

Smart usage of context information for the analysis, design and generation of power-aware policies for mobile sensing apps

Doctoral seminar 2016

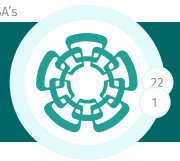
Rafael Pérez Torres

Dr. César Torres Huitzil
Dr. Hiram Galeana Zapién
LTI Cinvestav



Cinvestav

Agenda



Background

Problem statement

Related work

Methodology

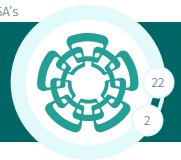
Proposed solution

Schedule

Conclusions

Background

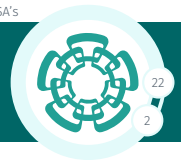
Motivation



- ▶ The popularity of mobile devices is a result of advances in their computation, **sensing**, and communication dimensions [1].
 - ▶ The sensing facilities improve interaction with user, turning them into *omni-sensors* able to *know* about its surrounding environment.

Background

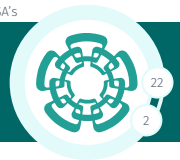
Motivation



- ▶ The popularity of mobile devices is a result of advances in their computation, **sensing**, and communication dimensions [1].
 - ▶ The sensing facilities improve interaction with user, turning them into *omni-sensors* able to *know* about its surrounding environment.
 - ▶ Smartphones have become *context-aware* devices, gaining understanding about user's activity and environment.

Background

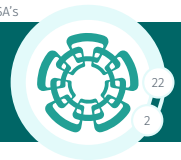
Motivation



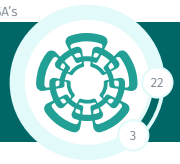
- ▶ The popularity of mobile devices is a result of advances in their computation, **sensing**, and communication dimensions [1].
 - ▶ The sensing facilities improve interaction with user, turning them into *omni-sensors* able to *know* about its surrounding environment.
 - ▶ Smartphones have become *context-aware* devices, gaining understanding about user's activity and environment.
 - ▶ **Context** is the set of environmental states and settings that either determines an application's behavior or in which an application event occurs and is interesting to the user [2].

Background

Motivation



- ▶ The popularity of mobile devices is a result of advances in their computation, **sensing**, and communication dimensions [1].
 - ▶ The sensing facilities improve interaction with user, turning them into *omni-sensors* able to *know* about its surrounding environment.
 - ▶ Smartphones have become *context-aware* devices, gaining understanding about user's activity and environment.
 - ▶ **Context** is the set of environmental states and settings that either determines an application's behavior or in which an application event occurs and is interesting to the user [2].
- ▶ However, battery is not evolving at the same pace than the advances in other smartphone's characteristics [3], growing only 5-10% each year [4, 5].
 - ▶ The energy constraint becomes critical when continuous access to sensors is needed, which is a core requirement of **mobile sensing applications**.



Background

Stages of mobile sensing applications

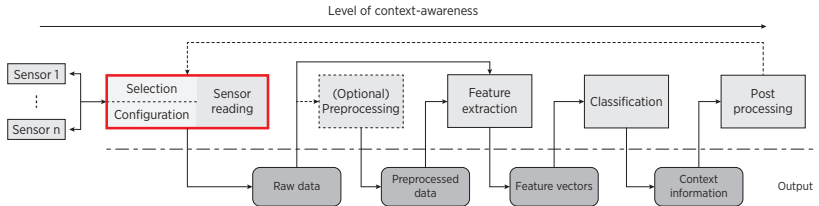
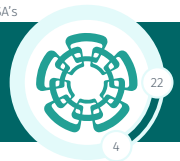


Figure: Stages of mobile sensing applications

There is a tradeoff between the accuracy of context information retrieved and the associated energy consumption [6, 7]. How to face it?

Problem definition

Hypothesis

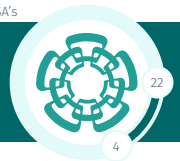


Hypothesis

Intelligent policies produced through context information built from sensors data could be employed to reduce the energy consumption in a mobile device when performing continuous sensor readings.

