Increasing Bicycle Usage in Smart Cities

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ABSTRACT

The emergence and market uptake of technologies for mobile and ubiquitous computing is opening a window of opportunities for innovative applications that promote cycling and walking in new forms. These technologies allow affordable and accessible ways of tracking the walking and cycling of individuals which, when combined with new community-centric applications, promise to unleash the behavior-change potential to unprecedented levels.

A particular synergy is between local businesses, who are interested in segmenting their customer base to attract new clients who arrive by bicycle or on foot; and potential customers, interested in obtaining discounts. Likewise, cities and governments are interested in attributing benefits to people choosing to cycle or walk. However, achieving so requires applications that are able to trace individual mobility choices, at the same time respecting both technical and social requirements.

This paper sheds some new light on the delicate balance between the the social and technical requirements that determine the actual outcome of behavior change towards more sustainable mobility in smart cities. We focus on a particular application, called Cycle-to-Shop, which is under development in the context of the TRACE H2020 project.

Keywords

Smart cities, mobile sensing, tracking, behavior change, urban planning

1. INTRODUCTION

The emergence and market uptake of technologies for mobile and ubiquitous computing is opening a window of opportunities for innovative applications that promote cycling and walking in new forms.

These technologies allow affordable and accessible ways of tracking the walking and cycling of individuals which, when combined with new community-centric applications, promise to unleash the behavior-change potential to unprecedented levels. These new technological opportunities promise to empower stakeholders willing to promote or benefiting from more cycling and walking. Examples of such stakeholders include local businesses, local authorities, and schools, among others.

At the same time, new and improved tracking tools and initiatives are able to encourage a wider and more active involvement of citizens, enabling effective and concrete win-win processes. The data generated by the tracking of cycling and walking movements can be applied in initiatives and tools to align the interests of stakeholders and the interests of individuals towards cycling and walking choices, in ways that were not possible before or which lacked effectiveness. The ability to link these interests may be found in different scopes, some of which are yet to discover, experiment or evaluate.

For example, while local businesses are interested in segmenting their customer base to attract new clients who arrive by bicycle or on foot, and potential customers are interested in obtaining discounts, the full uptake of this win-win outcome is still dependent on appropriate tracking-based applications. Likewise, cities and governments are interested in attributing benefits to people choosing to cycle or walk.

Achieving so requires applications that are able to trace individual mobility choices while meeting a number of technical requirements, such as precision, efficiency, usability, fault tolerance and privacy. For all such challenges, the Information and Communications Technology (ICT) research community has devoted strong attention and proposed sophisticated solutions, which have proven effective when evaluated in controlled experimental environments [9].

However, the practical success of such state of the art is not always guaranteed in real-world environments involving real citizens. The actual acceptance of a new application by the real citizens in a smart city and (most importantly) the success of such application in changing behaviors depends strongly on a delicate trade-off between often conflicting technical and social factors. On the one hand, it

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depends on the specific expectations and interests of stakeholders and individuals in today's smart cities. On the other hand, tracking is inevitably determined by the technological possibilities and constraints that current mainstream mobile technology imposes on its applications. Unfortunately, a correct understanding of the two above factors is often absent from academic research work.

This article sheds some new light on the delicate balance between the social and technical requirements that determine the actual outcome of behavior change towards sustainable mobility in smart cities. We focus on a particular application, called Cycle-to-Shop (CtS for short), which is under development in the context of the TRACE H2020 project.[1] The goal of CtS is to increase bicycle usage in a city by rewarding citizens (e.g., with discounts and other offers on shops) and, at the same time, to provide urban planners with mobility traces of such users.

As a first contribution, we present some assessment results of non-technical aspects regarding CtS-like applications. Secondly, we introduce the concept of cycle-to-shop and describe an architecture for the CtS application.

The remaining of this article is organized as follows. Section 2 introduces and discusses related work on tracking-based applications for behavior change in smart cities. Section 3 describes the CtS concept and proposes an architecture for supporting it. Finally, Section 4 draws some conclusions and addresses future work.

2. CHANGING MOBILITY BEHAVIOR IN SMART CITIES

The demand for research on spatial development and mobility issues seems to be growing since the start of the new millennium [4]. Data collection is crucial to implement novel, evidence-based approaches to urban mobility planning and behavior change initiatives. Tracking movement and trajectories provides opportunities for understanding mobility behavior and for validating interventions. Stakeholders are increasingly interested in tracking data: policy makers can use tracking data to understand which infrastructural changes increase the modal share of cycling and walking; campaigners can use tracking data to evaluate behavior change campaigns. A shift towards cleaner and more sustainable transport modes is necessary to future-proof European cities in terms of liveability and sustainability [3].

