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Mobile Crowdsensing-based Smart Lighting Solutions for Smart Cities

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Summary

Public lighting is a traditional city service provided by lampposts widely distributed in streets and roads. Lighting causes nearly 19% of worldwide use of electrical energy and entails a 6% of global emissions of greenhouse gases. A decrease of 40% of energy spent for lighting purposes is equivalent to eliminate half of the emissions from the production of electricity and heat generation of the US. Therefore, there is a substantial room for improvement. Specifically, public street lightning, which is an essential community service, impacts for around 40% on the cities' energy budget. Consequently, in preparation of the EU commitments, Horizon 2020, optimizing the lighting service is a primary objective for the cities.

The street lighting solutions currently implemented in cities are not energy efficient and not sustainable. Typically, every lamp performs at full intensity 12 hours a day on average: 8 hours during summer and 14 hours during winter period. As a result, the costs the municipalities sustain are high. A number of different types of lamps are applicable for public street lighting, including High Pressure Sodium (HPS), Metal-halide (MH) lamps, Compact Fluorescent lamps (CFL) and Light-emitting diode (LED). In Europe the HPS technology is the most common, however not efficient. LEDs have an average lifetime 4 times longer than HPS lamps and 10 times longer if compared to MH lamps. Installing LEDs is effective to reduce hardware, installation and maintenance costs. Low wattage provides significant energy savings and allows increasing the lamp efficiency. The HPS lamps do not support dimming and only LEDs can be employed to perform dimming properly. The use of LEDs is gradually gaining popularity due to its photo metric characteristics, such as low weighted energy consumption (kW/1000hrs), high luminous efficacy (lm / W), high mechanical strength, long lifespan and reduction of light pollution. LED lamps can dim the light intensity by more than 50% modifying therefore the output level of light according to the circumstances. For example, when traffic is low or in rarely visited areas of the city, like the parks at night. The city of Brittany in France, dims street lights by 60% between 11:00 PM and 5:00 AM to decrease waste energy.

This thesis aims at providing evaluation of benefits, in terms of energy spent for lighting and effective improvements costs, to strengthen street lighting making the lampposts *smart*. For this purpose, using an updated version of CrowdSenSim

simulator, developed during my internship in Luxembourg, I was able to evaluate three new heuristics for street lighting with a good compromise between capital expenditures and energy saving. In detail, all the new proposed methods are based on using lampposts equipped with presence sensors able to detect users walking within a coverage radius *R* justifying use of street lighting in that area. With policy the spent energy is optimized. In ENC heuristic each lamppost is switched upon the first encounter with at least one user and remain active the whole night. ENC provides a functioning with HPS as well, reducing the capital expenditures. Instead in DEL the lampposts are switched on when an user pass nearby and if nobody is present within the coverage radius *R*, the lampposts remain active for time window *W* and then are switched off. In DIM method each lamppost operates at 60 % light intensity in absence of users within the coverage radius *R*. Lampposts light up/dim the light intensity in proportion to the number of the users passing nearby. The last two methods were thought using equipped streetlights with LED lamps technology.

Final results were carried out using CrowdSenSim. It is a custom simulator for crowdsensing evaluation ables to perform an emulated environment in order to evaluate statically the goodness of crowdsourcing applications. I strengthened it adding a new module ables to set street lampposts layout. Exploiting CrowdSenSim's users mobility algorithms I computed the CAPEX and OPEX of the proposed methods after the first year since application. The final evaluations are applied to Luxembourg city. Assessments show the goodness and the valuations for each method. ENC method ensures a slight improvement in terms of OPEX of energy spent, nearly to 6.7 %. However obtained with a minimum lampposts reinforcement containing the CAPEX spent. Instead DEL permits an high OPEX saving close to 58 %, however in the other hand CAPEX spent for implemented. It is due to the expenditures for equip lampposts with LED lamps technology. Although the OPEX spent is already low compared with CUR with the same CAPEX spent it is possible to more improve the energy saving using DIM heuristic, reaching an improvement nearly to 67 %. The latter method is the most convenient, already economic after the first year since the implementation.

One equal temper of heroic hearts,
Made weak by time and fate, but strong in will
To strive, to seek, to find, and not to yield.

Ulysses
Alfred Tennyson

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I would first like to thank my thesis supervisors Prof. Fabrizio Granelli of University of Trento, Dr. Claudio Fiandrino from IMDEA and Dr. Dzmitry Kliazovich from ExaMotive. I would not have the chance to come in Luxembourg and to be assumed for the internship without them. A special thank to Dr. Claudio Fiandrino always readies to help and support me in time of need. This accomplishment would not have been possible without his advices. I am grateful to Prof. Fabrizio Granelli for believing in me, giving me the chance to express myself in this accomplishment. A special thank also to Dr. Andrea Capponi, to which I always wondered opinions about the internship period. Finally, I must immensely thank to my parents and my sisters for always encouraged me and then to my friends that have supported me in this experience abroad. Lastly I would thank to the wonderful people that I met in Luxembourg that even now are close to me. I am infinitely grateful to you all.

Contents

Chapter 1

Introduction

1.1 Motivation

Smart cities and green technology has becoming one of the world agenda in preparing for better future. Previous traditional autonomous street light design may have neglected the important of environmental issues such as emission of Carbone Dioxide(CO) in the implementation thus has exposed the world to new mankind challenges which is climate change. Acknowledging the important of preserving the world, smart city concept is introduced to monitor, control and manage the resources such as energy and water utilization in the building and outdoor. World population living in cities has experienced an unprecedented growth over the past century. While only 10% of the population lived in cities during 1900, nowadays this percentage corresponds to 50% and is projected to augment in the next years [24]. Sustainable development plays therefore a crucial role in city development. While nearly 2% of the world's surface is occupied by urban environments, cities contribute to 80% of global gas emission, 75% of global energy consumption [12] and 60% of residential water use [24].

With the aim of improving citizens' quality of life, significant research efforts are undergoing to provision citizens innovative and sustainable solutions for public services such as healthcare and wellbeing, safety and smart transportation among the others [56]. To achieve these objectives, smart cities rely on Information and Communication Technology (ICT) solutions [9, 56]. The application of the Internet of Things (IoT) paradigm to urban scenarios is of special interest to support the smart city vision [56, 34]. IoT is indeed envisioned as the candidate building block to develop sustainable ICT platforms. In IoT, everyday life objects are "smart", i.e., they are uniquely identifiable and are equipped with computing, storage and sensing capabilities and can communicate one with each other and with the users to enable pervasive and ubiquitous computing [2]. Taking advantage of the variety and the potentially enormous volume of the data generated by these devices will foster the development of innovative applications in a broad range of domains. Including citizens in the loop with crowdsensing approaches augments capabilities of existing infrastructures without additional costs and is proved to be a win-win strategy for smart city applications [10] [44] [3].

Public lighting is an traditional service provided by lampposts widely distributed in streets and roads. Augmenting lampposts capabilities with sensors and communication technologies making them IoT-based has the potential to unleash a number of services. To illustrate, lampposts can monitor traffic, noise and air pollution and increase coverage of cellular and WiFi networks and enable Visible Light Communications (VLC) [58] [47]. Unfortunately, the costs for deploying a new IoT-based lighting infrastructure appear to be high and the benefits in having an infrastructure provisioning a number of integrated services remain unclear. For this reason, in this thesis I provide an analysis on costs and benefits in deploying an IoT-based infrastructure for the *sole* service of public lighting. Nowadays urban street lighting is not energy efficiency. Generally, the lighting systems are built using old technologies and usually municipalities are not interested on improve them mostly due to the system geographical extension and consequently to the high initially expenditures. Typically, the lampposts are equipped with High Pressure Sodium (HPS) lamps. It is considered an old technology due to a low lifetime and to the low efficacy compared to Light-Emitting Diode lamps (LEDs). The latter are designed to augment/reduce the light intensity while HPS not.

1.2 Contribution

The thesis analyses and computes costs and benefits in bringing changes to the current street lighting system. Nowadays the current system is composed by technologies evaluated obsoletes and more broadly it is an expensive solution for municipalities. It is not efficient and it has an impact of the municipalities budget at least of 40% of the energy consumption. Consequently my purpose was proof how, with small changes, it is possible achieve a significant energy and cost saving. First of all I researched and analysed how the current method for street lighting works regarding the case of the city centre of Luxembourg. HPS lamps are widely used in our cities, suitable if compared with HPS lamps, however considered outdated from scientific community. Indeed they have a lifespan of a quarter and a less efficacy if compared to LEDs. Furthermore LEDs could be dim and have a less power consume in order to obtain the same brightness. The current method is based on the timing concept. Every lamppost exclusively stays on at maximum intensity, during certain hours, in which natural lighting is not enough to cover the needs of the city. More in details every lampposts stays on for 10 hours, between 9 pm to 7 am. During my internship I develop three new heuristics for smart lighting, based on the peculiar features of the available technology. The base idea of the new methods for lighting control is to take into account not timing concept exclusively, however the users presence nearby the lampposts. In this way, the whole system is more efficiency reducing the waste energy. Therefore, in order to know where pedestrians are approaching, all the heuristics are thought considering the installing of presence sensors.

The evaluations of the goodness of the new methods was carried out using a custom simulator named CrowdSenSim. Which was developed at Interdisciplinary Centre for Security, Reliability and Trust (SNT), to which I have taken part. A discrete-event simulator which supports realistic urban environments for the deployment of lampposts in the streets and pedestrian mobility. Its hallmark, it emulates the flow of pedestrians in the city, using a human mobility model defined as sequences of spatio-temporal movements. Through it was possible compute the energy consumption of each lamppost based on the presence of pedestrians nearby lampposts. Therefore, exploiting the main features of the above-named tool, I achieved the results of the operation of the new methods. Otherwise without it the spent time and above all money expenditures for the evaluations would have been really high. All the final results are computed considering just the first year since the updating of the lighting system. CAPEX are related to the improvements of each lampposts in order to support the new heuristics. OPEX spent are referenced to the energy spent for the correct operation. Thus this survey will give an economic evaluation on which are the possible solutions to improve the current street lighting system in terms of energy consumption and consequently of economic savings, specially considering the latter European commitments for environmental sustainability. It is worth to notice that the achieved results are not only applicable to the case study of Luxembourg city.

1.3 Organization

The thesis consists of Chapter 2 which describes the current implementation for street lighting in our municipalities, standardization efforts, nowadays lamp technologies and then the proposed heuristics for the management of street lighting in a smart cities scenario. Chapter 3 highlights the main features and theoretical assumptions regarding crowdsensing, analyzing the characteristics of *participating* and *opportunistic* crowdsensing, describing the currently state of the art regarding the simulators useful for emulation of large scale crowdsensing data acquisition. Afterwards are presented the features of CrowdSenSim simulator, developed during my internship at the University of Luxembourg, focusing on principles and main features. In the last part of the Chapter 3, is reported a descriptions of performances in terms of memory and time consuming of the presented tool. In Chapter 4, first focus on the changes made on CrowdSenSim in order to use it for the performance evaluations of the proposed heuristics for smart lighting discussed in Chapter 2 and lastly is reported the case study applied at Luxembourg municipality with the obtained results. Lastly, in Chapter 5, are discussed conclusion and future research works as well.

Chapter 2

Smart Street Lighting

2.1 Background on Smart Lighting

The Europe 2020 Strategy defines three targets in regards to climate change and energy: i) reduction of 20% of greenhouse gas emission, ii) increment the production of energy from renewable energy by 20%, and iii) increase of the energy efficiency by at least 20% [14]. Lighting causes nearly 19% of worldwide use of electrical energy and entails a 6% of total emissions of greenhouse gases. A decrease of 40% of energy spent for lighting purposes is equivalent to eliminate half of the emissions from the production of electricity and heat generation of the U [11]. In this context, public street lighting, which is an essential community service, plays an important role, as it impacts around 40% of the cities' energy budget. Consequently, in preparation of the EU commitments, optimizing the lighting service is a primary objective for the municipalities [50]. The street lighting solutions currently implemented in cities are not energy efficient. Typically, every lamp operates at full intensity and power nearly 12 hours a day according to the season, i.e., 8 hours during summer and 14 during winter [50]. As a result, the cost for the municipality is high [11].

Almost all luminaries that are used in street lighting do not have communications, control and management infrastructure, the current technology is thus obsolete. Furthermore, the system is also not capable to measure useful information from the luminaries, i.e energy consumption or detection of possible failures. The large majority of street lighting systems were designed using old equipment and techniques.

Unfortunately, the geographical extension of the existent infrastructure poses as well as the number of the street lampposts pose a serious economic challenge to municipalities, thus hindering the deployment of smart lighting systems in a wide scale.

Nowadays, due to the advance in science as well as the increase number of industrial researches regarding the development of modern devices and computational processes, it is possible improve the current system. Therefore, it is possible to notice that artificial lighting systems represent a wide prospective for energy cost saving and it is an indicator of life quality. Within this context, the usage of alternative methods, to reduce energy consumption could provide significant economic saving and reduction of environmental impacts. Without losing the comforts on conventional lighting systems. From this reasons the EU has actively promoted political campaigns toward energy efficiency such as Horizon 2020 [14]. The efficiency could be improved by adopting new equipment, such as lamps and sensors, with high performances and by arranging lighting design practices, in order to guarantee the best illumination level.