Problem definition

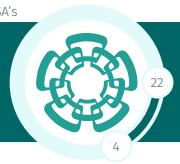
Hypothesis



Hypothesis

Intelligent policies produced through context information built from sensors data could be employed to reduce the energy consumption in a mobile device when performing continuous sensor readings.

- An intelligent policy is a special rule that defines how sensors should be selected and configured to reduce energy consumption and achieve the mobile sensing app's requirements. It is intelligent in terms of self-adaptness to changes detected in context information across time.



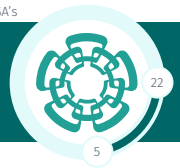
Problem definition

Hypothesis

Hypothesis

Intelligent policies produced through context information built from sensors data could be employed to reduce the energy consumption in a mobile device when performing continuous sensor readings.

- ▶ An intelligent policy is a special rule that defines how sensors should be selected and configured to reduce energy consumption and achieve the mobile sensing app's requirements. It is intelligent in terms of self-adaptness to changes detected in context information across time.
- ▶ This research work is aimed at employing GPS and inertial sensors data (accelerometer) for inferring context information in terms of mobility patterns. This context information will then be exploited to adapt sensors' operation and produce power savings.



Problem definition

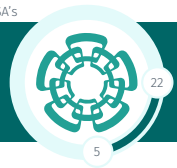
Problem statement

Problem 1: Mobility pattern identification

Given a set $V = \{v_1, v_2, \dots, v_n\}$ of data values read from sensor S in the time interval $T \in [t_1, t_2]$, identify the current mobility pattern p_S that represents the activity of user.

$$\text{PatternIdentifier}(V) \longrightarrow p_S \in \mathbf{Patterns} \quad (1)$$

Where **Patterns** is a set of patterns that represent a user's mobility context situation, specifically the set `{no movement, walking, running, vehicle transportation, arriving stay point, leaving stay point}`.



Problem definition

Problem statement

Problem 1: Mobility pattern identification

Given a set $V = \{v_1, v_2, \dots, v_n\}$ of data values read from sensor S in the time interval $T \in [t_1, t_2]$, identify the current mobility pattern p_S that represents the activity of user.

$$\text{PatternIdentifier}(V) \longrightarrow p_S \in \mathbf{Patterns} \quad (1)$$

Where **Patterns** is a set of patterns that represent a user's mobility context situation, specifically the set {no movement, walking, running, vehicle transportation, arriving stay point, leaving stay point}.

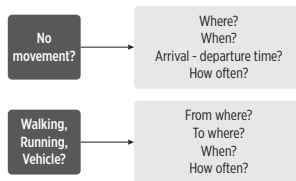
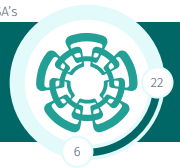


Figure: Context information related to mobility patterns



Problem definition

Problem statement

Problem 2: Policy generation

Given the set of detected mobility patterns $\mathcal{P} = \{p_{S_1}, p_{S_2}, \dots, p_{S_n}\}$ in data from sensors $\mathcal{S} = \{S_1, S_2, \dots, S_n\}$, accuracy required a , and physical constraints status c of a mobile device, find a policy that select the proper set of sensors \mathcal{S}_{new} and its associated configuration $\mathcal{S}_{new_{conf}}$ while meeting application requirements.

$$\text{PolicyGeneration}(\mathcal{P}, a, c) \longrightarrow \mathcal{S}_{new}, \mathcal{S}_{new_{conf}} \quad (2)$$

The $\mathcal{S}_{new_{conf}}$ configuration is referred to as the *adaptive duty cycle* of associated sensors.



