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On the Use of Mobile Sensors for Estimating City-Wide Pollution Levels

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IWCMC
August 2015

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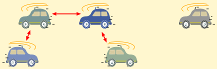

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Institutions

- Université de Technologie de Compiègne
  ~4500 students, master degree (engineer diploma), PhD
  http://www.utc.fr
  - One of the first French engineering school for computer science
  - Close to Paris and Charles de Gaulle airport

- Heudiasyc lab from the UTC & CNRS
  http://www.hds.utc.fr
  Equipex Robotex, Labex MS2T

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Approach

- Point of view
  - Dynamic networks are different!
- Methodology
  1. Real applications
  2. Designing new algorithms
  3. Proof of concept — Road tests

     Performances issues — Tests or network emulation

     Analytic proofs — Distributed algorithms
- Tools
  - Airplug Software Distribution
  - Communicating embedded disposals
  - On-Board-Units, Road-Side-Units in Compiègne

https://www.hds.utc.fr/airplug

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Projects

- Cooperative Mobility for Services of the Future
  European Celtic Plus project 2013-2015
- Inter-vehicles cooperative perception for road safety
  National project 2008-2011
- Distributed system for vehicle dynamic evaluation
  Regional project 2008-2011
- Data gathering from VANET to infrastructure
  Industrial project Orange lab 2008-2010
- Distributed applications for dynamic networks
  Regional project 2007-2010
- SafeSPOT European IP project 2006-2010
- Network services for com. between mobiles objects
  Industrial project Orange lab 2004-2008
- Road anticipating Regional project 2004-2007

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Contributions

- Experiments with dist. data fusion [VNC 2014]
- Experiments with sensors [WiSARN 2014]
- I2V experiments [ITSC 2014]
- V2I experiments [IWCMC 2014]
- V2V unicast communication [WCNC 2014]
- Distributed data fusion [SSS 2012]
- Data collection on the road [IV 2012]
- Performances in a convoy of vehicles [VTC 2011]
- V2I architecture [Mobiwac 2010]
- Distributed dynamic group service [SPAA 2010]
- Vehicular networks emulation [ICCCN 2010]
- Simulation of vehicular networks [VTC 2010]
- Experimenting on the road [VTC 2009]
- Messages forwarding [IEEE TVT 2007]

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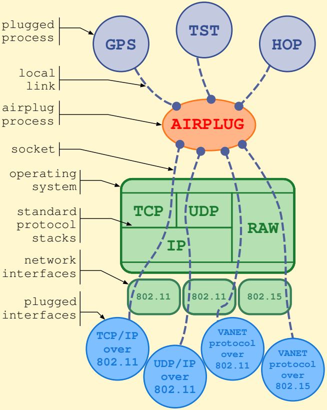
Airplug framework 1/2



- POSIX OS
- Core program
  - user-space process
  - networking
- Applications
  - user-space process
  - read on stdin
  - write on stdout
  - API close to IEEE WSMP
- Ensure tasks and OS independence for robustness
- Open to any programming language

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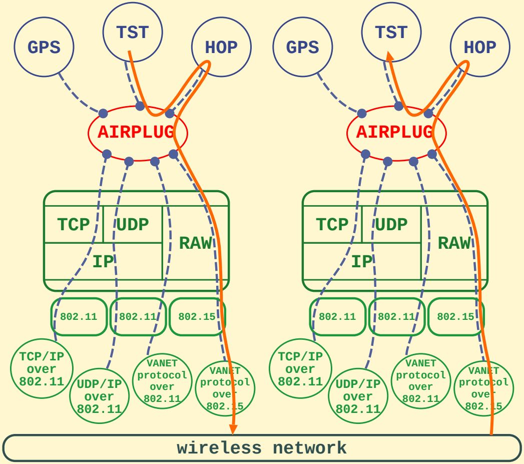
Airplug framework 2/2

- New protocols developed in user space processes
  - Open to new networking solutions
  - Cross-layer solutions facilitated



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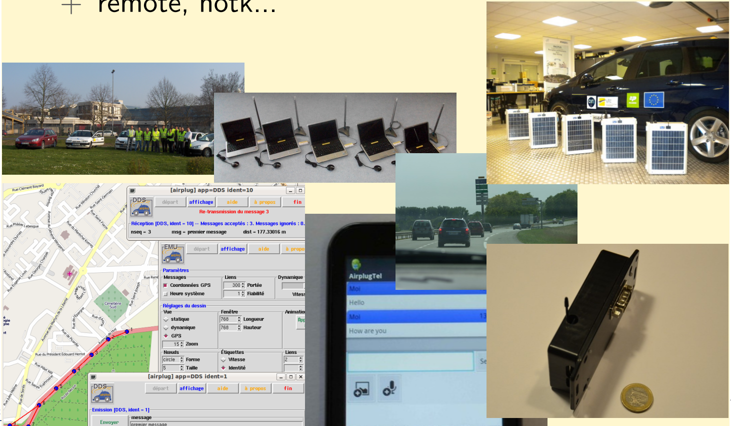
Complete platform

