Statistics of Parked Cars for Urban Vehicular Networks

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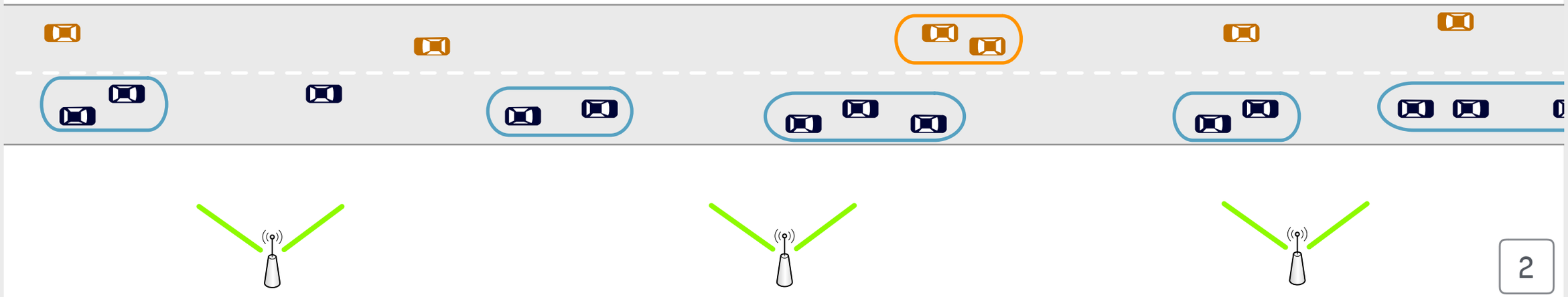
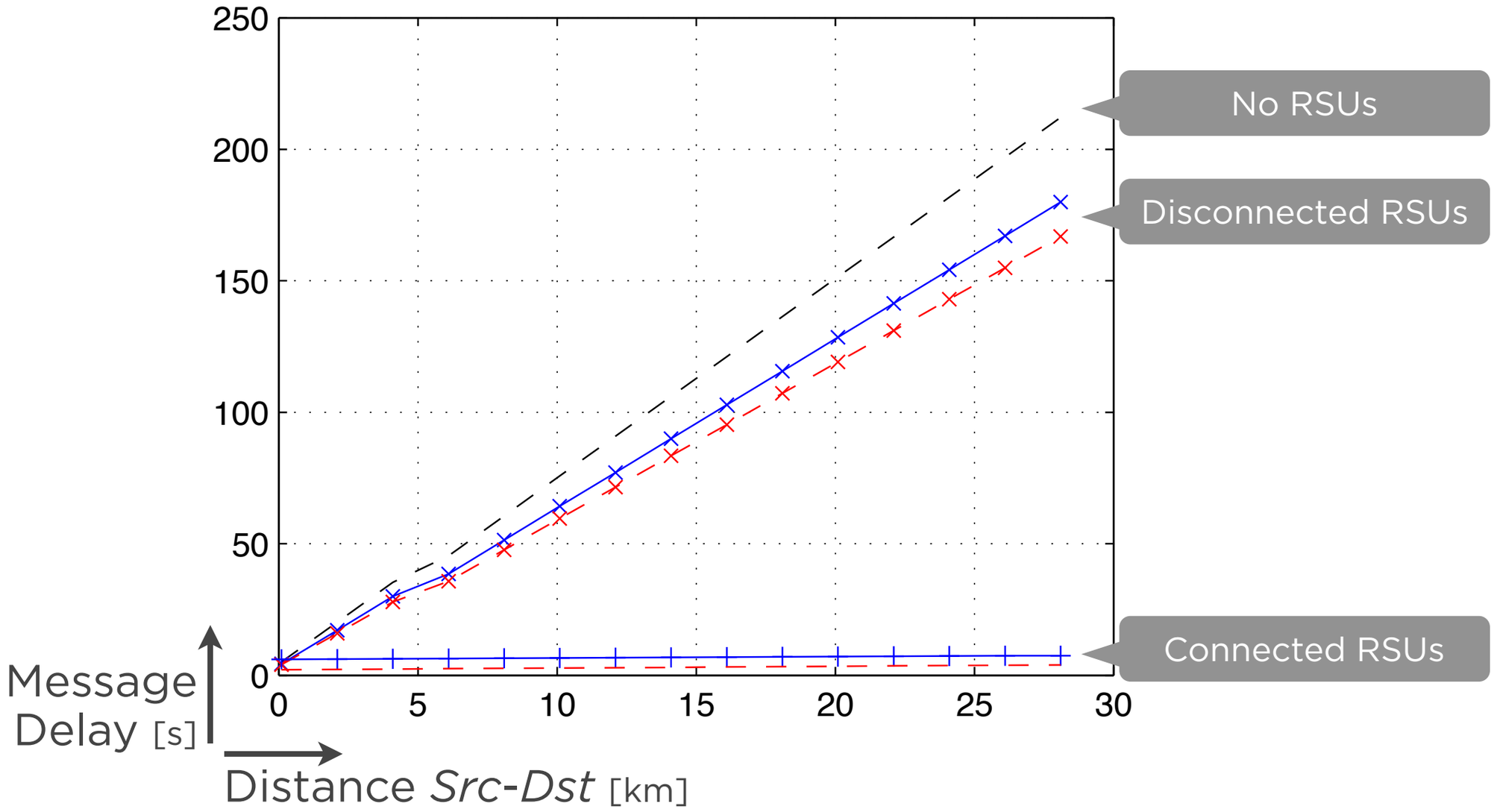
Roadside Units

- Road-Side Units (RSUs) are very important to a vehicular network
  - Central points of coordination
  - Improve connectivity
  - Content distribution
  - Controlled broadcasting



Sparse Networks

Multiple clusters — multiple gaps
Long distance communication



† A.B. Reis *et al.*,
"Deploying Roadside Units in Sparse Vehicular Networks: What Really Works and What Does Not," IEEE TVT, 2014.

