Enhancing Sustainable Mobility Awareness by Exploiting Multi-sourced Data: the Case Study of the Madeira Islands

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***Abstract*—In this paper we present a low-cost infrastructure to collect a variety of location-based multi-sourced data with the aim of providing personalized services and raising awareness for sustainable mobility solutions. The gathered data can be used to provide: (i) citizens and tourists with personalized location-based services to increase sustainability awareness; (ii) local authorities and tourism boards with a tool to identify and prevent mobility issues; and (iii) transport companies with an instrument to support urban mobility planning decisions. To collect data, we exploited a low-cost Wi-Fi passive tracking system and we augmented this infrastructure using sensors for detecting environmental conditions. To achieve this, we provided 60 points of interest and 20 buses with our solution, to spread out the sensors over the entire Madeira Island. Using the gathered data, we developed different scenarios to prove that in a world where sensing data is becoming inexpensive, there are opportunities to use our approach to deliver data back to the citizens, empowering local communities, with the goal of promoting sustainable mobility and tourism.**

Keywords—sustainable mobility; sustainable tourism; smart mobility, sensory data, passive wi-fi tracking, multi-sourced data

I. INTRODUCTION

In 1987, the World Commission on Environment and Development published the report, titled *Our Common Future*, bringing global attention on the need of sustainable development [1]. Since that moment, the concept of sustainable development has been investigated in all it aspects with the aim of facing the global challenges. One of the main challenges to cope with is transport and mobility, undisputed key issues of modern life affecting people's well-being and quality of life and impacting significantly the environment [2]. In this scenario, a critical role is played by road transport, that represents 73% of the share of transport greenhouse gas emissions [3], impacting on the increase of air pollution, generating N2O and CO2 and strongly affecting air quality in urban areas with high volumes of road traffic [4]. The problem becomes even more relevant in well-known touristic destinations since tourism is arising from mobility as a form of capital [5]. Therefore, the paradigms of sustainable tourism and sustainable mobility are strongly interconnected and need to be investigated together [6, 7].

These motivations are the basis of the DESTINATIONS project, a H2020 CIVITAS initiative co-financed by the European Union, to promote sustainable transport in touristic urban areas [8]. The project includes six islands where tourism extensively contributes to the local economy. The main goal of the project is to build an integrated approach to address mobility and tourism, achieving sustainable development and a better quality of life. In this project, a relevant case study is represented by Madeira, an archipelago located in the North Atlantic. With 270.000 inhabitants, Madeira attracts more than 1,3 million tourists per year, with a significant impact in the economy, but also on the environment. Moreover, Madeira represents a rich case study because of its layout. Due its volcanic origin, the island is very mountainous, making buses the only feasible public transport system. Despite that, residents are used to drive private cars and tourists prefer to pay for a private mode of transport to explore the island.

In light of the above, we here present a case study, developed under the DESTINATIONS framework. With the goal of inducing communities in developing sustainable strategies, we designed an infrastructure to generate multi-sourced data that can be explored to deploy new mobility services. To accomplish that, we instrumented 60 locations on Madeira Islands, with our passive Wi-Fi tracking system [9] and environmental monitoring sensors, and we equipped 20 buses with our multi-sensor stations, to spread out the sensors over the entire Island. In doing so, we contribute with a study showing how technical innovations and advanced information and communications technology (ICT) can be put to good use of the sustainable mobility paradigm, to investigate the complexity of urban mobility in touristic cities, and to strengthen the links between land use and transport.

II. RELATED WORK

The research work described in this paper is mainly motivated by two areas of interest: A) studies on mobility patterns recognition and users profiling; and B) studies on the use of ICT for promoting sustainable mobility.

