COMMUNITY SENSOR NETWORKS:
AN APPLICATION TO POLLUTION MAPS

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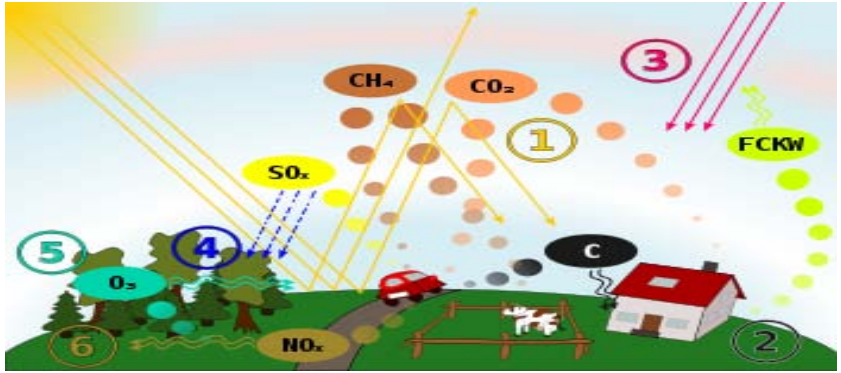
Outline

- Introduction.
- The CSN Architecture.
- The WaspNet System.
- Performance Evaluation
- Conclusion.

What is Air Pollution ?

- Presence of sufficient increases in the concentrations of various ambient pollutants in the air.

- Pollution is a result of the emission of gas, liquid vapor, or solid particulate matter into the atmosphere by human activity.



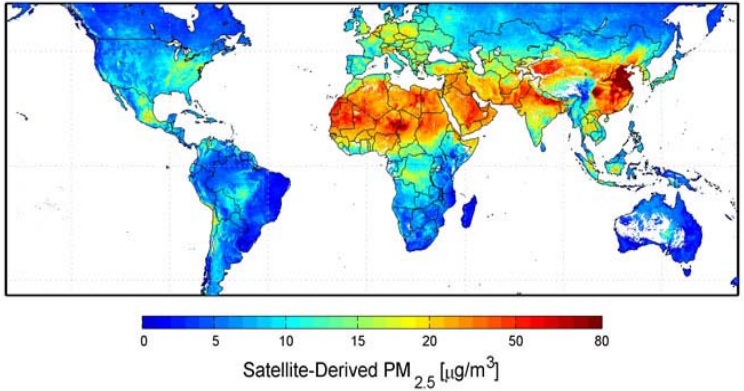
Why Bother About Air Pollution ?

- High concentrations of pollutants may become a threat to both our health , our environment and also limit visibility.

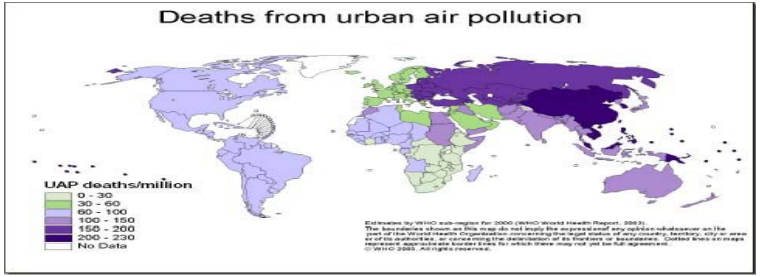
- Some catastrophic pollution episodes include:
  - Donora, Pennsylvania, in October 1948: Thick cloud of air pollution that lasted five days; killing 20 people and causing illness in 6,000 of the town's 14,000 people.
  - London's "Killer Fog" happened in 1952, killing over 3,000 people due to a thick smog creating a problem of visibility.
  - Meuse Valley fog in December 1930: Mysterious fog disaster involving several thousands of cases of illness and 60 deaths caused by acute fluorine intoxication.

Why Bother About Air Pollution ?

- Satellite derived PM map reveals that the north of Africa is among the most polluted parts of the world. However this is the part of the World where air pollution monitoring might be costly or inexistant.



- More recent episodes include
  - "Stop to Traffic" events when pollution in European towns is high blocking visibility.
  - World Health Organization documents on the high % of people dying from air pollution.



Pollution Mitigation

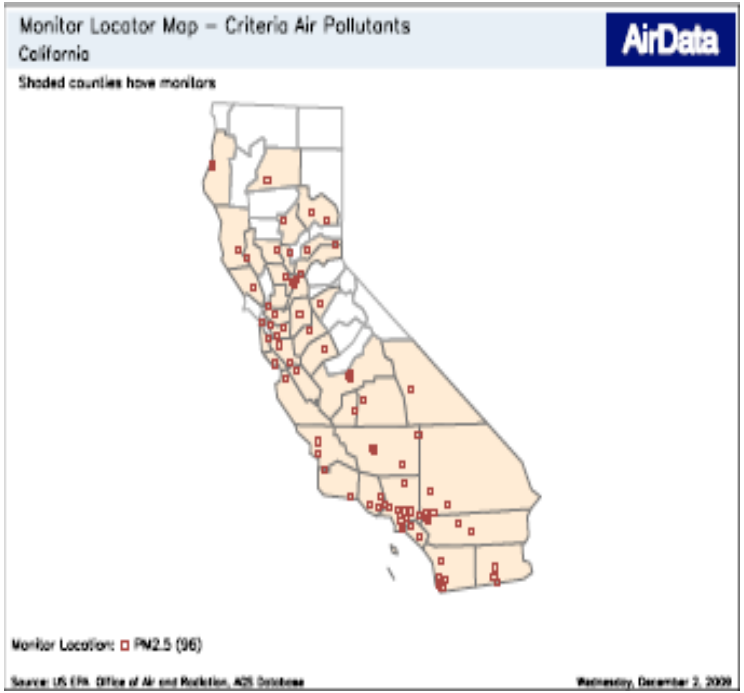
- Use regulations: Clean Air Act and Environmental Protection Agency (EPA) in the USA.
- Setting up of programs and policies.
- Promotion of activities that reduce air pollution.
- Use of cleaner and less polluting technologies to aids mitigation and reduce the levels of pollutants in the air.