- Road Side Units can very useful to a vehicular network
- But Road-Side Units are a costly proposition
  - RSUs are predicted to cost $17,000+ each to deploy, plus up to $2,400 per year for maintenance

Michigan Testbed DSRC Road Side Unit

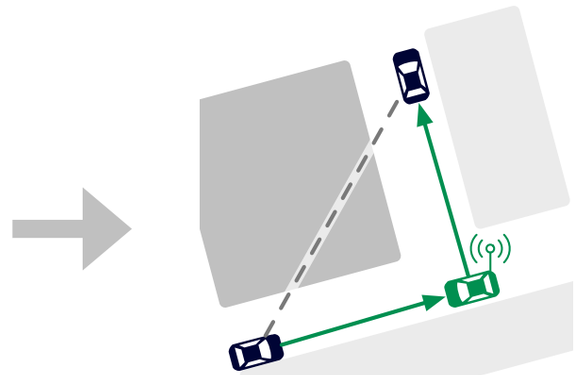
Cohda Wireless RSU

"One of the biggest challenges respondents see to the broad adoption of connected vehicle technology is funding for roadside infrastructure."

- Find ways to improve vehicular networks, without Road Side Units
- On highways, possibilities are limited
- In cities, we can use parked cars
  - When a vehicle parks, keep the on-board radios running
  - They already have the hardware (WiFi and DSRC radios)
  - *Stopped* means more consistent channel, less fading
  - *Stopped* means constant location, ideal for *geocasting*

Applications of parked cars

- Turn parked cars' radios on, to increase node density[1]
- Use parked cars on intersections as relays, to overcome obstructions[2]
- Use parked cars to store content, aid in content distribution[3]

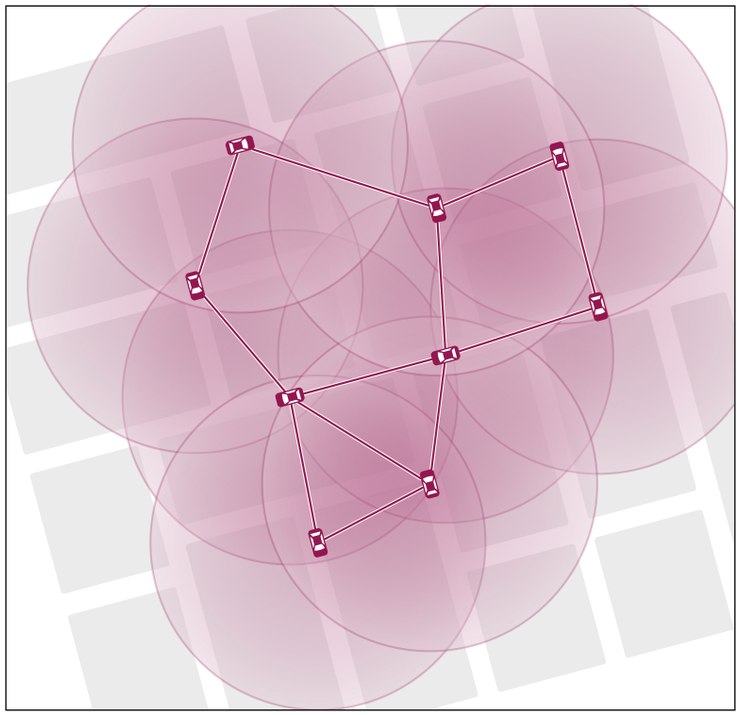


[1] Nianbo Liu *et al.*,
"**PVA in VANETs: Stopped cars are not silent**," IEEE INFOCOM, 2011.

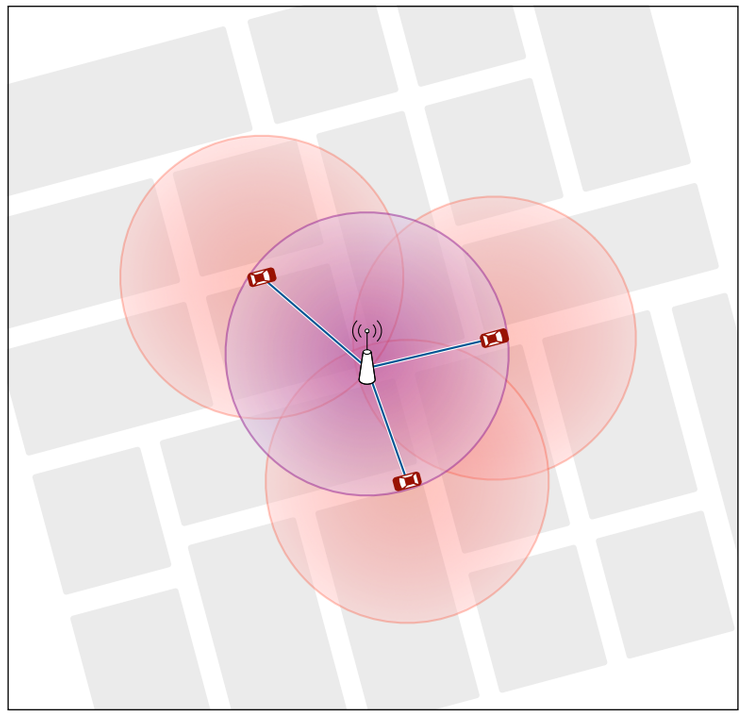
[2] D. Eckhoff *et al.*,
"**Cooperative Awareness at Low Vehicle Densities: How Parked Cars Can Help See through Buildings**," IEEE GLOBECOM, 2011.