Smart Lighting defines an heterogeneous lighting technologies such as light-emitting diode (LED), high pressure sodium (HPS) luminaries equipped of numerous sensors and actuators and with the possibility of incorporating a wide set of capabilities and connectivity interfaces. The most important intelligent features are related to enabling advanced functions such as adjustable spectral reproduction, colour tunable-lighting and adaptive dimming, combining energy efficiency with the real needs of the illuminated space taking into account available natural lighting. With the rise of the digital connectivity options, smart lighting systems have different wired and wireless interfaces oriented to increment the connectivity in smart grid systems. These systems allow to control and monitor modern and heterogeneous electrical equipments. The main interfaces conceived for wired lighting systems are Digital Addressable Lighting Interface (DALI), Power Line Communications (PLC), Digital Multiplex (DMX512) and KNX for intelligent buildings.

Ultimately, improve the current infrastructure represents a prominent prospective not only in economics term but especially in term of environmental impact.

2.1.1 Standardization Efforts for Street Lighting

Lighting systems, specially in the public sector, are still designed according to the old standards of reliability and they often do not take advantage of the latest technologies developments. In many case, this related to the plant administrators who have not completed the return of the expenses derived from the construction of existing facilities yet.

However, the recent increasing pressure related to the raw material costs and the greater social sensitivity to environmental issues are leading manufactures to develop new techniques and technologies which allow significant cost savings and a greater respect for environment.

European Standard for Street Lighting and Lampposts Position

Symbol	Description
$\tilde{L}$	Luminance of the road surface averaged over the carriageway, measured in cd/m^2
E_{min}	Lowest illuminance value on a road area, measured in lx
$\tilde{E}_{hs}$	Horizontal illuminance averaged over a road area, measured in lx

Table 2.1. Symbols description

European Committee for Standardization (CEN) approved the European Standard *EN 13201-2* in order to guarantee a common regulation for roads lighting in the CEN countries.

European Standard, according to photometric requirements and parameters, defines *lighting classes* for street lighting aiming at the visual needs of road users, and it considers environmental aspects of road lighting.

For this purpose, in the European Standard the following terms and definitions are took into account.

- Average Road Surface Luminance (of a carriageway of a road)($\tilde{L}$):
  luminance of the road surface averaged over the carriageway (cd/m^2).
- Minimum illuminance (on the road area)(E_{min}):
  lowest illuminance on a road area (lx).
- Average illuminance (on a road area)($\tilde{E}_{hs}$):
  horizontal illuminance averaged over a road area (lx).

The previous definitions determine the features and characteristics of the streets. More in details, according to those values reported in the document, the European Standard distinguishes five lighting classes:

- Medium illuminance (ME) is a class defining streets intended for drivers of motorized vehicles for user on traffic routes allowing medium to high speeds.
- Complexity illuminance (CE) is a class defining roads for drivers of motorized vehicles, however considered *conflict area* such as shopping streets, road intersections of some complexity, roustabouts and queuing area. These class have applications also for pedestrians and pedal cyclists.
- Cyclists street (CS) is a class defining roads intended for pedestrians and pedal cyclists for use on foot-ways and cycleways, emergency lanes and other road areas lying separately or along the carriageway of a traffic route, residential roads, pedestrians streets, parking areas, school-yards etc.

- Emergency street (ES) is an additional class in situations where public lighting is necessary for the identification of persons and objects and in road areas with a higher than normal crime risk.
- Vertical illuminance (EV) is an additional class as an extra class in situations where vertical surfaces need to be seen in such road areas as toll stations, interchange areas etc.

Table 2.2. Photometric requirements and parameters for classes streets

Class Street	$\tilde{L}$ **(cd/m^2)**	E_{min} **(lx)**	$\tilde{E}_{hs}$ **(lx)**
ME	2.0	40	43
CE	3.0	50	56
CS	2.0	15	21
ES	4.0	10	16
EV	3.0	50	56

For the purposes of the evaluation, I considered solely roads part of the class CE, ES and CS, since I tested the following *heuristics* in the case study of Luxembourg city centre. Particularly, in order to refer to the European Standard, the values reported in the Table 2.2 are considering for my purposes.

Regarding the distance between lampposts, in the previous European Standard there are interesting suggestions. However, unfortunately there is not a common standard value between the CEN countries. This is not possible because those countries have many geological, weather conditions which affect significantly the minimum distance between luminaries. For instance, in Italy, the european standard is strongly influenced by the local geographic conditions. The wind action sets limit to the lampposts minimum distance, specially in the regions with an high intensity. Statistically approximating, typically the height of each lampposts is a value between 5 m and 7 m. Instead the distance between lampposts is commonly of 20 m [48].

2.1.2 Lamp Technologies

There are several types of lamps applicable for the public street lighting, including HPS, Metal-halide (MH) lamps, Compact Fluorescent lamps (CFL) and LED. The list does not comprise all possible technologies. For example, the use of mercury-vapour lamps for lighting purposes was banned in the EU in 2015 [1]. HPS is the most common technology currently implemented in EU streets [32]. Nevertheless, in terms of average lifetime, maintenance, electrical performances and energy savings, LED technology appears to be the most convenient solution [37].

Table 2.3 compares different types of lamps. LEDs have an average lifetime 4 times longer than HPS lamps and 10 times longer if compared to MH lamp. Installing LEDs is an effective solution to reduce hardware, installation and maintenance costs. Low wattage provides significant energy savings. In addition, it allows to increase the lamp efficacy compared with the others lamps [35], [30]. LED lamps can dim the light intensity by more than 50% modifying therefore the output level of light according to the circumstances. For example when traffic is low or in areas of the city unvisited during a certain time like parks at night. The city of Brittany in France, dims street lights by 60% between 11 PM and 5 AM to decrease waste energy [50].

Below are reported descriptions about HPS and LED lamps. The first represents the most common lamp technology presence in the street lighting of the European countries, while the latter are the vanguard in terms of energy savings and environmental impact.

High Pressure Sodium (HPS)

A sodium vapour lamp is a gas-discharge lamp exploits *sodium* in an excited state in order to produce light with a common characteristic wavelength near to 589 nm. Nowadays, there are two differences configurations of this lamp: *low pressure* and *high pressure*. The first variety has an highly *efficacy*, however its characteristic yellow light narrows the application areas. Particularly it gives only a *monochromatic* yellow light and consequently inhibits colour vision at the night. Instead HPS produces a broader spectrum of the emission light. Commonly HPS lamp is widely use, not exclusively in the public street light, but also in the industrial lighting and also used in plant grow lighting systems. HPS lamps are quite *efficacy*, as Figure 2.3 illustrates, about $100\,\mathrm{lm\,W^{-1}}$. The higher power lamp, 600 W, has an *efficacy* of $150\,\mathrm{lm\,W^{-1}}$. The Figure 2.1 shows the diagram of HPS lamp. The sodium arc, presences inside the lamp, is extremely chemically reactive and it is triggered by Xenon at a low pressure used as starter gas.

Light-emitting diode (LED)

LED technology is based on two-lead semiconductor light source. In each LED there is a p-n junction diode, as reported in Figure 2.2, which emits lights when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in form of photons. This effect is called electro-luminescence and the colour of the light (corresponding to energy of the photon) is determined by the energy band gap of the semiconductor. They are essentially electronic component with excellent

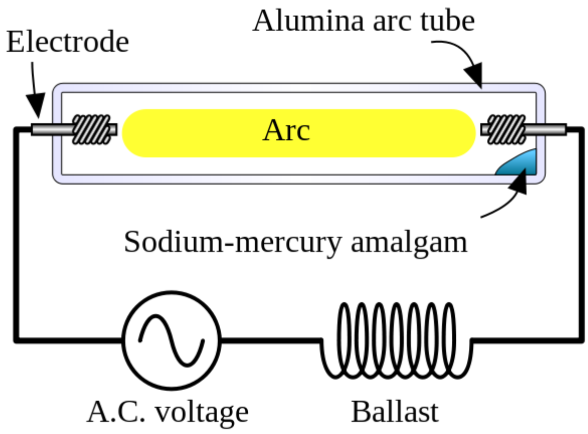


Figure 2.1. HPS technology

dimming capabilities and very narrow peak bandwidths, which allow a great degree of control over the produced light spectrum.

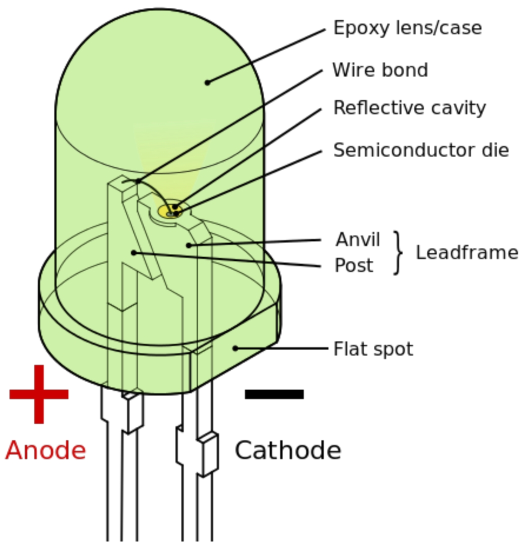


Figure 2.2. LED technology

The first commercial LED products were introduced in 1968. The initial performance of LEDs was poor, with maximum output fluxes of around one thousandth of a lumen, and only one colour, deep red.

However steady progress has been made, and efficiencies and brightness have surpassed those of incandescence, while the colour range has been extended to the entire visible spectrum. High *efficacy* if it is compared with the *power*, low driving voltage, fast switching characteristics and compatibility with networked computer controls enable LEDs to be the subject of a new technology called Smart Lighting with software controlled stability, operating function, adaptation and energy saving.

Table 2.3. Comparison of lamp features and technologies

Type of Lamps	Nominal Wattage (W)	Lamp Efficacy (lm/W)	Energy Consumption (kWh/1000 h)	Average life (h)
HPS-97241	150.0	110.0	172.7	24 000
HPS-93010296	250.0	129.0	283.4	24 000
MH-NaSc	100.0	90.0	165.0	10 000
LED-GRN60	46.8	131.0	51.8	100 000
LED-GRN100	73.3	138.0	82.7	100 000

Current Method for Controlling Public Lighting

Current Implementation (Cur): The most widely implemented methodology for road lighting makes lampposts to operate at full light intensity for a predefined period of time. Typically lampposts operate continuously for an average of 10 or 12 hours a day. More in details the average value depends on the different variables such as the current season and the natural light intensity. Nowadays, usually in European cities each lampposts of public lighting is equipped with HPSs lamp and, as seen in the Table 2.3, it is not the optimized choice in term of waste energy. Furthermore this implementation does not account at all for presence of users passing nearby the lampposts, as a results it is expected to be the lowest in terms of efficiency (see Table 2.4).

2.2 The Proposed Smart Lighting Solutions

This section presents the three new proposed heuristics for smart lighting solutions, detailing the technology and the control mechanisms employed. In the context of energy-aware lighting, a number of control mechanisms was proposed [31]. The most important strategy is *occupancy*, which makes the lamps switch or dim the light intensity according to the presence of users or vehicles. In this paper, we adopt the occupancy control strategy suitable for pedestrian zones in smart cities.

Lighting control can be performed in distributed or centralized manner. With the latter method, a coordinator unit is responsible to control a cluster of lampposts on the basis of their feedback on users presence [52]. With the former method, each lampposts operates independently. Distributed control systems require a significant change in the infrastructure while centralized solutions can be deployed with less invasive intervention on the existing infrastructure. However, as the employed control policy is occupancy-based, distributed systems have the potential to achieve higher energy savings because they react quickly to the change of user presence. In this work, we adopt a completely distributed system.

Table 2.4 briefly summarizes the properties of the three different smart lighting solutions proposed in comparison with current adopted approach. For each method, its efficacy is denoted as low (Lo), medium (Me) and high (Hi).

Table 2.4. Smart lighting solutions

Method	Acronym	Description	Efficacy
Current	Cur	Lampposts remain continuously active emitting maximum light intensity.	Lo
Delay-based	Del	Lampposts are switched on when users pass nearby. If nobody is present within the coverage radius R, the lampposts remain active for time window W and then are switched off.	Hi
Encounter-based	Enc	Lampposts are switched upon the first encounter with at least one user and remain active the whole night.	Me
Dimming	Dim	Lampposts operate at 60% light intensity in absence of users within the coverage radius R. Lampposts light up/dim the light intensity in proportion to the number of users passing nearby.	Hi

Unlike Cur the heuristics we propose take into account the presence of users nearby the lampposts to save energy. In order to satisfy the goal of notice the pedestrians presence, the lampposts must be modified. The objective is achieved installing a presence sensor like the SE-10 PIR motion sensor, which provides excellent performance and good reliability [28]. Equip every lamppost involves a consistent expenditures called Capex which are detailed in the following Chapter 4. The task of the detector sensor is to identify the passage of pedestrians, giving an input to turn on a lamp. This function depends on the model of the road; in case of a street without crossroads, a single sensor is sufficient, while for a road requiring more precise control, a solution with multiple presence detectors is necessary. The feature enables switching on the lamps only when necessary, avoiding a waste of energy. The main challenge with such a sensor is its correct placement. The sensor should be placed at an optimal height, not too low in order to avoid any erroneous detection of small animals, nor too high to avoid failure to detect children. A study of the sensor placement enables deciding the optimal height according to the user needs and considering the specific environment in which the system will work. With presence sensors, every lamppost is able to recognize the presence of citizens within a certain radius R like Fig. 2.3 illustrates. The Figure 2.4 shows the operating principles of the detector sensor. The user U^1 changes position in the following time instant t_1, however s/he is within the coverage radius R of the sensor. Instead, for the user U^2, at the time instant t_2 is not more inside the cover radius R, therefore the sensor is not able to recognize the user presence. Finally, the detector transfers the collected information to the controller that will take the decisions.