Pollution monitoring

- Air pollution Measuring is traditionally performed using fixed monitoring stations measuring Air Quality Index (AQI).
- Though being highly sensitive and well calibrated these stations are
  - Expensive: unaffordable for many developing countries.
  - Figure shows Cape Grim Air Pollution Base station (Australia): complex equipment hosted in a room.

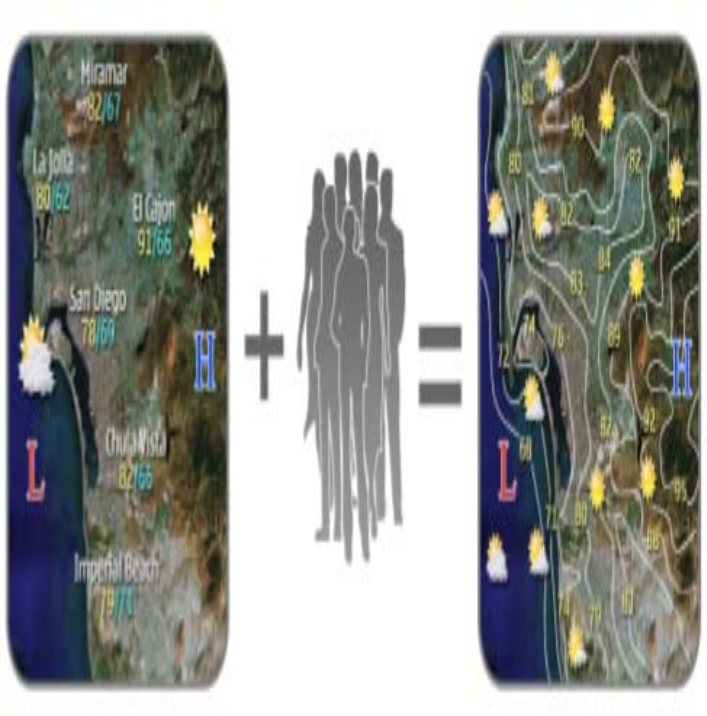
Pollution monitoring

- Air pollution Measuring is traditionally performed using fixed monitoring stations measuring Air Quality Index (AQI) sparsely located at fixed locations by government institutions.
- Despite the efficiency of these professional equipments, their poor deployment coverage raises issues:
  - Visibility gap: poor pollution map resolution.
  - Figure shows sparsely located PM monitoring stations in California



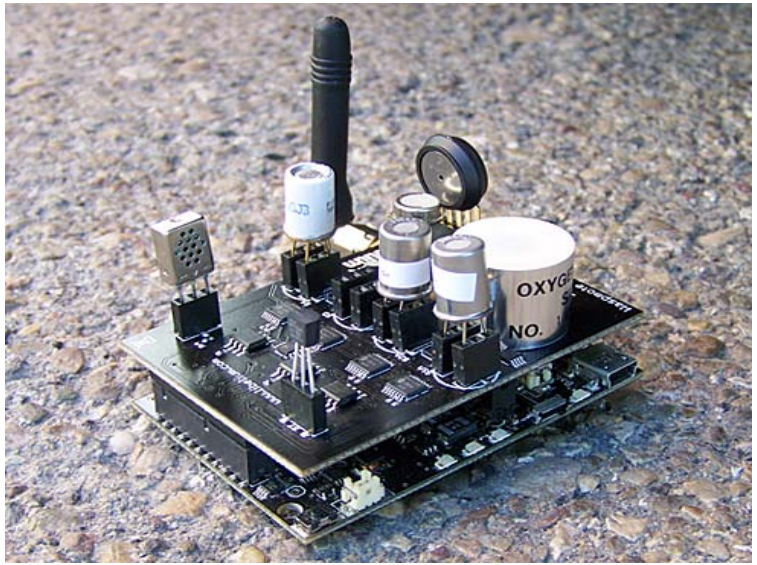
Participatory Sensing

- Bridge the visibility gap: by promoting public participation for better map resolution by taking advantage of the work of data collected from private personal observations of hundreds, or even thousands, of individuals.
- A participatory sensing system is one that starts and ends with people both as individuals and members of communities to allow individuals and communities to collect, share and organize information using cell phones and other mobile platforms, with the objective of making a case for change and exploring and understanding their life and relationship with the environment.