[3] F. Malandrino *et al.*,
"**Content downloading in vehicular networks: Bringing parked cars into the picture**," IEEE PIMRC, 2012.

Applications of parked cars



Standalone mesh
(providing extensive coverage)



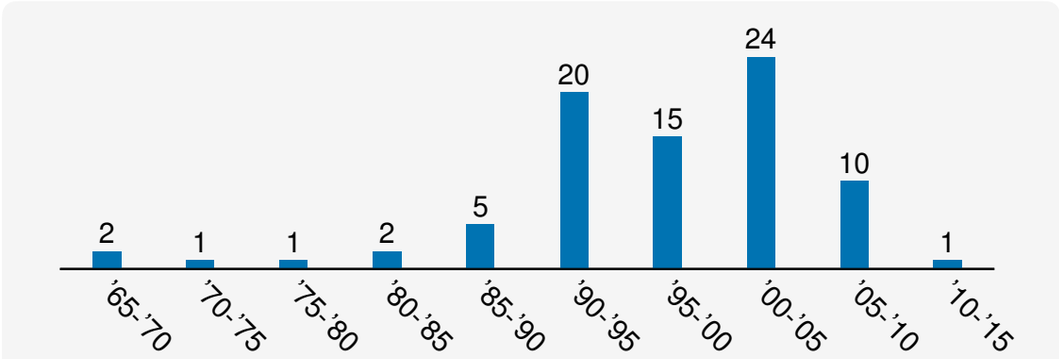
As RSU relays
(extending range of existing RSUs)

†† A.B. Reis *et al.*,
"**Leveraging Parked Cars as Urban Self-Organizing Road-Side Units**," IEEE VTC, 2015.
"**Parked Cars are Excellent Roadside Units**," arXiv preprint, 2016.

Statistics of Parked Cars

- Study the behavior of parked cars, to improve algorithms
  - How long do cars park for?
  - Does parking follow observable trends?
  - Do these behaviors change from city to city?

- Gather and analyze data from recent travel surveys
  - 2011, Atlanta (pop. 5.5m)
  - 2008, Knoxville (pop. 0.9m)
  - 2007, Chicago (pop. 9.5m)



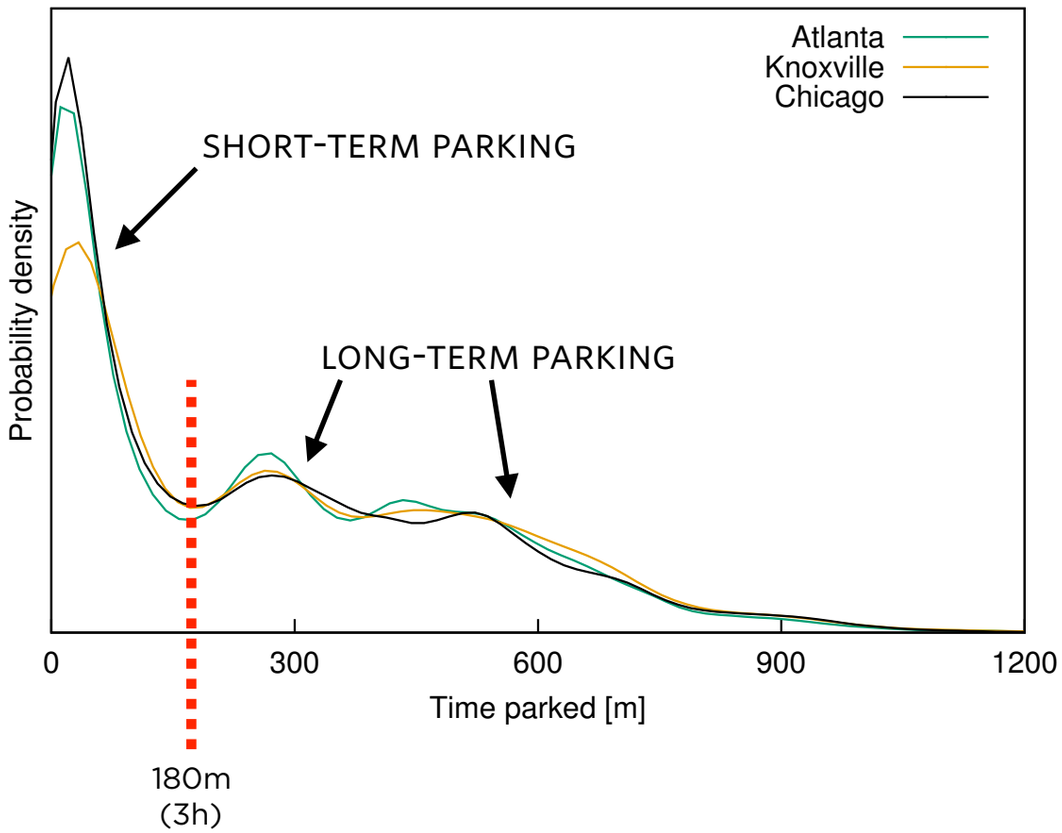
US Travel Surveys over the past 50 years

