CISTER - Research Centre in Real-Time & Embedded Computing Systems

# Bridging Vehicular and Urban Internet-of-Things

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Seminar Series – 7 March 2019

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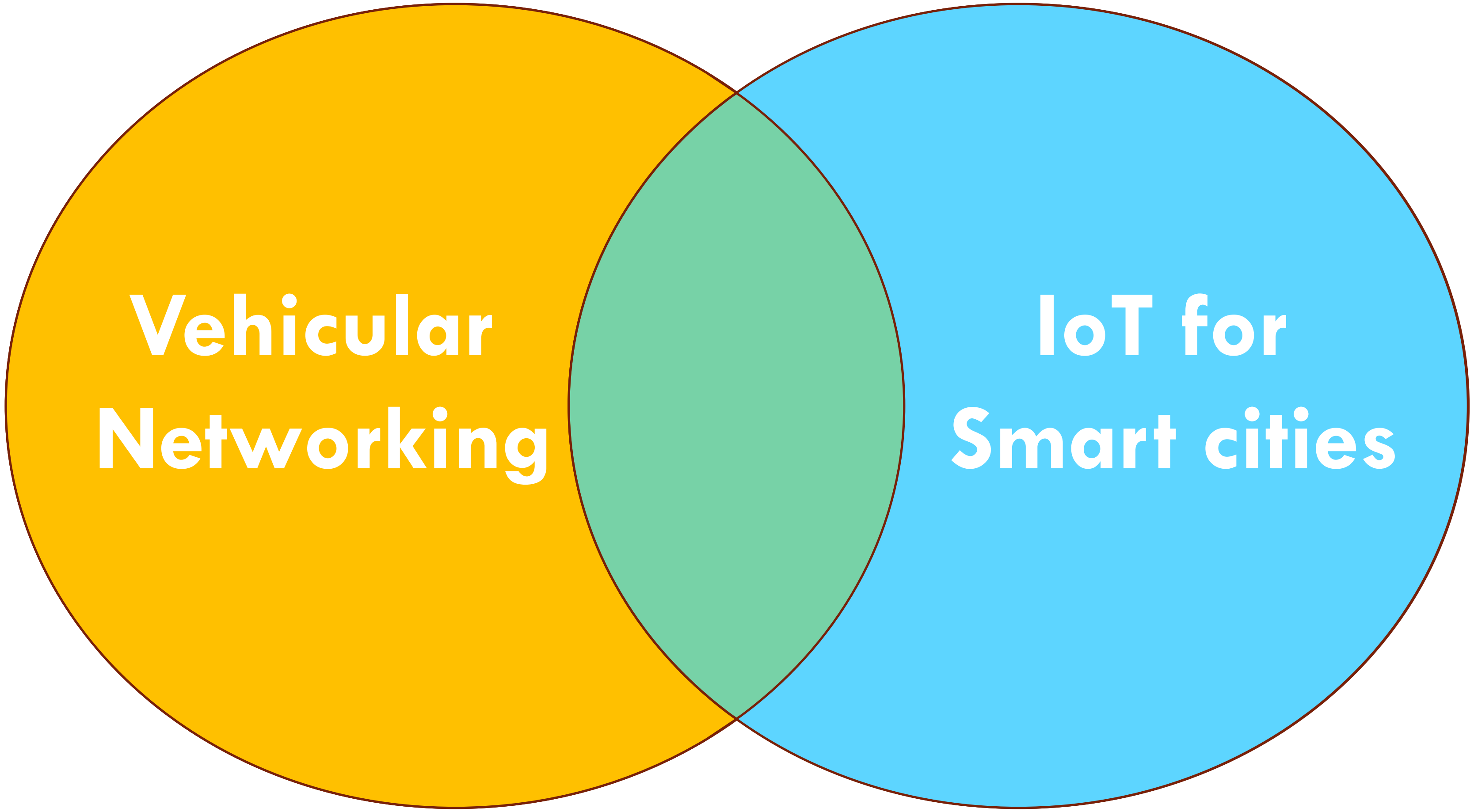
# Areas of Work

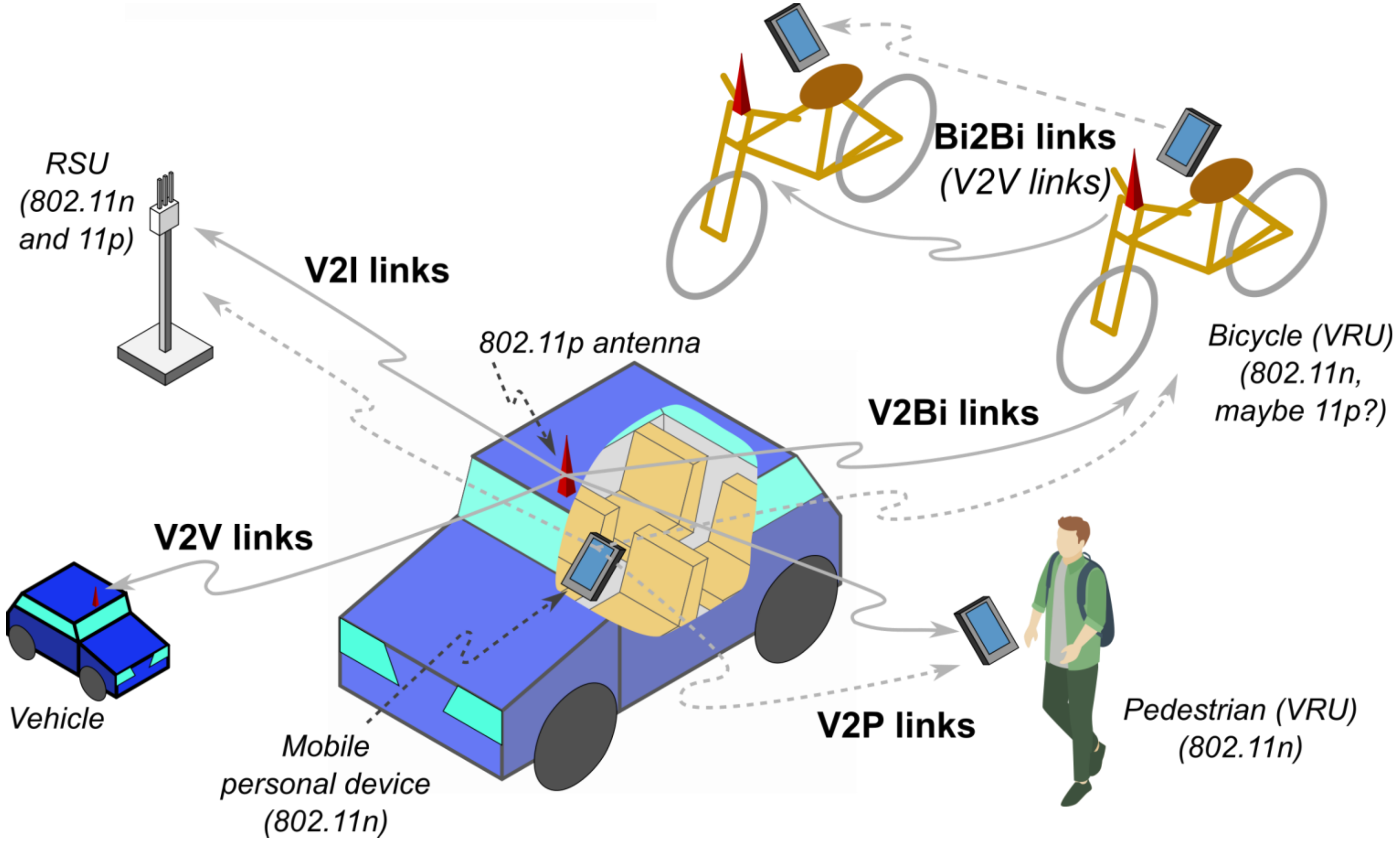


# Vehicular Networking

1. Propagation Modelling in Device-to-Device Links

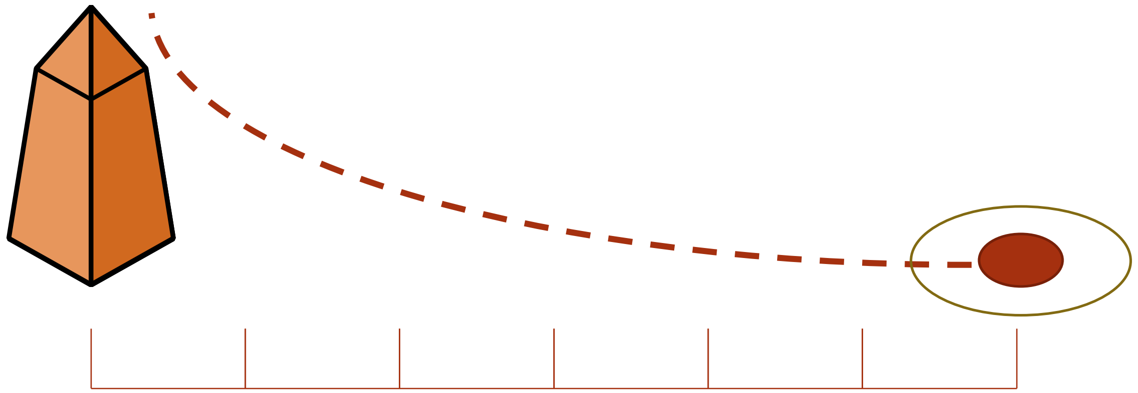
2. Bicycle-to-X Networking

    - *Propagation modelling*
    - *Link characterization*
    - *User applications*



# 1. D2D Channel Modelling & GPS Errors

- Channel modelling characterizes the **Received Signal Strength** (RSSI) versus distance
- Channels between moving nodes are often described with **empirical models –** e.g., the Log-distance Path Loss model



$$\rho(d) = \rho_0 - 10 \cdot \alpha \cdot \log(d)$$

True model

$$\rho(d) = \tilde{\rho}_0 - 10 \cdot \tilde{\alpha} \cdot \log(d_{\mathrm{GPS}}(d))$$

Erroneous model

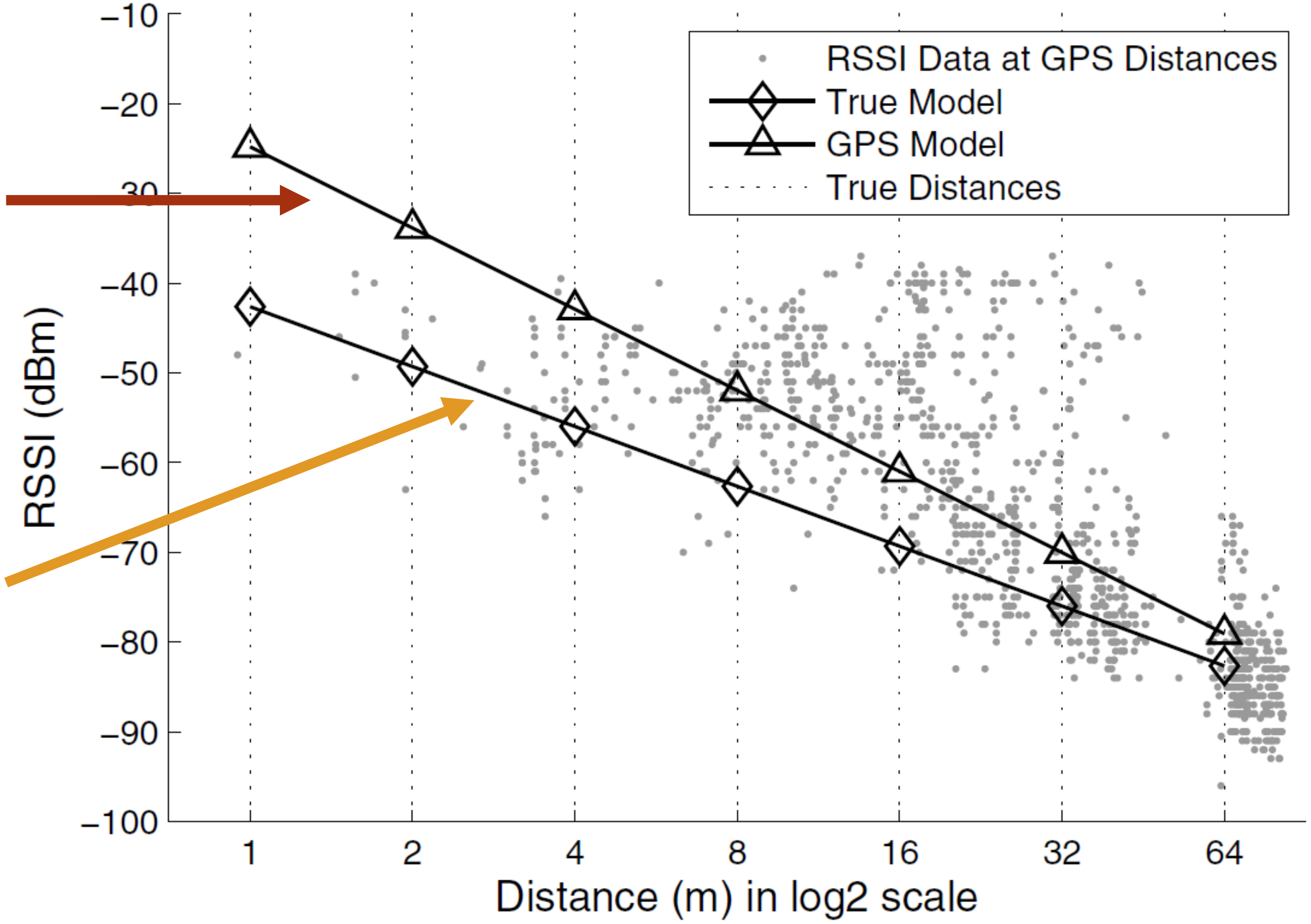
What is the impact of the GPS error in estimating the parameters of the channel model?

