Internet of Things

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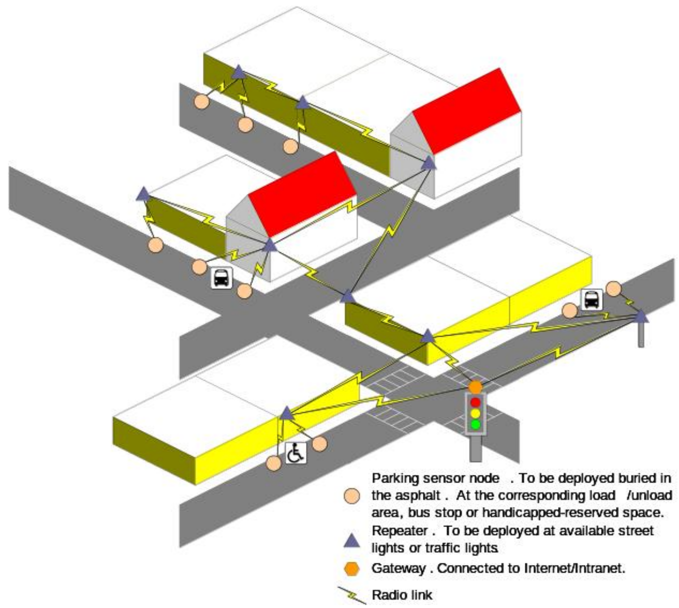
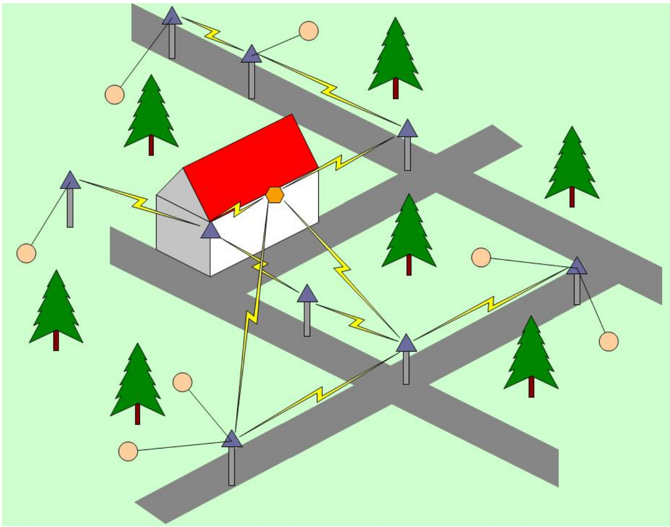
Lecture 17:
Participatory Sensing

- City-scale IoT deployment.
- 18,000 sensing points.
- Outdoor deployments, Mobile nodes, Human interaction.
- Real City Services – Continuous operation.
- Large variety of sensors – Large data.
- Business models and sustainable exploitation combining research & service support.





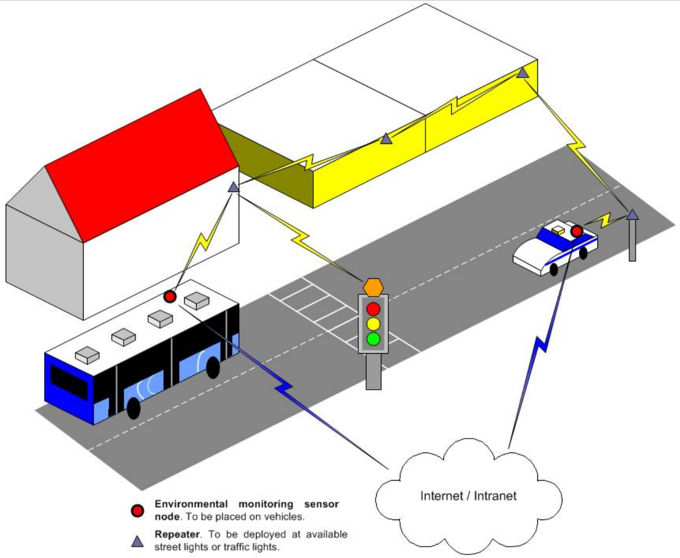
Park irrigation monitoring sensor. To be deployed buried in the ground.

Repeater. To be deployed at available street lights or traffic lights.

Gateway. Connected to Internet/Intranet.

Radio link

Wired link



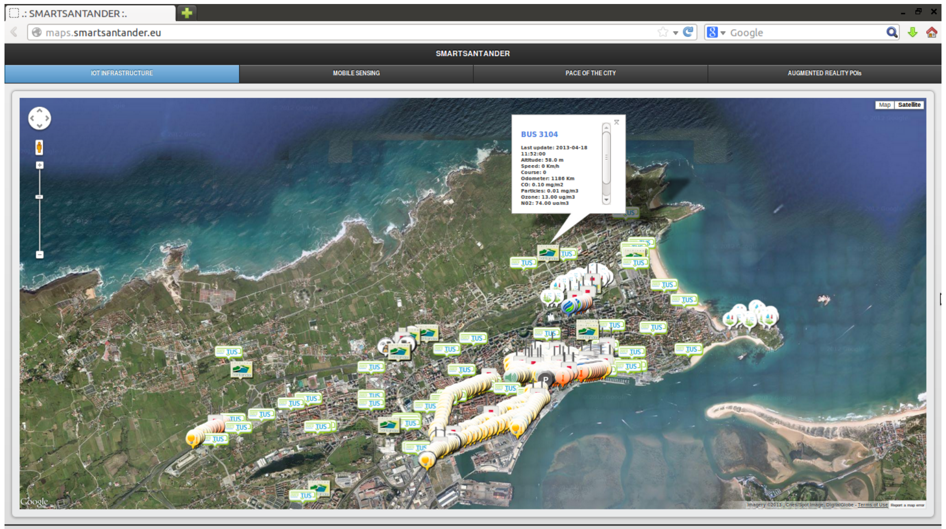
Environmental monitoring sensor node. To be placed on vehicles.

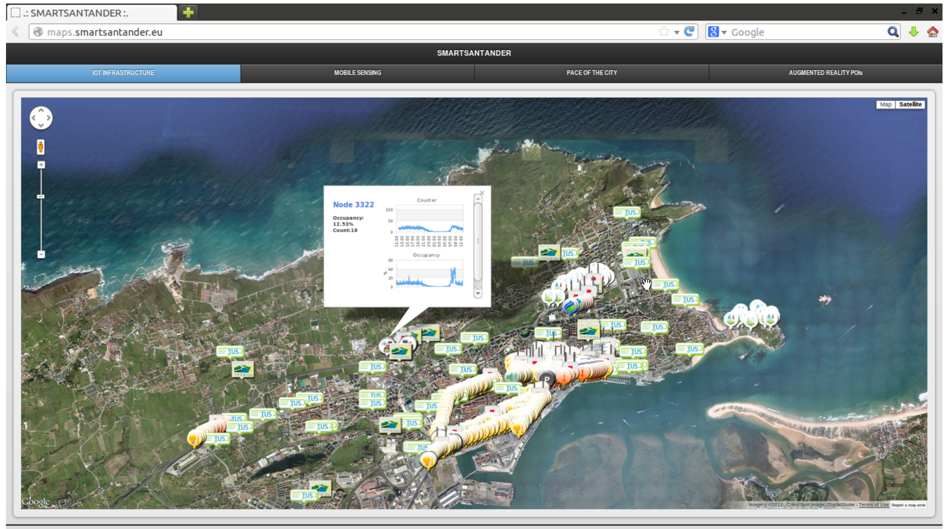
Repeater. To be deployed at available street lights or traffic lights.

