

GreenDays@Sophia 2017

# Evaluation of Energy-efficient Data Collection in Mobile Crowdsensing Systems with CrowdSenSim Simulator

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June 27, 2017

# Smart Cities: Introduction

- ▶ 50% of worldwide population lives in cities
- ▶ Cities account for
  - ▶ 80% of worldwide gas consumption
  - ▶ 75% of global energy consumption
  - ▶ 60% of residential water use

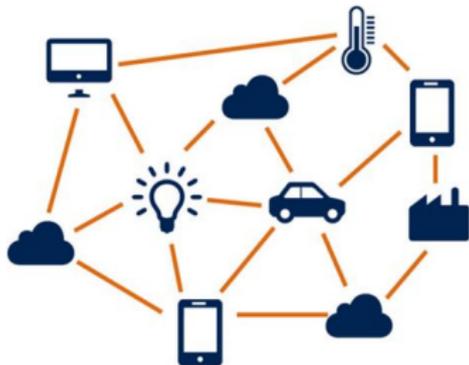


N. B. Grimm, S. H. Faeth, N. E. Golubiewski, C. L. Redman, J. Wu, X. Bai, and J. M. Briggs, "Global change and the ecology of cities," in *Science*, vol. 319, no. 5864, 2008, pp. 756–760.

# IoT for Smart Cities

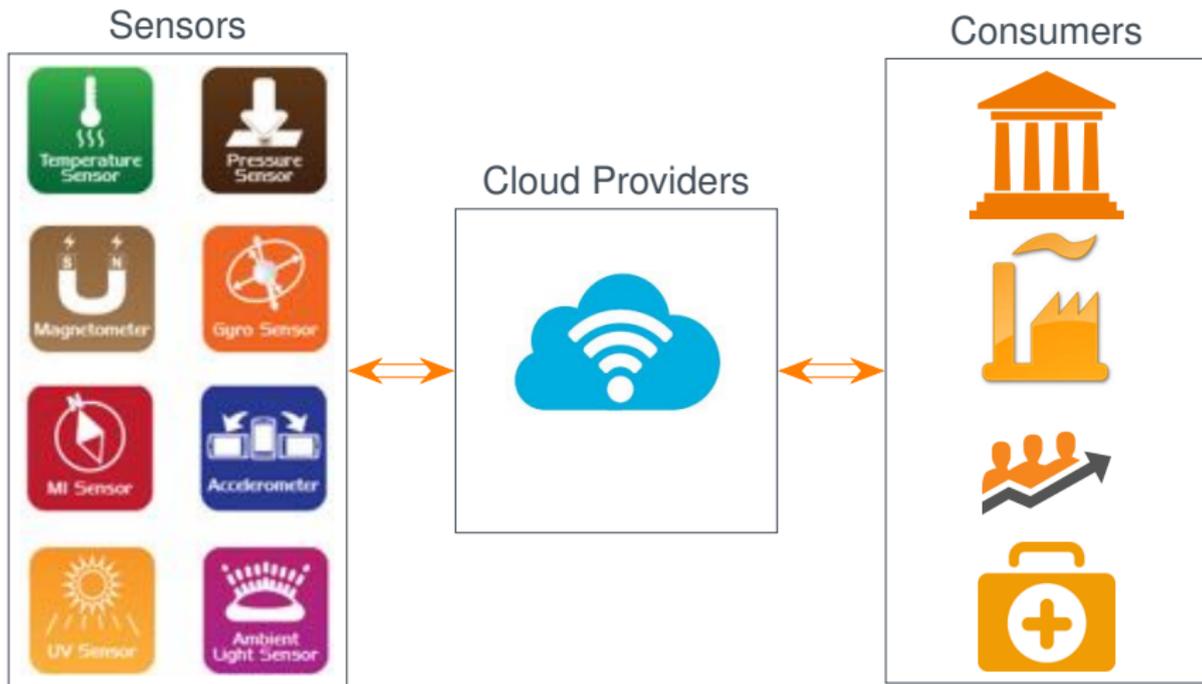
Improve citizens' quality of life with innovative and sustainable solutions for public services:

- ▶ Smart parking
- ▶ Waste management
- ▶ Public lighting



- ▶ IoT candidate building block for Smart Cities solutions

# Sensing as a Service (S<sup>2</sup>aaS) for IoT



# Mobile Crowdsensing

- ▶ Appealing paradigm for sensing and collecting data
  - ▶ Monitoring phenomena in smart cities
- ▶ Sensing as a Service ( $S^2$ aaS) business model
- ▶ Sensors commonly available in mobile and IoT devices

# Mobile Crowdsensing

- ▶ Appealing paradigm for sensing and collecting data
  - ▶ Monitoring phenomena in smart cities
- ▶ Sensing as a Service ( $S^2$ aaS) business model
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Figure: Diffusion of mobile devices

# Mobile Crowdsensing

- ▶ Appealing paradigm for sensing and collecting data
  - ▶ Monitoring phenomena in smart cities
- ▶ Sensing as a Service ( $S^2$ aaS) business model
- ▶ Sensors commonly available in mobile and IoT devices



Figure: Diffusion of mobile devices

# Sensing Paradigms

- ▶ Two sensing paradigms:

## Participatory

- ▶ Active user engagement
- ▶ Sensing and reporting user-driven
- ▶ Centralized, direct task assignment

## Opportunistic

- ▶ Minimal user involvement
- ▶ Sensing and reporting application- or device-driven
- ▶ Distributed, no direct task assignment