- Airplug-term ⇝ rapid prototyping
- Airplug-emu ⇝ study by emulation
- Airplug-live ⇝ real experiments (vehicles, UAV)

\+ remote, notk...



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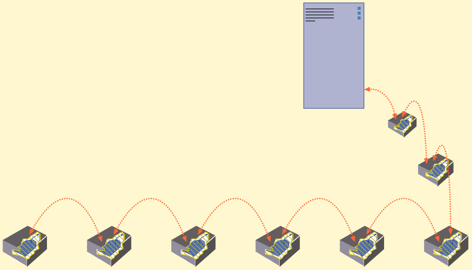
Architecture for sensing

Horizontal architecture



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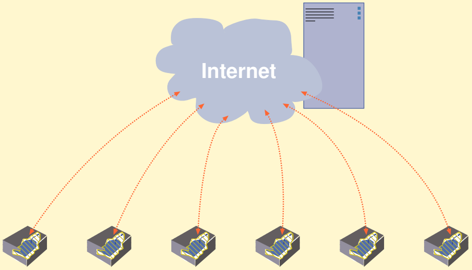
Vertical architecture



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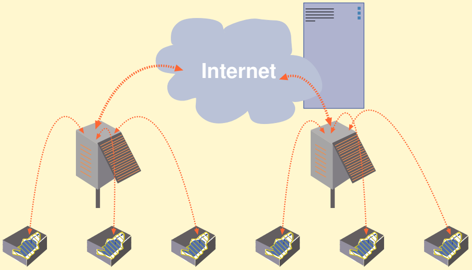
Hierarchic architecture



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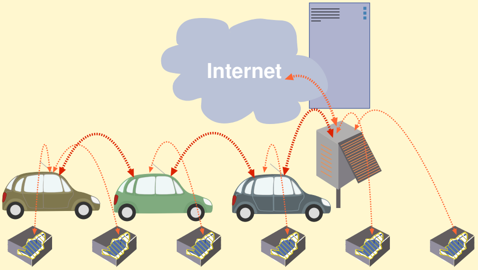
Vehicular architecture 1/2



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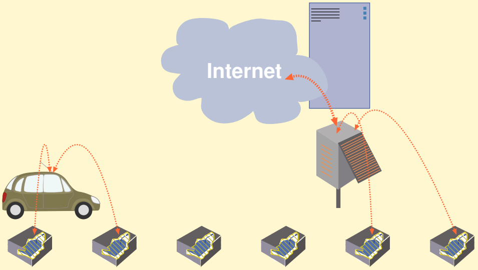
Vehicular architecture 2/2



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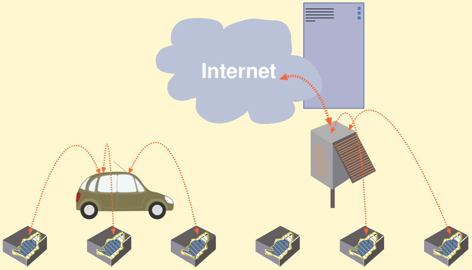
Vehicular architecture 2/2



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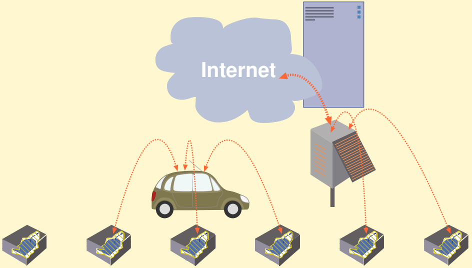
Vehicular architecture 2/2



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Go back

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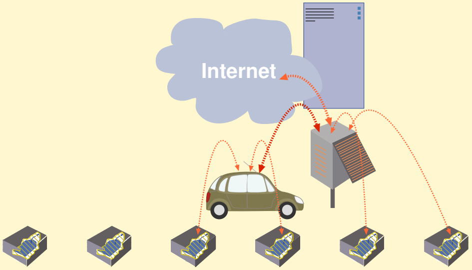
Vehicular architecture 2/2