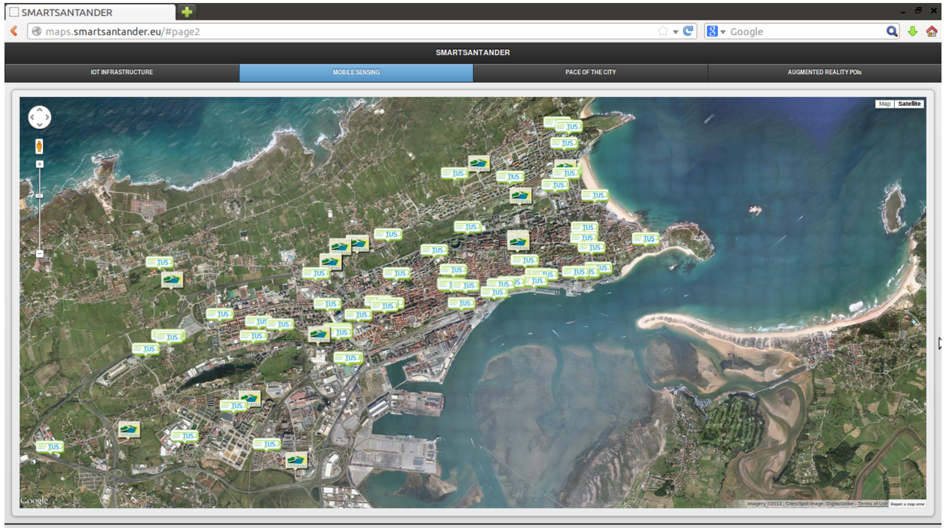
Gateway. Connected to Internet/Intranet.

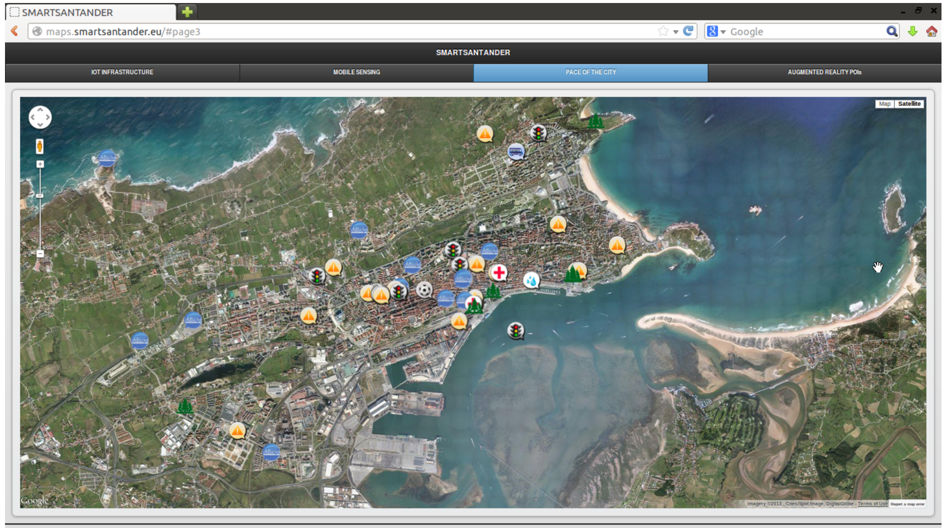
802.15.4 link

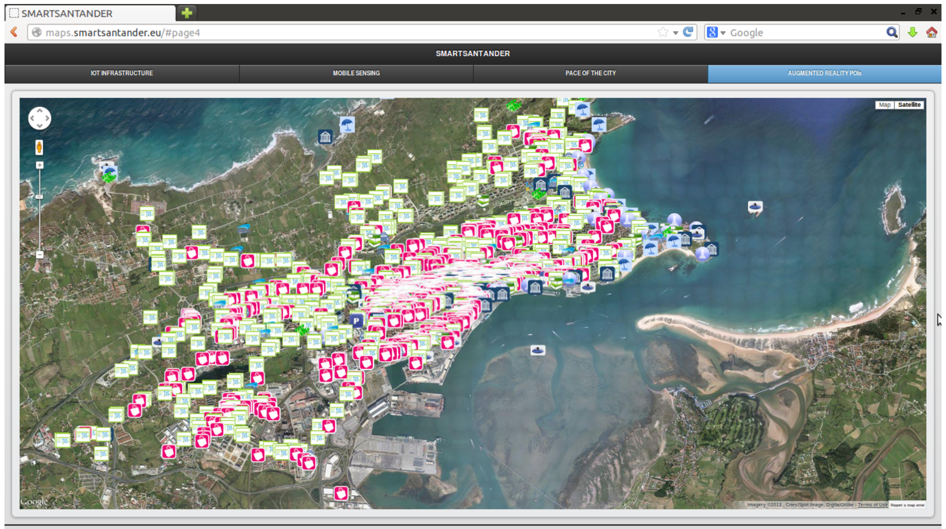
GPRS link











Application Scenaria

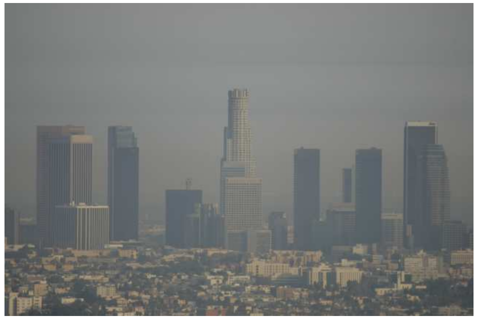
- Integrating the Internet of Things with the Web provides virtually unlimited ideas for new products.
  - A market predicted to generate trillion USD global impact by 2020.

Data gathering: a general problem

- Water: "U.N. has a limited success to get accurate information on water infrastructure and treatment systems".
  - Poor data, weak agencies hamstring U.N. environmental oversight, NY Times, 2009.
- Food: "Agricultural statistics has deteriorated over time" - weak estimation of global rice/wheat productions - fisheries data outdated.
  - Food and Agriculture Organization, Audit 2009.
- Health: "Exposure measures are sometimes completely lacking, frequently incomplete or otherwise uncertain".
  - Uncertainty and Data Quality in Exposure Assessment, World Health Organization, 2008.

An Example: Monitoring Pollution

- Important environmental issues in cities
- (long term) health, social and economic impacts
- An increasing problem, especially in developing countries
- Growing public concern & effort (European Directive -2002)
- but limited success of environmental policies.
- Complexity of monitoring the real exposure of the population.


Los-Angeles


Mumbai

- It is impossible to reach every corner of every neighborhood in the city.
- Even if you choose to do it ...
- We need a secure, reliable infrastructure that enables interconnectivity and scale.
- Building this infrastructure is difficult, expensive and time-consuming.
- Maintenance of such an infrastructure is expensive and requires continuous investements.

Issue #1: People are not exposed to data

- Modeling Emission vs Modeling Exposure
- Location-based Exposure vs Population-based Exposure
- Sparsity of deployments
- Uncertainty of results
- Infrastructure Costs

Issue #2: Peoples' role in pollution management

- Urban pollution is an anthropogenic effect
- No real citizens participation despite international agreements
- Need to involve the people in the loop:
  - to get a better representation of their environmental conditions,
  - to interact in a more direct and powerful way.

