# Estimating Energy Cost of continuous Context-sensing with Smartphone-embedded and neighborhood sensors

*ITRA Project: HumanSense - Development and deployment of mobile based systems for preliminary data collection to guide future directions of the project*

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## Objectives

1. Develop suitable mobile applications pertaining to different aspects of the proposal
2. Use the developed applications for energy aware preliminary data collection in real environments
3. Create mobile based system, incorporating both the applications and sensing systems for broader applicability in healthcare and energy domain

## Energy aware preliminary data collection

1. Context in our current work implies localized environmental data like temperature, humidity, atmospheric pressure, air/noise/water pollution parameters
2. Increase in number of on-board sensors sensing continuously leads to complications due to inter-sensor-interactions and/or their usage scenarios
3. Used Contemporary smartphones with embedded sensors interacting with neighborhood sensors on Sensordrone platform using Bluetooth 2.1
4. Developed on-line-on-device profiler with offline measurements to build device specific power models for Samsung Galaxy S4 and Google Nexus 5

## Experimental Setup

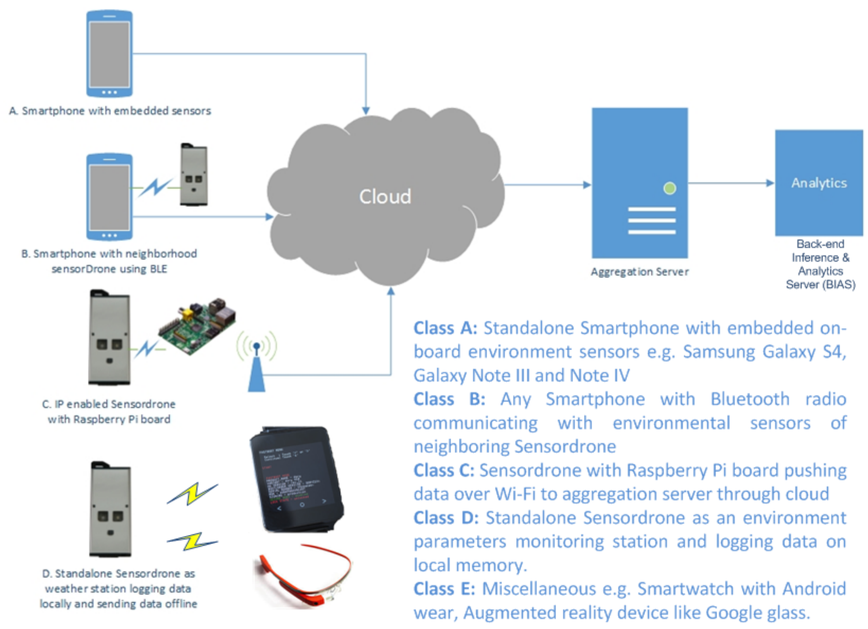



**Figure 1:** Schematic of our system for experimental study

## Building Power Model of Online Profiler

Extended PowerBooter model:

$$\begin{aligned}(\beta_{uh} \times freq_h + \beta_{ul} \times freq_l) \times util + \beta_{CPU} \times CPU_{on} + \beta_{br} \times AMOLED_{brightness} \\ + \beta_{Gon} \times GPS\_on + \beta_{Gsl} \times GPS\_sl + \beta_{WiFi\_l} \times WiFi_l + \beta_{WiFi\_h} \times WiFi_h \\ + \beta_{3G\_idle} \times 3G_{idle} + \beta_{3G\_FACH} \times 3G_{FACH} + \beta_{3G\_DCH} \times 3G_{DCH} \\ + \beta_{4G\_RRC\_idle} \times 4G_{RRC\_idle} + \beta_{4G\_RRC\_connected} \times 4G_{RRC\_connected} \\ + \beta_{sensor} \times Sensor_{ON} + \beta_{Bluetooth\_2.1} \times Bluetooth_{2.1} \quad (1)\end{aligned}$$

where $\beta$ is power coefficient and $util, CPU_{ON}....etc.$ are utilization factor for a particular component (system variables). We use customized setup to measure power consumption traces represented by P matrix. After collecting power traces in controlled environment, we use multi-variable regression to minimize Sum of Square errors for $\beta$ vector.