Framework for Data Collection in Opportunistic Sensing Systems

User Recruitment

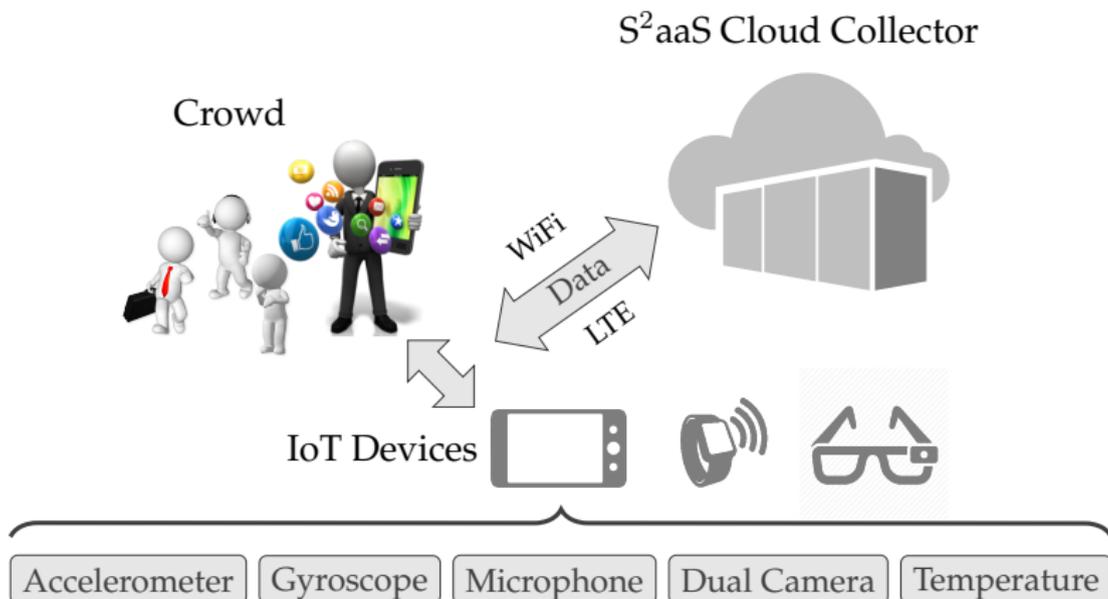
Smart Lighting

## Framework for Data Collection in Opportunistic Sensing Systems

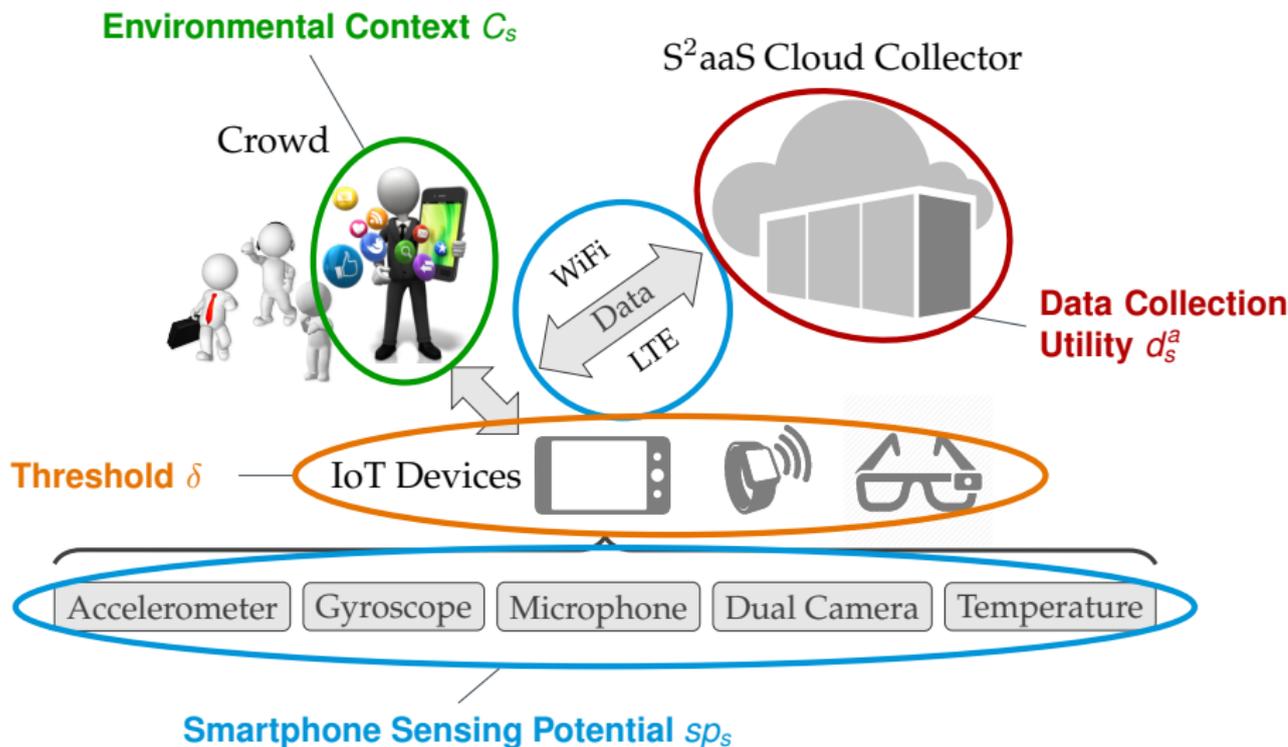
User Recruitment

Smart Lighting

# Mobile Crowdsensing Scenario



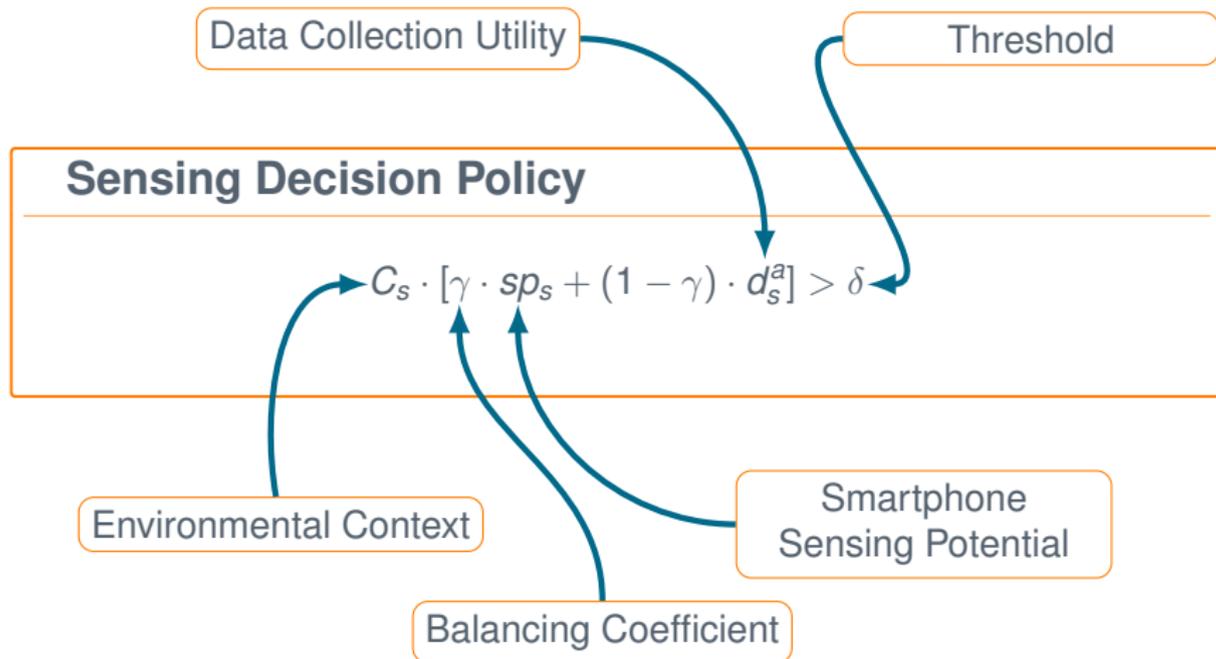
# Mobile Crowdsensing Scenario



## Sensing Decision Policy

$$C_s \cdot [\gamma \cdot sp_s + (1 - \gamma) \cdot d_s^a] > \delta$$

# Proposed Opportunistic Framework



# Proposed Opportunistic Framework

- ▶ Data Collection Utility  $d_s^a$ 
  - ▶ Defines utility for the cloud collector
  - ▶ Based on number of samples already received
- ▶ Smartphone Sensing Potential,  $sp_s$ 
  - ▶ Function of locally spent energy  $E_s$  for sensing and reporting

$$E_s = E_s^c + E_s^r$$

- ▶ Environmental Context  $C_s$ 