Tracking has a long history. For years, police forces, fire departments and medical units have tracked their vehicles by painting numbers on the roofs and citizen movements have been tracked using diaries and manual traffic counts [5]. Besides these laborious forms of tracking, automated tracking is becoming increasingly prevalent. Examples are tracking by road counters (e.g., pneumatic road tube counters, inductive loops, and piezo-electric sensors), radar waves, infrared beams, video footage and tracking of users of public transport services by the check-in data they generate whilst passing the entrance gates of a station. In recent years, the rise of technological applications and devices has yielded a vast new range of opportunities for tracking. Public transportation systems are increasingly equipped with Global Positioning Systems (GPS) connected to control centres through wireless networks [8]. An increasing number of people is carrying smartphones that include various instruments for tracking, such as GPS, Bluetooth, Wifi, and accelerometers. These new technologies offer numerous and novel opportunities for research on travel behavior [5].

Travel behavior changes in response to a wide range of policy measures, such as infrastructural changes, changes in prices (e.g., prices of public transport and fuel), improvements in public transport, and reallocation of road capacity [6]. As Goodwin (2003) points out, travel choices are made by millions of individuals and companies in function of their own well-being and profit. Changing this complex set of behaviors requires a coherent policy in which the individual elements strengthen each other. For changing travel behavior, campaigners have traditionally relied on Theory of Planned Behavior, Norm-activation Theory, and Stages of Change models [1]. In recent publications, Self-determination Theory and Cialdini's six principles of influence have been used as a theoretical framework [2]. Interestingly, several other theories offer additional inspiration for optimizing behavior change initiatives. To the best of our knowledge, there are no strong empirical findings showing that one of the presented theories is superior to others for changing travel behavior.

Indeed, in the scope of cycling and walking, web applications are being used to relatively simple purposes like guiding users in their journeys and informing them on spots of interest, in some cases based on crowd-sourced information. However, they clearly are at an early stage in taking advantage of the range of possibilities placed by ICT means.

The ability to track user trajectories opens up extensive new possibilities. Since it became available in commodity mobile devices, it changed many people's habits mainly through applications (like Endomondo, Strava and others) that provide them information on the benefits of their cycling, walking and running activities, and explore their social attributes by sharing it with friends. Simple as they are, these applications have already been used to promote cycling in the utilitarian urban context; most famously, in the European Cycling Challenge, which has held yearly competitions between cities since 2012.

3. CYCLE-TO-SHOP

The concept underlying Cycle-to-Shop (CtS) is a network of shops and bicycle users which will in a permanent and continuous way promote the use of the bicycle for urban travel. By providing permanent benefits and improving the sense of cycling community, we expect CtS to be responsible for a structural increase of cycling to the order of 5% to 20% in the long term.

Very simply, the user of the CtS app receives a notification when he arrives and stays at an adherent shop. The notification announces that the user is eligible for some benefit in the shop. The user shows the notification to the shop owner, who will attribute the benefit to the customer.

Shop owners choose and can edit at any time the benefit they attribute to a cycling customer. The benefit may be a discount in the items purchased, the offer of something, like a drink, or anything else with a minimum perceived value by the user. Shop owners may be as creative as they like.

The CtS app is an information platform for users, including a local map with the adherent shops, information about the benefits given by each shop and information about other facilities for cyclists at the shops (e.g., parking).

The basic criteria of eligibility to benefits is to arrive by bike at the site of the shop. The bike trip does not necessarily have to happen just previously to the arrival at the shop; for example, the user who went to work by bike and then at lunchtime walked to a nearby shop will still be eligible.

[1] http://h2020-trace.eu/

Therefore, not only trips to the shop, but also other types of trips are rewarded.

Both the shops and the local CtS manager may create special campaigns. Special campaigns occur within a timeframe and may have different awarding criteria.

3.1 Use Case

To illustrate the scenarios in which CtS is envisioned to promote behavior change, we describe a simple use case. Amanda is 25 years old and has recently started to ride the bike for leisure. When going to a nearby grocery store she noticed a sign announcing CtS: ride your bicycle and get discounts. She got intrigued.

At home she downloaded the CtS app and began looking at the advantages. "If I go to these shops by bike I can get discounts? Well, I've never really used my bike for other than fun, but this seems like a good opportunity to begin." And so it was.