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A. *Mobility Patterns Recognition, Analysis, and Profiling*

Different studies focus on how mobility tracking and analysis on urban environments could be used to estimate daily commutes, usual travel distances and route planning. These works have attempted to locate or count the number of people in specific locations, using wireless technologies. A large part of them explore technologies such as RFIDs [10], Bluetooth [11], and GSM signals and communication [12, 13]. Another approach used in several studies is based on Wi-Fi technology to capture/tracking human mobility information in highly crowded areas such as football games, university campuses and hospitals [14, 11, 15]. The motivations of these studies are various: facility management and planning [15]; crowding factors, flock detection and waiting times [11, 16]; real time public transport service-level monitoring and estimation [17]; social information like popularity of events [14].

There are different techniques to analyze and synthesize mobility information from tracking data [18, 19]. An advanced method described in [20] used the information broadcasted from 8000 Wi-Fi devices to perform what the authors called SSID profiling. This technique involves analyzing the captured information, focusing on the SSIDs (names of the saved networks on the devices) to associate different devices with social connections, using texts similarity algorithms, where each SSID is considered as a word. The connections were assessed with probabilistic algorithms based on the popularity of the SSIDs, and weighing the intersection of the same SSIDs through different devices accordingly to their popularity. In Beanstalk, we use the same approach to differentiate visitors from locals [9].

Several networking infrastructure vendors offer geo-marketing solutions for organizations, deploying large Wi-Fi networks in predefined locations, such as shopping malls, hotels and airports. However, concerns about the privacy issues related to these systems make information about them hard to find. Several attempts to deploy similar systems in public parks (e.g. London Hyde park and Olympic Park, and New York Bryant Park) and airports (e.g. Helsinki) have reached the media with concerns about the commercial use of tracking information, due to their sensitive nature. We are not aware of any research done on the data collected over the commercial systems described previously. Similarly, to the best of our knowledge, none of the academic studies lasted more than days or weeks and they focused on a specific area, such as a campus, a park or an infrastructure.

B. *Studies on ICT and Sustainable mobility*

Many studies were conducted looking at how ICT and innovative technologies could be used to support and develop sustainable mobility. A recent study [21] provides an overview of best practices to promote sustainable transport through ICT. These practices regard, among the others, identification and promotion of good strategies to reduce road accidents and traffic congestion; multimodal journey planners; real-time passenger information; pollution monitoring. In [22] authors present a framework for the development of sustainable urban mobility applications based on a cloud application collecting mobility information, performing data processing and producing personalized information for sustainable urban mobility. Also in this case, as in the previous one, a real case study is missing to validate the framework.

In [23], authors focus on exploring research challenges for location-aware ICT that provide users with suggestions of sustainable activity alternatives. The results confirm the importance of focusing on reflecting individual goals to provide personal feedback and recommendations. The research reported in [24] confirms the fact that mobility decisions can be influenced using carefully targeted information. Moreover, they found out that hard facts, like time and money, appear to be important motivators encouraging people to overcome their mobility routines. Following the same line, authors of [25] present a service-based framework based on gamification as a tool for facilitating and promoting more sustainable mobility.

An interesting study, presented in [26], exploits a low-cost wireless sensor to provide information about conditions in an area of interest to allow more efficient planning. However, authors presented, as a real application study, the outcome of a limited experiment conducted in a roundabout in the city of Málaga. Similarly, in [27] authors report on a study aimed to develop innovative services for sustainable transport and mobility in smart cities, by collecting environmental and social sensors data. Such data is pre-processed and analyzed by data mining techniques for determining useful information such as state of the traffic flow, special events, demonstrations and accidents. Although the research work seems really promising, no outcome obtained from a real scenario was reported.

The study described in [28] illustrates the design of a mobility system integrated with the mainland, that will assure safe routes and the exploitation of historical/cultural sites, in the Pontine territory, a large naturalistic area. The work highlights the importance of considering the natural environment when developing an ICT infrastructure for sustainable mobility. Considering the issue of involving different communities in developing sustainable strategies relevant is the work presented in [29] where authors report the results of transport and environmental analyses, indicating that there is an evident gap between what population, economic operators and stakeholders ask and what is decided by policy-makers.

III. The System Walk-through

In this section, we provide details about the Wi-Fi tracking system and the integrated environmental monitor sensors, and about the deployment of the infrastructure in the buses and in the points of interest (POIs) of the Madeira islands.