Daily behavior

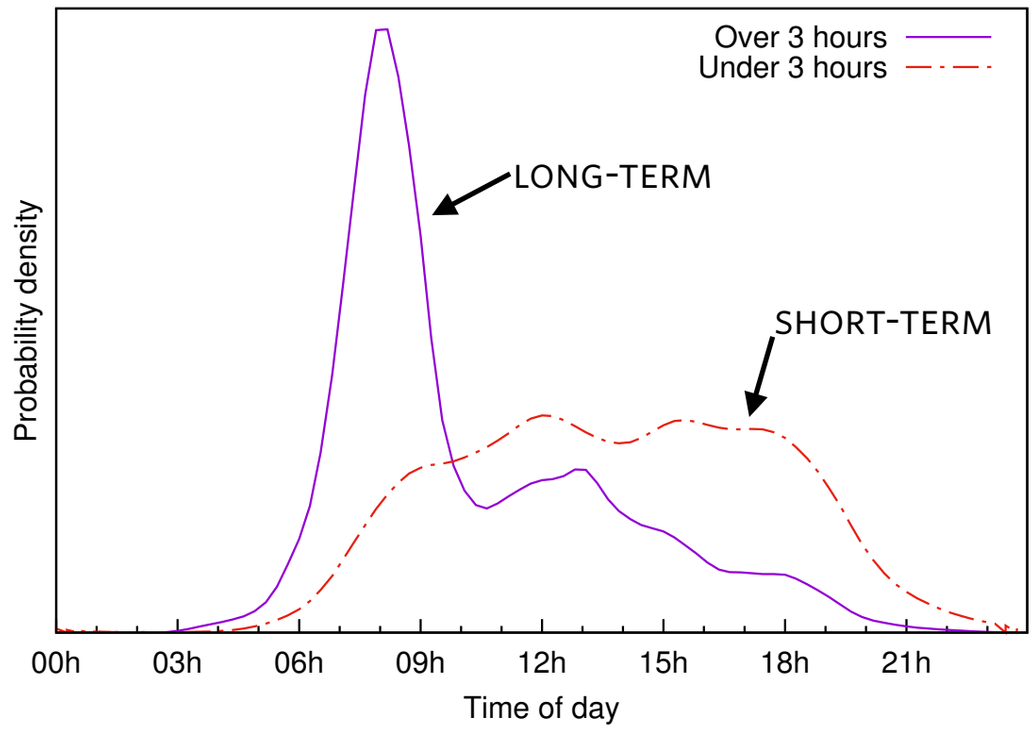
Patterns are remarkably similar from city to city

Two types of traffic: short-term and long-term

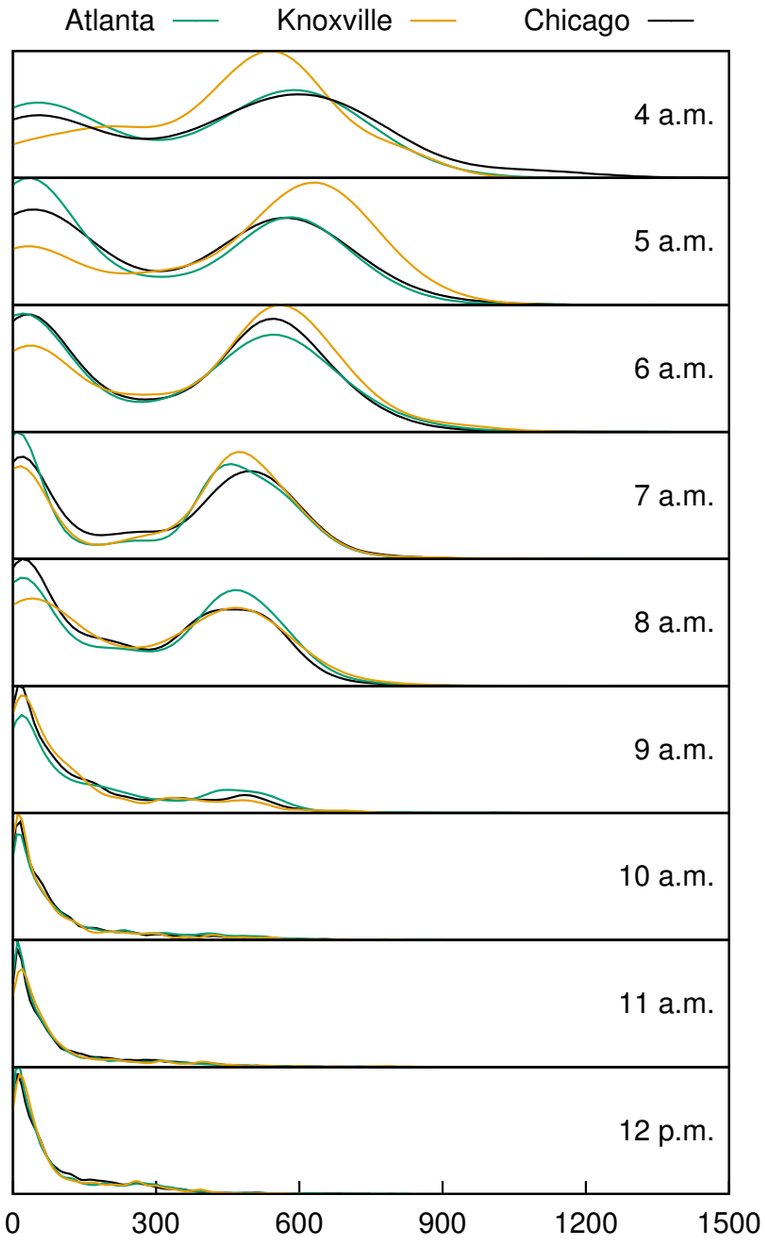
Duration of parking events (PDF)