Two days later she needed to buy some toothpaste. She looked at the app's map and saw that there was a convenience store that belongs to the CtS network, 10 minutes away from her house. She turned the GPS on and rode her bike to the store. When she got there, she received a notification stating she was eligible for a discount. She showed the notification to the store clerk, who activated the discount: 5% off.

Amanda was pleased, especially because she noticed that going by bike had been faster than any other alternatives. She started studying the shops that offered discounts and she saw that her favorite clothing store was one of them. Unfortunately, cycling to that shop's location was not very pleasant for beginners like Amanda. "Haven't you noticed, Amanda? The CtS app offers an alternative", explained Sarah, when Amanda complained about it. "You can get discounts for ride your bike to the shop, but also by being a regular user of the bicycle." "Well, that's interesting too."

So, the following weekend, before leaving on her usual bike ride, Amanda turned the GPS on. The app tracked her whole journey. At the end of the day, with her face red of enthusiasm, Amanda looked at her phone: she had done 32 km cycling around the city. It had been an amazing day! So, on the following day she rewarded herself with a new dress from her favorite shop, 10% off!

Amanda knew herself. She knew that after that initial rush of motivation caused by the discovery of something new, she might eventually stop using the CtS app, even though the discounts were always present. Luckily, CtS seemed to know this too, and soon Amanda received a notification: "Your city challenges you: come explore our new cycling lanes!" She opened the notification and read the rules of the challenge: "During the next week ride at least 10 km on the new cycling lanes on the oriental part of the city. You'll be rewarded with a monthly travel pass." Amanda embraced the challenge. After completing the required 10 km she won a virtual badge, which she showed to the worker when she bought the travel card for the next month. Some days later, Amanda received a notification announcing a challenge from the local pet shop, offering a special discount on baths for dogs. "Too bad I don't own even a gold fish", Amanda thought while deactivating notifications from that shop.

Fortunately, most of the campaigns were appealing to Amanda, both in terms of challenges (bringing a friend, cycling longer distances or specific areas, visiting certain shops) and rewards (additional discounts, small prizes, lotteries for big prizes), and Amanda kept participating in those challenges. And one day she noticed she had become used to ride the bike everywhere. Even to that one clothing store!

3.2 Assessing the Needs and Expectations of Stakeholders

Before designing and implementing CtS, we conducted a series of surveys in order to learn about the potential of tracking tools and campaigns in changing behavior. The survey targeted the main stakeholders groups that are involved in CtS: municipalities, shops, and citizens (as potential users).

Respondents of the surveys came from 25 different European countries. Regarding municipalities, 137 representatives of local authorities completed the survey. From shops, more than 100 responses were obtained.

Regarding citizens, we contacted several groups of users of previous and current mobility behavior change campaigns/ applications that, like CtS, rely on tracking. Participants were recruited via newsletters, personal e-mail and Facebook, and all other existing communication tools, hereby directly directing users of campaigns and tools.

3.2.1 Citizens

To assess the needs of individuals that use tracking tools to track their mobility behavior, we collected 820 responses from users of existing applications (RouteCoach, Bicycle Counting App, and Cycling365).

Users have various motivations to start using a tracking application. Sharing data with policy makers was important for 43% to 85% of the respondents, group participation for 18% to 57% of respondents, personal statistics for 23% to 43% of respondents, the possibility to win a prize for 6% to 21% of respondents, and participation of family and friends for 5 to 12% of respondents. The importance of the gaming aspect was only assessed for RouteCoach and Cycling 365. In addition, 23% of RouteCoach users indicated they installed the application for the personal travel advice and 20% to share data with other users. For Bicycle Counting app we also asked whether sharing on Facebook was a motivation to participate, but this was only the case for 2% of the individuals.

After the enrolment of users in a tracking program, the next challenge is to keep them using the application. We analysed reasons why users remove an application for RouteCoach (37% of respondents removed the app, 45 users), Bicycle Counting app (91% removed the app, 420 users), and Cycling365 (26% removed the app, 81 users). Apps are removed when the campaign is finished, when users are annoyed by bugs (with regards to the tracking or the app in general), when an app consumes too much battery or when the phone memory is needed for a new application.

Finally, we tried to assess how important end users considered different technical requirements. The results are presented in Figure 1. Ease of use of a tool is by far the most important requirement for the respondents. Looking at the different stakeholder groups, we have learned that parents and employees, put privacy on top, and ease of use as a second most important requirement.