Participatory Sensing

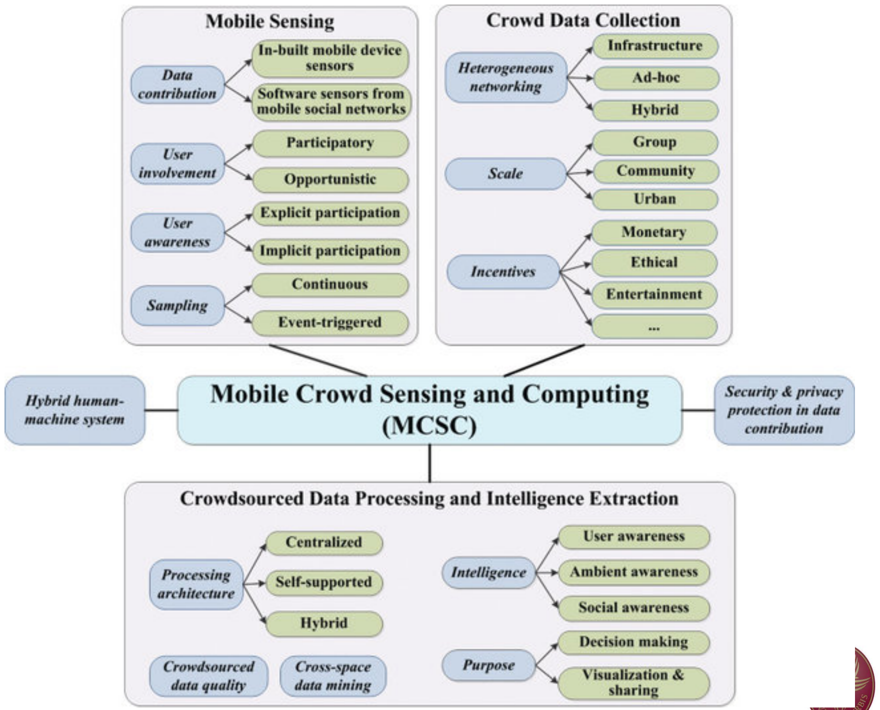
- Individuals and Communities
  - use mobile phones and cloud services,
  - collect data,
  - analyze data.
- Wide range of application scenaria:
  - Health and wellness,
  - Sustainability: transportation, consumption habits,
  - Governance: smart citizens, civic engagement.

The Approach of Participatory Sensing

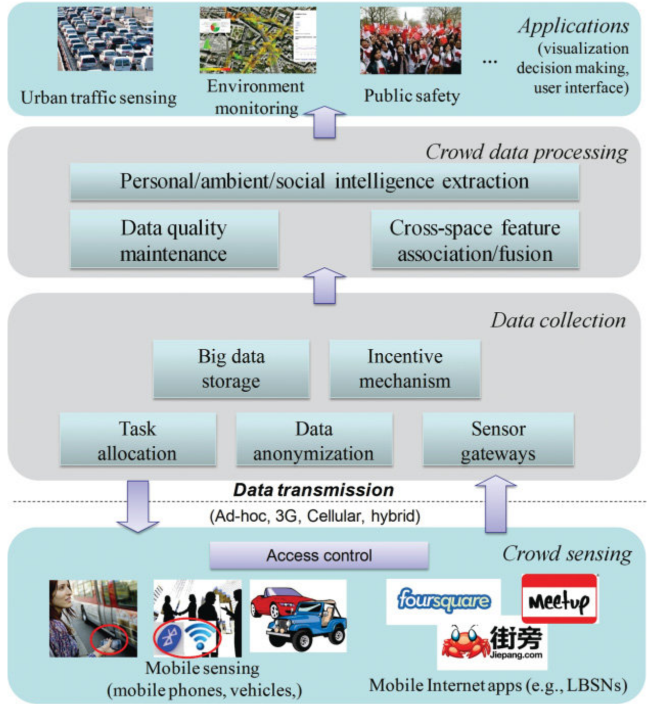
- Access to powerful, rich-sensor mobile devices.
- Use sensors for gathering quantitative information.
- Use people as sensors for gathering qualitative information.
- Synonyms:
  - Mobile Crowdsensing
  - Opportunistic Sensing

Opportunity of Participatory Sensing

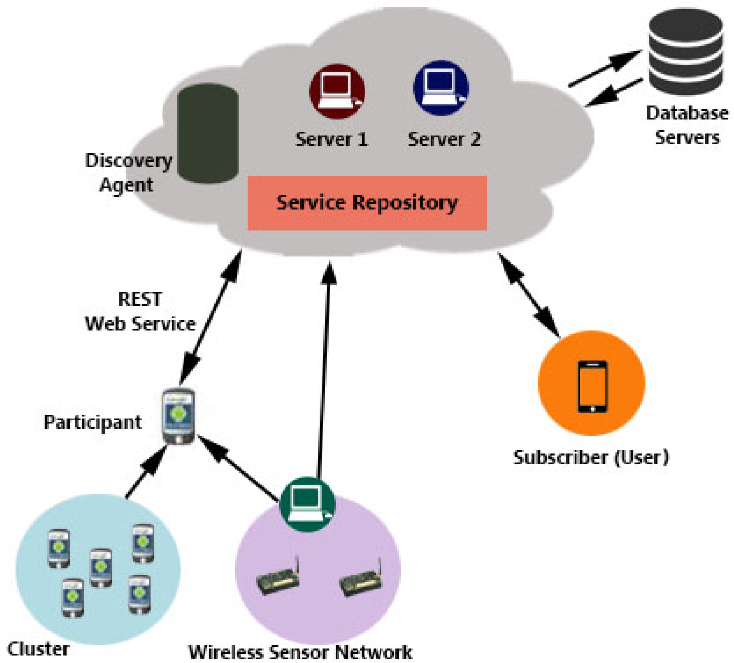
- Growing public concern.
- Cultural shift in digital world (Web 2.0).
- Addresses Issue #1
  - Low cost adaptive sensor network,
  - Collecting fine-grained real data,
  - Supplying real exposure data.
- Addresses Issue #2
  - Citizen empowerment,
  - Citizens in the loop: reporting directly their environmental conditions,
  - Building collective maps of their shared exposure to noise.