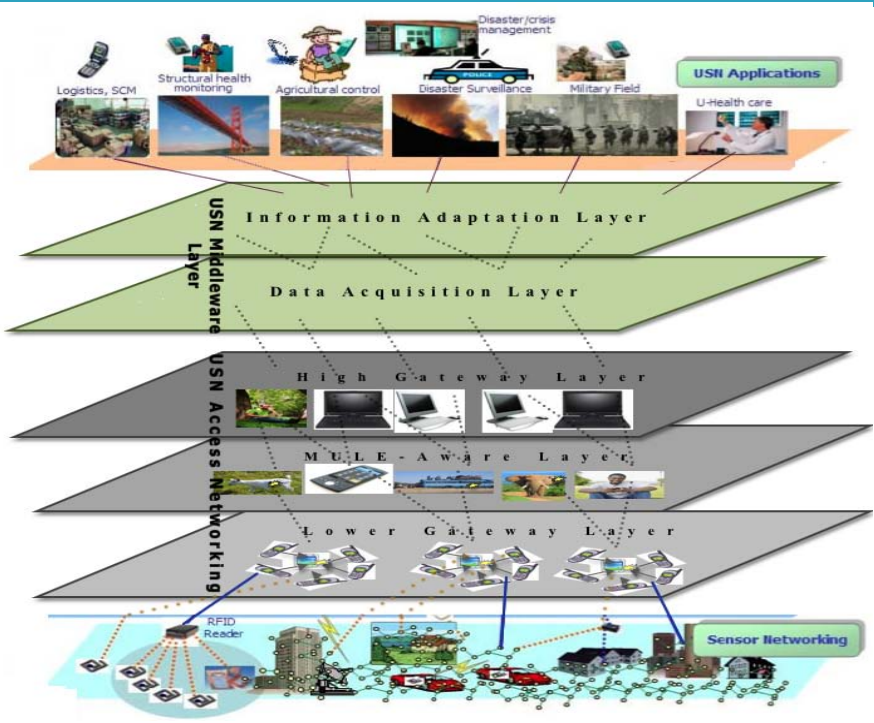
Participatory Sensing

- Reduce cost and size by using
  - Mobile phones: (1) sheer ubiquity (2) broad proliferation (3) possibility for participants to coordinate activities and upload data to servers that can process it and integrate it with other data.
  - Off-the-Shelf sensor devices: cheaper and easily replaced and/or repaired and/or adapted.



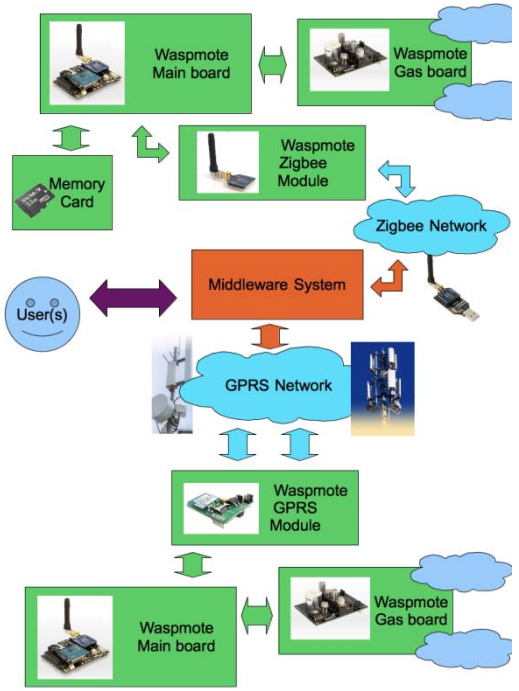
The CSN Architecture

- Launch Sensing devices into our daily living places to identify things and sense what is happening in the environment and translate this into services to different applications.
- Use a multi-layered networking architecture.
  - Sensor Layer
  - Three Gateway layers: Lower, Middle and Upper
  - Two Middleware layers: Lower and Upper
  - Application Layer: One layer where services are provided



An Implementation Model

- A combination of technologies: Sensor + GPRS technology using off-the-shelf devices to implement the CSN model.
  - Sensor Technology uses Waspmotes from Libelium, Spain. Waspmotes have an SD card, GPRS capabilities of sending an SMS and come in different communication flavors using the Xbee protocol.
  - GPRS technology uses Gateway from Telit as interface between the GSM network and a computer.



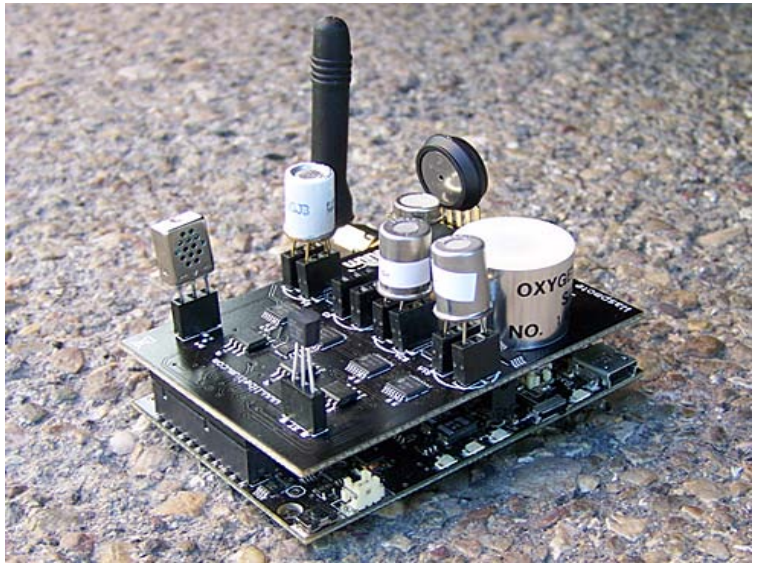
Using the Waspmote

- Waspmotes are built around the XBee transceivers which provide several advantages over other devices, in terms of multiplicity of operating power, protocols, and operating frequencies.
- Waspmote characteristics include (1) minimum power consumption of the order of 0.7μA in the Hibernate mode (2) flexible architecture allowing extra sensors to be easily installed in a modular way, (3) the provision of GPS, GPRS and SD card on the board, and (4) use of a lithium battery which can be recharged through a specially dedicated socket for the solar panel; this option is specially interesting for deployments in remote environments.