P.M. Santos, T.E. Abrudan, A. Aguiar, J. Barros. Impact of Position Errors on Path Loss Model Estimation for Device-to-Device Channels. IEEE Transactions on Wireless Communications, Vol.13, No.5, pp.2353-2361, May 2014.

# D2D Channel Modelling & GPS Errors

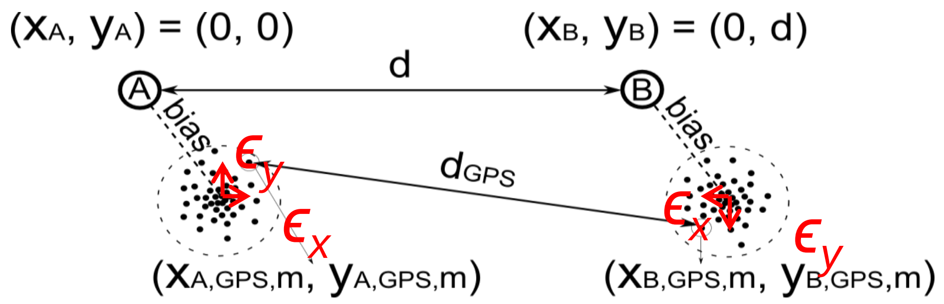
Path loss model with GPS distances

Path loss model with true distances

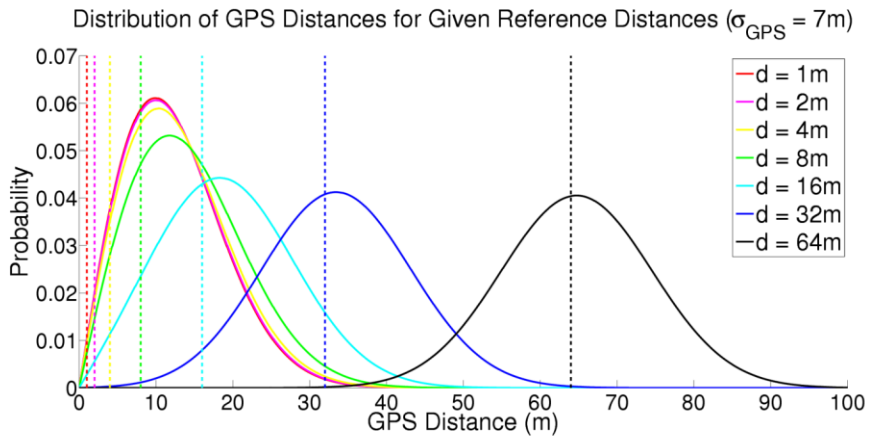


# D2D Channel Modelling & GPS Errors

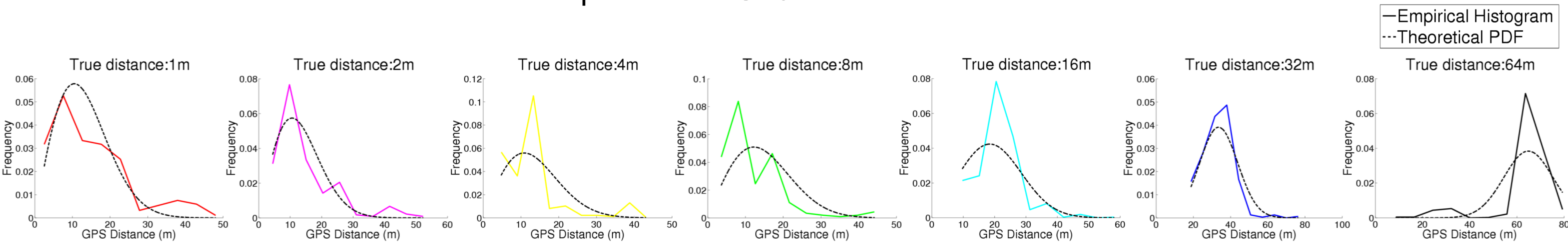
- We model the GPS error with a **systematic and stochastic components** (the later as Gaussian).




$$\hat{d}_{GPS} = \sqrt{(\epsilon_{y_A} + \epsilon_{y_B})^2 + (\epsilon_{x_A} + \epsilon_{x_B} + \hat{d})^2}$$




- The distribution of the distances computed from GPS estimates follows a **Rice distribution.**



# D2D Channel Modelling & GPS Errors

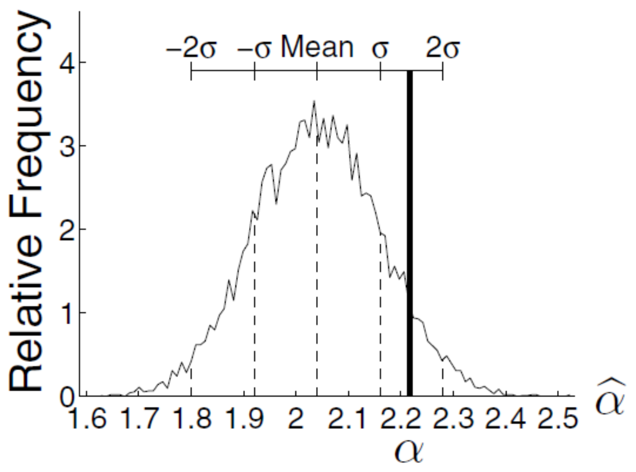
- **Guideline:** Measurements taken farther than $3\sqrt{2}\sigma_{\text{GPS}}$ are less affected by position uncertainty.
- **Correction:** We proposed a **Monte Carlo method** to estimate the true parameters.

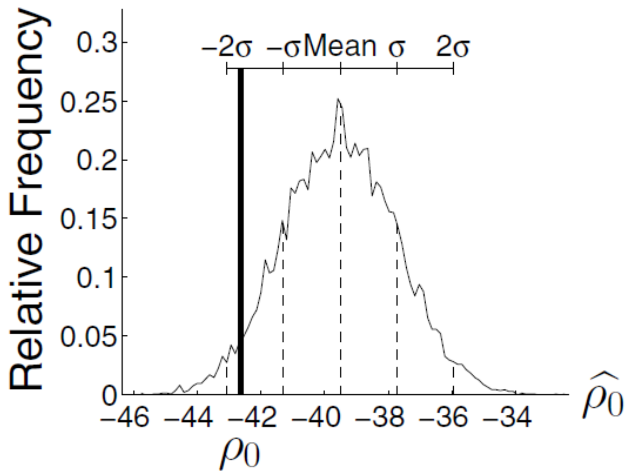
$$\rho(d) = \rho_0 - 10 \cdot \alpha \cdot \log(d)$$ *(True model)*

$$\rho(d) = \tilde{\rho}_0 - 10 \cdot \tilde{\alpha} \cdot \log(d_{\text{GPS}}(d))$$ *(Erroneous model)*

## Monte Carlo method

1. Produce sets of $\hat{d}$
2. $\hat{d}_{\text{GPS}} = \sqrt{(\epsilon_{y_A} + \epsilon_{y_B})^2 + (\epsilon_{x_A} + \epsilon_{x_B} + \hat{d})^2}$
3. $\hat{\rho}(\hat{d}) = \hat{\rho}(\hat{d}_{\text{GPS}})$
4. $\hat{\rho}(\hat{d}_{\text{GPS}}) = \tilde{\rho}_0 - 10\,\tilde{\alpha}\,\log(\hat{d}_{\text{GPS}}) + X_\rho$
5. Estimate true parameters from $\hat{\rho}(\hat{d})$ and $\hat{d}$