3.2.2 Shops

In the survey, respondents representing local businesses were presented the following scenario: "There is a network of local businesses that give discounts or rewards to bicy-

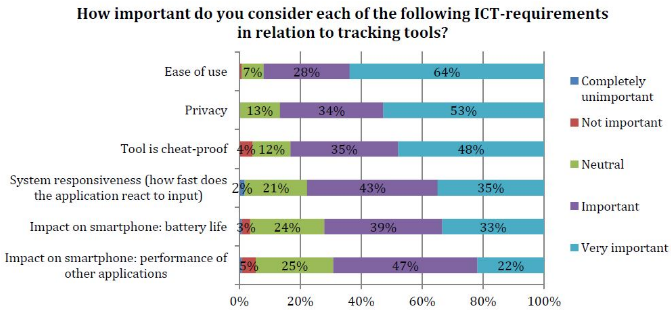

Figure 1: Importance of each technical requirement, from potential users perspective.

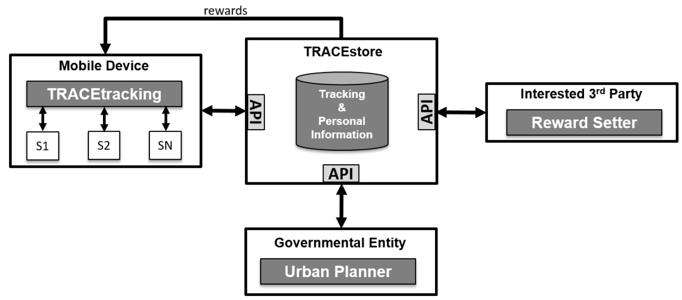

Figure 2: TRACE global architecture.

cle users/walkers if they consume in their business. The users can see in a mobile app where participating businesses are located and the kind of discounts or rewards they offer. The app automatically recognizes whether users are actually making their trips on bike/foot." The respondents were asked whether or not they would see it as a benefit for their business to belong to such a network. 53% of the local business responding see such a network as a benefit for their business. Attracting new customers and rewarding loyal customers are the main motives for respondents.

For respondents that were willing to participate in such a network, the main reasons were to attract new customers, having a green image, reward loyal customers and reward customers that use sustainable transport. Remarkably, identifying the number of customers that come by bike was regarded as the least important motive.

In order for tracking to take place, installing a piece of equipment on the premises of the local business could be a possibility. Interestingly, almost 29% of the responding local businesses does not want to install any equipment at their premises to participate in the network (e.g., a new power-plugged device). Then again, about 40% of the respondents would not mind installing one device.

The survey also showed that 57% of the respondents would, if belonging to the network would yield monetary gains, be willing to share a small part of the returns with the product developer.

3.2.3 Municipalities

From our survey we also learned that most of the municipalities currently do not use tracking data for public transport, walking and/or cycling. 10% of the respondents claim that they have used tracking for cycling policy, 4% for public transport and 4% for walking in the past. For each of these policies, respectively, 26%, 34% and 9% of the respondents use tracking data to this day. Interestingly, for public transport, cycling and walking, 21%, 12% and 14% of the respondents is unaware of the use of tracking devices or methods within the transportation policy, as to where 41%, 52% and 73%, respectively, clearly states not to use tracking data.

If tracking data is used, however, the most common device is the GPS (52%). 15% of the respondents claim that Near Field Technology is used, as to where 9% uses Bluetooth beacons and 6% Wi-Fi beacons. Interestingly, 18% of the respondents states "other" technologies are being used, of which mostly mobile phone data, smart card data, public bike renting system data, ticketing validation data, surveys, etc. However, almost all respondents believe that tracking data would be useful to their municipality for cycling and walking. Of all the respondents, respectively, only 3% and 4% believe that tracking data could probably not be of use for cycling and for walking policies in their municipality or region.

Of the respondents, 66% of cities or municipalities have experience in projects to promote cycling or walking to work, and 59% have experience in projects to promote cycling or walking to local businesses, now or in the past. Among those cities and municipalities with no past or current involvement in such kinds of projects, 26% expressed their interest in doing so in the future.

3.3 Architecture

CtS is part of the larger TRACE project, which proposes a general architecture for tracking-based applications (see Figure 2).