$$P = \beta U + c \quad (2)$$

where $P$ vector is $n \times 1$ measured power values, $\beta$ vector is $1 \times m$ power coefficients to be estimated and U is $m \times n$ matrix; where $U_{ij}$ represents system variable $i$ in $j_{th}$ state. Constant $c$ is minimum power consumed on the device.

$$18.8 + 70.1 \times x - 22.4 \times x^2 + 4.4 \times x^3 - 0.4 \times x^4 + 0.01 \times x^5 \quad (3)$$

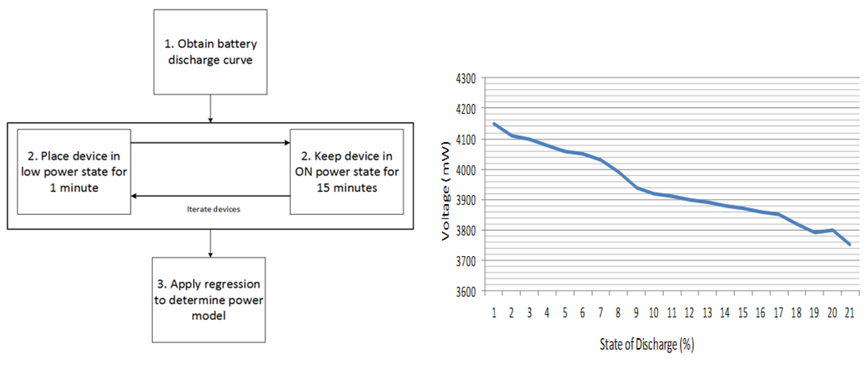
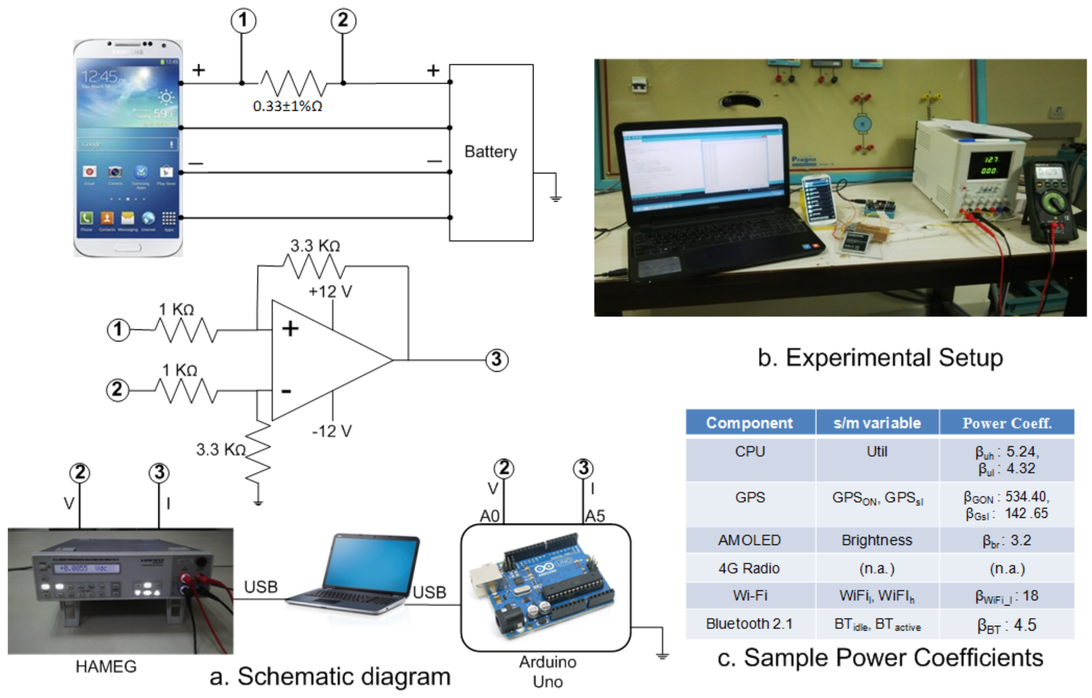