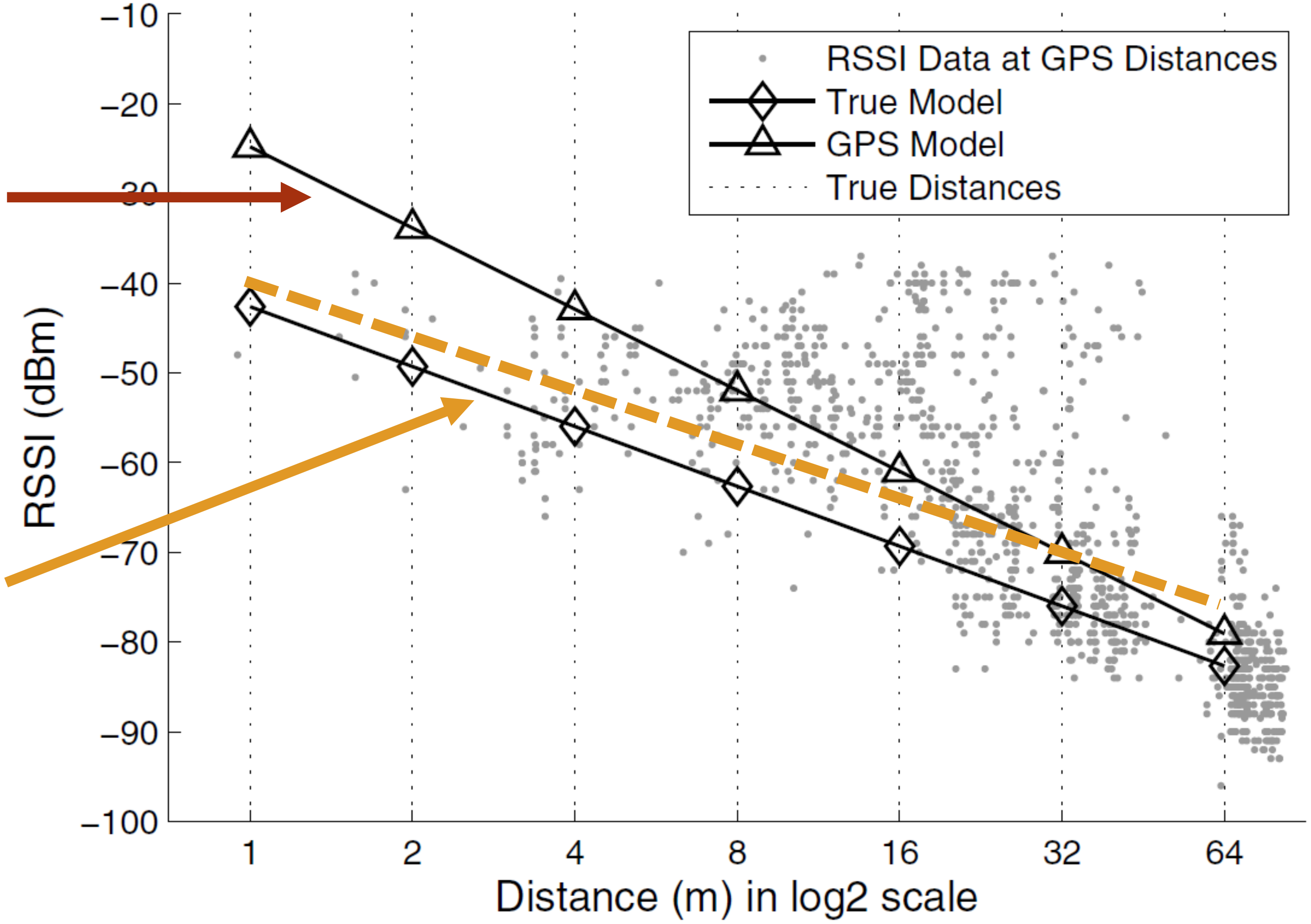


# D2D Channel Modelling & GPS Errors

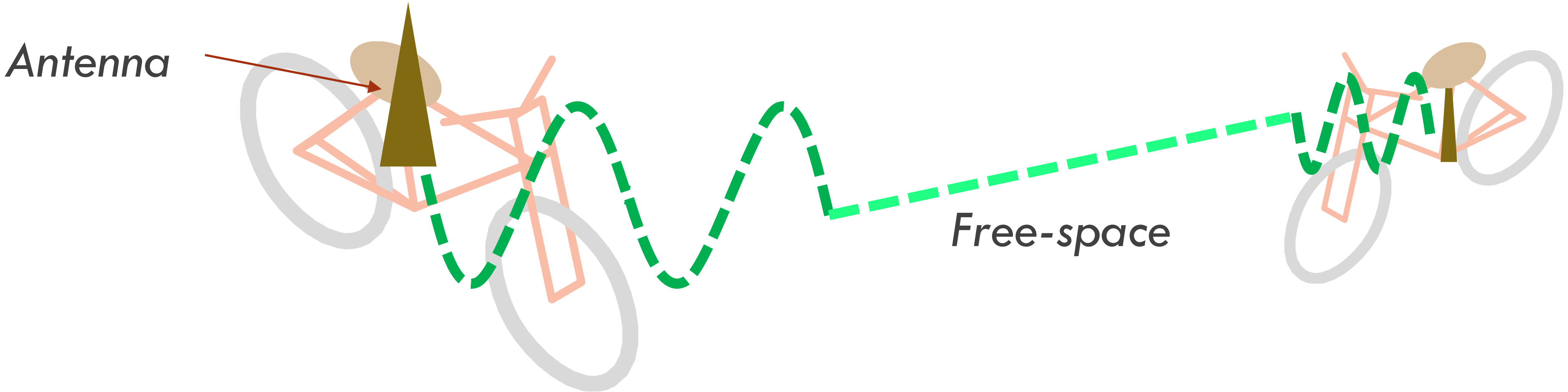
Path loss model with GPS distances

Path loss model with true distances



# 2. Propagation Modelling in Bike-to-X Scenarios

What is the impact of the bicycle body on the signal propagation?



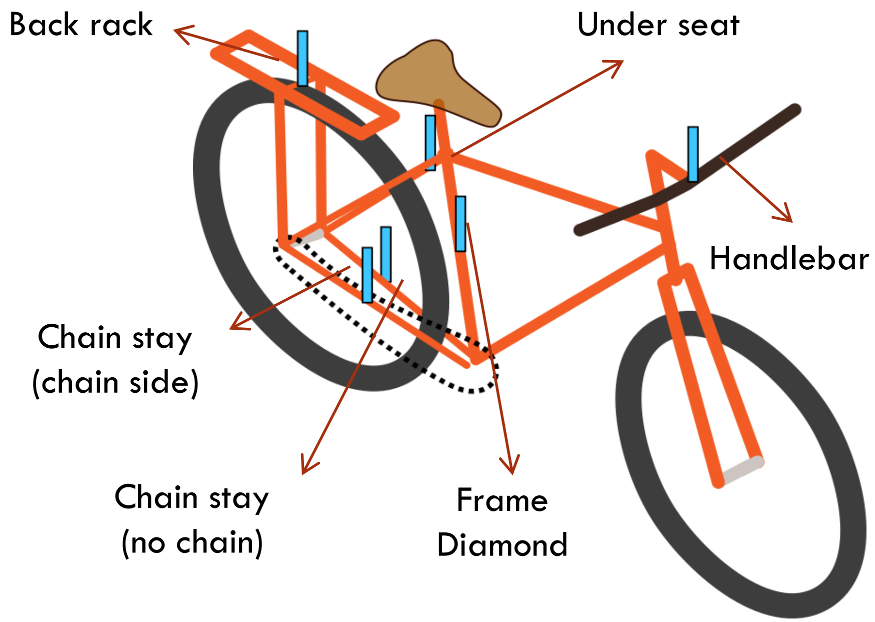

$$P_{rx}\ [\text{dBm}] = P_{tx} + L_{free\text{-}space}(d) + \boxed{G_{B\text{-}A(tx)}(p,\alpha)} + \boxed{G_{B\text{-}A(rx)}(p,\alpha)}$$

*(e.g., Log-distance Path Loss)*

- Impact of the bicycle can be characterized empirically and incorporated in a path loss model
- Open questions: behaviour w.r.t. antenna position; impact of frame material.

P. M. Santos, L. Pinto, L. Almeida, A. Aguiar: Characterization and Modeling of the Bicycle-Antenna System for the 2.4GHz ISM Band. In Proceedings of the 2018 IEEE Vehicular Networking Conference, December 5-7 2018, Taipei, Taiwan.

# Propagation Modelling in Bi2Bi Scenarios





Steel


Steel

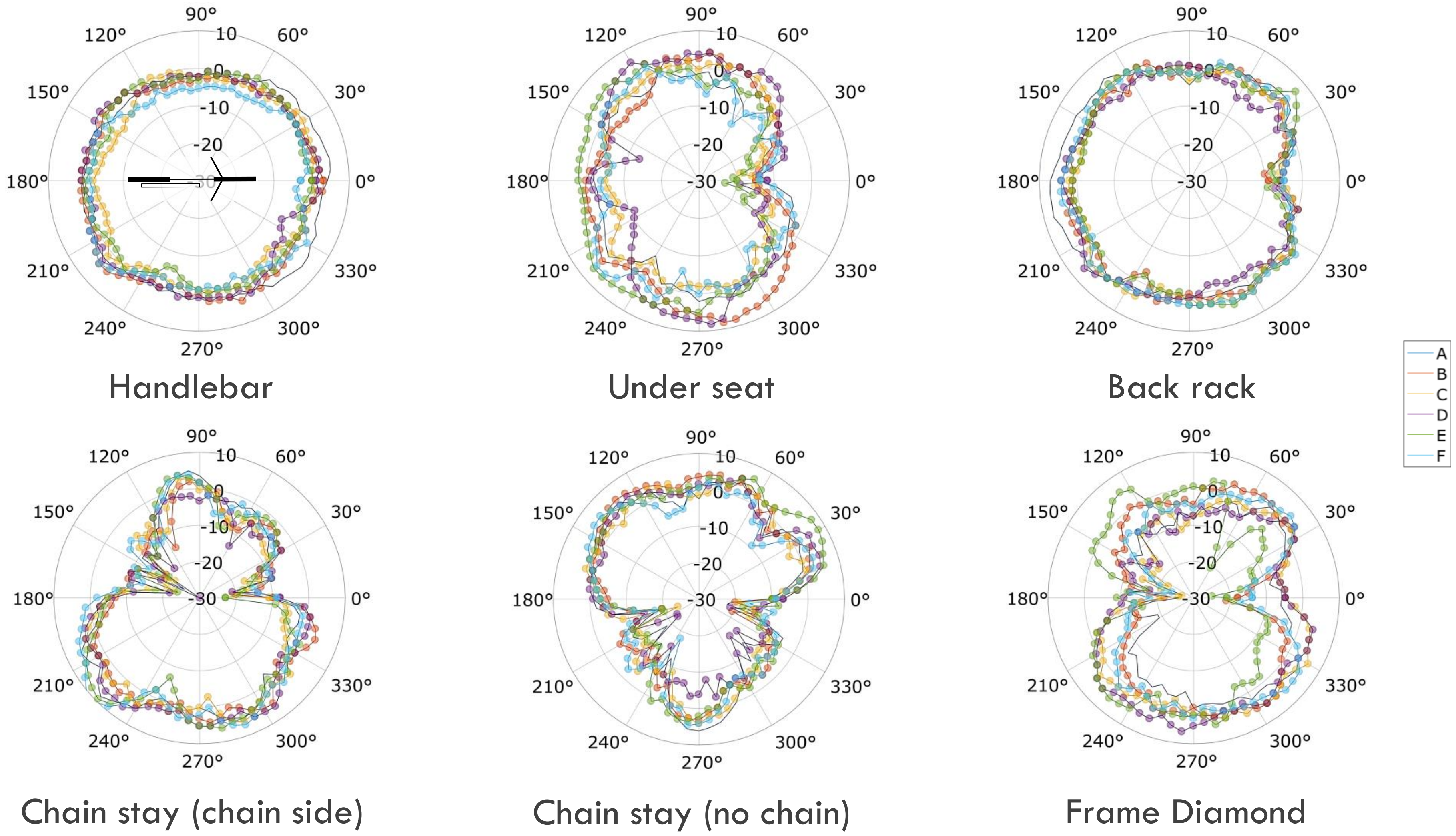

Aluminum


Aluminum


Steel

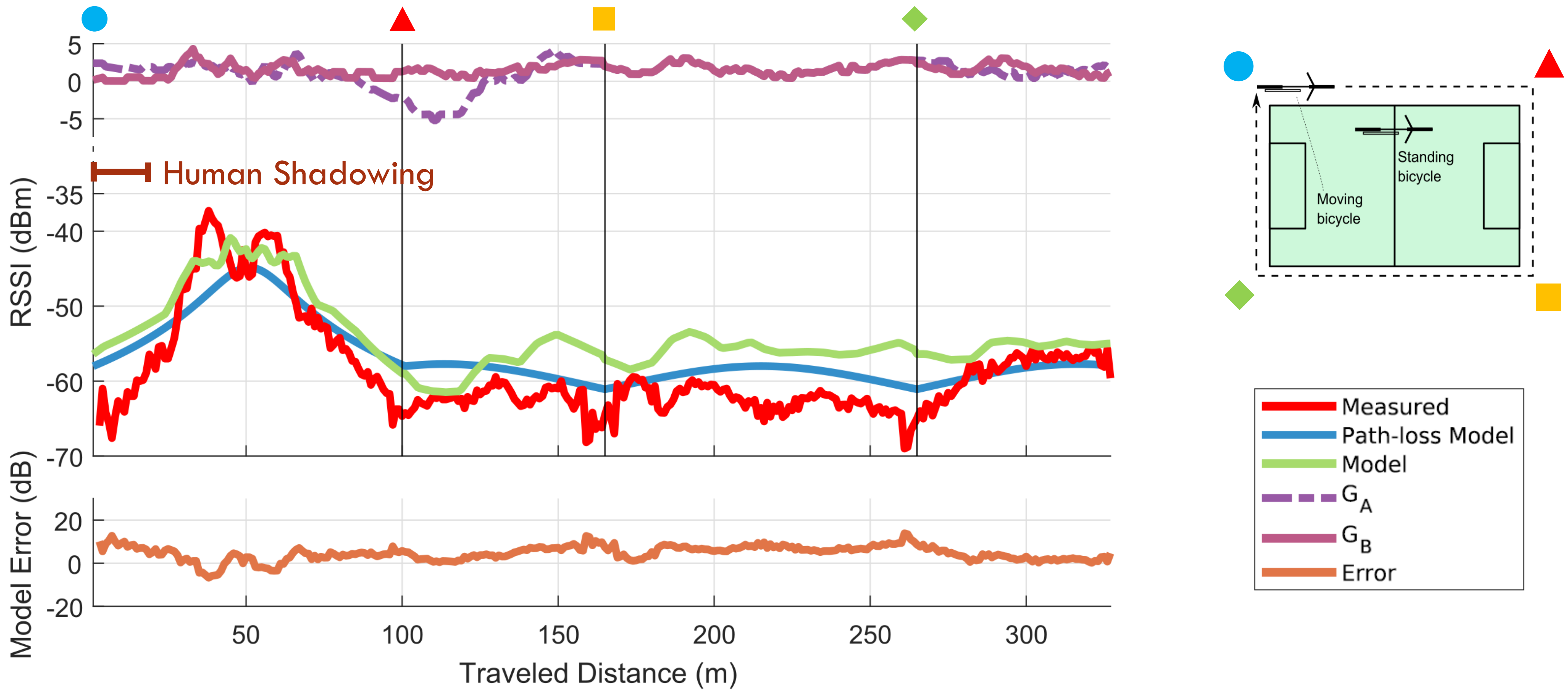

Aluminum

# Propagation Modelling in Bi2Bi Scenarios



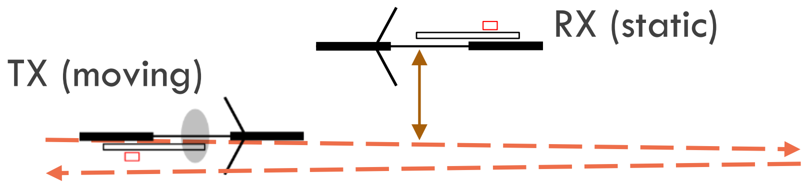
# Propagation Modelling in Bi2Bi Scenarios

$$P_{rx}\,[\text{dBm}] \leftrightarrow \hat{P}_{rx}\,[\text{dBm}] = \underbrace{P_{tx} - L_{pathloss}(d)} + G_{B\text{-}A(tx)}(p,\alpha) + G_{B\text{-}A(rx)}(p,\alpha) + L_{HS}(\alpha)$$