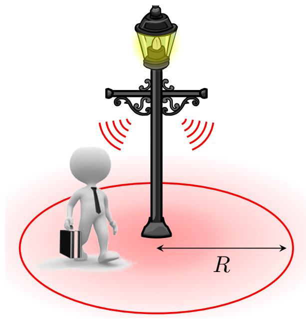


Figure 2.3. Coverage radius R

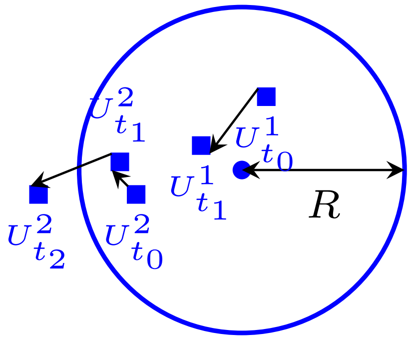


Figure 2.4. Operating principles of detection sensor

Delay-based (Del): As shown in the Algorithm 2 each lamppost remains active as long as the motion sensor detects presence of users. Then, when the sensor does not detect any user, signals to the lamp to wait for a time window W before turns off. If the lamp is turned off, the detection of any users within the distance R makes the lamp to turn on. The methodology can employ both LEDs and HPSs lamps. For the latter type of lamps, that are the most common in our cities [22], after turn on, it might take around 15 minutes to the lamp to reach the maximum brightness, because the sodium inside the bulb needs to be fully heated [54]. As a result, LEDs should be preferred for employment in Del. The method is expected to be highly energy-efficient.

Encounter-based (Enc): The Algorithm 1 shows the proposed method which is a variant of Del. The lampposts turn on after the first user passes nearby and remain active until the end of the predefined activity period in the morning. Although being simple, the method is expected to improve Cur. Moreover, as lamps do not need to be switched on and off frequently, HPS technology can be employed saving capital expenditures. For this reason, Table 2.4 rates Enc to be medium efficient.

Algorithm 1 Encounter-based(Enc) algorithm

Input : List of Users Events (L_1), List of Lampposts Positions (L_2), Coverage Radius of Lamppost Sensor (R)
Output: Period of Activity each Lamppost
$\forall$ *Lamppost* $\in L_1$
$\forall$ *User* $\in L_2$
compute the *haversine* distance d between *Lamppost* and *User* position
if $d \leq R$ **then**
  activate *Lamppost* till the end of predefined activity period
end

Algorithm 2 Delay-based (Del) algorithm

Input : List of Users Events (L_1), List of Lampposts Positions (L_2), Coverage Radius of Lamppost Sensor (R), Time Window (W)
Output: Period of Activity each Lamppost
$\forall$ *Lamppost* $\in L_1$
$\forall$ *User* $\in L_2$
compute the *haversine* distance d between *Lamppost* and *User* position
while *the predefined activity period is not ended* **do**
  if $d \leq R$ **then**
    activate *Lamppost* as long as the motion sensor detects an *User* within R
  end
  if *the User is not longer within R* **then**
    the *Lamppost* remains activate till the end of W
  end
end

Dimming (Dim): The last proposed method dims the light of lampposts in proportion to the number of users in the vicinity. Similarly to the solution adopted in Brittany, i.e., the minimum light intensity level is 60% if no users are within the coverage radius R and increases or decreases proportionally on the basis of the passage of the users. In our case study I opted to increase the light intensity of 10% for every two pedestrians detected. In more details, if the number of users

Algorithm 3 Dimming (Dim) algorithm

Input : List of Users Events (L_1), List of Lampposts Positions (L_2), Coverage Radius of Lamppost Sensor (R)
Output: Period of Activity each Lamppost
$\forall$ *Lamppost* $\in L_1$
$\forall$ *User* $\in L_2$
compute the *haversine* distance d between *Lamppost* and *User* position
while *the predefined activity period is not ended* **do**
  if $d \leq R$ **then**
    increase the *Lamppost* intensity by 10% or remains at 100%
  end
  if *the User is not longer within* R **then**
    the *Lamppost* remains to the intensity level previously reached till the end of W then decreases it by 10%
  end
end

is increasing, then the light intensity increases or remains at 100%, while if the number of users reduces from previous status, then the light intensity reduces until it reaches the minimum level. Particularly every lamppost decreases the light intensity after a time window W. With this delay the lamppost avoids unnecessary decreases if in that time window there are pedestrians entering within its coverage radius R. The Algorithm 3 illustrates the process for the new discussed heuristic Dim.

The HPS lamps do not support dimming [37] and only LEDs can be employed to perform dimming properly. The use of LEDs is gradually gaining popularity due to its photo metric characteristics, such as low weighted energy consumption (kW/1000hrs), high luminous efficacy (lm / W), high mechanical strength, long lifespan and reduction of light pollution [32, 37]. This solution is expected to be highly efficient (see Table 2.4).

Chapter 3

CrowdSenSim: a simulator for Mobile Crowdsensing

The following chapter introduces a simulation environment developed for analysing crowdsensing based applications in the Smart City domain. During my intern ship at SnT (nterdisciplinary Centre for Security, Reliability and Trust) research group I constantly worked on the elaboration of CrowdSenSim simulator. More in details I was involved in creating the first public release of CrowdSenSim. The simulator is totally implemented in C++ and it allows to investigate the critical issues of smart city applications based in crowd-sensing paradigm, and estimates the goodness of introducing such applications. Furthermore, CrowdSenSim permits to test new applications without spending large amounts of resources. I adapted the features of the new simulator to street lightning case study, in order to obtain an emulated environment to test the different proposed heuristics.

3.1 Mobile Crowdsensing

Nowadays, IoT (Internet of Things) devices market is well established and Cisco predicts the global Internet of Things market will be $14.4 trillion by 2022, with the majority invested in improving customer experiences. They constantly communicate with each other and with users, to continuously enable computing power. They are equipped with communication, computing, storage systems and most relevant, they have sensing capacities. Modern IoT devices, as smart phones, own several sensors capable of perceiving the surrounding environment.

Smart cities concept aim to improve the quality of life of citizen by improving the existing public services or by fulfilling innovative solutions for healthcare, public safety and smart transportation. Moreover, Smart cities heads toward to reduce the environmental impact of modern municipalities, in terms of waste energy. Smart cities concept aim at using ICT solutions to do that. The IoT paradigm is the most important candidate building block to develop sustainable ICT platforms for Smart Cities.

3.1.1 Background

Nowadays the most natural form of volunteered co-operation between people living city of the near future is crowdsensing. It is a distributed problem-solving model where a certain amount of agents are engaged to solve a complex problem. In this scenario, the network of 'sensors' consists of people, the group of human users are called 'crowd'. They can collect and share a several types of data with their modern smartphones and devices [21], which have a large multi-sensing capabilities including geolocation, light, movement, and audio and visual sensors. Thus, they perform some form of sensing and thereby become citizen sensors [23]. The time is not far when people will be continuously sharing useful information in urban environments [55]. In mobile crowdsensing (MCS), the data collection could be or *opportunistic* or *participatory* [18] [39] . In *participatory* sensing systems, every participant is engaged in accomplishing sensing.The MCS system assigns a particular *task* to an users available. This solution requires a "central intelligence" in order to manage all the *tasks* and all the participants to the sensing. In this scenario, one of the most key challenges is participant recruitment problem. In other words how to select appropriate users to perform different sensing tasks satisfying certain constraints. More studies in this context were conducted. In [29] are proposed new participant recruitment algorithms. In [57], the approach is totally different compared to the previous study, a centralized organizer is required. In order to choose among many users, the MCS organizer collect historical cellular signaling data of the users and study their trajectories and mobility patterns which indicate their capabilities in completing the crowdsensing tasks. All the mentioned studies were related to the user recruitment according to conditions of user sensors. In [27] is studied in deep a different point of view. The motivation part is served by monetary incentives. The sensor data providers chose the fees they charge for contributing to the information collection campaign and it is then up to the service provider to recruit those who sustain the highest value for money for the its service [25] [53].

In the *opportunistic* solution, the sensing data are generated and reported automatically by the crowd devices. Therefore it is much easier, compared to the previous one, but it is more appropriated for distributed solutions.

Therefore MCS plays an meaningful role, collecting cartographic and environmental data such street steepness, noise levels and pollution, traffic delay in urban areas becomes a tractable problem if the sensing can be crowdsourced.

In MCS data collection architectures the participants contribute information from mobile devices' sensors. This information is then delivered to a collector, typically located in the cloud, for data processing and analysis. The users deliver collected data using cellular 3G/LTE/4G or WLAN interfaces. Therefore, it becomes important to understand and assess the costs of sensing and data reporting for individual users as well as data collection capacity of the system, while maximizing the utility of the collected information. Fig. 3.1 illustrates the main elements of the MCS system.

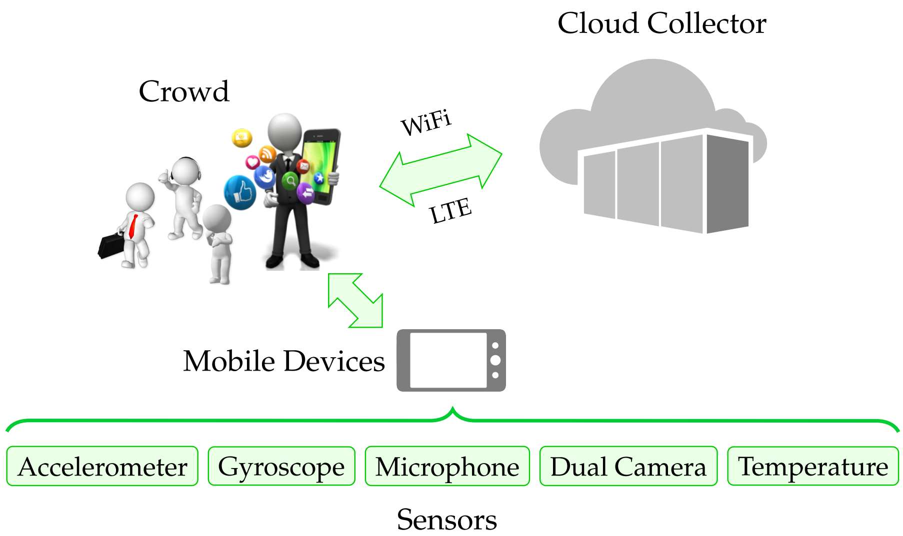


Figure 3.1. Cloud-based MCS system

A data collection framework defines the set of steps necessary to produce and deliver the information from the participants to the collector. Existing frameworks are all general-purpose or application-specific. Application-specific frameworks target only one type of application at the time. To illustrate with few examples, GasMobile [26] and NoiseMap [45] allows monitoring air and noise pollution respectively and DietSense [43] fosters healthy eating by collecting information on the type and location of consumed food.

Certainly the MCS domain, faces challenges like handling big data, developing suitable algorithms, or maintaining privacy and security. The main issue to confront, developing novel systems/applications, which utilize MCS, could be costly and the efforts could easily become unsuccessful. Therefore it is essential to perform extensive domain and risk analysis before embarking on developing a novel MCS application. One of the useful approaches in both domain and risk analysis is using simulations [46] [40] [42].

The most simple solution for testing MCS is creating simplified representation of the field of interest and developing tools for analysing the expected behaviour of the crowd in the problem domain. Simulating MCS scenarios is useful to investigate the possible prospective behaviours of the crowd and assess whether a suitable amount of information might be gathered to provide a pre-specified level of service quality, such as establish that a future MCS application will solve an issue for the end user. However, the number of existing simulation environments appropriate for inspecting MCS efforts is limited.

3.1.2 Existing Simulators for Crowdsensing

Network Simulator 3 (NS-3) is useful for crowdsensing simulation, how Tanas et al. suggest [49]. The goal is to estimate the performance of a crowdsensing network considering the the wireless interface in ad-hoc network mode together with mobility properties of the nodes. Afterwards the authors present a real application about how participants could report incidents in the public rail transport. The main feature of NS-3 is ensure highly accurate assessments of network properties. However, having detailed information on communication properties comes with the cost of losing *scalability*.

Due to this lack with NS-3 is not possible to emulate tens of thousands of users contributing data. Moreover, the duration of a single simulation is typically in the order of minutes and this sets strictly limits to its use. Indeed, the goal is to capture specific behaviours e.g. the changes of the TCP congestion window. However, the duration of real sensing campaigns is typically in the order of hours or days.

In [15] the authors introduce instead a simulation environment adapted to investigate performance of crowdsensing applications in an urban parking scenario. Though the application structure is only parking-based, the authors Farkas and Lendàk assert that their solutions could be enforced to other crowdsensing scenario as well. However, the scenario considers only drivers as type of users and them travel from one parking spot to another one. The authors consider humans as sensors that trigger parking events. However, to be widely applicable, a crowdsensing simulator has to take into account data generated from mobile and IoT devices' sensors carried by human individuals.

Mehdi et al. propose CupCarbon [33], which is a discrete-event wireless sensor network (WSN) simulator for IoT and smart cities. One of the major features is the possibility to model and simulate WSN on realistic urban environments through OpenStreetMap. To set up the simulation, the users have to deploy on the map the various sensors and the nodes such as mobile users, gas and media sensors and base stations. The approach is not intended for crowdsensing scenarios with thousands of users.