Problem definition

Interaction between problems

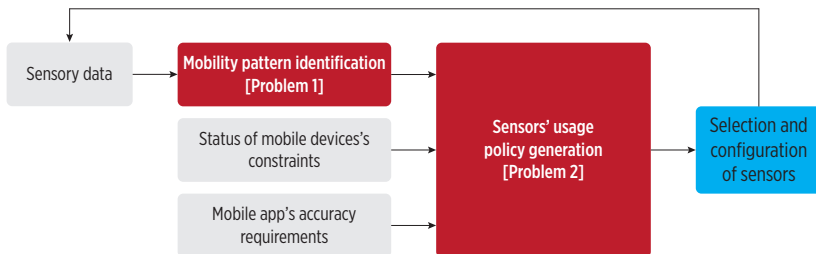
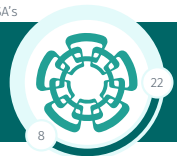


Figure: Interaction between problems

Problem definition

Objectives

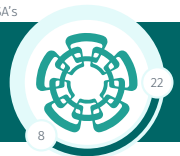


Main objective

To reduce energy consumption in the mobile sensing apps, which perform continuous sensor readings, through self-adapting power-aware policies generated from context information obtained from sensors data.

Problem definition

Objectives

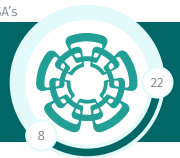


Main objective

To reduce energy consumption in the mobile sensing apps, which perform continuous sensor readings, through self-adapting power-aware policies generated from context information obtained from sensors data.

Particular objectives

- To identify mobility patterns from context information obtained from an inertial sensor (accelerometer) and location providers (GPS).



Problem definition

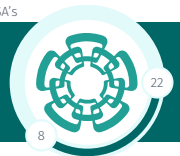
Objectives

Main objective

To reduce energy consumption in the mobile sensing apps, which perform continuous sensor readings, through self-adapting power-aware policies generated from context information obtained from sensors data.

Particular objectives

- ▶ To identify mobility patterns from context information obtained from an inertial sensor (accelerometer) and location providers (GPS).
- ▶ To generate an accurate representation of mobility patterns, which in conjunction with accuracy mobile app requirements and mobile device constraints, allows to generate power-aware GPS sensing policies.



Problem definition

Objectives

Main objective

To reduce energy consumption in the mobile sensing apps, which perform continuous sensor readings, through self-adapting power-aware policies generated from context information obtained from sensors data.

Particular objectives

- ▶ To identify mobility patterns from context information obtained from an inertial sensor (accelerometer) and location providers (GPS).
- ▶ To generate an accurate representation of mobility patterns, which in conjunction with accuracy mobile app requirements and mobile device constraints, allows to generate power-aware GPS sensing policies.
- ▶ To reduce energy consumption in location-based mobile sensing apps through a middleware that implements policies fed with mobility patterns learned from sensors data.

Problem definition

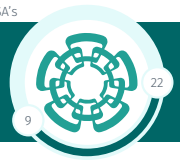
Expected contributions



- A mechanism for detecting mobility patterns from the data read by sensors of mobile devices (GPS and accelerometer).

Problem definition

Expected contributions



- ▶ A mechanism for detecting mobility patterns from the data read by sensors of mobile devices (GPS and accelerometer).
- ▶ A mechanism for generating policies for accessing sensors. The produced policies will allow to perform an intelligent usage of smartphone's sensing facilities in continuous sensor sampling, reducing the energy consumption.

Problem definition

Expected contributions



- ▶ A mechanism for detecting mobility patterns from the data read by sensors of mobile devices (GPS and accelerometer).
- ▶ A mechanism for generating policies for accessing sensors. The produced policies will allow to perform an intelligent usage of smartphone's sensing facilities in continuous sensor sampling, reducing the energy consumption.
- ▶ A middleware implementing the previous power-aware mechanisms for easing the development of location based services.

