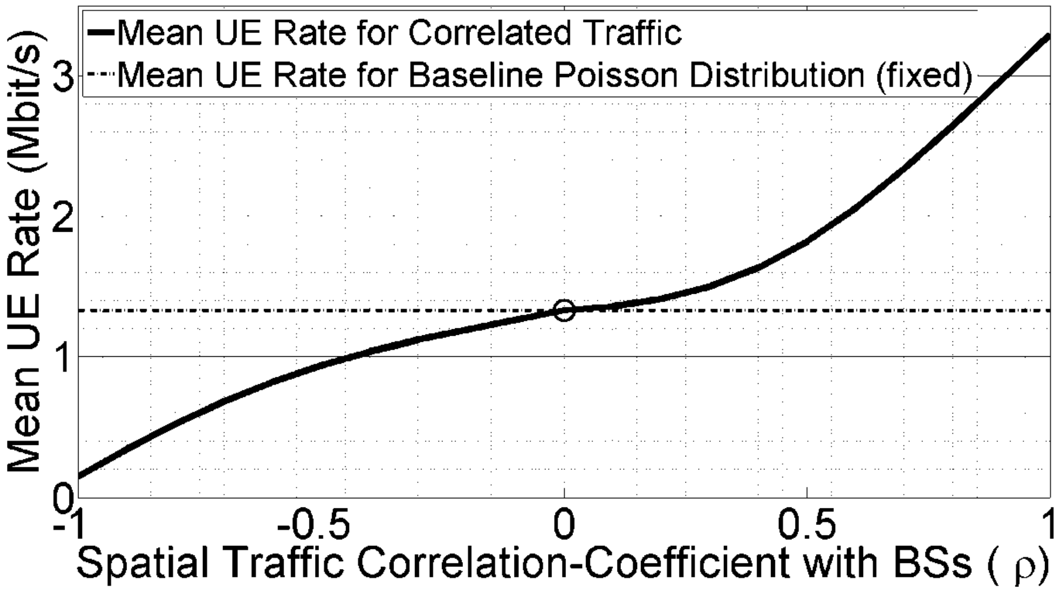
# WCN Performance subject to CoV and ρ




Result:
Quantitative performance results on how heterogeneity affects spectral efficiency

Result:
Quantitative performance results on how UT-BS correlation (affinity) affects spectral efficiency

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# Summary

We propose:

- accurate and unified traffic measures (instead of 10 methods)
- adjustable continuously from CoV=0,..,∞ (only one parameter)
- first-order parameter $\Lambda$ (mean user density) is unchanged
- in space domain and time domain
- simplify traffic measurements (one metric only!)
- enable modeling traffic in combined domain

Study cellular network performance in HetNets

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# Next Steps

- Traffic generation models:
  - Voronoi-Thomas
  - Weighted Voronoi
  - Correlation between BSs and users
- Combined traffic model in time and space (future work)
- HetHetNets
- Intercell Load Coordination (ICLC)
- User-In-The-Loop (UIL)

  IEEE Communications Magazine, Feb 2014
  http://en.wikipedia.org/wiki/User-in-the-loop