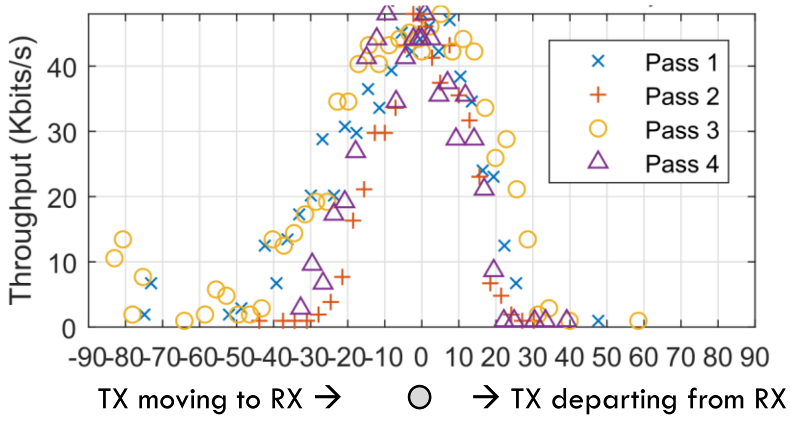


# Bi2Bi Networking – Technology Comparison

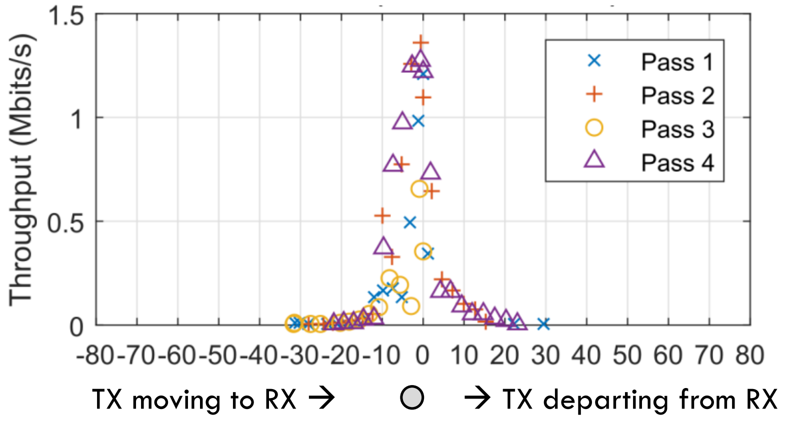
We compared the performance of **2.4GHz COTS technologies** in bicycle-to-bicycle parallel scenarios.



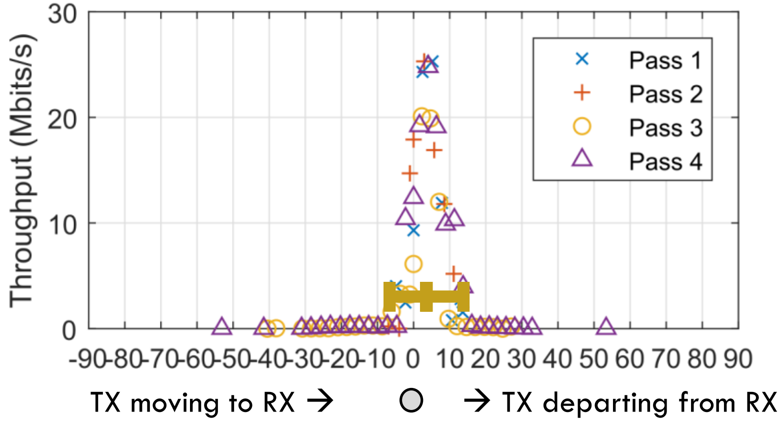

## IEEE 802.15.4



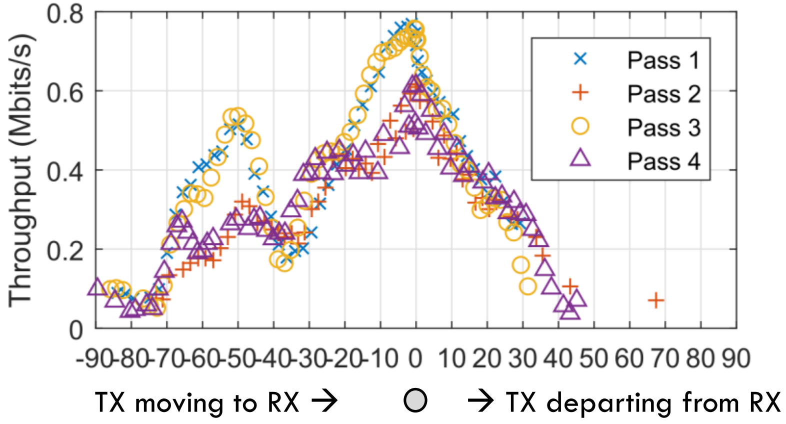

## Bluetooth



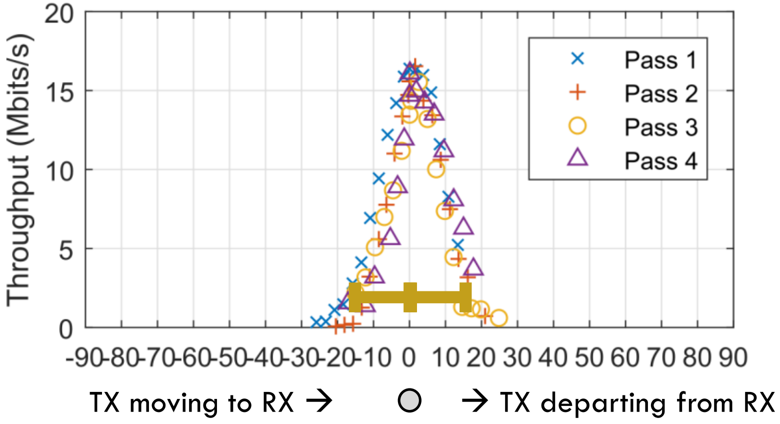

## 802.11g @ auto-rate




## 802.11g @ 1Mbit/s




## 802.11g @ 24Mbit/s

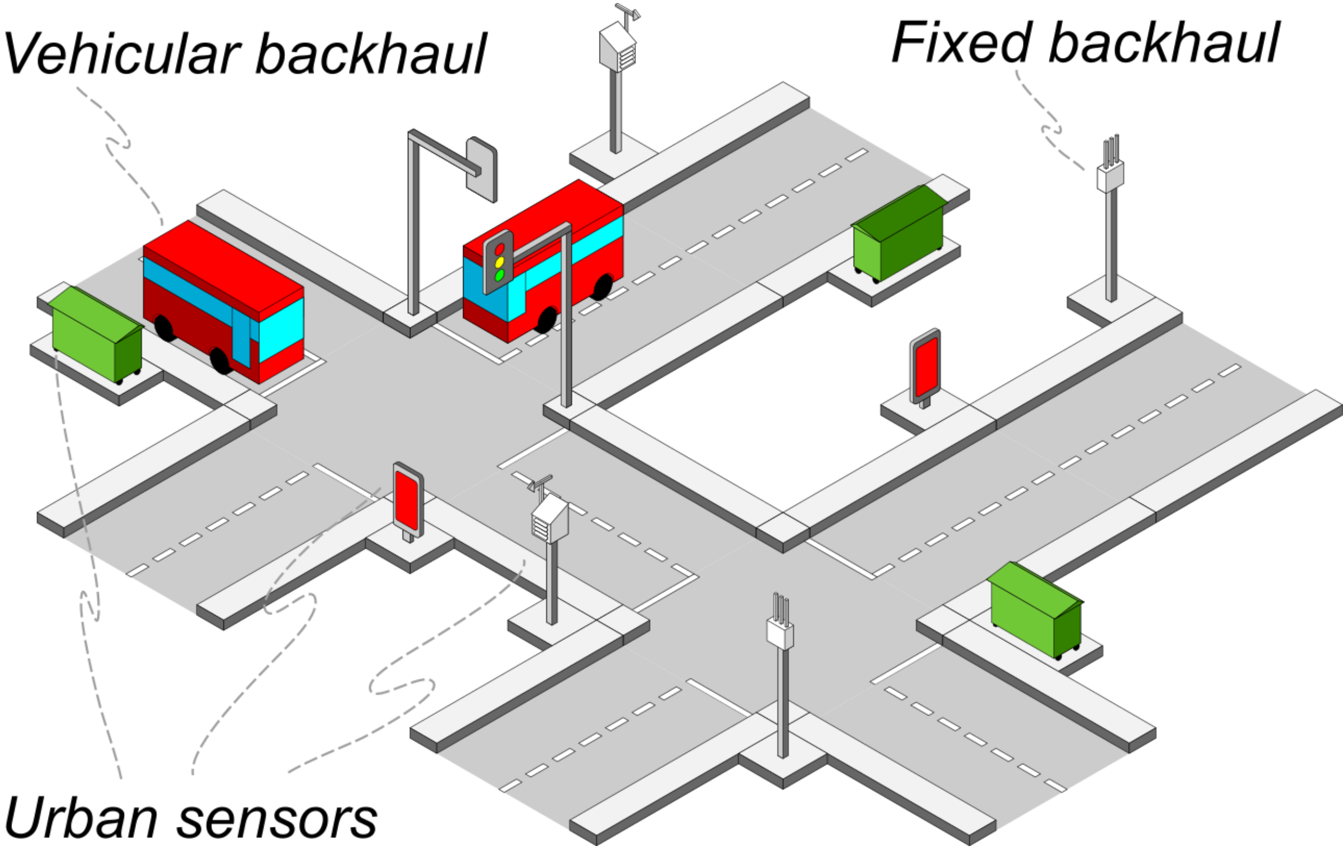



P.M. Santos, L. Pinto, A. Aguiar, L. Almeida. A Glimpse at Bicycle-to-Bicycle Link Performance in the 2.4GHz ISM Band. In Proceedings of the 29th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2018), September 9-12 2018, Bologna, Italy..5-8.