  - ▶ Binary value which depends on the context awareness
- ▶ Threshold  $\delta$ 
  - ▶ Depends on the *level of battery* of the devices ( $B$ ) and the *amount of reported data* that devices have already contributed ( $D$ )

## ► Custom simulator for crowdsensing activities

- Access and download: <http://crowdsensim.gforge.uni.lu>
- Contact: [crowdsensim@gmail.com](mailto:crowdsensim@gmail.com)



**CrowdSenSim** Mobile Crowdsensing Simulator



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## About the Simulator

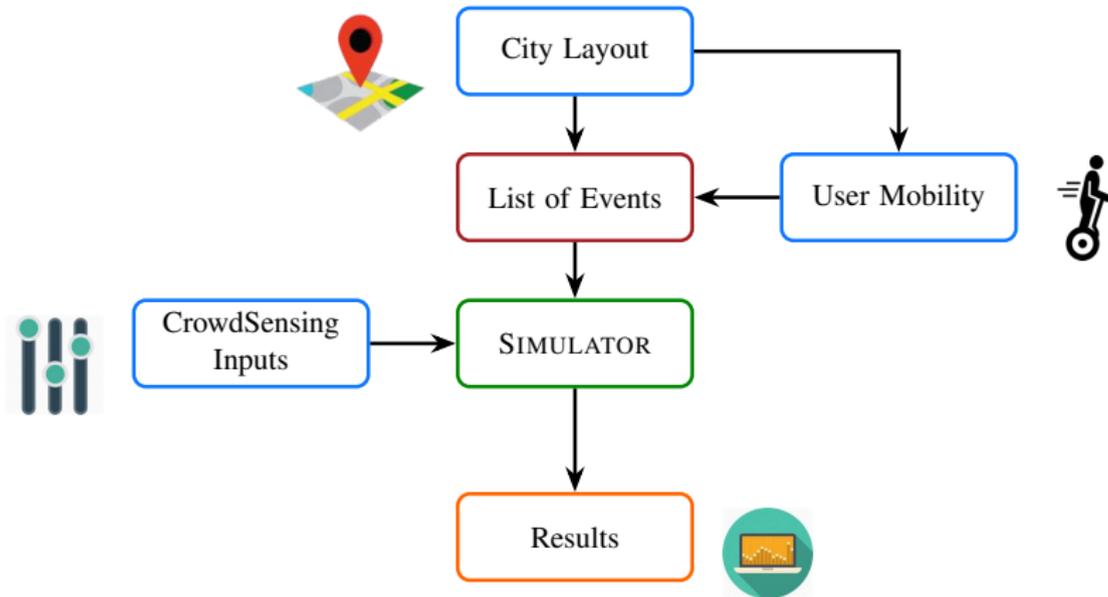
CrowdSenSim is a discrete-event simulator designed for research use in Mobile Crowd Sensing. It allows simulation of large-scale crowd sensing activities in urban scenarios and can be used to develop novel solutions in data collection, task assignment, monitoring and resource management. It is released under the GNU General Public License version 3.