The TRACEtracking module, which runs on mobile devices held by citizens in a smart city, allows CtS to gather tracking information and sends it to the storage system, namely the TRACEstore module. Essentially, TRACEtracking is a middleware that leverages the embedded sensors present on mobile devices to try to extrapolate users location, transportation modality, among other information. TRACEtracking also ensures that this process is energy efficient, effortless, robust with regard to potential fraudulent behavior and ensures the user's privacy and security.

3.4 TRACE Store

TRACEstore is the storage module used by CtS. Through it, CtS stores the users' movements, and their personal details along with the road network of cities. This information can then be used, anonymously, by the award system and by the city hall urban planners.

An additional client of the information stored in TRACEStore are shop owners. Shop owners are interested in rewarding users that cycle to their shop. Therefore, using the DBReward API, shop owners may specify rewarding policies, which define the rewards and corresponding conditions. When a user fulfills one of these policies, he/she is notified that he/she has been awarded something by that specific store owner.

The award system is responsible for encouraging TRACE users to walk and cycle more on their cities. In a simplistic way, interested third-parties can register with CtS and set rewards for its users. A simple example of this is a shop owner who wishes to award his clients for biking/walking there instead of driving. Through this reward system, TRACE can both promote local business and attractions, while at the same time encouraging people to walk

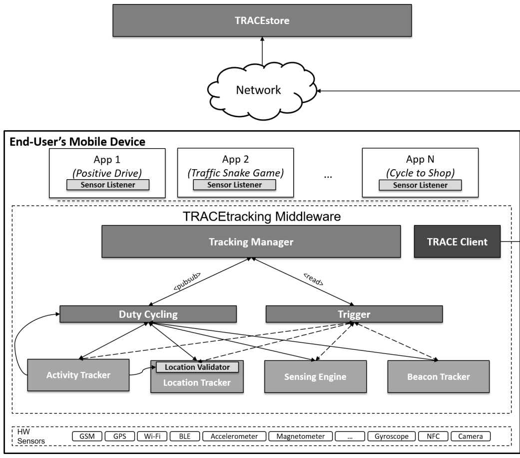

Figure 3: TRACE tracking module.

and cycle more.

Finally, there is the urban planner module. Unlike common interested third-parties, urban planners from municipalities are interested in querying for higher-level information that may support and improve urban planning initiatives. Hence, these stakeholders are interested in information such as the traffic density distribution, which streets are preferred for cycling and walking, among other information. This information is anonymous and untraceable back to its original users. Such statistical information is invaluable to city halls that wish to have a proper urban planning. Through this information, city halls can achieve a better understanding of its road network's use patterns, for instance which streets are the most congested and to which streets can then traffic be redirected to. At the same time, new infrastructures can be built to better fulfill the pedestrians' and cyclists' needs.

For greater flexibility, CtS will provide three possible tracking scenarios, using a combination GPS or LEBT (Low Energy Bluetooth) beacons:

- GPS tracking: this means that each cyclists holds a smartphone with a GPS which provides the location to the TRACEstore;
- Stationary LEBT beacon: this means that each checkpoint holds a beacon that regularly broadcasts its unique identifier; thus, each cyclists holds a smartphone (LEBT capable) that detects the beacon and sends the identifier to the TRACEstore;
- Moving LEBT beacon: this means that each cyclist carries a LEBT beacon (e.g. fixed to the bicycle) that keeps broadcasting its identifier; such an identifier is detected by a computer at the checkpoint (e.g. at a shop) that for each detected identifier, sends it to the TRACEstore.

In all the above scenarios, there must be a previous registration phase of both the cyclists and pedestrians along with the corresponding location technologies and data. The same applies to shop owners who register their shops location and rewards. Thus, these two kinds of users rely on a web page for such purposes.

3.5 TRACE Tracking

TRACEtracking is a middleware designed to enable and ease the development of mobile sensing location-based applications. The middleware offers two modes of operation: i) triggered, and ii) subscription modes.

Additionally, TRACEtracking also encompasses a TRACEClient module responsible for establishing a connection and transmitting the tracked information to the TRACEStore.

The TRACEtracking was designed as a middleware that may be shared by one or more applications, as is depicted in Figure 3. By enabling applications interested in tracking the user's mobility patterns, to do so through a common service, it becomes possible to maximize the use of the device's resources.

The Tracking Manager is TRACEtracking's core component. It is responsible for enabling tracking applications access the device's sensing and location capabilities, among other sources of information. Applications may take advantage of the device's capabilities through two supported modes of operation: i) triggered; and ii) subscription. The first enables an application to read a single value, while the second enables the applications to perform continuous tracking.