The Beanstalk Infrastructure. The Beanstalk passive tracking platform [9] takes advantage of the Wi-Fi technology that is increasingly embedded in smart devices that people carry in their daily commutes. Basically, it works by monitoring the network and storing the probe requests of the devices around the deployed node. Due to the standard active service discovery mechanisms enabled on mobile devices, Wi-Fi interfaces are periodically broadcasting frames containing their device address in order to discover networks to either: 1) automatically connect themselves or 2) to be able to roam to the access point with the strongest signal, while connected to a network. The devices look for networks in all channels consecutively and wait for a response of the access points in the range. To collect the probe requests, a standard low-cost router (GL-inet AR300M) is used with a modified operating system (OpenWRT). A python script is executed to filter the probe requests, tag them with the location ID of the router, and a timestamp. Finally, the data are sent to a central server through HTTP requests. To address the privacy concerns, MAC addresses are stored as a cryptographic hash.

The Integrated Sensors. We built a platform to integrate various sensors to monitor multiple environmental parameters (such as temperature, humidity, light, air quality and noise) around POIs. With the intent to make the system modular, we chose sensors that have a USB interface, or that could be read through an intermediate hardware (see Table 1). We use a USB hub to accommodate the sensors required for each location, connected with the Beanstalk router (so as to exploit its connectivity to access real time sensing data). The sensors that have output in current (mA) or voltage (V) are read by USB current and voltage sensors from Yoctopuce (Yocto-4-20mA-Rx and Yocto-0-10V-Rx).

TABLE I. SENSORS USED IN THE PLATFORM

Attribute	Sensor	Output/ Interface
Particles (PM2.5, PM10)	Nova PM sensor SDS011	USB
Ozone (O_3)	Sensoric O3 3E 1	4-20 mA
Carbon Dioxide (CO_2)	Yocto-CO2	USB
Sulphur Dioxide (SO_2)	SO2 SL 4-20mA Transmitter	4-20 mA
Nitrogen Dioxide (NO_2)	NO2 2E sensor with 4-20mA transmitter, 0-20ppm	4-20 mA
CO	CO ECO-Sure (2e) 4-20mA Transmitter	4-20 mA
Nitrogen Oxide (NO)	4-NO-2000	0-5 V
Temperature, humidity, air pressure	Yocto-Meteo	USB
Noise	Digital microphone with integrated sound card	USB

Tracking on public transport. Since the Beanstalk platform was robust and scalable we considered the possibility of implementing the same tracking mechanism in the public transport system. Partnering with the local bus company we integrated the Beanstalk tracking system in several public buses serving the main city of the Island. The main interest of the bus company was to be able to know where the passengers exit the vehicle, thus creating origin-destination matrices to optimize routes, and classify the profile of the public transport users using the anonymous statistics available on the Beanstalk platform. The modifications to the station included the addition of a 3G USB modem to provide connectivity to the central server for real time data uploads. On the server side, we process a cross-match between the data recorded from the Wi-Fi interface and the GTFS bus-stops schedule for each bus route, provided by the bus company, to calculate the origin-destination matrices.

The Deployment. As already described, the deployment was conducted in the Madeira Islands. After an initial test phase (in the airport, port and some squares in the capital city), the system was expanded to 60 routers placed nearby the main points of interest (POIs) covering the main touristic attractions. In each POI, internet access was guaranteed by the receiving entity (usually a local bar or tourism information kiosks). Moreover, we equipped 20 buses of the public bus company with our infrastructure. These buses are used to cover the high frequency routes in the capital city of Funchal, therefore expanding the coverage of the network. Over a period of over 80 weeks, we collected mobility data on 2.1 million unique devices, resulting in a total of 274 million data points.

IV. From Infrastructure Data to Services

To prove the effectiveness of our approach, in this section we describe different scenarios of use where the collected data are exploited to benefit (*A*) tourist, (*B*) citizens, (*C*) local governments and tourist board, and (*D*) transport companies, with the aim to raise awareness about sustainable mobility.