Model	***Protocol***	***Frequency***	***TX power***	***Sensitivity***
XBee-802.15.4	802.15.4	2.4 GHz	1 mW	-92 dB
XBee-802.15.4-Pro	802.15.4	2.4 GHz	63 mW	-100 dB
XBee-ZB	ZigBee-Pro	2.4 GHz	2 mW	-96 dB
XBee-ZB-Pro	Zigbee-Pro	2.4 GHz	50 mW	-102 dB
XBee-868	RF	868 MHz	315 mW	-112 dB
XBee-900	RF	900 MHz	50 mW	-100 dB
XBee-XSC	RF	900 MHz	100 mW	-106 dB

Using the Gaz Sensor Board

- Libelium produces a Gaz Board that may includes eleven gaz sensors. (1) Carbon Monoxide CO, (2) Carbon Dioxide CO2, (3) Molecular Oxygen O2, (4) Methane CH4 (5) Molecular Hydrogen H2 (6) Ammonia NH3 (7) Isobutane C4H10 (8) Ethanol CH3CH2OH (9) Toluene C6H5CH3 (10) Hydrogen Sulphide H2S and (11) Nitrogen Dioxide NO2.
- It allows the inclusion of 6 gases sensors at any one time, the regulation of their power through a system of solid state switches and the amplification of the output signal through a controllable amplifier.



Experimental Results and Discussion

- WaspNet was used in two different mote configurations in our experiments (GPRS and ZigBee) to assess the readiness for field deployment of the system in terms of (1) pollution level measurement and mapping and (2) information dissemination using both ZigBee and GPRS connectivity when measuring pollutant levels in the city of Cape Town, and publishing the results as pollution maps using Google Maps. Both devices were carried in a car driving in defined target areas.
- Three sets of trials during the experiment: one on the 23 July 2010, the second on 24 September 2010, and the third on 29 September 2010.
  - For the first set of experiments conducted on the 23 July, we used as starting point (as the source for the calibration) a house located in leafy and low-density population suburb called Fernwood, near the National Botanical Gardens. All subsequent readings were relative to the air pollution levels at this house.
  - The second and third sets of experimental trials were conducted on the 24th and 29th of September 2010, both using as starting point the higher campus of the University of Cape Town as the calibration point. The first and third trials targeted primarily the northern half of the "Southern" suburbs and "Northern" suburbs of Cape Town, while the second trail targeted the southern half of the "Southern" suburbs. The main results expected from our experimental setting were expressed in terms of

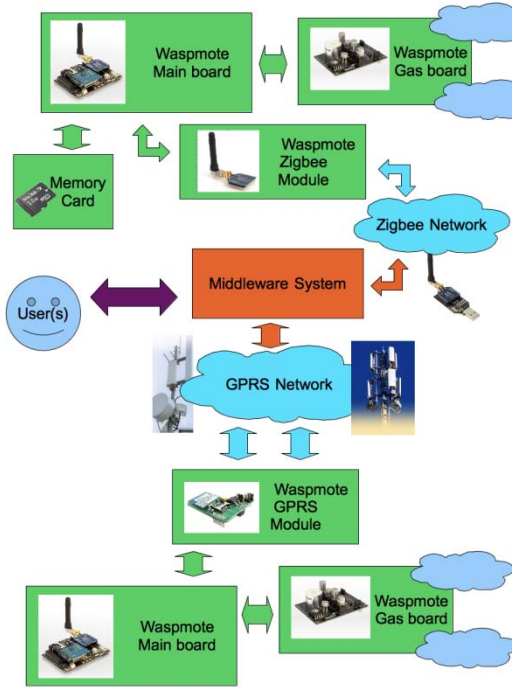
Performance parameters

- *Pollution mapping and publishing* by
  - (1) producing a pollution map with tagged locations of pollution thresholds using Google Maps based upon readings taken from all three experimental trials and
  - (2) proposing graphs of the levels of different pollutants to reveal their concentration.
- *Readiness for field deployment* by measuring
  - (1) the battery lifetime in both GRPS and ZigBee modes and
  - (2) the packet loss in both modes.

Experimental Setting

WaspNet uses two different mote configurations. In both configurations, Waspmote main board is used in conjunction with a gas board and GPS board.

- a GPRS module and a Telit GC864 GSM modem [21] interface to mobile network when using the GRPS mode
- a Waspmote XBeePro module and a Waspmote XBeePro gateway when operating in the ZigBee mode,
- Both configurations use a SD Card to store readings if either the GSM or Zigbee networks are not available at the time when the reading is taken. Then, when the presence of the respective data network is detected, all the outstanding stored readings are uploaded to the WaspNet gateway.



Pollution Map

✓ Two types of clouds are used: those without circles representing the pollutant levels taken in Zigbee mode and the ones with circles within them which present the pollutant levels taken in GPRS mode.