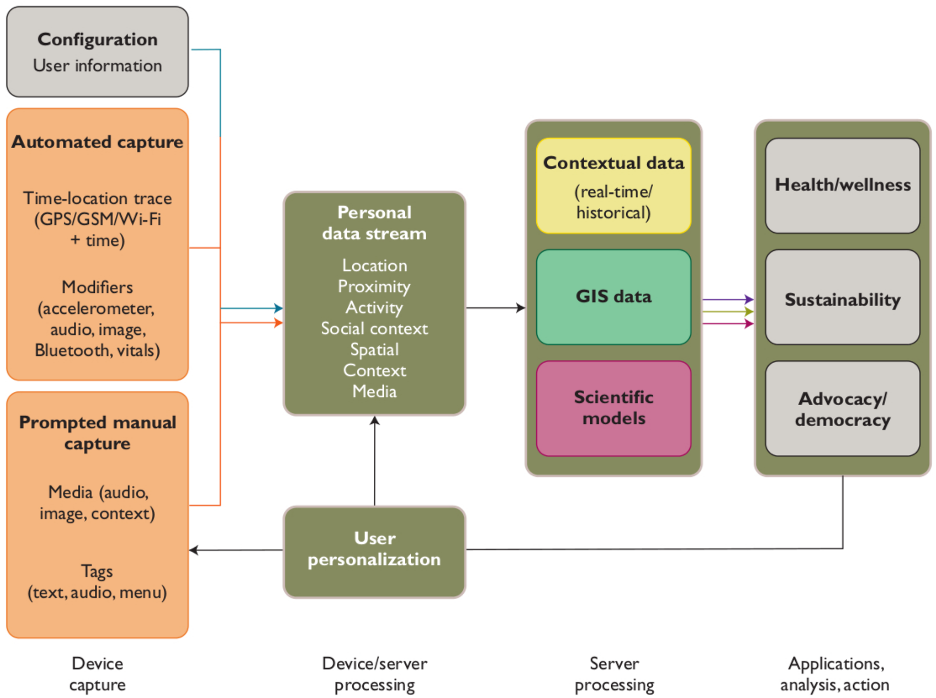
Conceptual Architecture



Network Architecture



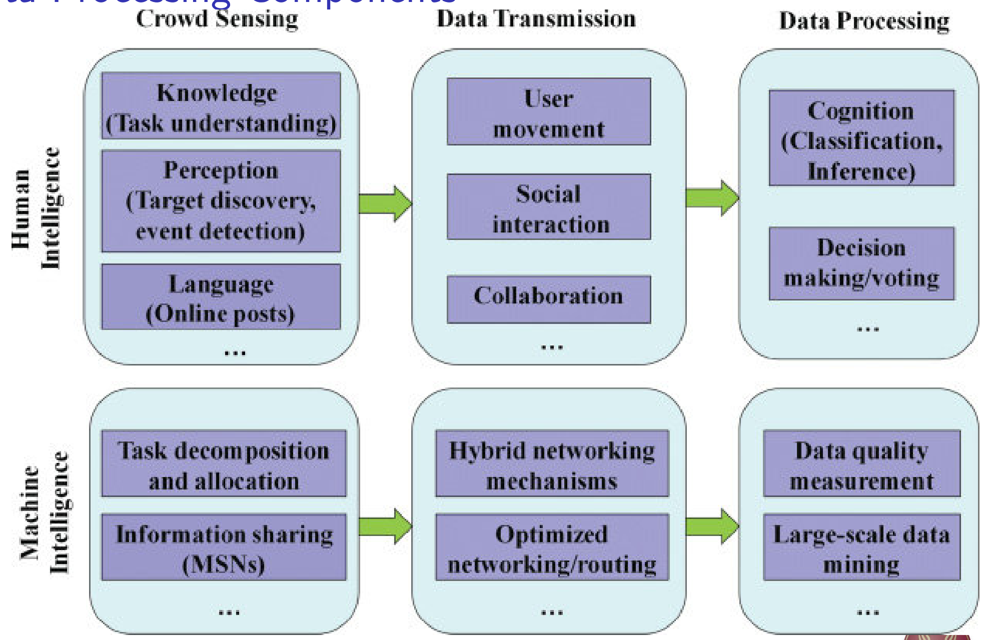
Common Architecture Components



Essential Components

- Ubiquitous Data Capture
  - Mobile phones collect data using sensors (image, audio, video, motion, proximity, location)
  - Context-aware data collection
- Data Processing and Management
  - Local processing at mobile phones
  - Cross-user data sources at cloud
  - Current data vs Historic
  - Simple data can be used to infer complex phenomena about individuals and groups.
- Personal Data Vault
  - Highly individualized, personal nature of data.
  - Protection of user privacy.

Data Processing Components



Noise

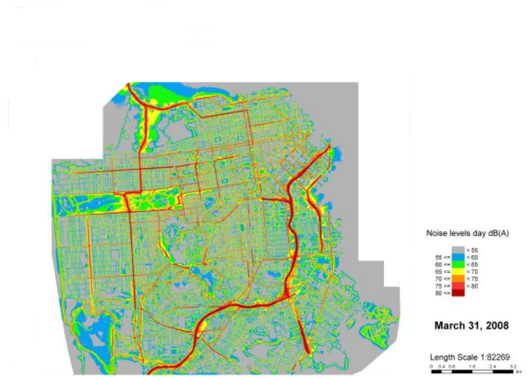
Among the leading causes for illness in urban areas

1. Stress
2. Poor sleep
3. Reduced life quality
4. Increased risk for hypertension
5. Hearing loss
6. Lower cognitive performance

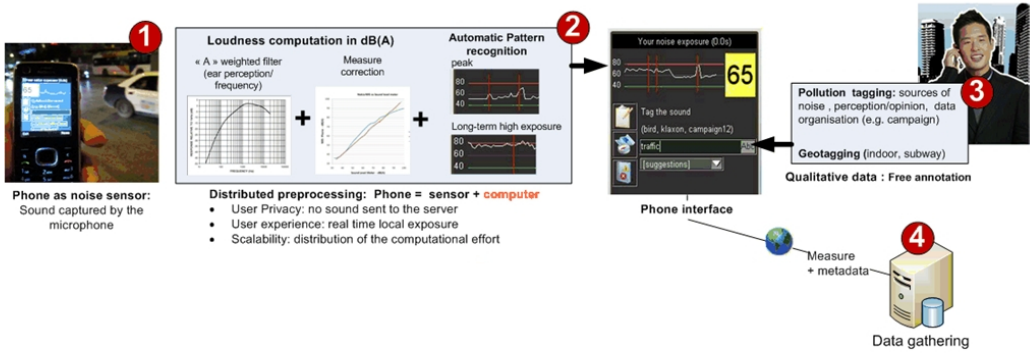
Noise Maps

Governments are using Noise-Exposure-Maps to understand the extend of the Problem.

1. Calculated
2. Missing areas
3. Every few years
4. Selective sources
5. Expensive
6. Commonplace in the EU, less in the US



NoiseTube: Citizen Sensor network for noise pollution



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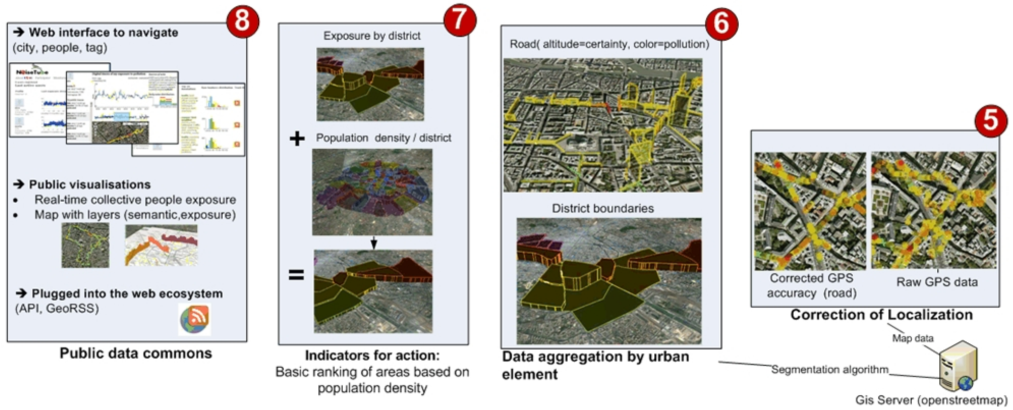
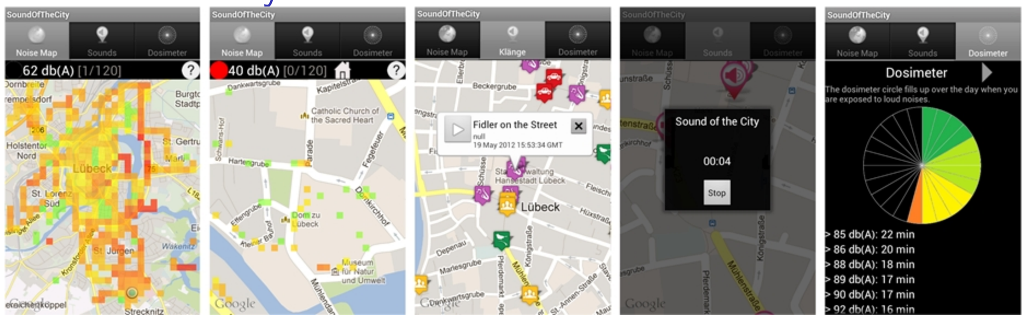
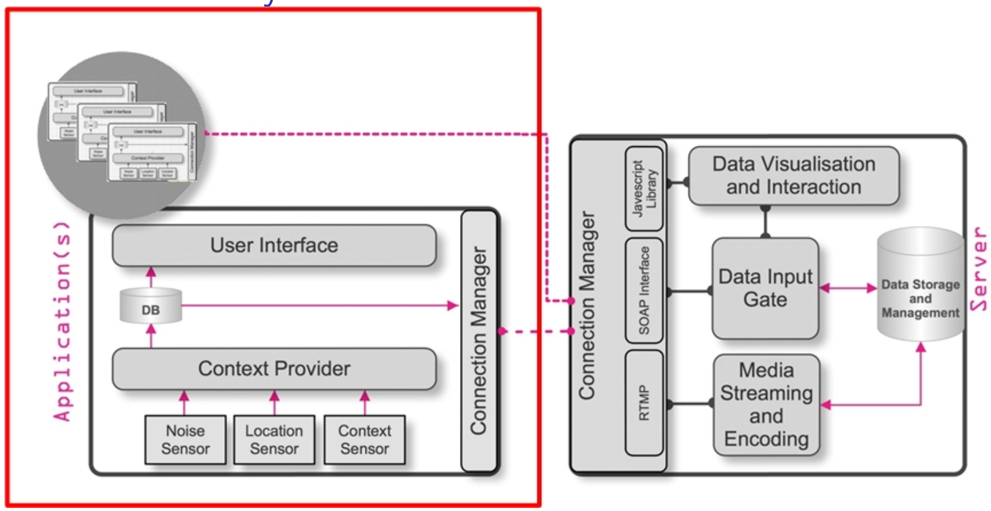