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# CrowdSenSim: Features and Architecture

- ▶ Large scale (time-space)
- ▶ Realistic urban environments

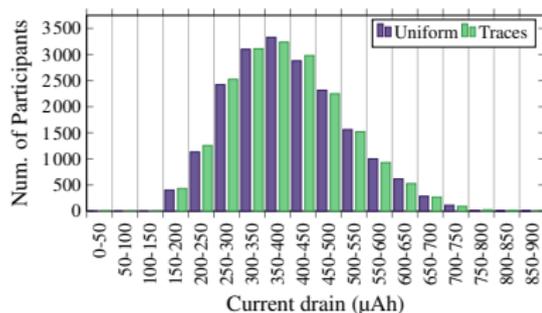


# Evaluation Settings

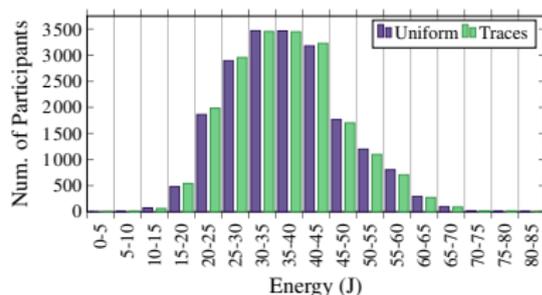
- ▶ 3 sensors: accelerometer, temperature, pressure
- ▶ Users: 20 000
- ▶ Walking speed:  $\mathcal{U}$  [1 – 1.5] m/s
- ▶ Walking period:  $\mathcal{U}$  [10 – 20] min
- ▶ Simulation period: 8 AM - 2 PM
- ▶ Digipoint to provide street-level maps
- ▶ City centers of Luxembourg, Madrid and Trento

# Performance Evaluation

- ▶ Energy spent for sensing and communications



(a) Sensing Cost



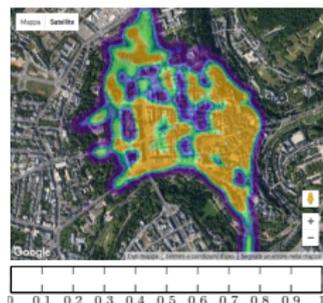
(b) Communication Cost

- ▶ Sensing and communication same distribution but different scales
- ▶ Real-world traces are the results of a study on pedestrian mobility and are public available on Crowdad (ostermalm\_dense\_run2) <sup>1</sup>

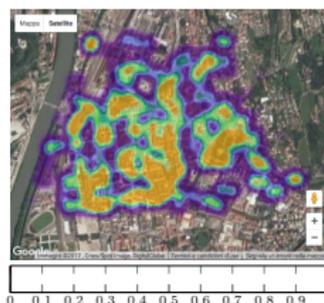
<sup>1</sup><http://crowdad.org/kth/walkers/20140505>

# Performance Evaluation

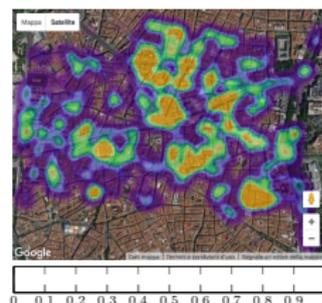
- ▶ Normalized distribution of amount of collected data for the different cities over the time period 8:00 AM - 2:00 PM



(a) Luxembourg



(b) Trento



(c) Madrid

Framework for Data Collection in Opportunistic Sensing Systems

User Recruitment

Smart Lighting

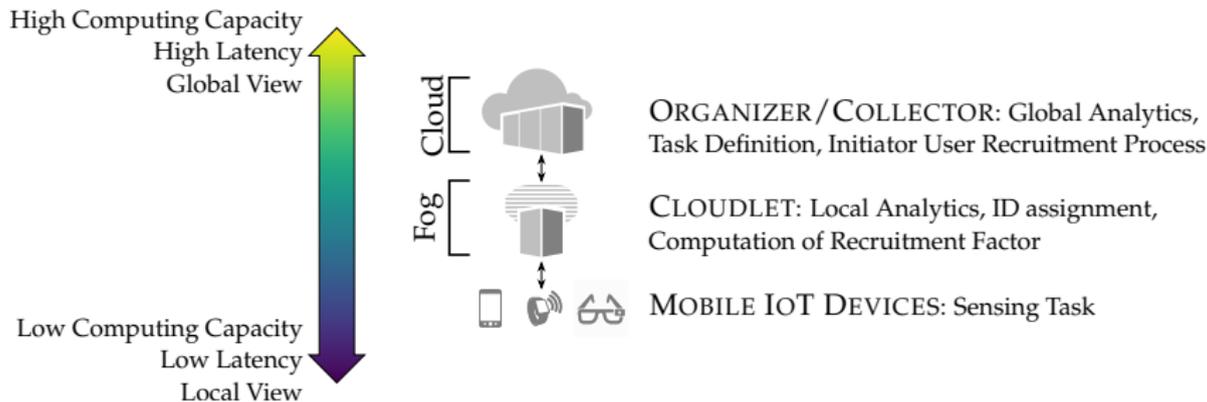
# The DSE Recruitment Policy

## The recruitment problem

- ▶ Select users able to fulfill the task with high accuracy
  - ▶ Minimize costs of the organizer/users
  - ▶ Recruit a minimum number of users  $N$
- 
- ▶ Three factors define user eligibility
    - ▶ Distance from sensing task
    - ▶ Sociability
    - ▶ Remaining battery charge
  - ▶ Acceptance: sociability and energy



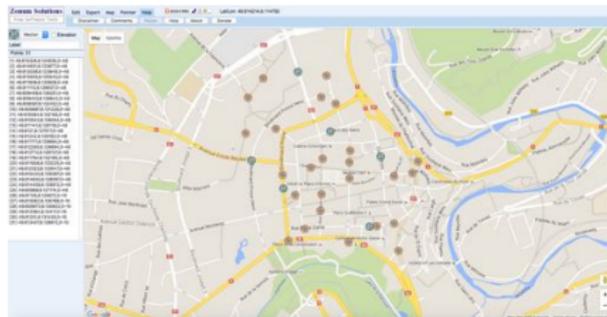
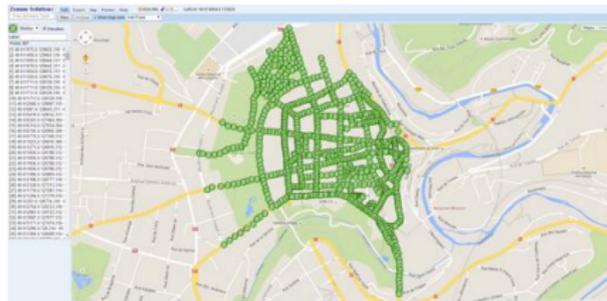
# Proposed Fog Platform