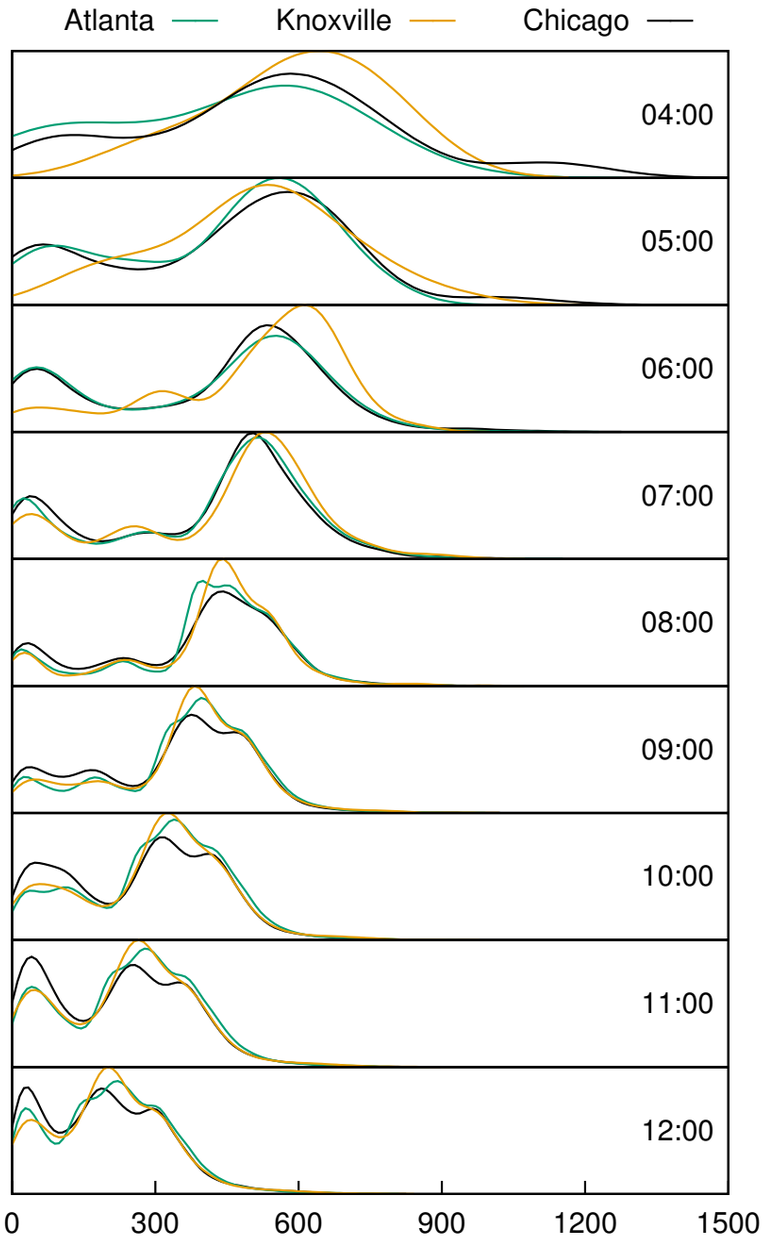
Times at which vehicles park (PDF)