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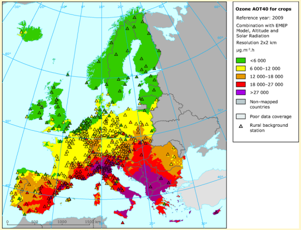
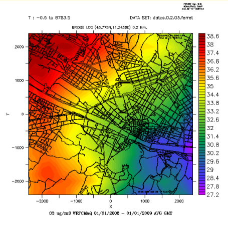
Introduction

Pollution problem

- Context
  - Excessive accumulation of the pollutants can occur in parts of cities
  - Detailed maps help at notifying people
- But
  - Pollution mapping relies on very precise sensors
  - Very high cost $\rightsquigarrow$ limited number
- Mobile cheaper sensors to improve the maps?





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Mobile sensing

Objectives: Ozone case study

- Good ozone
  - In the stratosphere 15 to 50 km above the Earth
  - Protects the life from the sun's harmful UV-b
  - ∼80% of 0_3 but the layer is thin...
- Bad ozone
  - In the troposphere 0 to 15 km above the Earth
  - Air pollutant damaging human health, vegetation...
  - Ground ozone created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) with sunlight
- Consequences
  - Even low level of 0_3 can cause health effect
  - Eg. inflame the lining of the lungs
    Especially children because their lungs are developping

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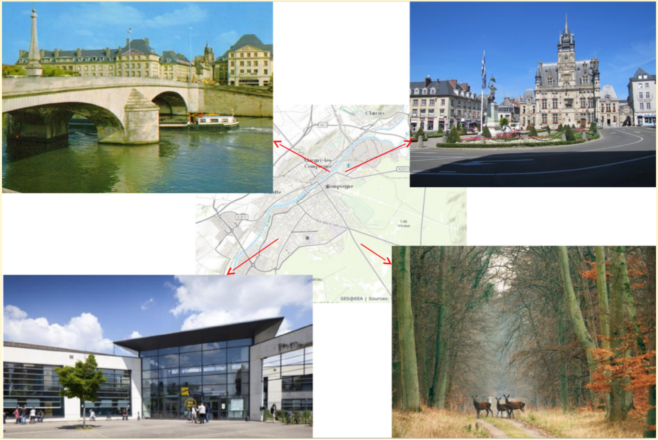
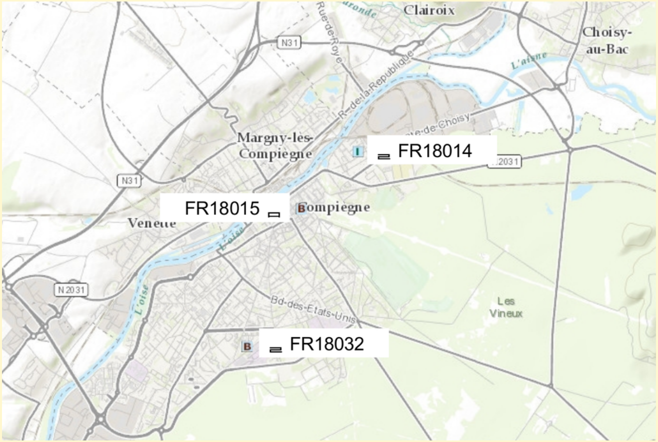
Mobile sensing

Objectives: Compiègne case study



Mobile sensing

Objectives: Compiègne case study



Mobile sensing

Objectives: Compiègne case study

Parameters	Station 1	Station 2	Station 3
station_european_code	FR18014	FR18015	FR18032
station_local_code	FR18014	FR18015	FR18032
country_iso_code	FR	FR	FR
country_name	France	France	France
station_name	A. Thierry COMPIEGNE	Mairie COMPIEGNE	Desbordes Compiegne
station_start_date	01/01/79	01/01/79	05/11/97
station_end_date			
type_of_station	Industrial	Background	Background
station_ozone_classification			urban
station_type_of_area	suburban	urban	suburban
station_subcat_rural_back			
street_type			
station_longitude_deg	2.838.058	2.827.789	2.818.055
station_latitude_deg	49.425.556	49.418.613	49.402.500
station_altitude	35	53	57
station_city			
lau_level1_code	6097	6097	6097
lau_level2_code			
lau_level2_name	Compiègne	Compiègne	Compiègne
EMEP_station	no	no	no
Measured indexes	SO2	SO2	SO2, PM10, O3, NO2, NOX, NO