- ▶ Fog computes social factor
- ▶ Extension: anonymity, privacy

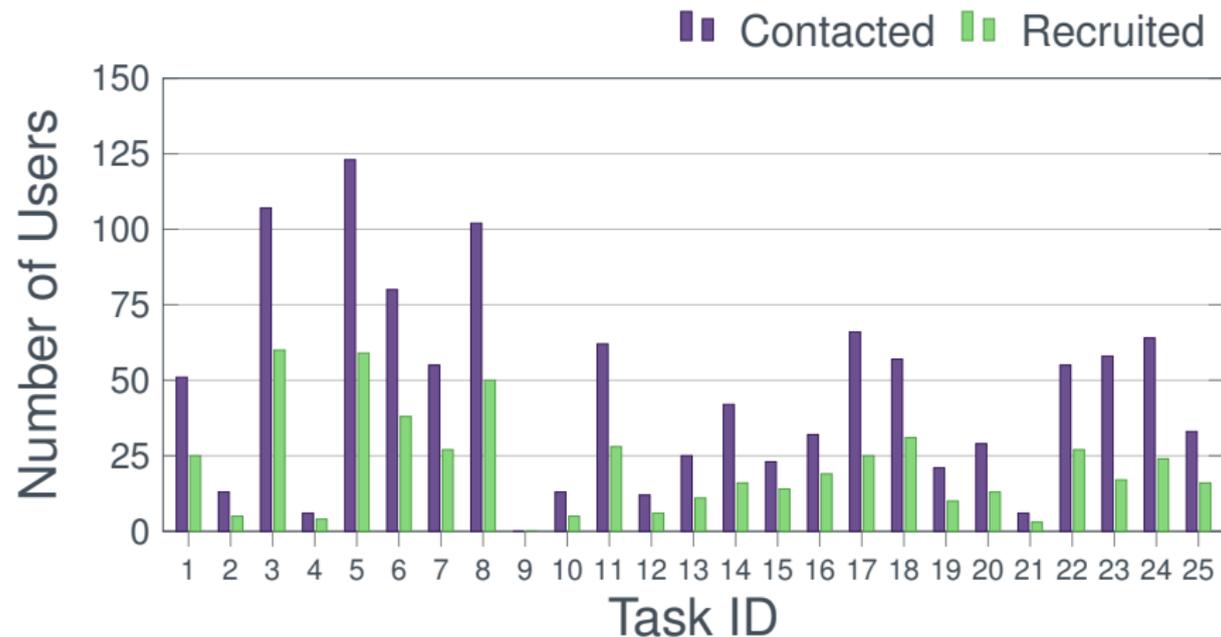
# Evaluation Settings

- ▶ 10 000 participants
- ▶ 6 cloudlets
- ▶ Walking speed:  $U$  [1 – 1.5] m/s
- ▶ Walking period:  $U$  [10 – 30] min
- ▶ Simulation period: 8 AM - 2 PM
- ▶ Set of 25 tasks (40 minutes each)



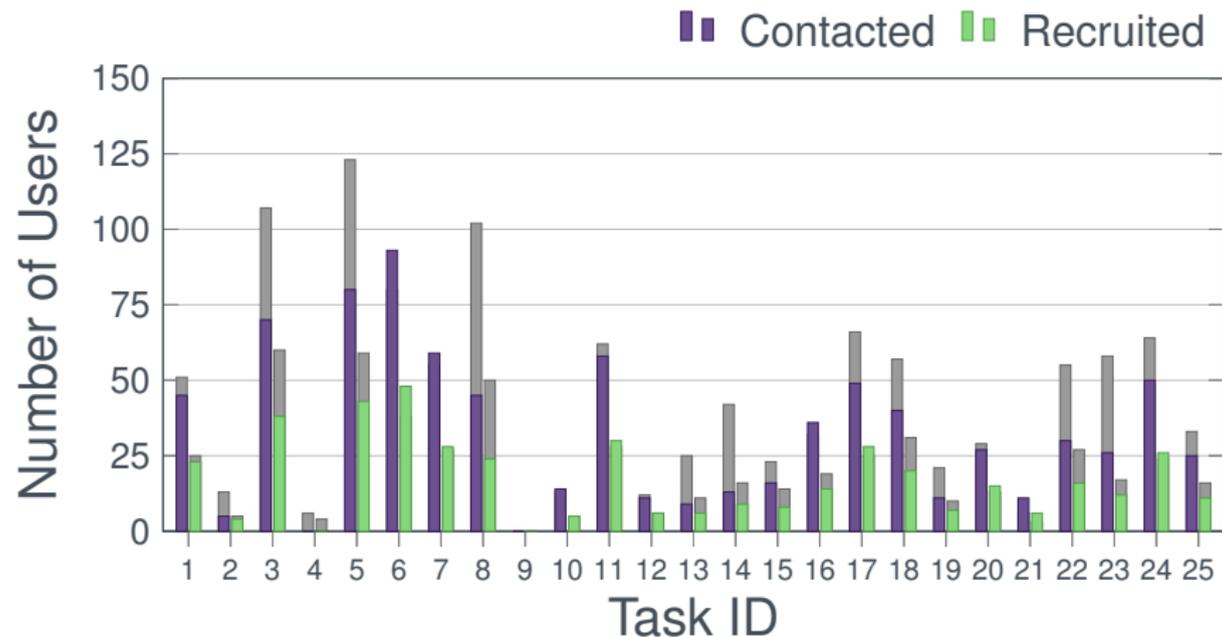
# Distribution of Contacted vs Recruited Users