✓ The readings were averaged at a particular point if multiple readings were taken at that geographic location and the time label considered was the one of the last reading taken at that point. Looking at the pollution map depicted by Figures 5 and 6, one should note that the sensor responds to the levels of the whole group of the gases, and so is a composite value of the various gas concentrations present. While this doesn't allow for accurate measurement of the level of a particular gas, it does give an effective "neighborhood" which the various gas levels fall within, and thus an indication of the level of air pollution.

Pollution Map: 1st Day

Experiments

Pollution Map: 2nd Day

Summary Pollution Map

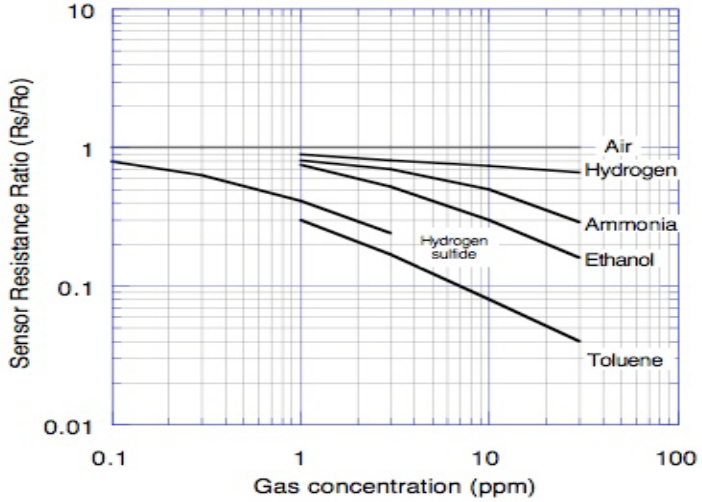
Using both map plots, it does seem to make sense that the Northern Suburbs of Cape Town which is more ”polluted” than the Southern Suburbs, especially given the presence of an oil refinery in the area.

Resistance vs Gaz Concentration

To measure these approximate concentrations of each gas, we calculated the resistance ratio of the gas sensor (which is the ratio of the resistance of the sensor against the calibrated reading). Using the gas curves, we derived functions which related the different resistance ratios to gas concentration readings. We then used that function to plot the potential concentration for the various gases under consideration.

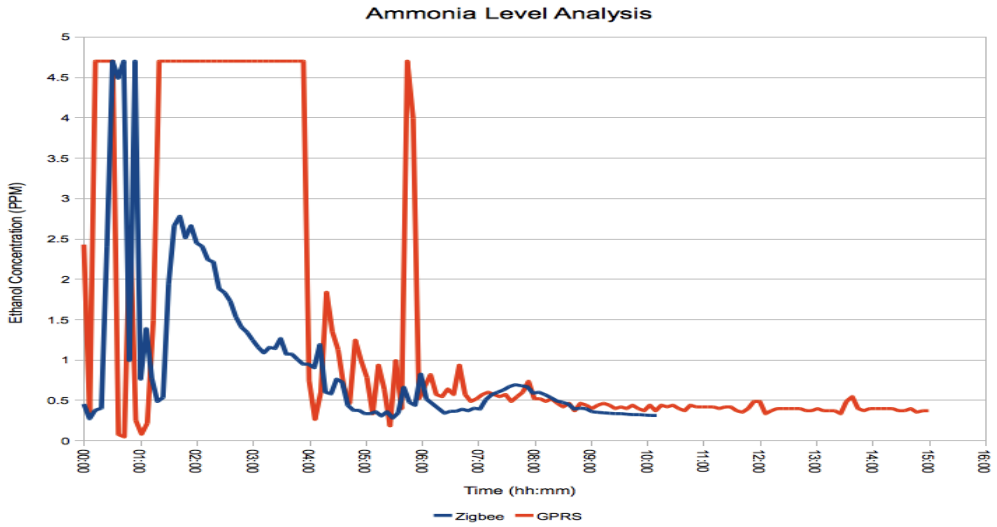
Rs = Sensor resistance in displayed gases at various concentrations
Ro = Sensor resistance in fresh air

Sensitivity Characteristics:



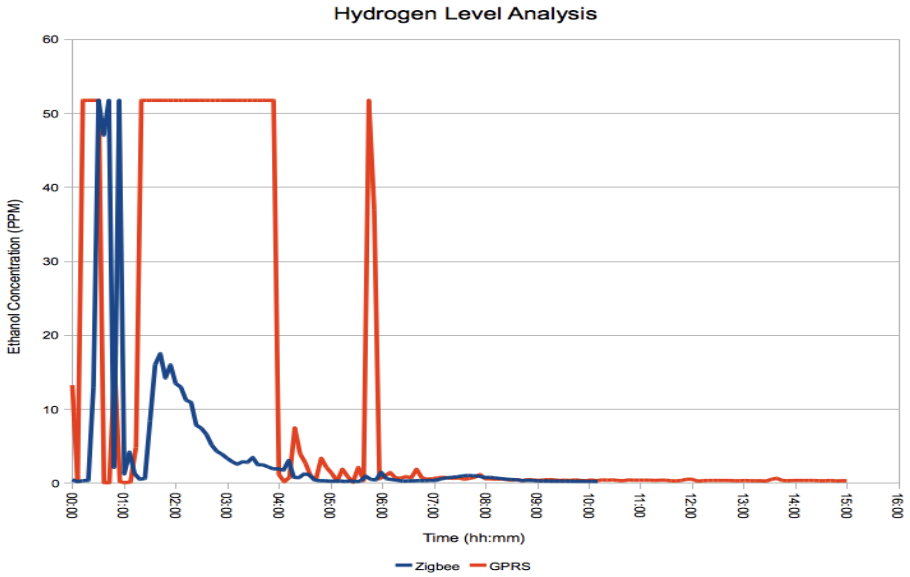
Ammonia Concentration

No correlation, However, there is a common trend of hikes and downs.