Regardless of the selected mode of operation, applications leveraging the TRACEtracking middleware can acquire different types of information. In particular, the middleware supports the different sources of information that are acquired by the following components:

- Location Tracker: enables access to the device's current location, which is characterized by a latitude and longitude pair, as well as the location's accuracy. While the middleware supports a wide range of positioning techniques, this component creates an abstraction layer that allows the application's developers to focus solely on the tracking endeavour.
- Activity Tracker: enables access to the user's current activity mode, i.e. if the user is stationary or in-motion, as well as the user's mode of transportation (walking, cycling, and motorised transportation).
- Beacon Tracker: enables access to a list of the beacons found in the user's vicinity.
- Sensing Engine: enables access to the device's additional sensor readings, for instance the accelerometer, pressure and luminosity readings. The supported sensor types depend on the device's sensing capabilities.

3.5.1 *Location Tracker*

While the GPS is a location technology that enables high-accuracy positioning, it also implies high energy consumption levels, as the GPS is one of the most energy demanding sensors. Mobile sensing location-based applications should be concerned with minimizing their energy consumption levels. Therefore, these applications should be able to rely on less energy demanding positioning techniques without compromising their tracked location's accuracy. With that in mind, the Location Tracker was designed. This component operates as an abstraction layer, in the sense that it allows the tracking applications to focus solely on the tracking logistics, while the component is the one that actually selects and manages the positioning technologies and techniques. The Location Tracker component encompasses several location techniques and technologies. Each technique is defined as an independent module, so that new location techniques may be easily introduced. In particular the Location Tracker will support the following location technologies: GPS, Network, WiFi GeoFi, BLE, Dead Reckoning (DR), NFC, QR, etc.

When an application registers a Sensor Listener for the Location Tracker, it may specify its accuracy and energy requirements. The Location Tracker will then manage these trade-offs so as to select the location technique that best benefits the application. Otherwise, the Location Tracker will always select the less energy demanding technologies, assuming that these are available. If not available, it will progressively select more energy demanding solutions.

If an application or system is concerned with the possibility of fraudulent users, the Location Tracker may also be configured to rely on more than one location technology. By relying on several location technologies it becomes harder to deceive the system, as the different locations may be used to co-attest each other. Additionally, this component also encompasses a Location Validator. The purpose of this component is to assure the validity of all the locations acquired. This is of great importance, especially for application that encompass incentive provision mechanisms.

It is important to mention that while NFC and QR code location technologies are the less energy demanding, these require direct user intervention. Therefore, they may only operate in triggered mode.

3.5.2 *Activity Tracker*

In order to promote more active modes of transportation applications should be aware of the user's mobility behaviors. The Activity Tracker monitors the user's activity levels and adopted transportation modality.

Besides allowing the applications to track their users' mobility patterns, this component is also crucial to enable energy efficient tracking. By detecting periods of inactivity, i.e. when the user is stationary, energy may be saved by adjusting the sensors' sampling rate. In order to do so, the Activity Tracker detects and reports the user's activity state changes (stationary or in-motion) to the Duty-Cycler component. This approach is based on the one proposed for the EnTrack project [7].

3.5.3 *Beacon Tracker*

To ease and improve the recruitment and retaining of participants, some applications and systems may be interested in providing rewards. Incentive provision mechanisms are a popular and advantageous approach. However, depending on the types of rewards, these may increase the interest and payoff of cheating the system.

Beacons are a new and rising technology that enable positioning through proximity sensing. Because they require a certain proximity to communicate with the users' devices, which in most beacons is configurable, it becomes harder to deceive the system. Therefore, beacons are an attractive technology to deal with possible fraud attempts.

The Beacon Tracker component operates as an abstraction layer, which allows the middleware to support different vendor SDKs. By doing so, applications that leverage the TRACEtracking middleware may rely on different beacon providers to address eventual fraudulent users.

It is important to note that, while beacons may be used to hinder fraudulent behavior, they can be susceptible to replay-attacks. Therefore, it is important to take this into account when employing this technology. However, it is important to note that some beacon vendors already offer security-oriented solutions.

4. CONCLUSIONS AND FUTURE WORK

The ongoing TRACE project aims at triggering innovative cycling and walking promotion initiatives and planning practices by expanding the knowledge and leveraging the potential of cycling and walking tracking. This paper focused on one such initiative, CtS.

The CtS application will be available in several pilot sites in the following cities during 2017: Esch, Breda, Plovdiv, Bologna, and Southend on Sea.

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