3.2 CrowdSenSim

CrowdSenSim is a new tool for simulating mobile crowdsensing activities in realistic urban environments. As following explained, after features street extraction, the tool allows evaluations about the data collected through users walking within the city. Therefore, it permits to estimate the goodness of proposed smart cities applications, decreasing the whole amount of money otherwise necessary. CrowdSenSim is specifically designed to perform analysis in large scale environments and supports both participatory and opportunistic sensing paradigms. CrowdSenSim allows scientists and engineers to investigate performance of the MCS systems, with a focus on data generation and participant recruitment. The simulation platform can visualize the obtained results with unprecedented precision, overlaying them on city maps. This permits to have data and information direct on the urban layout and allows to understand where apply changes for the study case application. During simulation CrowdSenSim computes runtime a number of statistics, including energy consumption and amount of data generated and provides the researcher to a visualization tool to display the results. In addition to data collection performance, the information about energy spent by participants for both sensing and reporting helps to perform fine-grained system optimization.

In the following sections are described the features and the characteristics of the proposed tool. The choice of implement it through independent modules permits to have an high modifiability according to needs.

3.3 Architecture and Features of CrowdSenSim

Fig. 3.2 describes the architecture of CrowdSenSim, implementing independent modules in order to characterize the urban environment of the current simulation, the user mobility, the communication and the crowdsensing inputs, which depend on the application and specific sensing paradigm current utilized. In Fig. 3.2 shows graphically all the relations between the different modules:

- City Layout module;
- List of Events module;
- User Mobility module;
- Crowdsensing input parameters module.

CrowdSenSim allows to emulate the flow of pedestrians in a *realistic urban environment*. The core of the proposed simulator is the concept of users *events*. The first two modules are in charge of defining the list of events, which is used to perform the simulations along with the inputs provided by the Crowdsensing input parameters module. All of the modules are totally independent by design. This programming choice represents one of the significant *feature* of the entire project. In this way we guaranteed an high level of *scalability*. The objective is to ensure to future developers the possibility to implement, for example, other mobility models without compromising the overall functionality of the simulator.

Table 3.1 describes the meaning of symbols that are useful hereafter. By definition, MCS systems require a substantial number of potential contributors. Therefore, CrowdSenSim is developed to take into account participants in the order of tens of thousand moving in a broad realistic urban environment. Each pedestrian could potentially own several number of IoT devices. The time duration is a crucial point as well. The duration of sensing campaign could range between hours to days and the developed simulator manages this challenge correctly. For instance, considering 10000 pedestrians taking a walk around the city, producing data with a duration of only 30 min per day. Having commonly available sensors on market like an accelerometer working at 50 Hz frequency with 12 bit long samples, the total amount of generated data by each user would be 1.35 GB. Considering the prolonged duration of the pedestrians contribution and additional sensors would considerably augment this figure. The remainder of this section describes the functionalities of each module in detail.

Table 3.1. Symbols list and description

Symbol	Description
C	Set of coordinates defining the city layout
T_{move}	Amount of time each user moves in the city
S_{move}	Velocity of user movement
c_a	Coordinate where a user starts moving
t_a	Time when a user starts moving from c_a
c_{next}	Next coordinate of user movement
t_{next}	Time of arrival in the next coordinate c_{next}
t_{travel}	Time necessary to move between two coordinates
E	Energy spent for communication purposes
P_{tx}	Power consumed for transmission over WiFi link

3.3.1 City Layout Module

In order to realize an appropriate level of accuracy and precision of the simulation, in CrowdSenSim, pedestrians move in a real urban scenario. Therefore it allows to perform analysis and statistics providing meaningful insight to the cities to comprehend the potential and the feasibility of the new proposed MCS application. This approach, guarantees an high precision and no less important a substantial amount of saving resources. CrowdSenSim is flexible and easy to adopt to any city. The Fig. 3.3 shows possible cities layout configurations. Through this choice we aim to offer an emulator useful for every circumstances, increasing the potential of the proposed tool.

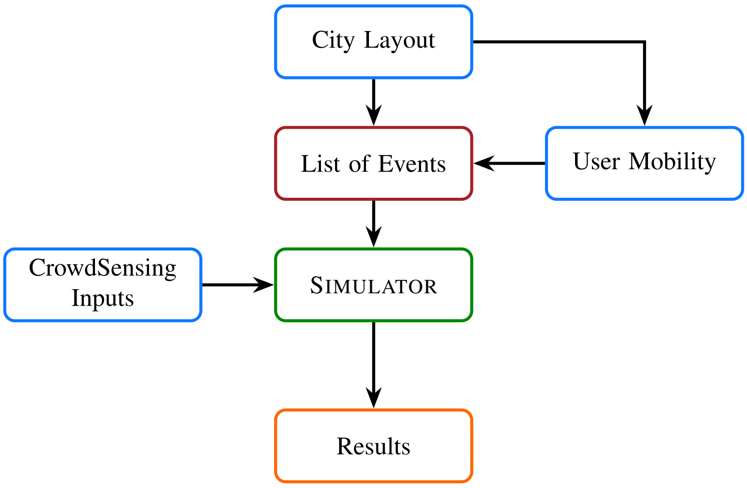


Figure 3.2. Architecture of CrowdSenSim

The information about the streets of the cities is obtained from a crowdsourced online tools like OpenStreetMaps or Digipoint[1] which provide free access to street-level maps in form of a set of coordinates C containing information on <*latitude, longitude, altitude*>, see Fig. 3.3. The set of coordinates composing the street layout is one input of the simulator and is used as basis for the user mobility model and the engine in charge of generating the list of events. More in details all set of points represent all the positions where pedestrians move inside the city.

Afterwords the download of CrowdSenSim it is possible to simulate, or a new scenario, with a new city layout or use the pre-configured simulation with the default cities environment. Fig. 3.3 shows off the urban environments current available for simulations, among which the city center of Luxembourg (see Fig. 3.3(a)), Trento (see Fig. 3.3(b)) and Madrid (see Fig. 3.3(c)). The center of Luxembourg city includes an area of 11.1 km s^2 with a population of 110 499 inhabitants as of the end of 2015 and is the home of many national and international institutional buildings. It is one of the three official capital of the European Union and the seats of the European Court of Justice. The city center of Trento covers an area of 1.18 km s^2 and has a population of 117 317 inhabitants as of the beginning of 2016 and is the capital of the homonym Province. It often ranks extremely highly out of all 103 Italian cities for quality of life, standard of living, and business and job opportunities. The city center of Madrid covers approximately an area of 5.23 km s^2 with a resident population of 149 718 residing inhabitants. Due to its economic output, high standard of living, and market size, Madrid is considered the major financial center of Southern Europe .

[1]DigiPoint: `http://www.zonums.com/gmaps/digipoint.php`

The city layout module allows the researcher to define the size of the city and the level of detail of the urban environment. High resolution of the city layout, which corresponds to choose a higher number of coordinates within *C* set, increases the precision of user movements, on the other side increases the cost of longer and more computationally expensive simulations. On the other side, a rough resolution of the city layout, due to choose a lower number of coordinates within *C* set, makes the simulations to run faster, but lowers the accuracy of users movements and precision of the urban environment. Therefore, according to the resolution of the simulation, CrowdSenSim can spend a consistent processing time, as Fig. 3.10(a) shows. It is important to notice that: having a high resolution of the urban environment permits to characterize places, e.g., to identify among the others bars, restaurants, schools or malls. Therefore increasing the number of coordinates allows a better definition of the cities and permits to reach an high accuracy.

3.3.2 List of Events Module

As previous mentioned, the concept of *event* is the center of the entire tool. An event is realized when a pedestrian moves from the *current position* c_a to the next c_{next}. When this happens, the user device sends, through the nearest base antenna, sensors data of the surrounding environment. The pre-configured scenario of CrowdSenSim contains three emulated sensors nowadays present on market, which features are reported in the Table. 3.2

Sensor	Parameter	Value	Unit
Accelerometer	Sample rate	50	Hz
	Sample size	12	Bits
	Current	35	µA
Temperature	Sample rate	182	Hz
	Sample size	16	Bits
	Current	182	µA
Pressure	Sample rate	157	Hz
	Sample size	16	Bits
	Current	423.9	µA

Table 3.2. Pre-configured sensors

In other words a *List of Events* is a sequence of users movements within the city, therefore a sequence of geographic succession positions, associated to the amount data sent. The choices of the users next *jump* are strictly related to the *Users mobility* algorithms, described later.

3.3.3 User Mobility Module

Understanding the rules that govern human mobility was a crucial point of the whole project. Human movements inside the city is determined from many variables, given by the human behavior. In mobile networks, human mobility pattern are the forefront, since it is the heart of the decision of the spatiotemporal position c_{next}. Every user chooses the next destination point following own needs. For instance a user, during a simulation day, could go at work place passing from city center and the taken path could be deeply different from another user. Broadly, human mobility is defined as sequence of spatiotemporal user movements. An high definition of users mobility in urban environment permits high accuracy of output data.

The user mobility module defines the user movements inside the city layout. At each user is assigned a *list of events* composed by a sequence of geographical positions among the set C associated to the city layout, each of which is "the arrival of an user in a given coordinate at a given instant of time". There are two different steps to determine the spatiotemporal list of events:

- *Initialization*: it characterizes the *location* and *time* of user arrival;
- *Mobility*: it characterizes the user movements after arrival.

Below are reported our choices of pedestrians mobility, available in CrowdSenSim.

Uniform Random Distribution

It is the simplest mobility algorithm developed and presents in the current implementation. The participants move along the streets of the city and their original location c_a is randomly assigned from the set of coordinates C. The initial time of user deployment t_a is also randomly assigned: by default it is uniformly distributed between 8:00 AM and 1:30 PM. In the current version of the simulator, the location is randomly determined among the set of coordinates C of the map. The design choice builds on the assumption that each of the coordinates has the same relevance, i.e., it does not exist a difference between popularity of places. This choice simplifies the pedestrians movements around the city layout, however it is still a consistent solution to evaluate a sensing campaign. Each participant owns the total amount of time T_{move} s/he travels, e.g. it is a value uniformly distributed between [10,30] min. The mobility model implemented is a random mobility model where user movements are constrained by the physical layout of the streets. There are not possible movements outside the C set of geographical points. More precisely, each participant *jumps* from a given coordinate c_a to another coordinate c_{next} in within the set of coordinates C. More deeply, every position has a related *adjacent list* of points, therefore the next *hop* c_{next}, is a location within the list, called *adjacent point*. It should be noted that c_{next} is selected as follows: by default, it is in the same street of c_a, otherwise it belongs to another street in case c_a is in proximity of intersections. In any case CrowdSenSim chooses a coordinate among C with a distance below a maximum radius. Given that the participant is in c_a at time t_a and s/he moves with an average speed S_{move} uniformly distributed between [1,1.5] m/s, it is possible to compute t_{next} after having determined the spatial distance between c_a and c_{next}. In details, the distance is computed by using the Haversine formula and, together with the speed of the movements, enables to determine the amount of time it takes between the two points t_{travel}.

Then, t_{next} is determined as follows:

$$t_{\text{next}} = t_a + t_{\text{travel}}, \tag{3.1}$$

and the total amount of time the user is allowed to travel T_{move} is updated as follows:

$$T_{\text{move}} = T_{\text{move}} - t_{\text{travel}}. \tag{3.2}$$

The user stops moving when $T_{\text{move}} \leq 0$. It is worth to highlight that during each movement the speed of the movement S_{move} changes. The new value is generated again uniformly distributed between $[1, 1.5]$ m/s to mimic the change of velocity during walking.

In the current version, users move only once during the simulation period, and it is not possible yet to define a direction of movement for each user. We plan to extend the simulator to take into account this possibility in the future extension of this study.

In CrowdSenSim, the arrival of a user in a given location at a given time is an *event*. Therefore the pedestrians collect data and forwarding them to the collector while moving. Once the walking period ends, each participant stops moving and contributing to the collecting process.

Time-based User Distribution

The pedestrians move around the city streets, however in this case their *first* location c_a is not randomly assigned. We opted to recreate an human mobility pattern had some more specifics.

We took into account that basically pedestrians within the city are not randomly present. The human density during a day depends, in a firstly analysis, on hour of day.

More in details, there are day hours, in which naturally there is a greater pedestrian density. Each user has a probability to start travelling that is defined by the probability density functions (PDF) defined in Fig. 4.3, 4.4, 4.5. The PDF shown in Fig. 4.3 contains information about pedestrians presence inside the city. More specifically, in the firsts and in the latest hours of the simulation day the users presence probability is more high. The probability function in Fig. 4.4 highlights a different situation. The presence of users in the urban environment is more high during the firsts hours of the simulation going to decrease by the hour. The last option is shown in Fig. 4.5. The pedestrians presence is more high at the latest hours of the simulation day. The whole previous concept could be expressed as follows:

$$u_{\text{slot}} = U * p_{\text{slot}}, \tag{3.3}$$

where u_{slot} is the number of users allocated inside the simulation urban layout at some time slot. U is the whole amount of pedestrians during a single simulation and p_{slot} is the value of the probability function at the same time slot, (see Table 3.3).

Furthermore, the following condition must necessary be fulfilled:

$$\sum_{k=1}^{N} p_{\text{slot}_\text{k}} = 1. \tag{3.4}$$

The Time-based User Distribution concept is available in the simulator and in order to present results and evaluation of it, below is presented the case study regarding Luxembourg city. It is a seat of several institutions of the European Union, including the Secretariat of the Parliament and European Stability Mechanism and there are several banking institutions. Considering overall 20 000 pedestrians, during 9 PM and 10 PM and using the PDF function shown in Fig. 4.3, nearly one third of the total number of users are allocated in the urban layout and at 7 AM all 20 000 users end travelling. The above reasoning would be unaffected using functions in Fig. 4.4 and in Fig. 4.5.