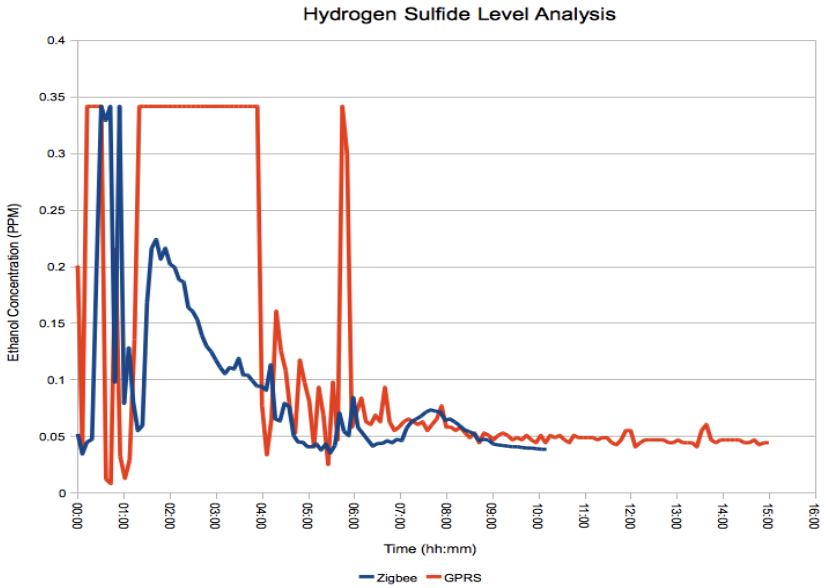
Hydrogen Concentration

No correlation, However, there is a common trend of hikes and downs.

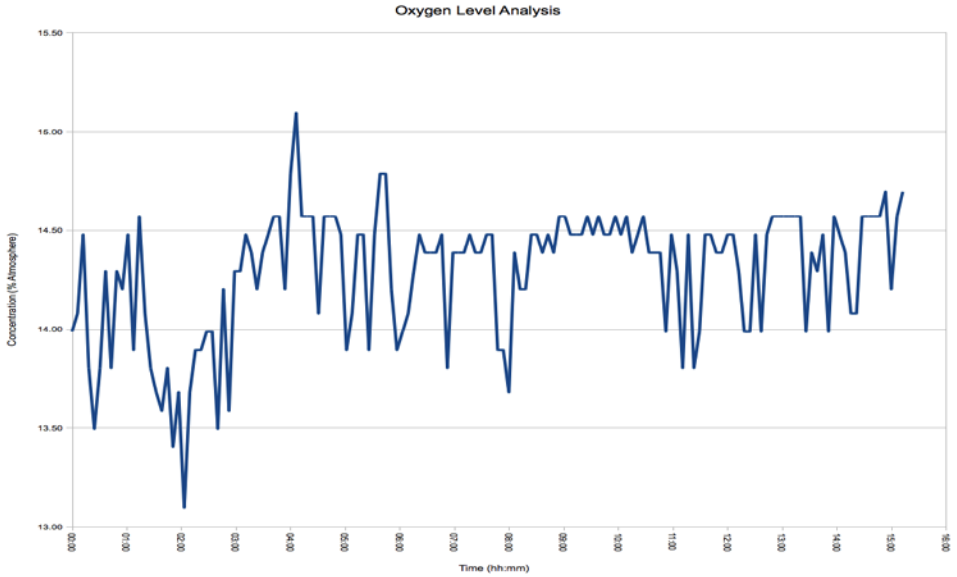


Hydrogen Sulfide Concentration

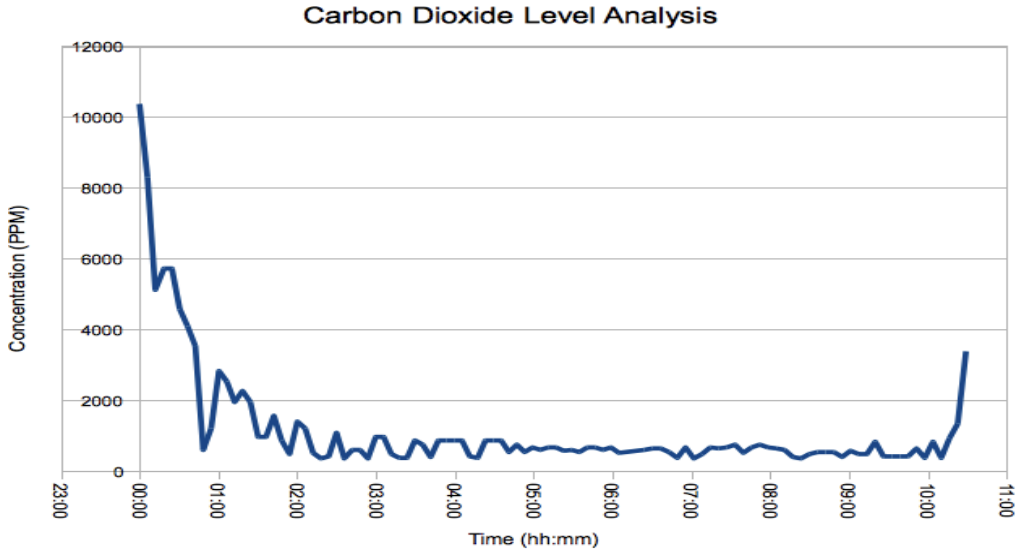
No correlation, However, there is a common trend of hikes and downs.