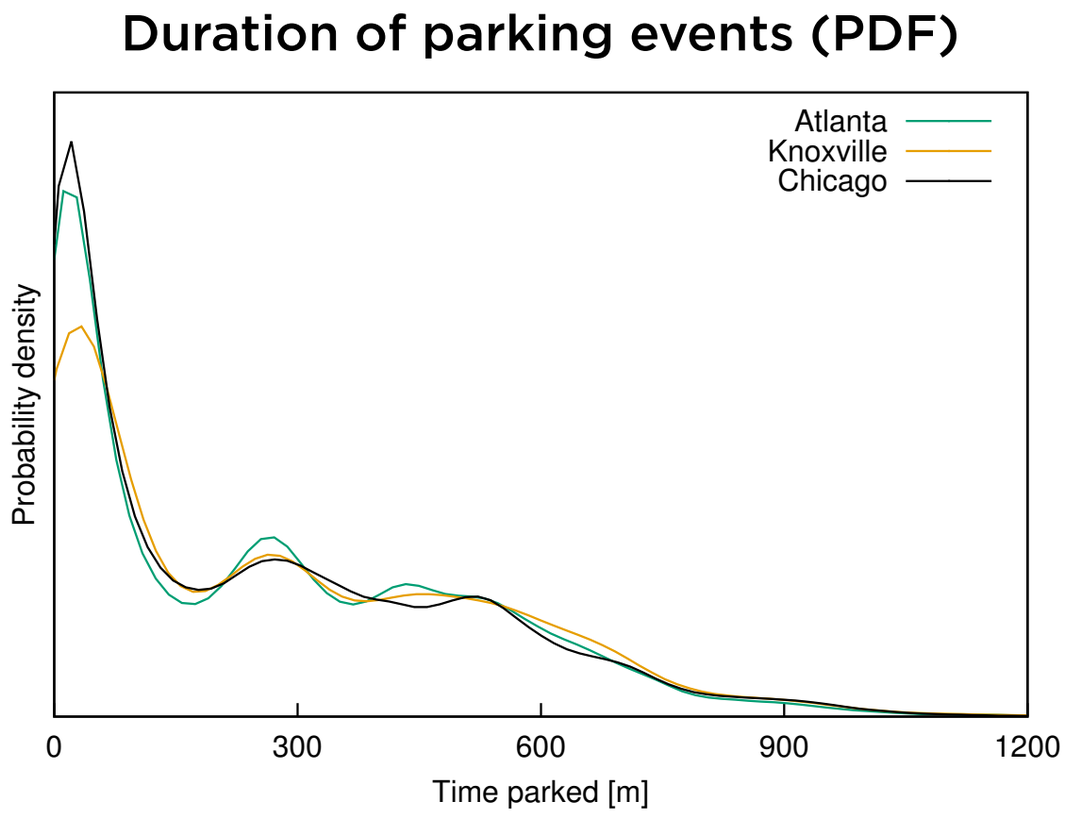
New vehicles parking at specific hours



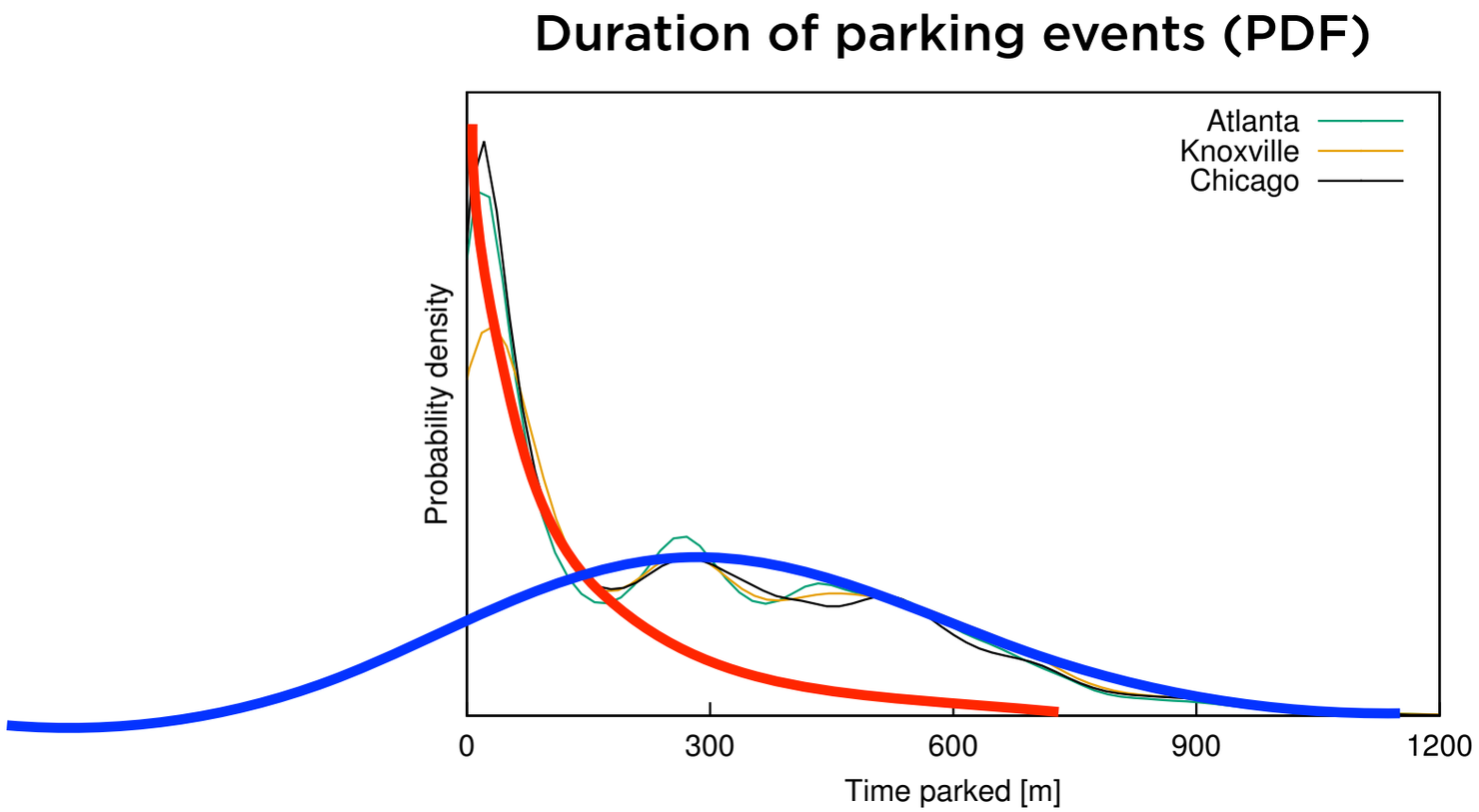
Snapshots of all parked vehicles



Probability Model



Probability Model



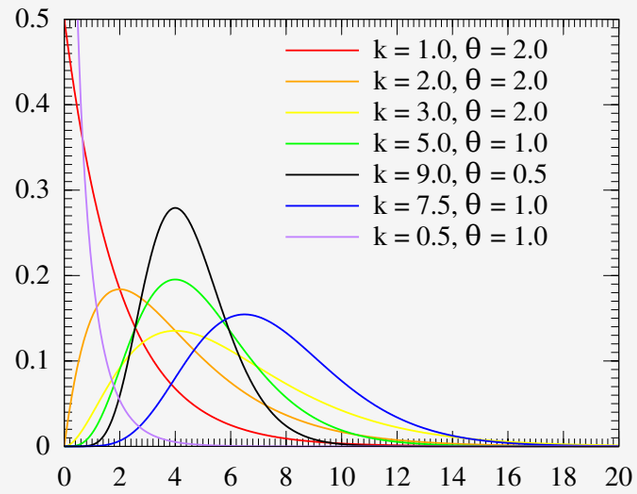
Probability Model

Model: a time-variant mixture distribution of dual-Gamma random variables

(stochastic process, discrete time)

$$f(\mathbf{x},\mathbf{t}) = \begin{array}{|l} D_{1,t} \times \dfrac{1}{\Gamma(\kappa_{s,t})\theta_{s,t}{}^{\kappa_{s,t}}} x^{\kappa_{s,t}-1} e^{-\frac{x}{\theta_{s,t}}} \\ \hline + D_{2,t} \times \dfrac{1}{\Gamma(\kappa_{l,t})\theta_{l,t}{}^{\kappa_{l,t}}} x^{\kappa_{l,t}-1} e^{-\frac{x}{\theta_{l,t}}} \end{array} \quad \begin{array}{l} \text{SHORT-TERM} \\ \\ \text{LONG-TERM} \end{array}$$