Specifically, every pedestrians has an initial position c_a among the set of coordinates C, even using *Conditioning distribution* s/he travels for a time T_{move} uniformly distributed between [10,30] min with an average speed S_{move} uniformly distributed between [1,1.5] m/s. Accordingly every pedestrians movements are forced by the physical layout of the streets. Therefore each participants *jumps* from a position c_a to another coordinate c_{next} in C. Still in this mobility pattern, every next location is randomly chosen among the *adjacent list* of the c_a *current position*. Here as well, the distance is computed by using the Haversine formula and, along with the speed of the movements S_{move}, permits to determine the amount of time it takes between the two points t_{travel}. The user stops moving when $T_{\text{move}} \leq 0$.

3.3.4 Crowdsensing Inputs Module

This module defines the inputs specific to crowdsensing analysis. CrowdSenSim relies on two types of inputs. The first set does not depend on the sensing paradigm

Table 3.3. Symbols list and description

Symbol	Description
u_{slot}	Number of users allocated in the urban layout at some time slot
U	Total amount of pedestrians during a simulation day
p_{slot}	User allocated probability at some time slot

employed and comprises all the parameters related to sensing and communication operations. The second set includes parameters that are specific to the participatory sensing paradigm. Unlike the opportunistic sensing paradigm which does not have particular input parameters, in participatory systems it is necessary to define the concept of task and how to assign tasks to users.

Sensing and Communication Parameters

In CrowdSenSim, data generation takes into account sensors commonly available in current IoT and mobile devices. Table 3.2 communication parameters. Specifically, CrowdSenSim generates sensing readings from the FXOS8700CQ 3axis linear accelerometer from Freescale Semiconductor [20] and the BMP280 from Bosch [5], which is a digital pressure and temperature sensor [16]. For a worst scenario analysis, in the default settings the sensors keep generating data according to their sampling frequency for the entire period of users movements [17].

For communication purposes, the current version of the simulator employs only WiFi technology, however in the next updates version of CrowdSenSim it will be possible to use other types of technologies as well. Based on the sample resolution of the sensors, data is first organized in packets of 1 500 Bytes and delivered to the collector continuously during users movements. Each user transmits data to the closes WiFi Access Point (AP) [41]. The APs are characterized by *<latitude, longitude>*, not necessarily from the set C. For the city of Luxembourg, the precise location of WiFi APs was obtained from an online tool[2].

Parameters for Participatory Sensing Paradigm

CrowdSenSim defines the following properties for tasks: location, time of deployment, duration and coverage. With the default settings, all the parameters are randomly selected from the set of coordinates C, uniformly distributed within the simulation period and as fraction of the simulation period for location, time of deployment and duration respectively. The task coverage defines the maximum

[2]Online: `https://www.hotcity.lu/en/laptop/www/About/Wi-Fi-coverage`

radius where users can actively contribute to the task and is fixed for all the tasks [6]. The researcher can also provide a file in input to the simulator describing the aforementioned properties [19] [6].

Setup Simulation

In order to run CrowdSenSim the *setup* file plays a crucial role. It is the core of entire simulator. Changing the input parameters we obtain new configurations and scenarios. Therefore understand which inputs come into play is the main object. The Fig. 3.4 shows the *Setup.txt* file:

- Days of simulation: total number of simulation days. It is a possible value between 1 and 7;
- Number of users: amount of pedestrians during simulation;
- Minimum travel time, Maximum travel time: travel time per user uniformly distributed between these values;
- Start hour simulation, Start minute simulation;
- Finish hour simulation, Finish minute simulation;
- Kind of antennas: base antennas system used, allocated in the city;
- Create a new list of events: it is possible choose to create a new list of events or using the default one;
- Ray: value in meters for the ray useful for list of adjacent.

CrowdSenSim provides the chance to select either the default *List of Events* or creating a new one.

Whether through the *Setup.txt* file it is chosen to create a new list, select a proper value in meter for the *Ray* is of outermost significance. As mentioned before, a *List of Events* is a sequence of users positions during the simulation. More in detail each users *hops* through different location chosen among the *adjacent list* of the user current position. An *adjacent list* contains all the geographical position, inside the actual city, demarcated by the ray centred in the current position . As a consequence, more the ray value is high more each user has the chance to perform a far hop to the next position.

Afterwards having applied the changes to the input parameters, it is possible to run the simulation and opting between *Uniform Random Distribution* or *Time-based User Distribution* through *terminal*.

3.4 Simulation and Results

Receiving in input the list of events ordered by time and the selected specific parameters of crowdsensing system, the simulation engine runs to provide the results. For that, a file is created which contains information on user, location, number of sensing events, energy consumption. The file is used in input of the engine responsible to generate results. Through scripts, simulations are run a number of times to generate statistical results with 95% confidence interval.

Lastly, the statistics and output graphs are automatically shown in a local web-page.

In Fig.3.5, the table at the left bottom part contains the *Settings of simulation*, in the reported case the default settings.

The table in the top right part contains simulation *Statistics* such as the *Average number of samples generated*. *Average amount of data generated*, measured in MB, represents all the amount of information generated during the days of simulation. Finally, *Average amount of current spent for sensing*, measured in μA h, counts all the current spent for sensing during the simulation, by all the pedestrians smartphones.

The bar chart in Fig.3.6 illustrates the *Average amount of energy spent for data transmission per-user (*J*)*, ordered by day. In details, the previous parameter reprasents the energy spent for the communication of the collected data during the simulation. Other studies, the *Average amount of current spent for sensing* is negligible comparing with the energy spent for communications [7] [8].

The pie chart in Fig.3.7 reports the information concerning the *Statistics users sensors (*MB*)*. In details, are shown the quantities of data generated by the three sensors equipped by default in CrowdSenSim as *Thermometer*, *Barometer* and *Accelerometer*. The reported quantities are strongly dependents by the sampling frequency of each sensor. The Table 3.2 shows the sensors equipment parameters using for performance evaluation in the default scenario.

Finally in the *Google Heatmap* are reported the realistic city WiFi Access Points used during the simulation. In more details, highly utilized WiFi AP are denoted in red, while lowly utilized AP in green.

The whole explained simulator is free available through the following web-page: `https://crowdsensim.gforge.uni.lu/download.html`

3.5 Performance Evaluation of CrowdSenSim

This section provides a technical evaluation of the simulator performance. The metrics evaluated concern processing time, CPU consuming and memory utilization.

Fig. 3.9 shows the profile of the CPU utilization expressed in percentage obtained with the `dstat` tool[3]. The experiment analyzes the performance in a scenario with a huge number of users, 100 000, in the city of Luxembourg. The statistics obtained have been filtered to spot the profile of the process running the simulation. The resulting graph shows that the CPU utilization can occupy as much as 25% of the available resources and this happens at the beginning where most of the computation occurs to process the events.

The next set of experiments aims at assessing the performance of processing time and memory occupancy.

Unlike the previous result, these experiments are carried out deploying CrowdSenSim in a Virtual Machine (VM) running Ubuntu 14.10 with two different profile settings, namely 1024 MiB and 2048 MiB of memory. The setting allows us to profile the performance of the simulator perceived by the end users. The VM is equipped with GNOME System Monitor which permits to verify the system performance. Fig. 3.8 shows an example for a simulation with 20 000 participants in opportunistic sensing scenario.

System time used

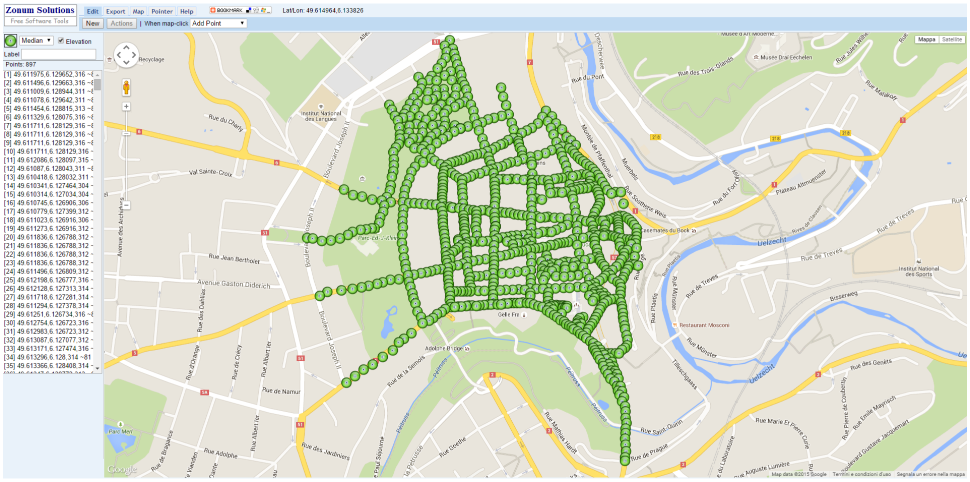
The Fig. 3.10(a) shows the system time used for different simulations. In order to obtain each value, I used the *Unix* command *command time -v* following by the *script* file of CrowdSenSim. Fig. 3.10(a) analyzes the processing time, which remains almost constant for a number of participants lower than 10 000 and then it increases exponentially for both the configuration settings. In details, varying the whole amount of pedestrians moving in the city layout, the system time used by CrowdSenSim linearly increasing to the maximum value measured of 27.27 s for $100 \cdot 10^3$ users. For the time processing evaluation we use number of pedestrians from the set {1 000,5 000,10 000,20 000,50 000,70 000,100 000} Furthermore in Fig. 3.10(a) are reported simulation time consumed for both VM configurations. The results obtained for time consuming using a VM with a memory set up of 1024 MB are noteworthy, since the VM provided on website is settled in this manner.

Memory resource used

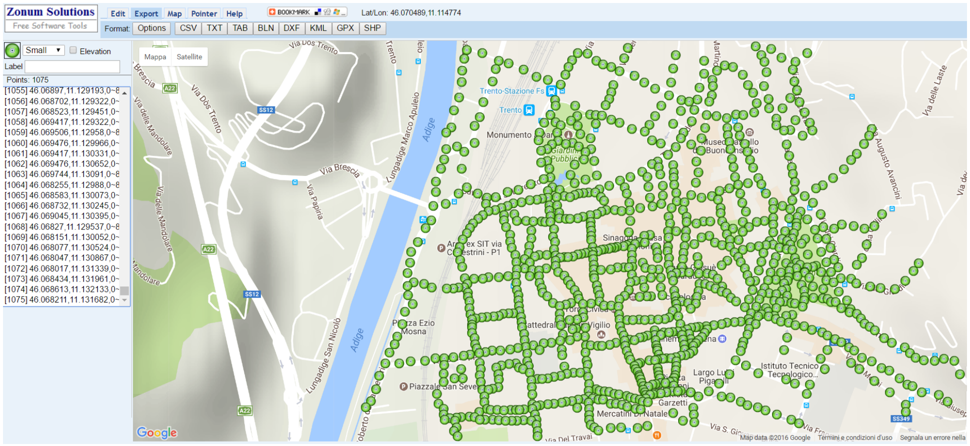
Fig. 3.10(b) analyzes the memory consumption with a focus on the Resident Set Size (RSS), which defines the amount of memory the process occupies in the RAM. For both configurations of the VM, the RSS remains almost identical for a number of participants lower than 20 000, then the process tends to occupy as much as possible all the available resources. For this evaluation, for both VMs configurations, we exploits the features of urban layout of Luxembourg city. Considering an increasing

[3]Available on: `http://dag.wiee.rs/home-made/dstat/`

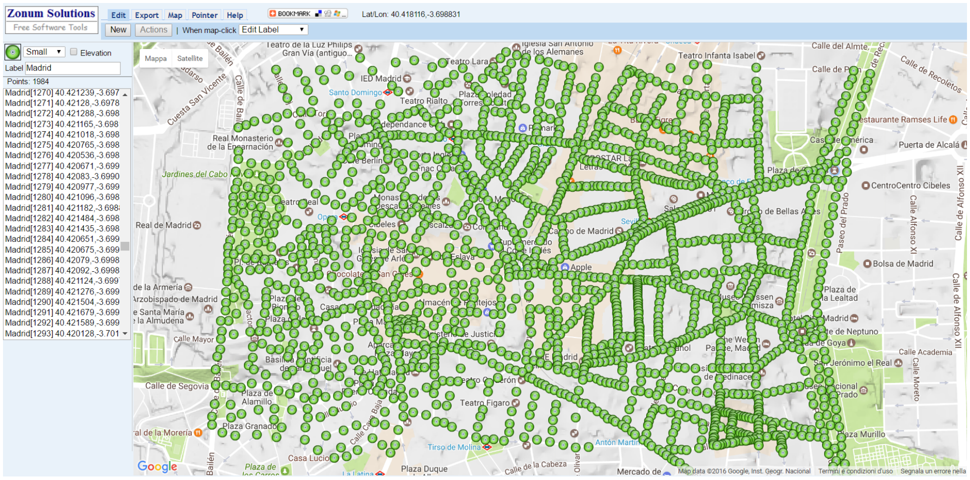
number of participants from the set {1 000,5 000,10 000,20 000,50 000,70 000,100 000}. The maximum number of users was selected consistently with the population of the city. Each value reported in the figure is obtained using the *Unix* command *command time -f "%M memory"* following by the *script* file of CrowdSenSim varying the total amount of pedestrians moving in the city. Particularly, I used the resident set size (RSS) parameter to understand the whole amount of memory occupied. RSS is the portion of the entire memory accessed by a process in the main memory (RAM). Generally, it is overestimated since it takes into account all the *libraries* requested by a process during the entire execution.