A. Personalized Services for Tourists

In this running example, we detail how our infrastructure can be used to provide personalized mobility services to tourists, increasing awareness in sustainable mobility and supporting them in using public transport.

To better clarify a possible context, let us consider a couple of visitors, who are enjoying for the first time Madeira. As most young-adult tourists, they decided to come to Madeira to enjoy its nature, attracted by the beautiful landscapes and the famous trekking paths. The first day, they decide to visit the botanical gardens in the small town of Monte. They enter the tourism office to ask information, but a long queue detracts them from getting personal feedback. An interactive public display attracts their attention. They notice the possibility to plan a journey, so they select the botanical gardens. The system provides a real-time map with the different buses available to reach Monte. Each trip is correlated with information of saved CO2 emissions comparing with the use of a car/taxi. Moreover, it alerts that in Monte is raining, so they decide to change their destination. They browse back the system, where they notice a sunny icon in the area of Ponta São Lourenço. They select that location and the interface shows real-time information and pictures about this touristic spot. Using the interface, they send the information of the journey to their phone mapping app.

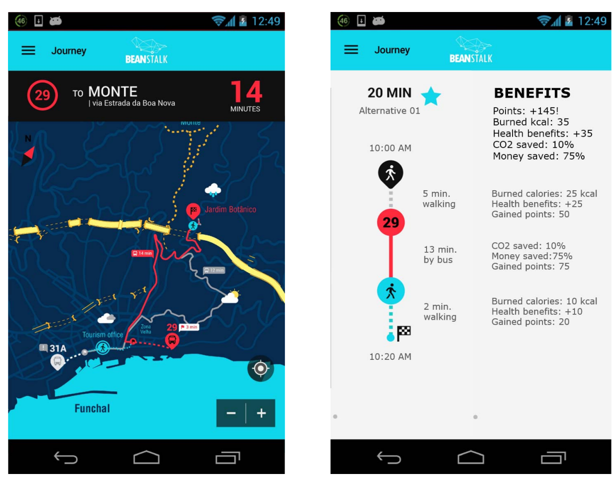

Fig. 1. Screenshots of the mobile app version.

B. Personalized services for citizens

This running example serves to illustrate how the system can support citizens in their daily routines, emphasizing the importance of sustainable habits. In this scenario we describe the use of the mobile version of the system, and how the application can be exploited to break the driving routine and increase awareness about sustainable behaviors.

Let us consider a local who lives close to the center of Funchal but who works in a restaurant in Monte. This location is 15 minutes driving by car from her house, but with about 400 m. of difference in altitude requiring more than an hour walk. Usually, she prefers to drive there with her car, but that day the car is in the auto repair shop, so she decides to install the bus company app to check information about the bus schedule. After inserting the destination, the interface shows a map with the real-time position of the buses stopping at Monte, and the weather conditions at the destination (see Figure 1). She then decides to select the first one available. The app sends to her two notifications: one alerting that it is raining in Monte and another one suggesting to go out quickly to catch the selected bus. Once at the destination, the app notifies her that, with that trip using bus, she saved a certain amount of money and CO2 emissions (compared to the use of a single car per person). The app computes that data tracking the user's position and checking-in/out of the user at the bus stop. This trip makes her gain points, since the app implements a gamification approach to motivate and engage users. When she finishes work, she catches the bus again. When she is close to her stop, the app notifies her that there is a queue due to the intense traffic and proposes her to get off at the next stop. The app shows that, in that way, she will arrive home in just 15 minutes, burning a certain amount of calories, reducing CO2 emissions and improving her health. She then decides to listen the recommendation and walk home, so the system rewards her with extra points, to encourage the use of environmentally-friendly modes of transport (i.e., walking).