**Figure 2:** Key Phases of the proposed power Model and discharge curve for S4

## Custom Setup for Power Measurement and Trace Analysis for S4 and Nexus5




| Component | s/m variable | Power Coeff. |
|---|---|---|
| CPU | Util | $\beta_{uh}$ : 5.24, $\beta_{ul}$ : 4.32 |
| GPS | $GPS_{ON}$, $GPS_{sl}$ | $\beta_{GON}$ : 534.40, $\beta_{Gsl}$ : 142 .65 |
| AMOLED | Brightness | $\beta_{br}$ : 3.2 |
| 4G Radio | (n.a.) | (n.a.) |
| Wi-Fi | $WiFi_l$, $WiFI_h$ | $\beta_{WiFI\_l}$ : 18 |
| Bluetooth 2.1 | $BT_{idle}$, $BT_{active}$ | $\beta_{BT}$ : 4.5 |

c. Sample Power Coefficients

**Figure 3:** Custom setup for online power consumption estimation

HAMEG HM 8112-3 precision Multi-meter and Arduino Uno for measuring component level power-consumption. Our proposed model for S4 does not consider presence of sensor hub along with on-board power management module to reduce wake-up time of Master CPU by Android apps.

## Results

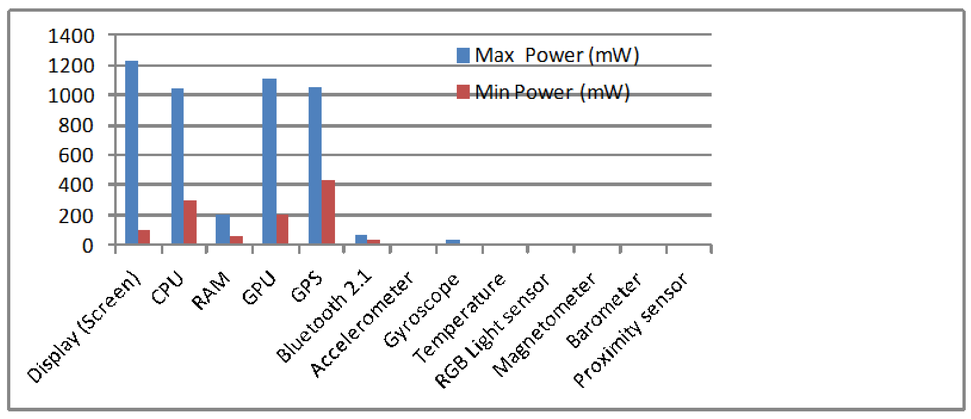



**Figure 4:** Average Component-wise Energy Consumption for Samsung Galaxy S4

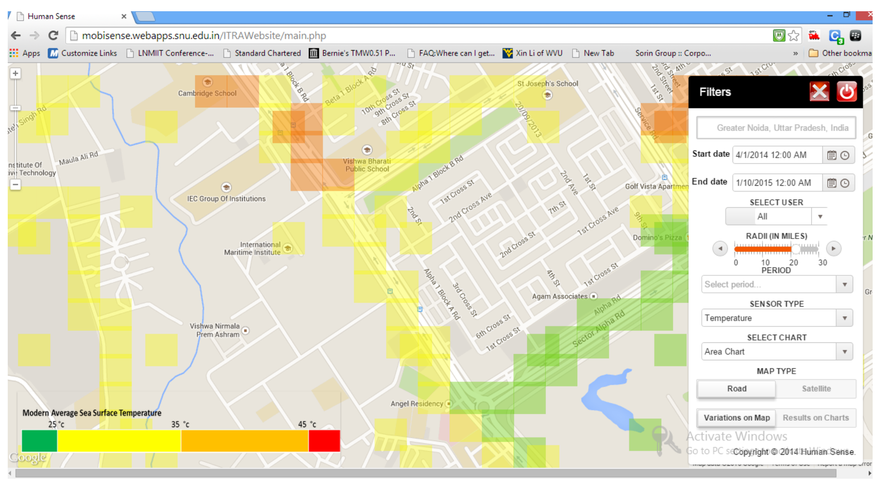



**Figure 5:** BIAS map of the Collected Data

## Conclusions and Future Work

- Online on device profiling is most convenient but it introduces bias and profiler itself becomes energy hog.
- Offline setup or using power monitor like Monsoon is accurate but less desirable for continuous context sensing
- Presence of sensor hub makes power modeling for latest Smartphones less accurate.

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