Oxygen Concentration



Carbon Dioxide Concentration

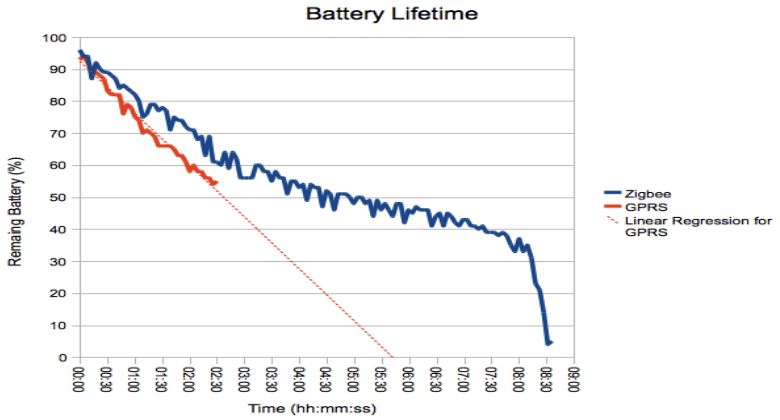


Summary Gaz Concentration

- ✓ The results did not reveal a great deal of correlation between the two sensors. However, they were both within the same range usually separated by a few parts per million.
- ✓ This lack of agreement may be justified by the fact that (1) the readings were taken while the vehicle was moving around, and since they were not taken at the exact same time, they were essentially taken at different locations (2) the general constant offset trend is due to the fact that the GPRS sensor had far fewer calibration readings than the Zigbee device. This is further exhibited by the volatility seen by this device against the Zigbee device's readings.
- ✓ Using both map plots, it does seem to make sense that the Northern Suburbs of Cape Town which is more "polluted" than the Southern Suburbs, especially given the presence of an oil refinery in the area.

Battery Lifetime

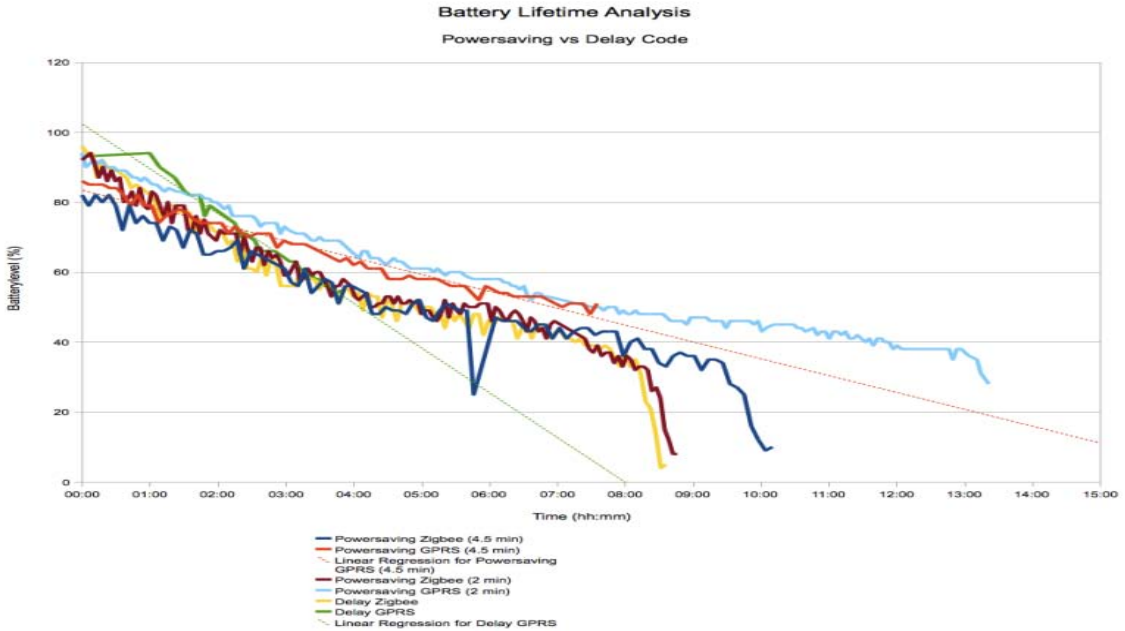
GPRS stops when battery level reaches 45% .