C. *Assisting local government and tourist board*

Our system can be efficiently used to assist the local government authorities and the tourist board to prevent mobility issues. To better explain how, let us describe a case study considering a big event, as the Flower Festival parade in Funchal center. The Flower Festival is a unique event which draws the attention of thousands of people, both tourists and residents. The local government mobility manager can be assisted in improving the urban sustainability during this kind of relevant events. For example, simply analyzing the historical data showing the number of people coming to assist to the event, and how their mobility affected the island, the local government can decide to close particular streets to avoid reaching important levels of air pollution in the places near the parade, due to the intensive traffic flow caused by the event. Moreover, they can check in real-time how the people are spread in the street of the parade and detect if there are some places where the number of people is critical for security reasons, and then intervene, if needed.

On the other hand, the tourist board can use the historical data to understand from where (which locations) the people are moving to Funchal and intensify the promotion of the event in those locations, emphasizing the possibility to reach the place using the public transport or ad-hoc buses made available just to connect the hotels located in those dense places.

D. *Supporting transport companies in planning decisions*

In this case study, we want to detail how our low-cost solution can be used to support transport companies in planning decisions about how to schedule buses and where to locate the bus stops, taking advantaged of both real time data and historical data. In fact, considering the latter one, analyzing historical data related to the counting of people on the bus, the mobility manager can see in which hours a particular bus becomes too crowded, and decide on the intensification of the service frequency for that specific time slot, to better meet the customers' needs. Opposingly, actions can be also taken to suspend some bus rides if the number of people using that service is too low to explain that cost, in terms of CO2 emissions. Another interesting example is the one to use historical data related to big events to increase the offer of public services to connect parking outside the city with the location of the events. Moreover, with the real-time data, the public transport company can analyze the dynamic of the urban mobility, and see if the bus is crowded or not and take this into account for route planning (see Figure 2).

Fig. 2. A real time visualization of the buses in the city center.

V. DISCUSSION

In the previous section, we detail four scenarios that cover three main issues of interest. More generally, other scenarios can be considered, involving all the different aspects of the mobility context in touristic destinations and the specific interests of local communities, such as the community of local artisans or the one of farmers, who sell products strictly related to a location and who are directly affected by the mobility flow of tourists and residents. In fact, using the collected data, it is possible to clearly obtain the more common tourists' mobility patterns and, accordingly, activate strategies to expand (or break) these patterns including less known but more unique and authentic places. This can become feasible thanks to our solution, that can represent a virtual place where the different community's needs can meet. It is worth to notice that, the authorities remain in charge to implement sustainable strategies and take decisions, but the tool can provide an easy way to visualize and detect relevant/not usual situations and to enhance awareness, supporting and facilitating the communication between the different community's needs. In fact, a sustainable development requires to join the effort of the different communities and authorities, to consider its social dimension and to become an effective framework to improve sustainable mobility and tourism.

VI. CONCLUSION AND FUTURE WORK

In this paper, we present a low-cost infrastructure capable of collecting location-based multi-sourced data and to provide personalized services to the different communities involved to solicit the adoption of sustainable mobility behaviors and strategies. The infrastructure exploits a Wi-Fi passive tracking system that we augmented with environmental monitors sensors. We deployed the infrastructure in the Madeira Islands, covering 60 POIs and equipping 20 buses. We describe four scenarios of use, considering real application cases to explain how the collect sensing data can be put to good use to improve the daily mobility experience, employing sustainable mobility. Moreover, we argue that our solution represents an opportunity to investigate the possibility to meet the different needs, by providing mobility-related information not only to the official entities, but also empowering the different communities, by collaborating in the sustainable development. To promote this idea, we plan to evolve our platform into a fully community network capable of offering other personalized services to communities, exploring crowdsourcing and crowdsensing.

ACKNOWLEDGMENT

We wish to acknowledge the Tourism Board and the Promotion Agencies of the government of the Madeira Islands. This research was supported by: LARSyS (Projeto Estratégico LA 9 - UID/EEA/50009/2013), MITIExcell (M1420-01-0145-FEDER-000002), ARDITI H2020-MG-2015, CIVITAS-DESTINATIONS, project n. 689031. A special thanks to Ana T. Bettencourt Fernandes who designed the system interfaces.

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