# IoT for Smart Cities

1. Urban sensor platforms
   - *PortoLivingLab and UrbanSense*
   - *Study on Solar Powered Autonomy*
2. Where Ends Meet: Infrastructure-to-Vehicle
   - *Characterizing and estimating I2V service*
   - *Supporting urban sensor deployment*
3. Protecting the Pedestrian Internet

   Experience from Vehicular Hotspots



# 1. PortoLivingLab

## BusNet

A set of 400+ vehicular nodes &

50 road-side units using DSRC

*On-board Units (OBUs)*

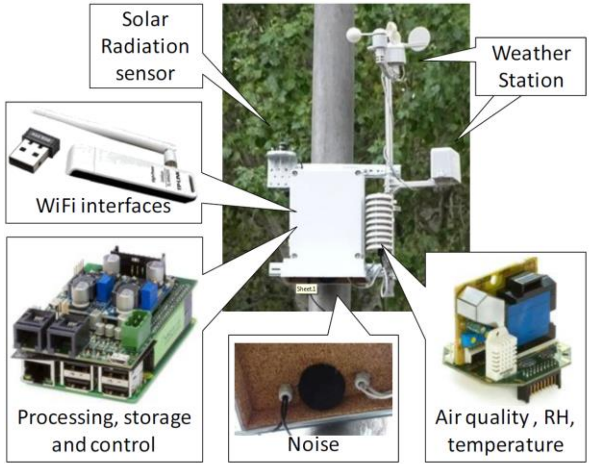
*Road-Side Units (RSU)*

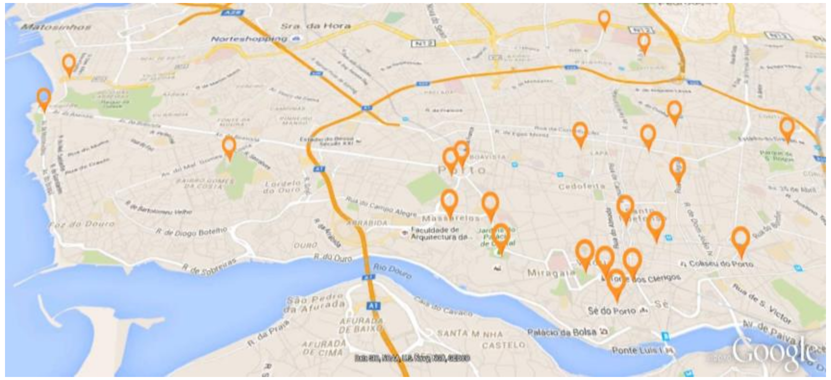
VENIAM®

## UrbanSense

A set of 20+ nodes to monitor 10

environmental parameters

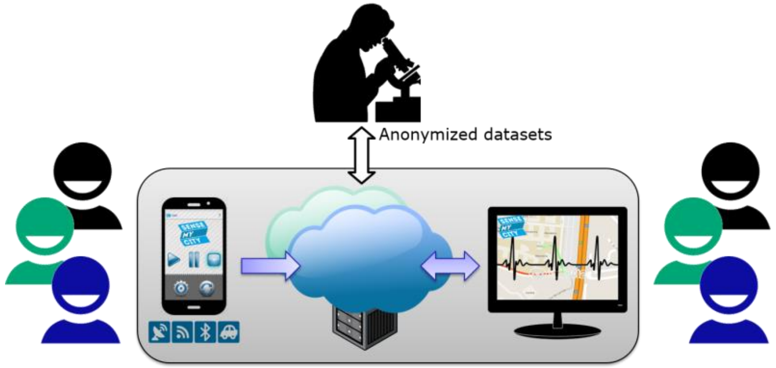


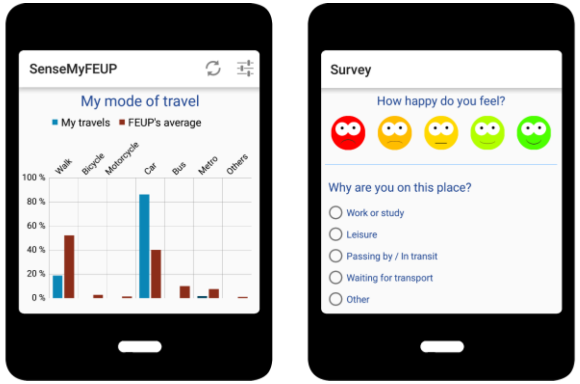




## SenseMyCity

An platform to collect user and context

data from Android smartphones

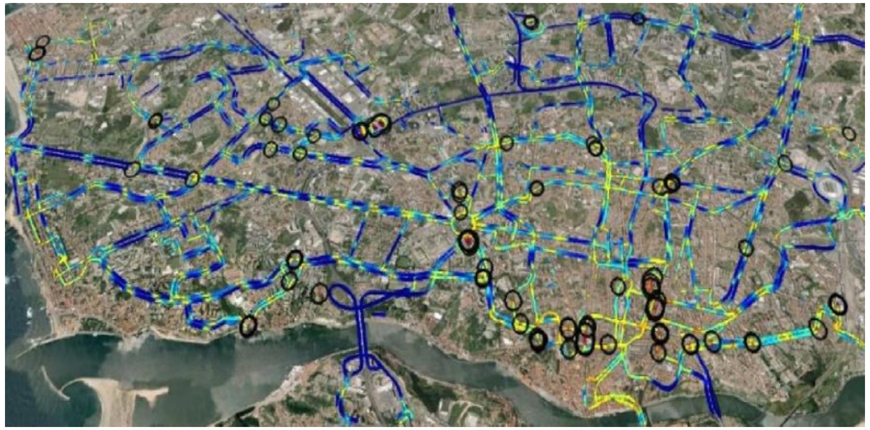


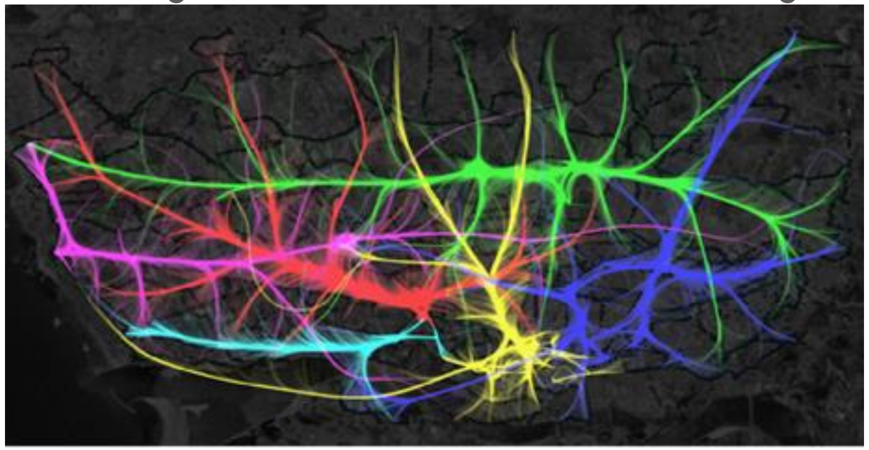
# PortoLivingLab

## BusNet

Average bus speed and critical spots

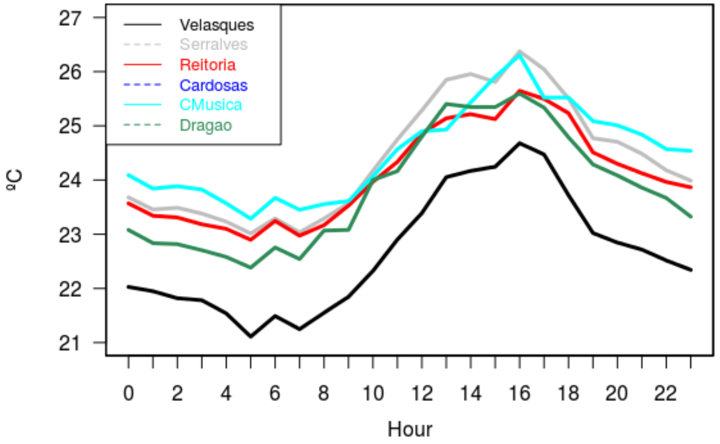


Passenger O-D matrices from WiFi usage

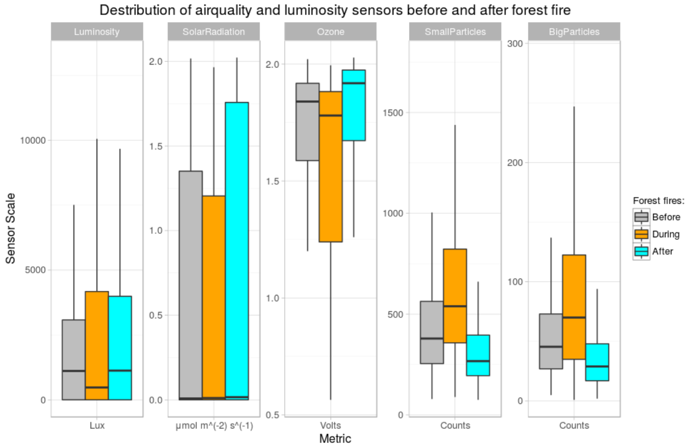


## UrbanSense

Temperature at different spots

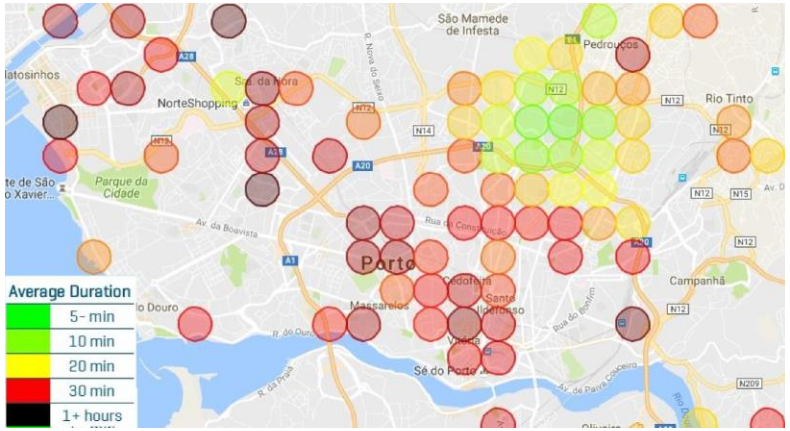



Impact of forest fires in air quality

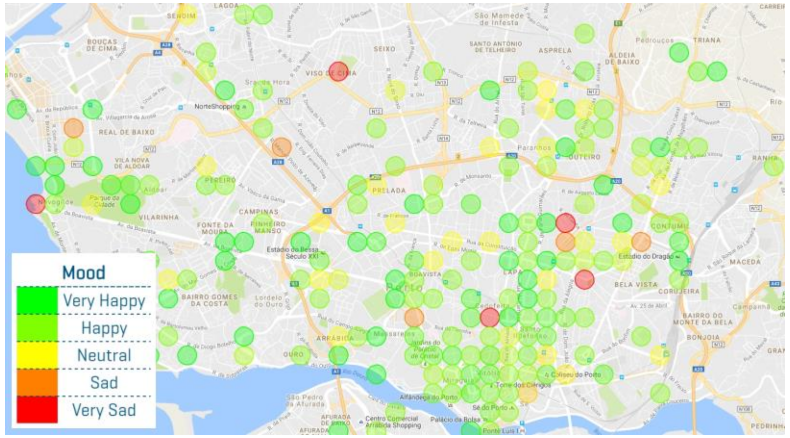



## SenseMyCity

Trip duration to FEUP




Reported happiness

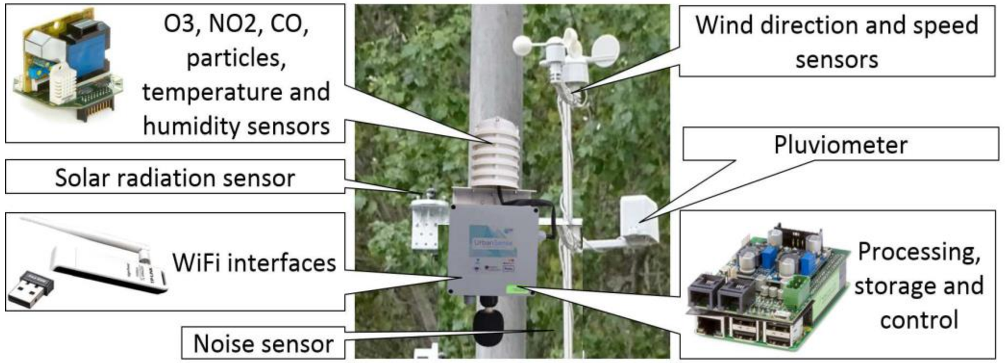



P. M. Santos, J. G. P. Rodrigues, S. B. Cruz, T. Lourenço, P. M. d'Orey, Y. Luis, C.Rocha, S.Sousa, S.Crisóstomo, C.Queirós, S. Sargento, A. Aguiar, J. Barros, [non-acknowledged: D.Moura, T.Calçada, A.Cardote, T.Condeixa]. PortoLivingLab: an IoT-based Sensing Platform for Smart Cities. IEEE Internet-of-Things Journal, January 2018.