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Mobile sensing

Objectives: summary and methodology

- Objectives
  - Comparing static and mobile sensing
  - To estimate the pollutant levels in a RoI
  - while varying the number of samples
  - and taking sensor errors into account.
- Methodology
  1. Reference map
  2. Extrapolating measures to compute a map
  3. Comparing the reference and the computed maps

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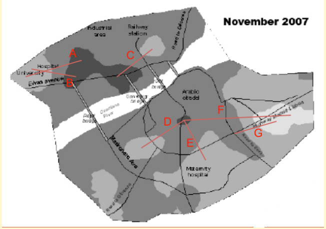
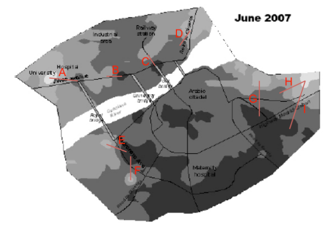
Methodology

Reference map 1/2

- Adapting spatial patterns from city of Badajoz [Moral-García et al. 2010]
- Using the June map
  - Appears to be more difficult to estimate
  - $f(x) = ae^{-\frac{1}{2}\left(\frac{x-x_0}{\sigma}\right)^2} + d$
  - Determining the parameters



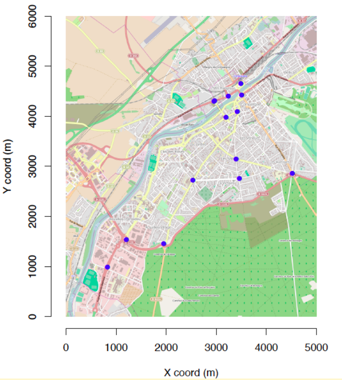


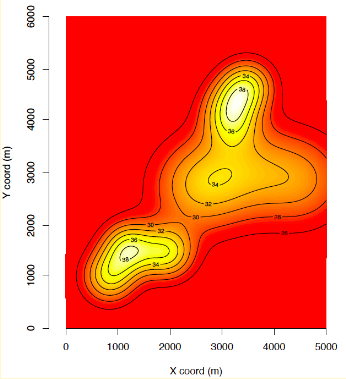
Methodology

Reference map 2/2

- Extending the function to two dimensions
- Determining hot spots

⤳ Reference map for Compiègne





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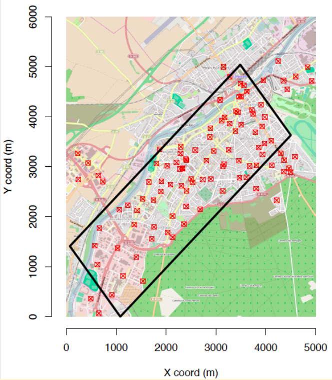
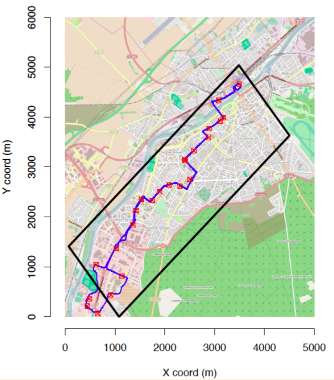
Methodology

Region of Interest (RoI)

- All bus stops
- Line 5 bus stops
- Line 5 route





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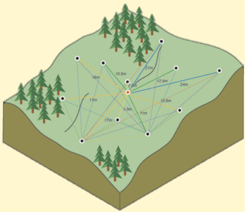
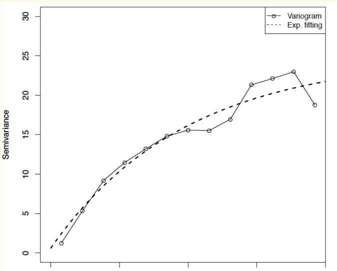
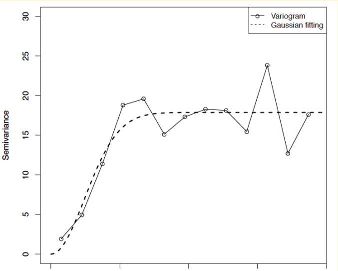
Methodology

Extrapolating the measures

- Extrapolating the measures to compute the map $\rightsquigarrow$ kriging
- Require to estimate the co-variance
  Mean variation as the distance from a sample increases
- Depends on the samples set
  All bus stops vs. line 5