(a) Luxembourg



(b) Trento



(c) Madrid

Figure 3.3. Maps of cities obtained from DigiPoint

```
Setup.txt
****************************SETUP SIMULATION****************************
|Days of simulation| = 3

*********************************USERS**********************************
|Number of users| = 2000

|Minimum travel time| = 20
|Maximum travel time| = 30

|Start hour simulation| = 6
|Start minute simulation| = 00

|Finish hour simulation| = 21
|Finish minute simulation| = 00

********************************ANTENNAS*********************************
|Kind of antennas| = 3G

*********************************EVENTS**********************************
|Create a new list of events|
        [1] YES [0] NO = 1


********************************IMPORTANT********************************
if you choose [1] YES, you have to insert:

|Integer value for the ray(meters)| = 250


*********IMPORTANT******
You can put 6 days of simulation maximum.
Hours between: 0 and 23
Minutes between: 1 and 59
Travel time, for each user, it is a random number between minimum and maximum value
Ray: it is preferable a value at least equal to 100 meters
*************************
```

Figure 3.4. Setup.txt file of CrowdSenSim

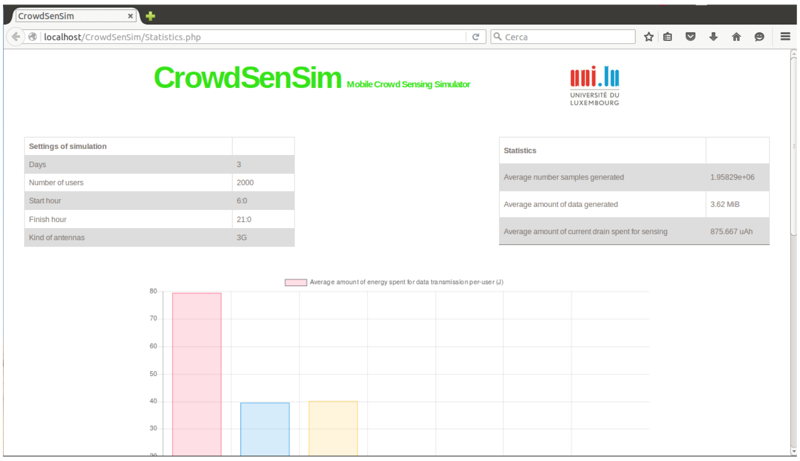


Figure 3.5. Output web-page with results

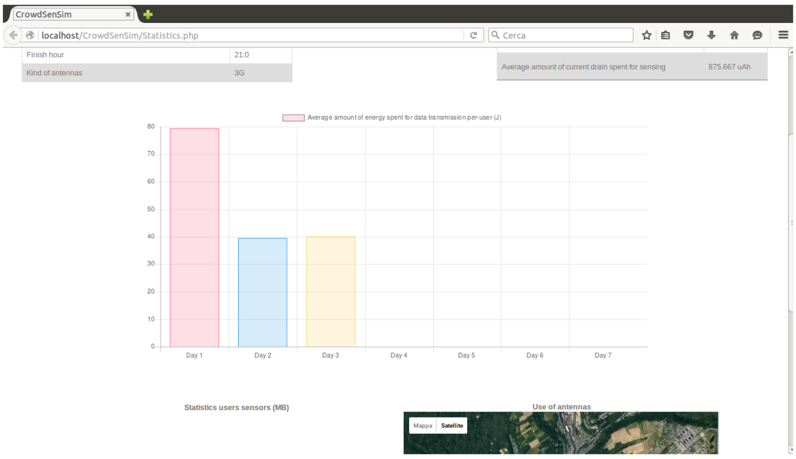


Figure 3.6. Output web-page with results

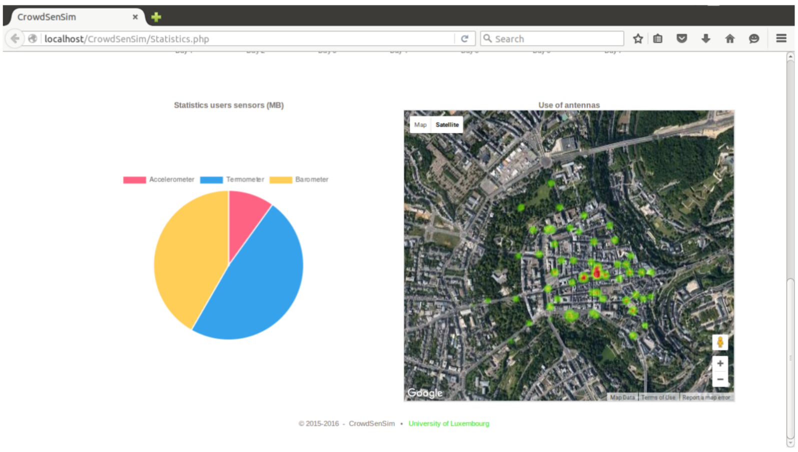


Figure 3.7. Output web-page with results

Figure 3.8. GNOME System Monitor

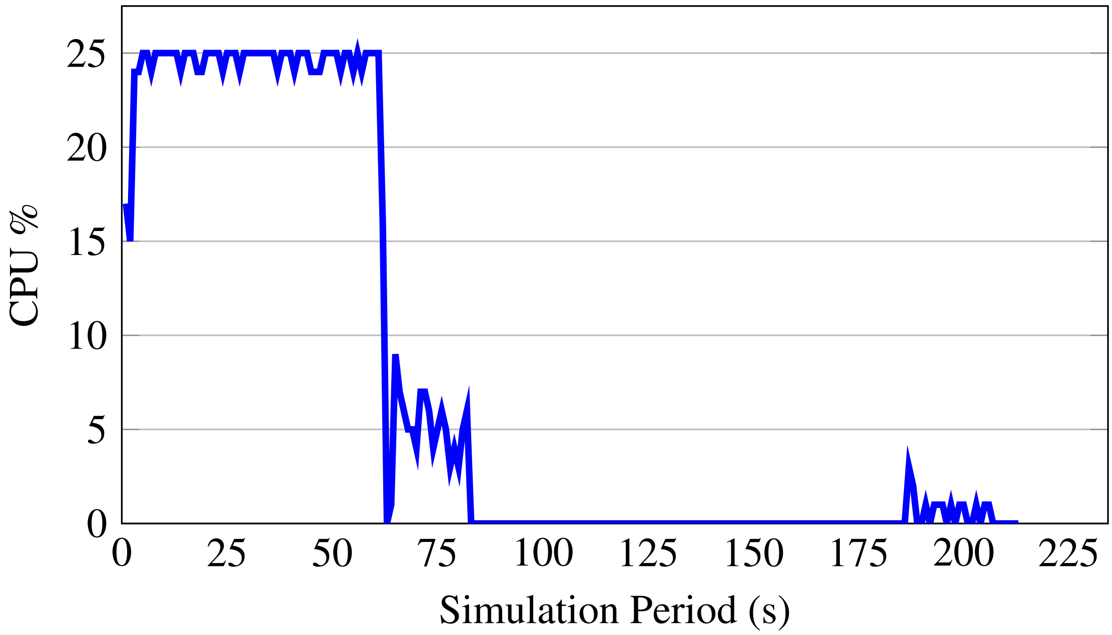
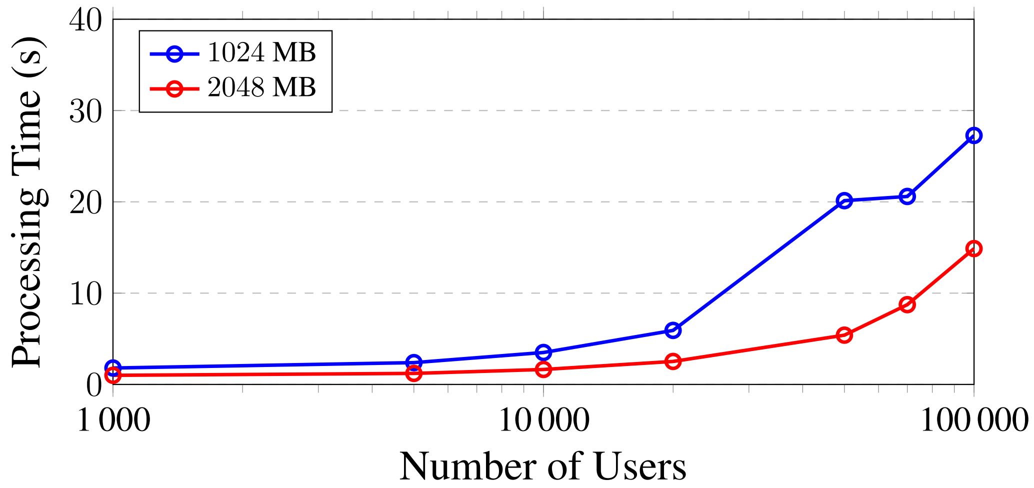
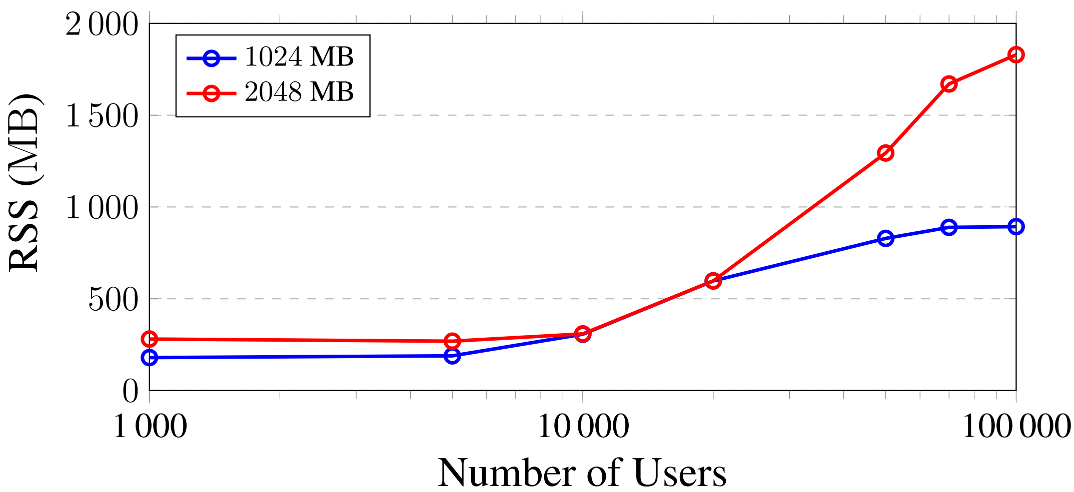


Figure 3.9. CPU utilization for a simulation run with 100 000 users



(a)



(b)

Figure 3.10. Analysis of a) processing time and b) memory with increasing number of users

Chapter 4

CrowdSenSim for Smart Lighting

In this chapter I present how exploit the main features of CrowdSenSim are used in order to evaluate the proposed heuristics for street lighting expounded in Chapter 2. The fundamental characteristics of the simulator are not only suitable for crowdsensing evaluations and this, more than other strengths renders it a extraordinary and potential tool for other applications as well.

4.1 Comparison Methodology for Smart Lighting Solutions based on CrowdSenSim

As explained in Chapter 3, CrowdSenSim emulates the pedestrians flowing inside the urban layout. During the simulation the pedestrians jump between different locations c_{next} among the C set of geographic. Therefore, the User Mobility Module has an high utility, however it is not only needful for crowdsensing data campaigns. In order to evaluate the goodness of the new heuristics for street lighting were two different ways. The first one consists in physically recreates *smart* lampposts, as proposed in Chapter 2 supporting the new lighting paradigms. Placing them in the streets and evaluates the performances of the proposed studies. No less simple, obtained a large amount of information about consuming and waste energy. All this process needs a large amount of time and realistically it is the next step. Firstly, the antecedent step was evaluate the potential of Smart Lighting paradigms using a simulation environment. From this considerations, I opted to use CrowdSenSim. Using the default mobility algorithms, explained in Chapter 3, was possible compute and evaluate the new heuristics reducing the amount of time and money used to obtain information regarding the goodness of them.

The following evaluations are carried out using an enhanced version of CrowdSenSim simulator, able to support along with its main features, streets information regarding the lampposts geographical positions inside the city layout.

As mentioned in Chapter 3, one of the main feature of the emulator tool is the *scalability*. Exploiting it adding a new module able to manage the lampposts location, was possible appending more information about the urban city environment represented by City Layout Module.

The layout of the city lampposts are extracted using a crowdsourced application which provides free access to street-level maps[1]. The information is given in form of a set of coordinates $C_{\text{lampposts}}$ that contains <*latitude, longitude, altitude*>. The lampposts are deployed according to their physical location in the streets. Fig. 4.1 describes the revisited architecture of CrowdSenSim ables to manage the lampposts layout, implementing independent modules in order to characterize the urban environment of the current simulation, the user mobility, the communication and the crowdsensing inputs, which depend on the application and specific sensing paradigm current utilized. It is essential to notice that for evaluations purposes, the following PDF shown in Fig. 4.3, 4.5, 4.4 are proposed. In detail, the Fig. 4.3 presents the probability density of users presence within the city, having high probability to find more pedestrians walk at first and at last hours of the day simulation. Fig. 4.5 shows a different situation in which there are more pedestrians at the end of the simulation day if compared with the early hours of the day. Instead Fig. 4.4 shows a diametrically opposite situation in which the probability presence of pedestrians is more high in the early hours of the simulation day.