Problem definition

Problem's scenario

10

22

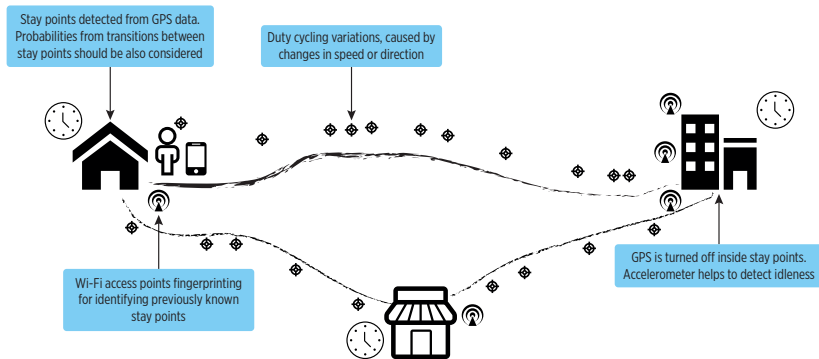


Figure: Basic problem's scenario

Related work

Previous work

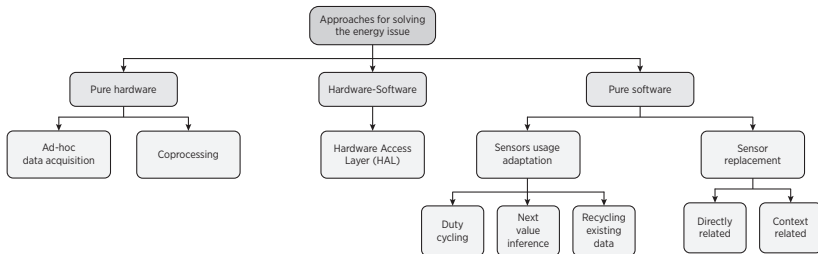
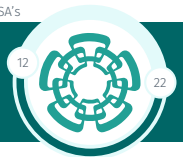


Figure: Taxonomy of related work solutions

Methodology

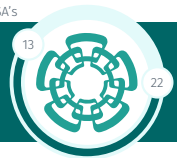
Methodology steps



1. Familiarization with state-of-art power-aware sensing related techniques
2. Formal definition and selection of mobility patterns to be identified
3. Research on pattern recognition algorithms focused on mobility patterns identification
4. Design of the Pattern Identification Element (PIE)
5. Research on (and proposition of) adaptive policies for energy efficient usage of sensors
6. Design of the Policy Generation Element (PGE)
7. Development of a middleware involving the PIE and PGE for the Android platform
8. Experimentation in terms of accuracy and energy efficiency

Proposed solution

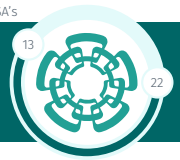
Characteristics



- Pure software approach.

Proposed solution

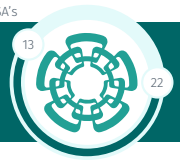
Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: **on trajectory, on stay point.**

Proposed solution

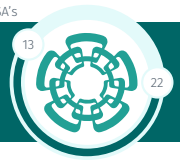
Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: `on trajectory, on stay point`.
 - ▶ Low level mobility states-events: `transportation mode changed, arriving to stay point, leaving stay point`.

Proposed solution

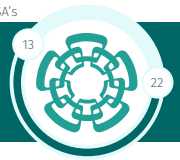
Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: `on trajectory, on stay point`.
 - ▶ Low level mobility states-events: `transportation mode changed, arriving to stay point, leaving stay point`.
- ▶ Inspired on Cognitive Dynamic Systems [8], including
 - ▶ Perception-action cycle.

Proposed solution

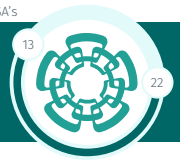
Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: `on trajectory, on stay point`.
 - ▶ Low level mobility states-events: `transportation mode changed, arriving to stay point, leaving stay point`.
- ▶ Inspired on Cognitive Dynamic Systems [8], including
 - ▶ Perception-action cycle.
 - ▶ Memory.

Proposed solution

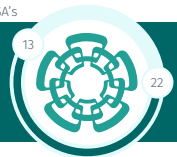
Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: `on trajectory, on stay point`.
 - ▶ Low level mobility states-events: `transportation mode changed, arriving to stay point, leaving stay point`.
- ▶ Inspired on Cognitive Dynamic Systems [8], including
 - ▶ Perception-action cycle.
 - ▶ Memory.
 - ▶ Attention.