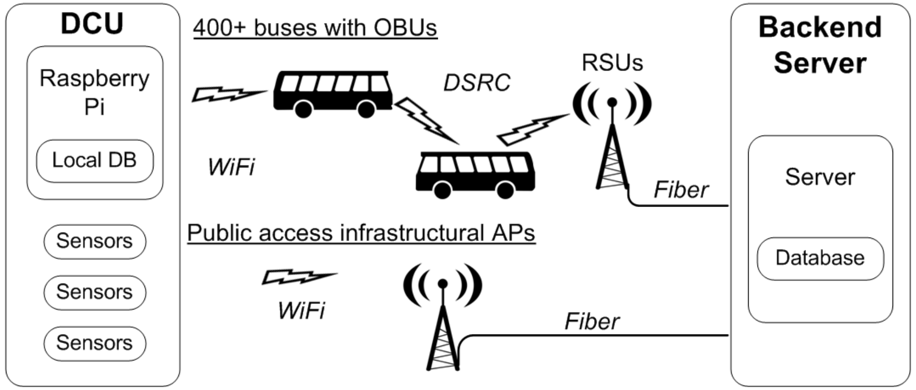
# UrbanSense

20 **Data Collection Units** (DCUs) equipped with 10 environmental sensors and WiFi interface

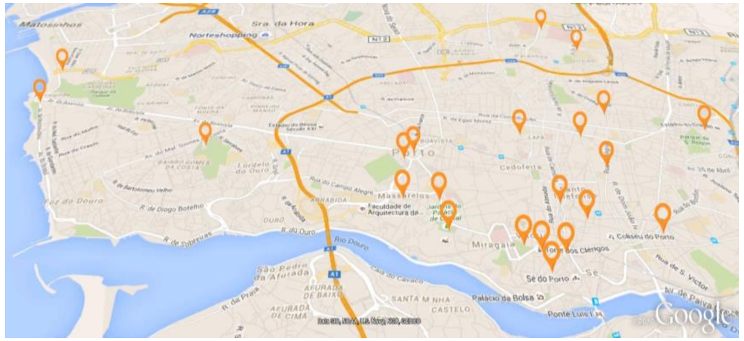
## Sensors




## Communications





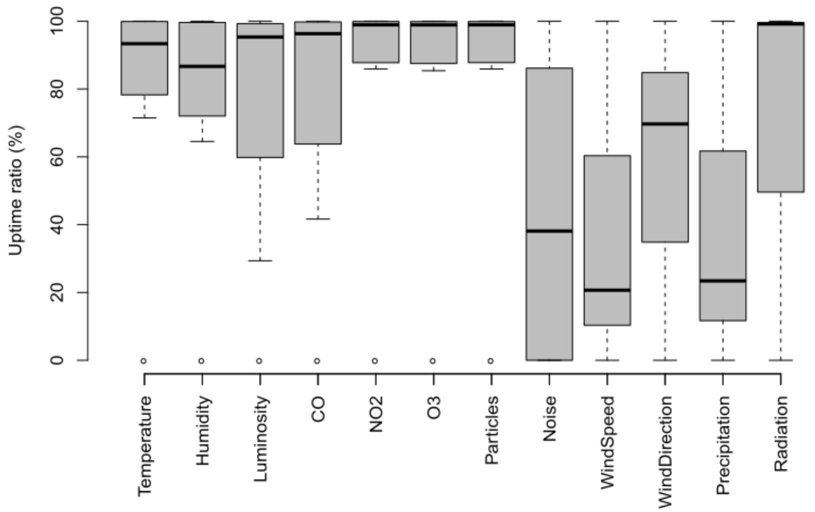



Y. Luis, P.M. Santos, T. Lourenço, C. Pérez-Penichet, T. Calçada, A. Aguiar. UrbanSense: An Urban-scale Sensing Platform for the Internet of Things. In Proceedings of the 2nd IEEE International Smart Cities Conference (ISC2 2016), September 12-15, 2016, Trento, Italy, pp.1-6. Recipient of the Best Student Paper Award.

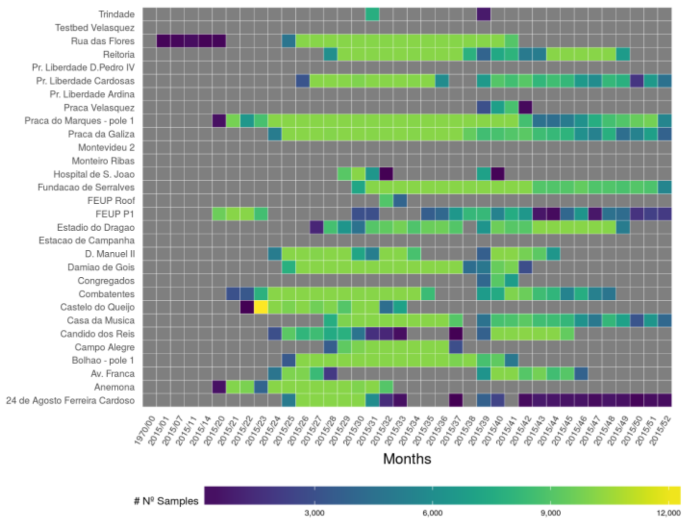
# UrbanSense

- Key Performance indicators (KPIs)
  - **Uptime** per site and sensor
  - **Data availability** over time
  - From a network perspective: **delay**
- Technical Problems
  - Low-cost platform (the **SDCard problem**)
  - Wear from the elements (e.g., salt water)
  - Third-party dependence (e.g., comms., power)
- Other Problems
  - Little support for maintenance rounds
  - Institutional coordination
  - Hard to publish (a lot of technical work)