4.1.1 Evaluation Settings

The following section exhibits the performance evaluations of the proposed new heuristics for smart lighting using the updated version of CrowdSenSim simulator along with *Lampposts layout Module*. For the performance evaluation, the experiments are carried on considering the urban city of Luxembourg. In detail, besides the streets city layout are extracted information regarding the city lampposts position as mentioned in the previous section. In the case study of the capital city of Luxembourg, the real geographical location of the luminaries is shown in Fig. 4.2. Furthermore, in the following evaluations, CrowdSenSim is settled using, as input constraints:

- 20 000 users walking around the city;
- T_{move} per each user uniformly distributed between [10,20] min;
- User average speed uniformly distributed between [1,1.5] $\text{m}\,\text{s}^{-1}$;
- Evaluation period set between 9 pm and 7 am;

[1]DigiPoint: `http://www.zonums.com/gmaps/digipoint.php`

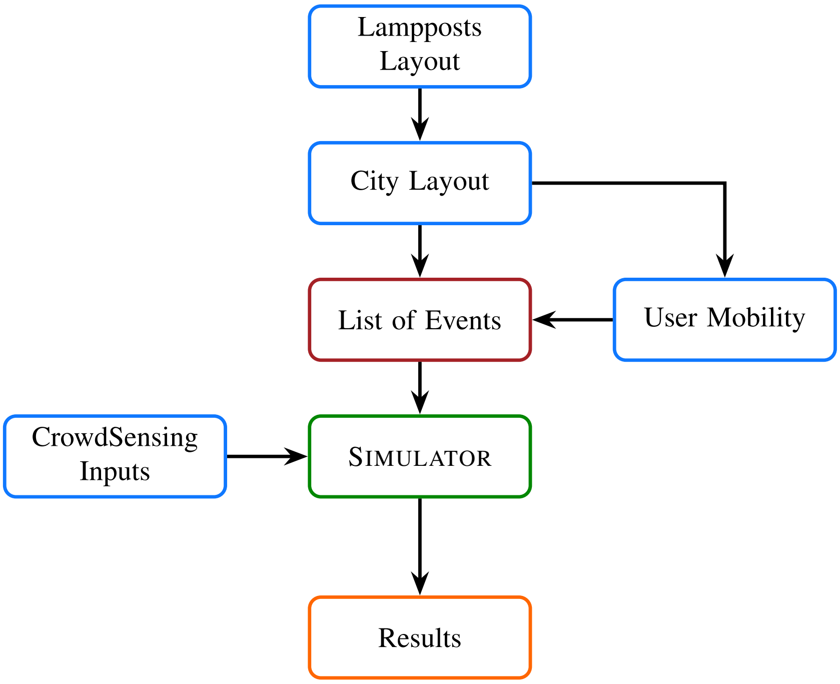


Figure 4.1. Architecture of CrowdSenSim for Smart Lighting

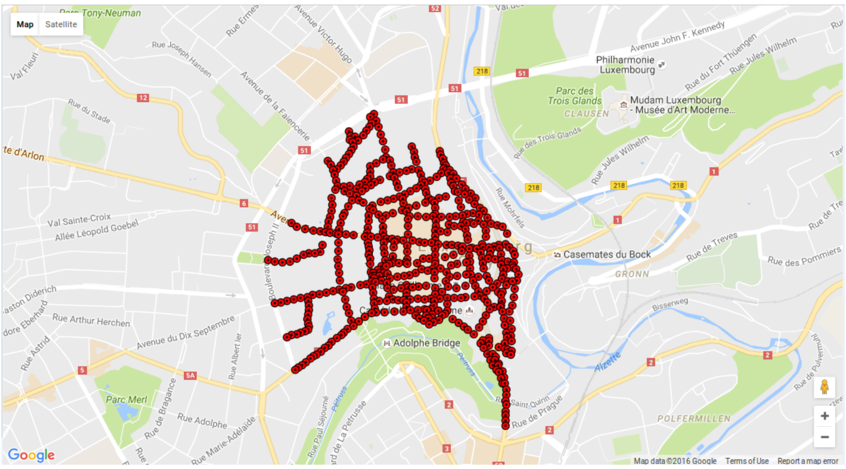


Figure 4.2. Position of lampposts in Luxembourg city center

- Each user is allocated inside the city layout according to the PDF in Fig. 4.3.

20 000 users which correspond to nearly one of fifth of the population of Luxembourg (110 499 inhabitants as of the end of 2015). T_{move} oscillates between [10,20] min as it is an approximative value of the duration of a user's path. The evaluation period is settled between 9 pm and 7 am because the street lighting

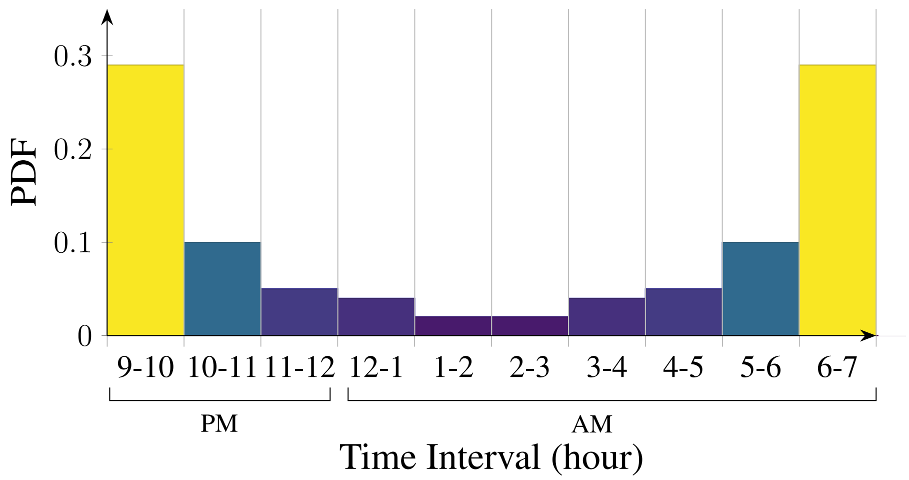


Figure 4.3. Probability density function of user mobility

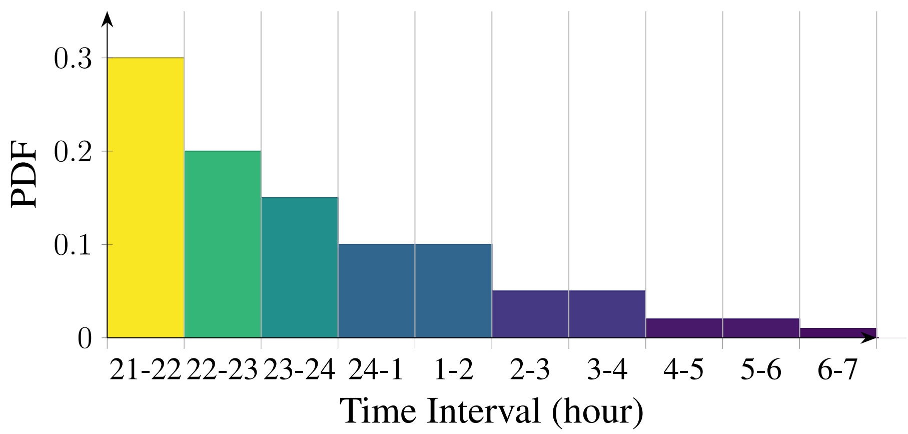


Figure 4.4. Probability density decreasing function of user mobility

lampposts do not work during the day, in the presence of the sun light. Therefore, this range is proper for smart lighting simulations. Each user is allocated using the algorithm, *Time-based User Distribution* explained in 3.3.3. Fig. 4.5 shows a PDF function in which there is an high probability to find users walking around the city in the last hours of the simulation day. Fig. 4.4 represents an opposite situation in which there are more users walking around the city during the first hours of the simulation day. For the purposes of the case study applied at Luxembourg city, I opted to use a PDF, describing the allocated function of users inside the city as shown in Fig. 4.3. It better describes the expected movement of users in a city like Luxembourg. There is an high probability to find pedestrians walking around the city during both the first and the last hours of the simulation day, emulating the

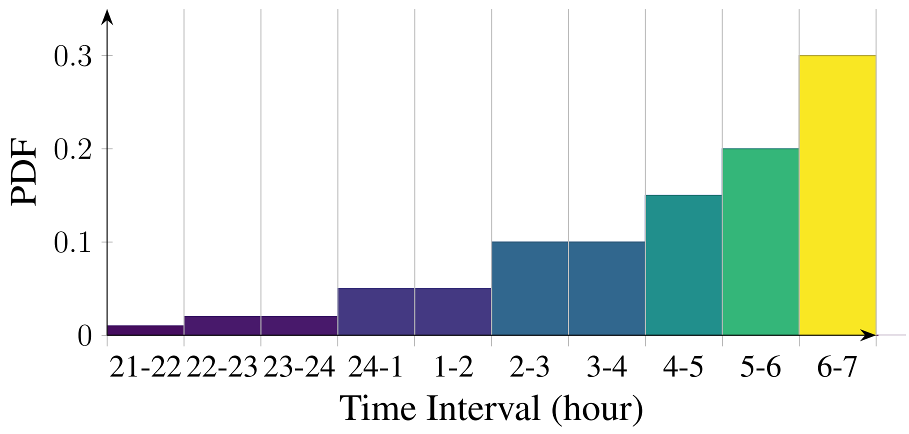


Figure 4.5. Probability density increasing function of user mobility

workers go to their work places. Considering the definitions of the new proposed heuristics explained in Chapter 2 below are reported the setting of the lampposts and their algorithm.

For the assessments, the experiments are carried on varying the coverage radius R and the time window W. The radius R identifies the covering area of each lamppost, therefore it represents portion of the surrounding space to which the lamppost is susceptible. On the other side W is the time used for checking the presence of pedestrians close to the lamppost. In more details, R assumes values equal to {10,30,50} m, while W assumes values equal to {2,5,10,20} min only for the Dim method. Instead for Del method the value of W is settled at 30 min, therefore this choice allows to use both HPS that LED technology.

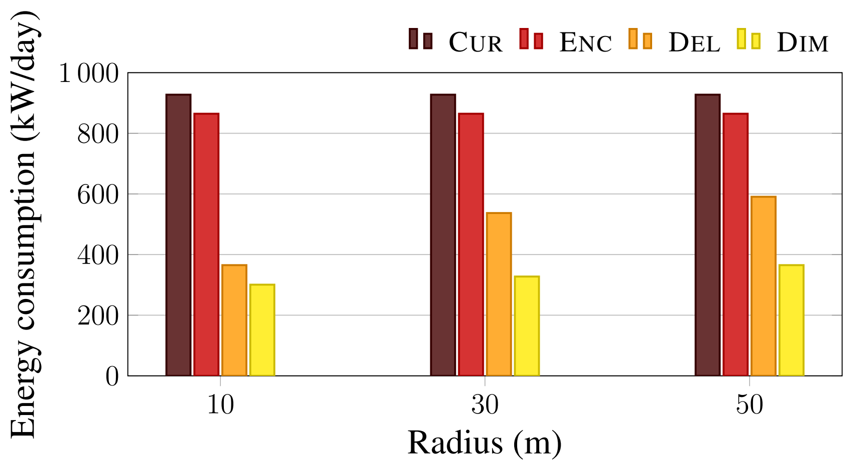


Figure 4.6. Comparison of smart lighting solutions

4.1.2 Performance Results

Fig. 4.6 compares the smart lighting solutions proposed in terms of energy consumed per 10 hours activity between 9 pm and 7 am, which corresponds to a working day. In detail the time window W value for DIM is $W = 5$ min and for DEL is $W = 30$ min. As expected, the current implemented methodology CUR is the least efficient if compared to the proposed heuristics. The ENC method improves CUR by nearly 6.7 %.Instead, DEL ameliorates CUR by nearly 58 % and DIM improves CUR of about 67 %. As the lampposts turns on only upon detection of users nearby, some of the lampposts remains initially idle while in CUR all the lampposts are active at 21:00. The most energy efficient techniques are DEL and DIM . For the DIM method, Fig. 4.6 shows the results for a time window $W = 5$ min. For DEL the time window W is fixed at 30 min. Both methodologies are most effective for short values of R because the probability of having users nearby the lamppost is lower. However, different values of R impact differently on the performance of DEL and DIM . For the former method, the energy consumption augments of nearly 38% while for the latter the increase is *only* 17%. Two are the main reasons: i) the LEDs used in DIM are more efficient than HPS lamps used for DEL , ii) the DIM checks presence of nearby users every more often than the DEL.