SoundOfTheCity

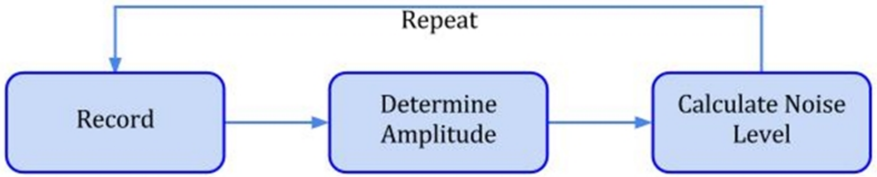


- ▶ Use available technology
- ▶ Involve citizens
- ▶ Collect and publish data
- ▶ Empower citizens

SoundOfTheCity Architecture



Measuring with Mobile Phones

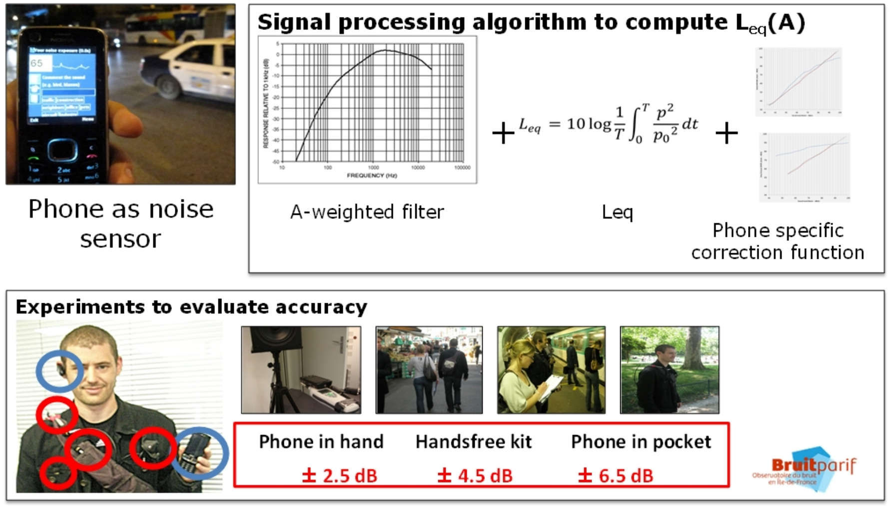


$$\times dBSPL = 20 \log_1 0 \left(\frac{p}{p_0} \right) dBSPL$$

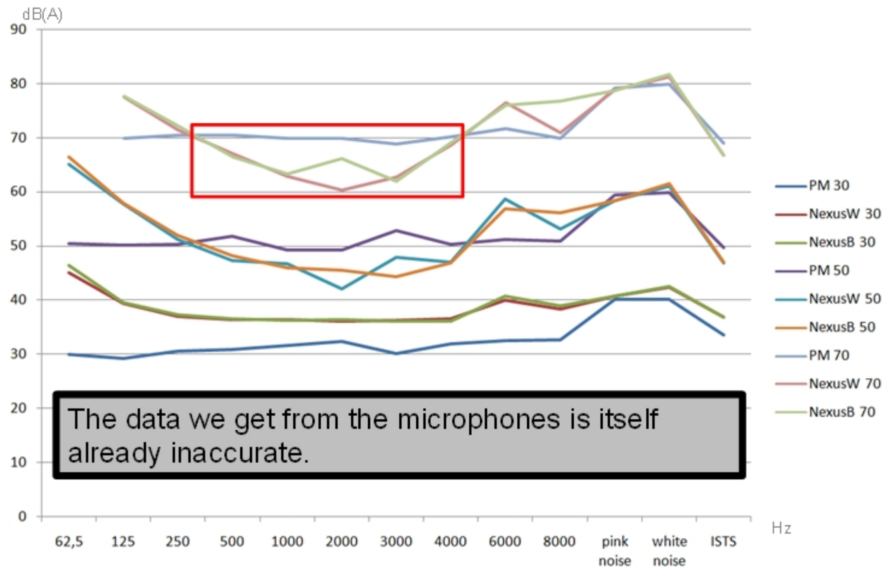
Problems:

- Handling (hands, pockets, bags)
- Protective cases
- Wind

Challenge 1: Accuracy



Mobile Phones Microphones



Context Awareness

- Using context can help reduce the amount of distorted measurements and reduce energy consumption
- Visualize noise that is relevant to the community there are possibilities of exclusion
  - Phone is in the pocket
  - User is indoors
  - User is traveling at high speed
- The measurements are still used to evaluate personal exposure

Context Awareness

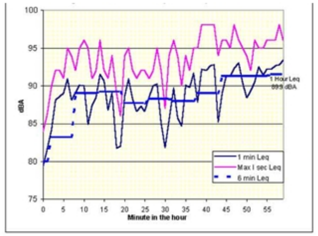
- Is the proximity sensor is evaluating to true (Pocket)
  - Turn off GPS and do not send noise levels
- Wifi is connected (Indoors)
  - Turn off GPS and do not send noise levels
- If GPS-Location has low accuracy (Indoors)
  - Do not send noise levels
- If the user is moving at high speed (cars, trains)
  - Do not send noise levels
- If the phone has not moved for several minutes
  - Do not send noise levels, reduce GPS rate

Challenge 2: Contextualizing environmental data

Why do we need the context?

Add meaning to raw data.

1. Hard to search in numerical datasets for humans.
   - Meaning of 75 dB(A): bad /good?
   - Lat,Lng=2.34, 12.5: which street?
2. Hard to identify the source of pollution with only numerical data.



Measurement done by real sensors

Only measurements,
No semantic information

Simulated map

People as semantic sensors for pollution

- New tagging usage.
- Great idea ...
- but limited (amount of) contextual information

Challenge 3: Visualization

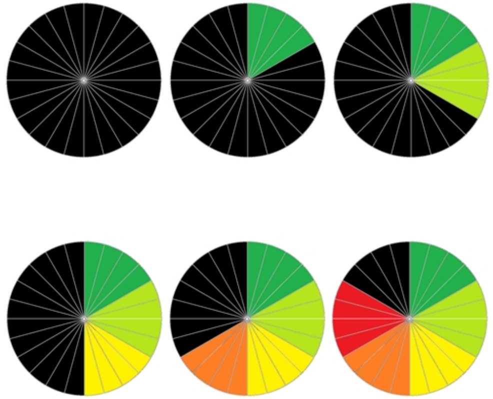
- Exposure layer
- Semantic layer
- Contextual information
- Contribution layer

Challenge 3: Visualization

- Real-time collective exposure
- Google Earth and Web-based

SoundOfTheCity: The Dosimeter

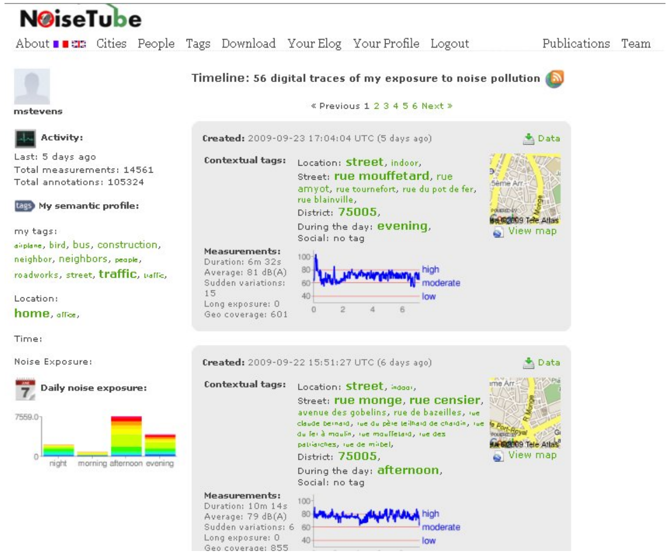
- Measure and visualize how a user is exposed to noise
- Generate personal benefit
- Provide an understanding of the personal exposure
- Provides risk assessment