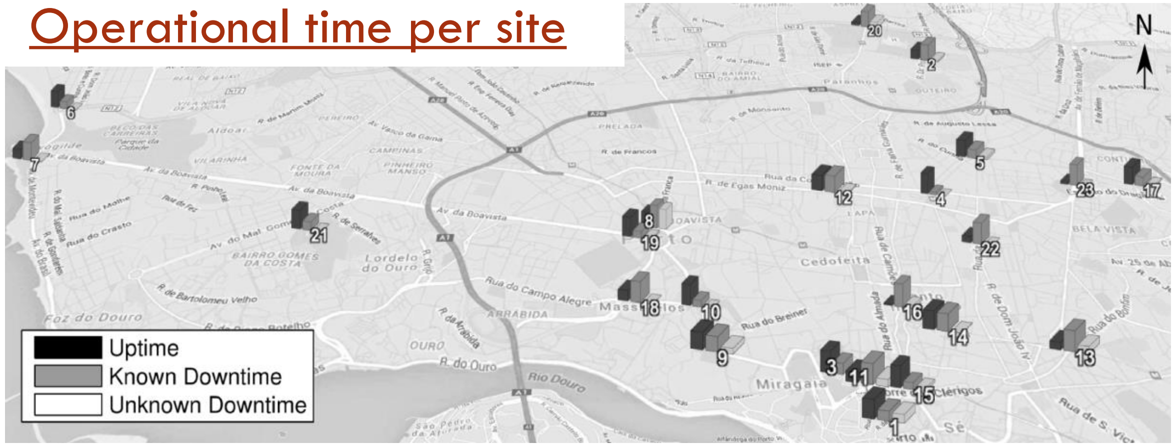
## Uptime per sensor time



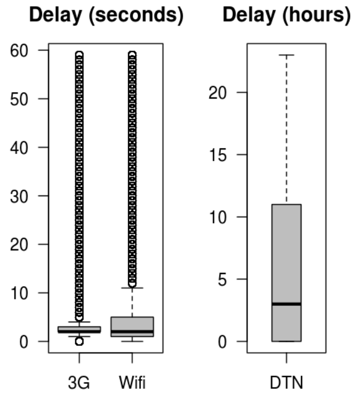

## Data Availability Maps



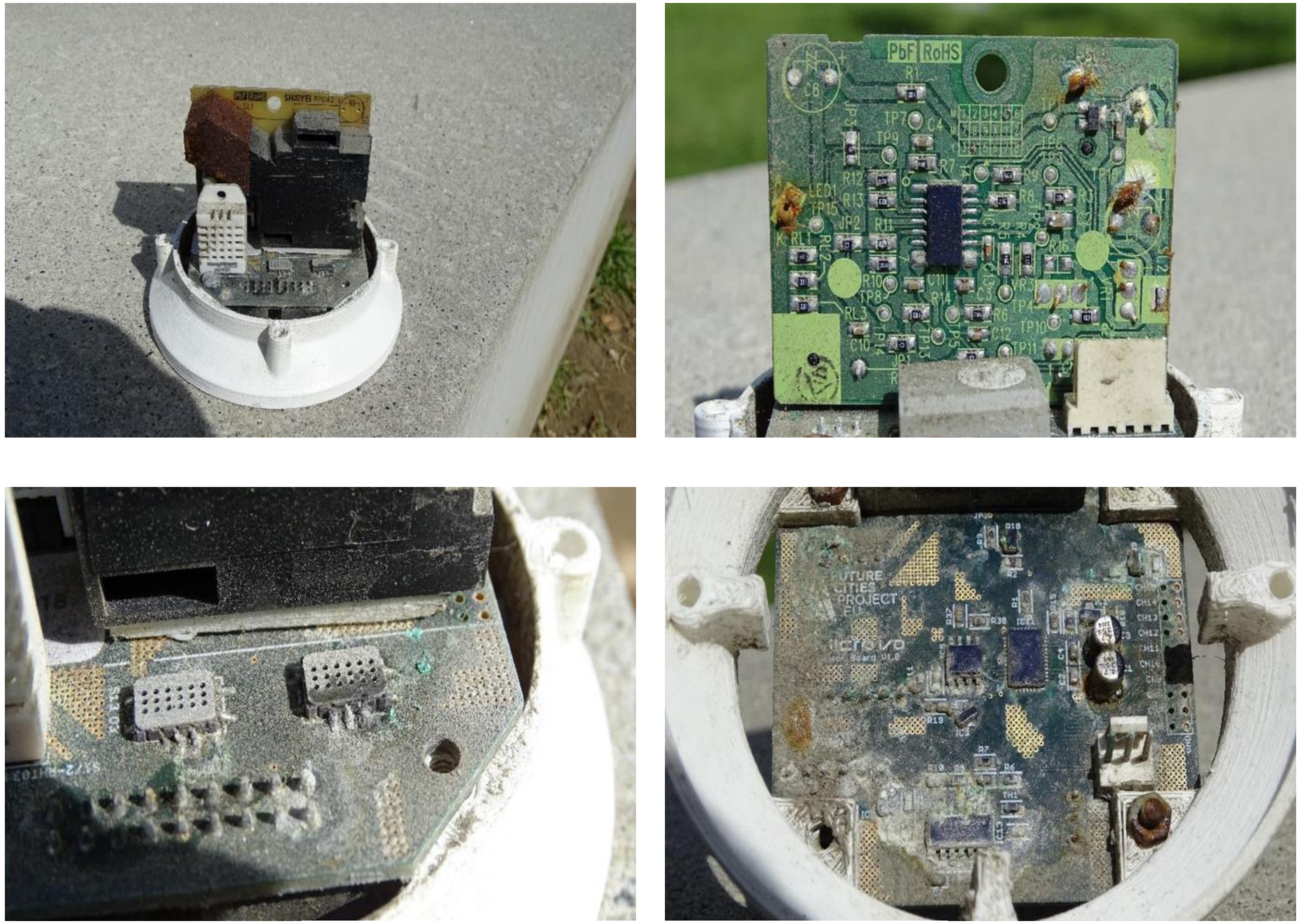

## Operational time per site




## Delay



# UrbanSense





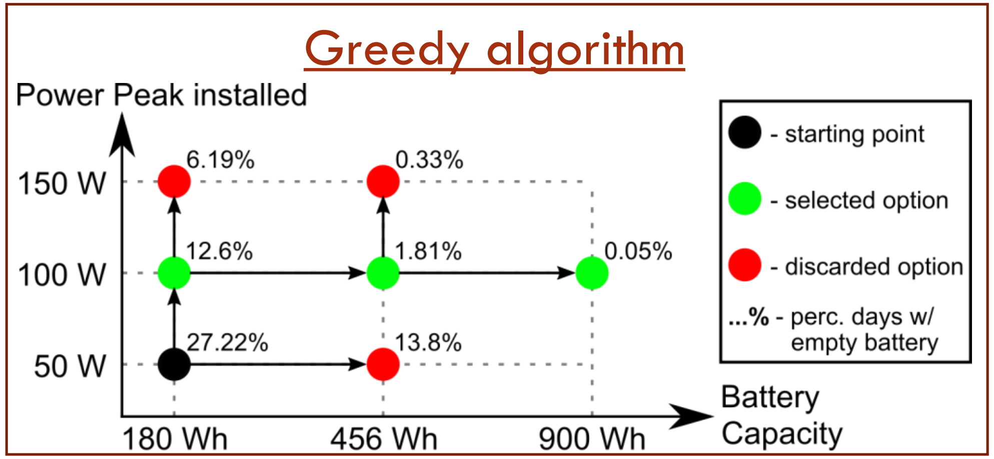
Wear by salt water

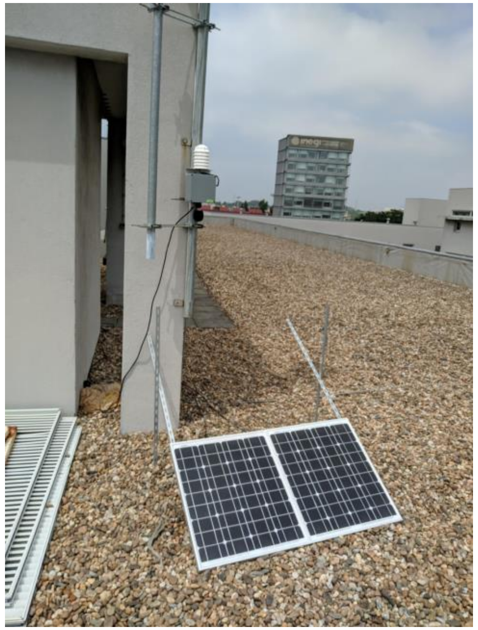


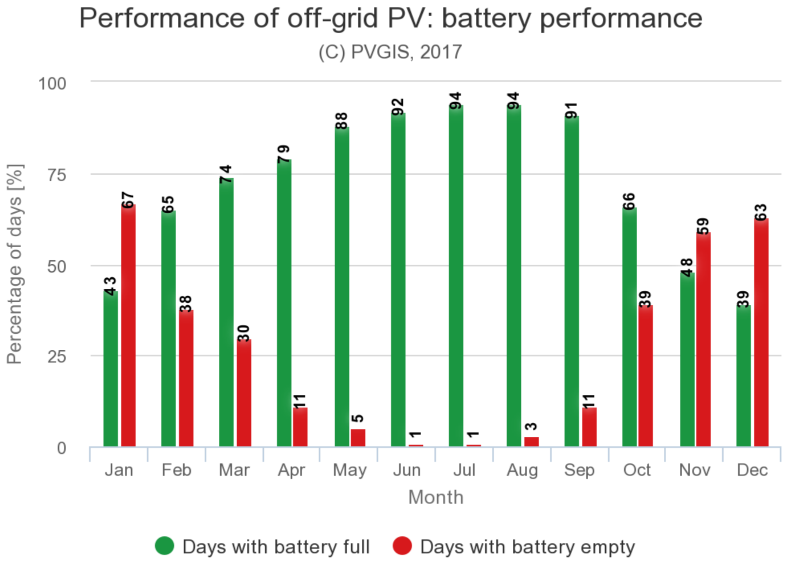
Dependence on third party

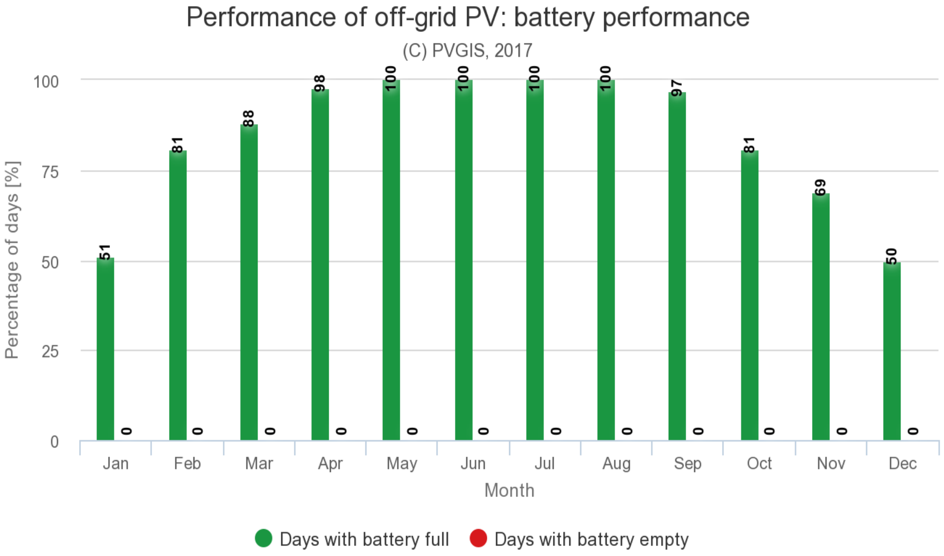
# Study on Solar-Powered Autonomy

- We evaluated if a DCU could be paired with a solar power generator for **energy autonomy**.
- We developed an **iterative greedy algorithm** to identify the best equipment configuration.





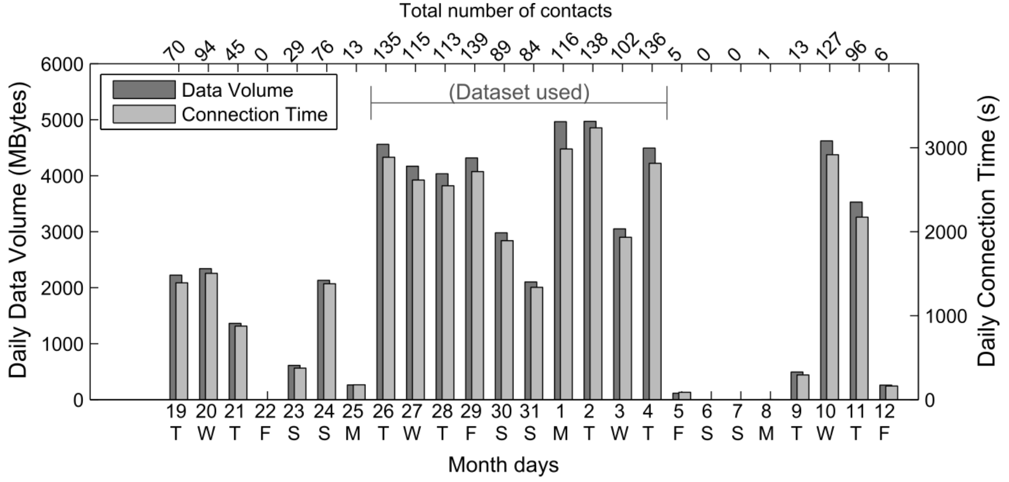




A. Nguyen, P. M. Santos, M. Rosa, A. Aguiar: Poster. Study on Solar-powered IoT Node Autonomy. In Proceedings of the 4th IEEE International Smart Cities Conference, September 16-19 2018, Kansas City, MO, USA.

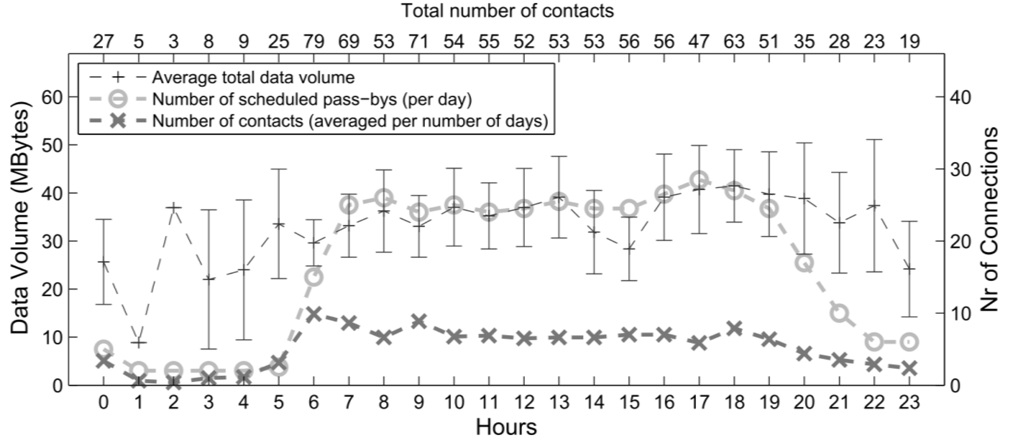
# 2. Where Ends Meet: Infrastructure-to-Vehicle

- Using the UrbanSense infrastructure, we evaluate the quality of **infrastructure-to-vehicle (I2V) service** that *BusNet* could offer.
- We measured **throughput and bus GPS positions** at a single location (Damião G.), and related data with **bus schedules**.


## Data volume transferred daily




## Data volume transferred per day hour

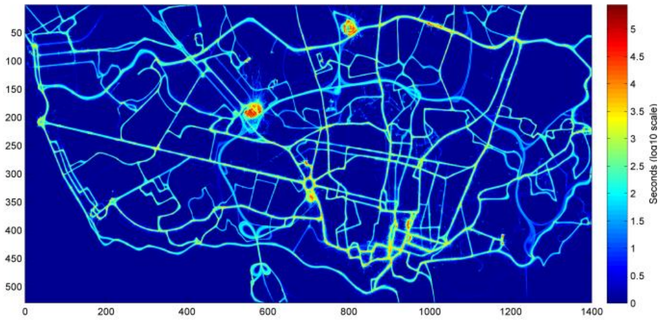



P.M. Santos, T. Calçada, S. Sargento, A. Aguiar, João Barros. Experimental Characterization of I2V Wi-Fi Connections in an Urban Testbed. In Proceedings of the 10th ACM MobiCom Workshop on Challenged Networks (CHANTS '15), September 7-11, 2015, Paris, France. ACM, New York, NY, USA, pp.5-8.

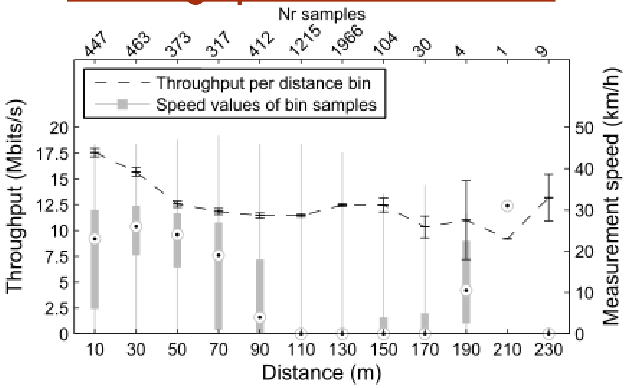
# I2V Service Estimation

- We extended the measurements to **4 more sites** (this time, with garbage disposal trucks).
- Using an empirical throughput-distance model and GPS traces, we **estimate transferrable data volume** at traffic lights.

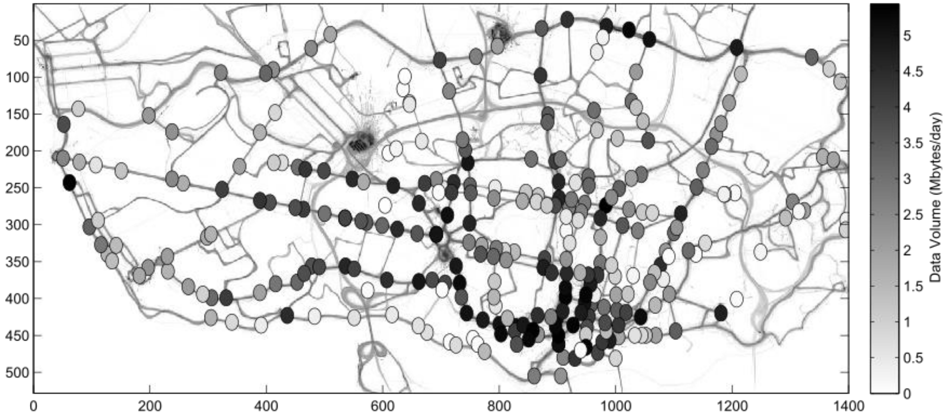
GPS traces of fleets



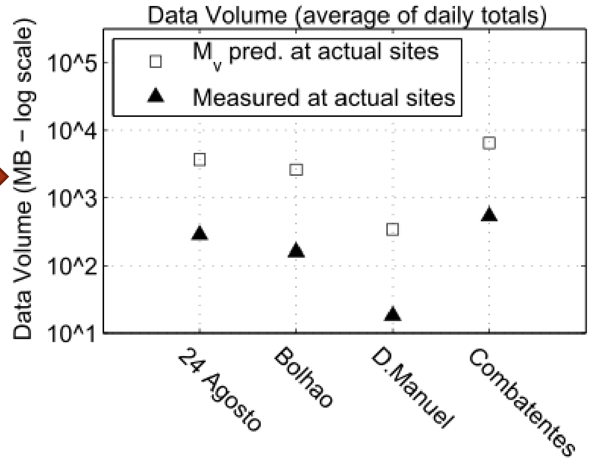

Throughput vs. distance




Data Volume Estimation at Traffic Lights




Evaluation at 4 sites




Estimating I2V service can support decisions about road-side sensor placement.