Table 4.1. Cost comparison of smart lighting solutions for different countries

COUNTRY	ENERGY COST (€ / KWH)	METHOD (€)			
		CUR (927.4 kWh per day)	ENC (865.1 kWh per day)	DEL (384.0 kWh per day)	DIM (298.5 kWh per day)
Luxembourg	0.18	166.9	155.7	69.1	53.7
Italy	0.24	222.6	207.6	92.1	71.6
Germany	0.29	268.9	250.9	111.3	86.6
France	0.17	157.6	147.1	65.3	50.7
China	0.07	64.9	60.5	26.9	20.9
USA	0.10	92.7	86.5	38.4	29.8

Table 4.2. Cost analysis in Luxembourg

METHOD	COST EXPENDITURE (€)		
	CAPEX	OPEX	TOTAL
CUR	–	60 930	60 930
ENC	4 779	56 835	61 614
DEL	36 999	25 227	62 226
DIM	36 999	19 611	56 610

Having determined the energy costs per kWh in different countries according to [13] [51] [4], Table 4.1 compares the daily cost to operate for a 10 hours long period the proposed smart lighting solutions. The proposed costs per country estimate the trend of the expenses for municipalities. The reported value is an high point of view that does not take into account the value spent for placing *smart* lampposts inside the municipality. The values of energy consumption of each method are determined as the average over 100 simulation runs of the energy consumption of all the 537 lampposts. Considering an average value the result is less susceptible to variations due to variables that change with each simulation. With a focus on Luxembourg, Table 4.1 compares capital and operational expenditures (Capex and Opex respectively). The Opex costs are determined for 537 lampposts for a time period of 1 year. In detail, Opex expenditure are evaluated only considering the spent energy due to the lampposts operation. Capex costs are determined considering the additional sensor components necessary to make operational the methods, excluding the expenditures due to the placing costs in Luxembourg. In Cur and in Enc methods, every lamppost is equipped with an HPS-97241 lamp [30] that is widespread in the mentioned municipality. In order to implement Enc it is essential to add a micro-controller (model PIC12F635 [36]) and a presence sensor (model SE-10 [38]) per lamppost, particularly recommended in previous studies. For Del and Dim in addition to the previous components, the lamp is not an HPS, but a LED lamp (model GRN100 [35]) described in Table 2.3. The mentioned LED lamp model is particularly advised in order to guarantee an high decrease amount of energy spent comparing to the HPS model, previous described. Through Table 2.3 is clear the benefits of preferring LED technology instead HPS. The *average life*, between two described models, is fourfold and the *lamp efficacy* is increased of 25 %. Interestingly, Table 4.2 shows that the Dim would be beneficial in providing an economical return already in his first year of implementation. The Enc method does not bring considerable advantages over CurHowever, it is worth mentioning that the simple operation of not turning on all the lampposts simultaneously saves operational expenditures for 6.7%. Considering only the Capex expenditures, implementing Enc is nearly 8× cheaper than implementing Del and Dim but the latter methods significantly lower the yearly Opex costs. Therefore, as Table 4.2 shows that after an year of operations, the total amount of expenditures for Dim is consistently less comparing with Cur whereas the initial costs due to the strengthening of each lampposts inside the city of Luxembourg. Considering Enc and comparing to Cur it is possible to have a decreasing amount of energy spent for lighting in the first year, however the Capex costs are higher, therefore after the first year there is not money saving. Of course already at the second year the total amount of expenditures is less with Enc method as well.

Fig. 4.7 analyzes the impact of the time window W used to check the presence of users nearby on the energy performance the Dim solution provides. The analysis is carried on with different values of the coverage radius R, since as previous studies proof, changing the position of the sensor per each lamppost the cover radius R changes influencing differently the performance evaluations. As expected,

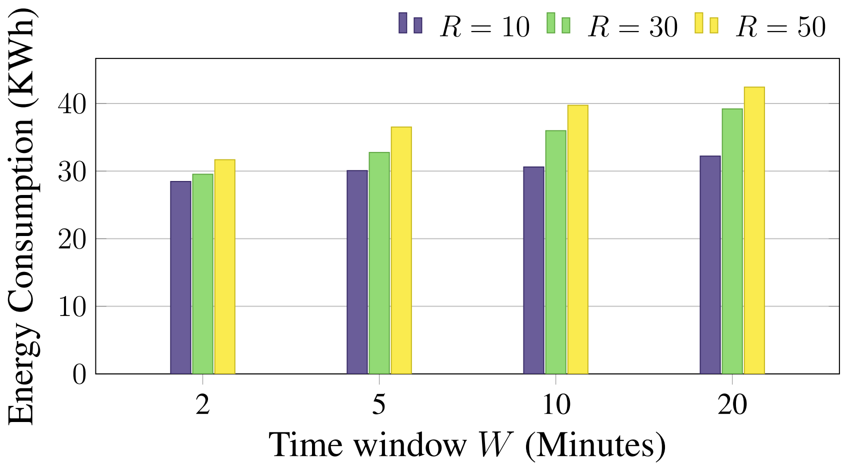
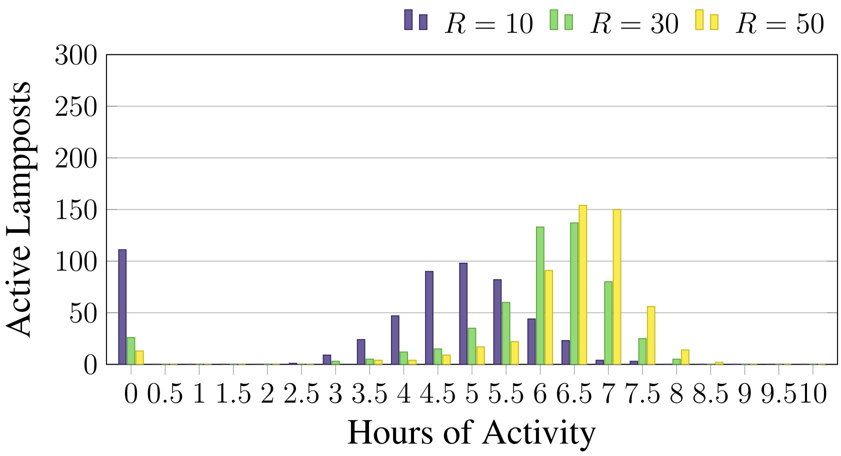


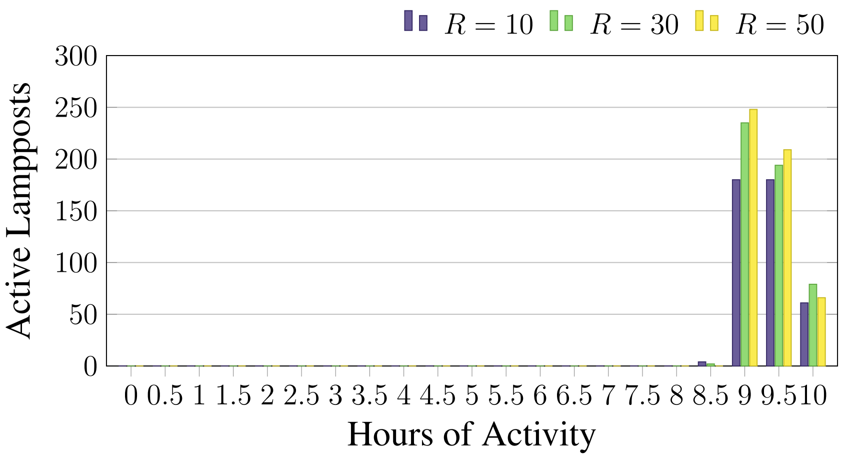
Figure 4.7. Impact of W on performance of DIM for different values of R

the energy consumption increases with the increase of W and R. Interestingly, the contribution given by R in the increase of energy consumption is higher for high values of time window W. As foregone, the energy consumption per each lamppost is more susceptible to the radius R. For $W = 2$ and $W = 20$, the increase of energy consumption from values of $R = 10$ to $R = 50$ is respectively 10% and 24%.

Having compared the performance of the proposed smart lighting solutions in terms of energy consumption and in terms of expenditures, I now investigate the distribution of hours of activity for the DEL and ENC . The results are displayed with the granularity of 30 min. Unlike the other smart lighting solutions, these methodologies turn off the lampposts if nobody is passing nearby. This do not happen using the other two heuristics, CUR and DIM . The DEL method, being more energy friendly than ENC reduces the hours of activity of the lampposts in proportion to the coverage radius R. Fig. 4.8(a) clearly highlights that the distribution of the number active lampposts follows a normal distribution whose center changes for different values of R. The higher the values R assumes, the higher is the average number of hours the lampposts remains active. The lower the values R assumes, the more energy efficient the DEL policy becomes. The number of lampposts that remain switched off is higher and on average, the lampposts are active for shorter time periods. Fig. 4.8(b) shows the distribution of the hours of activity for the ENC method. As the lampposts remain active until the end of the period once turned on, the distribution is significantly different than the one obtained for the DEL method and the impact of R is almost negligible. Having fixed $R = 10$, Fig. 4.9 compares with a heatmap the hours of activity of the lampposts for all heuristics analyzed CUR DEL ENC and DIM methods. The following Heatmaps



(a) DEL method



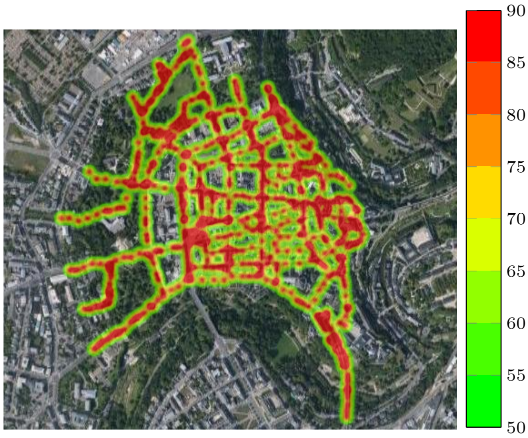
(b) ENC method

Figure 4.8. Distribution of lamppost activity

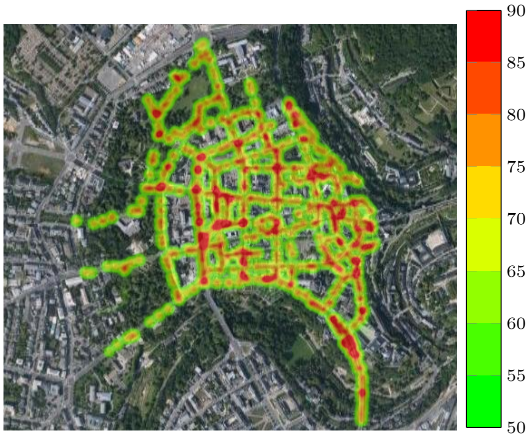
allow to understand in a visual manner the results of the proposed heuristics. Considering the case study settled the cover radius per each user at $R = 10$ and the time window per DIM is $W = 5$ min and for DEL is $W = 30$ min. Remembering that ENC compared to CUR permits an 6.7 % energy saving, DEL allows an economy of 58 % than CUR method. Instead, the most convenient heuristic is DIM with an energy spared of nearly 67 %. The results are obtained with Google Heatmap tool[2].

[2]Available on: `https://developers.google.com/maps/documentation/javascript/examples/layer-heatmap`

(a) Cur method



(b) Enc method



(c) Del method

Figure 4.9. Heatmap of lampposts activity (values in kW h)

(d) DIM method

Figure 4.9. Heatmap of lampposts activity (values in kW h)

Chapter 5

Conclusion and Future Work

5.1 Conclusion

Final goal of this study is to provides new solutions for street lighting understanding the advantages and disadvantages mostly considering the lack of environmental sustainability of the current implementation. Smart lighting solutions provides an high decrease of waste energy in city streets lighting. Demonstrating that the current management and the broadly use of HPS lamps technology need a substantial improvement, especially in the light of the new proposals and targets of the European community in order to counteract the climate change. In the light of the obtained results regarding the case study applied to Luxembourg city the proposed heuristics permit, strengthening street lampposts, to have a consistent energy saving, improving the current method. As a final conclusion it is possible to notice that for having a decreasing of spent energy for lighting an improvement lampposts is necessary. All this considerations are the results of performance evaluations made with CrowdSenSim. It permits along with its features to evaluate the goodness of many applications, not only related to crowdsensim however with other purposes as well. The current user mobility module allows to estimate smart cities solutions. Without the custom simulator all the possible considerations about street lighting could not be done. In the worse case, for the same accuracy the total amount of time and spent money will be high.

All the proposed heuristics take into account the chance to know the user position nearby each lampposts. This idea permits to focus the street lighting only if it is needed. This is possible adding presence sensors on each luminaries, therefore making them more *smart*.

The ENC heuristic along with lampposts update, allows a slight energy saving nearly 6.7 % compared to the CUR even if, after the first the expenditure is however greater than the latter method. Nevertheless, after the first not advantage year, the costs of upgrading are absorbed and the energy saving is in any case acceptable.

Instead the Del method permits to have a saved energy of nearly 58 %. Of course, to reach such an high economy the Capex costs are nearly 8× higher than Enc due to the use of LED technology instead HPS. Therefore, after the first year the benefits of the energy saving are neutralized by the Capex costs. Anyway, after the firs year the costs saving is considerable. In conclusion, the Dim method represents the best trade-off between the Capex and Opex already after the first year. Alongside the high Capex costs, just like Del the Opex costs are drastically low, nearly 67 % compared to Cur. After the first year the economy is already possible. Summing, Enc permits a saving content with a just e simple improvement. Del allows an important saving but ascertainable only after the second year and Dim heuristic that meets the needs of energy saving already from the first year of implementation.

5.2 Future Works

Regarding CrowdSenSim, the future works are directed to optimize the mobility pattern module. Since the current state of the tool do not permit to distinguish between a place, located at some geographical coordinate, with high probability to be visited by users, such as squares, restaurants or hospitals. Reinforcing the mentioned module the accuracy of performance evaluations, not only regarding street lighting heuristics however also crowdsensing applications, will increase. Regarding the proposed street lighting methods, the subsequent step is the physical realization of the lampposts and the testing in a real environment allowing a high accuracy evaluation even considering other variables surely not present in a simulated environment.

Related Pubblications

1. G.Cacciatore, C.Fiandrino, D.Kliazovich, F.Granelli, P.Bouvry. Cost analysis of Smart Lighting Solutions for Smart Cities. *Accepted In IEEE International Conference on Communications (ICC) Paris, May 2017.*

2. C.Fiandrino, A.Capponi, G.Cacciatore, D.Kliazovich, U.Sorger, P.Bouvry, B.Kantarci, F.Granelli, S.Giordano. CrowdSenSim: a Simulation Platform for Mobile Crowdsens- ing in Realistic Urban Environments. *Accepted In IEEE ACCESS, 2017.*

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