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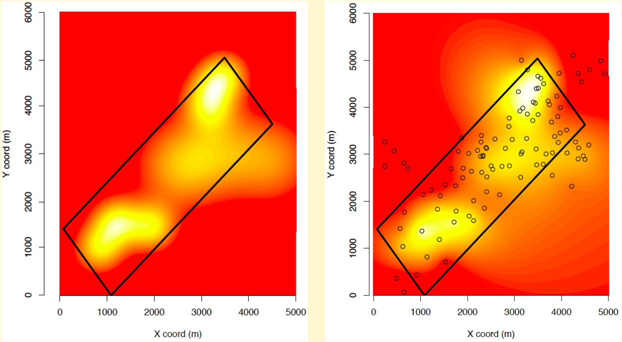
Results

Reference map vs. computed map 1/3

- Using all bus stops:
  average value of the relative absolute error = 1.87%



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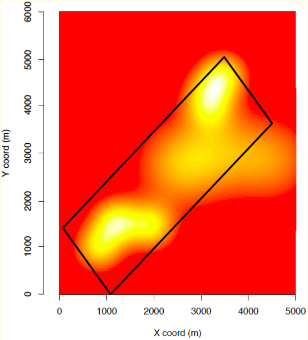
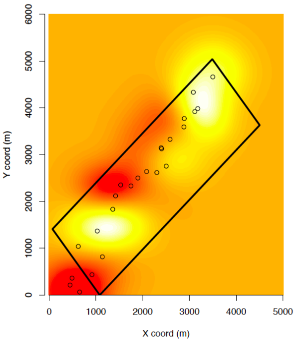
Results

Reference map vs. computed map 2/3

- Using only bus stops of Line 5
  average value of the relative absolute error = 5.33% (in the RoI)

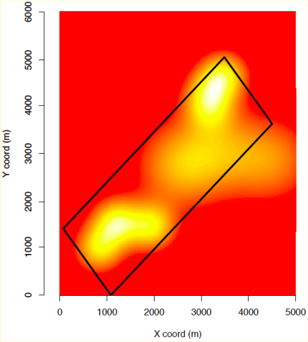


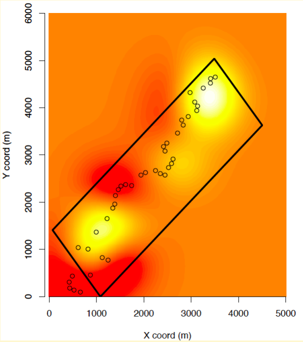


Results

Reference map vs. computed map 3/3

- Using the measures on the moving bus: average value of the relative absolute error = 2.27% in the Region Of Interest





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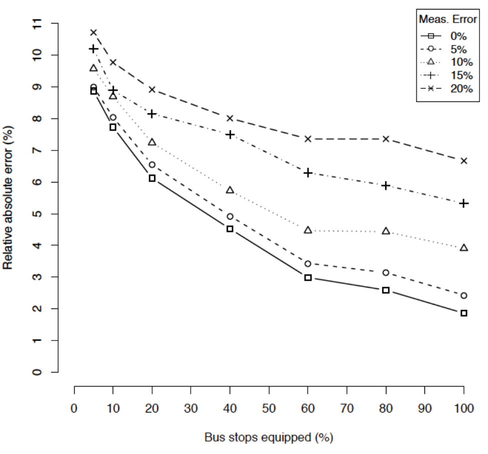
Results

Robustness against errors 1/2

- All bus stops
  - Measure errors up to 5% $\rightsquigarrow$ minimal impact
  - Only 60% of bus stops $\rightsquigarrow$ minimal impact



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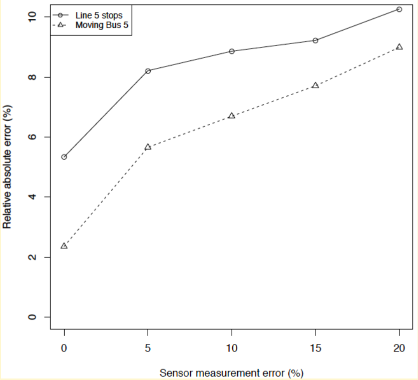
Robustness against errors 2/2

- Line 5 bus stops
  - Measure errors has a greater impact (linear)
- Moving sensor on the Bus 5
  - Less impact with the moving sensor
  - Measure error of 10% $\rightsquigarrow$ result error of 6.7%



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Conclusion

- Problem
  - Detailed pollutant maps are mostly unavailable
  - What about using cheaper less precise but mobile sensors instead?
- Method
  - Generating a reference map
  - Pick up some exact measures
    All bus stations / Line 5 only / Bus 5 only
  - Extrapolating using kriging
  - Measuring errors
- Results
  - A single equipped bus:
    - $\sim$ 40% of all bus stations
    - 2% better than only Line 5 stations
- Mobile sensing
  - Promizing
  - Still many things to confirm