## ► DSE policy



# Distribution of Contacted vs Recruited Users

## ► Distance-only policy



Framework for Data Collection in Opportunistic Sensing Systems

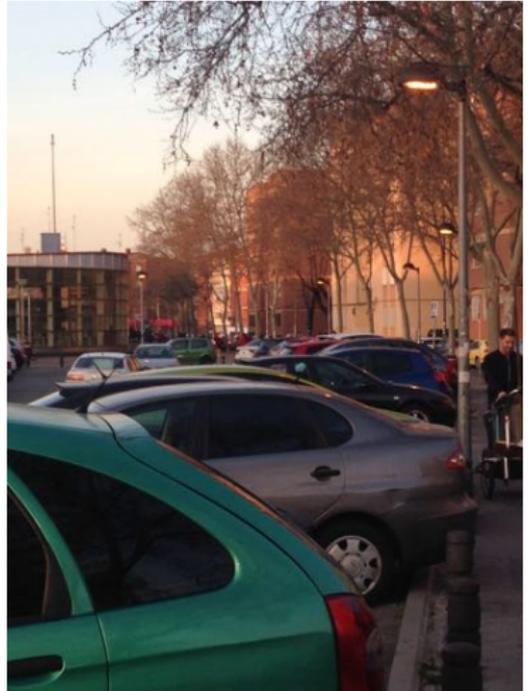
User Recruitment

Smart Lighting

# Current Street Lighting Implementations (I)

Not environmental sustainable:

- ▶ 19% of worldwide use of electrical energy
- ▶ 6% of total emissions of greenhouse gases
- ▶ 40% of the cities' energy budget



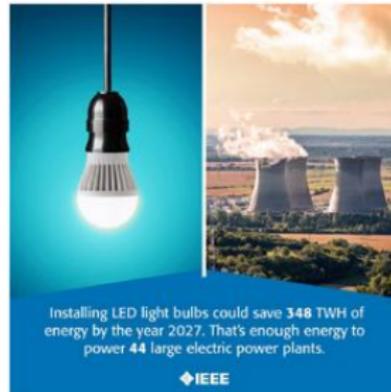
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European Energy Innovation Publisher, "LED Lighting Technologies", in 2nd Annual LED Professional Symposium & Exhibition.

# Current Street Lighting Implementations (II)

Not energy efficient because of

- ▶ technology
- ▶ control system

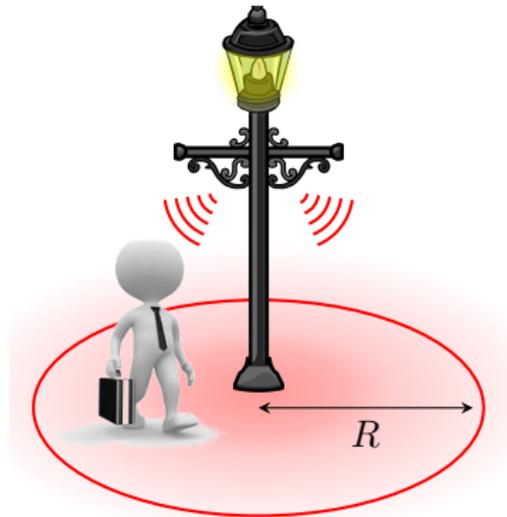


TYPE OF LAMPS	NOM. WATTAGE (W)	LAMP EFFICACY (LM/W)	ENERGY (kWh/1000 h)	AVERAGE LIFE (h)
HPS-97241	150.0	110.0	172.7	24 000
HPS-93010296	250.0	129.0	283.4	24 000
MH-NaSc	100.0	90.0	165.0	10 000
LED-GRN60	46.8	131.0	51.8	100 000
LED-GRN100	73.3	138.0	82.7	100 000

# New Heuristics for Street Lighting (I)

The new proposed heuristics rely on *occupancy*<sup>2</sup> and each lamppost operates *independently*

- ▶ IoT-augmented lamps
- ▶ Strategies:
  - ▶ Delay-based (DEL)
  - ▶ Encounter-based (ENC)
  - ▶ Dimming (DIM)



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<sup>2</sup>F. Leccese, "Remote-Control System of High Efficiency and Intelligent Street Lighting Using a ZigBee Network of Devices and Sensors," in IEEE Transactions on Power Delivery, vol. 28, no. 1, pp. 21-28, Jan. 2013.

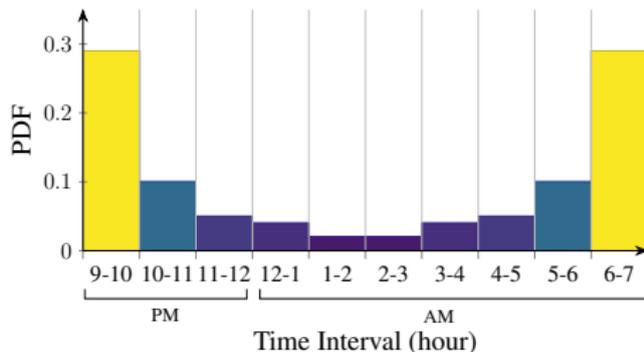
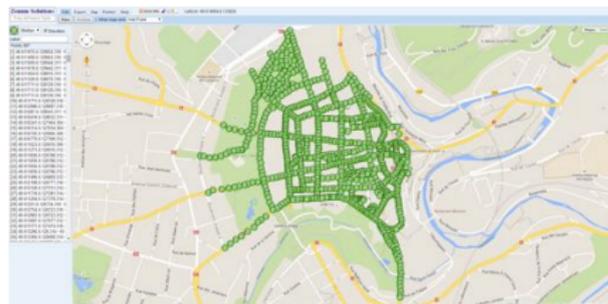
# New Heuristics for Street Lighting (II)