Proposed solution

Characteristics



- ▶ Pure software approach.
- ▶ Event-driven oriented, completely on device.
 - ▶ Top level mobility states-events: `on trajectory, on stay point`.
 - ▶ Low level mobility states-events: `transportation mode changed, arriving to stay point, leaving stay point`.
- ▶ Inspired on Cognitive Dynamic Systems [8], including
 - ▶ Perception-action cycle.
 - ▶ Memory.
 - ▶ Attention.
 - ▶ Intelligence.

Proposed solution

Overview

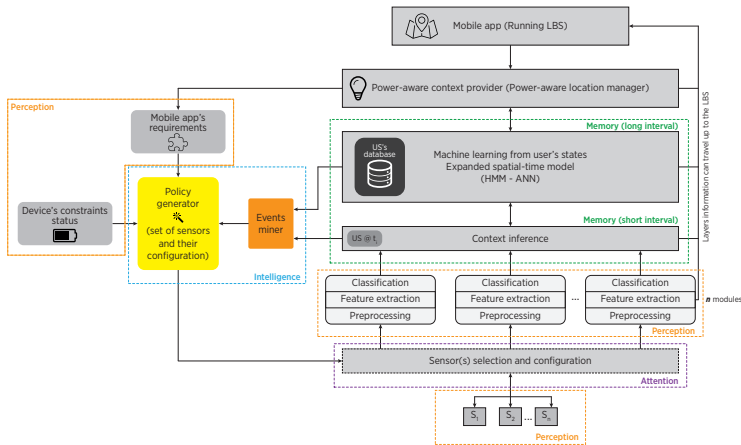


Figure: Overview of current solution

Proposed solution

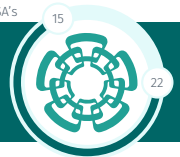
Operation



- ▶ Overall problem divided into:
 - ▶ Detection of stay points (The anchor points that user visits frequently).

Proposed solution

Operation



- ▶ Overall problem divided into:
 - ▶ Detection of stay points (The anchor points that user visits frequently).
 - ▶ Tracking of user commuting between stay points (Transition probability).

Proposed solution

Operation

- Overall problem divided into:
 - Detection of stay points (The anchor points that user visits frequently).
 - Tracking of user commuting between stay points (Transition probability).

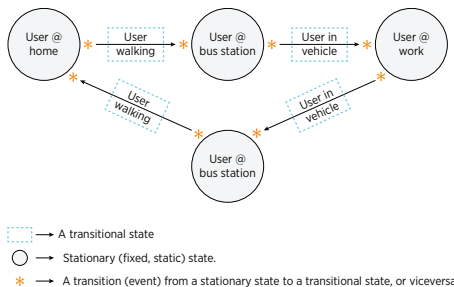
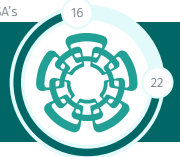


Figure: Information modeled by the expanded spatial-time model

Schedule



		2014		2015		2016		
Work: ● Done, ● In progress, ○ To be done		3rd	1st	2nd	3rd	1st	2nd	3rd
STEP I								
1	State-of-art reading	●	●					
2	State-of-art works categorization		●	●				
3	Documentation of information found (committee request)			●				
STEP II								
4	Development of a mobile app for accelerometer and location data collection			●	●			
5	Analysis of data				●			
6	Formal definition of mobility pattern				●			
7	Selection of mobility patterns				●	●		
STEP III								
8	Research on classification algorithms for mobility patterns				●	●		
9	Definition of metrics for evaluating algorithms					●		
10	Implementation of algorithms in mobile platform					●	●	
11	Selection of best algorithms according to metrics						●	
STEP IV								
12	Definition and modeling of parameters needed by the PIE				●	●	●	●
13	Building of the PIE				●	●	●	●

Table: Schedule of activities (each column represents a four months period)