Delayed Battery Lifetime

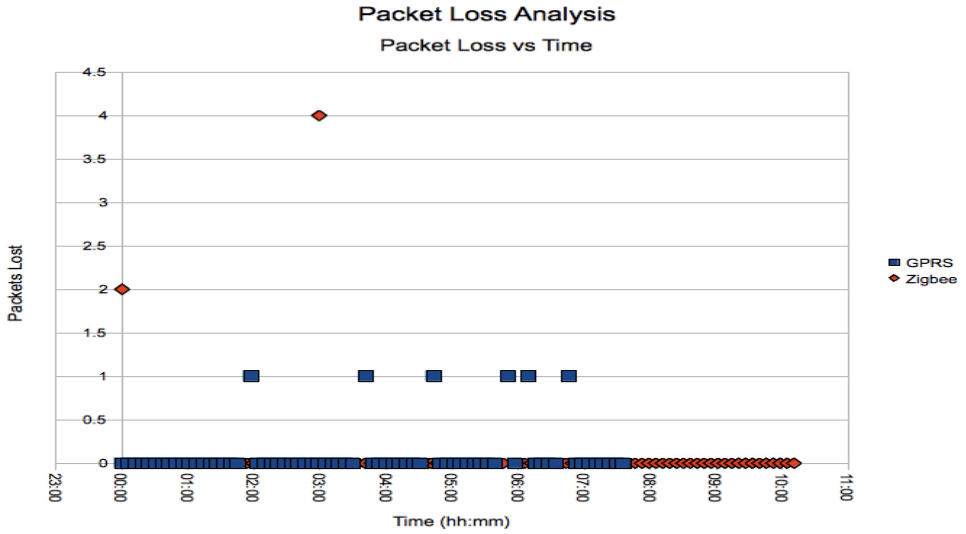
We could not implement sleeping mode but we could delay measurements.

Here again, GPRS stops sending earlier but battery lifetime is longer.



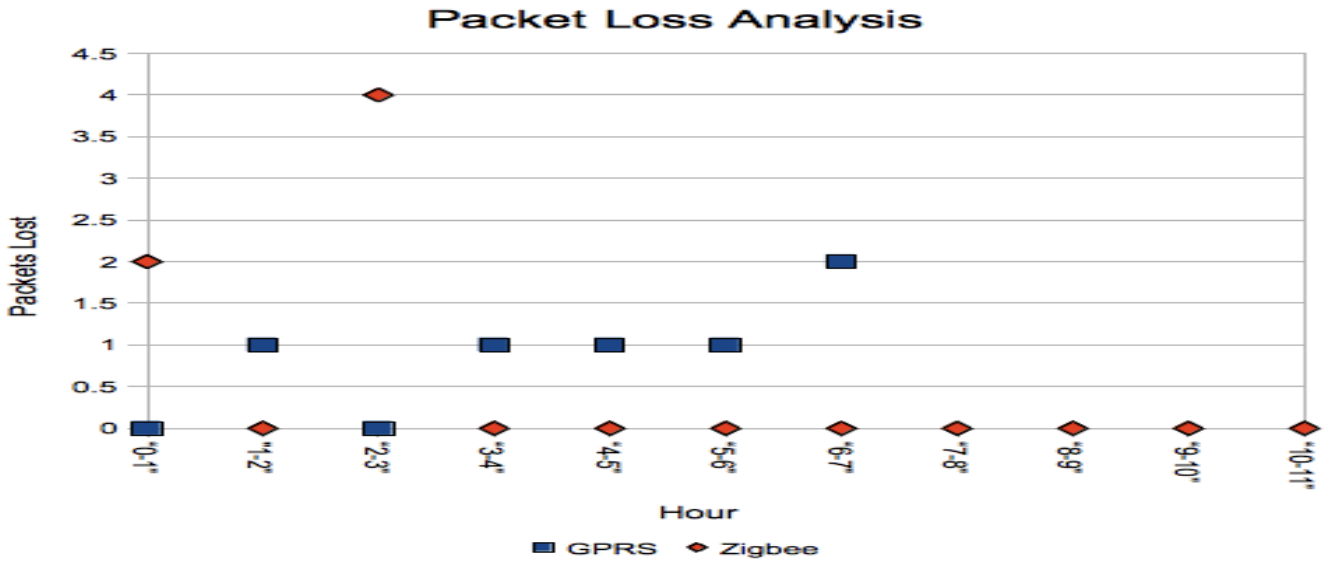
Packet Loss Analysis

The packet loss for the GPRS sensor of 10%, which is quite high, however this is in agreement with recent events in South Africa, where the mobile operators were fined heavily last year because 1 in 20 SMSs were not reaching their destination.



Hourly Packet Loss Analysis

The distribution of the dropped packets for the GPRS is quite widely spread, as is to be expected, while the Zigbee is concentrated at the beginning and one anomalous instance



Conclusion and Future Work

- We have presented the main ideas behind a community sensor networking model and an implementation system using off-the-shelf sensing devices.
- Using an experimental air pollution monitoring Testbed in the city of Cape Town, we illustrate the use of the proposed community sensor networking model in terms of sensor readiness for field deployment and air pollution recognition.
- Our experimental setting reveals that (1) pollutions map can be built using off-the-shelf sensor equipment (2) both Zigbee and GPRS can be used as information dissemination protocols for the sensed data (3) this can be done with low packet loss and (4) the experimental results may be published using web services such as Google Maps.

Conclusion and Future Work

However, there is room for further improvements in the way our experiments were conducted. These include

- better calibration of the sensors and comparison with data provided by fixed sensors,
- opportunistic transmission in the presence of different types of gateways and
- the running of the experiments to evaluate the impact of daily climate variations and road traffic fluctuations on pollution.
- pollution awareness through a pollution information dissemination network : pollution levels publication at http://www.ws4all.org as a starting point.

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