METHOD	DESCRIPTION	EFFICACY
Current (CUR)	Lampposts continuously active emitting maximum light intensity	Lo
Delay-based (DEL)	Lampposts switched on when users pass nearby. If nobody is present within $R$ , lampposts remain active for time window $W$ and then are switched off.	Hi
Encounter-based (ENC)	Lampposts switched upon the first encounter with at least one user and remain active the whole night.	ME
Dimming (DIM)	Lampposts operate at 60% light intensity in absence of users within $R$ . Lampposts light up/dim the intensity in proportion to the number of nearby users.	Hi

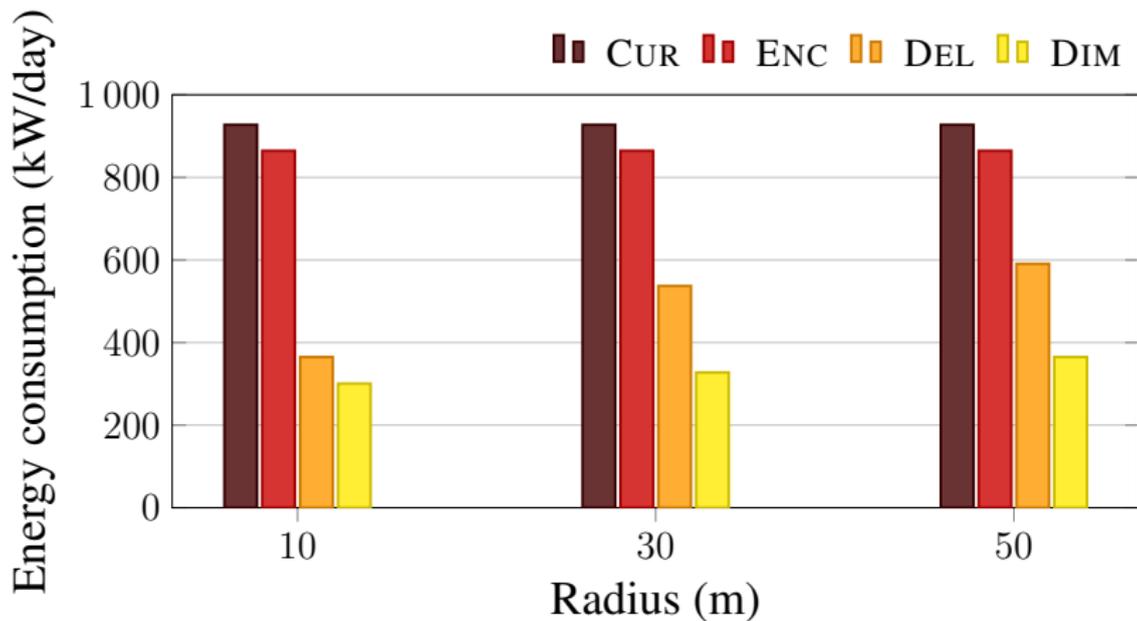


# Evaluation Settings

- ▶ Luxembourg City center
- ▶ Users: 20 000
- ▶ Walking speed:  $\mathcal{U}$  [1 – 1.5] m/s
- ▶ Walking period:  $\mathcal{U}$  [10 – 20] min
- ▶ Simulation period: 9 PM - 7 AM
  
- ▶ 537 Lampposts
- ▶  $R$ : {10, 30, 50} m



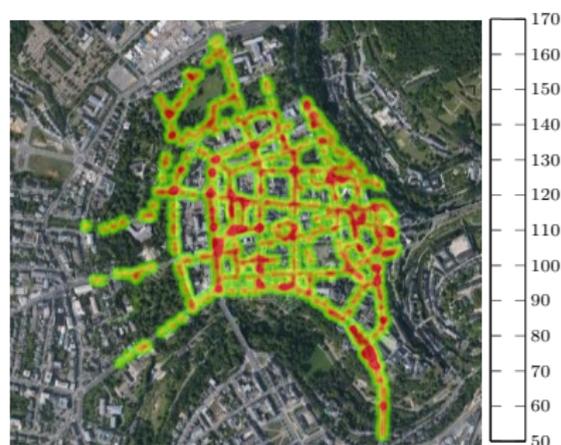
# Energy Comparison of Heuristics



- ▶ DIM significantly outperforms other heuristics
- ▶ ENC already improves current systems

# Heatmap of Energy Consumption

## ► Comparison ENC vs DEL<sup>3</sup>



<sup>3</sup><https://developers.google.com/maps/documentation/javascript/examples/layer-heatmap>

## CrowdSenSim

- ▶ Performance evaluation in large realistic urban environments
  - ▶ MCS systems for S<sup>2</sup>aaS applications in smart cities
    - ▶ Framework for cost effective data collection
    - ▶ Energy efficient user recruitment
    - ▶ Energy efficient public street lighting
- ▶ Custom simulator for crowdsensing activities
  - ▶ Access and download: <http://crowdsensim.gforge.uni.lu>
  - ▶ Contact: [crowdsensim@gmail.com](mailto:crowdsensim@gmail.com)

## Future work

- ▶ HyDACQ: Hybrid Data ACquisition paradigm
- ▶ Smartphone cooperation for sensing and data relaying using D2D
- ▶ More advanced solutions: predicted users' mobility, cluster control