Schedule

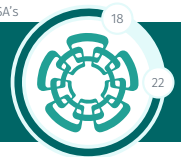


22

Work: ● Done, ● In progress, ○ To be done		2016			2017			2018
		1st	2nd	3rd	1st	2nd	3rd	1st
STEP V								
14	Formal definition of policy			●				
15	Research and evaluation of techniques for generation and adaption of policies			●	●			
16	Design and execution of experiments applied to use cases			●	●			
17	Selection of policies				●			
STEP VI								
18	Definition and modeling of PGE parameters					●		
19	Building of the PGE					●		
STEP VII								
20	Analysis of components into software abstractions					●		
21	Research on Android API for specialized components					●		
22	Development of middleware					●		
STEP VIII								
23	Definition of experiments aimed at accuracy and energy consumption metrics						○	
24	Development of experimental sample mobile apps						○	
25	Experiments execution						○	○
26	Final results analysis							○

Table: Schedule of activities (each column represents a four months period)

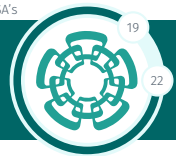
Schedule



		2014		2015		2016		2017		2018	
Work: ● Done, ● In progress, ○ To be done		3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
REQUIRED TASKS											
A	Related courses	●	●	●			●				○
B	Research articles submission				●		●				○
C	Predoctoral exam preparation							○			
D	Thesis writing	●			●			●		○	○

Table: Schedule of required activities

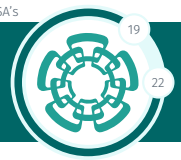
Conclusions



As conclusions, the current talk has been provided:

- The antecedents and motivation of the current research.

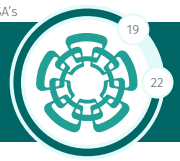
Conclusions



As conclusions, the current talk has been provided:

- ▶ The antecedents and motivation of the current research.
- ▶ A methodology based on the usage of context information for reducing energy consumption in location-based mobile apps.

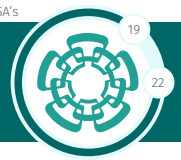
Conclusions



As conclusions, the current talk has been provided:

- ▶ The antecedents and motivation of the current research.
- ▶ A methodology based on the usage of context information for reducing energy consumption in location-based mobile apps.
- ▶ The main blocks of a middleware with an event-driven design and Cognitive Dynamic Systems fundamentals.

Conclusions



As conclusions, the current talk has been provided:

- ▶ The antecedents and motivation of the current research.
- ▶ A methodology based on the usage of context information for reducing energy consumption in location-based mobile apps.
- ▶ The main blocks of a middleware with an event-driven design and Cognitive Dynamic Systems fundamentals.
- ▶ The detailed work plan for addressing each of the methodology steps, including performed and pending activities.

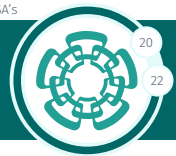
Thank you for your attention!

We make our world significant by the courage of our
questions and by the depth of our answers.

Carl Sagan



Cinvestav



References I

- [1] Nayeem Islam and Roy Want.
Smartphones: Past, Present, and Future.
IEEE Pervasive Computing, 13(4):89–92, 2014.
- [2] Guanling Chen and David Kotz.
A Survey of Context-Aware Mobile Computing Research.
Technical report, 2000.
- [3] Mikkel Kjaergaard.
Location-based services on mobile phones: Minimizing power consumption.
IEEE Pervasive Computing, 11:67–73, 2012.



References II

- [4] Xiao Ma, Yong Cui, and Ivan Stojmenovic.
Energy efficiency on location based applications in mobile cloud computing: A survey.
In Procedia Computer Science, volume 10, pages 577–584, 2012.
- [5] Eric C. Evarts.
Lithium batteries: To the limits of lithium.
Nature, 526(7575):S93–S95, oct 2015.
- [6] Jaemun Sim, Yonnim Lee, and Ohbyung Kwon.
Context-aware enhancement of personalization services: A method of power optimization.
Expert Systems with Applications, 41(13):5702–5709, 2014.



References III

- [7] Kiran K Rachuri, Cecilia Mascolo, and Mirco Musolesi.
Mobile Context Awareness.
Springer London, London, 2012.
- [8] Simon Haykin.
Cognitive Dynamic Systems.
Proceedings of the IEEE, 94(11):1910–1911, nov 2006.