Challenge 4: Sharing

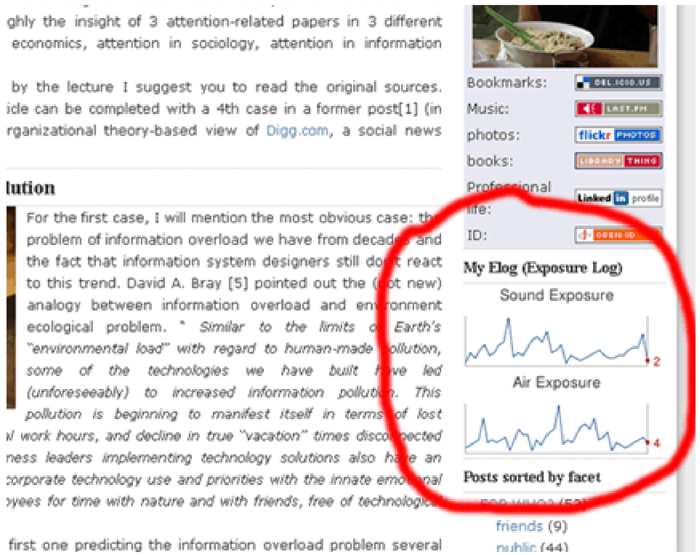
ELog: Environmental log

"See the digital traces of my exposure to pollution"



Challenge 4: Sharing

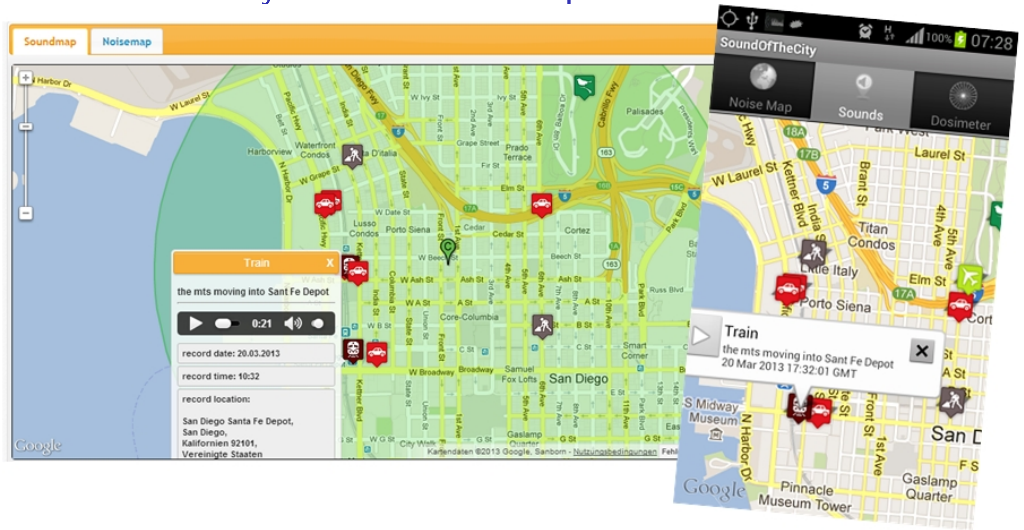
New Grid for personal environmental information: Spreading environmental information through Social Network (Twitter)



SoundOfTheCity: The Sound Map

- The Sound Map provides a dimension that is more easily accessible.
- It allows to capture the experience.
- Creating Records
  - Video
  - Sound
  - Picture
  - Text
- Augment the information conveyed by the sensor data

SoundOfTheCity: The Sound Map



Participatory Sensing in Commerce

Handbook of Economics and Information Systems, 2006

"The empirical evidence for price dispersion in both online and offline markets is sizeable, pervasive and persistent"

Solution: Using Mobile Phones to Track Market Price Dispersion

Participatory Sensing to Track Price Dispersion

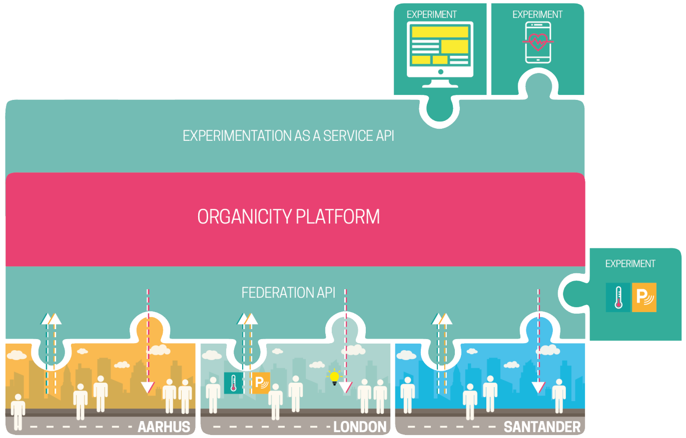
- Harness power of the collective via participatory sensing
- Consumers collect and share pricing information
- Design criteria:
  1. As automated as possible to reduce reluctance in participation
  2. Use camera phones to replace human sensing, processing and communication tasks

Two Applications: MobiShip vs PetrolWatch

- Nearly identical system architectures
- PetrolWatch – camera position important
  - Special computer vision algorithms for extracting fuel price information (on server/camera phone)
  - Use of GPS and GIS to simplify image processing

Large-Scale Participatory Sensing

- Most systems are still developed/tested on a small scale.
- A number of smart city testbeds can be used for suitable experimentation purposes.
- Deploy systems and applications utilising large-scale infrastructure already installed.



OrganiCity Smart City Platform

- Run "experiments" on Smartphones:
  - Virtualization of experiments on volunteers smartphones (deployment, execution, management, data exchange).
  - Transparent execution – Users can simply enable/disable if they wish no further interaction.
  - End-user customization options for privacy.
  - Integration with IoT infrastructure.
- Experimentation with:
  - Integrated smartphone sensors.
  - Interaction with IoT devices/networks/Web (WiFi, Bluetooth, other sensors).

Software technologies used

- OSGi, Ambient Dynamix
  - Android OS platform.
  - OSGi-based plug-and-play context sensing framework.
  - Provides a simple means for apps to request context support.
  - Download/install dynamically plug-ins on demand.
  - Mechanisms for plug-in execution management.
  - Manage access rights to smartphone resources.
- Plug-ins: Small, reusable and collaborative java components.
- Components can be composed into an application and then be automatically deployed.
- Project Plug-in repository on the Web (i.e., not a centralized market place like e.g. Google Play).