# Publications

1. A. Capponi, C. Fiandrino, C. Franck, U. Sorger, D. Kliazovich, and P. Bouvry, **"Assessing Performance of Internet of Things-Based Mobile Crowdsensing Systems for Sensing as a Service Applications in Smart Cities"**, in IEEE CLOUDCOM, Dec 2016, Luxembourg.
2. C. Fiandrino, A. Capponi, G. Cacciatore, D. Kliazovich, U. Sorger, P. Bouvry, B. Kantarci, F. Granelli and S. Giordano, **"CrowdSenSim: a Simulation Platform for Mobile Crowdsensing in Realistic Urban Environments"**, in IEEE ACCESS, Feb 2017.
3. A. Capponi, C. Fiandrino, D. Kliazovich, P. Bouvry and S. Giordano, **"Energy Efficient Data Collection in Opportunistic Mobile Crowdsensing Architectures for Smart Cities"**, in IEEE INFOCOM WKSHPS on Smart Cities and Urban Computing (SmartCity), May 2017, Atlanta, GA, USA.
4. A. Capponi, C. Fiandrino, D. Kliazovich, P. Bouvry and S. Giordano, **"A Cost-Effective Distributed Framework for Data Collection in Cloud-based Mobile Crowd Sensing Architectures"**, in IEEE Transactions on Sustainable Computing, Mar 2017, 2 (1), pp. 3-16. ISSN: 2377-3782, DOI: 10.1109/TSUSC.2017.2666043.
5. C. Fiandrino, F. Anjomshoa, B. Kantarci, D. Kliazovich, P. Bouvry, J. Matthews, **"Sociability-Driven Framework for Data Acquisition in Mobile Crowdsensing over Fog Computing Platforms for Smart Cities,"** in IEEE Transactions on Sustainable Computing, May 2017, doi: 10.1109/TSUSC.2017.2702060.
6. G. Cacciatore, C. Fiandrino, D. Kliazovich, P. Bouvry, and F. Granelli, **"Cost Analysis of Smart Lighting Solutions for Smart Cities"**, in IEEE International Conference on Communications (ICC), May 2017, Paris, France.

A decorative graphic consisting of several overlapping, flowing, light blue and white curved lines that resemble a stylized wave or a fan of feathers. The lines are semi-transparent and have a soft glow, creating a sense of movement and depth. They are positioned on the right side of the slide, partially overlapping the text.

# Thank You!

Andrea Capponi

`<andrea.capponi@uni.lu>`

# Data Collection Utility, $d_s^a$

- ▶ Based on number of samples already received
- ▶ Can be defined as the following sigmoid function:

$$d_s^a = \frac{1}{1 + e^{-\frac{\varphi_s}{\rho_s} \cdot (-\bar{N}_s^a|_t + (1 - \frac{\rho_s}{2}))}}$$

- ▶  $\varphi_s$  and  $(1 - \rho_s/2)$  coefficients control position and the speed of the incline
- ▶  $\bar{N}_s^a|_t$  is the average number of samples generated from sensor  $s$  in area  $a$ :

$$\bar{N}_s^a|_t = \sigma \cdot N_s^a|_t + (1 - \sigma) \cdot \bar{N}_{s-1}^a|_t$$

- ▶  $N_s^a|_t$  corresponds to the number of samples collected from sensor  $s$  in timeslot  $t$  in area  $a$
- ▶  $\bar{N}_{s-1}^a|_t$  is its previous value
- ▶  $\sigma$  is the exponential weighting coefficient

# Smartphone Sensing Potential, $sp_s$

- ▶ Function of locally spent energy  $E_s$  for sensing and reporting
- ▶ Can be defined as the following sigmoid function:

$$sp_s = \frac{1}{1 + e^{-\frac{\zeta_s}{\theta_s} \cdot (-E_s + (1 - \frac{\theta_s}{2}))}}$$

- ▶  $1 - \theta_s/2$  and  $\zeta_s$  control position of the center and speed of the incline
- ▶  $E_s$  is the energy spent attributed to sensing ( $E_s^c$ ) and reporting ( $E_s^r$ ):

$$E_s = E_s^c + E_s^r$$

- ▶  $E_s^r$  depends on the employed communication technology (LTE or WiFi)
- ▶  $E_s^c = \bar{E}_s^c \cdot U_s$
- ▶ Utilization context  $U_s$  is defined as:

$$U_s = \begin{cases} 0, & \text{if the sensor } s \text{ is used by another application} \\ 1, & \text{otherwise} \end{cases}$$

# Threshold $\delta$

- ▶ Depends on the *Level of battery* of the devices ( $B$ ) and the *Amount of reported data* that devices have already contributed ( $D$ )

- ▶ Defined as:

$$\delta = f(\delta_b, \delta_d) = (\delta_b + \delta_d)/2$$

- ▶ Level of battery:

$$\delta_b = \alpha^{\lambda \cdot B}$$

- ▶  $\alpha$  can assume arbitrary real values between  $[0, 1]$  ( $\alpha = 0.7$ )
  - ▶  $\lambda > 1$  ( $\lambda = 10$ )
- ▶ Amount of reported data:

$$\delta_d = \begin{cases} 1, & \text{if } D \geq D_{\max} \\ \log\left(1 + \frac{D}{D_{\max}}\right), & \text{otherwise} \end{cases}$$

$$D = \sum_{s \in S} D_s^W + D_s^L$$

# Evaluation Settings

- ▶ FXOS8700CQ 3-axis linear accelerometer from Freescale Semiconductor
- ▶ BMP280 from Bosch for temperature and pressure
- ▶ Energy cost related to communication  $E_s^r$  depends on WiFi

$$E_s^r = \int_0^{\tau_{tx}} P_{tx}^W dt$$

$$P_{tx}^W = \rho_{id} + \rho_{tx} \cdot \tau_{tx} + \gamma_{xg} \cdot \lambda_g$$

SENSOR	PARAMETER	VALUE	UNIT
Accelerometer	Sample rate	50	Hz
	Sample size	12	Bits
	Current	35	$\mu A$
Temperature	Sample rate	182	Hz
	Sample size	16	Bits
	Current	182	$\mu A$
	Current	182	$\mu A$
Pressure	Sample rate	157	Hz
	Sample size	16	Bits
	Current	423.9	$\mu A$

(a) Sensor Equipment

SYMBOL	VALUE	UNIT	DESCRIPTION
$\rho_{id}$	3.68	W	Power in idle mode
$\rho_{tx}$	0.37	W	Transmission power
$\rho_{rx}$	0.31	W	Reception power
$\lambda_g$	1000	fps	Rate of generation of packets
$\gamma_{xg}$	$0.11 \cdot 10^{-3}$	J	Energy cost to elaborate a generated packet

(b) Communication Equipment

# Ostermalm Traces