# Relating I2V Service & Site Features

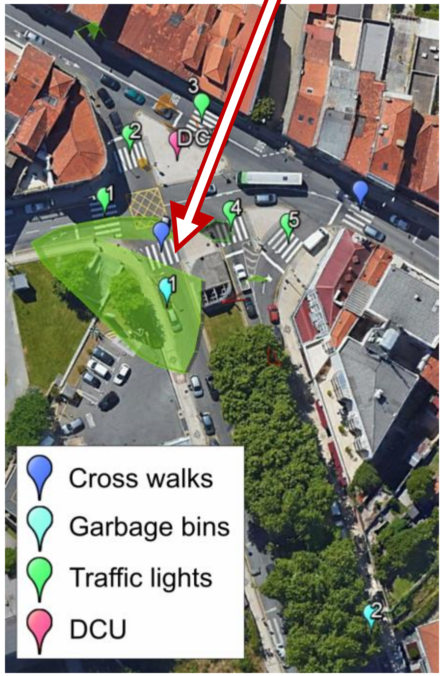
- We explore whether mobility and task-related **Points-of-Interest** (e.g., **traffic lights, garbage bins**) could inform about measured data volumes.
- The end-goal was to have a **qualitative** mechanism to estimate I2V service (thus requiring less datasets).

| Sites | Traffic Lights | Crosswalks | Garbage Bins |
| --- | --- | --- | --- |
| A | 82.6% | 7.5% | 9.9% |
| B | 100% | 0 | 0 |
| C | 6.8% | 0 | 93.2% |

Geographical density of throughput samples


Site A Intersection center

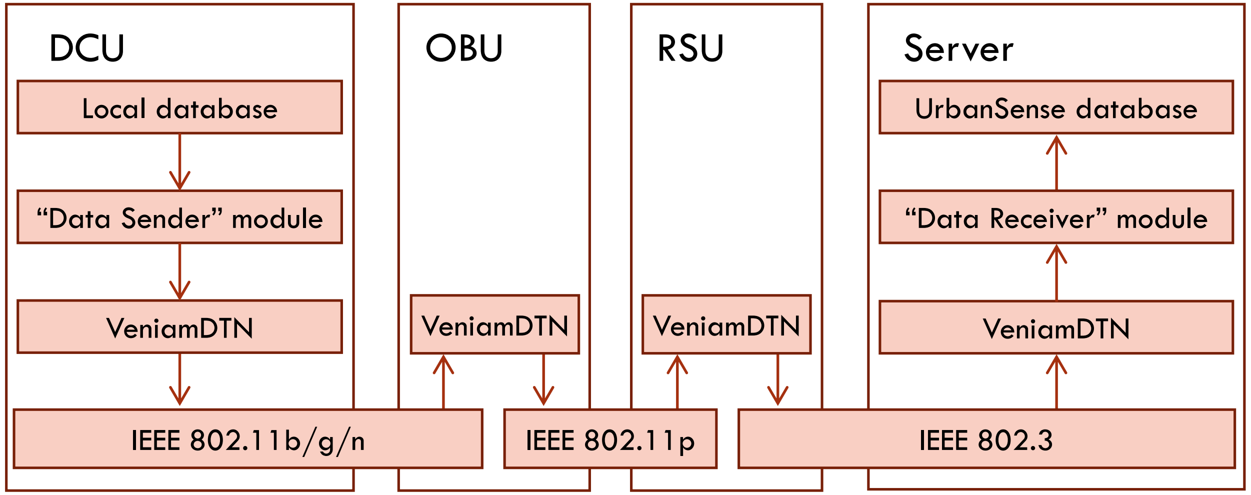

Site C Garbage bin

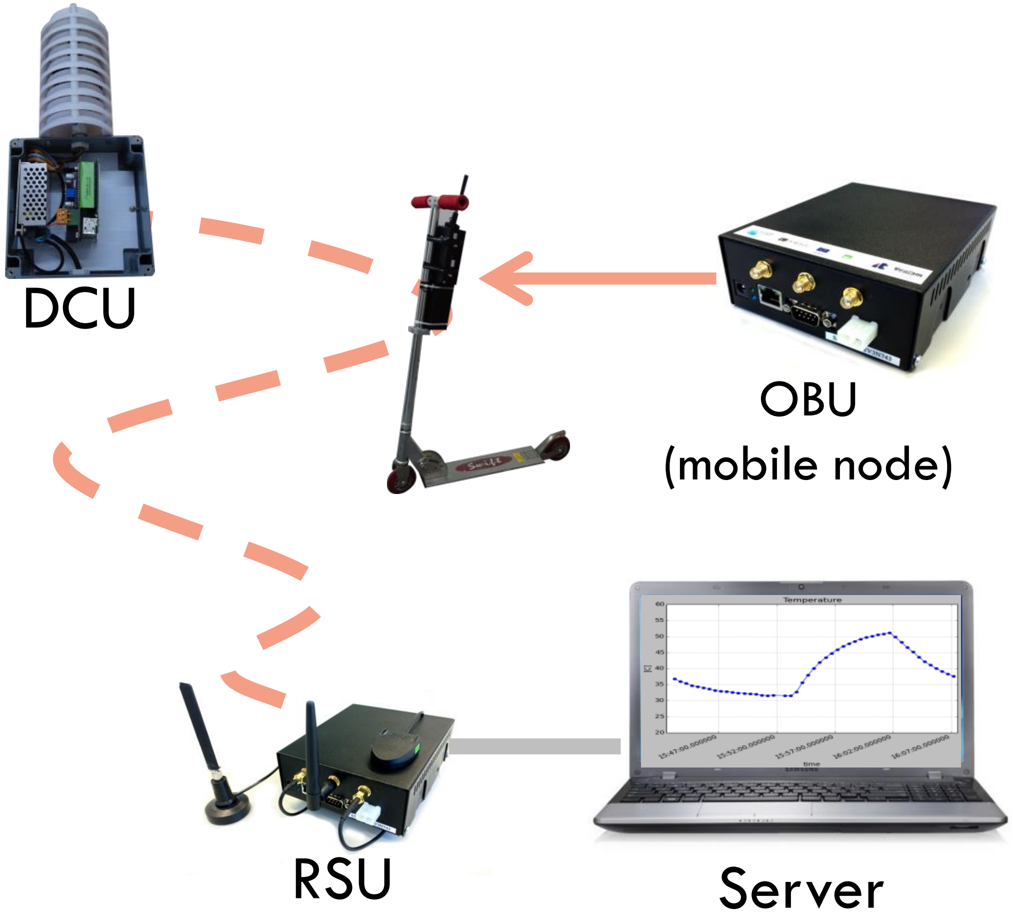



L. M. Sousa, P. M. Santos, A. Aguiar: An Exploratory Study of Relations between Site Features and I2V Link Performance.In Proceedings of the 2018 EAI Urb-IoT Conference, November 21-23 2018, Guimarães, Portugal.

# A Delay-Tolerant Networking Proof-of-Concept

- On a network level, we explored **Delay-Tolerant Networking.**
- The DCU data was transferred to OBUs and ferried to RSUs in a **data muling** strategy (no Epidemic, Max-Prop protocols).
- Existing implementations (IBR-DTN) showed too much memory consumption, so a in-house alternative was developed.




P. M. Santos, T. Calcada, D. Guimarães, T. Condeixa, S. Sargento, A. Aguiar, J. Barros. Demo: Platform for Collecting Data From Urban Sensors Using Vehicular Networking. In Proceedings of the 21st Annual International Conference on Mobile Computing and Networking (MobiCom). 2015. September 7-11, 2015, Paris, France. ACM, New York, NY, USA, pp.167-169.


DCU
Temperature sensor

# 3. Mobile Users & On-board APs

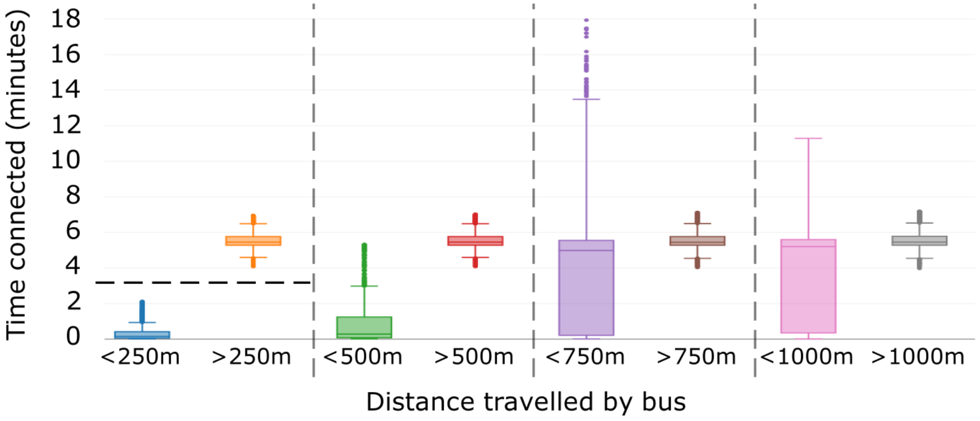

A new reality on the streets as vehicular backhauls become standard:

1. User on the street using cellular connection.
2. Bus passes by; smartphone attempts connection to on-board AP.
3. User gets experience of Internet access disrupted.

Can the on-board AP detect whether the user is inside or outside the bus?

We applied a **machine learning approach:**

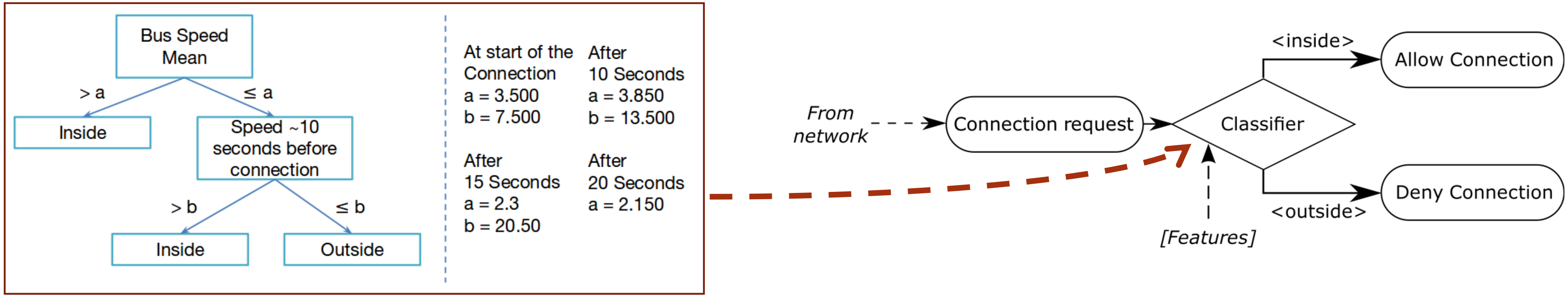
- We collected a dataset of RSSI (from user devices) and GPS from 7 on-board APs, for a week.
- A **classifier training tool** identified the most relevant features and produced a **decision-tree classifier.**




- P. M. Santos, L. Kholkine, A. Cardote, A. Aguiar: Context Classifier for Position-based User Access Control to Vehicular Hotspots. Elsevier Computer Communications, March 2018.
- L. Kholkine, P.M. Santos, A. Cardote, A. Aguiar. Detecting Relative Position of User Devices and Mobile Access Points. In Proceedings of the XXth IEEE Vehicular Networking Conference (VNC 2016), December 8-10 2016, Columbus, OH, USA, pp.1-8.

# Mobile Users & On-board APs

- The produced **decision tree classifier** was incorporated in an on-board AP, at the DHCP assignment stage




- To test the classifier, we installed the on-board AP in a private car advertising the **STCP SSID** name

(Ground truth is easy: everyone is outside!)

| *Classifier output* | *Classification* | *Prior Speed* | *Up to timeout* |
|---|---|---|---|
| *Gatekeeper decision* | Accepted | 109 | 114 |
| | Denied | 71 | 66 |
| *Classifier performance* | **Ratio correct** | **40%** | **37%** |

Thank you for your attention