The Experimentation Process

Experimenters/Server Side

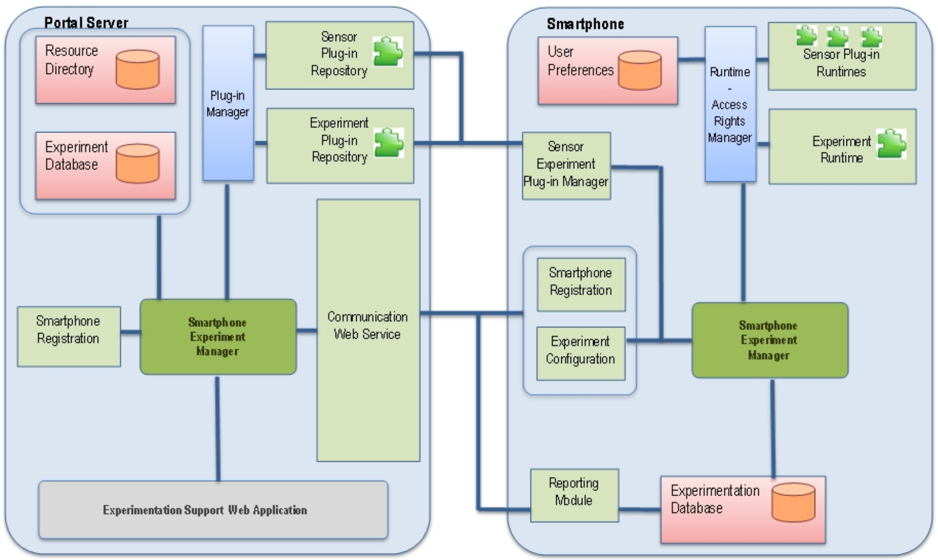
1. Define Campaign Parameters
   - Sensing modules
   - Areas of interest
   - Time of interest
   - Data collection priorities
2. Experimenters submit code written as plugins
3. Code is validated by OrganiCity
4. Available as a plug-in on the project's plug-in repository
5. Readings are available at OrganiCity portal server

The Experimentation Process

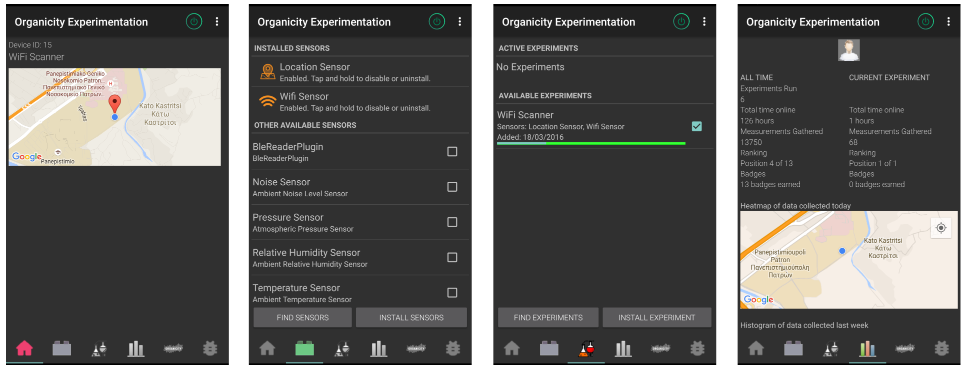
End Users/Smartphones

1. End-users download participatory experimentation application
2. End-user customizations – e.g., which sensors to use for experimentation, when to upload results, etc.
3. Smartphone app registers the device to OrganiCity and downloads an experimentation plug-in
4. Experiment readings are stored on the device and forwarded to OrganiCity server

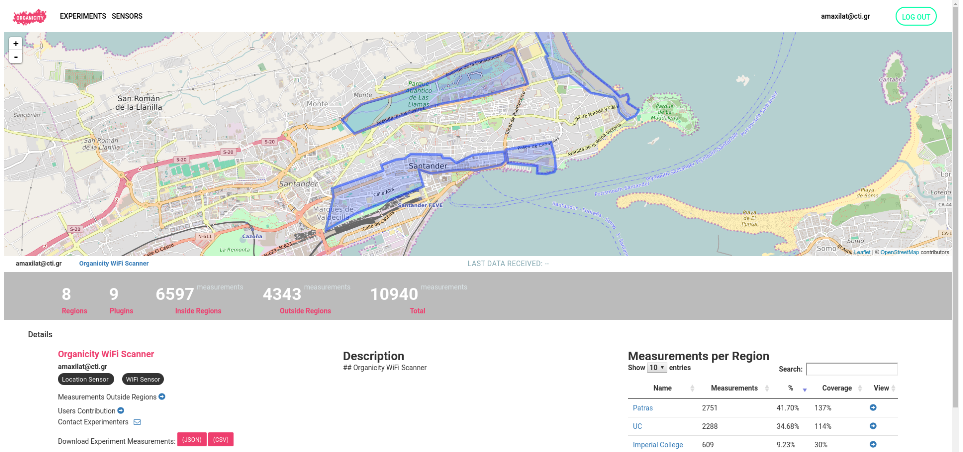
Smartphone Experimentation Components



Smartphone UI



Web Portal



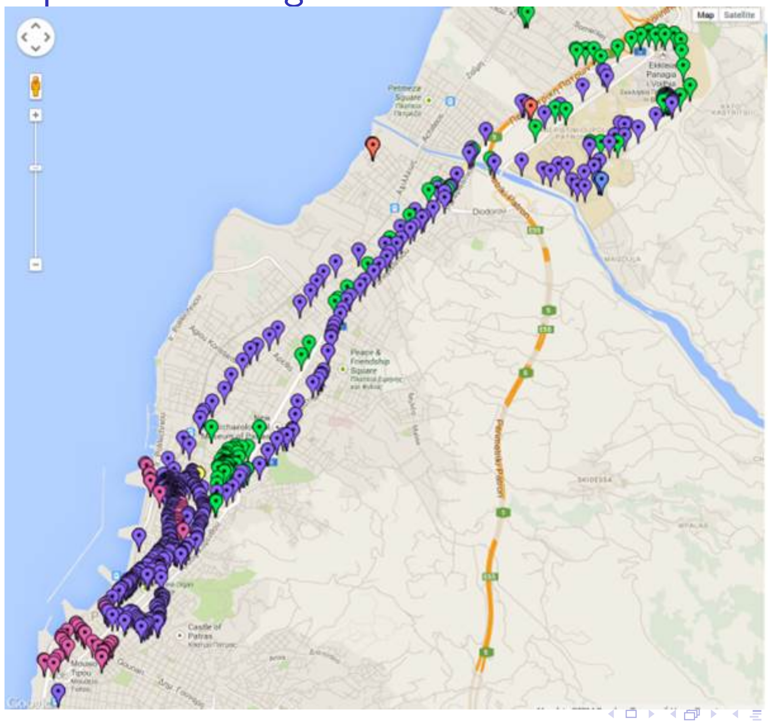
Example: Wardriving

- Pedestrians carry Android smartphones mapping free Wi-Fi networks along the city streets.
- Map of Wi-Fi availability over a city in just a few days.
- 8 users / 2 days, 3 Km^2
- 2878 WiFi networks discovered

Example: Wardriving

- Open source, available at GitHub.
- Implementation tested with a number of different Android devices and volunteers.
- 2 different scenarios.
- 30 volunteers participated in the experiments.
- 7 days duration, 130K readings produced.
- 6.8 Km^2 area covered.
- Tested in 2 cities – Santander (Spain) and Patras (Greece).
- Android versions 2.x, 4.x are supported, majority $> 4.0.3$.