$$\mathbf{x} > 0 \quad , \quad \mathbf{t} = 0, 1, 2, \ldots, 23 \quad ,$$

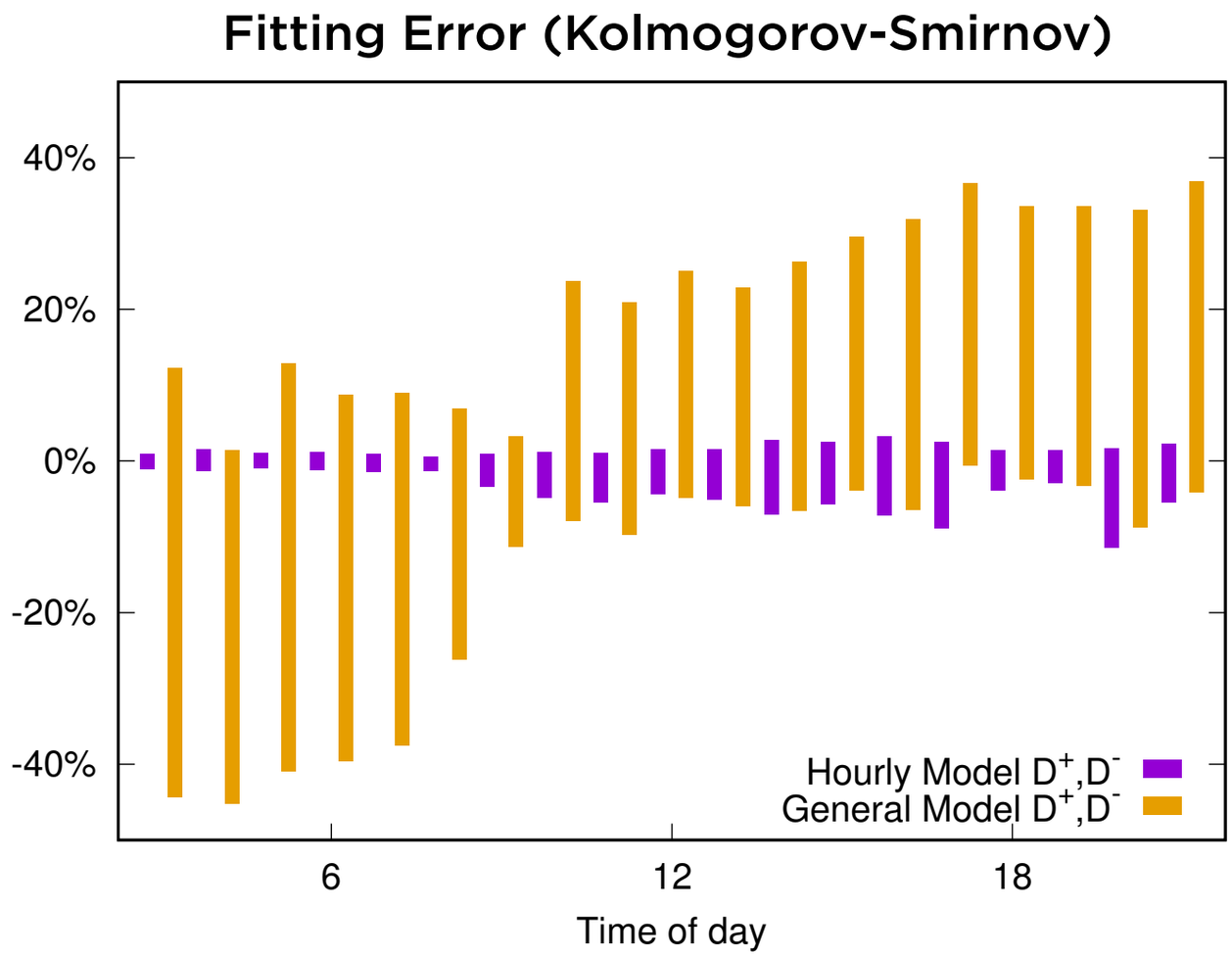


Gamma Distribution

- First-order density
- First-order distribution
- Average time parked
- Probability of *n* more hours of parking

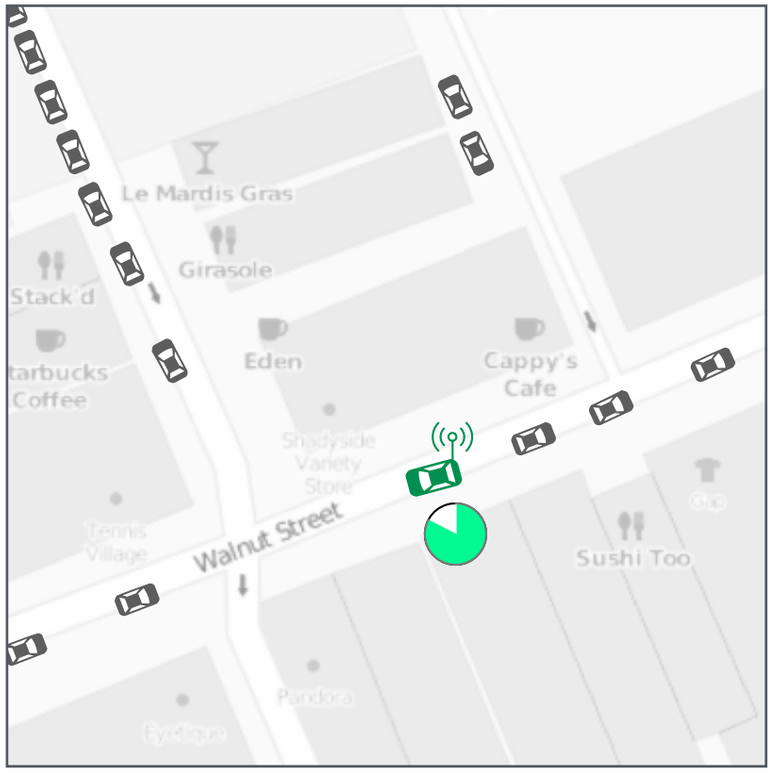
Probability Model

Survey data fitted with <5% error

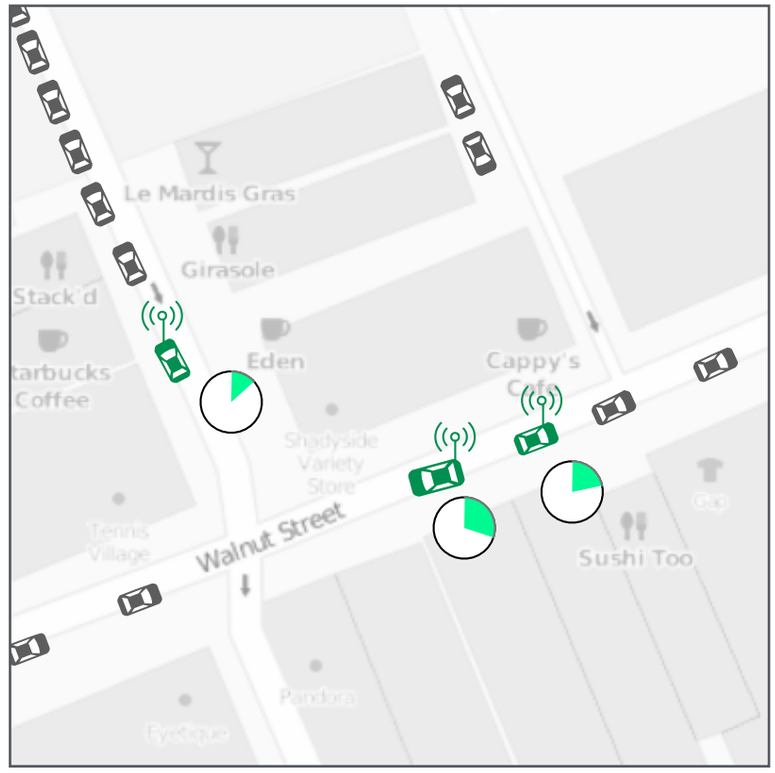


Example: conserving battery capacity

- Instead of having a single car act as an RSU until it leaves, rotate the RSU role among nearby cars
  - Consider parking statistics on the decision: which cars are likely to remain parked for longer
  - Determine best neighbors and optimal time allocation



Single car as the area's RSU



Multiple cars taking turns

Thank you