Example: Wardriving



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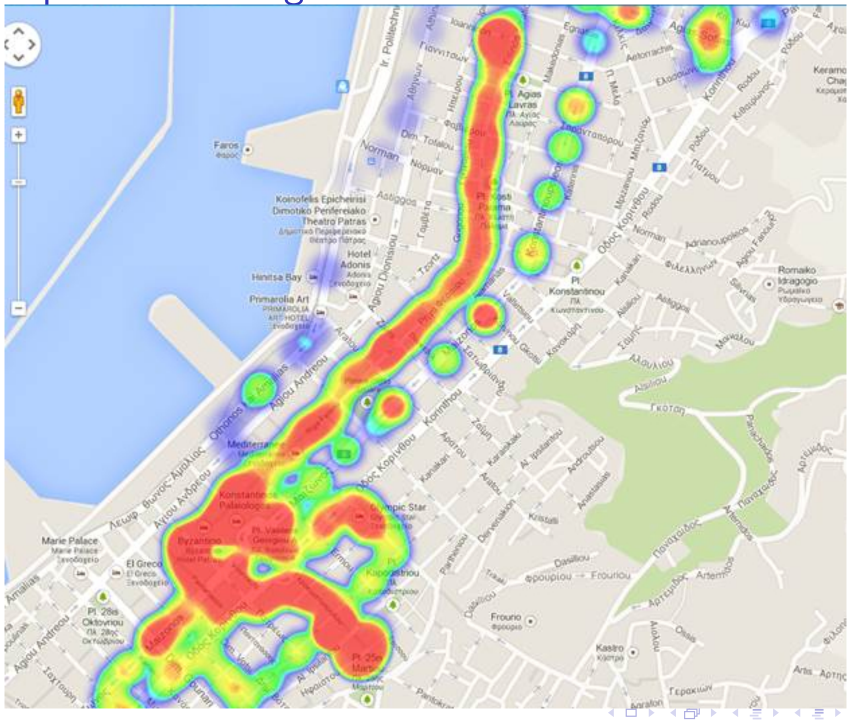
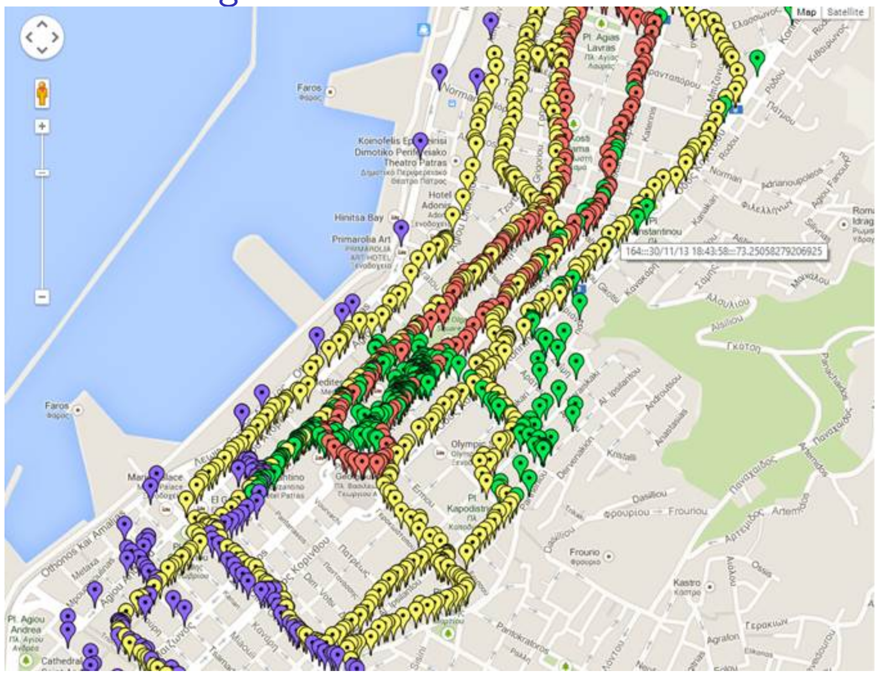


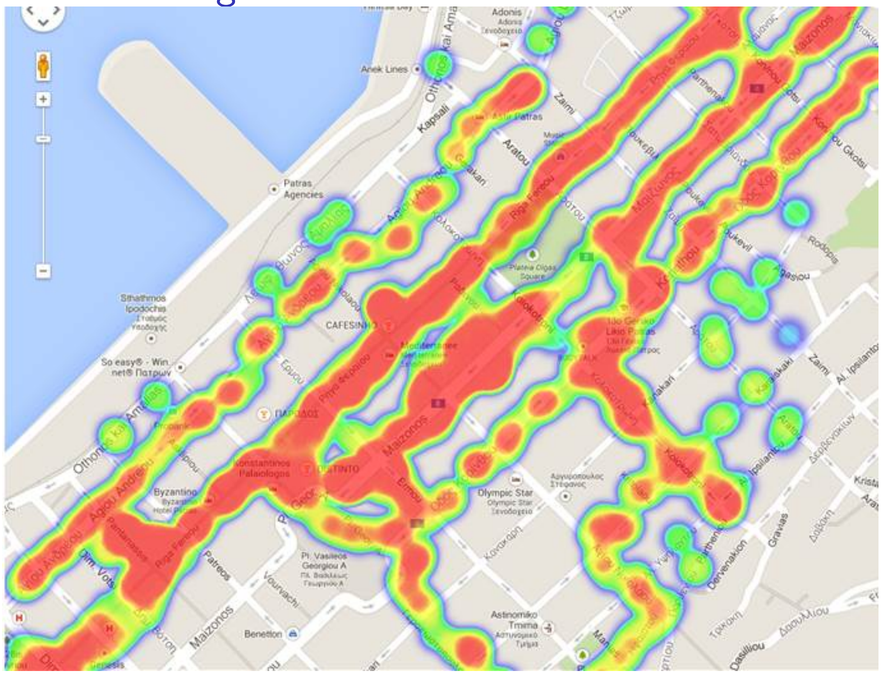
Noise Monitoring

- Detect ambient noise in city centers using smartphone microphone.
- Volunteers carry smartphones monitoring the ambient noise levels the way humans perceive them in their daily lives – 27 users / 5 days, 6.8 Km^2
- 45 IoT nodes equipped with microphones available in Santander - calibrated to return values between 50 and 100 dBA.
- Issues with smartphone mic accuracy, calibration profiles are required.
- Smartphone readings are close to static infrastructure readings (3-6 dBA)
- A 3dBA increase is barely noticeable to humans

Noise Monitoring



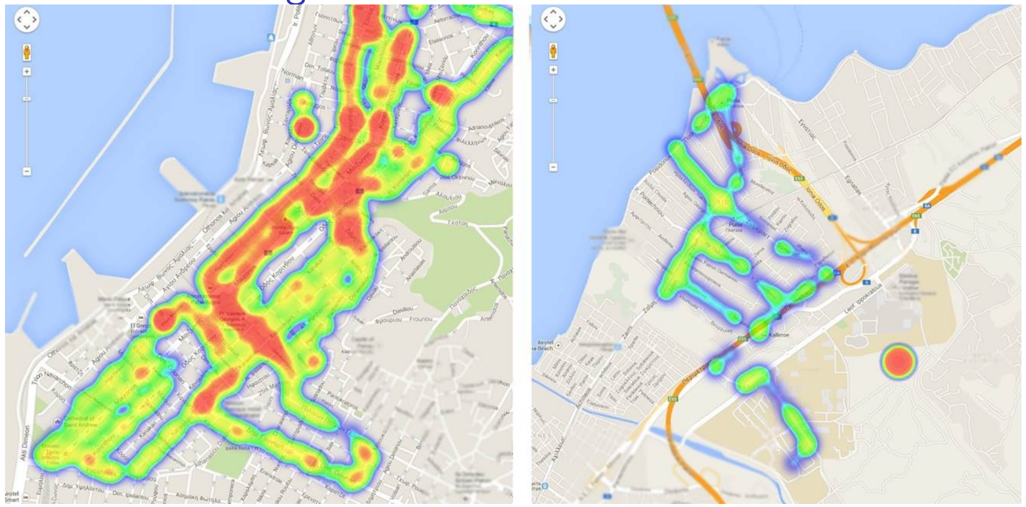
Noise Monitoring



Noise Monitoring

Stationary IoT nodes | Readings 12:00 – 18:00 | Readings 18:00 – 24:00

Noise Monitoring



City center (left) and suburb/campus (right) average noise levels between 18:00-24:00

Discussion - Limitations

- Volunteers in a smartphone experimentation platform can fill in "gaps" that are present in installation areas.
- Plugins implemented with ∼400 lines of Java code.
- There are challenges in integrating smartphones within an IoT sensing infrastructure.
- Tradeoff between the number of experimentation volunteers, their commitment, time to perform the experiment, quality of the results produced.
- Researchers avoid the complexity of developing for an embedded highly specialised platform and instead use popular development tools for smartphone platforms.
- Using such experimentation procedures can lead to creating an abundance of additional data.